RISK-BASED ASSESSMENT OF CLIMATE CHANGE IMPACTS AND RISKS ON THE BIOLOGICAL SYSTEMS AND INFRASTRUCTURE WITHIN FISHERIES AND OCEANS CANADA'S MANDATE – FRESHWATER LARGE AQUATIC BASIN

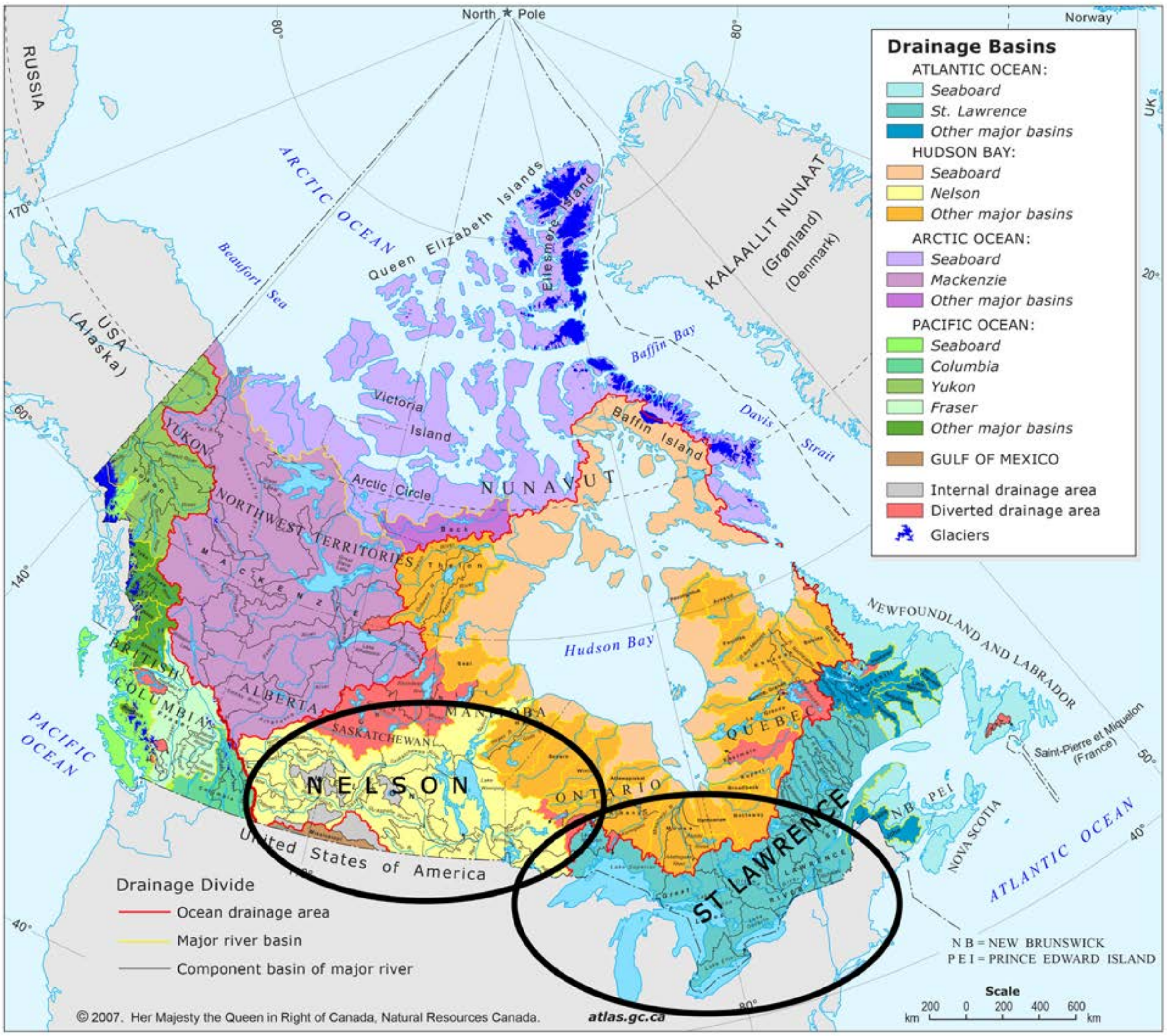


Figure 1. Map of the Freshwater Large Aquatic Basin (LAB) including the Prairies area (Nelson River – Lake Winnipeg Canadian Drainage) and the Great Lakes Basin.

Context

In keeping with the *Federal Adaptation Policy Framework*, Fisheries and Oceans Canada (DFO) received funding for the Aquatic Climate Change Adaptation Services Program (ACCASP; 2011-2016) in order to implement a science-based climate change program focused on adaptation and delivery of Fisheries and Oceans' mandated areas of responsibility. The Program will undertake risk assessments, foster the development of applied science-based tools and research projects to increase our understanding of the impacts of climate change and enable adaptation in support of DFO's strategic outcomes.

To tackle the primary objective of the Program, an assessment of the risks that climate change poses to the delivery of DFO's mandate across the diverse aquatic ecosystems of Canada were performed. To focus these assessments country was divided into four Large Aquatic Basins (LABs), namely the Arctic, Pacific, Freshwater and Atlantic, which share broad ecosystem features. The assessment of regional risks will help front-line managers respond to climate change.

As a first step, a nationally-led Science Special Response Process (SSRP) consisting of face-to-face expert meetings was held for each of the four LABs to assess the risks to the biological systems, services, and infrastructure that fall under the purview of DFO. This work follows two internal DFO climate change national risk assessment reports (Interis 2005, 2012) which provided a preliminary assessment of the impacts of climate change to the Department's strategic priorities, and focused these national evaluations of risks down to the scale of each of the large aquatic basins. This served as the departure point for the four LAB assessments. An SSRP was used instead of a full CSAS peer review because of the short timeframe for this Science advice. An SSRP can be used to respond to urgent or unforeseen requests when there is not sufficient time to prepare a full CSAS review.

The urgency of the advice stemmed from the need for linkages between the science, socio-economic and policy risk assessment background documents in preparation for the Integrated Risk Assessment meetings, scheduled for early winter 2012/2013. Following these Canadian Science Advisory Secretariat (CSAS) meetings, the results of the SSRPs, along with the results of concurrent socio-economic, and policy analyses (developed with linkages to the outcomes of the SSRP meetings) will be used collectively to inform an integrated risk assessment workshop for each of the large aquatic basins. The objective of these integrated workshops will be to take the evidentiary base provided by science, socio-economics, and policy and incorporate DFO program area (e.g. fisheries management, oceans management, etc.) considerations to determine the most acute basin-level climate risks for the Department. The results will help DFO decision-makers adapt decisions to reflect climate change considerations so that Canadians may continue to derive benefits from our oceans and inland waters. This information will also be instrumental in informing priorities for ACCASP's competitive funding envelopes, which are aimed at understanding climate change impacts and developing applied adaptation tools, for the 2013-14 funding year and beyond.

This Science Special Response Report is the product of the expert meeting for the Freshwater Large Aquatic Basin that provided peer review of Risk Summary Sheets developed for each of the six departmental risks established in the national risk assessment reports. Participants carried out their review having first considered background documents that presented scientific information available on trends and projections and the impacts, vulnerabilities and opportunities for each LAB. The basin risk assessments first considered descriptions of climatic "Trends and Projections" (TP) on the near-term (10 year) and long-term (50 to 100 years) time scales. Then the assessments considered evaluations of "Impacts, Vulnerabilities and Opportunities" (IVO) for each temporal scale. The detailed TP and IVO reports, which are extensive and detailed assessments of the climatic changes and impacts at the sub basin level in each LAB will be published at the beginning of the 2013-2014 fiscal year (to be published[1,2]). A separate review process for the background TP and IVO documents will occur once they are finalized.

This Science Response Report (SRR) details the results from the National SSRP that assessed the risks of climate change on the freshwater large aquatic basin. This meeting took place on November 20-22nd, 2012 in Winnipeg MB. The Science Responses resulting from each of the four large aquatic basin expert meetings will be posted as they become available on the Fisheries and Oceans Canada Science Advisory Schedule.

Background

Fisheries and Oceans Canada

Climate change will affect the Department's ability to meet its mandated obligations and commitments. Predicting how climate will change is difficult. Predicting the magnitude, location, timing, and processes of impacts of climate change on ecosystems and infrastructure is even more difficult. DFO's responsibilities and mandate are complex and diverse further complicating predictions about how climate change impacts will affect its sectors and regions.

To organize this assessment of risks of climate change the evaluation was focused on six main risks. The national assessment of risk of climate change to the Department's ability to deliver on its mandate (Interis 2005, 2012) identified six main risks:

- Risk 1: Ecosystem and Fisheries Degradation and Damage;
- Risk 2: Changes in Biological Resources;
- Risk 3: Species Reorganization and Displacement;
- Risk 4: Increased Demand to Provide Emergency Response;
- Risk 5: Infrastructure Damage; and
- Risk 6: Change in Access and Navigability of Waterways.

The extent of Canada's freshwaters considered was constrained in this evaluation to make the analysis tractable. The Freshwater Large Aquatic Basin, includes freshwater ecosystems from two of the largest inland regions in Canada; the Lake Winnipeg watershed (including drainage from prairie and boreal eco-zones) and the Great Lakes St. Lawrence drainage. The Lake Winnipeg watershed includes Lake Winnipeg, the Winnipeg River and Boreal sub-basin, the Red and Assiniboine River sub-basin and the Saskatchewan River sub-basin (Figure 2). The Great Lakes drainage included the Canadian drainages and main lakes of Lake Superior, Lake Huron and Georgian Bay, Lake Erie, Lake Ontario, and St. Lawrence River downstream to Quebec City, including all associated connecting channels, tributaries and inland lakes for the entire primary watershed (Figure 3). The extensive geography of these two subareas were found to have considerable observed differences in both the physical and chemical past trends which were

[1] Freshwater Large Aquatic Basin –Climate Change Trends and Projections – Aquatic Climate Change Adaptation Services Program. Can. Tech. Rep. Fish. Aquat. Sci. xxx (provisory title, unpublished manuscript)

[2] Freshwater Large Aquatic Basin – Climate Change Impacts, Vulnerabilities and Opportunities – Aquatic Climate Change Adaptation Services Program. Can. Manuscr. Rep. Fish. Aquat. Sci xxx (provisory title, unpublished manuscript)

confounded by natural climatic cycles and anthropogenic stressors. The evaluation of risk described here addresses the whole of the large Freshwater LAB and the resulting science advice is based on the integration of information from all of the sub-basins. Smaller-scale regional issues are not addressed in this report and details for many inland lakes and drainages were excluded because of time and data constraints. The freshwater drainages directly feeding the marine large aquatic basins were included in the considerations of those large aquatic basins (e.g. the MacKenzie drainage was considered in the Arctic large aquatic basin).

Fisheries and Oceans Canada has various responsibilities within these freshwater areas. DFO is responsible for management of all fisheries in Canada but in most freshwaters these responsibilities are delegated to the provinces. Fisheries management includes programs to conserve and manage fishery resources for sustainable use. Activities include Integrated Fisheries Management Planning, Conservation, Education, Enforcement, and Aquaculture. The Department has the same responsibility for aquaculture as it does for a fishery and has established management regimes for aquaculture with the provinces. Fish Habitat Management (or Fisheries Protection), Legislative responsibilities and policies are administered by Fisheries and Oceans Canada for the purpose of conserving, restoring and developing fisheries resources through sustainable development practices. Fisheries and Oceans Canada is responsible for administering the Species at Risk Act for aquatic species and does so in all freshwaters of Canada. Fisheries and Oceans Canada is responsible for aquatic invasive species in freshwaters. The Department carries out the world’s largest aquatic invasive species control program with the Sea Lamprey Control Program on the Great Lakes. DFO delivers aquatic invasive species monitoring and research programs including science supporting the Transport Canada in managing ballast water to prevent ship-mediated invasive species. Fisheries and Oceans Canada is beginning a new program to prevent establishment of invasive Asian carps in Canada.

The Canadian Hydrographic Service (CHS) of DFO Central and Arctic region conducts hydrographic surveys and produces the official nautical charts and publications for navigable waters in Ontario, Manitoba, Saskatchewan as well as the Arctic. The CHS also maintains a network of 34 permanent water level gauges on the Great Lakes; data which in turn are used by the IJC Regulation Boards, the marine navigation community and science support. An additional by-product from the data is a monthly water level bulletin for the Great Lakes and Montreal Harbour.

The Canadian Coast Guard is responsible for the delivery of maritime programs such as Marine Communications and Traffic Services (MCTS), Aids to Navigation, Waterways Management Services, Environmental Response (ER), Icebreaking Services, Search and Rescue (SAR) and Maritime Security.

Fisheries and Oceans Canada delivers science to support its mandate through the Great Lakes Laboratory for Fisheries and Aquatic Sciences (GLLFAS), the Freshwater Institute and the Environmental Science Division (ESD) of the Science Sector of the Central and Arctic Region (C&A). Research activities include complementary and overlapping studies on the topics of fish habitat, food web dynamics, fisheries production, ecosystem effects of aquaculture, species at risk, and biodiversity.

Figure 2. The Lake Winnipeg watershed/drainage (online map provided by Environment Canada, 2011)

Source: Based on a map from *The Atlas of Canada*. Adapted by CRS. (K.Yancey 3/23/06)

Figure 3. Portion of the Great Lakes Watershed. The full watershed considered included the St Lawrence River to Quebec City.

Freshwater Trends and Projections

Past climate trends indicate that the average air temperature in Canada has increased 1.2°C in the last 58 years (Environment Canada, 2006). However, the warming was not uniform across the country; air temperature increases of 1.2°C in south-central Canada have been observed, but the average range is 0 °C to 1.4°C across all Ontario (Chiotti and Lavender, 2008). Warming has been more significant in winter and spring and has contributed to changes in evaporation rates, less annual precipitation with less as snowfall and more as rainfall, and shorter periods of ice-cover; all of which affect freshwater ecosystems through hydrodynamic and thermodynamic processes. Furthermore, more Northern regions of the study areas are expected to experience an accelerated rate of change due to global warming.

Climate change is anticipated to alter freshwater ecosystems as a result of projected increases in air and consequently, water temperatures, changes in ice and snow dynamics — particularly declines in ice and snow cover, thickness and duration, as well as changes in the timing, pattern, distribution and amount of precipitation (Appendix 1). These changes will affect hydrologic cycles and therefore chemistry of the water. The changes in evaporation, precipitation patterns and ice dynamics are expected to increase the frequency of extreme events such as flooding and drought; this will physically alter habitat and the productivity of those habitats.

These climatic changes are likely to continue into the future, and are expected to further impact the delivery of the Department's activities in this Freshwater LAB. Impacts are not only for ecosystemic risks and their management, but for technical risks in the department's delivery of services and maintenance of infrastructure. Decreasing water levels and increasing storm frequency will require increased efforts to maintain usable infrastructure, increased need for charting, hydrographic surveys, and dredging to maintain navigable waterways.

Given the existing state of knowledge on climate trends and projections and their cascading impacts on ecosystems, services and infrastructure, these risks were discussed, analysed and are presented below. These results should be considered preliminary as they are based on summaries and are non-exhaustive and relied mainly on expert judgement in their assessment.

Analysis and Responses

Trends and Projections Summary

Participants reviewed and agreed on a summary table of climate trends and projections (TP) capturing the climatic changes for the Freshwater LAB described above (Appendix 1). The summary table included information about past trends (based on observations over the last 50 and 100 years as was available) as well as future projections (statistical projections based on climate models most commonly for the period of 2041-2070 (termed the 2050s) relative to the baseline period of 1970-2000) of several climate and limnological variables. Long-term trends could not always be established because not all variables had enough data for the subareas or they only had older projections with differing reference and projection periods. These limitations were noted in the detailed background tables for sub-basins but not at the high-level summary level presented here.

The climate trends and projections summarized in Appendix 1 and the risk summary sheets for each of the six main risks were developed from peer-reviewed literature. The detailed citations for this information are included in the comprehensive Freshwater LAB TP and IVO reports which will be published separately (*to be published* [3,4]). Select references, largely focusing on the IVO are available at the end of this science response.

The climate trends and projections identified in Appendix 1 are an effort to present a common understanding of past and future change across the entire Freshwater LAB. These simplifications are the basis of the resulting environmental changes and the resulting advice in this report (Appendix 1). Some assumptions were made when preparing the TP and IVO summary tables; these include:

- The trends and projections have been averaged or put into ranges to create an overall LAB-wide freshwater analysis; this simplification might not represent the full range and variability within the data.
- Human intervention or adaptation is not accounted for in projected trends and risk assessment and planning.
- The specific impacts on aboriginal fishing were not considered, this should be done in future exercises.
- Cumulative impacts and increased stressors (including those from climate) and their interactions are not addressed in this assessment.

Risk Summary Sheets

Participants reviewed risk summary sheets that describe the main climate change impacts, consequences, opportunities and gaps for each of the six risks identified in the national risk assessment (INTERIS 2005, 2012; Appendix 2-7). Definitions of the six risks, as well as a context for these are presented in the risk summary sheets. These risk summary sheets are based on the trends and projections identified in Appendix 1. The main risk drivers are supported by peer-reviewed literature; whereas the consequences, opportunities and gaps were developed through consensus among the experts participating in the meeting. Gaps reflect areas or topics where no data are available, and not areas or topics that were purposely not examined.

Each of the six risks were initially considered on near (10-year) and long (50-year) timescales into the future. However, these timescales were eventually combined either because: a) the10 year conditions were difficult to predict and/or model and were therefore inconclusive or; b) the impacts on both timescales were the same for each Departmental risk and only the likelihood or probability of occurrence changed with these timescales.

The risk evaluation was informed by the technical expertise of the expert participants. The first three climate change risks for the Department relate to different elements of freshwater ecosystems and the workshop participants from the Science sector are considered the primary government experts. Risks 4-6 focused on DFO's freshwater technical services and infrastructure (including but not limited to harbours, wharves, charts & charting, vessels, emergency response, equipment, buildings etc.). For these risks, participants assessed the risks to the best of their ability recognizing that this portion of the advice would have benefited from more input from technical

[3] Freshwater Large Aquatic Basin –Climate Change Trends and Projections – Aquatic Climate Change Adaptation Services Program. Can. Tech. Rep. Fish. Aquat. Sci. xxx (provisory title, unpublished manuscript)

[4] Freshwater Large Aquatic Basin – Climate Change Impacts, Vulnerabilities and Opportunities – Aquatic Climate Change Adaptation Services Program. Can. Manuscr. Rep. Fish. Aquat. Sci xxx (provisory title, unpublished manuscript)

experts from the DFO sectors that manage infrastructure (i.e., DFO sectors who manage navigation, emergency services, and infrastructure such as Canadian Coast Guard, Small Craft Harbours). While these sector experts were not able to participate in the meeting (see Contributors section below), some input was solicited from them before the meeting and that input was included in the individual risk sheets.

Each risk summary sheet (Risks 1-6) highlighted key drivers of potential impacts from climate change that were based on a compilation of the Freshwater LAB trends and projections and impacts, vulnerabilities and opportunities information (*Appendix 2-7)*. Participants discussed the main climate drivers and the potential consequences (or threats) resulting from these drivers. Several of the main risk drivers, consequences, opportunities and gaps were common to Risks 1, 2 and 3. Risk drivers and consequences were considered independently and are not presented in the tables with a direct linkage between the main risk drivers listed on the left side of the table and the lists of potential consequences on the right side. Positive consequences were considered separately as opportunities.

The risk summary sheets were constructed following these definitions:

- Risk driver: (also known as risk source) is an element that alone or in combination has the intrinsic potential to give rise to a threat.
- Consequence: is an outcome of an event affecting objectives (the event being the occurrence or change of a particular set of circumstances).
- Gap: identification of scientific areas where knowledge is not available or is insufficient.
- Opportunity (from Risk): the aspect from a risk that allows an organization to take advantage of the impact, depending on the specific set of circumstances.

The risk summary sheets represent an effort to cover all aspects of the ecosystem or infrastructure risk being considered however, participants noted that there are some gaps in the information available. For example participants noted a lack of knowledge in microbial, macrophyte and benthic algal response to climate change, as well as how the productivity of these organisms may change and alter the water characteristics. Similarly, the response of aquatic invasive species to climate change and their interactions with native species are not sufficiently understood and are difficult to predict.

Workshop participants also recognized the challenge of assessing the risk of climate change over a large and spatially complex geographical area. Spatial variation in the impacts and changes are difficult to assess when summarized across different sub-regions. Over the geographic scale of the Freshwater LAB there is substantial heterogeneity in climate systems (regional climate influences) and aquatic systems (characteristics and distribution of lakes, rivers, and streams). Participants also largely agreed that the uncertainty around the ecosystem consequences in the future is great and currently difficult to quantify. The ability to project future changes decreases the more systems change and this is compounded by an increase in vulnerability of the ecosystem.

Lastly, participants noted that this assessment does not predict, nor does it account for, human interventions and adaptations. These human actions would have subsequent impacts on the physical, chemical and biological variables affecting ecosystem dynamics. Examples of human interventions or adaptations include diversion of flows, armouring shorelines, construction of drainage ditches or dyking, regulation of water levels, changes in fishery practices, as well as changes to regulations and policies. A large number of water bodies in the Freshwater LAB currently experience many of these human activities but for different purposes and all have additional consequences on natural processes within ecosystems.

Risk Evaluation

Following the review and consensus about the elements of each of the Risk Summary Sheets, participants went through a formal risk assessment process defining for each risk its impact and the probability that it will occur. This formal process uses pre-established criteria (Appendix 8). Participants were asked to vote on the impact of each risk to the Department, and the probability of that risk occurring over a) the next 10 years, and b) the next 50 years. All participants were given the choice to vote and all voting was conducted anonymously (BPS Resolver Inc., Ballot software, 2013; n=16 for all voting exercises). Voting results were reviewed in plenary. In cases where there was a significant lack of agreement among the votes, results were discussed and the vote was repeated. The impact and the probability of each risk were considered independently.

Prior to the voting process, participants discussed and reviewed a list of assumptions that were prepared and noted during meeting discussions:

- Likelihood of the risk occurring is assessed for both 10- and 50-years
- Human stressors are expected to increase in the foreseeable future but are not taken into account in this exercise
- Spatial heterogeneity in the landscapes, waterscapes and human usage patterns affects the ability to integrate projections and impacts across the Freshwater LAB
- Need to assume DFO business as usual into the future
- Model projected trends may be too conservative

* Risk assessment was completed with under-represented expert groups from Small craft harbour and other infrastructure clients.

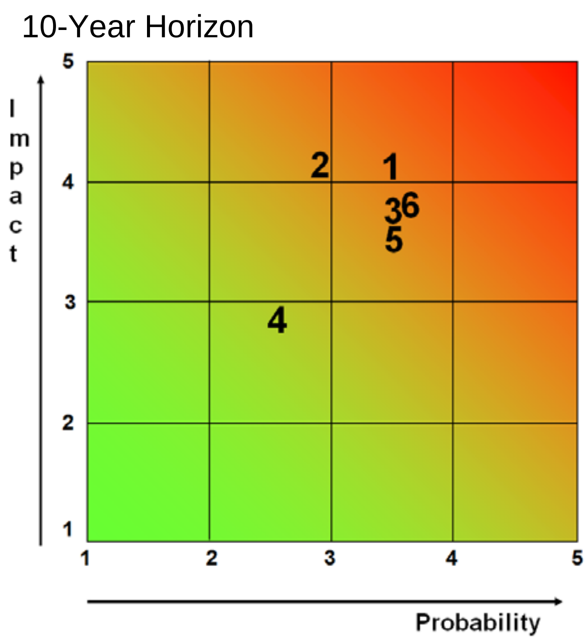
Most of the results of the voting followed a normal distribution, with the exception of Risk 2 (changes in biological resources), which had a uniform distribution for impact and probability voting.

Risk Heat Maps

Results

Voting results for the level of impact of each risk (Appendix 2-7) by the perceived probability of the impact occurring at the 10- and 50-year timescales were prepared as heat maps (Figures 4 and 6), using the Ballot software (BPS Resolver Inc., 2013). Voting for the impact ranking for each risk was only conducted once so the impact scores are the same in Figures 4 and 6, however, the probability of each risk on the 10- and 50- year heat maps are adjusted based on the voting for each timeframe. The Risk Index (i.e. risk exposure; product of impact and probability rankings) are presented for the 10 and 50 year timescales in Figures 5 and 7 respectively. A larger Risk Index indicates a greater threat for the Department.

Overall, based on the Risk Index, the greatest risks to the Department's mandate in the freshwater environment are ecosystem and fisheries degradation and damage (Risk 1; very high to extreme impact, moderate to almost certain probability) and changes in access and navigability of waterways (Risk 6; high to very high impact, moderate to almost certain probability) (Figures 4 to 7) – these risks have the highest Risk Indices on both timescales. The Risk Index of species reorganization, infrastructure damage and changes in biological resources (Risks 3, 5, and 2) were the most tightly grouped over the two timescales indicating a similarity in perceived impact and probability of occurrence. Of this grouping however, only changes in biological resources (Risk 2) presented very high to extreme impact concerns, although had a lower probability of occurrence into the future (Figures 4 and 6). Of all of the risks identified, increased demand of emergency response (Risk 4) is expected to provide the smallest overall risk exposure to DFO over both timescales.



Six Departmental Risks

1. Ecosystem and Fisheries Degradation and Damage
2. Changes in Biological Resources
3. Species Reorganization and Displacement
4. Increased demand to provide Emergency Response
5. Infrastructure Damage
6. Changes in Access and Navigability of Waterways.

Figure 4. Heat map showing the impact to the Department verses probability for each of the six Departmental risks for the 10-year horizon.

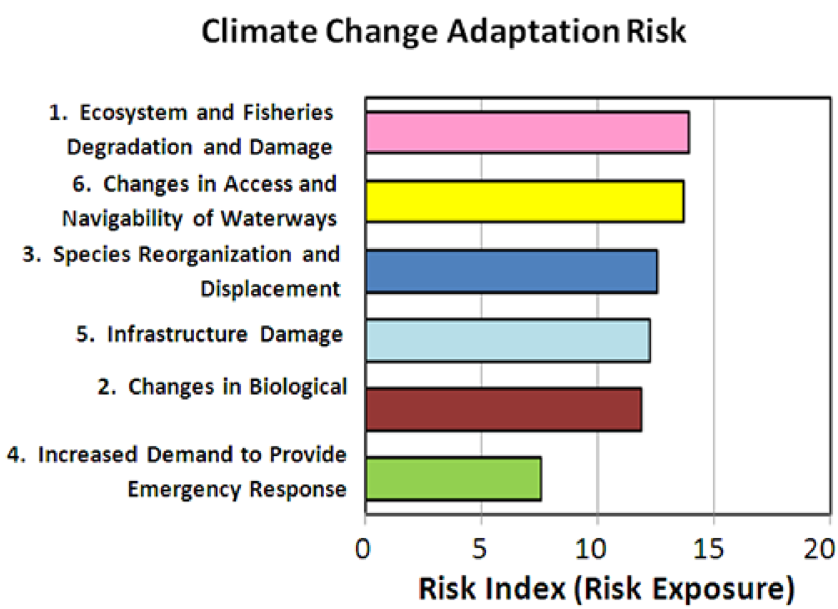


Figure 5. Histogram showing Risk Index (risk exposure) for each DFO Risk on the 10-year horizon. The Risk Index is the product of the risk's impact and probability rankings. A larger Risk Index indicates a greater risk exposure for the Department.

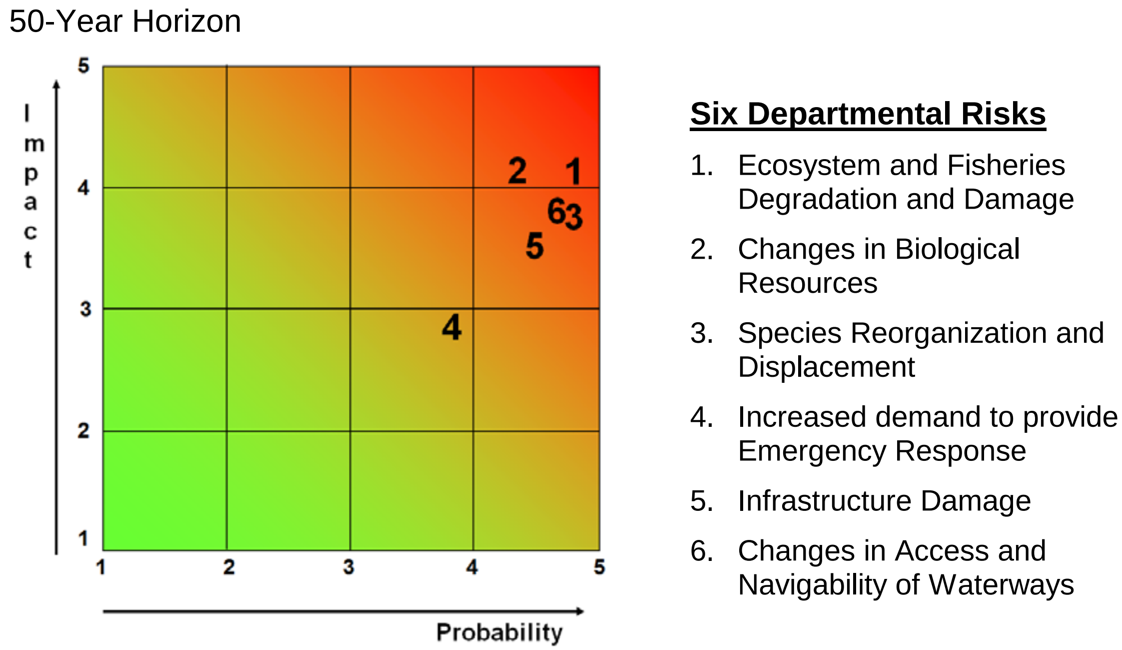


Figure 6. Heat map showing the impact verses probability for the six Departmental risks for the 50-year horizon.

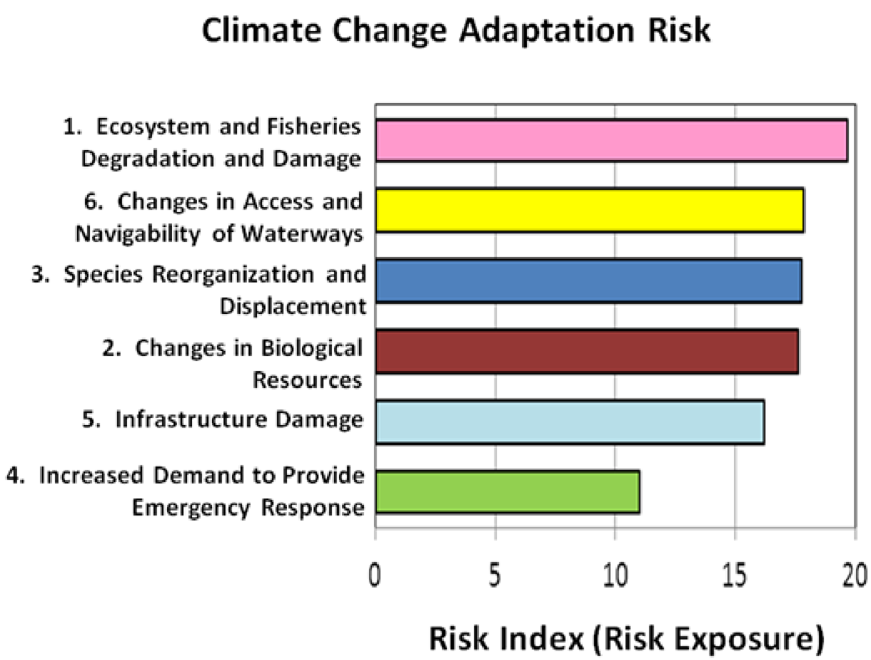


Figure 7. Histogram showing Risk Index (risk exposure) for each DFO Risk on the 50-year horizon. The Risk Index is the product of the risk's impact and probability rankings. A larger Risk Index indicates a greater risk exposure for the Department.

Considering the Risk Index components separately (impact and probability) and focusing on impact rankings, the three ecosystemic risks (Risks 1, 2, 3) as well as the risk of infrastructure damage (Risk 5), and change in access and navigation (Risk 6) were considered as having on average a very high impact on DFO in the future (Figures 4 and 6). Very high risk events can result in major damage and losses that require proper management to be addressed. The assessment of the impact of changes in biological resources (Risk 2) had a greater range of votes - ranging from low to extreme impacts; the majority of votes were evenly split between extreme and very high impact classes for Risks 1, 3, 5 and 6. The increased demand to provide emergency response (Risk 4) was anticipated to have a medium impact representing events that can be managed under normal circumstances by DFO. Increased demand to provide emergency response (Risk 4) involves two facets: the risk associated with the Department having to deal with environmental damage as a result of spills and the risk associated with managing human rescue operations throughout the region (e.g. search and rescue, and vessel assistance).

Examining the probability component of risk exposure, for ecosystem and fisheries degradation and damage (Risk 1), infrastructure damage (Risk 5) and changes in access and navigability of waterways (Risk 6), the probability of occurrence was ranked for the 10-year timeframe as likely and the 50-year timeframe was ranked as almost certain (Figure 4 and 6). The probability of occurrence of change in biological resources (Risk 2) was ranked in the 10-year timeframe as moderate and the 50-year timeframe as likely. Species reorganization and displacement (Risk 3) was ranked in the 10-year timeframe as likely to occur and the 50-year time frame as almost certain for occur. Increased demand to provide emergency response (Risk 4) had a probability at the 10-year timeframe of likely or moderate, and on the 50-year timeframe as likely. For all risks, the probability of occurrence was perceived to be much higher in the 50-year projection (probability ranged from almost certain to likely) than in the 10-year (probability ranged from likely to moderate).

Discussion

The high risk exposure to the Department of future climate change related damages to fisheries, biological resources, species displacement and community reorganization (Risks 1-2-3) are due to both the ongoing expansion in commercial, recreational or Aboriginal fishing pressure as a result of increased access to resources, and increased pressure on currently harvested species that are impacted negatively by the identified climate drivers and impacts on the system (cumulative impacts). A loss of coldwater fish species, and a shift toward smaller individuals could have a large impact on current commercial, recreational and subsistence (including Aboriginal) fisheries. As water temperatures increase, an increased northern distribution of cool and warmwater fishes may present new fishery opportunities. DFO has the ultimate responsibility for these resources and as climate change continues to change the biological systems and the environment, DFO may be called on to protect more of these harvested species or manage human activities around these fisheries differently. Changes in access and navigability (Risk 6) also present a high risk exposure to the department due to increased potential for erosion from strong storm events causing sedimentation that may require dredging and temporary re-routing. Periods of drought in some areas can have the potential to affect connectivity and locks due to reduced water levels. These changes will also have an effect on the infrastructure of DFO (Risk 5).

Sources of uncertainty and other considerations

For each of the six Departmental risks, participants identified gaps in knowledge that limited our understanding of the impacts of climate change on the Department (Appendix 2-7). During voting, participants ranked some impacts and probabilities of occurrence on qualitative information because the quantitative information was not available or has not been well documented in the literature.

Participants acknowledged that some of the aquatic systems in the freshwater LAB are managed. In some cases it is difficult to attribute the observed long-term trends to climate change compared to direct management practices (e.g. thermal effluents, contamination, water diversions, dams, water level regulations, other land-use impacts etc.). Participants also noted that the identification of management controls and their impacts could potentially be important for determining appropriate response to future climate change.

There is a general recognition that not all climate variables will change in a linear fashion; that current climate models do not include feedback factors (e.g. human adaptation); and that climate variables that are projected to change could interact in complex ways that are not fully understood. The implications of multiple stressors are also not sufficiently known (e.g. aquatic invasive species). Climate and ecosystem models do not incorporate all possible feedback effects or loops as of yet.

Participants recognized a lack of projection studies in the literature for several climate-mediated variables. Specifically, future changes to contaminant and nutrient loading to the water have not been fully evaluated or have incomplete models. Contaminant loading, for example, is difficult to predict, but will vary with changes in precipitation. Also, there is very little information about projections of erosion, accretion, flooding, storms, and changing water routing. There was a general lack of information on coastal and riverine process changes. Projections for wind exist for the region, however results varied substantially across studies and, thus this information could not be synthesized for this report. The lack of this information reduces our ability to predict impacts to connecting waterways and species movement. The effects of climate change on water acidity, groundwater, permafrost melt, and glacial melting at the headwaters are not clearly understood or have not yet been modeled explicitly.

Participants understood that some species may adapt to changes in climate. However, adaptation will occur at a slower rate than will change in the climate variables. For example, it is very unlikely that coldwater species, such as Lake Trout, would adapt to a changing climate in sufficient time to prevent large range shifts. These patterns of change are not sufficiently understood but, participants agreed that this could have major implications for the three biological risks (e.g. potentially leading to an overall decrease in biodiversity rather than simply distributional shifts).

While it is generally understood that extreme weather events are exacerbated by climate change, projections of such events are not available at the regional-level for the Freshwater LAB. Participants recognized that extreme events (e.g. wind/waves, storms) could have important implications for both the biological (Risks 1-3) and the technical risks (Risk 4-6). Particularly relevant is the impact this may have (e.g. erosion) on important habitats for fisheries, invasive species and for species at risk. In many cases, the understanding of climate extremes has been derived from global-level analyses from the Intergovernmental Panel on Climate Change (IPCC 2012) and from inferences made by participants based on other available information. The group also discussed that projected trends are conservative and that current observations are trending towards larger magnitudes of change.

Participants integrated the information provided in the summary sheets and background documents in their evaluation and ultimately their voting on risk impacts and probabilities. But, participants noted that the background reports and the information prepared for this risk assessment were prepared by sub-basin and were not all written by the same author. These differences and differences in methods of compiling information for each sub-basin could lead to differences in individuals’ interpretation of the risks.

Lastly, greater input prior to and during the meeting from technical experts from DFO's sectors that manage infrastructure would have been beneficial in addressing risks 4 to 6. However, prior to the meeting, some individuals representing these DFO clients were interviewed and their input was included in the risk summary sheets 4 to 6.

Conclusions

Participants identified a number of common threats and opportunities for the Department (Table 1). Looking across the six risks these common elements emerged for the biological (risks 1-3) or technical (risks 4-6) risks

Table 1. Threats and opportunities identified that are common for the biological risks (risks 1-3) and technical risks (risks 4-6).

	Threats	Opportunities
Biological Risks	Altered species distribution and composition.	Increased habitat and food availability for some species (warm and coolwater fishes).
	Loss of important, essential and critical habitats.	Increased opportunity for fisheries (commercial, Aboriginal, recreational).
	Smaller size-at-age for fishes.	
	Increased loading of contaminants and nutrients.	
Technical Risks	Increased health and safety issues (public and employee).	Longer season for open-water use (e.g. shipping, tourism, fisheries).
	Increased length of season and expansion of demand for services.	

Of the six risks, all the biological risks (Risks 1, 2, and 3) were considered to have a very high potential risk exposure for DFO, but thE ecosystem and fisheries degradation and damage (Risk 1) and changes in access and navigability of waterways (Risk 6) had the greatest impact and probability of occurrence in the next 10 and 50 years. Changes in biological resources (Risk 2), species reorganization and displacement (Risk 3), and infrastructure damage (Risk 5) were also considered very high risk areas. Increased demand to provide emergency response (Risk 4) was perceived to have present medium risk exposure to the Department. Overall, the probability of occurrence was greater in the 50-year time scale than in the 10-year time scale for all risks.

Several knowledge gaps for each risk were outlined in the summary sheets, as well as overall sources of uncertainty and other considerations. Identification of these gaps was important to help frame the context in which participants assessed the risk of climate change to the Department. Moving forward, addressing the knowledge gaps would benefit the Department in developing a better understanding of the risks of climate change.

Threats and opportunities were identified and outlined in the summary sheets. A few threats and opportunities were identified that were common across the biological or technical risks such as:

- loss of important habitats,
- increased length of season,
- demand for services (threats),
- increased opportunity for fisheries and
- longer season to fisheries (opportunity).

The results of this meeting suggest that the biological risks pose the greatest climate change risk to the Department in the Freshwater LAB. This assessment will benefit from future integration meetings (Science, socio-economic and policy assessment results) which will assist in the prioritization of risks and reflect more accurately departmental impacts in the Freshwater LAB. The ACCASP risk assessment is an iterative process; it is expected that information from the integration meetings, updated background documents and increased participation at future Science advisory risk assessment meetings by other scientific and technical experts outside the department (i.e., increased sample size for voting, broadened expertise and experience) will increase the confidence of the assessment results.

Contributors

List of participants and their regional sectors by alphabetical order

Name	Affiliation
Sommer Abdel-Fattah	DFO Science, Central & Arctic
Paul Blanchfield	DFO Science, Central & Arctic
Gavin Christie (co-chair)	DFO Science, Central & Arctic
Cindy Chu	DFO Funded Post-doc
Susan Doka	DFO Science, Central & Arctic
Alain Dupuis	DFO Science, Central & Arctic
Marie-Claude Fortin	DFO Science, National Capital Region
Haitham Ghamry	DFO Science, Central & Arctic
Ray Hesslein	Emeritus, DFO Science, Central & Arctic
Scott Higgins	DFO Science, Central & Arctic
Elizabeth Joyce	DFO Science, Central & Arctic
Marten Koops	DFO Science, Central & Arctic
Shidan Murphy	DFO Funded Post-doc
Gilles Olivier (co-chair)	DFO Science, National Capital Region
Tom Pratt	DFO Science, Central & Arctic
Patricia Ramlal	DFO Science, Central & Arctic
Jim Reist	DFO Science, Central & Arctic
Mike Rennie	DFO Science, Central & Arctic
George Schlagintweit	Canadian Hydrographic Service, Central & Arctic
Lee-Ann Smith	DFO Policy – Integrated Risk Management Specialist, Central & Arctic

Approved by

Helen Joseph, Director of Oceanography and Climate, Ecosystem Science, Ottawa, Ontario (Approved February 22, 2013).

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Appendix 1.

Trends and projections summary table for the Freshwater Large Aquatic Basin as part of the Aquatic Climate Change Adaptation Services Program's preliminary risk assessment for Fisheries and Oceans. Freshwater Trends and Projections summarized for the Prairies areas and Great Lakes Basin.

Climate Variable	Trends (~past 50 years)	Projections (~in 50 years) *Will and May represent likelihood of occurrence – see table below*
Mean Air Temperature	Annual temperatures between 1970 and 2000 increased more than 0.4^{o}C per decade with winter temperature increasing by 0.9^{o}C/decade. Winter temperatures increased more dramatically than during other seasons.	Annual temperatures will increase for all seasons in the range of 0.8-5.4^{o}C. Winter temperatures will increase more than summer temperatures. Minimum temperatures will increase at a higher rate than maximum temperatures.
Mean Surface Temperature	Open-water surface temperatures increased slightly from early 1900s to present (0.1-0.2^{o}C/decade) and more abruptly in recent decades (1.2^{o}C/decade since 1985). Limited studies for Lake Winnipeg watershed.	Surface temperatures will increase in the range of 1.5-4.0^{o}C. During summer stratification, the epilimnion temperature may increase by approximately 1.5-4.0^{o}C while the hypolimnion temperature may or may not increase.
Lake Stratification	Limited trend analysis available for the Lake Winnipeg watershed. For boreal lakes, dry periods were associated with deeper thermocline depths. Lakes Superior and Michigan and Huron are stratifying earlier by 0.5-0.8 days per year during the period 1979-2010. Limited data for Lakes Ontario and Erie.	Depth of the thermocline may become shallower. Summer stratification may increase in duration and strength.
Ice Dynamics	Overall, earlier ice break-up and later freeze-up (change of 0.6 days/decade from 1846-1995 and more abrupt change of 2.1-2.4 days/decade from 1969-2012), resulted in shorter ice cover duration. For the Great Lakes, the last spring freeze occurs 1 week earlier than in 1900. For Lake Winnipeg, no trend was observed. Ice thickness has declined in some Great Lakes while no trend has been observed for some boreal lakes.	Ice break-up will occur earlier (1-25 days), ice freeze-up will occur later (1-17 days), resulting in a shorter ice cover duration. One exception is for the Great Lakes where ice break-up is projected to become earlier by only 1-2 days. Overall, ice cover thickness will decrease by 1-25cm.
Annual Surface Runoff	No trend analysis available.	Spring runoff expected to increase, but occur earlier. Annual runoff may decrease.
Annual Precipitation & Storms	Mean annual precipitation increased across regions with the exception of a decrease in the Saskatchewan river sub-basin. The frequency of heavy rain events and cyclones in the Great Lakes has increased.	General increase in annual precipitation by 3-18%. Projections are more uncertain for the Saskatchewan river sub-basin (both an increase and a decrease have been predicted). Higher precipitation expected in winter compared to summer. Type of precipitation will change (e.g. more winter rain vs. snow). It is expected that there will be fewer precipitation events, but at higher intensity or more extreme weather events.

Climate Variable	Trends (~past 50 years)	Projections (~in 50 years) *Will and May represent likelihood of occurrence – see table below*
Streamflow	Mean annual streamflow volume increased south and east of Lake Winnipeg and decreased in the Saskatchewan River sub-basin (-1.4 to -16% /decade). Peak stream flow timing occurs earlier. Limited studies for the Great Lakes watershed.	Annual streamflow volume is projected to decrease in the Great Lakes watershed and to remain unchanged or increase in the Lake Winnipeg watershed. During the summer months, streamflow in the Saskatchewan river sub-basin could decrease by up to 50%. Overall, limited projections available.
Flood frequency	Flood frequency possibly increased for the Red River Basin (2 in 1892-1945 vs. 11 in 1945-1999).	No projections available. [See Precipitation / Storms]
Lake Levels	Lake levels are highly variable. Great Lakes experienced three decades of high water levels until the 1990s. Since 1997 water levels on L. Michigan and L. Huron have fallen 1.07m and a record drop in L. Erie in the late 1990s. Peaks and lows in hydrograph of Lake Ontario and Erie occur one month earlier. Decreases levels in closed-basin lakes in the Saskatchewan river sub-basin.	Lake level is variable but is largely supply driven with regulation modification. Great Lakes, particularly Lake Erie are projected slight to moderate average annual declines (does not include seasonality). Seasonal peaks and troughs will occur earlier. Closed-basin lakes projected to decline.
Wind	Mean annual wind speed decreased slightly. No trend analysis of frequency and magnitude of extremes available (e.g. storm surges).	Projections not available for extreme events. [See precipitations / storms]
Evaporation	Increasing trend in evaporation.	Evaporation is expected to increase due to increased temperatures and less ice cover.
Nutrient Loading	Phosphorus loading decreased throughout the Great Lakes watersheds. In contrast, phosphorus loading to Lake Winnipeg increased from the Red river/Assinniboine river sub-basins since the 1970s. [Caveat: A proportion of nutrient loading is related to increased runoff but also to land use changes.]	Expected to decrease in the Great Lakes watershed (likely due to farming/land practices and retention) and projected to increase in the Red river/Assinniboine river sub-basins (+5% Total Phosphorus, +33% Total Nitrogen).
Hypolimnetic Dissolved Oxygen Content	Decreased in some systems. Limited data available. A proportion of the change is likely related to changes in trophic status.	During open-water season, hypolimnetic oxygen concentrations are projected to decrease because of the increase in duration of stratification while the opposite will occur during ice-covered season. In some systems, increased nutrient loading may further decrease dissolved oxygen concentrations.
Salinity	None to increased salinity in Saskatchewan river sub-basin. Does not apply to Great Lakes region.	No projections available.

**All of the information contained in the trends and projections summary table is supported by peer reviewed literature.

Notes:

- Projections for the 10-year time scale were not shown (these are available). Decadal and inter-annual variability can be expected to be more important in driving short-term climate and limnological characteristics. Generally, information documented on trends may be more relevant in determining the direction of change for most variables in the short term.
- Not all freshwater in Canada is covered by this assessment, including a lack of information for some variables, regional inland lakes, secondary and tertiary watersheds and connecting channels.
- Continued human impacts and interventions are not captured in projection estimates outside of those implicitly included in IPCC (2007) scenarios.
- Some gaps in the summary of this material include solar radiation, cloudiness, albedo, coastal processes, contaminants and acidification, water clarity, groundwater, permafrost, and dewatering of glaciers and their subsequent impacts on trends and projections.

Definitions:

Extreme Events - weather on a larger, more intense scale that can cause damage to habitats and infrastructure.

Discharge- (streamflow and flow rate) is expressed as dimensions of volume per time.

Winter- Average of December, January, February conditions

Spring- Average of March, April, May conditions

Summer- Average of June, July, August Conditions

Fall- Average of September, October, November conditions

The standard terms used in this summary to define the likelihood of an outcome or result where this can be estimated are (Adapted from IPCC, 2007). (Note that the higher degrees of likelihood defined by IPCC are not differentiated in this analysis)

Terms	IPCC Likelihood Terminology	Likelihood of the occurrence/ outcome
Will	Extremely likely	> 95% probability
Will	Very likely	> 90% probability
Will	Likely	> 66% probability
May	More likely than not	> 50% probability
May	About as likely as not	33 to 66% probability
May not	Unlikely	< 33% probability
Will not	Very unlikely	< 10% probability
	Unknown	No probability can be assigned

* Events that were unlikely or very unlikely were not included in this summary.

Preparatory T&P and IVO Assumptions:

- The trends and projections have been averaged or put into ranges to create an overall LAB-wide freshwater analysis; this misrepresents range and variability.
- Human intervention or adaptation is not accounted for in risk assessment and planning.
- The size and impact of aboriginal fishing and aquaculture practices is not known.
- Cumulative impacts and increased stressors (including those from climate) and their interactions are not addressed in the assessment.

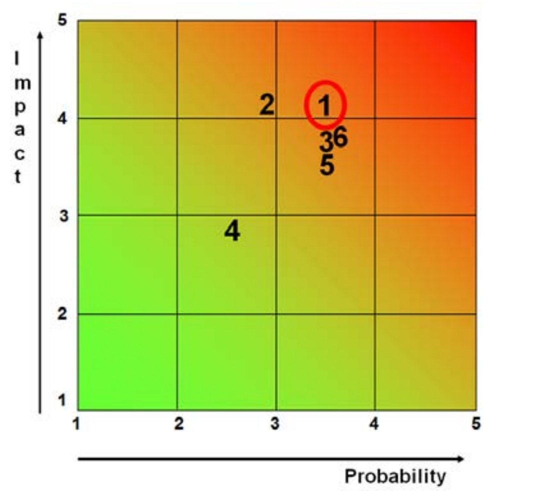
Appendix 2.

Risk summary sheet for the Ecosystem and Fisheries Degradation and Damage (Risk 1) for the Freshwater large aquatic basin

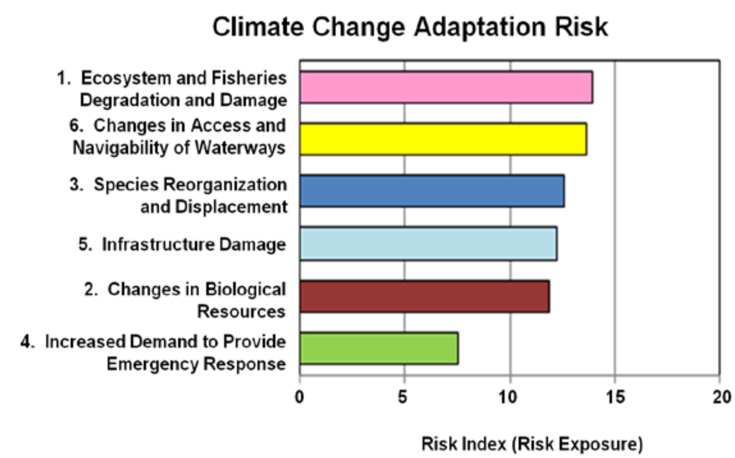
Note that the table is presented with no direct correspondence between the individual risk drivers (on the left side of the table) and the consequences (on the right). Letter coding refers to the sub-basin as described below.

Freshwater Large Aquatic Basin
Risk 1: Ecosystem and Fisheries Degradation and Damage
Risk Statement: There is a risk that climate change will affect DFO's ability to meet its strategic and policy objectives related to Oceans Management, and the sustainable development and integrated management of resources in Canada's aquatic environment.
Context: This risk focuses on DFO's stewardship role to managing and protecting fish habitat the leadership role of the department in the Canada's Ocean Strategy and the sustainability of the oceans and their resources (Enabling legislation includes the Ocean's Act, Fisheries Act).

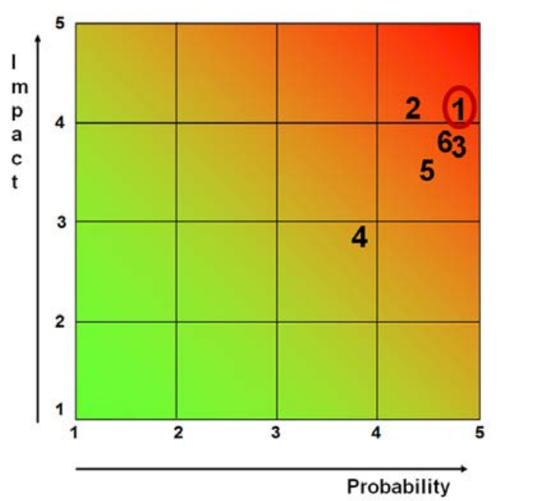
Position on Heat Map - 10 year Horizon



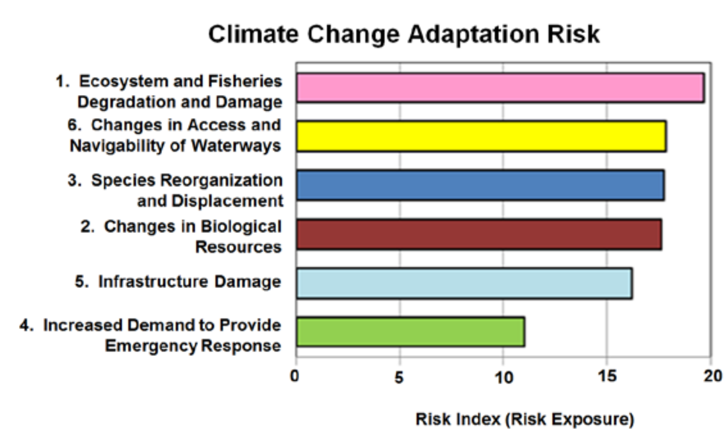
Risk Index (Probability x Impact) - 10 year Horizon



Position on Heat Map - 50 year Horizon



Risk Index (Probability x Impact) - 50 year Horizon



Main Risk Drivers	Potential Consequences: Threats
▪ Increases in stratification length and strength and altered thermocline depth could affect primary production through altered light and nutrient availability. (GL, WRB, SR, LW) ▪ Increased temperatures, primary production and stratification strength and length will decrease deepwater oxygen concentrations during the open-water season in some systems. (GL, WRB, SR, LW) ▪ Increase or continuation of high precipitation and extreme weather events will maintain or increase nutrient and contaminant loading. (GL, WRB, SR, LW) ▪ Increased water temperature, precipitation and increased nutrients increase risk of blue-green algal blooms. (GL, SR, LW) ▪ Increased length of growing season and higher water temperatures increases primary and secondary production and growth and production of fish. (GL, WRB, SR, LW) ▪ Increased evaporation and decreased precipitation will increase salinity in closed-basin lakes in Prairies altering habitat suitability for fishes. (SR-12). ▪ Increased water temperatures increases adult mortality for warmwater fishes and egg mortality particularly for spring and summer spawners. (GL, WRB, SR, LW) ▪ Change in timing of ice formation, break-up and change in stream discharge dynamics increases risk of disrupting spawning cues, shifting timing of spawning and decreasing success of spawning. (GL, WRB, SR, LW) ▪ Seasonal timing changes in spring and fall may cause asynchrony of predator-prey dynamics (predator needs and prey availability). (GL, WRB, SR, LW) ▪ Increasing temperature, primary production and length of growing season will lead to potential increases in northern range of warm-water fishes. (GL, WRB, SR, LW) ▪ Increasing temperature, primary production and length in growing season will lead to reduction of habitat for cold and coolwater species at southern edge of range. (GL, WRB, SR, LW) ▪ Increase temperature, will increase the range of expansion of current non-native species and invasion of new species. (GL, WRB, SR, LW) ▪ Predicted reductions in summer period stream discharge (particularly in Prairie rivers) and water levels decreases potential for maintaining instream flow needs and increases the risk of reduced quality of fish habitat and wetlands (rearing, food supply, and connectivity of suitable habitats) and probability of	▪ Increased nutrient concentrations increase the probability of shift to pelagic primary production and decreasing benthic primary production. This would affect energy pathways from primary producers to fishes. ▪ Increase in water temperature and contaminant loading increase potential for altering aquatic ecosystems and increasing fish body burden of some contaminants. (GL, WRB, SR, LW) ▪ Potential shifts to harmful blue-green algal blooms may have negative effects on secondary production. ▪ Depending on thermal guild, fish productivity could suffer (e.g. coldwater species). ▪ Decreasing deepwater dissolved oxygen concentration may increase the occurrence of summer fish kills in shallow stratified lakes. ▪ Increased primary productivity may contribute to decreased deepwater dissolved oxygen concentrations in stratified systems by increasing organic matter available for decomposition processes. ▪ Increased water temperature may increase pathogens and parasite occurrences. (GL, WRB, SR, LW) ▪ Increased salinity in closed-basin lakes in Prairies could decrease abundance and diversity and alter community composition of fishes. ▪ Increased referrals to Fisheries Protection (Fish Habitat Management) for shoreline re-building after storm events. ▪ Increased management and regulation needs to risk manage aquaculture operations (e.g. system-specific assessments for cage locations). ▪ Changes in fish community composition and structure. Wetlands and coastal systems may be more susceptible to degradation due to nutrient and contaminant loading as well as reduction of water levels. ▪ Shift to smaller body size for all trophic levels. ▪ Shortening of winter season may negatively impact fall spawning recruitment. ▪ Habitat alteration from all factors. ▪ Changes in phenology may impact foodwebs and fish productivity.

Main Risk Drivers	Potential Consequences: Threats
extreme low to no flow events. (SR) ▪ Increased temperatures and decreasing deepwater dissolved oxygen concentration will change community structure, native and invasive species distributions, foodweb interactions and diversity. (GL, WRB, SR, LW) ▪ Increased water temperatures, reduced oxygen and reduced water levels may affect fish connectivity, migration and habitat. (GL, WRB, SR, LW)	

Opportunities
▪ Shorter ice-on season leads to a decrease in winter fish kills in small Prairies lakes. (SR) ▪ Longer growing seasons will increase juvenile over-winter survival for warm-water fish. (GL, WRB, SR, LW) ▪ Expanded range and type of commercial, recreational, and aboriginal fishing and aquaculture. ▪ With increased growth and survival of warm-water fish, and expansion of warm-water fish production northward there is a potential for the development of new commercial fisheries and aquaculture. ▪ Overall increase in productivity for cool and warm-water fisheries (e.g. Walleye in LW).

Gaps
▪ Some climate-related research programs have been terminated causing a stagnation of climate research and data describing interactions between climate and fisheries ▪ More research is needed to improve existing knowledge and capabilities to forecast short and long-term precipitation trends, hydrodynamics of streams including ice and in-stream flow needs trends and projections. Ensemble precipitation prediction is needed to maximize forecast skill and further downscaling is needed to bring coarse-resolution to the resolution of a subwatershed. ▪ Challenge of compiling data from literature review to represent factual information (sometimes limited resources, limited knowledge about the process and model used, age of data etc.) ▪ There is a lack of modelling on habitat changes and associated ecological risks (how and where species composition and production will change). ▪ The effects of multiple stressors, interactions, and cumulative factors are not sufficiently known and should be addressed. ▪ Changes in trends often do not account for extremes and variability; extremes will be highly important for ecosystem risk. ▪ Limited projections of stream flow and runoff. ▪ Trends and projections are limited and/or not available for nutrient and contaminant loadings. For example, the link between precipitation, runoff and contaminant loadings is poorly understood. ▪ Human intervention/adaptation is not accounted for in risk assessment and planning. ▪ Ecosystems of the Great Lakes Basin and Prairies region are somewhat different but have been compiled into one generalized basin. ▪ Improved understanding of critical environmental thresholds and abrupt hydrologic changes is needed. ▪ There is little quantitative information available on the relationship between climate change and Aquatic Invasive Species in the Freshwater LAB. ▪ The relationship between climate changes and abrupt changes in water quality is not well understood.

Gaps
▪ Impacts to specific, yet ecologically important coastal wetlands and protected areas are difficult to predict and are not accounted for, but should be. ▪ Limited knowledge on benthic-pelagic energy pathways. ▪ Focus of most studies is offshore, while coastal impacts are highly important and needs addressing. ▪ Aboriginal fishery impacts are generally unknown. Information from St. Lawrence and Quebec maybe available but has been difficult to obtain. ▪ Link between climate change and aquaculture is unclear and unresolved. ▪ Limited knowledge related to storm events, flooding, and other extreme events (projections and impacts). ▪ Limited understanding between the linkage of severe events and their terrestrial impact with the aquatic system. ▪ Specific information on trends and projections regarding coastal and riverine processes is lacking and much needed.

Sub-basin codes:

LW – Lake Winnipeg

WRB – Winnipeg River and Boreal

GL – Great Lakes

SR – Saskatchewan River Basin

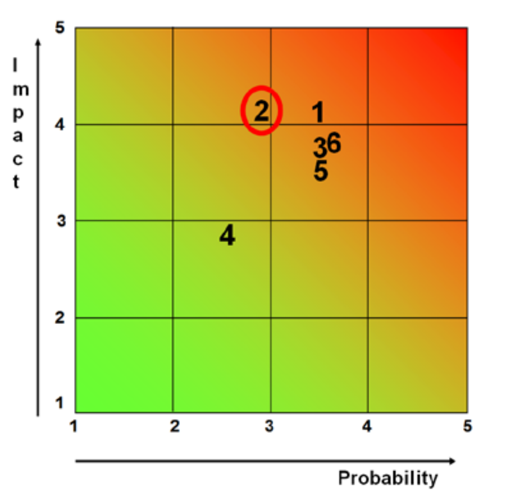
Appendix 3.

Risk summary sheet for the Changes in Biological Resources (Risk 2) for the Freshwater large aquatic basin

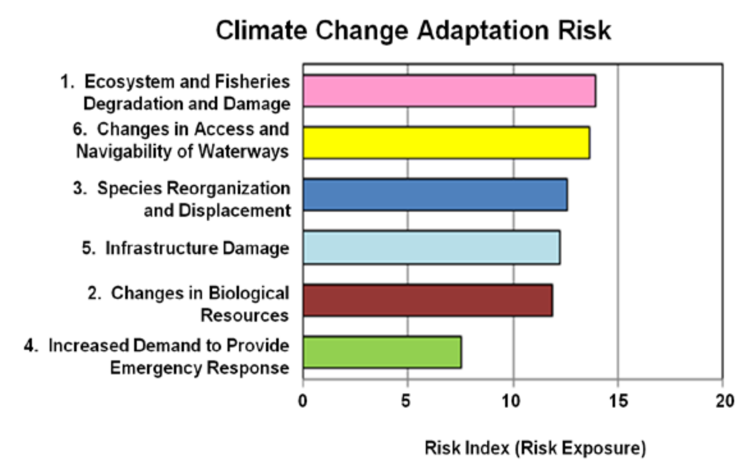
Note that the table is presented with no direct correspondence between the individual risk drivers (on the left side of the table) and the consequences (on the right). Letter coding refers to the sub-basin as described below.

Freshwater Large Aquatic Basin
Risk 2: Changes in Biological Resources
Risk Statement: There is a risk that climate change will affect DFO's ability to manage and protect the abundance, distribution and quality of harvested fisheries and aquaculture stocks.
Context: This risk refers to DFO's management of fisheries resources (fish stocks, shellfish and marine mammals) (Enabling legislation includes the Fisheries Act).

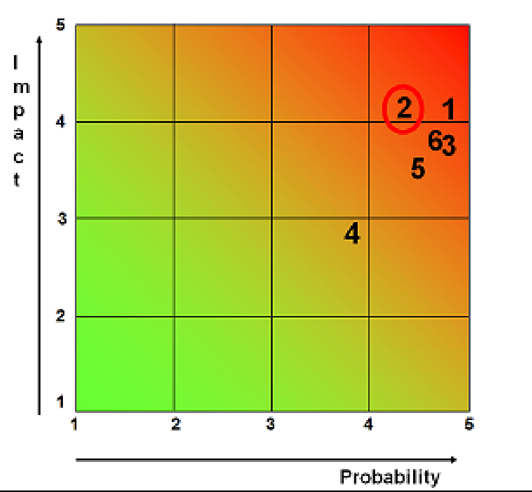
Position on Heat Map - 10 year Horizon



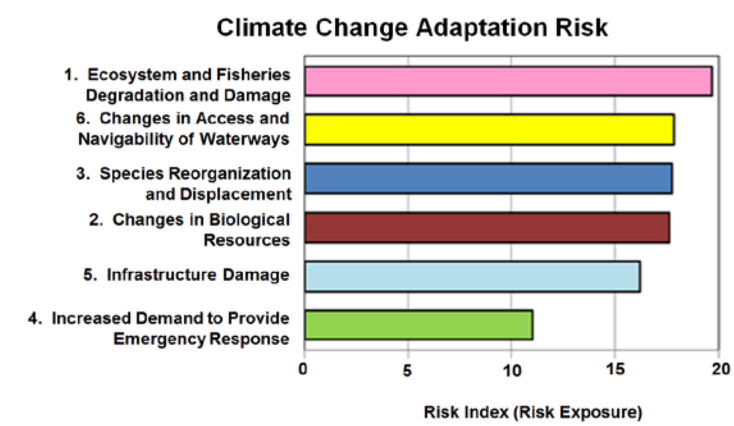
Risk Index (Probability x Impact) - 10 year Horizon



Position on Heat Map - 50 year Horizon



Risk Index (Probability x Impact) - 50 year Horizon



Main Risk Drivers	Potential Consequences: Threats
▪ Change in stratification length and strength and thermocline depths, increases the risk of constraining habitat availability (GL, WRB, SR, LW) and could impact primary production through altered light and nutrient availability (GL, WRB, SR, LW) ▪ Increased water temperature and increased eutrophication will increase blue-green algal blooms and biomass of phytoplankton, increasing risk of low oxygen concentrations in deep/cold water habitats. (GL, WRB, SR, LW) ▪ Increase or continuation of high precipitation and extreme weather events will maintain or increase nutrient and contaminant loading. (GL, WRB, SR, LW) ▪ Increased length of growing season and higher water temperatures increases primary and secondary production and growth and production of cool and warm-water fish (e.g. Walleye, Basses). (GL, WRB, SR, LW) ▪ Change in timing of ice formation and break-up and change in stream discharge dynamics increases risk of disrupting spawning cues, shifting timing of spawning and decreasing success of spawning (e.g. Walleye, Pike, Sturgeon). (GL, WRB, SR, LW) ▪ Seasonal timing changes in spring and fall may cause asynchrony of predator-prey dynamics (predator needs and prey availability). (GL, WRB, SR, LW) ▪ Increased water temperatures and longer growing seasons will increase fish growth rates for warm-water species but increase mortality for cold/coolwater species if thermal thresholds are exceeded. (GL, WRB, SR, LW) ▪ Temperature change, low ground water, dissolved oxygen, and stratification period will have a stronger affect in shallow lakes and streams (e.g. Brook Trout, Lake Trout). ▪ Increased water temperatures increases adult mortality for warm-water fishes. (GL, WRB, SR, LW) ▪ Increased evaporation and decreased precipitation will increase salinity in closed-basin lakes in Prairies altering habitat suitability for fishes (e.g. Walleye and Rainbow Trout). (SR) ▪ Increased temperature, primary production and length of growing season will lead to increases in potential northern range of warm-water fish. (GL, WRB, SR, LW) ▪ Increasing temperature, primary production and length in growing season will lead to reduction of habitat for cold and coolwater species at southern edge of range (e.g. Whitefish, Lake Trout). (GL, WRB, SR, LW) ▪ Predicted reductions in summer period stream discharge (particularly in Western Prairie rivers) and water levels	▪ Increased primary production and stratification strength and length leading to reduced deepwater oxygen concentrations. (GL, WRB, SR, LW) ▪ Increase in water temperature and contaminant loading increase potential for altering aquatic ecosystems and increasing fish body burden of some contaminants. (GL, WRB, SR, LW) ▪ Increase water temperature may increase pathogens, and parasite occurrences. (GL, WRB, SR, LW) ▪ Disruption of food webs from cascading effects. ▪ Distribution of coldwater fish will move or contract northward (due to increased water temperatures). ▪ Smaller size-at-age for fishes because of increased temperatures. ▪ Increased attention needed for instream flow needs especially within environmental assessments across Prairies. ▪ Reduction in ice cover change distribution of winter fisheries. ▪ Reduced habitat for cold and coolwater and coastal species. ▪ Reduction in ice cover will reduce winter fishing. ▪ Change in fish communities will increase eutrophication. ▪ Shift in type of fishery and behaviour of anglers. ▪ Decreased fisheries productivity may occur due to predator-prey asynchrony. ▪ Structural diversions may alter fish migration and cause displacement. ▪ Mercury contamination will affect the harvestable amount of fish. ▪ Increased frequency and magnitude of storms increases the risk of aquaculture cage damage and the incidence of non-native escapees. ▪ Shoreline changes and habitat alteration will affect fisheries production.

Main Risk Drivers	Potential Consequences: Threats
decreases potential for maintaining instream flow needs and increases the risk of reduced quality of fish habitat and wetlands (rearing, food supply, and connectivity of suitable habitats) and probability of extreme low to no flow events. (SR) ▪ Increased temperatures and decreasing deepwater dissolved oxygen concentration will change community structure, native and invasive species distributions, foodweb interactions and diversity. (GL, WRB, SR, LW) ▪ Increase temperature, will increase the range of expansion of current non-native species and invasion of new species. (GL, WRB, SR, LW) ▪ Increased water temperatures, reduced oxygen and reduced water levels may affect fish habitat connectivity, migration and habitat usage and supply. (GL, WRB, SR, LW) ▪ Reduced ice-cover, increased storm frequency, and changes in runoff will affect river and coastal processes altering fish habitat.	

Opportunities
▪ Shorter ice-on season may lead to a decrease in winter fish kills in small Prairies lakes. (SR) ▪ Increased length of growing season and higher water temperatures may increase primary and secondary production and growth and production of cool and warm-water fish (e.g. Walleye, Smallmouth Bass, Bluegill, and Yellow Perch. ▪ Expanded range and type of commercial, recreational, and aboriginal fishing and aquaculture. ▪ Decreased ice cover reduces winter fishing on vulnerable cold-water fishes. ▪ With the expansion of species distribution and longer growing seasons there is a potential for the development of new commercial, recreational and aboriginal fisheries and aquaculture. ▪ Overall increase in productivity and range of warmwater fish species. ▪ Increased salinity in some closed-basin lakes increases the potential for brine shrimp harvesting.

Gaps
▪ The effects of multiple stressors, interactions, and cumulative factors are not sufficiently known. ▪ Changes in trends often do not account for extremes and variability; extremes will be highly important for fish survival. ▪ Impacts of nutrient and contaminant loading changes with in-stream flow needs are not well understood. ▪ Human intervention/adaptation is not accounted for in risk assessment and planning. ▪ Fisheries and AIS and protected species of the Great Lakes Basin and Prairies region are very different but have been compiled into one generalized group. ▪ Improved understanding of critical thresholds (thermal, physiological, habitat) for fishes is needed. ▪ Specific and local wetlands are not accounted for as well as their importance for fisheries' life histories. ▪ Limited knowledge on fish productivity trends in a changing climate. ▪ Size and impact of aboriginal fishing and aquaculture practices not known. ▪ Effects of aquaculture on inland systems under altered climate scenarios largely unknown. ▪ Understanding of toxicology of algae impacts on fish unknown. ▪ Need for whole ecosystem approach due to complexity of pathways.

Sub-basin codes:

LW – Lake Winnipeg

WRB – Winnipeg River and Boreal

GL – Great Lakes

SR – Saskatchewan River Basin

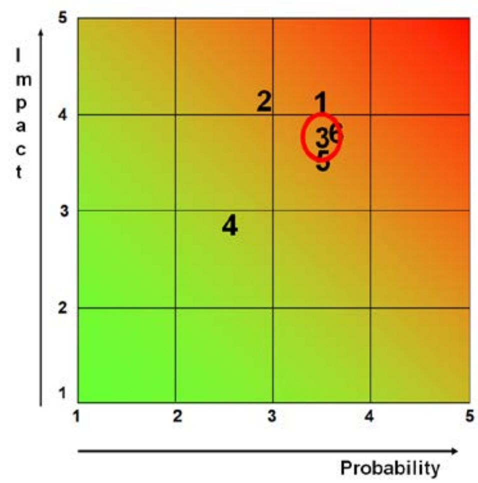
Appendix 4.

Risk summary sheet for the Species Reorganization and Displacement (Risk 3) for the Freshwater large aquatic basin

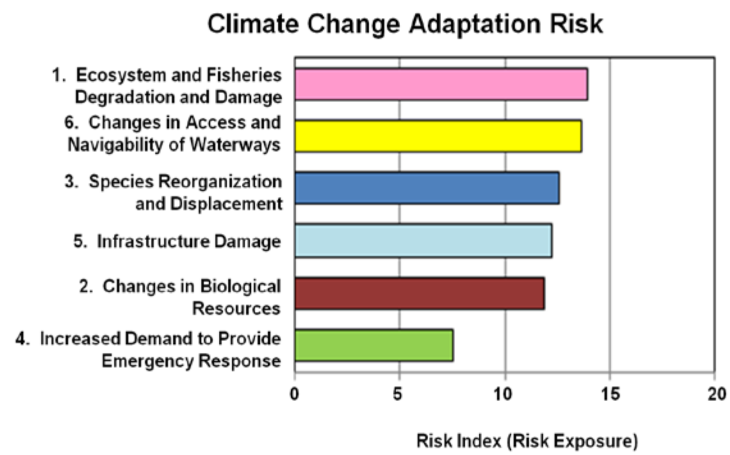
Note that the table is presented with no direct correspondence between the individual risk drivers (on the left side of the table) and the consequences (on the right). Letter coding refers to the sub-basin as described below.

Freshwater Large Aquatic Basin
Risk 3: Species Reorganization and Displacement
Risk Statement: There is a risk that climate change will affect DFO's ability to protect species diversity and species at risk.
Context: Climate change may lead to changes in the location and type of species in various Canadian aquatic habitats. Climate change can limit or extend the range of aquatic species or the introduction or spread of invasive species (Enabling legislation includes the Species at Risk Act).

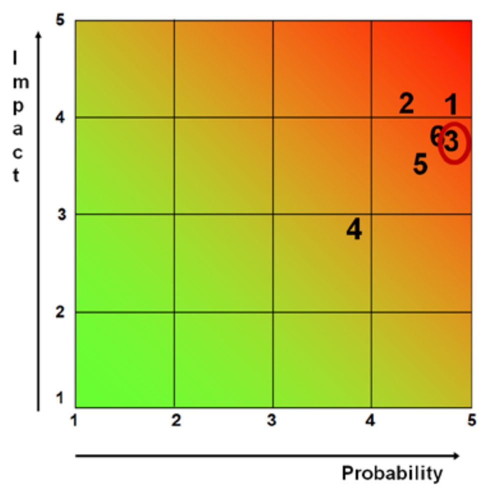
Position on Heat Map - 10 year Horizon



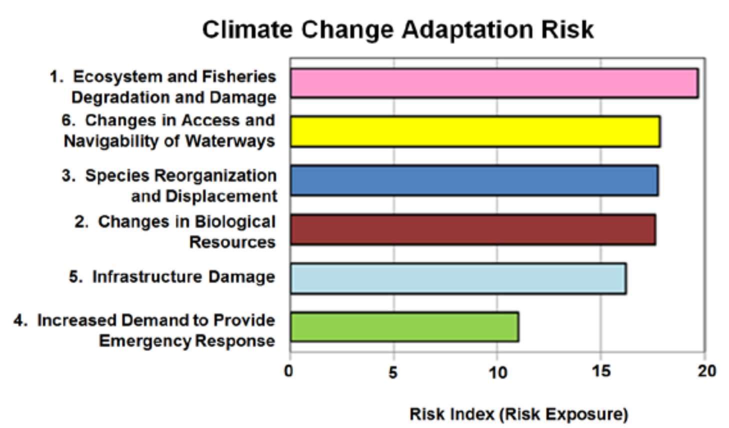
Risk Index (Probability x Impact) - 10 year Horizon



Position on Heat Map - 50 year Horizon



Risk Index (Probability x Impact) - 50 year Horizon



Main Risk Drivers	Potential Consequences: Threats
▪ Changes in hypolimnetic oxygen, stratification length and strength and thermocline depths, increases the risk of constraining habitat availability (e.g. Deep-water Sculpin, Kiyi) (GL, WRB, SR, LW) ▪ Increasing temperature, primary production and length of growing season will lead to increases in potential northern range of warm-water fish. (GL, WRB, SR, LW) ▪ Increasing temperature, primary production and length in growing season will lead to reduction of habitat for cold and coolwater species at southern edge of range (e.g. Pugnose Shiner, Brook Trout). (GL, WRB, SR, LW) ▪ Increased temperatures and decreasing deepwater dissolved oxygen concentration will change community structure, native and invasive species distributions, foodweb interactions and diversity. (GL, WRB, SR, LW) ▪ Increased water temperatures, reduced oxygen, reduced water levels, and streamflow changes may affect fish connectivity, migration and habitat (e.g. Lake Sturgeon, Bull Char). (GL, WRB, SR, LW) ▪ Predicted reductions in summer period streamflow decreases potential for maintaining instream flow needs and increases the risk of reduced quality of fish habitat and wetlands (rearing, food supply, and connectivity of suitable habitats) and probability of extreme low to no flow events (e.g. Eastslope Sculpin). (SR) ▪ Degradation of habitats, possible exploitation, competition and connectivity may affect some Species at Risk that have limited distribution or thermal niches (coolwater/coldwater species such as Rocky Mountain Sculpin and Westslope Cutthroat Trout-Threatened, Lake Sturgeon-under consideration, Endangered). Aquatic biodiversity may respond negatively to decreased streamflow and/or variable streamflow regimes. ▪ Increased temperatures will increase environmental matching for new and potential aquatic invasive species increasing their potential to become established in new, more northerly locations. ▪ Some aquatic invasive species may respond positively to warming (e.g. Common Carp) and/or altered streamflow regimes (e.g. Sea Lamprey) increasing their negative effects on food webs, fishes, and fisheries.	▪ Reduced habitat for cold and coolwater and coastal species. ▪ Simplified native fish community and reduced diversity. ▪ Increase demand to control invasive species (e.g. sea lamprey). ▪ Increased temperatures and ice free conditions leading to new or altered recreational and commercial activities (and other vectors) may facilitate range expansion and invasion of aquatic invasive species. (GL, WRB, SR, LW)

Opportunities
▪ Longer growing seasons, and expanded range of fish may influence type of commercial, recreational or Aboriginal fishing and may benefit commercial and aquaculture fish ▪ Warming may positively affect distribution and/or abundance of some Species at Risk when the current Canadian distribution represents the species' northerly range (e.g. Bigmouth Buffalo, Silver Chub, Carmine Shiner). ▪ Warming may negatively affect some Aquatic Invasive Species (AIS) where thermal habitat requirements are exceeded (e.g. southerly range of Sea Lamprey and Rainbow Smelt).

Gaps
▪ The ecology/biology of some Species at Risk and/or species under consideration for SARA is not fully understood within the context of climate change. ▪ The biology, timing and impact of new invaders are unknown and difficult to predict. ▪ Some evidence exists that increased storm events restructure fish habitat, but it is not well understood how this will impact displacement or reorganization. ▪ Human intervention; management planning, AIS control, re-stocking, barriers, fishing and recreational advances/changes and regulations not accounted for ▪ Rate of change in climate parameters and their integrated consequences for aquatic systems will be faster than potential adaptation responses within the systems. ▪ Climate is changing at a faster rate than ecosystems can adapt, thus our ability to predict impacts is uncertain. ▪ Cumulative impacts of multiple AIS and climate change are uncertain and the interactions may induce unprecedented regime shifts.

Sub-basin codes:

LW – Lake Winnipeg

WRB – Winnipeg River and Boreal

GL – Great Lakes

SR – Saskatchewan River Basin

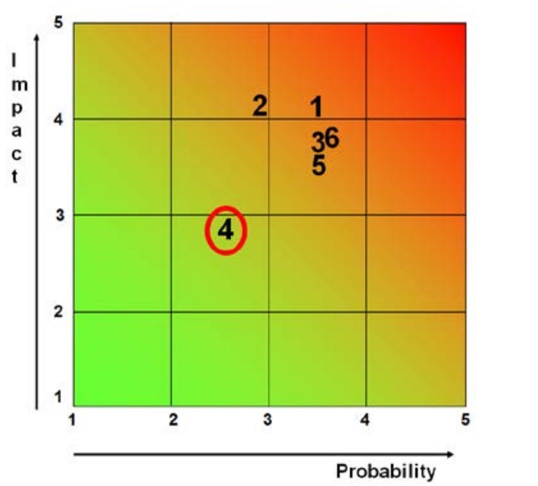
Appendix 5.

Risk summary sheet for the Increased Demand to Provide Emergency Response (Risk 4) for the Freshwater large aquatic basin

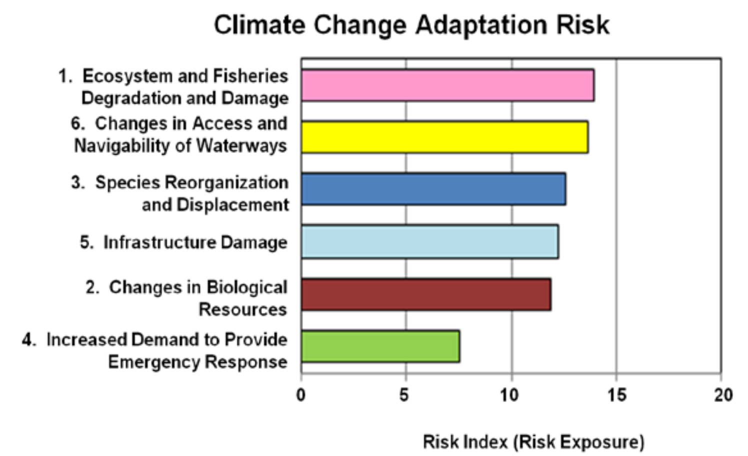
Note that the table is presented with no direct correspondence between the individual risk drivers (on the left side of the table) and the consequences (on the right). Letter coding refers to the sub-basin as described below.

Freshwater Large Aquatic Basin
Risk 4: Increased Demand to Provide Emergency Response
Risk Statement: There is a risk that climate change will affect DFO's ability to provide acceptable levels of environmental response and search and rescue activities.
Context: The emphasis in this risk is the potential for an increased incidence of marine incidents due to climate change factors and the associated strain on CCG's capacity to respond.

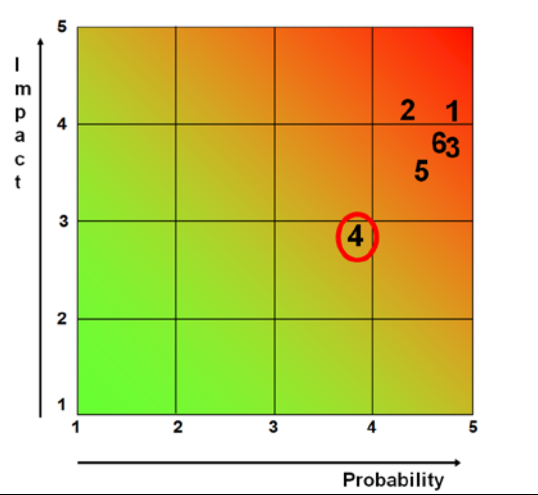
Position on Heat Map - 10 year Horizon



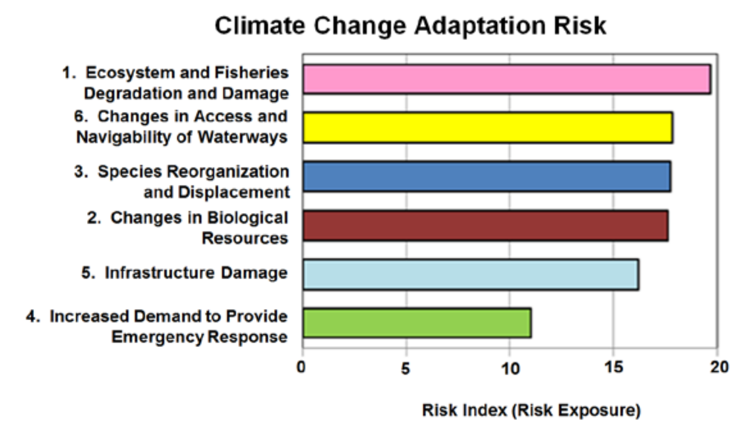
Risk Index (Probability x Impact) - 10 year Horizon



Position on Heat Map - 50 year Horizon



Risk Index (Probability x Impact) - 50 year Horizon



Main Risk Drivers	Potential Consequences: Threats
▪ Longer open water season increase the intensity, seasonal duration and geographical extent of boat traffic. (GL, WRB, SR, LW) ▪ Increased open water fishing activity. (GL, WRB, SR, LW) ▪ Storm events increase the demand for emergency search and rescue. (GL, WRB, SR, LW) ▪ Storms, flooding and extreme weather events cause erosion and sedimentation. (GL, WRB, SR, LW) ▪ Dangers associated with thinning ice and seasonal shifts in ice cover and thickness. (GL, WRB, SR, LW) ▪ Declining lake levels present risks to boating traffic and connectivity. (GL, SR)	▪ Increased in the geographic scope of DFO's emergency response, propositioning of emergency response equipment, navigational products, aids and channel maintenance activities. ▪ Loss of life associated with incidents. ▪ Increased shipping and boating traffic combined with reduced water levels increases risks of spills and other associated environmental issues with groundings.

Opportunities
▪ New threats allow for growth of new technologies and advancements to meet new demands.

Gaps
▪ Lake level projections are uncertain but will likely decline to some degree below average long term trend. There is a gap in information for watersheds (both rivers and lakes) draining into the Great Lakes proper and for the Prairies subarea. Great Lakes information needs to be updated with newest scenarios and models. ▪ Impacts from the expansion of mining and oil, gas and hydroelectric development are unknown especially under climate change. ▪ Inability to make accurate predictions about storm events, and extreme events affects the ability to assess impacts. ▪ Advancement of technologies not accounted for in analysis of projections, mitigation and adaptation.

Sub-basin codes:

LW – Lake Winnipeg

WRB – Winnipeg River and Boreal

GL – Great Lakes

SR- Saskatchewan River Basin

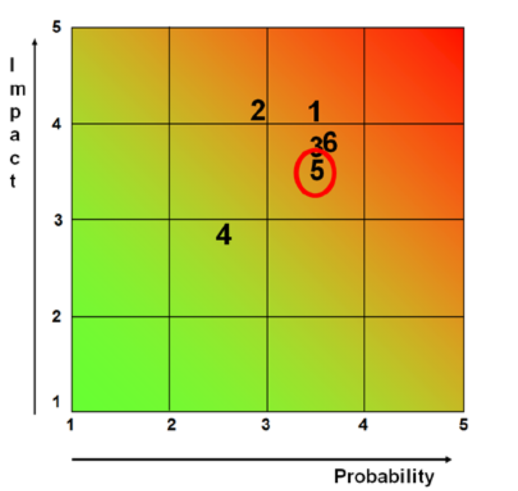
Appendix 6.

Risk summary sheet for the Infrastructure Damage (Risk 5) for the Freshwater large aquatic basin

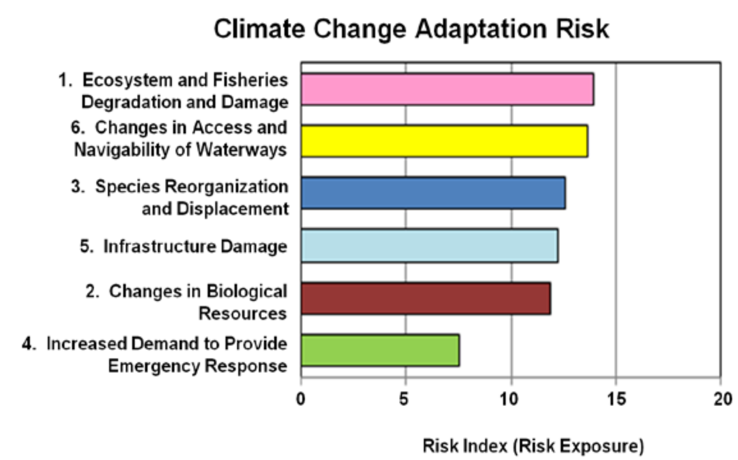
Note that the table is presented with no direct correspondence between the individual risk drivers (on the left side of the table) and the consequences (on the right). Letter coding refers to the sub-basin as described below.

Freshwater Large Aquatic Basin
Risk 5: Infrastructure Damage
Risk Statement: There is a risk that climate change will result in damage and the need for alterations to DFO vessels, coastal and Small Craft Harbour infrastructure.
Context: DFO maintains considerable infrastructure to support its operational and scientific activities in both the marine and freshwater environments (built infrastructure include: harbours, wharves, bases, stations, buoys, slipways, buildings, labs, lighthouses, navigation aids, hatcheries and DFO aquaculture activities).

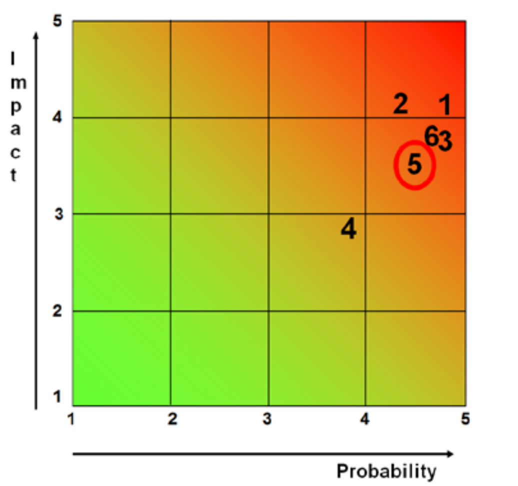
Position on Heat Map - 10 year Horizon



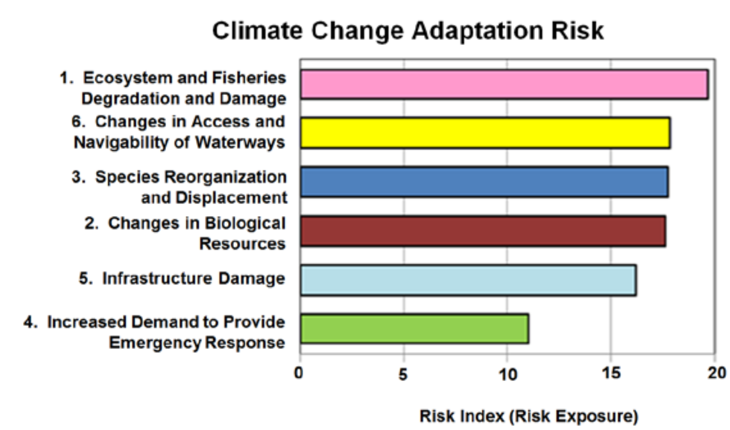
Risk Index (Probability x Impact) - 10 year Horizon



Position on Heat Map - 50 year Horizon



Risk Index (Probability x Impact) - 50 year Horizon



Main Risk Drivers	Potential Consequences: Threats
▪ Decreased water levels and/or increased frequency and magnitude of windstorms (e.g. storm surges, cyclones), increases the risk of shoreline erosion and sediment movement and needs for dredging (frequency, size of job and cost) for maintaining access to harbours. ▪ Increased temperatures increases rates of corrosion and material decay and/or decreased period of ice cover decreases period of construction/maintenance activities of some harbour structures. ▪ Reduced ice cover increases the exposure of navigation and infrastructure to storm and extreme weather events. (GL, WRB, SR, LW) ▪ Altered streamflow regimes, increased frequency and magnitude of spring floods and decreased lake water levels (e.g. in the Great Lakes) increases the risk of damage to harbours and other infrastructure. (GL, WRB, SR, LW) ▪ Intense storm events and wave action (height, frequency of extreme waves) increases the potential to damage infrastructure, and commercial, recreational and aboriginal fishing equipment (including boats, fishing gear, etc.). (GL, WRB, SR, LW) ▪ Reduced water levels may cause decreased access to piers, harbours, and boat launches. (GL, WRB, SR, LW) ▪ Lower water levels may cause intake pipes at water level gauging stations to become dry - water level measurement would be at risk. ▪ Episodic high water levels cause flooding; infrastructure may become inaccessible, damaged or eroded away.	▪ Increased cost to dredge around harbours, to fix physical damage to infrastructures. ▪ Reduced or interrupted service levels to infrastructure users (e.g. harbours: commercial, recreational and aboriginal fisheries; Coast Guard stations: search and rescue capabilities). ▪ Harbour re-locations could be considered (very costly). Reduced water levels may cause a reduction in loading capacity on ships. ▪ May require increased maintenance dredging. ▪ May require relocation of permanent water level network gauges. ▪ May be a requirement for increased number of recording gauges and increased level of service. ▪ May require increase maintenance of nautical publications.

Opportunities
▪ Potential decrease in snow clearing cost (small saving) ▪ Decrease in heating costs.

Gaps
▪ Detailed regional projections on wind speed and direction, extreme events (magnitude and frequency) and storms are lacking.
▪ Projections on water levels are generally lacking especially outside the Great Lakes proper; all projections even if available need to be updated with newest scenarios and models.
▪ Potential change in flow, circulation, and storm surges, cyclone, and hurricane, frequencies are unknown.
▪ Information is needed for appropriate elevation to build structures at shore (e.g. docks) given potential changes in water levels.
▪ Effect of climate change on infrastructure at specific locations not well known.
▪ Site specific impact assessments do not exist at all harbour locations. This is needed for decision making and for managing climate change risk (e.g. harbour design will likely be site-specific).
▪ Impact of AIS on infrastructure not clearly linked with climate.
▪ Specific information about coastal and riverine processes and physical changes in landscape is lacking.

Sub-basin codes:

LW – Lake Winnipeg

WRB – Winnipeg River and Boreal

GL – Great Lakes

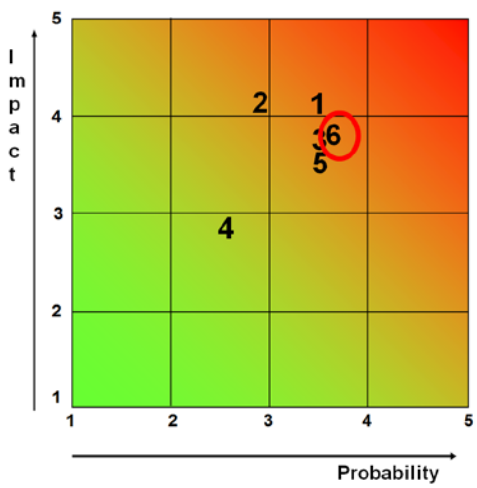
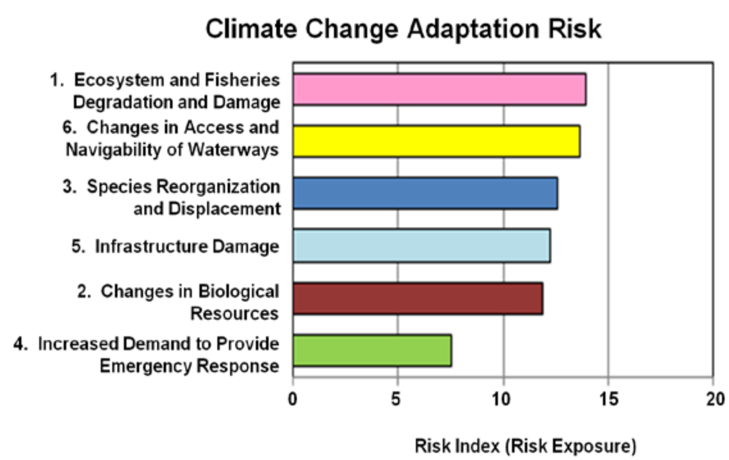
SR – Saskatchewan River Basin

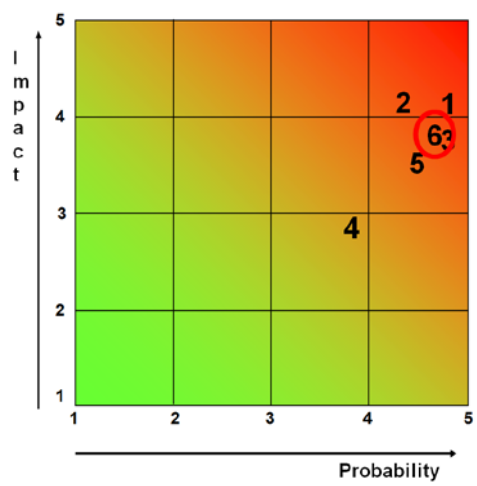
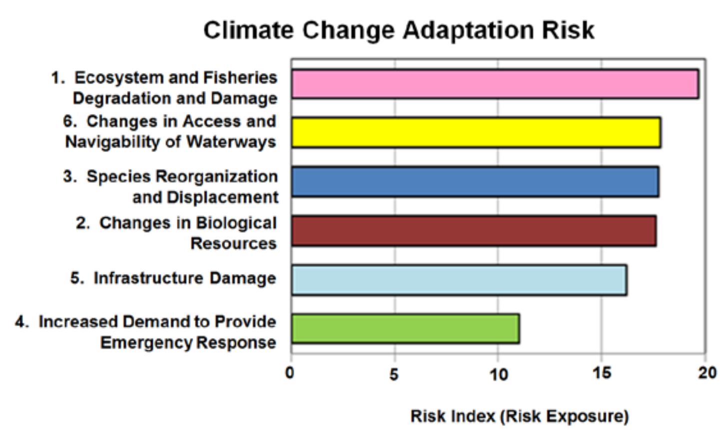
Appendix 7.

Risk summary sheet for the Changes in Access and Navigability of Waterways (Risk 6) for the Freshwater large aquatic basin

Note that the table is presented with no direct correspondence between the individual risk drivers (on the left side of the table) and the consequences (on the right). Letter coding refers to the sub-basin as described below.

Freshwater Large Aquatic Basin
Risk 6: Changes in Access and Navigability of Waterways
Risk Statement: There is a risk that climate change will affect DFO`s ability to provide safe access to waterways.
Context: This risk deals with impeded access due to changes in factors such as sedimentation, water levels, severe weather, wave energy, icebergs and sea ice.

Position on Heat Map - 10 year Horizon	Risk Index (Probability x Impact) - 10 year Horizon
	

Position on Heat Map - 50 year Horizon	Risk Index (Probability x Impact) - 50 year Horizon
	

Main Risk Drivers	Potential Consequences: Threats
▪ Reduced ice cover increases the exposure of navigation structures to storm and extreme weather events. (GL, WRB, LW) ▪ Changes in ice dynamics will have an impact on navigability. ▪ Fluctuating flow levels, decreased lake water levels and spring floods will affect navigation and associated structures. (GL, WRB, LW) ▪ Increased intensity, frequency and duration of storm events, wave action, and high water events increase the hazards to navigation. (GL, WRB, SR, LW) ▪ Increased intensity, frequency and duration of storm events, wave action, high water events may cause changes in erosion and accretion in dredged waterways thereby affecting least depth in navigation, (particularly commercial shipping) channels. ▪ Reduced water levels may cause decreased access to piers, harbours, and boat launches. (GL, WRB, SR, LW)	▪ Loss of life associated with incidents. ▪ Environmental damage from incidents. ▪ Increased need for hydrographic surveys (large-scale and revisory) and maintenance of nautical publications. ▪ Litigation to DFO regarding charting. ▪ Increased maintenance and monitoring for dredged areas. ▪ Increased need for monitoring for obstructions, dangerously low water levels, and damaged navigation aids. ▪ Long term and continuing drop in water levels may require a re-definition of low water datum (cost, effort, degraded safety due to confusion of chart interpretation, public outcry, and potential loss of revenue to "affected" marinas.

Opportunities
▪ Increased tourism. ▪ Increased shipping and navigation season depending on water levels. ▪ Potential decreased length of ice-breaking season on the GLs (cost savings). ▪ Potential increased access for open water fishing including commercial, aboriginal and recreational fishing.

Gaps
▪ Detailed regional projections on wind speed and direction, extreme events (magnitude and frequency) and storms are lacking. ▪ Potential change in flow, circulation, and storm surges, cyclone, hurricane frequency is unknown. ▪ Projections on ice cover and breakup exist but may not give information about their movement and how this will affect navigation or shipping. ▪ Water level declines will be variable in different regions and is not well understood. ▪ Expansion of recreational, aboriginal and commercial fishing geographically is unknown and may require adjustments to navigation or accessibility ▪ Difficulty in predicting ice conditions. ▪ Site specific impact assessments do not exist at all harbour locations. This is needed for decision making and for managing climate change risk (e.g. harbour design will likely be site-specific). ▪ Specific information about coastal and riverine processes and physical changes expected is lacking.

Sub-basin codes:

LW – Lake Winnipeg

WRB – Winnipeg River and Boreal

GL – Great Lakes

SR – Saskatchewan River Basin

Appendix 8.
Impact and probability definitions

Impact ranking (DFO Integrated Risk Management)

Impact	Definition of Impact
Extreme	A major event that will require DFO to make a large scale, long term realignment of its operations, objectives or finances.
Very High	A critical event that with proper management can be addressed by DFO.
Medium	A significant event that can be managed under normal circumstances by DFO
Low	An event, the consequences of which can be absorbed but management effort is required to minimize the impact.
Negligible	An event, the consequences of which can be absorbed through normal activity.

Probability ranking

Vote	Probability Level	% Probability
5	**Almost Certain**	More than 80%
4	**Likely**	61-80%
3	**Moderate**	41-60%
2	**Unlikely**	20-40%
1	**Rare**	Less than 20%

This Report is Available from the:

Canadian Advisory Secretariat (CSAS)
National Capital Region
Fisheries and Oceans Canada
200 Kent Street, Ottawa, Ontario K1A 0E6

Telephone: 613-990-0293
E-Mail: CSAS-SCCS@dfo-mpo.gc.ca
Internet address: www.dfo-mpo.gc.ca/csas-sccs/

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