2015

State of Climate Change Science in the Great Lakes Basin:

A Focus on Climatological, Hydrologic and Ecological Effects

Ontario

McMaster University

ONTARIO CLIMATE CONSORTIUM

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REPORT PURPOSE AND BACKGROUND

There is near unanimous consensus that climate change is occurring and its effects are already being observed across the Great Lakes Basin. Given the magnitude and range of the potential impacts on physical, chemical and biological processes in the Basin – and the importance of the environmental services those processes contribute to, including the well-being and livelihood of Great Lakes communities –"Climate Change Impacts" have been included as an Annex of the the 2012 Great Lakes Water Quality Agreement (GLWQA) and the recently ratified Canada-Ontario Agreement on Great Lakes Water Quality and Ecosystem Health, 2014 (COA).

The purpose of the 2015 State of Climate Change Science in the Great Lakes Basin report is to synthesize available science on the observed and projected impacts of climate change in the Great Lakes Basin and document the climate change assessment methods applied in the region. This report was initiated in support of commitments under Annex 9-Climate Change Impacts to take into account the climate change impacts on the chemical, physical and biological integrity of the Waters of the Great Lakes and communicate and coordinate binationally regarding ongoing developments of domestic science. The report draws upon the range of research conducted by various levels of government, academia and other organizations and the growing body of knowledge in areas of ecological research and climate change. This report provides researchers, managers and decision makers with a time-stamped, thorough and methodical examination of that climate change science.

The last 15 years have witnessed a tremendous outpouring of new research on the impacts of climate change on the physical, biological, chemical, economic, and social systems, as well as adaptive management research in the Great Lakes Basin. A review of this literature is presented and synthesized according to a framework of themes that addresses the impacts of climate change on: the physical environment; the chemistry of the Great Lakes Basin; aquatic and terrestrial ecosystems, the biodiversity of the Basin; and the socio-economic systems. Climate change practitioners and researchers were then consulted to develop consensus-based confidence levels for that information, to validate syntheses developed from the literature, and to identify any gaps in the information. In addition, a comprehensive review was conducted on studies within the past five years (2010-2014) that employed climate models. This review examined how climate models have recently been used in the region to assess future projections of climate, climate change impact assessments, adaptive management strategies, and characterizations of climate vulnerabilities.

OVERVIEW OF REPORT SECTIONS

The State of Climate Change Science in the Great Lakes Basin report consists of four sections.

Part 1: The Use of Climate Information in the Great Lakes Basin

This section summarizes recent trends and practices in the use of climate modelling and analysis across a range of management themes pertinent to the Great Lakes Basin, along with an overview of currently available datasets in the region. It discusses how climate information has been used in impact studies and vulnerability assessments, including the types of models, emissions scenarios and downscaling methods used in this research. In addition, it looks at the strategies used to mitigate uncertainty in the results of current climate change models.

Part 2: Data Confidence Assessment of Great Lakes Climate Change Science

This section presents the results from consultations with a cross-section of climate change researchers who were asked to rank the information for each impact theme on the basis of three criteria: (1) the agreement among the available studies; (2) the type, amount and quality of the evidence; and (3) any self-identified limitations of the research. This ranking was done both independently and using a group consensus approach for the two themes with which each participant was most familiar. The confidence levels for each theme were then categorized as low ◒, medium ◓, or high ●, corresponding to the framework used by the Intergovernmental Panel on Climate Change (IPCC). A summary of the confidence levels for each impact is present in the accompanying table, "Projected Impacts of Climate Change in the Great Lakes Basin."

Part 3: A Synthesis of Climate Change Impacts and Vulnerabilities in the Great Lakes Basin

This section provides a detailed state-of-the-art review of the vulnerabilities of the Great Lakes Basin. The review is based on key literature organized according to: (1) physical effects; (2) environmental chemistry and pollutants; and (3) ecological effects and biodiversity. A brief summary of the projected effects of climate change on each impact theme is presented in the accompanying table, "Projected Impacts of Climate Change in the Great Lakes Basin," and this information is also available in the database associated with this project.

Part 4: Knowledge Gaps

This section classifies knowledge gaps identified for each of the impact themes. In some instances, the authors of the literature cited identified knowledge gaps. In addition, experts in the environmental effects of climate change were asked at a workshop to provide insight into knowledge gaps, inconsistencies and uncertainties in the research. The identification of these knowledge gaps will help inform priorities-setting for future research to support climate change vulnerability assessments and action. A summary of the knowledge gaps is presented in the accompanying table, "Knowledge Gaps."

Accompanying Knowledge Database

As part of the comprehensive review of Great Lakes climate change studies conducted from 2010 through 2014, a Microsoft Access® database was created to house, allow the querying, and facilitate analysis of research, meta-information and results. This database contains 254 studies, and over 2000 individual estimates of climate change impacts across a wide range of research themes. The database is available for download at http://ontarioclimate.org/our-work/the-state-of-climate-change-science-in-the-great-lakes.

PROJECTED IMPACTS OF CLIMATE CHANGE IN THE GREAT LAKES BASIN

	Theme	General projections	Trend	Category	Data confidence
PHYSICAL EFFECTS	**Climatology**				
	Air temperature	• 1.5°c - 7°c increase by the 2080s depending on climate scenario and model used. • Greater increases in the winter. • Increased frost-free period and growing season.	↑		high evidence high agreement
	Precipitation	• 20% increase in annual precipitation across the Great Lakes Basin by 2080s under the highest emission scenario. • Increases in rainfall, decreases in snowfall. • Increased spring precipitation, decreased summer precipitation. • More frequent extreme rain events.	↑		high evidence medium agreement
	Drought	• Projected increases in frequency and extent of drought.	↑		low evidence high agreement
	Wind	• Increased wind gust events.	↑		low evidence low agreement
	Ice storms	• Greater frequency of freezing rain events.	↑		low evidence low agreement
	Water temperature	• 0.9°c - 6.7°c increase in surface water temperature by the 2080s. • 42-90 day increase in ice free season. • Increased period of stratification.	↑	Lakes Rivers Wetlands	high evidence low agreement low evidence high agreement low evidence low agreement
	Water levels & surface hydrology	• Water levels in the Great Lakes naturally fluctuate by up to 1.5m. • Long-term water levels in the Great Lakes peaked in the 1980s and have been decreasing since. • Projections of future lake water levels vary; however, they generally suggest fluctuations around lower mean water levels. • Lower water levels are due to several factors including warmer air temperatures, increased evaporation and evapotranspiration, drought, and changes in precipitation patterns.	↓	Lakes Rivers Wetlands	high evidence low agreement low evidence high agreement low evidence low agreement
	Ice dynamics	• Projected decreases in ice cover duration, ice thickness, and ice extent. • Increased mid-winter thaws, changing river ice dynamics.	↓	Lakes Rivers	medium evidence high agreement low evidence low agreement
	Groundwater	• Recharge rates will be greatest in the winter.	↑		low evidence low agreement
	Natural Hazards				
	Flood	• Increases in flood severity and frequency.	↑		medium evidence medium agreement
	Fire	• Projected increases in number and extent of fires.	↑		medium evidence medium agreement
ENVIRONMENTAL CHEMISTRY & POLLUTANTS	**Chemical effects** (Oxygen, Acidity (ph), Phosphorus, Nitrogen, Carbon, Mercury & other organohalogens)	• Likely increase in dissolved organic carbon, phosphorus, and nitrogen levels. • Likely increase to the toxicity and mobilization of mercury. • Due to increasing atmospheric CO_2 levels, CO_2 concentrations in the water will increase as well, resulting in lower pH levels.	↑		low evidence low agreement

	Theme	General projections	Trend	Category	Data confidence
ECOLOGICAL EFFECTS AND BIODIVERSITY	**Aquatic species**	• Range contraction: coldwater fish (e.g., Brook Trout, Lake Trout), Painted Turtle. • Range expansion: cool and warmwater fish (e.g., Walleye, Smallmouth Bass), American Bullfrog, Northern Leopard Frog. • Coldwater habitat space is decreasing while warmwater habitat space is increasing. • Competition is changing due to range expansions and contractions. • Fragmented rivers may impede expansion ability of species. • Advances in spring phenology of amphibians.	*Not Assessed*	Range shifts Genetic changes Altered phenology Habitat alteration	medium evidence medium agreement low evidence low agreement low evidence low agreement medium evidence medium agreement
	Trees and plants	• Range expansion: Oak-birch zone, Carolinian species, Sugar Maple, Hickory. • Range contraction: Boreal species, Spruce-Fir zone, Jack Pine, White Pine. • The climate niche for tree species in Ontario will dissipate and shift northwards. • In the south, trees will likely experience reduced growth rates, reproductive failure, and increased disease and mortality. • Forest fragmentation will reduce widespread tree migration. • Plant productivity will increase if they are not otherwise limited. • Distribution and abundance of wetland vegetation will change. E.g., wetland vegetation requiring little water such as sedges, grasses, wet meadows, and trees will replace emergent and submergent species.	*Not Assessed*	Range shifts Genetic changes Altered phenology Habitat alteration	medium evidence medium agreement medium evidence medium agreement medium evidence medium agreement medium evidence medium agreement
	Wildlife	• Range expansion: Southern Flying Squirrel, White Tailed Deer, American Woodcock, Fisher, Red Fox. • Range contraction: Canada Lynx, Alder Flycatcher, Northern Flying Squirrel. • Increase in 'generalist' species and decrease in 'specialist' species. • Shifting ranges may be impeded by geographic barriers, biotic stress, and landscape fragmentation. • >45% decrease in optimal habitat for 100 climate threatened bird species in Ontario. • Increased risk of hybridization (e.g., Carolina Chickadee and Black-capped Chickadee). • Earlier breeding and hatching of bird species. • Asynchrony between environment and life history needs. • Disruption of predator-prey relationships (e.g., Canada Lynx-Snowshoe Hare cycle).	*Not Assessed*	Range shifts Genetic changes Altered phenology Habitat alteration	medium evidence medium agreement low evidence low agreement medium evidence medium agreement medium evidence medium agreement
	Pathogens and parasites	• Pathogens and parasites are likely to increase in range and prevalence. • Parasite-host relationships are changing due to warming temperatures.	*Not Assessed*	Aquatic Trees and plants Wildlife	low evidence low agreement low evidence high agreement low evidence low agreement
	Invasive species	• Non-native species may increasingly become established. • Current invasive species will be able to expand their ranges further north due to warmer temperatures.	*Not Assessed*	Aquatic Trees and plants Wildlife	low evidence high agreement low evidence high agreement low evidence low agreement

KNOWLEDGE GAPS

Summary of Knowledge Gaps by Theme	Report Section
Climate Modelling in the Great Lakes Basin • The ability to model processes and feedbacks between the earth's surface and atmospheric systems at local scales across the Great Lakes Basin is limited. • The application and advancement of dynamical downscaling is limited in the Great Lakes Basin. There is a lack of integration of emerging model scenarios into research, needed to ensure future findings build on existing knowledge base. • A prognostic and retrospective analysis (such as hind casting) is needed to validate model performance. • The coverage and quality of information from climate and weather observations networks has not been assessed for its ability to support adaptive management and the development of climate change and impact information, including refinement of earth system models, analytical tools, and impact thresholds/system responses to climatic changes. • The limitations, deficiencies, and assumptions, used in non-climatological research and other applications, in particular downscaling techniques, Global Circulation Model (GCM) selection, emission scenarios, and overall confidence in findings has not been well communicated.	1.2, 3.1, 4.1
Water Temperature • Consideration of the spatial dynamics of lakes has not been incorporated into water temperature modelling. • There is limited monitoring and modelling of lake thermal profiles and surface-temperature based analyses. Changes in wind (due to climate change) have not been incorporated into ice dynamic models.	3.1.2, 4.2
Water Levels and Surface Hydrology • There are uncertainties in the relative roles of precipitation, runoff, evaporation and evapotranspiration in water level modelling. **Lakes** • There is a lack of clarity in the understanding of multiple factors (including hydroclimatic factors) influencing water level projections for the Great Lakes. • The diversity of inland lake types and the impacts of climate change on those lakes has not been well characterized. **Rivers** • There is a lack of clarity in the understanding of multiple factors (including hydroclimatic factors) influencing water level projections for the Great Lakes. • The diversity of inland lake types and the impacts of climate change on those lakes has not been well characterized. **Wetlands** • There has been a lack of detailed research on the vulnerability of wetlands, such as patterns of wetland drying. • There is limited understanding of how climate impacts the water budgets of wetlands. • Wetland monitoring has not been geared to evaluate impacts of projected changes in water levels.	3.1.3, 4.3
Groundwater • Groundwater recharge and discharge rates and patterns are not well understood in the Great Lakes basin. • An inventory of groundwater resources has not been completed for the basin. • There is limited understanding of the magnitude/direction of groundwater changes.	3.1.5, 4.4
Precipitation and Extreme Events • Research identifying indicators for extreme weather events related to flooding and drought risks is limited. • Precipitation projections have limited resolution and could better characterize precipitation cycle feedbacks. • The consequences of altered disturbance regimes, such as fire and drought are not well documented.	3.1, 3.1.6, 4.5

Chemical Effects • Projections of changes in lake and river chemistry are limited (such as oxygen, carbon, nitrogen and phosphorous levels). • Carbon dioxide fertilization effects have not been incorporated into carbon cycle modelling. • The changes in pesticides/biocide uses and applications, with pathogen, parasite and invasive species changes have not been factored into models of chemical effects. • Projections of changes in chemical uses and applications are limited. • Knowledge and data of climate change and its direct effects on chemical exposure, fate and transport are limited. • Monitoring is not geared up to conduct rigorous chemical and pesticide monitoring and testing, including a carbonate chemistry and acidification.	3.2, 4.6
Species Ranges and Ecosystem Shifts • Expanding ecological modelling beyond species-level responses to climate change could help address multi-species interactions and ecosystem changes. • The consideration of impacts of climate change on the local scale, including micro-climate niches is limited. • Research is limited on the impacts of climate change on coastal ecosystems. • Monitoring of species and community-level changes is necessary to refine hybrid models, which could lead to a better understanding of the reconfiguration of ecosystems and inform changes in chemical and pesticide use.	3.3.1, 3.3.4, 4.7
Genetic and Phenologic Change • There is a gap in research identifying and examining the genetics of fitness-related traits that will impact adaptation of species to climate change. • Research in genetic matching to identify genotypes best suited to future climates is limited. • Research of the political, ethical, operational and scientific aspects of the assisted migration of species is limited. • Research investigating asynchronies resulting from phenological changes in species and ecosystems is limited.	3.3.2, 3.3.3, 4.8
Invasive Species, Parasites and Pathogens • Limited integrated research on climate change and invasive species identify and investigate invasive species that may expand into the Great Lakes Basin. • Limited research on aquatic, tree and wildlife parasites and pathogens that may expand into the Basin.	3.3.5, 3.3.6, 4.9
Cumulative Effects and Integration of Land Use • Further integration of the cumulative effects of other environmental stressors into climate change impact analyses would be beneficial. • The integration of the impacts of land-use management decisions into climate change modelling is limited.	4.10, 4.11
Community and Human Effects* • Cumulative effects assessments that examine multiple environmental stressors have been limited. The synthesis of human effects would be helpful to ensure an integrated research strategy for Great Lakes climate change science, including effects on social, cultural, economic, health, built infrastructure, and political systems. • Dissemination of climate information to resource users, decision makers and practitioners could be improved. ** Note that these themes are given substantially less detail treatment throughout the report, and as such recommendations are less specific and detailed.*	3.4, 4.12
Use of Climate Science for Adaptive Management • The development and promotion of tools that increase accessibility and effective use of climate change science would help the use of this information in evidence-based adaptive management. • Leadership on evidence-based adaptive management and dialogue between researchers and decision makers is limited.	4.11, 4.13