Southwestern New Brunswick Climate Data Viewer

Documentation and Methodology: Version 1

Eastern Charlotte Waterways Inc.

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Author:

Lee Penney

Data Analyst and GIS Technician

Published by:

Eastern Charlotte Waterways Inc.

881 Main Street Blacks Harbour, NB Canada, E5H 1E5

Tel: (506) 456-6001 Fax: (506) 456-6187

E-mail: info@ecw.ngo

Web: www.ecw.ngo

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Eastern Charlotte WATERWAYS

Executive Summary

The purpose of this document is to outline the methodology and intended use behind the data shown in the Data Viewer, an interactive mapping application available at https://swnbclimate.ca/data-hub/. The Data Viewer is currently divided into four categories: sea level rise, inland flooding, infrastructure, and climate projections.

Sea Level Rise

The sea level rise category shows the estimated extent of sea level rise (SLR) in different scenarios, e.g., a 1% annual probability (1-in-100-year) storm surge in 2100. Sea level heights were calculated by R.J. Daigle Enviro (see Daigle, 2014) based on a high-emissions scenario known as **Representative Concentration Pathway (RCP)** 8.5, described in the fifth assessment report by the Intergovernmental Panel on Climate Change (IPCC, 2014). The SLR layers can be used for coastal vulnerability analyses, land use planning, and damage cost estimates[1].

Inland Flooding

The in-land flooding category features relevant infrastructure, such as dams culverts, in addition to wet area maps (WAMs). The WAMs model a 200 mm rainfall event over the course of 48 hours (for reference, hurricane Dorian brought ~150 mm of rain over ~24 hours). WAMs are made by running a digital elevation model through a flow simulation algorithm called **deterministic 8-node (D8)** (Hornberger, 1995 and references therein) and by using the principles of fluid dynamics to calculate metrics such as flow rate and required culvert size at road-stream crossings. These layers can be used in analyses involving inland flooding risks.

Infrastructure

The infrastructure category contains hydrologic features such as dams and culverts, other features such as emergency shelters and wharves, and municipal CO_2 emissions data collected by ECW Inc. in 2015 (see Hardy and Cowie, 2015). Some of these layers, particularly the hydrographic features and the emergency stations, are useful for analyses involving geometric networks such as modelling traffic during the flooding of key access roads. Other layers, such as the wharves and emissions data, are primarily for informational purposes at this time.

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[1] For site-specific adaptation measures that are potentially costly, it is recommended that hydraulic and hydrologic models be used in conjunction with the Data Viewer layers since certain factors, like bed friction and wave run-up, are not accounted for in this data (see section 1.2)

Climate projections

The climate projection category contains outputs from Global Climate Models for for the years 2020, 2050, and 2100 as well as historical (1981 - 2010) observations. These data cover the entire province and are based off of the Fifth Assessment Report from the Intergovernmental Panel on Climate Change (IPCC, 2014). The projections were done by Ouranos on behalf of the Province of New Brunswick (see Roy and Huard, 2016)[2]. The data (.xls) and maps (.png) are available at http://acasav2.azurewebsites.net/#

This document is organized by the four data categories described above. The sections within these categories are organized into (1) an introduction, which briefly summarizes the current knowledge and scientific context behind the data layers, (2) a methodology section, and (3) a usage information section detailing how this data should be used.

[2] This report was available online for a limited time. Contact ECW Inc. if you'd like to obtain a copy.

Acknowledgements

The Data Viewer would not have been possible without the time and effort of various contributors. We would like to thank Dr. Paul Arp and Dr. Jae Ogilvie of the University of New Brunswick for providing us with the wet area maps and equipping us with the knowledge of how they work. Thanks to Réal Daigle, who provided sea level rise estimates for the coastal zones across Charlotte County. The efforts of Kim Reeder and the Peskotomuhkati Nation brought critical, ground-truthed hydrographic features into the Data Viewer. The project that spawned the Viewer's creation, the *Southwestern New Brunswick Climate Adaptation Plan*, was made possible through funding provided by the Federation of Canadian Municipalities and through the oversight provided by the New Brunswick Regional Service Commission.

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1.0 Sea Level Rise

1.1 Introduction

1.1.1 Global sea level rise

The information presented in this section is mainly taken from Chapter 13 of "Climate Change 2013 - The Physical Science Basis" written by Church et al. (2013). This chapter appears within the fifth assessment report (**AR5**) released by the **Intergovernmental Panel on Climate Change** (IPCC, 2014). The main take-aways from this section are:

- **Thermal expansion and loss of land-based glaciers are the main drivers of both historical and future sea level rise.**

- **Thermal expansion and loss of land-based glaciers are strongly linked to anthropogenic CO_2 emissions.**

- **The global average sea level rise in a high-emissions scenario is projected to be between 0.52 and 0.98 m by 2100.**

It is the scientific consensus that anthropogenic CO_2 emissions are the major driver of global warming and climate change (IPCC, 2014). The effects of increased CO_2 emissions include a spatial expansion of the ocean (**thermal expansion**), and increased melting of the world's glaciers and ice sheets.

According to AR5, thermal expansion and the melting of land-based glaciers are the main contributing factors to historical (late twentieth century - 2010, Fig. 1) sea level rise, and it is likely that they will remain as such into the future (Fig. 2).

Global-scale sea level rise can be predicted using various modelling methods (e.g. Rahmstorf, 2007; Stroeve et al., 2012). The IPCC currently assigns the highest confidence to projections output by **Atmosphere-Ocean General Circulation Models (AOGCMs).** AOGCMs are a type of **processed-based** model - that is, they define the climate system based on established physical relationships and are calibrated against historical data. Additional chemical and biological processes are integrated when applicable and available. Sea level estimates reported in AR5 are the result of combining 21 different AOGCMs that were built under version 5 of the Coupled Model Intercomparison Project Protocol (**CMIP5**). In other words, using a set of best practices established under CMIP5, multiple climate models (AOGCMs) were built, and their outputs were combined to produce a range of projections for future sea level rise. "CMIP5" will henceforth be used to reference the combined AOGCMs which informed AR5.

Based on CMIP5, under a high emissions scenario, the *likely* range of sea level rise by 2100 relative to 1986–2005 levels is 0.52 - 0.98 metres, the median value of these models being 0.74 m.

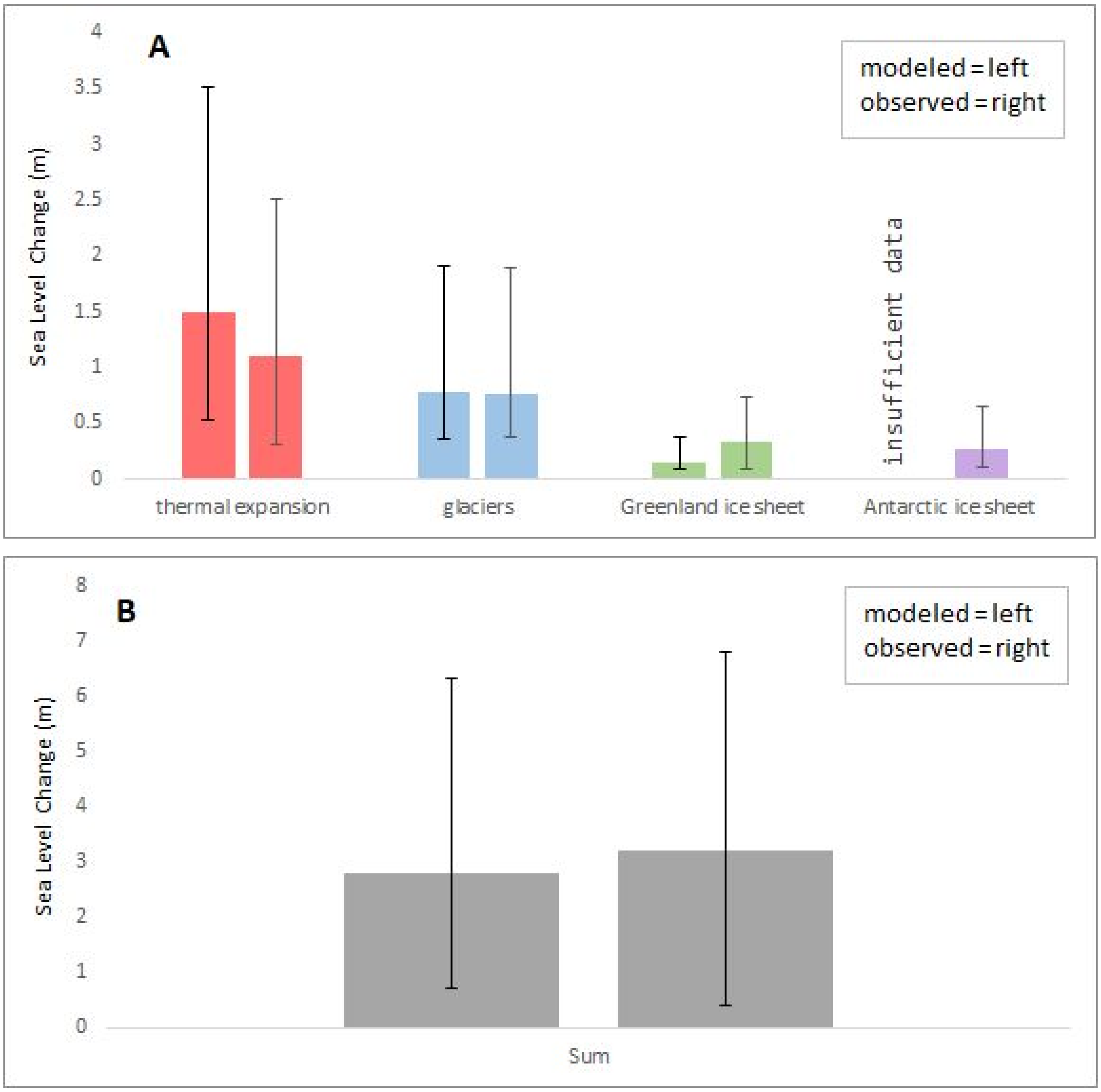

Figure 1: Historical Sea Level Rise (1993 - 2010) - means and 95% confidence limits. (A) Modeled and observed contributions. (B) Total sea level change. The values shown are taken from Church et al. (2013), Table 13.1.

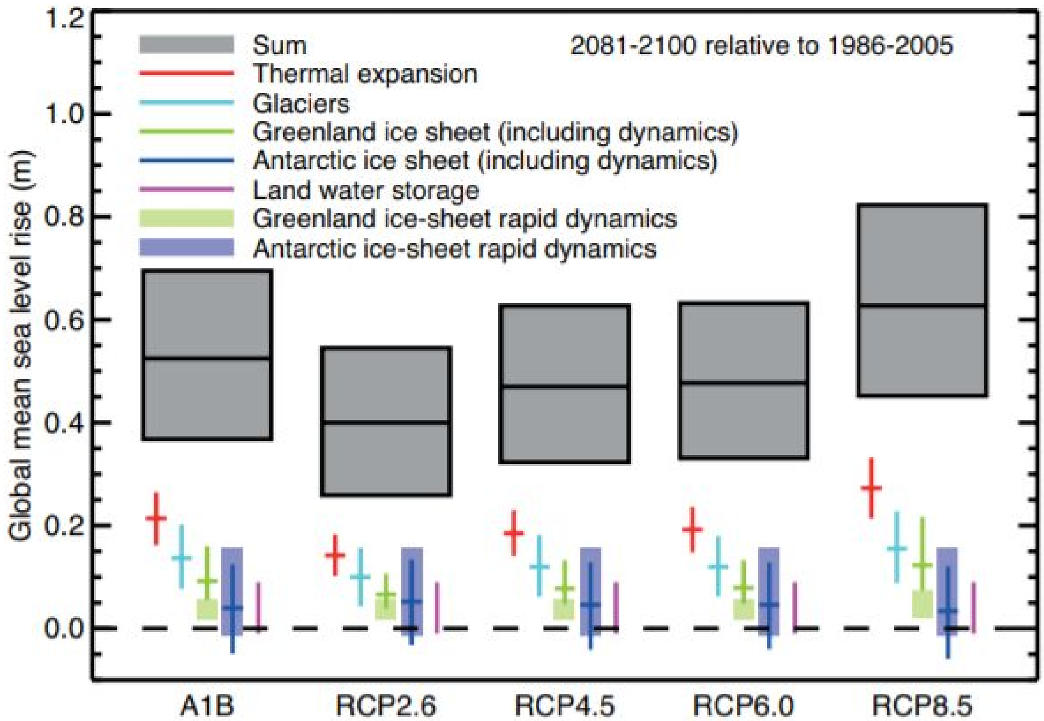

Figure 2: Projected Sea Level Rise in Various Climate Change Scenarios - median values and 95% confidence limits. Figure source: Church et al. (2013).

1.1.2 Regional sea level rise

The information presented in this section is taken from "Relative Sea-level Projections in Canada and the Adjacent Mainland United States" written by James et al., (2014), and "Updated Sea-Level Rise and Flooding Estimates for New Brunswick Coastal Sections" written by Daigle (2014). The main take-aways of this section are:

- **Regional sea level rise can differ substantially from the projected global average mainly due vertical land motion (VLM) and localized effects of glacier/ice sheet melting**

- **Sea level rise in southwestern New Brunswick by 2100 in a high-emissions scenario is projected to be 0.8 meters relative to 2010 levels.**

Regional sea level rise estimates of can differ substantially from the projected global average (PGA) due to a combination of vertical land motion and localized effects of glacier/ice sheet melting, including meltwater redistribution (**fingerprinting**), and the weakening of ocean circulation patterns caused by increased **freshwater forcing** or **freshening.**

SLR estimates in Canada range from 0.52 - 0.98 m (identical to the projected global average or PGA), in Atlantic Canada from 0.75 - 1.00 m, (higher than the PGA - largely due to land subsidence - see Bush and Lemmen, 2019), and across southwestern New Brunswick it is about 0.8 m (see Daigle, 2014. The document covers the entire province but the methods described therein were applied to southwestern New Brunswick as part of a contract between the researcher and Eastern Charlotte Waterways Inc.).

Vertical land motion

The largest regional factor affecting sea level rise across both Canada and New Brunswick is vertical land motion (VLM). VLM refers to the uplift (offsets sea level rise) or subsidence (exaggerates sea level rise) of the Earth's crust. VLM across Canada is mainly driven by **glacial isostatic adjustment (GIA)**. During the Wisconsin glaciation, Canada was buried underneath ice sheets. Following deglaciation, most of the Canadian land mass began to rise as it recovered from the weight of the ice. However, the Maritimes is currently experiencing subsidence at a rate of about 1-2 mm/year (Fig. 3) due to it being a **peripheral bulge** (Henton et al., 2006; Fig 4).

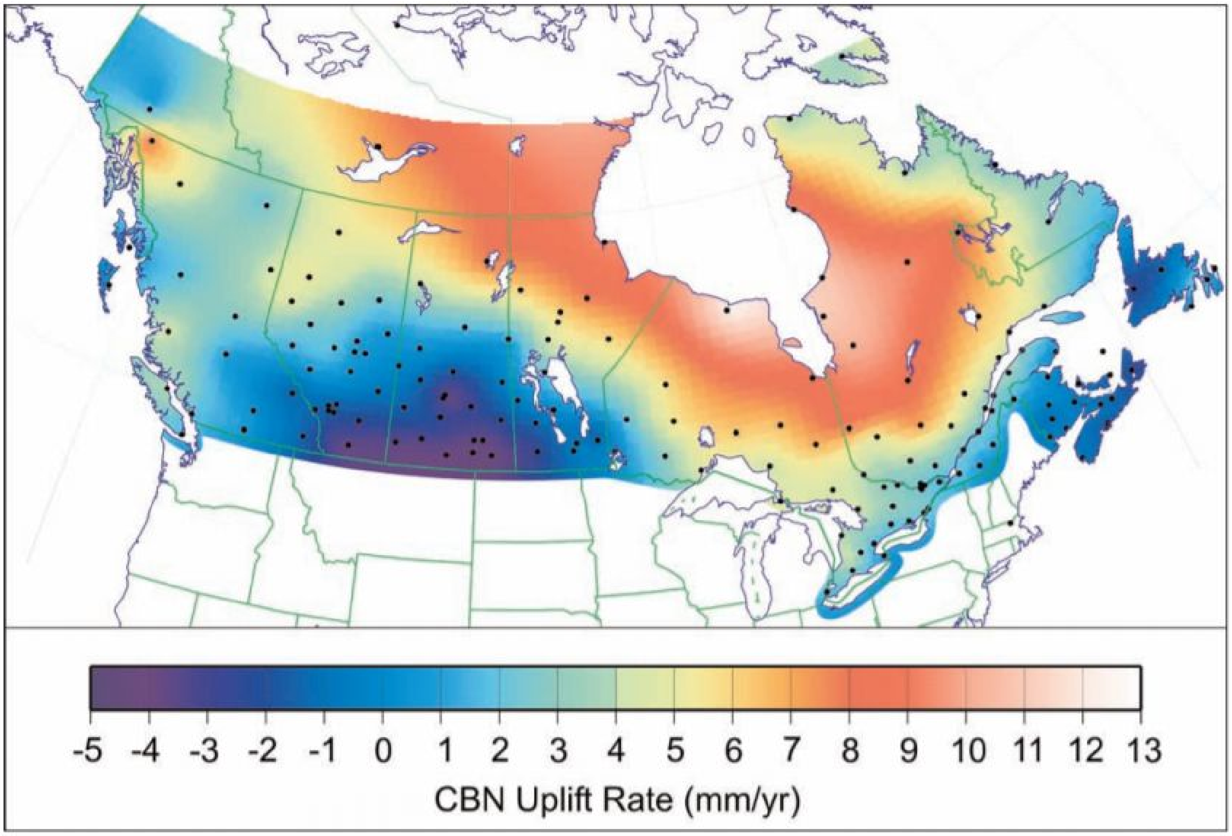

Figure 3: Rates of uplift and subsidence across Canada. Figure source: Henton et al., (2006)

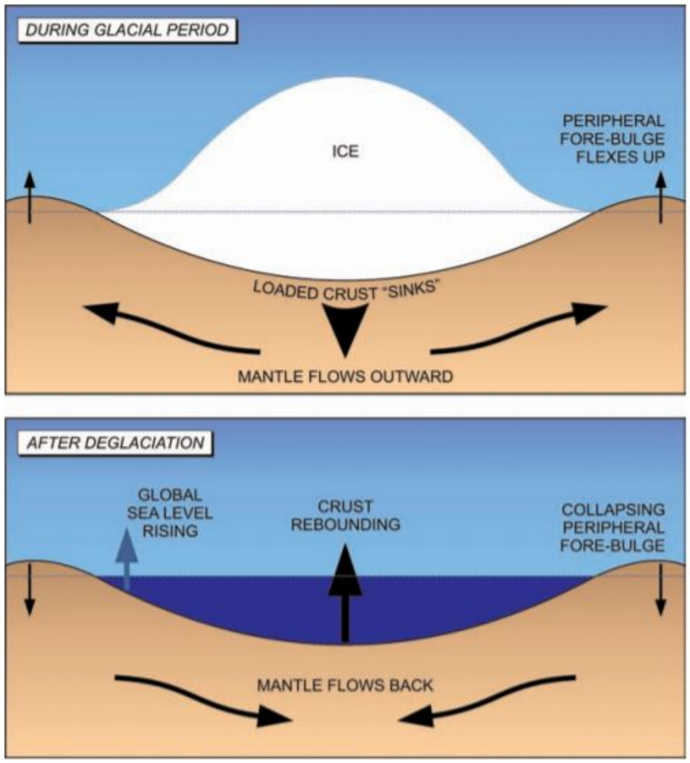

Figure 4: Illustration of peripheral bulges subsiding post-glaciation. Figure source: Henton et al. (2006)

Fingerprinting

The melting of large ice sheets (e.g., Greenland, Antarctic ice sheets) exert a counterintuitive effect on sea level. Sea level drops in the regions closest to the melt and rises in regions farther away. This is because these ice sheets are massive enough to exert their own gravitational pull on the ocean, thus raising the sea level in nearby regions. As the ice sheets melt, they have less mass and thus their gravitational pull on the ocean weakens, resulting in a sea level drop (Fig. 5). This phenomenon is known as meltwater redistribution or **fingerprinting**. For further reading, see Mitrovica (2001). Available information on fingerprinting has been integrated into regional sea level rise projections released by the IPCC (see Church et al., 2013).

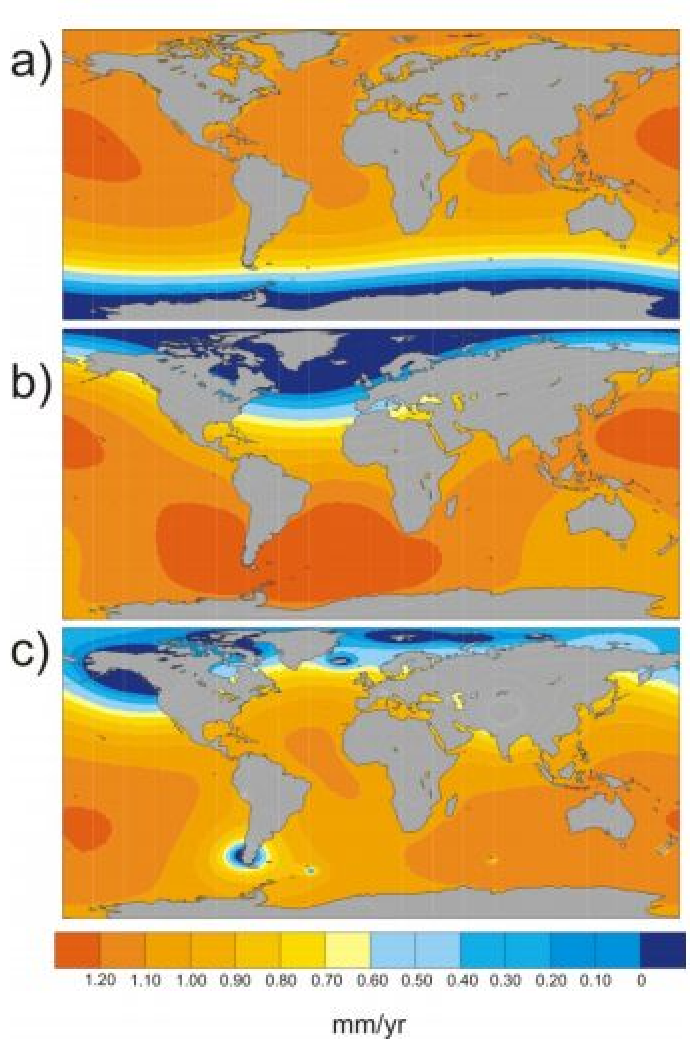

Figure 5: Effects of meltwater redistribution (fingerprinting) on sea level.
Figure source: Mitrovica et al. (2001)

Weakening ocean currents

The Atlantic-Meridional Overturning Circulation (AMOC) transports heat from the tropics to the mid-upper latitudes in the northern hemisphere. As the water flows poleward, temperature and salinity gradients cause an increase in density, promoting **deep water formation** and flow back toward the tropics. There, the water warms, becomes less dense and flows poleward again, completing the cycle.

Recent studies concerning the AMOC note a slowdown of its circulation. This could not only affect the terrestrial climate in major ways, but it may also result in sea level changes of varying degrees from coast to coast (Ezer et al., 2012; Qiu and Chen, 2012; McCarthy et al., 2015). Evidence suggests that **freshening**, or a decrease in ocean water salinity, is the main factor driving the slowdown (Otterå et al., 2003). The main cause of freshening, based on climate models, is thought to be a combination of increased poleward moisture transport due to warmer oceans, which increases precipitation and thus freshwater input (Manabe and Stouffer 1993, 1994; Jackson and Wood, 2017) and the melting of glaciers (Swingedouw et al., 2007; Schmittner et al., 2016).

The decrease in salinity results in a decrease in surface water density which in turn prevents deepwater formation (the cooler sea surface temperatures in this region notwithstanding). In other words, freshening causes the Atlantic Ocean's surface waters to be too light to sink like they normally would. The slowdown of heat redistribution caused by a weakened AMOC means that warmer waters pool beneath the ocean surface along the eastern Atlantic coast, leading to an overall increase in ocean temperatures, thus promoting thermal expansion, and thus causing increased rates of sea level rise in eastern North America (Ezer et al., 2013; Ezer and Atkinson, 2014).

1.2 Methodology

1.2.1 Local Sea Level Rise Estimates

This section briefly summarizes the approach developed and used by Daigle (2014) to produce the sea level rise estimates for southwestern New Brunswick. Note that the report referenced covers the estimation across all of New Brunswick, but the same methodological principles apply.

Most factors (fingerprinting, ocean circulation changes, and land water storage) are uniform across the region and can be inferred from existing studies. The vertical land motion component for southwestern New Brunswick was established by extrapolating estimates reported by James et al. (2014) to match the delineation of the coastal zones defined in this region. An additional factor, the “Bay of Fundy Effect”, was included to account for the predicted increase in tidal amplitude across the Bay of Fundy. The Bay of Fundy effect is currently predicted to contribute a 10 cm rise in sea level across the outer and inner bay (Greenburg et al., 2012).

Storm surge scenarios were projected by integrating sea level rise projections with historical data available from the Canadian Hydrographic Service. Storm scenarios are categorized by **return period** or equivalently, **annual probability**. Annual probability (AP) refers to the percent likelihood of a storm of a given severity occurring within a single year, with more severe storms having less annual probability. Return period is an equivalent metric expressed as years (e.g. 25-year, 50-year, etc), and while more intuitive, it is often misinterpreted as meaning that a storm will only occur once every *x* years, even though it is entirely possible, for example, for multiple 100-year storms (AP = 1%) to occur within a 100-year timespan. Sea levels and annual probabilities are reported with respect to the given storm event occurring at high tide.

Daigle (2014) notes that these estimates do not account for the wave run-up factor - this refers to the "rushing up" of water as waves meet the shoreline. Wave run-up is made more intense if landward wind speeds are high and if the shape of a bay or coastline forces stormwater through a narrow channel.

1.2.2 Translating sea level estimates to GIS

Sea level estimates produced by R.J. Daigle Enviro for southwestern New Brunswick were translated to GIS using a **bathtub approach**. The bathtub approach involves creating a **digital elevation model (DEM)** with culvert features "burned" in - this means tracing an artificial channel where known culverts exist. If this "burning" is not done, surrounding features such as roadways would block water flow within the model even though in reality, the culvert allows water to pass through. The DEMs used in this project were sourced from the Province of New Brunswick's open data portal at www.arcgis.com/apps/webappviewer/index.html?id=4b299c347a274b37abdd3de4adbc09b2 These DEMs are built from **light detection and ranging (LiDAR)** data - also available from the Province at www.arcgis.com/apps/webappviewer/index.html?id=a6d24f0cc5f149dfb8b569c4ab8aa9f4). T

While ECW Inc. possesses a culvert dataset (available on the Data Viewer), it is incomplete and it is possible that some records are outdated. Most of the hydrographic connectivity was established through inspection of satellite imagery. Thus, it is possible that certain areas which do not appear vulnerable due to an assumed lack of hydrographic connectivity may actually be at risk. ECW Inc. is actively working with its partners to achieve a more complete dataset of hydrographic features in the region.

1.3 Usage Information

The main take-aways from this section are:

- **These layers are most appropriate for generalized regional/neighborhood level analyses.**

- **Bathtub and site-specific models generally agree based on reported studies, though bathtub models tend to overestimate flood extent.**

The following estimates are included in the Data Viewer:

- Higher-High Water Large Tide (HHWLT)[3] for 2050 and 2100
- A 1% annual probability storm surge for 2050 and 2100

Projections for other years and scenarios are available by contacting ECW Inc.

These layers can be used for:

- Generalized cost analysis of property damage
- Identifying flooded coastal routes
- Identifying study sites for hydrologic/hydraulic models
- Comparing storm scenarios and allocating adaptation efforts accordingly
- Identifying valuable ecosystems that may be at risk due to sea level rise

The general-scale applicability of these layers is emphasized because neither the sea level estimates nor their translation to GIS account for site-specific factors that can influence sea levels during a storm surge such as wave run-up, wave refraction, and bed friction.

Regarding the bathtub approach versus site-specific modelling, comparative studies have shown a general agreement between the two methods, though bathtub models tend to overestimate flood extent (Seenanth et al., 2016; Dider et al., 2018). For example, Seenanth et al. (2016) found that flood extents mapped through a bathtub approach and through site-specific models agreed within 5% of one another. Similarly, Dider et al. (2018) tested both bathtub modelling and a numerical model called XBeach against a historical storm event and report that

[3] Higher-High Water Large Tide refers to the average of the maximum annual tide recorded over a period of 19 years, known as a "tidal epoch".

both performed well at predicted flooded areas (78 and 66%, respectively), but again it was found that bathtub modelling overestimated the actual flood extent.

2.0 Inland Flooding

2.1 Introduction

This section discusses the implications of climate change re. inland flooding and outlines the methodology used for creating wet area maps. The infrastructural features in this category are covered in section 3.0 - Infrastructure.

2.1.1 Implications of climate change

The main take-aways from this section are:

- **It is highly likely that the frequency and intensity of inland flooding will increase, but predicting just by how much is challenging.**

- **The most noticeable change will likely be in the spring, the season predicted to have both the greatest increase (~100 mm) and greatest total precipitation (~463-579 mm) compared to 1981-2010 levels.**

A key climatic factor driving inland flooding events is the water cycle and its links to precipitation regimes. Global warming influences precipitation in two ways: **dynamic changes**, which encompass changes in atmospheric circulation, and **thermodynamic changes**, which encompass changes in the amount of water vapor entering and leaving the atmosphere. Within global climate models, thermodynamic changes appear to be the dominant driver of the precipitation increases projected for the mid-latitudes (Collins et al., 2013). This refers to the process whereby an increase in sea surface temperature promotes increased evaporation over the oceans, and thus an increased amount of moisture is transported from the oceans to the land (via rain) through the atmosphere.

Climate models indicate that New Brunswick will experience more intense rain events during winter and spring (e.g. Fig. 6), but that these events will occur less frequently and the province may even experience abnormal dry periods (Roy and Huard, 2016).

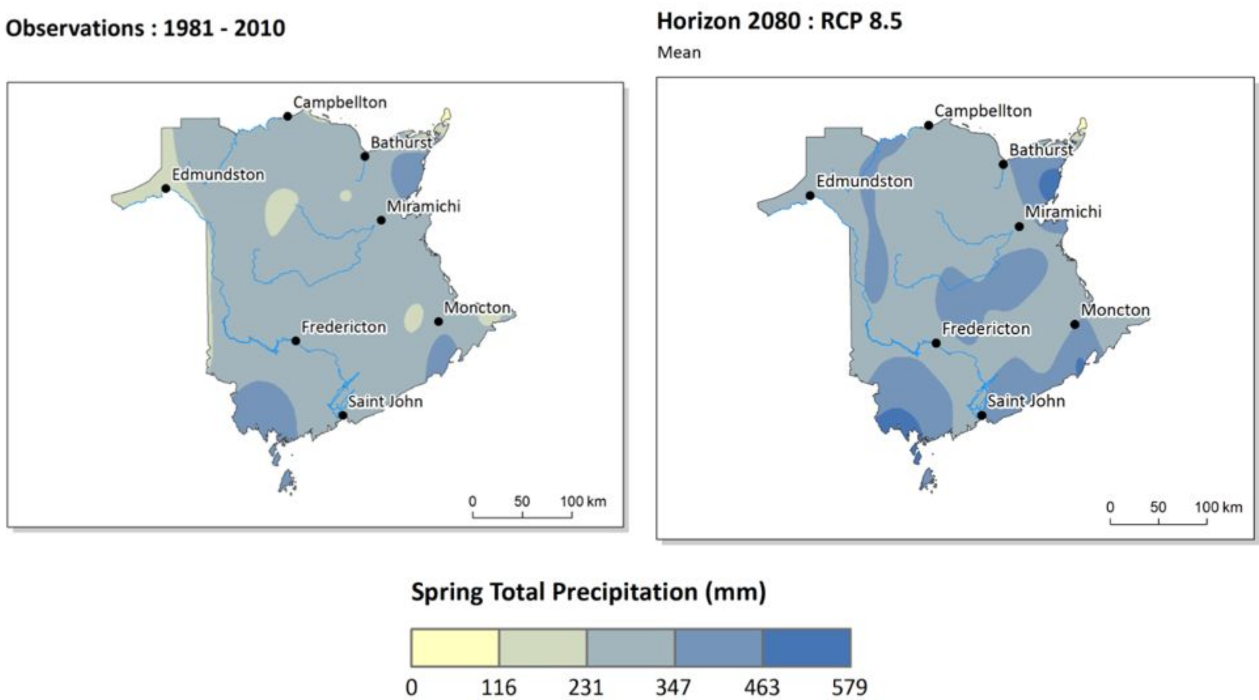

Figure 6: Total Spring Precipitation: Historical and Projected. Figure source: Roy and Huard (2016).

Precipitation patterns across a region can be highly variable, and decadal-scale datasets are needed to capture meaningful patterns. These patterns are used to graph **Intensity-Duration-Frequency (IDF) Curves,** which fit **Generalized Extreme Value (GEV) probability distributions** (i.e. graphs plotting disaster intensity *versus* their probability) to long-term precipitation data to define total precipitation (mm) and precipitation intensity (mm/hr) values for a given set of return periods (see section 1.2.1 for the definition of return period). In other words, IDF curves combine probability theory with existing data, and they inform users of how much rain is expected over a given amount of time for a precipitation event of a given probability.

For example, a rainfall event lasting for 12 hours in Saint George, NB, whose annual probability is 2% (a return period of 50 years) could produce up to ~131 mm of rain assuming a high-emissions scenario. The same rainfall event would have an intensity of ~11 mm/h (Fig. 7).

IDF curves are commonly used in the planning and design of water-based infrastructure such as storm sewers. Climate change presents a challenge to IDF construction in that IDF curves assume that precipitation patterns are stationary, meaning that given sufficient data over a long enough period, the emergent precipitation regime will remain constant. The predicted increase and intensification of precipitation events linked to climate change violates this assumption, necessitating an "update" of IDF curves. An online tool called IDF_CC achieves this for Canadian provinces and territories in a user-friendly manner, and is meant specifically for municipal and planning staff (for technical documentation see Schardong et al., 2018).

This tool can be used in conjunction with the WAMs to better understand inland flooding risk throughout the region.

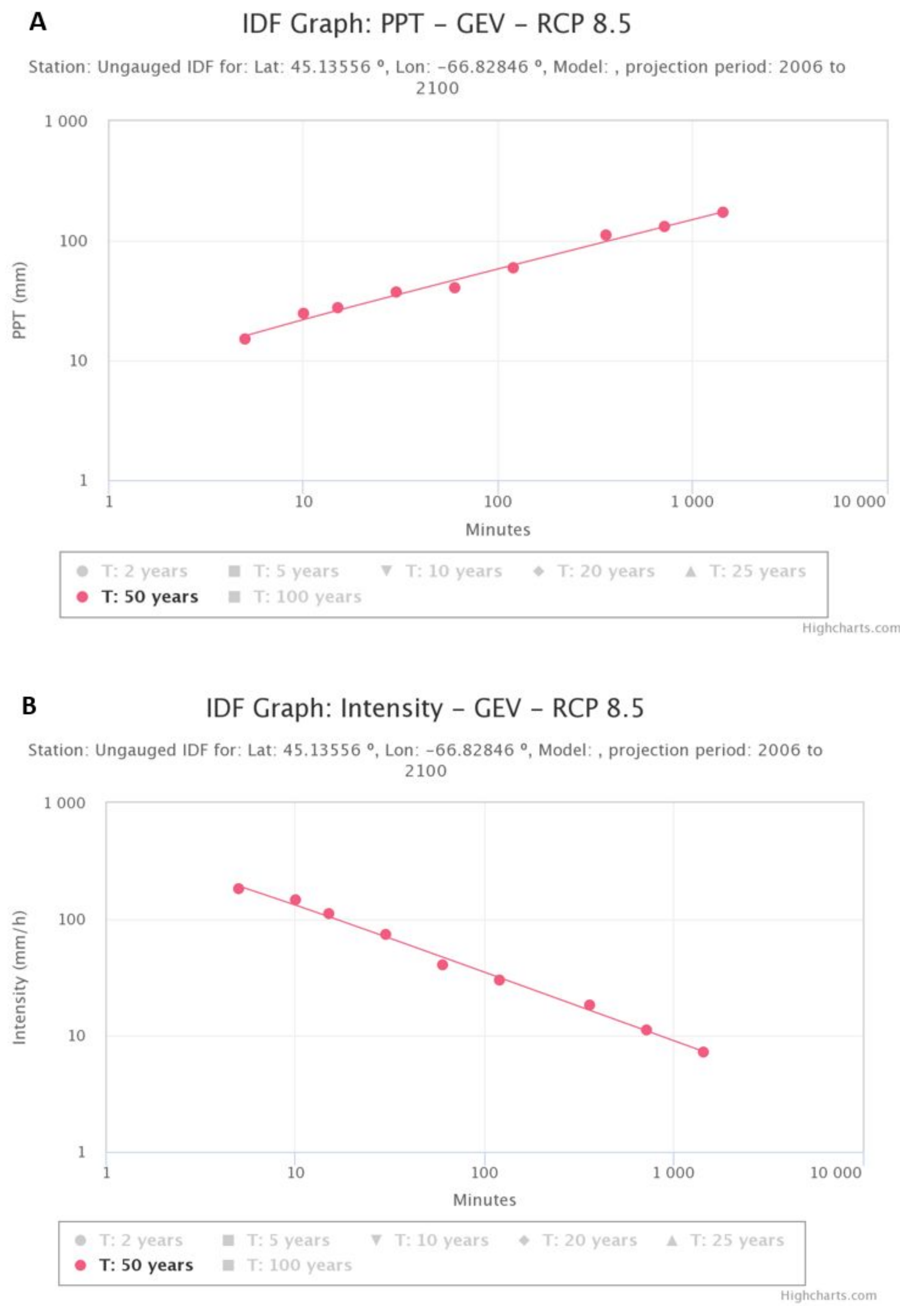

Figure 7: Intensity-Duration-Frequency Curve for St. George, NB. This graph was made using the IDF_CC tool developed by Schardong et al. (2018). This tool is freely available at https://www.idf-cc-uwo.ca/home

2.2 Methodology (wet area maps)

WAMs are made by modeling the water table height relative to the surface, using the **cartographic depth-to-water index (DTW)**. Surface flow direction and accumulation patterns are also mapped.

The WAMs featured in the Data Viewer were created by Dr. Paul Arp and Dr. Jae Ogilvie from the University of New Brunswick. No further processing was done to this data at ECW Inc. This section will thus serve as a brief outline of the full methodology described in White et al. (2012)

WAMs are constructed based on seasonality. During wetter seasons, less land area is required to reach soil saturation and initiate surface flow than in drier seasons. The WAMs shown in the Data Viewer represent a medium-wet spring season. Specifically, they represent a 200mm rainfall event over the course of 48 hours. For reference, hurricane Dorian brought ~150 mm of rain over 24 hours.

The process begins by building a bare-earth elevation layer and a vegetation-height layer from LiDAR data. The bare-earth layer allows for the delineation of flow channels, while the vegetation layer is used for visualization purposes and for identifying wetlands. Flow channels are identified and "filled" in the bare-earth layer, and the filled DEM is passed through an algorithm called the **deterministic 8-node (D8)** flow algorithm (Hornburger and Boyer, 1995 and references therein). D8 calculates flow direction, flow accumulation, and slope gradient, simulating the path that surface water would take across a given area. Areas with a DTW <= 1 can be classified as a "wet area".

The cartographic DTW of a given cell in the data layer is defined as the difference in elevation between the cell and its nearest "source" cell along the least-cost (minimum change in slope) path. The source cell is the nearest cell containing surface water. Cells representing lakes, rivers, and other water bodies have a DTW of 0 by definition. The height of the water table is defined as the ground elevation minus the DTW. This process is summarized in Fig. 8.

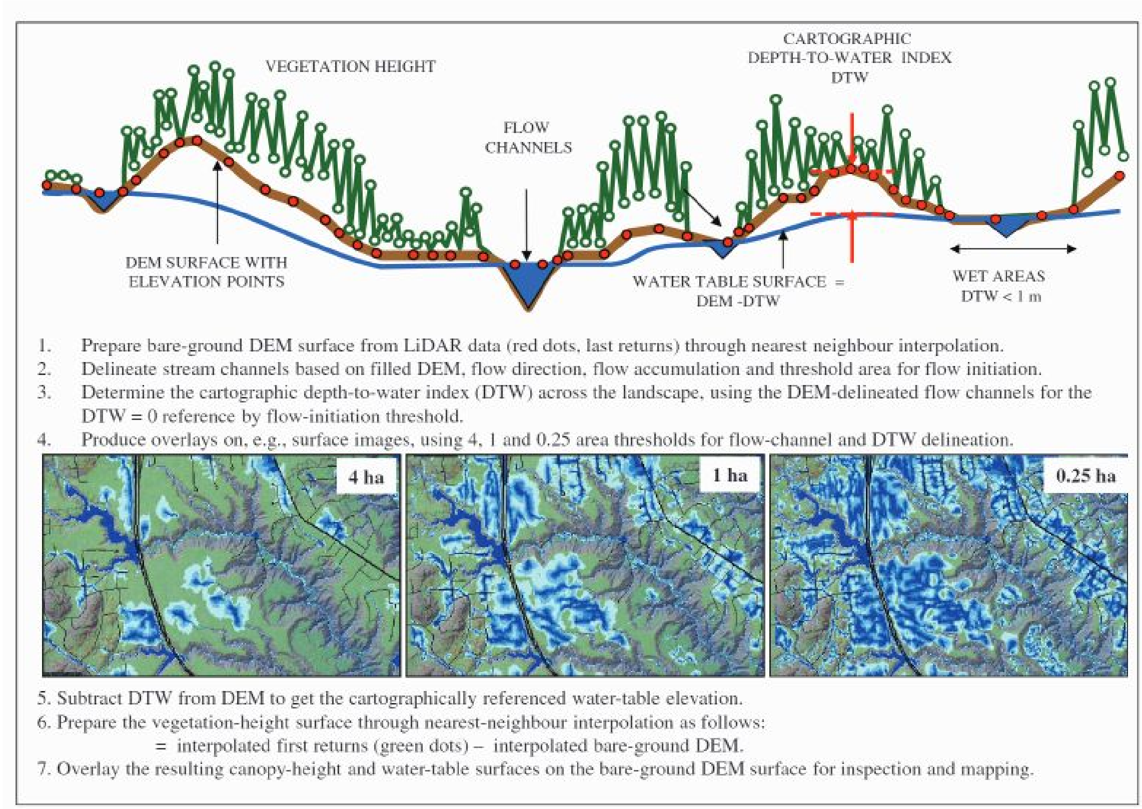

Figure 8: Method for producing wet area maps. Wet area maps show the height of the water table and surface flow channels in heavy precipitation events. Figure source: White et al. (2012).

2.3 Usage Information

The WAMs can be used as a tool for evaluating in-land flooding risk because they show where water is likely to pool and flow during heavy precipitation events. Note that there are several types of inland floods (riverine, pluvial, flash floods, etc.) that can occur in a given region. An important aspect to understand about WAMs is that they account for water flow **from** surface channels **to** permanent streams and rivers; **they do not model riverine flooding as this is not their intended purpose** (for such a dataset, please refer to the Active River Area project undertaken by the Nature Conservancy of Canada, found here: https://databasin.org/datasets/0ce6df639f504fa9931a2cfe5d100d1b)

The additional layers, including predicted road-stream crossings ("Predicted culverts" in the Data Viewer), existing culverts, and precipitation projections can be used to gain a fuller understanding of where flooding vulnerabilities lie currently and in the future.
The inland flooding layers in the Data Viewer include:

- WAM raster datasets, divided by region
- Existing culverts (2007)
- Predicted culverts
- Precipitation projections for 2050 and 2080

These layers can be used for:

- Assessing potential damage of inland floods, especially on properties with subsurface infrastructure (e.g., basements)
- Understanding flow patterns and catchment areas of ephemeral channels
- An input to hydrologic/hydraulic models
- Modelling road closures and traffic when used with a geometric network

3.0 Infrastructure

3.1 Introduction

This section breiflycovers infrastructural concerns/solutions related to climate change.

3.1.1 Vulnerabilities to climate change

During the development of the *Southwestern New Brunswick Regional Adaptation Plan*, ECW Inc. found that the largest infrastructural vulnerabilities faced by southwestern New Brunswick are impacts to wharves and ferry terminals caused by the compounding of sea level rise with increasingly severe storm events. These structures are vital to the region's sociocultural fabric, tourism sector, and the economic sector which relies heavily on the fishery industry (Cowie, 2019). These structures have been designed, however, according to a standard based on historical climate trends and not those projected for the future.

Other infrastructural vulnerabilities throughout the region include the flooding and increased deterioration rates of key access roads, increased risks to dams and energy infrastructure, and damage/contamination of municipal water infrastructure. Damage to roads is particularly concerning due to the fact that many residents in the region reside in rural areas. Further detailing the unique challenges and opportunities faced in rural communities is beyond the scope of this document; further information can be found in the Cowie (2019) and references therein.

3.1.2 Adaptation opportunities

There are several ongoing efforts meant to address infrastructural vulnerabilities in the region. The Canadian Department of Fisheries and Oceans (DFO) has developed a National Coastal Infrastructure Vulnerability Index (CIVI) for the small craft harbours they oversee (Greennan et al., 2018). The CIVI accounts for sea level rise and other climate change-related threats such as changing wind and ice conditions and coastal erosion.

Infrastructure Canada has developed a Climate Lens assessment guideline for both GHG mitigation and climate resilience projects. It is important to note that the Climate Lens is only required within certain project streams funded by Infrastructure Canada i.e., it requires project proponents to actively seek to perform an assessment, and it is not legally required under any conditions at a wider scale.

As previously stated, ECW Inc. has published a *Southwestern New Brunswick Climate Adaptation Plan* in which these vulnerabilities were explored and adaptation solutions, such as incorporation of climate scenarios into asset management, coordination among asset owners, and public awareness and monitoring programs are put forward and discussed.

3.2 Methodology

3.2.1 Emergency Stations and Coastal Features

Emergency station locations and use capacity were acquired by ECW Inc. from the regional Emergency Measures Organization, and this data was digitized in ArcGIS. Similarly, the wharves and terminals were digitized using satellite imagery and information on their use was gained via a contact from DFO, the provincial aquaculture site map (https://nbdnr.maps.arcgis.com/apps/webappviewer/index.html?id=24c65e8718724c5db1de77899172630d&locale=en), tourism sites, and the Google Maps database.

3.2.2 Municipal Emissions

The municipal emissions layer contains data pulled from ECW Inc.'s work in the Partners for Climate Protection Program (PCP) developed by the Federation of Canadian Municipalities (Hardy and Cowie, 2019). The goal of this program is to provide a milestone-based framework to guide greenhouse gas (GHG) emission reduction efforts. Milestone One, completed in 2016, involves the establishment of a GHG emissions inventory to understand the present-day emission rates in the corporate (emissions from municipally-managed services) and community (all other emissions) sectors. Inventories have been established for four municipalities in southwestern NB: St. Stephen, St. George, Blacks Harbour, and Grand Manan. Emissions were calculated by using the PCP Milestone tool to convert usage data (in kilowatt hours) to CO^2 emissions (in megatonnes of CO^2 per year).

3.2.3 Dams and culverts

Ecw Inc. acquired culvert datasets from the Department of Transportation and Infrastructure - one from 2007 and one from 2016. The datasets were merged and overlapping points were removed - overlapping points being any points within a 5 meter radius of one another.

Information on the culverts' type (wood, metal, or concrete) and size are found within this layer. Complementary to this layer is a predicted crossings layer derived from the wet area maps (section 2.0). These points occur where surface flow channels cross roadways and contain information about the flow rate and required culvert diameter in different precipitation scenarios. A ground-truthed dataset containing manmade and beaver dams developed by the Peskotomuhkati Nation is also featured in the Data Viewer.

3.3 Usage Information

The infrastructure section of the CDV contains the following layers:

- Emergency Shelters
- Wharves and Terminals
- Municipal Emissions
- Existing Culverts (2007)
- Predicted Culverts (based off the WAMs)
- Dams (man-made and beaver dams)

The Emergency Shelters layer can be used to model or design safety routes during flood events and other causes of road obstruction. The two culvert placement layers (actual and suggested) can be used in a similar manner and for planning purposes.

The wharves, dams, and existing culvert layers are intended to be a comprehensive inventory of these structures. Similarly, the GHG emissions data is mainly meant for observation purposes at this time.

4.0 Climate Projections

4.1 Introduction

The information in this section is mainly taken from the report written by Roy and Huard (2016), who produced the temperature and precipitation projections shown in the Data Viewer. The main take-aways from this section are:

- **There is a clear signal of long-term temperature increases, and the difference between emissions scenarios grows over time.**

- **Precipitation predictions are less robust, but do indicate a long-term increase in winter and spring (and hence annual) precipitation.**

As covered in sections 1.0 and 2.0, increased amounts of greenhouse gas emissions are linked to increases in air, land, and sea surface temperatures as well as changes in precipitation patterns. Projections for temperature and precipitation changes are available at a global scale from the IPCC (2014), and at a Canadian scale from the Environment and Climate Change Canada (ECCC, 2017).

Generally, southern New Brunswick is projected to experience a greater degree of both warming and precipitation changes than the northern parts of the province. There is strong agreement among the models' temperature increase signals. Less consensus was found among the precipitation projections, though they do project increases during the winter and spring.

The impacts of increased temperatures across the world's lands and oceans are wide-ranging and have consequences in economic, environmental, sociocultural, and public health sectors. In southwestern New Brunswick, a major concern regarding temperature changes is its impact on aquaculture and wild fishery industries. To understand this further, Allyn and Mills (2020, manuscript in progress) modeled the change species distributions in the Bay of Fundy given under moderate (RCP 4.5) and business-as-usual (RCP 8.5) emissions scenarios. Model projections suggest there will be a decline in the relative biomass of American lobster, a seasonal (autumn) decline in Atlantic herring and Atlantic cod, and no changes in that of the sea scallop (Fig. 9). The authors note a projected increase in longfin squid, summer flounder and black sea bass.

Using 2018 landing values as an index of species importance (Fig. 10), the projected declines in lobster appear concerning. A full discussion on this topic is beyond the scope of this document, and more work is needed to understand the localized socioeconomic impacts of these changes. ECW Inc. is actively working to develop a project surrounding fisheries and climate adaptation in the area.

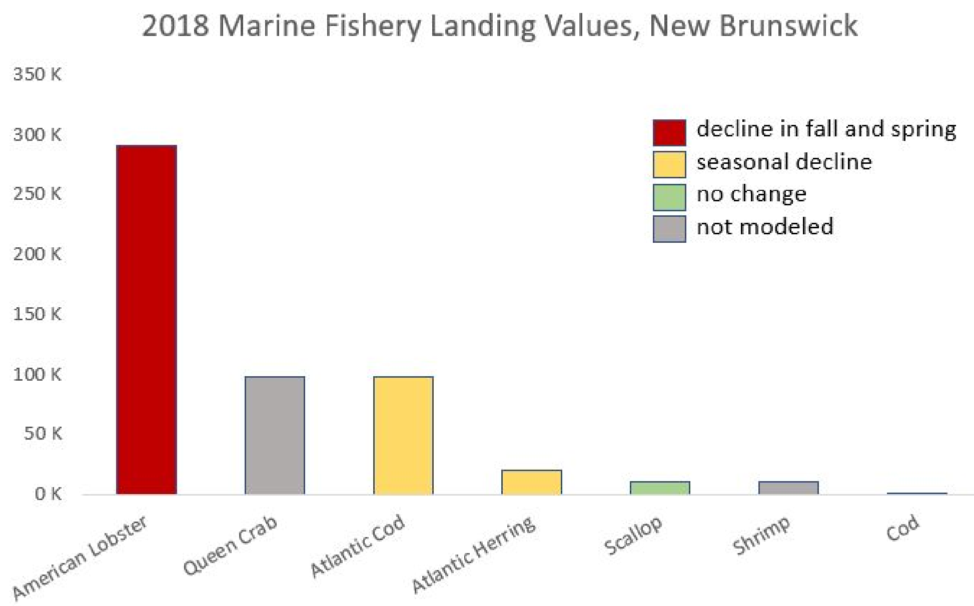

Figure 9: Landing values of selected marine species for New Brunswick, 2018. Chart shows top 5 values in addition to species whose future distributions were modeled by Allyn and Mills (2020). Data source: Department of Fisheries and Oceans - Seafishery Landings, 2018 (https://www.dfo-mpo.gc.ca/stats/commercial/land-debarq/sea-maritimes/s2018aq-eng.htm)

Other relevant impacts of increased temperatures include increased risk of lyme disease and heat stroke, as well as increased occurrence of extreme weather events like tropical cyclones.

The major impact of precipitation changes in a New Brunswick context is the increased risk of inland flooding which is discussed in section 2.0 and in the regional adaptation plan available on the climate hub (see Cowie, 2019).

4.2 Methodology

As with the wet area maps, no further processing of this data was done at ECW Inc. This section will thus serve as a brief outline of the methodology described in Roy and Huard (2016).

To obtain baseline climate indices, data from meteorological stations across the province was gathered (Fig. 10). The reference period of these data is 1981 - 2010; though not all stations possessed data for the complete time period. Stations with less than 15 years of data were omitted from the baseline.

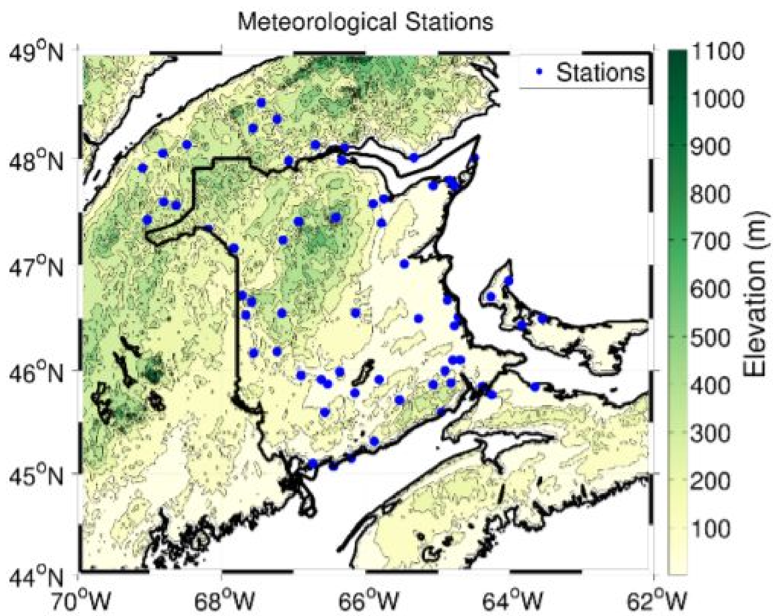

Figure 10: Weather stations across New Brunswick. Data from these weather stations were used to create climate change projections for the province. Note that not all stations contained sufficient data. Figure source: Roy and Huard (2016).

After calibrating the CMIP5 models against this reference data and configuring the simulation to run a given emissions scenario (all projections in the Data Viewer represent a high-emissions scenario, or RCP 8.5), the simulation is run over a virtual grid representing the province. This means that in each grid cell, for each year up to 2100, monthly delta (or "change in") values are calculated for each climate variable. (e.g. A given grid cell may say that in January of 2080 there will be +50mm more precipitation than in the January average from 1981 - 2010).

For each station, for each variable, the value at closest grid cell is taken as the adjustment value for each month of the chosen year. These monthly adjustment values are then applied to the observed daily time series, creating the projections.

It should always be kept in mind that uncertainty is an inherent component of these projections. Fig. 11 shows the model spread for the meteorological station in Moncton as an example. Uncertainty is introduced by various means, including the natural variability of climate indicators, uncertainties and differing sensitivities in the models themselves, and gaps in reference data. These uncertainties can be addressed by combining multiple models into an ensemble, as was done here, and by obtaining historical data from a long enough time period that seasonal and annual patterns can still emerge despite natural variability and data gaps.

However, there is no way to eliminate this uncertainty completely; these models are useful and based on the best available science, but they are not perfect and climate projections should always be interpreted with this caveat in mind.

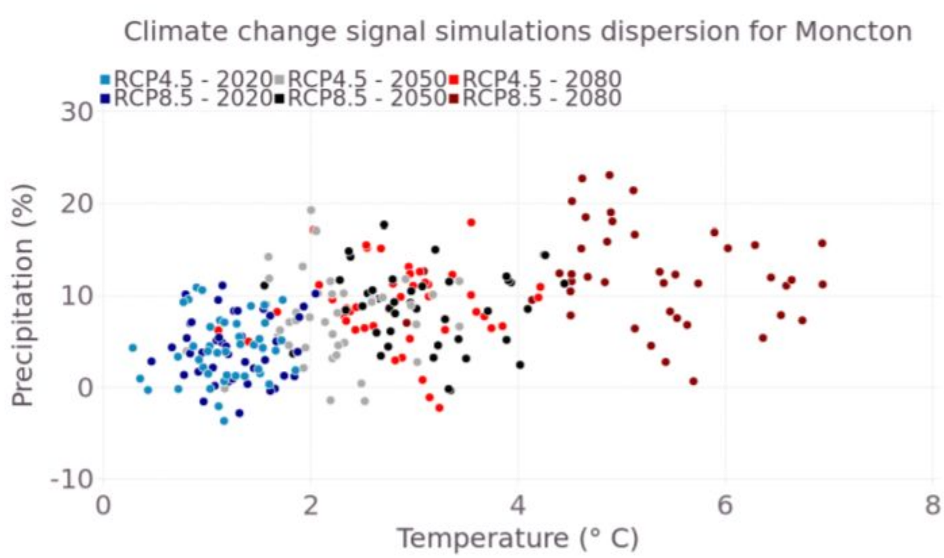

Figure 11: Model spread for temperature and precipitation projections - Moncton, NB. Figure source: Roy and Huard (2016).

4.3 Usage information

The following layers are included in the climate projection section:

- Annual temperature (2020, 2050, and 2100 for RCP 8.5)
- Annual precipitation (2020, 2050, and 2100 for RCP 8.5)
- Reference ("historical") annual temperature (1981 - 2010)
- Reference ("historical") annual precipitation (1981 - 2010)

The value ranges in the attribute tables represent ensemble means, except in the case of the reference period layers, where values represent the mean of the observed records.

These data layers are a testament to the effects that large and regional-scale climate forces, such as atmospheric circulation and proximity to the Bay of Fundy, exert on province-wide climate patterns. As such, these layers are intended to be illustrative; temperature and precipitation projections form an essential part of the matrix of vulnerabilities that a particular region or community may be exposed to, but they do not show the complete picture. Overlaying these projections with other data such as socioeconomic indicators, for example, would provide a more nuanced understanding of what aspects of climate change will be felt more intensely in different parts of the province.

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