CLIMATE CHANGE GUIDANCE FRAMEWORK PILOT PROJECT

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INTRODUCTION

The International Joint Commission (IJC) Climate Adaptation Working Group (CAWG) has developed a "Climate Change Guidance Framework" that can be used to assist IJC control, watershed, and pilot watershed Boards address climate change within the bounds of their mandates. The framework guides Boards to analyze and act on climate change issues in a logical manner.

The guidance framework consists of four primary steps: (1) **organize**, (2) **analyze**, (3) **act**, and (4) **update**. In the **organize** step, each Board formulates its climate change related objectives and assesses what information is available and what is needed to prepare to meet those objectives successfully. In the **analyze** step, the Board produces quantified estimates of how a change in climate might produce different outcomes for Board activities. The Board prioritizes the most critical, and evaluates the likelihood of the outcomes. In the third step, **act**, the Board uses the tools and networks to quantify the problem to evaluate different responses and based on this, the Board makes decisions that it believes would improve their response. The final step, **update**, is adaptive management or the establishment of a process to improve the Board's "act" decisions based on a formalized, ongoing effort to systematically assess the Board's challenges over time.

The pilot project introduced the first step of the four step guidance framework (Horizontal Roll Out **-** Step 1: Organize) across control, watershed, and pilot watershed Boards and introduced the entire four step framework to one watershed board (Vertical Roll Out), **-** The International St. Croix Watershed Board. The "Horizontal Roll Out" of the pilot involved an assessment of each Board's missions and objectives that could be impacted by climate change and what information the Board already has, or needs, to prepare for and minimize risks associated with climate change. The goal of the Horizontal Roll Out is to provide clear guidance to the Boards for addressing climate change in IJC policy and operations using the best available institutional and organizational science and stakeholder inputs available to the Boards.

The Boards that are included in the Horizontal Roll Out:

- St. Mary-Milk River Accredited Officers
- Columbia River Board of Control
- Kootenay Lake Board of Control
- Osoyoos Board of Control
- Lake Ontario-St. Lawrence Board
- Lake Superior Board of Control
- Niagara Board of Control
- Rainy-Lake of the Woods Watershed Board
- Red River Board
- Souris River Board

The Board selected for the four step Vertical Roll Out pilot is the International St. Croix Watershed Board. Dr. Casey Brown, Bill Werick, Dr. M Umit Taner and Alec Bernstein acted as consultants on the IJC's IWI Climate Change Guidance Framework Pilot Study.

BOARD RESPONSIBILITIES AFFECTED BY CLIMATE CHANGE

Each IJC Board has a unique mandate, and climate change can make it more challenging to meet these responsibilities in the future. There are six boards that have some regulation on water levels or flows: , the Lake Superior Board of Control, the Osoyoos Lake Board of Control, the Rainy-Lake of the Woods Watershed Board, the International Lake Ontario-St. Lawrence River Board, and the International St. Croix River Watershed Board. In addition to these Boards, the St. Mary-Milk Rivers Board monitors and apportions flow in these rivers and three prominent tributaries. The Souris River Board also monitors and apportions flows of the Souris River at its international boundary crossings. The Kootenay Board oversees the operations of the operator of the Corra Linn Dam making sure they are in compliance with the Commission's 1938 Order. The Niagara Board oversees water levels in the Chippaway-Grass Island Pool and installation of the Lake Erie-Niagara River Ice Boom.

Climate change is projected to have impacts on the hydrology and the water quality of these transboundary waters. The timing and quantity of water flows in all basins is expected to change as winter snows melt earlier due to increasing temperatures. In several basins across the eastern part of the continent, earlier peak spring flows have already been observed. Climate change is also expected to increase frequency of flow variability on the high and low ends of the flow regime. This will make it more difficult for Boards to maintain flows and levels within narrow ranges (although plan flow (Plan 2014) does favor widening of ranges). Drought periods will be drier, river flows can completely dry up, and land will become more susceptible to wildfires, affecting water quality. Wet periods can expect more intense, sustained, and varied precipitation events with associated flooding, erosion, sedimentation, and warming water quality issues (e.g. algae growth, warmer water temperatures affecting ecosystems).

If droughts become more prominent, Boards may have to reconsider minimum flow or release requirements. These flow requirements are traditionally based on a balance between instream flow needs to maintain ecosystem health and the desire to retain water in upstream reservoirs for longer dry periods. If droughts become more prevalent, water managers will have to consider whether high minimum flows (which would increase the risk of running out of storage) is worth drawing down storage reservoirs or the ability to supplement instream flows during longer dry periods.

Droughts may also reduce water levels in navigable streams and rivers, potentially disrupting maritime shipping and recreational boating. Low water levels can also affect drinking water intake systems. Low river flows during a drought will also reduce hydropower production, making it difficult to meet firm hydropower yields. Hydropower operators will not have substantial inflows to maximize their facility utilization – hydropower facilities have the benefit of going online within minutes to produce power during peak demand periods. If, during a drought, there is not sufficient inflow to maintain reservoir water levels, the benefits of hydropower facilities supplementing production during high demand periods may be lost. A drought can affect free passage of fish through lakes and tributaries. Small tributaries can dry up completely during extreme low flows, decreasing the habitat area available to riverine fish species. Reduced water availability for fish passage at dams can alter the channel shape and affect the passage rates through fish passage structures.

Droughts can be damaging to regions with arid landscapes and environments that rely heavily on water for agriculture and navigation, however, flooding is the most damaging natural disaster on earth. Extreme high flows may overtop or damage spillways and hydropower plants. Floods can inundate land areas and cause extensive property damage in dense, built up areas. Flood prevention infrastructure that was designed decades ago may no longer be sufficient to protect communities from floods since the character of high flow events is changing. High flows may also alter commercial navigation if not stop it entirely due to high flow velocities (for example on the St. Lawrence River).

More variable precipitation and more extreme rain events with associated flooding may lead to water contamination as fertilizers, pesticides, and other land waste are washed into streams and rivers during these events. A flood following a wildfire can cause amplified erosion and wash wildfire contamination such as ash and charcoal into rivers and streams, altering the chemical composition of the water. After a wildfire, the dearth of trees and roots to stabilize the ground makes the land extremely susceptible to erosion.

As water temperatures increase, algae growth will increase in water bodies and algae blooms will become more common. This can be a significant concern as the water chemistry can change and affect aquatic ecosystems. Another significant water quality concern is from non-point sources of nitrogen and phosphorus. These contaminants contribute to the growth of harmful algae blooms, which diminish the natural resources of the basin. Algae thrive in warm environments, and a slight water temperature change can greatly increase algae bloom coverage in basins. Climate change may accelerate the growth of these algae blooms as water temperatures rise and as intense precipitation events become more frequent.

Many Board decisions are based on assumptions grounded in a stationary climate. As the impacts of climate change are realized across the continent, it may be necessary that Board objectives change if the timing and extent of changes is known. However, the future climate is still uncertain, so tradeoffs between water uses need to be adjusted if threats and vulnerabilities for specific Boards change. In addition, consideration must be given to the impacts Board decisions have on multiple stakeholders in any given water sector, including balancing concerns of up and downstream residents, noting perceived harm to any one stakeholder group. The impacts of climate change become more uncertain as they accumulate in conjunction with other factors and adaptive management is necessary to ensure that accumulated effects are accounted for in climate adaptation plans. These specific changes are not known, so the four-step process in the Climate Guidance Framework is designed to identify where vulnerabilities within a Board exist and how these new tradeoffs can be analyzed.

GUIDANCE FRAMEWORK

The four steps are briefly outlined below, with one or more key responses in each step. The St. Croix case study (starting on "Vertical Roll Out") uses the same organization and provides one particular example that illustrates what these steps might look like in practice.

STEP 1 – ORGANIZE

WHAT ARE THE OBJECTIVES THE BOARD IS TRYING TO ACHIEVE?

The goal of this step is for the Board to do a self-analysis with a clear, complete understanding of the objectives that the Board is trying to achieve. The Board mandate is a logical place to begin to identify objectives. What is the objective of the Board and what are the roles and actions they can take to achieve these objectives? This creates a context where climate change can then be considered.

An example Board objective may be to maintain lake levels within a range and to maintain minimum flow requirements downstream of a dam. In this step, the Board will self-analyze what indicators or metrics are used to evaluate whether the objectives are met. United States Geologic Survey (USGS) or Environment and Climate Change Canada (ECC) stream gages and water level gages can be used to monitor water levels and flows.

This step also identifies gaps in information and data collection. If, for example, a Board identifies a pollution concern and is working toward improving water quality, some quantitative metrics are needed to manage their objective. Some type of automatic or manual water quality monitoring scheme will be needed.

After completion of step 1, Boards should understand and prioritize their objectives. In many cases the mandate drives this step, and Boards also will understand what knowledge gaps exist and what measures can be taken to fill those gaps.

STEP 2 – ANALYZE

ESTIMATE HOW A CHANGE IN CLIMATE MIGHT PRODUCE DIFFERENT OUTCOMES FROM BOARD ACTIVITIES.

This step involves analysis to quantify the effects of climate change on Board activities. The analyst will estimate how a change in climate may produce different outcomes for Boards. This step is based on the Board's responsibilities and includes direct and indirect impacts. For example, if a Board is charged to dictate releases for hydropower, the Board may consider how droughts will affect hydropower production and affect the ability to meet hydropower targets and affected grid performance.

In this step, the analyst can use general climate change information productions (IPCC reports, GCM projections, etc.) that give some general guidance of what changes the Board can expect. These are broad changes such as increased temperatures, earlier spring snow melt, etc. Changes in precipitation are less certain, however, plausible increases and decreases sustained and not in the magnitude and frequency precipitation should be considered. In some situations, it may be necessary to model a system to comprehend the complexities and to understand the effects of climate change on the Board's management objectives.

Which of these outcome changes are most important to the Board, for better and worse?

This step should reveal which Board objectives are the most vulnerable to climate change. The analyst would ask which objectives will be the most difficult to meet in a changing climate and the importance of those objectives. The output will be a list of the outcomes from Step 1 prioritized according to the magnitude of impact.

How plausible is it that climate will change in the way required to cause these outcome shifts?

Finally, the analyst will determine the plausibility that a change in climate will cause a significant shift in outcomes. The Board will consider a range of climate information, including past observations and projections to determine which objectives will be the most difficult to realize.

STEP 3 – ACT

Which of those potential outcomes could the Board change? What are the possible actions the Board could take to address the concerns identified?

The analyst will formulate alternative actions the Board can undertake to address the concerns identified in the previous steps. For example, a Board may now have a reservoir minimum release curve that changes from "winter" to "summer" configuration on May 1st each year. Because of rising temperatures and earlier spring snow melt, in the future, May 1st will be later into the summer season. The Board may adjust the threshold between summer and winter to April to account for the earlier peak spring flows. To the extent determined in Step 2, the Board may consider other alternatives to address the shift in outcomes because of warmer temperatures and earlier runoff.

EVALUATION OF ALTERNATIVE CLIMATE PREPAREDNESS ACTIONS.

The analyst will estimate how each alternative affects the Board's outcomes under different climate scenarios. The most valuable alternative actions to mitigate climate change impacts are management objectives (within the IJC mandates) that are creatively developed for a wide range of alternatives.

What would be required for the Board to carry out this work?

In some cases, the Board has all the power it needs to develop alternatives that produce good outcomes under the plausible range of future climate scenarios, in some cases Boards might encounter financial and legal constraints that make altering their policies difficult.

STEP 4 – UPDATE

ADAPTIVE MANAGEMENT

After completing the first three steps of the Guidance Framework, Boards may make decisions to act or not despite uncertainty about future impacts. However, in the future, as more information is gathered, and as more climate predictions are realized, the Board may revisit the decision using better information.

To ensure that these decisions are revisited based on new information, an institutional context for adaptive management is needed. A simple adaptive management plan would be to revisit the discussion every five years, passively reviewing information developed by others, and complete a short review to ask whether there is any reason to go through the steps again. In many cases a more complex formal adaptive management process with a specifically designed monitoring plan could be designed proportional to cost, risk, and uncertainty for each Board.

SEMI-ANNUAL MEETING AND IWI CLIMATE GUIDANCE WORKSHOP

Representatives of eleven Boards met in Washington during the International Joint Commission (IJC) semi-annual meeting on May 4th, 2017 to help shape an effort to advance Board preparedness for climate change. The steps of the Climate Change Guidance Framework were presented, and together with the consultants, Boards had a discussion on climate change adaptation pathways. Boards were asked to assess their climate change preparedness before the workshop, and their responses are included in Appendix A.

SHARED INFORMATION AND "LIVING DOCUMENT"

More scientific collaboration between Boards is important to share information and practices that can be universally accepted regardless of geographic location (i.e. rainwater harvesting, water metering, etc.). The IJC Boards should operate in harmony and are together the collective tissue that helps cope with climate change. The IJC can facilitate working groups and more active collaboration between IJC Boards to ensure that information is shared and practical climate change considerations are taking place.

During the workshop, Boards also discussed creating a single 'living document' (the Climate Change Guidance Framework) that would be useful to synthesize changes and strategies over time (e.g. story maps, web pages). The most critical climate change impacts now may be different in the future as populations, demographics, and economies change. How humans react is important to determining how resilient plans are. Additionally, some Board members noted that they likely will be gone by the time some changes are realized. As such, they suggested a dynamic document that will be periodically or continuously reviewed to meet changing expectations in the future.

“HORIZONTAL ROLL OUT”

STEP 1 – ORGANIZE – WHAT ARE THE OBJECTIVES THE BOARD IS TRYING TO ACHIEVE?

The horizontal roll out component of the pilot study involved the presentation and coordination of Step 1 – “Organize” of the Four step climate change Guidance Framework across the following control, watershed, and pilot watershed Boards:

- Accredited Officers for the St. Mary – Milk Rivers,
- Columbia River Board of Control,
- Kootenay Lake Board of Control,
- Osoyoos Board of Control
- Lake Ontario – St. Lawrence Board,
- Lake Superior Board of Control,
- Niagara Board of Control,
- Rainy-Lake of the Woods Watershed Board,
- Red River Board,
- Souris River Board,
- St. Croix Watershed Board (also the subject of the vertical pilot)

Each Board received a presentation on the four-step guidance framework during a Board meeting.

ACCREDITED OFFICERS FOR THE ST. MARY – MILK RIVERS

The St. Mary-Milk River Board was established in 1921, and the IJC Commission provided direction for the Board to measure and apportion water that crosses the international boundary in the St. Mary and Milk River basins. Measurement of flow and determination of shares are conducted by Environment and Climate Change Canada and U.S. Geological Survey. The Board is responsible for keeping a daily record of the natural flow of the St. Mary River at the international boundary, the Milk River at the Eastern Crossing, and the eastern tributaries of the Milk River at the international boundary. The Board fixes the amount of water each country is entitled to and communicates this to all interested parties. There are irrigation works on both sides of the international boundary, and the Board operates these works and allocates water to the two countries to ensure the greatest beneficial use.

The St. Mary River originates in the Rocky Mountains of northwestern Montana and flows north across the international boundary into Alberta. The Milk and North Milk Rivers originate in the foothills of the eastern slopes of the Rocky Mountains in Montana and also flow north across the international boundary into Alberta. The Milk and North Milk rivers converge and flow in Alberta for approximately 70 miles (120 km) before re-crossing the international boundary into Montana and eventually into the Missouri River.

The St. Mary River has a fairly regularly flow throughout the year. During the summer, flow is augmented by snow and ice in the headwaters, located in Glacier National Park. The Milk Rivers are more dependent on spring snowmelt and rainfall in the lower-elevation foothills, and the discharge is less regular and dependable throughout the year. Both of these main tributaries will be influenced by warming temperatures, and the Board will need to understand how climate change will impact these flows in the basin, especially during summer months. It is expected that the climate will warm in the future, and with that warming there will be less reliable snowpack and glacier melt to contribute to flows in warm months. The St. Mary-Milk River Board may have to re-consider the allocation strategy to account for flow changes as a result of climate change. In addition to climate changes, agricultural changes on either side of the border may influence the Board's allocation of water. If there is significant development on either side of the river and more water is required for agriculture, the Board will need to assess the allocation strategy to ensure the greatest beneficial use.

In order to organize for climate change, the Board needs to gather an understanding of the flows and snowpack it has historically experienced in the basin. It is important to establish this context through historical data to understand how future climate changes may affect the flows and objectives of the Board.

COLUMBIA RIVER BOARD OF CONTROL

The Columbia River Board of Control was established December 15, 1941, which granted approval for the U.S. to construct and operate the Grand Coulee Dam and to study the effect of the operation of the Grand Coulee Dam and reservoir upon water levels at and above the international boundary. The two member board contains a representative from each country who keep the IJC Commission apprised of streamflow and water level data on both sides of the international boundary.

The Columbia River rises in British Columbia on the western slope of the Rocky Mountains and flows 459 miles (739 km) through British Columbia before crossing the international boundary into Washington State. The Columbia continues approximately 740 miles (1191 km) before discharging into the Pacific Ocean near Astoria, Oregon.

Climate change is expected to impact the flows at the Grand Coulee Dam site. Much of the Columbia River headwaters located in Canada are in the Rocky Mountains of British Columbia. As global temperatures warm, the snowpack in the mountains will diminish and the timing of spring runoff is expected to change. These peak spring flows can be expected to arrive earlier, but it may be important for the Board to be able to forecast that timing with some skill. The timing of flows has a direct impact on the value of hydropower generation at Grand Coulee Dam as well as other dams downstream in the Columbia basin. Warmer temperatures may mean that more winter precipitation falls as rain, and infiltration will be limited if the rain falls on snow covering the ground. These rain-on-snow events can lead to high flows during the winter that the Board has not dealt with in the past. Increased flows due to rapid snowmelt and precipitation can also cause flooding; operators and the Board will need to be adaptive to handle the uncertain climate of the future. The rule curves the Board has historically used in operating Grand Coulee Dam may need to be altered in the future to account for climate change.

KOOTENAY LAKE BOARD OF CONTROL

The IJC Commission granted Orders of Approval on November 11, 1938 to the West Kootenay Power and Light Company to operate Corra Linn Dam to store six feet of water in Kootenay Lake. The Kootenay Lake Board of Control was established to supervise the construction and operation of the works. The dam is 16 miles (30 km) up the Kootenay River from its confluence with the Columbia River. Kootenay Lake is 62 miles (100 km) long and 2 to 3 miles (3 to 5 km) wide.

The Orders require a draw down to prepare for spring runoff such that the elevation not exceed 1739.32 feet (530.145 m) on (or about) April 1st. During the summer, water is discharged from Kootenay Lake, and once the elevation falls below 1743.32 feet (531.364 m), it must be held below that elevation until

August 31st to allow farmers to work in their fields along the flood plain. Between September 1st and January 7th, the maximum elevation is 1745.32 feet (531.974 m).

Climate change can impact the timing of spring runoff, which can affect the lake levels as well as impact salmon runs through the system. It may make it difficult for the Board to operate the lake using the same summer and winter thresholds. The magnitude and timing of the rule curve currently used to operate Kootenay Lake may need to be altered. With increased snowmelt and earlier spring runoff expected with warming temperatures, the Board may require the draw down to prepare for spring runoff to begin earlier than April 1st. The Board has one elevation target until August 31st, and then another starting September 1st. During the summer period, the Board might use forecasts to calculate the available water for farmers downstream of the dam to ensure that September 1st is an appropriate time to adjust the operating rule curve in that particular hydrologic year. These forecasts could help the Board decide on appropriate elevation levels to ensure that water is available downstream. The Board could work closely with the West Kootenay Power and Light Company to coordinate these operations.

OSOYOOS BOARD OF CONTROL

The International Osoyoos Lake Board of Control was established on September 12, 1946 to ensure the appropriate operations of the Zosel Dam, built in 1927, on the Okanogan River 1.7 miles (2.7km) below Osoyoos Lake. The lake straddles the international boundary, and is important to agriculture interests in the Osoyoos area in British Columbia and Washington State. The lake also serves as a recreation resource and domestic water supply. The deteriorating Zosel Dam was replaced in 1987, and is currently operated by the Oroville and Tonasket Irrigation District.

One of the Board's main responsibilities is to impose drought declarations until conditions for recovery are met. The rule curve for the lake was recently altered (in the Supplementary Order or Approval 2013-01-29) to include a 1 foot (0.30 m) range with a 912 foot (278.0 m) maximum in the summer under normal conditions, and a 2 foot (0.61 m) range with a 912.5 foot (278.13 m) maximum during drought years.

As climate changes, the Board may reconsider the importance of providing irrigation water from Osoyoos Lake. It may be necessary to modify the criteria and triggers for drought declarations to meet downstream requirements. If future droughts are more frequent, severe or prolonged, the Board may have to revise the rule curves to provide more storage for drought years by raising the current maximum elevation. Seasonal forecasts can help the Board identify drought years early in the season, and adaptive measures can be taken early to ensure that releases can supply water for agriculture through the driest periods. The timing of spring runoff is also expected to change, and these seasonal forecasts can help managers estimate snowpack, melt, and runoff. The timing and magnitude of the spring runoff is crucial for the lake's water supply, and it may be necessary to change regulation rules to accommodate less storage as snow which means higher winter flows and lower flows later in the year.

GREAT LAKES – ST. LAWRENCE RIVER ADAPTIVE MANAGEMENT COMMITTEE

The IJC's Great Lakes – St. Lawrence River Adaptive Management Committee (GLAM) was established in January 2015 to undertake the monitoring, modeling, and assessment needed to support on-going evaluation of the regulation of water levels and flows. The GLAM committee reports to the Lake Superior Board of Control, Niagara River Board of Control, and the Lake Ontario – St. Lawrence River Board and as such, is well positioned to assist the Boards to adapt to climate change.

Regulating water levels and flows is the main concern for the Superior and Ontario-St. Lawrence Boards, and these Boards must consider the uncertainty surrounding how extreme future levels might be as climate changes. The GLAM will help coordinate efforts related to hydroclimate science and work with other agencies to create coordinated models and datasets when it is appropriate. The committee's primary responsibility is to assess how well currently available scientific data, information, models and tools reflect real world conditions so that improvements and updates can be made. Using these updated tools, the Committee will work to assess regulation plans under a range of actual and potential future hydrologic conditions and extremes and track conditions over time to determine if there are changes that affect how we might regulate in the future.

This extreme variability also can impact water quality in the Great Lakes. Turbidity, suspension of contaminants, algae blooms, and invasive species are concerns for water quality in the lakes. The Great Lakes Water Quality Board can leverage its influence within the Great Lakes region to recommend approaches for climate change adaptation by other decision makers.

Information sharing between GLAM and all the IJC Great Lakes Boards could help improve each Board's operations to ensure traditional lake uses are met.

LAKE SUPERIOR BOARD OF CONTROL

The International Joint Commission established the basic objectives for and limits to the regulation of Lake Superior's outflow in 1914. The Orders of Approval allowed increased hydropower development in the St. Marys River. The conditions for regulation in the original Order acknowledged the needs of various interest groups on Lake Superior and the St. Marys River, including navigation, hydropower, and riparian owners. Since its inception, the Commission has issued several supplements to the original Orders of Approval. The Orders now specify that the levels of Lake Michigan and Lake Huron must also be considered when determining the outflow from Lake Superior. The Order also addresses concerns for the fisheries in the rapids. The releases of water from Lake Superior are made through structures located on the St. Marys River. The allocation of flows are determined on a monthly basis, based on the outflow specified by the regulation plan and conditions given in the Orders.

The main objective of the current regulation plan is to determine a flow that will bring the levels of Lake Superior and Lakes Michigan and Huron towards the same relative position within their respective ranges of actual historic levels. The plan also tries to prevent the level of Lake Superior from rising above or falling below certain water levels specified in the Order. The plan also contains provisions to safeguard against high levels in the harbor below the locks, provides a fixed minimum release, limits water flows, and employs a forecast of future water supply conditions.

The ability to regulate the outflow from Lake Superior does not mean that full control of lake levels is possible. The dam has some ability to change Superior levels, a small impact on Michigan-Huron and very little on Lake Erie and almost no useful effect on Lake Ontario levels.

Plan 2012 was adopted in 2014 to set flows out of Lake Superior and provide benefits for range of stakeholders. The plan attempts to maintain more natural variability in the lake levels than the previous plan, while still meeting stakeholder needs. The plan performs better under extreme water supply scenarios and results in flows that provide slightly great environmental outcomes in the St. Marys River. The plan better meets the needs of the upper Great Lakes, but can still benefit from climate change insight. The Plan 2012 was developed based on the most extensive climate change analysis an IJC study has ever provided. Forecasting that can better predict long term droughts in the summer or above average winter flows would be useful for operators, although they may not be available soon.

The Lake Superior Board of Control works closely with the GLAM committee and the Great Lakes Water Quality Board, and could build on that collaboration to better coordinate efforts for climate change adaptation amongst all Great Lakes Boards.

LAKE ONTARIO – ST. LAWRENCE BOARD

In the 1950s, Canada and the United States built the St. Lawrence River Hydropower Project, including a dam crossing the St. Lawrence River from Massena, New York, to Cornwall, Ontario and channel enlargements that increase the river's capacity to release water from Lake Ontario. The IJC issued "Orders of Approval" for the project in 1952 and supplementary orders in 1956 to provide dependable flow for hydropower, adequate navigation depths and protection for shorelines on Lake Ontario and other interests downstream in the Province of Quebec. Regulation of outflows from Lake Ontario through the control structures was managed by the International St. Lawrence River Board of Control in accordance with Plan 1958-D with deviations from 1963 through 2016. On December 8, 2016 after extensive study and public consultation and with the concurrence of the Governments of Canada and the United States, the Commission issued a new Supplementary Order of Approval for the project and adopted a new Lake Ontario – St. Lawrence River flow regulation plan. The updated order and plan, referred to as "Plan 2014" was implemented in January 2017 and replace the 1952 and 1956 orders and Plan 1958D. With the new supplementary order, the Board was renamed the International Lake Ontario-St. Lawrence River Board.

The supplementary Orders of 2016 reflect the priorities for water use set up by the Boundary Waters Treaty as well as suitable protections for riparian, environmental, commercial, and recreation interests on Lake Ontario and downstream. The supplementary Orders of 2016 specify conditions and a range of criteria that a regulation plan must satisfy, and also requires the Board to conduct on-going review and evaluation of regulation plans. To support the Board in this on-going evaluation, the Commission created the Great Lakes – St. Lawrence River Adaptive Management Committee (GLAM) to monitor and assess the performance of the regulation plan and to assess whether conditions are changing over time in such a way that would affect how the Board might regulate in the future. The Lake Ontario – St. Lawrence River Board should continue to work closely with the GLAM committee to coordinate efforts for assessing how the current regulation might function under climate changes and extreme events to determine if any modifications to the regulation plan may be warranted in the future to address changing conditions.

Given supportive scientific data, the regulation plan or criteria in the Orders may need to be altered in the future if extreme hydrologic events such as droughts and floods become more common, longer lasting,, or that their frequency may increase. The capacity to predict with more accuracy weather events is challenging even with the most modern technologies available such that those used by ECCC for the LOSL system.

NIAGARA BOARD OF CONTROL

The International Niagara Board of Control was established by the IJC Commission in 1953 to provide advice on matters related to water levels and flows in the Niagara River. The Board's main duties are to oversee water levels in the Chippawa Grass Island Pool and the installation and removal each year of the Lake Erie – Niagara River Ice Boom. The Board also collaborates with the International Niagara Committee to determine the amount of water available for Niagara Falls and power generation.

The International Niagara Control Works is a structure extending 0.5 miles (0.8 km) into the river from the Canadian shore downstream of the Chippawa-Grass Island pool. The sluice gates allow for precise control of the flow over Niagara Falls and adjustments to the water level as water is diverted for hydropower production. The ability to quickly alter water levels above Niagara Falls by adjusting sluice gates has assisted in river rescue operations to save people from going over the falls.

In 1964, the Commission approved the installation of a floating ice boom in Lake Erie near the entrance to the Niagara River. The purpose of the boom is to reduce the frequency and duration of heavy ice runs into the river. The ice boom speeds formation of and stabilizes the natural ice arch near the head of the river every winter. The boom is owned and operated by the power companies that operate hydroelectric facilities in the area. Installation of the boom may begin on December 16th, or when water temperatures at the Buffalo water intake reach 4°C (39°F). The boom is opened by April 1st, unless there is more than 250 mi^2 (650 km^2) of ice remaining in the eastern end of the lake.

Climate change can affect the objectives of the Board, especially related to the formation of ice on Lake Erie, and flows in the Chippawa Grass Island Pool. Warming temperatures will cause less ice to build up on the lake, and at a later date during the year. In the spring, the ice is expected to melt earlier. The Board may need to alter the dates for their ice boom installation in the future. A more accurate seasonal climate forecast, as well as temperature monitoring stations in Lake Erie can alert the Board to annual ice buildup and the Board can deploy the ice boom in the lake accordingly. The Chippawa Grass Island Pool operations may be affected by climate change. The flow regime of the Niagara River may be altered, and low flow scenarios may require the Board to consider lowering power production beneath historic minima to ensure there is adequate flow over the falls. As the population of both Ontario and New York increase, there may be the need to generate more hydropower around Niagara Falls in the future, limiting the water available to release over the falls. Hydropower generation may be more constrained in the future during droughts and seasonal forecasts can help the Board deal with these low flow scenarios.

RAINY-LAKE OF THE WOODS WATERSHED BOARD

The International Rainy-Lake of the Woods Watershed Board was formed by the IJC in 2013 by the merger of the International Rainy River Water Pollution Board and the International Rainy Lake Board of Control. The Board's mandate is to monitor and report on the ecological health of the Lake of the Woods and Rainy Lake boundary waters aquatic ecosystems, including water quality, and to assist the Commission in preventing and resolving disputes that may arise in the watershed.

In 1938, the Rainy Lake Convention between the U.S. and Canada gave the IJC power to determine when emergency conditions (both high and low water conditions) exist in the Rainy Lake watershed. There are two existing facilities in the watershed: a pair of dams at Kettle Falls, and a dam at the International Falls – Fort Frances, along the border between Minnesota and Ontario.

Water regulation is delegated to the Rainy and Namakan Lake Water Levels Committee. The Order specifies a water level band with upper and lower rule curves for each lake, minimum outflow requirements under normal low flow conditions and a drought line, defining lake levels below which outflows are further reducible. The discharge facilities at the Kettle Falls and International Falls-Fort Frances dams are operated by the companies in a manner to maintain the lake levels within rule curve bands. If extremely high or low flows are anticipated, the Water Levels Committee may request the Commission to authorize lake levels higher or lower than the prescribed bounds temporarily.

A study of the operating rules of these dams was completed in 2017. The current and alternative rule curves were tested with a variety of varying inflows representing the expectations of a range of climate change experts and interpretations of widely available federal projections from both Canada and the United States. The analysis showed that the relative performance of one plan to the others was more or less the same despite dealing with different inflows, but the outcomes, no matter the plan, could be very different from past outcomes. The study recommended an alternative that drew the lakes down less over the winter and lowered the Rainy Lake curve in spring if flooding was indicated using an ENSO based forecast. The Board is aware that climate change will also affect water quality in the watershed and will be incorporating, as a priority issue, climate change indicators and adaptation into its work to develop Objectives and Alert Levels relevant to the Rainy-Lake of the Woods Basin. The Board is also considering developing a web page for resources relevant to climate change in the basin to be used as a reference "library".

Although the Board, per se, has not done additional research on climate change beyond what was reported in 2016, it is aware of research which has been done by others, including the Experimental Lakes Area, Treaty 1854, the Province of Ontario and the State of Minnesota which is relevant to the Basin.

RED RIVER BOARD

The Red River Board's mandate does not include specific quantitative targets for flows or levels in the basin. The Board's mandate is to assist the Commission in preventing and resolving transboundary disputes regarding the waters and aquatic ecosystem of the Red River and its tributaries and aquifers.

The Board reports on basin-wide development activities that may affect water levels and flows, water quality, and ecosystem health, and has already considered how climate change could affect the Red River. Any development activities within the basin can affect the hydrology of the Red River, and climate change may amplify these effects. The Board also monitors and reports on flood preparedness and mitigation activities in the basin. Flooding can affect the transboundary aquatic ecosystems, and the Board encourages and facilities the development of flood-related data and information systems. Climate change can alter the natural variability and magnitude of floods, and the Board may need to adapt its practices and shift the focus of their efforts to gathering more information, performing studies, and gaining a better understanding of how climate change will affect the Red River basin.

Climate change work is also taking place within the basin but outside of the Red River Board. The St. Paul District has completed a quantitative assessment of climate change impacts on flood peaks within the Red River Basin for a pilot study conducted in support of the Corps' Climate Preparedness and Resilience Working Group.

SOURIS RIVER BOARD

The International Souris River Board was created by the IJC in April 2000 to combine the Souris River basin responsibilities previously assigned to the International Souris River Board of Control Reference and the Souris-Red Rivers Engineering Board Reference. This consolidated the responsibilities in the watershed associated with water quality, water quantity, and the oversight of flood forecasting and operations toward an integrated approach to water management in the Souris River.

The Board's objective is to report on existing and proposed developments, activities, conditions, and issues in the Souris River basin that may have an impact on transboundary water levels, flows, water quality, and aquatic ecosystem health, to investigate and report on water requirements and uses as they impact the transboundary waters of the Souris River basin, and to assist in the implementation and review of the Joint Water Quality Monitoring Program.

The Souris River basin is driven by variable climate. The Board has already observed a change in the spring peak runoff, coming from earlier snowmelt and heavy spring and early summer rains. The operating references and actions should be reviewed to address these changing precipitation patterns. The most significant challenge is greater knowledge and understanding of the potential cycles of climate variability which will affect the basin. Climate variability increases the potential for conflict amongst users in the basin and the Board governance mechanism must be sound in order to manage through these situations. Future work focused on tools and approaches to understanding climate change effects and how the Board can address this potential conflict situation will be required.

In addition to the Souris River Board, there is other climate change work being done in the basin. The IJC formed the International Souris River Study Board (ISRSB) in 2017. This group also does work in the basin and has included tasks related to assessing the potential future impacts of climate change on water management in the Souris Basin in their November 2017 work plan. Additionally, outside of its work with the IJC, the USACE St. Paul District has either completed or is in the progress of completing qualitative assessments of climate change impacts in accordance with USACE guidance (ECB 2016-25) for projects within the Souris and Red River Basins.

“VERTICAL ROLL OUT”

This section provides an overview of analyses performed on the St. Croix River Watershed within the context of the “Vertical Roll Out” component of the pilot study. The St. Croix River is a transboundary river along the Canada and United States border between New Brunswick and Maine on the eastern end of the continent. The river is 110 miles (185 km) long and drains an area of 1,642 square miles (4,271 km^2). The river is in a unique location and comprises the easternmost land border between the two countries.

The analysis presented in this section provides a bottom-up assessment of climate change vulnerabilities in the St. Croix Watershed associated with violating the Board’s specific performance targets. The method applied is also termed as “decision scaling” (Brown et al. 2011) focuses on identifying stakeholder-defined vulnerabilities in a given environmental resources system to climate uncertainty, rather than focusing on predictions of future climate that are subject to various climate modeling and downscaling approaches. This is typically done by considering a broad range of plausible futures, and then explore vulnerabilities across those futures using computationally inexpensive simulation models. Identified vulnerabilities are then linked to climate information obtained from climate models or experts for aiding the decision-making processes.

The bottom-up climate vulnerability analysis approach adopted to the St. Croix Watershed pilot study consists of four phases:

i) Definition of objectives and critical thresholds related to the minimum flows and lake levels at various points in the basin,
ii) Developing a coupled hydrology-water system model at the appropriate scale to analyze system performance under different conditions,
iii) Implementation of climate stress test, to assess the violations related to the previously defined critical thresholds across a broad range of plausible climates, and
iv) Identifying climate-informed risks by linking climate stress test outcomes to the outputs of Global Circulation Model (GCMs).

There are two principal chains of lakes in the watershed’s headwaters. The eastern chain of lakes follows the mainstem of the St. Croix River and includes two of the largest lakes in Maine and New Brunswick: Spednic and East Grand Lake. The Eastern branch of the St. Croix forms the international border. The western branch of the river is entirely within Maine and includes West Grand Lake and Big Lake. The two branches converge at Grand Falls Flowage, where the St. Croix River continues for approximately 18 mile (29 km) to the head-of-tide at Calais, ME, and St. Stephen, NB where it joins the St. Croix estuary. The 15 mile (24 km) estuary connects to Passamaquoddy Bay, an inlet of the Bay of Fundy.

The St. Croix River basin was first inhabited nearly 11,000 years ago by post ice-age populations and has been occupied by a succession of native populations since. The river was historically used as a travel route to the neighboring Penobscot and St. John River systems. In 1604, French explorers established the first New World colony on St. Croix Island, located in the estuary. The St. Croix River basin was subsequently settled by the English and others who have used the basin’s resources for lumbering, ship building, milling, and hydropower. Today, the natural, cultural, and historic resources of the St. Croix watershed still help support the local economy. The majority of the basin's area is covered by forests, and wood harvesting and processing is the most important industry in the St. Croix area. The watershed also provides abundant natural recreational opportunities and wildlife habitats. The St. Croix River is known to canoeists, anglers, and naturalists as one of the most pristine recreational rivers in the region.

The International St. Croix River Watershed Board of the IJC was established in 1915 and monitors the ecological health of the St. Croix River boundary waters. The Board ensures compliance with the IJC's Orders of Approval for structures in the St. Croix River. Today, there are approximately 25,000 people living in the basin, around five population centers (defined as incorporated municipalities with more than one thousand inhabitants): St. Stephen, St. Andrews, and McAdam in New Brunswick, and Calais and Baileyville in Maine. All of these municipalities except McAdam are located in the lower part of the watershed, and over 75% of the population lives at the lower end of the watershed within 10 miles (16 km) of the estuary. Most of the watershed is sparsely populated. An overview map of the St. Croix basin is shown in Figure 1 - Overview map of the St. Croix River watershed.

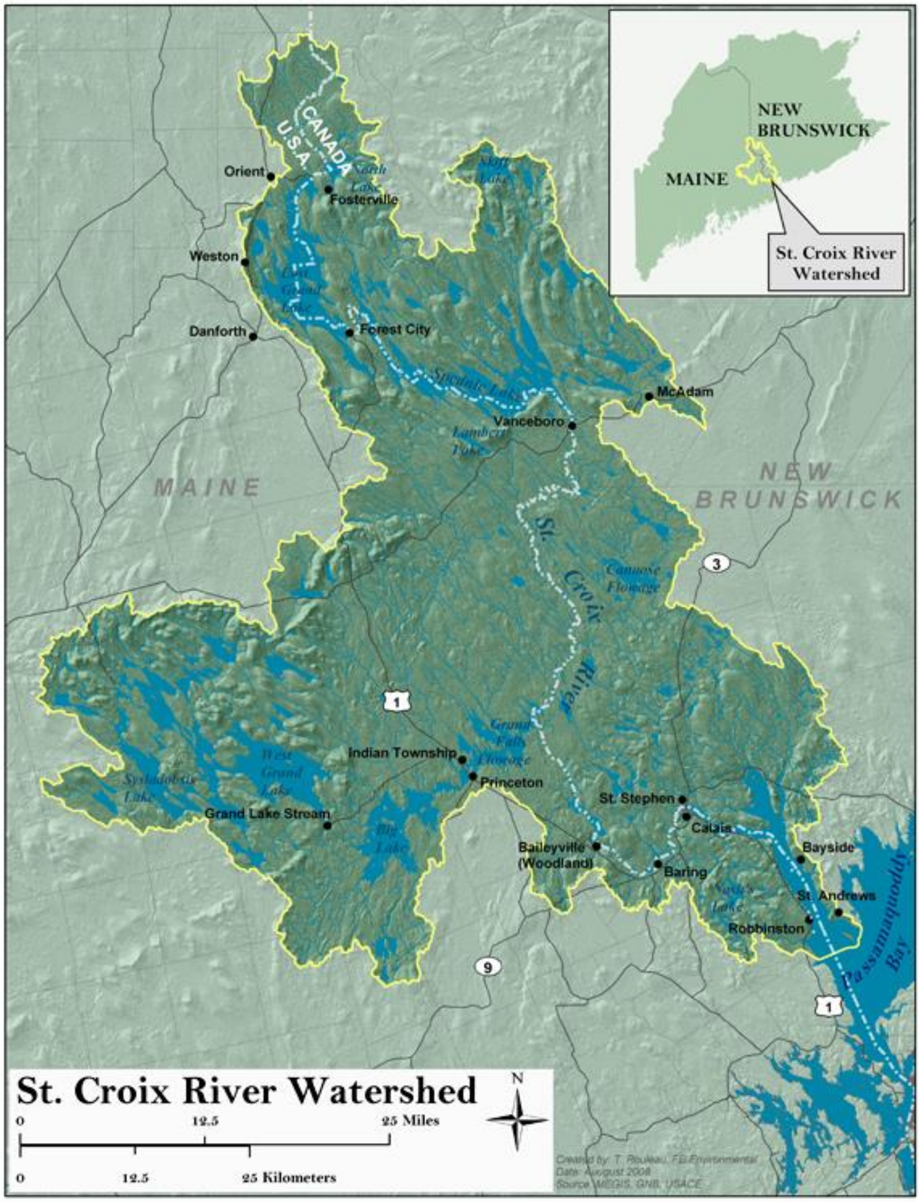

FIGURE 1 - OVERVIEW MAP OF THE ST. CROIX RIVER WATERSHED (SOURCE: FB ENVIRONMENTAL)

Forest covers 77% of the total watershed area, the dominant land cover in the region. Open water covers 11% and wetlands cover 8% of the watershed, and all other uses constitute less than 2% of the basin area. Forests are critical to healthy ecosystems and contribute to the watershed health. This forest cover helps filter nitrogen pollution, increase infiltration, moderate stream temperature, and provide important wildlife habitat. Many species in the basin require large unbroken tracts of forest to carry out some portion of their life cycle. Wetlands also play a vital role by protecting and improving water quality, providing fish and wildlife habitat, floodwater storage, and riparian stabilization. Approximately 67% of the St. Croix River watershed is under some form of protection, with 42% of the watershed permanently protected.

There are 38 impoundments in the watershed, including six major dams. The International St. Croix Watershed Board has mandates on four facilities on the mainstem between the U.S. and Canada. A summary of all the facilities in the St. Croix basin is found below in Table 1.

TABLE 1 - SUMMARY OF THE LARGE DAMS IN THE ST. CROIX BASIN

Name	Water Body	Built	Current Use	Owner	Height	Length	Minimum Flow
Forest City Dam	East Grand Lake	1908	Hydropower Storage	Woodland Pulp, LLC.	16 ft 4.9 m	500 ft 152 m	75 cfs 2.12 cms
Vanceboro Dam	Spednic Lake	1836	Hydropower Storage	Woodland Pulp, LLC.	22 ft 6.7 m	500 ft 152 m	200 cfs 5.67 cms
Grand Falls Dam	St. Croix River	1915	Hydropower Production	Woodland Pulp, LLC.	50 ft 15 m	1135 ft 345.9 m	n/a
Milltown Dam	St. Croix River	1881	Hydropower Production	New Brunswick Power Authority	24 ft 7.3 m	600 ft 183 m	n/a
***West Grand Dam**	West Grand Lake	1836	Hydropower Storage	Woodland Pump, LLC.	13 ft 4.0 m	485 ft 148 m	100 cfs 2.83 cms
***Woodland Dam**	St. Croix River	1906	Hydropower Production	Woodland Pulp, LLC.	46 ft 14 m	1350 ft 411 m	750 cfs 21.2 cms

** The International St. Croix Watershed Board does not have mandates on these facilities.*

Water in the upstream lakes and mainstem is regulated and managed to balance competing uses including the environment, recreation, and energy production. The major dams are operated consistent with various orders and agreements with the International Joint Commission (IJC), Federal Energy Regulatory Commission (FERC), Maine Department of Inland Fisheries and Wildlife (MDIFW) and the Main Department of Environmental Protection (ME DEP). The Canadian and New Brunswick agencies do not have specific operational agreements for these facilities.

Dams in the St. Croix River operate in two ways: 1) run-of-river dams use natural flow and elevation to generate electricity, and 2) storage dams regulate water releases to ensure continuous flow past downstream facilities. If the river were not regulated, the monthly distribution of runoff from precipitation would be more variable; summer flows and water levels would be lower than regulated flows. During dry years, rivers would run with zero flow if not for the storage that is available behind these dams.

STEP 1 – ORGANIZE

WHAT ARE THE OBJECTIVES THE BOARD IS TRYING TO ACHIEVE?

The International St. Croix River Watershed Board's main objective is to maintain appropriate flows and levels at several key locations within the basin, based upon the St. Croix River Orders of Approval. The Board has specific mandates on levels in Grand Lake at Forest City, Spednic Lake at St. Croix, and Grand Falls Flowage at Grand Falls, as well as flows (minimum discharge) at Forest City Dam and Vanceboro Dam. Shown in Table 2 are the specific flow and water surface elevation prescriptions.

TABLE 2 - FLOW AND LEVEL PRESCRIPTIONS AS IN THE ST. CROIX BOARD MANDATE

Location	Mandate	Minimum	Maximum
Grand Lake at Forest City	Water Level	130.436 m amsl	132.571 m amsl

Spednic Lake at St. Croix	Water Level	113.233 m amsl (Oct 1 – Apr 30) 114.757 m amsl (May 1 – Sept 30)	117.610 m amsl
Grand Falls Flowage	Water Level	---	62.106 m amsl
Forest City Stream below Forest City Dam	Discharge	2.12 m^3/s	---
St. Croix River at Vanceboro	Discharge	5.67 m^3/s	---

In accordance with its mandate from the IJC, the Board leaves the control of operation of the dams at Forest City, Vanceboro, Grand Falls, and Milltown to the owners. Forest City Dam, Vanceboro Dam, and Grand Falls Dam are owned by Woodland Pulp LLC, and the Milltown Dam is owned by New Brunswick Power Corporation.

The Board also monitors water quality at several locations in the basin, but control of water quality is not a part of their mandate. The Board uses data from monitoring stations run by the USGS and Environment and Climate Change Canada to analyze contaminants and report on any violations. The guidelines for each parameter come from various Canadian government entities (Canadian Council of Ministers of the Environment, Environment and Climate Change Canada, Provincial Ministries of the Environment, etc.). The Board monitors and reports on several water quality parameters including temperature, dissolved oxygen, pH, specific conductance, and turbidity. There are several point sources of pollution in the basin, mainly from small wastewater treatment plants, however, the Woodland Pulp LLC mill in Baileyville, ME is a large industrial complex in the basin. Generally, there are few – if any – annual violations of pollutants discharged in the St. Croix River.

The Spatially-averaged mean precipitation for the St. Croix Watershed over the 1950-2010 period marks a high interannual variability, ranging from about 700 mm to 1600 mm with a mean of 1100 mm. The mean precipitation data over this 50-year period also indicates a modest increasing trend (Figure 2).

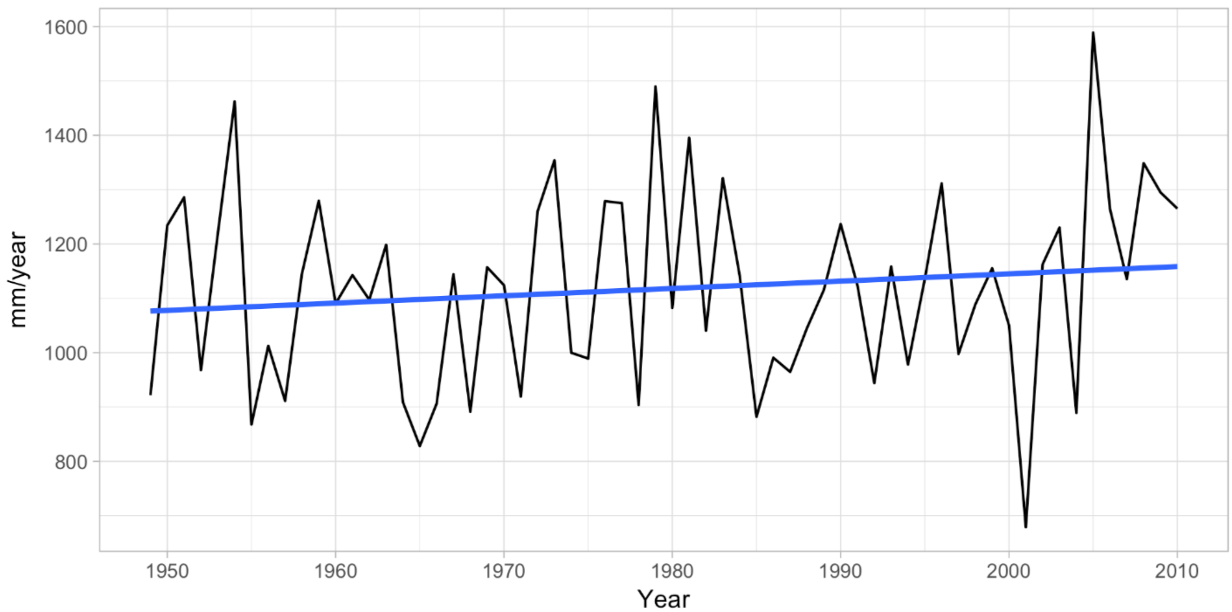

FIGURE 2 – SPATIALLY-AVERAGED MEAN ANNUAL PRECIPITATION FOR THE ST. CROIX WATERSHED FOR THE 1950-2010 PERIOD. THE BLUE LINE MARKS THE LINEAR TREND IN ANNUAL PRECIPITATION FITTED ON THE DATA.

The Board recognizes the natural value of the St. Croix River, and as such, monitors fish passage at dams in the basin. The main anadromous fish in the basin are River Herring (Alewife) and Atlantic Salmon, which each year travel upstream to spawn during the late spring. Anadromous fish are known to spawn in the same location year after year, so maintaining their habitats is crucial to ensure the productivity and viability of the species. There are artificial fish passage structures at each of the IJC facilities, and the structures are brought online sequentially (going upstream) once fish are observed to begin their migration. The IJC's International Watershed Initiative (IWI) supports many fisheries studies including an aquatic food-web study, an alewife count study at Milltown, and a fish tracking study. During the annual Board meeting, fish passage was a main topic of discussion. Fish passage has increased over the past several years (shown in Figure 4 - Fish count at Milltown dam from 2000-2017(source: St. Croix International Waterway Commission)) as improvements have been made to the fish passage structures at several facilities. However, these figures are still well below historic levels observed in the late 1980s (Figure 3 - Fish count at Milltown Dam from 1981-2017 (source: St. Croix International Waterway Commission)).

There are currently no requirements for dam operators to release water through fish passage ladders at any of the facilities. Nonetheless, the operators do now operate facilities to pass fish in accordance with FERC and U.S. Fish and Wildlife Service requirements. Because fish passage is a main concern for many constituencies in the basin, the Board could decide to add fish passage operational requirements to their operating rules. This will ensure that fish passage will be a long term operational objective in the basin. Over time, consistent operations of properly designed and constructed facilities can improve a fish spawn population, shown through historic fish count records in the basin, in Figure 3. Historically, fish counts were orders of magnitude higher than they have been in the past two decades. Fish passage as a priority year after year can help improve the fish runs, and due to the nature of the fish reproductive cycle, it takes several seasons for the population of a species to grow to historically high levels.

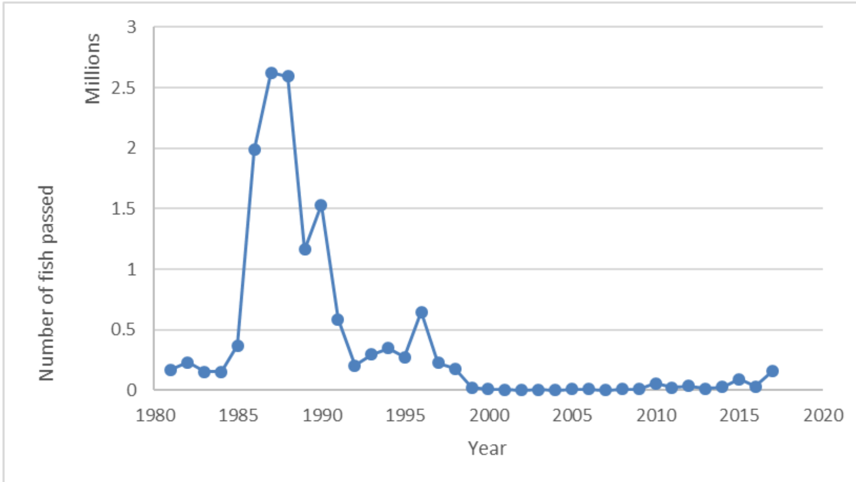

FIGURE 3 - FISH COUNT AT MILLTOWN DAM FROM 1981-2017 (SOURCE: ST. CROIX INTERNATIONAL WATERWAY COMMISSION)

Figure 4 shows that since 2000, fish passage rates have improved at Milltown Dam, concurrent with a concerted effort by operators to operate fish ladders in coordination with local environmental organizations. Improvements to the fish ladder took place in 2015, and an increase in fish runs has been observed, with 2017 passing the most fish in nearly 20 years. Because the nature of a healthy fish run is contingent on a variety of variables and not solely flow, it is difficult to predict how effective a particular flow regime would be on fish passage rates.

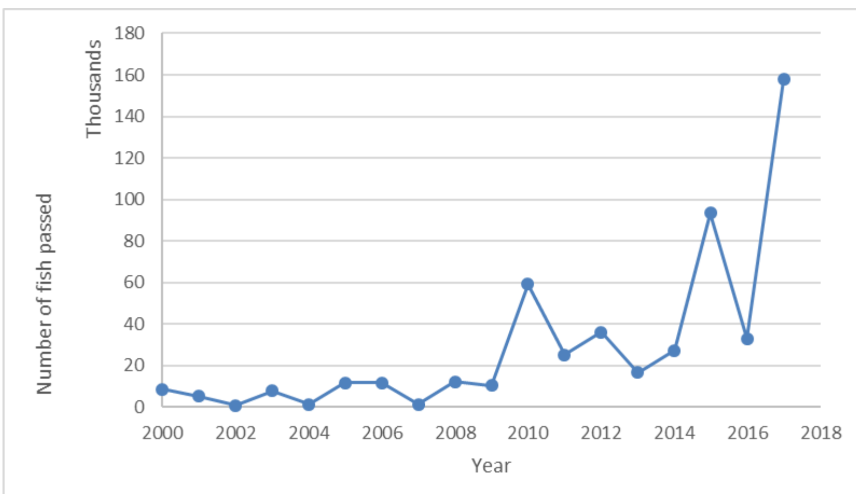

FIGURE 4 - FISH COUNT AT MILLTOWN DAM FROM 2000-2017(SOURCE: ST. CROIX INTERNATIONAL WATERWAY COMMISSION)

During the 2017 annual public meeting, the question of removing the Forest City Dam was raised, with strong opposition from landowners along East Grand Lake. The Forest City Dam, which holds back the waters of East Grand Lake, received a U.S. Federal Energy Regulatory Commission (FERC) license in December 2016. The facility was historically used for log runs down the St. Croix, but it is no longer used for this purpose. Currently, the main purpose of the dam is recreational; there are many cottages on both sides of the border along East Grand Lake and residents boat and fish. The license requires the owner, Woodland Pulp LLC, to perform several studies and assessments to continue operating the facility. Canada does not have licensing of facilities. Woodland Pulp LLC views the requirements of the FERC license as an economic burden, and holds that completing the required studies and assessments will render the project financially infeasible. As a result, Woodland Pulp LLC attempted, unsuccessfully, to invalidate the FERC license. Woodland Pulp LLC is in the process of selling the U.S. half of the dam to the State of Maine, and it believes then it will not be obliged to complete the FERC license requirements. Another option is to keep ownership of the facility and remove the dam. During the public meeting, many landowners voiced their opinions about the lake levels and against removing the dam. If the facility were to be removed, the cottages along the lake would no longer have waterfront access, and in certain areas, the lake itself would be diminished down to a small creek. The St. Croix Board heard these opinions, however, they (along with Woodland Pulp LLC and the public) must wait until the State of Maine takes ownership and/or FERC completes their process. A decision as to the next steps for the Forest City Dam is expected in fall 2017.

The Board's main objectives are the flows and levels on the facilities it has a mandate on in the St. Croix Basin. Other tangential objectives are to maintain pristine water quality and encourage fish passage throughout the basin.

STEP 2 – ANALYZE

ESTIMATE HOW A CHANGE IN CLIMATE MIGHT PRODUCE DIFFERENT OUTCOMES FROM BOARD ACTIVITIES.

Climate change is predicted to influence the climatology and hydrology of the St. Croix Basin. The question for the Board is, how might that affect the ability to meet the objectives described in Step 1? There is general consensus from climate models that the St. Croix Basin will warm in the future, however, there is less certainty as to how precipitation patterns will change. Figure 5 shows the global circulation model (GCM) projections for the St. Croix Basin for the periods of 2036-2065 (centered on 2050) and 2070-2099 (centered on 2085) relative to the historic period from 1971-2000. All of the GCM models predict some warming to occur by 2050, from 0.2°C to over 4°C, and by 2085 from 1°C to over 7°C. Projected changes in mean annual precipitation range from 5% decrease to about 25% increase by 2050, and from about 5% decrease to 35% increase by 2085 (Figure 5).

The variations in projected mean climate changes on Figure 5 results from various sources of uncertainty associated with climate model projections. These include the differences in the model representations of the physical earth-climate dynamics, model initial conditions, and finally the uncertainty associated emission scenarios used in each simulation run (shown by different colors on Figure 5). Overall, the results from the CMIP5 ensemble suggests a warmer and wetter future. A warming climate has implications for the St. Croix basin as warmer temperatures can increase early season snowmelt, and shift the timing of the spring peak flows.

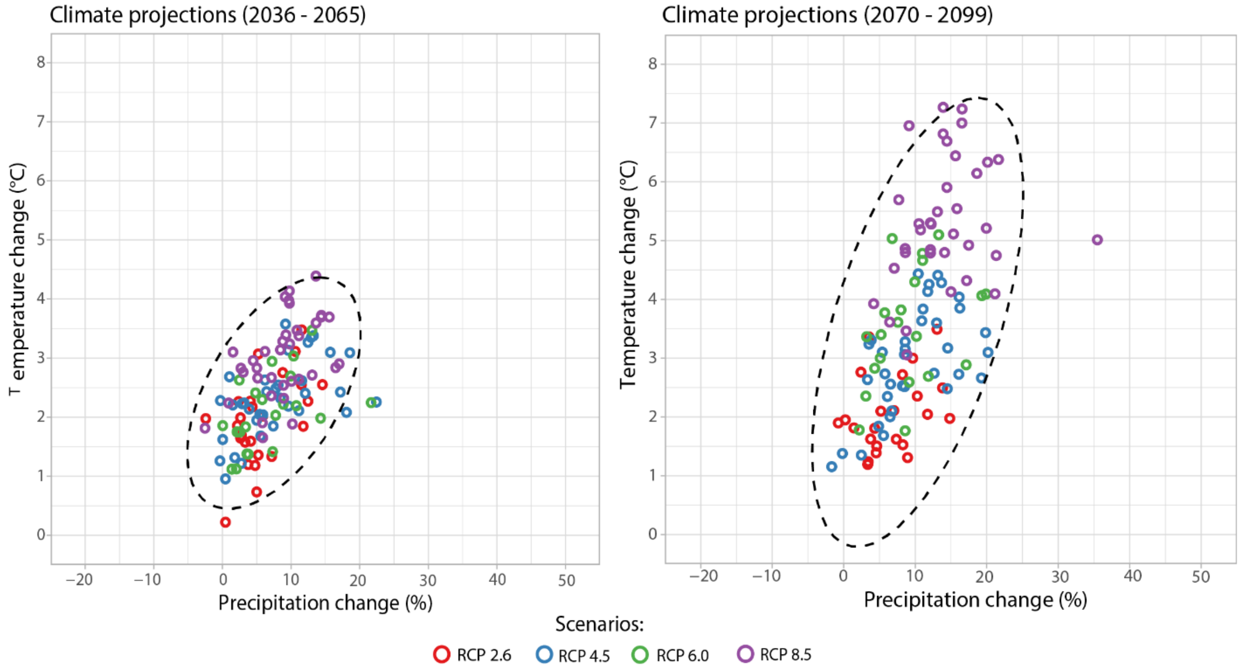

FIGURE 5 - PROJECTED MEAN CHANGES FROM THE CMIP5 CLIMATE MODEL ENSEMBLE FOR THE ST. CROIX WATERSHED. RESULTS SHOW CHANGES BETWEEN THE MEAN OF FUTURE PERIOD OF 2036-2065 (ON THE LEFT) AND 2070-2099 (ON THE RIGHT) RELATIVE TO THE HISTORICAL PERIOD OF 1971 – 2000. EACH POINT REPRESENTS THE RESULTS FROM A SINGLE MODEL RUN. COLORS SHOW UNDERLYING CONCENTRATION SCENARIOS AS INDICATED.

All of the GCM models predict some warming to occur by 2050, from 0.2°C to over 4°C. The colors on the plot represent models run over various emission scenarios, from lowest emission scenarios (RCP 2.6) to the most extreme emission scenario (RCP 8.5). A warming climate has implications for the St. Croix basin as warmer temperatures can increase early season snowmelt, and shift the timing of the spring peak flows. The Board's mandates are constant throughout the year, except for Spednic Lake. The minimum water surface elevation target at Spednic Lake is dynamic. April 30 is when the minimum water surface elevation is increased by 5 feet (1.52 m). A temperature increase in the basin would be expected to increase and time shift the snowmelt. This, accompanied by earlier spring runoff, may constrain the operations at Vanceboro.

Droughts are expected to become more intense in the future. Drier periods may last longer in the future, impacting the hydrology of the basin. It is also important to note that as the temperature rises, more precipitation will fall as rain. The declining snowpack will affect the timing of runoff. Historically, the snowpack has held a majority of the winter precipitation until the spring, when the snow melts and the runoff reaches the streams and rivers in the basin. As the snowpack decreases and there are more rain-on-snow precipitation events, the temporal storage that the snowpack historically has provided will decrease its influence in the basin, producing impacts similar to those that would be seen if reservoir storage was reduced.

Long-term drought trends are evaluated using the "Weighted Anomaly Standardized Precipitation" (WASP) index (For the calculation steps, see Lyon and Brand, 2005). WASP provides an estimate of the relative deficit or surplus of precipitation based on standardized monthly anomalies. For the 12-month WASP Index (shown on Figure 6), values outside the range of +/- 1.0 mark unusually dry and wet conditions respectively. WASP values outside the range of +/- 2.0 can be treated as severe dry and wet conditions respectively. According to the WASP index values shown for the St. Croix (Figure 6), two severe droughts over the past sixty years have occurred in relatively recently, in the years of 1986 and 2002.

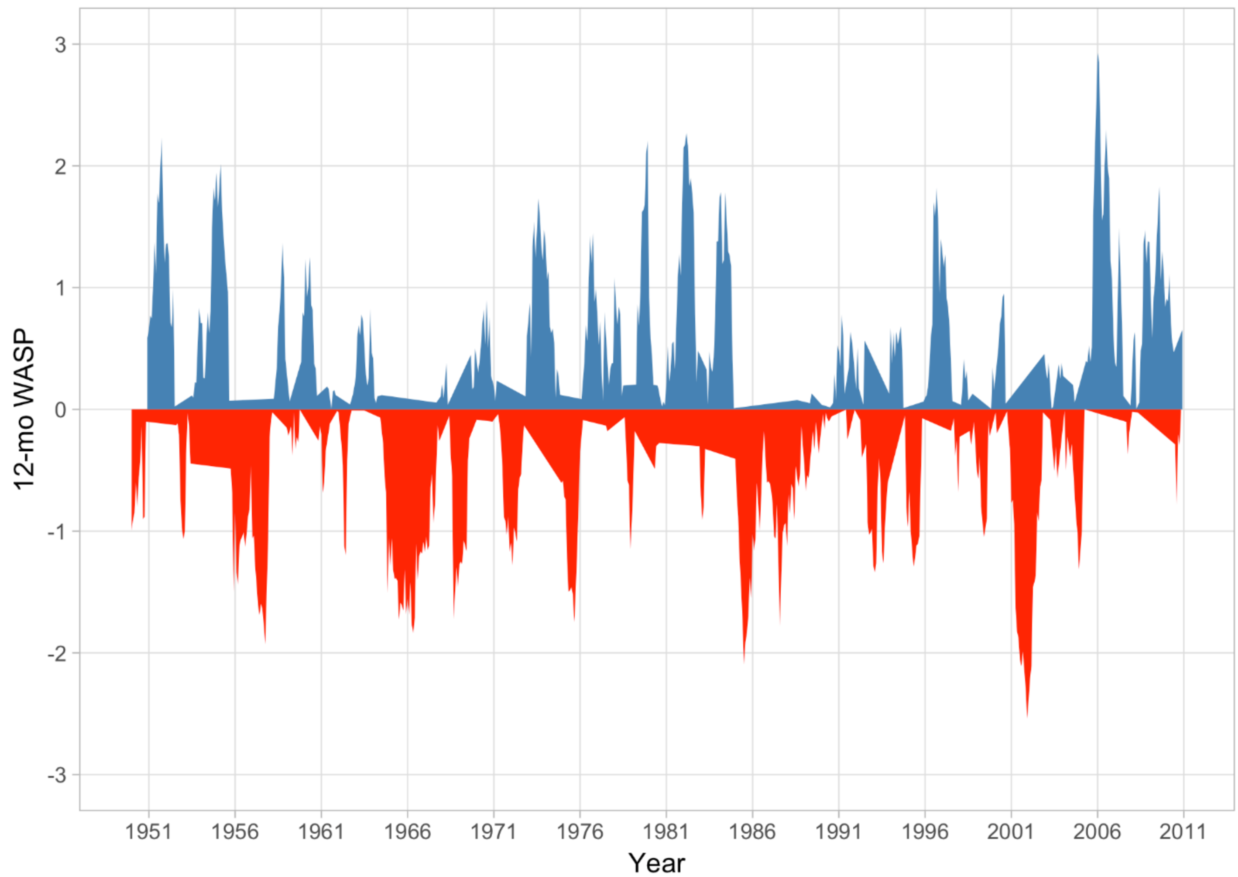

FIGURE 6 – TIME-SERIES OF 12-MONTH WASP INDEX VALUES CALCULATED FOR THE ST. CROIX WATERSHED.

The St. Croix Board is interested in promoting fish passage and water quality health throughout the basin, despite not holding a mandate on these parameters. Higher temperatures in the basin will influence the water temperature in the river. This can affect the growth rate of algae in the lakes and other water quality parameters. These temperature increases can also promote more evaporation of water from the lakes in the basin, decreasing the available water for downstream uses.

As the climate warms, anadromous fish in the basin may find it more difficult to prosper. The anadromous fish in the basin, mainly River Herring (Alewife) and Atlantic Salmon, have evolved to live and breed in specific conditions. Any changes in water quality or temperature can affect the fish's ability to migrate upstream to spawn. Fish migrating in the basin have to expend a lot of energy to pass through artificial fish passage structures, and slight variations in temperature can decrease the efficiency of the fish as they swim upstream. This can have an effect on the passage rate at these facilities as less fish are able to climb through the ladders.

MODELING APPROACH

The Consultants utilized a hydrologic-systems model to explore the vulnerabilities associated with violating the Board's specific performance targets. The first step is to define these objectives. For the St. Croix Board, these objectives are defined in terms of preferred flows and levels at various points in the basin. To assess vulnerabilities associated with meeting these objectives in an uncertain future, the consultants performed a "stress test" on the system to reveal under what climate conditions and at what frequencies the Board's mandate may be violated.

An integrated physical hydrology and reservoir system simulation model was developed for assessing climate vulnerability of the St. Croix Watershed system. The hydrology component of the integrated model is based on the Sacramento Soil Moisture Accounting (SAC-SMA) model, which is used by the National Weather Service (NWS) for flood forecasting in United States (Burnash 1995). The reservoir system model simulates lake levels and releases at the four major dams in the watershed: West Grand Lake, Forest City Dam, Vanceboro Dam, and Grand Falls Flowage. Data required to develop and calibrate the model, including physical dimensions, elevation-area-storage curves, and reservoir operating rules were obtained from an existing study implemented by the New England District of US Army Corps of Engineers (USACE 2007). The simulation model runs at a daily time-step. The following sections briefly describe for the hydrology and reservoir system components of the simulation model.

The stress test is performed by first generating a wide range of future climate conditions, and then simulating the system response (i.e., the physical hydrology and water system operations to those climate conditions). The domain of climate futures used in the process represents both natural climate variability and long-term climate changes, and is obtained through a two-step process. First, the new realizations of the historical climate are obtained from a weather generator to sample natural climate variability. Next, these variability realizations are perturbed by temperature and precipitation change factors to reflect long-term climate change effects on the natural variability realizations.

The next step involves performing a climate informed risk analysis, where the results from the climate stress test are evaluated with the GCM projections to identify the future conditions of the greatest concern. This is done by weighing the specified vulnerabilities based on their occurrence likelihoods according to the most recent GCM projections, and finally summarizing the risks identified from the analysis.

ST. CROIX BASIN HYDROLOGIC MODEL

The physical hydrology of the St. Croix system is simulated using the Sacramento Soil Moisture Accounting (SAC-SMA) model (Burnash 1995). SAC-SMA is a conceptual model that represents a watershed by two upper zone reservoirs and three lower zone reservoirs shown in Figure 7. The SAC-SMA model application is developed by subdividing the watershed area into a set of hydrological response units (HRUs), where each unit is a basic, homogenous area with similar land uses, soils, and slopes with a homogenous runoff response. Daily flow at each HRU is calibrated by adjusting 17 parameters describing baseflow, tension water capacities, and surface runoff. Computed daily runoff from the HRUs are then routed through the system to obtain the river discharge.

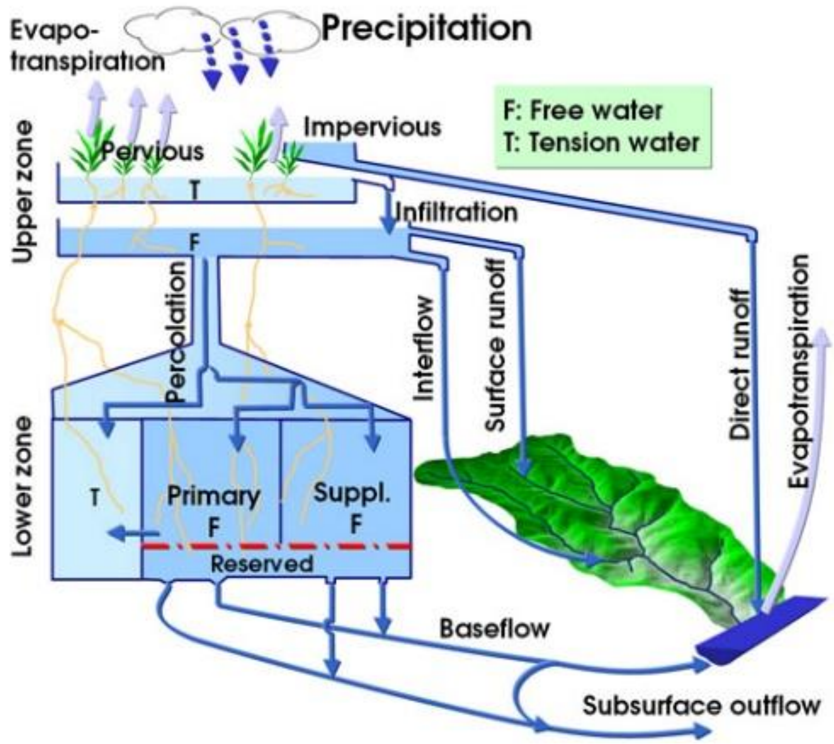

FIGURE 7 - CONCEPTUAL ILLUSTRATION OF THE SAC-SMA MODEL

For a detailed representation of the St. Croix system, the watershed area is divided into 50 HRUs (Figure 8). Simulated daily river discharge at the basin outlet is calibrated against the observed flow from the USGS Gauge 01021000 St. Croix River at Baring, Maine over a 20-year period, from the year 1980 to the year 2010.

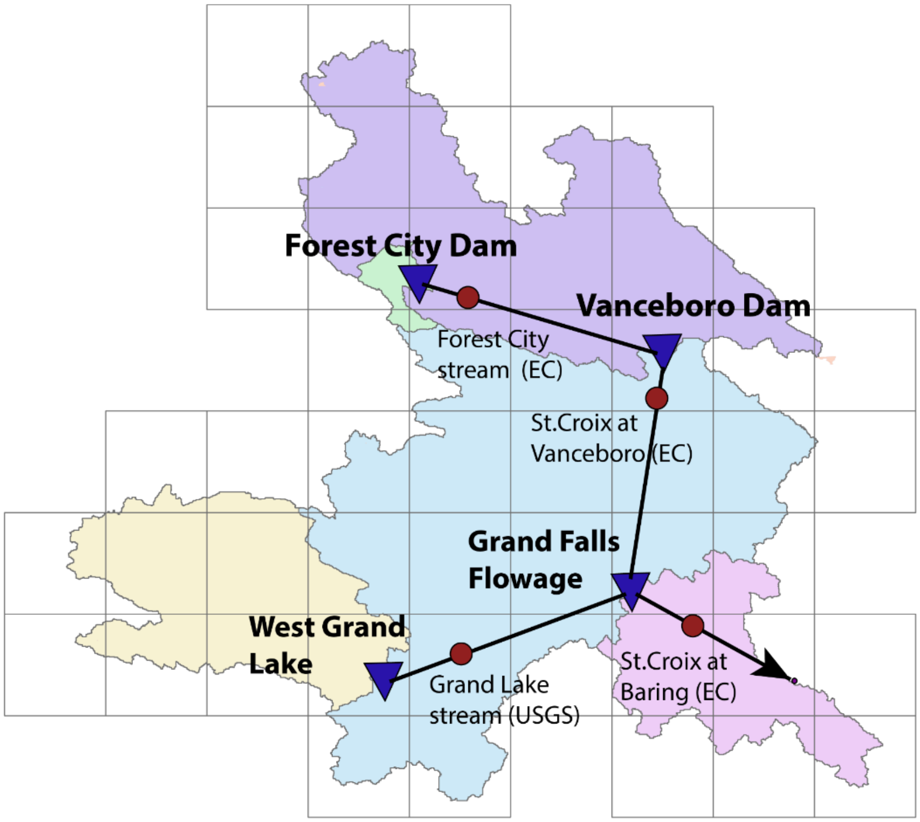

FIGURE 8 - ILLUSTRATION OF THE HRUS TO REPRESENT THE PHYSICAL HYDROLOGY OF THE ST. CROIX BASIN

The goodness of fit of the hydrology model of the St. Croix system was evaluated using the "Kling Gupta Efficiency" (KGE) measure (Gupta et al. 2009). The KGE measures model performance in terms of mean bias, variability bias and correlation, where a value of 1 indicates a perfect result, and a value of 0 indicates no agreement between the observed and simulated flow.

At the daily scale, the St. Croix hydrology model application produces a KGE value of about 0.83, indicating a good performance.

ST. CROIX BASIN SYSTEMS MODELING

A simple water resources system model has been developed for the St. Croix basin which provides: i) improved calibration of hydrological processes, ii) analysis of critical performance thresholds to maintain the recreational and environmental uses along the St. Croix River and its tributaries, including water level and discharge targets.

The general schematic of the system model is shown on Figure 9. The model consists of six water regulation structures, namely West Grand, Forest City, Vanceboro, Woodland, and Milltown respectively. Among these six facilities, the Forest City, Vanceboro, and West Grand Falls dams have storage, whereas the remaining facilities are run-of-the-river dams providing hydropower.

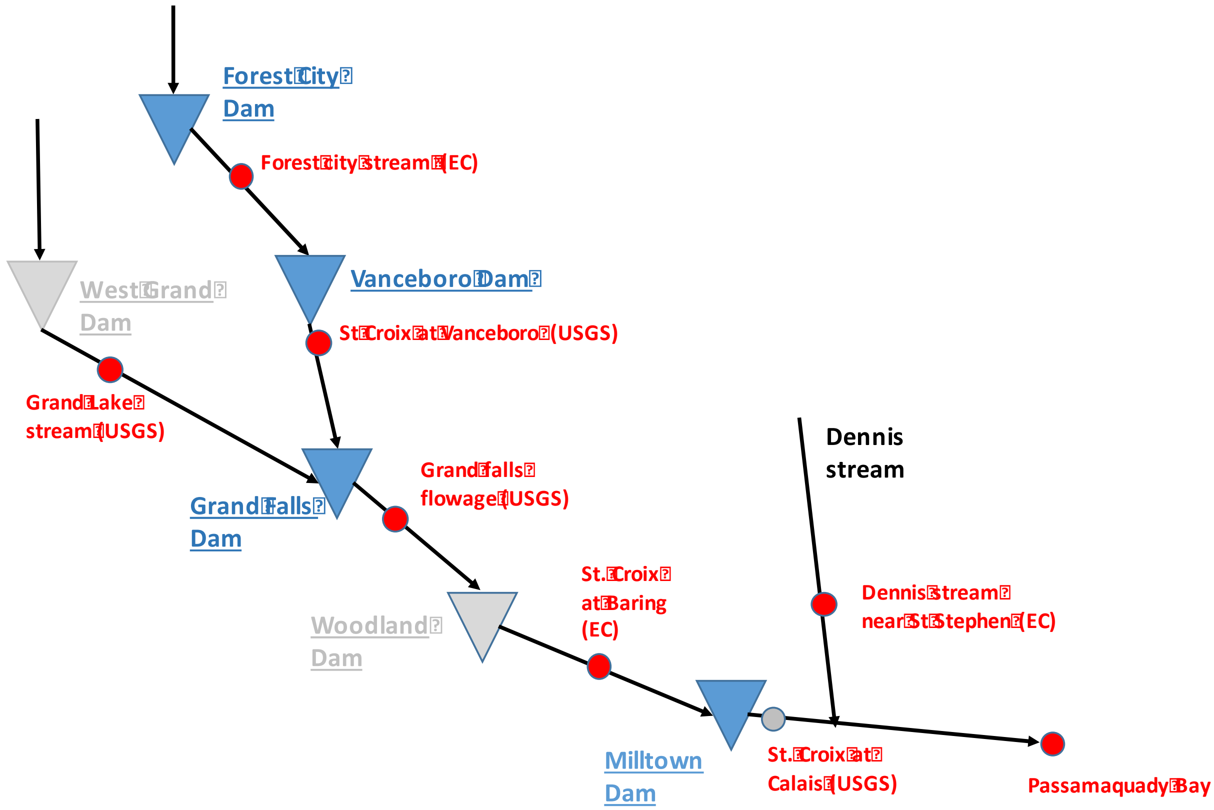

FIGURE 9 - MAJOR FEATURES OF THE ST. CROIX WATER RESOURCES SYSTEM. TRIANGLES IN BLUE COLOR MARK THE DAMS THAT HAVE MANDATES THROUGH THE IJC. THE TRIANGLES IN GRAY COLOR REPRESENT DAMS THAT ARE OUTSIDE OF THE IJC MANDATE.

During any given period *t*, the total inflow to the reservoir (Q_t) is equal to the sum outflows from the reservoirs (R_t), net change in reservoir storage volume ΔS_t, and total losses from net evaporation and seepage (L_t):

$$Q_t = R_t + \Delta S_t + L_t \quad (1)$$

Daily inflows to each reservoir Q_t is calculated based on two terms: the local inflows generated at the HRUs in the given sub-catchment, and the summation of outflows from the upstream reservoir(s). Releases from the reservoir is simulated based on a set of zone-based operating rules, shown in Figure 10 – Illustration of reservoir storage pools considered in the reservoir modeling. The reservoir operating zones used in the analysis are briefly described as follows:

i) *Flood-control pool* is the top section of the reservoir between the maximum elevation level and the flood control level. The flood control zone is kept empty at all times for safety reasons.

ii) *Upper-target pool* is given by the maximum target elevation (assumed to be the same as the flood control level) and the seasonal target elevation. In this zone, reservoir releases are equal to summation of all downstream release requirements plus the excess storage volume above the seasonal target elevation.

iii) *Conservation pool* is defined by the seasonal target elevation and the minimum target elevation. In this zone, reservoir releases are equal to sum of all downstream release requirements. However, there are no additional releases to match the seasonal target elevation as the water level is already below this point.

iv) *Buffer pool* is defined by the minimum target elevation and the minimum lake elevation. In this zone, reservoir releases are reduced to a fraction of the total downstream release requirement to prevent larger supply deficits in the near future.

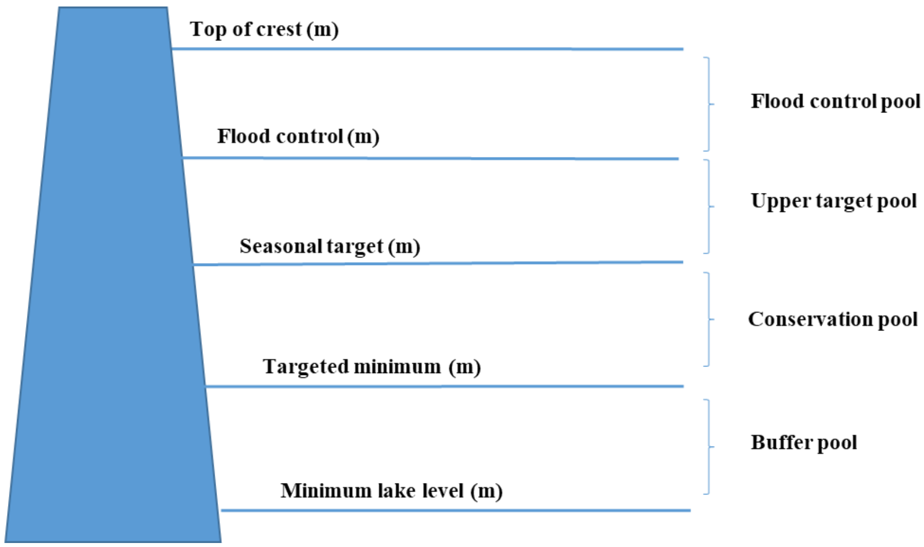

FIGURE 10 – ILLUSTRATION OF RESERVOIR STORAGE POOLS CONSIDERED IN THE RESERVOIR MODELING

Figure 11 illustrates the operating rules specified for Forest City Dam, Vanceboro Dam, and the Grand Falls Flowage (in dashed lines), along with the lake level mandates specified (red lines), and long-term average lake levels (blue lines).

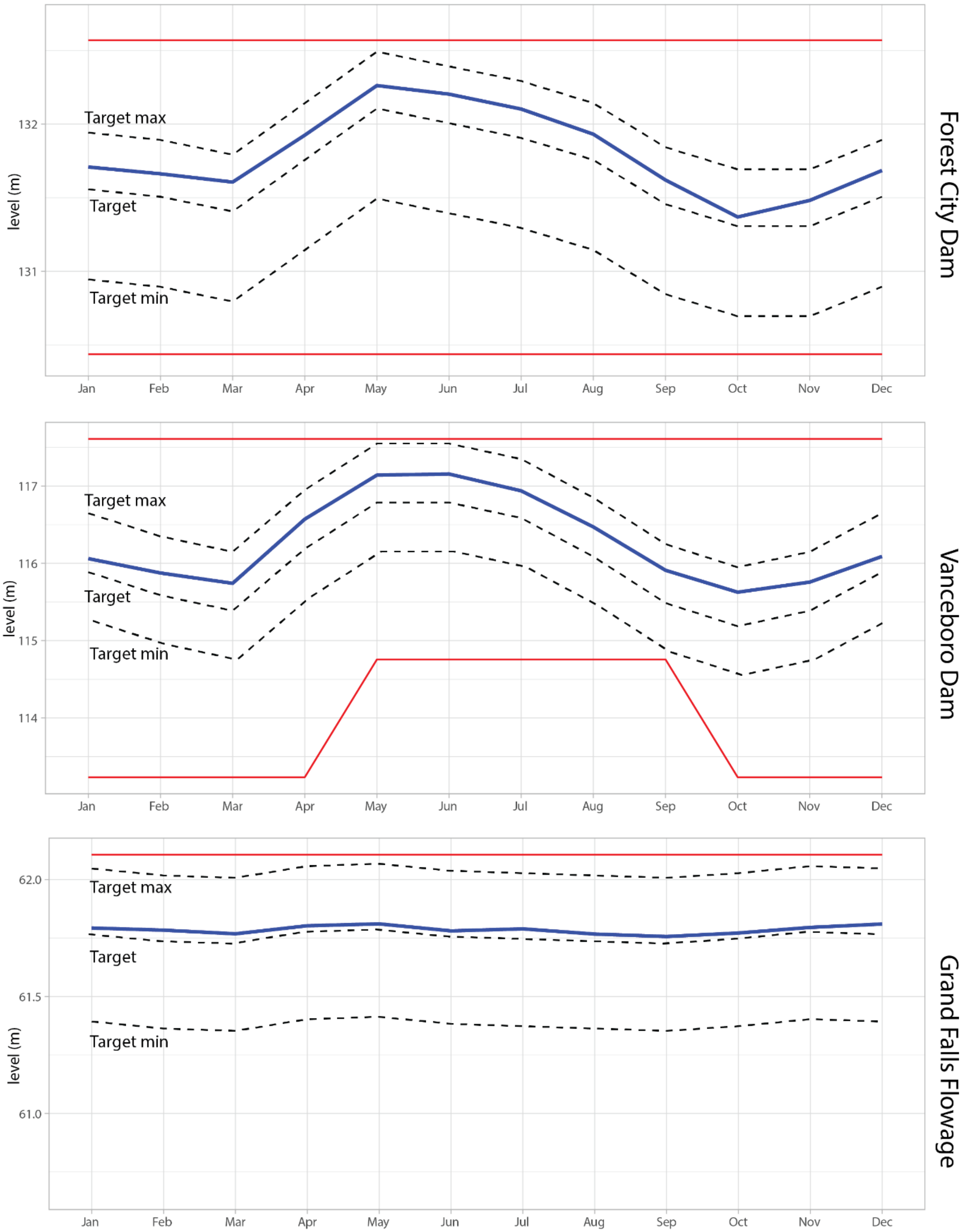

Figure 11 – Operating rules, mandates, and long-term observed lake levels in selected reservoirs within the St. Croix Watershed. Lines in red color mark IJC Board mandates. Lines in blue color mark monthly mean levels.

Climate Stress Test

The results from the climate risk analysis study aim to show how the St. Croix system would perform in the future under a wide range of climate conditions. One way to visualize such a broad range of information is to develop climate response surfaces that relate the selected set of output metrics (i.e., flow or water level) to the uncertain variables (i.e., higher temperature). The climate stress test for the basin explores climate vulnerability of the water resources system by considering three major sources of uncertainties: natural climate variability, long-term changes in mean annual precipitation, and long-term changes in mean annual temperature. The climate stress test is implemented through the following analytical steps:

1. The procedure begins with generating a set of new realizations of the historical climate record to account for the natural variability of the climate. The new climate realizations are obtained from a weather generator, which is a first-order autoregressive wavelet model (Steinschneider and Brown 2013). The new climate data obtained from the weather generator preserves important statistical properties of the historical climate time-series including mean and standard deviation of daily precipitation and temperature as well as the spatial and temporal correlations between climate variables. Based on the gridded daily climate data representing the historical period from 1960 to 2010, a total of ten new climate realizations were produced.
2. The second step is to impose long-term climate changes on the generated set of ten climate realizations. The process consists of six plausible additive factors for temperature changes ranging from 0 to 5 °C with 1°C increments, and six multiplicative factors for precipitation changes ranging from -20% +30% with 10% increments. The factors used in the process increase linearly by year for the entire simulation period, starting at no-change conditions and ending at the level of specified change (e.g., a 5°C increase). The process yielded a total of 360 climate futures from each unique combination of six temperature changes times six precipitation changes times ten natural variability realizations, each representing a 32-year future climate data from the year 2018 to 2050. Thus, the resulting set of climate traces provide a broad range of plausible futures that sample uncertainty from both natural climate variability and long-term climate changes.
3. The third step is to simulate the integrated water system model of the St. Croix Watershed repeatedly to assess system performance under each of the 360 plausible climate futures. The results from the daily simulation runs are then summarized in terms of four key metrics. These are:
    a. Frequency of violations in lake level mandates (violations per year),
    b. Frequency of violations in minimum flow mandates (violations per year),
    c. Average magnitude of lake level mandate violations (m per day), and
    d. Average magnitude of minimum flow mandate violations (m^3 per day).

These four metrics are first calculated for each site of interest and under each plausible climate future. Next, mean results are obtained under each unique mean temperature and precipitation change by averaging the results over the natural variability dimension.

RESULTS

The results from the climate stress test reveal the plausible effects of climate variability and long-term climate change on the St. Croix system, and indicate that it may not be possible to sustain IJC Board mandates on minimum flows and reservoir lake levels over the next 30 years.

SENSITIVITY OF VIOLATIONS INDEPENDENTLY TO FUTURE TEMPERATURE AND PRECIPITATION CHANGES

Figure 12 displays the frequency of violations associated with the minimum and maximum lake level mandates at the Forest City Dam, Vanceboro Dam, and Grand Falls Flowage with respect to increases in future mean temperature. From Figure 12, it is seen that the temperature increases only result in a slight increase in lake level mandate violations. In contrast, Figure 13 shows that the long-term precipitation changes result in a higher number of violations, especially in substantially wetter futures with mean increases of 20% or above. The sensitivity of violations in lake level mandates are found to be higher at two locations: Forest City Dam and Grand Falls Flowage respectively (Figure 13).

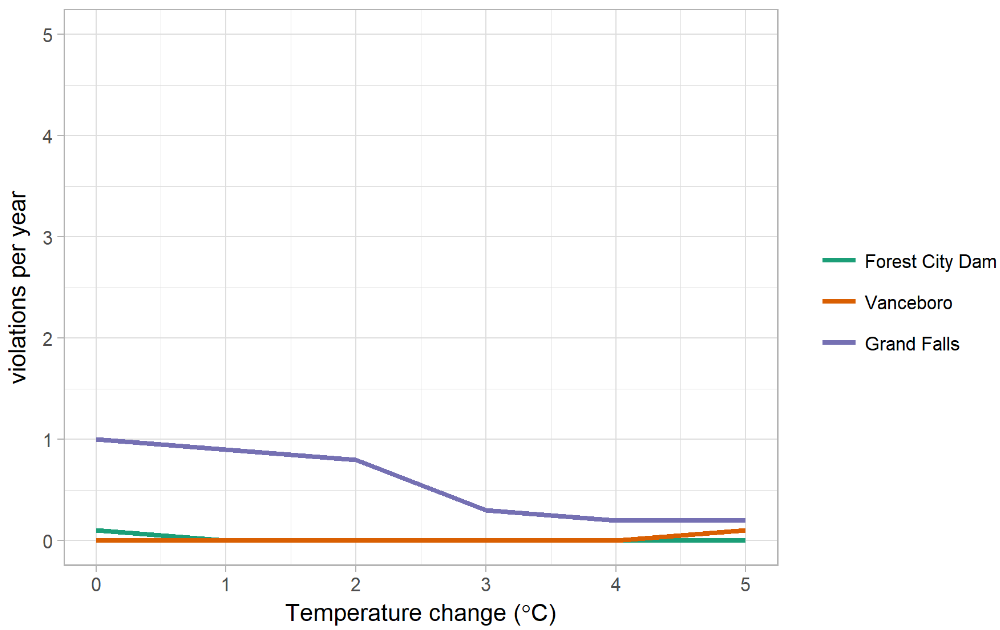

FIGURE 12 - SENSITIVITY OF THE FREQUENCY OF LAKE LEVEL VIOLATIONS TO FUTURE TEMPERATURE CHANGES (MEAN PRECIPITATION CHANGE IS ASSUMED TO CONSTANT, I.E., NO CHANGE OVER THE HISTORIC MEAN)

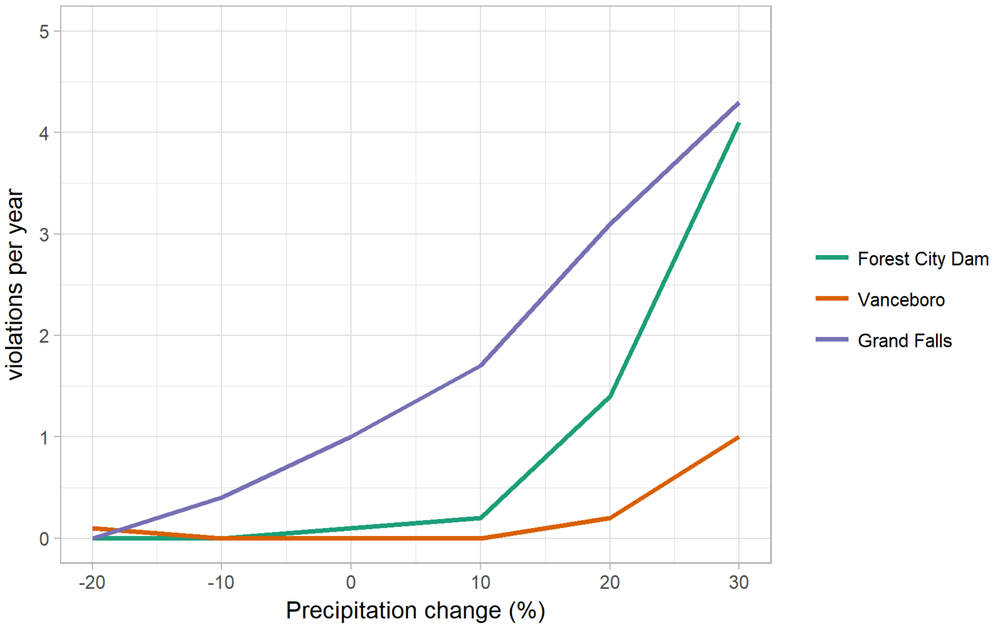

FIGURE 13 - SENSITIVITY OF THE FREQUENCY OF LAKE LEVEL VIOLATIONS TO FUTURE PRECIPITATION CHANGES (MEAN TEMPERATURE CHANGE IS ASSUMED TO CONSTANT, I.E., NO CHANGE OVER THE HISTORIC MEAN)

SENSITIVITY OF VIOLATIONS JOINTLY TO FUTURE TEMPERATURE AND PRECIPITATION CHANGES

Climate vulnerability of the St. Croix Watershed is evaluated by making use of a total of 360 simulation runs that represent system response to natural climate variability as well as a broad range of temperature and precipitation changes that may occur in the future. The results are visualized in terms of climate response surfaces depicting the average system vulnerability under each specific climate change evaluated.

Figure 14 shows the climate response surface for the frequency of total lake level violations in terms of annual mean precipitation changes from -20% to 30% (on the x-axis) and annual mean temperature increases from 0 to 5 °C (on the y-axis). The results from different natural variability traces under each specific climate future (e.g., a 10% precipitation change and a 1 °C temperature increase) are averaged in order to obtain a single value under each plausible climate change.

On Figure 14, it is seen that the frequency of violations associated with the lake level mandates can be as high as 12 times per year under the wettest future (Figure 14, bottom-right corner) and about 5 times under the driest future (Figure 14, top-left corner). The violations under wet futures are associated with the maximum level mandates, whereas the violations under drier climates result from failure to meet minimum level and release mandates. Climate model projections are also superimposed on the climate response surface for gaining insights about the likelihood of underlying conditions (shown by circles). The GCM-informed plot shows that the frequency of lake level violations is less than 5 violations per year over the GCM-projected range. Higher frequency of violations (e.g., 10 per year) are less likely to occur by the year 2050 according to the GCM projections evaluated.

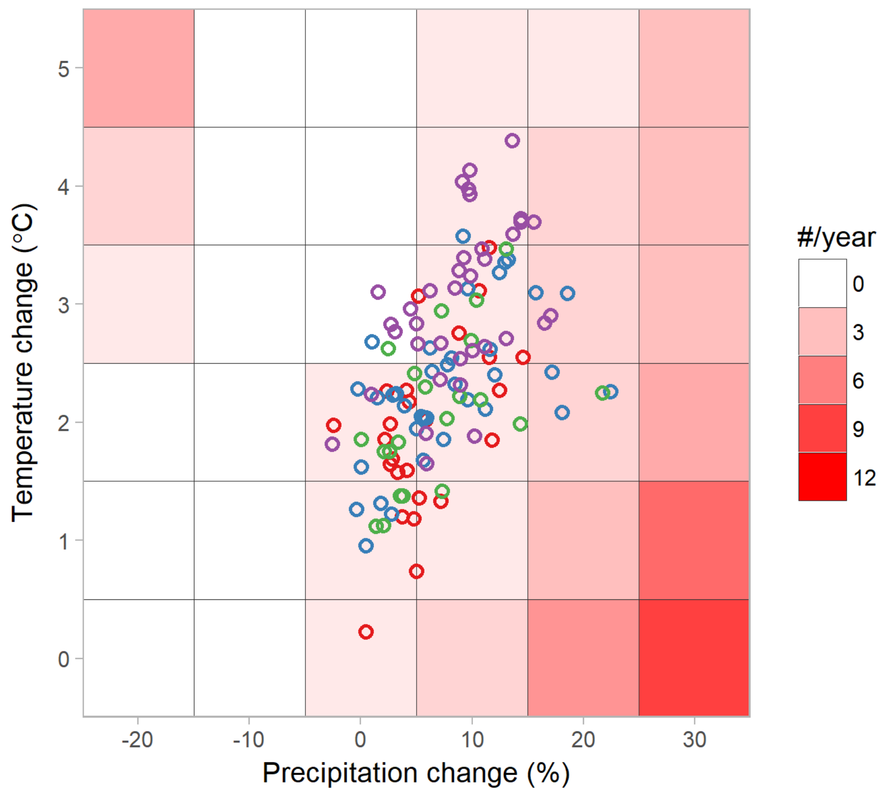

FIGURE 14 – CLIMATE RESPONSE SURFACE SHOWING THE TOTAL FREQUENCY OF VIOLATIONS IN LAKE LEVEL MANDATES (IN THE FOREST CITY DAM, VANCEBORO DAM, AND GRAND FALLS FLOWAGE). SUPERIMPOSED CIRCLES OVER THE RESPONSE SURFACE SHOW GCM PROJECTIONS OBTAINED FROM THE CMIP5 ENSEMBLE FOR THE ST. CROIX WATERSHED.

Figure 15 depicts the climate response surface for lake level violations, but this time separately for the Forest City Dam, Vanceboro Dam, and Grand Falls Flowage respectively. The comparative analysis reveals the differences between each reservoir system. The figures show that under the existing operating rules explored, Forest City Dam (Figure 15, top-left) poses no risk of violating minimum level mandates, whereas a relatively larger risk of violating maximum level mandates under wetter futures (up to 4 violations per year). In Contrast, Vanceboro Dam (Figure 15, top-right) faces a risk of violating minimum level mandates under a 20% decrease in precipitation, and a relatively low risk of violating maximum level mandates under a 30% increase in precipitation. Among the three dams, the larger risks are found to be associated with the Grand Falls Flowage (Figure 15, bottom), with maximum level violations of at least 2 per year under all future climates that are wetter than the historical average.

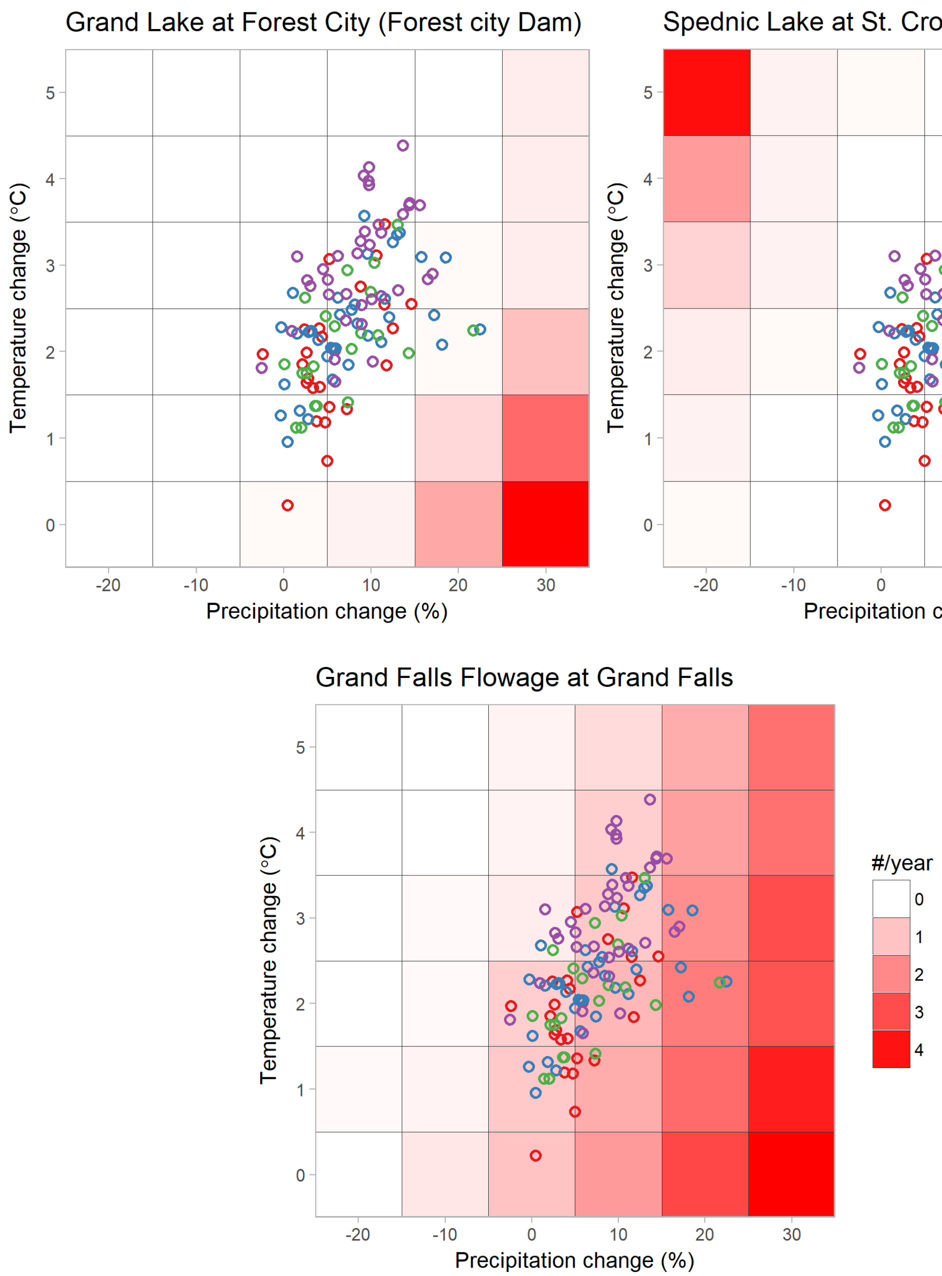

FIGURE 15 CLIMATE RESPONSE SURFACE SHOWING THE FREQUENCY OF VIOLATIONS IN LAKE LEVEL MANDATES IN THE FOREST CITY DAM, VANCEBORO DAM, AND GRAND FALLS FLOWAGE RESPECTIVELY. SUPERIMPOSED CIRCLES OVER THE RESPONSE SURFACE SHOW GCM PROJECTIONS OBTAINED FROM THE CMIP5 ENSEMBLE FOR THE ST. CROIX WATERSHED.

Figure 16 shows the climate response surface of total frequency of minimum flow violations in the St. Croix system. Results indicate that the number of violations can be as high as 60 per year under very dry (-20% decrease in precipitation) and very warm (5 °C increase in temperature) future conditions. However, violations are less than 5 times per year in the GCM-projected range of climate changes (shown by the circles on Figure 16).

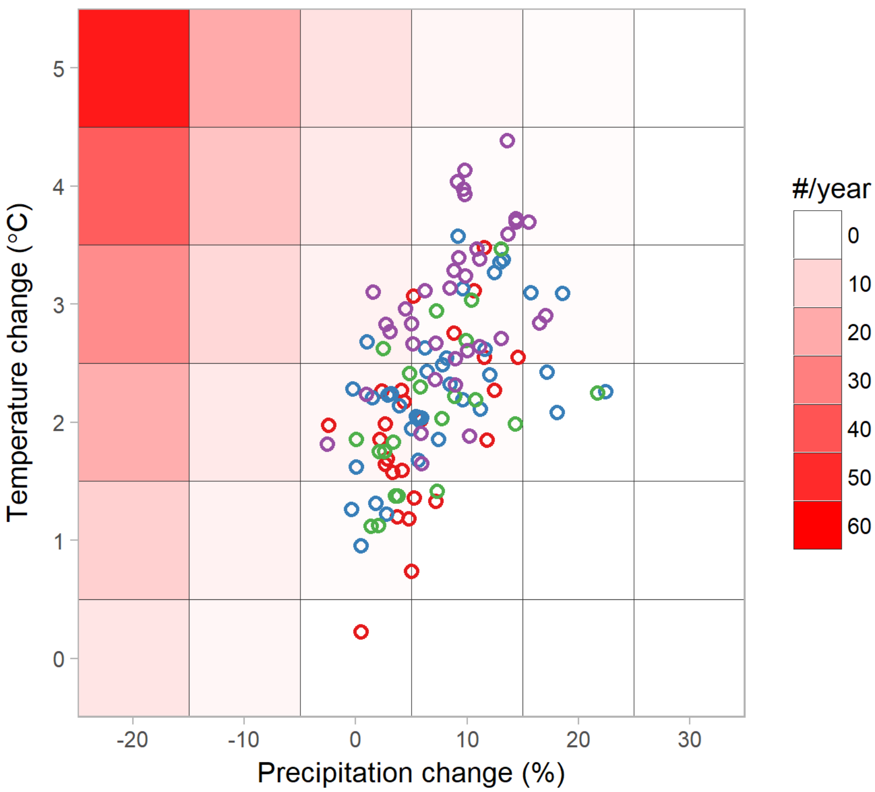

FIGURE 16 – CLIMATE RESPONSE SURFACE SHOWING THE TOTAL FREQUENCY OF MINIMUM FLOW VIOLATIONS IN FOREST CITY DAM, VANCEBORO DAM, THE ST. CROIX RIVER AT BARING, MAINE. SUPERIMPOSED CIRCLES OVER THE RESPONSE SURFACE SHOW GCM PROJECTIONS OBTAINED FROM THE CMIP5 ENSEMBLE FOR THE ST. CROIX WATERSHED.

Figure 17 depicts the frequency of minimum flow violations for Forest City Dam, Vanceboro Dam, and St. Croix River at Baring, Maine. Among the three locations, Forest City Dam is found to have the lowest risk of violating the minimum flow mandates, and then only under very dry futures (Figure 17, top-left). The risk of minimum flow violations increases in the downstream at the Vanceboro Dam (Figure 17, top-right) with violations of up to 20 times per year under very dry futures (i.e., a decrease in mean precipitation by 20%). Risks associated with the minimum flow is highest at the St. Croix River at Baring, Maine (Figure 15, bottom). However, as with the other locations, number of violations are generally low (less than 3 times per year) in the GCM-projected range of climate changes.

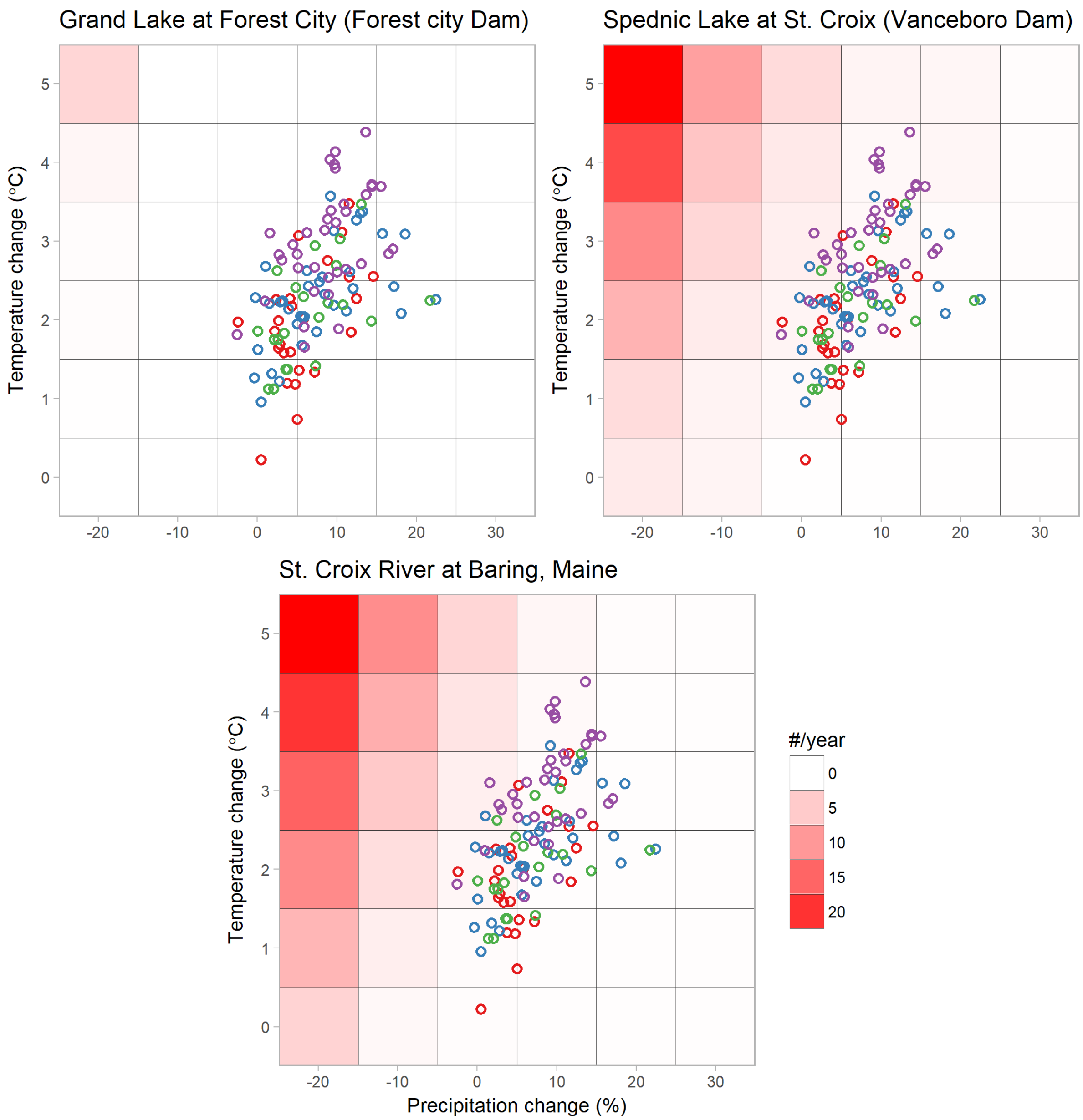

FIGURE 17 – CLIMATE RESPONSE SURFACE SHOWING THE FREQUENCY OF MINIMUM FLOW VIOLATIONS IN THE FOREST CITY DAM, VANCEBORO DAM, AND ST. CROIX RIVER AT BARING RESPECTIVELY. SUPERIMPOSED CIRCLES OVER THE RESPONSE SURFACE SHOW GCM PROJECTIONS OBTAINED FROM THE CMIP5 ENSEMBLE FOR THE ST. CROIX WATERSHED.

Although the Figure 16 and Figure 17 show that the number of minimum flow violations generally increase with increasing temperatures and decreasing temperatures, they do not indicate the magnitude of failures; i.e., how bad the violations are. Average magnitude of violations under each plausible future climate condition is depicted on Figure 18. It is seen that under drier and warmer futures, the magnitude of flow deficits also increases to up to about 10 cubic meters per second (cms). In contrast, minimum flow deficits are relatively modest in the GCM-projected range (< 2.5 cms).

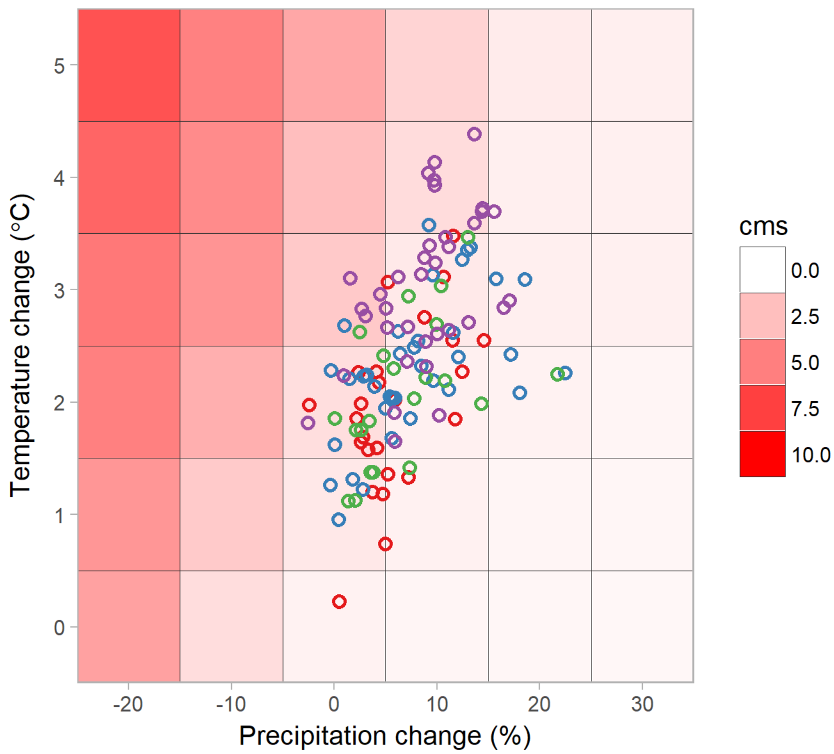

FIGURE 18- CLIMATE RESPONSE SURFACE SHOWING THE AVERAGE MAGNITUDE OF MINIMUM FLOW VIOLATIONS IN THE ST. CROIX WATERSHED. SUPERIMPOSED CIRCLES OVER THE RESPONSE SURFACE SHOW GCM PROJECTIONS OBTAINED FROM THE CMIP5 ENSEMBLE FOR THE ST. CROIX WATERSHED.

SUSTAINABILITY OF MINIMUM FLOWS UNDER SEVERE DROUGHT

Natural climate variability in the St. Croix Watershed has increased over the past few decades resulting in severe droughts as well as extremely wet years (previously shown on Figure 2). The maintenance of the IJC Board mandates on the minimum flows can be very challenging under such severe drought conditions, especially at the Vanceboro Dam and at the St. Croix River at Baring, Maine (Figure 17).

The future risks associated with the minimum flow violations can be further evaluated by focusing directly on the severe drought events. To construct such a test, we first calculated the WASP drought index scores for each of the ten natural climate variability traces and subsequently identified the "worst-case" drought within the entire dataset. As each natural variability trace is a new weather sequence similar to the historical record, it is possible to identify a drought condition that is worse any other drought observed in the past, but still plausible – even in the absence of climate change.

Figure 19 shows the 12-month WASP scores calculated for each of the ten natural variability traces (shown in different colors) with respect to the WASP scores calculated from the historical record (black line). The selected worst-case condition (marked by the circle) represents a severe but plausible multi-year drought event. The next step of the analysis is to evaluate minimum flow violations under the given "worst-case" drought event.

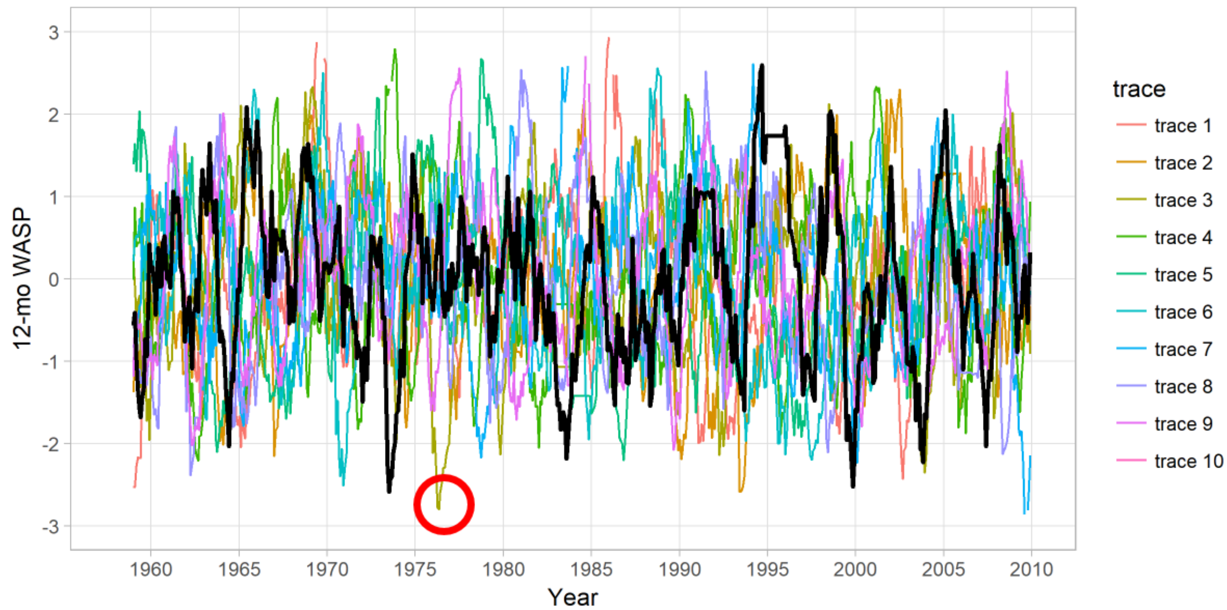

FIGURE 19 – TIME-SERIES OF 12-MONTH WASP DROUGHT INDEX FOR EACH OF THE 10 CLIMATE VARIABILITY TRACES (SHOWN BY DIFFERENT COLOR). WASP VALUES FOR THE HISTORICAL PERIOD (1960-2010) IS MARKED BY THE BLACK COLOR. THE RED CIRCLE SHOWS THE SINGLE WORST CASE DROUGHT EVENT WITHIN THE TEN STOCHASTICALLY GENERATED CLIMATE TRACES.

The simulated streamflow at the St. Croix River at Baring, Maine under the worst-case drought shown on Figure 20 - Simulated streamflow at the St. Croix River at Baring, Maine under the worst-case historical drought condition. The dashed black line indicates the minimum flow requirement of 21.2 cms.. Results depict that it is possible prevent violations in the minimum flow requirement of 21.2 cms under the current operating rules. However, note that the results on Figure 20 - Simulated streamflow at the St. Croix River at Baring, Maine under the worst-case historical drought condition. The dashed black line indicates the minimum flow requirement of 21.2 cms. do not depict additional risks due to future climate change, which may worsen the historical "worst-case" drought.

Figure 21 shows the combined effects of the historical worse-case drought and future climate change on the minimum flows at Baring, Maine. The figure shows that the minimum flow requirement could not be met under a number of simulated streamflow series, resulting in continuous flow violations lasting up to 2 months. Comparing the drier futures to the historical record, the total number of violations increase from 20 times (under a mean temp. change of +3°C and a precipitation change of -10%) to as high as 130 times (under a mean temp. change of +5°C and a precipitation change of -20%) (Figure 21).

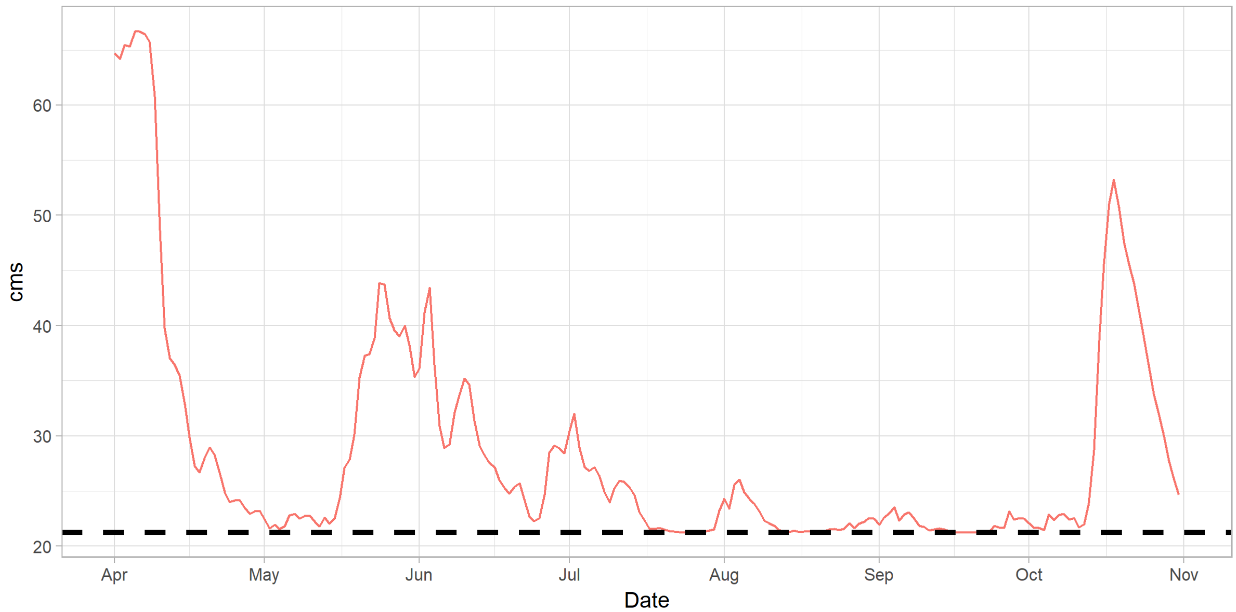

Figure 20 - Simulated streamflow at the St. Croix River at Baring, Maine under the worst-case historical drought condition. The dashed black line indicates the minimum flow requirement of 21.2 cms.

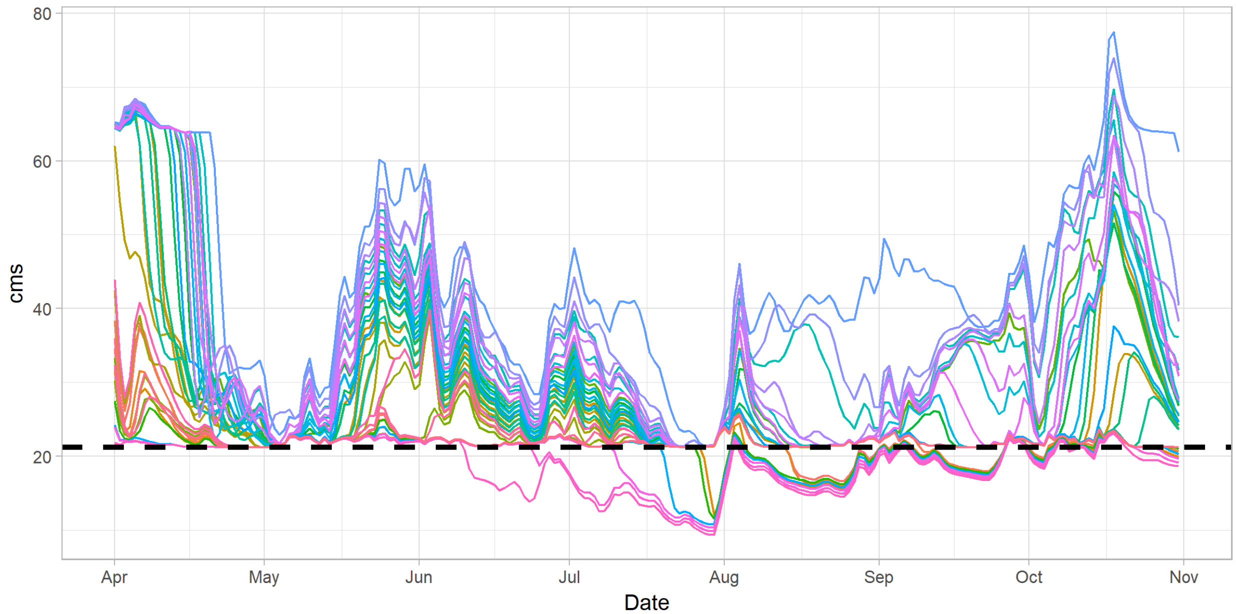

Figure 21 – Simulated streamflow at the St. Croix River at Baring, Maine under the worst-case historical drought condition under 36 different climate change scenarios (shown in different colors). Each climate scenario shows the combined effects of worst-case historical drought and a plausible mean precipitation and temperature change. The dashed black line indicates the minimum flow requirement of 21.2 cms.

Analysis Conclusions

In this work, a bottom-up climate vulnerability analysis was applied to the St. Croix Watershed in New Brunswick and Maine to assess the long-term climate risks associated with the violations of the IJC Board mandates on the minimum flows and the minimum and maximum lake levels. The analysis did not rely solely on GCM-projections, but explored a broad range of plausible future climates by considering natural climate variability and mean changes in long-term precipitation and temperature. Most recent GCM projections are used following the vulnerability analysis to assess the risk of violations in future plausible climate realizations. The outcomes from the analysis are summarized as follows:

- Long-term average precipitation in the St. Croix Watershed already shows an upward trend over the past fifty years, with a large year-to-year variability with very dry and very wet years in the 2000s.
- Annual maximum daily precipitation has also increased gradually over the past fifty years, resulting in the intensification of flood risk.
- The decision-scaling analysis has shown that there is considerable risk of violating the IJC Board mandates by the year 2050. There are risks are associated with drier futures (from violations of minimum flow requirements and minimum lake levels) and with wetter futures (exceedance of the maximum lake level mandates).
- The total frequency of lake level violations are highly sensitive to changes in the annual mean precipitation, and range from zero to more than 10 violations per year. The frequency of violations could be up to 5 violations per year under a precipitation change of -20%, and up to 12 violations per year under a precipitation increase of 30%. However, the total frequency of lake level violations in the GCM-projected range is less than 5 violations per year.
- Among the reservoirs, the Forest City Dam poses no risk of violating minimum level mandates, whereas the frequency of violations of maximum level mandates are up to 4 violations per year. In contrast, Vanceboro Dam faces a risk of violating minimum level requirement up to 4 violations per year under the driest future (-20% change in precipitation). Among the three reservoirs, the Grand Falls Flowage exhibits the largest risks, with at least one violation per year under almost all plausible future climates that are wetter than the historical averages.
- The total frequency of minimum flow violations can be as high as 50 times per year under the driest (-20% change in precipitation) and the warmest (+5 °C) future. However, based on the current set of GCM projections, these future changes are less likely to occur. The frequency of violations in the GCM-projected range ranges from about 0 to 5 violations per year.
- Over the broad range of plausible future climates assessed, the risk of minimum flow violations increase from upstream to downstream. There is almost no risk identified for the Forest City Dam, whereas minimum flow violations at Vanceboro Dam and St. Croix River at Baring, Maine can be up to 20 violations per year. Based on the analysis, the magnitude of violations can be as high 10 cms.

STEP 3 – ACT

WHICH OUTCOMES COULD THE BOARD CHANGE?

WHAT ARE THE POSSIBLE ACTIONS THE BOARD COULD TAKE TO ADDRESS THE CONCERNS IDENTIFIED?

WHAT WOULD BE REQUIRED FOR THE BOARD TO CARRY OUT THIS WORK?

The International St. Croix Watershed Board's mandate covers flows and levels in the basin. It may be necessary for the Board to adjust its water level and flow prescriptions, in both timing and magnitude, to account for changes in climatology and hydrology that are expected in the future. The Board may need to pay special attention to extreme events if, as expected, they become more commonplace in the basin.

Extremely high-water levels and flows are expected to be more common in the future as more intense and more frequent storms are predicted for the basin. The analysis shows that the basin is expected to receive more precipitation according to most GCMs. The Board can create a plan for extreme drought and or flood under which operators could deviate from normal operating procedures. For example, if it is known that a large precipitation event is forecast for the St. Croix basin (such as a nor'easter, remnants of a hurricane, or a large rain-on-snow event), the Board may allow operators to release water to below their minimum level to allow storage to absorb some of the runoff from the forecasted event. Even though the facilities were not designed to store water for flood control, in extreme cases, their operations could mitigate downstream flooding. Flooding could impact downstream facilities as well as produce environmental impacts on riparian zones and cause erosion. These extreme flood events may be exacerbated by antecedent moisture already saturating the soil from previous precipitation. These adaptive procedures may become more crucial in the future as precipitation events are expected to be more intense and frequent.

During extreme low flow periods, particularly during the late summer when the baseflow is expected to be smaller because of the earlier snowmelt, the Board may need to allow operators to reduce water levels below their minimum elevation requirements to meet minimum flow requirements. Maintaining some baseflow in the river is a critical component of maintaining good ecosystem health, and the Board may need to act to allow operators to release water at below minimum levels to maintain minimum environmental flows. Lower water levels as a result of drought may affect water quality in a warmer climate as bacterial and algae growth is more likely to occur in warmer water temperatures and where there are low flows. The Board will need to balance maintaining minimum flows with recreational uses of the reservoirs, since lowering the water level too much below the minimum mandate may impede on lakeside residents waterfront recreation. If a drought occurs during a critical fish passage window in early summer, it is even more crucial to maintain environmental flows. However if a drought occurs later in the summer, the Board may consider recreation in its decision.

Extreme events may occur which exceed the capacity of water management to alleviate. Heavy precipitation and prolonged storms at non-traditional times (such as mid-winter) could increase water volumes when storage areas are already full and flows are high. During these times the Board and dam operators would be challenged to find a balance between storing and releasing water.

As flooding and droughts become more common with the increased variability expected in the future climate, the Board may also consider adjusting fish passage flow requirements.

STEP 4 – UPDATE

An adaptive management framework would allow the Board to refine its plans as future monitoring reveals the actual changes in precipitation and temperature. At a minimum, the Board should revisit this analysis from time to time using available data, following the procedures in the Climate Change Guidance Framework. In the future – even if the Board "Acts" now – those decisions may need to be adjusted to ensure that Board objectives are met. Changing precipitation patterns over the next decade may convince the Board to adjust water level requirements; nonetheless, it is plausible that a prolonged drought in the following decade may still make it difficult to meet these objectives. Additional monitoring may be may be needed to monitor climate changes and related impacts. It also makes sense to develop a way to share what this Board learns with other Boards across the border and with those who will replace members who are currently on the St. Croix Board.

Based on the Consultants collective experience, it makes sense for the International St. Croix Watershed Board to name a point-person for climate change-this exists in the St. Croix representative to the Climate Adaptation Working group. The responsibilities of this role would include developing and leading an adaptive management plan and performing a short review of progress at regular intervals. A short review may show that the Board is successfully fulfilling its objective, and no action is needed. The short review may also show that the Board has missed several mandate targets in recent years due to drought or flooding. In this scenario, the Board then may decide to engage the full Climate Change Guidance Framework.

All Boards have expressed a desire to learn from one another's experiences. The workshops held for this project showed how much the Board's appreciated that opportunity, but also showed that it does not happen without a conscious effort. Face to face discussions are very effective, but very expensive, and the sharing is contained to some degree by the particular people, presentations and conversations that occur. The IJC may want to research and experiment with the use of electronic methods of bringing the most important news about Board responses to climate change to other Boards. The Consultants suggest that the IJC should name a point person in each country to specifically deal with climate change knowledge sharing and adaptation. This currently exists in the form of the International Watersheds Initiative and the team responsible for that initiative.

CONCLUSION

There has already been a substantial amount of work done by IJC Boards in advancing the state of climate science and decision making in their basins, and the IJC Boards have made substantial contributions in the development of the Climate Change Guidance Framework. There has already been a substantial amount of work done by IJC Boards in advancing the state of climate science and decision making in their basins, and the first step of the pilot study has been implemented across the continent during the horizontal roll out. Through the completion of the Step 1 (Organize), Boards were able to identify objectives in their mandate that might be more difficult to meet under climate change. Some Boards reported they were more prepared than others at this time.

The vertical roll out of the entire four-step Guidance Framework was implemented in the St. Croix basin. The St. Croix Board was extremely engaged in the process, and the work produced valuable insights on climate change's effects on their mandate. The consultants underwent a decision-scaling modeling process to quantify the extent to which the system is vulnerable to predicted climate futures.

This work demonstrated that the St. Croix Board should plan for and adaptively manage a response to climate change, and the horizontal reporting suggests that could be true for other Boards. The IJC should now consider how to sustain this effort at an affordable level, possibly in the short term for the LOSL system following the 2017 events and specifically, how to most effectively share lessons learned by each board with all the others.

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    c. Kootenay Lake Board of Control
    d. Lake Ontario – St. Lawrence Board
    e. Lake Superior Board of Control
    f. Niagara Board of Control
    g. Osoyoos Board of Control
    h. Rainy-Lake of the Woods Watershed Board
    i. Red River Board
    j. Souris River Board
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10. World Climate Research Programme. Coupled Model Intercomparison Project – Phase 5. Special Issue of the CLIVAR Exchanges Newsletter, No. 56, Vol. 15, No.2.

APPENDIX A: BOARD SELF-ASSESSMENTS

Boards were asked to perform a self-assessment for climate change preparedness and grade themselves on a scale of 1 to 10. The text of their self-assessment and their grade is included here:

St. Croix – 3/10

Current Assessment: We have held 2 scientific forums as well as done a state of the river report and discussed and had presentations on climate change issues such as flooding and drought. However we have not completed a Board statement specific to climate change. We have discussed a potential project in our 5 year plan to assess climate change.

Next Steps: We have to conduct a climate change assessment of the issues that relate to the basin. Bring together the data and do an analysis. We have discussed this for our planning period. From this work, we would be in a better position to publicly discuss the topic. We feel this will be an important initiative but has been overtaken at the moment by other more pressing issues. It will also require additional resources.

Learning from other Boards: We would like to know where they stand and what approaches they are taking.

Gathering, accessing information or process: They are all challenges. At the moment gather information and monitoring conditions is challenging because we require resource support. The basin is small with small communities and we will have to seek out where long term information exists.

What is missing in the guidance?: I think your approach is good. The problem is finding the resources and the time of the Board members to oversee the studies necessary to address climate change.

Red River – 2/10

Current Assessment: Means the Board had some elements of step one but hadn't produced a summary report. For example, Board minutes might show which missions Board members were concerned about; the Board may have invited presentations on climate change and discussed what actions the Board should be considering. **This question is structured to miss much of the work done by the IRRB.** To date work of the IRRB has been couched in the terms used in its assigned mandate: flood preparedness; water quality; ecosystem health. It is only recently that the IJC has suggested that work should be focused via a climate change lens.

Next Steps: 1. Continue the good work already initiated. 2. Begin to organize work under a climate change umbrella.

Learning from other Boards: Has (or will) work on currently mandated responsibilities been slowed or deferred in order to organized under a climate change umbrella?

Gathering, accessing information or process: Having a process to follow and finding the capacity to implement the process.

What is missing in the guidance?: What effect will the attitude of the current US Administration have on this initiative?

Niagara – 1/10

Current Assessment: Means the Board had done nothing to consider how climate change could affect the Board's missions.

Next Steps: Invite a presentation on climate change from GLAM and it's potential impacts on Lake Erie water levels and temperatures which would provide an indication of potential impacts on Niagara River flows with impacts on Chippawa Grass Island Pool operation and/or Lake Erie/Niagara River Ice Boom rules.

Gathering, accessing information or process: Separating out the differences between climate variability and climate change and knowing when it is for certain the latter.

GLAM, Lake Superior, and Lake Ontario – St. Lawrence River – 7/10

Current Assessment: GLAM is established and working. Climate Change initiatives are in our strategic plan and we've done some initial surveillance on potential factors that may be influenced by climate change. GLAM has not revisited the climate change analyses conducted during the IUGLS and LOSLRS. The GLAM will be looking at the CCFWG framework to see how aspects can be integrated into the GLAM strategic plan.

Next Steps:

1) Improve our understanding of existing Great Lakes Basin climate change science and associated confidence and uncertainty.
2) Assess options for using the climate science to test the robustness of the existing regulation plans - How will we apply this new information?

Learning from other Boards: It would help to understand the issues and needs of other (non-Great Lakes) Boards to see where collaborative efforts would be most beneficial.

Gathering, accessing information or process: All three items pose challenges. However, the big question is what is the uncertainty in the climate change projections and how that affects our planning processes.

What is missing in the guidance?: How will climate change affect other things that will impact our planning? There may be secondary impacts because of climate change that would fundamentally change the vulnerability of interest groups beyond just the management of water levels and flows.

Kootenay Lake – 4/10

Current Assessment: Means the Board had completed step one (i.e., Organize). The Board had discussions about how its mission might be affected by climate change, some relevant science had been identified and considered by the Board, and the Board had made a statement on the potential impact of climate change on specific responsibilities of the Board. No quantitative analysis had been done, but the Board had determined what would be necessary to do that. During the 2016 water year the IKLBC supported a preliminary analysis and presentation of regional climate change data at the board and public meeting.

Next Steps:

1. The board should continue to review and disseminate information on regional climate change impact assessments of relevance to hydrologic conditions in the Kootenay(ai) River Basin using the Board website for the purpose of public access.

2. Develop a statement describing the dynamics and drivers for the system, how sensitive the system is to changes in those drivers, and how climate change may challenge the board in carrying out its responsibilities. February is a month that is warming the most relative to other months with the potential to impact low and mid elevation melt water, will this impact the ability to achieve the rule curve or should a modification be considered to allow for earlier runoff periods especially episodic warmings.

Learning from other Boards: The IKBLC would like to learn what level of analysis and action other boards are taking with respect to climate change.

Gathering, accessing information or process: The biggest challenge in the Kootenai basin will be to determine whether or when to take action based on changes in the climate.

Rainy Lake of the Woods – 3/10

Current Assessment: The Board has yet to officially organize however, we will be starting to address step one of the framework as part of the webinar with the project contractors on April 28th. Although not part of the IRLWWB, the Rainy- Namakan Rule Curve Review Study Board has considered climate change in its work which will be directly applicable to the IRLWWB's work on water quantity. In addition, climate change was considered in the development of the Water Quality Plan of Study (POS) and climate science that is being undertaken in the basin has been showcased during the annual Science Forum over the years. The Board has not synthesized this information nor has it explicitly considered how climate change will impact its mandate at this time. Some CAWG members from the IRLWWB have compiled relevant climate science presented at the annual science forum as well as the 2014 State of the Basin Report as a starting point.

Next Steps:

1. Essentially Step 1 - Organize - Set aside some dedicated time for the Board to discuss how it's mandate is affected by climate change.

2. Have a presentation by the Rule Curves Study Board on what they have learned and will be proposing with regards to climate change.

Learning from other Boards:

1. What **benchmarks** are other boards using/considering with respect to more **extreme events being more normal?** (e.g. 50year floods and droughts)
2. What are the political pressures facing each Board about identified climate change issues/developments and how are these being addressed?

3. Climate change impacts on water quality may be as significant as impacts on water quantity: **what are other boards seeing or learning about the links to algae blooms, AIS, etc?**
4. What challenges are other boards identifying and what kinds of creative solutions are they proposing to address them?
5. Learning more about the **depth and breadth of climate change impacts** various jurisdictions are facing.

Gathering, accessing information or process: Determining the biggest challenge in planning for climate change will require further discussion by the entire Board. From the small number of responses received, widespread and long-term monitoring data was cited are being a challenge as well as having a planning process to follow.

What is missing in the guidance?: One aspect that may require consideration is the level of harmonization between American and Canadian science, policy, preparedness and governance for a given basin. A discrepancy in the level of science and monitoring on either side of the border in the Rainy-Lake of the Woods basin was identified as an example.

Health Professionals Advisory Board – 3/10

Current Assessment: As an advisory to the IJC our responsibilities are not defined geographically and we have not gone through the adaptive mgt. plan process. However, climate related hazards to health are high on our list of priorities and figure prominently in our work. For example our recent report on harmful algal blooms has clearly delineated climate related impacts. Our health indicators of GL water quality are all effected by climate and our pilot project on acute gastro-intestinal illness is driven largely by extreme weather events related to climate.

Next Steps: Develop a robust understanding of the implications for transboundary water security of new policies related to GHG mitigation on both sides of the border.

Learning from other Boards: How do other boards view the interplay between mitigation measures and adaptive capacity in their jurisdictions?

What is missing in the guidance?: Communication of CC hazards and policy options in local and trans-national context is crucial. Do we have a geographically referenced primer for commissioners on the implications of climate change for transboundary waters? This could be very helpful.

Osoyoos Lake – 7/10 (note: there were multiple responses)

Current Assessment:

- This board is about a 7 prepared for climate change more because of our limited preview (we only oversee lake elevation of Osoyoos Lake and more specifically only in relationship to the orders) than because we have good information.
- I think we are at about a 6. Yes we have limited scope at present with the order but we do have to maintain a watch on issues such as this that will impact the system in order to provide advice to the commission.
  We need to have a better understanding of potential impacts on flows and water levels to be able

to provide advice/recommendations on changes in the orders. An understanding of impacts on potential biological and species changes in the system due to climate change is important.

- Suggest this board is a “7”. In preparation for order renewal this board completed a study titled “Climate Change and its implications for managing water levels in Osoyoos Lake: Summary Report”, April, 2011. This report organized and analyzed climate change information available at the time and made recommendations for the order renewal process. While the report could use updating it was a strong first step.

Next Steps: We need to read scientific reports, and be pushy with public awareness.

Learning from other Boards: Sharing ideas and workable plans gives us food for thought on what we can pursue.

Gathering, accessing information or process: All parts are challenging. Plans change and we need to have adaptive strategies. Weather patterns are not always predictable, and social media comments can be misleading and confusing.

What is missing in the guidance?: As an educator, we need to pay attention to our youth and inform them of appropriate information. Wearing seatbelts and recycling campaigns worked because of young people insisting that parents change their thinking.

Souris River – 2/10

Current Assessment: 2 rating means the Board had some elements of step one but hadn’t produced a summary report. For example, Board minutes might show which missions Board members were concerned about; the Board may have invited presentations on climate change and discussed what actions the Board should be considering.

Next Steps: The Souris basin is a basin of extremes, driven by a variable climate. The Board has been addressing a change in the spring freshet with great influence from heavy spring and early summer rains. The operating references and actions are being reviewed to address this.

Learning from other Boards: It will be interesting to hear what climate variability the other boards face and how they are managing this variability**.**

Gathering, accessing information or process: The most significant challenge is greater knowledge and understanding of the potential cycles of climate variability, which will affect the basin, and implications for the Board to administer its Directive.

What is missing in the guidance?: Climate variability increases the potential for conflict and the Board governance mechanism must be sound in order to manage through these situations. Some thought on tools and approaches for the Boards to address this potential conflict situation will be required.