NATIONAL CAPITAL COMMISSION – STANDARDS COUNCIL OF CANADA
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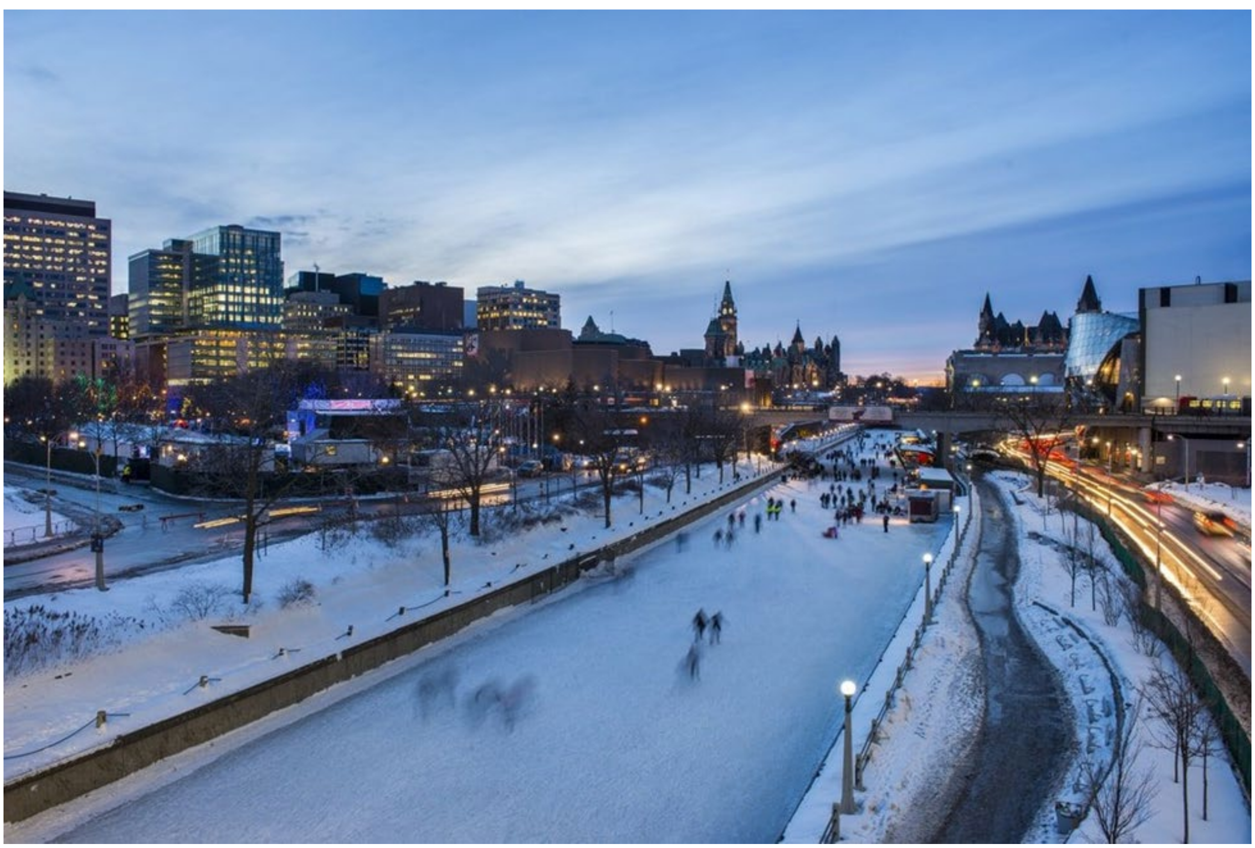
RISK ASSESSMENT OF THE EFFECTS OF CLIMATE CHANGE ON THE RIDEAU CANAL SKATEWAY

ANALYSIS AND RECOMMENDATION OPTIONS

JULY 19, 2021



FINAL REPORT

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EXECUTIVE SUMMARY

The Rideau Canal Skateway (the Skateway or RCS) is among one of the longest natural skating rinks in the world and has been maintained by the National Capital Commission (NCC) since 1971. Questions have started to surface regarding the long-term viability of the Rideau Canal Skateway under changing climate conditions. Warming temperatures and increased temperature variability, shorter winter seasons, and changes in winter precipitation patterns will all affect the operations, equipment, and infrastructure needed to maintain a high-quality skating surface for the longest period possible every year.

The NCC and the Standards Council of Canada (SCC) have commissioned WSP to conduct a climate change risk assessment that will define the climate change impacts on the RCS, analyse the severity of consequences and likelihood of these impacts, and propose recommendations to mitigate the greatest climate risks and increase the resilience of the RCS. The scope of this assessment includes impacts to all access, welcoming and decorative features, food and sanitary facilities, health and safety services with a focus on skating surface and ice maintenance operations. This work was involved a qualitative and quantitative desktop risk analysis, supplemented with a literature review and a water temperature and conductivity monitoring program that was conducted in February 2021 to address immediate data gaps. This report summarizes key information about the RCS under future climate conditions, the risk assessment and impact prioritization process, and potential adaptation planning and risk reduction measures.

SKATING SEASON PROJECTIONS

Analysis was conducted to explore the projected changes in skating conditions in the future under two greenhouse gas (GHG) emission scenarios. The selected scenarios were RCP4.5 (decrease in GHG emissions by the 2040s referred to as the “moderate” or stabilization scenario) and RCP8.5 (regular increase in GHG emissions until the end of the century, often referred to as the “business as usual” scenario). The main conclusions from this analysis are:

- In the next decades, under a moderate GHG emission scenario (RCP4.5), the NCC should prepare for seasons with less than 40 days of skating approximately 50% of the time;
- Winters of greater than 60 skating days are unlikely to occur in the future under both RCP scenarios;
- Under both GHG emissions scenarios, the probability of having at least 20 skating days annually is high until the 2050s, although this probability could drop below 50% in the second half of the century under a high GHG emission scenario;
- In the next decades, under a moderate GHG emission scenario, the NCC should expect to open the RCS on average, one to two weeks later than historically;
- Opening of the RCS in December is unlikely to occur in the future;
- Significant changes in the beginning of the skating season are projected to occur in the second half of the century; and
- The date of the end of the skating season is not projected to change as much as the beginning of the season. This is consistent with historical data where there were no significant trends for the last day of the season.

CLIMATE CHANGE RISK ASSESSMENT

A qualitative risk assessment was conducted following the ISO 14091 adaptation to climate change methodology to investigate the social, environmental, and economic consequences associated with the impacts of climate change on the RCS. In summary, the climate risk assessment process includes:

- Identification of relevant climate hazards and potential impacts for the RCS considering each climate hazard; and

— Determination of a risk rating for each impact, which considers sensitivity, adaptive capacity, vulnerability, likelihood, and the severity of the relative consequence of each impact should it occur.

Out of the 22 impacts identified, 12 pose a high or very high risk to the RCS, which are summarized in the table below.

High and very high climate change risks to the RCS

Impact ID	Potential Impact	Likelihood	Severity	Risk
1	Increased warm stormwater output from higher rain-based precipitation melting the canal ice.	High	High	**High**
2	Increased warm stormwater output from greater snow melt due to higher temperatures melting the canal ice.	High	High	**High**
3	Higher night time temperatures delaying the onset of flooding and thickening of the ice.	Very high	High	**Very high**
4	Reduced cold snap frequency limiting the operational ability to flood the canal overnight.	Very high	High	**Very high**
9	Loss of direct economic opportunity from reduced attendance to the annual Winterlude event.	High	High	**High**
10	Loss of indirect economic opportunity from reduced tourism and associated spending including nearby restaurants, hotels, and other activities.	High	High	**High**
11	Loss of a cultural Canadian icon.	High	High	**High**
12	Delayed start to the skating season reducing the viable number of skating days.	Very high	High	**Very high**
13	Early end to the skating season reducing the viable number of skating days.	Very high	High	**Very high**
14	Increasing warm periods during the season reducing the stability of the ice and reducing the number of viable skating days.	Very high	High	**Very high**
20	Increased cost of operations to maintain the canal under changing winter conditions.	High	High	**High**
21	Reduced enjoyment of the canal by skaters as a result of poor weather conditions.	High	Moderate	**High**

One positive impact was also identified for the RCS, that reduced periods of extreme cold could increase enjoyment when using the RCS and therefore increase the number of skaters and visitors.

The high and very high risks to the RCS pertained to indirect impacts to ice formation and quality (e.g. increased stormwater drainage in the canal which increases the water temperature and salinity), increased variability in ice conditions during winter, economic losses due to the reduced skating season and cultural impacts due to the iconic aspect of the RCS. The impacts of warmer stormwater discharge, assumed to be linked to the Laurier Avenue drain, are already observed near the National Arts Centre section of the RCS, requiring seasonal closures for safety. Therefore, improvements in ice formation, strength or quality would mitigate all the high and very high risks that were identified.

RECOMMENDATIONS

The NCC has already implemented many operational practices to increase ice thickness and quality after the formation of the initial ice cover. This study provides a series of recommendations to complement these existing practices in the near to medium term to improve the resilience of the RCS to climate change, summarized in the table below. The projected changes to the beginning of the season are of greater significance to overall season length than the end of the season, therefore, most of the recommendations aim at increasing the effectiveness of early ice formation.

The unique nature of the RCS means that this study can contribute to a small but important body of literature and standards for outdoor winter recreational facilities, and so it is also recommended that the NCC look for opportunities to share these findings.

In the long term, the NCC should determine the threshold for which investing in maintaining the ice surface will exceed the benefits provided, and consider diversification of winter programming surrounding the canal.

Table E.1 Summary of potential ice/management improvement methods for the RCS

Method	Description	Potential improvement			Main advantage	Main disadvantage	Level of confidence about effectiveness	Level of effort / resources required
		Earlier freeze-up	More resilient cover	Other				
Early Ice Flooding	Start flooding on top of thin ice cover using a pump and hose system from the bank	x	x		Earlier thickening	Additional cost	High	Moderate
Slush Cannon	Mimic heavy snowfall in the early season to initiate ice cover	x	x		Earlier freeze-up	Additional cost	High	Moderate
Stormwater Outfalls Diversion	Reduce or eliminate flow of salt-contaminated stormwater into the canal	x[1]			Remove heat source	Local impact only	High	Moderate
Deeper Water – Increased Level	Increase water depth by rising the winter water level, achieved by modifying the cofferdam used by Parks Canada (PC) at the Ottawa Locks	x	x		Ice cover stabilization	Need to modify existing NCC structures	Moderate/High	Very high
Colder Inflows – From Lock	Modify winter configuration at Hogs Back Locks to bring colder water from the river surface into the canal	x	x		Colder water during winter	Need for PC to modify winter management	Moderate	High
Vegetation management	Remove all vegetation from the canal		x		Ice cover stabilization	Additional cost	Moderate	Moderate
Diversification of Winter Activities	Increase attractiveness of Rideau Canal as a winter destination even during seasons of low ice quality			x	Decrease the dependency on ice conditions to attract visitors	Increased resource needed in equipment and staffing	Moderate	High
Colder Inflows – Open water	Bring colder inflow to the canal by increasing the air/water heat exchanges on the canal reach between Hogs Back and Hartwells Locks	x	x		Colder water during winter	Theoretical	Low	Low
Deeper Water - Dredging	Increase water depth by dredging the canal, as depth has decreased in areas over time		x		Ice cover stabilization	Displacement of contaminated material	Low	Very high
Safety Practices	Identify patrolled no-stopping zones, move concessions away from ice surface to limit static gatherings, and/or limit number of visitors on the RCS		x	x	Limit load on the ice	Increasing dissatisfaction of some users; additional cost; complex implementation	Low	Moderate
Ice Strengthening	Install central piles anchored in the canal bed where the ice bond can help to increase the buoyancy of the ice		x		Increase buoyancy	Additional cost, risk of weakening the ice cover	Very Low	High

1. In the upstream sections.

NEXT STEPS

There are significant uncertainties regarding the effectiveness of the different measures as summarized in the table above, due to the lack of data for the canal and the unique nature of the RCS. For this reason, to help overcome these barriers, WSP recommends that the NCC follow a three-phase process:

- Phase 1: Gather data and knowledge (Years 1-3)
- Phase 2: Pilot projects (Years 2-5)
- Phase 3: Permanent implementation (>Year 5)

Summarizing the next steps for NCC, the table below presents the recommended tasks in preparation for and during the 2021-2022 winter season.

Table E.2 Recommended tasks in preparation for and during the 2021-2022 winter season.

Period	Recommended tasks (in chronological order)
Summer 2021	1. Conduct canal bathymetric survey. 2. Plan fall/winter 2021-2022 canal monitoring/observations campaign. 3. Plan 2021-2022 pilot projects and procure equipment (Early Ice Flooding (EIF), cannon, aerator).
Oct – Nov 2021 (Fall)	4. Install monitoring instruments and pilot project equipment in the canal. 5. Start ice monitoring and observations.
Nov – Dec 2021 (Freeze-up)	6. Continue monitoring and observations. 7. Start pilot projects (EIF, cannon, aerator).
Dec 2021 – Mar 2022 (Winter)	8. End EIF and cannon pilot projects. 9. Continue monitoring, observations and aerator pilot project. 10. Measure ice thickness regularly and record in logbook.
End of skating season	11. End aerator pilot. 12. Prepare technical report to summarize monitoring campaign, observations and pilot project. 13. Assess pilot effectiveness and make recommendations for winter 2022-2023.
2022	14. Perform thermal ice/water study, based on the results of the winter 2021-2022 monitoring campaign. 15. Assess the effectiveness of other potential solutions (i.e. colder inflow, deeper water and outfalls diversion) based on the thermal study.

This is the first climate change risk assessment commissioned by the NCC. It is recommended that this report be updated at a minimum of every five years to account for changes in socioeconomic conditions, policy development, and the latest climate science.

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1 INTRODUCTION

The Rideau Canal Skateway (the Skateway or RCS) is among the longest natural skating rinks in the world and has been maintained by the National Capital Commission (NCC) since 1971. Celebrating its 50th anniversary during the 2019-2020 winter season, it is an iconic feature of the National Capital Region (NCR) and part of Canada's cultural heritage, recognized as such in 2007 when it became a National Historic Site of Canada and UNESCO World Heritage Site.

Questions have started to surface regarding its long-term viability under changing climate conditions. Warming temperatures and increased temperature variability, shorter winter seasons, and changes in winter precipitation patterns will all affect the operations, equipment, and infrastructure needed to maintain a high-quality skating surface for the longest period possible every year.

In its 2018-2023 Sustainable Development Strategy, the NCC committed to "evaluate the risk of climate change impacts on NCC assets, programs and services". Having partnered with the City of Ottawa and Environement and Climate Change Canada (ECCC) to obtain a robust set of climate projections relevant to the regional vulnerabilities, the NCC is looking to use these projections as the basis for its climate change risk assessments. Given the cultural importance of the RCS, the NCC identified it as the first asset to benefit from a climate change risk assessment. The scope of this assessment includes impacts to all access, welcoming and decorative features, food and sanitary facilities, health and safety services with a focus on skating surface and ice maintenance operations. A literature review was undertaken to increase understanding of climate change impacts on outdoor natural skating facilities and associated national and international standards and best practices in building resilience.

The NCC partnered with the Standards Council of Canada (SCC) to seek a climate change risk assessment that will define the climate change impacts on the RCS, analyse the severity of consequences and likelihood of these impacts, and propose recommendations to mitigate the greatest climate risks and increase the resilience of the Skateway. SCC hopes to use the results of the assessment to identify opportunities regarding the development of outdoor winter recreation standards and communicate adaptation options for other similar outdoor skating facilities.

1.1 BACKGROUND

1.1.1 *SITE DESCRIPTION*

The Skateway is located on the Rideau Canal in Ottawa between the Hartwells Locks and Ottawa Locks (Figure 1-1). It has a total length of 7.8 kilometers and includes a loop on Dow's Lake and a smaller one on Patterson Creek.

During the navigation season, the canal is used by boats to cross between Ottawa and Rideau Rivers. Water from the Rideau River flows through the Hogs Back Locks (n°11-12) and Hartwells Locks (n°9-10) before entering the Skateway reach. Water leaves the Skateway reach by Ottawa Lock n°8, located adjacent to the Chateau Laurier. These locks are all maintained and operated by Parks Canada (PC).

During the winter season, the NCC transforms the canal into the world's largest outdoor skating rink. In addition to the main attraction, the RCS includes a multitude of amenities at rest areas that have washrooms and change rooms, accessibility ramps, fire pits, picnic tables, rental facilities, and food and beverage concessions, depending on the location.

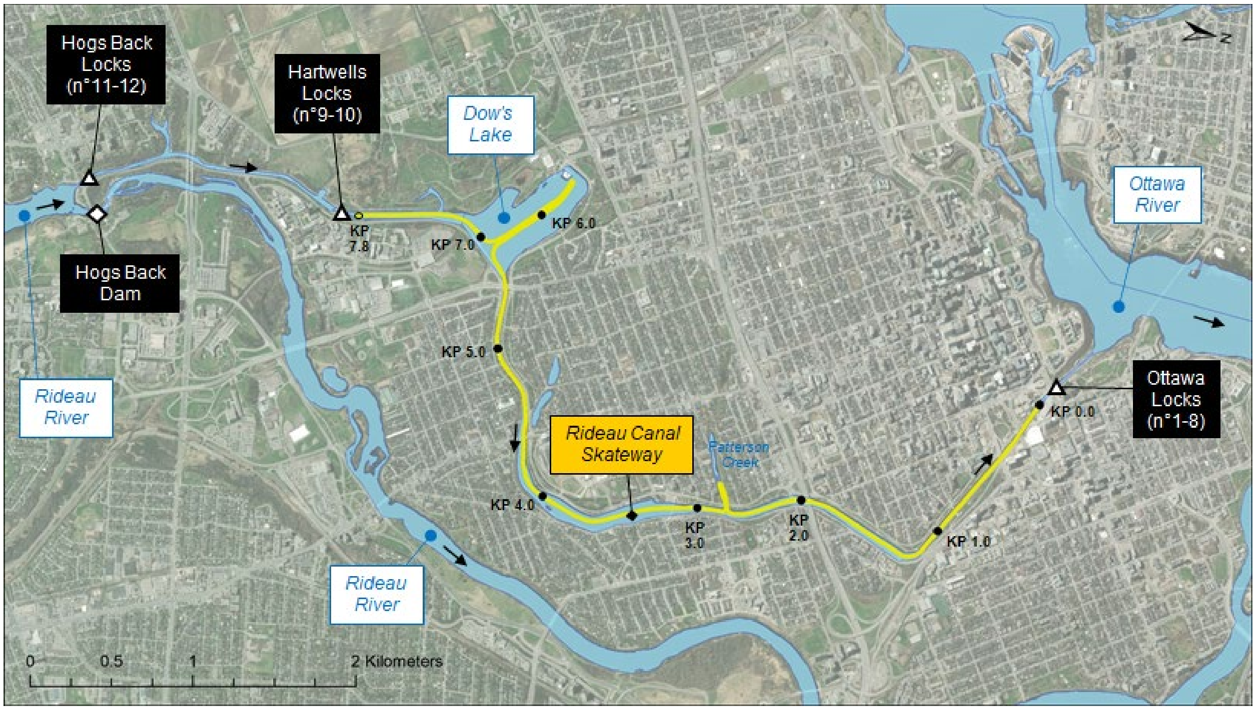

Figure 1-1: RCS Location Map (KP are "Kilometric Points" along the Skateway)

1.1.2 *JURISDICTION OF THE RIDEAU CANAL SKATEWAY*

The RCS operates within a complex jurisdictional context. It is managed by the NCC within a heritage facility under the jurisdiction of PC in the center of the City of Ottawa, which is the fourth largest city in Canada. Collaboration amongst multiple organizations is required in order for the NCC to successfully operate the RCS and these organizations in turn benefit from the presence of the RCS. The NCC's jurisdiction includes the operations and management of the RCS and the management of both pathways and parkways on either side of the canal, including Queen Elizabeth Driveway and Colonel by Drive ("NCC parkways"). Beyond this, the jurisdiction over the canal, its infrastructure, the surrounding environment and the waterway involve broader management including these stakeholders:

- At the Federal level, PC is the year-round owner and primary steward of the Rideau Canal. The canal is a UNESCO World Heritage Site and a National Historic Site. As such, PC is responsible for the maintenance of the infrastructure, oversees the management of ecosystems (weed management, zebra mussels, etc.) and controls the water levels.
- At the Provincial level, the Ministry of Environment and Energy of Ontario has the legislative authority to manage water quality under the Ontario Water Resources Act and the Environment Protection Act. The Ministry is supported by the Rideau Valley Conservation Authority, although its role is limited within the boundaries of the canal.
- At the municipal level, the City of Ottawa is responsible for the maintenance of the roads on each side of the Rideau Canal beyond the NCC parkways. In addition, stormwater and sanitary sewer management fall under the jurisdiction of the City. According to the operation and maintenance staff of the RCS, there are about 600 stormwater outfalls in the canal. Stormwater temperature, along with its concentration in salt and sediments, affects ice formation and bearing strength.

1.1.3 *INFRASTRUCTURE*

Access to the RCS by stairs (9-13 steps) is provided at 29 entry points. In addition to these, universal access ramps are installed at the Rideau, Mackenzie King West, Holmwood and Bronson entrances. The RCS has four rest areas:

— Rideau: one change chalet and one washroom chalet;
— Concord: one change chalet and one washroom chalet;
— Fifth Avenue: one change chalet and one washroom trailer; and
— Bronson: one change chalet and one washroom chalet.

The partners of the RCS also install concessions. At Dow's Lake Pavilion, a partner sets up a changing tent and runs an off-ice skate rental trailer. Skate rental trailers are operated by a third party at Rideau and Fifth Avenue. There are also close to 20 lots available for food concessions, but those lots are not always occupied or occupied by the same concessions.

1.2 REPORT STRUCTURE

As a first step, the report identifies relevant impacts related to climate change, assesses associated vulnerability and risk, and outlines recommendations to address these impacts. The report covers the main steps of the internationally recognized ISO 31000 risk management standard (Figure 1-2), with the risk assessment portion following the ISO 14091 adaptation to climate change standard.

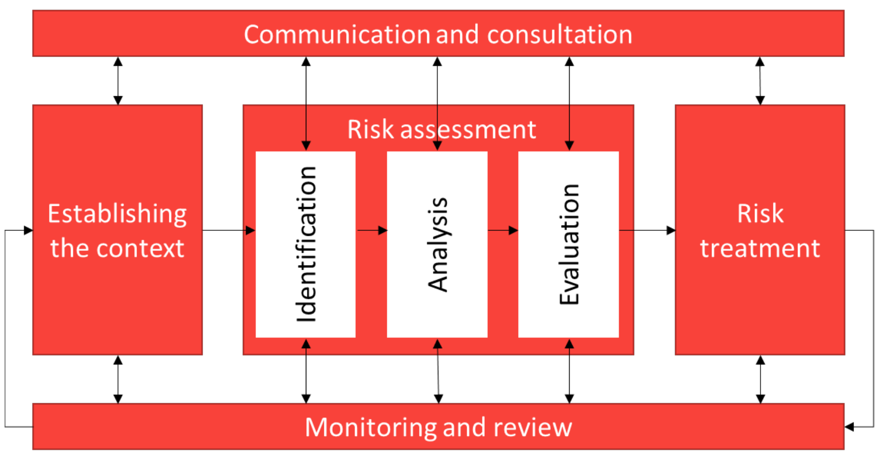

Figure 1-2: ISO 31000 Risk Management Framework

In line with the above framework, the report includes the following sections, which have been reorganized for enhanced readability:

— **Section 2 – Summary of literature review:** Summarizes the state of the information on climate hazards and risks to outdoor skating facilities. Additional information is provided in Appendix A.
— **Section 3 – Analysis:** Presents the climate change risk assessment process for the RCS, along with key information that was factored into the assessment, with a major focus on the relationship between ice quality and climate.
— **Section 4 – Recommendations for risk treatment:** Includes recommendations to mitigate climate change risk for the RCS, an implementation plan, and considerations to incorporate climate change in winter recreation facilities standards generally.

Following the main body of the report, the appendices include:

- **Appendix A – Establishing the context:** Provides a thorough analysis of the context of the RCS to identify the boundaries of the risk assessment, as well as jurisdictional and geographical considerations.
- **Appendix B – Additional literature review content and database:** Provides a complete overview of the background research conducted to identify climate change impacts on ice and best practices in climate change adaptation for outdoor skating facilities.
- **Appendix C – Monitoring program report:** Provides a description of the fieldwork and summarizes the temperature and conductivity data acquired during winter 2021.
- **Appendix D – Climate change risk assessment database:** Presents a detailed description of the risk profile of the RCS.
- **Appendix E – Risk assessment rating matrices:** Defines the processes to rate the different parameters of the risk assessment.

2 SUMMARY OF LITERATURE REVIEW

2.1 INTRODUCTION

An important initial step to climate change risk assessment is understanding the context of the problem. Not only is the Rideau Canal Skateway amongst the longest natural skating rinks in the world, but it also has a reputation for offering a high-quality experience due to extensive care and maintenance by the NCC. However, outdoor skating rinks in Canada and around the world are faced with the challenges of a changing climate and are looking for ways to adapt to a warming planet. To provide a thorough background and foundation for the current climate risk assessment project, WSP has conducted a literature review focused on standards, guidelines and best practices for climate adaptation of outdoor skating facilities. Additional review was conducted on other outdoor ice bodies such as lakes, rivers, and ice roads to determine if any information could be directly or indirectly applicable to the canal.

This literature review consists primarily of international sources but included some Canadian references that provide relevant insights to this project. Reviewed topics include climate hazards and climate risks to outdoor skating facilities, standards and guidelines for operating outdoor skating rinks, adaptation measures and best practices adopted by rink operators internationally, and other items related to these main themes. This chapter summarizes the reviewed literature, discusses common themes and identifies the key takeaways for the RCS.

Several documents have been reviewed and their findings and key themes are presented below. A more detailed summary of each of the sources consulted and their relevance to this study has been included in Appendix B.

2.2 ICE FORMATION PROCESSES

This section describes the general ice formation processes that occur on a lake or calm water body, like the Rideau Canal. Over the course of the season, the evolution of the ice cover will go through these three steps:

1. **Formation:** Lakes first cool from top to bottom in colder temperatures, until all the water in the lake is at 4°C and reaches its maximum density. With further cooling, a lighter layer of water forms the surface. Ice forms on the surface either through the freezing of the body of water (primary nucleation) or through atmospheric snow and ice particles falling onto the water body (secondary nucleation). Secondary nucleation allows the initiation of the ice cover even if the surface water is not at freezing point.
2. **Growth:** Further ice formation occurs when surface air temperatures become low enough to allow freezing of water to the underside of the ice sheet. The ice cover can also grow through the aggregation of snow to the ice cover.
3. **Decay:** Lake ice decay begins when the snow cover on top of the ice melts, forming pools of water and decreasing the albedo of the top surface. During decay, ice typically melts at the top and bottom surfaces simultaneously.

During winter, growth episodes can be interrupted by a thermal discharge, the process of warm water entering a water body. Thermal discharges raise the water temperature but also reduce the amount of ice that would otherwise form.

2.3 CLIMATE CHANGE IMPACTS ON SKATING OPERATIONS

Since the 1980s, the effects of climate change on winter tourism have become a popular topic in tourism and climate research. However, it has been found that the bulk of this literature has focused on skiing or natural water bodies, and there is limited data and reports available on skating and other ice-related activities (Liu et al., 2017). The research into skating shows that climate change is not only narrowing the timing available for skating by both delaying the start date and shortening the season, but also increasing the number of injuries and changing tourists' preferences and demands in response (Liu et al., 2017).

Much of the literature reviewed focused on the impacts that climate change is having on outdoor skating and on different methods of predicting annual operations. In a study of Beijing's Bei Hai Park, a popular outdoor skating destination that has been in operation for over 1,000 years, historical weather data was analyzed to determine its impact on operating windows. It found that increases in temperature of 1°C in December were associated with a 3.8-day delay in opening dates and a 4.49-day decrease in operation duration times (Liu et al., 2017). During the study period (1989-2015) researchers found that there were natural three-year variations in climate and the timing of ice breakup and freeze up, however after 2000, there were more marked fluctuations with a higher frequency of abnormally in earlier or later openings. This impacted the skating season as it reduced opening dates, reduced ice thickness, limited the number of days where the operational minimum ice thickness (15 cm) was met, and therefore decreased the number of tourists. It is important to note that the study also concluded that the individual characteristics of the water in various parts of the country also contributed to their freezing characteristics (Liu et al., 2017). The primary factor noted was the size and depth of the lake, with qualitative and engagement data showing that smaller and shallower lakes opened approximately half a month earlier.

These findings are all consistent with the Canadian context which has seen an increase in average winter temperature of over 2.5 C since the 1950s and a decrease in the frequency, duration, and intensity of winter cold spells everywhere except in the Northeast (Damyanov et al., 2012; Zhang et al., 2010). These changes have led to a studied reduction in the operational skating season almost everywhere in the country.

The NCC, City of Ottawa and ECCC recently partnered to commission a major study on Climate Projections for the National Capital Region (NCC et al., 2020). These projections show that under a worst-case greenhouse gas emission scenario (RCP8.5), the annual average temperature is projected to increase by 9.3°C by the 2050s and 11.4 °C by the 2080s. The same study projected a decrease in cold extremes, deep freeze events, an increase in winter freeze-thaw cycles, and a change in seasonal characteristics to include a shift to a later fall frost and earlier last spring frost.

Using data collection on outdoor rinks collected from a citizen science project called RinkWatch, skating data was compared for 10 Canadian cities, including Montreal, over two seasons. By comparing the data with daily temperature simulations based on the Intergovernmental Panel on Climate Change's A2 emissions scenario, the study projected that the number of skating days by the year 2080 would decline on average by 34% in Montreal (Robertson, 2015).

In Montreal, an analysis was performed to determine which weather indicator was the best predictor of outdoor skating operations, and a predictive model was generated based on findings to project skating operation windows into the future for different climate scenarios (Dickau et al., 2020). Dickau et al. (2020) found that the outdoor skating season in Montreal could decrease by 15% to a mean of 41 days under RCP2.6 (7-day decrease) or 75% to a mean of 11 days (37-day decrease) under RCP8.5 by the end of the century.

In the Netherlands, historical data was used to develop a climate indicator based on the likelihood of an outdoor speed skating race (Elfstedentocht) being held each year which depends upon ice thickness (Visser, Peterson, 2009). The race, which covers a 200 km tour through eleven cities, had a 20% chance of occurring every year as of 1909. In 2019 this chance was reduced to 8% and in the last 50 years, only three tours have been organized (Oldenborgh et al., 2019). The authors conclude that by the end of the 21st century, there will be a 4% annual chance of the event happening under an optimistic scenario, and minimal chances (<0.2%) under a pessimistic scenario. The impact this uncertainty has on political climate action were also discussed in the study by Visser and Peterson (2009).

2.4 CONCLUSIONS OF LITERATURE REVIEW

In a Canadian and international context, the climatic factors that most influence the operations of outdoor skating venues are the temperatures during the shoulder seasons (spring and autumn), the temperature of the winter seasons, the stability and rate of shift of temperatures (both cooling and warming), solar radiation, wind speed and temperature, and snow quantity, timing, and composition. Factors during the formation of the ice, such as snow and air bubble formation, salinity, and turbidity will also influence the structural properties of the ice, with air-filled "white ice" being considered inferior to the denser "clear ice". Climate change, with a trend of increasing annual and winter temperatures, has already begun to reduce the operational skating season and integrity and safety of ice used for recreation and economic purposes. Nationally and internationally there have been reports and studies of shortened operational seasons and later start dates, though there are outliers.

There have been several suggested and tested adaptational measures to increase the usability of ice as it relates to outdoor skating facilities and ice roads. Operationally, reducing the stressors on ice, such as snow windrows or the weight it is expected to carry, reinforcing weak spots, changing operation times, reducing the albedo, and both macroscopically and microscopically reinforcing the ice itself have been suggested, though all have situational benefits and drawbacks. Reducing the quantities of warm water sources via stormwater discharge, and salinity via road salt could also help protect the ice and decrease its freezing temperature. Ice that is carefully maintained in a controlled water body such as the Rideau Canal offers some advantages over naturally occurring ice. The creation and protection of ice can be more controlled and less influenced by external hydrological factors such as waves, intrusion of other water sources, and dynamic water levels. Likewise, adaptation can be implemented on a local scale which could open the way for measures that would be cost-prohibitive at larger geographical scales such as natural lakes or remote ice roads.

Reviewed international guidelines, standards and best practices do not specifically address the adaptation of outdoor skating rinks to climate change. The literature presented adaptation measures that focus on accepting the shortened skating season and adapting tourism and business practices to accommodate this. However, due to the controlled nature of the Rideau Canal, some adaptation measures suggested for strengthening ice roads could be considered to increase the resilience of the Skateway. This can also be viewed as a potential opportunity and need for a governing body to develop climate change adaptation guidelines for winter recreational facilities.

3 ANALYSIS

Our approach to climate change risk assessment for the RCS follows the ISO 31000 and ISO 14091 standards in risk management, as this framework is internationally recognized. The first step was to establish the context as described in Section 3. The second step is to assess the risk which involves:

1. Identifying the climate change hazards and associated impacts;
2. Analyzing the exposure and the vulnerabilities of the RCS to these hazards; and
3. Evaluating the severity of the consequences and likelihood of climate impacts is the last step of the risk assessment.

At a high level, in addition to ice formation, the study will consider the following infrastructure in the climate change risk assessment:

- Drainage infrastructure;
- Machinery;
- Trailers and chalets; and
- Food concession buildings.

From the beginning of the project, it was made clear by the different stakeholders that the main concern regarding climate change was whether there will be sufficient ice in the future on the Rideau Canal to safely operate the Skateway during winter. These concerns significantly guided the following assessment.

As part of the full risk assessment a statistical analysis of the relationship between historical climate and skating season duration, beginning and ending, was produced by the Project Team. These skating season projections are presented below with a focus on parameters that will affect ice performance and safety. This historical analysis is complemented by temperature and conductivity data that were collected through a monitoring program during winter 2021.

Following this analysis, the Project Team produced a qualitative risk assessment in order to underline the impacts and associated risk to the expected changes in climate. The steps of this framework are defined and covered in detail below with examples provided for each step. The complete assessment is available in the Risk Assessment Matrix located in Appendix D.

3.1 AVAILABLE DATA

Table 3-1 summarizes the available information about the ice conditions on the RCS, provided by the NCC for WSP to use in the analysis.

Table 3-1: Available data for the ice analysis

Description	Period (number of years)
Date of beginning/end of the skating season	1970 – 2021 (51)
Number of days closed	1995-2021 (26)
Number of visitors	1992-2021 (29)
Ice thickness observations	Winter 2020-2021 (<1)
Time-lapse camera images along the RCS	Winter 2020-2021 (<1)
Under-ice water temperature and conductivity measurements	February 2021 (<1)

3.2 HISTORICAL DATA ON SKATING DAYS

Since 1971, the average length of the skating season on the RCS has been 57 days. The longest skating season was 90 days in 1972, while the shortest season was 26 days in 2021. Every season has been interrupted by warmer spells where the ice conditions restrict the activities. For example, between 1996 and 2020, there was an average of 43 skating days and eight days where the RCS was closed.

Historically, the RCS opens on average around the 3rd of January and closes around the 2nd of March, although there is variability around these dates. The earliest opening date was December 18 (in 1972 and 1981) and the latest opening was February 2, 2002. The earliest closing date was February 13, 1984, and the latest closing date was March 25, 1972.

Significant trends in changes in skating days are already observable. Since 1971, the season length has been decreasing by 3.8 days per decade on average (Figure 3-1), which is mostly due to a later onset of the skating season (4.6 days per decade; Figure 3-2).

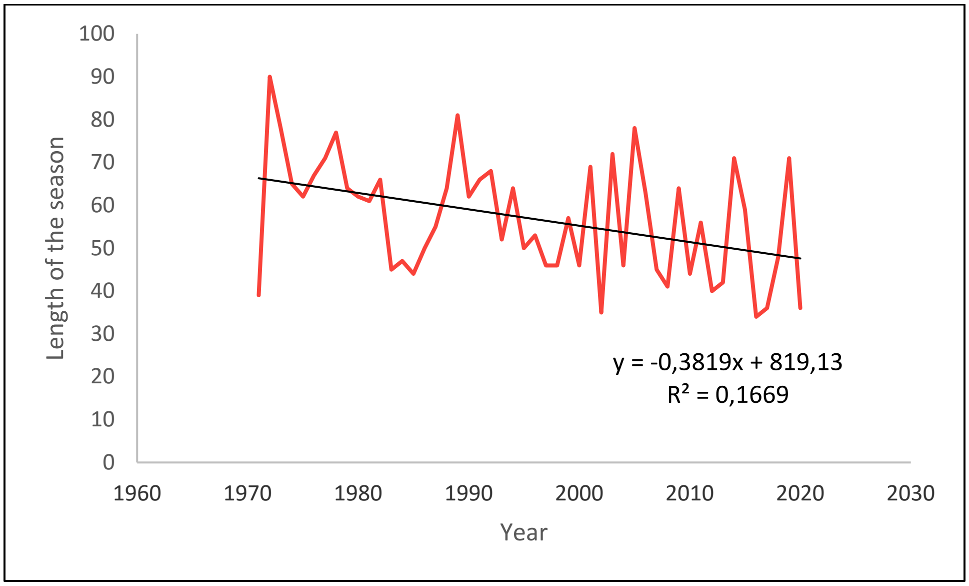

Figure 3-1: Decreasing trend in the skating season length from 1971 to 2020.

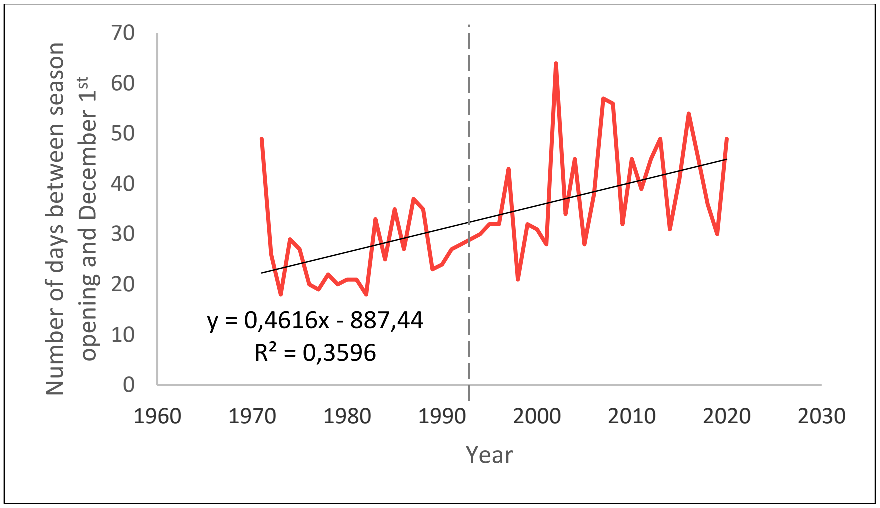

Figure 3-2: Increasing delay in the beginning of the season from 1971 to 2020. The 1971 season can be considered as an outlier given that it was the first year of operation. The vertical dashed line shows the switch from a low variance to a high variance regime in 1996.

There is no significant trend in the last day of the season. This is consistent with the fact that early-season cold conditions likely define the dynamics of the ice formation. In addition to the increasing trend observable in Figure 3-2, there is a noticeable change in the climate regime around the year 1996. Before 1996, the interannual variability in the starting date was lower (standard deviation of 5.5 days) compared to the last two decades (standard deviation of 10.5 days). This is synchronous with a change between above-average and below-average skating season length, as illustrated in Figure 3-3. This figure represents the cumulative difference to the mean in the skating season length. A rising slope is representative of a period of longer skating seasons and a negative slope suggests the opposite.

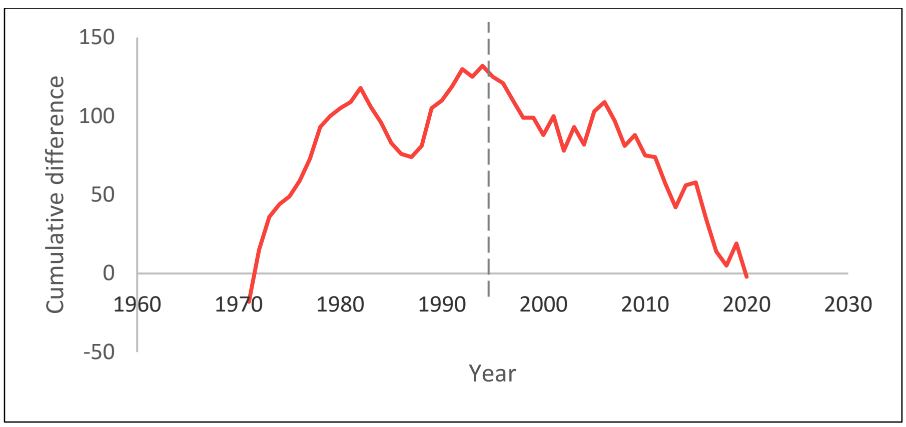

Figure 3-3: Cumulative difference to the historical average in the skating season length. This figure illustrates that the skating conditions were better than average until the mid-1990s, except for a five-year hiatus from 1982 to 1987. The vertical dashed line shows the tipping point towards a general degradation of the skating conditions in 1996.

3.3 SUMMARY OF THE MONITORING PROGRAM

Appendix C describes the monitoring program conducted by WSP from February 9, 2021 to March 1, 2021 for the RCS. During that campaign, water temperature and conductivity were monitored under the ice cover at multiple locations. The main purpose of the program was to acquire data about the thermal regime of the water in the Rideau

Canal during the winter season. Figure 3-4 illustrates the water temperatures recorded at 6 gauges installed by WSP along the canal; at kilometres 0.0, 0.3, 0.7, 1.4, 2.4 and 7.8. The main conclusions from the program are the following:

— Water entering the canal is relatively warm (in the order of 1°C) and tends to slightly cool down as it flows downstream.
— Near-ice water temperature at the entrance of the Skateway (Kilometric Point or KP 7.8) is often warmer (in the order of +0.3°C) than in the canal downstream. This seems to indicate that water is typically cooling as it flows downstream in the canal.
— The data also suggest that near-ice water is significantly warmer at KP 0.0, with an average temperature of 1.7°C. The temperature difference (compared to the rest of the canal) is typically about +1°C, increases to +2°C on February 25 and reaches +5°C on March 1st. It is suspected that this significant temperature could be explained by the urban stormwater outfalls, particularly the Laurier Avenue drain, that discharge warmer water in the canal.
— Results show that the water temperature on the downstream reach of the canal (KP 0.0, 0.3 and 0.7) was more influenced by the air temperature rising above 0°C than the upstream reaches. On March 1st, 2021 records at gauges at KP 0.0 and 0.7 show a major increase in water temperature, in the order of +4°C. Water temperature increase at KP 0.3 (Laurier Avenue) was less significant (+0.7°C), which seems to indicate that the pipes installed by the NCC at the Laurier Avenue drain were relatively effective at diverting the warmer water downstream.

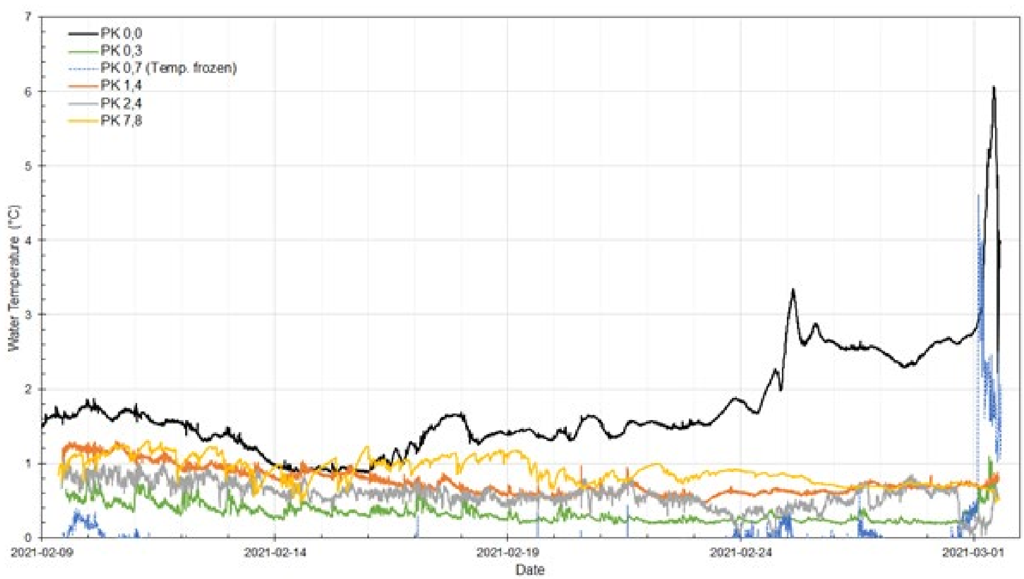

Figure 3-4: Water temperatures measured in the Rideau Canal Skateway between February 9 and March 1, 2021

3.4 REMOTE SENSING

Remote sensing techniques can be used to estimate the surface temperature of a water body. Since no fall/winter temperature data is available in the canal, except for the February 2021 measurements taken by WSP (Appendix C), remote sensing appears to be a promising method of collecting new data or past observations from historical aerial imagery.

Water temperature can be estimated from remote sensing aerial images (taken from a satellite or aircraft) before the formation of the ice cover. A comparative analysis between the Rideau River and the canal is possible using the temperature derived from the images.

WSP has performed a preliminary analysis of the water temperature in the Rideau River at the entrance of the canal and in the canal itself (Dows Lake) by using the images captured by Landsat 8 satellite. Preliminary results show that the availability of the images is limited and is influenced by the presence of clouds. Unfortunately, there was insufficient evidence within the period of interest, i.e. between canal watering[1] and ice formation (end of November to mid-December typically).

Figure 3-5 illustrates an example of a temperature raster derived from Landsat 8 image captured on November 2, 2014. Preliminary results indicate that water in the river near the canal entrance is typically warmer (by 0.5 to 1.0°C) than in the canal (Dows Lake) prior to canal watering (typical on the third week of November). These preliminary findings were consistent throughout several early November images but will need to be validated by in-situ water temperature measurements in future phases of the project.

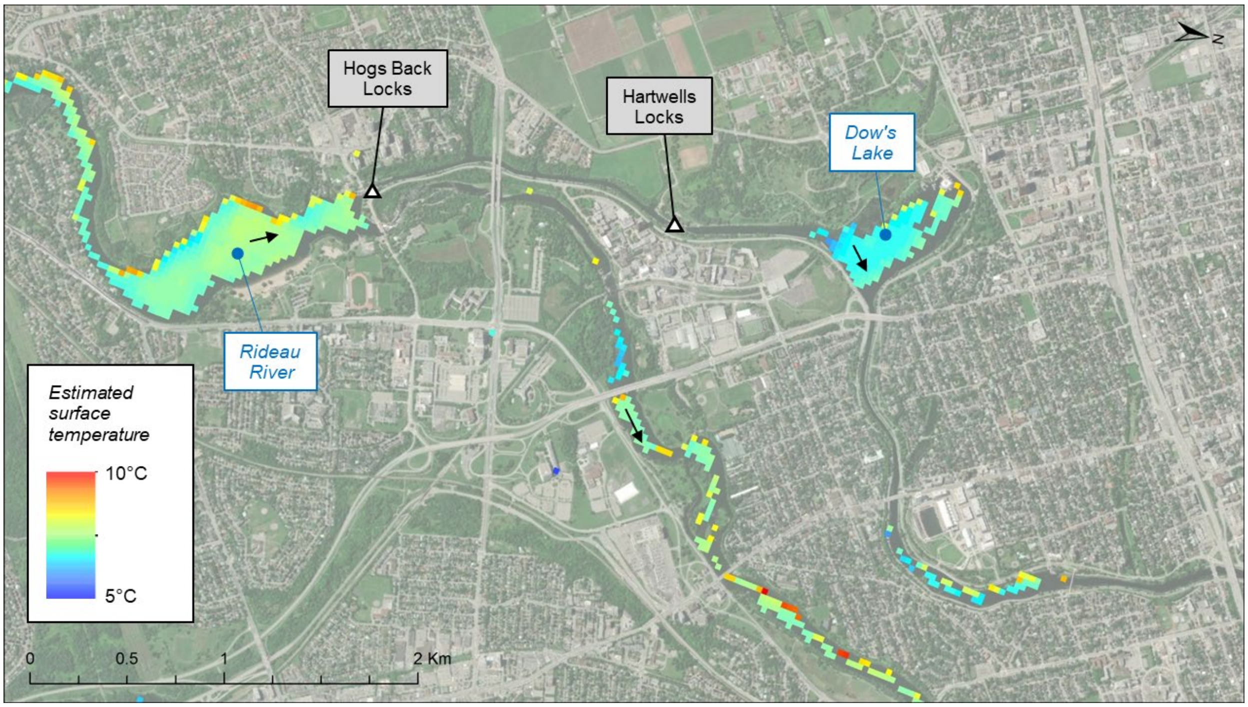

Figure 3-5: Estimated water temperature derived from Landsat 8 image on November 2, 2014 – preliminary results.

3.5 SKATING SEASON PROJECTIONS

3.5.1 *OBJECTIVE*

The objective is to observe the projected changes in skating conditions for three different time horizons (the 2030s (2021-2050), 2050s (2041-2070) and 2080s (2071-2100)) under two greenhouse gas (GHG) emission scenarios. The selected scenarios were RCP4.5 (decrease in GHG emissions by the 2040s) and RCP8.5 (regular increase in GHG emission until the end of the century, often referred to as the "business as usual" scenario).

[1] Canal watering is the process of opening the upstream locks to fill the Rideau Canal to its proper level for skating or navigation season.

3.5.2 DATA

To conduct this analysis, the following datasets were used:

— Skating conditions: the RCS yearly statistics provided by the NCC (Table 3-1);
— Historical weather data: Environment and Climate Change Canada (ECCC) Ottawa CDA Weather Station (ID# 6105976), daily data for 1971-2020; and
— Climate change projections: ECCC 24-model ensemble, statistically downscaled through BCCAQ2 and following ANUSPLIN grid.

3.5.3 METHOD

1 Identify relationships between ice conditions and weather variables.

Calculate the Pearson's correlation between historical weather variables and ice condition data. The following weather variables were investigated at the monthly, bi-monthly (November-December, December-January, January-February, etc.) and seasonal (November-March and December-February) scales:

— Mean average daily temperature;
— Mean minimum daily temperature;
— Total number of freezing degree-days;
— Total number of deep freeze events (where the minimum temperature drops below -10°C).
— The following ice statistics were investigated:
— Beginning of the season (number of days after December 1st);
— End of the season (number of days after February 1st);
— Length of the season (number of days between opening date and closing date);
— Number of skating days; and
— Number of closed days.

2 Build a linear regression model between the best weather predictors and ice condition predictands.
3 Transfer this predictive relationship to the climate projections for each model of the ensemble.
4 For each model and each time horizon, verify the assumption of a normal distribution of the results using the Lilliefors test.
5 Project the anticipated skating conditions under three different time horizons (the 2030s (2021-2050), 2050s (2041-2070) and 2080s (2071-2100)) for two GHG emission scenarios (RCP4.5 and RCP8.5).

3.5.4 RESULTS

3.5.4.1 CLIMATE-ICE RELATIONSHIPS

For every ice condition parameter used, relationships between cold temperature parameters often produced strong correlations (0.5 or above), as summarized in Table 3-2.

Table 3-2: Summary of the relationship between climate and ice

	Beginning of skating season (n=51)	End of skating season (n=51)	Length of skating season (n=51)	Number of skating days (n=26)	Number of days closed (n=26)
Mean minimum temperature – Dec	**0.54**	0.07	**-0.44**	**-0.56**	-0.01
Mean minimum temperature – Jan	**0.36**	0.01	**-0.32**	**-0.69**	**0.35**
Mean minimum temperature – Feb	0.15	**-0.40**	**-0.42**	**-0.59**	**0.44**
Mean minimum temperature – Mar	0.02	**-0.29**	-0.25	**-0.44**	0.09
Mean minimum temperature – DJF	**0.57**	-0.14	**-0.62**	**-0.87**	**0.36**
Freezing degree-days – Dec	**-0.50**	-0.09	**0.40**	**0.56**	0.00
Freezing degree-days – Jan	**-0.35**	-0.04	**0.29**	**0.69**	**-0.40**
Freezing degree-days – Feb	-0.15	**0.38**	**0.41**	**0.53**	**-0.45**
Freezing degree-days – Mar	-0.06	**0.27**	0.25	0.37	-0.04
Freezing degree-days – DJF	**-0.54**	0.10	**0.56**	**0.86**	**-0.42**
No. of deep-freeze events – Dec	**-0.52**	-0.05	**0.44**	**0.60**	-0.10
No. of deep-freeze events – Jan	**-0.31**	-0.06	**0.27**	**0.61**	**-0.43**
No. of deep-freeze events – Feb	-0.10	**0.47**	**0.40**	**0.61**	**-0.50**
No. of deep-freeze events – Mar	0.00	0.23	0.19	0.30	-0.09
No. of deep-freeze events – DJF	**-0.52**	0.15	**0.59**	**0.85**	**-0.47**

Bold numbers indicate statistically significant correlations ($p < 0.05$). Blue cells highlight the predictors that were selected for the following steps. Positive correlations indicate a direct relationship (both the weather parameter and the ice statistic increase or decrease simultaneously). Negative correlations indicate an inverse relationship (The increase of the weather predictor is associated with a decrease in the ice statistic or vice versa).
DJF: December, January, February

From this correlation matrix, for each ice statistic, weather variables were selected to build a predictive model using linear regressions. The process was the following:

— Build a simple regression model using the predictor with the strongest correlation (i.e. closer to -1 or 1); and
— Compare this model with other predictors or with multivariate models to select the model that has the strongest predictive power while being the most parsimonious.

The model for the length of the skating season followed the same trend as the model for the number of skating days. The models for the number of days closed were not performing well. Therefore, they are not presented below.

3.5.4.2 PROJECTED SKATING DAYS

The best relationship was between the number of skating days and the mean winter daily minimum temperature. Figure 3-6 illustrates this relationship.

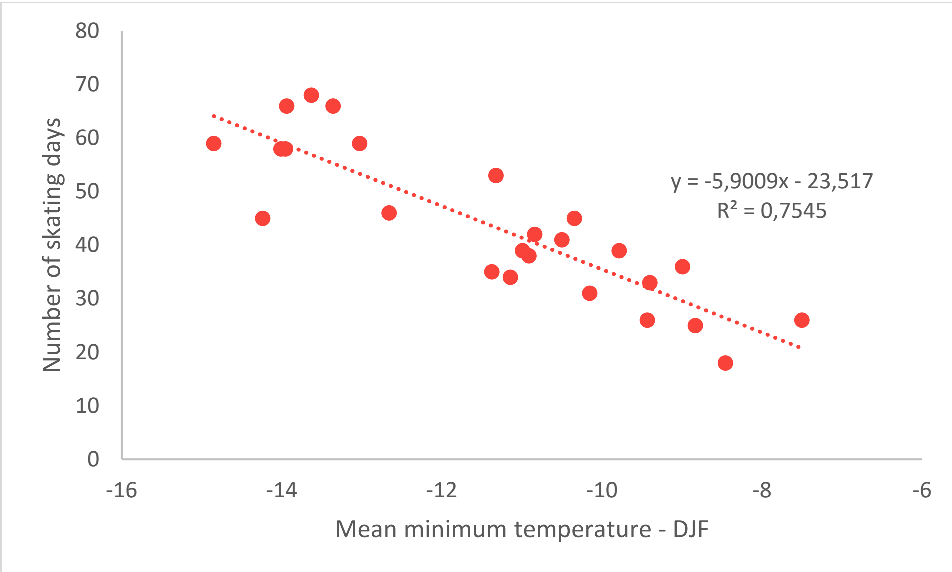

Figure 3-6: Relationship between the mean daily minimum temperature and the number of skating days for the RCS

The interannual variation (75%) in the number of skating days is explained by the mean minimum daily temperature from December to February. More complex regression models including more than one predictor did not sufficiently increase the power of the relationship to justify the added complexity. Therefore, we concluded that the relationship between the number of skating days (y) and the mean minimum daily winter temperature (x) can be modelled from climate projections using the following equation:

$$y = -5.9009x - 23.517 \quad \text{(Eq. 1)}$$

The projected skating days fit a normal distribution, and the annual probability of having a certain amount of skating days (20, 40 or 60) was calculated following the assumption of normality, and assuming a stationary relationship between winter temperature and ice. Figure 3-7 illustrates the projected changes in the probability of occurrence of a year with 20, 40 and 60 skating days.

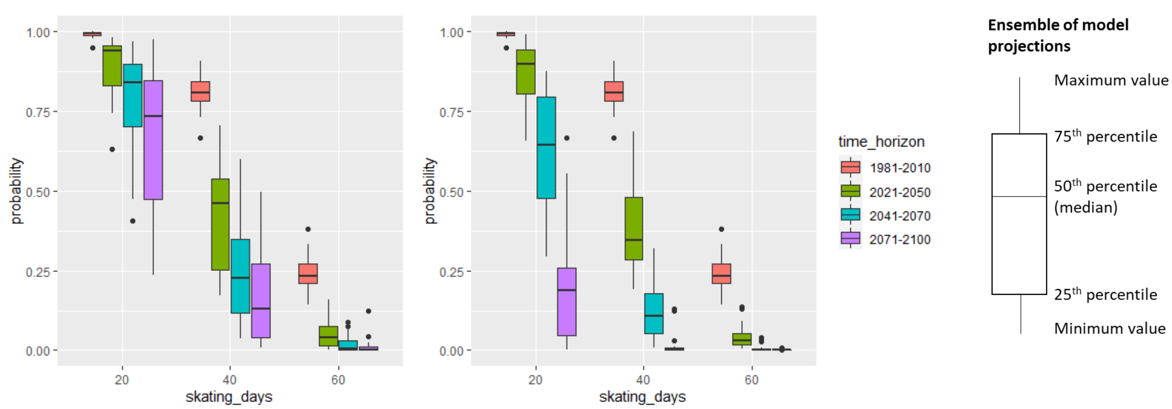

Figure 3-7: Projected changes in the probability of occurrence of annual skating days for the RCS with 20, 40, and 60 skating days under RCP4.5 (left) and RCP8.5 (right) scenarios.

Both figures indicate a significant decrease in skating days between the historical period and the near future, as summarized in Table 3-3.

Table 3-3: Summary of the decreasing annual probabilities of observing 20, 40 or 60 skating days for the RCS under RCP4.5 and RCP8.5 as compared to the historic baseline

No. skating days	1981-2010 Baseline	2030s (2021-2050) RCP4.5	2030s (2021-2050) RCP8.5	2050s (2041-2070) RCP4.5	2050s (2041-2070) RCP8.5	2080s (2071-2100) RCP4.5	2080s (2071-2100) RCP8.5
20	99% [98%; >99%]	94% [77%; 97%]	90% [72%; 97%]	84% [55%; 95%]	64% [34%; 82%]	73% [34%; 90%]	19% [<1%; 43%]
40	81% [75%; 88%]	46% [19%; 61%]	34% [22%; 58%]	23% [5%; 47%]	11% [3%; 27%]	13% [2%; 42%]	<1% [<1%; <1%]
60	23% [16%; 30%]	4% [<1%; 11%]	3% [<1%; 9%]	1% [<1% ; 6%]	<1% [<1%; 2%]	<1% [<1% ; 2%]	<1% [<1%; <1%]

The main conclusions from this analysis are:

- In the next decades, under a moderate GHG emission scenario, the NCC should prepare for seasons with less than 40 days of skating approximately 50% of the time;
- Winters of greater than 60 skating days are unlikely to occur in the future under both RCP scenarios; and
- Under both GHG emissions scenarios, the probability of having at least 20 skating days annually is high until the 2050s, although this probability could drop below 50% in the second half of the century under a high GHG emission scenario.

3.5.4.3 PROJECTED SHIFT IN THE DATE OF SEASON OPENING

The strongest statistical relationship was between the number of days after December 1st that the skating season began and the mean winter daily minimum temperature. Figure 3-8 illustrates this relationship.

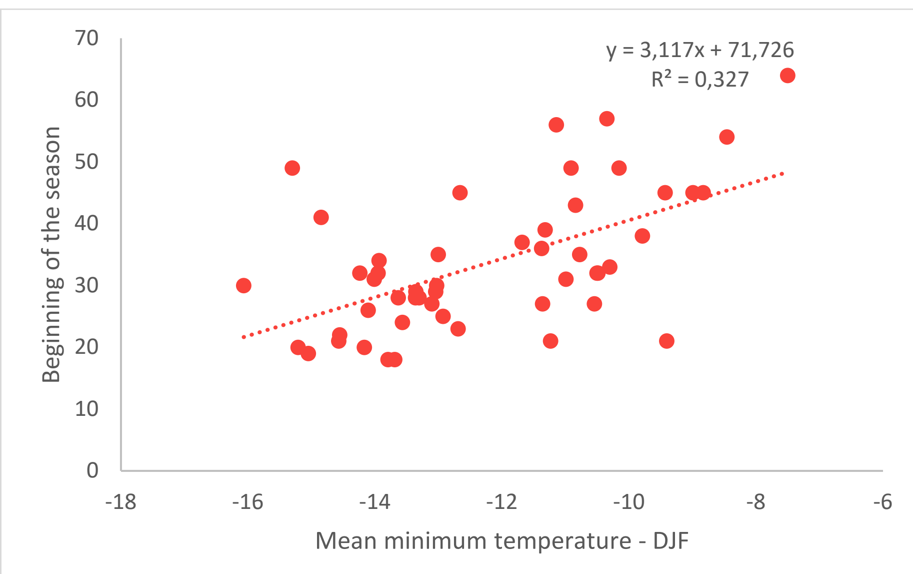

Figure 3-8: Summary of the relationship between the number of days after December 1st that the RCS skating season has historically begun and the mean winter daily minimum temperature

The variation (33%) in the number of skating days can be explained by the mean minimum daily temperature from December to February. More complex regression models including additional predictors did not sufficiently increase the power of the relationship to justify the added complexity. Therefore, we concluded that the relationship between the date of the beginning of the season (y) and the mean minimum daily winter temperature (x) can be modelled from climate projections using the following equation:

$$y = 3.117x + 71.726 \quad \text{(Eq. 2)}$$

Figure 3-9 illustrates how the beginning of the season is projected to evolve based on this relationship. The fit between historical statistics from the NCC and the projected values for the period 1981-2010 was good. For example, the historical median date for the beginning of the skating season between 1981 and 2010 is January 1, which is the exact date projected by Equation 2 using climate model data.

Looking at future projections, the skating season is expected to start six to seven days later on average over the short-term and approximately two weeks later on average over the long term. The distribution of the data shown in the boxplots in Figure 3-9 or detailed in Table 3-4 illustrates that there will be increasing variability in the beginning of the skating season. It is also important to note that using a linear regression model of moderate strength to project future values will tend to underestimate the extreme values of the models. This means, for example, that for the 2050s (2041-2070) period under the RCP8.5 scenario, while the 90th percentile of the distribution is January 25th (i.e. in 90% of the model iterations, the beginning of the skating season was prior to January 25th), this value is underestimated and we believe that the occurrences where the skating season begins later than this date will be more frequent.

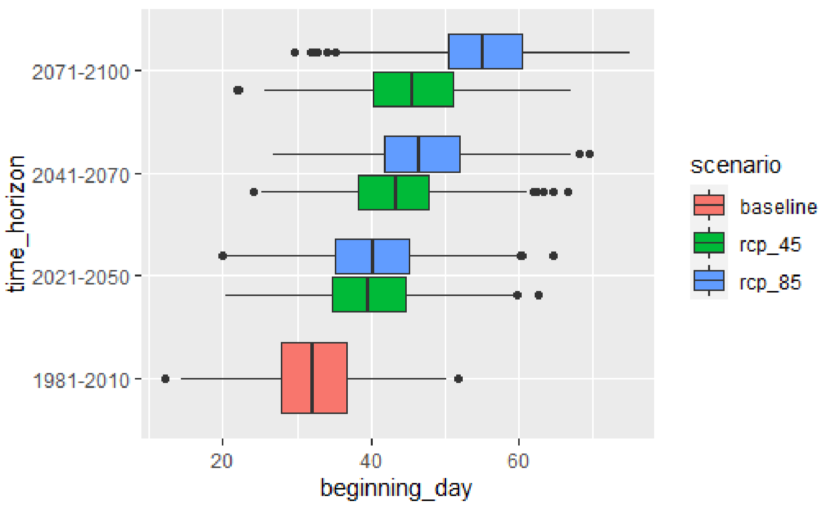

Figure 3-9: Projected beginning date of the season under two time horizons and two GHG scenarios. The beginning day represents the number of days after December 1st.

Table 3-4: Projected median date for the beginning of the skating season. Dates in brackets represent the 10th and 90th percentiles of the distribution.

Scenario	Baseline	2021-2050	2041-2070	2071-2100
RCP4.5	Jan. 01 [Dec. 24; Jan. 10]	Jan. 09 [Dec. 30; Jan. 18]	Jan. 12 [Jan. 02; Jan. 22]	Jan. 15 [Jan. 04; Jan. 25]
RCP8.5	Jan. 01 [Dec. 24; Jan. 10]	Jan. 09 [Dec. 31; Jan. 19]	Jan. 15 [Jan. 05; Jan. 25]	Jan. 25 [Jan. 15; Feb. 03]

The main conclusions from this analysis are:

— In the next decades, under a moderate GHG emission scenario (RCP4.5), the NCC should expect to open the Skateway on average, one to two weeks later than historically; and
— Opening of the RCS in December is unlikely to occur in the future.

3.5.4.4 PROJECTED SHIFT IN THE DATE OF SEASON CLOSING

The end of the skating season is the parameter for which the model had the weakest statistical strength. This was to be expected as the weakening of ice is multifactorial and affected by the weather events of the whole season. The best relationship was between the number of days after February 1st that the skating season ended and the number of deep freeze events in February. Figure 3-10 illustrates this relationship.

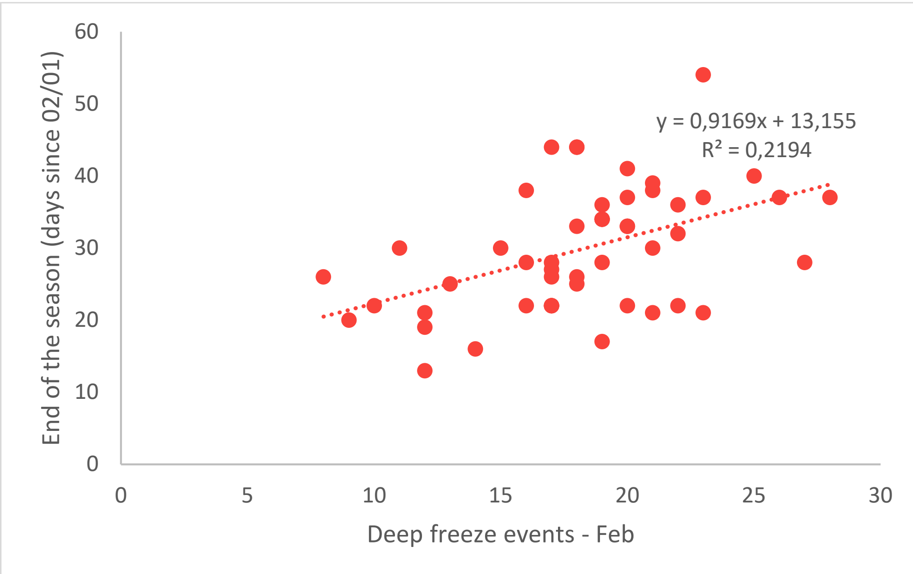

Figure 3-10: Summary of the relationship between the number of days after February 1st that the RCS skating season has historically ended and the number of deep freeze events in February

The variance (22%) in the number of skating days is explained by the number of deep freeze events in February. More complex regression models including more than one predictor or other algorithms did not sufficiently increase the power of the relationship to justify the added complexity. Therefore, we concluded that the relationship between the date of the season end (y) and the number of February deep freeze events (x) can be modelled from climate projections using the following equation:

$$y = 0.9169x + 13.155 \qquad \text{(Eq. 3)}$$

Figure 3-11 illustrates how the end of the season is projected to evolve based on this relationship. The fit between historical statistics from the NCC and the projected values for the period 1981-2010 was good. For example, the historical median date for the end of the skating season between 1981 and 2010 is March 2, which is only a difference of one day from the date predicted by Equation 2 using climate model data for the historical period.

Looking at future projections, the skating season is expected to close approximately a week earlier on average over the long term, although the most pessimistic models project a season end around mid-February. Additionally, the distribution of the data illustrated in the boxplots in Figure 3-11 or detailed in Table 3-5 illustrates that there will be increasing variability in the end of the skating season. It is also important to note that using a linear regression model of moderate strength to project future values will tend to underestimate the extreme values of the models. This means, for example, that for the 2050s (2041-2070) period under the RCP8.5 scenario, while the 10th percentile of the distribution is February 23rd (i.e. in 10% of the model iterations, the end of the skating season was before February 23rd), this value is underestimated and we believe that the occurrences where the skating season ends earlier than this date will be more frequent.

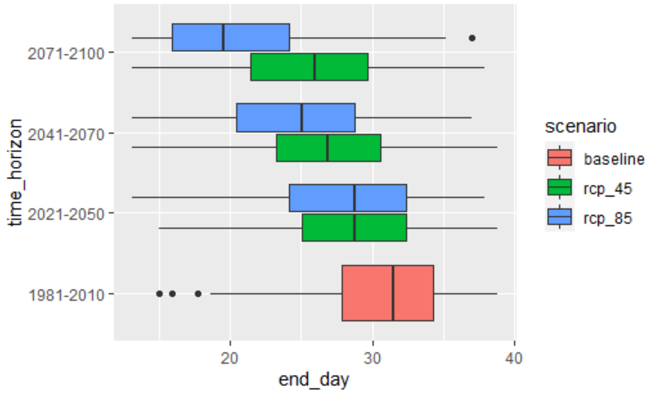

Figure 3-11: Projected closing date of the season under two time horizons and two GHG scenarios. The end day represents the number of days after February 1st.

Table 3-5: Projected median date for the end of the skating season. Dates in brackets represent the 10th and 90th percentiles of the distribution.

Scenario	Baseline	2030s (2021-2050)	2050s (2041-2070)	2080s (2071-2100)
RCP4.5	Mar. 03 [Feb. 24; Mar. 08]	Mar. 01 [Feb. 22; Mar. 07]	Feb. 27 [Feb. 20; Mar. 04]	Feb. 26 [Feb. 19; Mar. 05]
RCP8.5	Mar. 03 [Feb. 24; Mar. 08]	Mar. 01 [Feb. 21; Mar. 06]	Feb. 25 [Feb. 18; Mar. 04]	Feb. 19 [Feb. 13; Feb. 28]

The main conclusions from this analysis are:

— Changes in the end of the skating season are projected to occur in the second half of the century; and

— The date of the end of the skating season is not projected to change as much as the beginning of the season. This is consistent with historical data where there were no significant trends in the last day of the season.

This analysis illustrates that under any GHG emission scenario, in the short term, the skating seasons will be shortened significantly, especially due to a later start of the season. Indeed, under a business as usual scenario, the annual probability of reaching 40 days of skating drops to less than 50% for the 2030s time horizon to reach 11% by mid-century (2050s). The annual probability of having at least 20 days of skating remains high for the 2050s time horizon, although it drops significantly by the end of the 21st century. This means that without any changes in stormwater inputs or ice growing operations, it is highly likely that the RCS will be able to operate in the future decades.

It also appears that February is the month where the opening of the RCS is most likely in the future, and therefore any on ice winter activities should be planned during this period for the near future.

3.5.5 *SUMMARY*

In summary, the main conclusions from this analysis are:

— In the next decades, under a moderate GHG emission scenario, the NCC should prepare for seasons with fewer than 40 days of skating approximately 50% of the time;

— Winters of greater than 60 skating days are unlikely to occur in the future under both RCP scenarios;

— Under both GHG emissions scenarios, the probability of having at least 20 skating days annually is high until the 2050s, although this probability could drop below 50% in the second half of the century under a high GHG emission scenario;

— In the next decades, under a moderate GHG emission scenario (RCP4.5), the NCC should expect to open the Skateway on average, one to two weeks later than historically;
— Opening of the RCS in December is unlikely to occur in the future under both RCP scenarios; and
— The date of the end of the skating season is not projected to change as much as the beginning of the season. This is consistent with historical data where there were no significant trends in the last day of the season.

3.6 RISK ASSESSMENT

3.6.1 *METHOD*

Our approach to risk assessment aligns with the ISO 31000 risk management standard, ISO 14091:2021 *Adaptation to Climate Change – Guidelines on Vulnerability, Impacts and Risk Assessment* and follows the Intergovernmental Panel on Climate Change (IPCC) framework where risk is defined as the product of the likelihood of impacts and the severity of the consequences associated with the impacts (Figure 3-12). The latest release from the International Organization for Standardization, ISO 14091 builds on the foundation of previous standards, covering the preparation, implementation and reporting of a climate risk assessment. It also provides guidance on implementation and monitoring and evaluation for different kinds of projects.

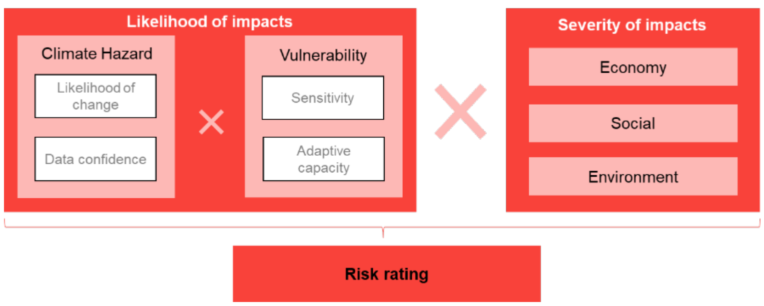

Figure 3-12: Climate risk assessment framework

In summary, the climate risk assessment process includes:

— Identification of relevant climate hazards for the RCS and potential impacts for the RCS considering each climate hazard;
— Evaluation of likelihood of the hazards, based on future climate projections and data confidence regarding climate hazards;
— Determination of the vulnerability rating for each potential impact, based on consideration of sensitivity (i.e. the degree to which a system will be affected by climate change) and adaptive capacity (i.e. the degree to which adjustments are possible in reaction to climate change);
— Rating of the likelihood of each impact, given the hazard level and the assessed vulnerability;
— Determination of the severity of the relative consequence of each impact should it occur, considering social, economic, and environmental factors; and
— Assessment of overall risk, which is a function of the likelihood that a given impact will occur and the severity of impact should it occur.

The overall risk rating serves to prioritize impacts for adaptation planning and risk reduction measures.

3.6.1.1 IMPACT IDENTIFICATION

In the context of this assessment and as per the ISO 14091 standard, an impact is defined as “an effect on natural and human systems” and refers primarily to the effects on these systems from extreme weather, climate events, and climate change. Impacts may affect lives, livelihoods, health, ecosystems, economies, societies, cultural services, and infrastructure. Impacts are not necessarily negative and could be either positive or negative. For the purposes of this report, impacts will be assumed to be negative unless otherwise noted.

Impacts to the RCS were considered through multiple lenses including operational, economic, physical, environmental, health and safety and community wellbeing. They were determined through professional judgement, literature review, comparative circumstances, interviews/discussions with the NCC and other stakeholders, as well as historic impacts. At this stage in the assessment, impacts were not i]ncluded or excluded based on their likelihood (see section 3.6.1.4) or severity of consequence (see section 3.6.1.5), but rather their potential relevance to the RCS and NCC operational objectives.

When determining a preliminary list of impacts, the exposure of the area to different climate parameters was considered. Exposure is defined as "the nature and degree to which a system is exposed to significant climate variations" (IPCC, 2018). It considers what types of climate parameters the system could be exposed to based on the larger global context and local considerations. For example, the RCS is located in an urban area by a controlled water source far from the coast. These features would indicate that hazards like sea level rise, forest fires or hurricanes have not been or will not be relevant to the subject site, and so these hazards were not considered in the assessment.

3.6.1.2 CLIMATE HAZARDS

A hazard is defined as "the potential occurrence of a natural or human-induced physical event or trend that could cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources." (IPCC, 2018). In this context, it is a function of the projected changes in climate for the area in relation to historic instances of hazards and known operating limits. Hazards analysis takes into consideration the likelihood of change (of the climate) and the confidence in the data.

Using climate projection data, this assessment considered *if* individual climate variables would be changing, *how much* they would change, and the *direction* of that change. The robustness of the data source is also considered when making recommendations. For example, average winter temperatures are projected to increase, and this increase is projected to be significant which indicates a higher level of hazard. If the projections show that a climate parameter is not projected to change, that change is relatively small or insignificant, or the confidence in the scientific quality of the model is low, then the hazard would be considered smaller.

The hazards were determined through the use of online geographic and historical imagery of the RCS, materials and information provided by the NCC, available literature for the area, a previous report created for the National Capital Region (NCC et al, 2020) and downscaled climate projections as discussed in Section 3.5.4. Hazards were ranked using a five-point rating system ranging from "very low" to "very high" for each individual climate impact, with the rationale given to support the rating choice. A scale describing the rating system can be found in Appendix E. At the beginning of the project, it was agreed that the hazard assessment will be based on a high greenhouse gas emission scenario (RCP 8.5) over the 2050s (2041-2070) time horizon. The choice of a further time horizon was motivated by the fact that most risks will be exacerbated over the longer term and therefore the climate projections will be more significantly different than the historical baseline over the long term.

3.6.1.3 VULNERABILITY ANALYSIS

Vulnerability is the propensity or predisposition of a system to be adversely affected. In a risk assessment context, vulnerability is the function of two concepts: sensitivity and adaptive capacity (Table 3-11).

Sensitivity is defined as "the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli (either direct or indirect)" (IPCC, 2001). The sensitivity to climate change of a system could be affected by several factors such as the age of the system, reliance on single sources of income or pieces of infrastructure, geographic location and features, and existing conditions. For example, a coastal community that is dependent on sea-based tourism could be more sensitive to a cyclone than a similar community with a different primary economic input. The RCS could be considered particularly sensitive because it is directly exposed to the outdoor climate with little to no direct protection. Sensitivity was ranked using a five-point rating system ranging from "very low" to "very high" for each individual climate impact and given a rationale to support the rating choice.

Adaptive capacity is defined as "the ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences" (ISO, 2019). It is a measure of the ability to adjust to climate risks and develop resilience. There is no single metric for adaptive capacity as it is relative to each individual system. In general, available resources (financial or personal), flexibility, and diversity increase adaptative capacity. Adaptive capacity was ranked using a five-point rating system ranging from "very low" to "very high" for each individual climate impact and given a rationale to support the rating choice. In contrast to sensitivity, a higher adaptive capacity has a mitigating effect on vulnerability as it allows a system to increase its resilience to a changing climate.

Adaptative capacity and sensitivity are compared using a simple matrix shown in Table 3-6. When the sensitivity is high, and the adaptive capacity is low the vulnerability of the system would be considered high because the system is sensitive to the potential impacts but has very little adaptive capacity to increase its resilience. Likewise, if the sensitivity is low and the adaptive capacity is high then the system's vulnerability would be considered low.

Table 3-6: Vulnerability rating matrix

		Adaptive Capacity				
		Very Low	**Low**	**Moderate**	**High**	**Very High**
Sensitivity Rating	**Very Low**	Very Low	Very Low	Very Low	Very Low	Very Low
	Low	Low	Low	Low	Very Low	Very Low
	Moderate	Moderate	Moderate	Low	Low	Low
	High	High	High	Moderate	Moderate	Low
	Very High	Very High	High	High	Moderate	Moderate

3.6.1.4 LIKELIHOOD OF IMPACTS

The likelihood of impact is a function of the hazards and vulnerabilities present in a system. Hazards are compared to the vulnerabilities of a system in the matrix presented below in Table 3-7. The result of this comparison is a likelihood of impacts score, which denotes how likely an impact is to occur given the individual vulnerabilities of the system as well as the probability that a hazard or particular climate trend will occur.

Table 3-7: Likelihood of Impact rating matrix

		Vulnerability				
		Very Low	**Low**	**Moderate**	**High**	**Very High**
Hazard	**Very High**	Low	Moderate	High	Very High	Very High
	High	Low	Moderate	High	High	Very High
	Moderate	Low	Low	Moderate	High	High
	Low	Very Low	Low	Low	Moderate	Moderate
	Very Low	Very Low	Very Low	Low	Low	Moderate

3.6.1.5 SEVERITY OF IMPACTS

The severity of impact is the relative consequence an impact will have on a system. It answers the question of what degree of damage or benefit would occur if an impact were to happen. The severity of impact is based on the consequence to the following categories:

— **Economic:** This includes any impact on the monetary well-being of the system including damages, maintenance costs, and revenues;

— **Health, Safety, and Community:** This includes any impact on the physical, emotional, or cultural health of the community of the system and

— **Environmental:** This includes any impact on the immediate or downstream environment of the system.

The severity of impact was ranked using a five-point rating system ranging from "very low" to "very high" for each climate impact and given a rationale to support the rating choice. For this risk assessment, the highest of the three categories of severity was chosen as the final ranking. For example, if the severity of impacts for economics was high (4), health, safety and community low (2), and environmental very low (1), the final severity score would be a high (4). This was done to maintain a conservative approach to risk ranking, and to avoid a potentially high risk being overlooked because its impact was only severe in one category. A scale describing the rating system can be found in Appendix E.

3.6.1.6 RISK EVALUATION

The final risk rating is a function of the likelihood of impact and the severity of impact, combining all the concepts mentioned above. Likelihood of impacts and severity of impacts are compared with the matrix presented below in Table 3-8.

Table 3-8: Risk evaluation rating matrix

		Severity of Impacts				
		Very Low	**Low**	**Moderate**	**High**	**Very High**
Likelihood of Impacts	**Very High**	Low	Moderate	High	Very High	Very High
	High	Low	Moderate	High	High	Very High
	Moderate	Low	Low	Moderate	High	High
	Low	Very Low	Low	Low	Moderate	Moderate
	Very Low	Very Low	Very Low	Low	Low	Moderate

3.6.1.7 SUMMARY OF RESULTS

The following section presents a high-level summary of the results of the risk assessment analysis. The full results can be found in the Climate Change Risk Assessment (CCRA) located in Appendix D. Each section below will present an overview of the results of the analysis, and an explanation of how the results are presented in the risk register in Appendix E for clarity with an accompanying example.

3.6.1.8 IMPACT IDENTIFICATION

Both direct and indirect impacts were considered during this assessment. A direct impact is one where climate operates on the object being impacted. For example, higher temperatures will melt ice. Indirect impacts are often a result of those direct impacts, but still initially influenced by climate. For example, if the ice is melted it could no longer be safe for skaters and the business community will receive less revenue from tourists which will impact the economy. These main climatic drivers can in turn influence a cascade of other impacts and climatological events and can also work synergistically. For example, increased winter precipitation alone could mean more snow, but increase winter precipitation *and* temperature could signal more rain. Likewise, events such as snow or rainstorms are products of wind, temperature, and precipitation working together. These climate drivers can have direct or indirect impacts on the RCS. For example, an indirect effect of heavy rain could be that additional, warmer stormwater is released onto the ice and accelerates melting. Figure 3-13 demonstrates a high-level relationship between climate and climate impacts with a more detailed overview provided in Table 3-9.

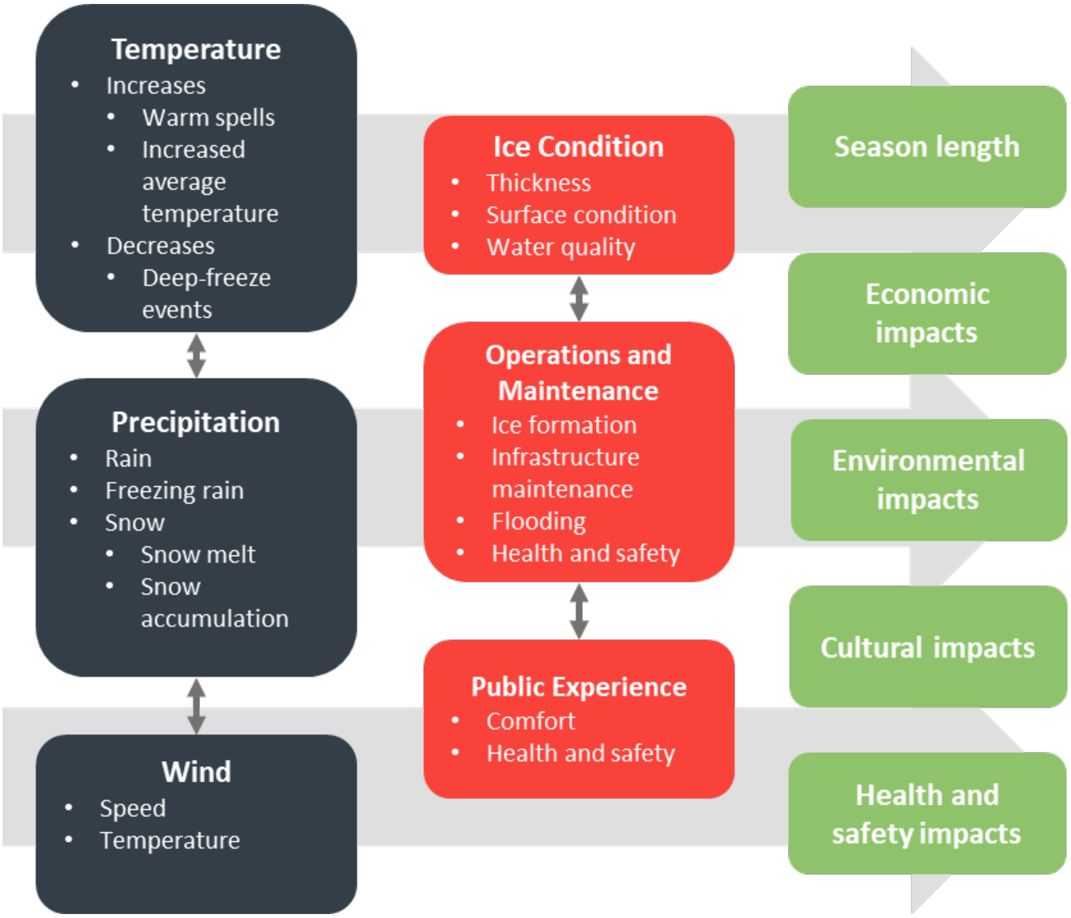

Figure 3-13: High-level diagram of the potential impacts of climate on the RCS

Table 3-9: Overview of climate and climate impacts

Climate Parameter			Climate Impacts
Temperature	Precipitation	Wind	
Direct Climate Impacts			
X			1) Higher nighttime temperatures delaying the onset of flooding and thickening of the ice. 2) Reduced cold snap frequency limiting the operational ability to flood the canal overnight. 3) Delayed start to the skating season reducing the viable number of skating days. 4) Early end to the skating season reducing the viable number of skating days. 5) Increasing warm periods during the season reducing the stability of the ice and reducing the number of viable skating days. 6) Increase in freeze-thaw cycles reducing the stability and viability of the ice.
X	X		7) Increased warm stormwater output from higher rain-based precipitation melting the canal ice. 8) Increased warm stormwater output from greater snow melt due to higher temperatures melting the canal ice. 9) Increased salt use on the nearby roads due to poor winter conditions decreasing the freezing point of the water. 10) Increased frequency of snow events reducing the ability to flood the Rideau Canal to create new ice.
X	X	X	11) Increased frequency of snow events requiring increased maintenance and operations. 12) Increased magnitude of snow events requiring increased maintenance and operations. 13) Increased frequency of winter storm events reducing the number of viable skating days. 14) Reduced enjoyment of the canal by skaters as a result of poor weather conditions.
Indirect Climate Impacts			
X			15) Loss of direct economic opportunity from reduced attendance to the annual Winterlude event and in general.
X			16) Loss of indirect economic opportunity from reduced tourism and associated spending including nearby restaurants, hotels, and other activities.
X	X		17) Loss of a cultural Canadian icon.
X	X	X	18) Increased risk to the health and safety of Skateway visitors.
X	X	X	19) Increased risk to the health and safety of Skateway staff.
X	X	X	20) Increased cost of operations to maintain the Skateway under changing winter conditions.
X	X		21) Reduced public trust in the reliability of the RCS.
Positive Climate Impacts			
X			22) Reduced periods of extreme cold increasing the enjoyment and therefore number of skaters and visitors.

This assessment identified 22 impacts from climate change to the RCS. Of these, 21 were considered to have the potential to in some way harm the RCS operations and assets, while one, “reduced periods of extreme cold increasing the enjoyment of skaters and visitors” has the potential to positively impact the RCS. The full risk matrix is presented in Appendix D.

3.6.1.9 CLIMATE HAZARDS

The seasonality and outdoor, uncovered nature of the RCS significantly increase its exposure to climate phenomena and hazards. At a high level, winter temperatures, rain, and snow patterns are projected to shift significantly for the region. Storm events and variability in weather are also projected to increase, though there is a higher degree of uncertainty. Each potential impact has a unique hazard rating as well as a full rationale. Unless otherwise stated, when two values are reported for each climate index (e.g. [8.2;9.3] °C), they are not ranges; they represent the mean values for the moderate (RCP 4.5) and high (RCP 8.5) emission scenarios respectively. If the second number presented is lower than the first, this means that the values projected under the higher emissions scenario are lower than those projected under the moderate emissions scenario, as compared to baseline. For tracking and organizational purposes, they have each been assigned a numeric identification (ID) number. These numbers are for clarity of reporting only and do not denote any level of analysis or ranking for each impact. Table 3-10 presents an example of a hazard rating and rationale for potential impact ID 1. The full list of hazards is presented in Appendix D.

Table 3-10: Example of a hazard rating and rationale for the RCS

ID	POTENTIAL IMPACT	HAZARD RATING	HAZARD RATING RATIONALE
1	Increased warm stormwater output from higher rain-based precipitation melting the canal ice.	**High**	There is a projected increase in total precipitation in the winter months, but a decrease in projected total snowfall. A decrease in annual total snowfall is projected in the NCR, from approximately 223 cm in the baseline to [193;201] cm in the 2030s, [179;184] cm in the 2050s and [124;154] cm in the 2080s. This represents a decrease of 31-44% by the 2080s. This could indicate an increase in precipitation falling as rain which is consistent with other findings for the province. Winter precipitation is projected to increase from a historic (1976-2005) baseline of 199 mm to [169;318] mm in the 2050s under RCP8.5.

In the event that an impact resulted from multiple climate parameters, the final ranking was attributed using professional judgement or the more conservative probability used. There were 19 out of the 22 potential impacts determined to have exposure ratings of “moderate” or higher.

3.6.1.10 VULNERABILITY

SENSITIVITY

Sensitivity was determined by estimating the relative impact climate has on various aspects of the RCS using professional judgement, information received from the NCC, historic information, and a small literature review of similar systems. Sensitivity was ranked using a five-point rating system ranging from “very low” to “very high” for each climate impact and given a rationale to support the rating choice. The RCS is dependent on both the timing and magnitude of a variety of climate factors which significantly increases its sensitivity to climate change. For example, timing and minimum temperature in the early winter season, duration of the winter season, precipitation falling as either rain or snow, and temperature fluctuations will influence the integrity and strength of the ice. The sensitivity of this system is heightened because of the high level of safety standards employed by the NCC before opening the ice each season and day. Table 3-11 presents an example of a sensitivity rating and rationale for potential impact ID1 in the context of vulnerability. The sensitivity assessment for each impact is presented in Appendix D. 20 out of the 22 potential impacts were determined to have sensitivity ratings of “moderate” or higher.

ADAPTIVE CAPACITY

The RCS has a higher adaptive capacity in factors such as the timing and number of skaters on the ice, the surrounding infrastructure, and ice maintenance. It has a lower adaptive capacity regarding the ice itself, which is uncovered and covers a significant area. Unlike the other ratings in this assessment, adaptive capacity has a mitigating effect on risk. As a result, this summary will present potential impacts that have a rating of "moderate" or lower, as those are the ones that will contribute to a higher risk rating. Table 3-11 presents an example of vulnerability for potential impact ID 1. The adaptive capacity assessment for each impact is presented in Appendix D.

Table 3-11: Example of a vulnerability rating for the RCS including sensitivity and adaptive capacity rankings and rationales

ID	Potential Impact	Sensitivity		Adaptive Capacity		Vulnerability
		Rating	Rationale	Rating	Rationale	
1	Increased warm stormwater output from higher rain-based precipitation melting the canal ice.	**High**	Stormwater will be warmer and more polluted with darker, light-absorbing and saline materials which can increase the melting rate of the ice.	**High**	This is an existing problem and the RCS already has adaptive capacity built into its operations. Approximately six weeks before the beginning of the skating season a customized stormwater outfall mitigation system is installed to divert warmer stormwater away from the skating areas. In the fall of 2020, a third pipe was added to divert the overflow in the center of the Rideau Canal and favour the thickening of ice in the sections from Rideau Street to Laurier Bridge.	**Moderate**

There were 14 out of the 22 potential impacts determined to have adaptive capacity ratings of "moderate" or lower.

3.6.1.11 LIKELIHOOD OF IMPACTS

Table 3-12 presents an example of a likelihood of impact rating for potential impact ID1. No rationale is presented as this is a direct function of the exposure and vulnerability for each potential impact.

Table 3-12: Example of a likelihood of impact determination for the RCS

ID	Potential Impact	Hazard (2080 – RCP8.5))	Vulnerability Rating	Likelihood of Impact
1	Increased warm stormwater output from higher rain-based precipitation melting the canal ice.	**High**	**Moderate**	**High**

During the assessment, 16 out of the 22 potential impacts were determined to have a likelihood of impact rating of "moderate" or higher. The full impact assessment is presented in Appendix D.

3.6.1.12 SEVERITY OF IMPACTS

The severity of the impacts on the RCS (i.e. the relative consequence should it occur) centers primarily around the loss of revenue from fewer skating days, the loss of a cultural and community icon, and the health, safety, and enjoyment of visitors. Table 3-13 presents an example of a severity of impact rating and rationale for potential impact ID1. The full list is presented in Appendix D.

Table 3-13: Example of a severity rating and rationale for the RCS

ID	Potential Impact	Likelihood of Impact	Severity of Impact: Economic	Severity of Impact: Health, Safety, and Community	Severity of Impact: Environmental	Severity Rating	Severity Rationale
1	Increased warm stormwater output from higher rain-based precipitation melting the canal ice.	**High**	**High**	**Moderate**	**Low**	**High**	A reduction in viable skating days reduces the economic potential for local vendors, transportation, and accommodations. In addition, a shorter season increases the cost of operations per skating day. Reduced skating days could also impact the community and users of the RCS. This severity primarily impacts two groups. The first is regular users who use the RCS to commute to work or for daily purposes and who have been historically frustrated when these activities are impeded. The second are visitors from out of town who must plan, travel, and make larger sacrifices to use the RCS.

All of the 22 potential impacts were determined to have a severity of impacts ratings of "moderate" or higher.

3.6.1.13 RISK ANALYSIS

Out of the 22 impacts identified, 12 pose a high or very high risk to the RCS, as exhibited in Table 3-14.

Table 3-14: High and very high climate change risks to the RCS

ID	Potential Impact	Likelihood	Severity	Risk
1	Increased warm stormwater output from higher rain-based precipitation melting the canal ice.	High	High	**High**
2	Increased warm stormwater output from greater snow melt due to higher temperatures melting the canal ice.	High	High	**High**
3	Higher nighttime temperatures delaying the onset of flooding and thickening of the ice.	Very high	High	**Very high**
4	Reduced cold snap frequency limiting the operational ability to flood the canal overnight.	Very high	High	**Very high**
9	Loss of direct economic opportunity from reduced attendance to the annual Winterlude event.	High	High	**High**
10	Loss of indirect economic opportunity from reduced tourism and associated spending including nearby restaurants, hotels, and other activities.	High	High	**High**
11	Loss of a cultural Canadian icon.	High	High	**High**
12	Delayed start to the skating season reducing the viable number of skating days.	Very high	High	**Very high**

ID	Potential Impact	Likelihood	Severity	Risk
13	Early end to the skating season reducing the viable number of skating days.	Very high	High	**Very high**
14	Increasing warm periods during the season reducing the stability of the ice and reducing the number of viable skating days.	Very high	High	**Very high**
20	Increased cost of operations to maintain the canal under changing winter conditions.	High	High	**High**
21	Reduced enjoyment of the canal by skaters as a result of poor weather conditions.	High	Moderate	**High**

We also identified one positive impact for the NCC (Table 3-15).

Table 3-15: Climate change opportunity to the RCS

ID	Potential Impact	Likelihood	Severity	Risk
5	Reduced periods of extreme cold increasing the enjoyment and therefore number of skaters and visitors.	Very high	Moderate	Positive impact

The high and very high risks to the RCS pertained to indirect impacts to ice formation and quality (e.g. increased stormwater drainage in the canal which increases the water temperature and salinity), increased variability in ice conditions during winter, economic losses due to the reduced skating season and cultural impacts due to the iconic aspect of the RCS. Therefore, improvements in ice formation, strength or quality would mitigate all the high and very high risks that were identified.

3.7 CONCLUSIONS OF RISK ASSESSMENT

The Project Team conducted a climate change risk assessment on the RCS. The first part of this assessment was to produce a qualitative assessment of the projected changes in the skating season length, beginning date and ending date. The results of this assessment suggest that by the middle of the 21st century, the annual probability of having a skating season of 40 days or more will be less than 50%. This is associated with a one to two-week average delay in the beginning of the season and a closing date that will be almost one week earlier on average.

The second part of this analysis consisted of a multidisciplinary climate change risk assessment that investigated the social, environmental and economic consequences associated with the impacts of climate change on the RCS. Of the 22 impacts, the 12 associated with a high or very high risk could be mitigated by using ice building practices to enhance ice stability and increase the skating season duration.

The next step of this assessment is to provide preliminary recommendations. Investigated adaptation measures will pertain to these categories:

- Thermal measures to encourage an earlier freeze-up and a thicker ice cover;
- Planning measures to decrease the impact of stormwater drainage on water temperature and salinity (water level, drainage deviations);
- Technical measures to strengthen the ice; and
- Monitoring methods to better assess the ice load capacity to decrease the required thickness to operate.

4 RECOMMENDATIONS FOR RISK TREATMENT

In the following chapter, WSP provides recommendations to mitigate the impacts of climate change on the operations and activities of the RCS. In the first section, we detail the different methods that could potentially improve the resilience of the RCS.

As discussed in the previous chapter, the major risks were associated with challenges in ice formation due to rising air or water temperatures. Therefore, the first recommendations outline methods to modify the thermal water balance of the Rideau Canal to increase resilience in the medium term. The second set of recommendations present other methods that could improve other aspects of the RCS infrastructure, operations and services in the medium and long term. Finally, given the relative lack of data on the physical and chemical characteristics of the water in the RCS, the third set of recommendations pertains to improving the understanding of the characteristics of the water and ice in the canal during the winter season. WSP then proposes a plan to implement adaptation actions. The second part of the chapter addresses considerations to include climate change adaptation in future winter recreation standards.

Climate change information is constantly evolving. As new model outputs are produced, it is likely that:

- The uncertainty regarding some climate parameters will decrease;
- New climate indicators that better capture risk will become available;
- Climate data and projections will become available at a better spatial resolution; and
- Projected climate trends will be modified.

Along with changes in socioeconomic conditions, demography and policy development, this ongoing improvement in climate science will contribute to the need of updating this assessment. The best practices prescribe an update of any climate change risk assessment at a minimum of every five years.

4.1 POTENTIAL ICE MANAGEMENT METHODS

The ice regime and properties on the Rideau Canal are influenced by multiple factors; both natural and anthropogenic, summarized in Table 4-1. Ice mostly grows thermally at the beginning of the winter, after the canal has been watered. Early freeze-up processes are mainly driven by natural conditions. Once the ice cover has formed on the canal, the heat exchange between the air and the water becomes limited. The canal water thermal balance is then driven by the inflows and stormwaters drains and, to a lesser magnitude, by the ground heat exchange. In winter, water entering the canal at the Hogs Backs Locks flows through near-bottom sluice gates.

Flow variation during winter is limited by the upstream locks. However, mid-winter thaw and rain events can increase inflows from the Rideau River and tributaries. Warmer and saltier water can flow into the canal during these events. Mid-winter events, such as rain and warm temperature, can alter the ice cover by melting and flooding the ice surface. Water on top of the ice is obviously undesirable for skating but can also create an irregular surface when it refreezes. Heavy snow adds weight on top of the ice, which tends to sink and bend the cover, creating stress fractures. These fractures can, in turn, bring water up to the surface. Maintenance crews work to limit the impact of mid-winter events. However, temporary closure during winter can still occur.

Extensive skating activities and maintenance operations generate load and stresses on the ice cover. For example, the congregation of people can create point load and initiate local fractures (Sinha, 1985). Maintenance vehicles can also create stresses when they travel or park on the ice. The skating season ends when the ice conditions become irreversibly unsafe.

Table 4-1: Factors influencing the ice regime on the Rideau Canal

Type	Factor
Natural	— Air temperature — Precipitation (rain and snow) — Wind — Solar radiation
Anthropic	— Water level and inflow control at Hogs Back and Hartwells Locks — Water level and outflow control at Ottawa Locks — Tributaries and stormwater drain inflows — Winter maintenance operations — Skating activities

The glaciological winter is the period during which ice is present on the Rideau Canal. It starts at freeze-up and ends when the ice is completely gone.

Ice maintenance is the period when the NCC works to maintain or improve the RCS ice conditions. Currently, this period starts with the first ice flooding and ends when the skating conditions become irreversibly unsafe. The objectives of the ice maintenance operations are the following:

— Smooth the ice surface to ensure high quality skating conditions.

— Remove snow from the RCS to reduce the dead load on the cover, increase water/air heat exchange, limit the potential for snowmelt on top of the ice and ease the ice smoothing operations.

— Increase ice thickness by adding and freezing water on top of the existing ice cover.

The skating season corresponds to the periods during which the RCS is open to the public. It is also the period during which the skating conditions are considered adequate and safe. By definition, the skating season is shorter than the glaciologic winter and the ice maintenance period. It starts when the ice thickens and ends when the ice becomes too thin, too fractured or too flooded. The RCS can be closed temporarily during the season whenever the skating conditions become inadequate or unsafe.

Figure 4-1 illustrates a typical skating season chronology. This figure illustrates that there is a window of opportunity to implement ice growing operations before the Ice Maintenance stage to hasten the formation of the ice cover.

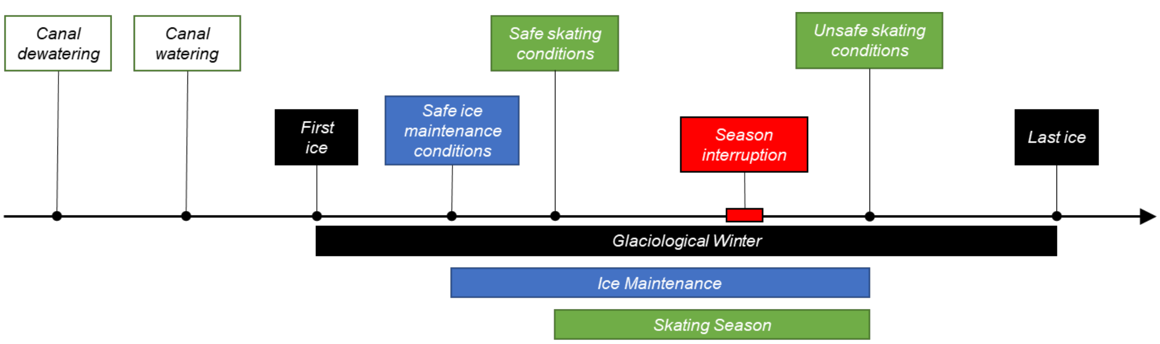

Figure 4-1: Typical skating season chronology on the Rideau Canal

4.1.1 *THERMAL EXCHANGES*

Thermal water balance in the canal could potentially be modified to promote early freeze-up, and stronger and more resilient ice cover. Improvement approaches could have a direct impact on the skating season length by hastening the season beginning and by reducing the probability of season interruptions.

4.1.1.1 EARLY ICE FLOODING

NCC crew members currently start the ice flooding operations once the ice thickness is considered safe for them to walk on it. One option would be to start this flooding operation before that time. For instance, water could be added on top of a thin ice cover (few centimeters) using a pump and hose system operated from the bank. A tanker truck filled with cold water and fire hydrants could be used for the operation.

Earlier ice flooding would have a direct impact on ice thickening and would increase the capacity of the ice cover to resist potential mid-winter events. For example, during the 2020-2021 winter, early ice flooding could potentially have been used as early as December 16, 2020 when the temperature dropped below -10°C for few days. The resulting early ice thickening would have been beneficial for the ice to resist the December 24-25, 2020 rain event. As a comparison, ice flooding by the NCC (crew on the ice) started on January 21, 2021. The ice thickness measured on that day by the NCC was ranging between 14 and 36 cm.

One recommendation for ice flooding is to use the coldest possible water, which might not be from the canal itself. The temperature of water that is being flooded onto the ice should also be monitored.

4.1.1.2 SLUSH CANNON

A slush/snow cannon could be used to add ice crystals or wet snow in the canal early in the season, and therefore initiate an ice cover several days before thermal ice formation. Such a cannon would mimic a heavy snowfall and would promote secondary nucleation (see section 2.2).

The cannon could be placed on a trailer and towed by a maintenance vehicle along the canal. Cannon operations could start downstream and move progressively upstream.

Cannon technology is now very advanced thanks to multi-year developments by the many Canadian manufacturers for the snowmaking needs of alpine and cross-country skiing. Products now exist with narrow directional throw, to be used in tight spaces and avoid spreading ice or snow outside the zone (i.e. on adjacent pathways and parkways).

The range of operation and snow quality of a cannon is influenced by the air temperature and humidity. Good snow quality can typically be created around -4°C when the air is dry.

In all cases, adding cold, slushy material to the water surface at the beginning of the season would help to promote early ice formation, especially on the downstream reach of the canal.

4.1.1.3 COLDER INFLOWS

Winter monitoring in February 2021 has shown that the water entering the canal is relatively warm. Colder inflow to the canal is desirable to promote thermal ice thickening and limit melting of the basal ice.

Starting in late November and lasting throughout the winter, water from the Rideau River enters the canal through the sluices of Hogs Back Locks. These sluices are located near the bottom of the lock gates where water is warmer than near the surface due to natural thermal stratification.

Modifying the winter configuration at Hogs Back to bring colder water from the river surface into the canal is desirable but appears hardly feasible due to PC winter drawdown constraints and given the logistical challenges of altering this heritage infrastructure.

Another way to bring colder water into the canal during all winter season would be to increase the air/water heat exchanges on the canal reach between Hogs Back and Hartwells Locks. This could be achieved by preventing the ice cover to form on a portion of that reach using bubblers or recirculatory systems. Such systems can be automatically turned on during cold periods and off during warm winter spells.

Additional winter thermal data will be required to assess the benefits of these approaches.

4.1.1.4 DEEPER WATER

In discussions with the NCC and its ice maintenance crew, both emphasized that the deeper sections of the RCS typically have a thicker ice cover and remain open longer. This is corroborated, to a certain extent, by the seasonal observations of each of the canal reaches that are available from the NCC (Table 5-1). Observations show that the Pretoria to Bank reach (KP 2.0-4.4) and Dow's Lake reach (KP 5.4-7.8) typically remain open for a longer period. During Winter 2019-2020, the most downstream reach (KP 0.0-0.4) remained closed, the other 1.8 m maximum depth reaches (KP 0.4-0.8 and 4.4-5.4) have experienced only about 10 days of skating and the deeper reaches (KP 0.8-4.4, 5.4-7.8) have provided about 30 days of skating.

Table 4-2: Number of skating days in the different canal reaches of the RCS

Kilometric Point	Canal Reach	Max. Water Depth (m)*	Winter 2016-2017	Winter 2018-2019	Winter 2019-2020
0.0 to 0.4	Ottawa Locks to Laurier	1.8	22	51	0
0.4 to 0.8	Laurier to Somerset	1.8	23	53	11
0.8 to 2.0	Laurier to Pretoria	2.7**	23	53	28
2.0 to 4.4	Pretoria to Bank	4.3	26	60	31
4.4 to 5.4	Bank to Bronson	1.8	24	55	10
5.4 to 7.8	Bronson to Hartwells (including Dow's Lake)	5.2	21	53	25

* FROM NAUTICAL CHARTS
** MAX. DEPTH = 2.4m (KP 0.8-1.4; SOMERSET-CONCORD)

Theoretically, shallow water can create ice cover stability problems. Ice is more likely to sit on the riverbed on a shallow reach than on a deeper one, creating fractures in the cover. Also, shallow water means less vertical thermal stratification and thus warmer water near the ice. Shallow water bodies are also more sensitive to environmental thermal variations as they contain less water. This is concerning as the winter water depth on the downstream reach of the RCS is very shallow (less than 1 m). This reach also conveys warmer water coming from the stormwater outfalls, including the Laurier and Cooper drains. Therefore, deeper water could help to alleviate this problem through:

— Flotation of the ice cover instead of sitting on the riverbed;
— Thermal stratification that should keep warmer stormwater farther from the ice;
— A larger volume of water to dilute the salt conveyed in stormwater during winter rain episodes; and
— Heat-exchange reduction between side walls and water in the canal.

Theoretically, a higher water level during winter could limit the degradation of the side walls of the canal. Indeed, the wall below water would not be affected by freeze-thaw cycles. It also appears that a higher water level would better equilibrate the horizontal load produced by the saturation and freezing of the ground from the outer side of the Rideau Canal. However, this hypothesis should be corroborated by geotechnical experts to confirm the benefit of higher water levels on the walls of the Rideau Canal.

Water depth on the canal could be increased by raising the winter water level. This could be achieved by modifying the cofferdam used by PC at the Ottawa Locks. This option would require the NCC to modify some Skateway structures (e.g. stairs, stakes, temporary building foundations) to adjust to the new/higher water level.

Water depth could also be increased locally, for example on the downstream reach, by dredging the canal. However, this option would require dealing with contaminated sediments. Also, it should be noted that dredging is a temporary solution that needs to be periodically repeated. From our understanding, the canal has never been dredged. Thus, it appears that the water depth has been reduced over the years in many areas in the canal. This reality, in addition to climate change, can possibly explain some of the recent issues to maintain the ice quality on the downstream reach.

Increasing the water depth should be considered as a potential solution to improve the resilience of the RCS to climate change. However, with the information available, it is not possible to establish the relationship between potential gain in skating season length and different water levels. Moreover, given the jurisdictional constraints regarding water level and the investment in infrastructure modification to accommodate for a higher water level, moving forward with this solution represents a significant commitment. Therefore, WSP recommends that the benefits of increasing the water depth (by level increase or dredging) on the ice quality and skating season length be evaluated based on an ice/water thermal study. Additional information would need to be collected for this study, including canal bathymetry, water level and temperature data.

4.1.1.5 VEGETATION MANAGEMENT

As the climate warms, the productivity of ecosystems is generally increasing. The operation and maintenance staff mentioned that the increasing weed activity in the canal was deleterious to the ice formation process. Indeed, decaying vegetation decreases the albedo of the water body (more solar radiation will be absorbed), increases sedimentation (thus affecting water depth) and weakens ice bonding. Therefore, WSP recommends implementing an annual vegetation management program in partnership with Parks Canada to effectively clean the canal before winter watering.

4.1.1.6 STORMWATER OUTFALL DIVERSION

Stormwater outfalls bring additional water into the canal that likely has higher salt content due to runoff from roads and surfaces, thus impacting the ice quality of the RCS. One solution to mitigate the impact of the outfalls on local ice quality is to divert the outfalls so the stormwater flows into the canal is significantly reduced or even eliminated.

As discussed in Appendix A, the NCC already installs a stormwater outfall mitigation system to divert warmer stormwater away from the skating areas at the Laurier stormwater outfall. Similar mitigation systems could be also be implemented to divert the water of other large stormwater outfalls along the canal.

Outfall diversion could also be performed by intercepting the flow before it enters the canal. This type of diversion solution was evaluated as part of the Capstone Project (Al-Saeed et al., 2021) with the idea of connecting the existing storm sewer pipe to the existing below combined sewer pipe using a 20 m high drop structure. The cost of that project was estimated to $3.4M (Al-Saeed et al., 2021). Although not discussed in the Capstone report, this solution would likely have an adverse impact on other infrastructure and present jurisdictional challenges as well.

4.1.2 GENERAL RECOMMENDATIONS

4.1.2.1 ICE STRENGTHENING

The RCS generally opens to the public when a section reaches 30 cm of clear ice. The issue with opening the canal with thinner ice is the buoyancy factor, or the capacity of the ice sheet to float when withstanding the load of thousands of visitors. In the narrow sections of the canal, the installation of central piles anchored in the canal bed to which the ice bond could help to increase the buoyancy of the ice. This solution is theoretical and comes with significant drawbacks:

- The albedo and thermal inertia of the material of the pile will cause it to warm and cool down at a differential rate from the ice. This can cause melting of the ice around the pile and therefore weakening of the ice cover;
- Installing piles in the center of the canal will cause additional operational constraints (installation of the piles in the Fall, more obstacles for ice maintenance); and
- The installation of piles does not change the thermal regime and as such will not favour the onset of an earlier ice cover.

4.1.2.2 IMPLEMENTATION OF SAFETY PRACTICES

During lower ice quality periods, where the RCS is closed for safety concerns, the NCC should evaluate the possibility of implementing safety practices such as:

- Identifying patrolled no-stopping zones, as non-moving point loads need to be supported by thicker ice;
- Moving the concessions away from the ice surface to limit static gatherings; and
- Implementing a limit on the number of visitors on the RCS, although this practice requires installing a control system at every entrance.

4.1.2.3 DIVERSIFICATION OF WINTER ACTIVITIES

During the 2021 winter season, due to the COVID-19 pandemic, the Queen Elizabeth Driveway was open for pedestrians and cyclists during the day, between Fifth Avenue and Somerset Street. The fact that the Queen Elizabeth Driveway, the Rideau Canal Pathways and the RCS fall under the jurisdiction of the NCC is an opportunity to diversify the offering of winter activities along the Rideau Canal, such as:

— Hiking;
— Cross-country skiing; and
— Fat biking.

The main benefit of diversifying the winter activities is to make sure that the Rideau Canal corridor remains an attractive winter destination even during seasons of low ice quality. Many activities and events could be planned around the Rideau Canal and not on the Skateway. There is also an opportunity to offer concessions to install away from the ice, should the shorter skating season become less attractive from a commercial standpoint.

4.1.3 *SUMMARY*

Table 4-3 summarizes the potential methods to improve the skating conditions and season duration.

Table 4-3: Summary of potential ice/management improvement methods for the RCS

Method	Description	Potential improvement			Main advantage	Main disadvantage	Level of confidence about effectiveness	Level of effort / resources required
		Earlier freeze-up	More resilient cover	Other				
Early Ice Flooding	Start flooding on top of thin ice cover using a pump and hose system from the bank	x	x		Earlier thickening	Additional cost	High	Moderate
Slush Cannon	Mimic heavy snowfall in the early season to initiate ice cover	x	x		Earlier freeze-up	Additional cost	High	Moderate
Stormwater Outfalls Diversion	Reduce or eliminate flow of salt-contaminated stormwater into the canal	x[1]			Remove heat source	Local impact only	High	Moderate
Deeper Water – Increased Level	Increase water depth by rising the winter water level, achieved by modifying the cofferdam used by Parks Canada (PC) at the Ottawa Locks	x	x		Ice cover stabilization	Need to modify existing NCC structures	Moderate/High	Very high
Colder Inflows – From Lock	Modify winter configuration at Hogs Back Locks to bring colder water from the river surface into the canal	x	x		Colder water during winter	Need for PC to modify winter management	Moderate	High
Vegetation management	Remove all vegetation from the canal		x		Ice cover stabilization	Additional cost	Moderate	Moderate
Diversification of Winter Activities	Increase attractiveness of Rideau Canal as a winter destination even during seasons of low ice quality			x	Decrease the dependency on ice conditions to attract visitors	Increased resource needed in equipment and staffing	Moderate	High
Colder Inflows – Open water	Bring colder inflow to the canal by increasing the air/water heat exchanges on the canal reach between Hogs Back and Hartwells Locks	x	x		Colder water during winter	Theoretical	Low	Low
Deeper Water - Dredging	Increase water depth by dredging the canal, as depth has decreased in areas over time		x		Ice cover stabilization	Displacement of contaminated material	Low	Very high
Safety Practices	Identify patrolled no-stopping zones, move concessions away from ice surface to limit static gatherings, and/or limit number of visitors on the RCS		x	x	Limit load on the ice	Increasing dissatisfaction of some users; additional cost; complex implementation	Low	Moderate
Ice Strengthening	Install central piles anchored in the canal bed where the ice bond can help to increase the buoyancy of the ice		x		Increase buoyancy	Additional cost, risk of weakening the ice cover	Very Low	High

1. In the upstream sections.

4.2 RECOMMENDATIONS FOR IMPROVING KNOWLEDGE

The understanding of the ice regime on the Rideau Canal Skateway is currently limited due to the lack of data, recorded measurements and monitoring. The field monitoring program initiated by WSP throughout the month of February 2021 has provided preliminary information about the winter thermal regime but now should be extended to cover additional or entire ice season(s), from freeze-up in November-December until the end of the skating season February-March (three to five months).

WSP recommends the NCC standardize the way the ice information is collected, managed and stored. For instance, an official digital logbook with ice daily observations from the operational team leader should be implemented. The logbook would help communicate the evolution of ice cover, before and during the skating seasons. Weather conditions, ice thickness, ice conditions, maintenance operations and specific issues should be described on a daily basis in this database.

WSP also recommends implementing a monitoring network to collect information about the water quality, flow and ice conditions in the canal. The network should include surveillance cameras, water pressure transducers, and water temperatures and conductivity gauges, all distributed along the canal. At least one weather station should also be placed next to the canal. To maximize data collection potential, the monitoring network should be in place in October 2021, ready for the 2021-2022 skating season. The NCC could commission an expert (consultant or academic institution) to plan and perform that monitoring program in accordance with NCC expectations.

Additional information about the City of Ottawa stormwater outfalls should also be collected by the NCC. Monitoring flow, temperature and conductivity in stormwater outfalls, especially in the Laurier and Cooper drains, should be included in the monitoring program.

Measurements collected during an entire ice season will ultimately allow the NCC to get a better understanding of the canal winter thermal regime and assess its vulnerability. Based on this information, the thermal budget of the water in the canal could be calculated. Improvement methods, including increased diversion of stormwater outfalls and maintenance of deeper water levels (Section 4.1), could also be assessed.

Another recommendation is for the NCC to commission an expert (e.g. university professor, consultant, etc) to work with the operations crews and monitor the canal to prepare an exhaustive description of the ice freeze-up process, starting right after canal watering (approximately during the third week of November). This work would likely require making observations during cold nights at the end of November or early December. These observations will be highly valuable to assess the potential of implementing early freeze-up techniques, as described in Section 4.1 above.

All stakeholders involved around the canal would benefit from enhanced water quality data. A joint effort between the NCC, Parks Canada and City of Ottawa is therefore recommended. A global database could be developed for all stakeholders to share information collaboratively.

4.3 IMPLEMENTING THE RECOMMENDATIONS

There are significant uncertainties regarding the effectiveness of the different measures summarized Table 4-3. This is due to lack of data on the canal and because that most of the recommendations rely on theoretical reasoning due to the uniqueness of the RCS (i.e. there are no examples of applications of such complex methods to mitigate the climate change risk to any outdoor natural skating facilities subject to the various jurisdictional constraints). Other applications of managing changes to natural ice roads are also not directly applicable to this assessment.

To help overcome these barriers, WSP recommends that the NCC follow a three-phase process illustrated in Figure 4-2.

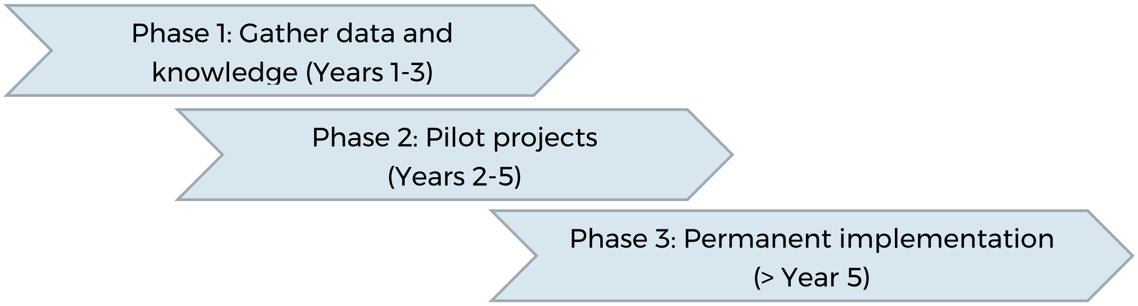

Figure 4-2: Timeline for implementing recommendations

During **Phase 1**, the NCC should continue to gather data on the thermal and chemical conditions of the water within the Rideau Canal by conducting a thorough monitoring program. The different aspects of knowledge acquisition are identified below:

— During summer 2021, conduct a complete bathymetric assessment to have an up-to-date survey of water depths.
— Measure the water temperature and salinity profiles in the Rideau Canal during the full winter season, defined as starting at the moment when the canal is filled at winter level (approximately the 3rd week of November) until the decay of the ice cover (typically in April). The monitoring campaigns should follow a similar protocol to during the winter 2021 monitoring program. Sensors should be positioned to capture the impacts of stormwater outfalls on the canal water.
— Acquire remote thermal imagery through drone flights with a thermal camera when the water is at the lowest level and after the canal is filled at skating level. This will provide a better understanding of the temperature gradient of the water on the length of the RCS.
— Prepare an ice quality survey technique, using either ice cores or ground-penetrating radar. Ensure that the results are consistently recorded in a digital database.
— Install sensors to monitor the impact of machinery, snowfall events and users on the deflection of the ice.
— Visually inspect the ice formation process during the first very cold nights (around -10°C) of the season, to better appreciate the location and process of early ice formation.

The acquisition of all this data would allow the NCC to calibrate a thermic model which could provide more robust answers to questions such as:

— What would be the impact of different increases in water levels?
— How much ice thickness is lost due to stormwater runoff events?

Understanding the ice formation in the context of a controlled stream such as the Rideau Canal is an incredible research opportunity. The NCC could partner with local academics or research institutes to assist or to lead this effort.

Having comprehensive results from a thorough monitoring program might not meet the desired timelines of the NCC. However, WSP believes that it is prudent to make data-driven decisions to reduce the level of uncertainty. The risk of focusing on strategies that are almost irreversible, such as rising skating water levels and adapting all of the associated physical infrastructure, without acquiring knowledge first, could in fact be less cost-effective over the longer operating horizon.

Planning for **Phase 2** should start as soon as possible, once the necessary information has been gathered, with implementation to be carried out over several years. In this phase, the NCC should prepare pilot projects for the recommendations that they prefer in order to test the effectiveness in growing a quality ice cover more quickly, but also the feasibility and associated operational constraints. WSP recommends that the pilot projects should focus on the following solutions:

— Early ice flooding;
— Slush cannon; and

— Aerators.

These solutions do not require further analysis and should be tested during winter 2021-2022.

Finally, the results of monitoring and implementing experimental pilot projects will help the NCC to better understand which recommendations could better mitigate the climate change risks on the RCS. **Phase 3** consists of the implementation of permanent or semi-permanent measures, such as a significant rise in the skating water level.

4.4 NEXT STEPS

Table 4-4 presents the recommended tasks in preparation for and during the 2021-2022 winter season. Each of these tasks is briefly described following the table.

Table 4-4: Recommended tasks in preparation for and during the 2021-2022 winter season.

Period	Recommended tasks (in chronological order)
Summer 2021	16. Conduct canal bathymetric survey. 17. Plan fall/winter 2021-2022 canal monitoring/observations campaign. 18. Plan 2021-2022 pilot projects and procure equipment (Early Ice Flooding (EIF), cannon, aerator).
Oct – Nov 2021 (Fall)	19. Install monitoring instruments and pilot project equipment in the canal. 20. Start ice monitoring and observations.
Nov – Dec 2021 (Freeze-up)	21. Continue monitoring and observations. 22. Start pilot projects (EIF, cannon, aerator).
Dec 2021 – Mar 2022 (Winter)	23. End EIF and cannon pilot projects. 24. Continue monitoring, observations and aerator pilot project. 25. Measure ice thickness regularly and record in logbook.
End of skating season	26. End aerator pilot. 27. Prepare technical report to summarize monitoring campaign, observations and pilot project. 28. Assess pilot effectiveness and make recommendations for winter 2022-2023.
2022	29. Perform thermal ice/water study, based on the results of the winter 2021-2022 monitoring campaign. 30. Assess the effectiveness of other potential solutions (i.e. colder inflow, deeper water and outfalls diversion) based on the thermal study.

4.4.1 *BATHYMETRIC SURVEY*

A bathymetric survey will need to completely cover the reach between the Rideau River at the entrance of the Hogs Back Locks and Ottawa Locks. The bathymetric survey should be conducted during navigation season to improve boat mobility and data acquisition. A multibeam bathymetric survey is recommended in order to get more complete, precise and detailed information about bed elevation. Figure 4-3 presents examples of a survey boat and multibeam survey outputs (point cloud).

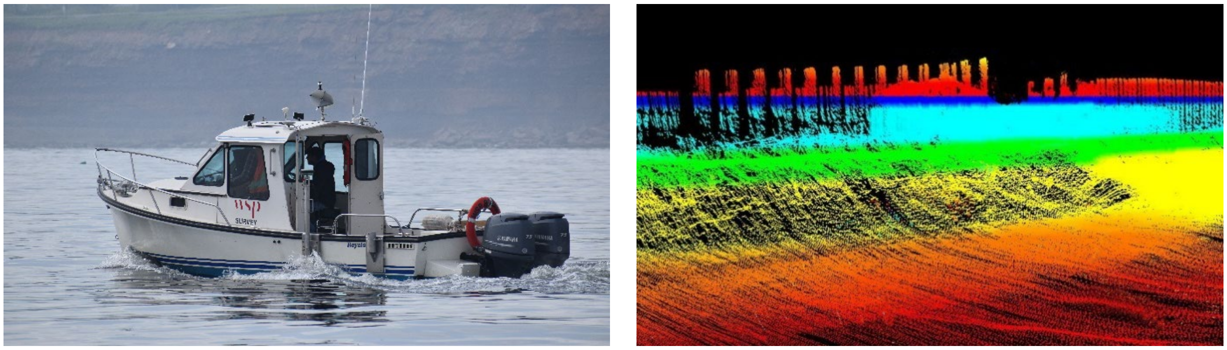

Figure 4-3: Examples of survey boat and multibeam survey results

4.4.2 *MONITORING*

A monitoring initiative would include the installation of several instruments along the canal: cameras, pressure loggers, water temperature and conductivity sensors. The exact type and location of these instruments will need to be defined in a survey plan to be developed during summer 2021. Instruments should be be deployed at multiple locations distributed between Hogs Back and Ottawa Locks. Instruments should also be positioned next to the pilot projects (both upstream and downstream) to closely monitor the effectiveness of the pilots. Data from the instruments would be frequently downloaded during winter to ensure proper functioning and that data is not lost.

4.4.3 *PILOT PROJECTS*

Three pilot projects are recommended for winter 2021-2022: Early Ice Flooding (EIF), cannon, and aerators. The exact definition and locations of the pilots will need to be described in a technical document to be prepared during summer 2021. Discussions between NCC and suppliers will also happen in summer 2021 to procure the required equipment in preparation for the pilot projects.

WSP recommends conducting EIF at one specific location between Somerset and Bronson. The choice of location for the EIF pilot should be based on the specific 2021-2022 freeze-up conditions (which reach freezes first) and the access to water (e.g. fire hydrant). EIF pilots should be located upstream of the cannon pilot, described below. The EIF pilot could start right when a thin ice cover (few centimeters) has formed on the canal. It could end when the ice cover gets thick enough for NCC crew to physically go on the ice and start standard ice flooding with pumps. Ice coring and/or ice mapping with georadar should happen right after the end of the EIF pilot to assess its effectiveness on ice thickening.

The cannon pilot should be conducted at one specific location between Somerset and Fifth, for example in the park directly upstream of Pretoria. The position of this pilot is to be defined based on access to water (e.g. fire hydrant) and proximity to roads and residences to limit potential nuisances (e.g. ice on road, noise). The type of cannon will need to be discussed with suppliers. A cannon with a narrow directional throw is recommended (Figure 4-4). This equipment could be rented or purchased by the NCC for the season. Water temperature sensors should be installed in the canal directly upstream and downstream of the cannon to assess the effectiveness of the pilot to lower water temperature during the freeze-up period.

An intensive observation campaign including on-site presence (particularly at night) and cameras should be carried out during the pilot. The primary purpose of these observations would be to describe the transport and accumulation of slushy material in the canal and the associated formation of early ice cover. The cannon pilot could start after canal watering (end of November) at the moment when weather conditions are favourable for snow/slush making. The pilot would stop when a stable ice cover is formed on the canal next to the cannon.

Figure 4-4: Example of cannon with narrow direction throw (www.hkdsnowmakers.com)

The aerator pilot should be carried out on the reach between Hogs Back and Hartwells Locks. The type of equipment and location of the pilot should be described in a technical document to be prepared during summer 2021. A series of two or three aerators are recommended for the pilot project. Discussion with suppliers should be initiated by NCC. Figure 4-5 presents an example of a surface aerator that could be tested during winter 2021-2022. Water temperature sensors should be installed in the canal directly upstream and downstream of the aerator. An intensive observations campaign including on-site presence and cameras should be carried out during the pilot, primarily to describe the formation and transport of crystals in the canal and the potential associated formation and thickening of the ice cover. The aerator pilot could start right after canal watering (end of November) and end with the skating season. Ice coring should occur during the winter season, next to the aerator, to describe the ice crystal accumulation and travel distance under the ice cover.

Figure 4-5: Example of surface aerator (www.arbrux.com).

At the end of the skating season, a technical summary report should be prepared describing the ice and thermal regime for winter 2021-2022 and evaluating the effectiveness of the three pilots (EIF, cannon, and aerator). This document should also include recommendations for further investigations and pilot projects in the upcoming years.

Throughout all winter season, the NCC technical lead should be assigned the responsibility to maintain a logbook containing daily observations, descriptions of ice conditions, skating conditions, ice measurements and maintenance operations.

4.5 RECOMMENDATIONS FOR STANDARDS DEVELOPMENT

The risk assessment was conducted in conformity to the ISO 31000 risk management standard and ISO 14091 adaptation to climate change standard. Both standards were applicable to the context of the RCS and provided the advantage of aligning this assessment to internationally recognized processes.

As mentioned in Section 2, WSP was unable to find national or international standards relevant to outdoor winter recreational facilities. ISO is currently preparing a standard for the risk assessment of sports and other recreational facilities and equipment (ISO/WD 4980). This study highlighted the importance of considering climate change in the operation, maintenance, management and planning of outdoor recreational facilities. This study also showed that the context of the RCS is highly specific as a natural skating rink on a controlled water body in an urban context, falling under the jurisdiction of three major organizations.

At a national level, if winter recreational standards are to be developed, they should consider the overall national trends in climate projections that could impact operations. Such standards should refer to recognized guidelines on how to use climate information such as the Ouranos guide on climate scenarios (Charron, 2016).

Another gap in standardization that was identified was regarding the ice thickness. A future standard for outdoor winter recreational facilities could standardize the safe ice thickness to support a certain weight, considering the ice quality and buoyancy issue as well. Methods to test the strength of ice could also benefit from a standard.

Finally, the processes outlined in Section 4.3 about data acquisition, storage and interpretation could also be of interest from a standardization standpoint. Indeed, there are opportunities to standardize:

- Water monitoring processes in terms of equipment, location and parameters;
- Ice thickness monitoring either through cores or ground-penetrating radar; and
- Data storage in a logbook.

4.6 CONCLUSION

The Rideau Canal Skateway will experience growing challenges in a warming climate. NCC will need to open the Skateway later in the season and the number of days where skating is viable will generally decrease, with this trend intensifying towards the end of the century. This will have effects on the economic and cultural significance of the RCS and NCC operations.

A climate change risk assessment was conducted considering potential impacts for the RCS and the overall risk rating for each impact. The high and very high risks to the RCS pertained to indirect impacts to ice formation and quality (e.g. increased stormwater drainage in the canal which increases the water temperature and salinity), increased variability in ice conditions during winter, economic losses due to the reduced skating season and cultural impacts due to the iconic aspect of the RCS.

This study has recommended a series of measures focused on ice formation, ice strength, health and safety, and diversification of winter activities. These should be implemented through a phased approach that includes data collection, monitoring, and pilot projects to assess the effectiveness of each measure. In the long term, the NCC should determine the threshold for which investing in maintaining the ice surface will exceed the benefit provided, and consider diversification of winter programming surrounding the canal. The unique nature of the RCS means that this study can contribute to a small but important body of literature and standards for outdoor winter recreational facilities, and so it is also recommended that the NCC look for opportunities to share these findings.

This is the first climate change risk assessment commissioned by the NCC. It is recommended that this report be updated at a minimum of every five years to account for changes in socioeconomic conditions, policy development, and the latest climate science.

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LIST OF ACRONYMS

AFDD	Accumulated Freezing Degree-Days
CCRA	Climate Change Risk Assessment
CPR	Cardiopulmonary Resuscitation
DJF	December, January, and February
ECCC	Environment and Climate Change Canada
GNWT	Government of Northwest Territories
GHG	Greenhouse Gas
GPR	Ground Penetrating Radar
ID	Identification
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
KP	Kilometric Points
NCC	National Capital Commission
NCR	National Capital Region
ORFA	Ontario Recreation Facilities Association Inc.
PC	Parks Canada
PSU	Practical Salinity Unit
RCP	Representative Concentration Pathway
RCS	Rideau Canal Skateway
TBS	Treasury Board of Canada Secretariat
UNESCO	United Nations Educational, Scientific, and Cultural Organization

APPENDIX

A CONTEXT

APPENDIX A

5 CULTURAL SIGNIFICANCE

5.1 HISTORY

Opened in 1832, the Rideau Canal was constructed as an alternative to the St. Lawrence River in case of war (Parks Canada, 2021). Today, the Rideau Canal is a National Historic Site of Canada, a Canadian Heritage River, and a UNESCO World Heritage Site and contributes to the beauty, sense of place and vitality of Ottawa's urban landscape. The NCC has intimate ties to the Rideau Canal. One of the NCC's first projects was the construction of the Rideau Canal Driveway, known today as the Queen Elizabeth Driveway, a scenic road running from Laurier Avenue to Dow's Lake.

In 1971, the NCC launched the RCS, which has become an iconic experience as one of the longest and largest naturally frozen skateways in the world, located in the heart of the National Capital Region (NCR). Indeed, when the NCC issued a regional and coast-to-coast survey for the 150th anniversary of Confederation in 2017, the RCS ranked first as the principal, the preferred, and the most visited attraction of the region. The results of this survey reinforced that public perception of the Skateway is synonymous with the cultural brand of the NCR and as a Nordic region and a centre for winter recreation.

5.2 UNESCO WORLD HERITAGE SITE

In 2007, the Rideau Canal was designated a United Nations Educational, Scientific and Cultural Organization World Heritage Site (UNESCO). "The Rideau Canal is a large strategic canal constructed for military purposes which played a crucial contributory role in allowing British forces to defend the colony of Canada against the United States of America, leading to the development of two distinct political and cultural entities in the north of the American continent, which can be seen as a significant stage in human history.

- Criterion i: The Rideau Canal remains the best-preserved example of a slackwater canal in North America demonstrating the use of European slackwater technology in North America on a large scale. It is the only canal dating from the great North American canal-building era of the early 19th century that remains operational along its original line with most of its original structures intact.
- Criterion iv: The Rideau Canal is an extensive, well preserved and significant example of a canal that was used for military purposes linked to a significant stage in human history – that of the fight to control the north of the American continent (UNESCO, 2007)."

The Skateway contributes to the designation with its overall recreational heritage value. The Canadian Heritage Rivers System calls it "a must-see tourist destination for the national capital in the winter months" (Canadian Heritage Rivers System, 2020). Furthermore, the canal also offers a variety of key iconic and scenic locations along its banks:

- From Laurier Bridge to Ottawa Locks, with the view of Parliament Hill and the Château Laurier;
- The Patterson Creek section with the Patterson Creek Bridge;
- The section near the Bank Street Bridge, which is a heritage asset as one of the first reinforced concrete structures in Ottawa; and
- The southernmost section from Dow's Lake to Hartwells Locks, which borders the Dominion Arboretum.

5.3 PUBLIC PERCEPTION

Skating on the canal is an experience that has been cherished by millions of Canadians and international visitors alike. For its 40th anniversary, the Skateway was highlighted in the Ottawa Citizen:

> *It serves as a microcosm of Canadian society; people from all over the world, of all ages, can be seen strapping on their skates and taking a stride down a part of Ottawa's living history. Those scenes alone will keep us all forever young* (Imre, 2010).

APPENDIX A

Hundreds of reviews and memories can be found online of childhood winters spent learning to skate on the Skateway, in addition to enjoying a well-earned snack or hot chocolate in frigid weather. The excerpts below demonstrate the importance of the Skateway to locals and their pride in showcasing it to visitors:

> *Skating on the Rideau Canal is a rite of passage for all Ottawa residents and a must-do for tourists in the winter* (Amanda, 2008).
>
> *I would consider it a travesty to not visit the Skateway during a winter visit to Ottawa. I'll never forget my first experience with the Skateway. When I walked down the rubber covered steps from the main road down to the canal, I wasn't sure where exactly where the ice started. This was until 2 skaters zipped right by me. It was then that I realized how massive the canal really was as I had been standing on it* (Devan, 2009).
>
> *I lived in Ottawa for 10 years, and some of my fondest memories of the city involve skating on the canal!* (Deanna, 2012).

Photo courtesy of E.Paré, 1980

In the context of climate change, where in recent years the ice quality has been harder to maintain and the lengths of the skating seasons are shortening, there have been different reactions from the public. In general, recreational users are understanding, recognizing that very little can be done to control the weather that creates poor conditions or closures. Other more frequent users of the Skateway tend to express disappointment during closures on social media. The most affected users tend to be visitors to the region who have travelled a distance to experience skating on the Rideau Canal. Most of the time, these users have committed resources to come to the National Capital Region and are unable to modify travel plans based on the weather.

The cultural significance of the RCS reinforces the need to implement solutions in order to maintain the Skateway, despite the anticipated warming of winter temperatures. Locals and visitors alike associate the Skateway with winter recreation in Ottawa and look forward to the season every year. Indeed, the 2019-2020 season was the 50th season of the RCS and the first where the downtown section from the Ottawa Locks to Laurier Bridge remained closed for the whole season. This situation received important media attention and caused concerns regarding decreased tourism and ultimately lower visitor spending in retail businesses.

5.4 USER DEMOGRAPHICS AND ECONOMIC IMPACTS

5.4.1 *USER DEMOGRAPHICS*

In the winter of 1970-1971, under the direction of NCC chairman Doug Fullerton, a group of NCC employees broke out their shovels and brooms and cleared a small section of ice near the National Arts Centre. That opening weekend, 50,000 people would skate on the canal making it an immediate success. Fifty years later, the Skateway sees an average of one million visitors per year (Patowary, 2016).

There is significant variation in the number of users as a result of winter weather. The 2018-2019 skating year saw a record 1,493,524 visitors skate on the canal due to a 71-day skating season (i.e. the number of days between the season opening date and closing date) which included 59 skating days - the longest on record in 13 years. The following 2019-2020 season was one of the poorest on record due to mild weather, rain, and snow conditions (Britneff, 2020). Figure 5-1 shows the estimated number of skaters per winter season on the Skateway since the 1992-1993 season (NCC, 2020).

APPENDIX A

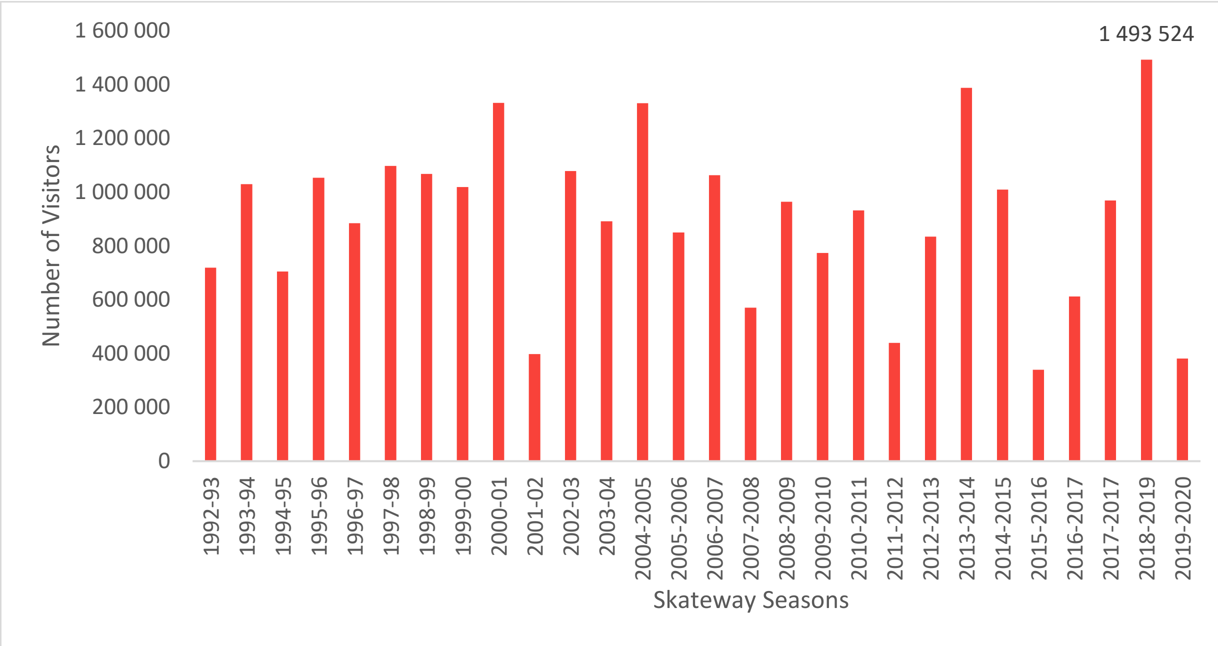

Figure 5-1: Estimated number of skaters on the Rideau Canal 1992-2020 (NCC, 2020)

In interviews with NCC staff, they have noted that they take pride that the canal promotes multiculturalism. Over the past 59 years, there have been several hosted events aimed at celebrating both national and international culture. One important recurring event is Winterlude, which the NCC created in 1979 as a celebration of Canada's unique northern culture and climate. In 1983, Winterlude organizers included an international component to the festival with the creation of a snow sculpture designed by Italian artists. The following year, Winterlude hosted its first international competition with the arrival of 400 Dutch skaters, a tradition that continues to this day with both skaters and ice and snow sculptors from around the world participating in various competitions (Cultural Heritage, 2020). Between the Skateway and Winterlude, these two attractions draw many out-of-town visitors, with an estimated 85% of visitors being from out-of-town, and approximately 30% from outside the region (Sims, 1998; CTV News, 2019).

Important to note is that the NCC no longer organizes Winterlude, which is now hosted by the Department of Canadian Heritage. The festival has been working to lessen its reliance on the RCS in anticipation of changing climate conditions.

5.4.2 *ECONOMIC IMPACTS*

Skating on the Rideau Canal is a free activity that draws in thousands of visitors each year and injects money into the region's local economy (Ottawa Tourism, 2020). A 2003 study found that 75% of visitors surveyed stated the Skateway was somewhat important in their decision to visit the NCR (Rideau Canal Skateway Factsheet, 2006). Notably, these visits coincide with Winterlude, an annual winter festival held in Ottawa-Gatineau, where the RCS is the primary signature attraction. While the NCC created Winterlude in 1979 to celebrate Canada's unique northern culture and climate, responsibility for its organization transferred to Canadian Heritage in 2013 (Canada, 2021).

Winterlude occurs over a series of three weekends, typically in mid-January to late February. It is a key economic driver for local businesses which report seeing increased revenue in the restaurant and hospitality sector, transportation, and souvenir sales. In 2014, the NCC estimated that 650,000 visitors would come to the Nation's Capital for the 32nd edition of Winterlude. A 2004 economic study estimated that visitors for the festival brought in $152 million in spending in Ontario and Quebec, with $82.5 million of that specific to Ottawa (CTV News, 2010). This is consistent with a slightly earlier 2003 report to the Corporate Service and Economic Development Committee which estimated that the economic impact of Winterlude to the region was $143,500,000 (as a result of $56,500,000 in direct spending) (Kirkpatrick, 2003). Winterlude's direct economic impact was reported to be about $68 million in 2013 according to then Senior-Vice President, Guy Laflamme (Roche, 2013).

The Ottawa Tourism and Convention Authority has noted that the Winterlude festival is the "biggest event to bring people to the community in the winter and solidifies Ottawa as a winter destination" (Sims, 1998). NCC media relations advisor Kathryn Keyes notes that areas expected to earn the most money are those that are near the festival's major sites, including the Byward Market and Dow's Lake, though areas further from the canal will still experience moderate increases, with visitors spending money on hospitality outside of the core (Li, 2007).

Weather has had the greatest impact on spending by regional visitors who are more likely to visit the Skateway and festival spontaneously, while out-of-town visitors often must book reservations for accommodations weeks in advance (CBC News, 2020). In response to varying weather conditions, as an early adaptation measure, Winterlude has been diversifying its offerings and moving events off of the canal, including the popular annual ice carving competition which was moved into the ByWard Market (Jay, 2019).

5.5 OPERATIONS

5.5.1 *OPERATIONAL PRACTICES*

Figure 5-2: The new drainage installation near Laurier Bridge. Left photo from Larocque and Pringle (2020). Right photo courtesy of NCC.

Approximately six weeks before the beginning of the season, the Rideau Canal water level is lowered to its minimum to allow for the preparation of the site. This includes installing various supporting infrastructure and connecting the buildings to the plumbing and electrical systems before raising the water level to the skating level. Another activity that is conducted during this phase is the installation of a customized stormwater outfall mitigation system (Figure 5-2) to divert warmer stormwater away from the skating areas. In 2020, a third pipe was added to divert the overflow in the center of the Rideau Canal and encourage the thickening of ice in the sections from Rideau Street to Laurier Bridge (Larocque and Pringle, 2020).

Between the third week of November and early December, PC increases the water level in the canal, approximately two feet below the summer navigation level. PC also installs a cofferdam upstream of Ottawa Lock n°8, near the Chateau Laurier to control the winter water level. Flow entering the canal is controlled by locks, which limits the winter water level variation and stabilizes the ice cover. Water velocity along the canal is typically low, which promotes the formation of thermal ice. In this context, ice on the canal is apparent to lake ice.

When the water level has risen to the established skating level, the second pre-season phase consists of ice formation. As soon as there is a minimal ice cover and when the nighttime temperature drops below -10°C for a minimum of five consecutive days and the daytime temperature remains below -5 C, the operations team begins the process of flooding the ice to accelerate ice thickening. This step consists of pumping a 2.5 cm layer of water above the ice, based on the principle that the water will freeze more quickly at the contact of air temperature during cold snaps. This process continues until the ice has a minimum thickness of 20 cm - enough to support the weight of the snow maintenance machinery and to allow the installation of the on-ice assets. Once the ice thickness reaches 30 cm, skaters are welcomed. Ice thickness and quality are measured by extracting cores in every section of the RCS (Figure 5-3), as well as with ground-penetrating radar surveys which allow the investigation of micro-scale variations in the ice cover.

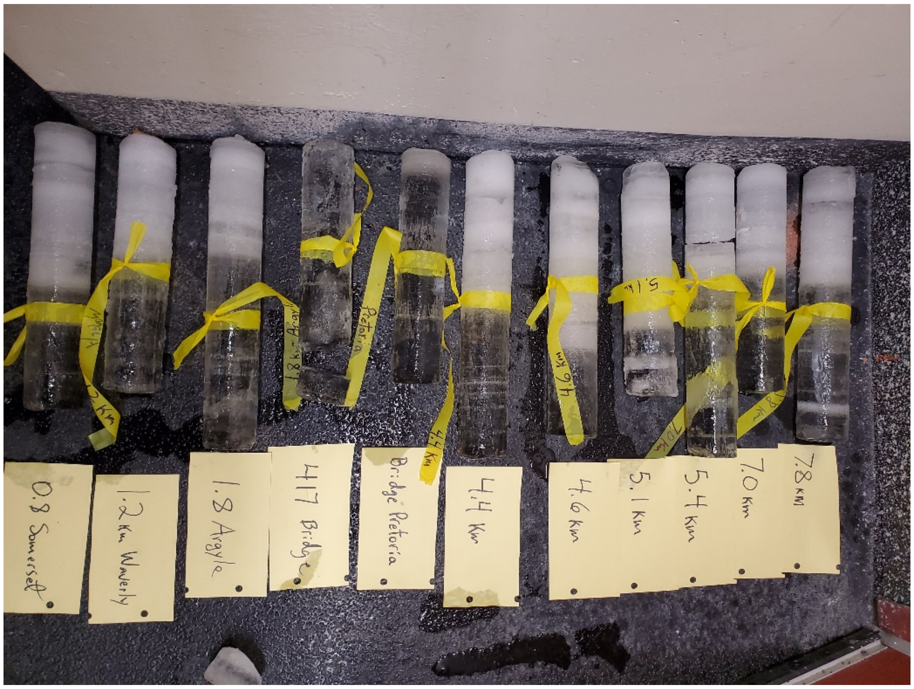

Figure 5-3: Ice cores sampled at different locations along the RCS, which illustrate the variability in ice condition (white ice vs black ice content) and thickness.

During the skating season, the maintenance of the RCS is conducted every evening (regardless of whether the RCS is open). The operations consist primarily of ice monitoring, resurfacing, ice creation through intense flooding during cold snaps and snow removal and management.

In terms of safety, the NCC uses a flag system to indicate RCS conditions. The green flag means fair to good conditions, but caution should always be used while skating. The red flag means that the RCS is closed and that conditions are unsafe. The RCS has its own skate patrol trained in first aid and CPR (cardiopulmonary resuscitation).

5.5.2 *GUIDELINES AND BEST PRACTICES*

The RCS operations team has relied on the ice safety guidelines established by Dr. Nirmal Sinha, formerly of the National Research Council of Canada, a world leader in the science of ice. Presented below are general best practices and guidelines for the operation of outdoor natural water bodies and the safety of staff and visitors. This information was supplied by the NCC, the Risk Management Centre of Excellence's Risk Management Considerations for Outdoor Skating Rinks, and the Ontario Recreation Facilities Association Inc (ORFA)'s Guidelines for Creating and Maintaining Outdoor Ice (Center of Excellence, 2020; ORFA, 2007). It should be noted that these practices are already implemented by NCC staff.

Snow management:

— Snow should be shovelled off the rink after every snowfall when the ice thickness permits to ensure safe, even surface conditions, reduce weight, and lessen the insulating effect.

Equipment:

— There should be ample lighting around the RCS, and it should be ensured that the lighting is in working order for night skating.
— Benches should be provided for users to rest and to put on/take off their skates.
— Waste receptacles should be available so that garbage is not left on the ice and subsequently in the canal.

- Flooding equipment, such as the Froster[2], shovels, and hoses should be readily available and safely stored.
- Ensure the ice is stable enough to maintain the weight of the equipment.

Flooding:

- Flood as often as necessary and allowable by weather conditions to maintain a smooth, safe ice surface.
- Do not flood the ice surface if it is snowing or if there is snow on the ice surface as this can result in uneven and potentially dangerous surfaces when frozen.
- Perform pre-flooding inspections of the ice and remove any debris or snow before flooding.
- Do not flood on extremely cold days (<-20 °C) to avoid ice cracks and boils.

Ice Thickness and Conditions:

- Ensure a minimum ice thickness of 30 cm of good, clear ice.
- Monitor ice thickness, quality and vertical movement frequently, with more frequent inspections during warmer weather.
- Inspections should be documented, including any repairs or maintenance done that should be completed.

Hazards

- Inspect and repair all hazards immediately including:
  - Cracks;
  - Frost boils;
  - Exposed water;
  - Chopped up ice surface, and
  - Ice shavings.

Signage:

- Signage should be posted around the rink including information on:
  - Hours of operation;
  - Code of conduct;
  - Open or closed for skating (signalled on the canal by a green or red flag);
  - Alcohol allowances/prohibitions;
  - Helmet recommendations;
  - Children should be supervised;
  - Locations of medical stations, and
  - Any other warnings.

5.5.3 *ICE REGIME*

The ice regime and properties on the Rideau Canal is influenced by multiple factors; both natural and anthropogenic, summarized in Table 5-1. This section describes, the ice regime and related hydraulic conditions on the canal. The analysis is based on the available information and a general understanding of the ice processes.

Ice mostly grows thermally at the beginning of the winter, after the canal has been watered. Early freeze-up processes are mainly driven by natural conditions. Once the ice cover has formed on the canal, the heat exchange between the air and the water becomes limited. The canal water thermal balance is then driven by the inflows and stormwaters drains and, to a lesser magnitude, by the ground heat exchange. In winter, water entering the canal at the Hogs Backs Locks flows through near-bottom sluice gates.

[2] The Froster is the ice resurfacer that revolutionized the maintenance of the RCS in 2011.

Flow variation during winter is limited by the upstream locks. However, mid-winter thaw and rain events can increase inflows from the Rideau River and tributaries. Warmer and saltier water can flow into the canal during these events. Mid-winter events, such as rain and warm temperature, can alter the ice cover by melting and flooding the ice surface. Water on top of the ice is obviously undesirable for skating but can also create an irregular surface with it freezes back. Heavy snow adds weight on top of the ice, which tends to sink and bend the cover, creating stress fractures. These fractures can, in turn, bring water up to the surface. Maintenance crews work to limit the impact of mid-winter events. However, temporary closure during winter can still occur.

Extensive skating activities and maintenance operations generate load and stresses on the ice cover. For example, the congregation of people can create point load and initiate local fractures (Sinha, 1985). Maintenance vehicles can also create stresses when they travel or park on the ice.

The skating season ends when the ice conditions become irreversibly unsafe.

Table 5-1: Factors influencing the ice regime on the Rideau Canal

Type	Factor
Natural	— Air temperature — Precipitation (rain and snow) — Wind — Solar radiation
Anthropic	— Water level and inflow control at Hogs Back and Hartwells Locks — Water level and outflow control at Ottawa Locks — Tributaries and stormwater drain inflows — Winter maintenance operations — Skating activities

5.5.4 *CHRONOLOGY*

The glaciological winter is the period during which ice is present on the Rideau Canal. It starts at freeze-up and ends when the ice is completely gone.

Ice maintenance is the period when the NCC works to maintain or improve the RCS ice conditions. Currently, this period starts with the first ice flooding and ends when the skating conditions become irreversibly unsafe. The objectives of the ice maintenance operations are the following:

- Smooth the ice surface to ensure high quality skating conditions.
- Remove snow from the RCS to reduce the dead load on the cover, increase water/air heat exchange, limit the potential for snowmelt on top of the ice and ease the ice smoothing operations.
- Increase ice thickness by adding and freezing water on top of the existing ice cover.

The skating season corresponds to the periods during which the RCS is open to the public. It is also the period during which the skating conditions are considered adequate and safe. By definition, the skating season is shorter than the glaciologic winter and the ice maintenance period. It starts when the ice gets thick and ends when the ice gets too thin, too fractured or too flooded. The RCS can be closed temporarily during the season whenever the skating conditions become inadequate or unsafe.

Figure 5-4 illustrates a typical skating season chronology.

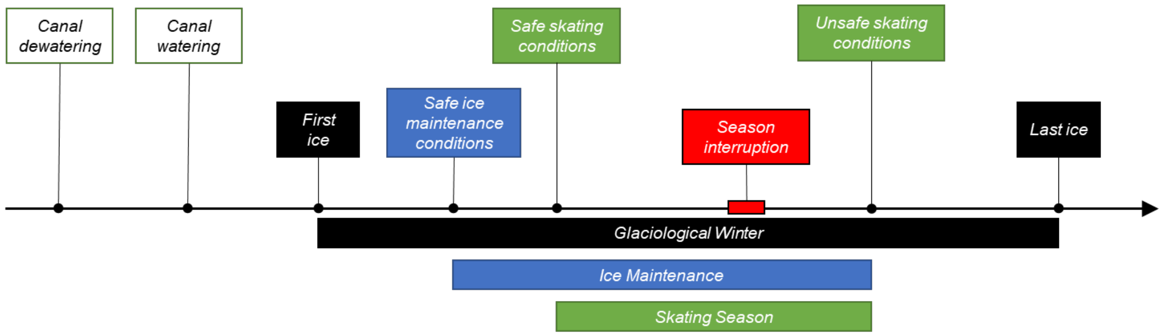

Figure 5-4: Typical Skating Season Chronology on the Rideau Canal

5.6 CLIMATE TRENDS

The following climate projections are taken from the *Climate Projections for the National Capital Region Executive Summary* (NCC et al., 2020a) and the *Climate Projections for the National Capital Region Volume 1: Results and Interpretation for Key Climate Indices* report (NCC et al., 2020b; available at www.ncc-ccn.gc.ca/our-plans/climate-change-adaptation-initiative). The general projections are presented for three time horizons: the 2030s (2011-2040), the 2050s (2041-2070) and the 2080s (2071-2100). Two greenhouse gas (GHG) emission scenarios have been considered, a moderate emissions scenario (RCP4.5; decrease in GHG emissions by the 2040s) and a high emissions scenario (RCP8.5; regular increase in GHG emission until the end of the century, often referred to as the “business as usual” scenario). These projections will be presented in comparison to the historic baseline years of 1981-2010. The climate parameters presented below are those relevant to outdoor ice-skating operations on the Rideau Canal.

The numbers presented below represent 30-year averages. Any given year could have values that are higher or lower due to year-to-year climate variability.

Note: In the following sections, the two values reported for each climate index (e.g. [8.2; 9.3] °C) are not ranges; they represent the mean values for the moderate (RCP 4.5) and high (RCP 8.5) emission scenarios respectively. When a decrease is projected, such as for the amount of snow, the second value will be lower than the first value.

5.6.1 *TEMPERATURE*

Overall, it is projected that winters in the National Capital Region will become shorter and warmer under both projected emissions scenarios [RCP4.5; RCP8.5]. The average annual temperature is projected to increase from a historic baseline of 6.1 °C to [7.5; 7.9] °C in the 2030s, [8.2; 9.3] °C in the 2050s, and [8.8; 11.4] °C in the 2080s. While this encapsulates an increase in both daytime high and nighttime low temperatures, nighttime lows are projected to rise faster. This could signal a decrease in the frequency and intensity of cold extremes, which most often occur during that nighttime period.

The coldest monthly temperature for January has historically been an average of -30.0 °C. This is projected to increase to [-26.2; -26.9] °C in the 2030s, [-22.9; -25.2] °C in the 2050s and [-18.2; -23.4] °C in the 2080s. This is an increase of approximately 6.6 – 11.8 °C by the 2080s (Figure 5-5).

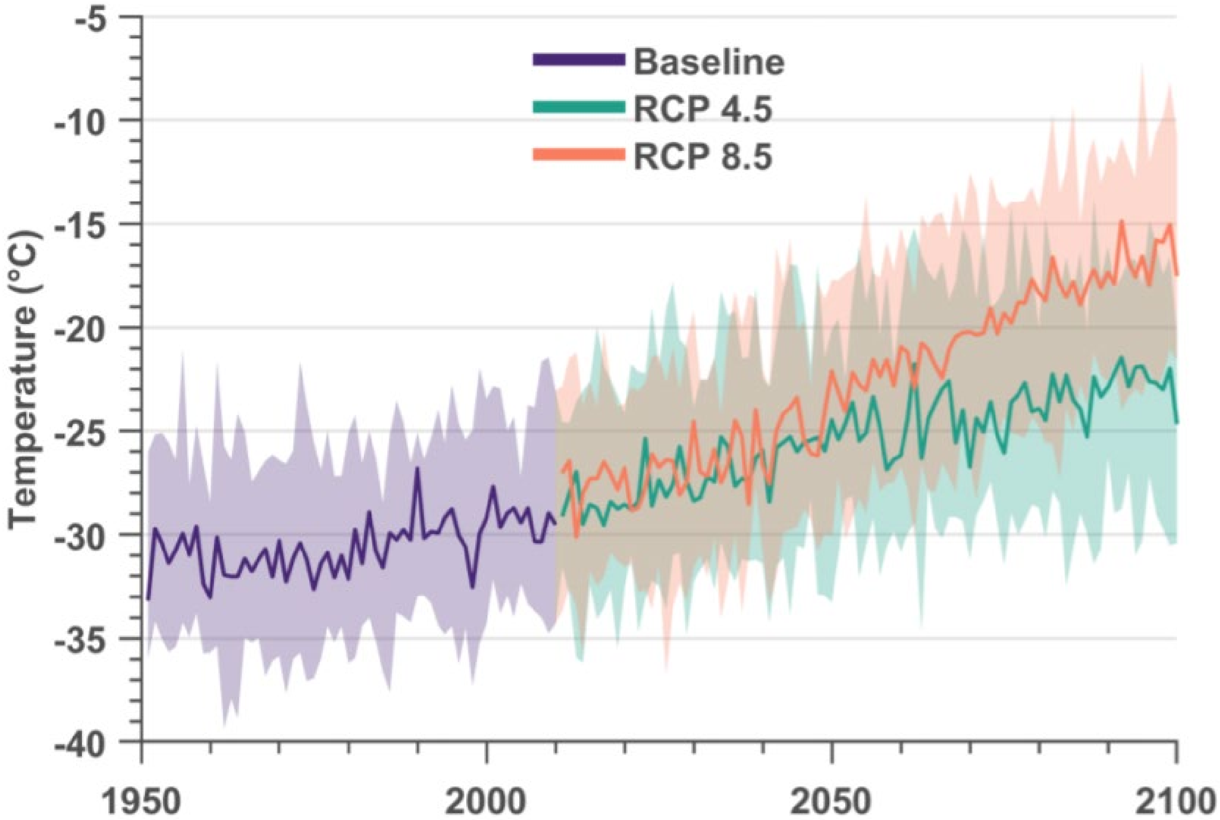

Figure 5-5: Coldest monthly temperature - January (NCC et al., 2020)

This increase will also impact the number of so-called “deep-freeze events”, or the number of days where the daily minimum temperature is less than -10 °C. They are projected to decrease from approximately 71 days per year in the baseline to approximately [57; 59] days in the 2030s, [46; 53] days in the 2050s and [28; 48] days in the 2080s.

Models predict that winter temperatures will hover around 0°C more frequently in the future. As a consequence, the number of winter freeze-thaw cycles are projected to increase from approximately 24 days in the baseline to approximately [27; 28] days in the 2030s, [30; 32] days in the 2050s and [32; 37] days in the 2080s.

5.6.2 CHANGES IN WINTER DURATION AND TIMING

Winter, here defined as December to February, is projected to begin later and end earlier. The timing of the first fall frost which represents the first day when minimum daily temperatures will fall below 0 °C, will shift from late September/early October to mid-October: approximately [1; 2] weeks later by the 2030s, [2; 3] weeks later by the 2050s, and [3; 4] weeks later by the 2080s. The timing of the last spring frost which represents the last day when minimum daily temperatures are below 0 °C, is projected to occur earlier: approximately [1; 2] weeks earlier in the 2030s and 2050s, and [2; 4] weeks earlier in the 2080s, compared to the baseline.

5.6.3 PRECIPITATION AND SNOWFALL

The models show a projected increase in total precipitation in all months except for summer. Total annual precipitation in the NCR is expected to increase from approximately 921 mm/year in the baseline to approximately [949; 968] mm in the 2030s, [979; 993] mm in the 2050s and [983; 1028] mm in the 2080s. There is no projected change in the frequency of wet days, or days when precipitation occurs, however there is a projected increase in the intensity of precipitation events. The number of days with precipitation > 20 mm is projected to increase from approximately 6 days in the baseline to 7 days in the 2030s, 8 days in the 2050s and [8; 9] days in the 2080s.

Despite an increase in total precipitation, there is a projected decrease in total snowfall. A decrease in annual total snowfall is projected in the NCR, from approximately 223 cm in the baseline to [193; 201] cm in the 2030s, [179; 184] cm in the 2050s and [124; 154] cm in the 2080s. This represents a decrease of 31-44% by the 2080s (Figure 5-6).

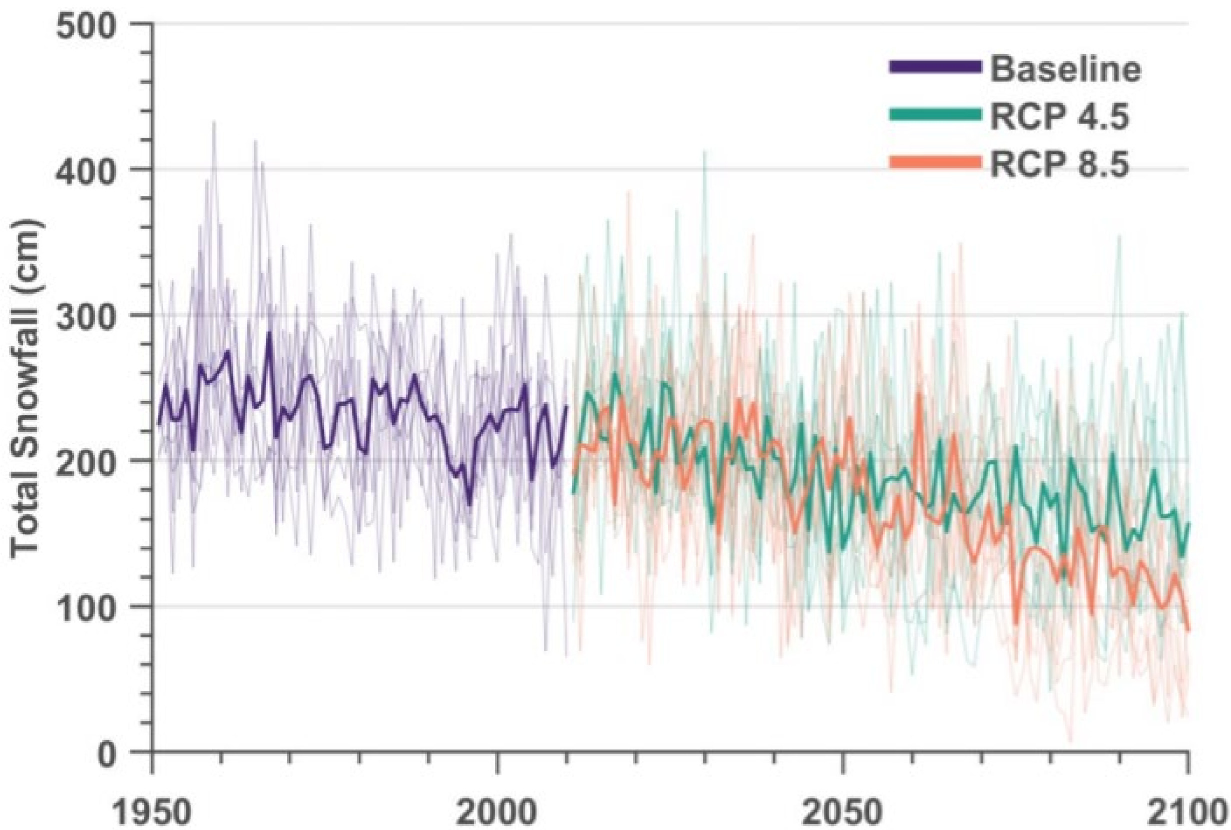

Figure 5-6: Annual total snowfall (NCC et al., 2020)

The timing of the first snowfall (≥ 1 cm) is projected to occur approximately one week later in the 2030s, two weeks later in the 2050s, and [2; 3] weeks later in the 2080s compared to the baseline. The timing of last snowfall (defined as the last date in the spring when snowfall ≥ 1 cm) is projected to occur approximately [0; 1] weeks earlier in the 2030s, [0; 2] weeks earlier in the 2050s, and [1; 3] weeks earlier in the 2080s compared to the baseline. The number of days with snowfall (defined as the number of days where snowfall ≥ 1 cm occurs) is projected to decrease from approximately 41 days in the baseline to approximately 37 days in the 2030s, [32; 33] days in the 2050s and [21; 31] days in the 2080s. Average projections suggest that annual maximum 1-day snowfall will change from approximately 20 cm in the baseline to [20; 21] cm in the 2030s, [20; 22] cm in the 2050s and [16; 20] cm in the 2080s. Annual maximum snow depth is expected to decrease from approximately 59 cm in the baseline to [48; 50] cm in the 2030s, [40; 45] cm in the 2050s and [29; 42] cm in the 2080s.

It should be noted that precipitation extremes and intensities are difficult to project and have a larger degree of uncertainty.

5.6.4 *WIND AND WIND CHILL*

There is no detectable trend in average changes for the yearly distribution of wind speeds. Wind chill, a calculation combining cold temperature extremes and wind and here denoted as the number of days with a wind chill that is between -25°C and -35°C, is projected to decrease from approximately 17 days in the baseline to [8; 11] days in the 2030s, [5; 6] days in the 2050s and [1;5] days in the 2080s. It should be noted that wind regimes are difficult to project and have a larger degree of uncertainty.

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B

ADDITIONAL LITERATURE REVIEW CONTENT AND DATABASE

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6 REVIEWED STANDARDS

The international and Canadian standards adopted in the field of risk assessment are relevant to the RCS in that they provide methodologies, tools, and guidance on identifying and treating risks. The International Organization for Standardization (ISO) 31000 and International Electrotechnical Commission (IEC)/ISO 31010 Standards can be adopted by the NCC when assessing and monitoring risks to the RCS. The ISO 14090 and 14091 standards for adaptation to climate change are relevant to the RCS operations in that they provide information to decision-makers on how to assess the impacts of climate change on operations, prepare a climate adaptation plan, implement adaptation strategies and monitor and evaluate the success of climate adaptation projects. These standards are also helpful for framing the climate risk assessment project by presenting foundational concepts to this work including mainstreaming climate adaptation throughout the organization and operations, incorporating climate mitigation alongside adaptation measures, applying a systems-thinking perspective to the operation and its interaction with the community and stakeholders, transparency and accountability (ISO, 2019). Used in conjunction with site-specific data and international best practices for recreational ice-skating facilities' climate risk assessments and adaptation measures, these standards will provide the NCC with a robust risk assessment of the RCS.

ISO is currently preparing a standard for the risk assessment of sports and other recreational facilities and equipment (ISO/WD 4980), which could provide directly useful information for the NCC if it includes outdoor skating facilities and climate change. The research used to inform this standard could also be an important resource for the NCC.

Other international and Canadian standards have relevance to the RCS operations but are not directly relevant to the current climate risk assessment work. Standards related to the operation of outdoor recreation facilities, measuring water flow under ice, management of heritage structures, and others might need to be referenced as changes to operations begin to occur, but are not critical in informing this stage of the climate risk assessment of the Skateway. This review included a search for international standards related to recreational ice-skating facilities, which provided some results in the USA, China and Germany, none of which were open source at the time of this study. In Canada, standards for ice road operation, use and maintenance have been prepared by provincial and territorial governments, the Transportation Association of Canada, and others (Barrette, 2015). These provide strong detail on the formation, quality and requirements of ice roads, and provide some climate change adaptation measures for ice roads that could be relevant to the NCC.

6.1 ICE PROCESSES

This section describes the general ice formation processes that occur on a lake or calm water body, like the Rideau Canal.

6.1.1 *FORMATION*

Lakes cool from top to bottom in colder temperatures when the surface water loses heat, becomes denser and sinks. This process continues until all the water in the lake is at 4°C, when the density of water is at its maximum. With further cooling (and without mechanical mixing) a stable, lighter layer of water forms at the surface. When this layer cools to its freezing point, ice begins to form on the surface (Ashton, 1986).

There are two ways in which the first ice can appear in a lake. The first involves water at the surface of a calm or slowly moving body of water phasing from liquid to solid (i.e. primary nucleation). The second is involves snow or atmospheric ice particles falling onto the water surface (secondary nucleation).

One of the simplest ways to initiate ice cover on a water body is by secondary nucleation, with ice particles coming from the atmosphere when the water is close to the freezing point. In a lake or calm water body, a heavy snowfall will often initiate the ice cover when the floating snow particles refreeze at the top, even if the surface water temperature is not at a freezing point during the snowfall (Michel, 1978).

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6.1.2 GROWTH

Further ice formation occurs when surface air temperatures become low enough to allow the freezing of water to the underside of the ice sheet. Crystals grow downward into the water column through a process called congelation and resulting in congelation ice (Ashton, 1986).

Typical ice coverage features snow ice (secondary) above a layer of lake ice (primary). Water infiltrates snow to form snow ice in several ways. Snow deposited on a thin ice cover can depress the ice, allowing lake water to rise through cracks and holes into the overlying snow, which then becomes slush and forms snow ice upon freezing. Rain and melting snow can percolate downward and refreeze in the lower levels of an unconsolidated snowpack.

6.1.3 DECAY

Lake ice decay begins when the snow cover on top of the ice melts, forming pools of water and decreasing the albedo of the top surface (Ashton, 1986). During decay, ice typically melts at the top and bottom surfaces simultaneously. At some point, the ice cover becomes sufficiently weak to be physically broken up by wind forces or water currents.

6.1.4 THERMAL DISCHARGE

Thermal discharge is a term to describe warm water entering a water body. In winter, thermal discharges not only raise the water temperature but also change, and generally reduce, the amount of ice that would otherwise form. Warm water released into a lake can suppress the ice cover by melting it or by preventing initial formation.

6.2 CLIMATE CHANGE AND ICE FORMATION IN DIFFERENT CONTEXTS

6.2.1 LAKES

Nationally and internationally there has been considerable research conducted on the historic and projected impacts of climate change on the ecology, hydrology, and socio-economic impacts of climate change on lakes and lake systems. Projected trends for air temperature and snow cover in the Northern Hemisphere suggest that seasonal ice cover duration will continue to decline (Shter et al., 2013; Yao et al., 2014; Magee and Wu, 2017; Hewitt et al., 2018; Sharma et al., 2019). In the Arctic region, key hydrological changes caused by climate change that impact the formation of lake ice include changes to low flows, lake evaporation regimes, and water levels (Prowse, 2011).

6.2.2 RIVERS

Research into arctic rivers has found that key hydrological impacts to rivers include changes to low flows, lake evaporation regimes and water levels, and ice break-up severity and timing. The latter is of particular concern because of its impacts on river geomorphology (Prowse et al., 2011). Ice formation in rivers is complicated by the effects of water velocity and turbulence. Unlike relatively still water in lakes, turbulent mixing in rivers causes the entire water depth to cool uniformly even after the temperature has fallen below the temperature of maximum density (4°C). The formation of larger ice sheets on rivers is dictated by the acceleration of gravity, the densities of the water and ice, the thickness of the accumulation of ice, and the depth of flow just upstream (Ashton, 2019).

It is important to note that though this information can inform the impacts and adaptational strategies of the RCS, rivers differ inherently from canals in their structure, formation, and the level of control that can be imposed by human operations.

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6.2.3 ICE ROADS

Ice roads are winter roads that run on naturally frozen water surfaces, such as rivers or lakes in cold climates and are commonly found in northern regions. They typically begin as thin layers of snowfall on calm water surfaces and form crystals, which then grown downward. This process can be complicated by any type of water dynamics such as wind, waves, or currents (Barrette, 2015).

Much like in canal systems, ice roads typically form two types of ices (Barrette, 2015):

1 **Clear ice**. Also known as black ice or natural ice, this is a transparent layer of ice, typically free of air bubbles that are expelled at the ice-water interface. Note, constructed ice (ice that was created by pumping water directly onto the surface of a bare ice sheet), if constructed using sound construction practices, can be considered as having strength similar to clear ice (Government of Northwest Territories, 2015).
2 **White ice**. Also known as snow ice, this ice often originates when snow on the ice gets flooded by water and the dissolved air has no way to escape. Because of the air content, the density of white ice is slightly lower than that of clear ice and can be mechanically much weaker. Flooding ice with water pumps (often used to increase ice thickness) will also lead to the formation of white ice. However, unlike snow ice, this ice will be relatively strong, though still less dense than clear ice. Poor quality ice is typically excluded from ice safety calculations in most transportation guides.

Climate change, and specifically warming temperatures, have been projected to be a threat to the integrity and safety of these ice roads, and by extension the economic viability of the areas they service. A recent example of these ramifications occurred in the Northwest Territories in 2006, when a standard 72-day operation window was brought down to 49-days for the Tibbitt-to-Contwoyto roads due to the weather (McGregor et al., 2008; Rawlings et al., 2009). As a result, materials had to be airlifted to a mining site, costing over $100 million CAD. Within Canada, several guidance documents describing the safe creation, use, and operation of ice roads have been created and included in the attached summary.

6.3 ENVIRONMENTAL FACTORS AFFECTING ICE FORMATION

6.3.1 HYDROLOGICAL FACTORS AND WATER LEVELS

In river and lake systems where there is a dynamic flow of water turbidity, waves and currents will hinder ice formation (Ashton, 2019). Initial water levels appear to be a consideration primarily in lakes, where larger lakes have been noted to require longer periods to freeze. In any water system, rising and falling water levels can present lower ice quality or strength. Lowering water levels may impact the buoyancy of the ice while rising water levels could result in the formation of two ice layers with an intervening water layer (Treasury Board of Canada Secretariat, 2002). Waterways that are influenced by dams or other human influences are particularly vulnerable to changes in water level which could cause ice cracking. Cracks can occur frequently in rivers and lakes that are downstream of water control structures such as dams or spillways (Government of Northwest Territories, 2015).

6.3.2 TEMPERATURE

Several sources used different indicators of temperature to determine the safety of human interaction with ice. The organizers of the 200 km Elfstedentocht ice race through rivers and canals in the Netherlands require a 15-day average temperature lower than -4.2ºC before announcing a race (Visser, Petersen, 2009). The Government of Alberta's "Best Practice for Building and Working Safely on Ice Covers in Alberta" recommends using the air freezing index (freezing degree day) and tracking the accumulated freezing degree-days for a station as winter develops to provide an indication of a winter's severity, which they have linked to ice growth (Government of Alberta, 2013).

On an annual scale the average date of the shoulder seasons, fall and spring, will impact the length of the operational skating season. Factors such as first and last fall and spring frosts and an overview of the timing of ice breakup and freeze up (phenology) can indicate trends in ice formation and temperature.

Significant temperature drops can cause temporary internal stress through the thermal contraction of ice and reduce the bearing capacity (Treasury Board of Canada Secretariat, 2002; Government of Northwest Territories, 2015). Note, the removal of snow from ice during periods of low temperature will have a similar effect and should be treated with caution.

It is important to consider that temperature is not necessarily a sufficient stand-alone indicator. Factors such as precipitation, especially snow, and wind could reduce or increase the temperature thresholds.

6.3.3 SALINITY

While pure freshwater has a freezing point of 0 °C, seawater with a salt content of about 35 ppt will not begin to freeze until about -1.8°C, and brackish water will freeze slightly below 0 C (Ocean Networks Canada, 2020). Generally, for every five practical salinity unit (psu) increase in water salinity, the freezing point decreases by 0.28 °C (National Snow and Ice Data Center).

6.3.4 SOLAR RADIATION

Incoming solar radiation introduces energy into the surface of the ice that will warm it and eventually cause melting. The amount of solar radiation reaching the ice is a product of the amount of radiation reaching the earth, which fluctuates about 7% during a year, and varies throughout a day based on the local conditions of cloud cover (Hock, 2005).

6.3.5 WIND SPEED AND TEMPERATURE

In extreme cases, very high winds can aggravate existing cracks and cause severe damage to ice cover (Government of Northwest Territories, 2015). Open areas with limited wind cover are most susceptible to high winds. In addition, areas completely shielded from wind may not benefit from its cooling effect. This was noted as a suspected cause of a shortened 2019-2020 season on the Rideau Canal (Montgomery, 2020).

6.3.6 SNOW COVER

The impacts of snow cover on ice are dependent on the timing and temperature of the snowfall, surface air, and solar radiation. Snow that falls while air temperatures are cold acts as an insulator and keeps the ice warmer, reducing freezing. Wet snow near its melting point could also freeze on top of the ice, creating a layer of structurally weakened white ice. In addition, if the existing ice is thin enough a sufficient layer of snow could push the surface down and cause water underneath the ice to rise through cracks, increasing melting or creating a layer of water or white ice. If the snow cover occurs during warmer temperatures and sunnier conditions, snow could do the opposite and act as an insulator against temperatures and solar radiation, reducing the melt (Government of Northwest Territories, 2015).

If sufficient snow is built up on the surface of the ice, there is also a danger of the standing load becoming large enough to cause sagging and cracking. Blowing snow, while not a danger to the ice itself, could cover up physical markings such as cracks and sagging and delay maintenance (Government of Northwest Territories, 2015).

6.4 ADAPTATION MEASURES AND BEST PRACTICES

A major theme in the literature that directly discusses outdoor ice skating is that there are studies and observations about how climate is impacting skating operations and how we can predict this change in the future, but there is not much discussion on what can be done to increase the resilience of outdoor skating. Liu et al. found that little was being done to attempt to increase the outdoor skating season since efforts would be futile or not feasible (Liu et al., 2017). Artificial snow can be made to increase the ski season in small or concentrated areas (Sievanen et al., 2005), but an equivalent adaptation measure is not being used for ice skating. Instead, efforts were being made in China to increase skating tourism when the rink was available to make up for the loss in revenue of a shorter season (Liu et al., 2017). Predicting and analyzing changes to outdoor skating facilities can inform planning, investments and decision making for skating tourism operators and business owners, but it will do nothing to extend the skating season. This review found that much of the literature related directly to outdoor ice skating focuses on accepting the risk of a reduction in skating operations rather than taking action to prevent it.

However, several adaptation measures relating to reinforcing ice strength, reducing fracturing, and ensuring the safety of users were found in scientific journals and in relation to ice road maintenance. Included below are those which could have relevance to the Rideau Canal Skateway operations. Those which would not be relevant to a contained ice-skating canal and those which focus on large-scale transportation operations have been excluded from this memo.

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- **Reinforcing ice with a geogrid**. Floating freshwater ice sheets can be reinforced with a high-strength polymeric mesh (geogrid) frozen into the ice sheets. Laboratory bearing capacity tests conducted found that the mesh increased the bearing capacity of thin (49 mm) ice up to 38% and thick (96 mm) ice about 10-15%. Failure with a mesh grid was also localized instead of dispersed (Haynes et al., 1992). The cost could be a significant drawback of this solution, but it could be applied employed in a localized problem area.
- **Reducing discharge from wastewater and sewage treatment sources**. Wastewater and sewage water, such as that from the cooling of power plants, sewage treatment, or a reservoir, is maintained at a higher temperature than naturally occurring water such as in the canal. Releasing this water into rivers has previously been used as a method of melting localized ice accumulation. Weakening of the ice could be reduced by determining which inputs into the Rideau Canal are causing the most significant localized melting issues and identifying additional mitigation strategies to manage drainage discharge (Ashton, 2019). It is assumed that stormwater is the primary discharge, but should be confirmed with the City of Ottawa that combined sewers are not discharged into the Rideau Canal.
- **Regular ice inspection to report on the accumulation of dirt.** Surfaces should be kept clear of dirt or other dark spots such as oil spots, which will absorb solar radiation and melt into the ice (Treasury Board of Canada Secretariat, 2002). For example, municipal drainage systems introduce sediment into the water, which can decrease the albedo of ice and make it more vulnerable to melting.
- **Restricting the use of the canal to the night or periods of cold temperature.** During warmer periods reducing the use of the canal to avoid additional stress (Barrette, 2015).
- **Improving the technology for conducting stress analyses and for estimating ice bearing capacity** (Barrette, 2015) to update thresholds developed for the Rideau Canal Skateway (BMT Fleet Technology, 2011), if possible.
- **Improving monitoring the ice thickness** by optimizing ground-penetrating radar technology, assessing temperature and strength. The ice contractor (CPG) has begun to use a ground-penetrating radar within the last several years for this purpose.
- **Limiting the size of snow windrows and piles.** Snow windrows or any snow piles can cause cracks to form in the center of an ice road, thereby inducing ice flaking and surface deterioration. Ice behaves elastically under moving loads and will recover its position. Ice under a stationary load will sag continuously and could fail. The Treasury Board of Canada Secretariat (2002) recommends a safe bearing capacity for stationary loads be 50 percent less than for moving loads. Stationary loads, such as large snow piles, should be moved if radial cracks develop, sagging is observed, if the rate of sagging increases, if continuous cracking is heard or observed, or if water appears on the surface. Snow windrows and snowdrifts can both contribute to and mask these signs. It is recommended that if a pile of snow is higher than 1 m it should be levelled out, or if it is two-thirds of the ice thickness, whichever is larger (Treasury Board of Canada Secretariat, 2002).
- **Spraying ice crystals.** In some locations, this method of spraying ice crystals, similar to snow making devices on ski hills, can be used to help maintain ice thickness. This technique has previously been attempted on the Skateway with limited success due to the proximity of roads and pathways on either side of the canal. It was difficult to contain ice spraying operations to the canal with the specific equipment employed and it was causing ice formation on the nearby roadways.
- **Microscopically reinforcing the ice**. Using various small-scale/fine grain materials such as sawdust, shredded bark, alluvium, and shredded newspaper has been tested in laboratory conditions and found to reduce the required ice thickness and increase fracture toughness. While these could increase strength and alleviate some of the temperature stresses, there are external considerations of cost, material availability, additional operational load, the darkness of the material in relation to the solar radiation, environmental recovery, and material deployment in the field (Nixon and Smith, 1987, Nixon and Weber, 1991, Coble and Kingery, 1963; Kuehn and Nixon, 1988, Vasiliev et al., 2014; Michael et al., 1974, Ohstrom and DenHartog, 1976; Haynes et al., 1992; Jarette and Biggar, 1980). It has been noted by Barrette (2015) that with the advancement of new technologies and materials it could be time to revisit the idea of reinforcing ice.
- **Macroscopically reinforcing the ice.** The bearing capacity of ice could potentially be increased through reinforcement using larger materials. Potential options include logs, steel cables, tree branches, aircraft cables, wooden dowels, fabrics, fiberglass yarn, fiberglass insulating mats, wood fibers, asbestos fiber, newspaper mash, bond paper mash, bond paper strips, starch, and steel bars (Gold, 1971; Michel et al., 1974; Ohstrom and DenHartog, 1976; Jarrett and Biggar, 1980; Coble and Kingery, 1963; Cederwall, 1981).
- **Maintaining snow on surfaces during periods of sun and warm temperature.** Snow is a weaker thermal insulator than ice. The Treasury Board of Canada Secretariat (2002) recommends that a covering of 7.5 to 10 cm of clean snow will significantly reduce the solar radiation penetration to the ice and prolong the period of use. This is further confirmed by the Government of Northwest Territories (2015) which notes that the effects of warm temperature are greatest on bare ice and reduced by increasing depth of snow cover.

- **Adjusting operational guidelines.** Warmer winters could require a shift in operational guidance. For example, the Government of Alberta has a series of recommendations for the operation of their ice roads, if the temperature is greater than 0°C for more than 48 hours including changed measurement schedules and reducing the allowable weight by 50% (Government of Alberta, 2013).
- **Flooding the skateway.** Manually pumping water onto an existing sheet of ice is an effective and proven way to increase the thickness of good quality clear ice for skateways, rinks, and ice roads. The Treasury Board of Canada Secretariat (2002) created helpful guidance for flooding ice roads and bridges which could be adapted for outdoor skateways. Flooding could begin when the natural ice is approximately 7.5 cm thick and strong enough to bear the weight of a person and pumps, and the initial flooding should be limited to approximately 2.5 cm. Subsequent floodings should be limited to the depth of water that will freeze within 12 hours. Wind or snow on the surface could increase or decrease the freezing rate. Creating thicker lifts could lead to a layer of water between the old ice and the new ice and could reduce the overall strength of the ice and overload and crack the existing ice cover (Treasury Board of Canada Secretariat, 2002). The NCC and partners have developed advanced ice flooding practices considering the unique application for the Skateway.
- **Reducing the use of road salt.** Salt can decrease the freezing temperature of water. Salt on nearby roads flows into the canal via stormwater drains and can therefore impact the quality of the ice. Consult the TAC Best Practices Road Salt Management for alternatives to chloride-based de-icers and investigate options in partnership with the City of Ottawa. https://tac-atc.ca/sites/tac-atc.ca/files/site/doc/resources/roadsalt-10.pdf
- **Reduce the flow and turbidity of the water.** Along sections of the Rideau Canal, especially between Rideau Street and Laurier Avenue, there are drainage pipes installed to capture and reduce the volume of stormwater flow to protect the fragile ice (Larocque and Pringle, 2020).

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6.5 LITERATURE REVIEW DATABASE

#	Reference	Date	Location	Type	In-text Citation	Link	Summary of Content	Relevance (1-3, 3 being the most relevant)	
1	CSA ISO 31000:18 Risk management - Guidelines	2018	Canada	Standard	(CSA Group, 2018)	https://www.iso.org/standard/65694.html	• Provides guidance on identifying and managing risks to an organization • Establishes a framework for risk management; context and scope definition, risk assessment, risk treatment, monitoring and reporting	• Risk assessment methodology that could be applied to the Rideau Canal climate risk assessment • Does not discuss hazards, risks or risk treatments that specifically apply to the Rideau Canal Skateway operation	2
2	IEC 31010:2019 Risk management - Risk assessment techniques	2019	International	Standard	(IEC, ISO, 2019)	https://www.iso.org/standard/72140.html?browse=tc	• Provides guidance on the implementation of risk assessments; planning, information collection and analysis, review, decision-making • Describes risk assessment techniques and guidance on selecting the most appropriate one	• Describes risk assessment techniques that could be applied to the Rideau Canal climate risk assessment • Does not discuss hazards, risks or treatments that specifically apply to the Rideau Canal Skateway operation	2

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#	Reference	Date	Location	Type	In-text Citation	Link	Summary of Content	Relevance (1-3, 3 being the most relevant)	
3	ISO 14090:2019 Adaptation to climate change - Principles, requirements and guidelines	2019	International	Standard	(ISO, 2019)	https://www.iso.org/standard/68507.html	• Provides context and principles for climate adaptation work; flexibility, mainstreaming, sustainability, incorporating mitigation alongside adaptation, systems thinking, transparency and accountability • High-level guidance on creating an adaptation plan	• Provides foundation and context for climate adaptation work • Does not include adaptation measures specific to the Rideau Canal Skateway operation	2
4	ISO/TS 14092:2020 Adaptation to climate change - Requirements and guidance on adaptation planning for local governments and communities	2020	International	Standard	(ISO, 2020)	https://www.iso.org/standard/68509.html?browse=tc	• Provides a methodology for climate adaptation work which is similar to ISO 31000; identifying vulnerabilities, climate impacts, and risk. • How to develop an adaptation plan specific to governments and/or communities, including governance structures, planning, implementation and monitoring of the plan	• Provides a methodology for climate adaptation planning • Does not include adaptation measures specific to the Rideau Canal Skateway operation	2

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#	Reference	Date	Location	Type	In-text Citation	Link	Summary of Content	Relevance (1-3, 3 being the most relevant)	
5	ISO/FDIS 14091 Adaptation to climate change — Guidelines on vulnerability, impacts and risk assessment	n/a	International	Standard		ISO/FDIS 14091 Adaptation to climate change — Guidelines on vulnerability, impacts and risk assessment	• Provides guidelines for assessing the risks related to the potential impacts of climate change. • Indicates how to assess vulnerability and can be used for present or future climate risks.	• Risk assessment methodology that is be applied to the Rideau Canal climate risk assessment • Does not discuss hazards, risks or risk treatments that specifically apply to the Rideau Canal Skateway operation	1
6	ISO/WD 4980 Risk assessment for sports and other recreational facilities and equipment	n/a	International	Standard		ISO/WD 4980 Risk assessment for sports and other recreational facilities and equipment	no access		2
7	ISO 13822:2010 Bases for design of structures — Assessment of existing structures	2010	International	Standard	(ISO, 2010)	ISO 13822:2010 Bases for design of structures — Assessment of existing structures	no access		1

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#	Reference	Date	Location	Type	In-text Citation	Link	Summary of Content	Relevance (1-3, 3 being the most relevant)	
8	ISO 9196:1992 Liquid flow measurement in open channels — Flow measurements under ice conditions	1992	International	Standard	(ISO, 1992)	ISO 9196:1992 Liquid flow measurement in open channels — Flow measurements under ice conditions	no access		1
9	ISO/TR 11328:1994 Measurement of liquid flow in open channels — Equipment for the measurement of discharge under ice conditions	1994	International	Standard	(ISO, 1994)	ISO/TR 11328:1994 Measurement of liquid flow in open channels — Equipment for the measurement of discharge under ice conditions	no access		1

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#	Reference	Date	Location	Type	In-text Citation	Link	Summary of Content	Relevance (1-3, 3 being the most relevant)
10	ISO 5667-4:2016 Water quality — Sampling — Part 4: Guidance on sampling from lakes, natural and man-made	2016	International	Standard	(ISO, 2016)	ISO 5667-4:2016 Water quality — Sampling — Part 4: Guidance on sampling from lakes, natural and man-made	no access	1
11	DIN 18036 Ice-sport facilities - Ice-sport facilities with artificial ice - Rules for planning and construction	2017	Germany	Standard	(DIN, 2017)	https://shop.snv.ch/Standard/Sports-equipment-and-facilities/DIN-18036/2017-10.html?listtype=search&searchparam=%22skating%22	no access	2
12	Technical requirements and test methods for natural material sports field Part 3: Ice Rink	2006	China	Standard	(SPC, 2006)	https://webstore.ansi.org/Standards/SPC/GB199952006	no access	2

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#	Reference	Date	Location	Type	In-text Citation	Link	Summary of Content	Relevance (1-3, 3 being the most relevant)	
13	ASTM F1703-13 Standard guide for skating and ice hockey playing facilities	2013	USA	Standard	(ASTM, 2013)	https://webstore.ansi.org/Standards/ASTM/ASTMF170313	no access		2
14	Nature-based tourism, outdoor recreation and adaptation to climate change	2005	Finland	Research Paper	(Sievanen et al, 2005)	https://helda.helsinki.fi/bitstream/handle/10138/41057/SYKEmo_341.pdf?sequence=1&isAllowed=y	• Discussion of the attitudes that the public and tourism operators had (in 2004) towards the impact of climate change on winter and summer activities • Projected future participation in summer and winter tourism activities based on climate projections • Found that (in 2004) winter tourism operators were not concerned with the impact of climate change, or did not believe it would have an impact, therefore presenting a need for further investigation and dissemination of potential impacts on Finland's tourism sector	• Projected recreational participation modelling could be applied to the Rideau Canal Skateway, but the findings of this study are not applicable • Suggests skating as an alternative to cross-country skiing in the absence of snow	2

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#	Reference	Date	Location	Type	In-text Citation	Link	Summary of Content	Relevance (1-3, 3 being the most relevant)	
15	Projections of declining outdoor skating availability in Montreal due to global warming	2020	Canada	Research Paper	(Dickau et al, 2020)	https://iopscience.iop.org/article/10.1088/2515-7620/ab8ca8/pdf	• Research on the weather conditions required to maintain an outdoor skating rink in good condition is limited • Evaluated various models for predicting outdoor skating rink availability, finding the best indicator was the mean of the preceding six-day maximum temperatures • Predicts that the outdoor skating season in Montreal could decline by between 15-75% by 2090. At the end of the century (2090s), the skating season is predicted to have a mean of 41 days under RCP 2.6 and 11 days under RCP 8.5 in Montreal	• Outdoor skating rink-specific findings • This study and its methods can be used to evaluate the method or results of the Rideau Canal Skateway's climate projections and risk assessment	3

APPENDIX B

#	Reference	Date	Location	Type	In-text Citation	Link	Summary of Content	Relevance (1-3, 3 being the most relevant)	
16	Effects of climate change on outdoor skating in the Bei Hai Park of Beijing and related adaptive strategies	2017	China	Journal Article	(Liu et al, 2017)	https://www.mdpi.com/2071-1050/9/7/1147/htm	• Analyzed impacts of historical weather on skating operations in Beijing • Discusses changes to operation of the Ben Hai skating rink including reduction of available skating areas, reduction of number of skaters due to insufficient ice depth • Operating on January 1st is important to operators as it is the busiest day of the year, but some years the ice was not thick enough yet on that date • Chinese government requires a minimum of 15 cm ice thickness with one person per 10 square meters (as reported in this paper with no specific standard referenced) • Adaptation measures are limited. Some include hosting events on the ice to increase tourism during operable times, flooding rink to add ice layers.	• Discusses climate impacts to skating facilities to operations (based on historical data) and business owners and skaters (based on interviews) • Does not provide many useful adaptation measures or risk management strategies other than hosting tourism events when ice is thick enough to make up for lost revenues due to shorter seasons	3

APPENDIX B

#	Reference	Date	Location	Type	In-text Citation	Link	Summary of Content	Relevance (1-3, 3 being the most relevant)	
17	The likelihood of holding outdoor skating marathons in the Netherlands as a policy-relevant indicator of climate change	2009	Netherlands	Journal Article	(Visser, Peterson, 2009)	https://link.springer.com/article/10.1007/s10584-008-9498-6	• Discusses using the likelihood of hosting skating racing events as a political driver for climate action and as an indicator for climate change in the Netherlands • Investigates trends in ice thickness and the related decision making process in choosing to host the skating race event or not	• Discusses weather and climate indicators and trends and their impacts on outdoor skating, and how this can be used to communicate the climate emergency • Does not provide risk management or adaptation measures for outdoor skating facilities	2
18	Projections of Climate Change Effects on Water Temperature Characteristics of Small Lakes in the Contiguous U.S.	1999	United States	Journal Article	(Fang, Stefan, 1999)	https://link.springer.com/article/10.1023/A:1005431523281	• Modeled the impacts of climate change, namely temperature, on the water temperature characterises of small lakes to quantify the sensitivity of lake water to latitude, longitude, lake geometry, and trophic status. • Determined that ice covers of lakes in the northern US would change strongly. • No access to the full article	• Strong focus on lake-specific characteristics such as depth and trophic layers could potentially not apply to canal systems. • Does not discuss hazards, risks or risk treatments that specifically apply to the Rideau Canal Skateway operation	1

APPENDIX B

#	Reference	Date	Location	Type	In-text Citation	Link	Summary of Content	Relevance (1-3, 3 being the most relevant)	
19	Simulated climate change effects on ice and snow covers on lakes in a temperate region	1997	Minnesota, United States	Journal Article	(Fang, Stefan, 1997)	https://www.sciencedirect.com/science/article/abs/pii/S0165232X96000237	• Modeled ice and snow cover to predict the effects of climate warming on ice and snow cover using a temperature. • No access to the full article	• Strong focus on lake-specific characteristics such as depth and trophic layers could potentially not apply to canal systems. • Does not discuss hazards, risks or risk treatments that specifically apply to the Rideau Canal Skateway operation	1
20	Effects of Changes in Arctic Lake and River Ice	2012	Arctic	Journal Article	(Prowse et al., 2012)	https://link.springer.com/article/10.1007/s13280-011-0217-6	• Literature review of the effects of changes in arctic freshwater lake and river ice from a ecological, hydrological, and socio-economical perspective. • The paper concludes that of particular concern to hydrological regimes are alterations to river low flows, lake evaporation and water levels, and river-ice break up severity and timing. River geomorphology, vegetation regimes, and nutrient/sediment fluxes that sustain aquatic ecosystems.	• Though river systems and canals differ due to the controlled nature of the latter, there are some overlapping parameters that could be helpful in conducting an assessment.	2

APPENDIX B

#	Reference	Date	Location	Type	In-text Citation	Link	Summary of Content	Relevance (1-3, 3 being the most relevant)	
21	Impact of Climate Change on River Ice Phenology in Lithuania	2008	Lithuania	Journal Article	(Šarauskienė, Jurgelėnaitė, 2008)	https://www.researchgate.net/profile/Diana_Sarauskiene/publication/265983287_Impact_of_Climate_Change_on_River_Ice_Phenology_in_Lithuania/links/551931f40cf273292e70d238/Impact-of-Climate-Change-on-River-Ice-Phenology-in-Lithuania.pdf	• Study of the historical impacts of differing climate on 8 rivers during 13 historic periods. The paper includes discussion of the requirements of ice formation in rivers and focuses on duration and timing of ice. • It was noted that the largest impact on ice formation and its decrease was the construction of a dam on one of the rivers.	• Discussions on freeze-time and duration in relation to changes in temperature could be applied to the canal system. • Though river systems and canals differ due to the controlled nature of the latter, there are some overlapping parameters that could be helpful in conducting an assessment.	2
22	Overview of ice roads in Canada: design, usage and climate change mitigation	2015	Canada	Technical Report	(Barrette, 2015)	https://nrc-publications.canada.ca/eng/view/ft/?id=5984226f-bee8-48fe-a138-5a23c800f435	• A comprehensive review of the guidances, best practices, and adaptation measures of ice roads in Canada	• The adaptation measures and climate risks identified in the review can be directly applied to the canal. Some information could not be relevant and has been excluded from the review.	3

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#	Reference	Date	Location	Type	In-text Citation	Link	Summary of Content	Relevance (1-3, 3 being the most relevant)	
23	Climate change impacts and adaptation: Case studies of roads in Northern Canada	2008	Canada	Conference Presentation	(McGregor et al., 2008)	NA	• A presentation on tested adaptation options for Northern Canadian roads	• Could provide a basis for potential adaptation options	2
24	Safe Operating Procedures for Winter Roads Committee. Winter Roads Handbook	2009	Saskatchewan, Canada	Guide	(Government of Saskatchewan, 2009)	http://www.highways.gov.sk.ca/Doing Business with MHI/Ministry Manuals/Winter Roads Handbook/Winter Roads Handbook.pdf	• A comprehensive guidance on the creation, maintenance, health and safety, and operations of ice roads including determination of the safe weight to thickness ratio and consideration of climate hazards	• Could provide a basis for potential adaptation option • Provides quantitative values for ice thickness that could be useful for determining relevant climate projections	3
25	Safety Guide for Operations Over Ice		Canada	Guide	(TBS, 2002)	https://www.collectionscanada.gc.ca/eppp-archive/100/201/301/tbs-sct/tb_manual-ef/Pubs_pol/hrpubs/TBM_119/CHAP5_3_e.html	• A comprehensive guidance on the creation, maintenance, health and safety, and operations of ice roads and bridges including determination of the safe weight to thickness ratio and consideration of climate hazards	• Could provide a basis for potential adaptation option • Provides quantitative values for ice thickness that could be useful for determining relevant climate projections	3

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#	Reference	Date	Location	Type	In-text Citation	Link	Summary of Content	Relevance (1-3, 3 being the most relevant)	
26	Guideline for Safe Ice Construction	2015	Northwest Territories, Canada	Guide	(GNWT, 2015)	www.inf.gov.nt.ca/sites/inf/files/resources/0016-001_norex_ice_road_constr._web.pdf	• A comprehensive guidance on the creation, maintenance, health and safety, and operations of ice roads including determination of the safe weight to thickness ratio and consideration of climate hazards • Provides an overview of ice types and their formation	• Could provide a basis for potential adaptation option • Provides quantitative values for ice thickness that could be useful for determining relevant climate projections	3
27	Best Practice For Building and Working Safety on Ice Covers in Alberta	2013	Alberta, Canada	Guide	(Government of Alberta, 2013)	open.alberta.ca/dataset/612530c3-9f41-41f3-ad45-4b62b47a0b06/resource/74decde6-8120-46be-b137-158bb63ee569/download/whs-pub-sh010.pdf.	• A comprehensive guidance on the creation, maintenance, health and safety, and operations of ice roads including determination of the safe weight to thickness ratio and consideration of climate hazards.	• Could provide a basis for potential adaptation option • Provides quantitative values for ice thickness that could be useful for determining relevant climate projections	3
28	Ice in Lakes and Rivers	1998	General	Encyclopedia Entry	(Ashton, 1998)	www.britannica.com/science/lake-ice/Ice-in-rivers	• Overview of the formation and characteristics of ice in lakes and water	• Provides background materials and the baseline science for ice formation considerations such as turbidity and temperature	2

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#	Reference	Date	Location	Type	In-text Citation	Link	Summary of Content	Relevance (1-3, 3 being the most relevant)	
29	A Laboratory Study on the Flexural Strength of White Ice and Clear Ice from the Rideau Canal Skateway	2011	Ottawa, Canada	Journal Article	(Barrette, 2011)	NA	• Provided a Rideau-specific understanding of the impacts of White Ice and its flexural strength	• Provides a basis for understanding the relationship of white ice and clear ice in the canal	3
30	Ice Reinforcement	1963	Cambridge	Journal Article	(Coble, Kingery, 1963)	NA	• An investigation of a number of options to macroscopically reinforce ice including fiberglass, yarn, fiberglass insulation mat, wood fiber, asbestos fiber, newspaper mash, bond paper mash, bond strips, and starch and the associated increase in ice strength	• Could provide a basis for potential adaptation options	2
31	Observed Decreases in the Canadian Outdoor Skating Season Due to Recent Winter Warming	2012	Canada	Journal Article	(Damyanov, 2012).	NA	• Describes trends in the Canadian outdoor skating seasons due to winter warming.	• Provides background and support for climate projections and risk	3

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#	Reference	Date	Location	Type	In-text Citation	Link	Summary of Content	Relevance (1-3, 3 being the most relevant)	
32	The State of Climate Change Adaptation in the Arctic	2014	Arctic	Journal Article	(Ford, 2014)	NA	• Describes 157 Arctic adaptation initiatives to a changing climate	• The primary focus is on sustenance farming. Minor references to ice roads.	1
33	Use of Ice Covers for Transportation	1971	Canada	Journal Article	(Gold, 1971)	NA	• Provides information on the formation and structure differences between white ice and clear ice • Provides the basis for calculating the strength of ice when there is combination of ice layers	• Provides background and support for determining ice thresholds and could inform climate projection selection.	2
34	Bearing Capacity Tests on Ice Reinforced with Geogrid	1992	General	Journal Article	(Hayne et al., 1992)	NA	• An investigation on the bearing capacity of ice reinforced with Geogrid	• Could provide a basis for potential adaptation options	2
35	Reinforced Ice: Mechanical Properties and Cost Analysis for Its Use in Platforms and Roads	1988	General	Conference Proceeding	(Kuehn, Nixon, 1988)	NA	• Cost analysis of the economic aspects of microscopically reinforcing ice	• Could inform potential adaptation options	2

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#	Reference	Date	Location	Type	In-text Citation	Link	Summary of Content	Relevance (1-3, 3 being the most relevant)	
36	The NCC's Secret Weapon to Freeze the Downtown Section of the Rideau Canal Skateway This Winter	2020	Ottawa, Canada	News Article	(Larocque, Pringle, 2020).	ottawa.ctvnews.ca/the-ncc-s-secret-weapon-to-freeze-the-downtown-section-of-the-rideau-canal-skateway-this-winter-1.5192844.	• Journalistic reporting on the plan to add an additional pipe to the Rideau Canal to reduce and absorb the volume of water coming out of a drain	• Could provide a basis for potential adaptation options	3
37	Ice Bridges in the James Project	1974	Alberta, Canada	Journal Article	(Michel et al., 1974)	NA	• Reference to the amount of extra time needed for microscopic ice reinforcement	• Could inform potential adaptation options	2
38	"It's Too Late: Short Ice-Skating Ends for the Season on Renowned Rideau Canal	2020	Ottawa, Canada	News Article	(Montgomery, 2020)	[www.rcinet.ca/en/2020/03/02/its-too-late-short-ice-skating-ends-for-the-season-on-renowned-rideau-canal/.](www.rcinet.ca/en/2020/03/02/its-too-late-short-ice-skating-ends-for-the-season-on-renowned-rideau-canal/)	• Describes trends in the skating season for the Rideau Canal due to winter warming.	• Provides background and support for climate projections and risk	3

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#	Reference	Date	Location	Type	In-text Citation	Link	Summary of Content	Relevance (1-3, 3 being the most relevant)	
39	Salinity and Brine	2020	General	Website	(National Snow & Ice Data Center, 2020)	nsidc.org/cryosphere/sea ice/characteristics/brine_salinity.html#:~:text=For every 5 psu increase, Celsius (28.8 degrees Fahrenheit).&text=This raises the salinity of the near-surface water.	• Overview of the impacts of salt on the melting point of water	• Could inform potential adaptation options • Could inform climate risks	2
40	The Fracture Toughness of Some Wood-Ice Composites	1987	General	Journal Article	(Nixon, Smith, 1987)	NA	• An investigation on the thickness and fracture toughness of ice reinforced with softwood, sawdust, shredded bark, and shredded newspaper	• Could provide a basis for potential adaptation options	2

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#	Reference	Date	Location	Type	In-text Citation	Link	Summary of Content	Relevance (1-3, 3 being the most relevant)	
41	Ice Profiler	2020	General	Website	(Ocean Networks Canada, 2020)	www.oceannetworks.ca/learning/ocean-sense/resources-lessons/ice-profiler#:~:text=Detailed explanation, freezes at 0°C).&text=If the water is brackish, little below 0°C.	• General resource and background information on ice properties and melting points	• Provides background and support for determining ice thresholds and could inform climate projection selection.	2
42	Cantilever Beam Tests on Reinforced Ice	1976	General	Book	(Ohstrom, DenHartof, 1976)	NA	• Reference to the amount of extra time needed for microscopic ice reinforcement	• Could inform potential adaptation options	2
43	Winter Roads and Ice Bridges: Anomalies in Their Records of Seasonal Usage and What We Can Learn from Them'	2009	Canada	Conference Proceeding	(Rawlings et al., 2009)	NA	• Presentation on seasonal anomalies in winter roads and ice bridges	• Could inform potential adaptation options • Provides background and support for climate projections and risk	2

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#	Reference	Date	Location	Type	In-text Citation	Link	Summary of Content	Relevance (1-3, 3 being the most relevant)	
44	Winters Too Warm to Skate? Citizen-Science Reported Variability in Availability of Outdoor Skating in Canada	2015	Canada	Journal Article	(Robertson et al., 2015)	NA	• An analysis of two years of citizen science reports for ten skating locations across Canada, including Montreal	• Provides background and support for climate projections and risk	2
45	" A Review on Development of Reinforced Ice Structures and Dams	2014	General	Conference Proceeding	(Vasiliev et al., 2014)	NA	• A presentation on the development of ice structures	• Could inform potential adaptation options	2
46	A Review on Processes and Their Modelling	2005	General	Journal Article	(Hock, 2005)	www.atmos.albany.edu/daes/atmclasses/atm551/OtherReadingMaterials/Hock_ProgPhysGeogr-2005.pdf.	• An overview of energy modeling of solar radiation and the impact on glacier melt	• Provides background and support for climate projections and risk	2

APPENDIX

C

MONITORING PROGRAM REPORT

ENGINEERING BRIEF

RECIPIENTS:	Bruce Devine, National Capital Commission Kelly Symes, National Capital Commission
SENDER:	Simon Nolin, WSP Canada Inc.
COPY:	Jean-Philippe Martin, WSP Canada Inc. Pierre Pelletier, WSP Canada Inc.
DATE:	April 15, 2021
SUBJECT:	**Rideau Canal Skateway – February 2021 Monitoring Campaign** **WSP Ref.: 201-10298-00**

1.0 CONTEXT AND OBJECTIVES

In February 2021, the National Capital Commission (NCC) has mandated WSP Canada Inc. (WSP) to conduct a winter monitoring campaign on the Rideau Canal Skateway in Ottawa. The monitoring program developed by WSP included water temperature and conductivity measurements under the ice cover at multiple locations along the Skateway.

The main purpose of the monitoring campaign was to acquire data about the Rideau Canal's thermal regime in winter. The information collected by WSP in February 2021 is a first step in the understanding of the environmental processes that impact the extent, quality, and integrity of the ice on the Skateway.

The 2021 campaign was accomplished as part of an ongoing Project by WSP called "Risk Assessment of the Effects of Climate Change on the Rideau Canal Skateway". Findings will hopefully help define mitigation solutions to improve safe ice conditions and extend the duration of the future skating seasons.

2.0 SITE DESCRIPTION

The Skateway is located on the Rideau Canal in Ottawa between Hartwells Locks and Ottawa Locks (Figure 2.1). It has a total length of 7.8 kilometers and includes a loop on Dow's Lake, and a smaller one on Patterson Creek.

The Rideau Canal is located between the Rideau River and the Ottawa River (Figure 2.1). Water from the Rideau Canal flows through Hogs Back Locks (n°11-12) and Hartwells Locks (n°9-10) before entering in the Skateway reach. Water leaves the Skateway reach by Ottawa Lock n°8. These locks are all maintained and operated by Parks Canada (PC).

In late Fall, PC temporally lowers the water level in the canal to allow the NCC team to install the Skateway infrastructures. After the installation period, PC rises back the water level in the

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canal but to a lower elevation than during the navigation season. PC installs stoplogs upstream of Lock n°8 to control the winter water level.

The Rideau Canal flows through an urban area. Several outlets drain into the canal, including large ones next to Cooper Street (KP 0.7) and Laurier Avenue (KP 0.3).

Vertical concrete wall runs on both sides of the canal on its entire length, except for Dow's Lake west shore. Downstream of Dow's Lake (KP 0.0 to 5.4), the Canal width varies between 20 and 100 m, approximately.

Navigation charts show that the minimum water depth ([1]) in the center of the Canal is about 1.5 m (5 ft). In winter, the depth is about 1.2 m lower than during the navigation season. The maximum depth in Dow's Lake ([1]) is about 6.4 m (21 ft).

The total surface area of the canal ([1]), between KP 0,0 and 7,8 and including Dow's Lake, is 0.5 km².

On the most downstream Reach (KP 0.0 to 1.0), the Canal is narrow (±20 m width) and shallow (<1 m water depth in its center).

Figure 2.1 Rideau Canal Skateway Location Map (KP are "Kilometric Points" along the Skateway)

[1] During navigation season.

3.0 WINTER 2021 SKATING SEASON

The 51st skating season on the Rideau Canal began on January 28 and ended on February 23, 2021 (26 days of skating).

In November 2020, NCC has installed pipes (Photo 3.1) at the outlet of Laurier Avenue Drain to divert and convey more downstream the incoming inflow.

The first reach to open on January 28 was the one between Pretoria Bridge (KP 2.0) and Bank Street Bridge (KP 4.4). Three days later, on January 31, the canal was opened on its full length: between KP 0.0 and 7.8.

Figure 3.1 illustrates the hourly air temperature recorded by Environment Canada at station Ottawa CDA RCS (#6105978). This station is located about 1.5 km south-west of Dow's Lake.

Table 3.1 presents a summary of the climate data recorded in Ottawa by EC between December 1, 2020 and February 23, 2021 (end of skating season).

An important rain event occurred on December 24-25, 2020. The total rain recorded by EC on December 24 at station Ottawa CDA was 56.2 mm. This rain and warm weather altered the ice and even opened leads in the ice cover (Photo 3.3).

NCC started flooding the ice with pumps on January 20, 2021 at Dow's Lake (KP 5.8) and on January 20 at Laurier (KP 0.2; Photo 3.2).

The Skateway opened partially on January 28 after a continuous period of 11 days with hourly air temperature inferior to 0°C. The Accumulated Freezing Degree Day (AFDD[2]) on that day was 276°C-d.

In comparison with the Climate Normals during the period 1981-2010 published by Environment Canada, winter 2021 was milder than usual. The AFDD value was 323°C-d by the end of January 2021, which is 36% less than the 1981-2010 normal (508°C-d).

The season ended on February 23, 2021 after a heavy snow event. Maximum daily temperature on February 22, 23 and 24 were respectively 0.2, 3.0 and 2.2°C and the total precipitations were respectively 5.5, 0.7 and 14.5 mm.

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[2] Sum of daily temperature below 0°C starting on December 1st.

Photo 3.1 Pipes Installed by NCC at the Outlet of Laurier Avenue Darin (CTV News, 2020)

Photo 3.2 First Ice Flooding at Laurier (KP 0.2) on January 21, 2021

Photo 3.3 Opened Leads in the Ice Cover at Laurier on December 28, 2020 After the Rain Event

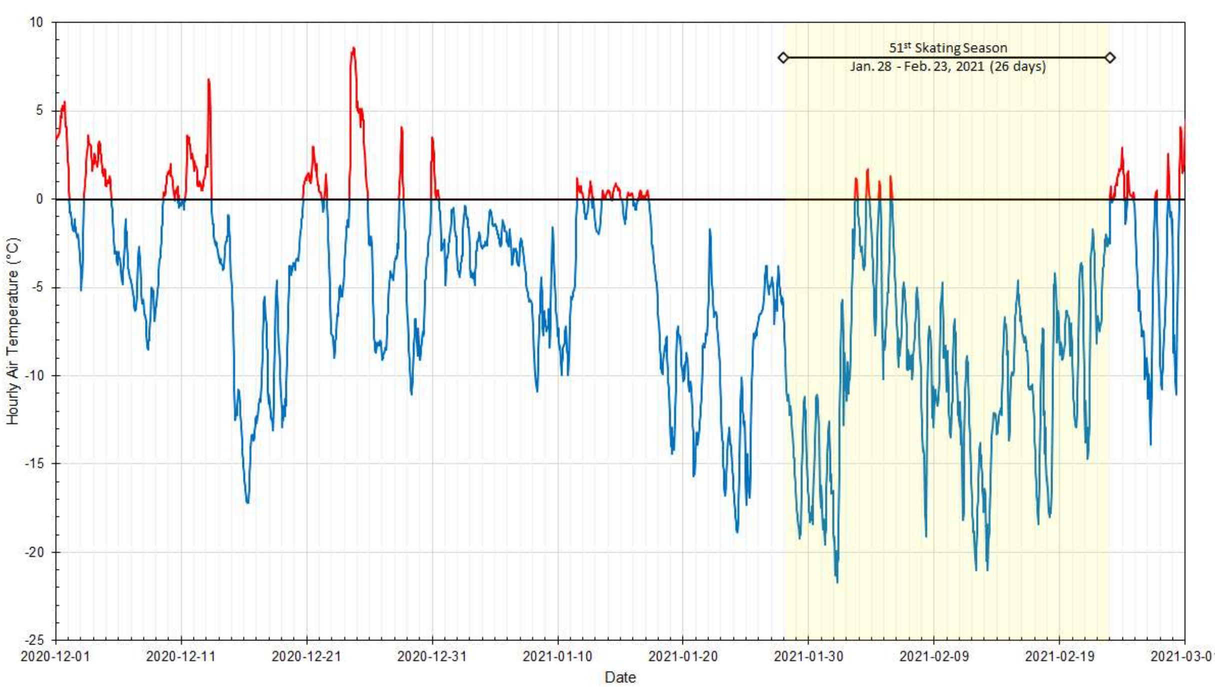

Figure 3.1 Hourly Air Temperature in December-January-February 2021 - Station Ottawa CDA RCS (#6105978, Environment Canada)

Table 3.1 Summary of Climate Records in Ottawa Between December 1, 2020 and February 23, 2021 - Station Ottawa CDA and Ottawa CDA RCS

PARAMETER	DECEMBER	JANUARY	FEBRUARY**
Average monthly temperature (°C)	-3.0	-6.8	-9.1
Maximum daily temperature (°C)	3.0	0.4	1.4
Minimum daily temperature (°C)	-14.8	-16.6	-17.7
Maximum daily rain (mm)	56.2***	5.6	n/a
Maximum AFDD* (°C-d)	111	323	534
Normal AFDD 1981-2010+	190	509	739

* Accumulated freezing degree-day from December 1st.
** February 1 to 23 (end of skating season).
*** On December 24 at station Ottawa CDA.
+ 1981 to 2010 Climate Normals (EC, 2020)

4.0 MONITORING NETWORK

Figure 4.1 illustrates the location of the gauges installed by WSP as part of the winter 2021 monitoring network. A total of eight (8) gauges were installed on February 9, 2021:

- Five (5) temperature (T) gauges at KP 0.3, 0.7, 1.4, 2.4 and 5.6;
- Three (3) conductivity-temperature (CT) gauges at KP 0.0, 3.3 and 7.8.

The gauges were placed about 0.15 m below the underside of the ice cover using a support (Photo 4.1). Water temperature and conductivity were measured using a constant 5 minutes interval.

Gauge 0.3 was placed near the outlet of the Laurier Avenue Outlet Drain (Photo 4.2). At that location, a by-pass conduit has been installed by NCC to convey downstream the drain inflow.

All gauges were retrieved on March 1, 2021; six (6) days after the end of the skating season.

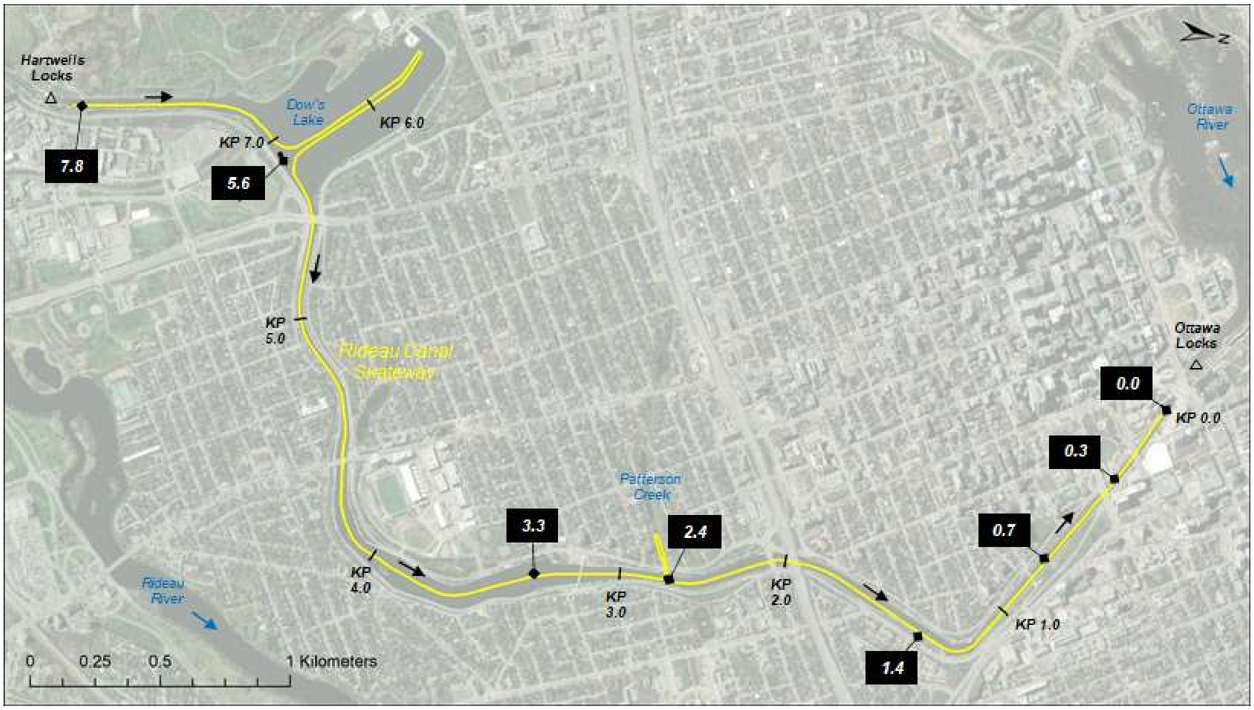

Figure 4.1 **Winter 2021 Monitoring Network - Gauges were Installed at Kilometric Points (KP) 0.0, 0.3, 0.7, 1.4, 2.4, 3.3, 5.6 and 7.8**

Photo 4.1 Gauge Support

Photo 4.2 Gauge Installation at KP 0.3 (Laurier Avenue Drain Outlet)

5.0 RESULTS

5.1 Gauges Status

Table 5.1 summarizes the gauges status when they were retrieved on March 1, 2021.

Six (6) gauges (0.0, 0.3, 0.7, 1.4, 2.4 and 7.8) were successfully retrieved. The conductivity readings from gauge 0.0 are aberrant and cannot be used in the analysis.

Readings from gauge 0.7 show that the instrument was frozen most of the time (trapped in the ice; temperature reading < 0°C) and got released on February 28.

Gauges 3.3 and 5.6 were unfortunately lost and could not be retrieved by WSP. It appears that the support of gauge 5.6 got damaged during ice maintenance.

Table 5.1 Gauges Status - Winter 2021 Monitoring Campaign

GAUGE	TYPE*	STATUS	C	T
0.0	CT	Gauge retrieved but conductivity readings are aberrant.	-	x
0.3	T	Gauge retrieved.		x
0.7	T	Gauge retrieved. Temporary freezing.		x
1.4	T	Gauge retrieved.		x
2.4	T	Gauge retrieved.		x
3.3	CT	Gauge was lost.	-	-
5.6	T	Gauge was lost. Support was damaged.		-
7.8	CT	Gauge retrieved.	x	x

* T = temperature, CT = conductivity and temperature

5.2 Water Temperature

Figure 5.1 and Figure 5.2 illustrate the water temperatures recorded at gauges 0.0, 0.3, 0.7, 1.4, 2.4 and 7.8. Table 5.2 presents, for each gauge, the average and maximum hourly temperature, and the maximum intra-day temperature variation.

Appendix A presents the relation between the hourly air temperature (at station Ottawa CDA RCS) and water temperature measured along the Skateway.

Measurements shows that near-ice water temperature at the entrance of the Skateway (PK 7.8) is often warmer (in the order of +0.3°C) than in the canal downstream. This seems to indicate that water is typically cooling as it flows downstream in the canal.

Data shows that near-ice water is significantly warmer at PK 0.0, with and average temperature of 1.7°C. The temperature difference (compared to the rest of the canal) is typically about +1°C, increases to +2°C on February 25 and reaches +5°C on March 1st. It is suspected that this important temperature could be explained by the urban drainage outlet, particularly Laurier Avenue, that conveys warmer water in the canal.

Results show that the water temperature on the downstream reach of the canal (KP 0.0, 0.3 and 0.7) was more influenced by the rising air temperature above 0°C than upstream. On March 1st, records at gauges at KP 0.0 and 0.7 show major increase in water temperature, in the order of +4°C. Water temperature increase at KP 0.3 (Laurier Avenue) was less important (+0.7°C), which seems to indicate that the pipes installed by NCC (Photo 3.1) were relatively efficient to convey more downstream the warmer water coming out of Laurier Avenue Drain.

An interesting feature was monitored on few days at gauge 0.3: a water temperature increase of about +0.4°C near midnight. This increase coincides with the passage of the ice maintenance vehicle, which may bend locally the ice cover and push deeper the gauge in the water column.

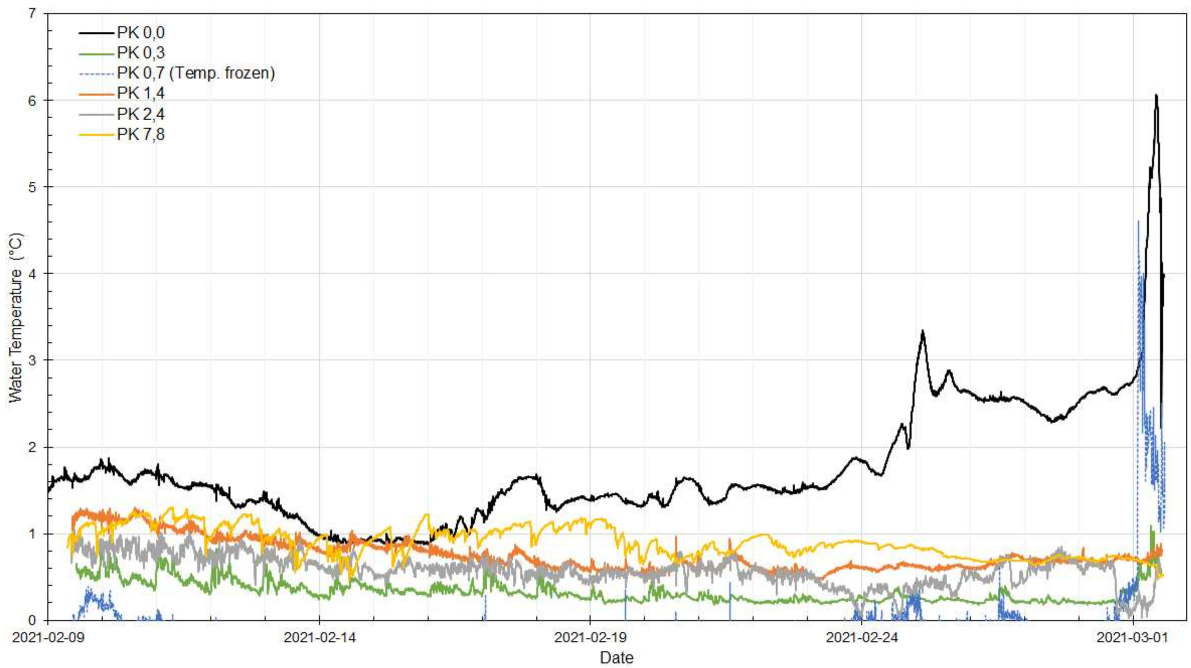

Figure 5.1 Water Temperatures Measured in the Rideau Canal Skateway Between February 9 and March 1, 2021

Table 5.2 Water Temperature Records Between February 9 and March 1, 2021

GAUGE (KP)	DESCRIPTION	WATER TEMPERATURE (°C)		
		AVERAGE	MAXIMUM	ΔT_{MAX}*
0.0	Skateway downstream end	1.7	6.0	+3.8
0.3	Laurier Avenue (Drain)	0.3	1.1	+0.8
0.7	Cooper Street (Drain)	n/a	4.6	+4.4
1.4	Concord Street	0.8	1.3	+0.5
2.4	Patterson Creek	0.6	1.0	+0.7
7.8	Skateway upstream end	0.9	1.3	+0.6

* Maximum intra-day variation.

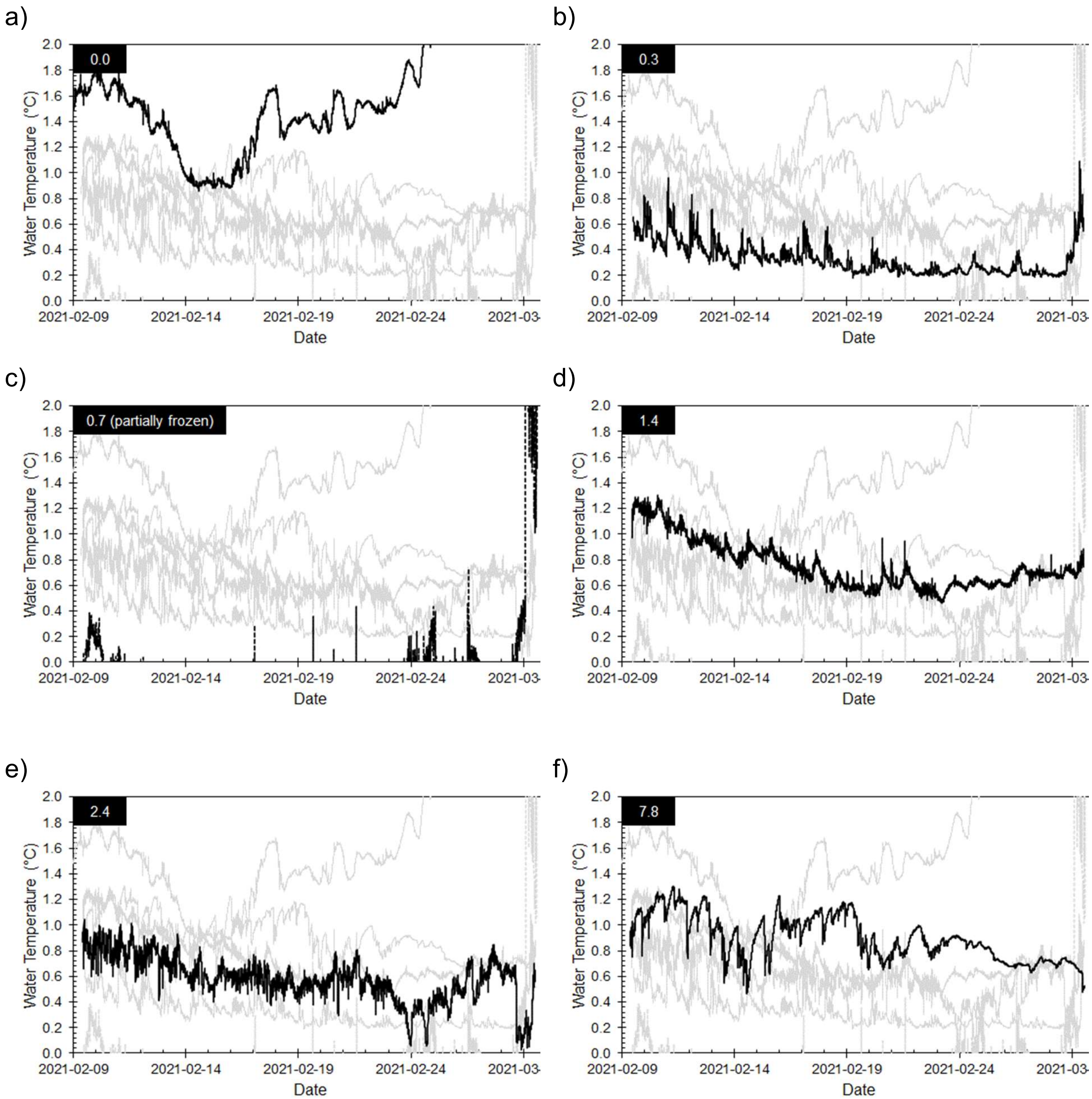

Figure 5.2 Water Temperatures Measured in the Rideau Canal Skateway etween February 9 and March 1, 2021 - Gauges at Kilometric Points (KP) Along the Skateway: KP 0.0 (a), 0.3 (b), 0.7 (c), 1.4 (d), 2.4 (e) and 7.8 (f)

5.3 Conductivity

Conductivity data could only be extracted from gauge at KP 7.8. Therefore, no spatial comparison of conductivity measurement is currently possible.

Figure 5.3 illustrates the conductivity variation at KP 7.8 between February 9 to March 1, 2021. The recorded values range between 641 and 1,637 µS/cm, which is within the typical range for river water. In comparison, seawater has a conductivity in the order of 50,000 µS/cm (Sensorex, 2021).

Because conductivity could not be monitored at other gauges, the impact of the stormwater drains could be analysed based on the February 2021 data. However, it is believed that these drains bring saltier water in the Canal, which would result in higher conductivity on the downstream reach.

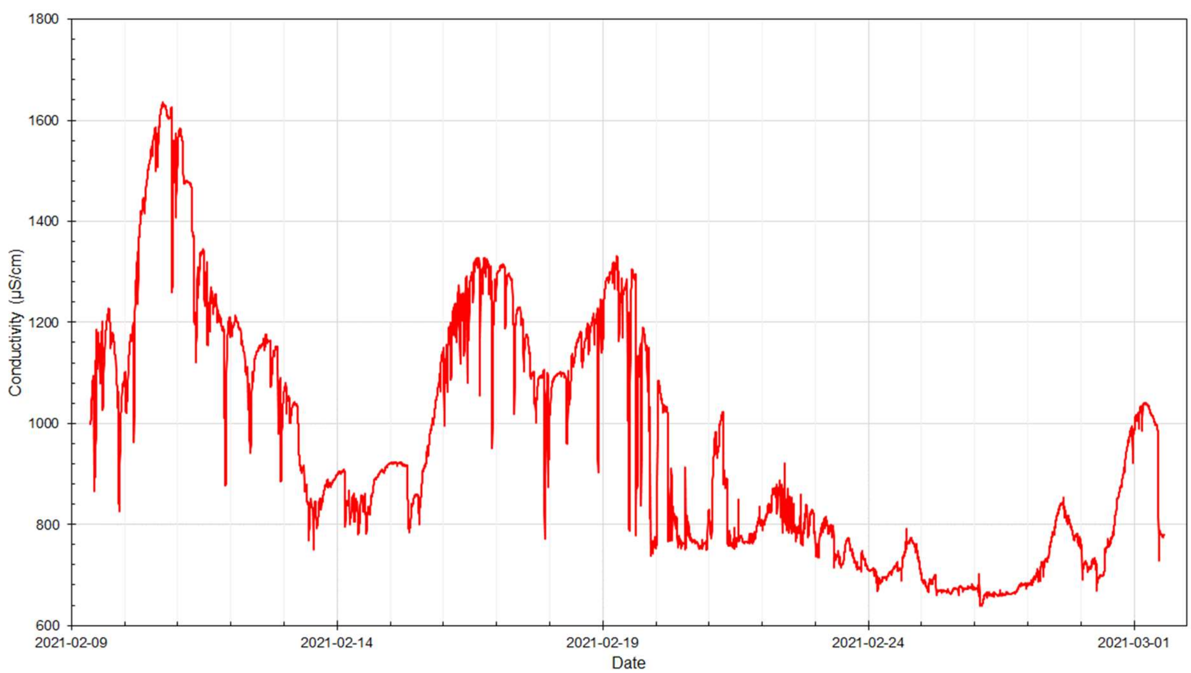

Figure 5.3 Conductivity Measured at PK 7.8 Between February 9 and March 1, 2021

6.0 SUMMARY

In February 2021, WSP has monitored water temperature and conductivity under the ice cover at multiple locations along the Rideau Canal Skateway. The main purpose of the monitoring campaign was to acquire data about the Rideau Canal's thermal regime in winter.

Results shows that water entering the canal is relatively warm (in the order of 1°C) and tends to slightly cool down as it flows downstream.

Results also show that the most downstream reach of the canal (KP 0.0 to 0.7) is highly influenced by warm weather, which increase snowmelt, salt, and sand runoff into the Canal. Water temperature on that reach rose by about +4C°C on March 1st. Maximum air temperature on that day was 4.5°C.

The information collected by WSP in February 2021 is a first step in the understanding of the environmental processes that impact the extent, quality, and integrity of the ice on the Skateway.

7.0 RECOMMENDATIONS

WSP recommends resuming the monitoring campaign on the Rideau Canal Skateway for winter 2021-2022. This campaign could be conducted in collaboration with Parks Canada Agency (PCA), who also has an interest in water quality measurement in the Canal.

Monitoring campaign should start as early as possible in the season, ideally in October, to capture the water cooling processes before the initial ice freeze up.

As planned by WSP for the February 2021 campaign, air temperature gauges should be installed near the Canal to get local information, instead of relying on nearby Environment Canada weather stations.

Additional gauges should be considered when planning the upcoming field campaign. For instance, gauges should be placed near the Hogs Back and Hartwell Locks to monitor the water temperature entering the Canal. Water temperature in the Rideau River, directly upstream of the Hogs Back Locks should be monitored, by installing a new gauge in the river and/or by getting the data collected by PCA at Mooney's Bay.

Additional information about the stormwater drains should also be collected to get a better understanding of their type, dimension, catchment, and spatial location. Information as whether they serve as overflow to sewer system should also be gathered.

8.0 REFERENCES

- CTV NEWS. 2020. The NCC's secret weapon to freeze the downtown section of the Rideau Canal Skateway this winter. Published Tuesday, November 17, 2020. https://ottawa.ctvnews.ca/the-ncc-s-secret-weapon-to-freeze-the-downtown-section-of-the-rideau-canal-skateway-this-winter-1.5192844
- ENVIRONMENT CANADA. 2020. Canadian Climate Normals 1981-2010 Station Data – Station Ottawa CDA #6105976. Website consulted on March 18, 2021. https://climate.weather.gc.ca/climate_normals/results_1981_2010_e.html?stnID=4333&autofwd=1
- SENSOREX. 2021. Conductivity Monitoring for Reverse Osmosis. Website consulted on April 6, 2021. https://sensorex.com/blog/2017/07/12/conductivity-monitoring-reverse-osmosis/

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APPENDIX

D

CLIMATE CHANGE RISK ASSESSMENT DATABASE

Climate Change Risk Assessment

		Climate Hazard			Vulnerability					Risk						
					Sensitivity		Adaptive Capacity				Severity of Impact					
ID	Potential Impact	Related Climate Hazard(s)	Hazard (2080)	Rationale	Rating	Rationale	Rating	Rationale	Vulnerability Rating	Likelihood of Impact	Economic	Health, Safety, and Community	Environmental	Severity Rating	Severity Rationale	Risk Rating
1	Increased warm stormwater output from higher rain-based precipitation melting the canal ice.		High	There is a projected increase in total precipitation in the winter months, but a decrease in projected total snowfall. A decrease in annual total snowfall is projected in the NCR, from approximately 223 cm in the baseline to 193-201 cm in the 2030s, 184-179 cm in the 2050s and 154-124 cm in the 2080s. This represents a decrease of 31-44% by the 2080s (NCC et al., 2020a). This may indicate an increase in precipitation falling as rain which is consistent with other findings for the province. Winter precipitation is projected to increase from a historic (1976-2005) baseline of 199 mm to 169 mm-318 mm in 2051-2080 under RCP8.5.	High	Stormwater will be warmer and more polluted with darker, light-absorbing materials which can increase the rate of melt of the Canal.	High	This is an existing problem and the Skateway already has adaptive capacity built into its operations. Approximately six weeks before the beginning of the skating season a customized stormwater outfall mitigation system, is installed to divert warmer stormwater away from the skating areas. In the fall of 2020 a third pipe was added to divert the overflow in the center of the Rideau Calan and favour the thickening of ice in the sectors from Rideau Street to Laurier Bridge.	Moderate	High	High	Moderate	Low	High	A reduction in viable skating days reduced the economic potential for local vendors, transportation, and accommodations. In addition, a smaller season increases the cost off operation per skating day. Reduced skating days may also impact the community and users of the Skateway. This severity primarily impacts two groups. The first are regular users who use the Skateway to commute to work or for daily purposes and who have been historically frustrated when these activities are impeded. The second are visitors from out of town who must plan, travel, and make larger sacrifices to use the Skateway.	High
2	Increased warm stormwater output from greater snow melt due to higher temperatures melting the canal ice.		High	Overall models project that the winters in the National Capital Region will become shorter and warmer (NCC et al., 2020a). Under RCP8.5 by 2021-2050 mean winter temperatures are projected to increase from a historic average of -8.5°C to -6.1°C (+2.4°C) (Climate Atlas, 2020). By 2051-2080 under the same scenario mean winter temperatures are projected to increase to -3.4°C (+5.1). Notably, by 2051-2080 the maximum winter temperatures are project to increase from a historic average of -2.4°C to 0.1°C, a temperature above the melting point of snow and ice. These trends all indicate increased warming conditions in the future. There is a projected increase in total precipitation in the winter months, but a decrease in projected total snowfall. A decrease in annual total snowfall is projected in the NCR, from approximately 223 cm in the baseline to 193-201 cm in the 2030s, 184-179 cm in the 2050s and 154-124 cm in the 2080s. This represents a decrease of 31-44% by the 2080s (NCC et al., 2020a).	High	Melted snow will be warmer, more polluted with darker, light-absorbing materials and potentially additional ice melting agents such as salt, which can increase the rate of melt of the Canal.	High	This is an existing problem and the Skateway already has adaptive capacity built into its operations. Approximately six weeks before the beginning of the skating season a customized stormwater outfall mitigation system, is installed to divert warmer stormwater away from the skating areas. In the fall of 2020 a third pipe was added to divert the overflow in the center of the Rideau Calan and favour the thickening of ice in the sectors from Rideau Street to Laurier Bridge. In addition snow on the Skateway itself is promptly removed during maintenance.	Moderate	High	High	Moderate	Low	High	A reduction in viable skating days reduced the economic potential for local vendors, transportation, and accommodations. In addition, a smaller season increases the cost off operation per skating day. Reduced skating days may also impact the community and users of the Skateway. This severity primarily impacts two groups. The first are regular users who use the Skateway to commute to work or for daily purposes and who have been historically frustrated when these activities are impeded. The second are visitors from out of town who must plan, travel, and make larger sacrifices to use the Skateway.	High
3	Higher nighttime temperatures delaying the onset of flooding and thickening of the ice.		Very High	Models project a decrease in 'deep-freeze' events, or the number of days when the daily minimum temperature is less than -10°C. They are projected to projected to decrease from approximately 71 days per year in the baseline to approximately 59-57 days in the 2030s, 53-46 days in the 2050s and 48-28 days in the 2080s (NCC et al., 2020a).	Very High	Ice formation occurs during the second phase of the pre-season and requires minimal ice cover and temperatures below -10°C at night and -5°C during the day. If this temperature is not consistently reached the Skateway cannot be flooded and thickened and the season will be delayed.	Low	There are several potential adaptation measures such as installing a mesh grid or microscopically reinforcing the ice however these may be costly and still require minimum temperatures to operate.	High	Very High	High	Moderate	Low	High	A reduction in viable skating days reduced the economic potential for local vendors, transportation, and accommodations. In addition, a smaller season increases the cost off operation per skating day. Reduced skating days may also impact the community and users of the Skateway. This severity primarily impacts two groups. The first are regular users who use the Skateway to commute to work or for daily purposes and who have been historically frustrated when these activities are impeded. The second are visitors from out of town who must plan, travel, and make larger sacrifices to use the Skateway.	Very High
4	Reduced cold snap frequency limiting the operational ability to flood the canal overnight.		Very High	Models project a decrease in 'deep-freeze' events, or the number of days when the daily minimum temperature is less than -10°C.They are projected to projected to decrease from approximately 71 days per year in the baseline to approximately 59-57 days in the 2030s, 53-46 days in the 2050s and 48-28 days in the 2080s (NCC et al., 2020a).	High	As part of maintaining the Skateway ice is created through intense flooding during cold snaps during the regular season. The lack of these cold snaps reduces the ability to thicken and stabilize the ice.	Low	There are several potential adaptation measures such as installing a mesh grid or microscopically reinforcing the ice however these may be costly and still require minimum temperatures to operate.	High	Very High	High	Moderate	Low	High	A reduction in viable skating days reduced the economic potential for local vendors, transportation, and accommodations. In addition, a smaller season increases the cost off operation per skating day. Reduced skating days may also impact the community and users of the Skateway. This severity primarily impacts two groups. The first are regular users who use the Skateway to commute to work or for daily purposes and who have been historically frustrated when these activities are impeded. The second are visitors from out of town who must plan, travel, and make larger sacrifices to use the Skateway.	Very High

5	Reduced periods of cold increasing the enjoyment of skaters and visitors.		Very High	This is a complex opportunity as it is only applicable as long as ice conditions are suitable for skaters. Dimishing skating days will dimishing the opoprtunity for enhanced enjoyment of those skating days. Overall models project that the winters in the National Capital Region will become warmer (NCC et al., 2020a). Under RCP8.5 by 2021-2050 mean winter temperatures are projected to increase from a historic average of -8.5°C (-11.0°C--5.9°C) to -6.1°C (-8.9°C--3.1°C) for an increase of 2.4°C (Climate Atlas, 2020). By 2051-2080 under the same scenario mean winter temperatures are projected to increase to -3.4°C (-6.2°C--0.6°C) for an increase of 5.1°C. Notably, by 2051-2080 the maximum winter temperatures are project to increase from a historic average of -2.4°C (-6.5°C--1.7°C) to 0.1°C (-2.5°C-2.9°C), a temperature above the melting point of snow and ice. These trends all indicate increased warming conditions in the future (Climate Atlas,2020).	Moderate	Skating on the canal is an almost exclusively outdoor activity and by extension the weather on each available skating day will impact the enjoyment of the users. The most sensitive users will likely be those who live more locally and enjoy daily or weekly use of the canal, while those who travel are less likely to be selective about the weather on skating days due to time constraints.	High	Weather and announcements about the Skateway openings are already easily and publicly accessible through social media and the internet. Clothing choices are up to the individual and as the Skateway does not require bookings or tickets users may take advantage of nice days as they see fit.	Low	Low	Moderate	Moderate	Low	Moderate	An increase in nice weather during viable weather may increase use of the Skateway and by extension local vendors and events. This is likely to mostly impact local users, as those visiting from out of town have less flexibility when choosing skating days.	Opportunity
6	Increased frequency of snow events requiring increased maintenance and operations.		Low	There is a projected increase in total precipitation in the winter months, but a decrease in projected total snowfall. A decrease in annual total snowfall is projected in the NCR, from approximately 223 cm in the baseline to 193-201 cm in the 2030s, 184-179 cm in the 2050s and 154-124 cm in the 2080s. This represents a decrease of 31-44% by the 2080s. There is no projected change in the frequency of wet days, or days when precipitation occurs . The number of days with snowfall (defined as the number of days where snowfall ≥ 1 cm occurs) is projected to decrease from approximately 41 days in the baseline to approximately 37-37 days in the 2030s, 33-32 days in the 2050s and 31-22 days in the 2080s. Average projections suggest that annual maximum 1-day snowfall will change from approximately 20 cm in the baseline to 21-20 cm in the 2030s, 22-20 cm in the 2050s and 20-16 cm in the 2080s (NCC et al., 2020a).This suggests a low exposure to an increased frequency of snow events.	Moderate	Standard practice for skate ways and ice roads as well as the Rideau Canal Skateway is to remove and manage snow. This includes shovelling snow off the surface after every snowfall to ensure safe, even surface conditions, reduce weight, and reduce the insulating effect of snow (early in the season).	High	Snow clearing and maintenance is already a component of Skateway maintenance with existing staff and materials already available.	Low	Low	Moderate	Low	Low	Moderate	A reduction in viable skating days reduced the economic potential for local vendors, transportation, and accommodations. In addition, a smaller season increases the cost off operation per skating day. Additional maintenance may also accrue additional costs. Reduced skating days may also impact the community and users of the Skateway. This severity primarily impacts two groups. The first are regular users who use the Skateway to commute to work or for daily purposes and who have been historically frustrated when these activities are impeded. The second are visitors from out of town who must plan, travel, and make larger sacrifices to use the Skateway.	Low
7	Increased magnitude of snow events requiring increased maintenance and operations.		Low	There is a projected increase in total precipitation in the winter months, but a decrease in projected total snowfall. A decrease in annual total snowfall is projected in the NCR, from approximately 223 cm in the baseline to 193-201 cm in the 2030s, 184-179 cm in the 2050s and 154-124 cm in the 2080s. This represents a decrease of 31-44% by the 2080s.Average projections suggest that annual maximum 1-day snowfall will change from approximately 20 cm in the baseline to 21-20 cm in the 2030s, 22-20 cm in the 2050s and 20-16 cm in the 2080s, indicating a slight increase and then a dip (NCC et al., 2020a).	Moderate	Standard practice for skate ways and ice roads as well as the Rideau Canal Skateway is to remove and manage snow. This includes shovelling snow off the surface after every snowfall to ensure safe, even surface conditions, reduce weight, and reduce the insulating effect of snow (early in the season). Snow maintenance is an existing issue, where snowload on the ice can affect its structural integrity and safety. While the average amount of snowfall is expected to decrease, there is an anticipated opportunity to reduce the snow management requirements.	High	Snow clearing and maintenance is already a component of Skateway maintenance with existing staff and materials already available.	Low	Low	Moderate	Moderate	Low	Moderate	A reduction in viable skating days reduced the economic potential for local vendors, transportation, and accommodations. In addition, a smaller season increases the cost off operation per skating day. Additional maintenance may also accrue additional costs. Reduced skating days may also impact the community and users of the Skateway. This severity primarily impacts two groups. The first are regular users who use the Skateway to commute to work or for daily purposes and who have been historically frustrated when these activities are impeded. The second are visitors from out of town who must plan, travel, and make larger sacrifices to use the Skateway.	Low
8	Increased frequency of snow events reducing the ability to flood the Rideau Canal to create new ice.		Low	There is a projected increase in total precipitation in the winter months, but a decrease in projected total snowfall. A decrease in annual total snowfall is projected in the NCR, from approximately 223 cm in the baseline to 193-201 cm in the 2030s, 184-179 cm in the 2050s and 154-124 cm in the 2080s. This represents a decrease of 31-44% by the 2080s. There is no projected change in the frequency of wet days, or days when precipitation occurs . The number of days with snowfall (defined as the number of days where snowfall ≥ 1 cm occurs) is projected to decrease from approximately 41 days in the baseline to approximately 37-37 days in the 2030s, 33-32 days in the 2050s and 31-22 days in the 2080s. Average projections suggest that annual maximum 1-day snowfall will change from approximately 20 cm in the baseline to 21-20 cm in the 2030s, 22-20 cm in the 2050s and 20-16 cm in the 2080s (NCC et al., 2020a).This suggests a low exposure to an increased frequency of snow events.	Moderate	Standard practice is for skate ways to remove snow prior to flooding the surface to reduce uneven surfaces. If too much snow is present and requires additional clearing there may be a delay in flooding.	High	Snow clearing and maintenance is already a component of Skateway maintenance with existing staff and materials already available.	Low	Low	High	Moderate	Low	High	A reduction in viable skating days reduced the economic potential for local vendors, transportation, and accommodations. In addition, a smaller season increases the cost off operation per skating day. Reduced skating days may also impact the community and users of the Skateway. This severity primarily impacts two groups. The first are regular users who use the Skateway to commute to work or for daily purposes and who have been historically frustrated when these activities are impeded. The second are visitors from out of town who must plan, travel, and make larger sacrifices to use the Skateway.	Moderate

9	Loss of direct economic opportunity from reduced attendance to the annual Winterlude event.		Very High	Overall models project that the winters in the National Capital Region will become shorter and warmer (NCC et al., 2020a). Under RCP8.5 by 2021-2050 mean winter temperatures are projected to increase from a historic average of -8.5°C (-11.0°C--5.9°C) to -6.1°C (-8.9°C--3.1°C) for an increase of 2.4°C (Climate Atlas, 2020). By 2051-2080 under the same scenario mean winter temperatures are projected to increase to -3.4°C (-6.2°C--0.6°C) for an increase of 5.1°C. Notably, by 2051-2080 the maximum winter temperatures are project to increase from a historic average of -2.4°C (-6.5°C--1.7°C) to 0.1°C (-2.5°C-2.9°C), a temperature above the melting point of snow and ice. These trends all indicate increased warming conditions in the future (Climate Atlas,2020). The timing of the first fall frost which represents the first day when minimum daily temperatures will fall below 0°C, will shift from late September/early October to mid October: approximately 1-2 weeks later by the 2030s, 2-3 weeks later by the 2050s, and 3-4 weeks later by the 2080s.	High	For years the Rideau Canal has been a prime draw of the annual Winterlude festival. A 2003 study found that 75% of visitors surveyed states that the Skateway was somewhat important in their decision to visit the National Capital Region (Rideau Canal Skateway Factsheet, 2006). It is a large component of winter tourism for the region. Changes to the Skateway's availability are more likely to impact local visitors who go to the festival spontaneously, rather than out-of-town guests who have to book accommodations weeks in advance (CBC News, 2020).	Moderate	In recent years in response to variable weather the festival has been diversifying its offerings and moving events off of the Canal (Jau, 2019). Initiatives such as those could mitigate the damage caused by a shorter and more variable skating season, though the Skateway may remain a main draw for many.	Moderate	High	High	High	Low	High	A reduction in viable skating days reduced the economic potential for local vendors, transportation, and accommodations. In addition, closure of the Skateway may reduce attendance at the Winterlude festival and reduce the local economic benefits the festival provides. Reduced skating days may also impact the community and users of the Skateway. This severity primarily impacts two groups. The first are regular users who use the Skateway to commute to work or for daily purposes and who have been historically frustrated when these activities are impeded. The second are visitors from out of town who must plan, travel, and make larger sacrifices to use the Skateway.	High
10	Loss of indirect economic opportunity from reduced tourism and associated spending including nearby restaurants, hotels, and other activities.		Very High	Overall models project that the winters in the National Capital Region will become shorter and warmer (NCC et al., 2020a). Under RCP8.5 by 2021-2050 mean winter temperatures are projected to increase from a historic average of -8.5°C to -6.1°C (+2.4°C) (Climate Atlas, 2020). By 2051-2080 under the same scenario mean winter temperatures are projected to increase to -3.4°C (+5.1). Notably, by 2051-2080 the maximum winter temperatures are project to increase from a historic average of -2.4°C to 0.1°C, a temperature above the melting point of snow and ice. These trends all indicate increased warming conditions in the future. The timing of the first fall frost which represents the first day when minimum daily temperatures will fall below 0°C, will shift from late September/early October to mid October: approximately 1-2 weeks later by the 2030s, 2-3 weeks later by the 2050s, and 3-4 weeks later by the 2080s.	High	The visitors drawn in by the Skateway produce a significant economic boost for local vendors who report seeing boosts in food, hospitality, transportation, and souvenir sales. In 2014 it was estimated that 650,000 visitors came to the National Capital Region for the Skateway and Winterlude festival (CTV News, 2010). The Region's winter economic health is directly linked to the Skateway and Festival. A 2004 economic study estimated that visitors for the festival brought in $152 million in spending in Ontario and Quebec, with $82.5 million of that specific to Ottawa (CTV News, 2010).	Moderate	In recent years in response to variable weather the festival has been diversifying its offerings and moving events off of the Canal (Jau, 2019). Initiatives such as those could mitigate the damage caused by a shorter and more variable skating season, though the Skateway may remain a main draw for many.	Moderate	High	High	Moderate	Low	High	A reduction in viable skating days reduced the economic potential for local vendors, transportation, and accommodations. Reduced skating days may also impact the community and users of the Skateway. Reduced skating days may also impact the community and users of the Skateway. This severity is more likely to impact out-of-town spending and tourism as locals are more flexible with their arangements and ability to visist and spend money.	High
11	Loss of a cultural Canadian icon.		High	There has already been an observed decreasing trend in the skating seasons length from 1971 to 2020 which is expected to continue as temperatures are projected to increase. Overall models project that the winters in the National Capital Region will become shorter and warmer (NCC et al., 2020a). Under RCP8.5 by 2021-2050 mean winter temperatures are projected to increase from a historic average of -8.5°C to -6.1°C (+2.4°C) (Climate Atlas, 2020). By 2051-2080 under the same scenario mean winter temperatures are projected to increase to -3.4°C (+5.1). Notably, by 2051-2080 the maximum winter temperatures are project to increase from a historic average of -2.4°C to 0.1°C, a temperature above the melting point of snow and ice. These trends all indicate increased warming conditions in the future. The timing of the first fall frost which represents the first day when minimum daily temperatures will fall below 0°C, will shift from late September/early October to mid October: approximately 1-2 weeks later by the 2030s, 2-3 weeks later by the 2050s, and 3-4 weeks later by the 2080s.	Very High	The Skateway has a tremendous amount of cultural significance both locally and internationally. For decades it was the longest outdoor skate way in the world and is a beloved Canadian icon visited by millions. It is also a key attraction of the annual Winterlude festival, a culturally significant event.	Low	The Winterlude festival which is centered around the Skateway has been adapting to move more events off-ice to better withstand variable weather and warmer winters. However, the Skateway has more limited options. In recent years the annual budget to maintain the Skateway has been approximately $1.5 million (Tumilty, 2017). When the Skating season is shortened the costs per day increase dramatically, providing less enjoyment for more money. The need for upfront budget and planning for an attraction with variable success reduces its adaptive capacity. In addition, while there are potential adaptive technics such as installing grid meshes and microscopically reinforcing the ice, these may be cost or environmentally prohibitive and are still dependent to a degree on temperatures cooperating.	High	High	High	Moderate	Low	High	A reduction in viable skating days reduced the economic potential for local vendors, transportation, and accommodations. In addition, loss of a cultural icon may negatively affect community image and spirit. Reduced skating days may also impact the community and users of the Skateway. This severity primarily impacts two groups. The first are regular users who use the Skateway to commute to work or for daily purposes and who have been historically frustrated when these activities are impeded. The second are visitors from out of town who must plan, travel, and make larger sacrifices to use the Skateway.	High
12	Delayed start to the skating season reducing the viable number of skating days.		Very High	The timing of the first fall frost which represents the first day when minimum daily temperatures will fall below 0°C, will shift from late September/early October to mid October: approximately 1-2 weeks later by the 2030s, 2-3 weeks later by the 2050s, and 3-4 weeks later by the 2080s. This is consistent with observed trends from 1971 to 2020 which show increasing delays in the beginning of the season.	Very High	In addition to determining the start of the Skating season, early season cold conditions likely define the dynamics of ice formation, impacting the entire season. A late start has and may mean a reduced Skating season.	Low	There are several potential adaptation measures such as installing a mesh grid or microscopically reinforcing the ice however these may be costly and still require minimum temperatures to operate.	High	Very High	High	Moderate	Low	High	A reduction in viable skating days reduced the economic potential for local vendors, transportation, and accommodations. In addition, a smaller season increases the cost off operation per skating day. Reduced skating days may also impact the community and users of the Skateway. This severity primarily impacts two groups. The first are regular users who use the Skateway to commute to work or for daily purposes and who have been historically frustrated when these activities are impeded. The second are visitors from out of town who must plan, travel, and make larger sacrifices to use the Skateway. Reduced skating days may also impact the community and users of the Skateway. This severity primarily impacts two groups. The first are regular users who use the Skateway to commute to work or for daily purposes and who have been historically frustrated when these activities are impeded. The second are visitors from out of town who must plan, travel, and make larger sacrifices to use the Skateway.	Very High

13	Early end to the skating season reducing the viable number of skating days.		Very High	The timing of the last spring frost which represents the last day when minimum daily temperatures are above 0°C, is projected to occur earlier: approximately 1-2 weeks earlier in the 2030s and 2050s, and 2-4 weeks earlier in the 2080s, compared to the baseline.	Very High	An early end has an may mean a reduced Skating season.	Low	There are several potential adaptation measures such as installing a mesh grid or microscopically reinforcing the ice however these may be costly and still require minimum temperatures to operate.	High	Very High	High	Moderate	Low	High	A reduction in viable skating days reduced the economic potential for local vendors, transportation, and accommodations. In addition, a smaller season increases the cost off operation per skating day. Reduced skating days may also impact the community and users of the Skateway. This severity primarily impacts two groups. The first are regular users who use the Skateway to commute to work or for daily purposes and who have been historically frustrated when these activities are impeded. The second are visitors from out of town who must plan, travel, and make larger sacrifices to use the Skateway.	Very High
14	Increasing warm periods during the season reducing the stability of the ice and reducing the number of viable skating days.		Very High	Overall models project that the winters in the National Capital Region will become shorter and warmer (NCC et al., 2020a). Under RCP8.5 by 2021-2050 mean winter temperatures are projected to increase from a historic average of -8.5°C to -6.1°C (+2.4°C) (Climate Atlas, 2020). By 2051-2080 under the same scenario mean winter temperatures are projected to increase to -3.4°C (+5.1). Notably, by 2051-2080 the maximum winter temperatures are project to increase from a historic average of -2.4°C to 0.1°C, a temperature above the melting point of snow and ice. These trends all indicate increased warming conditions in the future. In addition, historically there has already been a decreasing trend in the skating season length from 1971 to 2020, indicating a high and already present exposure.	High	Warm spells during a season have and may reduce the viable skating days and could delay the start or expedite the end of the season.	Low	There are several potential adaptation measures such as installing a mesh grid or microscopically reinforcing the ice however these may be costly and still require minimum temperatures to operate.	High	Very High	High	Moderate	Low	High	A reduction in viable skating days reduced the economic potential for local vendors, transportation, and accommodations. In addition, a smaller season increases the cost off operation per skating day. Reduced skating days may also impact the community and users of the Skateway. This severity primarily impacts two groups. The first are regular users who use the Skateway to commute to work or for daily purposes and who have been historically frustrated when these activities are impeded. The second are visitors from out of town who must plan, travel, and make larger sacrifices to use the Skateway.	Very High
15	Increase in freeze-thaw cycles reducing the stability and viability of the ice.		Very High	Model predict that winter temperatures will hover around 0°C more frequently in the future and lead to an increase in freeze-thaw cycles. Winter freeze-thaw cycles are projected to increase from approximately 24 days in the baseline to approximately 28-27 days (+3-4 days) in the 2030s, 30-32 days (+6-8 days) in the 2050s and 32-37 days (+8-13 days) in the 2080s.	High	By some estimates ice that has frozen, thawed, and then frozen again is only half as strong as new, clear ice (Patillo, 2017). Repeated freeze-thawing events can reduce the integrity, stability, and safety of the ice and by extension the number of viable skating days.	Low	There are several potential adaptation measures such as installing a mesh grid or microscopically reinforcing the ice however these may be costly and still require minimum temperatures to operate.	High	Very High	High	Moderate	Low	High	A reduction in viable skating days reduced the economic potential for local vendors, transportation, and accommodations. In addition, a smaller season increases the cost off operation per skating day. Reduced skating days may also impact the community and users of the Skateway. This severity primarily impacts two groups. The first are regular users who use the Skateway to commute to work or for daily purposes and who have been historically frustrated when these activities are impeded. The second are visitors from out of town who must plan, travel, and make larger sacrifices to use the Skateway.	Very High
16	Increased risk to the health and safety of Canal visitors.		High	Overall models project that the winters in the National Capital Region will become shorter and warmer (NCC et al., 2020a). Under RCP8.5 by 2021-2050 mean winter temperatures are projected to increase from a historic average of -8.5°C to -6.1°C (+2.4°C) (Climate Atlas, 2020). By 2051-2080 under the same scenario mean winter temperatures are projected to increase to -3.4°C (+5.1). Notably, by 2051-2080 the maximum winter temperatures are project to increase from a historic average of -2.4°C to 0.1°C, a temperature above the melting point of snow and ice. These trends all indicate increased warming conditions in the future. In addition, historically there has already been a decreasing trend in the skating season length from 1971 to 2020, indicating a high and already present exposure.	Very Low	The quality and thickness of the ice area regularly monitored and users are not allowed on the ice if safety parameters are not met.	Very High	The Skateway has stringent rules in place for the minimum ice thickness and conditions of the ice, as well as systems including flags, barriers, and communication through media outlets to warm skaters to remain off unsafe ice. The systems are already in place to avoid any undue injuries or deaths.	Very Low	Low	Moderate	High	Low	High	Injured skaters may cost the Skateway additional fees or settlements as well as tarnish the image of the event.	Moderate
17	Increased risk to the health and safety of Canal staff.		High	Overall models project that the winters in the National Capital Region will become shorter and warmer (NCC et al., 2020a). Under RCP8.5 by 2021-2050 mean winter temperatures are projected to increase from a historic average of -8.5°C to -6.1°C (+2.4°C) (Climate Atlas, 2020). By 2051-2080 under the same scenario mean winter temperatures are projected to increase to -3.4°C (+5.1). Notably, by 2051-2080 the maximum winter temperatures are project to increase from a historic average of -2.4°C to 0.1°C, a temperature above the melting point of snow and ice. These trends all indicate increased warming conditions in the future. In addition, historically there has already been a decreasing trend in the skating season length from 1971 to 2020, indicating a high and already present exposure.	Low	The quality and thickness of the ice area regularly monitored and users are not allowed on the ice if safety parameters are not met. As staff are the ones checking these levels there is a slightly heightened chance of incident, which is mitigated by following proper safety procedures and protocols.	Very High	The Skateway has stringent rules in place for the minimum ice thickness and conditions of the ice, as well as systems including flags, barriers, and communication through media outlets to warm skaters to remain off unsafe ice. The systems are already in place to avoid any undue injuries or deaths. In addition staff are/can be trained to follow the most relevant safety protocols when testing the ice.	Very Low	Low	Moderate	High	Low	High	Injured staff may cost the Skateway additional fees or settlements as well as the money to hire additional support.	Moderate

18	Increased frequency of winter storm events reducing the number of viable skating days.		Moderate	While overall snowfall events may be declining, heavy snowstorms are still expected (City of Ottawa, 2019). There is no projected change in the frequency of wet days, or days when precipitation occurs, however there is a projected increase in the intensity of precipitation events. (NCC et al., 2020a).	High	Storm events may damage the ice or supporting infrastructure, load the ice with extra water or snow, and directly prevent Skaters from skating.	Moderate	Existing maintenance practices in place after large snow events can provide flexibility and adaptive capacity to future events. Ottawa as a city also experiences annual large snow storm events which increases the Skateway's adaptive capacity due to the infrastructure already in place. There are limited options in relation to large winter rain events, with the exception of already established storm management piping systems, or lightning. Existing communications, testing, and maintenance strategies may help reduce any negative impacts to staff and skaters' health and safety as well as reduce delay in opening.	Moderate	Moderate	Moderate	Moderate	Low	Moderate	A reduction in viable skating days reduced the economic potential for local vendors, transportation, and accommodations. In addition, a smaller season increases the cost off operation per skating day. Unlike warmer temperatures storms are more likely to be discrete events causing shorter term damage and disruption, reducing the economic impact. Reduced skating days may also impact the community and users of the Skateway. This severity primarily impacts two groups. The first are regular users who use the Skateway to commute to work or for daily purposes and who have been historically frustrated when these activities are impeded. The second are visitors from out of town who must plan, travel, and make larger sacrifices to use the Skateway.	Moderate
19	Increased salt use on the nearby roads due to poor winter conditions decreasing the freezing point of the water.		High	Several projected climate factors may contribute to the increased need to salt the roads and pathways near the Canal, most notably the amount of freeze-thaw days. Models predict that winter temperatures will hover around 0°C more frequently in the future. As a consequence, the number of winter freeze-thaw cycles are projected to increase from approximately 24 days in the baseline to approximately 28-27 days in the 2030s, 30-32 days in the 2050s and 32-37 days in the 2080s. Freeze-thaw days, especially in combination with new or existing rain or snow, may cause continuous icing on roads that requires additional salting.	Moderate	Several sections of the Canal are directly adjacent and downslope to roads or sidewalks which may need to be salted during the winter. In addition to numerous negative environmental effects, road salt can decrease the freezing point of water and reduce the stability and viability of the ice.	Moderate	Numerous municipalities have begun to reduce or replace road salt use on roads near environmentally sensitive areas using a variety of different techniques that may be applies here. Physical barriers may also be applied to reduce direct runoff into the Skateway.	Low	Moderate	Moderate	Moderate	Moderate	Moderate	A reduction in viable skating days reduced the economic potential for local vendors, transportation, and accommodations. In addition, a smaller season increases the cost off operation per skating day. Reduced skating days may also impact the community and users of the Skateway. This severity primarily impacts two groups. The first are regular users who use the Skateway to commute to work or for daily purposes and who have been historically frustrated when these activities are impeded. The second are visitors from out of town who must plan, travel, and make larger sacrifices to use the Skateway. After the Skateway melts for the year salt in the Canal system may impact local or downstream flora and fauna as well as impact water quality.	Moderate
20	Increased cost of operations to maintain the Canal under changing winter conditions.		High	Projected increases in temperature, winter rains, later start times, and earlier closings indicate more maintenance will be required to maintain and operate the Skateway. There has already been an observed decreasing trend in the skating seasons length from 1971 to 2020 which is expected to continue as temperatures are projected to increase. Overall models project that the winters in the National Capital Region will become shorter and warmer (NCC et al., 2020a). Under RCP8.5 by 2021-2050 mean winter temperatures are projected to increase from a historic average of -8.5°C to -6.1°C (+2.4°C) (Climate Atlas, 2020). By 2051-2080 under the same scenario mean winter temperatures are projected to increase to -3.4°C (+5.1). Notably, by 2051-2080 the maximum winter temperatures are project to increase from a historic average of -2.4°C to 0.1°C, a temperature above the melting point of snow and ice. These trends all indicate increased warming conditions in the future. The timing of the first fall frost which represents the first day when minimum daily temperatures will fall below 0°C, will shift from late September/early October to mid October: approximately 1-2 weeks later by the 2030s, 2-3 weeks later by the 2050s, and 3-4 weeks later by the 2080s. The timing of the last spring frost which represents the last day when minimum daily temperatures are above 0°C, is projected to occur earlier: approximately 1-2 weeks earlier in the 2030s and 2050s, and 2-4 weeks earlier in the 2080s, compared to the baseline.	High	In recent years the annual budget to maintain the Skateway has been approximately $1.5 million (Tumilty, 2017). When the Skating season is shortened the costs per day increase dramatically, providing less enjoyment for more money. Operation of the Skateway has large upfront and staffing costs regardless of the variability of the season. Additional costs, such as new ice techniques or additional operational requirements, will increase the budget.	Low	Adaptive measures vary by cost and there is flexibility in choosing strategies and vendors but protecting the ice under warming conditions will likely require additional budget.	High	High	High	Low	Low	High	New operations or materials may incur additional charges to maintain the Skateway. In addition, a smaller season increases the cost of operation per skating day.	High

21	Reduced enjoyment of the canal by skaters as a result of poor weather conditions.		Very High	Historical the Skateway has closed either entirely or partially due to poor ice conditions caused by warms temperatures. In addition, if the ice cannot be maintained and re-frozen during the season the quality will deteriorate. Shorter seasons may also reduce the availability or enjoyment of the Canal for skaters. Projected increases in temperature, winter rains, later start times, and earlier closings indicate more maintenance will be required to maintain and operate the Skateway. There has already been an observed decreasing trend in the skating seasons length from 1971 to 2020 which is expected to continue as temperatures are projected to increase. Overall models project that the winters in the National Capital Region will become shorter and warmer (NCC et al., 2020a). Under RCP8.5 by 2021-2050 mean winter temperatures are projected to increase from a historic average of -8.5°C to -6.1°C (+2.4°C) (Climate Atlas, 2020). By 2051-2080 under the same scenario mean winter temperatures are projected to increase to -3.4°C (+5.1). Notably, by 2051-2080 the maximum winter temperatures are project to increase from a historic average of -2.4°C to 0.1°C, a temperature above the melting point of snow and ice. These trends all indicate increased warming conditions in the future. The timing of the first fall frost which represents the first day when minimum daily temperatures will fall below 0°C, will shift from late September/early October to mid October: approximately 1-2 weeks later by the 2030s, 2-3 weeks later by the 2050s, and 3-4 weeks later by the 2080s	High	Shortened skating days and poor ice conditions garner mixed reviews on social media forums. General recreation users are often understanding, but those who use the Skateway as a commuting alternative or those visitors from further away who need to travel and invest to use the Skateway have been and may be more disappointed and vocal. In addition conditions such as freeze-thaw events and snow may cause less smooth ice.	Moderate	There are existing communications and maintenance procedures and strategies in place to mitigate poor experiences. In addition Winterlude, the festival which uses the Skateway as a focal point, has begun moving some activities off of the ice to reduce the impacts of uncertain weather. There are limitations to what can be done to ensure consistent qualify of outdoor ice.	Moderate	High	Moderate	Moderate	Low	Moderate	Reduced enjoyment may impact the use of the Skateway as well as the cultural perception of the event. Reduced skating days/conditions may also impact the community and users of the Skateway. This severity primarily impacts two groups. The first are regular users who use the Skateway to commute to work or for daily purposes and who have been historically frustrated when these activities are impeded. The second are visitors from out of town who must plan, travel, and make larger sacrifices to use the Skateway.	High
22	Reduced public opinion of the Skateway.		Very High	Historical the Skateway has closed either entirely or partially due to poor ice conditions caused by warms temperatures. In addition, if the ice cannot be maintained and re-frozen during the season the quality will deteriorate. Shorter seasons may also reduce the availability or enjoyment of the Canal for skaters. Projected increases in temperature, winter rains, later start times, and earlier closings indicate more maintenance will be required to maintain and operate the Skateway. There has already been an observed decreasing trend in the skating seasons length from 1971 to 2020 which is expected to continue as temperatures are projected to increase. Overall models project that the winters in the National Capital Region will become shorter and warmer (NCC et al., 2020a). Under RCP8.5 by 2021-2050 mean winter temperatures are projected to increase from a historic average of -8.5°C to -6.1°C (+2.4°C) (Climate Atlas, 2020). By 2051-2080 under the same scenario mean winter temperatures are projected to increase to -3.4°C (+5.1). Notably, by 2051-2080 the maximum winter temperatures are project to increase from a historic average of -2.4°C to 0.1°C, a temperature above the melting point of snow and ice. These trends all indicate increased warming conditions in the future. The timing of the first fall frost which represents the first day when minimum daily temperatures will fall below 0°C, will shift from late September/early October to mid October: approximately 1-2 weeks later by the 2030s, 2-3 weeks later by the 2050s, and 3-4 weeks later by the 2080s	Moderate	Shortened, uneven, and unpredictable skating seasons have previously drawn the ire of regular commuters and the disappointment of out-of-town visitors, however general recreation users are usually understanding of the situation.	Moderate	There are existing communications and maintenance procedures and strategies in place to mitigate poor experiences. In addition Winterlude, the festival which uses the Skateway as a focal point, has begun moving some activities off of the ice to reduce the impacts of uncertain weather.	Low	Moderate	Moderate	Moderate	Low	Moderate	Reduced enjoyment may impact the use of the Skateway as well as the cultural perception of the event. Reduced skating days may also impact the community and users of the Skateway. This severity primarily impacts two groups. The first are regular users who use the Skateway to commute to work or for daily purposes and who have been historically frustrated when these activities are impeded. The second are visitors from out of town who must plan, travel, and make larger sacrifices to use the Skateway.	Moderate

APPENDIX

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RISK ASSESSMENT RATING MATRICES

APPENDIX

HAZARD SCALE

Scale	Criteria
Very Low	Projected ranges in future climate are similar to historic ranges and no trend can be identified.
Low	Projected ranges in future climate completely or significantly overlap historic baseline means and uncertainty ranges and/or do not exceed historic or design thresholds.
Moderate	Projected ranges in future climate overlap historic baseline means and lower or upper uncertainty ranges (dependant on if the trends are increasing or decreasing) and/or meet or marginally exceed historic or design thresholds.
High	Projected ranges in future climate overlap historic lower or upper uncertainty ranges (dependant on if the trends are increasing or decreasing) and/or exceed historic or design thresholds.
Very High	Projected ranges in future climate are entirely out of the range of historic baseline means and uncertainty ranges and/or significantly exceed historic or design thresholds.

APPENDIX

SEVERITY SCALE

Assessment of Consequence									
Factor	**People**					**Environment**	**Financial**		
Degree	Health and safety	Social	Reputation	Quality of service	Governance	Physical	Cost of Restoration	Legal/litigation	Economy
1- Very low	First aid	No tangible impact on society	Localized temporary impact on public opinion	No tangible impact to services	No changes to management required	No adverse effects on natural environment. Localized to point source. No recovery required	Little financial loss or increase in operating expenses	No litigation and/or legal action	No effect on the broader economy
2- Low	Minor injury, medical treatment with/or restricted work.	Localized, temporary social impacts.	Localized, short term impact on public opinion.	Localized or temporary disruption to services.	General concern raised by regulators requiring response action.	Minimal effects on the natural environment. Localized within site boundaries. Recovery measurable within 1 month of impact.	Additional operational costs. Financial loss small, <10% of turnover.	Minimal individual legal action.	Minor effect on the broader economy due to disruption of service provided by the asset.
3 - Moderate	Serious injury or lost work.	Localized, long term social impacts.	Local, long term impact on public opinion with adverse local media coverage.	Localized long-term disruption to services.	Investigation by regulators Changes to management actions required.	Some damage to the environment including local ecosystems. Some remedial action may be required. Recovery in 1 year.	Moderate financial loss, 10-50% of turnover.	Multiple claims and/or litigations.	High impact on the local economy with some effect on the wider economy.

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4- High	Major or multiple injuries, permanent injury or disability.	Failure to protect poor or vulnerable groups. National, long term social impacts.	National, short term impact on public opinion; negative national media coverage.	Failure to provide services with long-term region-wide impacts.	Notices issued by regulators for corrective actions. Changes required in management. Senior management responsibility questionable.	Significant effect on the environment and local ecosystems. Remedial action likely to be required. Recovery longer than 1 year. Failure to comply with environmental regulations / consents.	Major financial loss, 50-90% of turnover.	Major litigation and/or legal action by multiple claimants.	Serious effect on the local economy spreading to the wider economy.
5- Very high	Single or multiple fatalities.	Loss of social license to operate. Community protests.	National, long term impact with potential to affect stability of Government.	Permanent disruption and/or termination of services.	Major policy shifts. Change to legislative requirements. Full change of management control.	Very significant loss to the environment. May include localized loss of species, habitats or ecosystems. Extensive remedial action essential to prevent further degradation. Restoration likely to be required. Recovery longer than 1 year. Limited prospect of full recovery.	Extreme financial loss >90% of turnover.	Class action legal action.	Major effect on the local, regional and state economies.