This Our File: McElhanney Project 2121- 2121-00993-99

To	From
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Re	Date
Bragg Creek Trails	Aug 21, 2023
Climate Risk Assessment and PIEVC Evaluation	

1. Introduction

Bragg Creek Trails (BCT) has been an active steward of multi-use, year-round recreational trail amenities in West Bragg Creek and Rocky View County. With increasing realisation that weather is a key factor in infrastructure degradation, assessing what infrastructure is susceptible to extreme weather and changing conditions is an evolving aspect of stewardship, as are developing climate-related mitigation strategies to ensure that infrastructure will continue to perform well into the far future.

These are core outcomes of a climate resiliency study, the initial stages of which have now been completed for the trails and other associated infrastructure managed by BCT. In conjunction with research work conducted by Mark Empey of the University of Calgary, multiple dimensions of weather phenomenon such as precipitation (rain/snow), temperature and wind speed have been investigated for their potential impacts on various asset classes managed by BCT. As well as the consideration of current conditions, work has been done to use available climate models to determine the likely future nature (magnitude/frequency/timing) of weather phenomena. Within the broader University study, several frameworks for establishing the severity of various impacts have been evaluated, and this memo summarizes the outcomes of applying the Public Infrastructure Engineering Vulnerability Committee (PIEVC) protocol to the prioritization of infrastructure risks (https://pievc.ca/).

Note that the purpose of this study is *not* to identify if climate change is or is not occurring or to identify its causes, nor is this to be considered an engineering report advising of recommended upgrades to infrastructure or changes in design specifications. Rather, the goal is to broaden the consideration of what types of extreme weather might impact infrastructure and to evaluate the use of the PIEVC protocol as a risk analysis tool. In this way, this study provides the starting point for further investigation and the development of appropriate mitigation and adaptation measures.

2. PIEVC Climate Risk Assessment Methodology

A core portion of a climate resilience study is the identification, evaluation, and prioritization of climate related risks to infrastructure – however, this activity is only one aspect of developing a more resilient asset management strategy.

For example, once risks have been prioritized, then mitigation measures will have to be developed to manage those risks and the performance of the measures monitored over time. Such mitigation activities could include adapting design standards for future infrastructure stresses (such increasing culvert capacities to handle increased precipitation) or modifying operating practices to accommodate changing conditions (such as harvesting snow for use during periods of lower snowfall during a season). A full cycle process is shown below.

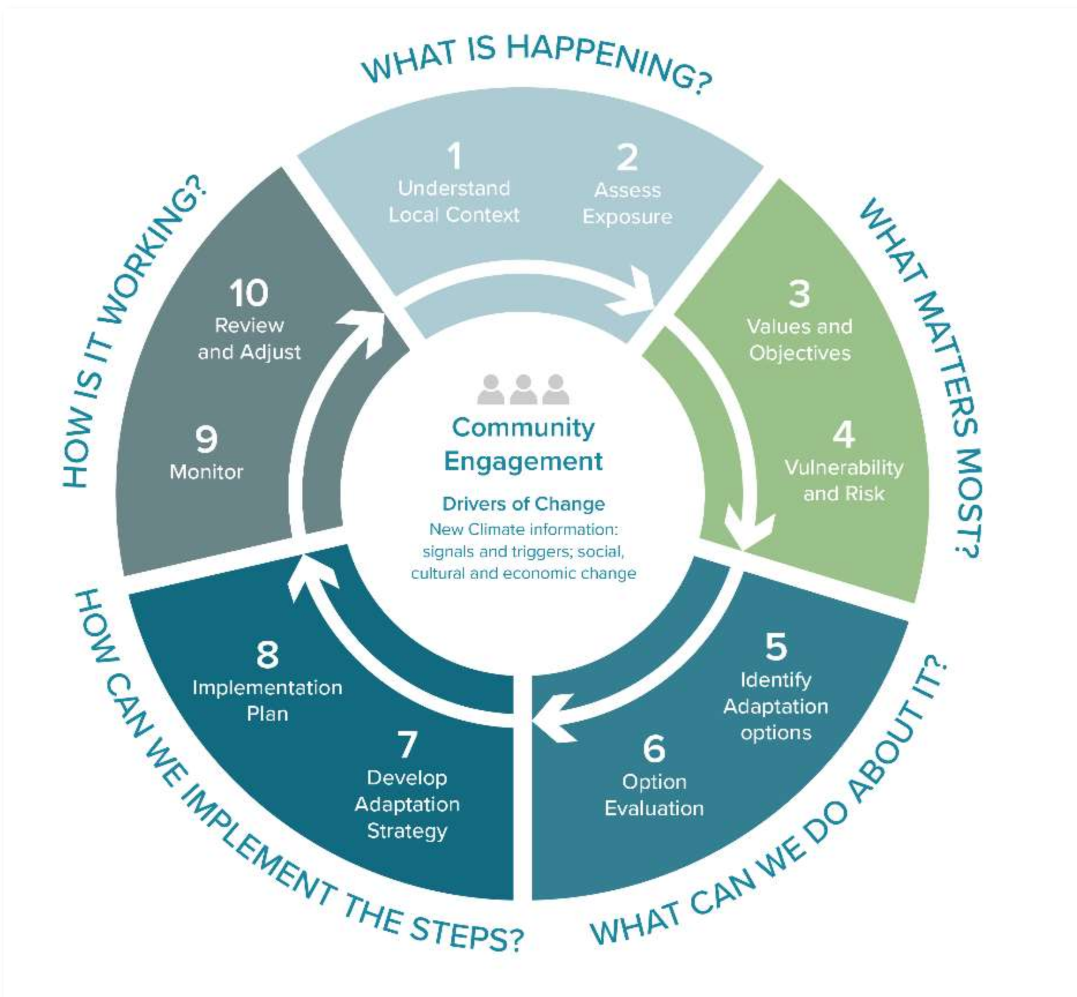


Figure 1. Sustainable Infrastructure Management Process. Climate Risk Assessment covers Steps 1-4.

In this study, the PIEVC Protocol was used as a sample framework for risk analysis, and specifically its High-Level Screening Guide (PIEVC HLSG). This framework was designed to be flexible enough to be applied to full assets or systems, to a single element of infrastructure, or to an entire portfolio of numerous assets. PIEVC HLSG assessments result in the characterization and ranking of climate risk scenarios and the identification of those scenarios of highest priority for adaptation planning or more comprehensive analysis. The steps of the PIEVC HLSG are presented below.

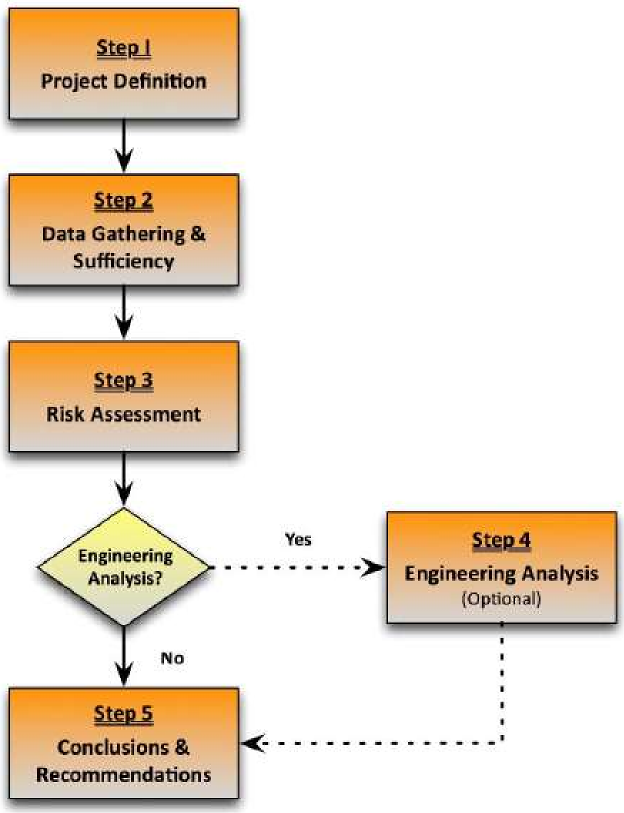


Figure 2. Steps of the PIEVC HLSG (from PIEVC). Note this study does not involve an engineering analysis.

An essential component of most climate risk evaluation frameworks (including PIEVC) is the collection of weather and climate data and the assessment of long term trends based on published future-looking climate models. Probabilities of various future outcomes are established and then combined with the consequence, or the seriousness, of their possible impacts on infrastructure. Consequence scores are generally broken into physical, social, economic, and environmental impacts and are commonly established through workshops with the infrastructure managers and operators and used to determine priorities for mitigations and adaptations.

3. Overview of Bragg Creek Trails

The Bragg Creek Trail Association (BCT) is a non-profit organization in Alberta, Canada, which aims to promote and maintain a network of recreational trails in and around the Bragg Creek area. The organization works to develop and maintain trail systems for hiking, biking, horseback riding, and cross-country skiing, and promotes environmental conservation and education.

The trails network that BCT supports is becoming progressively more popular with surrounding areas residents - based on data from parking lot usage, it is estimated that Bragg Creek received approximately 160,000 annual visitors from 2015 to 2019, with the number of visitors increasing to nearly 300,000 in 2019.

Thanks to the relatively recent construction of the trails and the regular maintenance practices that are followed at BCT, the condition of the trails is generally very good. However, growing pressure from increased trail usage, extreme weather events, and climate change may lead to faster deterioration of assets managed by BCT. This requirement for more resilient trail development has already been implicitly acknowledged by BCT, with practices evolving towards re-routing of trails away from low areas and strategic construction of trails to maximize shedding of water for example.

3.1. BCT ASSETS UNDER CONSIDERATION

A list of BCT assets was identified through a review of materials provided by BCT including asset management plans, operating frameworks, and strategic plans. In addition to this review, a virtual workshop was conducted with BCT to refine the list of relevant infrastructure and analyze past climate-related events. Infrastructure components identified include:

- All season trails
- Winter multi-use trails
- Ski trails
- Culverts
- Bridges
- Grooming and Maintenance Equipment
- Buildings

As reported in the Bragg Creek Trails Asset Management Plan 2021-2030, BCT is responsible for managing a trail network spanning around 170 km in the West Bragg Creek region of Kananaskis Country, in addition to approximately 12 km of trails in Rocky View County. These areas are situated approximately 40 km west of the City of Calgary and east of the Rocky Mountains. The landscape of the region is characterized by gentle rolling terrain with a mixed forests, creeks, and wetlands. In addition to the trails network under management, BCT is also responsible for associated maintenance and grooming equipment and ancillary building structures. The cost of reconstructing this network was estimated to be roughly $5.5 million in 2021, and the replacement value of buildings and equipment was approximately $450 000.

3.2. LOCAL WEATHER AND CLIMATE

The local climate of Bragg Creek is described as “temperate continental” featuring large temperature differences between winter and summer and moderate overall precipitation. Historical weather information for the Bragg Creek region is shown below based on the previous 30 years of available information at surrounding meteorological stations.

As can be seen, the region can experience significant temperature fluctuations at any time of year, but in general precipitation events are moderate in intensity, with only 1-2 days in June expected to see daily precipitation of greater than 20 mm. Winds tend to be gustiest in the winter and are correlated to Chinook (sudden warming) events. In general, the basic dimensions of temperature, precipitation and wind can be considered fundamental quantities that combine to generate weather-related attributes such as freeze-thaw days, snowpack depth, drought conditions or level of wildfire risk.

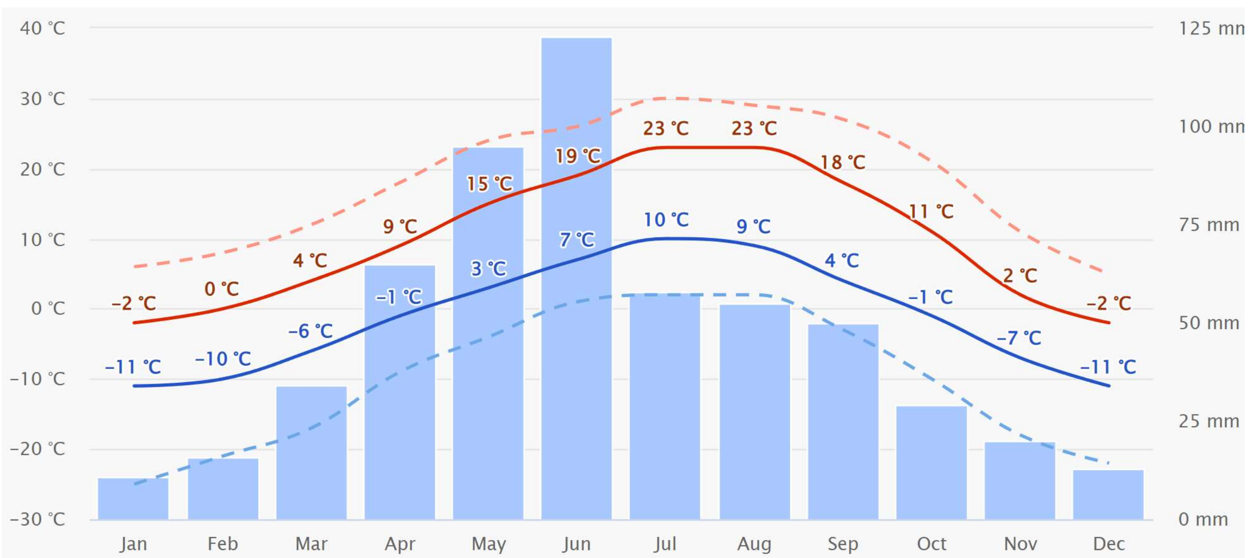


Figure 3. Average Monthly Temperature and Precipitation for the Bragg Creek Region (from Meteoblue).

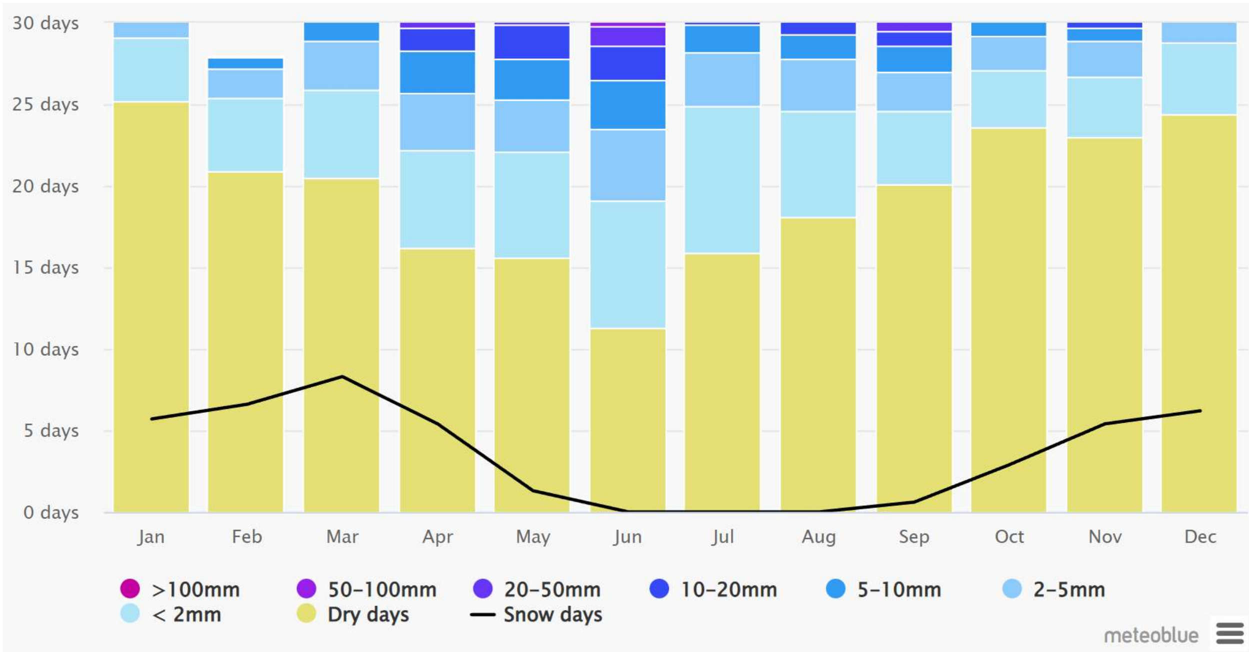


Figure 4. Average Precipitation Intensities for the Bragg Creek Region (from Meteoblue). Days featuring > 20 mm / day precipitation are considered "heavy precipitation days."

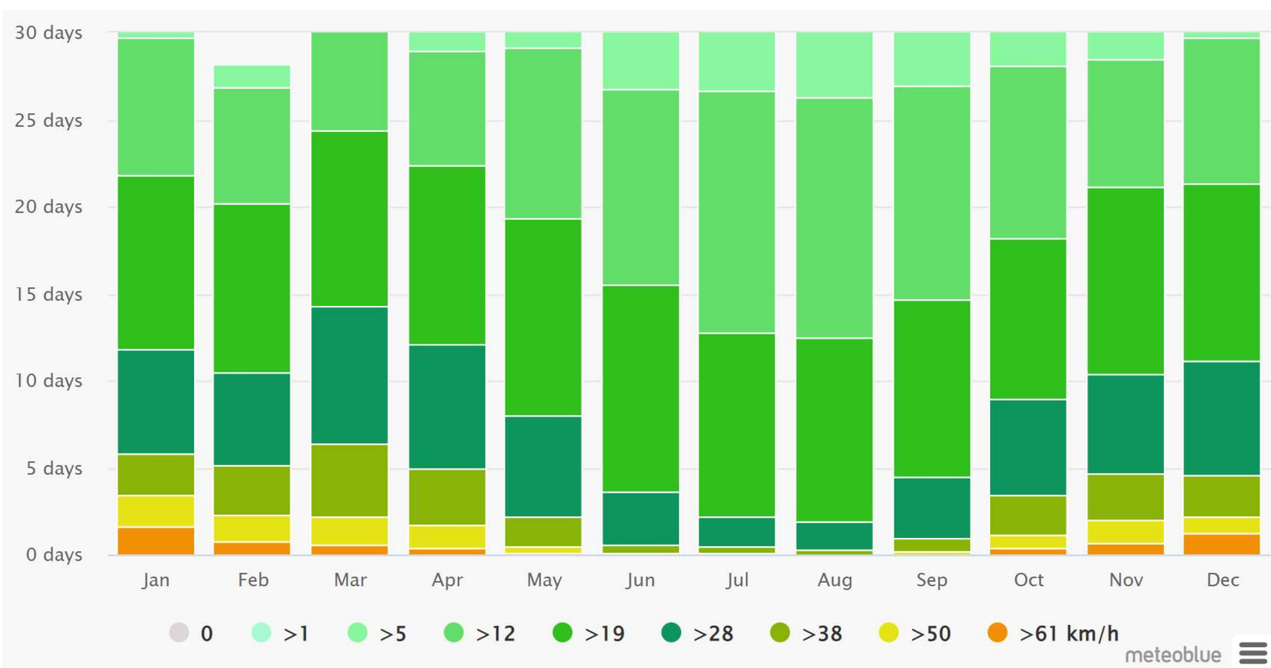


Figure 5. Average Windspeeds the Bragg Creek Region (from Meteoblue). Winds tend to come from the South-West.

3.2.1. Future Climate Estimates

Generally, infrastructure is built to be appropriate for local weather conditions. However, infrastructure resilience requires evaluation of how well infrastructure will perform under likely *future* weather conditions. To arrive at these estimates of likely future weather conditions, climate models are used which assume various levels of overall global temperature variation (as global temperature tends to be a major driver of other subsequent weather-related phenomena). For the purposes of this study, an “RCP 8.5” model was used, which assumes an energy increase of 8.5 watts per square meter across the planet and predicts a temperature increase of about 4.3˚C by 2100, relative to pre-industrial temperatures. This is generally considered a “business as usual” scenario situation by climate scientists, with minimal mitigation of current greenhouse gas emission trends.

The weather-related results of a given climate model are calculated by a variety of publicly available climate analysis tools such as the Climate Atlas of Canada (used in this study), Climate WNA and ClimateInformation.org. Sample expected changes in key weather parameters are shown below based on an RCP 8.5 pathway. In general, long-term climate predictions reviewed for the Bragg Creek area indicates a general trend of warmer, wetter weather punctuated by increased storm activity.

In addition to fundamental weather parameters such as annual precipitation and mean temperature, Table 1 features several of the ‘derived’ quantities discussed above, such as freeze-thaw days, heavy precipitation days, etc.

Table 1 – RCP 8.5 mean values obtained from Climate Atlas of Canada

Climate variable	Recent Past	2021-2050	2051-2080	Overall
Annual Precipitation (mm)	603	646 (+7.13 %)	675 (+11.94 %)	↑
Days with Heavy Precipitation (20mm)	3.1	3.6 (+16.3 %)	4.0 (+29.03 %)	↑
Freeze Thaw Cycles (days)	136.7	128.4 (-6.07 %)	118.0 (-12.68 %)	↓
Dry days (no precipitation)	233.7	233.4 (-0.13 %)	233.7 (0 %)	-
Average annualized daily temperature	1.3	3.3 (+153.85 %)	5.3 (+307.69 %)	↑
Average annualized minimum daily temp.	-5.1	-3.0 (+41.18 %)	-1.0 (+80.39 %)	↑
Average annualized maximum daily temp.	7.7	9.6 (+24.68 %)	11.6 (+50.65 %)	↑

With regards to freeze-thaw events, further analysis was completed by collecting historic data for the past 140 years. The definition of freeze-thaw event was calculated using the equation provided in the Climate Atlas of Canada (2023), as a day where the maximum temperature is above $0^{o}C$ and the minimum temperature was below $0^{o}C$. Since BCT is not concerned with freeze-thaw events outside of the winter operating season and shoulder season, a monthly analysis was also conducted based on available weather data from the Calgary International Airport weather station. This indicated that the number of freeze thaw days within the main and shoulder season is increasing.

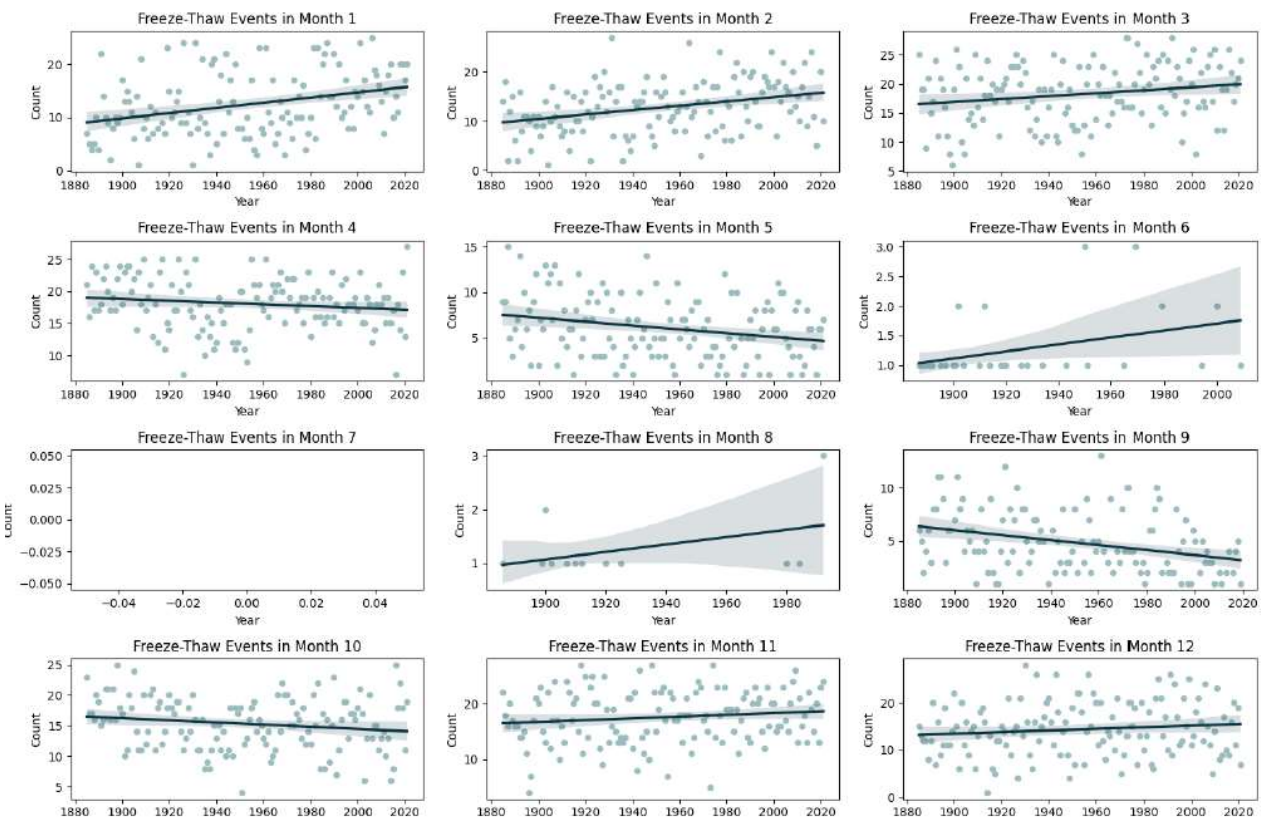


Figure 6 Freeze-Thaw days per year at Calgary International Airport for the past 140 years

Various sources of literature were used to establish the expected change in wildfire activity at Bragg Creek in the future and Historic wildfire data was collected from the Historical Wildfire Perimeter Data (1931 to 2022) provided by the Alberta Government and the count of wildfires per year was plotted for both a 25km and 50km radius from Bragg Creek. This review of data included a general trend for increasing number of wildfires in the areas surrounding BCT. It is noted that due to significant fires in 1910 and 1936, there were limited or very young trees in the area through the 1930s, which, given the time taken for forests to mature, could explain the low incidence of fires in the following decades. Interestingly, despite increases in overall predicted precipitation, wildfire counts are expected to increase, possibly due to increasing temperatures and variability in terms of when precipitation occurs (e.g., overall precipitation may increase, but in the form of storm events and runoff, leading to overall increases in soil dryness).

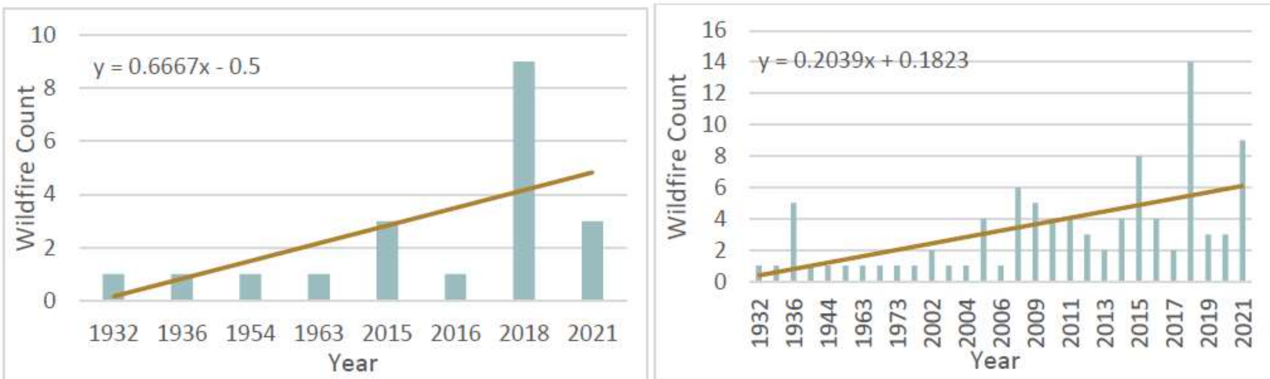
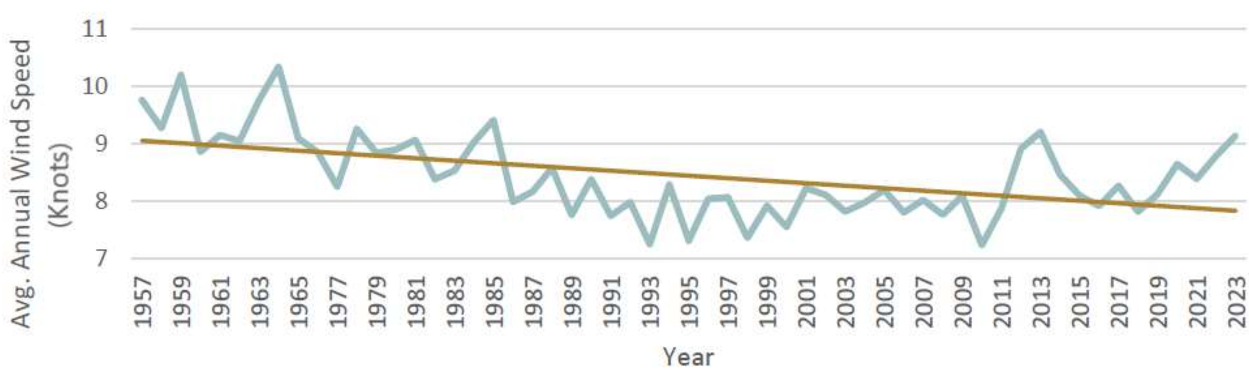
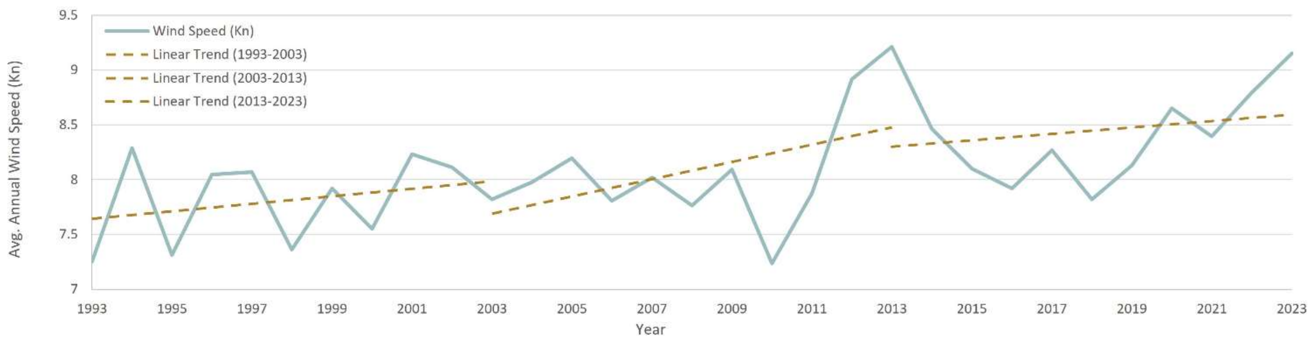


Figure 7 Count of wildfires per year within a 25km (left) and 50km (right) radius of the Bragg Creek study area boundary.

Wind observations were collected from the Iowa Environmental Mesonet for the Calgary International Airport weather station. The mean annual windspeed for each year of data available was calculated and compared against time. This review indicates that over the last 50 years wind in Calgary is moving towards less extreme wind and the average wind speed is also decreasing over time, however, when considering the last 30 years, the trends indicate that while the frequency of wind speed/direction does not change significantly, the trends indicates an increase in wind speed, which matches anecdotal information.





Mean Annual Windspeed

General Trend

Figure 8. Trend in mean annual windspeed over the last 50 and 30 years

4. Evaluating Climate Risk

As discussed above, understanding future weather trends is only one aspect of a climate risk assessment – the critical component is understanding how infrastructure is likely to be impacted by these changes so that appropriate plans and actions can be put into place to better protect it in a cost-effective manner.

A key aspect of risk management is establishing which impacts are *significant* enough to warrant mitigation. This requires evaluation of both the *severity* of an impact on operations or assets (also known as the *consequence*) and the *likelihood* of the impact actually occurring. The overall risk criticality is then calculated as the multiplication of the consequence and likelihood of a given impact.

*Criticality = Consequence * Likelihood*

Note that precise, quantitative, estimations of consequence and likelihood is not the goal of risk assessment. Instead, the goal is to evaluate multiple potential risks and identify the ones that have a significant enough criticality to warrant further consideration. Furthermore, risks with high criticality relative to others should be *prioritized* for mitigation. As a result, risk assessment relies on semi-quantitative evaluations of consequence and likelihood on a relative scale (e.g., 1-5) as opposed to strict calculations of probability of occurrence and dollar-level evaluation of consequences.

4.1. HOW SEVERE WEATHER EVENTS IMPACT INFRASTRUCTURE

To evaluate potential risks to infrastructure, a workshop was conducted involving BCT personnel to evaluate the infrastructure most likely to be impacted by changing weather, and the nature of these impacts. Sample impact mechanisms across asset classes are shown in Table 2, but five primary dimensions of weather-related concern became evident, namely:

- Flooding - generally impacting trails, bridges, and culverts through washouts during sudden precipitation events.
- Change in snow-covered days – negatively impacting availability of cross-country skiing but increasing the availability of trails for other uses.
- Change in freeze thaw days – most significantly impacting wear-and-tear on grooming equipment, as well as impacting the quality of groomed ski tracks and causing damage to other infrastructure through ice-damning.
- Increase in wildfire risk – potentially resulting in closures of the trail network (including due to reduced air quality) or creating risks in the form of dead trees, or damaged buildings.
- High winds – resulting in increased blow-down of trees necessitating increased maintenance of the trail network.

Table 2 – Evaluation of Severe Weather Impacts on BCT Infrastructure

	Grooming and Maintenance Equip	Buildings	Culverts / Bridges	All Season Trails	Winter Multi-Use	Ski Trails
Average Temperatures (mean, min, high)		Minimal heating / AC requirements for high/low temps		Minimal impacts on user numbers with hotter temps	Fewer freezing days result in less use.	
Precipitation (average and peak)		Minimal impact to roof if snow load increases	Potential issues of handling / diverting larger flows	Wetter conditions lead to increased wear/tear	Positive ski impact if precipitation is snow, bad impact if it is as rain. Increased grooming costs for ski trails with more snow (positive experience, but increased cost)	
Freezing Days				Availability for dry season use	Longer shoulder season for winter trails with more freezing days.	Increased grooming requirements with longer season.
Freeze Thaw Cycles	Equip works harder on icy conditions	Slips/Trips/ Falls	Ice Damming	Potential improvement for fat biking	Ice Damming.	Significantly increased grooming requirements with more variability.
Winds Speed (average and gust)	Increased use for maintaining trails			Blowdown resulting in increased maintenance		
Wildfire frequency	Significant danger if wildfire passes through area		(Bridges) Damage if wildfire passes through area	Closures / less visitation if increased smoke in area. Potentially more downed trees resulting in increased maintenance if wildfire passes through area.		

4.2. CONSEQUENCE EVALUATION

Consequence refers to the known or estimated outcomes of a particular climate-related impact (PIEVC, 2023). For risk assessment, consequences do not need to be purely economic, but can be evaluated along multiple dimensions such as reputational damage, health and safety consequence, or ability to operate. For example, increased freeze-thaw days may have a direct economic consequence to the maintenance of ski grooming equipment but may also have a non-economic impact on the quality of ski trails and the enjoyment users derive from them.

The first step in consequence evaluation is the establishment of a semi-quantitative scale to evaluate impacts against. This was done through workshops with BCT staff to establish what types of impacts would be 'catastrophic' (5) vs 'insignificant' (1) across the dimensions of operational ability (the ability to provide services to users), economic costs, social / reputational impacts, and environmental damage. Examples of the resulting significance thresholds are shown below in Table 3.

Once the consequence rating scale was established, further discussions with BCT focused on how various severe weather-related scenarios might impact each asset class under consideration. These resulted in an evaluation of the *sensitivity* of various asset classes to different severe-weather conditions and were summarized by scoring against the consequence thresholds shown in Table 3. The results of this assessment are shown in Table 4, which indicates for example, that culverts are more sensitive to extreme rainfall than buildings, but that conversely, buildings are more sensitive to wildfire impacts than culverts.

Table 3 – Consequence Thresholds

Consequence	1	2	3	4	5
Operations	Closure of the trail for 0 to 3 days	3 days to 2 weeks	2 weeks to 6 weeks	6 weeks to 10 weeks	Greater than 10 weeks
Economic	< $5000	$5,000 to $20,000	$20,000 to $35,000	$35,000 to $50,000	> $50,000
Social	Bad social media review	Active discussion thread (> 5 comments) re: issue with BCT	Generalized public perception that BCT is providing a low level of service	Indications from Government that BCT is providing low lever of service	Loss of operating agreement
Environmental	Minor pollution or litter that can be dealt with immediately	Minor pollution or litter requiring defined work task	Fuel spill (> 2 L) from vehicle	Major spill (>80 L) into an intermittent watercourse	Major spill (>80L) into a permanent watercourse

Table 4 – Consequence Scoring

	Annual Av. Temp. High	Annual Av. Temp. Low	Average Rainfall	Extreme rain Frequency/ Magnitude	Number of freezing days	Number of Freeze-Thaw Days	High Wind	Number of wildfires
Grooming and Maintenance Equipment	-	-	-	-	-	4	2	5
Buildings	2	-	2	2	-	3	3	5
Culverts	-	-	2	4	-	3	3	-
Bridges	-	-	2	3	-	3	-	4
All season trails	3	-	3	4	2	3	-	2
Winter multi use trails	-	3	-	-	3	2	3	2
Ski trails	-	4	2	3	5	5	-	2

4.3. LIKELIHOOD

In the evaluation of the likelihood component of climate-related risk, forward-looking models of likely weather are used to evaluate what the frequency of extreme weather will be in the future. A key concept in this evaluation is that extreme weather currently occurs at a certain frequency – for example, culverts may be designed to handle levels of stormwater anticipated in 1 in 100-year floods. However, if the same magnitude of stormwater occurs once every 20 years, culverts may now begin to significantly degrade. Following examples established by PIEVC, a five-point likelihood scale to evaluate the change in weather-related events was established and is shown below.

Table 5 – Likelihood Thresholds

Likelihood Score	
1	Extreme weather situation will happen 50-100% less frequently compared to current frequency.
2	Extreme weather situation will happen 10-50% less frequently compared to current frequency.
3	Frequency of extreme weather situation will remain the same as the current frequency.
4	Extreme weather situation will happen 10-50% more frequently compared to current frequency.
5	Extreme weather situation will happen 50-100% more frequently compared to current frequency.

As with consequence, the next step in evaluation was to apply this likelihood scale against severe-weather events that were previously identified to have relevant impacts on the assets BCT manages. By using forward-looking climate predictions, likelihoods for two evaluation horizons of 2021-2050 and 2051-2080 were calculated and are shown in Table 6. Note that these likelihoods focus on the weather events, as opposed to the assets themselves (the impacts of which were evaluated in the previous section).

Table 6 – Likelihood Scoring

Evaluation Time period	Annual Av. Temp. High	Annual Av. Temp. Low	Average Rainfall	Extreme rain Frequency/ Magnitude	Number of freezing days	Number of Freeze-Thaw Days	High Wind	Number of wildfires
2021-2050	4	4	3	4	4	4	3	5
2051-2080	5	5	4	4	4	5	2	5

4.4. RISK CRITICALITY

The final step in the risk evaluation process is to establish the joint severity / likelihood combination defining the risk criticality as shown in Table 7. In general, risks with higher criticality scores can then be identified as higher priority for investigation / mitigation than those with lower criticality scores. As well, this framework can be used to establish ongoing risk management policies – e.g., establishing a process whereby risks with any criticality above a certain threshold require a formalized / documented mitigation plan, whereas risks below a threshold can be acknowledged but not directly mitigated.

By multiplying the asset-oriented consequence scores established in section 4.2 against the weather-related likelihood scores established in Section 4.3, a combined risk criticality for each asset category can be determined. The resultant scores for the evaluation period 2021-2050 are shown in Table 8.

This risk assessment indicates that the most significant risk factor is the occurrence of wildfire events, followed closely by an increase in freeze-thaw events. Increases in storm precipitation (as opposed to changes in overall precipitation) are also significant climate trends to consider.

The findings of this table serve to validate and provide a quantitative basis of the opinions provided by BCT. For example, the importance of freeze-thaw events as a risk factor was highlighted during workshops, where BCT staff indicated that from their experience freeze-thaw events can result in damage to their equipment and increase difficultly with carrying out trail maintenance. The consequence of wildfires destroying equipment and buildings is so significant that, while the probability of such an occurrence may currently be small, the fact that these events may increase in the future indicates that mitigation plans should be put into place.

On the other hand, the risk associated with increasing warm temperatures appears to be the least among the climate-factors analyzed. While this may seem counterintuitive for winter-multi-use and ski trails, as it would decrease the infrastructures operating season, it does make sense regarding other assets. Equipment, culverts, bridges, and all-season trails would likely be minimally affected by rising temperatures. Hence, the findings suggest that the impact of increasing warm temperatures on these assets is not a significant concern.

Table 7 – Calculation of Risk Criticality

Consequence / Likelihood	0 no effect	1 Insignificant	2 Minor	3 Moderate	4 Major	5 Catastrophic
5 Likely	0	5	10	15	20	25
4 Normal	0	4	8	12	16	20
3 Occasional	0	3	6	9	12	15
2 Remotely Possible	0	2	4	6	8	10
1 Highly Unlikely	0	1	2	3	4	5
0 Negligible	0	0	0	0	0	0

Based on this the risk assessment calculations, the following action classification was identifed.

0	Negligible
1 to 5	Minimal Action
5 to 9	Medium
10 to 14	High Medium
>= 15	High-priority Action

Table 8 – Risk Criticality for Managed Assets (2021-2050 horizon)

	Annual Av. Temp. High	Annual Av. Temp. Low	Average Rainfall	Extreme rain Frequency/ Magnitude	Number of freezing days	Number of Freeze-Thaw Days (Operating Season)	High Wind	Number of wildfires	Total Risk by Asset
Grooming and Maintenance Equipment	0	0	0	0	0	16	6	25	47
Buildings	8	0	6	8	0	12	9	25	68
Culverts	0	0	6	16	0	12	9	0	43
Bridges	0	0	6	12	0	12	0	20	50
All season trails	12	0	9	16	8	12	0	10	67
Winter multi use trails	0	12	0	0	12	8	9	10	51
Ski trails	0	16	6	12	20	20	0	10	84
Total Event Risk	20	28	33	64	40	92	33	100	

The assets identified as likely to be at greatest risk are the ski trails, followed by all-season trails and the buildings used by BCT. These findings related to trails are consistent with the results shared by BCT staff during workshops, where the ski trails were identified as being more vulnerable and having an increased consequence to their business. This vulnerability stems from their proximity to watercourses and lower elevation, which puts them at a higher susceptibility to adverse effects of climate and weather events such as flooding. Additionally, their significance to BCT exacerbates the potential consequences of such impacts. Conversely, the assets that appear to be least vulnerable to risks are culverts and grooming and maintenance equipment. Although this may be surprising, it is primarily attributed to relatively limited dimensions of weather impacts that would impact these assets.

5. Conclusions and Next Steps

The primary conclusions stemming from this high-level climate risk assessment can be summarized as follows:

- In general, the Bragg Creek area is expected to become warmer and wetter, although precipitation is expected to fall increasingly in the form of storm events.
- Higher average temperatures will likely increase the number of days that experience freeze-thaw and exacerbate wildfire risk.
- Increased freeze-thaw events have the potential to create variable snow conditions and ice damming, leading to impacts across all asset types (it is noted that while freeze-thaw cycles result in reduced ski quality and increased ski grooming equipment damage, they also result in increased fat-bike and winter hiking quality).
- Wildfire can pose significant direct risks to a wide variety of infrastructure (although individual probability of destruction by wildfire is low). However, increased wildfire occurrence regionally can adversely impact trail use through excessive smoke and is predicted to increase in frequency.
- All season and ski trails are asset classes that are at highest risk due to extreme weather, with buildings being significantly at risk as well.

These initial findings suggest several subequent courses of action, namely:

- *Development of updated trail construction specifications*: Workshop discussions had indicated that there is already an awareness that trails should be built to an enhanced specification to increase water shedding and increase robustness, as well as being located away from watercourses. However, it would be useful to investigate the adoption of a documented design guideline that would support increased trail resiliency for all-season, winter use and ski trails.
- *Review of wildfire response plans*: Due to the significant impact of wildfires and the likely increase in wildfire risk, a review of the current wildfire response plan could be conducted, including an assessment of how BCT would deal with a local wildfire impacting the visitors centre, insurance and safety considerations, management of potential closure of the trail system and how risk can be assessed during a developing wildfire situation.
- *Creation of a climate resiliency policy*: Increasingly, organizations are incorporating the development of a climate resilience policy to demonstrate stewardship of assets under management. This can be incorporated within a broader Asset Management Policy, or as a standalone document, but a climate resilience policy will generally include a commitment to

ensure that asset development and maintenance is done with a consideration to future potential climate scenarios, the selection of a scenario (e.g., RCP 8.5) upon which evaluations will be done and the development of a risk framework and process to identify assets at risk.

In all cases, it is assumed that Alberta Environment and Parks would be involved in discussions as significant stakeholders in operation of the trails in the West Bragg Creek area.

We appreciated the opportunity to be involved in this preliminary climate risk assessment and look forward to assisting BCT with any further workshop facilitation or framework development opportunities as they arise. If you would like additional information on the broader University of Calgary research work, please do not hesitate to ask and we will reach out to Mr. Empey.

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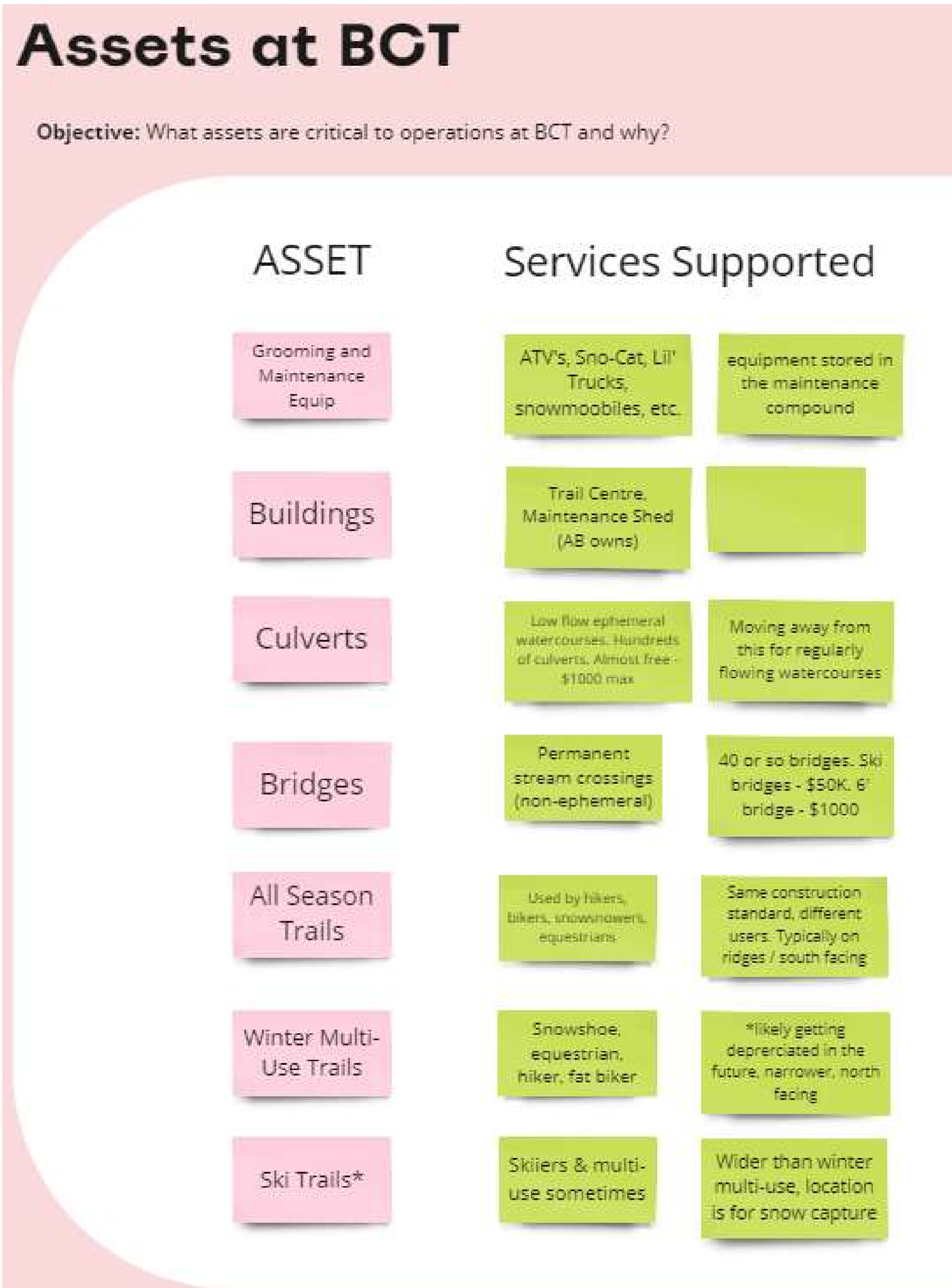
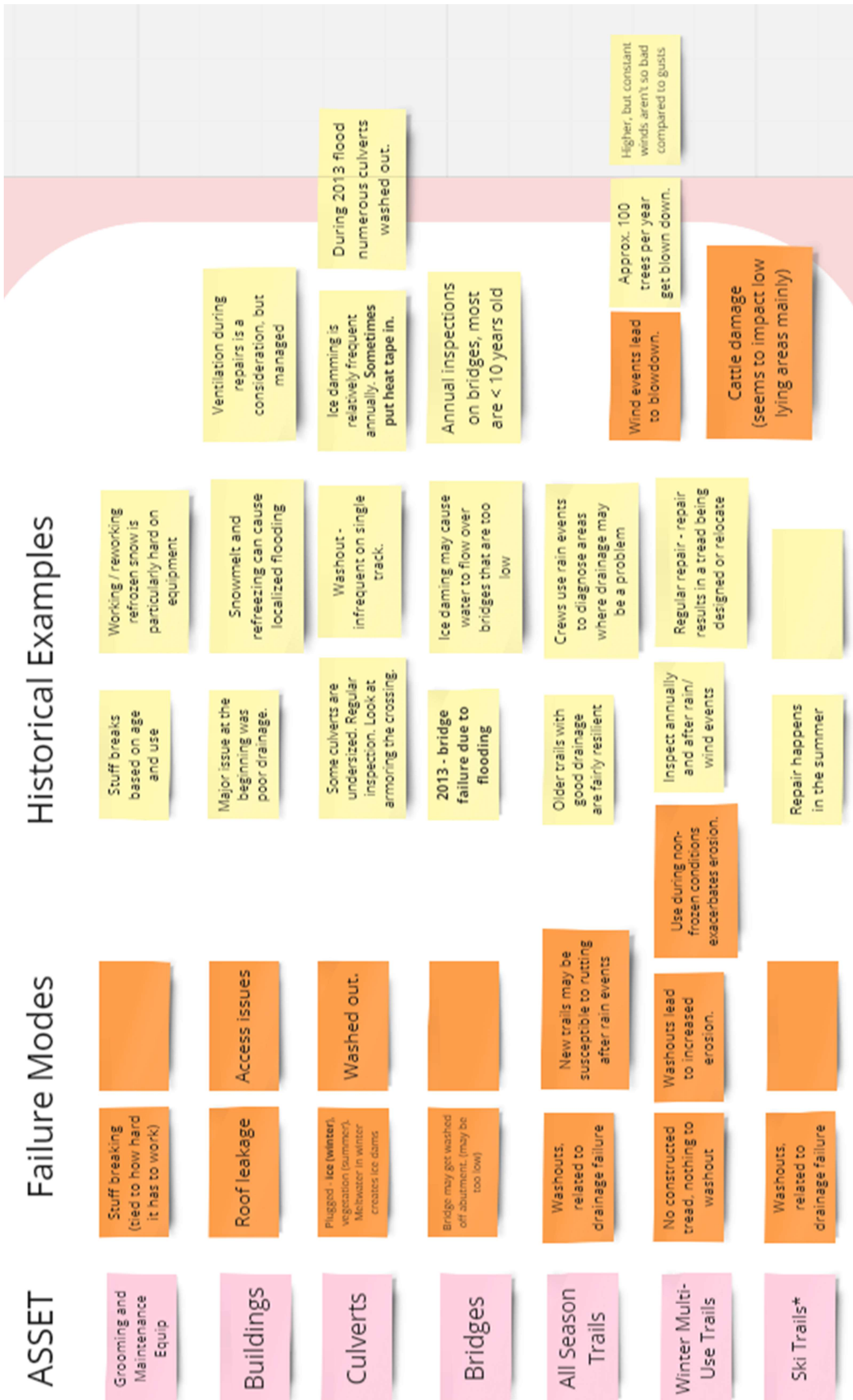
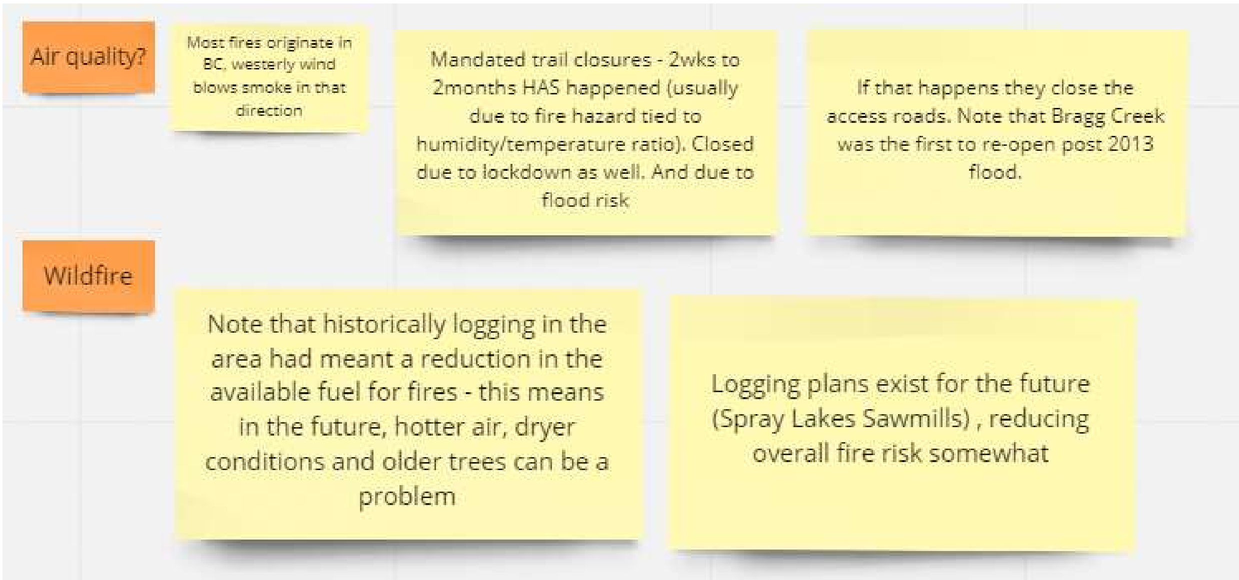
6. Appendix – Workshop Notes

This section contains examples of workshop exercises completed with Bragg Creek Trails representatives during this climate resilience assessment.

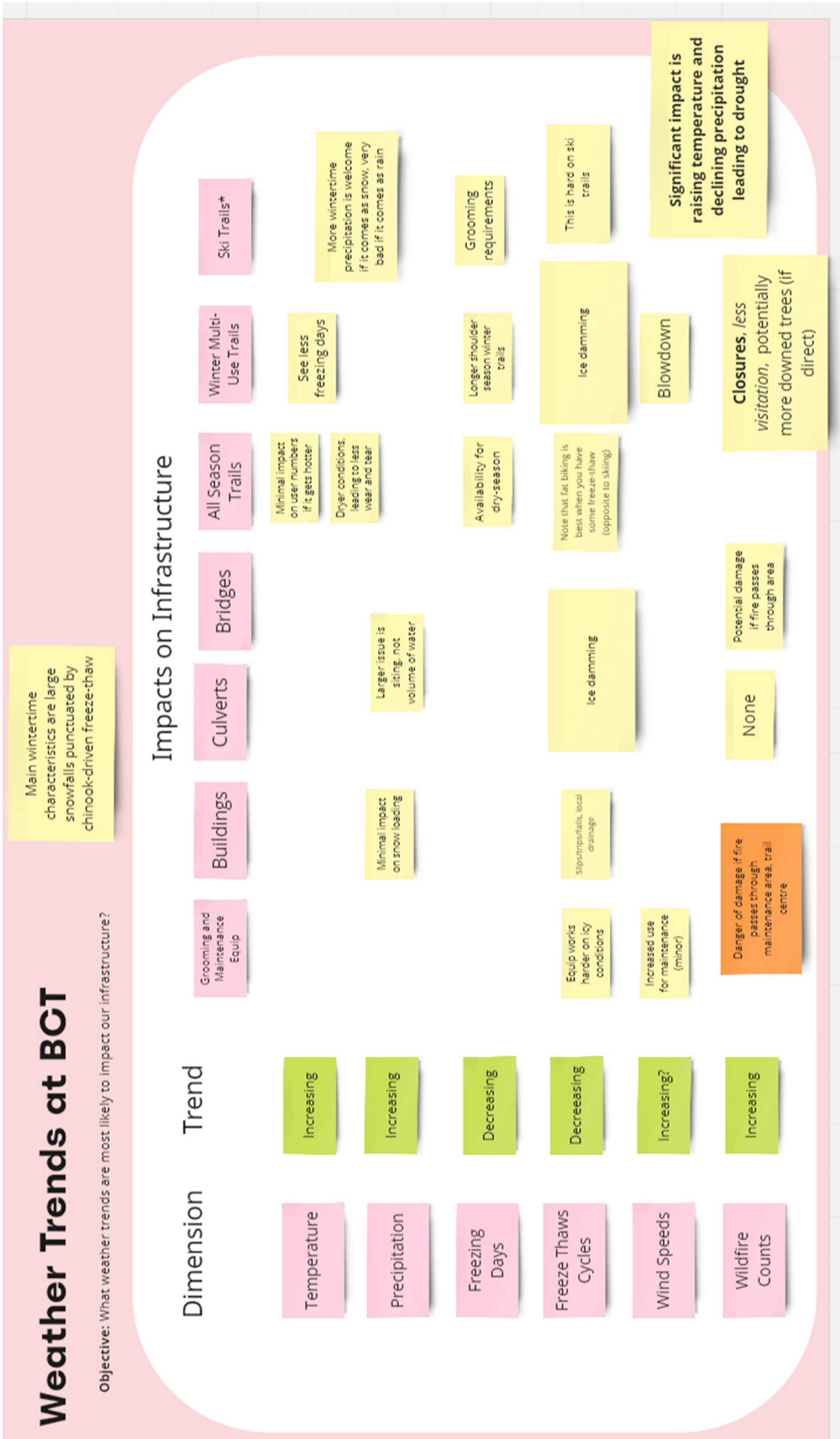
Step 1. Asset Identification and Failure Mode Determination




ASSET
Failure Modes
Historical Examples
Grooming and Maintenance Equip
Stuff breaking (tied to how hard it has to work)
Stuff breaks based on age and use
Working / reworking refrozen snow is particularly hard on equipment
Buildings
Roof leakage
Access issues
Major issue at the beginning was poor drainage.
Snowmelt and refreezing can cause localized flooding
Ventilation during repairs is a consideration, but managed
Culverts
Plugged - ice (winter), vegetation (summer). Meltwater in winter creates ice dams
Washed out.
Some culverts are undersized. Regular inspection. Look at armoring the crossing.
Washout - infrequent on single track.
Ice damming is relatively frequent annually. Sometimes put heat tape in.
During 2013 flood numerous culverts washed out.
Bridges
Bridge may get washed off abutment. (may be too low)
2013 - bridge failure due to flooding
Ice daming may cause water to flow over bridges that are too low
Annual inspections on bridges, most are < 10 years old
All Season Trails
Washouts, related to drainage failure
New trails may be susceptible to rutting after rain events
Older trails with good drainage are fairly resilient
Crews use rain events to diagnose areas where drainage may be a problem
Winter Multi-Use Trails
No constructed tread, nothing to washout
Washouts lead to increased erosion.
Use during non-frozen conditions exacerbates erosion.
Inspect annually and after rain/ wind events
Regular repair - repair results in a tread being designed or relocate
Wind events lead to blowdown.
Approx. 100 trees per year get blown down.
Higher, but constant winds aren't so bad compared to gusts
Ski Trails*
Washouts, related to drainage failure
Repair happens in the summer
Cattle damage (seems to impact low lying areas mainly)


Air quality?
Most fires originate in BC, westerly wind blows smoke in that direction
Mandated trail closures - 2wks to 2months HAS happened (usually due to fire hazard tied to humidity/temperature ratio). Closed due to lockdown as well. And due to flood risk
If that happens they close the access roads. Note that Bragg Creek was the first to re-open post 2013 flood.
Wildfire
Note that historically logging in the area had meant a reduction in the available fuel for fires - this means in the future, hotter air, dryer conditions and older trees can be a problem
Logging plans exist for the future (Spray Lakes Sawmills) , reducing overall fire risk somewhat

Step 2. Identification of Weather-Related Trends and Impacts.



Provided Workshop Materials (attached)

Climate Resilience Assessment

Bragg Creek Trails

February 27, 2023

BRAGG CREEK TRAILS

Agenda

01. Introduction
02. Future Weather Trends
03. Weather Impacts
04. Risk Analysis
05. Mitigations

Introduction

Protecting Outdoor Infrastructure:

- Improve resiliency to extreme weather events
- Preserve investments and prevent damage
- Ensure safety of users and reduce burden on staff

Climate Impact Assessments:

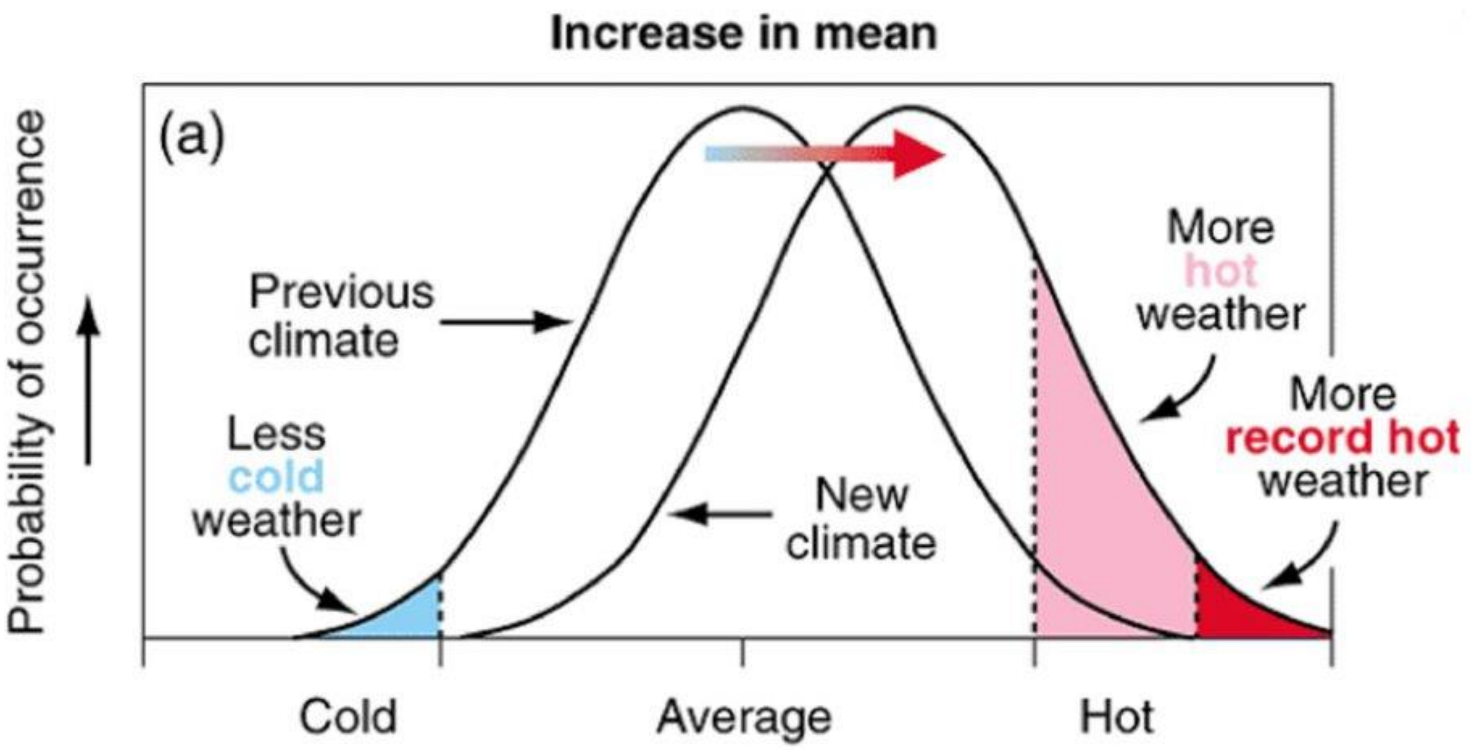
- Review historic and future weather and climate
- Evaluate vulnerability to extreme weather and climate
- Establish consequences and estimate severity
- Identify high risk infrastructure and mitigations

Weather impacts on infrastructure

Weather impacts on infrastructure

Shifting average conditions:

- More frequent extreme events
- More severe rare events
- New concerns
- Changing patterns



Case studies

Washington

North Cascades and Olympic Park have identified the following primary concerns from their recent climate vulnerability assessments

- Reduced Snow-On-Ground Days
  - Expecting a decline from 142 days of snow on the ground from 1950 to 1999, to an average of 87 days in the 2080s.
- Increased Staffing Concerns
  - Earlier trail and campground access in the spring, and later in the fall due to reduced amounts of snowfall. Meaning increased burden on staff.
  - Increased flooding and erosion leading to increased burden on staff to clean up and maintain trail networks.
- Changing River Levels
  - Higher river flow in fall and winter will increase erosion and slides leading to washout and burial of trails, bridges, and roads. This impact is also amplified by upstream wildfires creating conditions prime for flooding.
  - Less peak flow from lower snow levels, and earlier spring melt meaning lower peak flow and a shift in the ideal time to white water raft (up to a month earlier).
- Increased Trail Closures
  - Increased frequency of fires leading to more trail closures, poor air quality concerns and increased trail maintenance to clear downed trees. Some trails may be mandated to close due to safety concerns for falling trees.

Colorado

- Changing Snowpack
  - By the end of the century, Aspen Mountain is expecting snowpack to be confined to the top quarter of the mountain under a high emissions scenario.
- Increased Trail Closures and Reduced Trail Access
  - Post-wildfire flooding resulted in a 7 year-long closure of the Young Gulch Trail in Poudre Canyon.
  - The 2012 Waldo Canyon fire in central Colorado closed all of Rampart Range Road for 2 years and prevented access to numerous climbing spots.

Northwestern Rockies

- Increased Air Quality Issues
  - Smoke from wildfires is regularly creating issues with planning races and adventures between July and August.
- Increase in Downed Trees
  - Insects like bark beetles flourish in drought conditions and higher temperatures and have killed more trees than wildfire over the past 30 years.
- Changing Snowpack & Increased Safety Concerns
  - Decreases in winter snowpack, shortened snow seasons, and increases in wet-snow avalanches

Case studies

Arizona

- **Mandated Trail Closures**
  - In 2021, the City of Phoenix approved a program to restrict the use of certain trails during extreme heat to protect the safety of the public and first responders.
- **Increased Trail Closures**
  - Arizona's 2020 record-setting fire season burned 978,000 acres and over 100 miles of the Arizona Trail, hindering access to recreational areas for trail users. Resulting in frequent changes in trail usage, route planning, and the creation of unsanctioned paths.

California

- **Increased Air Quality Issues**
  - In 2018, the North Face 50- Mile Championships in Marin, California was canceled due to persistently poor air quality and smoke.
- **Increased Trail Damage**
  - In 2020, wildfires in California destroyed 1,023 miles of trail, 80 bridges, and kiosks and signs that were collectively worth between $20–40 million.
- **Changing Snowpack**
  - In the Sierra Nevada Mountain range, snowpack is expected to decrease between 40-70% by 2050 under higher-emissions scenarios.

Montana

- **Increased Air Quality Issues**
  - The cancellation of the Butte Montana 100 event, as a result of wildfire smoke, has placed the event directors in a difficult financial position.

Oregon

- **Increased Trail Closures**
  - Fire closures are resulting in the Oregon Timber Trail (700mile of trail) potentially never being entirely rideable in a single season.

Utah

- **Changing Snowpack**
  - Park City is expected to lose all mountain snowpack by the end the century.
- **Reduced Visitation Levels**
  - Utah's 5 National Parks lost 11,125 to 30,851 annual visitors due to wildfires, resulting in a direct loss of $780,000 to $2.34 million in visitor spending.

Case studies

Alaska

- Reduced Winter Season
  - Snow cover is expected to decrease, increasing the length of the snow-free season.

Idaho

- Increased Event Cancellation
  - Pierre's Hole 50/100K Mountain Bike race in Targhee, Idaho, was canceled due to a smoke storm.

New York and New England

- Reduced Winter Season
  - Snow cover is expected to decrease, reducing the number of days with snow cover by 50% under a lower emissions scenario, and by 75% under a higher emissions scenario.

North Carolina

- More Frequent & Longer Trail Closures
  - When Hurricane Florence hit in 2018, it shut down trails for two and a half years in Wilmington, NC. As of 2021, work was still being done to open the trail due to downed trees.
- Increased Safety Concerns & Trail Closures
  - Drier summers and more moisture in the winters is resulting in more landslides in the municipalities of Asheville and Boone.

Doing a Resiliency Assessment

Step 1. Define the assets your operation requires. Include both assets you operate, and assets you depend on. This is the boundary of your study.

Step 2. Establish the timeline of your study. 20 years – 50 years is typical.

Step 3. Obtain projections of key climate drivers for your region of operations.

Step 4. Identify potential ways changes in climate can impact those assets. Consider both positive and negative impacts. Engage affected parties and local knowledge!

Step 5. Rank climate-related risks based on probability *and* severity.

Step 6. *For risks above a certain threshold*, develop mitigation plans to design for potential outcomes.

Step 7. Document and communicate your findings back to decision makers and interested parties.

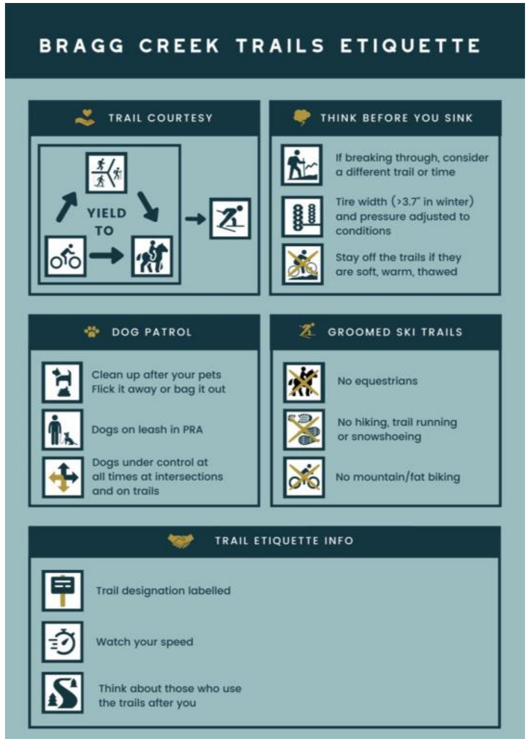
Assets Under Consideration

- Grooming and Maintenance Equipment
- Buildings
- Culverts
- Bridges
- Trail Networks
  - All Season
  - Multi-Use
  - Winter Multi-Use
  - Ski Trails
  - Winter Equestrian

- Additional Considerations?

Human Resources (Users, Volunteers and Employees)

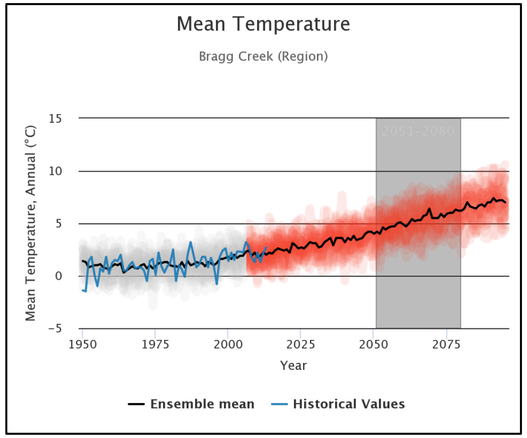
How Do Assets Fail at BCT?



Local Weather Trends

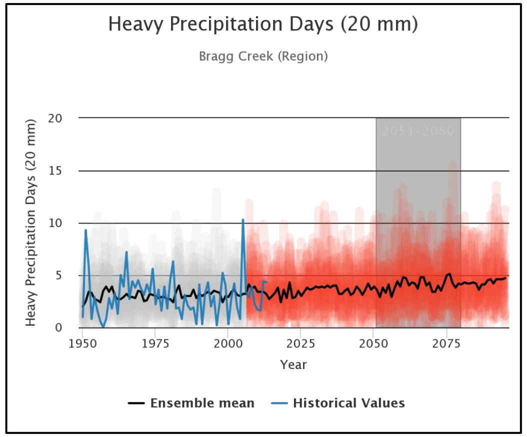
Temperature

- Mean annual temperature
- Minimum annual temperature
- Maximum annual temperature
- **Overall: Expected to increase**



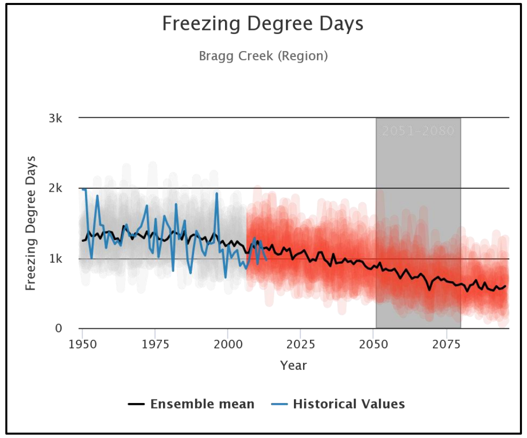
Heavy Precipitation

- Mean annual precipitation / Heavy precipitation
- Number of dry days / Mean annual aridity
- Mean annual water discharge / Mean annual runoff
- **Overall: Expected to increase**



Snowfall

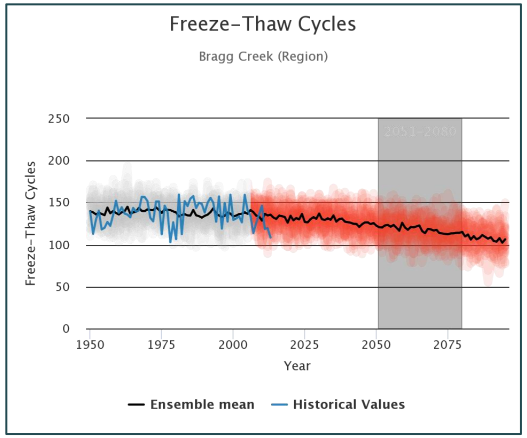
- Precipitation as snow
- Freezing degree days / Winter freezing degree days
- Frost free days / Winter frost free days
- **Overall: Expected to decrease**



Local Weather Trends

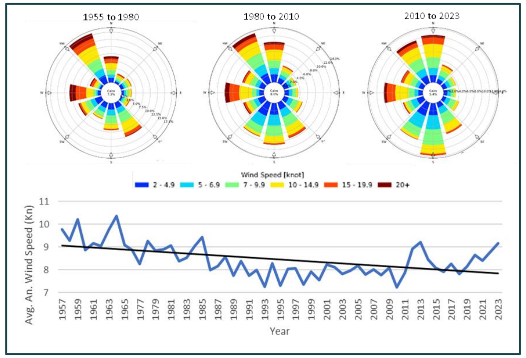
Freeze-Thaw Cycles

- Freeze-Thaw cycles
- Mean annual soil moisture
- **Overall: Expected to decrease**



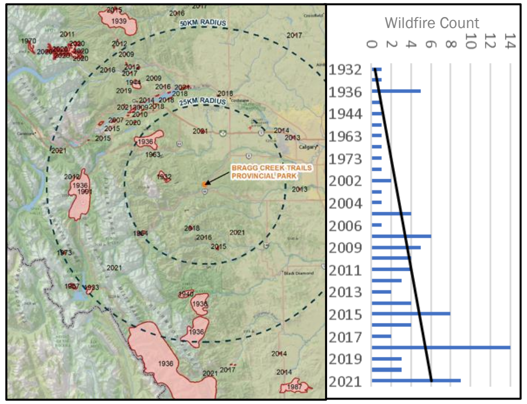
High Winds

- Historic wind speeds are decreasing
- Case studies and literature indicate an increase
- **Overall: Expected to increase in the future**

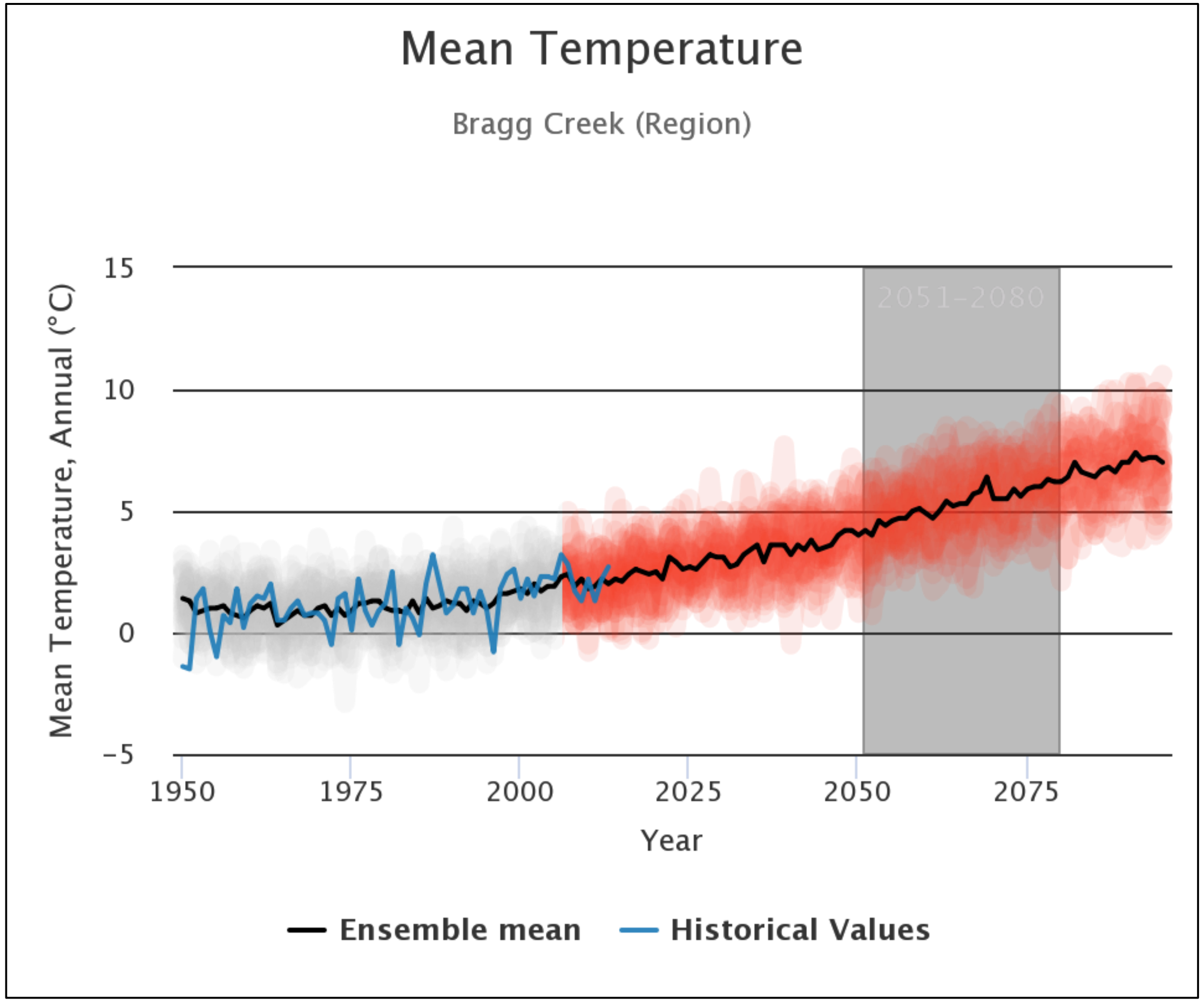


Wildfire

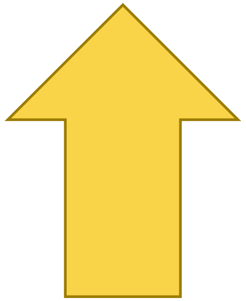
- Historic wildfires within 25km (1931 to 2022)
- Historic wildfires within 50km (1931 to 2022)
- Literature review
- **Overall: Expected to increase**



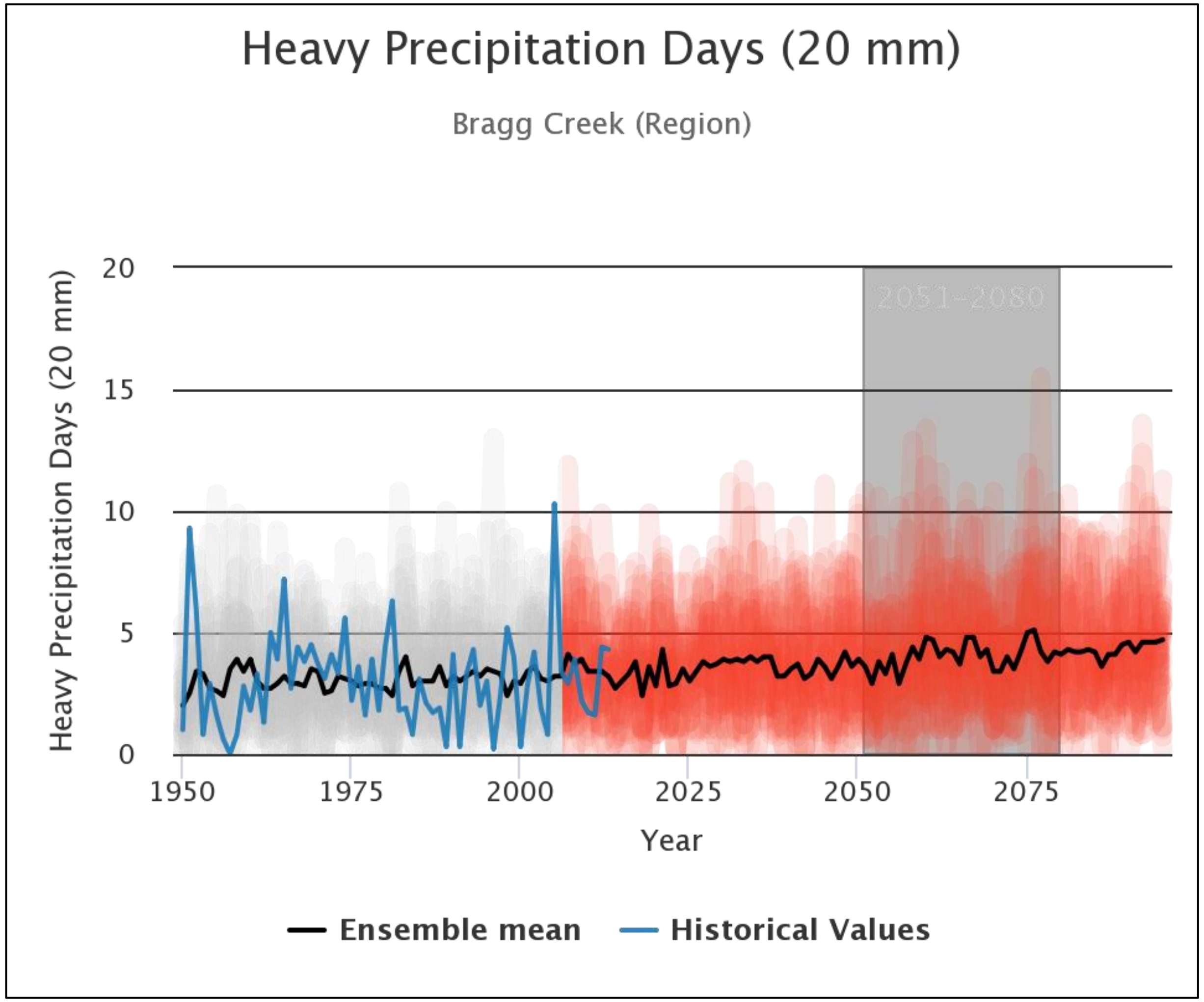
Local Weather Trends



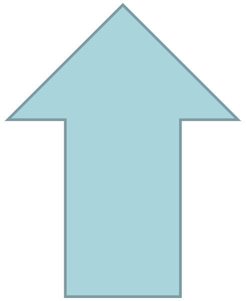
Overall: Expected to increase



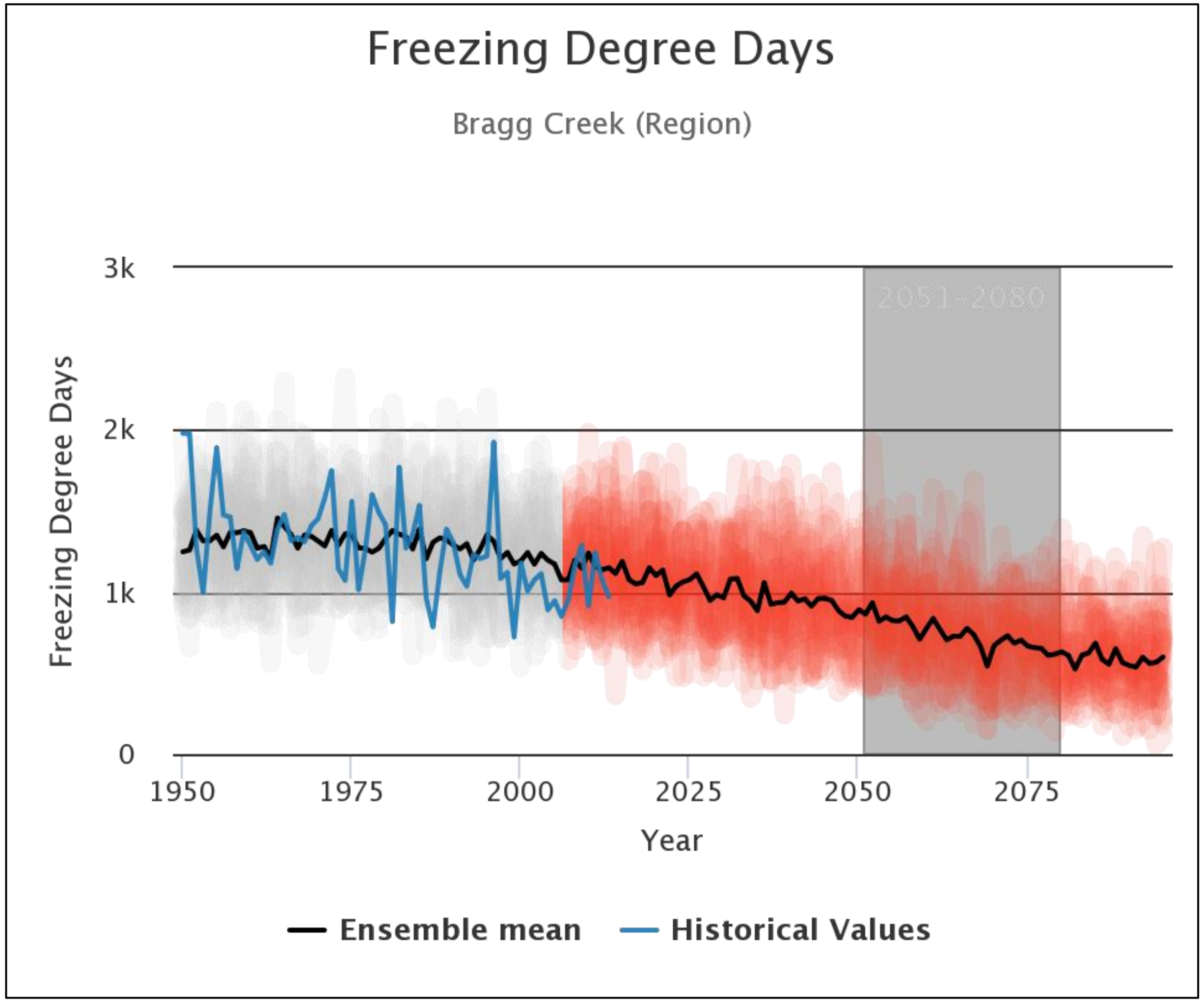
Local Weather Trends



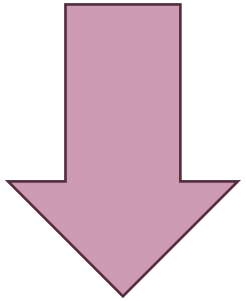
Overall: Expected to increase



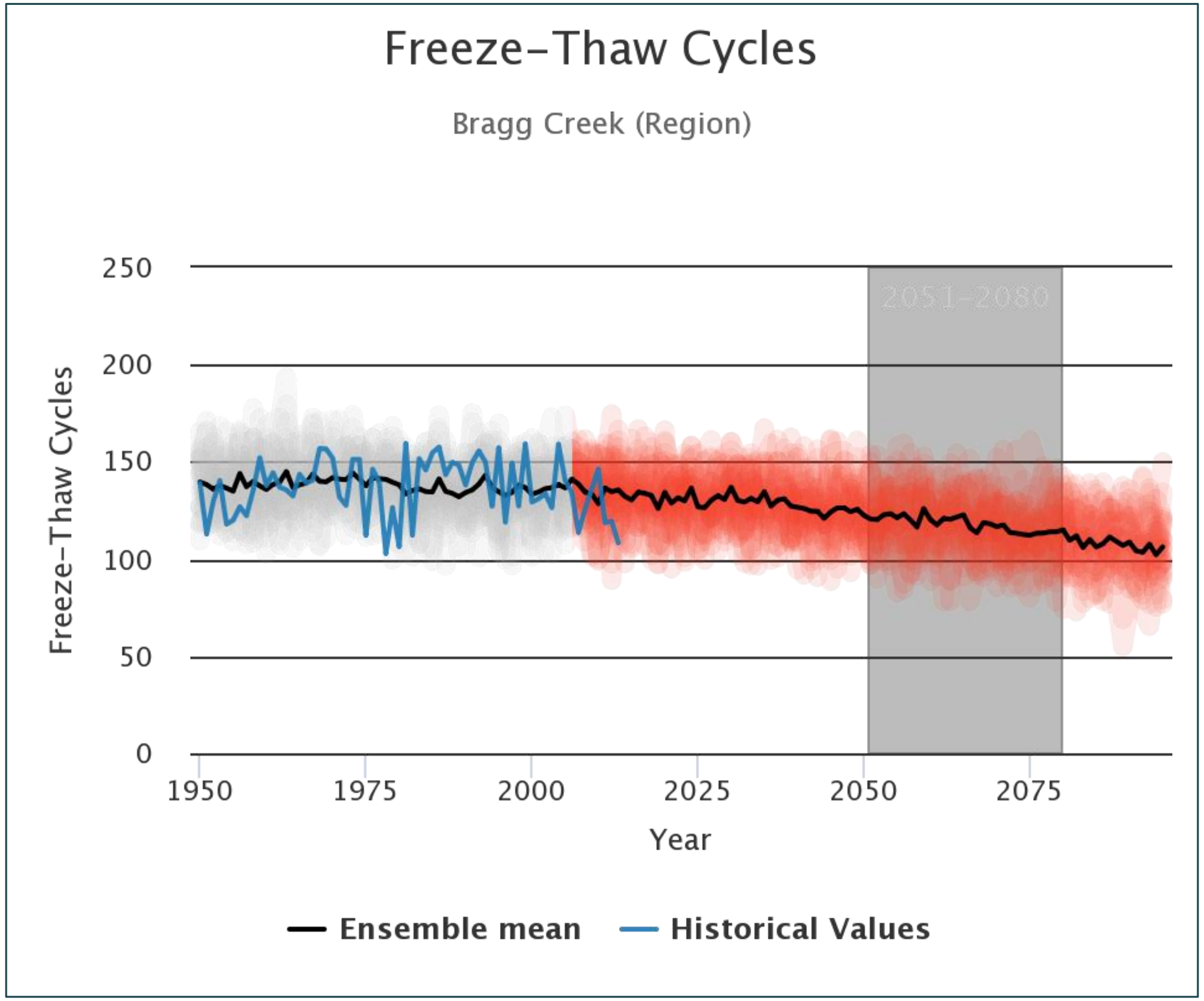
Local Weather Trends



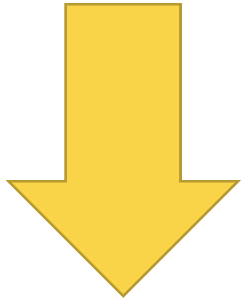
Overall: Expected to decrease



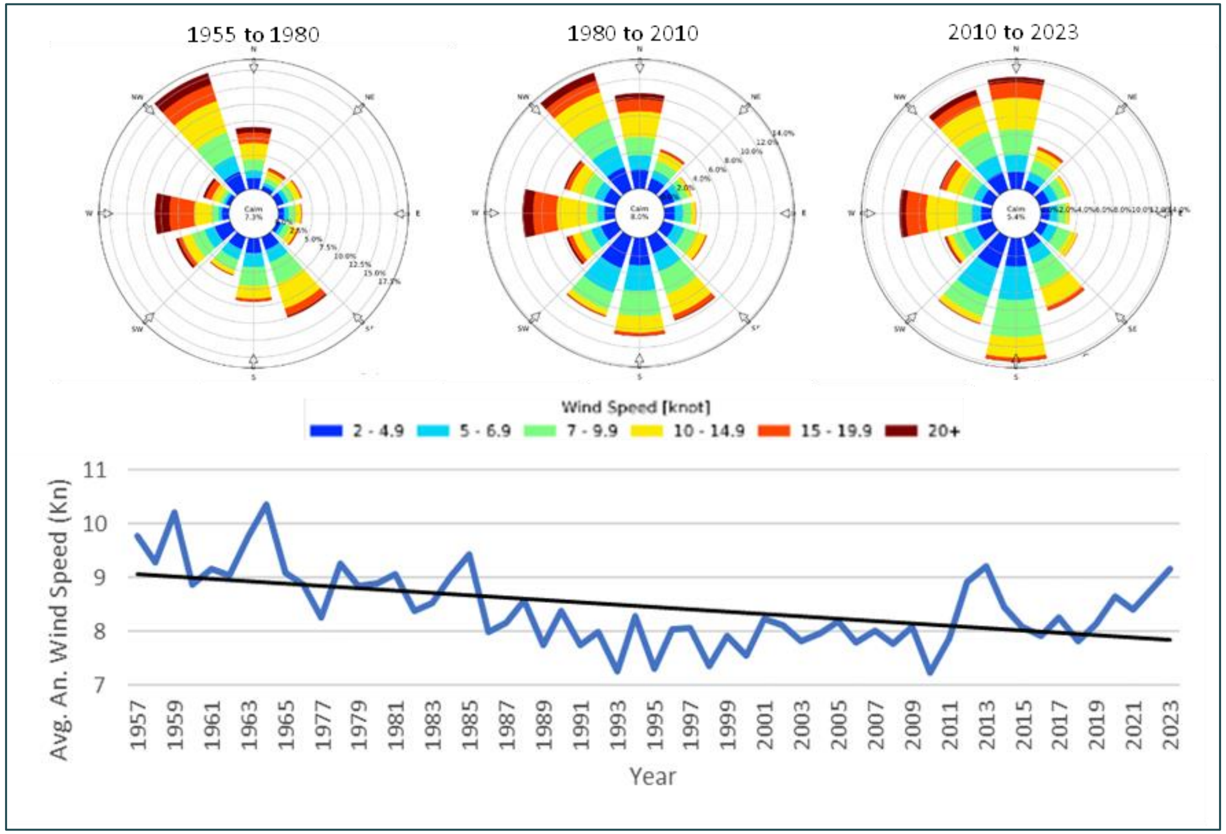
Local Weather Trends



Overall: Expected to decrease

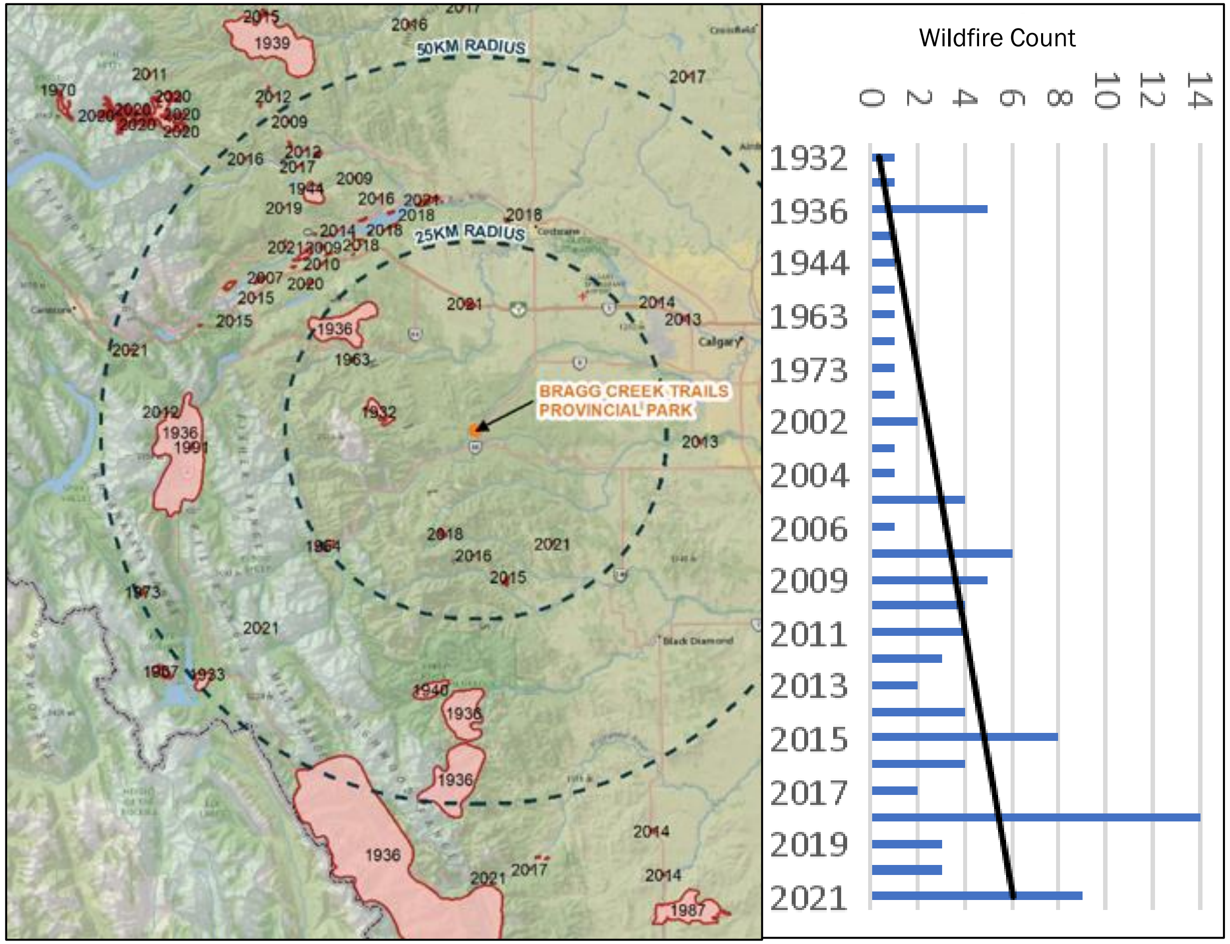


Local Weather Trends



Overall: Expected to increase

Local Weather Trends



Overall: Expected to increase

Brainstorming Potential Impacts

Temperature

- Reduced winter season
- Mandated trail closures
- Health and safety concerns
- Change in peak visitation time(s)

Freeze-Thaw Cycles

- Expansion and contraction of structural elements
- Increased trail maintenance

Heavy Precipitation

- Changing river levels
- Surcharging of drainage infrastructure
- Staffing concerns & Increased trail maintenance

High Winds

- More frequent and longer trail closures
- Structural damage and downed trees
- Flying debris
- Power outages

Snowfall

- Reduced winter season & Staffing concerns
- Changing river levels
- Changing snowpack

Wildfire

- Canceled events
- Decreased air quality & Health and safety concerns
- Reduced Visitation
- Trail closures & Creation of user defined trails

Identifying Infrastructure at Potential Risk

	Temperature	Heavy Precipitation	Snowfall	Freeze-Thaw	High Winds	Wildfire
Culverts	Yes/No					
Bridges						
Buildings						
Equipment						
Ski Trails						
Multi-Use Trails						
All Season Trails						
Winter Multi-Use Trails						
Winter Equestrian Trails						

Consequence Scales

What is a severe impact? What is a low impact?

Assess the potential consequences of various risks and hazards to prioritize response efforts and allocate resources more effectively.

Dimension	1	2	3	4	5
Operational Impacts (Staffing)		Some disruption to operations (interruption < 3 hours)			
Economic Impacts (Season Duration)			Moderate financial impact (cancelled event)		
Social Impacts (Reputation)				Public outrage and media attention (major safety incident)	
Environmental Impacts (Habitat Fragmentation)					Catastrophic impact on community natural resources (massive wildfire)

Probability Scales

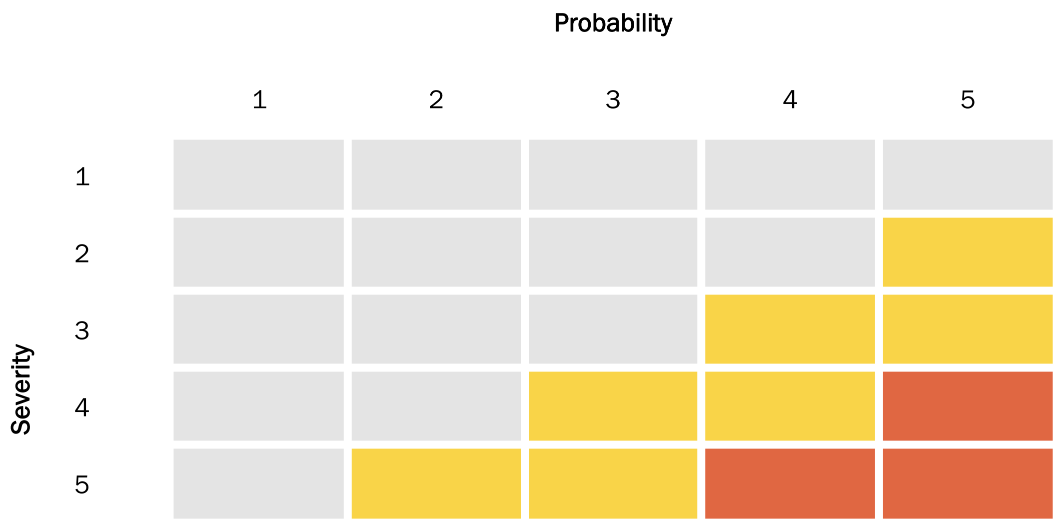
Probability is assigned based on the magnitude of change, using levels ranked from 1 to 5: Small (1), Medium (3), and Large (5)

- Probability is how likely an impact is to occur.
- Project team will assess based on available data.

Change magnitude	Temperature (°C)	Timeframe (days)	Percent (%)
Small	< 1.5	< 5	< 25
Medium	1.5 to 2	5 to 10	25 to 75
Large	> 2	> 10	> 75

Risk Analysis

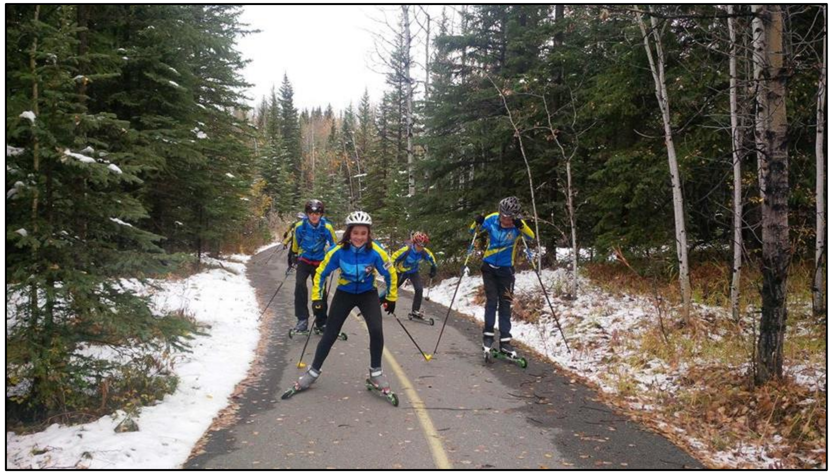
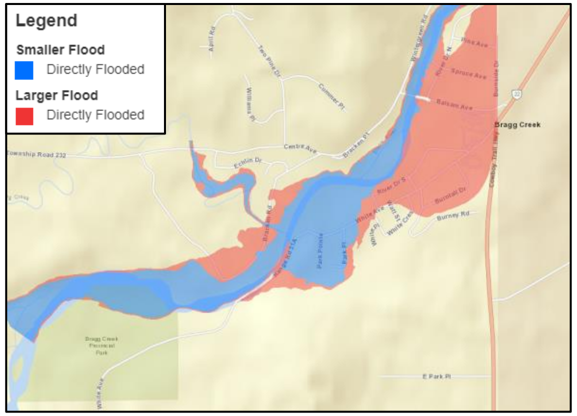
- Once probability and severity of impacts have been ranked from 1 to 5, they are multiplied to assign a final risk score from 1 to 25.
    - Scores from 1 to 9 are classified as low risk.
    - Scores from 10 to 16 are classified as moderate risk.
    - Scores from 17 to 25 are classified as high risk
- Recommendations will focus on moderate and high-risks



Risk Score	Risk Classification	
1-9	Low	Minimal action
10-16	Moderate	Possible further action
17-25	High	Further action required

Mitigation Options

- Recommendations/Mitigation Examples:
  - Infrastructure Upgrades
  - Operations and Maintenance Alterations
  - Increased monitoring
  - Emergency planning
  - Investment planning (snow guns)
  - Enhanced programming
  - Trail stewardship and advocacy

Thank you/Questions

BRAGG CREEK TRAILS