Incorporating Climate Change Risk Assessment into Pavement Asset Management Plans: A Case Study for York Region

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Abstract

Climate change impacts, especially in terms of rising temperatures and changes in precipitation patterns, have been noted in several regions across Canada over the past two decades. From a pavement/asset management perspective, such changes raise concerns about pavement serviceability and sustainability since both temperature and excess precipitation can affect the pavement material properties.

A risk assessment can be used to evaluate how climate change will affect a pavement network. Climate change risk assessment considers the likelihood, consequence, and required response to climate change impacts, and the options for addressing these impacts under financial and societal constraints.

This paper presents the methodology used for a climate change risk assessment for the Regional Municipality of York in Ontario (York Region or Region). The results of the risk assessment were incorporated into the York Region`s Pavement Asset Management Plan (Pavement AMP).

The study included:

1. Evaluating the likelihood of climatic changes in York Region. These climatic changes include the increase in annual mean temperature, extreme heat, annual precipitation, and extreme storms.
2. Conducting quantitative analysis to determine the consequence of climatic changes on pavement performance. Adjustments to the Region`s pavement deterioration curves were used to quantify the change in performance related to climate change impacts. These changes resulted in changes to pavement treatment timing and life cycle costs.

As a case study example, risk assessment results are presented in terms of likelihood vs consequence, in which risk factors were rated in a scale of 1 to 25 (low to high risk). For each risk factor, a mitigation strategy was proposed. The methodology and findings presented in this paper can serve as a reference for the development of climate change risk assessment, and the subsequent implementation in AMPs.

1 Introduction

Changes in climatic conditions can directly impact pavement performance. With record-setting temperatures and the increased frequency of extreme weather events, Canadian infrastructure could be at risk if adaptation strategies in pavement design and management are neglected.

Climate change impacts, especially in terms of rising temperatures and changes in precipitation patterns, have been noted in several regions across Canada over the past two decades. From a pavement/asset management perspective, such changes raise concerns about pavement serviceability and sustainability since both temperature and excess precipitation can affect the pavement material properties.

A risk assessment can be used to evaluate how climate change will affect a pavement network. A risk assessment can provide an important basis for identifying adaptation requirements and analyzing loss and damage. Climate change risk assessment considers the likelihood, consequence, and required response to climate change impacts, and the options for addressing these impacts under financial and societal constraints.

To that end, the likelihood of climatic changes in the Regional Municipality of York, Ontario (York Region or Region), were analyzed. These climatic changes include the increase in annual mean temperature, extreme heat, annual precipitation, and extreme storms. The implications of the climatic change on pavement performance were evaluated. Adjustments to the Region`s pavement deterioration curves were made to account for the change in performance related to climate change. Applying the suggested deterioration curves in the Region`s Pavement Management System (PMS) resulted in changes to pavement treatment timing and life cycle costs.

2 Likelihood of Climate Change Events

The 2019 Climate Change Report (CCCR2019) developed by the Government of Canada shows that Canada's climate is warming at more than double the global rate (Environment and Climate Change Canada, 2019). Predictions show that heat waves will occur more often and last longer. Increased rutting is likely to occur with higher pavement temperatures. Extreme precipitation events in many regions will likely become more severe and frequent, which will lead to flood damage (Barbi, Zhao, Nahidi, Achebe, & Tighe, 2021).

The combination of a climatic hazard likelihood and the impact it may cause are important factors for a risk level assessment. An example of a risk matrix, in which risk levels are represented by different colors and descriptions, is shown in Figure 1.

Likelihood \ Impact	Negligible	Minor	Moderate	Significant	Severe
Very Likely	Low Med	Medium	Med Hi	High	High
Likely	Low	Low Med	Medium	Med Hi	High
Possible	Low	Low Med	Medium	Med Hi	Med Hi
Unlikely	Low	Low Med	Low Med	Medium	Med Hi
Very Unlikely	Low	Low	Low Med	Medium	Medium

Figure 1: Example of Risk Matrix (Lu, 2020)

An event that is unlikely to happen could be classified as having a medium to medium-high risk, if the impact of the event is significant or severe. On the other hand, an event with a severe impact could be considered medium risk, if the event is very unlikely to happen.

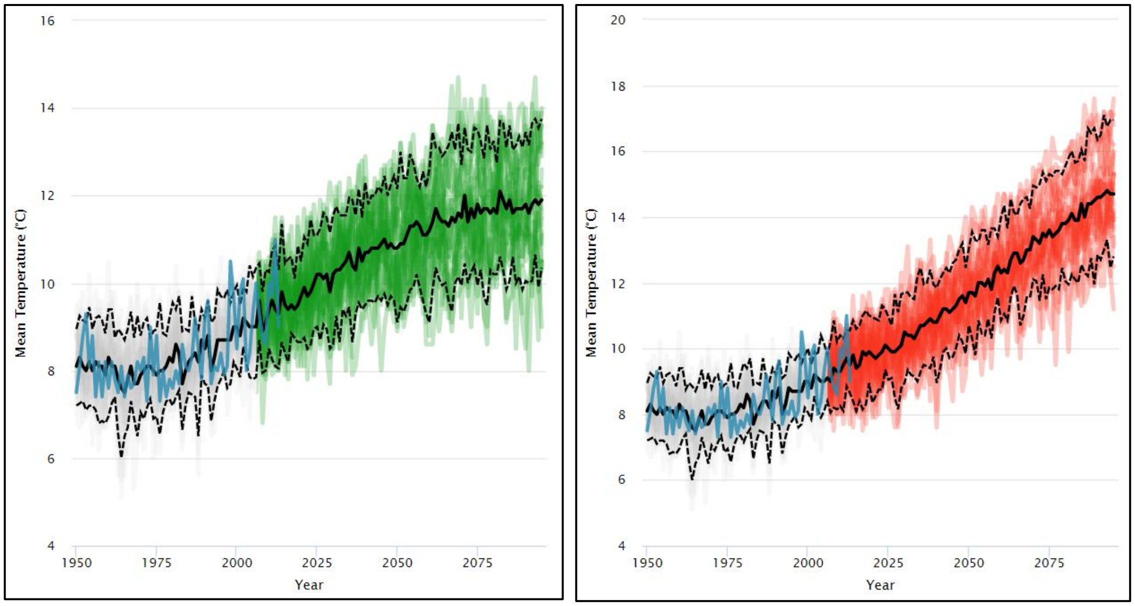
Climate projections in Canada and the York Region/Toronto, and the likelihood of such projections occurring are presented in the following sections.

2.1 Temperature

Environment and Climate Change Canada (Environment Canada) published a report in 2019 that showed that the average spring and autumn temperature increased by 1.7ºC in Canada from 1948 to 2019. Moreover, during the same timeframe, summer got warmer by 1.4ºC and winters by 3.3ºC. Not only did the average seasonal temperature get warmer, but the number of extreme heat days also increased. Extreme heat days are defined as days with a maximum temperature above 30ºC. According to the report, the annual average number of hot days increased by 3 in southern Canada (as defined by Environment and Climate Change Canada) from 1948 to 2016 (Environment and Climate Change Canada, 2019).

The Government of Canada developed an online tool called Climate Atlas of Canada. The tool can show possible climate change scenarios, providing climatic predictions for Canada as a whole, and for specific regions. The long-term projected temperature changes in Toronto are shown in Figure 2.

The prediction scenarios are based on the amount of Greenhouse Gas (GHG) emission levels or Representative Concentration Pathway (RCP). The projected annual mean temperature changes based on RCP 4.5, which represents low carbon emissions, is presented in Figure 2 (a). The projected annual mean temperature changes based on RCP 8.5, which represents high carbon emissions, is presented in Figure 2 (b). In both scenarios, the annual mean temperature predictions increase by 2075.



(a) **(b)**

Figure 2: Projected Annual Mean Temperature Changes in Toronto According to (a) RCP 4.5 (b) RCP 8.5 (Praire Climate Centre, 2023)

The annual mean temperature and the number of days above 30 °C were estimated, based on data published at the Climate Atlas of Canada for the years 2050 and 2080, and are presented in Table 1. The scenarios were generated using RCP 8.5.

Table 1: Projected Temperature Changes for 2050 and 2080

Projected Climatic Changes	Historical (1976-2005)	Future (2050s)	Future (2080s)
Annual mean temperature (°C)	Mean = 8.5°C	10th Percentile = 9.4°C Mean = 10.6°C 90th Percentile = 11.9°C	10th Percentile = 11.3°C Mean = 12.8°C 90th Percentile = 14.4°C
Extreme heat (number of days above 30°C)	Mean = 12 days	10th Percentile = 13 Mean = 30 90th Percentile = 48	10th Percentile = 31 Mean = 55 90th Percentile = 80

The predictions show that there is a 90% probability that the annual mean temperature will increase from 8.5°C to any temperature equal to or below 11.9°C by 2050 and increase to any temperature equal to or below 14.4°C by 2080. The predictions also show that there is a 90% probability that the number of extreme heat days will increase from 12 up to 48 days by 2050 and up to 80 days by 2080.

2.2 Precipitation

Precipitation in Canada varies significantly due to wide temperature ranges and diverse topography. According to the Intergovernmental Panel on Climate Change, precipitation has increased since 1901 in the mid-latitude land areas of the Northern Hemisphere. In general, Canada has become wetter with increasing annual average precipitation trends in many parts of the country.

Flooding is already identified as the most frequent natural hazard in Canada. Due to the rise of sea levels, the risk of flooding hazards may increase, becoming even more evident in coastal areas (Lu, 2020). Flooding of road infrastructure can jeopardize mobility, safety, and functionality, resulting in social and economic losses.

The flood return period is used in engineering to analyze and design structures. It is the inverse of the Annual Exceedance Probability (AEP). Table 2 shows that a 200-year flood is unlikely, while a 25-year flood is almost certain.

Table 2: Likelihood of Impact (Dillon Consulting, 2022)

Likelihood Grade	Description	Flooding or short duration high intensity rainfall return period and AEP
1	Rare	1:200 (0.5% chance)
2	Unlikely	1:100 (1% chance)
3	Possible	1:75 (1.3% chance)
4	Likely	1:50 (2% chance)
5	Almost Certain	1:25 (4% chance)

Studies show that climate change is predicted to increase precipitation for various event return periods. The annual mean precipitation and the magnitude of extreme storms are estimated and presented in Table 3. The scenarios were generated using RCP 8.5. The annual precipitation data is based on data published at the Climate Atlas of Canada for 2050 and 2080. The extreme storms are presented in terms of the amount of precipitation in a 24-hour period (24 h), with the average duration of a storm being four (4) days. The extreme storms data was collected from the IDF_CC tool, based on a station located in York Region. The IDF_CC tool is a web-based tool for the development of intensity-duration-frequency curves under climate change (Simonovic, Schardong, Gaur, & Sandink, 2025).

Table 3: Projected Precipitation Changes for 2050 and 2080

Projected Climatic Changes	Historical (1976-2005)	Future (2050s)	Future (2080s)
Annual precipitation (mm)	Mean = 793 mm	10th Percentile = 675 mm Mean = 845 mm 90th Percentile = 1022 mm	10th Percentile = 699 mm Mean = 870 mm 90th Percentile 1058 mm
Extreme storms (Precipitation depth, 24h)	1:50 event (Likely) - 129 mm 1:100 event (Unlikely) - 161 mm	1:50 event (Likely) – 135 mm 1:100 event (Unlikely) - 165 mm	1:50 event (Likely) – 140 mm 1:100 event (Unlikely) - 171 mm

There is a 90% probability that the annual amount of precipitation will increase from a mean of 793 mm to an amount equal to or below 1022 mm by 2050 and increase to an amount equal to or below 1058 mm by 2080.

Extreme storm events with a return period of 50 years are predicted to increase from 129 mm to 135 mm in 2050 and to 140 mm in 2080, while extreme precipitation with a return period of 100 years is predicted to increase from 161 mm to 165 mm in 2050 and 171 mm in 2080.

2.3 Permafrost and Freeze-thaw Cycles

With warming temperatures, locations where pavement layers have long frozen periods, such as the discontinuous permafrost areas, will likely experience more freeze-thaw (FT) cycles. In southern areas of Canada, however, frost penetration depth will decrease due to the shortening of the winter season along with freeze thaw cycles (Barbi, Tavassoti, & Tighe, 2023).

A study done at Toronto Pearson International Airport, less than 10 km from the York Region border, shows that based on data from 1950 to 2018, the average number of FT cycles has slightly decreased, as presented in Figure 3.

As this local study indicates that the number of FT cycles is not expected to increase, the analysis of an increase in FT cycles on pavement performance has been removed from further consideration.

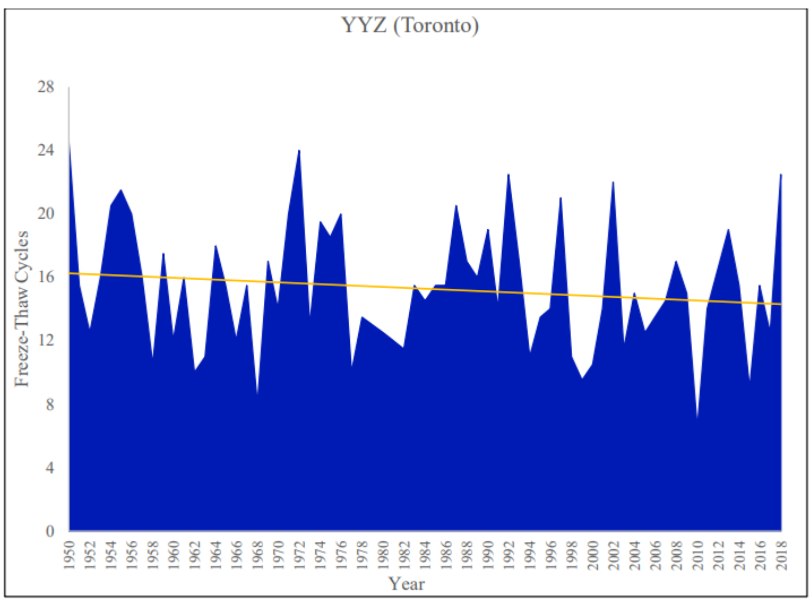


Figure 3: Annual Freeze-Thaw Cycles for Toronto Pearson International Airport (Abreu, 2019)

3 Pavement Deterioration Curves

Climate factors affect pavement deterioration through interactions with materials, structure, traffic, construction, and maintenance. Mechanistic-empirical models capture this by relating performance to these variables. Climate change alters deterioration curves (Figure 4), with higher temperatures, precipitation, and extreme events accelerating damage and reducing service life. Floods and hurricanes can cause sudden degradation ("jump") followed by delayed effects. Adjustments to account for these impacts are detailed in Sections 3.1 and 3.2.

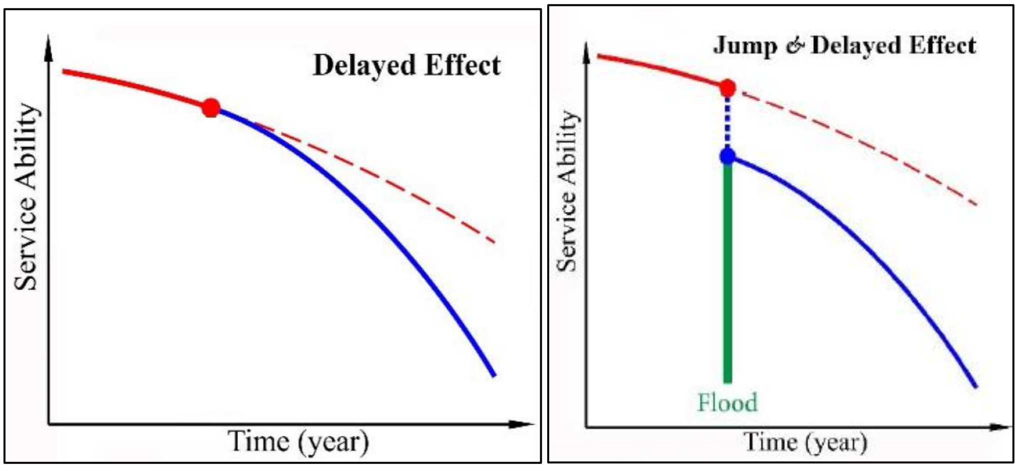


Figure 4: Pavement Deterioration Curves for Climate Change. Modified from (Lu, 2020)

3.1 Deterioration Curve Adjustment for Climate Change

Asphalt concrete (AC) is temperature- and time-dependent, with high temperatures causing rutting, shoving, and premature binder aging. Excess moisture, influenced by precipitation, runoff, groundwater, and drainage, also degrades pavements by:

(1) lowering the resilient modulus of granular layers and subgrade, increasing deformations;

(2) raising tensile strain in the AC layer due to a decrease in support, leading to fatigue cracking; and

(3) weakening AC bonds, causing stripping or raveling (Barbi P. S., 2022).

A study published in 2007 evaluated the implications of climate change for pavement infrastructure in southern Canada. The study used the AASHTOWare Pavement ME Design software to design pavements in a variety of locations, considering traffic, pavement structure and material data from Long Term Pavement Performance (LTPP) test sites. Past climate data was obtained from Environment Canada, while climate change data was obtained through the Intergovernmental Panel on Climate Change (IPCC).

The study considered two climate change scenarios based on different GHG emission levels: one based on the A2x emission experiment from the Canadian Centre for Climate Modeling and Analysis Coupled Global Climate Model 2 (CGCM2A2x), the other from the B21 experiment run through the Hadley Climate Model 3 (HadCM3B21). The pavement structure considered for the Ontario case study has the following characteristics: AC = 143 mm; Crushed Gravel = 180 mm; River-run Gravel = 792 mm.

The pavement structure sits on a Silt (ML) subgrade, which typically has low bearing strength (weak). The traffic has an average annual daily traffic (AADT) of 2,744, which is considered low. The results from the analysis of the baseline scenario and the two climate change scenarios are presented in Table 4.

Table 4: Performance Results (Mills, Tighe, Andrey, Smith, & Parm, 2007)

Scenario	IRI	Long Cracking	Alligator Cracking	Transverse Cracking	AC Deformation	Total Deformation[2]
Baseline	1.92 m/km	33.3 m/km	4.6%	399.6 m/km	4.2 mm	12.1 mm
CGCM2A2x[1]	1.0%	1.7%	10.5%	0.0	27%	9.0%
HadCM3B21[1]	1.6%	5.7%	13.1%	0.0	28.9%	10.3%

[1]Results from climate change scenarios are presented in terms of % change.

[2]Includes all pavement layers

The design life of the baseline scenario is 20 years. An increase in pavement distresses would decrease the pavement service life.

Consider that the maximum total pavement deformation should be 12.1 mm in 20 years. With climate change (scenario HadCM3B21), the pavement would reach a total deformation of 13.35 mm (10.3% more than the baseline). With the assumption that the increase in deformation is linear over time, the 12.1 mm deformation will be reached at year 18 instead of year 20. This approach was extended to other pavement performance data, such as International Roughness Index (IRI), longitudinal cracking, alligator cracking, transverse cracking, and AC deformation, to determine the new service lives, as presented in Table 5.

Table 5: Service Life Changes due to Climate Change

Scenario	IRI	Long Cracking (m/km)	Alligator Cracking (%)	AC Deformation (mm)	Total Deformation (mm)	Design Life (years)
Baseline	1.92	33.30	4.60	4.20	12.10	20.00
HadCM3B21	1.95	35.20	5.20	5.41	13.35	-
New SL* (years)	19.7	18.9	17.7	15.5	18.1	17.6

*SL = Service Life

The average service life under the climate change scenario HadCM3B21 was calculated as 17.6 years, which is 12% shorter than the original service life of 20 years.

Pavement deterioration mainly depends on traffic loading, layer thickness, and subgrade strength. Performance can be modeled using:

- Thickness: Equivalent Granular Thickness (EGT) – (thin, medium, thick)
- Traffic: Equivalent Single Axle Loads (ESALs) – (low, medium, high)
- Subgrade: Subgrade Strength – (weak/fair, strong)

The Region’s PMS includes 18 deterioration curves corresponding to 18 combinations of thickness/traffic classes/subgrade.

The pavement from the case study mentioned above is classified as thick/low/weak. It resulted in an average 12% decrease in pavement service life under the climate change scenario HadCM3B21.

Pavements that are thinner, or with higher traffic, would be subject to faster deterioration; therefore, the average decrease in the pavement service life could be considered higher than 12%.

Ideally, AASHTOWare simulations with varying thickness, traffic, and subgrade strength would yield more accurate results, but this is beyond the study's scope. Instead, deterioration curves were adjusted by these factors, as shown in Table 6.

Table 6: Deterioration Rate Changes

Pav. Thickness	Thick	Medium	Thin
% Change	0	2	4
Traffic	**Low**	**Medium**	**High**
% Change	0	2	4
SG stiff.	**Weak/Fair**		**Strong**
% Change	0		-3

The percent decrease in service life for each pavement deterioration curve is presented in Table 7.

Table 7: % Decrease in Pavement Service Life

Curve #	Description (Pav. thickness/Traffic/SG Stiff.)	% Decrease in Service Life
1	Thin/Low/Strong	13
2	Thin/Medium/Strong	15
3	Thin/High/Strong	17
4	Thin/Low/Weak	16
5	Thin/Medium/Weak	18
6	Thin/High/Weak	20
7	Medium/Low/Strong	11
8	Medium/Medium/Strong	13
9	Medium/High/Strong	15
10	Medium/Low/Weak	14
11	Medium/Medium/Weak	16
12	Medium/High/Weak	18
13	Thick/Low/Strong	9
14	Thick/Medium/Strong	11
15	Thick/High/Strong	13
16	**Thick/Low/Weak**	**12**
17	Thick/Medium/Weak	14
18	Thick/High/Weak	16

The proposed adjustments were applied to the Region's PMS deterioration curves. Examples of changes for three (3) out of the 18 deterioration curves are presented in Figure 5.

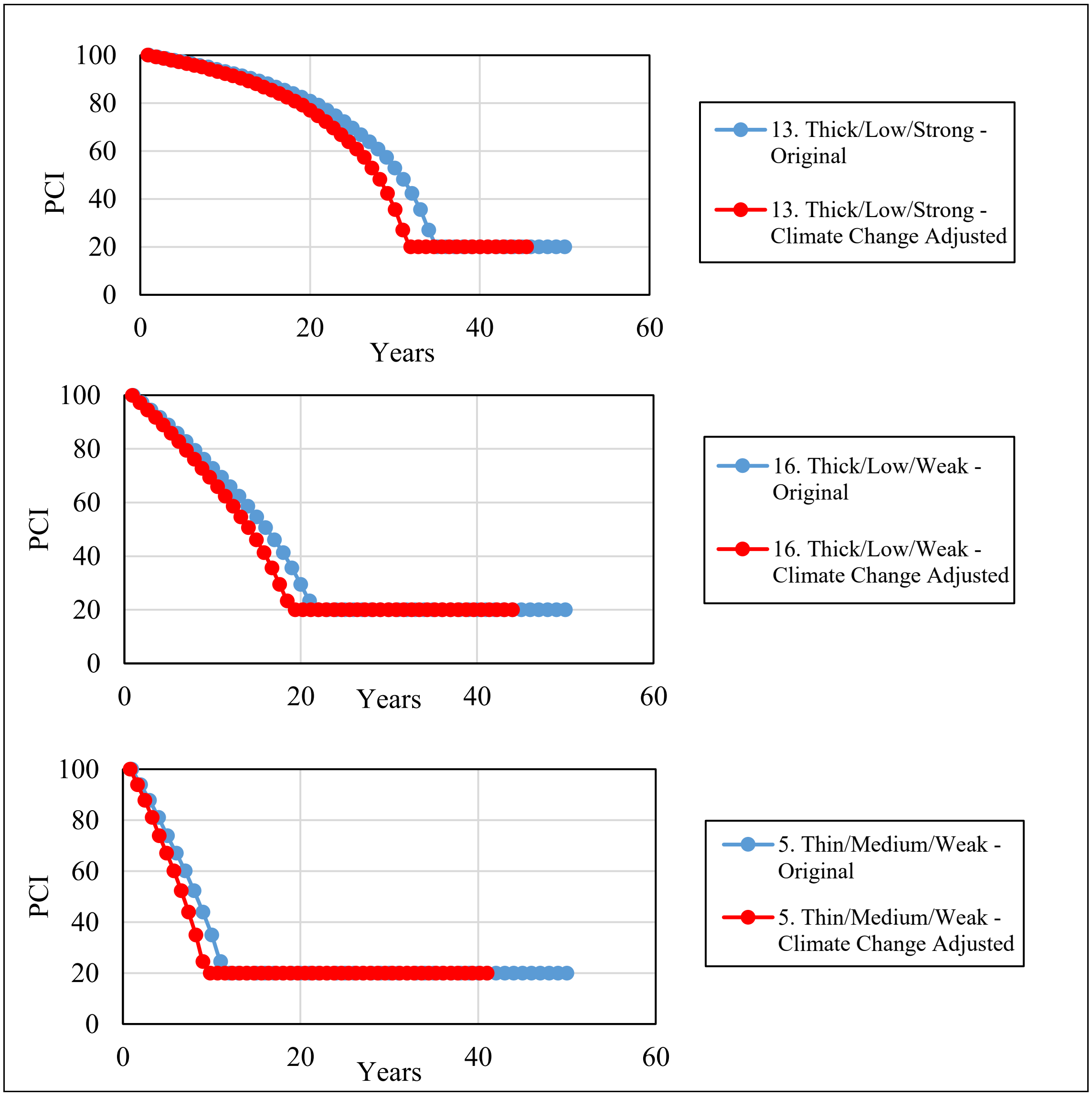


Figure 5: Deterioration Curves Before and After Climate Change Adjustment

3.2 Deterioration Curve Adjustment for Flooding

Flooding impacts pavements in both the short and long term through water ingress, debris, and washouts, with moisture accelerating damage via cracks and joints (Lu, 2020). An Australian study found flooding causes rapid deterioration, increasing rutting and cracking while reducing structural capacity. FWD tests after the Brisbane flood confirmed significant drops in Structural Number (SN). Two sections of an AC pavement with both pre-flood and post-flood data are shown in Figure 6 (Sultana, 2016).

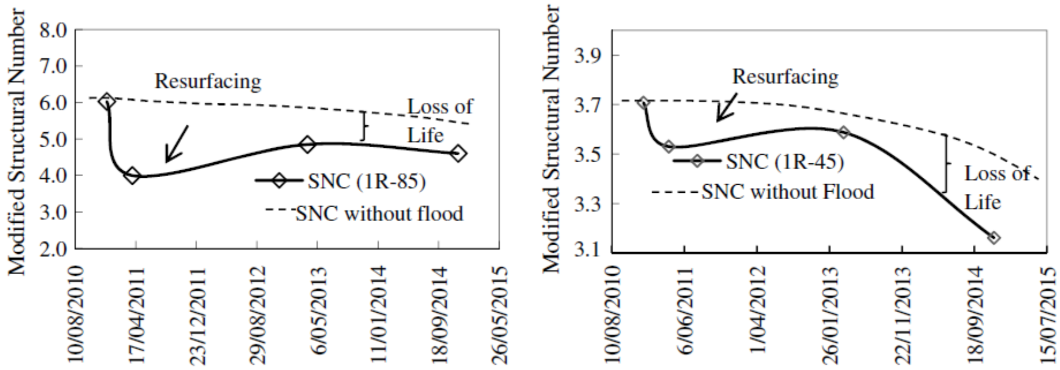


Figure 6: Comparison of Deterioration of Structural Strength of an Industrial Road (Sultana, 2016)

Flooding greatly reduced pavement strength. The dotted line shows predicted performance without flooding. After resurfacing in 2011, the 2013 survey showed improved strength, likely from both resurfacing and subsequent dry weather.

A study investigated the impact of hurricane Harvey, and the associated flooding, in Southeast Texas and Southwest Louisiana. Results of the investigation showed a rapid deterioration, with the decrease in distress index post flooding ranging from 11 to 30 points (Romanoschi, 2019).

New deterioration curves were developed for flood-prone pavements using hazard maps (Section 4). Pavements on weak subgrades were assumed to deteriorate faster, with PCI drops of 25 points versus 20 for strong soils (Figure 7).

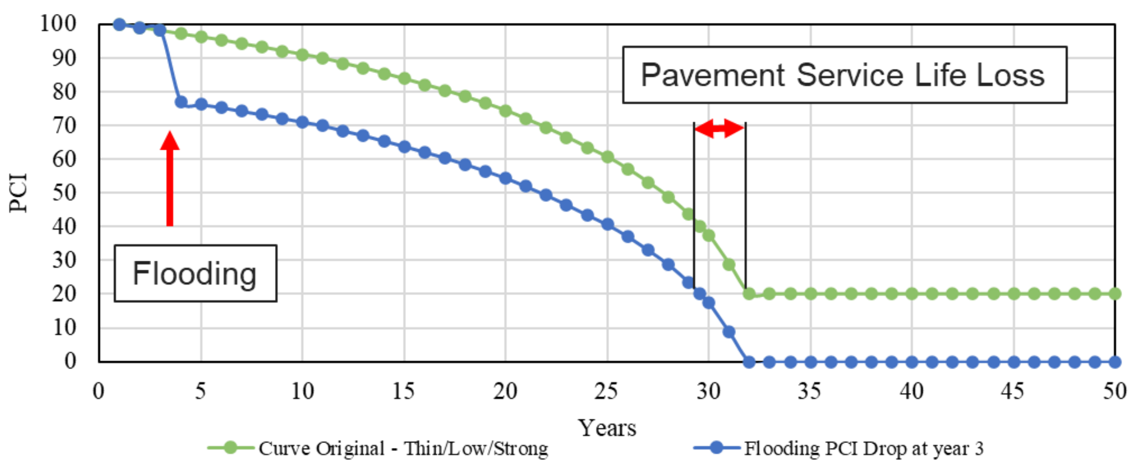


Figure 7: PCI Drop due to Flooding

The exact period in which a flooding event will happen over the course of a pavement life is unknown. It would be unreasonable to incorporate a sudden drop in the pavement PCI curve at a random point in time. For this reason, adjusted deterioration curves were estimated with the goal of maintaining the same loss in total pavement service life (Figure 8).

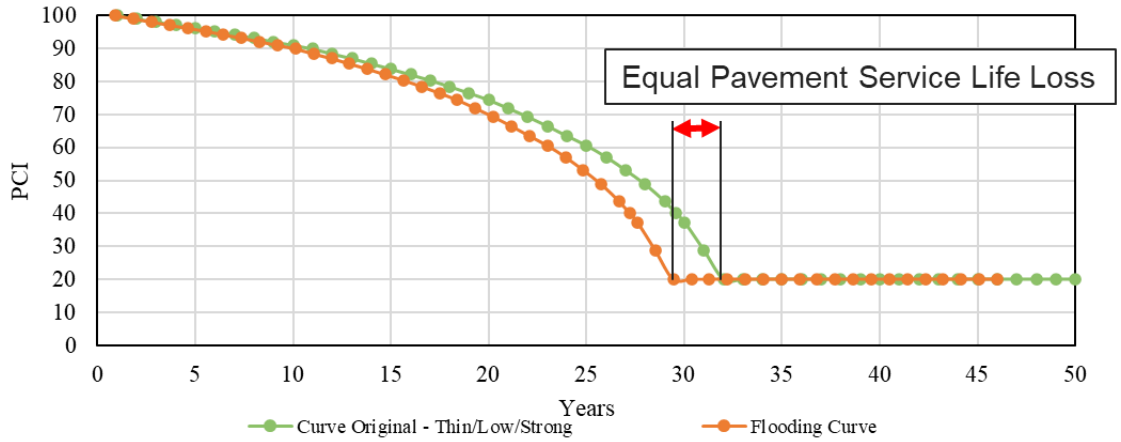
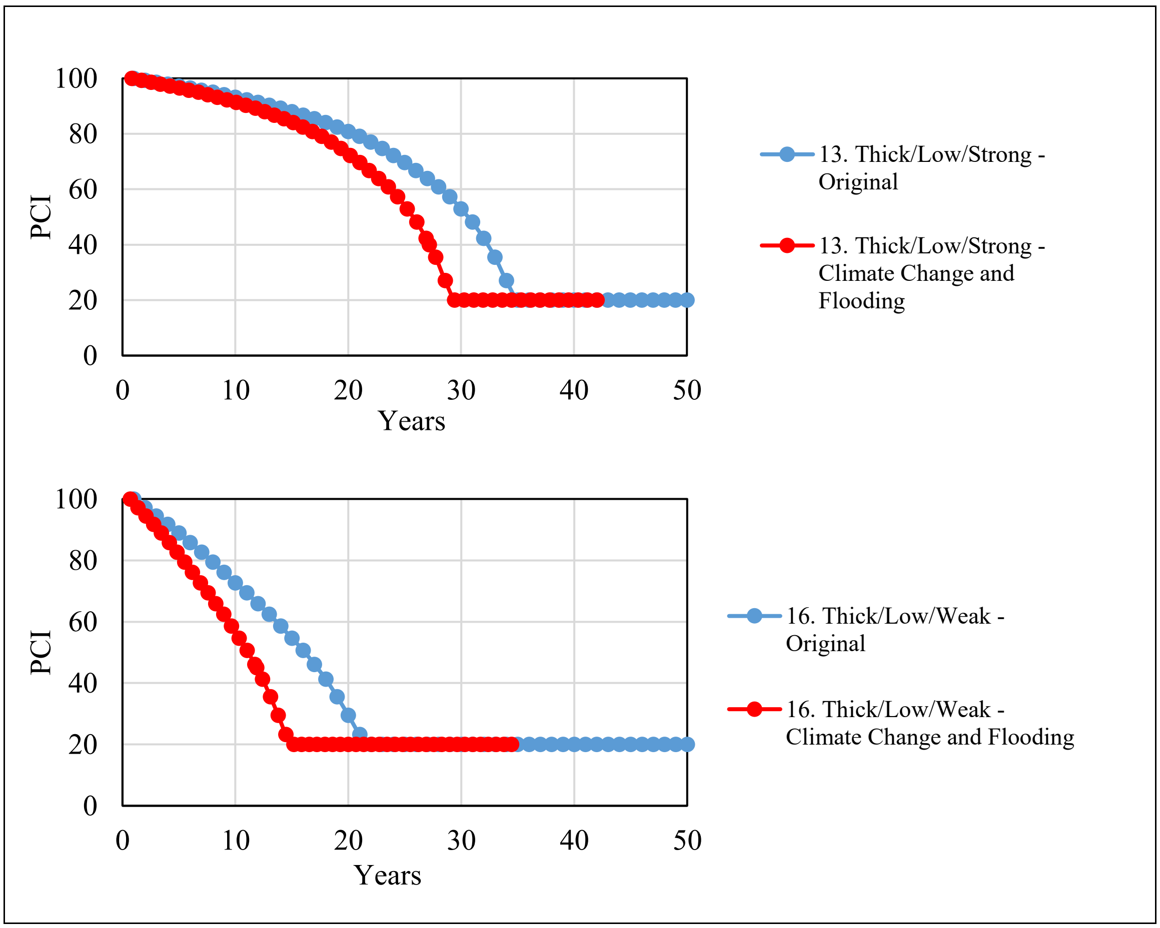


Figure 8: PCI Deterioration Curve Adjusted for Flooding

Note that the pavement service life was reduced by the same number of years in both Figure 7 and Figure 8. This analysis incorporated the service life loss caused by one flooding event over the course of 50 years. As an example, the changes due to climate change and flooding for three (3) of the 18 deterioration curves are presented in Figure 9.



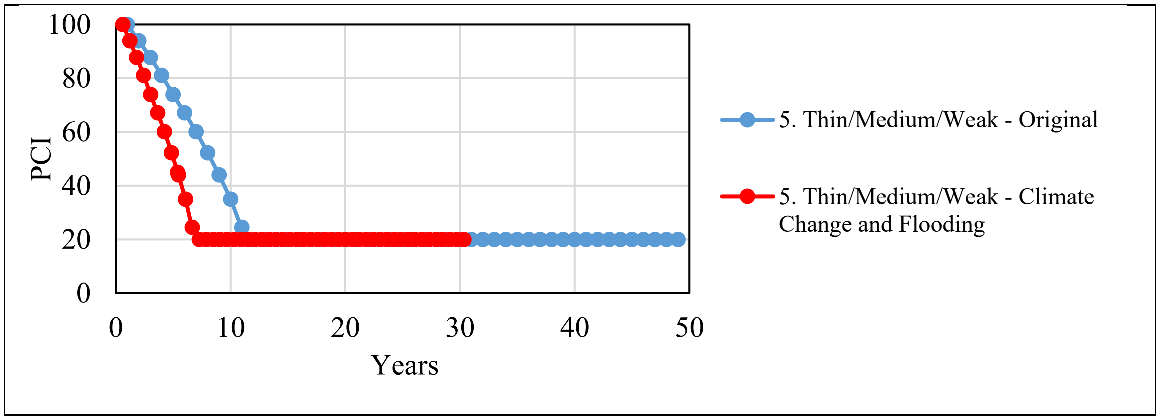


Figure 9: Deterioration Curves Before and After Climate Change and Flooding Adjustment

The adjusted curves presented in Figure 9 include the effects of climate change as presented in Section 3.1 as well as the effects of flooding. A curve set that includes flooding deterioration should only be applied in areas that are prone to flooding. Flood prone areas can be identified through flood hazard maps.

4 Flood Hazard Maps

Flood risk is estimated by combining pavement exposure with structural vulnerability. Flood hazard maps, showing flood type, extent, depth, and velocity, are key for network-level risk analysis. When overlaid with road network data (elevation, functional class, structure, asset value), GIS tools can identify submerged road sections. Maps can be generated using 1D-2D MIKE FLOOD models (DHI, 2011).

Toronto and Region Conservation Authority (TRCA) have generated regulatory engineered floodline mapping providing flood characterization maps and visual tools for communicating potential issues. Further studies have developed road network inundation maps and flood extent for various flood events for the region surrounding the Lower Don River, as presented in Figure 10.

As a flood hazard becomes more severe, the spatial extent of the road submergence covers more road sections. It can be observed that as the return period increases from 50-year to 100-year and higher, the roads experience a noticeable increase in the inundation length (Lu, 2020). The length of inundated road sections surrounding the Lower Don River in Toronto is presented in Figure 11.

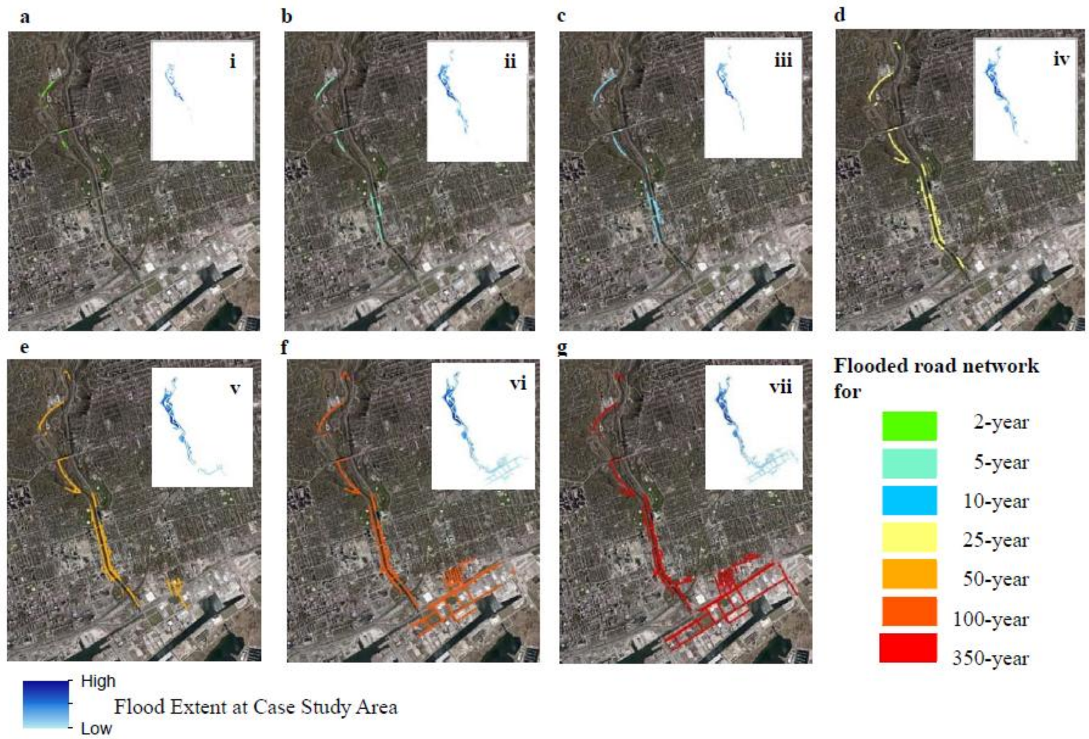


Figure 10: Road Network Inundation Maps and Flood Extent for Various Flood Events at the Lower Don River Region (Lu, 2020)

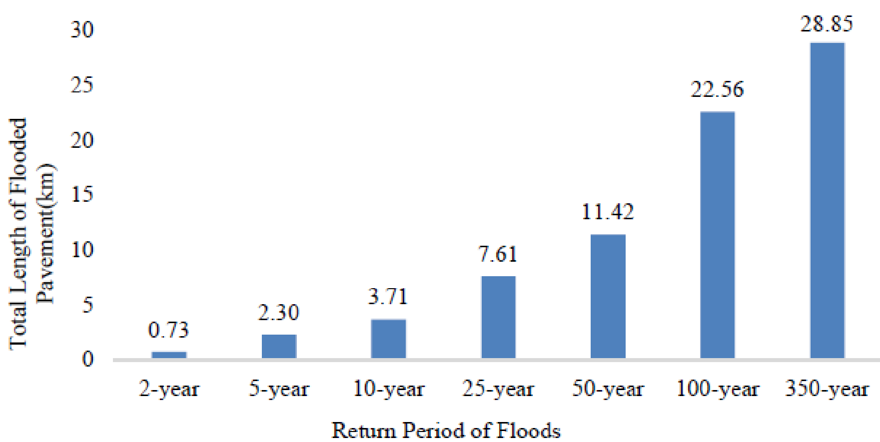


Figure 11: Length of Inundated Road Sections (Lu, 2020)

TRCA provides an online flood plain map for land use planning and emergency management (TRCA, 2023). These technical assessments use watershed data, topography, infrastructure, land use, weather, and stream flow to model flood extent.

Flood plain maps are updated every 10 years to reflect current conditions. Areas affected by a 100-year flood or Hurricane Hazel magnitude storms, including North Lake Road and Lakeland Crescent, are presented in Figure 12.

Figure 12: Flood Plain for the Wilcox Lake in York Region using the TRCA Map Viewer (TRCA, 2023)

The 2021 York Region Transportation State of Infrastructure Report Card provides a map of York Region indicating the historical flooding locations. The map, presented in Figure 13, shows 11 locations that have previously experienced flooding.

The flood prone area map can provide some guidance; however, the information is limited since it was developed based solely on historical floodings. The TRCA flood plain map online tool should be used to provide better predictions of future flooding extension in York Region.

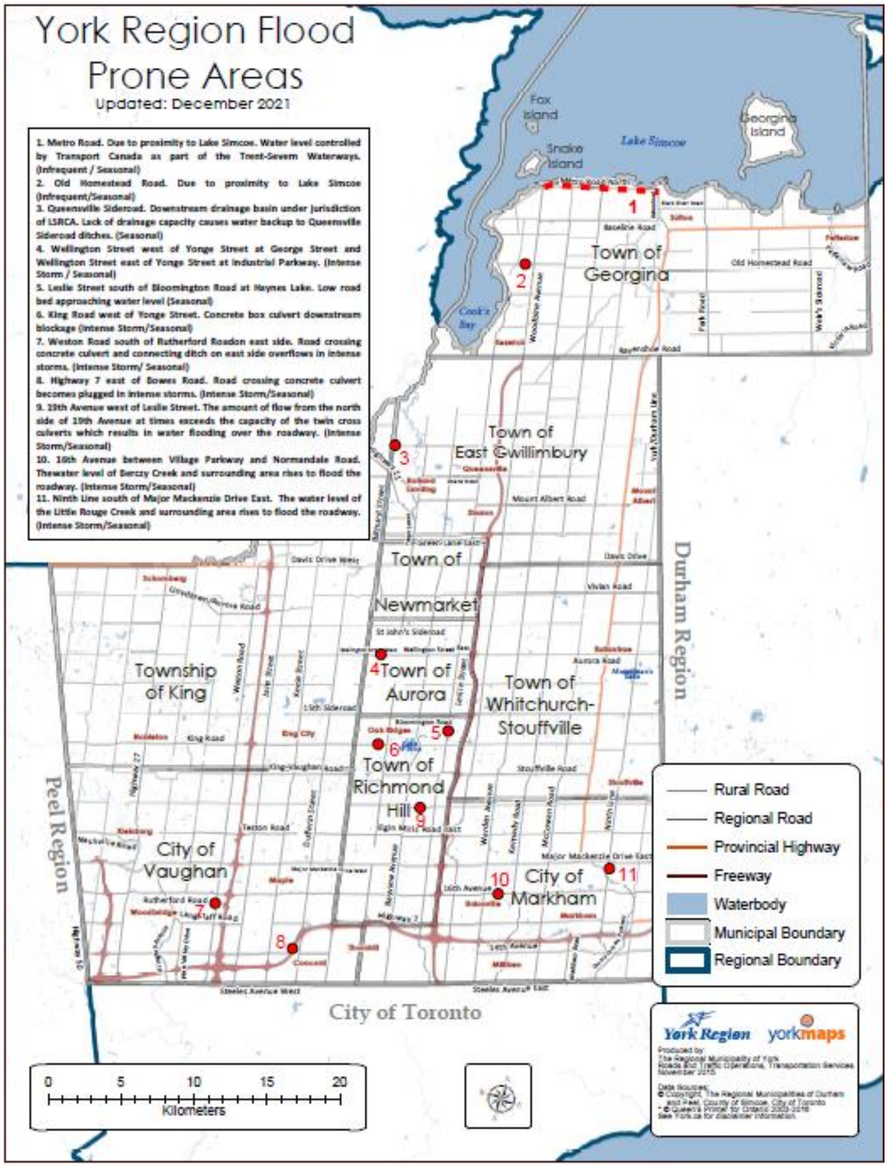


Figure 13: York Region Flood Prone Areas (The Regional Municipality of York, 2022)

5 Analysis of Binder Performance Grade

Temperature plays an important role in the performance of AC pavements. Higher temperatures can reduce the stiffness of the asphalt mix and interrupt the distribution of loads. The increase in temperature due to climate change can also accelerate asphalt concrete aging and the development of cracks. Mitigation requires selecting the appropriate Performance Grade (PG) binder and aggregate structure.

PGs measure binder performance under different temperatures and aging, guiding binder choice for rutting, fatigue, and low-temperature cracking. PGs are specified by maximum and minimum design temperatures in 6°C increments (Figure 14).

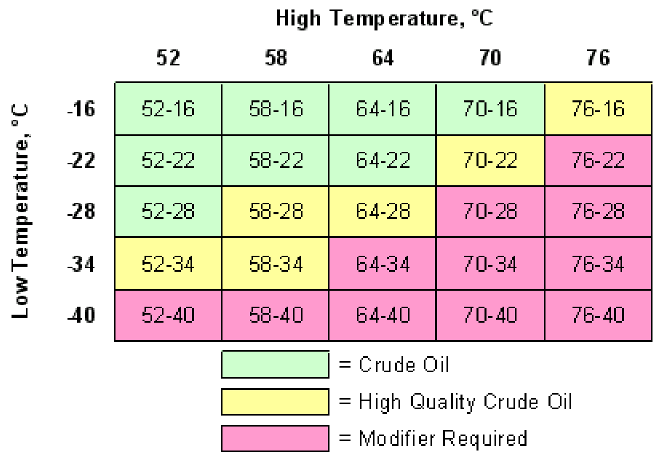


Figure 14: Prediction of PG grades for different crude oil blends (Pavement Tools Consortium, 2023)

To improve rutting resistance, the maximum design temperature for high volumes of heavy loads should be increased or “bumped” by one grade. Roadways with a high percentage of heavy truck traffic at slow speeds and frequent stops should be considered for a two-grade increase (Ontario Hot Mix Producers Association, 1999). York Region has historically used the PG 58-28 binder and bumped the PG grade one or two times to accommodate higher volume and/or slower traffic. The Region`s PG selections are appropriate based on past climate.

Climate change studies suggest many Canadian regions will need PG binder adjustments, but Toronto and York Region can maintain current selection until 2050 (Mills, Tighe, Andrey, Smith, & Parm, 2007). By 2080, one PG bump may be needed, raising the minimum binder to 64-28, with one to two more bumps depending on traffic speed and volume.

6 Pavement Risk Summary

The risks identified in Section 2 were analyzed in terms of likelihood vs consequence of occurrence, in which risk factors were rated in a scale of 1 to 25 (low to high risk). For each risk factor, mitigation strategies/risk treatments were proposed. For each mitigation strategy, the evaluation presented a risk treatment objective that could meet one of the following categories: avoidance (prevention of the risk trigger), mitigation (reduction of the risk impact), transfer (diversion of the risk to another party), and acceptance (risk detection for information).

The results also included the estimated cost and benefit of the treatment activity, called residual risk score. A summary of the potential triggers, risk events and adverse impacts on pavement is presented in Table 8. The proposed risk mitigation strategies include improving drainage conditions in flood prone areas and ensuring roads affected by such events are built and maintained with proper drainage of the granular layers. It is recommended that pavement performance be tracked so that prediction models accurately reflect the pavement deterioration.

Table 8: Pavement Risk Register

Identify Risks			Analyze Risks			Treatment to Risks		
Trigger	**Possible Event**	**Impact**	**Event Likelihood (1 to 5)**	**Consequence (1 to 5)**	**Current Risk Score**	**Proposed Risk Treatment**	**Risk Treatment Objective**	**Residual Risk Score**
By 2050, an increase in annual mean temperature from 8.5°C to or below 11.9°C, and in number of extreme heat days from 12 up to 48 days	Causes reduced asphalt mix stiffness	Leads to an increase in rutting, shoving and age hardening of the asphalt mix	4 (likely)	1 (very low)	4 (low)	None as currently pavement standard Performance Grade (PG) 58-28 binder is sufficient to 2050	N/A	No change 4 (low)
By 2050, increase in temperature as above PLUS an increase in annual precipitation from a mean of 793 mm to an amount equal to or below 1022 mm	Causes reduced asphalt mix stiffness and excessively saturated pavement layers	Leads to an increase in pavement deformations and decrease in pavement service life (from 9% to 20% depending on thickness, traffic, and subgrade stiffness)	4 (likely)	3 (medium)	12 (high)	Reduce # GHG emissions by implementing alternative treatments	Avoid (reduce risk trigger)	No change 12 (high)
						Continue tracking how accurately decay curves predict actual performance	Accept (detect risk for info)	No change 12 (high)
By 2050, an increase in extreme storm events with a return period of 50 years from 129 mm to 135 mm	Causes short-term flooding and washouts	Leads to an increase in rutting and cracking, and a decrease in the pavement structural number and service life (for segments susceptible to flooding)	4 (likely)	3 (medium)	12 (high)	Continue tracking areas susceptible to flooding	Accept (detect risk for info)	No change 12 (high)
						Ensure flood prone roads are built and maintained with proper drainage of the granular layers	Mitigation (risk reduction)	Change 12 (high)
By 2050, an increase in annual mean temperature from 8.5°C to or below 11.9°C	Cause more freeze-thaw cycles	Leads to accelerated deterioration of the pavement structure	1 (very low)	2 (Low)	2 (low)	None, event is unlikely in York Region	N/A	No change 2 (low)

7 Conclusions

An assessment of the likelihood of climate change factors in York Region was performed to identify possible hazards that may occur over the short- and long- term. Predictions showed that there is a 90% probability that the annual mean temperature will increase in 3.4°C by 2050 and 5.9°C by 2080, and the same probability that the number of extreme heat days will increase from 12 up to 48 days by 2050 and up to 80 days by 2080.

The studies also indicate a 90% chance that precipitation will increase from a mean of 793 mm to an amount equal to or below 1022 mm by 2050 and increase to an amount equal to or below 1058 mm by 2080. Extreme storm events with a return period of 50 years are predicted to increase from 129 mm to 135 mm in 2050 and to 140 mm in 2080, while extreme precipitation with a return period of 100 years is predicted to increase from 161 mm to 165 mm in 2050 and 171 mm in 2080.

The changes in temperature and precipitation will affect the pavement materials, accelerate pavement deterioration, and shorten its service life. Therefore, pavement deterioration curves were adjusted to account for the effects of climate change. A methodology for the incorporation of climate change and flooding in pavement deterioration curves was discussed, and two new curve sets were proposed. The curve set that represents flooding as well as changes in average precipitation and temperature should be applied only in areas that are prone to flooding, while the curve set that represents average climatic changes can be applied to the rest of the Region's pavement network. The use of the adjusted pavement deterioration curves will affect treatment timing. Interventions will be triggered sooner, and a 10-year budget will become more costly.

The asphalt binder Performance Grade currently used by the Region was assessed and found to be adequate to cope with the current environmental conditions. It was found through recent studies that the York Region will not require a change in its current PG binder until 2050. One bump in the base PG might be necessary for the 2080 timeframe, and consequently the minimum binder specification will become PG 64-28, with the associated 1 or 2 bumps depending on the traffic speed and volume.

Finally, risk assessment results are presented in terms of likelihood vs consequence, in which risk factors were rated in a scale of 1 to 25 (low to high risk). For each risk factor, risk treatments were proposed. The risk treatments include improving drainage conditions in flood prone areas, and ensuring roads affected by such events are built and maintained with proper drainage of the granular layers. It was also recommended that pavement performance continues to be tracked to adjust the deterioration curves accurately.

The methodology and findings presented in this paper can serve as a reference for the development of climate change risk assessment, and the subsequent implementation in Pavement Asset Management Plans.

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