CLIMATE CHANGE IMPACT ON DESIGN AND BUILDING CRITERIA OF INFRASTRUCTURE ASSETS – SIMULATION MODEL

By

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Abstract

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Master of Engineering 2019

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Current design codes and criteria for the construction of infrastructure assets is unable to account for anticipated environmental changes due to climate change. This study developed a simple simulation model based on MS Excel Precision Tree to consider the effects of adding a correction factor for climate change to justify then intent to proceed or not with a construction project. After many iterations, it appears that climate change can result abandoning certain projects as any investment in them would to be beneficial.

A simulation model was also developed to determine the allocation of funds for an initial construction project using climate change control parameters. This model showed that for a 100-year span, on average, there would be a deficit caused by costs involved with repairing the asset due to climate change deterioration. This can be counteracted by attributing 95% contingency to reduce the risk of climate change damage to 5%.

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1. Introduction

I. Scope

In this project, we will explore the changing landscape of environmental phenomena. This includes, water, temperature, CO2 levels and wind. For water, we will explore coastal, rivers and lakes. Temperature can be thought of as both high and low extremes which in turns changes weather patterns such as wind. CO2 levels not only contribute to the greenhouse effect which raises temperature but accelerates deterioration of concrete in many structures, we will explore this further. Many papers and studies have been published about these topics and we will be exploring them and discussing their findings to better understand how everything fits together.

We will then proceed with developing a decision tree model as well as a simulation to showcase how climate change in the next century will affects infrastructure assets in Canada and the world.

II. Objective and significance of work

The intention is to raise awareness that current building standards and codes may be outdated in meeting the present and future needs in infrastructure. From these simulations we will discuss further their significance and how they can be interpreted. Following this, we will reflect on this project and results and elaborate on any potential next steps than can be taken to drive further the accuracy and reliability of the findings.

2. Water

When it comes to water and climate change, rising levels are what will be affecting the design code. Higher levels mean more added load. Furthermore, the level varies depending on the geographical location. These locations can be divided into coastal and river.

I. Coastal – sea level rise

In Canada, there are three major coastal areas with significant infrastructure and population to be considered; the Maritimes or Atlantic, the St Lawrence seaway and the Pacific. However, climate change is also affecting other major coastal areas in the country such as the polar regions and Hudson's Bay.

In the Maritimes, studies have shown that the relative sea level rise is expected to average 50cm for the next 100 years (2000-2100) that's compared to an average of 17-35cm/ 100 years for the last 10,000 years (Canada, 2006). In Charlottetown for instance, where record taking was enough to cover the last century, we clearly notice a steady rise pattern (Figure 1). This pattern is due mainly to the melting ice caps and where more water is added to the world's oceans. Subsidence is certainly a factor in rising sea level and has been for thousands of years, however it's due to the thermal expansion caused by the melting of continental ice, the rising sea levels have significantly increased and are projected to continue as such in the decades to come (Forbes & George S. Parkes, 2006).

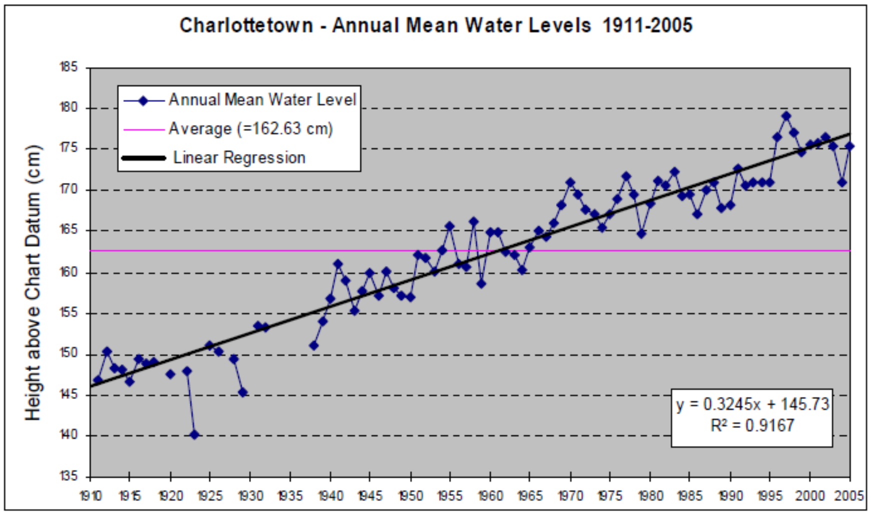

Figure 1: Annual mean water level for Charlottetown (Forbes & George S. Parkes, 2006)

Rising sea level becomes more serious during storm events as surges cause further penetration inland. This is of concern to coastal communities that are isolated with vulnerable population such as the elderly. Important infrastructure such as health services, emergency response, roads and bridges can be hit thus making the task of search and rescue even harder (Manuel, Rapaport, & Keefe, 2015). Taking the example of Mahone Bay, NS (Figure 2); we can clearly see that any rise in water level compounded by a storm event can paralyse this community. The emergency services will be impacted and the damage to community centres, which are typically doubled as shelters will expose the vulnerable population to the natural environment. This will accelerate the deterioration of the population's health resulting in a potential humanitarian crisis. It should also be noted that Figure 2 is modeled on 2025 sea level rise & storm surge which is estimated at 3.44m above current level. Based on the understanding that the sea level rise will increase linearly, the damage will be more significant in 2035, 2045 and so on. We can therefore conclude that some unaffected areas in the Figure 2 can be next in the decades following this model.

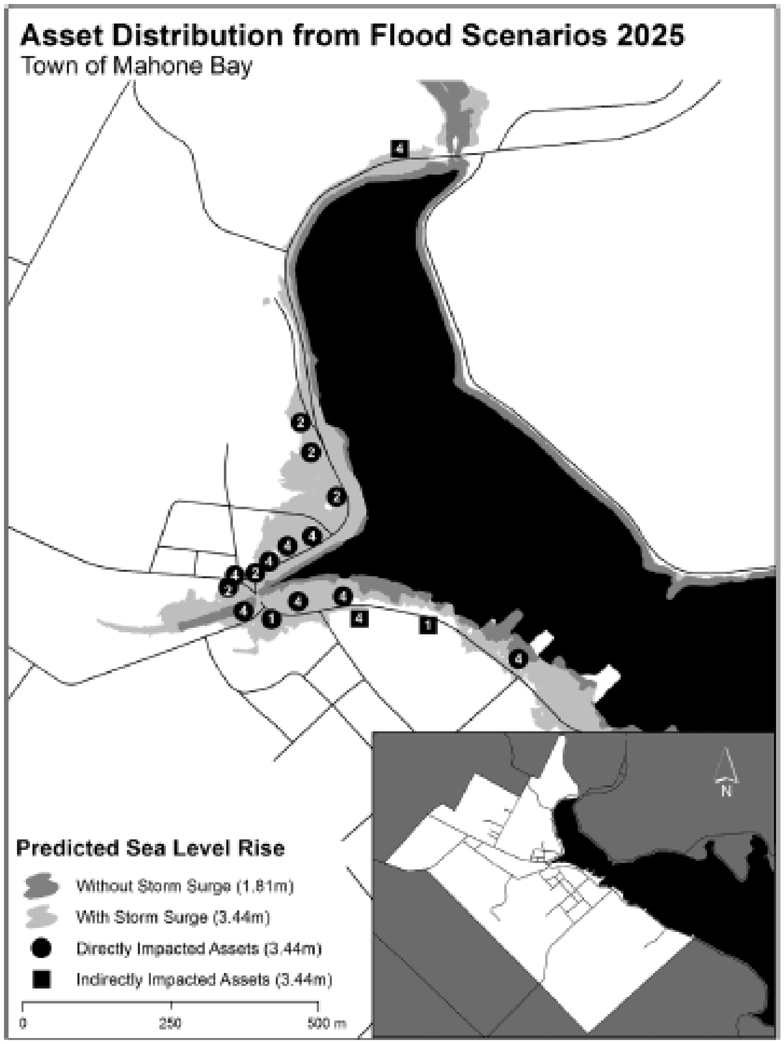

Figure 2:Asset distribution and 2025 Flood Scenarios in Mahone Bay, 1- Health Services, 2- Social Engagement, 3- Security and Emergency Services (Manuel, Rapaport, & Keefe, 2015)

Going into the gulf of St Lawrence, we notice the case of Iles de la Madelaine that's surrounded by a rising sea with a current population just over 12,000. The main highway artery connecting the island has encountered a lot of changes in sea level and erosion since the 1950's (Figure 3) (Serge Jolicoeur, 2007). The continuous "pounding" of the sea on the shoreline necessitates a quick reactive undertaking to ensure the highway is maintained in operation.

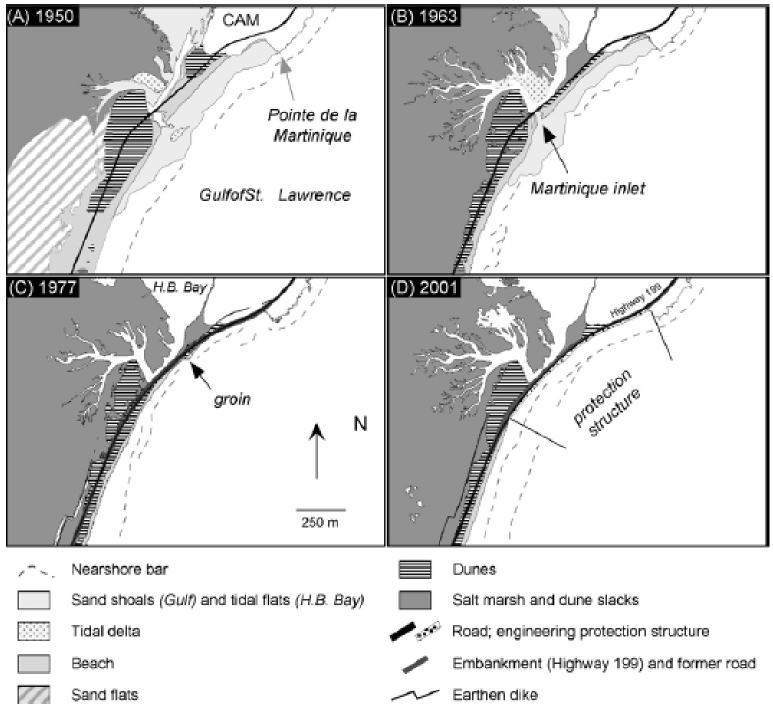

Figure 3: North part of ile de la Madeleine, Dune de l'Est (Serge Jolicoeur, 2007)

Similarly, in the west coast the increase in average sea level has been accelerating near the end of the 20th century (Figure 4). In northern British Columbia (BC) for instance, sea level rise can be expected to reach a maximum of 34cm in the next 100 years (Abeysurugunawawrdena & Walker, 2008). Many communities are scattered along the coast and archipelago of islands and peninsulas. These communities rely on the ferry system to receive goods and transport their residents. Therefore, the docks and ports infrastructure are vulnerable to sea level rising as it could render them obsolete and possibly overload them. Having said that, we can notice that sea level rise is different between east and west coast, in fact part of the sea level rise in the west coast specifically and the pacific generally is thought be part of natural cycle. Furthermore, recent studies have concluded that the contribution from the melting ice in the poles and mountains is less related to rising sea level and that the thermal expansion of the oceans is more significant than previously thought (Cazenave & Nerem, 2004). In fact, anthropogenic contributions such as dams, reservoirs and irrigation systems reduced the flow of fresh water into oceans and contributed to other impacts on river systems and lakes.

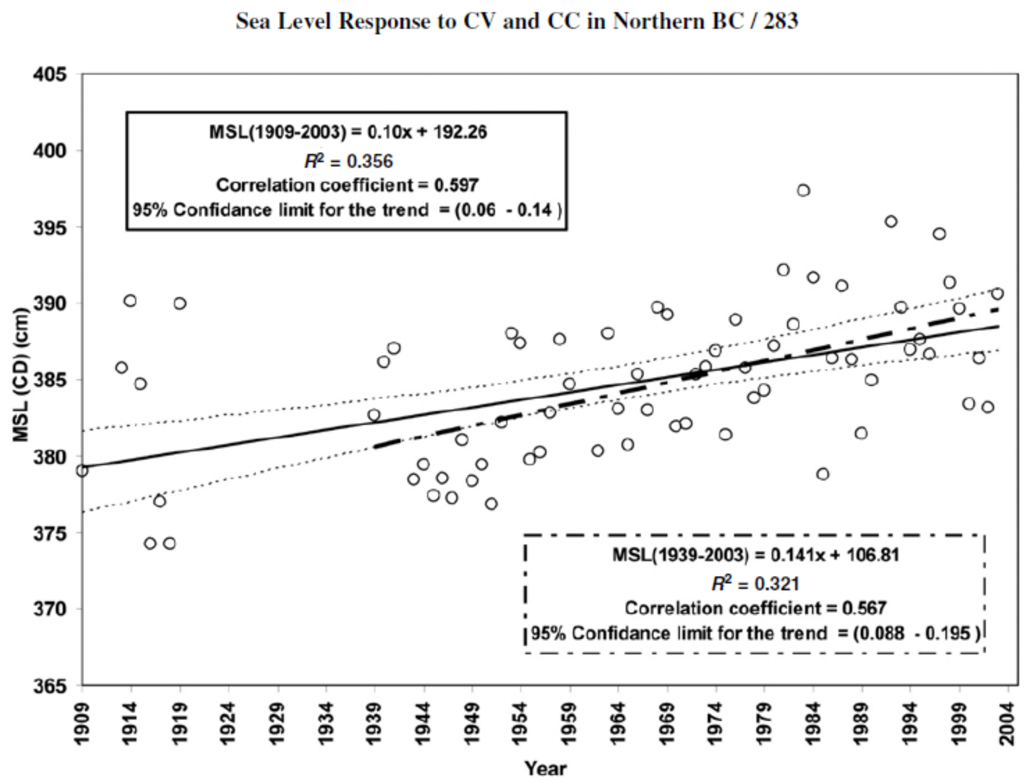

Figure 4: Average sea level in Norther BC 1909-2003 (solid line) and 1939-2003 (dashed) (Abeysurugunawawrdena & Walker, 2008)

II. Rivers and Lakes

Rivers and lakes constitute a basin system, some basins are entirely made of rivers such as the Fraser River Basin (FRB) in BC (Figure 5). According to (Rajesh R. Shrestha, 2012) climate change in the FRB is shifting some sub basins from snow dominant to hybrid and even to rain dominant. Snowmelts are occurring earlier; increased runoff in spring and winter and decreased runoff in summer. The average discharge is increasing however in the 30 years model, the peak discharge is decreasing. There are also noticeable extremes in runoff and drought. The findings of (Rajesh R. Shrestha, 2012) are painting a changing landscape in the FRB and the hydrological nature of the area. We can also observe man-made structures used to control and monitor water level and conclude that the existing infrastructure and demographics will be seriously affected by this change. In fact, the paper concludes the findings should be used in a follow up study for adaptation measures.

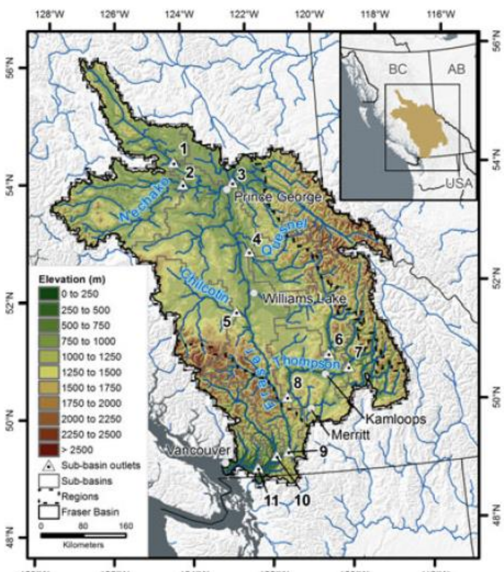

Figure 5: Location map and elevation of the Fraser River Basin. the numbers 1-11 indicate the sub-basins. (Rajesh R. Shrestha, 2012)

Moving east to the great lakes region, we notice a different problem where the water level is decreasing (Figure 6). From the models and studies performed by (Chao, 1999) the drop-in water level of great lakes has serious economical and environmental implications. Shipping for instance will be affected, vessels will not be allowed to carry a much tonnage, so they will have to either perform more trips or rely on other means of delivery. It has also been concluded that freezing periods are getting shorter, meaning navigation season can be extended, which can increase the likelihood of ships carrying more contaminants in the lakes.

Given the high demographic and industrial activity present in the great lakes, the effects on shipping could result in increased road and rail usage so that goods and services are delivered from ports on the Atlantic. This will result in an increased demand on the existing transportation infrastructure.

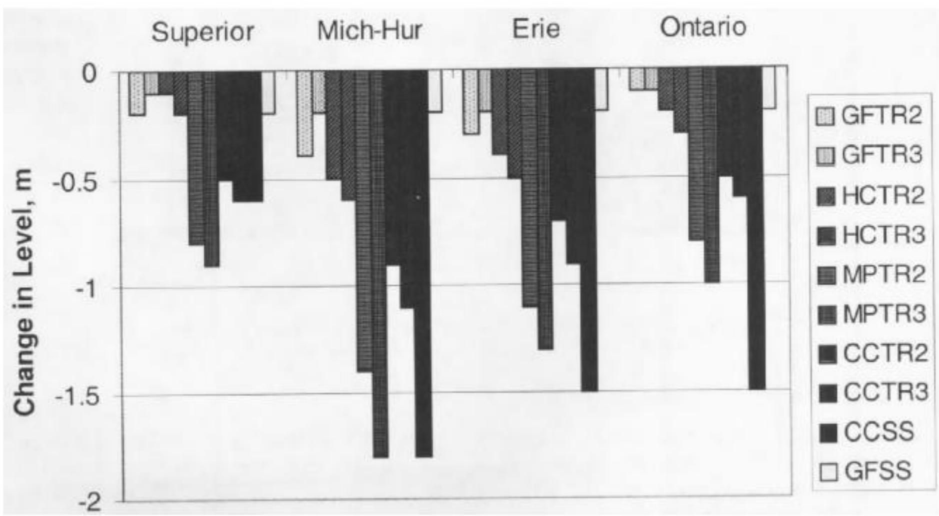

Figure 6: Change in annual water level from base climate, the procedures used are listed on the right which also depends on the period tested, typically within the past few decades of the 20th century (Chao, 1999)

3. Temperature & CO2

Within the great lakes, many simulation models have shown that as global temperature rises, moisture will increase in the region. This will in turn result in changes in weather patterns such as precipitation, wind and more weather extremes. The later is driven by the fact the that great lakes region is located between a wetter and colder area in the north and drier and warmer zone in the south. We will therefore see harsher winters and hotter summers (Kutsbach, Williams, & Vavrus, 2005). These temperature extremes mean that any design for bridge expansion joints could be affected resulting in unexpected stresses on the various bridge components which would accelerate deterioration and damage.

Road asphalt is another infrastructure asset that is affected by temperature extremes. Many design codes in the US and Canada set temperature parameters as static for road designs that are supposed to last decades. Yet with the new anthropogenic weather patterns, this assumption is proving to be less accurate. A temperature increment of 6 degrees Celsius for instance could reduce the 20 years lifetime of a road segment to 16-17 years. If that increment increases by another 6 degrees (which it does in some areas) the lifetime drops to 14 years (Underwood, Guido, Gudipudi, & Feinberg, 2017).

Similarly, concrete deteriorates differently under temperature extremes. These temperatures, along with humidity and CO2 levels are causing higher levels of carbonation and chloride induced corrosion than was anticipated. Reinforcement is corroding faster and the cover that was designed to account for the lifetime of the structure is not protecting the steel as it should be. Again, this is caused by the higher concentration of CO2 in the atmosphere, higher temperatures in coastal regions that result in more humidity and higher chloride concentrations (Stewart, Wang, & Nguyen, 2011).

4. Wind

With temperatures varying as we noticed, low and high-pressure systems are resulting in wind speeds that may not have existed in the past. (Sydeman, et al., 2014) studied the effects on wind speed changes on upwelling which is a major source of food and nutrition for mankind mainly through finishing as shown on Figure 7. For this study, we can refer to the result of this study to confirm that in fact wind speeds are increasing and it is a function of the latitude, meaning the more north or south we go the higher the wind speeds are changing. Certainly, being in a coastal area also adds to the increase more so in the Atlantic than the Pacific in the case of Canada given that the pacific upwelling source is more south (Sydeman, et al., 2014).

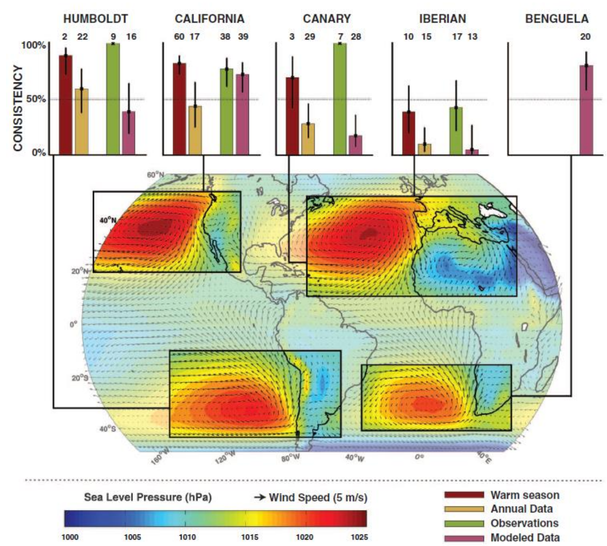

Figure 7: Variations in wind speeds based on seasonal temperature changes of major wind systems in the world

Wind gusts and speeds are also projected to increase through the next century following studies and simulations that proved to be accurate and reliable (Cheng, Lopes, Fu, & Huang, 2019) . Figure 8 and Figure 9 shows us the case of 70km/h wind gusts and their projected increases, this was also the case for 30kmh and 90km/h gusts where the higher the speed the more expected changes are more noticeable (Cheng, Lopes, Fu, & Huang, 2019).

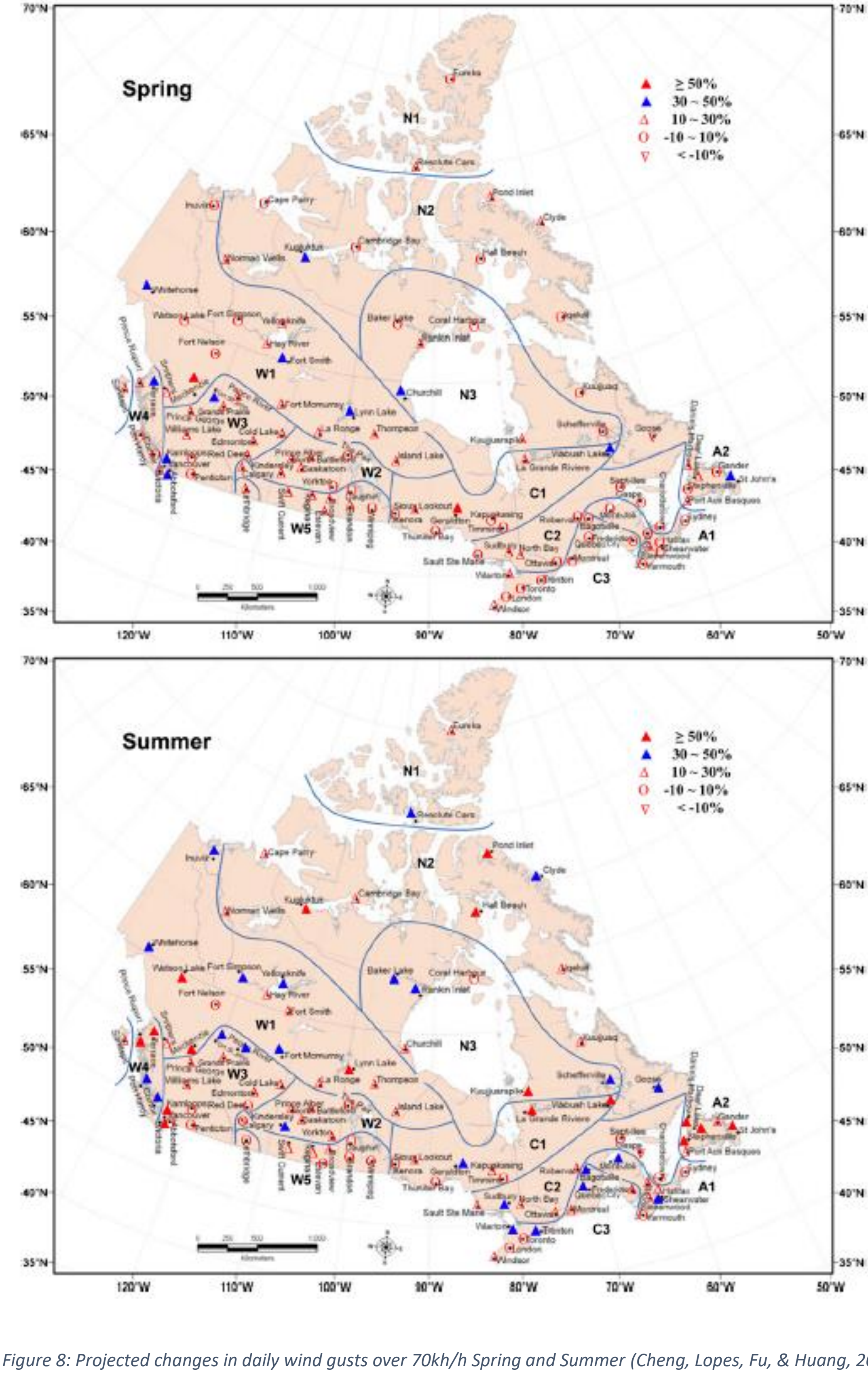

Figure 8: Projected changes in daily wind gusts over 70kh/h Spring and Summer (Cheng, Lopes, Fu, & Huang, 2019)

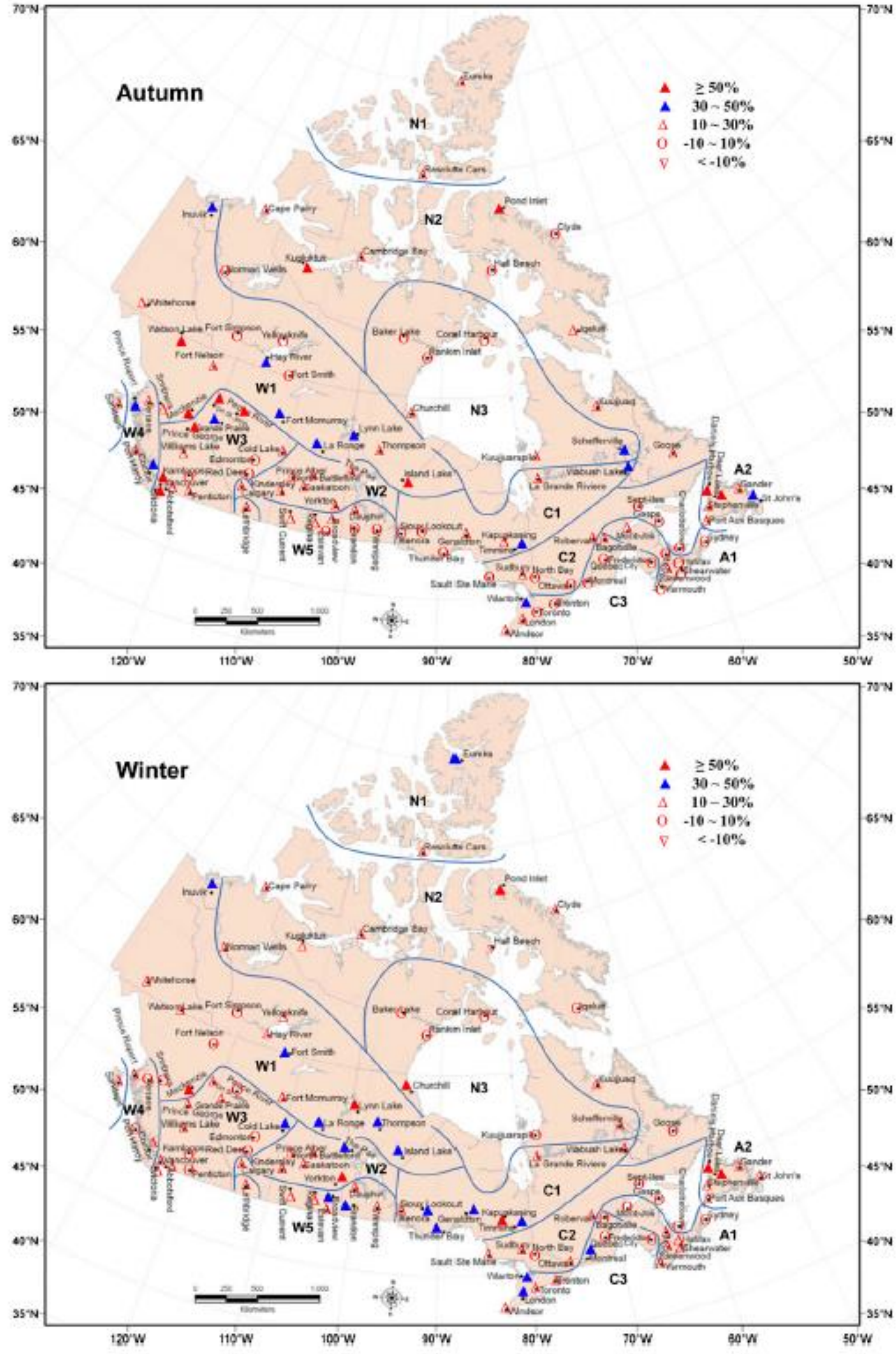

Figure 9: Projected changes in daily wind gusts over 70kh/h Autumn and Winter (Cheng, Lopes, Fu, & Huang, 2019)

5. Method of developing a decision model using

Based on the many factors discussed above, we would then have to decide if the current assets and infrastructure can withstand the effects of climate change in the near and far future. To do so, we can develop a decision tree model as well a simulation along with the appropriate probabilities and costs. In this model, we can identify the asset as a bridge, a building, a road, underground sewer system etc. where we can add the appropriate probabilities and input the costs associated with replacement, repair or demolition.

We can also expand on this further by having a model for future construction sites and projects where it would be feasible to undergo the endeavour in the present however due to the unpredictability of the future weather patterns the risk could be higher.

I. Model definitions

For our model we will define the following

Structure Type: This can be a bridge, road, large, medium or small building or any underground works such as foundations, pipelines or sewage.

Cost (C): Is the initial construction cost of the structure in Canadian Dollars

Location: For the purposes of this project we will focus on the major regions of Canada which are the Maritimes, Quebec, Ontario, the Prairies, Pacific and Arctic.

Wind factors (WF): Through the literature review and based on geographic location, the wind factors for this model are as indicated in Table 1 below. The wind has a larger effect in coastal regions such as the Maritimes and parts of Quebec. The Artic, and by extension the prairies given their close geography has the second most important wind factor. Ontario and Pacific are somewhat sheltered from wind forces are serious as the other regions. However, it should be noted these values can change especially in Ontario where wind patterns can be sporadic and could become the norm in the years to come.

Table 1: Wind factors for model

Location	Wind Factors
Maritimes	1.25
Quebec	1.15
Ontario	1.1
Prairies	1.15
Pacific	1.1
Arctic	1.25

Coastal Factors (CF): This relates to sea levels rising and its impact on infrastructure. It comes as no surprise that coastal regions such as both coasts have the highest value given their geography and population. The Maritimes are slightly higher given the nature of the weather patterns in the north Atlantic. The pacific region is better sheltered such as the BC lower mainland and the east coast of Vancouver Island. Quebec and the Artic are exposed to oceans and seas and as such come in second in their factors. Finally, Ontario and the Prairies are the most sheltered from sea level rise (Table 2).

Table 2: Coastal Factors for model

Location	Coastal Factors
Maritimes	1.6
Quebec	1.2
Ontario	1
Prairies	1
Pacific	1.5
Arctic	1.3

River/Lake Factors (RF): This factor is more prevalent in Ontario and parts of the prairies where lakes and rivers can flood and cause major damage. The pacific and Quebec also have watersheds with rivers and lakes that can not be ignored. Finally, the Maritimes' populations are mainly coastal, and the river/lakes factor will not impact any major infrastructure assets. The Arctic is assigned a value of 1, due to the low population and presence of major infrastructure (Table 3).

Table 3: Rivers/Lakes Factors for Model

Location	River/Lake l Factors
Maritimes	1
Quebec	1.3
Ontario	1.7
Prairies	1.6
Pacific	1.4
Arctic	1

Water Factor (WatF): is calculated using the equation

$$WatF = 0.5CF + 0.5RF$$

Equation 1

The equation can be further modified depending on the weight of the coastal factor or the river/lakes factor on the region in question. Variations in climate patterns could also influence how much weight is given to each factor and that is subject to change anytime in the future.

Temperature/CO2 Factor (TF): is driven by the industrial activity in each region. Naturally, Ontario is highest by a factor of 2. Quebec follows with 1.8. The prairies, driven by Alberta is third at 1.8. The Arctic is last and is assigned a value less than 1 given the low population density and near absence of industrial activity.

Table 4: Temperature and CO2 factors for model

Location	Temperature/ CO2 Factors
Maritimes	0.9
Quebec	1.8
Ontario	2
Prairies	1.7
Pacific	1.6
Arctic	0.7

Expected lifetime in years (LFT) is the conventional estimate lifetime of the structure before it should be replaced.

Climate change lifetime in years (CCT) is calculated using the following equation

$$CCT = \frac{LFT}{0.25WF + 0.25WatF + 0.5TF}$$

Equation 2

Rounded up to the nearest integer. We notice that in this equation the temperature/CO2 factor is assigned 50% of the weight given the effects of carbonation and accelerated deterioration caused by it. Wind and Water add up to the same weight as industrial activity with equal weight between them. These proportions can again be varied based further studies and determinations of what each region is mostly affect by.

Yearly Benefit with respect to Location and Structure (YBL & YBS) is assigned based on geographical location and the nature of the structure. As per Table 5 below, we assigned yearly benefit based on location depending on the demographics, this means that regions with higher population provide the highest benefit such as Ontario whereas other like the Arctic are relatively low. For the structures, benefit is assigned based on the convenience of the asset for the well being of society coupled with the complexity and cost of said asset. Underground works for instance is important for any community and the cost of building and replacing them is relatively high given the complexity of excavation, backfilling and all associated risks with it. A Total Benefit (TB) is then assigned by summing both benefits. The Yearly Benefit (YB) will be calculated by multiplying the total benefit by the cost

$$YB = C \; x \; TB$$

Equation 3

Table 5: YBL and YBS for model

Location	Yearly Benefit
Maritimes	0.50%
Quebec	0.75%
Ontario	0.80%
Prairies	0.60%
Pacific	0.60%
Arctic	0.10%

Structure	Yearly Benefit
Bridge	1.50%
Road	1.25%
Large Building	0.95%
Medium Building	0.90%
Small Building	0.85%
Underground	1.60%

Expected Benefit (EB) and Expected Benefit after Climate change (EBC) is calculated by multiplying the yearly cost by the expected lifetime with and without climate change consideration

Equation 4

$$EB = YB \; x \; LFT \qquad EBC = YB \; x \; CCT$$

Climate Change Probability (CCP) is a percentage value used to assess the confidence in the likely occurrence that climate change will take place within the lifetime of the structure and affect its integrity.

6. Method of developing a simulation model using @RISK 7.5

Using @RISK 7.5 simulation, we will develop a model to reproduce a 100 years span of an infrastructure asset to observe potential costs associated with unexpected climate change events. First, we will identify the cost **(C)** of the structure. We will then develop a probability distribution for the percentage cost in repairs with respect to **(C)**. We used Table 6 to identify the average and standard deviations of each event through a normal distribution. @RISK will then generate random values representing each event every year. Using the literature review in the introduction section we have determined that water damage event (P_{water}) would on average cost 5% of the construction cost **(C)** with a standard deviation of 0.75%. Wind events (P_{wind}) would be more damaging and CO2/carbonation (P_{CO2}) is a continuous process that significantly reduces the lifetime of the asset and as such is the highest value but scattered over a longer period.

Table 6: Average and standard deviatio distribution for damage events on asset

	Average	Stdev
Water	5%	0.75%
Wind	25%	8%
CO2	60%	35%

We will also consider the likelihood of a wind, water or CO2 event occurring on a given year. To do this, we will use a poison distribution with values as listed in Table 7. Again using the literature review and based on our understanding of weather phenomena, we anticipate that a major water (λ_{water}) event would occur once in 10 years, a wind event (λ_{wind}) would be once in two year and a CO2/temperature damage (λ_{CO2}) would be noticed once every 5 years.

Table 7: Lambda values for poison distribution

	Lambda
Water	0.10
Wind	0.50
CO2	0.20

The event occurrences can be seen in Figure 10. For instance, we can see that there is 90% change of no water damage event occurring in any given year or that it is possible to see up to 2 wind damage events occurring in a year with a probability of 7%. Using the probabilities and Poison we can calculate the wind water (D_{water}), wind (D_{wind}) and CO2 (D_{CO2}) damage as follows:

$$D_{water} = P_{water} \, X \, \lambda_{water} \qquad D_{wind} = P_{wind} \, X \, \lambda_{wind} \qquad D_{CO2} = P_{CO2} \, X \, \lambda_{CO2}$$

Equation 5 Damage caused by weather events on a given year

Summing up the damages from Equation 5, we will have the total damage (D_T), we will add this to the construction cost **(C)** and compare it to construction cost plus contingency by subtracting the former from the latter:

$$Deficit\ or\ suplus = C(1 + contingency) - (C + D_T)$$

Equation 6: Deficit or surplus each year

Equation 6 means that a surplus on a given year accounted for climate change whereas a deficit would require additional resources. We would run through 100 iterations/years and obtain a distribution of the deficit or surplus resulting from this simulation. One might argue that not a lot of assets have such a lifetime, but this exercise is simply to initiate a longer and more detailed process of simulation and modeling of how climate change will affect structures. Furthermore, the iterations do not necessarily mean a year and can be considered a construction season or an inspection cycle.

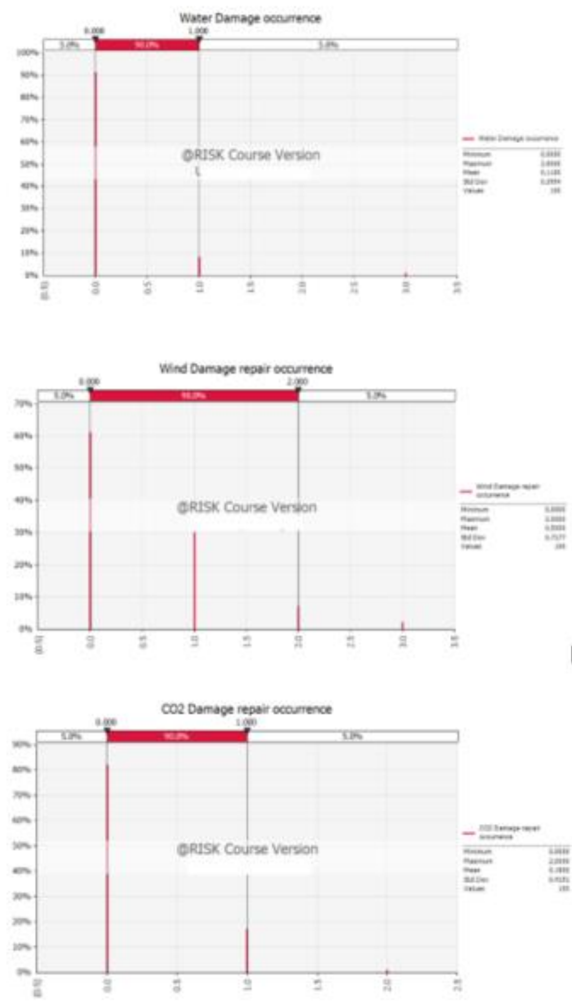

Figure 10: Poison distribution of Wind, water and CO2 event occurrences

7. Model execution

I. Decision Tree Model 1: $10 million Bridge in Ontario

We used Palisade Decision Tree through Excel to generate the simulation. The simulation was running for a $10,000,000 bridge in Ontario (Table 8).

Table 8: Simulation input information – Bridge in Ontario

Structure Type	Bridge	
Cost	$	(10,000,000)
Location	Ontario	
Wind Factor		1.1
Water Factor		1.35
Coastal		1
River/Lake		1.7
Temperature and CO2 factor		2
Expected Lifetime (years)		50
Climate Change lifetime (years)		**32**
Yearly Benefit (Location)		1%
Yearly Benefit (Structure)		2%
Total Yearly Benefit		**2%**
Yearly Benefit in dollars	**$**	**230,000**
Expected Benefit	**$**	**11,500,000**
Expected Benefit after CC	**$**	**7,360,000**
Climate Change Probality		**10%**

The model was ran using an initial decision of "build" and "no build". The "no build" option nets $0 whereas the "build" options starts with a deficit of $10,000,000 or the cost of building the bridge. Moving along the tree, there will be a probability node where the climate change assumption is tested, as per Table 8, we're assuming a 10% probability that the climate change scenario will occur. The probability node will split in a no climate change event with a net added benefit using (Equation 4) for EB. The climate change node will have EBC from (Equation 4) which then splits into structure deterioration or loss due to wind, water or temperature. Since the deterioration will not allow us to fully use the structure for its intended purpose, we will consider it a total loss and assign it the cost of the total benefit gained (Figure 11).

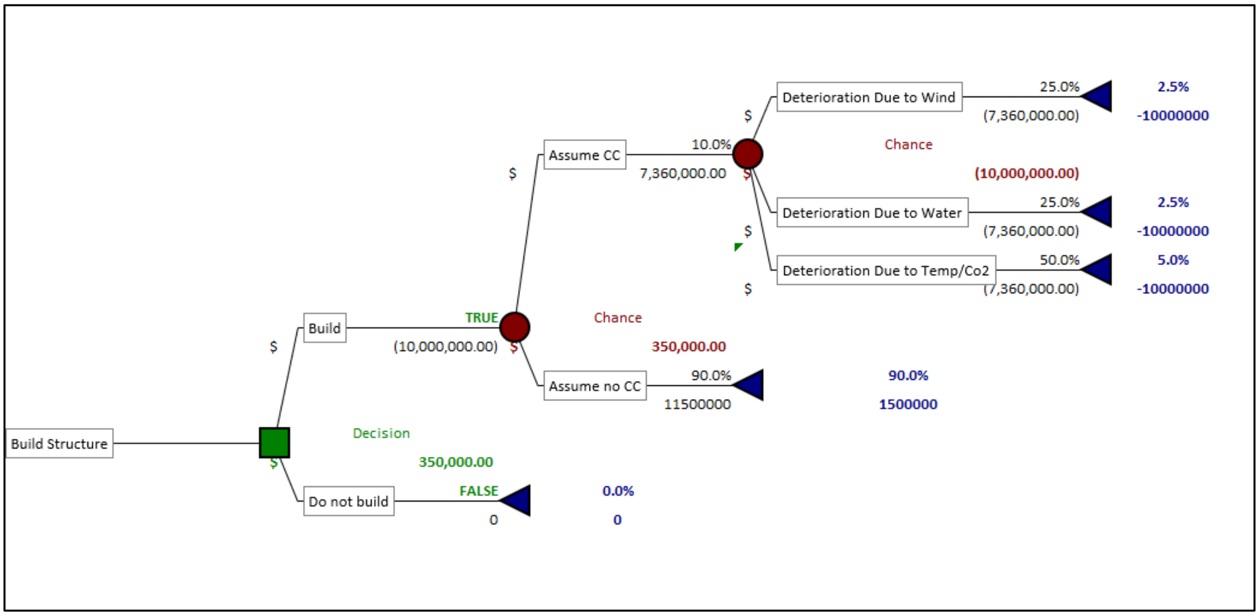

Figure 11: Decision tree for $10million bridge in Ontario

II. Decision Tree Model 2: $100 million underground asset in the Prairies

We used Palisade Decision Tree through Excel to generate this simulation. The simulation was running for a $100 million underground (pipeline) asset in the Prairies (Table 9 & Table 8). In this case, we raised the climate change probability to 50% given the expected lifespan of the infrastructure where climate change effects are expected to be more significant in the next century and beyond. The size of the investment is also influencing the probability raise since such an amount can be direct to a renewable source infrastructure or any other form of sustainable development project.

Table 9: Simulation input information – Pipeline in Prairies

Structure Type	Underground	
Cost	$	(100,000,000)
Location	Prairies	
Wind Factor		1.15
Water Factor		1.3
Coastal		1
River/Lake		1.6
Temperature and CO2 factor		1.7
Expected Lifetime (years)		100
Climate Change lifetime (years)		**69**
Yearly Benefit (Location)		1%
Yearly Benefit (Structure)		2%
Total Yearly Benefit		**2%**
Yearly Benefit in dollars	**$**	**2,200,000**
Expected Benefit	**$**	**220,000,000**
Expected Benefit after CC	**$**	**151,800,000**
Climate Change Probality		**50%**

In this case, one might automatically question the need to assign a wind deterioration factor. After all, the asset is located underground. However, elements such as pumping stations, the source and end receiver of the pipeline are all structure located above ground that could be impacted by wind loads and should they get damaged or not be able to operate as needed, the pipeline would be obsolete. As construction is underway and any future repair and maintenance works takes places, should there be significant wind loads, equipment such as cranes may not be operable or operate with reduced load which will add to budget cost and schedule.

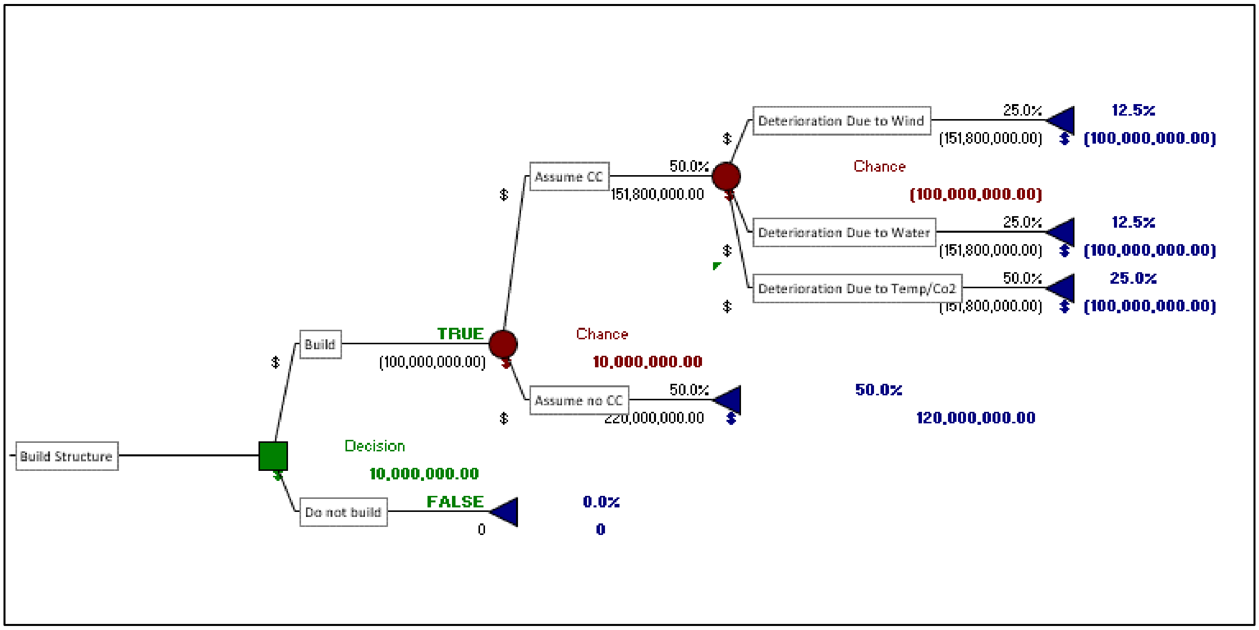

Figure 12: Decision tree for $100million pipeline in the Prairies

III. Simulation Model

Table 10 shows the reference table used to generate percentage costs and events. In this one instance, there was a wind and CO2 damage at 28.68% and 0.45% of construction cost respectively. No water damage occurred. Using @RISK, a random percentage value is generated from Table 6 and the Poison distribution from occurrence from Table 7.

We have assigned a contingency value of 15%, which is what typically assigned during construction projects with low to medium complexity. Again, in this year we see that by using Equation 6 there is a net deficit of over $3 million. Both the wind and CO2 damage resulted in unexpected costs. Once we gather this data over a 100-year span through randomly generating percentage cost values and occurrences we get a distribution of the deficit and surplus (Figure 13**Error! Reference source not found.**). In this distribution, we notice a mean of -$2,120,039 indicating that over 100 years, we can expect an average deficit of this amount.

Table 10: Sample year with wind and CO2 damage

Construction Cost	$ 25,000,000
Water Damage repair %	4.31%
Wind Damage repair %	28.38%
CO2 Damage repair %	0.45%
Water Damage occurrence	-
Wind Damage repair occurrence	1.00
CO2 Damage repair occurrence	1.00
Repair Cost	
Water Damage	$ -
Wind Damage	$ 7,094,664
CO2/Temperature Damage	$ 112,971
Total Repairs	$ 7,207,635
Construction Cost contingency	15%
Budgeted total cost	$ 28,750,000
Construction cost with repairs	**$ 32,207,635**
Deficit/surplus	**$ (3,457,635)**

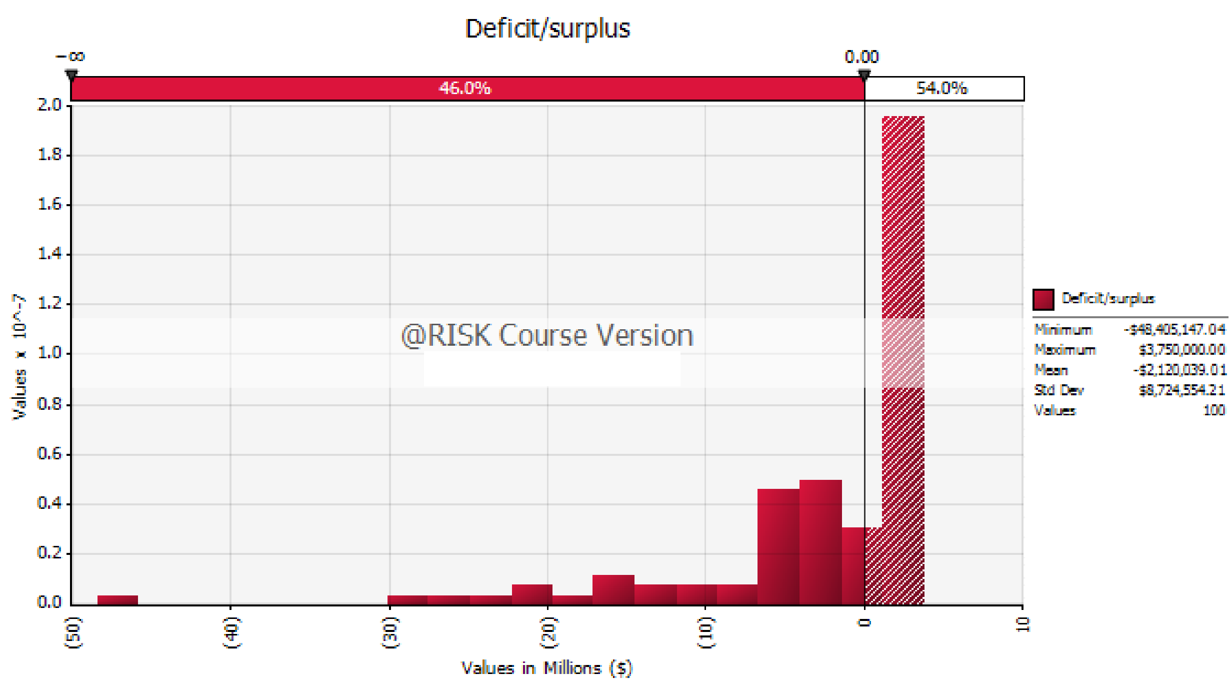

Figure 13: Distribution of surplus and deficit of simulation model

8. Results and interpretation

I. Decision Tree Model 1

Figure 11 shows us that with a 90% risk of climate change not affecting the outcome of the construction, we can expect a net benefit of $350,000. Of course, if there were no climate change likelihood of climate change at all the net benefit would be $1.5 million which is the difference between the initial cost of $10 million and benefit of $11.5 million. Therefore a 10% consideration for climate change has already cost $800,000 in benefit. If we assume that in the next 5 years, climate change events would convince everyone that it is a fact of life, we can increase the probability to 20%(Figure 14). Under this scenario, we see that the best decision would be not to proceed with the project because if we do so, we're looking at a net loss of $800,000. This means that society would not benefit from the bridge if climate change with its impacts of wind, water and temperature/CO2 take place. In this scenario, the bridge would become obsolete long before its lifetime is due, and the capital spent on it could have been used for a better investment.

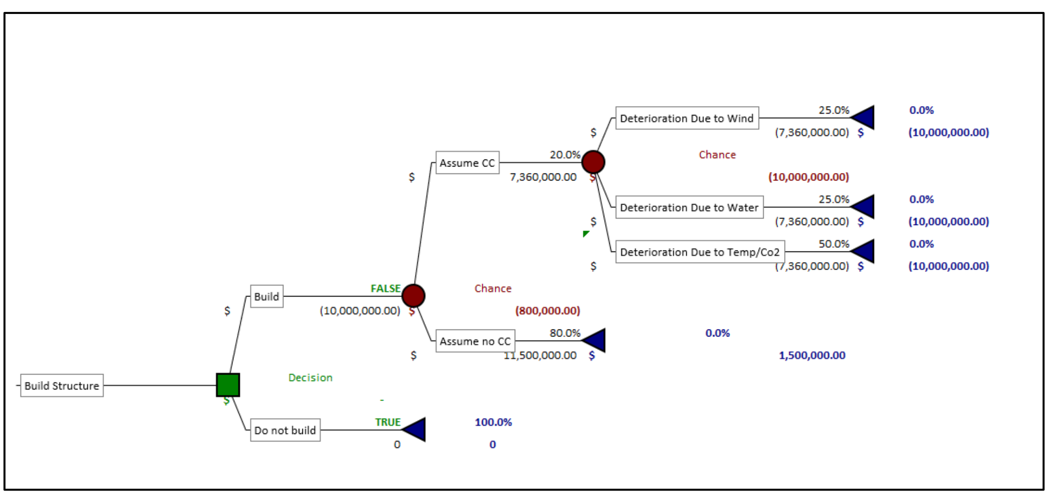

Figure 14: Decision tree for $10million bridge in Ontario with 20% risk of climate change impact

II. Decision Tree Model 2

Figure 12 shows us that even at 50% risk of climate change, the pipeline may still be beneficial but a reduced value of $10 million from an initial $151 million or 93% loss. However, if we increase that by simply 5%, we see that the investment is no longer justified. At 55% risk of climate change, we'll be looking at a net benefit loss of $ 1 million, the more the likelihood of climate change increases, the higher the cost will be. The answer would therefore be to either simply abandon the project or develop a more robust construction that could keep the lifespan of the infrastructure as planned. To achieve this in the decision tree model, we would have to modify the factors with respect to the region. In this case, temperature/CO2 is the largest factor. A reduction in this factor, will bring the climate change lifetime closer to the desired lifetime, and the model can be re-aligned to observe if the more likelihood of climate change will be accounted for in the design. This can be done by reducing the risk of pre-mature deterioration of the concrete due to carbonation for example. Adding more cover will help with this, which will be resulting is added concrete cost. Another solution would be to coat the concrete surface as an added layer of protection against carbonation. All these approaches can be incorporate into design codes and standards to become the best practise in the industry.

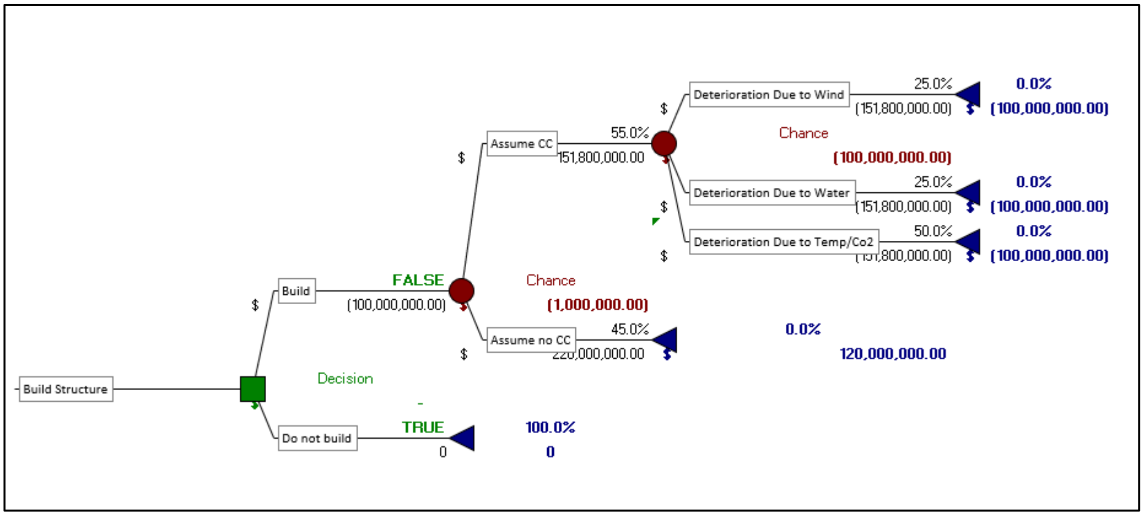

Figure 15: Decision tree for $100 million pipeline in the Prairies with 55% risk of climate change impact

III. Simulation Model

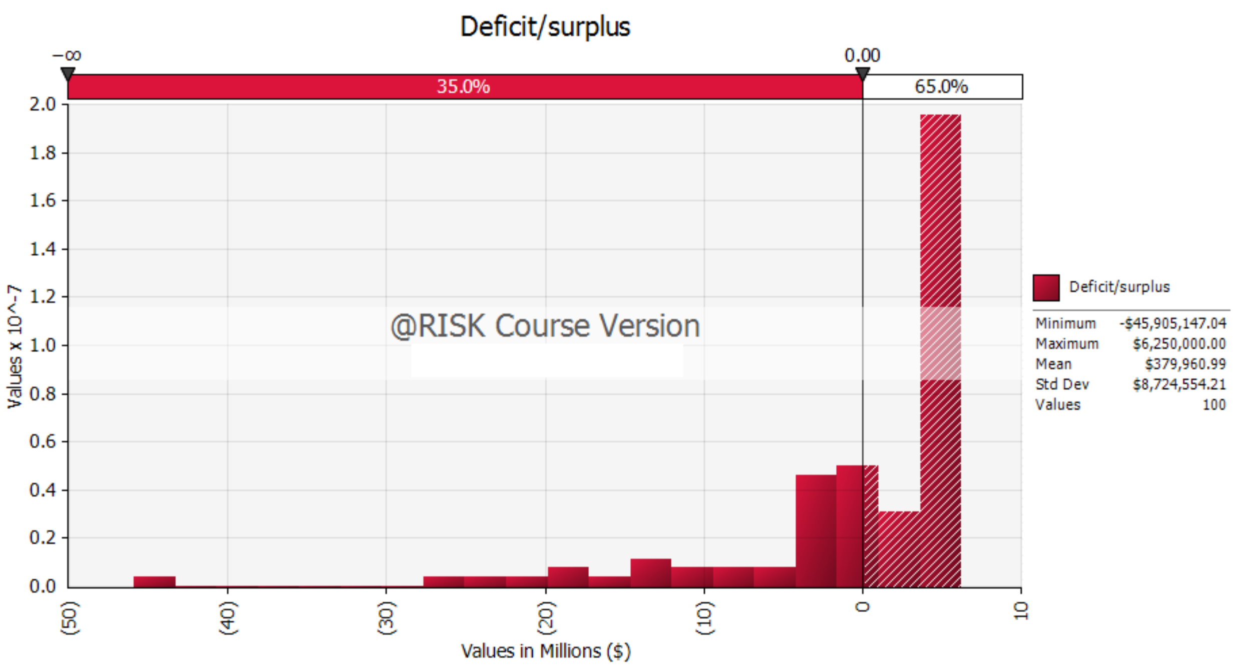

Figure 16: Distribution of simulation model using 25% contingency

Figure 13 showed us that at 15% contingency, we can expect an average deficit in performing repairs to keep the structure functional for its lifetime. What if we change the contingency? Figure 16 is the result of the same model by entering the values in Table 10 with the modification of contingency to be 25% instead. In this scenario we see that the mean is positive so on average there will not be a deficit and in 35% of the cases, or 35 years there will be a deficit. What if we want to limit the occurrence to 5%? To do so, we'll have to increase our contingency to 95% (Figure 17). At 5% risk of deficit, there would be more confidence in the intention to proceed with the project. This comes however at the heavy initial cost of over $48 million.

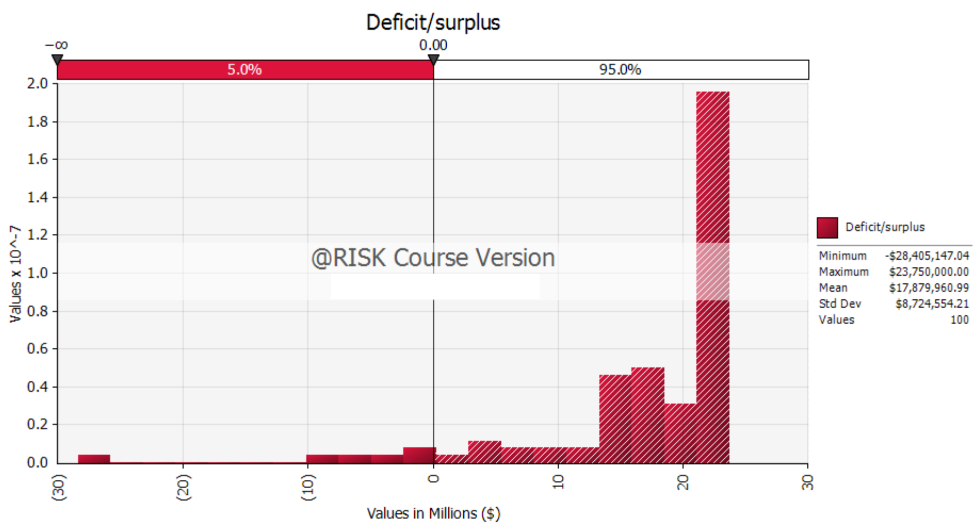

Figure 17: Distribution of simulation model using 95% contingency

Table 11:Sample year with wind and CO2 damage at 95% contingency

Construction Cost	$ 25,000,000
Water Damage repair %	5.86%
Wind Damage repair %	30.43%
CO2 Damage repair %	42.34%
Water Damage occurrence	-
Wind Damage repair occurrence	-
CO2 Damage repair occurrence	-
Repair Cost	
Water Damage	$ -
Wind Damage	$ -
CO2/Temperature Damage	$ -
Total Repairs	$ -
Construction Cost contingency	95%
Budgeted total cost	$ 48,750,000
Construction cost with repairs	**$ 25,000,000**
Deficit/surplus	**$ 23,750,000**

9. Conclusion

Current design codes and criteria for the construction of infrastructure assets are unable to account for anticipated environmental changes due to climate change. This study developed a simple simulation model based on MS Excel Precision Tree to consider the effects of adding a correction factor for climate change to justify the intent to proceed or not with a construction project. After many iterations, it appears that climate change can result in abandoning certain projects as any investment in them would not be beneficial.

A simulation model was also developed to determine the allocation of funds for an initial construction project using climate change control parameters. This model showed that for a 100-year span, on average, there would be a deficit caused by costs involved with repairing the asset due to climate change deterioration. This can be counteracted by attributing 95% contingency to reduce the risk of climate change damage to 5%.

I. Decision tree models

We developed a decision tree model using Precision Tree 7.5 using parameters of wind, water and temperature changes reported. This model showed with varying probabilities of climate changes, there is noticeable costs associated with remediation. Some shortcomings of this model are the low selection of assets. A next step would be to add assets like dams, power plants, water treatment and sewage plants, industrial installations and refineries to cite a few . Furthermore, the geographical selections can be developed more, we can add rural and urban areas for instance.

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