IX. Climate Change Vulnerability and Adaptation Assessment

Climate Change Vulnerability and Adaptation Assessment for the Kanata Light Rail Transit (LRT) Planning and Environmental Assessment Study

Project No. 2160553 August 30, 2018

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1. INTRODUCTION

The City of Ottawa is preparing an Environmental Assessment (EA) Study for the expansion of its Light Rail Transit (LRT) network to Kanata to accommodate existing and future rapid transit demand. The EA Study will identify the preferred corridor, the recommended plan for LRT alignment and stations, as well as the project staging and implementation based on future ridership and affordability. As part of this EA Study, Morrison Hershfield has been retained to conduct a screening level risk assessment of climate change vulnerabilities for the Kanata LRT and to identify potential adaptation requirements. The climate change risk assessment work was completed in conjunction with a carbon footprint assessment summarized under separate cover.

Transportation infrastructure in the Ottawa area and other regions of Ontario is currently designed and operated to handle a broad range of climate impacts, all based on experience with historic climate. However, because of climate change, the historical information used for infrastructure planning and design, as well as for purposes of ongoing operations and maintenance, is becoming less and less relevant, posing additional challenges for its sustainability, reliability, effectiveness, and costs for servicing.

Furthermore, there are growing expectations for organizations including governments to reduce the greenhouse gas (GHG) emissions associated with their services and reduce their vulnerability to changing climate conditions. Metrolinx's *Planning for Resiliency: Toward a Corporate Climate Adaptation Plan* (2017) report suggests three reasons for why organizations should enhance their adaptive capacities in the face of a changing climate:

1. Doing nothing would expose an organization to the full force of extreme weather events and impede their ability to meet organizational objectives.

2. Canadians who depend on public transit have a growing expectation that organizations will consider climate change when planning, building and operating infrastructure.

3. There is potential for adaptation measures to create new opportunities for job growth and prosperity i.e. through innovative engineering solutions. (*Planning for Resiliency: Toward a Corporate Climate Adaptation Plan, 2017*).

Moreover, taking into account climate change in infrastructure planning is increasingly becoming an expectation at both the provincial and federal levels as further discussed in Sections 1.1 and 1.2.

1.1 Provincial Guidance

The 2014 Provincial Policy Statement (PPS), issued by the Ontario Ministry of Municipal Affairs and Housing under the Planning Act, requires that planning authorities support climate change mitigation and adaptation through land use and development.

In October of 2017, the Ministry of the Environment and Climate Change (MOECC) issued a new guide titled *Considering Climate Change in the Environmental Assessment Process*. This guide supports the 2014 PPS, as well as the province's *2016 Climate Change Action Plan*, by setting out the ministry's expectations for including climate change in environmental assessment studies.

In the 2017 guide, the MOECC advises that climate change impact considerations are part of responsible planning and due diligence, and that considerations should include, at a high level, three key components:

- A review of the project's potential for producing greenhouse gas emissions;
- An assessment of the project's vulnerability to climate change; and
- The impact of the project on the environment's adaptive capacity.

For streamlined environmental assessments, such as those under the Transit Project Assessment Process, the guide recommends a scaling of the climate change considerations to the significance of the project's environmental effects. Climate change considerations in an environmental assessment should assess the need to include measures for adapting to and mitigating climate change throughout project implementation. These measures could include design modifications, additional studies, and revised operation and maintenance procedures.

1.2 National Guidance

The *Pan-Canadian Framework on Clean Growth and Climate Change* is Canada's national strategy developed with the Provinces, Territories and Indigenous groups to meet national emissions reduction targets, adapt to the impacts of a changing climate and maintain a healthy economy. The Pan-Canadian Framework has four main pillars: pricing carbon pollution, complementary climate actions across various sectors (e.g. electricity, built environment, transportation, industry, forestry, agriculture and waste), adapt and build resilience, and invest in clean technology, innovation and jobs. Key actions are identified for each of the four pillars.

With regards to transportation the Framework identifies the following key action item:

- Shifting from higher-to lower-emitting modes and investing in infrastructure (e.g. enhance investments in public-transit).

With regards to adaption and resiliency, building climate resiliency through infrastructure is one key area identified with the following key action items:

- Investing in infrastructure to build climate resilience; and,
- Developing climate-resilient codes and standards.

The Government of Canada's commitment and priorities as they relate to climate change adaptation are further discussed in the following documents:

- *The Federal Adaptation Policy Framework for Climate Change: Canada's strategy to guide medium term domestic action on climate change adaptation*.

- *Pan-Canadian Framework on Clean Growth and Climate Change First Annual Synthesis Report on the Status of Implementation*.

- *Measuring Progress on Adaptation and Climate Resilience Recommendations to the Government of Canada*: In August 2017 the Government of Canada launched the Expert Panel of Climate Change Adaptation and Resiliency which was mandated to propose a set of indicators to measure progress on adaptation and climate resilience in Canada. Its report, *Measuring Progress on Adaptation and Climate Resilience: Recommendations to the Government of Canada* was released in 2018.

Engineers Canada has become a leader in raising awareness and providing guidance on climate change impacts and engineering practice in Canada. To advance climate change considerations in engineering practice Engineers Canada has developed the following guidance documents and reports:

- *National Guideline: Principles for Climate Change Adaptation for Engineers*;

- *Public Infrastructure Engineering Vulnerability Committee (PIEVC) Engineering Protocol for Infrastructure Vulnerability Assessment and Adaptation to a Changing Climate*; and,

- *National Infrastructure and Buildings Group Climate Change Adaptation State of Play Report*.

Within Canada engineering is regulated under the jurisdiction of each Province and Territory. The *National Guideline: Principles for Climate Change Adaptation for Engineers* was prepared by Engineers Canada in collaboration with the provincial and territorial engineering regulators to promote consistent engineering practices across Canada. The guideline is intended to inform upon why consideration of climate change adaptation and mitigation is relevant in professional engineering practice. The guideline consists of eleven (11) principles under three (3) categories. The principles are as follows:

- **Category #1 - Professional Judgment**
  - Principle # 1: Integrate climate adaptation and resiliency into practice
  - Principle # 2: Integrate climate mitigation into practice
  - Principle # 3: Review adequacy of current standards
  - Principle # 4: Exercise professional judgement

- **Category #2 - Partnerships**
  - o Principle # 5: Interpret climate information
  - o Principle # 6: Emphasize innovation in mitigation and adaptation
  - o Principle # 7: Work with specialists and stakeholders
  - o Principle # 8: Use effective language

- **Category #3 - Practice Guidance**
  - o Principle # 9: Plan for service life and resiliency
  - o Principle # 10: Apply risk management principles for uncertainty
  - o Principle # 11: Monitor legal liabilities *(National Guideline: Principles for Climate Change Adaptation for Engineers, 2018)*

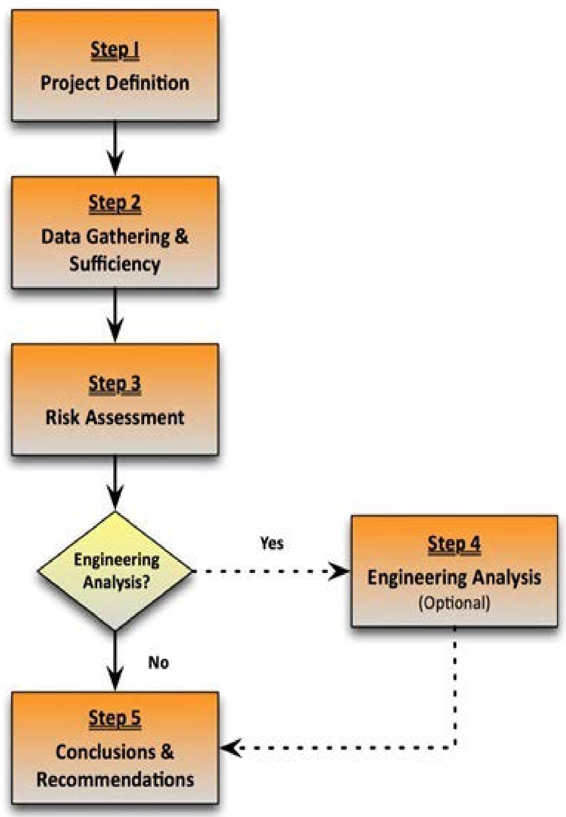

Figure 1 – PIEVC Five-Step Process (Source: Engineers Canada)

In 2005, Engineers Canada created the Public Infrastructure Engineering Vulnerability Committee (PIEVC, "the Committee") to conduct an engineering assessment of the vulnerability of Canada's public infrastructure to the impacts of climate change. The Committee developed the PIEVC Protocol ("the Protocol") as a tool for the *systematic review* of historical climate data and projections of future climate events, and for the *evaluation* of the severity of potential climate change impacts on infrastructure components. This tool can also be used to establish the adaptive capacity of infrastructure components.

The Protocol is composed of a five-step program: Project Definition, Data Gathering and Sufficiency, Risk Assessment, Engineering Analysis, and Conclusions and Recommendations (Figure 1).

Engineer's Canada PIEVC Protocol defines vulnerability as:

- "The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes."

Engineering vulnerability is a subset of vulnerability and is a function of:

- Character and magnitude of climate change to which infrastructure is exposed;
- Sensitivity of infrastructure to the changes; and,
- Capacity of infrastructure to absorb negative impacts.

In 2017 the Infrastructure and Buildings Working Group, established by the Institute for Catastrophic Loss Reduction and Engineers Canada, completed a State of Play report (*National Infrastructure and Buildings Climate Change Adaptation State of Play Report*) to identify the state of climate change resilient infrastructure in Canada. The report was developed in collaboration with experts across Canada to study the range of barriers and next steps for integrating climate change into the design of water infrastructure, transportation systems, engineered and non-engineered buildings and other infrastructure. 62 opportunities for strengthening adaptation action across Canada were identified in the report.

2. STUDY CONTEXT

At this stage of the Kanata LRT Project, only major features of the project are known. This assessment aims to evaluate the infrastructure components that are known or can be reasonably assumed, including track, guideway, station components, and major watercourse crossings. The following section provides a general description of the proposed infrastructure.

2.1 Description of Infrastructure

The Kanata LRT project is a component of the City's planned primary rapid transit network. It is identified in the City's Transportation Master Plan (TMP) as part of the Ultimate Rapid Transit Network, with implementation currently anticipated beyond the TMP's 2031 horizon year.

The preferred LRT route follows the previously approved Bus Rapid Transit (BRT) corridor along Highway 417 before extending south at Palladium Drive. Station locations include March/Eagleson, Kanata Town Centre, Terry Fox Station, Didsbury Road, Campeau Drive, Canadian Tire Centre, Maple Grove Road, and Hazeldean Road. The preferred alignment of the Kanata LRT is shown in Figure 2.

Infrastructure components considered in this assessment include:

- Rail and Ballast (11 km)
- Catenary System
- Underpasses / Overpasses (4)
- Elevated Rail Segments (~4 km)
- Open Cut Rail Segments(<1 km)
- Watercourse Crossings (6)
- Stations (8)
- Park and Rides (2 existing, 1 new)
- Bus Terminal Facilities
- Passenger Pick-up and Drop-off Facilities
- New / Improved Pedestrian and Cycling Facilities
- New Multi-Use Pathway Bridges (2)
- Traction Power Substations
- Lighting
- Landscaping
- Stormwater Management.

2.2 Jurisdictional Considerations

The proposed alignment could require acquisition of provincial, federal, and private land. The study area is bisected by Highway 417, which is under Provincial ownership and jurisdiction. The proposed alignment also passes through parts of the Greenbelt, owned and managed by the National Capital Commission (NCC).

The Rideau Valley Conservation Authority (RVCA) and Mississippi Valley Conservation Authority (MVCA) have jurisdiction over the east and west sections of the study area, respectively.

Figure 2 – Preferred Alignment of the Kanata LRT and Design Overview

3. CLIMATE CHANGE ADAPTATION – KEY CONCEPTS AND METHODOLOGIES

This report provides a screening level climate risk assessment of the Kanata LRT project, considering modeled climate change projections and comparing projected future conditions to historic conditions for selected climate event variables.

3.1 Methodology

The methodology used in this risk assessment takes into consideration methodologies such as the PIEVC Protocol (Engineers Canada) (see Section 1.2) and the MOECC's *Guide to Considering Climate Change in the EA Process*. The approach involves developing a list of climate variables (e.g. rain, snow) and a list of project components (e.g. rail, stations), and reviewing the potential interactions between each one.

Given that the Kanata LRT project is still at the planning stage and full details of the project are not confirmed at this time, this work is being completed as a high-level risk assessment that does not implement a formal assessment as per the PIEVC Protocol. One possible outcome of this study is the recommendation for a more detailed risk assessment (such as with the PIEVC Protocol) during a later stage of the Kanata LRT Project.

3.2 Climate Change Projection Data

Climate change projection models used for this study were primarily sourced from an international body referred to as the Intergovernmental Panel on Climate Change (IPCC). The IPCC was established by the United Nations and World Meteorological Organization in 1988 to review information on climate change. The IPCC has since been preparing Assessment Reports that, among other things, aggregate global climate models and projection data. The latest such report, the Fifth Assessment Report (AR5), included projection information from forty Global Climate Models (GCMs).

For this climate change risk assessment, projected changes for various climate elements were computed through the GCMs from AR5 using historical climate data from Environment and Climate Change Canada. This was accomplished using the Climate Change Hazards Information Portal (CCHIP), a climate analysis tool developed by Risk Sciences International (RSI).

AR5 also uses the concept of Representative Concentration Pathways (RCPs) to denote scenarios of various climate change intensities. Each scenario is named after 'radiative forcing values', a measure of the rate of energy change per unit area of the globe, measured in watts per square metre.

Figure 3 – Representative Concentration Pathways of AR5 (Source: Risk Sciences International)

The scenario with the lowest projected change, or 2.6 W/m^2, is represented by RCP 2.6, while the highest projected change, or 8.5 W/m^2, is represented by RCP 8.5 (Figure 3).

The two RCPs used in this risk assessment were RCP 4.5 (moderate future emissions), and RCP 8.5 (highest future emissions).

The historical climate data used in the computation of climate projections comes from the Ottawa CDA meteorological station. Although other stations are closer to the study area, stations with at least 30 years of historical data are recommended for an accurate baseline, and stations with the longest periods of data are generally preferable. In the case of the Kanata LRT, the nearest meteorological stations are the Carp and Ottawa Britannia stations (Figure 4), however these stations only have data for 15 years or less. The Ottawa CDA station, located at the Central Experimental Farm has over 100 years of data. The Ottawa Macdonald-Cartier International Airport station is another good option for projects in the City of Ottawa, however the Ottawa CDA station is closer to the study area.

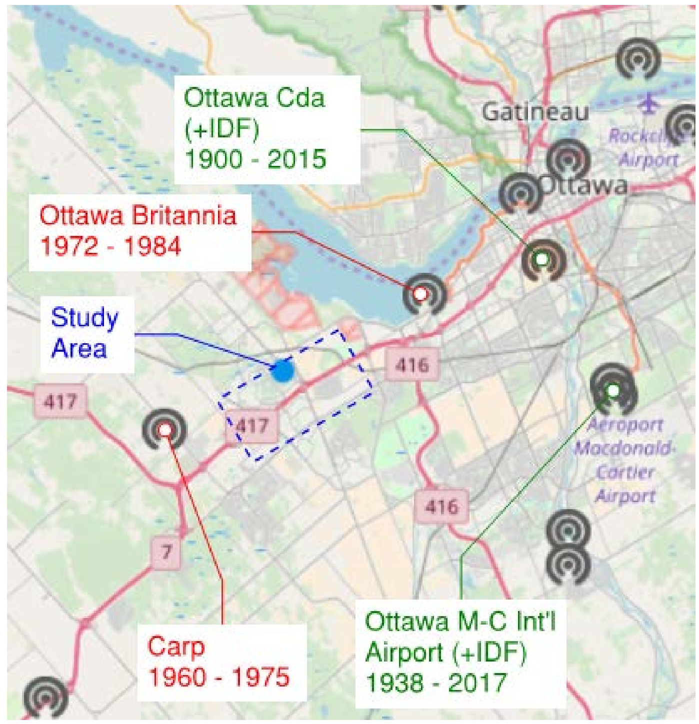

Figure 4 – Climate Data Stations closest to Study Area

In addition to CCHIP, historical trends and climate projections were identified through the review of past climate change risk assessments from the Ottawa area and academic papers from the field of climate science.

Climate projections for the Ottawa CDA station, as computed by CCHIP using AR5 climate models, are presented in the following pages. Results from both the moderate (RCP4.5) and high (RCP8.5) climate change scenarios are included.

4. CLIMATE CHANGE PROJECTIONS

4.1 Daily Average Temperature

Temperatures in the Ottawa area are projected to increase in future under the RCP 4.5 and 8.5 climate scenarios. Overall, annual daily average, maximum, and minimum temperatures are projected to increase at similar rates. As shown in Table 1 all three variables are projected to increase on average between 2.4 and 3.1 degrees by 2050, and between 3.3 and 5.8 degrees by 2080.

Table 1 – Annual Daily Average, Maximum, and Minimum Temperature Projections

Annual Daily Average Temp (°C)					
		RCP4.5		**RCP8.5**	
Data Source	**Historical Average 1980-2010**	**2050**	**2080**	**2050**	**2080**
Average Temperature	6.7	9.1	9.7	10	12.2
Difference	-	2.4	3	3.3	5.5
Annual Daily Max Temp (°C)					
		RCP4.5		**RCP8.5**	
Data Source	**Historical Average**	**2050**	**2080**	**2050**	**2080**
Average Temperature	11.4	13.8	14.4	14.7	16.9
Difference	-	2.4	3.0	3.3	5.5
Annual Daily Min Temp (°C)					
		RCP4.5		**RCP8.5**	
Data Source	**Historical Average**	**2050**	**2080**	**2050**	**2080**
Average Temperature	1.9	4.4	5	5.4	7.7
Difference	-	2.5	3.1	3.5	5.8

This increase in temperature would have an impact on the number of heating and cooling degree days. Degree days represent the accumulated difference in temperature above or a below a standard temperature (18°C in this case), and are used to assess the need for space heating or cooling. As shown in Table 2 and Table 3, heating degree days may decrease by 20% to 36% for the scenarios considered while cooling degree days may increase by 97% to 258%.

Table 2 – Heating Degree Days Projections

Heating Degree Days		RCP4.5		RCP8.5	
Data Source	**Historical Average**	**2050**	**2080**	**2050**	**2080**
Annual Average (°C)	4625	3702	3557	3473	2963
Percent Change (%)	-	-20.0	-23.1	-24.9	-35.9

Table 3 – Heating Degree Days Projection

Cooling Degree Days		RCP4.5		RCP8.5	
Data Source	**Historical Average**	**2050**	**2080**	**2050**	**2080**
Annual Average (°C)	242	477	533	582	867
Percent Change (%)	-	97.1	120.2	140.5	258.3

4.2 Extreme Heat Days

Along with an increase in average daily temperatures, an increase in extreme temperatures is projected for the study area under the RCP 4.5 and 8.5 climate scenarios. This can be observed in the projections for the number of days with daily maximum temperatures above 30°C, which may increase from an annual average of 12 days, historically, to between 33 and 37 days in 2050 and to between 42 and 69 days in 2080 as shown in Table 4.

Table 4 – Max Daily Temperature Occurrences above 30°C

Max Daily Temperature > 30 °C		RCP4.5		RCP8.5	
Data Source	**Historical Average**	**2050**	**2080**	**2050**	**2080**
Annual Average (days)	12.2	32.5	42.2	37.2	69.4
Percent Change (%)	-	166	246	205	469

4.3 Precipitation

Extreme precipitation is one of the most difficult climate change variables to project, however it is also one of the most important in terms of impacts to infrastructure. In general, according to current projections under the RCP 4.5 and 8.5 climate scenarios:

- Total annual precipitation would increase; and
- Extreme precipitation would increase at a faster rate than total annual precipitation.

Table 5 and Table 6 support both of the above. Whereas total annual precipitation is projected to increase by up to 11% in 2080, the average maximum 24hr precipitation is expected to increase by 17% in that same time frame. Another way to look at this is to consider the distribution of precipitation events throughout the year. The data aggregated by CCHIP shows that the total precipitation from events in the 95th and 99th percentile (that is, events in the top 5% and 1% respectively when ranked by precipitation amounts) may increase by an average of 51% and 92% in 2080, respectively, under the RCP 4.5 and 8.5 climate scenarios. This indicates that the 11% increase in total annual precipitation would predominantly occur in the form of extreme rain events.

Table 5 – Total Annual Precipitation Projections

Total Annual Precipitation		**RCP4.5**		**RCP8.5**	
Data Source	**Historical Average**	**2050**	**2080**	**2050**	**2080**
Annual Precipitation (mm)	925	983	991	997	1023
Percent Change (%)	-	6.3	7.2	7.8	10.6

Table 6 – Increase in Total Rainfall during Extreme Precipitation Events

Precipitation Extremes		**RCP4.5**		**RCP8.5**	
	Historical Average	**2050**	**2080**	**2050**	**2080**
1 Day Max Precipitation (mm)	42	47	46	47	49
Percent Change (%)	-	11.9	9.5	11.9	16.7
Total Precipitation of Events in 95th Percentile (mm)	240	301	306	321	362
Percent Change	-	25.4	27.5	33.8	50.8
Total Precipitation of Events in 99th Percentile (mm)	73	106	105	114	140
Percent Change	-	45.2	43.8	56.2	91.8

4.4 Average and Extreme Snowfall

The CCHIP tool could not provide the analysis required for average and extreme snowfall projections. Below are the historical total annual snowfalls for the Ottawa CDA station. A downward trend can be identified in the historical data (Figure 5), and this generally aligns with projections for annual increases in temperature. Further, the increase in annual daily average temperature is not distributed evenly throughout the year, but rather will impact the winter season disproportionately compared with all other seasons, as is shown in Table 7.

Even less information is available for extreme snowfall. One PIEVC study for the Toronto Hydro-Electric System (AECOM / RSI, June, 2015) found a slightly decreasing, though highly variable, trend for days with more than 10 cm of snowfall. Another climate change study for Ottawa (Ouranos, 2008) looked at two Canadian Regional Climate Models and found that one model indicated a slight increase in the maximum annual snowfall, while the other model indicated no change or a slight decrease.

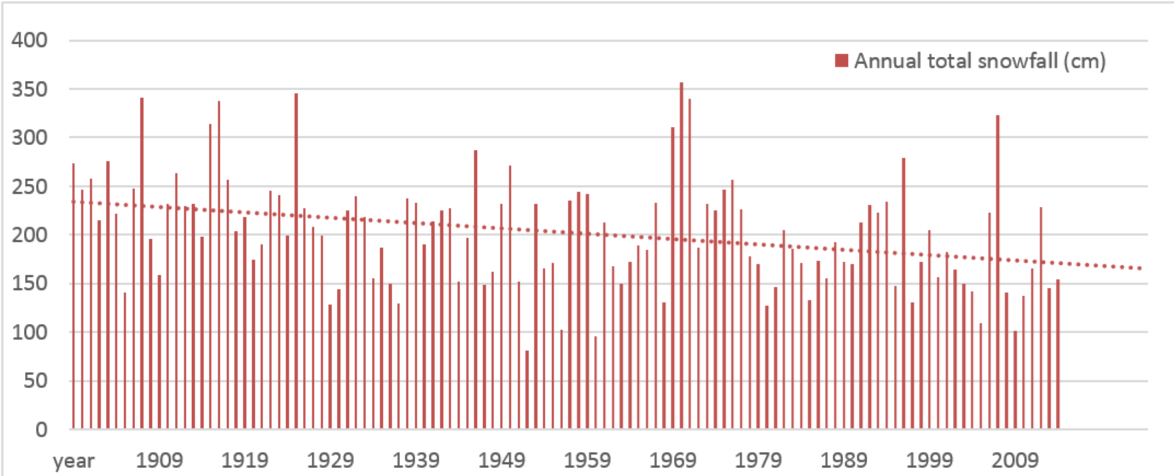

Figure 5 - Historical Annual Total Snowfall (cm), Ottawa CDA

Table 7 – Seasonal Average Daily Temperature Increase Projections

Temperature Increase Compared to Historical Average (2010) (°C)	**RCP4.5**		**RCP8.5**	
	2050	**2080**	**2050**	**2080**
Annual Daily Average	2.4	3	3.3	5.5
Winter (Dec, Jan, Feb) Daily Average	**2.9**	**3.6**	**3.9**	**6.3**
Spring (Mar, Apr, May) Daily Average	2.2	2.8	3	4.9
Summer (Jun, Jul, Aug) Daily Average	2.2	2.7	3.2	5.5
Fall (Sep, Oct, Nov) Daily Average	2.2	2.8	3.1	5.3

4.5 Freeze-thaw Cycles

The ensemble of projections for both the moderate and high concentration pathways (RCPs) show a noticeable decrease in the total number of days with freeze-thaw cycles in 2050 and 2080. The months of April and October would see 62% to 95% fewer freeze-thaw cycles on average under the RCP 4.5 and 8.5 climate scenarios. December, January, and February would all see an increase in freeze-thaw cycles. The month of March would continue to see the most days with freeze-thaw cycles in 2080.

Table 8 – Freeze-thaw Cycle Projections

Freeze-thaw cycles (days)		RCP4.5		RCP8.5	
	Historical Average	2050	2080	2050	2080
January	6.7	7.8	8.2	8	8.3
February	6.7	9.4	9.9	10.2	10.8
March	15.6	14.2	13.3	13.2	11.7
April	12.4	4.7	3.7	3.5	1.8
May	1.5	0.1	0	0	0
June	0	0	0	0	0
July	0	0	0	0	0
August	0	0	0	0	0
September	0.6	0	0	0	0
October	7.1	2.3	1.8	1.2	0.3
November	14	9.9	8.8	8.2	5.6
December	9	10.6	10.5	10	8.7
Total	73.6	59	56.4	54.3	47.3

4.6 Freezing Rain

Certain climate variables, such as freezing rain, cannot be derived directly from temperature or precipitation and require regional modelling with higher resolution. CCHIP is unable to project this particular climate variable. Although few studies have been conducted to look at the impacts of climate change on freezing rain, an Environment and Climate Change Canada study by Cheng et al. (2007) concluded that freezing rain events are very likely to increase in northern, eastern, and southern Ontario in the coming century. The study concluded that eastern Ontario is likely to see a 60% and 95% increase in freezing rain event frequency by 2050 and 2080, respectively, during the months of December, January, and February. The study projected that the frequency of freezing rain events would remain unchanged for the months of November, March, and April.

4.7 Wind

Similar to freezing rain, wind is considered a complex climate variable, requiring detailed and costly modelling. Therefore, the number of projection sources for this climate variable are limited. One Environment and Climate Change Canada study by Cheng et al. (2012) looked at increases in daily and hourly wind gusts for various regions of Ontario, including eastern Ontario. The study analyzed projected climate data from eight GCMs under two climate change scenarios. Like RCPs but developed for the IPCC's fourth assessment report (AR4), different scenarios represent alternative future greenhouse gas emissions. Under AR4, scenario A2 assumes higher GHG emissions, while scenario B1 assumes less.

The results of the 2012 study suggests modest increases in wind gusts are likely in the coming decades (Table 9). Wind gusts over 70 km/h will see the highest increase in frequency, occurring 23% to 46% more often than current conditions.

Table 9 – Daily and Hourly Wind Gust Projections (Cheng et. al., 2012)

Wind gust event	**Daily wind gust (% increase in frequency)**					**Hourly wind gust (% increase in frequency)**			
	2046-2065		**2081-2100**			**2046-2065**		**2081-2100**	
	A2	B1	A2	B1		A2	B1	A2	B1
≥28 km/h	3	2	4	2		7	6	9	6
≥40 km/h	5	4	6	4		7	6	9	7
≥70 km/h	10	10	13	9		47	33	23	35

4.8 Water Balance

During meetings held with the City, drought was identified as a climate variable with potential interactions with project components. Although it is difficult to obtain a clear measure of predicted frequency or duration of drought periods, a look at water balance projections provides context for qualitative projections. Figure 6 shows projected water deficits and surpluses for every month of the year, as computed and graphed by CCHIP. Water deficits exist when potential evapotranspiration is greater than actual evapotranspiration. Results for the RCP 4.5 and 8.5 climate scenarios show that water surplus in the region would increase during the winter months (December to March), while water deficits will increase from May to October, with pronounced deficits in July and August.

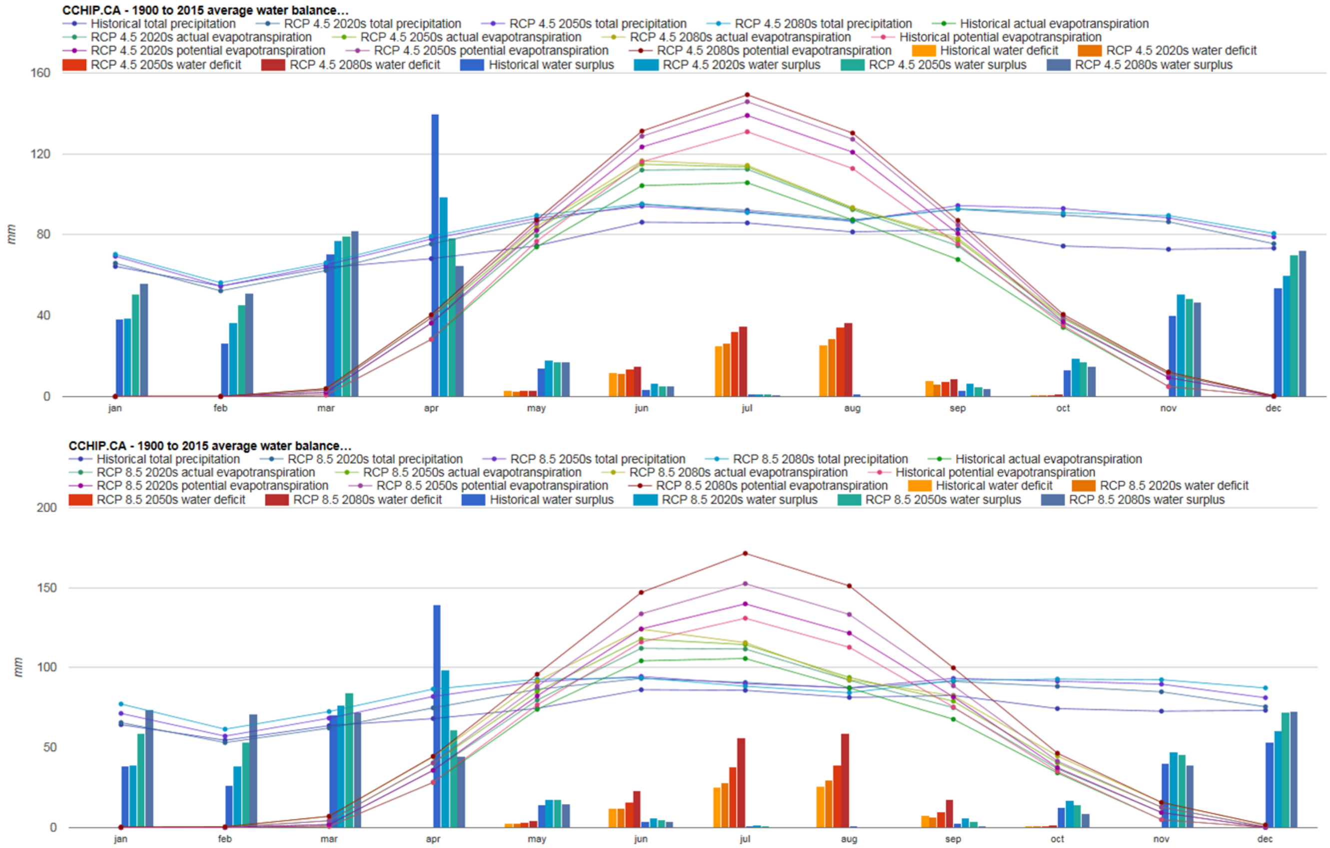

Figure 6 – Water Budget Projections, RCP 4.5 (top) and RCP 8.5 (bottom), Ottawa CDA.

4.9 Lightning

Lightning is a complex variable, related to precipitation and temperature. An initial desktop review of current climate science on lightning and future changes to its frequency or intensity found no consensus on projections. During risk assessment working meetings held for this study, it was agreed that the implications of a direct lightning strike on the system should be considered as part of the design, regardless of change in probability of occurrence.

4.10 Rainfall Intensity Duration Frequency

In water resources, Intensity Duration Frequency (IDF) relates rainfall intensity with its duration and frequency, and is used for flood forecasting and drainage design. This parameter was cited during working meetings held with the City of Ottawa as one that could have direct impacts on the design, in particular when sizing sewers, stormwater management facilities, and watercourse crossings. For this parameter, the IDF_CC tool, developed by Western University and the Institute for Catastrophic Loss Reduction, was used to project the change in total 24-hour precipitation for various design return periods. The results, shown in Table 10, project a 19-22% increase in the 5-year, 24-hour rainfall amount, and a 17-30% increase in the 100-year, 24-hour rainfall amount.

Table 10 – Total 24-hour Precipitation Projections for Various Return Periods

Total 24hr Precipitation for Return Period	Historical (mm)	RCP4.5 (2080)		RCP8.5 (2080)	
		mm	% change	mm	% change
2-year	47	54	14%	56	19%
5-year	61	75	23%	78	27%
10-year	72	89	23%	95	32%
25-year	88	108	22%	119	35%
50-year	102	122	19%	142	39%
100-year	118	142	20%	169	43%

4.11 Combined Variables

The combination of certain climate variables can, in some cases, intensify the interaction with project components and increase risk. For example, extreme rain events may combine with strong winds, which could result in debris being blown into streams and blocking flow through a culvert.

For this study, a qualitative assessment of the potential impact of combined variables on infrastructure resiliency was discussed in the working meetings held with the City of Ottawa. Combined variables should continue to be considered throughout the design of the project.

4.12 Data Sufficiency

The project as discussed in this report is preliminary and subject to change as the design progresses. This high-level assessment captures the major infrastructure components of the project and does not focus on design details.

A site visit was not conducted for this assessment. Web mapping services and preliminary plan and profile documents were used to inform this assessment.

During consultation and working meetings with City of Ottawa staff and industry experts, additional climate change variables were discussed for consideration. Of the variables discussed, extreme snow, lightning, and drought were proposed to be considered either as part of the current assessment or at a later stage of the project. Additionally, IDF curves were added as an additional way to understand the potential projected changes to rainfall intensity and frequency, in particular as these relate to extreme rain events.

5. RISK ASSESSMENT

Risk assessment of climate change vulnerabilities is a multi-disciplinary process that should consider a broad base of expertise and professional experience. In order to ensure a multi-disciplinary process, two half-day working meetings facilitated by Morrison Hershfield were conducted with the study team and City of Ottawa staff, including a number of professionals with wide-ranging expertise related to the design, construction, operation, and maintenance of transit projects. Meeting participants were introduced to concepts of climate change vulnerability and adaptation and were given the opportunity to explore and discuss the issues of potential infrastructure vulnerability, resilience, and risk in the context of projected climate change.

5.1 Risk Assessment Process

Step 3 of the PIEVC process (Figure 1) is the completion of a risk assessment. A risk assessment generally follows the following five (5) steps:

1. Identify Potential Hazards (i.e. potential infrastructure component x climate factor interactions).
2. Assess the probability of a negative event (low to high).
3. Assess the severity of an event if it happens (low to high).
4. Determine the risk level, whereby Risk = Probability x Severity.
5. Categorize the risk levels by low, medium and high (Figure 7).

Probability (P)
Negligible / N/A
Unlikely
Possible / Occasional
Likely / Frequent
Highly Probable

X

Severity (S)
Negligible / N/A
Change in Serviceability
Moderate Loss of Some Capability
Loss of Critical Function
Loss of Asset

=

Risk Thresholds	
Low Risk	(green)
Med. Risk	(yellow)
High Risk	(red)

Figure 7 – Methodology for Determining Risk Level

5.2 Potential Infrastructure x Climate Factor Interactions

There are many possible potential hazards (potential infrastructure x climate factor interactions) that can be assessed during a risk assessment. Table 11 provides examples of potential hazards as they relate to transportation infrastructure. A full list of the potential hazards assessed as part of the Kanata LRT EA can be found within Table 12.

Table 11 – Examples of Potential Infrastructure x Climate Factor Interactions

Possible Infrastructure Component x Climate Factor Interactions	Potential Resulting Impact	
Extreme Heat x Track / Guideway	Buckled Rails	
Extreme Precipitation x Track / Guideway	Overflowing Ditches / Inundated Guideway	
Extreme Precipitation x Bridges / Culverts Over Water	Culvert Washout	
Extreme Wind x Pathways	Loss of Access	

Extreme Rain x Pathway Culverts	Damage / Loss of Access	
Extreme Rain x Pathways	Flooding / Loss of Access	

5.3 Potential Risk Responses / Adaptation Strategies

Integration of risk responses / adaptation strategies can alleviate and reduce infrastructure vulnerability to changing environmental conditions. Risk assessment and risk response / adaptation strategies need to consider the Public Transit Needs Hierarchy: Safety, Service and Loss for both Criticality and Serviceability of Infrastructure.

The US Federal Transit Administration's (FTA) 2011 *Flooded Bus Barns and Buckled Rails: Public Transportation and Climate Change Adaptation* Report defines four categories of risk response / adaptation strategy:

- **Maintain and manage**: absorb increased maintenance and repair costs associated with changing climate conditions and incorporate real-time responses to severe weather events (i.e. integration of sensor technologies to detect changing system conditions and alert of approaching damage thresholds).

- **Strengthen and protect**: design new infrastructure and retrofit existing infrastructure to withstand potential future climate conditions (i.e. use of heat resistant materials).

- **Enhance redundancy**: identify / plan for system alternatives in the event of disruption to the system / service.

- **Retreat**: abandon or relocate existing infrastructure in areas highly vulnerable to future climate conditions, plan new infrastructure in less vulnerable areas.

The FTAs 2011 report also defines components of infrastructure design that can be significantly affected by future climate conditions and in to which risk responses / adaptation strategies can be built:

- **Subsurface conditions**: the stability of infrastructure (e.g. rail tracks, roads, bus shelters etc.) depend upon the soils they are built upon.

- **Material specifications**: different materials respond differently under varying conditions (e.g. freeze-thaw, temperatures, loads and precipitation levels).

- **Cross-sections / standard dimensions**: slope of paved surfaces which will affect run-off and vertical clearance of bridges over waterways.

- **Drainage and erosion**: flood levels, flood flow patterns and hydraulic controls.

5.4 City Meeting #1

During the first working meeting, participants were introduced to the Kanata LRT EA scope and recommended design and presented with the methodology selected for the climate change vulnerability assessment. Participants were invited to ask questions and provide feedback on the project definition, climate variables, climate data, and infrastructure components identified. Refer to **Appendix A** for the contents of the presentation.

Throughout the presentation, participants provided valuable feedback for the study team's consideration. The following is a brief list summarizing key comments received:

- For complex variables that are difficult to project, such as lighting and extreme snowfall, the risk assessment approach was discussed, favoring qualitative analysis at this stage and identifying gaps for future study.

- Additional climate variables discussed for consideration include drought, wildfire, flooding, smog, acid rain, airborne contaminants, and tornadoes.

- The group discussed the possibility of considering the impacts of compounded variables, for instance extreme wind combined with extreme rain.

- The group discussed interactions between climate variables and infrastructure – such as rail buckling due to temperature, air conditioning needs for trains, shading needs for passengers at stations, and culvert washouts or similar risks due to extreme flooding.

The full meeting minutes are located in **Appendix B**.

Following Meeting #1, the feedback received was considered by the study team. Wherever feasible and valuable to the assessment, additional data gathering and review was completed to address comments received during the working meeting. As a result, the following climate variables were added to the list of climate variables of interest:

- Drought / Water Balance
- Extreme Snowfall
- Lightning

5.5 Working Meeting with Kanata LRT EA Study Team

In between the two working meetings with the City, a working meeting with design consultants from the Kanata LRT EA study team was conducted to complete a preliminary planning / screening level risk assessment. The risk assessment process that was followed is summarized in section 5.1.

The group reviewed each project component against each climate factor and discussed the probability and severity of the potential interactions. Some of the potential hazards identified included: extreme rain impacts to track, guideway, bridges, culverts, and underground structures; freezing rain impacts to overhead wires, catenary systems, roadways and walkways; extreme heat impacts to steel rails and public health; and extreme wind impacts to landscaping and emergency access routes. The hazards identified were categorized by risk level (Table 12).

Following the risk assessment working meeting, further analysis was completed to identify areas requiring further evaluation, gaps in data availability and quality, interactions with no or negligible risk, and key recommendations. The conclusions and recommendations of the risk assessment were presented at the second working meeting with the City (Table 13).

5.6 City Meeting #2

During the second City working meeting, the study team updated participants on material presented during Meeting #1 as well as the preliminary conclusions and recommendations drawn from the risk assessment process. Additional climate data, gathered as a result of the feedback received during Meeting #1, was reviewed and discussed with participants. The presentation, the contents of which are included in **Appendix C**, summarized the potential hazards identified considering climate variables and project components, as well as the approximate level of risk assigned to each hazard.

Once more, participants were invited to participate in a discussion on the study's findings and limitations, the risks identified or overlooked, and potential adaptation measures to be put forth as recommendations. Key points of discussion included:

- The implications of increased extreme precipitation on design methods, including the variability among projected changes to IDF curves used in design. The group discussed the City's current "stress test" approach (i.e. increasing 100-year flows by 20%). It was suggested that IDF curves based on historical data may no longer provide designers with a comfortable level of certainty, and that worst case projections should at least be considered during design to better understand potential consequences.

- The impacts on human health of projected potential changes to various climate variables, including extreme heat, extreme rain, and extreme wind. The group agreed that, beyond considerations for public safety that are paramount to designers, impacts to human health could also translate to ridership impacts, discouraging use of the LRT if adequate shelter from extreme elements is not available when weather is less than ideal. Suggested adaptation measures included ensuring adequate shade, access to water, and shelter from wind and rain at stations. It was suggested that a Health Impact Assessment be completed in the future.

The full meeting minutes are located in **Appendix D**.

5.7 Summary of Screening Level Risk Assessment

The conclusions and recommendations of the risk assessment are presented within Table 12 below. A colour scheme was utilize to present the risk thresholds, whereby low risk is represented by green, medium risk by orange and high risk by red. As noted above the conclusions and recommendations of the risk assessment were presented at the second working meeting with the City of Ottawa.

5.8 Climate Change Risk Response / Adaptation Considerations

Potential considerations arising from this screening level risk assessment for integrating climate change risk response / adaptation within preliminary and detail design of the Kanata LRT project are presented in Table 13.

Table 12 – Risk Assessment of Climate and Infrastructure Interactions

		Climate Change Factors					
ID #	**Infrastructure Component**	***Average Temp.***	***Extreme Heat***	***Annual Rain***	***Extreme Rain***	***Freezing Rain***	***Extreme Wind***
1	**Track / Guideway (Incl. Ballast and Drainage)**						
2	**Bridges - Underpasses / Overpasses**						
3	**Bridges / Culverts - Over Water**						
4	**Retaining Structures**						
5	**Overhead Contact / Catenary Systems**						
6	**Power Distribution (Cabling, Troughs, Raceway, Terminal Units)**						
7	**Power Supply (Substations) Ground Level and Underground**						
8	**Communications Systems**						
9	**Emergency Systems (Exit Doors and Windows, Access Roads, Routes)**						
10	**Stations - Buildings, HVAC Systems**						
11	**Bus Terminal and Passenger Pick-up and Drop-Off Facilities**						
12	**Park and Ride Lots**						
13	**Pedestrian and Cycling Facilities**						
14	**Landscaping**						
15	**Stormwater Management Facilities**						

Table 13 – Preliminary Recommendations for Climate Change Adaptation

<table>
<tr><th>ID #</th><th>Infrastructure Component</th><th>Potential Functional Design / Environmental Assessment Considerations:</th><th>Potential Preliminary Design / Detail Design Considerations:</th><th>Potential Maintenance / Operations Considerations</th></tr>
<tr><td>1</td><td>Track / Guideway, (Incl. Ballast and Drainage)</td><td>• Linear drainage is a key concern for this component. Increased peak runoff could result in larger trackside ditches or other drainage components, having implications on property requirements.</td><td>• Extreme heat could increase likelihood of steel rail buckling.
• Temperature projections / thermal expansion should be considered during design.</td><td rowspan="15">• Assess / monitor climate change implications for maintenance / operations planning and standards.
• Develop Standard Operating Procedures (SOPs) for:
a. Monitoring
b. Response Plans
c. Contingency / Back-up Plans
d. Restoration / Lessons Learned</td></tr>
<tr><td>2</td><td>Bridges - Underpasses / Overpasses</td><td rowspan="2">• Crossings over Poole Creek, Feedmill Creek and Carp River are well above the high water level. Crossings over Watts Creek and Stillwater Creek have less flexibility, and should be designed with consideration for increased extreme precipitation and potentially increased risk of flooding. Need to assess possible design / property implications.</td><td rowspan="2">• Continue to consider climate change implications during design (e.g. peak design storms, flood mapping for extreme events, stress testing of designs, IDF curves for future conditions).</td></tr>
<tr><td>3</td><td>Bridges / Culverts - Over Water</td></tr>
<tr><td>4</td><td>Retaining Structures</td><td colspan="2">Low Risk (Consider further at Preliminary / Detail Design)</td></tr>
<tr><td>5</td><td>Overhead Contact / Catenary Systems</td><td>• Document issues for consideration at Preliminary / Detail Design.</td><td>• Overhead wire design (or maintenance) to consider projected temperature conditions to avoid sagging wires.
• Overhead wires design to consider potential increases in freezing rain and extreme wind.</td></tr>
<tr><td>6</td><td>Power Distribution (Cabling, Troughs, Raceway, Terminal Units)</td><td colspan="2">Low Risk (Consider further at Preliminary / Detail Design)</td></tr>
<tr><td>7</td><td>Power Supply (Substations) Ground Level and Underground</td><td>• Document issues for consideration at Preliminary / Detail Design</td><td>• Substations in low lying areas should be assessed for flood risk / inundation from increased extreme precipitation.</td></tr>
<tr><td>8</td><td>Communications Systems</td><td colspan="2">Low Risk (Consider further at Preliminary / Detail Design)</td></tr>
<tr><td>9</td><td>Emergency Systems (Exit Doors and Windows, Access Roads, Routes)</td><td>• Document issues for consideration at Preliminary / Detail Design.</td><td>• Station and emergency exit near March/Eagleson are below grade and could be at risk of flooding.
• Emergency Plans should consider projected future climate conditions.</td></tr>
<tr><td>10</td><td>Stations - Buildings, HVAC Systems</td><td rowspan="3">• Document issues for consideration at Preliminary / Detail Design.</td><td rowspan="3">• Extreme heat should be considered when choosing materials and designing buildings and systems (e.g. HVAC).
• Extreme precipitation could have implications for rooftop and site drainage design.
• Design of site drainage should consider extreme precipitation events and, where applicable, ensure that mechanical rooms are protected.</td></tr>
<tr><td>11</td><td>Bus Terminal and Passenger Pick-up and Drop-Off Facilities</td></tr>
<tr><td>12</td><td>Park and Ride Lots</td></tr>
<tr><td>13</td><td>Pedestrian and Cycling Facilities</td><td>• Document issues for consideration at Preliminary / Detail Design.</td><td>• Consider potential drainage / flooding effects of extreme precipitation.</td></tr>
<tr><td>14</td><td>Landscaping</td><td>• Document issues for consideration at Preliminary / Detail Design.</td><td>• Design should consider future climate change conditions (landscaping composition, tolerance to changing climate, growth rates, invasive species).
• Tree planting should consider implications of broken off limbs or downed trees.</td></tr>
<tr><td>15</td><td>Stormwater Management Facilities</td><td>• Sizing/design of SWM facilities should consider accommodation of and/or resilience to projected extreme rainfall events.
• Consider property implications at EA Stage.
• Consider future environmental implications to receiving watercourses at EA Stage.</td><td>• Design should consider future climate change conditions.</td></tr>
</table>

5.9 Other Considerations for Preliminary and Detail Design

5.9.1 Design Standards and Design Guidelines

The application of some infrastructure design standards and guidelines may be affected by changing climate conditions. These may include, but are not limited to the following:

- American Railway Engineering and Maintenance-of-Way Association (AREMA) Standards;
- Canadian Highway Bridge Design Code;
- Ontario Building Code (OBC);
- National Fire Protection Association (NFPA) 130 Standard for Fixed Guideway Transit and Passenger Rail Systems;
- City of Ottawa Sewer Design Guidelines; and
- MOE Stormwater Management Planning and Design Manual.

Further review of the above should be undertaken at future stages of project.

5.9.2 Graham Creek Stormwater Infrastructure PIEVC Study

The *Graham Creek Stormwater Infrastructure PIEVC Study* prepared for the City of Ottawa in 2017 provides a number of recommendations for integrating climate change adaption into drainage design. The study's recommendations are intended to be generally applicable to drainage infrastructure throughout the City of Ottawa. The following recommendations from the *Graham Creek Stormwater Infrastructure PIEVC Study* should be considered during preliminary and detail design of the Kanata LRT.

Design Approaches

- The design philosophy should acknowledge climate change has altered the design loads from being static in time to being variable in time (i.e. design loads will increase over the design life of infrastructure and beyond).
- The structural and functional capacity of new drainage infrastructure should be based on the loads at the end of its design life. In the absence of updated climate information, design loads should be increased to a minimum of 20% over historic values for infrastructure with an end of service life by the year 2050 and 40% over historic values for infrastructure with an end of service life by the year 2100.

- Incorporate flexibility into the design to enable upgrades before the end of service life should the climate change assumptions and design parameters prove to be insufficient. This may include: expanded easements for equipment and personnel access (potential future upgrades as well as access for inspections, maintenance and emergency response) and ensuring adequate space to add an additional barrel to increase capacity.

Operation and Maintenance Approaches

- Operations and maintenance should be considered during design, and elements to facilitate this should be included. This may involve acquiring land for adequate access (easements), including access points for personnel and/or equipment such as platforms and ladders, etc. At the design stage, an inspection plan should also be developed to assess the infrastructure throughout the design life and provide timely adaptation measures, if needed.

- With debris accumulation expected to increase in changing climate, operations and maintenance becomes even more important in the future. For both culverts and catch basins, regular maintenance to clear inlets, screens, and outfalls is key.

- Clearly define the responsibility and authority for inspection, clearing of debris, and emergency response.

- Prioritize staff and resources for operations and maintenance work on drainage infrastructure based on risk.

(Graham Creek Stormwater Infrastructure PIEVC Study, 2017)

6. CONCLUSION / ADDITIONAL STUDY

This high-level assessment was undertaken to identify potential vulnerabilities of major infrastructure components of the Kanata LRT project based on the information available at this stage of the planning process. The assessment results and recommendations are preliminary only and are based on a limited review of climate projections without direct input from climate scientists.

Climate change projections provided through this work offer an initial look at potential future climate scenarios and are subject to very significant uncertainty. Additional risk assessment (such as a PIEVC Protocol or other detailed climate change risk assessment) should be undertaken at the preliminary design stage of this project and should be supported by updated climate change projections with acceptable confidence, as determined by qualified climate change risk assessment professionals.

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Appendix A: City of Ottawa Meeting #1 Presentation

Appendix B: City of Ottawa Meeting #1 Minutes

Appendix C: City of Ottawa Meeting #2 Presentation

Appendix D: City of Ottawa Meeting #2 Minutes

X. Carbon Footprint Assessment

MORRISON HERSHFIELD

Report

Carbon Footprint Assessment for the Kanata Light Rail Transit (LRT) Planning and Environmental Assessment Study

Project No. 2160553 August 30, 2018

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1. INTRODUCTION

The City of Ottawa is preparing an Environmental Assessment (EA) Study for the expansion of its Light Rail Transit (LRT) network to Kanata to accommodate existing and future rapid transit demand. The EA Study will identify the preferred corridor, the recommended plan for LRT alignment and stations, as well as the project staging and implementation based on future ridership and affordability. As part of this EA Study, Morrison Hershfield has been retained to carbon footprint assessment for the Kanata LRT. The carbon footprint assessment work was completed in conjunction with a screening level climate change risk assessment summarized under separate cover.

1.1 Provincial Guidance

The 2014 Provincial Policy Statement (PPS), issued by the Ontario Ministry of Municipal Affairs and Housing under the Planning Act, requires that planning authorities support climate change mitigation and adaptation through land use and development. In October of 2017, the Ministry of the Environment and Climate Change (MOECC) issued a new guide titled *Considering Climate Change in the Environmental Assessment Process*. This guide supports the 2014 PPS, as well as the province's *2016 Climate Change Action Plan*, by setting out the ministry's expectations for including climate change in environmental assessment studies.

In the 2017 guide, the MOECC advises that climate change impact considerations are part of responsible planning and due diligence, and that considerations should include, at a high level, three key components:

- A review of the project's potential for producing greenhouse gas emissions;
- An assessment of the project's vulnerability to climate change; and
- The impact of the project on the environment's adaptive capacity.

The guide recommends that proponents consider climate change impacts of alternatives as part of the selection process, and that they report on the expected performance of the preferred alternative with respect to climate change impacts.

The approach to evaluate the project's climate change impacts was shaped by the following broad-scope questions identified in the guide:

1. How might the project/alternatives generate greenhouse gas emissions or the removal of carbon dioxide from the atmosphere?
2. To what extent have the project/alternatives already taken into account impacts on climate change in project planning?

3. Are there alternative methods to implement the project that would reduce any adverse contributions to a changing climate?

4. What commitments can be made to reduce the impacts on climate change from the project over time, i.e. when the project is implemented?

For streamlined environmental assessments, such as those under the Transit Project Assessment Process, the guide recommends a scaling of the climate change considerations to the significance of the project's environmental effects. Climate change considerations in an environmental assessment should assess the need to include measures for adapting to and mitigating climate change throughout project implementation. These measures could include design modifications, additional studies, and revised operation and maintenance procedures.

In 2007, the Ontario government set targets to reduce greenhouse gas (GHG) emissions in the province to 15% below 1990 levels by 2020 and to 80% below 1990 levels by 2050. These commitments were renewed in 2015 in *Ontario's Climate Change Strategy*.

1.2 National Guidance

The *Pan-Canadian Framework on Clean Growth and Climate Change* is Canada's national strategy developed with the Provinces, Territories and Indigenous groups to meet national emissions reduction targets, adapt to the impacts of a changing climate and maintain a healthy economy. The Pan-Canadian Framework has four main pillars: pricing carbon pollution, complementary climate actions across various sectors (e.g. electricity, built environment, transportation, industry, forestry, agriculture and waste), adapt and build resilience, and invest in clean technology, innovation and jobs. Key actions are identified for each of the four pillars.

With regards to transportation the Framework identifies the following key action item:
- Shifting from higher-to lower-emitting modes and investing in infrastructure (e.g. enhance investments in public-transit).

The Framework also provides a pathway to meeting the Federal target to reduce GHG emissions to 30% below 2005 levels by 2030. Public transit and green infrastructure are among several emission reduction measures identified as a means to achieve this target.

1.3 City of Ottawa

In May 2014, the City of Ottawa adopted the updated *Air Quality and Climate Change Management Plan* (AQCCMP), a framework that sets out goals and objectives for Ottawa to mitigate and adapt to a changing climate. The Plan's mitigation goals, such as reducing energy demand and dependency on fossil fuels, are tied to the implementation of an electric light rail transit system in the City as well as transit-oriented development to encourage ridership. The Plan sets a per capita emissions target of 4.6 tCO_2e by 2024 in order to achieve a 12% reduction in emissions from 2012 while accounting for the projected population growth.

In February 2016 a City of Ottawa motion was carried directing City staff to pursue a long-term GHG reduction target of 80% below 2012 levels by 2050.

In support of the AQCCMP as well as the City's long-term GHG reduction target of 80% below 2012 levels by 2050, City staff have been developing a renewable energy strategy since 2016, of which the first phase, *Energy Evolution: Ottawa's Community Energy Transition Strategy – Phase 1*, was presented to Council in late 2017. The Strategy lists Stages 1 and 2 of the Ottawa LRT as notable energy initiatives in Ottawa, with a combined projected GHG emissions reduction of at least 204,000 tonnes annually by 2048.

1.4 International Projects

Internationally, carbon footprint assessments have been completed to assess the impacts of similar transit projects. The following are examples of such projects.

Central Business District and South East Light Rail Project – Sydney, Australia

The Sydney LRT will consist of 12 km of new light rail track extending north from the Circular Quay area of Sydney to south of the University of New South Wales in the southern part of Sydney. In addition to the new track 20 light rail stops are to be built along with 12 substations to power the light rail vehicles.

As part of the project an Environmental Impact Statement (EIS) report was produced which included an assessment of the project's anticipated GHG emissions. GHG emissions associated with both construction and operation of the LRT were assessed and were expressed by their carbon dioxide equivalents (CO2e). Scope 1, 2 and 3 emissions were assessed as part of the study and for the construction stage of the project were estimated at approximately 70,000 tonnes of CO2e.

Caltrain - California, U.S.A.

Caltrain provides commuter rail service along the San Francisco Peninsula, through the South Bay to San Jose and Gilroy on the west coast of California. The Peninsula Corridor Electrification Project (PCEP) is a key component of the Caltrain Modernization program. The PCEP is to electrify the approximately 83 km of Caltrain Corridor from San Francisco to San Jose and will include new electrical infrastructure in the form of traction power facilities and overhead contact system improvements. The project includes no new rail extensions and no new stations.

As part of the proposed Caltrain electrification project an Environmental Impact Report (EIR) was produced which detailed the effects of switching from diesel-powered trains to electric on GHG emissions. Caltrain used the IPCC's global warming potential (GWP) methodology that converts all GHG emissions into their carbon dioxide equivalents ($CO2_e$).

Crossrail – London, England

The London Crossrail is to include 110 km of new track, 21 km of tunnels and 10 new stations for regional travel. A carbon footprint model was developed to estimate net carbon dioxide emissions resulting from the construction and operation of the railway. Efforts were subsequently made to reduce the carbon footprint for both the construction and operation of the railway project – particularly the latter which is estimated to account for 78% of the carbon footprint over the project's lifetime of 120 years.

The Crossrail project achieved its target for construction-related emissions by implementing energy efficiency measures like the use of LED lighting inside stations and tunnels, hybrid and hydrogen technologies, and solar panels. Furthermore, the Crossrail project committed to reducing the embodied footprint of the project by requiring a minimum of 50 per cent cement replacement in its concrete, as long as performance requirements were met.

2. STUDY CONTEXT

At this early planning stage of the Kanata LRT Project, only major features of the project have been identified. This assessment aims to evaluate the carbon footprint of infrastructure components that are known or can be reasonably assumed, including track, guideway, station components, and major watercourse crossings. Furthermore, this assessment does not evaluate the emissions savings realized by the combination of the switch from diesel buses to electrified rail plus expected modal shift from fossil fuel powered personal vehicle use to transit. It is assumed that these savings will far outweigh the embodied carbon footprint of the construction of the Kanata LRT project as evaluated herein.

The following section provides a general description of the proposed infrastructure.

2.1 Description of Infrastructure

The Kanata LRT project is a component of the City's planned primary rapid transit network. It is identified in the City's Transportation Master Plan (TMP) as part of the Ultimate Rapid Transit Network, with implementation currently anticipated beyond the TMP's 2031 horizon year.

The preferred LRT route follows the previously approved Bus Rapid Transit (BRT) corridor along Highway 417 and moving south at Palladium Drive. Station locations include March/Eagleson, Kanata Town Centre, Terry Fox Station, Didsbury Road, Campeau Drive, Canadian Tire Centre, Maple Grove Road, and Hazeldean Road. The preferred alignment of the Kanata LRT is shown in Figure 1.

Infrastructure components considered in this assessment are limited to:

- Rail and Ballast (11 km);
- Elevated Rail Segments (~4 km);
- Stations (8);
- Park and Rides (2 existing (Palladium and Eagleson), 1 new (Hazeldean));

Other infrastructure components will have an impact on the results, but the design would need to progress further to estimate the impact. Components not modelled at this time include, catenary systems, underpasses, overpasses, open cuts, watercourse crossings, pedestrian cycling facilities, multi-use pathway bridges, power substations, landscaping, and stormwater management.

Figure 1 - Preferred Alignment of the Kanata LRT

3. KEY CONCEPTS AND METHODOLOGY

Life cycle assessment (LCA) is a scientific procedure for calculating multiple environmental impacts of a material, product, activity or process over its lifetime, often referred to as “cradle to grave”. LCAs take into account both direct and indirect impacts on the environment and can include assessment of multiple environmental impacts including, natural resource use, ecosystem health, climate change and human health. LCAs are thus considered multi-criteria analyses.

There are defined international standards for completing LCAs, these include:

- ISO 14044: requirements and guidelines for completing LCAs; and,
- ISO 14040: principles and framework for completing LCAs.

A carbon footprint assessment, also referred to as a GHG emissions assessment is one output of LCA, and is the sole focus of this report. A carbon footprint assessment is a scientific procedure for calculating the greenhouse gas emissions from the production of a material or product, or associated with an activity or process. GHG accounting typically takes into account six GHG’s: carbon dioxide (CO_2), methane (CH_4), sulfur hexafluoride (SF_6), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), and perfluorocarbons (PFCs). To compare the impacts of multiple greenhouses gasses, carbon footprint assessments convert the calculated emissions for each GHG into a carbon dioxide equivalent (CO_2-eq). Unlike LCAs carbon footprint assessments consider environmental impacts through one lens only, climate change from GHG emissions. Carbon footprint assessments can be considered a subset of a LCA.

Defined international standards for greenhouse gas (GHG) accounting and reporting include:

- International Organization for Standardization (ISO) 14064: standard for the GHG quantification and reporting at the organization level;
- ISO/TS 14067: standard for the GHG quantification and reporting of a product;
- British Standards Institution (BSI) Publically Available Specification (PAS) 2050: standard for GHG quantification of a product;
- World Resources Institute (WRI) GHG Protocol: standard for the GHG quantification and reporting at the business and government level; and,
- WRI GHG Protocol Product Standard: standard for the GHG quantification and reporting of a product.

In order to calculate GHG emissions, sources of GHG must be identified. GHG emission sources are generally categorized into three scopes:

Scope 1: Direct sources – GHG emissions from sources that are owned or controlled by a company / organization (i.e. GHG emissions from onsite fuel combustion, company owned vehicles).

Scope 2: Energy indirect sources – GHG emissions from the generation of electricity purchased and consumed by a company / organization.

Scope 3: Other indirect sources – GHG emissions resulting from activities of a company / organization not from sources owned or controlled by the company / organization (i.e. business travel, purchased materials etc.).

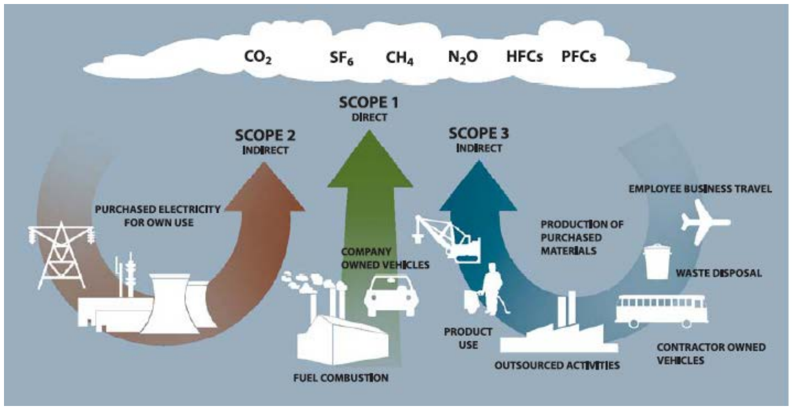

Figure 2 - Three Scopes of GHG Emissions (graphic from wri.org)

3.1 Methodology

3.1.1 Scope

Defining the boundary of the project is a critical step in determining which GHGs to account for in a carbon footprint assessment. The project boundaries of the Kanata LRT study included within the carbon footprint assessment were limited to material impacts of the stations, railways, elevated platforms, and parking lots through the entire life cycle of these systems. The project boundaries did not include the trains, train energy, station energy, parking lot lighting, corridor planting, bridges, or other tertiary systems.

The Kanata LRT carbon footprint assessment considered only scope 3 emissions limited to the carbon footprint of materials (embodied impacts). Scope included LRT materials and construction but did not account for GHG emissions associated with LRT operation nor did it include the effects of avoided travel due to the presence of the LRT.

3.1.2 Baseline

Ideally a baseline comparison would be helpful to understand the magnitude of the impact and the potential improvements. This baseline could be a comparable operational system such as "business as usual" or the use of a diesel bus rapid transit system instead of electrified light rail. However, to include a meaningful baseline one would need to expand the project boundaries and make many assumptions such as ridership, vehicle efficiency over time, and population growth. These types of assumptions were beyond the scope of this project, as such this assessment was limited to reporting the results as mass of CO_2e for the project construction.

3.1.3 Athena

Athena software was used to conduct the Kanata LRT carbon footprint assessment. Athena software and data is developed by the Athena Sustainable Materials Institute. The Athena suite of software is ISO 14040 and 14044 compliant and specifically designed for conducting LCAs of construction projects within North America. Athena software and life cycle data inventories provide information for assessing the environmental effects of building materials, products and transportation from the construction and operating phases of a project to the demolition and disposal phases.

Two software tools from Athena were utilized:

Impact Estimator (IE) for Buildings: This whole-building tool can be used to explore the environmental footprint of different material choices and core-and-shell system options. It was first released in 2002 and has undergone numerous updates since then. The IE for Buildings was developed in collaboration with Morrison Hershfield. The Athena Impact Estimator is applicable for new construction, renovations and additions in all North American building types. It can model over 1,200 structural and envelope assembly combinations. The Impact Estimator provides a cradle-to-grave life cycle inventory profile for a whole building. The inventory results comprise the flows from and to nature: energy and raw material flows plus emissions to air, water and land. The software reports footprint data for the following environmental impact measures consistent with the latest US Environmental Protection Agency (EPA) Tool for Reduction and Assessment of Chemicals and other Environmental Impacts (TRACI) methodology: global warming potential, acidification potential, human health respiratory effects potential, ozone depletion potential, smog potential, and eutrophication potential. The Impact Estimator additionally reports fossil fuel consumption. However as noted above, GHG emissions assessment is the sole focus of this report. The software is regionally customized—appropriate electricity grids, transportation modes and distances, and product manufacturing technologies are applied depending on the building location. The Impact Estimator takes into account the environmental impacts of the following life cycle stages: material manufacturing, including resource extraction and recycled content; related transportation; on-site construction; maintenance and replacement effects; and demolition and disposal. Note that for this application maintenance and replacement effects of the building were included, as they are integral to the software, but maintenance and replacement effects of the rail system material were ignored.

Pavement LCA: This is a web based tool that provides environmental life cycle assessment (LCA) and Life Cycle Cost Analysis (LCCA) results for

Canadian regional materials manufacturing, roadway construction and maintenance life cycle stages. It allows users to enter custom roadway designs, or draw on a library of over 48 existing Canadian roadway designs. Pavement LCA reports results for the following environmental impact measures consistent with the US EPA TRACI methodology: global warming potential, acidification potential, human health, particulate, ozone depletion potential, smog potential, and eutrophication potential. Pavement LCA additionally reports various resource uses such as primary energy and water, and emissions to air, water, and land.

3.1.4 Assumptions

A number of assumptions were necessary to perform the carbon footprint exercise. These assumptions were necessary primarily because the system and component design is not at a level of detail needed to accurately calculate material quantities. Assumptions were informed by input from the engineering team that developed the recommended plan for the Kanata LRT.

Stations:

- Stations are assumed to be identical to the Kanata LRT station shown below.

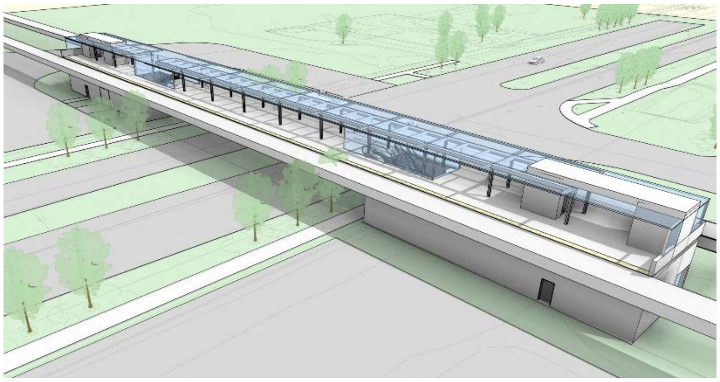

Figure 3 - Kanata LRT Station Design

- No information regarding footings was provided, as such, we have assumed that there is a typical footing below the lower levels with no below grade levels.
- Superstructure bay sizes are assumed to be identical at all stations.
- Number of superstructure columns and beams were estimated from the design rendering.
- Column and beams are assumed to be wide flange beams (WF).
- Interior walls on the lower level and elevator area are assumed to be concrete block with reinforcement.

- The roof is modeled as double glazed curtain wall, as the building rendering shows a glass canopy.

- Glass at the top of the escalators on the platform is assumed to be curtain wall.

- Building cladding is not indicated, as such we have assumed the exterior side of concrete block is assumed to have a metal panel system installed.

- No insulation has been included as the stations as they are assumed to be mostly open air systems with no envelope enclosure.

Elevated Platforms

Elevated platform materials were estimated from available renderings and sections. A typical sections is shown below:

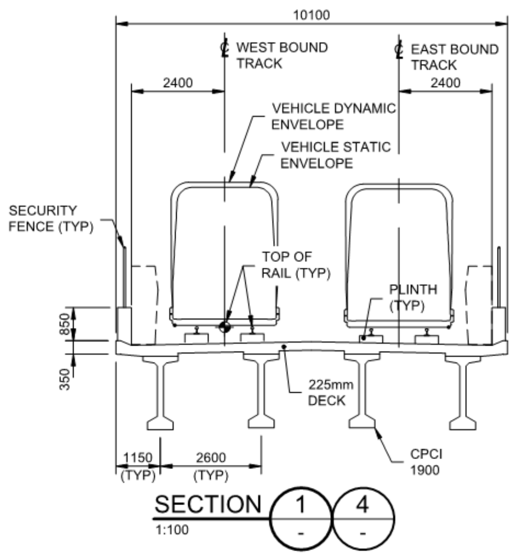

Figure 4 - Typical Elevated Platform Section

Assumptions include:

- Spacing of piers is 37 m.

- Two rows of piers run along the track.

- Elevated platform total length is 3000 m.

- Piers are assumed to be round with a radius of 0.9 m and a height of 9m.

- Pier caps assumed to be 29 m3 of concrete per pier.

- Piles: 36H piles = 54kg/m, assume 20 m long, assume 2 piles per pier.

- Steel content of concrete assumed to be 120 kg/m3.

- Precast Girders: CPCI girders, 4 in parallel (12,000 m total length).
- Due to lack of data, no maintenance or replacement information was used in the analysis of the elevated platforms.

Parking Lots

No drawings or renderings were provided regarding the paving. As such it was assumed that the parking lots will be typical asphalt paving, as shown below:

- Surface Course (asphalt): 50mm.
- Granular A: 150mm.
- Granular B: 300mm.
- Assumed that three new areas will be paved:
    - Bus Terminal and PPUDO west of Huntmar Drive: approx. 7500m2.
    - Hazeldean Parking Lot: 36500m^2.
- Palladium Park and Ride: to be expanded, the size is still to be determined, as such it was excluded from this analysis.
- Due to lack of data, no maintenance or replacement information was used in the analysis of the parking lots.

Rail Systems

Details were not available regarding the rail systems. As such the following assumptions were made:

- Assumed one rail system in each direction (4 steel rails) with a mass of 70 kg/m / rail.
- Rail system is assumed to be supported on a continuous reinforced concrete slab, 3 m wide and 800 mm thick. Other supporting and subgrade materials were ignored.
- Due to lack of data, no maintenance or replacement information was used in the analysis of the rail systems.

4. CARBON FOOTPRINT ASSESSMENT

The carbon footprint assessment was conducted with input from a broad base of expertise and professional experience obtained during two half-day working meetings facilitated by Morrison Hershfield with the study team and City of Ottawa staff. Key highlights from these workshops are presented below.

4.1 City Meeting #1

During the first working meeting, participants were introduced to the Kanata LRT EA scope and recommended design and presented with the methodology selected for the carbon footprint assessment. Participants were invited to ask questions and provide feedback on the project definition / project boundaries, and scope of the carbon footprint assessment. Refer to **Appendix A** for the contents of the presentation.

Throughout the presentation, participants provided valuable feedback for the study team's consideration. The following is a brief list summarizing key comments received:

- The group discussed whether the carbon footprint assessment could integrate information from previous studies / use past information, including carbon footprint estimates for the first two stages of Ottawa LRT.
- The group discussed GHG accounting and ownership of emissions.
- Various baseline scenarios were discussed as the group worked to determine what would be the most useful comparison of existing to future conditions.
- The group discussed the difficulty in striking a balance between climate change mitigation measures and cost, and ways in which these measures can be incorporated in decision-making.

The full meeting minutes are located in **Appendix B**.

Following Meeting #1, the feedback received was considered by the study team. Wherever feasible and valuable to the assessment, additional data gathering and review was completed to address comments received during the working meeting.

4.2 City Meeting #2

During the second City working meeting, the study team updated participants on the material presented during Meeting #1 as well as the preliminary conclusions and recommendations drawn from the carbon footprint assessment process. The presentation, the contents of which are included in **Appendix C**, summarized the results of a LCA on one station, a parking lot and the rail system.

Once more, participants were invited to participate in a discussion on the study's findings and limitations. Key points of discussion included:

- There is a need for emission reduction measures to be cost effective in order to be considered.
- Material choice will have the largest impact on the embodied footprint of the LRT. An increased use of fly ash in concrete is one possible way to reduce emissions.
- A group discussion on what carbon footprint can be attributed to operation of the LRT stations (i.e. through heating and cooling). The study team explained that stations would be largely open to the elements with little requirement for heating and cooling aside from small rooms with critical systems.
- When asked whether LRT stations and maintenance storage facilities would be LEED certified, the study team explained that they likely would not meet the minimum requirements and therefore would not be suitable for LEED certification.

The full meeting minutes are located in **Appendix D**.

4.3 Summary of Carbon Footprint Assessment

The carbon footprint of the various assemblies as listed in section 2.1 are presented in the table and graphic below:

Table 1 - Global Warming Potential Tonnes CO_2e for Kanata LRT

	Raised Platforms	**Parking**	**Buildings**	**Rails**	**Total**
Global Warming Potential ($T\ CO_2e$)	13800	3666	3500	8300	29266

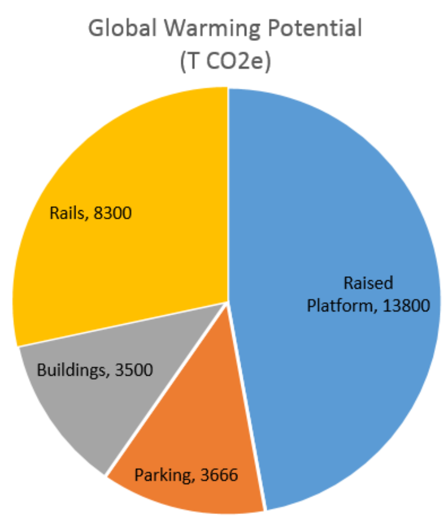

Figure 5 - Global Warming Potential Tonnes CO_2e for Kanata LRT

The total embodied carbon footprint of the project is estimated at approximately 30,000 T CO_2e. As not all project elements were included in the assessment may be somewhat of an underestimate.

For perspective, a typical car in Canada produces about 4.6 T CO_2e per year. Accordingly, the embodied effects of the systems studied equal the use of about 6000 cars for one year.

As previously mentioned, the GHG reductions that will be achieved over the lifespan of the Kanata LRT by the switch from diesel buses and the modal shift from private vehicles to electric rail far outweighs the embodied carbon footprint of the Kanata LRT. It is worth noting that both Stages 1 and 2 of the Ottawa LRT have estimated yearly GHG reductions greater than the total embodied carbon footprint of the Kanata LRT. In *Transforming Our Nation's Capital – The Benefits of Light Rail*, the GHG emissions reduction achieved by the first Stage of Ottawa LRT is estimated be 94,000 tons, yearly. In the *Stage 2 Ottawa LRT Business Case*, yearly reductions were estimated at 155,000 tons of GHG emissions.

5. CONCLUSION / ADDITIONAL STUDY

From the above results, it can be seen that the raised platform seems to be the largest contributor to the carbon footprint, but each of the systems reviewed were significant contributors. Further, the amounts are large enough that it would be worthwhile to make efforts to minimize embodied effects. However, as the CO_2 reductions associated with the function of the LRT system, such as reductions of single occupant vehicle and diesel bus use, would far outweigh the embodied effects, it is suggested that the function of the system should not be reduced in any way simply to reduce embodied impacts.

5.1 Carbon Footprint Mitigation Measures

Embodied impact reductions can be achieved by material substitutions, system substitutions, material ingredients, and a focus on durability. There are numerous opportunities that can be investigated during the design and construction phases of the project that would result in embodied effects reductions without sacrificing performance.

The use of cement in concrete is one example of a possible material substitution. Cement production results in approximately 5% of global CO_2 emissions. Its production releases greenhouse gases both from the process of calcination, whereby limestone is heated in a kiln, releasing CO_2 directly, and from the combustion of fossil fuels required to heat the kiln. The cement industry has been developing various innovative measures to reduce emissions from both of these sources, such as switching to alternative fuels that are less carbon-intensive, replacing some of the limestone with recycled fly ash, or employing carbon capture and storage. One Canadian company, CarbonCure Technologies, has developed a process by which captured CO_2 is injected into concrete to replace a small amount of cement, effectively storing the carbon as limestone, without compromising the concrete's strength. Others are developing low-cement or cement-free concrete products, such as Cemfree. Specifying low-carbon concrete where suitable during detailed design could play a significant role in reducing the embodied carbon footprint of the project. Use of locally sourced materials or recycled materials such as recycled metals, are other examples of material substitutions that could reduce emissions during construction. Ultimately, however, it is the carbon that matters, and it is critical to understand the carbon impact when making decisions on materials, rather than relying on less accurate indicators such as recycled content, regionality, etc.

It's important to keep durability and practicality of design at the forefront when evaluating various climate change mitigation measures. Materials with low up-front carbon footprint but reduced longevity or frequent maintenance needs could have a higher footprint when considering their entire lifecycle. In addition to embodied emissions resulting from earlier repairs to or replacements of less durable system components, repairs that require suspension of LRT service would temporarily negate GHG reductions achieved from the shift to electric rail. Similarly, if service interruptions became frequent, this could affect the perceived reliability of the system and impact ridership numbers.

Another important contributor to emissions related to the construction of the LRT system is the fuel consumption of construction equipment. In other light rail projects, such as the Sydney LRT, these emissions accounted for up to 25% of construction emissions (materials, for comparison, accounted for another 71%). Implementing low-carbon work practices where suitable, such as the use of low-carbon fuels in vehicles and equipment, use of fuel-efficient or electric equipment, as well as regular maintenance and inspection of equipment will help further optimize fuel efficiency and reduce construction emissions. Furthermore shifting use of energy efficient vehicles to higher intensity tasks and less efficient vehicles to lower intensity tasks can reduce the emissions associated with the construction equipment.

5.2 Additional Study

It is proposed that design teams are mandated to understand and reduce embodied effects through comparisons of proposed materials and systems as the design progresses. More specifically we would suggest that the Athena suite of tools (or similar) be mandated for use by the design team, and that they be requested to present the carbon footprint of an early design and encouraged to consider reductions to the base design with alternative scenarios. As the pursuit of lower carbon materials could impact function, we do not suggest a percent reduction be mandated, only that reductions are encouraged, and that the process to consider reductions is mandated.

Other strategies could also be encouraged or mandated to reduce the embodied effects, such as:

- Purchasing electrical energy derived from a renewable energy source or carbon offsets.
- Adopting energy efficient work practices. These might include items such as lights-off practices, vehicle idling requirements, etc. These could include mandatory items such as planning and training.
- Material avoidance practices, such as paperless offices, packing material substitutions or eliminations.
- Mandatory monitoring, auditing and reporting on energy, resource use and associated greenhouse gas emissions could also be considered.

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APPENDIX A: City of Ottawa Meeting # 1 Presentation

APPENDIX B: City of Ottawa Meeting #1 Minutes

APPENDIX C: City of Ottawa Meeting #2 Presentation

APPENDIX D: City of Ottawa Meeting #2 Minutes