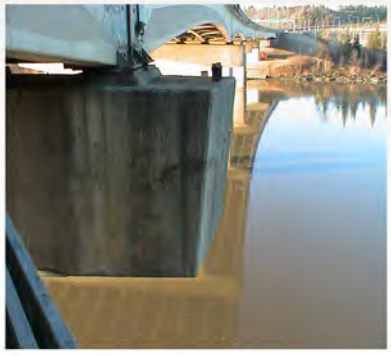

Adapting to Climate Change

Canada's First National Engineering Vulnerability Assessment

of

Public Infrastructure

April 2008

Appendix A
Case Studies Summaries

Canada

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Appendix A

Case Study Summaries

Appendix A

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1 City of Portage la Prairie – Water Resources Infrastructure Assessment

1.1 Background

The Public Infrastructure Engineering Vulnerability Committee (PIEVC) has identified water resources infrastructure vulnerability as one of four priority areas for review within the first national engineering assessment of Canadian public infrastructure vulnerability to changing climatic conditions. The City of Portage la Prairie water works system and the drinking water treatment plant served as:

- a case study to apply PIEVC's Process and Engineering Protocol to water resources infrastructure; and
- pilot study to refine the parameters of the PIEVC's Process and Engineering Protocol.

PIEVC contracted Genivar and TetrES Consultants to lead a study team and to conduct the step-by-step vulnerability assessment based on PIEVC's Process and Engineering Protocol. OURANOS, a Montreal-based consortium, developed regional climate information and scenarios for the case study. (Historic incident data compiled by the City of Portage La Prairie were also used.)

1.2 Where, What and How

This case study focuses on the water works system and the drinking water treatment plant in the City of Portage la Prairie. The community of 13,000, located 100 kilometres west of Winnipeg, Manitoba, draws raw water from the Shellmouth Reservoir located Assiniboine River. The river is subject to large annual and seasonal variations in flow and turbidity, and can be vulnerable to drought. The Assiniboine is linked

Figure A-1 Location of Portage La Prairie

to water-control infrastructure to lessen flooding between Portage la Prairie and Winnipeg. Portage la Prairie experiences wide seasonal temperature extremes (sometime below -40ºC n winter and close to +40ºC in summer).

In addition to the City of Portage la Prairie, the water works system with its capacity of 34 million litres a day, also serves as a regional water system for residents in the rural municipalities of Portage la Prairie and Grey. Two large potato-processing plants use more than half of the water treated by the plant. Originally built in the 1970s, the Portage la Prairie water treatment facilities underwent major upgrades in 2004. The standard life span of a treatment facility is 30 years, while the distribution and larger controls structures have anticipated time frames of 80 to100 years.

A total of 25 PIEVC and affiliated stakeholders participated in a workshop and plant tour to review and provide input on applying the Protocol to the Portage la Prairie infrastructure.
The PIEVC Protocol was used to assess the degree to which the Portage la Prairie water and related infrastructure are vulnerable to climate-change-related events. That included identifying anticipated adverse climatic effects and then assigning probabilities of their anticipated severity (from negligible or not applicable, to certain/highly probable) on specific aspects of the water resources infrastructure. Numerical values assigned based on the severity of the impact, allowed prioritizing of the recommendations according to whether:

- remedial action is required to upgrade the infrastructure;
- management action is required to account for changes in the infrastructure;
- no further action is required; and
- additional data and study are required.

1.3 Technical Summary

This case study used the following probability scale (Method A in the PIEVC Protocol) when assessing the vulnerability or likelihood of an effect on infrastructure components due to climate change.

Scale	Probability
0	**Negligible or not applicable**
1	**Improbable/highly unlikely**
2	**Remote**
3	**Occasional**
4	**Moderate/possible**
5	**Often**
6	**Probable**
7	**Certain/highly probable**

The PIECV Protocol and climatic data were applied to the following Portage la Prairie infrastructure components: personnel, facilities/equipment; Shellmouth Dam/Reservoir;
the Assiniboine River system; pre-treatment; softening; storage; valves/pipelines (water treatment plant site); pump stations; pipelines and valves; substations/transformers; standby generation; vehicles; maintenance facilities; supplies; roadway infrastructure; telephones and telemetry. Individual infrastructure components were matched to the following climatic variables: floods; ice jamming, ice build-up; ice storms, high temperatures, drought; intense wind/tornadoes and hail.
Consideration of the infrastructure components in combination with the climatic variables
and the assigned numerical values allow decisions on whether:

Figure A- 2 Shellmouth Dam

- vulnerability exists – when total load exceeds the infrastructure's total capacity; and
- adaptive capacity exists – when total load is less than the infrastructure's total capacity.

None of the assessments of infrastructure components or climatic variables resulted in a probability rating greater than 3 (occasional). Using Step 4 (Qualitative Evaluation) of the PIEVC Protocol, led to recommendations for:

- Remedial action
- Management action
- No further action
- Additional study required

(See Policy Makers Executive Summary for more details on the recommendations.)

1.4 Policy Makers' Executive Summary

The case study points out factors that leave components of Portage la Prairie's water infrastructure potentially sensitive to climate change. Where climate change places demands in excess of infrastructure capacity, the system is vulnerable and action is required. Where climate-changes result in loads upon infrastructure that are less than capacity, adaptive capacity exists in the system and action is not required.

These principles are applied in the key PIEVC findings and professional judgement, as well as the recommendations relating to aspects of Portage la Prairie's water infrastructure summarized below.

Administration/ Operations

City Personnel

Although possibly vulnerable to floods, ice-related jams and backups, and storms, city staff can adapt without further action. Review of emergency preparedness for intense wind and tornadoes is recommended.

Facilities/Equipment

High temperatures; floods; ice-related jams, backups and storms; intense winds and tornadoes could impact water treatment and equipment. However, based on climate projection to 2080, which is beyond the current equipment's projected life (30 years), no action is required to deal with high temperatures.

Management action is suggested to review the City's protection response to floods, ice jams and build-up, coupled with remedial action, as required. Similar readiness recommendations apply to windstorms and tornadoes, and ice storms – including installing full standby/backup power.

Source Water

Shellmouth Dam/Reservoir

Based on engineering judgement, The Shellmouth Dam/Reservoir is assumed to be a critical point requiring further study. The Assiniboine River presents vulnerabilities due to drought as well as flooding and ice build-up. Cooperation with the province is urged to assess vulnerability relating to the Assiniboine and Portage Rivers.

Control Dam Structure

The control dam serving the water infrastructure should be reviewed in terms of flooding and any further needed actions taken.

Intake Wells and Pumps

The dam's intake wells and pumps are also vulnerable and action plans are needed to deal with flooding and to remedy ice blockages. Working with the Province of Manitoba, the City should review watershed effects, including drought, related to climate change.

Figure A-3 Chemical mixer

Water Treatment

Pretreatment

Relative to pretreatment (Actiflo) of water, no action is recommended in response to high temperature variables or to floods, ice jams or ice-build-ups. The anticipated range of water-quality changes are within the limits of current seasonal variations. However, engineering judgement suggests the pre-treatment is very highly vulnerable in the event of drought. The City should request further study by the Province of climate-change effects on the Assiniboine watershed.

Softening/Clarification

High temperatures due to variable climate are not expected to exceed seasonal spikes. No action is recommended for the existing softening/clarification equipment.

Storage

Treated-water storage may be vulnerable to drought. More study, with provincial involvement, of the watershed is suggested.

Chemical Storage/Hazardous Material

One-site chemical and hazardous material storage could become vulnerable due to floods, ice-related jams and build-ups, intense winds and tornadoes. Management action – and where the infrastructure is highly vulnerable – remedial action is suggested to protect bulk chemical and other storage, and to guard against flooding. The City should review emergency preparedness for intense winds and tornadoes.

Treatment Plan Valves/Pipelines

Based on engineering judgement, no action is suggested for valves and pipelines in response to floods, ice jams and ice build-up.

Distribution

Pumping Stations

Further study is recommended on the vulnerability of the water treatment plant's pumping stations to high temperatures, floods, ice jams and build-up, intense winds and tornadoes. This should include City review of flood protection and, where there is high

vulnerability, carrying out remedial works. The City should review emergency preparedness for intense wind and tornadoes. Given projected temperature variances and the current pumping equipment's projected life, no action is needed to deal with higher temperatures associated with climate change.

Pipelines and Valves

Based on engineering judgement, it is assumed that the distribution system's pipeline and valve infrastructure has the ability withstand flooding and ice-related events.

Electrical Power

Substations/ Transformers

The water plant and pumping stations rely on substations and transformers to supply power. It is assumed that these facilities are adequately flood-proofed but this should be confirmed through added study. Remedial action is suggested for ice storms – including installing full-standby power for the treatment plant. In response to vulnerability to intense wind or tornadoes, cooperation with Manitoba Hydro is recommended to bury transmission lines.

Standby Generators

The vulnerability of existing standby generators to floods, ice jams and ice build-up is not expected to increase. This should be confirmed through additional study. No action is required on standby generators in response to high temperature climate variables.
Ice storms require more study – including their frequency and the need for standby power in such situations. Climate changes related to extreme winds and tornadoes could raise vulnerability and need for backup power. The City should review its emergency preparedness and work with Manitoba Hydro to bury power lines where possible.

Transmission Lines

Transmission lines are vulnerable to ice storms and remedial action is recommended as is a review of City preparedness in ice storms and installing full standby power at the water treatment plant.

Figure A-4 Shellmouth Dam in relation to Portage la Prairie

Transportation

Service Vehicles

Ice storms, hail, intense wind and tornadoes could impact City service

vehicles. Additional study is recommended to determine the frequency of ice storms. Review of emergency preparedness for intense winds and tornadoes is recommended to ensure vehicles are operational. Vulnerability of service vehicles due to hail is low but projections are not available regarding hail and more information is needed.

Maintenance Facilities

More information is needed on the frequency of ice storms and how they affect maintenance facilities. Management action is suggested to review emergency preparedness for intense wind and tornadoes to ensure operation and protection of infrastructure**.**

Supplies

More study is required on frequency of ice storm and impact on supplies. A City review of emergency preparedness should include needs in the event of tornadoes. Consider backup and alternative supply sources.

Roadway Infrastructure

Study is needed of roadway infrastructure to determine the impact of floods, ice dams and ice build-up. Based on available evidence, it is not expected that in the case of the Portage la Prairie water facilities that roadway infrastructure is more vulnerable due to climate change. However, the greater vulnerability exists due to intense winds and tornadoes. A City review of emergency preparedness should consider alternative means to access critical infrastructure.

Communications

Telephone and Telemetry

Telephones and telemetry are vulnerable to ice storms, hail, intense winds and tornadoes. More study is needed to determine ice storm frequency. More information is need on hail, although the vulnerability of telephone networks to hail is low. Climate change could cause greater vulnerability to intense wind and tornadoes. The City should review preparedness and consider burying telephone lines where possible and having back-up wireless communication.

1.5 Pilot Study Comment

Besides providing a case study of the PIEVC Protocol relative to water resources infrastructure vulnerability, the Portage la Prairie assessment also served a pilot study of the general applicability of the PIEVC's Process and the Protocol. Observations and

suggestions arising from the Portage la Prairie study for fine-tuning the Process and Protocol included:

- Potential absence of necessary weather data, including about extreme weather events. Incomplete weather data may render speculative the results of assessments made using the PIEVC Protocol.
- Gathering and processing necessary weather data may take longer than anticipated.
- Recording results about infrastructure and climate events on matrices proved simpler than using the worksheets initially developed for the PIEVC Protocol.

It is important to clarify that probabilities DO NOT relate to the probability of weather events occurring but rather to the probability of weather events affecting the infrastructure.

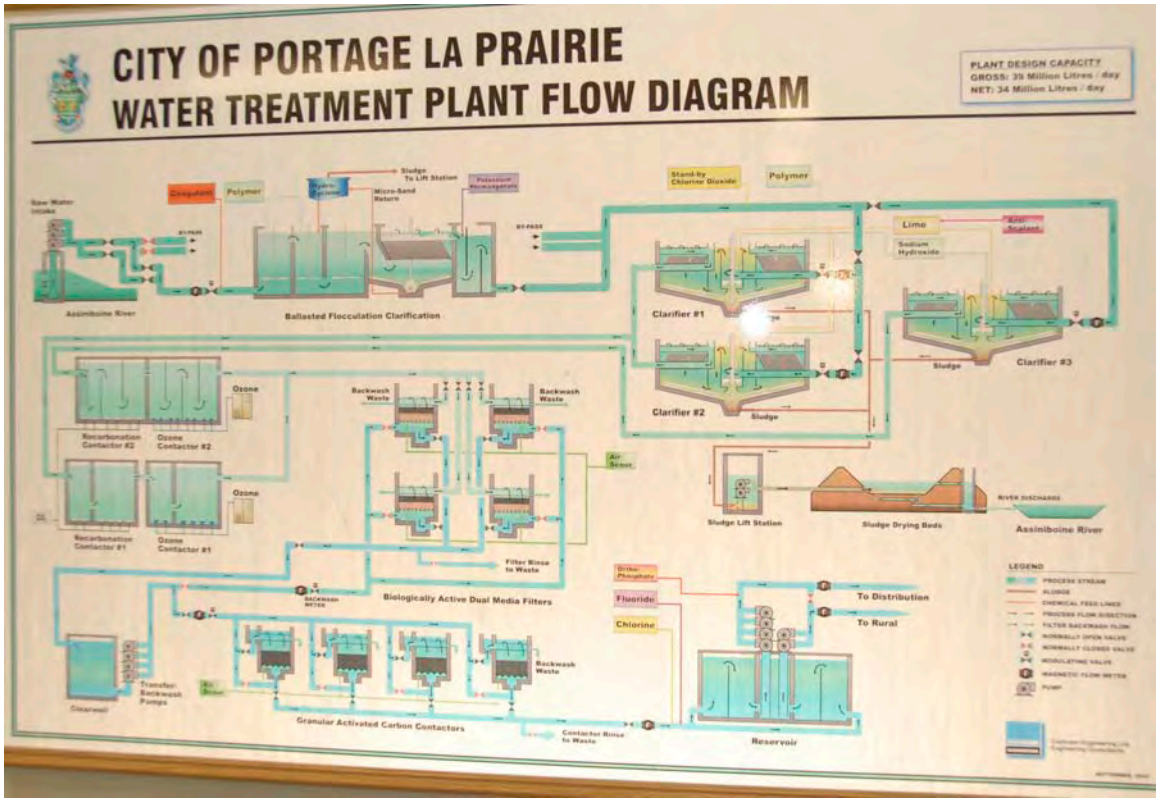

Figure A- 5 Water Treatment flow diagram

2 Town of Placentia, Newfoundland, Water Resources Infrastructure

Figure A- 6 Town of Placentia, Newfoundland

2.1 Background

Water resources infrastructure vulnerability was one of four priority areas selected for review as part of the First National Engineering Vulnerability Assessment.

The Town of Placentia, Newfoundland, was chosen as the focus for one of the two water-resources case studies.

This case study centers on four pieces of infrastructure in the Town of Placentia, located on Newfoundland's Avalon Peninsula and on the east coast of Placentia Bay. The community encompasses Dunville, which forms the northwestern section of the town and is connected to downtown by a lift bridge. The Placentia area is subject to frequent storms, which have caused serious flooding in low-lying locations.

Specific infrastructures assessed were a breakwater, a steel floodwall, a stretch of highway and related culvert systems, and a building within the flood plain in downtown Placentia.

This case study provides a useful snapshot of engineering and municipal considerations presented by the prospect of rising sea levels and other factors associated with climate change.

Cameron Consulting Incorporated of Halifax, Nova Scotia, and AMEC Earth & Environmental (a Division of AMEC Americas Limited) of St. John's, Newfoundland, prepared the report for PIEVC and Newfoundland and Labrador Environment and Conservation. Data gathering for the case resulted from site visits, teleconferences, a workshop as well as through information provided by the Newfoundland and Labrador departments of Transportation and Works; Municipal Affairs; Environment and Conservation, and the Town of Placentia. OURANOS supplied climate-change modeling data.

2.2 Where, What and How

Located in southeast Newfoundland, about 100 km southwest of St John's, the historic Town of Placentia lies on the east side of Placentia Bay. The bay is bounded by the Burin Peninsula to the west and the Avalon Peninsula to the east.

With a current population of about 4,000, Placentia was first settled early in the 17th century. Fishery has been a traditional mainstay but the economy also benefited, starting in the Second World War, from the nearby but now-closed U.S. Armed Forces Northwest Atlantic Operations. The Newfoundland ferry terminal of Argentia–North Sydney, operated by Marine Atlantic Inc., is in the area.

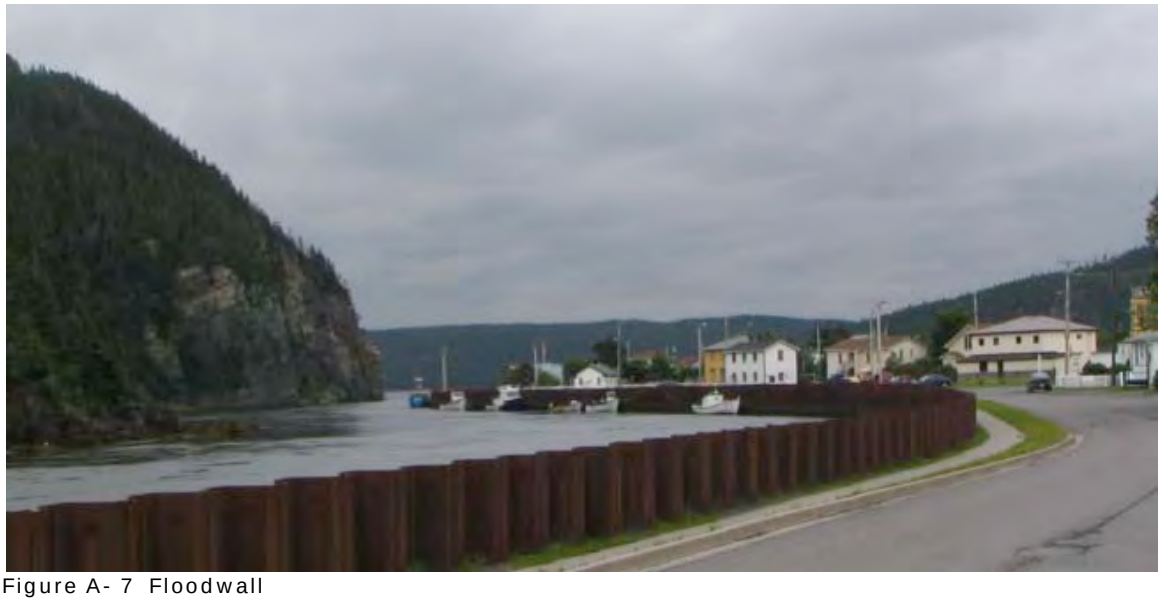

Figure A- 7 Floodwall

Placentia Bay has an abundant and diverse marine ecosystem and is considered an environmentally sensitive area. The region is the site of present and planned petroleum refineries as well the proposed locale for processing ore from the Voisey's Bay nickel-

copper-cobalt deposit. Its low-lying location on a flood plain adjacent to the sea has contributed to the town historically having to deal with serious flooding. In response to this threat, two pieces of infrastructure were built to hold back seawater. A stone and timber breakwater – begun in the 1960s and extended in the 1990s – was built. To prevent flooding by water diverted by the breakwater, a sheet-steel pile floodwall was constructed in 1993 along the inside (northeast) face of the downtown peninsula.

This case study reviews both the breakwater and the floodwall. Two other infrastructure elements of the case study are:

- the Town Hall located in Placentia's downtown floodplain; and
- the main coast highway, along with related culverts, where it runs through the Dunville area of Placentia. (Dunville is linked to the downtown by a lift bridge.)

For this case study, key climate-change considerations are sea level rise, wind-assisted surge waves and intense rainfall events with resulting runoff. Besides causing flooding, such phenomena can increase possibilities of erosion.

Figure A- 9 Breakwater

Placentia-area infrastructure located in low-lying sites in communities and along roadways is vulnerable to flooding. For example, in August 2007, heavy rain from the post-tropical storm Chantal washed out bridges and submerged roads, basements and parking lots. One road collapsed under a car's weight when a culvert beneath the pavement washed away, creating a gap six meters wide and six meters deep. In 2007, Dunville experienced flooding related to Chantal but downtown Placentia escaped flooding.

Eastern Newfoundland's climate is mid-boreal, marked by cool summers and winters. Communities fringing Placentia Bay, like Newfoundland and Labrador in general, currently are subject to a wide range of climatic events, including mid-latitude storms, hurricanes and tropical storms, snowfall and frost, plus summer drought. Recent trends suggest that such events are becoming more frequent and intense.

The need to understand and adapt to changes in the coastal environment is becoming increasingly clear. Most of Atlantic Canada, for example, has experienced a rising sea level for thousands of years and further rises in sea levels are anticipated due to climate change.

2.3 Technical Summary

Climate Modeling

Portions of the Town of Placentia, including those behind the breakwater and the floodwall, now lie at sea level (0m). This is an important consideration relative to future climate-change scenarios.

Data from two climate simulations provided by OURANOS, the climate research and development consortium, target the year 2050.

Climate-change projections for 2050 assume Placentia will face:

- Mean rise in sea level of 0.15m from 0m at present;
- Wind-assisted storm waves (surge waves), whose elevation will vary depending on the affected infrastructure (0.25m for breakwater and for the floodwall); and
- 12% increase in the rainfall intensity.

This means that at the breakwater and the floodwall, when sea-rise increases are combined with a potential storm surge, the total anticipated rise would amount to 0.4m.

At the breakwater, currently the potential exists for of a surge wave of 7m or about 1.2m higher than the breakwater. Similarly, at present along the floodwall, the potential exists for a surge wave of 5 to 5.25m or about 3m higher than the current top of the floodwall.

The increased rainfall intensity is anticipated temporarily but repeatedly to elevate the groundwater table elevation by 0.45m, from 0m.

It is also noted that data records indicate that the temperature pattern in Newfoundland does not follow the general trend of the interior of North America. While the areas may be subject to climate variability currently occurring in Atlantic Canada, no statistically significant long-term warming trend is observed in the Avalon Peninsula. Though climate warming may not be directly evident in eastern Newfoundland at present, global warming trends will impact the sea level along Newfoundland's coast.

Climate-model projections, provided by OURANOS, forecast little anticipated change in wind intensities at Placentia by 2050.

Other Influencing Factors

The North Atlantic Oscillation (NAO) could influence projected increases in rainfall intensity in Newfoundland. The NAO results from cyclic variations in the pressure regimes produced by differences in atmospheric pressure regimes in the Atlantic Ocean. Changes in these relationships can produce differing weather patterns manifested by cyclical changes in temperature, wind, precipitation, sea ice and snow cover.

Scientific literature included with the case study suggests that sea-level changes also can involve complex interplay of factors that include:

- Melting polar glaciers; and
- Gradual rebounding or rising of land as glacier disappear.

Studies have also noted that, depending on the localized geographic features factors and tide pattern, the impact of sea-level change can vary considerably even among geographically adjacent locations.

Performance Measures

The impact of climate changes, including hydrological alterations, were assessed for the four Placentia infrastructure components. The assessment took into account the following performance measures:

- Strength;
- Capacity;
- Stability;
- Maintenance, operations and monitoring;
- Emergency planning;
- Property protection (insurance);
- Policy and procedures; and
- Lifecycle planning.

Main Breakwater

The breakwater is owned by the Town of Placentia and located along the west side of the main community, including the downtown area. The breakwater is constructed from stone, used creosoted railway ties, and pressure-treated wood in one portion. A boardwalk runs along the top. The breakwater, which receives continuous wave action, runs parallel to the main beach along Beach Road and forms the western limit of development for the downtown peninsula section of the Town of Placentia. The breakwater deflects storm surge seawater along the perimeter of the downtown peninsula. The typical top elevation of the breakwater is 5.8m and under normal conditions the top of the breakwater is between 2 and 4m above beach sediment on the seaward side.

For the main breakwater, the climate factors of interest are:

- Sea-level elevation change;
- Storm surge seawater elevation change (associated with wind speed).

A catastrophic failure of the breakwater would flood portions of downtown Placentia. Although spray and slush have reached the adjacent road, to date the breakwater has prevented flooding.

According to the consultants, insufficient human, equipment, time, opportunity and financial resources are being directed toward the breakwater. Based on the defined performance measures, specific recommendations are made to deal with:

- Strength;
- Capacity;
- Maintenance, operations; monitoring – including for sediment and erosion; and
- Lifecycle planning.

For other performance measures, sufficient adaptive capacity exists.

Steel Sheet Pile Floodwall

The steel sheet pile floodwall was constructed in 1993 along the back of the peninsula (northeast) of the newer portion of the Town of Placentia. The floodwall is build at a location where the geodetic elevation is 0m and typical tide (1992) is 1.2m under calm conditions. The infrastructure runs parallel to and between the main beach and a road.

The top elevation is 2.2m at typical sections of the floodwall, which has been effective in conveying the deflected storm-surge water away from the town.

For the floodwall, climate factors of interest are:

- Sea-level elevation change;
- Storm-surge sea water elevation change (associated with wind speed).

Catastrophic failure of the floodwall would flood much of downtown Placentia Bay. According to the consultants, insufficient human equipment time, opportunity and financial resources are being directed to the floodwall. Based on the defined performance measures, specific recommendations are made to deal with:

- Capacity;
- Maintenance, operations and monitoring;
- Lifecycle planning; and
- Strength.

For other performance measures, sufficient adaptive capacity exists.

It is noted that insufficient information is available but the potential does exist for a wave up to 5m high, or about 3m higher than top of the floodwall rolling up against it. Given the potential that already exists for a large wave to pass over the top of the floodwall, an additional increase of 10% in the level of wave water resulting from climate change is not considered an unacceptable threat to the performance of the floodwall.

Corrosion represents the most likely challenge to the floodwall's integrity (the town has proposed a $300,000 cathodic protection system).

Town Hall in Flood Plain – Town of Placentia

The Town Hall is used as representative of buildings located in the floodplain in downtown Placentia, an area of potential flooding identified in maps developed through the Canada-Newfoundland Agreement on Flood Damage Reduction.

Relevant considerations are: 0m the current mean sea level; 0.45m the anticipated upper future mean groundwater elevation; 0.55m approximate bottom of foundation footing; 1.75m floor elevation of the Town Hall; and the 2.2m typical top elevation of the floodwall. (See above.)

For the Town Hall, climate factors of interest are:

- Sea-level elevation change;
- Increased rainfall characterized by greater intensity duration and frequency, and more stormwater runoff; and
- Combined sea-level elevation and storm-surge wave elevation.

While there is a past history of flooding in downtown Placentia, it has not occurred (including during the post-tropical storm Chantal in August 2007) since construction of the breakwater and floodwall. If the floodwall and breakwater function effectively, the principal climate risks posed to the Town Hall are increased rainfall and decreased capacity of the ground to absorb stormwater due to rises in the groundwater or tidal elevations.

According to the consultants, insufficient human, equipment, time, opportunity and financial resources are being directed to potential downtown flooding, including of the Town Hall. Based on the defined performance measures, specific recommendations are made to deal with:

- Policies and procedures capacity; and
- Lifecycle planning.

For other performance measures, sufficient adaptive capacity exists.

Community of Dunville Road and Culvert System

A provincially owned, two-lane highway (Route 100) from St. John's runs through Dunville, which forms part of Placentia. Dunville, which lies northwest of the downtown, is reached by crossing the Sir Ambrose Shea Lift Bridge spanning the Placentia Gut.

To one side of the road is a steep slope with some residences, small evergreen trees on minimal soil cover, and outcrops of bedrock. There are some barren patches to the tree cover. The forest is not currently logged, but was in the past, and when the exposed soil blew away, barren patches without tree cover resulted. To the other side of the road,

sloping downward steeply towards the water, are more residential homes. The road is almost perpendicular to the water runoff route.

Figure A-10 Dunville Road

The area has been subject to flooding events, partially and temporarily blocking culverts (with designs based on 1:100 year water flows) and water build-up along the upslope of the road. Results (including when post-tropical storm Chantal brought 200mm of rain to the area in August 2007) have entailed washout of portions of the road, need to replace sections of the road and culverts, flooding of homes and temporary isolation of part of the community.

For the Dunville road and culvert system, climate factors of interest are increased rainfall characterized by greater intensity duration and frequency, and more stormwater runoff.

According to the consultants, insufficient human, equipment, time, opportunity and financial resources are being directed to the Dunville road and culvert system. Based on the defined performance measures, specific recommendations are made to deal with:

- Capacity;
- Stability;
- Maintenance, operations and monitoring;
- Property protection (insurance);
- Policy and procedures; and
- Lifecycle planning.

For other performance measures, sufficient adaptive capacity exists.

2.4 Policy Makers Executive Summary

General Climate Change Impact

Over the time horizon to the year 2050, the Town of Placentia is likely to experience several climate-related changes that will impact local infrastructure, including the breakwater, floodwall, buildings in the downtown flood plain, and road and associated facilities in Dunville.

Influencing climate-related phenomena are:

- Sea level rise;

- Higher storm surges; and
- Increased rainfall intensity.

The first two factors could adversely affect the town's breakwater, floodwall, and the downtown flood plain, in and around the Town Hall. The latter could also be affected by increased rainfall intensity.

Road and culvert systems in Placentia's Dunville area are likely to be affected by the more intense rainfall leading to greater stormwater runoff from steep slopes.

Recommendations

- Establish a land-use plan to minimize storm water run-off on the steep slopes:
- Monitor corrosion rate of steel wall and establish a protocol and plans for wall replacement;
- Account for rise in flood plain groundwater for any new construction, including storm sewer;
- Set up and follow a monitoring protocol/schedule of sediment and erosion around the breakwater.

3 Metro Vancouver Case Study – Vancouver Sewage Area Infrastructure Vulnerability to Climate Change

3.1 Background

Within the First National Engineering Vulnerability Assessment, the Public Infrastructure Engineering Vulnerability Committee identifies stormwater and wastewater among the four priority classes of infrastructure to assess for vulnerability and adaptability to climate change.

The Vancouver Sewage Area (VSA) was selected as a case study in the stormwater and wastewater category. Kerr Wood Leidal Associates Ltd. and Associated Engineering (B.C.) Ltd. conducted the case study. The consultants used the Engineering Protocol for Climate Change Infrastructure Vulnerability Assessment and various information sources (including sewerage-area personnel, climate models, a stakeholders' workshop and a wastewater-treatment plant tour).

Figure A- 11 Metro Vancouver area

3.2 Where, What and How

The VSA is bounded by Burrard Inlet (north), the Strait of Georgia (west) and the north arm of the Fraser River (south). Located within a west-coast marine climate zone, the

area is subjected to generally west-to-east weather patterns, dominated by repeated cyclonic storms. Often high winds are accompanied by relatively high levels of precipitation, especially in the winter. Annual total rainfall in the affected area is 1,881 mm and the average annual one-day maximum rainfall is 73.1 mm. The area's average low January temperature is minus 0.64°C and average high for the same month is 5.22°C. The summer high and low averages (in August) are 11.4°C and 23.47°C. The VSA covers 13,000 hectares and receives flows from the sewer system of the City of Vancouver, the University of British Columbia, the University Endowment Lands, and parts of the cities of Burnaby and Richmond.

The sewage area largely relies on a combined system that conveys both wastewater and stormwater in the same pipe. During heavy rainfall, overflows from the combined sewers, known as combined sewer overflows (CSOs), can be directed into waterways such as the Fraser River and Vancouver Harbour.

The Vancouver Sewage Area's major infrastructure consists of:

- the collection system

and

- the Iona Island Wastewater Treatment Plant (IIWWTP).

The collection system includes:

- combined trunk sewers carrying flow from municipal mains;
- four major combined sewer interceptors that gather flow and convey it to the Iona Island Wastewater Treatment Plant;
- Other collection components as noted in the following paragraph;
- About 16 overflow pipes that can discharge overflows into local receiving waters during significant rain events.

Collection components include designated pump stations and force mains (to raise sewage from areas at lower elevations); flow and level monitors; flow-control structures (weirs to limit or control flows) and grit chambers (to slow flows to drop out rocks and sand). The collection system relies on power sources (generally through BC Hydro); communication (including SCADA telemetry) and transportation networks (to carry response staff); support equipment and personnel, and record-keeping systems (including for weather data). Mains have a design life of up to 100 years and a large number of mains are nearing their design life.

The IIWWTP, built in the 1960s and since expanded six times, lies at the mouth of the north arm of the Fraser River where it flows into Georgia Strait. The plant serves a population of approximately 600,000 and it is the second largest such facility in Metro Vancouver, a regional government body with responsibilities that include managing five treatment plants. The Iona Island facility currently provides treatment to a primary level prior to discharging treatment flow at a depth of 90 metres in the Strait of Georgia via a 7.5-kilometre outfall (including a 4 km jetty and 3 km marine section). The plant treats more than 200 billion litres of wastewater a year. Expansion to accommodate population growth and upgrading to full secondary treatment is planned by approximately 2021.

Plant infrastructure includes screens (to remove coarse debris); centrifugal pumps; facilities for grit removal and chemically-enhanced primary treatment; and thickening, digestion and lagoon systems for sludge. Supporting equipment includes onsite pipelines, building, tankage, process equipment and standby generators. Many parts of the infrastructure will reach their expected service life in the relatively near term.

A Liquid Waste Management Plan (LWMP) commits Metro Vancouver by Jan. 31, 2012 to eliminate all sanitary sewer overflows (SSOs) during storm and snowmelt events of a magnitude that occur more frequently than one every five years on average. Metro Vancouver is also committed to eliminate CSOs by 2050. CSO reduction in the VSA is primarily being achieved by sewer separation (i.e., separating the combined sewer into separate sanitary and storm sewers, often with the existing regional sewer ultimately becoming a dedicated storm sewer).

Climate modeling done by OURANOS suggests that by 2020 and to a greater extent by 2050, the case-study region will experience:

- increased rainfall, including more frequent and more intense rainfall events;
- rises in the sea level; and
- increases in storm surges, floods, and extreme winds and gusts.

3.3 Technical Summary

Climate Modeling

The case study of the VSA infrastructure vulnerability and adaptability to climate change relies on climate modeling by OURANOS and use of the Canadian Regional Climate Model. The years 2020 and 2050 were selected as the bases for analysis. By 2020, much of the oldest piping used in the infrastructure will have reached the end of its normal design life. By 2050, it is planned in the VSA plans to eliminate combined sewer overflows by separating the majority of the contributing sewerage area.

Climate scenarios applied to Metro Vancouver point to:

- increased total amount of annual and seasonal rain (14 per cent by the 2050s);
- increased frequency and magnitude of rainfall events; and
- increased monthly average minimum and maximum temperatures increases – of 1.2 to 1.3° C by 2020 and 2.1 to 2.3° C by 2050.

The global sea level is forecast to rise 0.06 m by 2020 and 0.14 m by 2050. Parts of the case-study area, including Iona Island, are sinking while some adjacent areas are rising. It is important to note, however, that some more recent studies (Inter-Governmental Panel on Climate Change) project changes between 1980–2000 and 2090–2099 forecast significantly higher estimates of sea-level rise.

Other phenomena likely to increase due to climate change are: storm surges, floods and extreme winds and gusts. Average maximum length of dry spells may increase but the model results are inconclusive.

Cyclical atmospheric circulation patterns already impact the region's precipitation, stream flow and sea levels. Phenomena with possible additive or mitigating effects on the impact of climate change are:

- El Niño and La Niña events;
- Pacific Decadal Oscillations (warming and cooling patterns of the Pacific historically occurring in 25-to-35-year phases).

Probability Scales

The case study employs two probability scales (Method A – Climate Probability Scale Factors and Method E – Response Severity Scale Factors) from the Protocol for Climate Change Infrastructure Vulnerability Assessment to gauge vulnerability of VSA infrastructure to climate change.

Scale	Method A Climate Probability Scale Factors	Method E Response Severity Scale Factors
0	Negligible or not applicable	Negligible or not applicable
1	Improbable/highly unlikely	Very low/Unlikely/Rare Measurable change
2	Remote	Low/Seldom/Marginal Change in Serviceability
3	Occasional	Occasional Loss some capacity
4	Moderate/possible	Moderate Loss of some capacity
5	Often	Likely Regular Loss of Capacity and Loss of Some Function
6	Probable	Major/Likely/Critical Loss of Function
7	Certain/Highly probable	Extreme/Frequent/ Continuous Loss of Asset

Only climate events likely to occur with greater frequency or intensity than at present are assessed. For this reason, the assessment does not cover extremely low temperatures and increased snowfall intensity. Climate-change scenarios indicate that such events are less likely to occur in the case-study area in the future.

Climate Change Impacts

Intense Rain

Climate change is expected to increase the frequency of intense rainfall events in the VSA.

Generally speaking, wastewater infrastructure is impacted most by rainstorm events (e.g., on a short-term, event basis) and to a lesser extent by total annual rainfall (e.g., in terms of long-term operating costs).

Intense rainfall events will reduce the capacity to convey sanitary flows to the treatment plant and increase the frequency and volume of CSOs. It is also likely to increase inflows and infiltration into the sewer system such as via storm-sewer cross-connections and flow through manhole lids.

Collection System

Increased rain with resulting higher flows and velocities in the sewers could impact collection infrastructure through:

- increased demand and wear on pumps and force mains;
- increased erosion at the mouth of the outflow pipe and higher flow also may turn overflows into choke points with flow surcharging upstream.;
- overflow of water through unbolted or unsealed manholes;
- failure of flow and level monitors with impact on sewer system SCADA operation;
- needed changes in operation or sizing of flow-control structures; and
- need for more frequent clearing of grit chambers to remove coarse material.

Treatment Plant

Constraints within the collection system limit amounts of wet-weather wastewater reaching IIWWTP. However, increased frequency and flow volumes related to intense rain still could affect the treatment process through:

- reduced performance of primary clarification, leading to increased contamination discharge into the marine environment;
- added transfer of grit to the anaerobic digester;
- reduced opportunities to take components (e.g., clarifiers and screens) out of operation for servicing, thereby risking greater operating difficulties;
- additional energy expended on pumping;
- increased wear and tear on liquid stream process mechanical components.

Total Annual/Seasonal Rain

Collection System

More rain and rainfall days, plus more intense rain events will reduce the number of days suitable for maintenance – potentially leaving trunk, interceptors and sanitary sewers as the most vulnerable components. (Increased rainfall actually might improve system performance by diluting wastewater and reducing its temperature. This would yield benefits through reduced corrosion and less odor.)

Treatment Plant

Additional rainwater will reach overflows and will not enter the wastewater treatment plant. However, some added water will reach the plant and influence:

- performance of the liquid-stream treatment process;
- capacity (including by displacing some wastewater that otherwise would have been treated); and
- increasing operating costs, including for pumping.

Sea-Level Elevation

Collection System

Rising sea levels could impact the collection system by affecting the hydraulics of outfalls but this effect likely will be minimal. A significant rise in sea level, if combined with high tide and storm surge, could allow seawater to enter the collection system but the expected impact would be minimal.

Treatment Plant

At the treatment plant, a sea-level rise could influence the ionic strength and relative ionic concentration in wastewater. This could impact performance by affecting the particle coagulation and flocculation in the primary clarifiers and gravity sludge thickeners. There is a low probability of such climatic effects.

A rising sea level may affect hydraulics of treatment-plant effluent disposal and require additional energy needed to pump effluent though the marine outfall. There is a high probability of such an effect but its severity may vary.

Moderate-severity effects are likely to be associated with rising sea levels as higher hydrostatic uplift forces affect below-grade pipelines, open channel conduits and structures lower than the current water table.

Flooding of buildings, tankage and process equipment presents a further risk from higher sea levels. Most of the treatment plant site is above 3.5m geodetic elevation but

uncertainty exists because of sinking of land at the Iona Island site. Flooding due to rising sea levels is considered a remote possibility but would have severe impacts if it occurred.

Storm Surge

High tides and storm surges govern water levels on the Fraser River lower estuary. Higher extreme water levels caused by climate changes are expected to produce greater storm surges, or rises in level of the ocean caused by the decrease in atmospheric pressure associated with hurricanes and other storms. This will lead to increases in extreme static head and hamper effluent disposal into the ocean. Considering the system's current capacity and experience during storms, this warrants a "major response" severity factor.

Increased storm surge can impact the site in terms of flooding, particularly if combined with a large wave event.

British Columbia has adopted 2.9 m above geodetic elevation as a flood standard (without consideration of sea-level rise). Much of the Iona Island site, including the access road, lies only slightly above 3.5 metres. When considered in combination with land sinking in the area, the consultants "suggest that little margin may be available for the future." Bases on probability scales A and E, and a conservative assessment, they assigned a "probable" and "major response severity factor" to this situation.

Floods

Street flooding due to rain may cover pump stations (depending on design and location) and damage electrical equipment. Flooding could make it difficult to refuel standby power and hamper response by service crews. Pump failure could cause local environmental damage and human health risk. Though the impacts of such events are severe, the probability of vulnerability is assessed as moderate.

High Temperatures

Higher ambient temperatures will have some negative impacts, including increasing odor (due to increased fermentation) during the treatment process, influence the HVAC systems (affecting staff and process equipment) and increasing corrosion. Higher temperatures could benefit anaerobic sludge digestion. The probably climate effects upon the infrastructure from increased temperature are relatively low.

Drought

Longer periods of summer dry-weather could result in wastewater being less diluted by rain. This could influence the effluent quality and require more frequent use of chemically enhanced primary treatmen. However, the probability of climate change affecting the treatment plant in this way is considered remote and the severity response is low.

Wind

Higher winds could cause SCADA antenna damage and impede communications. In the absence of adequate backup, winds could also disrupt power needed for the collection system.

Figure A- 13 Overflow

At the treatment plant, higher winds could slow settlement of solids in the sludge lagoons. Increased high winds could also increase the frequency of BC Hydro power loss. Without adequate power backup, operating effluent pumps could be difficult. More frequent bypass of effluent into the shore outfall may occur. The severity of this situation is linked to access to on-site power generation.

3.4 Policy Makers Executive Summary

General Climate-Change Impact

While climate changes are anticipated to impact Metro Vancouver, the region is not currently affected by ice storms, tornadoes, drought or extreme cold. Probabilities for such sudden weather events are likely to decrease for the Vancouver Sewage Area (VSA) with climate changes that are predicted to bring warmer and more rainy conditions.

Currently, flooding from the Fraser River and sea represents the highest magnitude threat to the VSA from sudden weather changes. Because of its location near the mouth of the Fraser River, the flooding threat from the river is associated with winter storm-surge conditions and not the snowmelt-generated freshet or spring breakup.

Climate-change effects upon the VSA will generally be gradual, and therefore allow the system to mitigate and adapt to the effects of these changes.

The most severe vulnerability rating relate to public health risks from contamination arising from overflows from combined sewer and wastewater sewers into spaces such as streets and basements. Extreme weather events also could delay construction and reduce opportunities for servicing, as well as increase wear and tear on equipment and add to insurance costs.

Specific Impacts on Vancouver Sewage Area Infrastructure

Some specific components of the VSA infrastructure are expected to be impacted by climates changes, notably changes associated with increases in overall rainfall and more frequent severe rainfall. However, the wastewater infrastructure tends to be affected to a greater degree by discrete rainstorm events than by the total annual rainfall handled.

Collection System

Anticipated increases in rainfall will affect the collection system by increasing flows under sewer configurations that a) involve combined wastewater and stormwater sewers, and b) those where the two flows are divided (i.e., separated). This should encourage acceleration of plans within the VSA for sewer separation to ensure elimination of CSOs by 2050. More study is needed to determine the extent of work required.

In addition to sewer separation, a number of other anticipated developments could affect the collection system by mitigating or intensifying possible impacts on the infrastructure from climate changes. These developments include:

- construction plans for additional and replacement sewage-system infrastructure;
- plans to reduce inflow and infiltration of wastewater flows into the sanitary sewers;
- population growth and impact on sewer loading;
- land use (e.g., increased runoff by addition of impervious areas, or decreased wastewater flows due to diminished industrial land use in Vancouver);
- water conservation resulting in decreased sanitary loading;
- seismic events leading to landslides or ground shifts affecting sewer line integrity.

Because several local sewage systems link with the VSA infrastructure, recommendations for the sewage area can be implemented most effectively through effective coordination with the affected municipalities. A comparable vulnerability study with the City of Vancouver may help more clearly identify actual vulnerability.

Iona Island Water Treatment Plant

Climate changes leading to storm surges could impact the VSA's Iona Island Wastewater Treatment Plant by affecting the current disposal system, which relies on a 7.5-kilometre outfall into Georgia Strait. This represents the highest area of climate change vulnerability for the treatment plant.

A lower order of vulnerability for the plant is associated with rises of the mean sea level. This issue requires more study. Similarly, lower levels of vulnerability relate to wet-weather waste flows.

The VSA collection system, along with some other Metro Vancouver facilities, is not adequately equipped with backup to deal with power failure. The treatment plant has an emergency response plan. However, the current availability of standby electrical power leaves the treatment plant somewhat vulnerable. This situation could become more acute as a result of climate changes and remedial action is recommended.

The age of the infrastructure and other issues, such as the possibility of seismic events, are vulnerability factors requiring further study and attention.

Figure A- 14 Water Treatment Plant

Mitigating and Favorable Factors

The aim in the VSA of separating wastewater and stormwater streams will reduce peak flows in the collection system and amounts delivered to the treatment plant. The expected reduction in flows to the plant will exceed the anticipated adverse impact on the treatment plant stemming from climate-based rainfall effects.

Plans to upgrade treatment within the VSA to secondary by approximately 2021 provide an opportunity to include climate-adaptation measures in the design.

4 City of Greater Sudbury – Roads and Associated Structures Assessment

4.1 Background

Within the First National Engineering Vulnerability Assessment, the Public Infrastructure Engineering Vulnerability Committee (PIEVC) identifies roads and associated structures among the four priority classes of infrastructure to assess for vulnerability and adaptability to climate change.

The City of Greater Sudbury was selected as a case study in the roads and associated structures category. Dennis Consultants and Hydro-Com Technologies, divisions of R.V. Anderson Associates, conducted the case study. The consultants used the Engineering Protocol for Climate Change Infrastructure Vulnerability Assessment and various information sources (including City of Sudbury personnel, climate models and a stakeholders workshop).

Figure A-15 City of Greater Sudbury

4.2 Where, What and How

The City of Sudbury, population approximately 158,000, operates and maintains about 3,500 km of roads. The city covers an area of about 3,600 sq. km, and is located on the Canadian Shield, about 340 km northwest of Toronto and 425 km west of Ottawa. An unusual feature of the area is that, due to recent amalgamations, Greater Sudbury has 330 lakes within its boundaries, more than any other municipality in Canada. They include Lake Wanapitea, the largest lake in the world completely contained within the boundaries of one city. The diverse soil conditions of the area can range from Precambrian Shield Rock to swamp within a few metres, creating road design and construction challenges.

Northern Ontario climate conditions, such as snowfall, sleet and particularly freeze/thaw cycles, pose infrastructure challenges. Daily temperatures in winter can drop as low as -40°C and as high as the upper +30°s C in summer. Although Sudbury is one of Ontario's sunniest communities, frost penetrates almost two metres into the ground on average and can reach three metres depending on freeze-thaw cycles. Mid-winter thaws now appear regularly in January and February and contribute to maintenance costs. Snowfall accumulations ranged from 256 cm to 286 cm between 2003 and 2006.

Increased variation in climatic conditions over the winter makes it difficult to forecast maintenance expenses. (The City maintains a "bare pavement" standard.) Winter control maintenance is the most significant (and rising) contributing factor to road-infrastructure costs.

The case study considers urban, rural, arterial and collector roads, with traffic volumes of up to 30,000 a day on major roads, and related components including:

- Above-Ground Components (e.g., the surface and surface treatment, curbs, sidewalks, bike paths, bridges and related structures, traffic signals, street lighting, municipal signage, etc.);
- Below-Ground Components (e.g., road sub-base, storm sewer systems, distribution systems, collection systems and underground utilities); and
- Miscellaneous: administration/personnel, surface maintenance (markings, crack sealing), winter maintenance (plowing, salting, etc.) and record-keeping.

The expected lifespan of roads and associated structures in the Sudbury area is about 30 years. This lifespan depends on interim rehabilitation being done when needed.

Data on climate change effects on ice accretion or ice storms that would have been of interest to this case study was not available. Interviews with city staff responsible for road maintenance did yield helpful information on what components might be more vulnerable to climate change. OURANOS, however, is able to make the following projects about the following types of climatic conditions the case-study region will experience by 2020 and to a greater extent by 2050 and 2080:

- a general warming trend, with hotter summers and warmer, shorter winters;
- slightly increased rainfall, with more frequent and intense precipitation, and more frequent and severe storms (but no change in total rainfall in summer);
- a decrease in the amount of snow, with a reduction in the number of minor storms, and an increase in major storms and “rain on snow” events; and
- a shorter frost season and a decrease in the number of freeze/thaw events.

Figure A-16 Sudbury industries

A sizeable portion of the City’s nearly $500 million annual budget goes toward road operation and maintenance. In recent years, the amount of capital spending on roads has not kept pace with maintenance requirement and this has led to higher repair costs.

It is noted that the Sudbury region has major mines (Xstrata and Vale Inco) and these operations contribute to the overall economy. However, in terms of covering costs related to roadways, they City has limited powers to tax these resource operations.

4.3 Technical Summary

Climate Modeling

The Greater Sudbury case study of infrastructure vulnerability and adaptability to climate change draws on climate modeling by OURANOS and uses the Canadian Regional Climate Model. The years 2020, 2050 and 2080 were selected as the bases for analysis.
It should be noted that OURANOS was unable to model expected changes in ice build-up and accretion due to insufficient data. The Sudbury PIEVC workshop identified this potential climate event as being important in assessing possible impacts of climate change on roads.

However, OURANOS can make the following general projections about changes in temperature, rainfall, snowfall, wind and frost that are likely to affect the case study region:

1) Temperature

A warming trend is predicted, with higher average maximum and minimum temperatures on both a monthly and annual basis. This is in line with the general warming trend predicted worldwide (hotter summers and warmer, shorter winters).

2) Rainfall

Rainfall is expected to increase slightly. This follows general trends for Ontario and Eastern Canada that suggest somewhat more precipitation will fall as rain, and more frequent severe storms will occur. Little change in rainfall amounts is expected during the summer months (June, July and August).

3) Snowfall

Snowfall is expected to decrease overall, with fewer minor snow storms (less than 20 cm) and more large snow storms (20 cm or more). An increase in the occurrence and severity of “rain on snow” events is also suggested.

3) Wind

No changes are suggested.

4) Frost

A shorter frost season and a decrease in freeze-thaw cycles are suggested.

5) Cumulative Effects

No significant impacts are expected on infrastructure as a result of the cumulative effects of climate factors.

Probability Scales

The case study employs two probability scales (Method A – Climate Probability Scale Factors and Method E – Response Severity Scale Factors) from the Protocol for Climate Change Infrastructure Vulnerability Assessment to gauge vulnerability of Vancouver Sewage Area infrastructure to climate change.

Scale	Method A Climate Probability Scale Factors	Method E Response Severity Scale Factors
0	Negligible or not applicable	Negligible or not applicable
1	Improbable/highly unlikely	Very low/Unlikely/Rare Measurable change
2	Remote	Low/Seldom/Marginal Change in Serviceability
3	Occasional	Occasional Loss some capacity
4	Moderate/possible	Moderate Loss of some capacity
5	Often	Likely Regular Loss of Capacity and Loss of Some Function
6	Probable	Major/Likely/Critical Loss of Function
7	Certain/Highly probable	Extreme/Frequent/ Continuous Loss of Asset

The climate change effects that were considered include average daily high temperature, average daily low temperature, extreme temperature range, rainfall and snowfall frequency and intensity, freeze/thaw cycles, and wind.

Climate Change Impacts

Based on the data provided, none of the infrastructure components assessed was considered to be highly vulnerable to climate change effects. However, the study pointed to some potential vulnerability related to the effects of rainfall on drainage infrastructure and gravel road surfaces.

It should also be noted that lack of detailed information made it difficult to evaluate the capacity of Sudbury's drainage infrastructure in the event of heavy rainfall or snowfall. The development of a database with more information on conveyance capacity and design flows, including type, size, age and location, would be helpful. This gap is significant, in light of the fact that predicted rainfall events are large enough to affect structural integrity and other aspects of the infrastructure. Although the City of Sudbury is equipped to deal with heavy snow events, and vulnerabilities are not expected to arise, there is a lack of data to substantiate this belief.

High Temperatures

Roads – Asphalt road surfaces could lose their rigidity due to extremely high temperatures, impacting the structural integrity and functionality of the roadway.

Intense Rain

Drainage System (includes bridges and related structures, storm sewer systems, catch basins, culverts and ditches) – Intense rain events could cause overloading of the drainage infrastructure, overflowing private property with insurance and economic ramifications. As well, overloading of the combined sewers could impact public health, and contaminants and sediments could be washed into watercourses, affecting the environment.

*Road*s – Rain could pool on road surfaces, affecting emergency responses. Gravel surfaces may be eroded, resulting in ruts and depressions, requiring more maintenance and in some cases making roads impassable.

Embankment – The structural integrity of embankments may be affected, raising the possibility of washouts, more repair work and loss of sediment to watercourses, affecting the environment. Falling rock and soil material could also cause vehicle accidents and personal injury.

Intense Snow

Roads – Intense snow would greatly affect functionality of the road system, impact emergency response and public safety and require greater maintenance.

Culverts – Large snowfalls could block culverts. The need for larger, more versatile equipment for snow clearing would increase.

Frost

Curbs, sidewalks and surface maintenance (repairing holes) – A shorter frost season and freeze/thaw cycles would reduce maintenance requirements of these infrastructure components.

4.4 Policy Makers Executive Summary

General Climate-Change Impact

The City of Greater Sudbury area can anticipate hotter summers and warmer, shorter winters as a result of climate change. Rainfall is expected to increase slightly, not only in frequency and amount but also in intensity. More frequent and severe storms are also likely, although relatively little change is anticipated in total rainfall during the summer months. Warmer winters will bring a decrease in snowfall and in the number of minor storms. However, an increase in the number of major snowstorms is predicted, as well as more "rain and snow" combination events. A shorter frost season is anticipated, along with a reduction in freeze/thaw cycles.

Climate-change effects upon Greater Sudbury roads and associated structures do not suggest high vulnerability of any of the components assessed. High temperatures and intense rain and snowfall events will, however, have an impact on road surfaces and could potentially cause overflow of the drainage system and related infrastructure, including embankments. This could pose public health, emergency response and environmental risks, as well as increasing maintenance costs.

It should be noted that lack of data on drainage capacity limited assessment of infrastructure vulnerability resulting from heavy rain and snowfall.

It must also be pointed out that, due to lack of data, this case study does not evaluate potential infrastructure vulnerabilities related to ice storms. This is a significant gap, particularly since this type of weather event could increase. In future, the availability of suitable data may lead to more information about potential vulnerabilities.

Specific Impacts on Sudbury Area Infrastructure

Some specific components of the Greater Sudbury roads and associated structures are expected to be impacted by climate changes, notably changes related to increases in intense rainfall and more severe snowstorms, along with more "rain on snow" events.

Drainage System (*including bridges and related structures, storm sewer systems, catch basins, culverts and ditches)*

The system's capacity to deal with heavy rain and snowfall events requires further study and attention. Increased rain with higher flows and velocities could result in overflowing,

which could affect private property, adding to insurance costs, and cause public health and environmental risks. There is also concern that heavy snowfalls could block culverts, resulting in further overflowing.

Roads (asphalt and gravel)

Extremely high temperatures, and a longer duration of high temperatures, could contribute to wear and tear on asphalt road surfaces, causing them to lose their rigidity. Intense rain could result in pooling, impeding emergency responses and causing surface contaminants to be washed into the drainage system and nearby water courses. On gravel surfaces, intense rain could hasten erosion, adding to maintenance costs, and even making roads impassable. Major snow events could significantly impact traffic flows as well as impede emergency response and cause public safety challenges.

Embankments

Intense rainfall could cause washouts, and result in falling rock, posing safety risks to vehicles and occupants. Soil material could also be carried away, increasing maintenance costs.

Curbs, sidewalks and surface maintenance (repairing holes)

A positive impact is that warmer winters and decreased freeze/thaw cycles will reduce the maintenance required for road surfaces, curbs and sidewalks.

Recommendations

Although this case study does not identify vulnerabilities for the components assessed, the consultant makes “medium-priority” recommendations for remedial action or further study. Key recommendations centre on stormwater management related to roads and drainage infrastructure, the impact of high temperatures on paved roads, mitigating the effects of rainfall (groundwater) on embankments, and further study of vulnerabilities related to ice events. They were presented in order of importance:

- Develop a database with hydraulic information for all culverts within Greater Sudbury.
- Perform a capacity evaluation of minor and major drainage systems within Greater Sudbury.
- Perform impact assessments of the functionality and environmental effects associated with increased rainfall intensity and frequency on gravel surfaced roads.
- In response to the lack of reliable information related to potential increases in ice accretion/ice storms, do a risk and criticality assessment of the roads and associated infrastructures, design standards, and operations and maintenance procedures that could be impacted by ice accretion and ice storms. (Specific

attention should be paid to the suspected drastic impacts of ice, snow and the re-freezing of pooled water and slush on the functionality of sidewalks in general, and the priority that is assigned to the winter maintenance of sidewalks in particular).

- Evaluate the possibility as well as the lifecycle costs associated with changing the asphalt mixes used in Greater Sudbury to accommodate higher temperatures. Alternatively, consider the use of trees to provide shade on low-speed roads to reduce the urban "heat island effect."
- Perform sensitivity analyses on the slope stability of large and "high risk" embankments/cuts within Greater Sudbury in response to increased groundwater levels.

5 City of Edmonton Quesnell Bridge, Roads and Associated Structures Assessment

5.1 Background

Within the First National Engineering Vulnerability Assessment, the Public Infrastructure Engineering Vulnerability Committee (PIEVC) identifies roads and associated structures among the four priority classes of infrastructure to assess for vulnerability and adaptability to climate change.

The Quesnell Bridge in Edmonton was selected as a case study in the roads and associated structures category. CH2M HILL conducted the case study. The consultants used the Engineering Protocol for Climate Change Infrastructure Vulnerability Assessment (the Protocol) and various information sources, including City of Edmonton personnel, historical weather event information, and climate-model projections. PIEVC and affiliated stakeholders participated in a workshop and bridge tour to review and provide input on applying the Protocol to the infrastructure.

5.2 Where, What and How

The Quesnell Bridge crosses the North Saskatchewan River Valley in the west part of the City of Edmonton, population approximately 730,000. Built in 1968, the bridge, which is a critical element of Whitemud Drive, a major multi-lane arterial roadway running east-west and forming part of Edmonton's inner ring road system. The six-lane bridge is a key crossing over the North Saskatchewan River, linking the northwest and southwest areas of Canada's fifth largest city. Owned, operated and maintained by the City of Edmonton, it carries about 120,000 vehicles per day, as well as cyclists and pedestrians. It is located within the steeply sloped and relatively intact North Saskatchewan River Valley, which is nationally recognized as an environmentally sensitive area. The 315-metre structure consists of three lanes in each direction, a 4.5-metre sidewalk, and a superstructure of ten lines of parabolic prestressed and post-tensioned concrete girders with a cast-in-place deck.

One reason for selecting this case-study site is that Edmonton represents a geographic location that experiences a northern continental climate with a variety of extreme climate conditions and weather events. Edmonton is located south of the permafrost region at 53 degrees north latitude and 113 degrees west latitude. The average monthly minimum temperature in January is -18°C and the average maximum monthly temperature in July is 22°C. As the bridge is a heavily used water crossing, the site provides further opportunities to explore climatic impacts. Unique climatic and geographic considerations include extreme cold temperature and its effect on the durability of concrete, frequent

snow (sometimes heavy), ice build-up on the river, and the impact of increased rainfall on erosion, due to the long, steep river valley banks.

Coincidentally, the bridge is currently undergoing rehabilitation and upgrading to meet increased traffic loads and to extend the life of the structure for 50 years. This work adds a further dimension to the study, as resulting recommendations may find immediate practical application. The upgrades, which are to be completed in 2010, include replacing the concrete deck and widening the bridge to accommodate two additional lanes. The goal is to achieve serviceability with minimum maintenance and no major rehabilitation until 2060.

Figure A-17 Quesnell Bridge, Edmonton

All components of the bridge are considered in this study, including operations and maintenance; deck; expansion joints; bearings; girders; abutment; piers–columns; drainage system; accessories (e.g. pedestrian railing, lamp posts); the riverbank and adjacent infrastructure (upstream dam).

The case study identified two infrastructure components as showing signs of vulnerability: the wearing surface of the deck and the drainage system, including the deck drainage and the retention pond. As these components are being replaced in the bridge rehabilitation program, the vulnerability is assessed in terms of potential proposed alternatives, in particular whether they should be designed according to current standards and typical climatic data.

Climate data used for climate modeling is based on observed weather data and may not capture all the extreme events that are of interest in this study. For that reason, local

extreme climate events and their impacts are also considered, based on City of Edmonton sources and other local knowledge. OURANOS reported that the following categories were the most difficult to predict via climate models and observed data are insufficient to validate the model outputs for these particular events:

- increased wind and "storm-type" effects including tornadoes, thunderstorms and wind gusts;
- increased ice build-up, ice accretion and freezing rain; and
- rapid snowmelt, leading to potential flooding.

5.3 Technical Summary

Climate Modeling

The Quesnell Bridge case study of infrastructure vulnerability and adaptability to climate change draws on climate modeling by OURANOS and uses the Canadian Regional Climate Model. The years 2020, 2050 and 2080 were selected as the time horizons for analysis.

It should be noted that OURANOS was unable to satisfactorily model several of the climate elements that were requested for this study. They include the precipitation frequency indices (both rain and snow) for 5 mm, 10 mm and 20 mm cutoffs. Future changes modeled appear erratic in some cases and are not statistically reliable. This is most likely due to the fact that the Edmonton area experiences very low levels of precipitation in general (approximately 480 mm of precipitation and 124 cm of snowfall every year). This significantly reduces the available sample size. OURANOS recommends that if all requested indices are necessary for vulnerability assessment, further in-depth modeling and analysis be done.

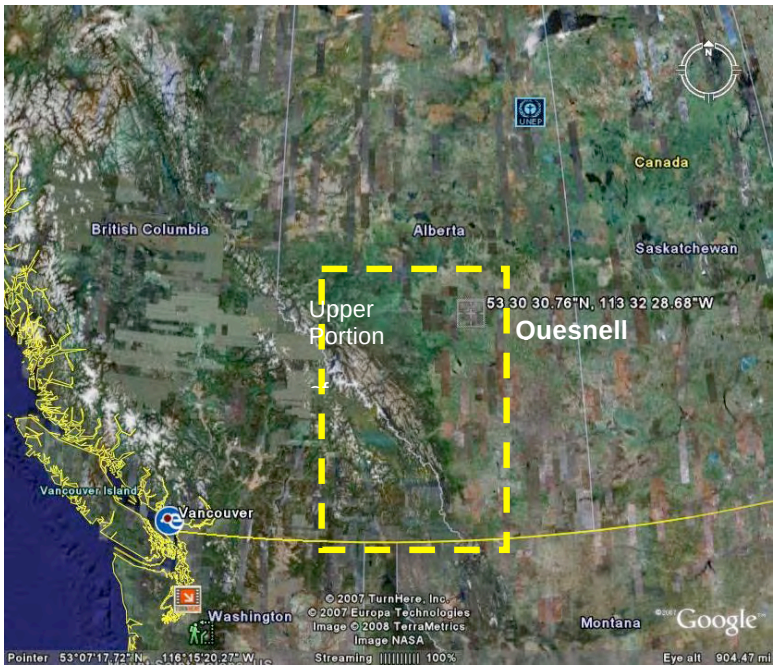

Figure A-17 Saskatchewan River Drainage Basin

However, OURANOS can make some general projections about changes in wind, ice and rapid snowmelt events although these projections are among the least reliable since the climate model cannot reliably capture them. These projections were considered relevant because extreme events have occurred in the past and are likely to occur again in the future. They are also the ones most likely to contribute to infrastructure vulnerability, particularly if they occur in combination or sequentially. It must be emphasized that these types of events are difficult to model as they are either localized or involve complex, inter-related processes.

Climate models applied to the North Saskatchewan River Drainage Basin, within which the Quesnell Bridge is located, suggest the following:

1) Wind (hurricanes, tornadoes, thunderstorms, wind gusts)
   Increased instability in mid-latitude regions, such as Edmonton, may increase the magnitude and frequency of "storm-type effects", including tornadoes and hurricanes.

2) Ice (ice build-up, ice accretion, freezing rain)
   Although it is expected that winters will become warmer, ice build-up (in waterways) and ice accretion (on structures) may increase due to possible increases in freeze/thaw cycles.

3) Snow (rapid melt events)
   Although difficult to predict, OURANOS notes that there is a concern that rapid snowmelt followed by extreme rainfall may load the infrastructure system, leading potentially to flooding events.

OURANOS concludes that the unpredictable nature of these three categories required a more qualitative vulnerability assessment. For that reason, it suggests taking a "what if" approach to assessing the impact of future events, with consideration to local historical events and local knowledge of extreme climate events.

Probability Scales

The case study employs two probability scales (Method A – Climate Probability Scale Factors and Method E – Response Severity Scale Factors) from the Protocol for Climate Change Infrastructure Vulnerability Assessment to gauge vulnerability of the Quesnell Bridge, roads and associated structures to climate change.

Scale	Method A Climate Probability Scale Factors	Method E Response Severity Scale Factors
0	Negligible or not applicable	Negligible or not applicable
1	Improbable/highly unlikely	Very low/Unlikely/Rare

		Measurable change
2	Remote	Low/Seldom/Marginal Change in Serviceability
3	Occasional	Occasional Loss some capacity
4	Moderate/possible	Moderate Loss of some capacity
5	Often	Likely Regular Loss of Capacity and Loss of Some Function
6	Probable	Major/Likely/Critical Loss of Function
7	Certain/Highly probable	Extreme/Frequent/ Continuous Loss of Asset

The climate effects that were considered included average daily high temperature, average daily low temperature, extreme temperature range, rainfall and snowfall frequency and intensity, freeze/thaw cycles, ice accretion, ice force (force of river on the piers), extreme wind, flooding of the North Saskatchewan River, and fog.

In addition, the combined impact of individual weather effects was considered, including:

- temperature and relative humidity;
- heavy winter snow, early spring and heavy rain, resulting in major flooding and debris; and
- snow/ice, rain, and freezing temperatures, resulting in heavy snow.

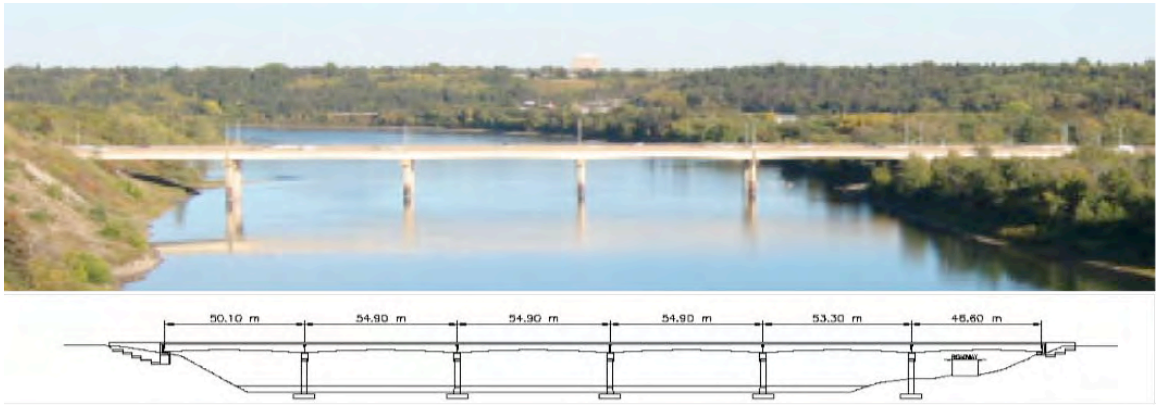

Figure A-18 Quesnell Bridge

Climate Change Impacts

Operations and Maintenance

The work of the regular maintenance crew and snow removal personnel is crucial to the performance of the infrastructure. Extreme climate effects may affect their ability to function, increasing emergency response risk, public health and safety.

Deck System – Wearing Surface

The deck system will be entirely replaced during rehabilitation scheduled for completion in 2010. Although a final decision on the system has not yet been made, it will likely consist of a cast-in-place concrete deck, topped by a water-proofing membrane and then an asphalt wearing surface. While the membrane is not expected to be compromised if installed correctly, concern exists about the integrity of the wearing surface, which is exposed directly to weather elements as well as regular vehicle loads and maintenance vehicle loads. As this involves the direct interface between vehicle tires and bridge surface, this could become a safety issue for road users. This component could be vulnerable to two climatic factors: snow intensity/frequency and major flooding.

Snow intensity/frequency

- More frequent use of snowplows and other de-icing measures may result in more rapid degradation of the wearing surface.
- Driving hazards may increase, along with more likelihood of delays in clearing snow off driving surface.

Major Flooding

- Recent climate change trends point to an increase in the frequency of major flooding following a heavy snowfall, followed by an early spring and subsequent heavy rain.
- Climate loads suggest the wearing surface may be vulnerable to such events in the 2020 timeframe. (In this event, it is assumed that heavy snow/ice has blocked the catch basin of the drains.)

Drainage System – Drainage and Retention Pond

The drainage system diverts water away from the bridge deck and the water is proposed to be stored in holding areas near the structure to avoid discharge into the river system.

Rainfall Intensity

- Rainfall intensity is expected to increase by about 4% in 2020 and 7% in 2050.

- This suggests a high probability that the deck drainage will be affected toward the end of the 50-year life cycle of the infrastructure, although the minor increase by 2020 may be insignificant.

Major Flooding

Early warming, followed by heavy rain, may result in drains not functioning properly.

5.4 Policy Makers Executive Summary

General Climate-Change Impact

Climate changes anticipated in the Edmonton region include an increase in the magnitude and frequency of "storm-type" effects such as tornadoes, thunderstorms and wind gusts. Although winters are expected to become warmer, the amount of ice may increase due to more frequent freeze/thaw cycles. This includes ice build-up on the North Saskatchewan and other water bodies, as well as on bridge and road surfaces, sidewalks and other structures.

There is also concern about a potential increase in combination events, such as a rapid snowmelt followed by extreme rainfall, which could cause major flooding. Such events are extremely difficult to predict. However, they have happened in Edmonton's past and are likely to occur again. More frequent snowfall could result in increased use of de-icing salts, leading to increased maintenance costs, while heavy snowfall or rainfall could affect emergency response times and affect public safety. Rising river levels could reduce clearances for marine traffic, while ice accumulation along the river could increase pressure on the bridge infrastructure.

The two components of the Quesnell Bridge that have the highest vulnerability ratings are the wearing surface of the deck system and the drainage system. The vulnerability of these components would not lead to catastrophic failure of the bridge, but could impact vehicle performance, public safety, maintenance and related issues.

Plans to rehabilitate the bridge by 2010 provide an opportunity to include climate adaptation measures in the design.

Some of the climate data used in the current bridge design standards date back to 50 or 60 years. This suggests a need to review the relevant data used in affected codes to assess how it may be updated to reflect not only more current data collection, but also potential climate-change impacts.

Specific Impacts on Quesnell Bridge Infrastructure

Deck System – Wearing Surface

The deck system will be entirely replaced during rehabilitation, although a final design decision has not yet been made. The design likely will consist of a cast-in-place concrete deck, topped by a waterproofing membrane and then an asphalt wearing surface. Although the membrane is not expected to be compromised if installed correctly, concern exists about the integrity of the wearing surface, which is exposed directly to weather elements as well as regular vehicle loads and maintenance vehicle loads. As this involves the direct interface between vehicle tires and bridge surface, this could become a safety issue for road users. This component could be vulnerable to two climatic factors: snow intensity/frequency and major flooding.

This could be noticeable through the following.

1) **Greater snow intensity and frequency** resulting in:
    - more rapid degrading of the wearing surface due to snowplowing and de-icing; and
    - increased driving hazards and delays related to snow removal from driving surfaces.

2) **Increases in frequency of major flooding,** following heavy snowfall, early spring and heavy rain, may leave wearing surfaces vulnerable in the 2020 timeframe if the heavy snow and ice block catch basins of drains.

3) **Effects on the drainage system and retention pond** may be felt with rainfall intensity anticipated to increase by about 4% in 2020 and 7% in 2050. There is a high probability the deck drainage will be affected by the end of the infrastructure's 50-year life (minor increases by 2020 may be insignificant). Early warming, followed by heavy rains resulting in drains not functioning, may also impact the drainage system.

Key Recommendations

Based on these findings, the consultant makes the following recommendations:

- Review and conduct further study of a number of applicable design procedures and designs, so that design of these components will consider changing or extreme climatic events.

- Review the relevant data used in affected codes to assess how it may be updated to reflect 1) more current data collection, and 2) potential climate change impacts.

The consultant also notes that although only two areas of potential vulnerability were identified for the Quesnell Bridge, other general areas of concern were identified that may be applicable to bridges of other types and in other locations. The consultant states that to obtain a more comprehensive assessment of bridge infrastructure across the country, it would be prudent to undertake further assessments to capture a range of bridge types and locations across Canada.

In general, the infrastructure data set was considered to be complete and adequate, and was readily available from City of Edmonton records. The consultant points to the value of complete maintenance records and in particular notes that a complete maintenance record of specific frequency, approach and quality of snow removal used during each winter season would have been of interest in this assessment.

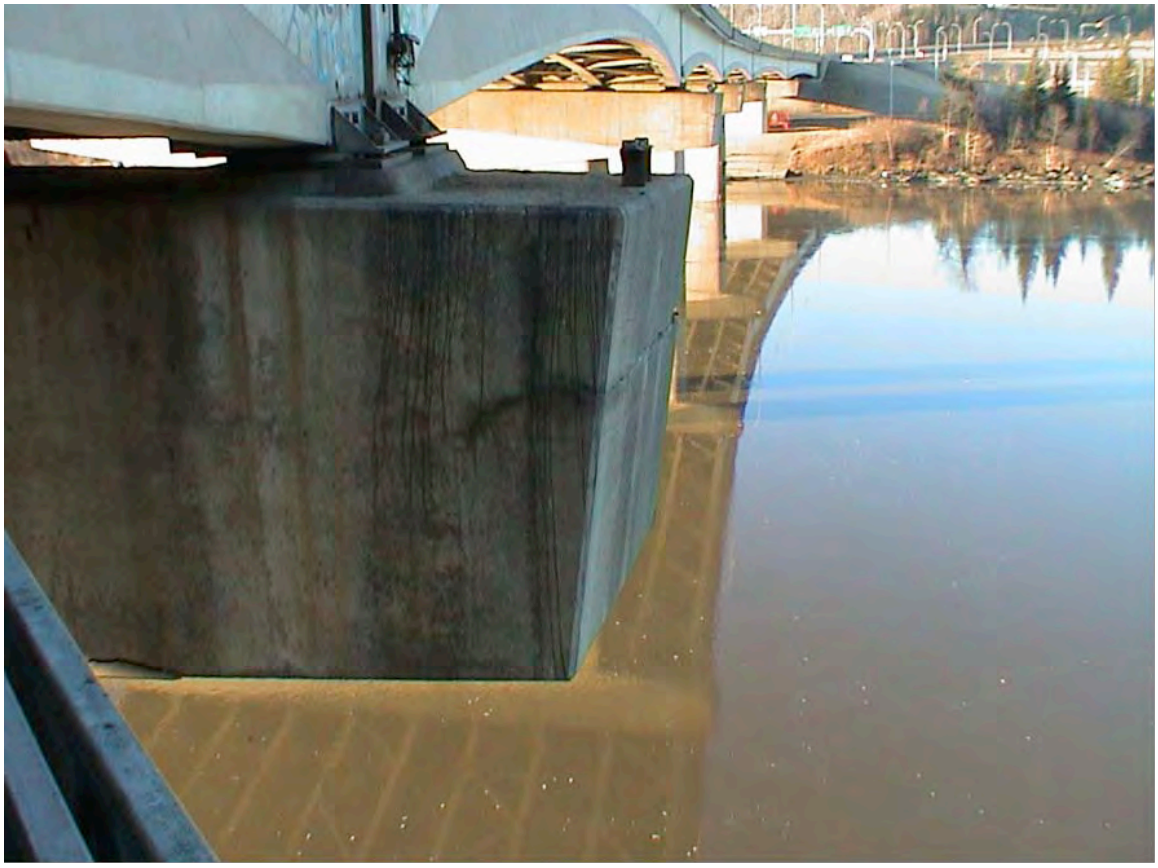

Figure A-19 Quesnell Bridge - underside

6 Northwest Territories Thermosyphon Foundations in Warm Permafrost— Building Resources Infrastructure

6.1 Background

As part of the First National Engineering Vulnerability Assessment, the Public Infrastructure Engineering Vulnerability Committee and the Government of the Northwest Territories Public Works and Services contracted I. Holubec Consulting Inc. to examine and report on the implication of climate warming on permafrost, ground temperature and foundations.

The consultant produced one of seven case studies included in this First National Engineering Vulnerability Assessment Report. The series of case studies examines the vulnerability and adaptive capacity of infrastructure to climate changes. This case study, on thermosyphon foundations in warming permafrost, is one of two on buildings commissioned as part of the National Engineering Assessment of the Vulnerability of Public Infrastructure to Climate Change. While the six other case studies focus on infrastructure at one site or within a limited geographic area, this case study uniquely assesses information from a number of locations across northern Canada.

Figure A-20 Visitor Centre, Inuvik

Permafrost and Current Responses in Infrastructure Design

Permafrost – consisting of soil, rock, organic material and ice lenses that remain frozen below 0°C for at least two consecutive years – is a common phenomenon throughout northern Canada. Even in very cold climates, the ground temperature in permafrost does not fall below approximately -10°C.

In regions with permafrost, the very top layer thaws and freezes every year. Observations in recent years show that the depth of this active layer is increasing. As with soil, clay and rock, the composition of permafrost varies greatly from one location to another. These variations in permafrost properties and the fact that it can thaw when exposed to increased temperatures and precipitation present challenges when designing infrastructure. Traditionally, design considerations focused especially on preventing heat from the infrastructure melting the permafrost supporting structures. Failure to avoid such permafrost melting can leave infrastructure, including buildings, vulnerable to settling into the ground.

Historically, design features to prevent the permafrost from melting and to avoid the infrastructure settling have included:

- Placing the structures on natural rock, wooden or concrete blocks; or
- Positioning the structures on pilings – usually made of wood or steel. The pilings then are held in place by a wet-sand slurry that freezes the piloting in place under ground.

These approaches create a space between a building or other structure, and the ground. This spacing prevents heat from the infrastructure melting the permafrost.

These methods are relatively effective in preventing infrastructure settling in “cold” infrastructure regions but have proven to be less effective in “warm” permafrost areas where the ground temperature reaches -2°C or higher.

There is increasing evidence that besides heat from infrastructure thawing permafrost below, atmospheric climatic warming is extending:

- the “warm” permafrost regions and
- the areas without permafrost.

In parts of the Arctic, unless preventive measures are taken, this increases the vulnerability to settling both of existing structures and future infrastructure.

Thermosyphon systems, a major focus of this case study, offer a means of preventing permafrost near infrastructure from melting. Such systems extract heat from the ground, and so avert settling and help maintain the integrity of the infrastructure. First used in Alaska in the 1960s, variants of these installations are found at close to 160 sites in Canada’s North. Russia also employs such systems Thermosyphon systems may be further adopted to stabilize foundations as the areas where the permafrost continues shrink. Use of thermosyphons would be enhanced by:

- Better understanding of such systems; and
- Availability of more reliable information on how climate change affects ground temperatures.

6.2 Technical Summary

Permafrost and Relationship With Air and Ground Temperature

In permafrost regions, for the first 10–15 cm below ground level, ground temperature fluctuates with air temperatures. Below this 10–15 top zone, there is zero annual amplitude (or change) in temperature and the area is characterized as being permafrost The ground temperature at the point of zero amplitude depends on the mean annual air temperature and the type of ground cover. According to the Geological Survey of Canada, generally the mean annual temperature at the ground surface is about 4.4° C warmer than the mean annual air temperature. The mean annual ground temperature at the point of zero amplitude is normally the same as the mean annual ground temperature.

Increases in the average air temperature will impact the ground temperature. However, ground temperatures also depend on other factors, such as the vegetation cover, terrain (including the slope), winter snow cover, mineralogy, and the water/ice saturation in the ground or soil.

Observations indicate that average Arctic temperatures are increasing at twice the global average. Also, according to the Intergovernmental Panel on Climate Change's *Climate Change 2007; The Physical Science Report*, the temperature at the top of the permafrost layer in the Arctic has generally increased by 3°C since the mid-1980s. The average temperature varies by regions within the Arctic. Furthermore, climate models predict that such average temperature increases will continue until 2100.

Rises in the average atmospheric temperature that raise ground temperatures above 0°C can be expected to turn regions of "cold" permafrost into areas of "warm" permafrost (locations where ground temperature reaches -2°C or warmer). It will also reduce the total area impacted by permafrost. For both existing and future infrastructure, this extends the area where structures built on permafrost are vulnerable to settling.

This case study presents 2006 information on mean annual air temperature and mean annual ground temperature (extrapolated by adding 4.4°C to the mean annual air temperature) at 17 climatic stations within five permafrost regions (Yukon; Western Arctic and Mackenzie Valley; Central Mainland Arctic; and Eastern Arctic and Arctic Islands). The case study also reports on the warming rates of mean annual air temperature and mean annual ground temperature since 1985 for these locations.

Thermosyphon Systems

Thermosyphons are passive systems without power requirements or moving parts. They utilize two-phase liquid-vapour and convection heat-transfer devices to extract heat from the ground and release it to the atmosphere. The lower portion of the thermosyphon is installed in the ground and serves as an evaporator, and the above-ground portion acts as a condenser. Where used in buildings, insulation above the evaporator pipes slows the

heat flow from the building towards the foundation. The thermal properties and thickness of the insulation minimize the introduction of heat into the cooled foundation so that the foundation remains frozen the summer when the thermosyphons do not operate.

Thermosyphon cooling first was used on communications towers in Alaska, starting in the 1960s and similar systems then were adopted for the Trans Alaska Pipeline Systems, where 120,000 thermosyphons were positioned to prevent pipeline supports from settling. Since 1985, approximately 160 thermosyphon systems have been installed at sites in Canada's three northern territories (mostly in the Northwest Territories and Nunavut) as well as in Quebec, Manitoba and Ontario. They have been installed from Thompson, Manitoba, (55° 48'N, 97° 22W) in the south, and north as far as Alert, Nunavut (82° 31N, 62° 17W). These areas have respectively means annual air temperature of -3°C and -18°C.
Canada's first thermosyphons installations were vertical probes used to maintain permafrost around earth embankment. Related solutions in the form of thermopiles and sloped thermosyphons kept structures supported on frozen ground.
Development of more efficient and easier-to-install flat-loop thermistors resulted in increasing use of this innovation at permafrost sites. Since 1994, about 80 such flat-loop systems have been used – mostly for buildings (65) and the rest on dams (15) – to stabilize foundations built on permafrost.

This case study draws on information 11 from thermosyphon projects at 10 sites in northern Canada. They included thermosyphon foundations at three Inuvik, N.W.T. locations – the Female Young Offender Facility, Visitor Centre and Inuvik Hospital – as well as a school in Rankin Inlet, NU. Two detailed thermosyphon case histories from the Yukon – an ice rink in Dawson City and a school at Ross River also were among those reviewed.

The consultant found that in the few cases where buildings supported by thermosyphon foundations functioned poorly, it related to: a) poor design/construction of the granular pads on which the thermosyphon evaporator pipes are founded; b) inadequate construction details, construction scheduling; and c) inadequate insulation design. The case histories of installations with problems do not challenge the thermosyphons foundation design concept but demonstrate the need to improve the design, construction and monitoring of this foundation design.

6.3 Policy Makers Executive Summary

Findings and Observations

Ground-temperature information is important in determining the condition of permafrost and its capacity to support infrastructure.

There is a general lack of such ground-temperature data and, where accessible, it is only available from scattered locations. In the absence of data, a Geological Survey of Canada approach based on average air temperatures being 4.4°C cooler than the mean ground

temperature has been used to estimate the latter. However, there are no standards or guidelines available to estimate the design factors relating to air temperatures, climate warming and ground temperatures. Given increased climate warming, the normal values provided by Environment Canada covering 1970–2000 do not reflect present air temperatures and the length of the freezing season.

Climate information from Environment Canada used by the consultant shows that permafrost temperatures in 80 per cent of 17 representative communities examined in the case study are in the -1°C to -5°C range. Based on projected warming trends, it means the ground will start to thaw within the life span of buildings constructed within the last decade. The severity of the impact on infrastructure will depend on underlying ground conditions and building design.

Figure A-21 Permafrost layers

Buildings in these communities generally are designed to stay stable to a temperature of -2°C. A number of the communities have ground temperature of this value and foundations are showing sign of changes in the magnitude of heaving and settlement. Responses to these conditions have included:

- Locating the buildings on bedrock or ice-free ground underlain by bedrock;
- Using end-bearing piles extending below the ice-rich soil and with designs that allow for settlement correction at the pile cap; and
- Installing thermosyphon foundations.

Thermosyphon systems, which allow permafrost to be kept frozen, have been used since the 1960s. A variant, the flat-loop thermosyphon system used in foundation designs, has been installed in Canada since 1994. Depending on the effective warming of temperatures, both in winter to allow proper re-freezing, and in summer to avoid too much thawing, flat-loop thermosyphons can permit ground to remain frozen for the life span (50 years) of the building.

The current case study – drawing from Canadian sites, the consultant determined that except for six sites studied that had design or construction or materials-quality problems, thermosyphon systems are performing effectively. However, the consultant notes that limited performance records are available and generally are limited to less than one year at most installations.

Thermosyphons cooling systems must be monitored regularly to ensure proper operation. Currently guidelines/standards are not available for design, construction and monitoring of such systems. (See recommendations below.)

Recommendations

The consultant makes several recommendations to better assess the vulnerability and adaptive capacity to climate change of infrastructure foundations in permafrost regions.

Key recommendation centre on preparing guidelines for the collection of data, design, construction, operation, maintenance and monitoring of thermosyphon foundations. The resulting information should be applied to thermosyphon systems now in place and those that will be built.

Specifically, the following recommendations are made.

1) Establish design air temperature and climate warming criteria. This would allow present "normals" and climate warming rates to better reflect the current rates (with "normals" being about 2°C warmer) rather than relying on historic data from 1970 to 2000.
2) Prepare guidelines for geotechnical investigations and collection of design information. Deeper drilling (than the 8 to 10m now common) during initial investigation would provide better information for designing appropriate foundations for permafrost experiencing warming. It would also allow installation of temperature sensors at greater depths, where there are only minor temperature fluctuations.
3) Conduct a calibration and parametric thermal analysis study of thermosyphon foundation design at typical sites to better understand robustness of this design. Such study would provide information on the best combination of design measures (e.g., insulation thickness, evaporator pipe spacing, radiator lengths, pad thickness and saturation) to deal with climate warming.
4) Identify codes and standards that apply to thermosyphon piping. Since thermosyphon piping is a pressure vessel, a qualified engineering firm specializing in pressure vessels should report on this subject.
5) Prepare design and construction guidelines for thermosyphon foundations to inform designers, architects, geotechnical engineers, contractors, inspectors, reviewers and project owners. Issues dealt with by the guidelines would include; foundation pad design, surface and groundwater control, design and location of services within granular pad in slab-on-grade design, as well as construction materials, scheduling and controls.
6) Prepare guidelines for the instrumentation and monitoring for buildings with thermosyphon foundations. The guideline would include information on the design and location of temperature sensors in the ground, the evaporator pipes and radiators. Guidance should be offered for analyzing the resulting data.
7) Preparation of baseline documentation at key existing thermosyphon foundations for monitoring and future studies.

7 Government of Canada Buildings, Tunney's Pasture Campus, Ottawa, Building Infrastructure Vulnerability to Climate Change

7.1 Background

The Public Infrastructure Engineering Vulnerability Committee identified buildings as one of four priority classes of infrastructure for consideration using the First National Engineering Vulnerability Assessment to gauge vulnerability and adaptability of infrastructure to climate change.

Three buildings – one low-rise and two high-rise – at Tunney's Pasture Campus in Ottawa were assessed in this case study. The Sustainable Development Group of HOK Architects of Ottawa conducted the case study.

The consultant used the Engineering Protocol for Climate Change Infrastructure Vulnerability Assessment as a framework. Further information was gathered during site tours and from meetings with facility managers. A knowledgeable site team with many years of experience with the properties also proved helpful.

Figure A-22 Tunney's Pasture, Ottawa, Ontario

7.2 Where, What and How

The Tunney's Pasture Campus is a 46-hectare federal government office colony in the western sector of the City of Ottawa and adjacent to the Ottawa River. The campus contains buildings serving several federal departments and agencies. The federal government owns roads and servicing infrastructure within the campus, which is connected to off-site city owned services.

The case study reviewed three buildings – the Main Statistics Canada Building, the Jean Talon Building and the Brooke Claxton Building – each at varying lifecycle stages. Each site is well documented in building condition reports and asset management plans. Public Works and Government Services Canada owns the buildings and SNC ProFac operates them under contract.

Main Statistics Canada Building

The Main Statistics Canada Building (Building #3) is a two-storey masonry property, with a full basement and partial third and fourth floors. Constructed in 1952, it currently is in its second life-cycle phase. It comprises 39,445.9 m^2 of rentable area. In 2005 the building was designated as a FHBRO (Federal Heritage Buildings Review Office) heritage building. Mainly occupied by Statistics Canada, the building is part of a larger node that includes the internally linked Jean Talon (part of this case study) the R.H. Coats buildings. Other tenants include Health Canada, and Public Works and Government Services Canada. Besides office space, Building #3 provides some storage, class/training rooms, a daycare centre, cafeteria and gym.

Jean Talon Building

The Jean Talon Building is a 13-story high-rise office tower (with a mechanical penthouse) with 55,462m^2 of usable space and Statistics Canada as sole tenant. It has precast concrete-panel construction, was built in 1979 and is at the end of its first life-cycle phase.

Brooke Claxton Building

The Brooke Claxton Building a high-rise with first-generation curtain-wall construction (precast concrete), dates from 1964 and is 10 years into its second lifecycle phase.

Climatic Conditions

Ottawa lies in a continental climate zone characterized by wide swings in seasonal high and low temperatures. Summers are warm (may exceed 30°C) and humid. Snowy and icy

conditions prevail in winter, when temperatures can reach -25°C and ice storms can occur.

The case-study area is served by five Environment Canada weather stations recording temperatures, rain and snow, and one collection wind data.

7.3 Technical Summary

Climate Modeling

In focusing on the vulnerability and adaptability to climate change of three buildings on the Tunney's Pasture Campus, the case study relies on two climate-modeling simulations (Canadian Regional Climate Model) provided by OURANOS. The forecast horizons are based on the years 2020, 2050 and 2080. The OURANOS climate scenario report did not cover humidity; groundwater and water table or flooding from the Ottawa River.

The study draws on Environment Canada weather stations that cover with records back at least 20 years and that have less than 10% missing data.

The following key anticipated weather and climatic factors were considered:

- Temperatures – average monthly and annual maximums and minimums are expected to increase throughout the years under review;
- Rain average total – forecast to increase;
- Rain frequency measured in six-hour and one-day rain event – slight increase expected;
- Snow average totals – decreasing;
- Snow-on rain events – increasing;
- Frost season – decreasing;
- Heating degree days – decreasing;
- Wind – based one weather station;
- Humidity – based on historical data

Hurricanes, tornadoes, thunderstorms, wind gusts were considered but not deemed relevant as they are beyond the current modeling capabilities

Although humidity levels, albedo and solar isolation are beyond current modeling capabilities, they can affect the buildings' heating and cooling loads. Groundwater and the water table (with the proximity of the Ottawa River) are other factors not covered in the OURANOS scenarios.

Sites Reviews

The Tunney's Pasture Campus has a central heating plant that delivers steam and chilled water. For this reason, the cases study boundary is limited to the near vicinity of the buildings and does not include the heating plant.

The infrastructure was reviewed at the following levels:

- Building systems;
- Building operations; and
- Occupant level – comfort levels for occupants.

The following building systems were reviewed for each building:

- Site conditions;
- Building envelope; and
- Mechanical and electrical systems.

Power reliability is a key consideration to ensure electricity is available for lighting, computers and local area network (LAN) rooms. Other key considerations are: meeting life safety requirements of the Building Code and Federal Labour Act requirements for air and lighting levels.

These considerations are outlined below for each of the three buildings.

Main Statistics Canada Building

Overall, the asset is in "average" condition and is reasonably functional. It has received periodic upgrades and refurbishments and, in recent years, various tenant and common areas have been upgraded to current accommodation standards. The present occupancy load is beyond that intended in the original design.

The following outlines key characteristics and conditions of the Main Statistics Canada Building reviewed in the case study.

Building Envelope – The walls, consisting of exterior brick-masonry with terracotta backup, were constructed without proper drainage. Thus, water or moisture can become trapped within the wall system. During cold weather, lack of sufficient insulation affects both the comfort level for the occupants and the performance of the mechanical hot-water radiators on the perimeter walls. With only minimum insulation between the radiator and exterior brick, the supply/return piping can freeze.

Granite stone surrounds the windows and the main entrances, and is predominant on the eight end wings of the building. There are few random cracks in the stone pieces and some of the window sills have spalled on the exterior surface.

Based on the above, the exterior wall construction is considered thermally deficient and requires comprehensive upgrading, including new air barrier, insulation and retrofit of the heating system.

The windows, main and secondary entrance doors and curtainwall assembly above the entrance doors were replaced in 1993-1994 and are in fair-to-good condition.
The building has 16 different roof areas varying from one to 20+ years in age and from excellent to fair condition. Replacement will be staggered throughout the next 30 years. There have been no recent reports of moisture infiltration.

Structural – Believed to be sitting on limestone bedrock, the structural system is in average condition with no apparent sign of significant problems. Seismic screening has been performed with the intent to identify buildings where "reasonable doubt" as to the seismic adequacy exists. Based on the screening, the Structural Index is 17.15 and Non-structural Index is 9.0 with the Seismic Priority Index being 26.15. As such, the SPI indicates a high priority and further investigation is warranted at this time.

Exterior Elements – Although physical inspection of the exterior site conditions was not possible, based on the building condition report, the site components are generally in fair condition. However, some grass-covered areas adjacent to the building have a reverse slope (caused by settlement) towards the building foundation walls and require prompt attention. Other exterior elements considered in the case study include:

- Concrete and masonry walls, including retaining walls;
- Stairs (both in metal and concrete);
- Metal handrails;
- Landscape furnishings (tables, benches and waste receptacles);
- Plazas, decks and loading bays;
- Window and stair wells;
- Manhole and other access point to site services and mechanical systems;
- Playgrounds and daycare exterior program areas;
- Exterior mechanical units (i.e. generators, etc.);
- Signage, flag poles, etc.;
- Areas of storm water discharge being too close to the building;
- Walkways and areas (bituminous, concrete and pavers);
- Parking lots;
- Vegetation (grass, shrubs, trees, etc.); and
- Some foundation walls have areas of water infiltration.

Mechanical Systems – Most of the central air-handling systems were replaced between 1997 and 2007. Some computer-room cooling units were replaced in 2006. Washroom fixtures and piping replacement, started in 2001, continue. Most chilled-water piping was replaced in 1995.

Electrical Systems – Voltage was converted to 347/600V 3ph 4W in the late 1990s and the lighting is being converted to 347V (about 60% completed). Exit lighting and emergency lighting was reviewed and upgraded in 2006. One of the original generators

was removed in the generator room, and a new 1250 KW genset added adjacent to the building in the courtyard, for the fourth-floor data centre.

Figure A-23 Sloping Roof

Jean Talon Building

Built in 1979, the Jean Talon Building connects to the Main Statistics Canada Building (also part of the case study) and the R.H. Coats Building.

The following outlines key characteristics and current conditions of elements the Jean Talon Building reviewed in the case study.

- **Building Envelope –** The roofs, comprised of inverted membrane assemblies, with waterproofing completely hidden by insulation and ballast, have about a 25-year service life and require replacement in 2019. Except for sloped glazing, the window systems are the original ones and should be scheduled for complete replacement in 2029. Throughout the building, window coverings are horizontal metal slat blinds or roller sunshades. The primary entrance doors have a remaining life expectancy of just over 20 years. Service doors are in good condition with replacement required between 15 to 25 years. Cladding consists of a precast concrete curtain-wall. Localized bowing is evident along with failed joint sealant.

- **Exterior Elements –** generally site components are in fair condition. Some areas adjacent to the building have a reverse slope towards the building foundation walls and require prompt attention.

- **Structural –** The structural system is generally in good condition with no sign of significant problems. All footings bear on limestone bedrock with the following allowable bearing pressure capacity: Columns – 120 ksf; Elevator Core, Stairs, Elevator Pits – 50 ksf ; Perimeter Wall, Retaining Walls – 15 ksf. Drawings available for review did not indicate design loading of the concrete slabs. Therefore maximum floor loading is not known. With respect to floor or roof loading, no problems have been reported. Recently, seismic screening has been performed to identify buildings where "reasonable doubt" of seismic adequacy exists. Based on the screening, the Structural Index indicates a low priority and further investigation is not warranted at this time.

- **Mechanical –** Most of the mechanical equipment and materials date from 1976. Generally, setpoints, flow rates, temperatures and capacities have all changed since the building was originally designed. Thus all replacement equipment might be resized to a different capacity from original.

  The building is sprinklered throughout with sprinkler and standpipe systems (combined above grade but separate below grade).

  Mechanical equipment runs according to Treasury Board Secretariat standards. Based on this requirement, a random sample was performed on the 6^{th} floor with supply air from all systems at about 21,236 l/sec (45,000 cfm) and the approximate general airflow rate at about 5.87l/sec per m^2 (1.15 cfm/ft^2). These flow rates are conventional and indicate a sufficient overall airflow rate.

- **Electrical –** Electrical systems are in good condition. The base building lighting fixtures have been upgraded to T-8 fluorescent fixtures. The emergency diesel generator is regularly tested and is in good condition. Variable speed drives for the air-handling units will have to be replaced with new drives. The fire alarm and voice communication system is relatively new and should provide reliable service for many years.

- **Conveying Systems –** The building includes 11 passenger elevators and two hydraulic freight elevators. All passenger and freight elevators were completely modernized four years ago.