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PNGS Climate Resilience Assessment Summary

The effects of climate change are expected to impact many parts of Canadian society, including our energy infrastructure. To better understand these potential impacts, Ontario Power Generation's (OPG's) Pickering Nuclear Generating Station (PNGS) completed an assessment to demonstrate safe and efficient operation of the station for at least the next 30 years under changing climate parameters. This assessment focused on systems related to safety or those having significant economic importance.

The assessment concluded the nuclear safety analysis remains valid. In many cases, existing probabilistic safety assessments already account for worst-case scenarios from weather events, with the Severe Weather Emergency Preparedness Procedure mitigating impacts and ensuring safe operation during extreme weather. OPG is well prepared for extreme weather events, regardless of their cause.

In the longer term, current climate science indicates there is sufficient time to adapt to changing environmental conditions. Analysis of climate projection data for the next ten years provides confidence that any exceedances in operating limits will result in reduced component efficiency or lifespan through accelerated aging, rather than sudden failure. OPG has robust aging management, preventative maintenance and surveillance programs already in place that can accommodate such gradual changes within the anticipated timeframe.

To conduct this analysis, OPG developed a first-of-a-kind industry methodology that aligns with guidance from the Electric Power Research Institute (EPRI) and the Institute of Nuclear Power Operators (INPO). This methodology progresses through four stages:

1. **Climate Hazard Identification and Projections:** Working with climate scientists to understand historical and projected climate risks, including those from Gradual Climate Change (GCC), Extreme Weather Events (EWEs), and Other Natural External Events (ONEEs).
2. **Exposure Assessment:** Determining exposure to climate hazards for high-value or critical Systems, Structures and Components (SSCs).
3. **Vulnerability Assessment:** Evaluating exposed SSCs for potential performance impacts.
4. **Adaptation Options Strategy:** Developing potential adaptation options for identified SSCs.

Further detailed analysis is being planned that incorporates system and site-specific climate projections prior to determining appropriate treatment plans and associated timeframes, while leveraging existing systems and processes wherever feasible. OPG's resilience strategy combines the site's proven ability to manage extreme conditions with a graded approach to risk management.

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REPORT

KINECTRICS

PICKERING NGS UNITS 5-8: CLIMATE SUSCEPTIBILITY AND ADAPTATION SUMMARY REPORT

PV273/RP/0002 R03

March 31, 2025

Prepared for

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EXECUTIVE SUMMARY

Ontario Power Generation's (OPG) Pickering Nuclear Generating Station Station is located on Williams Treaties First Nations traditional and Treaty Territory, situated on the north shore of Lake Ontario, within the City of Pickering, in the Regional municipality of Durham, Ontario. OPG values the relationship it holds with the Williams Treaties First Nations and remains committed to meaningful engagement with them, including in the areas of environmental stewardship and climate change.

OPG developed an industry first of a kind methodology to generally align with the nuclear industry accepted Electric Power Research Institute (EPRI) "*Climate Vulnerability Assessment Guidance for Nuclear Power Plants*" Technical Report # 3002023814 which is available to public online at https://www.epri.com/research/programs/061177/results/30 02023814. The climate resilience assessment at OPG involved a sequence of evaluations including: climate hazard identification and projections, exposure assessment, vulnerability assessment followed by identification of adaptation options.

Analysis of recent data from 2010 through 2020 shows that extreme events have an essentially negligible impact on nuclear generation capacity factors (the percentage of the time the nuclear power plant (NPP) is running at full power and providing electricity to the grid), which are by far the highest of any carbon-free source of generation.

Climate-related hazards may negatively impact operation of Pickering 5- 8. These hazards may come in the form of gradual climate change (GCC), extreme weather events (EWEs), or other natural external events (ONEEs). Modifications to safety-related and economically important equipment and other adaptive measures may be required to ensure the continued safe operation of the plant and in turn would help alleviate effects from climate-related hazards.

A project was initiated by OPG to identify and assess the climate vulnerability of high value, either safety-related or economically important, systems. A screening assessment was performed to narrow down the list of systems, structures and components (SSCs) to those that were considered safety-related or high value and that were potentially impacted by climate change hazards. A vulnerability assessment (summarized in Section 3.0) was performed for 39 systems and 17 hazards. Systems which were determined to have one or more components that are impacted by climate change were concluded to be potentially susceptible to climate change. SSCs which were not determined to be impacted by a climate change hazard but are expected to have reduced, or encroached upon, margins for operation were also identified.

Adaptation options were presented in a graded approach to take advantage of improvements to existing programs/procedures first, followed by adaptations by the site which increase in complexity to potentially replace infrastructure to improve PNGS resilience to climate change. With the implementation of updates to many of OPGs programs and plans, many of the climate-related hazards would be addressed; however, OPG will need to implement design changes or updates to systems for longer term adaptation.

Climate change is seen as a gradual change which is likely to increase the severity of hazards already evaluated and screened routinely. Routine preventative maintenance programs and measures to monitor the daily operation of the plant are seen as sufficient to discover changes being brought on to PNGS by climate change.

An important procedure for adapting to climate change is the Severe Weather Emergency Preparedness procedure (N-PROC-RA-0095) as it addresses responses to storms and more severe weather events anticipated with climate change. This procedure also helps to mitigate climate hazards where there is low confidence in available climate projection data. Additionally, the winterization and summarization procedure (NK30-ESI-01510-00001 R001) addresses many climate-related impacts, although it is expected that this procedure will need to be revised as climate shifts. These procedures will help adapt to climate hazards, especially those where there is low confidence on climate projections data.

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1.0 INTRODUCTION

Ontario Power Generation's (OPG) Pickering Nuclear Generating Station (PNGS) is located on Williams Treaties First Nations traditional and Treaty Territory, situated on the north shore of Lake Ontario, within the City of Pickering, in the Regional municipality of Durham, Ontario. OPG values the relationship it holds with the Williams Treaties First Nations and remains committed to meaningful engagement with them, including in the areas of environmental stewardship and climate change. OPG plans to share this report with First Nations rights holders and welcomes feedback and perspectives to inform future revisions.

As a climate change leader, one of the guiding principles from the OPG Climate Change Plan[1] includes engaging Indigenous Nations and communities and reaffirms OPG's commitment to grow long-term, mutually beneficial working relationships with Indigenous Nations and communities near our current and future operations. The Plan highlights OPG's climate goals, including the value of nuclear refurbishment and continued operations, as well as an action plan. Additionally, OPG's Reconciliation Action Plan[2] includes a key pillar of Environmental Stewardship, and specifically for climate change, identifies opportunities to work towards seeking to incorporate Indigenous values and priorities within climate assessments, and to work with Indigenous Nations and communities to gather and share perspectives about climate change.

OPG developed an industry first of a kind methodology to generally align with the nuclear industry accepted Electric Power Research Institute (EPRI) "*Climate Vulnerability Assessment Guidance for Nuclear Power Plants*" . The climate resilience assessment at OPG involved a sequence of evaluations:

1. **Climate Hazard Identification and Projections:** Climate hazards identification and characterization constitute a critical step in performing a site climate change resilience assessment. OPG collaborated with multiple climate scientists to identify various climate-related hazards, including gradual climate change (GCC), extreme weather events (EWEs), and other natural external events (ONEEs). OPG completed a customized assessment of physical climate hazards at PNGS nuclear to better understand historical and projected climate-related risks.
2. **Exposure Assessment:** A screening assessment was performed to evaluate a list of Systems Structures and Components (SSC) and determined if they met criteria for being high value or critical components and determined if they are exposed to climate hazards.
    a) **Climate Hazard Identification and Projections:** Climate hazards identification and characterization constitute a critical step in performing a site climate change resilience assessment. OPG collaborated with multiple climate scientists to identify various climate-related hazards, including gradual climate change (GCC), extreme weather events (EWEs), and other natural external events (ONEEs). OPG completed a customized assessment

[1] OPG's Climate Change plan outlines the goals that will guide OPG's actions to address climate change. https://www.opg.com/documents/opg-climate-change-plan-2020/

[2] OPG's Reconciliation Action Plan is the roadmap for partnership with Indigenous communities, businesses, and organizations. https://www.opg.com/documents/reconciliation-action-plan-pdf/

of physical climate hazards at PNGS nuclear to better understand historical and projected climate-related risks.

b) **Exposure Assessment:** A screening assessment was performed to evaluate a list of Systems Structures and Components (SSC) and determined if they met criteria for being high value or critical to safety components and determined if they are exposed to climate hazards.

3. **Vulnerability Assessment**: Assess the possible impact of climate on identified SSC. This involved comparing the climate data against the SSC design requirements to assess the impact of climate on the system. Existing margins to key parameters were identified and compared with projected future changes to environmental/climate indicators to identify systems which may be subject to climate change effects.

This document provides a summary of the reports, presenting first the exposure and vulnerability assessment followed by the adaptation measures identified. This document is intended to provide an accessible, yet complete, summary of the evaluation.

1.1 Objectives

The objective of the project was to:

- Determine the systems, structures and components that are important for nuclear safety, or which have economic importance to the station and may be impacted by climate change. These results are in [1] and [2].
- Evaluate the effect of climate change on the list of SSCs determined, based on projected changes to environmental parameters, and identify which environmental/climate parameters will impact the equipment, as well as where limits may be exceeded for each SSC identified in the exposure assessment. These results are in [3] and [4].
- Identify possible adaptation measures to address the risks associated with climate change. This strategy in full is [5].

1.2 Acronyms

ACU	Air Condition Unit
CCW	Component Cooling Water
CER	Control Equipment Room
CERC	Control Equipment Room Cooling
DAWR	Design/Analysis Work Require
DWI	Deep Water Intake
ECI	Emergency Coolant Injection
EPG	Emergency Power Generator
EPRI	Electric Power Research Institute
EWE	Extreme Weather Event
EWS	Emergency Water Supply
EWPSB	Emergency Water and Power Supply Building
FADS	Filtered Air Discharge System

GCC	Gradual climate change
GHG	Greenhouse gas
HX	Heat exchanger
HVAC	Heating, Ventilation and Air Conditioning
IPCC	Intergovernmental Panel on climate change
MPO	Main Power Output
ONEE	Other Natural External Events
OPEX	Operating Experience
OPG	Ontario Power Generation
PEVS	Powerhouse emergency venting
PNGS	Pickering Nuclear Generating Station
RCP	Regional climate projection
RMP	Risk monitoring plan
SIS	Systems important to safety
SG	Standby Generator
SSC	systems, structures and components

2.0 CLIMATE HAZARDS

The changing climate poses potential threats and uncertainties to existing and planned infrastructure. Widespread and rapid changes in the atmosphere, ocean, cryosphere, and biosphere have occurred. Human-caused climate change is already affecting many weather and climate extremes in every region across the globe. Due to the changes both globally and regionally, design parameters based on historical weather and climate information might no longer be sufficient and may need to be revised to consider local climate change. Analysis of recent data from 2010 through 2020 shows that extreme events have an essentially negligible impact on nuclear generation capacity factors (the percentage of the time the nuclear power plant (NPP) is running at full power and providing electricity to the grid), which are by far the highest of any carbon-free source of generation [6].

Climate change is caused by anthropogenic emissions of greenhouse gases (GHGs) arising from unsustainable energy use; the large-scale transformation of land use, primarily urbanization and deforestation; and lifestyles and patterns of consumption and production across regions. Historical GHG emissions have led to an increase of the global mean temperature of about 1.1°C in 2011-2020 compared to 1850-1900. GHG emissions in 2030 implied by nationally determined contributions make it likely that warming will exceed 1.5°C during the 21st century and make it harder to limit warming below 2°C. Depending on the future emissions of GHGs, the global mean temperature could increase by up to 3.3°C by 2100 [7].

Based on the site location, the climate change-related hazards identified in Table 1 were determined by OPG, and subsequently prioritized based on assessment of climate bounded data [8].

Table 1: List of Climate Change-Related Hazards Grouped by Priority

High Priority	Medium Priority	Low Priority
Gradual Climate Change (GCC)		
Increasing ambient temperature	Low lake/river-level and hydrological drought	Air quality (pollution)
Increasing water temperature	Acidification (of the ocean or lake)	Humidity
Total precipitation	-	-
Extreme Weather Events (EWEs)		
Extreme high water temperature	Blizzard/snowstorm	Extreme soil temperature
Extreme low water temperature	Cold spell	Extreme air pressure
Flooding due to rising lake water level	Downburst/derecho	Flash freeze
Flooding due to runoff, riverine flooding, local site area flooding (including snow melt)	Extra-tropical storm	-
Flooding due to waves, storm surges, seiche, meteotsunami, waterspout, and tsunami	Extreme snowfall	-
Extreme high air temperature	Extreme snowpack/snow accumulation	-
Extreme low air temperature	Heat wave	-
Extreme rainfall (probable maximum precipitation)	Hurricane/typhoon	-
Tornado	Ice storm/freezing rain/sleet	-
Other Natural External Events (ONEEs)		
Flooding due to high groundwater	-	Landslide/slope instability
Flooding due to sudden release of water from natural or artificial storage	-	Soil frost
Flooding due to upstream obstruction upstream of river channels (by landslides, ice jams, logs, debris, or volcanic materials)	-	Coastal erosion (erosion by water)
-	-	Frazil ice/ice barrier/surface ice (on river or lake)
-	-	Biofouling

The assessments in this project are evaluated only against the high and medium priority climate hazards.

The PNGS Climate Change Bounding Analysis memo [8] provides the bounding/threshold values for each climate change-related hazard selected, their source, climate projections associated under the Intergovernmental Panel on Climate

Change's (IPCC) Regional Climate Projection (RCP) 8.5 and RCP 4.5[3] scenarios, and justification for their selection. Where a bounding/threshold value could not be identified, a rationale was provided. The bounding/threshold values for RCP 4.5 and RCP 8.5 were used to assess the impact of the climate change-related hazards on the exposed SSCs.

A summary of the results of the PNGS Climate Change Bounding Analysis memo [8] can be found in Table 2 for both RCP4.5 and RCP8.5. Based on the results of this memo, some climate change-related hazards were not assessed further as their projections indicated that future climate-related hazards are expected to be bounded by historic conditions.

Table 2. Summary of PNGS Climate Hazards Bounding Analysis Results

Hazard			Result	Assessed (Y/N)	
				RCP4.5	RCP8.5
Gradual Climate Change (GCC)	Increasing ambient temperature		For both the RCP4.5 and RCP8.5 scenarios, the daily and monthly minimum, mean, and maximum temperature increases with progressing climate change.	Y	Y
	Increasing water temperature		The overall agreement between water and air temperature is good. Therefore, as the ambient temperature increases, the average annual mean water temperature increases.	Y	Y
	Total precipitation		In both the RCP4.5 an RCP8.5 scenarios, the annual precipitation and rainfall increases with progressing climate change. The annual snowfall increases in both scenarios for the 2021-2050 period before it reverts to the historical amount in the RCP4.5 scenario and significantly decreases in the RCP8.5.	Y	Y
	Low lake/ river-level and hydrological drought		With the projected increase in air temperature, evaporation of the lake will increase. Although no significant overall trend in low lake levels is projected for either emission scenario, it is probable that low lake level events will become more frequent and lower in amplitude over the course of the century. For high lake water levels, see "Flooding: Rising Lake Water Level".	Y	Y
	Acidification (of the ocean or lake)		A decrease in mean annual pH value and hence an increase in acidity is projected for high-emission (RCP8.5) scenarios. While lower mean pH levels could point towards lower absolute minima, additional detailed information is missing to assess extreme values for Lake Ontario at this time.	N	Y
Extreme Weather	Water Temp	Extreme high	The extreme water temperature is projected to increase by 1.2 °C and 3.1 °C in the RCP4.5 and RCP8.5, respectively.	Y	Y

[3] The IPCC has defined four RCPs which describe different 21st century pathways of GHG emissions and atmospheric concentrations, air pollutant emissions, and land use leading to specific radiative forcing characteristics extending up to the year 2100. The RCPs are used for making projections based on the factors which primarily drive anthropogenic GHG emissions: population size, economic activity, lifestyle, energy use, land use patterns, technology, and climate policy. The RCPs include a stringent mitigation scenario (RCP2.6), two intermediate scenarios (RCP4.5 and RCP6.0) and one scenario with very high GHG emissions (RCP8.5) [6].

Hazard			Result	Assessed (Y/N)	
				RCP4.5	RCP8.5
Events (EWEs)		Extreme low	The measured extreme low water temperatures will be higher than historical temperatures under the influence of either emissions scenario. While the water temperature extreme will increase by 0.6 °C in the RCP4.5 scenario, it is projected to increase by 1.4 °C in the high emission scenario. Therefore, the extreme low water temperature that SSCs will be subjected to will be higher than what they have been subjected to in the past. This hazard will not be assessed further as it represents a less extreme low temperature than previously experienced.	N	N
	Flooding	Rising lake water level	An increase in the annual lake level maximum is projected for both emission scenarios.	Y	Y
		Runoff, riverine flooding, local site area flooding	Extreme rainfall events can lead to flooding when either the design limits of the storm sewer systems are exceeded or when the soils cannot absorb the rainfall fast enough. Extreme rainfall events are expected to increase, and therefore incidents of flooding due to runoff can be expected to increase.	Y	Y
		Waves, storm surges, seiche, meteotsunami, waterspout, and tsunami	The historical absolute maximum wave height 3.1 m will not be reached as the projected highest wave of all storms will likely be 2.8 m. However, on average, the projected wave height is 2.2 m compared to the historical one of 2.1 m. Hence, no significant trend in wave height and consequent flooding is projected for PNGS. Therefore, this will not be assessed further.	N	N
	Air Temp	Extreme high	There is expected to be an increase in extreme high air temperatures for PNGS.	Y	Y
		Extreme low	There is expected to be an increase in extreme low air temperatures for PNGS. Therefore, the extreme low air temperature that SSCs will be subjected to will be higher than what they have been subjected to in the past. This hazard will not be assessed further as it represents a less extreme low temperature than previously experienced.	N	N
	Extreme rainfall		The 10-year event of annual maximum of the daily rainfall is projected to increase under both emissions scenarios.	Y	Y
	Tornado		The frequency, intensity, and areal extent of thunderstorms and their associated features such as tornados in relation to climate change is difficult to assess. The occurrence of more and more severe thunderstorms and tornados with progressive warming is possible in southern Ontario. However, a conclusive statement about the change in frequency or intensity of tornados with climate change is not possible due to the limited predictability of these features.	Y	Y
	Blizzard/ snowstorm		For the end of the century, the frequency of snowstorms north of Lake Ontario is projected to decrease by 20 to 30% in the RCP8.5 scenario as more winter precipitation will shift to rainfall. Due to limited predictability, it is currently not possible to provide projections regarding changing in intensity of blizzards and snowstorms with climate change.	Y	Y
	Cold spell		Cold spells, defined as at least 3 consecutive days with daily minimum temperatures below -20 °C are unlikely to be a significant climate hazard at PNGS. Although, the probability of cold spells will likely	N	N

Hazard		Result	Assessed (Y/N)	
			RCP4.5	RCP8.5
		increase over the mid-term, it will remain very low. Therefore, this hazard will not be assessed further.		
	Downburst/ derecho	The impact of climate change on the ‘ingredients’ for derechos points towards the potential of more frequent and/or more intense derechos, no scientific consensus has been reached. However, as the jet stream shifts further poleward with climate change due to the faster warming of the Arctic, the favorable conditions for derechos will also shift further north. This could increase the frequency of derechos in southern Ontario.	Y	Y
	Extra-tropical storm	With a warmer Arctic, the jet stream will likely shift further north in winter, potentially bringing PNGS into the path of the jet stream and extra-tropical cyclones. No scientific consensus on the impact of climate change on the path, strength, and frequency of extra-tropical cyclones has been reached and future changes to these storms remain uncertain.	Y	Y
	Extreme snowfall	Overall, the trend in extreme snowfall amounts is weak likely due to offsetting effects of increased winter precipitation and warmer winter temperatures. There is projected to be a small decrease in extreme snowfall for PNGS. Therefore, this hazard will not be further assessed as it is projected to be less extreme than previously experienced.	N	N
	Extreme snowpack/ snow accumulation	There is projected to be an increase in extreme snowpack for PNGS for the intermediate-emission scenario (RCP4.5) and in decrease for the high-emission RCP8.5. Therefore, this will not be assessed for RCP8.5.	Y	N
	Heat wave	Heatwaves, defined as at least 3 consecutive days with daily maximum temperatures above 30 °C are likely to increase in frequency, length, and intensity at PNGS.	Y	Y
	Hurricane/ typhoon	The wind speed and rainfall associated with tropical cyclones are projected to increase as a result of climate change.	Y	Y
	Ice storm/ freezing rain/ sleet	Freezing rain is projected to decrease under the RCP8.5 scenario as winter temperature will increase and precipitation will shift to rainfall. No projection was provided for the RCP4.5 scenario; it is assumed to remain unchanged. Therefore, this hazard will not be assessed further as it is not projected to be more extreme than previously experienced.	N	N
Other Natural External Events (ONEEs)	Flooding due to high groundwater	These hazards are bounded by Extreme Rainfall and High Lake Water Levels.	N	N

2.1 Climate Projections

All climate projections used in this project are shown in Appendix A.

3.0 CLIMATE EXPOSURE AND VULNERABILITY ASSESSMENT

3.1 Summary

The exposure assessment evaluated a list of SSCs and determined if they met criteria for being high value or critical components and then if they were possibly impacted by climate hazards. This exposure assessment limited the SSCs to those at potential risk of exposure to climate change-related hazards, in addition to several systems that were added by OPG as high value. The next phase was to take the equipment from the climate exposure assessment, and to identify which environmental/climate parameters were expected to impact the equipment, as well as where limits may be exceeded for each of the critical SSCs identified in the memo. This assessment also evaluated potential consequences of a changing climate and provided options for responding or adapting to manage the exposure.

The vulnerability assessment was performed for 39 systems and 17 hazards. Two hazard combinations of concurrent hazards which may result in increased impact to the SSCs were also assessed. Systems which were determined to have one or more components that are impacted by climate change were concluded to be susceptible to climate change. SSCs which were not determined to be impacted by a climate change hazard but are expected to see their margins for operation encroached on were also identified.

In total, 31 systems were identified as susceptible to climate change-related hazards or having their margins encroached on as a result of climate change. No systems were identified to be impacted by low lake/river level and hydrogeological drought. Although a number of systems were determined to be potentially impacted by high wind-related hazards, climate change projections are not currently available for these hazards. This susceptibility was not new with climate change impacts as they are assessed in high wind-specific assessments.

3.2 Methodology

Evaluating and managing the risk of climate change consists of a sequence of assessments. It begins with an assessment of the climate related hazards, evaluating potential changes in physical climate conditions (e.g., increase in lake temperature or ambient temperature) and is followed by evaluating the impact on the exposed systems [9]. The exposure assessment evaluated which SSCs might be in harm's way while the vulnerability assessment evaluated the potential consequences of exposure to a changing climate and provided preliminary options for responding or adapting to manage the impact.

The climate exposure assessment used a list of systems provided by OPG for consideration and the list of climate hazards listed in Table 1 as input and performed a screening assessment as follows:

1. Screened the list of systems for critical and high-value components / equipment among impacted assets to avoid redundant screening. Critical and high-value components and equipment included those important for nuclear safety and those which are economically important. Equipment important to nuclear safety was identified by searching through Operational Safety Requirements and other related documents, while economically important equipment was identified by having experienced operations staff review system design and operating documents and apply judgement. This screening of systems is described further in [1].

2. Of the critical components and equipment that were screened in during the previous step, screening was performed for susceptibility to climate-related impacts to determine SSCs which may be exposed to climate change-related hazards. The existing list of climate hazards includes external hazards resulting from GCC, EWEs, and ONEEs. Only the hazards identified as high- and medium-priority were considered in this assessment.
3. For SSCs which were screened in during step 2, key components were identified.

Subsequently, these identified SSCs were further evaluated to assess the susceptibility of these systems to the impacts of climate change, based on projected environmental values. This assessment was performed as follows for each identified asset:

4. Impacting climate variables (e.g., lake water/ ambient air temperatures) were identified. Indicators were selected to represent these variables.
5. Key limits and operational constraints for the equipment were identified.
6. Existing margins to key parameters were identified and compared with projected future changes to environmental/climate indicators to identify systems which may be subject to climate change effects. Impacts under different scenarios and concurrent hazards (i.e., hazard combinations) were considered.

To propose initial adaptation measures, existing programs were identified which are in use currently and can be adapted to consider impacts from climate change.

3.3 Exposure Assessment

3.3.1 Screening Criteria

Systems Important to Safety (SIS) include those structures and systems of the power plant which contribute significantly to the initiation, prevention, detection or mitigation of any failure sequence which could lead to damage of fuel or associated release of radionuclide or both [10].

The list of systems provided was screened to determine critical and high-value systems and components, which included those important for nuclear safety and those which are economically important. The screening was performed sequentially, with items screened first for safety and then for economics if not screened in for safety. The systems which were screened IN for safety or economic importance were then screened to determine their exposure to climate change-related hazards. The systems which were determined to be important and potentially susceptible to climate change-related are listed in Table 3. OPG requested several additional systems be included for consideration; these included:

- High value and critical heat exchangers such as moderator heat exchangers, shutdown cooling heat exchangers, and irradiated fuel bay heat exchangers.
- Rooms that contain batteries or other critical control equipment.
- Other equipment which may provide cooling.

Table 3. Safety or Economically Important Systems Exposed to Climate Hazards

Systems	
Air Systems	Irradiated Fuel Storage Bay Cooling

Systems	
Annulus Gas	Liquid Zone Control
Boiler Feedwater	Main Power Output
Buried Piping	Main Steam/Boiler Blowdown
Class I/II Battery Rooms	Moderator System
Class III	Powerhouse Emergency Venting
Class IV	Powerhouse Ventilation
Condenser Cooling Water	RAB Chilled Glycol System
Control Equipment Room Cooling	RB Ventilation and Vapour Recovery
Cover Gas	Reactor Building Cooling
Emergency Coolant Injection	Recirculating Cooling Water
Emergency Power Generator Cooling	Screenhouse
Emergency Power Supply	Service Water
Emergency Water Supply	Shutdown Cooling
End Shield Cooling	Standby Generators
Filtered Air Discharge System	Standby Generator Cooling
Fire Systems	Structures
Generator	Turbine
Generator/Turbine Cooling	Vacuum Building
Heating, Ventilation, and Air Conditioning	-

3.4 Vulnerability Assessment

The screened in systems were then assessed against the climate hazards presented in Section 2.0. In the context of this report, "susceptibility" to climate change-related hazards is defined as a projected hazard condition which may exceed operational parameters of the SSC at some point during the life of the station brought on by the long-term effects of climate change. It is also possible that the design and operational parameters for key SSCs will not be exceeded, but the projected hazard condition brought on by climate change may encroach on the margin for operation; in this case, an SSC has not been designated as being "susceptible", but it has been noted that the margin for operation may be reduced.

A summary of the SSCs susceptibility to climate hazards is presented in Table 4. Systems which were determined to have one or more components that are susceptible to climate change are marked with "S". SSCs which were not determined to be susceptible to a climate change hazard, but which may see a reduced margin for operation are marked with "M". Hazards for which climate change projections are not available are marked with "P".

Table 4. Summary of SSC Status

System/Climate Hazard	Gradual Climate Change (GCC)					Extreme Weather Events (EWEs)												Combined Hazards	
							Flooding				High Winds							Precipitation and	
	Incr. ambient temp	Incr. water temp	Total precip.	Low lake/ river-level and hydrological drought	Acidification (of the ocean or lake)	Water Temp: Extreme high	Rising lake water level	Runoff, riverine flooding, local site area flooding	Air Temp: Extreme high	Extreme rainfall	Tornado	Extra-tropical storm	Down burst/ derecho	Blizzard/ snow storm	Extreme snowpack/ snow accumulation	Heat wave	Hurricane/ typhoon	Flood	High Wind
Air Systems	S	-	-	-	-	-	-	-	S	-	P	P	P	-	-	S	S	-	P
Annulus Gas	-	-	-	-	-	-	-	-	-	-	P	P	P	-	-	-	S	-	P
Boiler Feedwater	-	M	-	-	S	M	-	-	-	-	-	-	-	-	-	-	-	-	-
Buried Piping	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Class I/II Battery Rooms	S	-	-	-	-	-	-	-	S	-	P	P	P	-	-	S	-	-	P
Class III	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Class IV	M	-	S	-	-	-	-	S	M	S	P	P	P	S	S	M	S	-	P
Condenser Cooling Water	-	M	-	-	S	M	-	-	-	-	-	-	-	-	-	-	S	-	-
Control Equipment Room Cooling	M	-	-	-	-	-	-	-	M	-	P	P	P	S	-	M	-	-	P
Cover Gas	-	S	-	-	-	S	-	-	-	-	-	-	-	-	-	-	-	-	-
Emergency Coolant Injection	-	-	-	-	-	-	-	S	-	S	P	P	P	-	-	-	-	S	P
Emergency Power Generator Cooling	S	-	-	-	-	-	-	-	S	-	P	P	P	S	-	S	-	-	P
Emergency Power Supply	S	-	S	-	-	-	S	S	S	S	P	P	P	-	-	S	-	S	P
Emergency Water Supply	-	S	-	-	S	S	M	-	-	-	P	P	P	-	-	-	-	S	P
End Shield Cooling	-	S	-	-	-	S	-	-	-	-	-	-	-	-	-	-	-	-	-
Filtered Air Discharge System	-	-	-	-	-	-	-	-	-	-	P	P	P	-	-	-	-	-	P
Fire Systems	-	-	-	-	-	-	-	-	-	-	P	P	P	S	S	-	-	-	P
Generator	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Generator/Turbine Cooling	-	S	-	-	-	S	-	-	-	-	-	-	-	-	-	-	-	-	-
Heating, Ventilation, and Air Conditioning	M	-	-	-	-	-	-	-	M	-	P	P	P	S	-	M	-	-	P
Irradiated Fuel Storage Bay Cooling	-	S	-	-	S	S	-	-	-	-	-	-	-	-	-	-	-	-	-
Liquid Zone Control	-	M	-	-	-	M	-	-	-	-	-	-	-	-	-	-	-	-	-
Main Power Output	M	-	S	-	-	-	-	S	M	S	P	P	P	S	S	M	S	-	P
Main Steam/Boiler Blowdown	-	-	-	-	-	-	-	-	-	-	P	P	P	-	-	-	-	-	P
Moderator System	-	S	-	-	S	S	-	-	-	-	-	-	-	-	-	-	-	-	-
Powerhouse Emergency Venting	-	-	-	-	-	-	-	-	-	-	P	P	P	S	S	-	-	-	P
Powerhouse Ventilation	M	-	-	-	-	-	-	-	M	-	P	P	P	S	-	M	-	-	P
RAB Chilled Glycol System	M	-	-	-	-	-	-	-	M	-	P	P	P	-	-	M	S	-	P
RB Ventilation and Vapour Recovery	M	-	-	-	-	-	-	-	M	-	P	P	P	S	-	M	-	-	P
Reactor Building Cooling	-	S	-	-	-	S	-	-	-	-	-	-	-	-	-	-	-	-	-
Recirculating Cooling Water	-	M	-	-	-	M	-	-	-	-	-	-	-	-	-	-	-	-	-

System/Climate Hazard	Gradual Climate Change (GCC)					Extreme Weather Events (EWEs)												Combined Hazards	
							Flooding				High Winds							Precipitation and	
	Incr. ambient temp	Incr. water temp	Total precip.	Low lake/ river-level and hydrological drought	Acidification (of the ocean or lake)	Water Temp: Extreme high	Rising lake water level	Runoff, riverine flooding, local site area flooding	Air Temp: Extreme high	Extreme rainfall	Tornado	Extra-tropical storm	Down burst/ derecho	Blizzard/ snow storm	Extreme snowpack/ snow accumulation	Heat wave	Hurricane/ typhoon	Flood	High Wind
Screenhouse	-	-	-	-	S	-	S	S	-	S	-	-	-	-	-	-	S	-	-
Service Water	-	S	-	-	S	S	-	-	-	-	-	-	-	-	-	-	S	-	-
Shutdown Cooling	-	S	-	-	S	S	-	-	-	-	-	-	-	-	-	-	-	-	-
Standby Generator Cooling	S	-	-	-	-	-	-	-	S	-	P	P	P	-	-	S	-	-	P
Standby Generators	S	-	S	-	-	-	-	-	S	S	P	P	P	-	-	S	-	-	P
Structures	-	-	-	-	-	-	-	-	-	-	P	P	P	-	-	-	-	-	P
Turbine	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Vacuum Building	-	-	-	-	-	-	-	-	-	-	P	P	P	-	-	-	-	-	P

S – SSC is susceptible to the hazard

M – SSC is not considered susceptible but may see reduced margin for operation.

P – Climate change projections are not currently available

“-“ – No climate change hazard susceptibility anticipated

4.0 CLIMATE RISK ADAPTATION STRATEGIES

4.1 Summary

This section summarizes the potential adaptation options for SSCs which may be impacted by climate change-related hazards.

Adaptation options were provided for the SSCs identified for the impacted systems listed in Table 4, with the following exceptions:

- Systems that were determined to have no impact from climate change-related hazards:
    - Buried piping.
    - Class III.
    - Generator (Main Generator, 41000-TURBINE GEN).
    - Turbine (High-Pressure Turbine (41110-HP) and the Low-Pressure Turbines (41110-LP1/2/3).
- Systems that were only impacted by high wind hazards, as suitable recommendations are made for these hazards in existing assessments and no additional climate change adaptation will be required:
    - Filtered Air Discharge System (FADS).
    - Main Steam/Boiler Blowdown.
    - Structures.
    - Vacuum Building.

For the remaining systems, adaptation options were provided for 90 pieces of equipment, divided into different equipment types. The adaptation options are provided for each equipment type, with options presented for specific equipment as applicable in Table 5.

The adaptation options presented fall under five general categories, as shown in Figure 1:

- Design/Analysis Work Require (DAWR).
- Risk Monitoring Plan Required (RMP).
- Update to OPG governance/procedure required.
- No risk treatment required.

The majority of adaptation options are for design or analysis work, but options also include updates to OPG governance and procedures, and risk monitoring plans. Items that fall under “No risk treatment required” include existing programs, procedures, and the flood protection system, for which updates are not currently required but which can be leveraged to adapt to the risks of climate change. Many risks which are within the near-term can be adapted to through, or with minor revisions to, current OPG processes, programs or procedures.

4.2 Methodology

Adaptation and climate change response options were identified for each of the SSCs identified as susceptible to climate change-related hazards. These adaptation and risks response options consider a graded approach to take advantage of improvements to existing programs/procedures first, followed by adaptations by the site which will increase in complexity and cost up to eventual consideration of capital expenditures to upgrade under-performing infrastructure.

4.3 Adaptation Strategies

4.3.1 Existing Programs/Initiatives

There are several general programs currently in place which can be leveraged or updated to accommodate the potential changing conditions to which the SSCs will be exposed. Outlined below are the inspection and maintenance programs in place to mitigate for corrosion, wear, aging, and damage of safety-related equipment:

- Equipment Reliability [11].
- Component And Equipment Surveillance [12].
- Integrated Aging Management [13].
- Equipment Strategy Manuals.
- PNGS Component Surveillance and Maintenance Requirements-Winterization/Summerization Program [14].
- System Performance Monitoring Plans, system based.

The measures mentioned above are applicable to climate hazards such as acidification of the lake, elevated temperatures of air and the lake, and flooding. Mitigation of corrosion to various equipment from acidification of the lake can be achieved through these existing programs.

The flood protection system at Pickering Units 5-8, which consists of the shoreline breakwater works, Catch Basins, and storm sewers [15], and in the Switchyard, which has subsurface drainage [16] acts as a mitigation for many of the flood related hazards. Other mitigating actions for severe weather events such as heavy rain, flooding events, high heat, blizzards and other winter storms, and high winds, are outlined in the Severe Weather Emergency Preparedness procedure [17]. This procedure has been successfully implemented at PNGS for severe weather events, with no production losses. The procedure includes actions which vary for each weather event but include actions such as monitoring plant areas for ingress of water, a review of equipment affected by high heat, and clearing snow and ice from around high voltage outdoor transformers.

The Pickering Snow Removal and Winterization program is in place October to April. The Snow Removal procedure specifies the requirements to assess the needs for snow removal or salting and to monitor weather conditions to anticipate changes [18]. Additionally, the Winterization/Summerization Program strategy instruction [19] and program [14] outline the seasonal hazards and the process for preparing the station for winter and summer conditions. However, these documents focus on the hazards of cold weather and the requirements for winter weather conditions. These programs should be expanded as follows:

- Additional hazards associated with increasing temperatures should be considered. The average ambient temperature is expected to increase year-round, but additional actions should be considered for increasing summer temperatures.
- The dates for winter and summer conditions (November 1 and May 15, respectively) should be periodically reviewed to ensure they remain reflective of the change in seasonal conditions.
- When preparing the scope for the following season, challenge any existing station seasonal checklist or scope for robustness, considering industry best practices.
- Snow removal is currently limited to areas of site, additional areas such as transformers, rooftops, and vents (where accessible) should be added.

There are several design changes which will also address several climate hazards:

- Find a replacement SG: The logic of the SGs will bypass the intake air temperature trips under emergency conditions and run the machines to failure. The potential impacts of changes in ambient climate will need to be considered during the design phase of the new machines.
- Deep Water Intake (DWI): Installation of a DWI has been proposed at Pickering Units 5-8. Design and environmental work have already begun on this initiative. A DWI supplying LPSW at a cooler temperature may mitigate against the impacts of increasing ambient air temperatures. A DWI may protect the margins on equipment that would otherwise be encroached on by increasing lake temperature in addition to a reduction of debris or other foreign material.
- Perform equipment redesign and replacement as recommended.
- CCW/ Service Water: Clean the CCW intake duct and Service Water suction pits. Accumulated debris (zebra mussels, sild, etc.) can have an adverse effect on CCW pumps and/or downstream equipment. Zebra mussels and other biofouling conditions may change under climate change conditions. Overhaul the CCW pumps.
- Inspection of various components, and repairs based on these inspections.

4.3.2 Climate Change Adaptations

The following options for climate change adaptation are consistent across systems and have been presented in order of increasing complexity and cost:

- Routine monitoring of climate conditions and OPEX to:
    - Determine if climate projections match actual climate data.
    - Learn from industry partners.
- Update operational and safety limits for the equipment:
    - Perform assessments to determine if margins on existing equipment can be updated given climate projections.
    - Determine the adaptive capacity of existing equipment.
    - If limits are not available, determine if there are specific conditions under which equipment becomes unavailable.

- Increase inspection and maintenance frequency on equipment to ensure it is not experiencing accelerated degradation due to increased temperatures, and extreme weather events.
- Update site safety analysis and meteorological limits as scheduled and required.

Additional adaptation measures by equipment are in Table 5.

Table 5. Adaptation Measures Specific to Equipment

Equipment and System(s)	Specific Adaptation Options

Air Compressors
- Air Systems
	• Rotating Equipment Strategy [20]
	• Improve performance of existing air compressors:
	  - Increase cooling water flow rate to intercooler and aftercooler
	  - Install more efficient aftercooler
	• Install additional intercooler and aftercooler components to improve performance.

Electrical Equipment - Class IV - Main Power Output (MPO) - Powerhouse Emergency Venting (PEVS) - Standby Generators - Control Equipment Room Cooling (CERC)	• Cable Surveillance Program and equipment strategy instruction • Create a procedure that outlines responsibilities between OPG and Hydro One for snow removal from the Switchyard and related infrastructure • Install additional intercooler and aftercooler components to improve performance. • Develop flooding protection for equipment location outside or at building elevations below the design flood level • Ensure circuit breakers and protection relays for both line and bus that are near end of service life are replaced • Determine if the DCCs can produce less heat while in service, and add additional cooling sources to the DCCs to lessen their impact on room temperatures • Replace equipment with ratings for use at higher maximum air temperatures, while maintaining the low air temperature limits
Fan - Emergency Power Generator (EPG) cooling - Powerhouse Ventilation - Reactor Building Ventilation and Vapour Recovery - Standby Generator (SG) Cooling	• Rotating Equipment Strategy [20] • Purchase two spare SG lube oil fans • Add inspection and lubrication of SG cooling fans to outage field work instructions • Place standby fans on manual mode to improve ventilation in associated spaces • Bring in auxiliary fans for additional cooling capacity • When equipment is scheduled for replacement, replace with fans that are designed with a higher air movement capacity • Determine if additional cooling is required for rooms primarily cooled by fans. Consider including a glycol air

Equipment and System(s)	Specific Adaptation Options
	cooling circuit on the air intake for EPG cooling should the increased air temperature be a consistent challenge
Filter - Air Systems - Annulus Gas	• When replacing existing air filter units, replace with units with higher maximum operating temperatures • Determine if filters require additional cooling, and provide if required
Generator - Emergency Power Supply (EPS) - Standby Generators (SG)	• Resolve documentation and jurisdictional issues with generator rental company to reinstate regular maintenance of EPG, as recommended [21] • Develop flooding protection for equipment located outside or at building elevations below the design flood level • Determine if additional cooling is required for rooms primarily cooled by fans. Consider including a glycol air cooling circuit on the air intake for EPG cooling should the increased air temperature be a consistent challenge • Purchase replacement EPG3 generator to ensure proper maintenance and reduce long-term costs and with generators that can maintain capacity at higher ambient temperatures, as recommended [21]

Equipment and System(s)	Specific Adaptation Options
Heat Exchangers - Annulus Gas - Class I/II Battery Rooms - Control Equipment Room Cooling - RAB Chilled Glycol Systems - RB Ventilation and Vapour Recovery - Cover Gas - Generator/Turbine Cooling - Reactor Building Cooling - Emergency Coolant Injection (ECI) - End Shield Cooling - Irradiated Fuel Storage Bay Cooling - Liquid Zone Control - Moderator System - Recirculating Cooling Water - Shutdown Cooling	• Heat Exchanger Program Requirements and strategy manual • For accessible rooms, bring in mobile chillers for supplemental room cooling capacity • Study the impact to habituality, equipment reliability, and degradation rates by increasing temperatures and resultant reductions to humidity in conditioned spaces. During walkdowns and inspections of equipment during period of high air temperatures, note equipment condition, exterior air temperature, and room temperature for trending. If increased equipment degradation or reduced reliability is found with increasing temperature, additional means of cooling the equipment rooms should be considered. • Acidification of the lake should be monitored and included in the chemistry control manuals to be measured on a routine basis. If acidification occurs, then inline processing of lake water will need to be considered. • Improve performance of existing equipment: increase coolant flow rate without modification or modify the equipment to allow for increased coolant flow • Replace the coolers with the consideration for a larger capacity for cooling • Purchase a spare HX to avoid extended outages • Replace the HXs with the consideration for a larger capacity for cooling • Increase cooling capacity of the HXs through either adding additional HXs to the system or relocate the HX to a cooler environment • Proactive ACU coil replacements • Update HX design requirements with the requirement that when HXs are chosen for new systems, or existing HXs are replaced, components that interface with the service water should be made of corrosion-resistant material
Motor - Emergency Water Supply (EWS) - Service Water - SG Cooling	• Rotating Equipment Strategy [20] • Motor Strategies • The main LPSW pumps will need to be shipped offsite for complete refurbishment within 30 years [22] • Install triaxial vibration sensors for additional monitoring for reliability and ESA on all 4 kV motors for improved reliability [23] • Develop flooding protection for pumps and pump motors located at building elevations below the design flood level • Improve performance of existing pumps and pump motors

Equipment and System(s)	Specific Adaptation Options
	• Consider additional means of reducing the ambient air in the pump motor location, such as installing or improving the ACU • Replace pump motors with consideration for use at a higher maximum air temperature, while maintaining the low air temperature limit, as well as improving energy efficiency
Pump - Emergency Power Supply - Standby Generators (SG) - Boiler feedwater - Condenser Cooling Water (CCW) - Emergency Coolant Injection (ECI) - Emergency Water Supply (EWS) - Fire Systems - Screenhouse - Service Water	• Rotating Equipment Strategy [20] • Pump Strategy • Develop flooding protection for pumps located at building elevations below the design flood level • Acidification of the lake should be monitored and included in the chemistry control manuals to be measured on a routine basis. If acidification occurs, then inline processing of lake water should be considered. • Improve performance of existing pumps, such as as-needed replacement of pump components with improve components or adding a variable-speed drive on existing motors to improve pump efficiency • Consider additional means of reducing the ambient air in the pump location, such as installing or improving the ACU • Modification of the system for online pump testing will improve outage duration, execution, and licensing requirement compliance. • Apply corrosion protection to pumps with components located in the forebay and exposed directly to lake water • Consider alternative supply sources for the service water to increase water volume and reduce water temperature. This could include the DWI or adding additional pumps • Replace pumps with the following considerations: larger capacity for water intake to provide cooling water to the station, corrosion-resistant materials, improved-energy efficiency
Screens and Strainers - Emergency Water Supply - Fire Systems - Screenhouse - Service Water	• Consideration for adding anti-corrosion coatings on the screens and strainers to fortify equipment against long term changes brought on by climate change, alternatively replace screens and strainers with corrosion resistant materials • Develop flooding protection for screens, strainers, and associated equipment, such as motors, located at building elevations below the design flood level • Acidification of the lake should be monitored and included in the chemistry control manuals to be measured on a routine basis. If acidification occurs, then inline processing of lake water will need to be considered. • Consider alternative supply sources for the service water to increase water volume and reduce water temperature, this could include the DWI. Consider including a submerged intake structure similar to those used at

Equipment and System(s)	Specific Adaptation Options
	Darlington, Bruce Power, or Nanticoke as part of DWI construction.
Tank - Emergency Coolant Injection - Emergency Power Supply	• Replace tanks as per industry best practices [24]
Transformer - Class IV - Emergency Power Supply - Main Power Output - Standby Generators	• Paint transformer cabinet bright white to reflect some heat. • Perform a one-time inspection on SG power transformers (PT1 to PT4 for each SG) to assess degradation and remaining life, as these components have not been previously inspected [25] • Develop flooding protection for equipment located outside or at building elevations below the design flood level. • Add auxiliary cooling equipment, such as fans or water spray equipment, to improve transformer performance. • Replace transformers with higher ratings or increased temperature margin
Turbine - Emergency Power Supply (EPS)	• Resolve documentation and jurisdictional issues with generator rental company to reinstate regular maintenance of EPG • Develop flooding protection for equipment located outside or at building elevations below the design flood level • Determine if additional cooling is required for rooms primarily cooled by fans. Consider including a glycol air cooling circuit on the air intake for EPG cooling should the increased air temperature be a consistent challenge • Purchase replacement EPG3 generator/turbine set to ensure proper maintenance and reduce long-term costs • Purchase replacement EPG3 generator/turbine set to ensure proper maintenance and reduce long-term costs
Vent - Heating, Ventilation and Air Conditioning (HVAC) - Powerhouse Emergency Venting (PEVS) - Reactor Building Ventilation and Vapour Recovery	• As permitted by facility procedures, block open doors, hatches, fire dampers, or re-align pipe/duct conveyances to improve airflow to reduce load on ventilation cooling system during hot weather or if vents blocked by snow. • Weatherize vents and louvres to ensure they can withstand winter weather conditions, such as protection from snow or ice buildup.

5.0 CONCLUSION

Analysis of recent data from 2010 through 2020 shows that extreme events have an essentially negligible impact on nuclear generation capacity factors (the percentage of the time the nuclear power plant (NPP) is running at full power and providing electricity to the grid), which are by far the highest of any carbon-free source of generation [6].

As a crucial part of the adaptation strategy, OPG has implemented a severe weather emergency preparedness procedure. The severe weather emergency preparedness procedure is important to ensuring the safe operation of the power plant during extreme weather events. This procedure includes actions like monitoring plant areas for water ingress, reviewing equipment affected by high heat, and clearing snow and ice from critical areas. It helps mitigate climate hazards, especially where there is low confidence in available climate projection data, such as high wind scenarios.

Additionally, the winterization and summarization procedure [19] addresses many climate-related impacts, although it is expected that this procedure will need to be revised as climate shifts. These procedures will help mitigate climate hazards, especially those where there is low confidence on climate projections data.

Climate change is seen as a gradual change which is likely to increase the severity of hazards already evaluated and screened routinely. Routine preventative maintenance programs and measures to monitor the daily operation of the plant are seen as sufficient to discover changes being brought on to PNGS by climate change.

Adaptation options were presented for the SSCs that were determined to be potentially susceptible to, or have margins eroded by, climate change-related hazards.

Condition assessments for the SSCs were reviewed to determine the existing condition of the equipment, the inspection and maintenance performed on the equipment, and any actions that may have been previously recommended. Climate hazards in the short-term may be addressed through the implementation of and improvements to existing processes and programs and implement adaptation options for consideration based on conditions assessments.

The adaptation options presented fall under four general categories and have been categorized and presented in Figure 1. The majority of adaptation options are for design or analysis work, but options also include updates to OPG governance and procedures, and risk monitoring plans. Items that fall under “No risk treatment required” include existing programs, procedures, and the flood protection system, for which updates are not currently required but which can be leveraged to mitigate the risks of climate change.

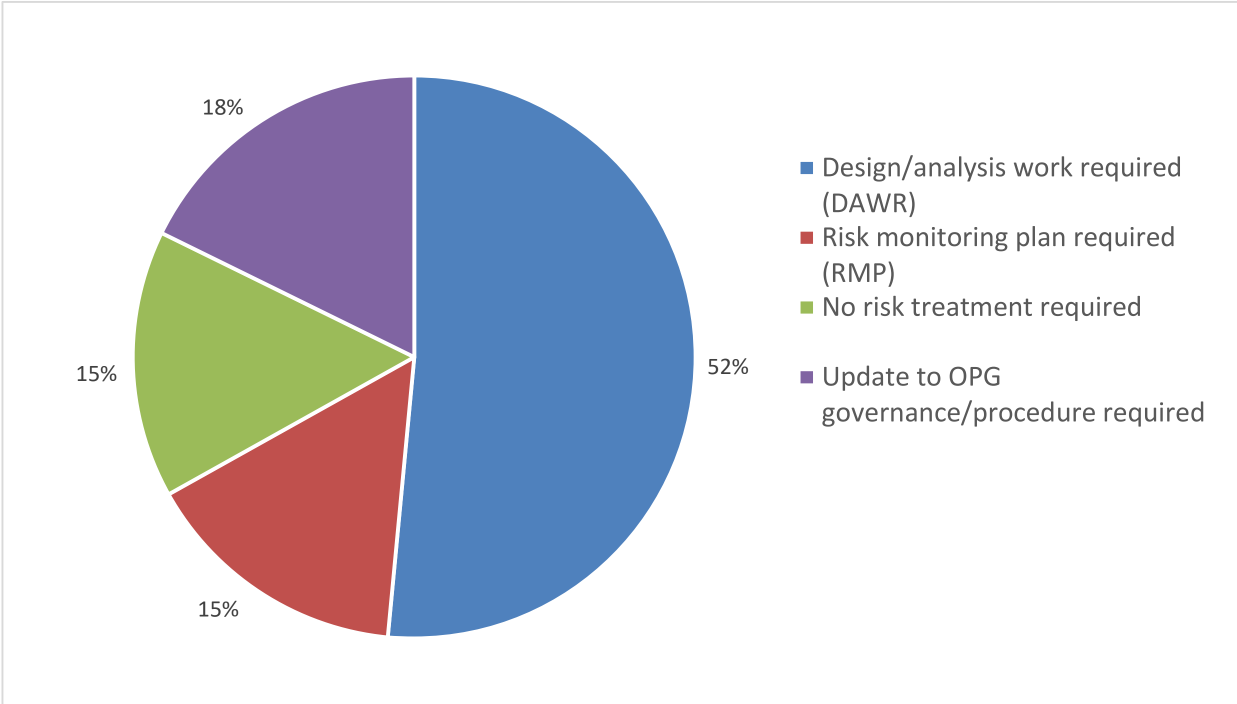

Figure 1. Categorization of Adaptation Options

Given the adaptation strategies available and identified, nearly half of adaptations options require little additional investment by OPG. However, there are many adaptions options which would require design or analysis work to address the climate susceptible SSCs. A strategy and tracking mechanism should be developed to ensure that all systems identified are appropriately addressed to meet climate hazards.

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Appendix A: Climate Projections

A.1 CLIMATE PROJECTIONS

A.1.1 Increasing Ambient Temperature

The ambient temperature includes the averages of the annual ambient minimum, mean, and maximum temperatures averaged over each time horizon using the median of the climate simulations.

Annual Average Temp (℃)	1981-2010	2021-2050		2051-2080	
		RCP4.5	RCP8.5	RCP4.5	RCP8.5
Minimum	4.1	5.0	5.3	6.0	7.4
Mean	8.2	9.7	9.9	10.6	11.9
Maximum	12.2	14.3	14.4	15.1	16.5

A.1.2 Water Temperature

The annual mean water temperature is based on the projected air temperatures; the average of the annual mean water temperature for each time period are given.

Annual Mean Temp (℃)	2017-2022	2021-2050	2051-2080
RCP4.5	10.4	11.1	11.8
RCP8.5		11.6	13.5

A.1.3 Total Precipitation

The total precipitation is the average of the annual precipitation sums for each time period using the median of the climate simulations.

Average annual precipitation	1981-2010	2021-2050		2051-2080	
		RCP4.5	RCP8.5	RCP4.5	RCP8.5
Precipitation (mm)	862	853	871	892	890
Rainfall (mm)	758	736	760	789	804
Snowfall (cm)	103	115	113	101	82

A.1.4 Low Lake/River Level and Hydrological Drought

The lowest annual lake levels and the probability of a dry period (with less than 0.1 mm of precipitation) of at least 10 days for the future time periods were determined.

	1981-2010	2021-2050	2051-2080
Lowest annual lake level (m)			
RCP4.5	74.3	74.1	74.4
RCP8.5		74.0	74.4
Probability of dry periods of at least 10 days (%)			
RCP4.5	82	83	81
RCP8.5		82	84

A.1.5 Acidification

The projected mean annual pH for the Great Lakes under the high-emissions scenario was determined.

Mean pH	**1981-2010**	**2021-2050**	**2051-2080**
RCP4.5	8.44	-	-
RCP8.5		8.33	8.20

A.1.6 Water Temperature Extreme High

The extreme high water temperature is the bias-corrected 99th percentile high water temperature projected for the period.

Temp (℃)	**2017-2022**	**2021-2050**	**2051-2080**
RCP4.5	24.3	24.9	25.5
RCP8.5		25.6	27.4

A.1.7 Flooding: Rising Lake Water Level

The highest annual lake level for each time period was determined.

Highest lake level (m)	**1981-2010**	**2021-2050**	**2051-2080**
RCP4.5	75.3	75.8	76.4
RCP8.5		76.0	76.3

Flooding caused by runoff, riverine flooding, local site area flooding and other types of precipitation related flooding has no projections and qualitative assessments were performed.

A.1.8 Air Temperature: Extreme High

The extreme high air temperature is the averaged return values for annual maximum air temperature for the 10-year return period for the stated time period.

Temp (℃)	1981-2010	2021-2050	2051-2080
RCP4.5	35.9	37.2	38.2
RCP8.5			40.1

A.1.9 Extreme Rainfall

The extreme rainfall is the annual maximum of the daily rainfall for the 10-year period.

Annual Maximum Daily Rainfall (mm)	1981-2010	2021-2050	2051-2080
RCP4.5	64.1	75.1	80.0
RCP8.5		73.2	84.9

A.1.10 Extreme Weather Events

No projections are available, qualitative assessments were performed. This includes tornado, blizzards/snowstorms, downbursts/derecho, and extra-tropical storms

The occurrence of more and more severe thunderstorms and tornadoes with progressive warming is possible in southern Ontario. However, a conclusive statement about the change in frequency or intensity of tornados with climate change is not possible due to the limited predictability of these features.

The frequency of snowstorms north of Lake Ontario is projected to decrease by 20 to 30% in the RCP8.5 scenario as more winter precipitation will shift to rainfall. Due to limited predictability, it is currently not possible to provide projections regarding changing in intensity of blizzards and snowstorms with climate change.

Downbursts are high wind events that involve a powerful wind which descends from a thunderstorm and spreads out quickly once they hit the ground. Downbursts involve high winds and heavy rains. Derecho are a straight-line wind storm event that occur as part of a severe thunderstorm event and can involve high winds, heavy rains, and flash floods.

The impact of climate change on the ‘ingredients’ for derechos points towards the potential of more frequent and/or more intense derechos, no scientific consensus has been reached. However, as the jet stream shifts further poleward with climate change due to the faster warming of the Arctic, the favorable conditions for derechos will also shift further north. This could increase the frequency of derechos in southern Ontario.

The impact of climate change on the path, strength, and frequency of extra-tropical cyclones remains uncertain.

A.1.11 Extreme Snowpack or snow accumulation

The extreme snowpack is the maximum snow on the ground for the time period.

Maximum snow on ground (cm)	1981-2010	2021-2050	2051-2080

RCP4.5	51.0	87.6	66.4
RCP8.5 (not assessed)		46.5	42.7

A.1.12 Heatwave

Described as at least 3 consecutive days with maximum temperatures above 30°C.

Number of heatwaves	1981-2010	2021-2050	2051-2080
RCP4.5	0.4	2.6	3.5
RCP8.5		2.8	5.2

A.1.13 Hurricane/Typhoon

The wind speed and rainfall associated with tropical cyclones are projected to increase as a result of climate change. The data below applies to a 2℃ warmer threshold which applies to the time horizon 2051-2080 for the RCP4.5 emission scenario or the climate for the 2021-2050 periods in the RCP8.5 scenario.

	Historical		**2℃ Warmer World**	
	Wind speed (km/h)	**Rainfall (mm)**	**Wind speed (km/h)**	**Rainfall (mm)**
Tropical cyclones	51.8	51.1	52.3-57.0	56.2-58.8
Extra-tropical cyclones	66.1	46.6	66.7-72.7	51.3-53.6

Appendix B: Equipment Impacted by Climate Hazards

The following equipment was determined to be impacted by climate-related hazards.

Table 6. Equipment Impacted by Climate Hazards

System	Equipment
Air Systems	Compressors (5/6/7/8-75120-CP1, CP2, CP3 and CP4)
	Filter Assembly (058-75120-FR1, FR2, FR3, FR4)
Annulus Gas	Annulus Gas CO2 & Air Cooler (5/6/7/8-34980-HX1)
	Annulus Gas Compressor Intake Filter (5/6/7/8-34980-FR1 to FR3)
Boiler Feedwater	Main Boiler Feed Pumps (5/6/7/8-43230-P6 to -P8)
	CL3 Aux Boiler Feedwater Pump (5/6/7/8-43230-P5)
Class I/II Battery Rooms	Class I: 55100-BY1, BY2 in 317 TAB Battery Room
	Class II: 54230-BY1A, -BY1B, TAB EL 316'6"
	Glycol cooler on roof (5/6/7/8-73230-CD1 to -CD6)
Class IV	Station service transformer: Generator and System Service Transformers, including all CLIV transformers
	Electrical components
Condenser Cooling Water (CCW)	CCW pumps (5/6/7/8-71210-P1, P2)
	Condenser (5/6/7/8-71200-CD1/2/3)
Control Equipment Room Cooling	Air coolers (8-73160-ACU1, 7-73160-ACU2, 6-73160-ACU3, 5-73160-ACU4, 058-73160-ACU5)
	DCCs (5/6/7/8-66400-DCCX and -DCCY)
Cover Gas	Cover gas system cooling jackets (5/6/7/8-32310-Y7 and Y8)
Emergency Coolant Injection (ECI)	ECI Water storage tank (058-33350-TK1)
	HP Pumps (058-33350-P5 to P7)
	Recovery Pumps (056/078-33350-P1 to P3)
	Recovery HX (056/078-33350-HX1)
Emergency Power Generator Cooling	EWS pumphouse fans (058-73990-VE1, -VE2)
	Electrical equipment room fans (058-73990-VE3, -VE4)
	Turbine room fans (058-73990-F1, -F2)
Emergency Power Supply (EPS)	Generators (058-54800-EPG1, EPG2, EPG3)
	Emergency Power Generator (EPG) Auxiliary Power Transformers (058-54800-EPG1/2-T1)
	EPG Lube Oil Tank (058-54800-EPG1/2-TK1)
	EPG Fuel Tank (058-54800-EPG1/2-TK2)
	EPG Turbines (058-54800-EPG1/2-TU1)
	EPG Oil Pumps (058-54800-EPG1/2-P1 to P5)
	Common EPS 4.16 kV/600 V transformers (058-54330-T1, T2)
	Fuel Oil Storage Tank (058-54860-TK1 and TK2)
	EPG Fuel Forwarding Pumps (058-54860-P3 to P6)
Emergency Water Supply (EWS)	Main EWS pumps (058-71380-P1, P2, P3)
	EWS Pump Motor (058-71380-PM1 to PM3)
	CLIII/EPS Recovery Pump (056/078-71380-P1)
	Strainers (058-71380-STR1, STR2)

System	Equipment
	Travelling Screens (058-71380-SC1 and SC2)
End Shield Cooling	End Shield Cooling (5/6/7/8-34110-HX1 and HX2)
Fire Systems	Excess Pressure Pumps (5/6/7/8-71410-P2030, P2035)
	Strainer (5/6/7/8-71410-STR2023)
Generator/Turbine Cooling	Hydrogen gas coolers (5/6/7/8-41230-HX1 to -HX4)
Heating, Ventilation, and Air Conditioning (HVAC)	Louvres
	Roof ventilators (5/6/7/8-73220-VE1 to VE4)
Irradiated Fuel Storage Bay Cooling	Irradiated fuel storage bay cooling (058-34410-HX1 and HX2)
	Irradiated fuel storage bay cooling (058-34410-HX3)
	Irradiated fuel storage bay cooling (0-34410-HX1 to -HX3)
Liquid Zone Control	Liquid zone control cooling (5/6/7/8-34810-HX1)
Main Power Output	23 kV Isolated Phase Bus (IPB) (5/6/7/8-51150-IPB)
	Main Output Transformer (MOT) (5/6/7/8-51200-TM1)
	230 kV switchyard
Moderator System	Moderator system heat exchangers (5/6/7/8-32110-HX1, HX2)
Powerhouse Emergency Venting (PEVS)	Venting Panels
	PEVS Electrical Components
Powerhouse ventilation	Powerhouse Main Supply Fan (5/6/7/8-73220-F1)
RAB Chilled Glycol System	Glycol Chillers (058-73180-RFU4 to -RFU6)
Reactor BuildingVentilation and Vapour Recovery	Louvres
	Intake Air Conditioning Unit (ACU) (5/6/7/8-73130-ACU1)
	Exhaust Fans (5/6/7/8-73130-F501, F502)
Reactor Building Cooling	Boiler room coolers (5/6/7/8-73110-ACU1 to ACU6)
	Fuelling machine vault coolers, R208 and R209 (5/6/7/8-73110-ACU7 to ACU14)
	Reactor building south access area coolers, R103 (5/6/7/8-73110-ACU15 to ACU20)
	Fuelling machine service and access rooms (5/6/7/8-73110-ACU21 to -ACU24)
	Fuelling machine auxiliary rooms R112 and R113 coolers (5/6/7/8-73110-ACU25 and ACU26)
	Moderator auxiliary rooms R104 and R105 (5/6/7/8-73110-ACU27 and ACU28)
	Moderator room R101 coolers (5/6/7/8-73110-ACU29 to ACU31)
	Heat transport auxiliaries room coolers (5/6/7/8-73110-ACU32)
	Heat transport auxiliaries room coolers (5/6/7/8-73110-ACU33)
	RB Coolers (5/6/7/8-73110-ACU34 and ACU35)
	Reactor Building Mezzanine coolers, R308 and R309 (5/6/7/8-73110-ACU36 and ACU37)
Recirculating Cooling Water	Recirculating cooling water heat exchanger (5/6/7/8-71320-HX501 and HX502)
Screenhouse	Bar screens (056-71110-SC7 to SC12, 078-7111-SC7 to SC12)
	Travelling water screens (056-71110-SC1 to SC6, 078-71110-SC1 to SC6)
	Screen Wash Pumps (056-71110-P1 to P3 and 078-71110- P1 to P3)
	Trash Sump Pumps (056-71120-P1 and P2, 078-71120-P1 and P2)
Service Water	High Pressure Service Water (HPSW) Pumps (5/6/7/8-71340-P1 to P4)

System	Equipment
	HPSW Pump Motor (5/6/7/8-71340-PM1 to PM4)
	Emergency LPSW Pumps (5/6/7/8-71310-P1 to P4)
	Low Pressure Service Water (LPSW) Pumps (5/6/7/8-71310-P5 to P7)
	LPSW Strainer (5/6/7/8-71310-STR1)
	LPSW Pump Motor (5/6/7/8-71310-PM1 to PM4)
Shutdown Cooling	Heat transport shutdown coolers (5/6/7/8-33410-HX1 to HX4)
Standby Generator Cooling	SG Lube Oil Cooling Fan (056/078-54600-F11, -F12, -F21, -F22, -F31, -F32)
	Motors with fans for SG ventilation (056/078-54600-SG1-FM1 to -FM3 to -SG3-FM1 to -FM3)
Standby Generators (SGs)	Standby Generator (056/078-54600-SG1 to SG3)
	SG Power Transformers (056/078-54600-SG1/2/3-PT1 to PT4)
	SG Electrical Equipment
	SG Fuel Oil Equipment
	Fuel Oil Pump (056/078-54600-SG1/2/3-P2073)
	SG Lube Oil Equipment
	Lube Oil Pumps (056/078-54600-P13- P18, -P23-P28, -P33-P38, -P113, -P114, -P213, -P214, -P313, -P314)