Whitby Climate Emergency Response Plan

Phase 1: Resilience
Technical Summary

Whitby

SSG

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Purpose of this Document

This document summarizes the climate hazards and risks in Whitby and the actions that can be taken to protect the people, places, businesses, and infrastructure in the town. Using locally-downscaled climate change modelling completed for the Region of Durham, a review of the current and future impacts from flooding and heat was completed to assess present and future damages from severe weather, heatwaves, and other climate events. This document reviews the impacts, costs, and benefits of adaptation measures to reduce the impacts of climate change on the people and places in Whitby. This document is a strategic-level plan to be used for planning and prioritization of adaptation measures within Whitby. It is not to be used as a detailed, engineering-level analysis of site-specific conditions for locations and activities within Whitby.

A Derecho In Whitby

While this document was being finalized, a powerful windstorm called a derecho moved across Ontario, causing at least 11 deaths and untold damage[1] in areas such as Whitby. While it is difficult to directly correlate the derecho with climate change,[2] the storm is a stark reminder that climate risks can take many forms. Derechos are not directly addressed in this plan, but many of the measures identified will increase resilience against windstorms and risks that are location-specific, such as flooding. In particular, this approach reduces the impact of compounding hazards when windstorms are combined with floods.

[1] Canadian Press (2022). 11th person dies from weekend storm, tens of thousands Ontarians still without power. Retrieved from: https://www.thestar.com/news/canada/2022/05/26/tens-of-thousands-in-southern-ontario-still-without-power-after-deadly-storm.html

[2] Canadian Underwriter (2022). Was derecho storm damage caused by climate change? Retrieved from: https://www.canadianunderwriter.ca/catastrophes/was-derecho-storm-damage-caused-by-climate-change-1004221681/

Acknowledgements

Land acknowledgement

The Town of Whitby acknowledges that we are on the traditional treaty territory of the Mississaugas of Scugog Island First Nation of the Mississauga Nation. The Town respectfully shares in the responsibility of the stewardship and environmental protection of these ancestral lands.

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- Climate Risk Institute
- Durham District School Board
- Elexicon Energy
- Enbridge Gas
- Municipality of Port Hope
- Region of Durham
- Toronto and Region Conservation Authority
- Town of Whitby
- Stakeholder Engagement Group
- Blue Dot Whitby
- Canadian Centre for Climate Science
- Central Lake Ontario Conservation Authority
- Clean Air Partnership
- Climate Justice Durham
- Ducks Unlimited Canada
- Durham District School Board
- Durham Region Home Builders' Association
- Durham College
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- Intact Center for Climate Adaptation
- Malone Given Parsons Ltd
- Mattamy Homes
- Ontario Technical University
- Ontario Power Generation
- Region of Durham
- Spark Centre

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1. The Context

1.1 Geography

The Town of Whitby lies on the shores of Lake Ontario, to the east of Toronto. The southern regions of the town are more urbanized, with residential development along naturalized areas and agricultural and undeveloped lands predominantly in the north (Figure 1).

Whitby has a total area of approximately 150 km^2 and is nested within the Regional Municipality of Durham. The Region and the Town share responsibility for municipal services within Whitby, with Durham managing waste, water, emergency medical services, police, and transit, and Whitby managing all other municipal services, including fire, waste collection, building bylaws, parks and recreation, and some roads.

The Lynde Creek, Pringle Creek, and Corbett Creek watersheds cover most of Whitby's area (Figure 2). Watershed management, including environmental management and monitoring and development permitting, is the responsibility of the Central Lake Ontario Conservation Authority (CLOCA), and CLOCA shares responsibility for development permitting with the Town of Whitby. The Federal and Provincial governments, as well as the Region of Durham and the Town of Whitby, all share a legal and moral responsibility to protect watersheds in the area.

Whitby is underlain by well-draining, loamy soils from multiple soil groups (Figure 3).[4] Well-draining soils are an important asset for mitigating localized flooding, especially in urbanized, impervious areas. The loamy soils in the north of Whitby contribute to fertile areas for agricultural uses.

[4] Ontario Ministry of Agriculture, Food, and Rural Affairs and Agriculture and Agri-Food Canada, 2019. Soil Survey Complex. Accessed through Ontario GeoHub: https://geohub.lio.gov.on.ca/datasets/ontarioca11::soil-survey-complex/explore?location=43.970709%2C-78.896668%2C9.37

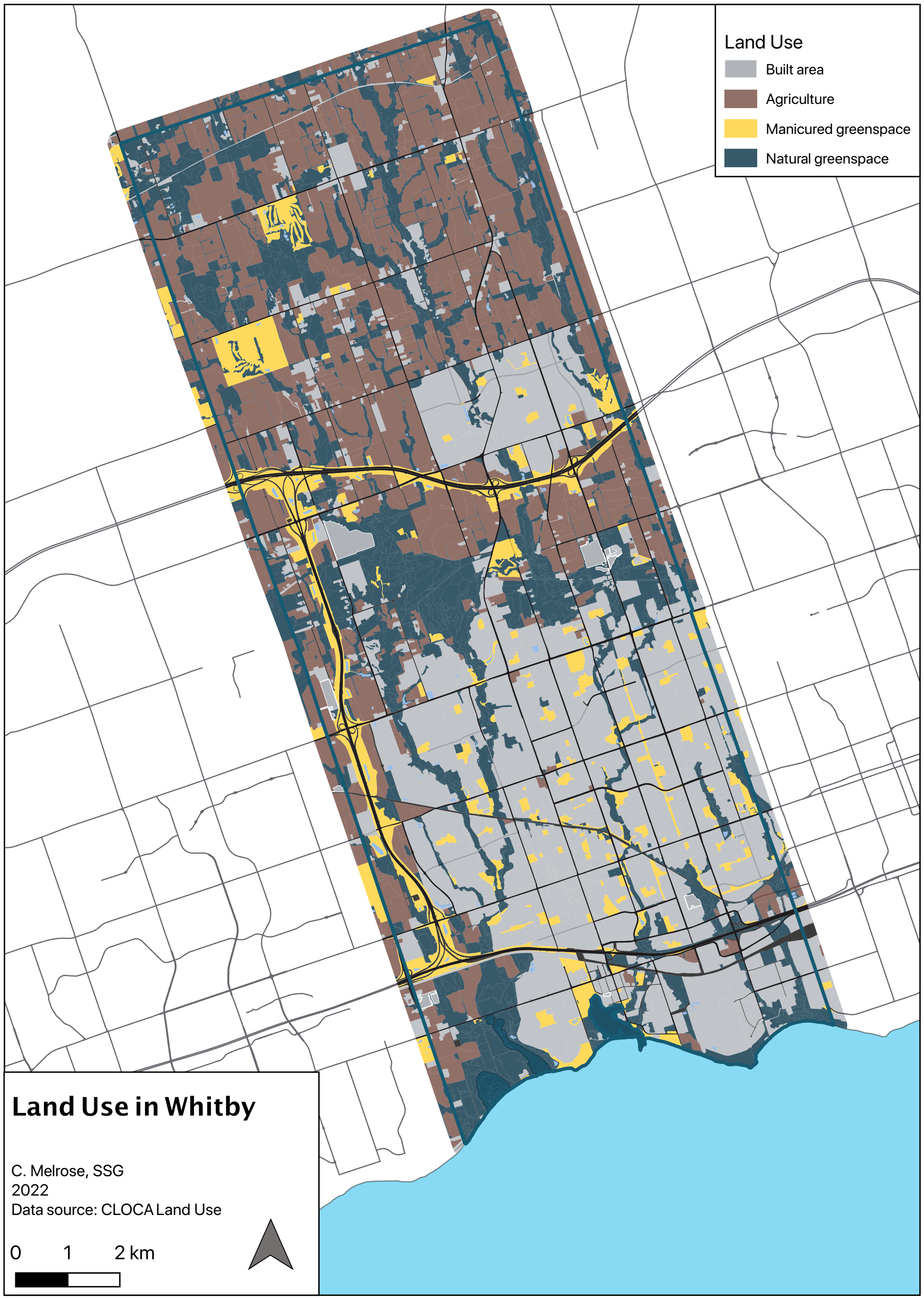


Figure 1. Map of land use in the Town of Whitby. Denser development is located in the southern region of the town, greenspaces are located along primary waterways, and agricultural lands are found in the northern sections.

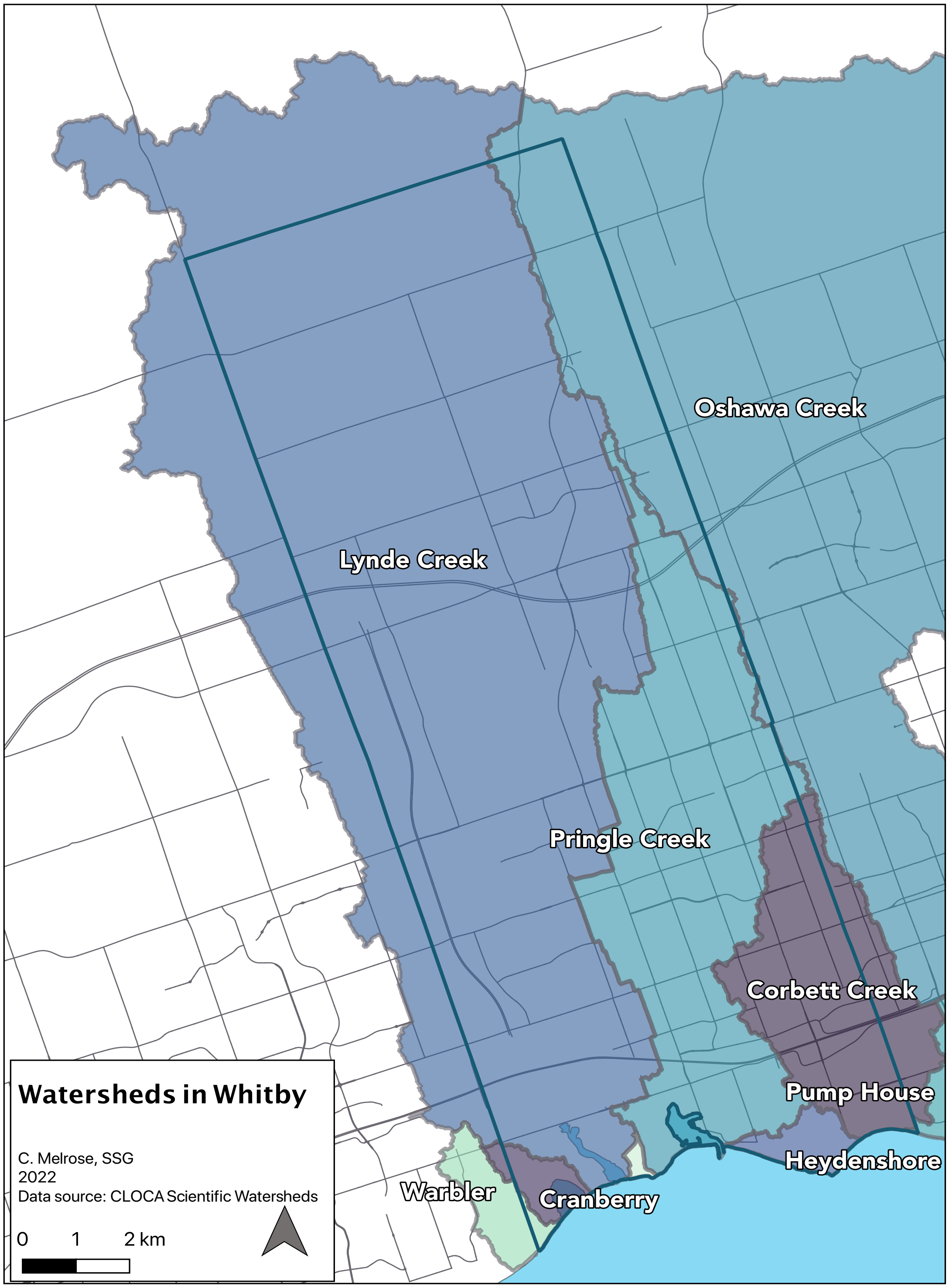


Figure 2. Watersheds in Whitby. Watershed management is the responsibility of the Central Lake Ontario Conservation Authority (CLOCA).

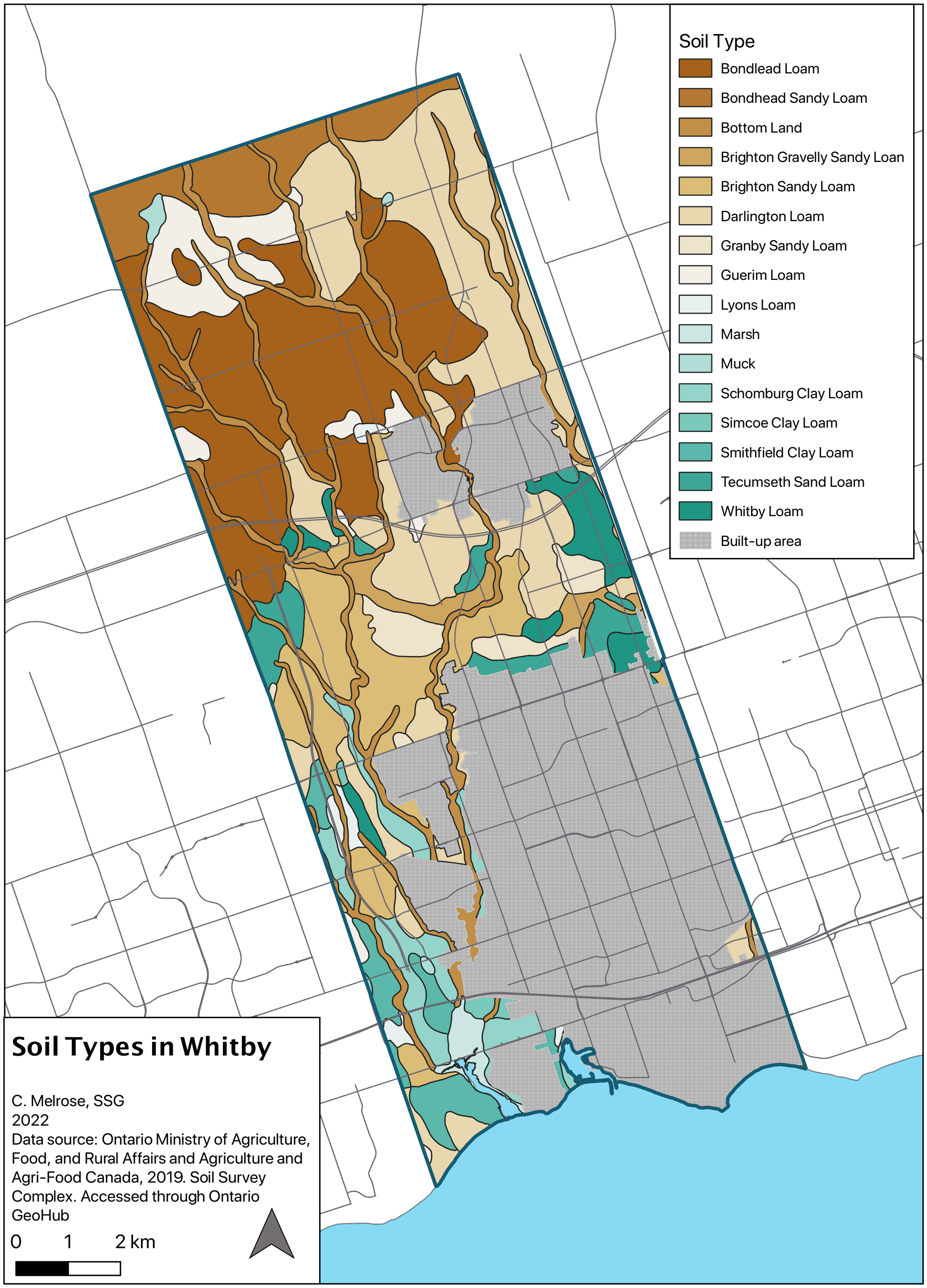


Figure 3. Soil types in Whitby, as well as the location of urbanized, built-up areas.

1.2 Demographics

Whitby is a community of 137,000 people. Many Whitby residents commute to other regions within the Greater Toronto Area for work. The town is expected to grow by 140% by 2070, to 331,000 people (Figure 4).

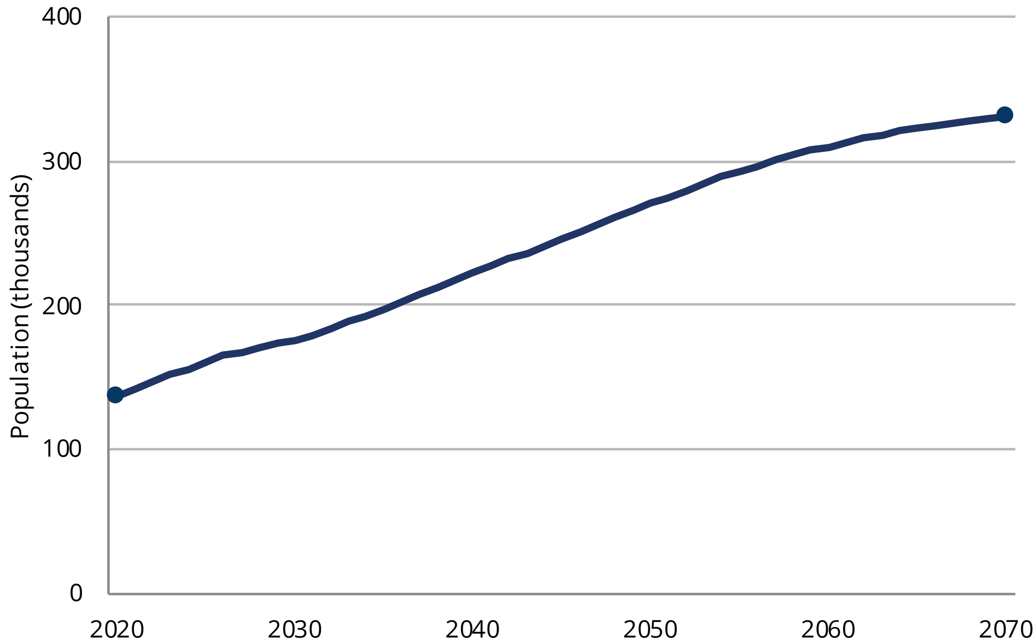


Figure 4. Population growth in Whitby, 2020–2070.[5]

The labour force in Whitby works in a variety of sectors. Retail, healthcare and social services, education, and professional, technical, and scientific services are the largest employers in the town (Figure 5).[6]

[5] Population projections from the Durham Population and Land-Use Model were used until 2051 and linearly interpolated until 2070.

[6] Statistics Canada. 2017. Whitby, T [Census subdivision], Ontario and Durham, RM [Census division], Ontario (table). Census Profile. 2016 Census. Statistics Canada Catalogue no. 98-316-X2016001. Ottawa. Released November 29, 2017.

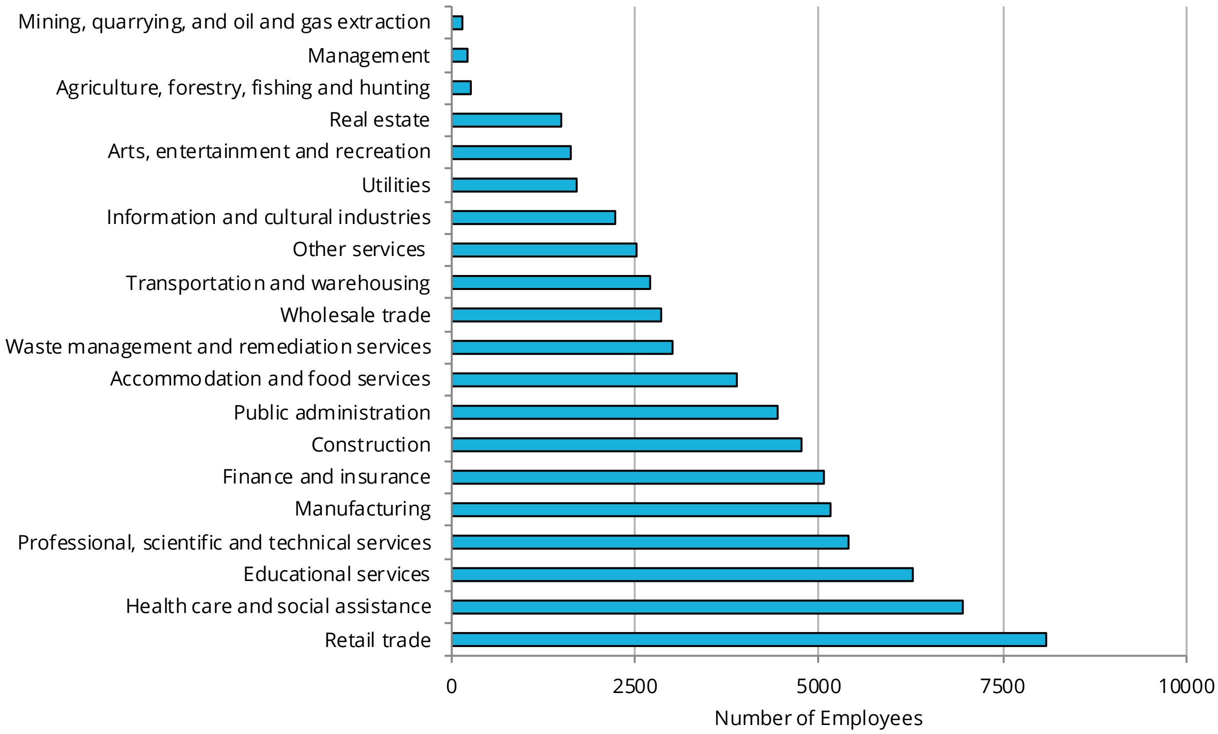


Figure 5. Employment by sector in Whitby, 2016.

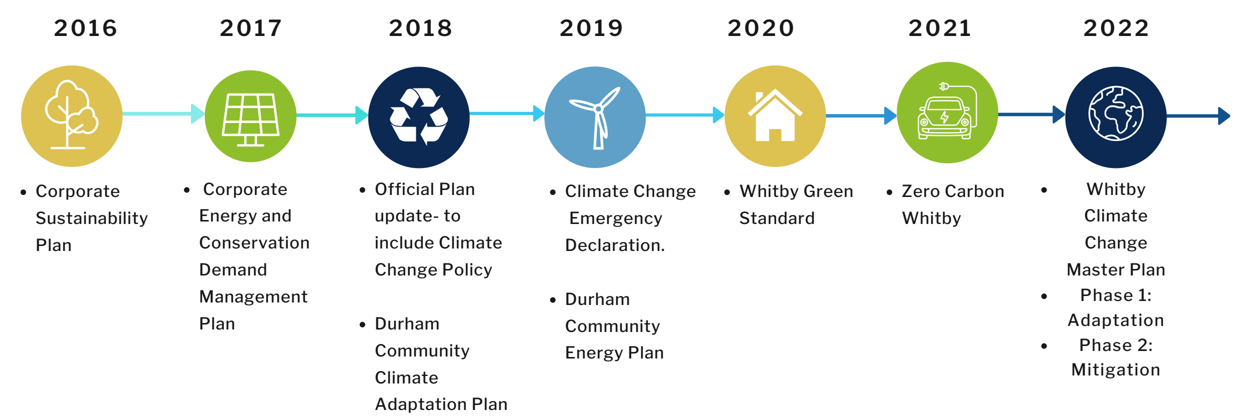
1.3 Climate Action in Whitby

Whitby declared a climate emergency in June 2019, recognizing the need for immediate, transformative action to reduce the emission of greenhouse gases (GHGs) and ensure that the community is prepared for inevitable climate impacts.

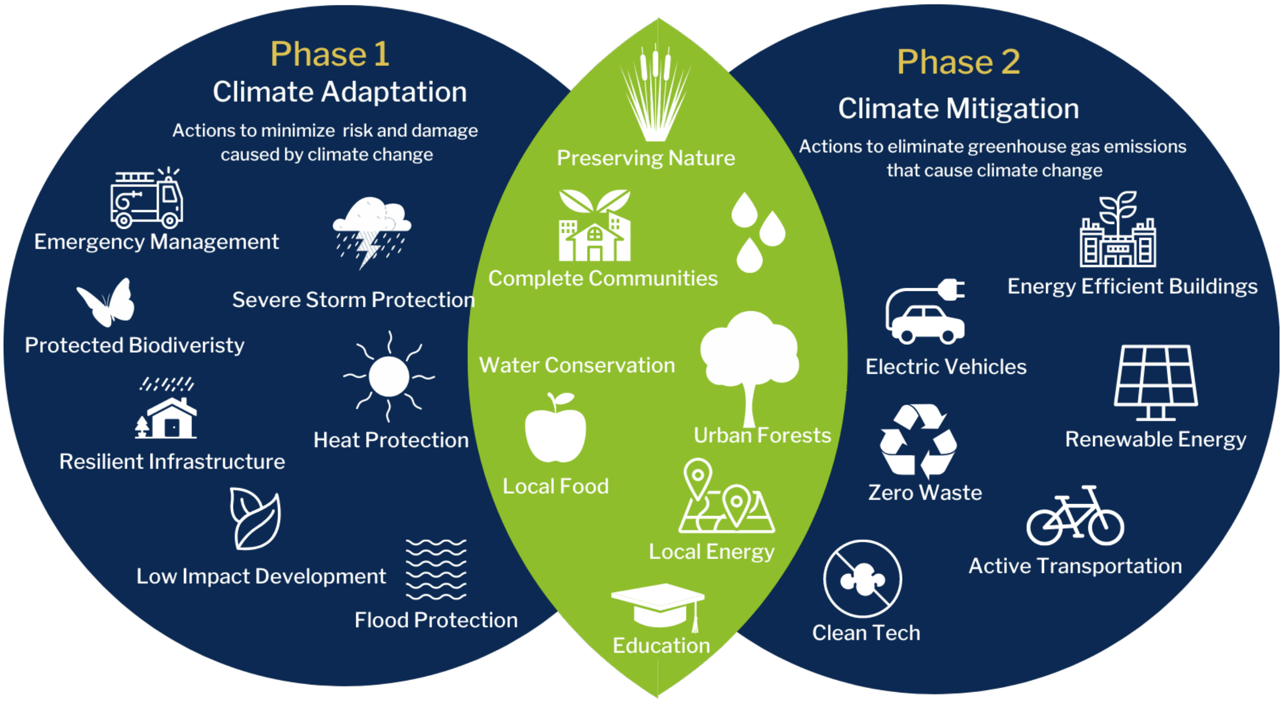
Whitby and the Region of Durham have developed several plans to address the climate emergency. A plan has been developed to identify a pathway to net-zero emissions for the Town of Whitby's corporate operations, and Whitby has developed a new building standard for greater efficiency and resilience across the whole community. The Region of Durham has developed a community climate adaptation plan, which is a high-level strategic plan to help improve the resilience of the entire region of Durham. Additionally, Durham has developed a community energy plan, outlining a pathway to reduce GHG emissions across the entire region.

This project addresses a gap—a detailed, community-level plan for the Town of Whitby that identifies specific ways to adapt to climate change. In a parallel effort, Whitby is undertaking a community plan to reduce GHG emissions all across Whitby.

The Town of Whitby's Climate Change Master Plan is divided into two phases to address these gaps. Phase 1 focuses on Climate Adaptation, identifying specific risks to the Town and the community from climate change. It identifies actions the Town and community can take to reduce the impacts of climate change and the associated risks. It provides a high-level overview of the costs and economic impacts of these actions, as well as the costs of inaction.



Phase 2 focuses on Climate Mitigation and will identify the sources of GHG emissions in Whitby, as well as the flow of energy across the community. Phase 2 develops a pathway to dramatically reduce emissions. Implementing the pathway will result in improved energy efficiency in all sectors and will create opportunities for economic growth and community development.



2. Climate Change

2.1 Definitions

Definitions and frameworks that systematize hazards, exposure, vulnerability, risk, and adaptation in the context of climate change are multiple, overlapping, and often contested. Today, key reports and most authors differentiate between hazards, vulnerability, risk, and impacts. The recent literature underscores that risks from climate change are not solely externally generated circumstances or changes in the climate system to which societies respond, but rather the result of complex interactions among societies or communities, ecosystems, and hazards arising from climate change. This exhibits the social construction of risk more deeply through the concept of vulnerability.[7]

Adaptation is the process by which human systems adjust to actual or expected climate change and its effects. Adaptation seeks to moderate or avoid harm or even to exploit potential beneficial opportunities with the changing climate.

Resilience is the capacity of a system, either social, economic, or environmental, to cope with hazardous events or disturbances. This can involve responding to hazards or reorganizing systems in ways that allow them to maintain their essential function, identity, and structure.

[7] Oppenheimer, M. et al. 2014: Emergent risks and key vulnerabilities. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

Climate hazards refer to the potential occurrence of climate-related physical events, such as extreme weather (heatwaves or floods), or climate change trends, such as increasing temperatures, that result in an impact on natural, built, or human systems.

Impacts, which are also referred to as consequences or outcomes, primarily refer to the effects of climate hazards on natural, built, and human systems. This includes the effects on lives, livelihoods, health, ecosystems, economies, societies, cultures, services, and infrastructure. Impacts generally manifest in some form of damage, disruption, or complete (irretrievable) loss and can be generally categorized as physical, social, or economic. Impacts result due to the interaction of climate events or trends (occurring within a specific time period) and the vulnerability of an exposed society or system. Additionally, impacts can be considered direct (damage to a building) or indirect (loss of a job or income as a result of damage to a building).

Exposure refers to the presence of people, livelihoods, species or ecosystems, environmental functions, services and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected by climate-related events. For example, assets located in a floodplain or people living in poor-quality housing.

Vulnerability refers to the likelihood of being adversely affected and primarily refers to characteristics of human or social-ecological systems that are exposed to hazardous climatic events or trends. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt (adaptive capacity). Ecosystems, geographic areas, assets, humans, etc. can be classified as vulnerable, and this is of particular concern if vulnerability in one area (e.g. humans) increases as a result of potential impairment or increased vulnerability in other areas (e.g. assets).

Risk results from the interaction of vulnerability, exposure, and hazard, and in this context, the term primarily refers to the risks of climate change impacts (see Figure 6). Risk is also referred to as the potential for consequences where something of value is at stake and where the outcome is uncertain. It is often represented as the probability of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur. However, this mathematical approach requires the consideration of vulnerability and exposure intrinsically for it to be valuable.

Lastly, stressors refer to events and trends, which are often not climate-related, that have an important effect on the system exposed and can increase vulnerability to climate-related risk. For example, growing income inequality is a stressor that is pushing already low-income families to their financial limits, further increasing these families' vulnerability because they have fewer resources (and therefore decreased capacity) to respond to the impacts of a major climate event.

This framing underscores that the development of a society has significant implications for exposure, vulnerability, and risk. Climate change is not a risk per se, rather climate changes and related hazards interact with the evolving vulnerability and exposure of systems and determine the changing level of risk. Identifying key vulnerabilities facilitates the estimation of key risks when coupled with information about evolving hazards and exposure associated with climate change.

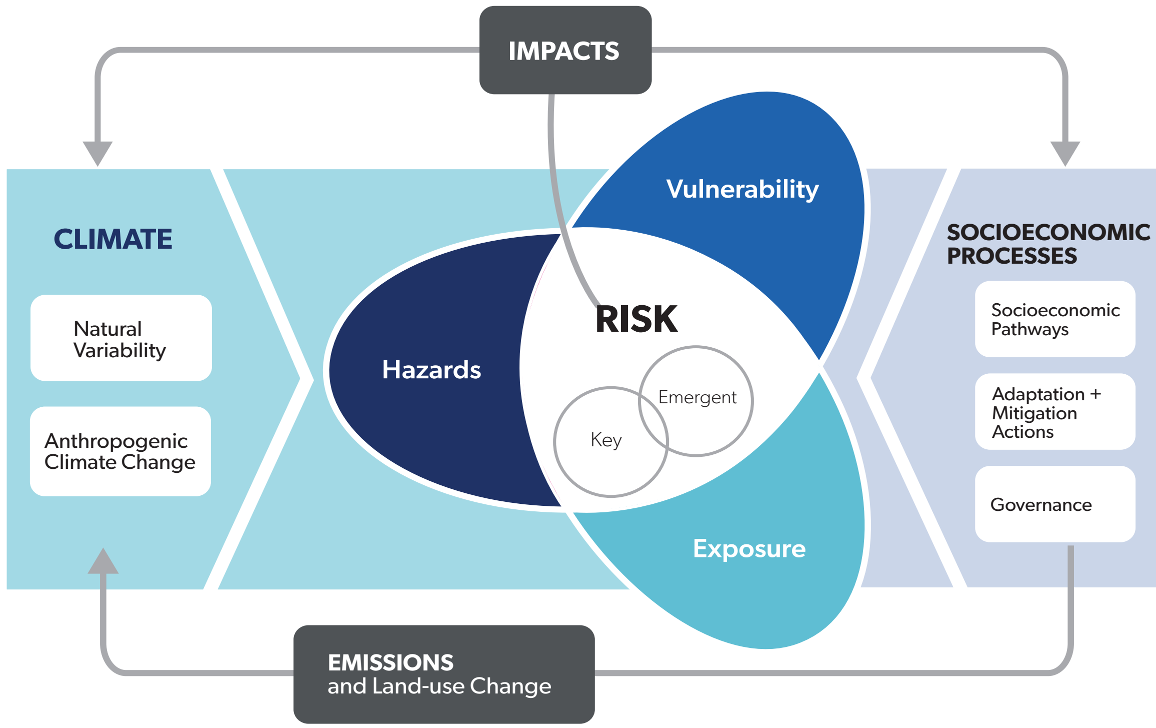


Figure 6. Schematic of the interaction among the physical climate system, exposure, and vulnerability producing risk.[8]

2.2 Climate Hazards in Whitby

Globally, GHG emissions are increasing.[9] Policies and actions that aim to reduce emissions are being implemented by many governments, but collectively, these policies and actions are insufficient to prevent dangerous levels of warming.[10]

The Region of Durham has conducted a detailed assessment of climate change impacts based on an analysis of several climate models downscaled and corrected for the region (Table 1).[11] The 2020 summary of these models tells a story of a warmer, wetter, and wilder Whitby in the future.[12] The future climate scenario used in this model is the RCP 8.5 scenario, a worst-case scenario.[13]

Under this scenario, the annual mean temperature in Whitby is expected to rise and will be accompanied by an increase in the number of extreme heat days. The number of extreme cold

[8] Oppenheimer, M. et al. 2014: Emergent risks and key vulnerabilities. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

[9] WMO (2021). Greenhouse Gas Bulletin: Another Year, Another Record. Retrieved from: https://public.wmo.int/en/media/press-release/greenhouse-gas-bulletin-another-year-another-record#:~:text=That%20trend%20has%20continued%20in,of%20the%20pre%2Dindustrial%20level.

[10] For example, Canada's climate policy, which is considered ambitious domestically, is aligned with 4 degrees of warming. See Climate Action Tracker (2022). Canada. https://climateactiontracker.org/countries/canada/.

[11] The four climate data portals used in this downscaled ensemble model are:
York University's Laboratory of Mathematical Parallel Systems (LAMPS) Climate Change Portal; University of Toronto's Peltier Climate Change Ensemble Data; University of Wisconsin's Notaro Climate Change Ensemble Data Portal; and the second phase of the North American Coordinated Regional Climate Downscaling Experiment (NA-CORDEX) Portal.

[12] Ontario Climate Consortium, 2020. Guide to Conducting a Climate Change Analysis at the Local Scale: Lessons Learned from the Durham Region.

[13] A sensitivity analysis that compares the impacts of the RCP8.5 to a scenario wherein GHG emissions do not increase and climatic conditions remain constant is found in Appendix C.

days will decrease, as will the number of potential ice days and the number of freeze-thaw cycles per year.

The total annual precipitation is expected to increase, as are the maximum one-day and three-day precipitation amounts in storm events. The number of consecutive dry days is projected to increase slightly, leading to a slight increase in droughts in spite of the increased total annual precipitation.

The number of growing degree days is expected to increase, but this will be accompanied by an increased risk of inundation from intense precipitation events and an increased risk of pests and disease.

2.3 Why RCP 8.5?

This study uses the ensemble model climate projections developed in 2019 by the Region of Durham in partnership with the local municipalities and conservation authorities to determine future climate projections. Two scenarios, RCP 4.5 and RCP 8.5, were leveraged through this model to identify climate projections to the year 2100. It is also important to note that global emissions released into the atmosphere have a lifecycle spanning 12–24 years once emitted into the atmosphere. As a result, emissions put into the atmosphere today will have impacts on the climate over the next two decades (2020–2040).

The RCP 8.5 scenario has been criticized for an overestimation of global coal reserves, leading to continued coal use and greater contributions of GHGs to the atmosphere.[14] The world has a 35% chance of exceeding RCP 8.5 by the end of the century.[15] While the RCP 8.5 scenario may be an overestimation of atmospheric carbon by the end of the century, RCP 4.5 is most likely an underestimation.[16] The RCP 8.5 scenario represents a future where GHG emissions continue to rise in the atmosphere, primarily due to continued use of fossil fuels. In the event that emissions trend closer to the RCP 4.5 scenario, the conditions modelled for this project will be delayed by a period of time, but not eliminated entirely.

Global GHG emissions in 2022 are tracking the RCP 8.5 scenario emissions, and this is expected to continue to the mid-century based on the current global emissions pathway.[17]

Due to these trends, RCP 8.5 was selected as the most suitable scenario for analyzing Whitby's climate risk. However, assuming the policies to reduce the emissions of GHGs across the globe are successfully implemented, the expected actual climate scenario at the end of the century will fall between RCP 4.5 and RCP 8.5. When including the uncertainties of factors such as melting permafrost, increased forest fires, and changes to existing carbon sinks on land and in the ocean, the pathway lies much closer to RCP 8.5. Future riverine flooding data is available for Whitby only for the RCP 8.5 scenario. Based on the above rationale, these data are appropriate for this high-level strategic analysis of riverine flooding risk. The flooding risk for urban flooding is based on current conditions, as no future data were available. Similarly, heat risk data is available only for current conditions, so no changes have been made to the location of high-risk areas for heat

14 Hausfather, Z. and G. P. Peters,, Jan 2020. Emissions- the "business as usual" story is misleading. Nature, Jan 29 2020. Accessed April 2022: https://www.nature.com/articles/d41586-020-00177-3

15 Christensen, P., Gillingham, K., & Nordhaus, W. (2018). Uncertainty in forecasts of long-run economic growth. Proceedings of the National Academy of Sciences, 115(21), 5409-5414.

16 Ibid.

17 Schwalm, C.R., S. Glendon, and P. B. Duffy., 2020. RCP8.5 tracks cumulative CO_2 emissions. Proceedings of the National Academy of Sciences. Aug 3, 2020; 117 (33) pp 19656-19657

impacts.

Consequently, the only analysis impacted by the use of the RCP 8.5 scenario is the riverine flooding section. A comparison of the costs, damages, and return on investment of adaptation actions between the RCP 8.5 scenario and the current climate conditions projected on the built environment of Whitby in 2070 is included to help demonstrate the relative impact of this decision on the modelling. Should the global emissions pathway change, the modelling in this project can be updated to reflect this.

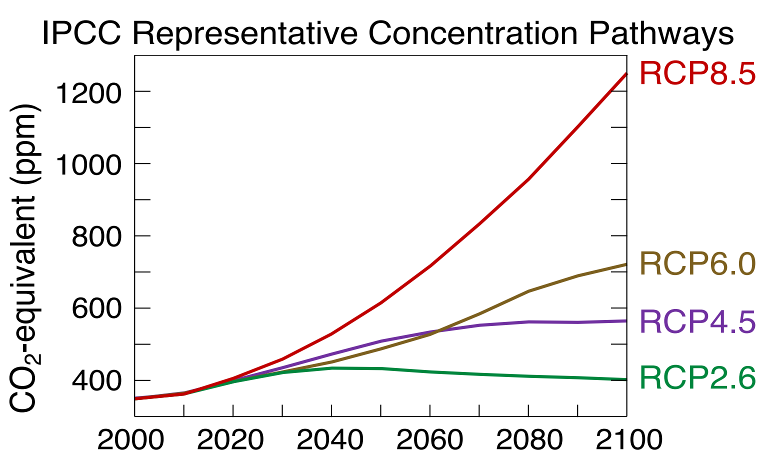
What is an RCP?

An RCP, or Representative Concentration Pathway, is a scenario used to project rates and severity of climate change based on the concentration of various GHGs in the atmosphere. Each scenario accounts for changes to land use and land cover, as well as the lifecycle of various gasses and aerosols in the atmosphere. The pathways differ in the actions taken to reduce GHG emissions.[19] The RCP model has been developed for use by the United Nations Intergovernmental Panel on Climate Change, the recognized global authority on advancing understanding on global climate change.

RCP 2.6: The most ambitious pathway, **RCP 2.6** requires emissions to decline starting in 2020, reach zero emissions by 2100, and then decline further through carbon capture and sequestration.

RCP 4.5 and **6.0:** Intermediate-emissions pathways, where emissions peak at 2040 and 2080, respectively. These pathways also include carbon capture and sequestration, but result in more serious climate consequences.

RCP 8.5: The high-emissions scenario, where emissions continue to rise throughout the 21st century. It is based on continued ongoing high levels of emissions, which could be driven by population growth, ongoing global use of coal, economic growth, or other fossil fuel use.



[19] van Vuuren et al (2011) The Representative Concentration Pathways: An Overview. Climatic Change, 109 (1–2), 5–31.

Table 1. Climate projections for Whitby under the RCP 8.5 scenario.[20]

CLIMATE PARAMETER	DETAILED PARAMETER	RCP 4.5 BY YEARS			RCP 8.5 BY YEARS			TREND
		2011- 2040	2041- 2070	2071- 2100	2011- 2040	2041-2070	2071-2100	
Mean Temperature (°C)	Annual	9.3	11.1	11.5	8.4	9.8	11.8	up
Maximum Temperature (°C)	Max Annual Temperature	13.9	15.8	16.3	13.0	14.5	16.5	up
Minimum Temperature (°C)	Min Annual Temperature	4.6	6.6	7.0	4.1	5.7	8.0	up
Extreme Heat (days/year)	Days Above 35°C	2	9	12	2	6	13	up
Extreme Cold (days/year)	Days Below -20°C	4	1	1	8	4	1	down
	Days Below 0°C (freezing days)	125	99	96	128	112	90	down
Total Precipitation (mm)	Annual (mm/year)	986	986	1059	1059	1132	1205	up
Extreme Precipitation	Max Precipitation in 1 day (mm)	34	91	56	51	57	62	up
	Max Precipitation in 3 days (mm)	67	76	77	73	78	87	up
Dry Days (days/year)	Total Annual	218	223	208	204	204	198	down
	Total Annual Consecutive Dry Days	24	22	23	23	24	233	No change
Growing Season	Growing Season Length (days/year)	168	197	198	182	196	217	up
Agricultural Variables	Corn Heat Units[21]	3866	4374	4542	3749	4253	4876	up
	Growing Degree Days - Risk of Presence of Pests (Base 15°C)	734	959	1051	680	899	1200	up

[20] Ontario Climate Consortium, 2020. Guide to Conducting a Climate Change Analysis at the Local Scale: Lessons Learned from the Durham Region.

[21] Corn Heat Units is a temperature-based index often used by farmers and agricultural researchers to estimate whether the climate is warm enough (but not too hot) to grow corn.

CLIMATE PARAMETER	DETAILED PARAMETER	RCP 4.5 BY YEARS			RCP 8.5 BY YEARS			TREND
		2011- 2040	2041- 2070	2071- 2100	2011- 2040	2041-2070	2071-2100	
Ice and Snow	Freeze-Thaw Cycles (cycles per year)	75	62	59	69	64	55	down
	Ice Potential (days per year)	13	9	11	18	15	11	down

3. Method

The climate adaptation modelling was a multiphase approach to understanding the dynamics of climate change, development, the built environment, and the natural environment in Whitby. Using the CityInSight modelling platform, people, places, and spaces were modelled both in time and in space. A full description of the modelling, data sources, and assumptions can be found in Appendix A.

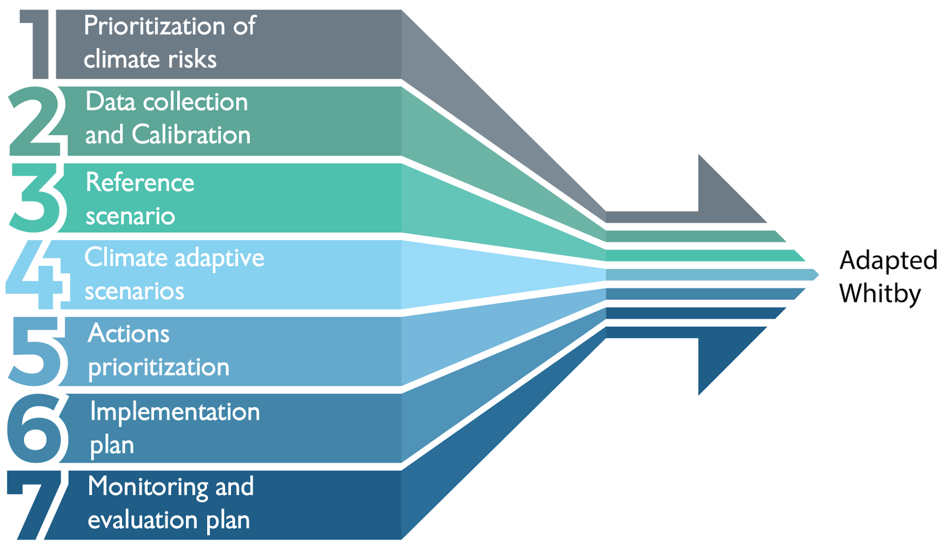


Figure 7. The role of modelling in the development of the adaptation plan.

3.1 Prioritizing Hazards

Climate hazards were identified by reviewing climate modelling and engaging with advisory groups and the public. Increased heat and risk of heatwaves, as well as increased flooding from precipitation, were identified as the highest priority hazards with measurable spatial variability across the town. Modelling of hazards was limited by data availability, particularly the projected changes spatially and temporally of that hazard on people, infrastructure, and natural spaces. Hazards that could not be modelled are discussed in section 4.5.

3.2 Scenarios

The spatial and temporal analyses (Figure 8) enable the development of multiple scenarios for Whitby.

- In the first scenario (Whitby 2020), current climate hazards are evaluated against the physical environment (exposure) of Whitby today to assess the climate risk.
- The second scenario evaluates Whitby in (2070) with the growth, development, and actions as they are planned today in the context of climate change (Whitby 2070 BAP).
- The third scenario evaluates the impacts of deliberate actions that reduce the risk of damages and impacts from climate change (Whitby 2070 Adaptive).

Both future scenarios use an RCP 8.5 climate model to predict the scale of climate change impacts.

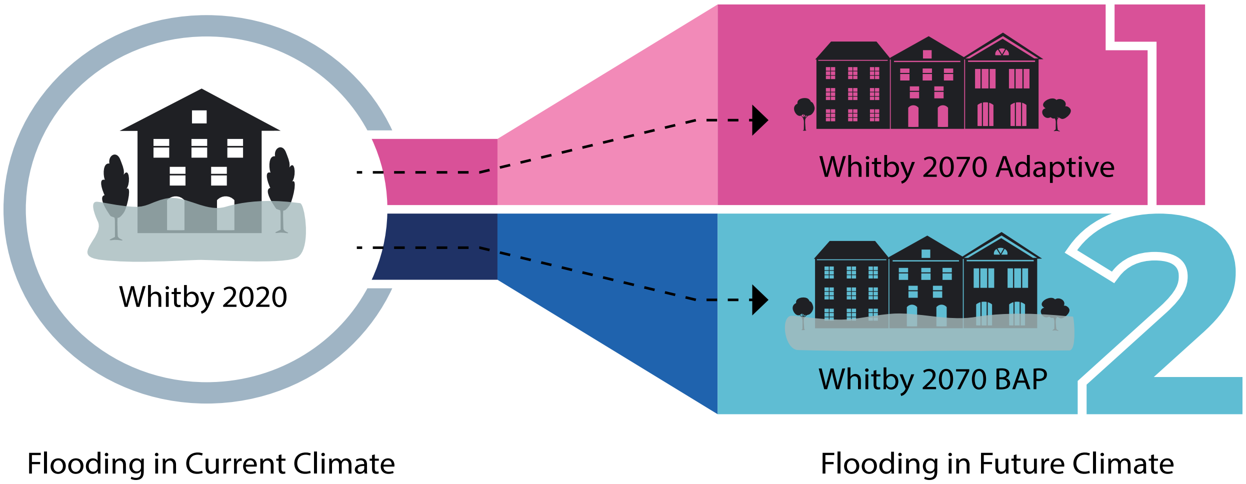


Figure 8. Three scenarios explore the impacts of a changing climate and adaptation actions on Whitby.

3.3 Financial Analysis

In addition to spatial and temporal modelling, the costs and benefits of adapting to climate change need to be understood. Financial modelling of the damages from climate change in the present day and in the two future scenarios allows for a comparison of the costs of action to adapt to climate change with the costs of inaction (Figure 9). Detailed financial assumptions are shown in Appendix A.

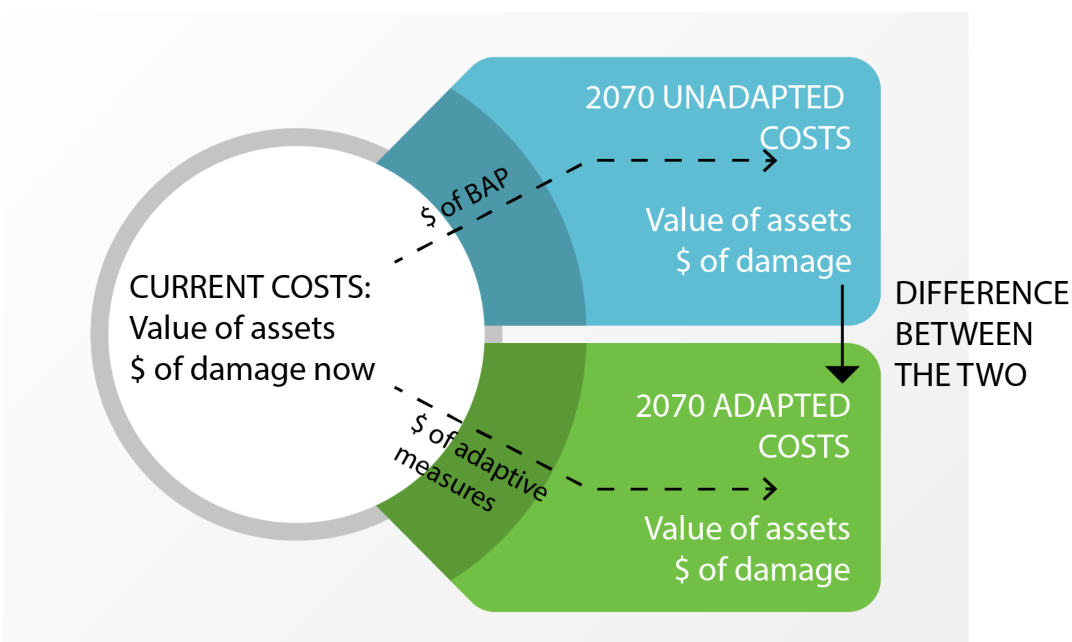


Figure 9. Method for evaluating the financial impacts of climate change and adaptive actions.

The combination of the spatial, temporal, and financial analyses of Whitby today, in the business-as-usual future, and in an adapted scenario allows for a deeper understanding of the impacts of climate change on the community and Town of Whitby and helps to develop and prioritize a list of immediate actions to reduce climate risk across all sectors.

4. The Climate Risks

4.1 Riverine and Coastal Flooding

4.1.1 THE STATE OF PLAY

Riverine flooding occurs when natural waterways, such as streams and rivers, exceed the capacity of their natural or constructed channels during high water flow, causing water to spill out onto adjacent dry land.

Riverine flooding is known to occur along the creeks that run through Whitby, in particular,Lynde Creek, Pringle Creek, and Corbett Creek. In Whitby, CLOCA is responsible for the development and implementation of a watershed management plan to limit exposure to flooding within a given watershed. The watershed is a two-way system where upstream activities affect downstream areas, and downstream flow can impact upstream areas. Changes to permeability, ecological health, and land use are major factors that affect the volume and speed of flooding in rivers and streams, impacting areas downstream from those changes. Dams and structures that restrict flow, including roads, culverts, and other development, not only affect the flow of water downstream but can result in localized flooding in the immediate upstream vicinity of those structures.

Coastal flooding occurs with changes in lake water levels in Lake Ontario and due to storm surges and waves. Water flow into Lake Ontario is primarily from inflow from Lake Erie, with minor contributions from surface runoff and groundwater discharge into the lake.[22] Outflow from Lake Ontario is controlled by a combination of natural evaporation and the capacity of the St. Lawrence River, with some regulation by the Moses-Saunders Dam. This dam generates electricity and regulates the flow of water from Lake Ontario into the St. Lawrence River.[23]

[22] Toronto and Region Conservation Authority, 2020. Lake Ontario: Water Levels and Resources. Accessed April 2022: https://trca.ca/news/lake-ontario-2020-water-levels/

[23] International Lake Ontario-St. Lawrence River Board, 2022. Lake Ontario Outflow Changes. Access April 2022: https://ijc.org/en/loslrb/watershed/outflow-changes

What is a 100-year flood?

Floods are classified by return periods, or the frequency with which they are expected to occur. These classifications are based on historical records and statistical modelling.

A 100-year flood is a flood of a magnitude that is statistically likely to occur once every 100 years. This does not mean such a flood will only occur every 100 years, like clockwork. Instead, it means that a flood of this size is predicted to have a 1-in-100 (1%) chance of occurring in any given year.

Similarly, a two-year flood is one that is predicted to occur once every two years, so has a 50% probability of happening in any given year.

A two-year flood is smaller and less severe than a 25-year flood or a 100-year flood.

The statistical models used to classify flood strengths must be recalibrated with climate change considerations, and the “future weather” scenarios in this analysis include this consideration. Thus, a 100-year storm in 2020 is less severe than a 100-year storm in 2070.

4.1.2 NEW DEVELOPMENT IN WHITBY

The Region of Durham is anticipating rapid population growth in the future, and Whitby is no exception. Whitby is expected to grow from 137,000 people today, to 331,000 people in 2070. With this increase in population comes a need for new homes, businesses, shops, schools, and roads.

New development is challenging to predict, as planning policies change over time. Currently, the southern area of Whitby is more densely developed and populated, with less dense single-family homes dominating the northern stretches of the town. Development is expected to take place in these northern stretches, as well as in currently undeveloped areas within the downtown.

The location and the nature of development will have impacts on the ecosystem health and hydrologic dynamics within the town. Anticipated development is shown in Figure 10, below.

The location and types of new development projected to occur by 2070 strongly influence the potential damages and associated costs from riverine flooding. New development is expected to occur in agricultural or naturalized areas in the north of Whitby and along creeks and waterways throughout the town.

Developing agricultural lands will have downstream impacts as the surface transitions from porous and absorbent to impermeable and hard. Development along creeks and waterways will expose more infrastructure to direct damages from flooding and will reduce the ability of natural systems to regulate floodwaters through infiltration and evapotranspiration.

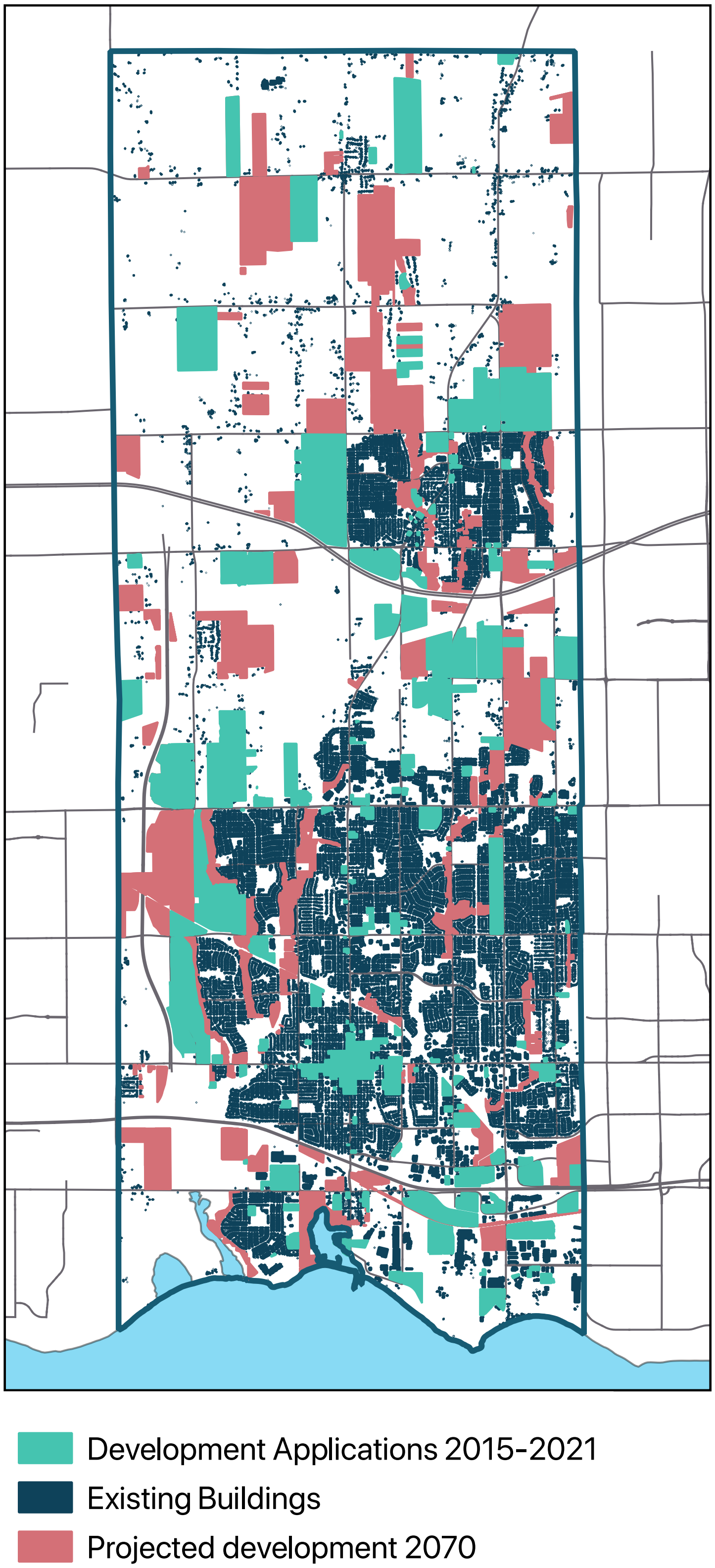


Figure 10. Existing buildings, planned development, and projected development for Whitby.[24]

[24] Future building locations were assigned to traffic zones following data from the 2018 PLUM model for the Durham Region.

Figure 11 compares the probability of damages to existing buildings now and with future climate conditions, as well as the probability of damages to new development in today's climate, the future climate, and under the Adapted Scenario. As much of the new development is projected to occur in locations at risk of flooding, these buildings and new infrastructure will experience elevated flood risks even in today's climate conditions.

Large flooding events that cause extensive damages are less likely to occur than smaller events, but even a two-year flood (probability of 0.5) will cause millions of dollars in damages for Whitby and its residents. These costs will continue to rise as climate change results in more severe flooding and intense storms. By adapting current and new buildings for resilience to the future climate, the probability of damages is greatly decreased. New buildings experience lower probable damages in the future climate scenario than current buildings. For larger storms (greater than a 10-year flood), the risk of damages to new buildings aligns with the risk to current buildings in the current climate conditions.

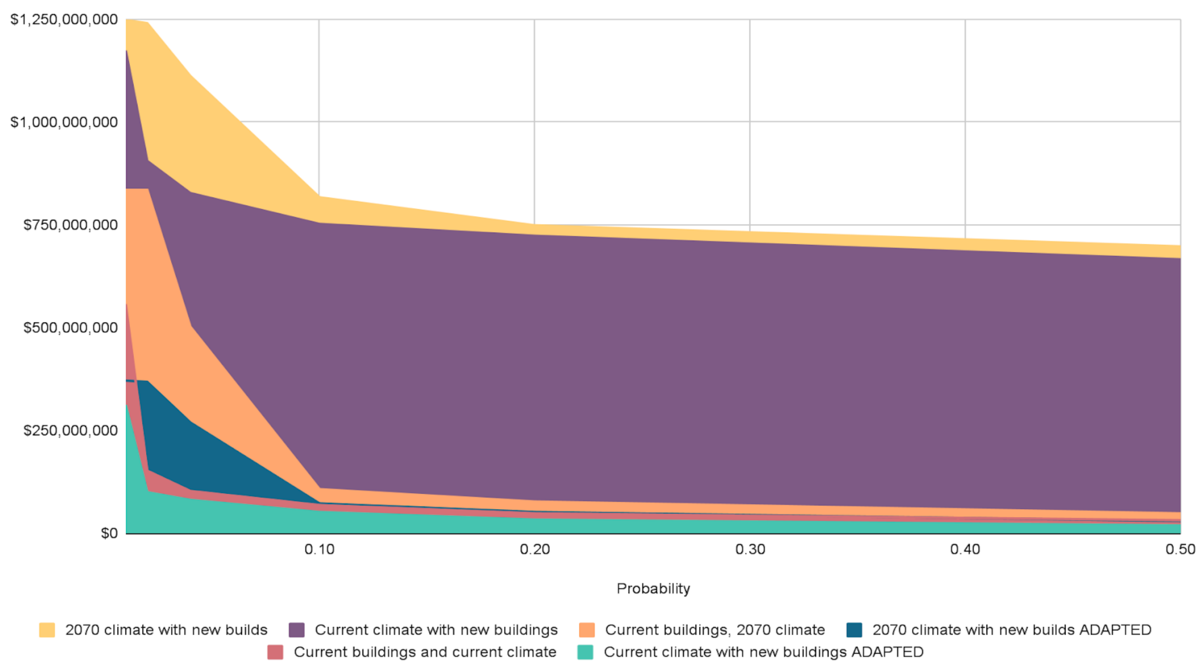


Figure 11. Damages to current buildings in the current climate, current buildings with future climate conditions (2070 under the RCP 8.5 scenario), new development with the current climate conditions, and development with future climate conditions. Current and new buildings in the Adapted Scenario experience the RCP 8.5 climate conditions but have been adapted to reduce the risk of damages from flooding.

4.1.3 FLOODING NOW AND IN THE FUTURE

Modelling the risk of flooding, as well as modelling to identify those most vulnerable to flood damages, was completed using a variety of flooding and hydraulic data. The flood levels for current return periods were based on data that considers unconstrained flow. This means that existing engineered structures and systems that work to slow the flow of floodwaters in storms and work to reduce flood risks are not considered in the hydraulic models. As a result, the flooding from riverine sources can be considered a "most-severe" scenario, and detailed site-specific studies will be required before any detailed projects are undertaken.

The use of unconstrained flow aligns with the recommended Regional floodplain mapping regulations, where all stormwater management facilities and other man-made storage are excluded. This flood modelling is based on precipitation events and not seasonal flooding from ice/snow thaw in the spring freshet.

The actions modelled to reduce the risk of flooding from riverine and coastal sources are described in Table 2.

Table 2. Actions to reduce risk from riverine and coastal flooding.

ACTION	DESCRIPTION
New development restricted from flood zones	• No new building development is within the 2070 RCP 8.5 100-year floodplains. • New development was shifted away from parcels at risk of flooding during a 100-year storm to other parcels within the same traffic zone. • The average density (land area per building) per zone was checked to ensure buildings could physically fit in the available area.
Flood berm constructed in West Lynde	• A flood berm is constructed between Hwy 401 and residential lots to the north to prevent floodwaters from Lynde Creek flowing east and north into the area around Michael Boulevard and Flemington Court. It is based on the design in the Michael Boulevard Flood Mitigation Strategy.[25] • Backflow prevention devices are installed on the four storm sewer outfalls to prevent storm discharge from backing up into the residential areas
Flood berm constructed along Pringle Creek	• A flood berm is constructed near Kilberry Drive and Garden Street to stop floodwaters from Pringle Creek from expanding into the neighbourhood. • Based on the design of the Michael Boulevard flood berm, with a length of 700 m and height of 1.5 m, this location was selected because of the existing flooding risk during 100-year storms.
Dry-proofing and wet-proofing buildings	• Building-level dry-proofing and wet-proofing measures applied to top 10% highest damage parcels. • Dry-proofing measures were applied to parcels with a flood depth less than 1m. • Wet-proofing measures were applied to parcels with a flood depth greater than 1m.

A comparison of the flood extent in the three scenarios (2020, 2070 BAP, and 2070 Adapted) shows distinct differences. The extent and the severity of riverine flooding increases between 2020 and 2070, through a combination of climate change and development. Figure 12, below, highlights the differences between flooding of different return periods in the three modelled

[25] The Municipal Infrastructure Group, Ltd, 2020. Michael Boulevard Flood Mitigation Strategy, FInal Report.

scenarios. The map shows traffic zones that experience damage from coastal and riverine flooding in each of the scenarios.

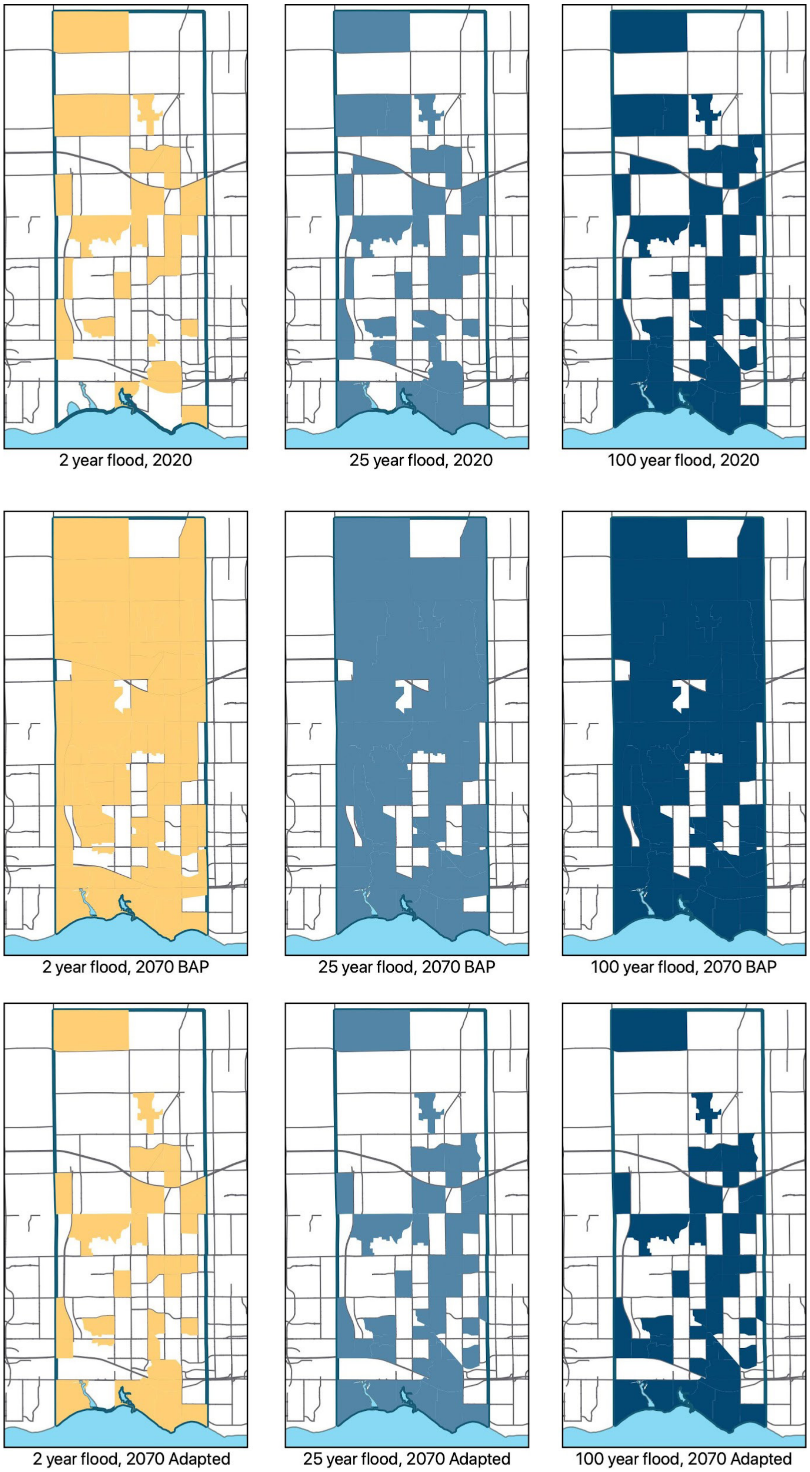


Figure 12. Traffic zones that experience coastal and riverine flooding in two-year, 25-year, and 100-year floods in 2020 and in the 2070 BAP and 2070 Adapted scenarios.

The West Lynde neighbourhood is an area that is currently experiencing flooding. The CN and Metrolinx rail bridges over Lynde Creek restrict flow along the creek, resulting in upstream flooding during storm events in the West Lynde/Michael Boulevard neighbourhood.[26] The Michael Boulevard Flood Mitigation Strategy (2020) identifies possible solutions to the flooding issue, ranging from replacing culvert, using engineered flood berm and backflow prevention devices to provide localized flood protection, working with the community to reduce potential damages from floods, and ensuring adequate emergency management and response planning.[27]

Similarly, the Pringle Creek area has experienced flooding. For the purposes of this study, a specific neighbourhood with concentrated flood damages was selected, and similar flood-prevention measures from the Michael Boulevard strategy were implemented here. The Pringle Creek flood berm was modelled based on the parameters for Michael Boulevard to help illustrate the potential damage reduction opportunities of engineered solutions in high-risk areas. A detailed engineering study of this area would need to be completed before such work could be considered in the real world. The locations of the West Lynde/Michael Boulevard area and the Pringle Creek area are shown in Figure 13.

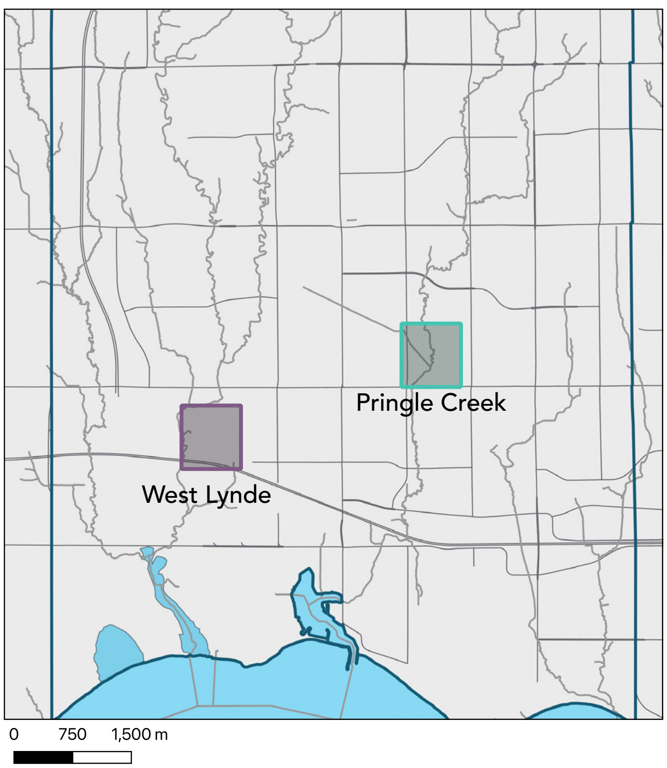


Figure 13. Focus areas in West Lynde and Pringle Creek where flood berms were modelled to reduce riverine flooding.

Figure 14 details the extent of flooding in the West Lynde area from two-year, 25-year, and 100-year return period floods for the three modelled scenarios. Flooding in a 100-year storm in 2020 is comparable to a 25-year storm in 2070. By implementing the physical measures described in the Strategy, the two-year flooding extent in the West Lynde neighbourhood in 2070 is

26 The Municipal Infrastructure Group, Ltd, 2020. Michael Boulevard Flood Mitigation Strategy, FInal Report.

27 Ibid.

comparable to the current two-year flood extent and reduced below current levels in a 100-year storm.

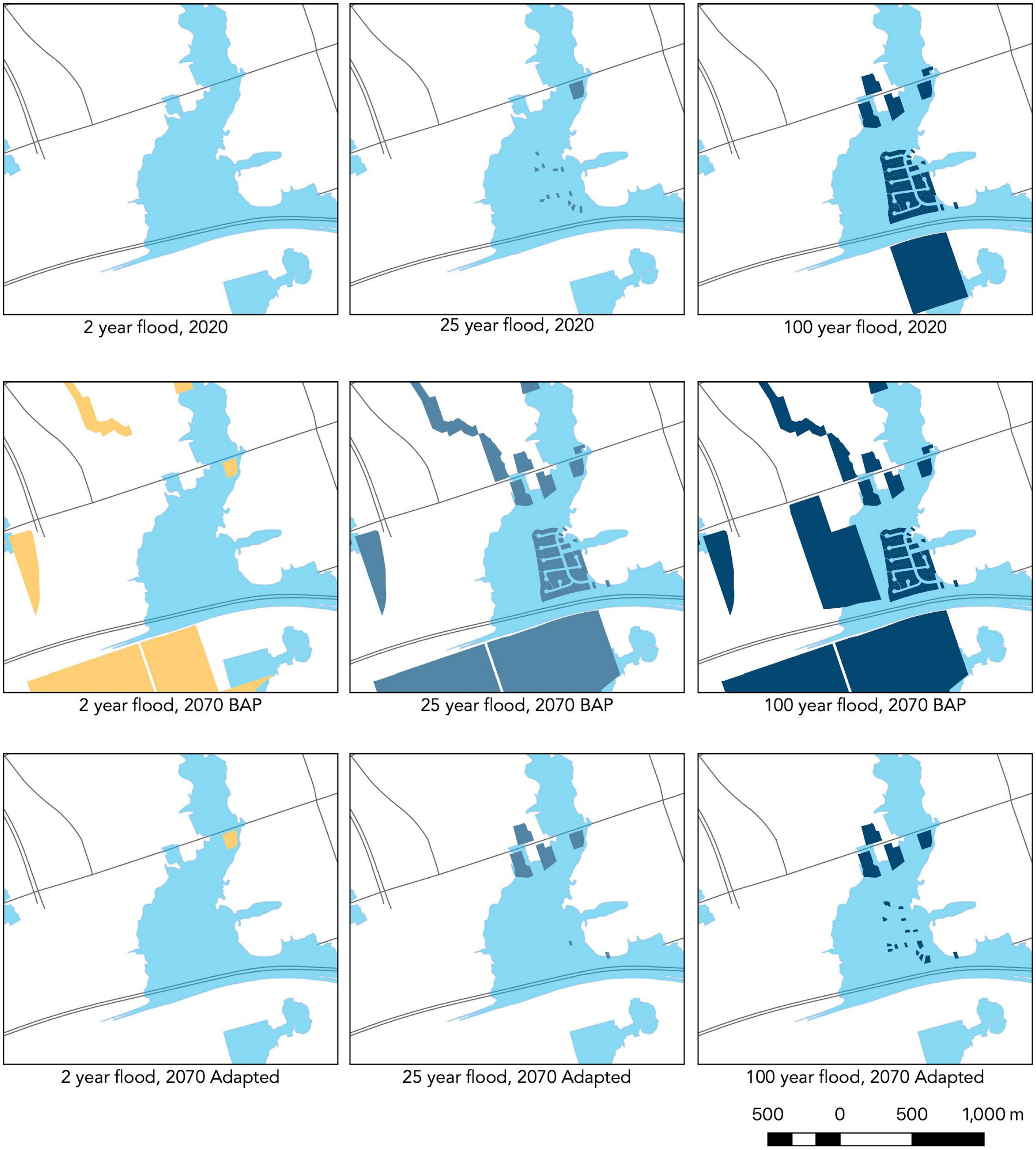


Figure 14. Parcels in West Lynde affected by flooding of Lynde Creek in 2020 (top row), 2070 BAP (middle row), and 2070 Adapted (bottom row) by flood interval. The blue outline is the extent of current (2020) flooding in a 100-year flood, according to monitoring data.

The study neighbourhood along Pringle Creek shows a similar pattern with flood adaptation measures in place (Figure 15). Smaller, two-year storms will still impact the parcels, but larger 25-year and 100-year floods are limited to an extent and severity in 2070 that is comparable to a 2020 flood of the same return period.

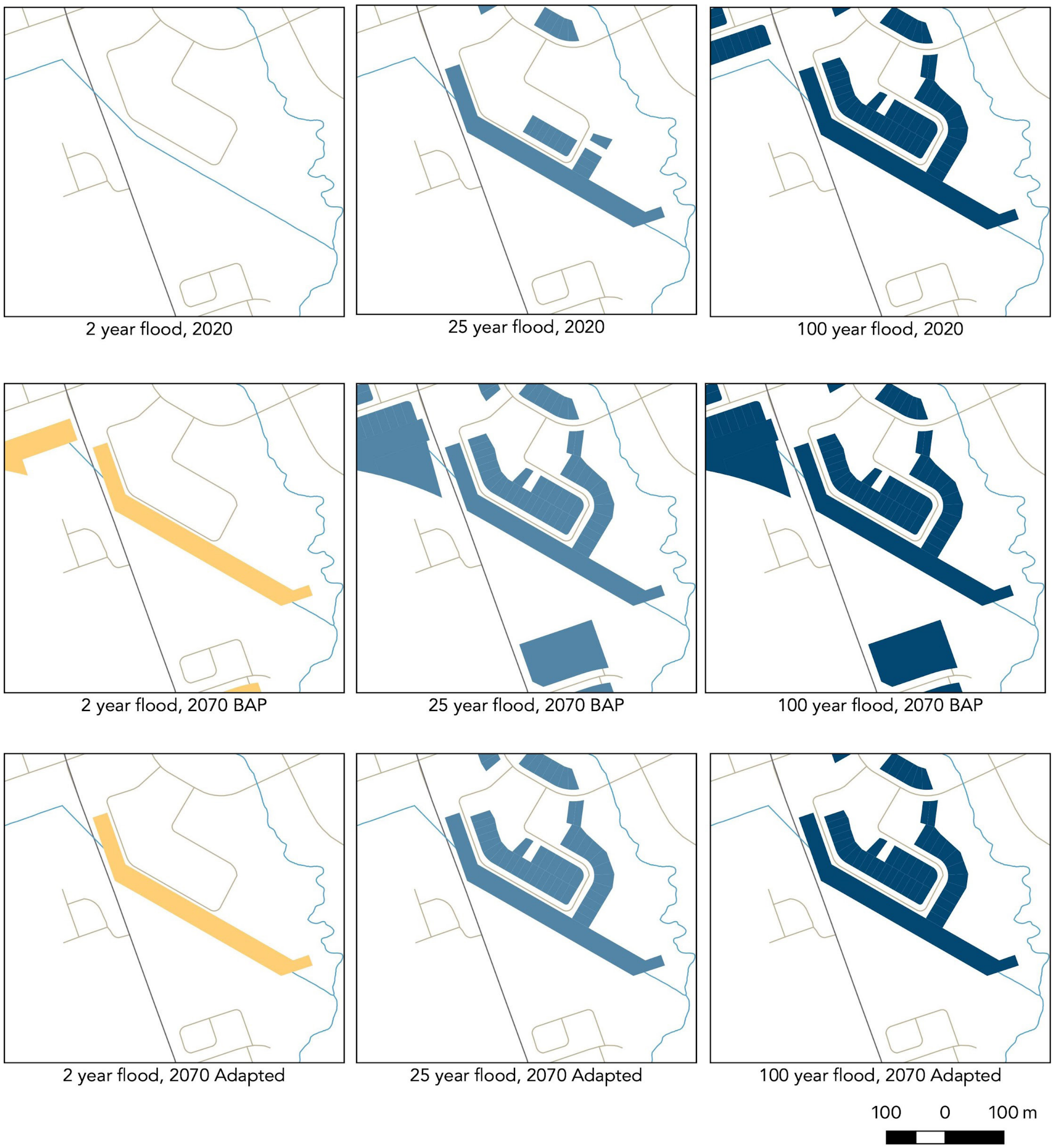


Figure 15. Parcels along Pringle Creek that are affected by flooding in 2020 (top row), 2070 BAP (middle row), and 2070 Adapted (bottom row) by flood interval.

4.1.4 COSTS AND BENEFITS OF ADAPTATION ACTIONS

The costs of taking action to reduce the risk of flooding and its associated damages are compared with the damages avoided by taking action (Table 3). The total capital costs and the project lifetime operations and maintenance costs show how much an action will cost to implement and maintain. The project lifetime avoided damages allow us to understand the financial impacts of the action, as well as the return on investment of the actions. These are based on the future climate scenario. The number of people either fully or partially protected from flooding is shown for each action.

Table 3. Costs and benefits of adaptation actions.

ACTION	CAPITAL COSTS ($)	LIFETIME OPERATIONS AND MAINTENANCE COSTS	PROJECT LIFETIME AVOIDED DAMAGES WITH FUTURE CLIMATE	RETURN ON INVESTMENT WITH FUTURE CLIMATE	NUMBER OF PEOPLE WITH RISK PARTIALLY OR FULLY ELIMINATED
New development restricted from flood zones	$0[28]	N/A	$17,034 million	$17,034 million	9,060
Flood berms constructed in West Lynde and along Pringle Creek	$7.7 million	$930,000	$77 million	$68 million	880
Dry-proofing and wet-proofing buildings	$1.2 million	$0	$60 million	$59 million	200

Coastal and riverine flooding results in significant financial costs, as well as disruptions in daily life, the operation of businesses, and the function of emergency services in Whitby. This analysis focuses on the financial impacts flooding has on the community.

A detailed analysis of the types of structures, buildings, and infrastructure in Whitby highlights the potential impacts of flooding both now and in the future. A comparison of the net damages per traffic zone by flood interval (Figure 16) highlights the risks of even minor flooding today, and emphasizes the importance of understanding the predicted impacts of climate change on development in the future. As development continues in the northern regions of Whitby, more zones are at risk of flooding impacts. The more densely developed areas in the southern part of town show increased potential for damages as flooding intensity increases into the future.

[28] This action is a regulatory change, so no capital costs are assigned.

Potential damages in Whitby can be avoided primarily by restricting building in future flood zones. Whitby is a growing community and is expected to continue to grow rapidly throughout the next 50 years. Careful planning and regulations that direct where new development occurs are essential to protect Whitby residents, their homes, and infrastructure, including roads and electrical and water utilities, that provides essential services.

Damages from riverine and coastal flooding can be reduced to levels similar to those in 2020 by implementing development zoning regulations, establishing neighbourhood-level actions to protect existing at-risk communities, and protecting individual homes from the impacts of flooding.

Figure 16. Damages by zone by return period for two-, 25-, and 100-year floods in 2020 (upper row) ,2070 BAP (middle row), and 2070 Adapted (lower row).

These damages are illustrated in Figure 17, which shows the statistically probable average annual damages to buildings, transportation infrastructure, and utilities now and in the future. Residential development shows significant increases in costs in the future and will be a key consideration in developing an adaptation strategy for the Town. These damages can be avoided by positioning new development, particularly residential development, in locations outside of flood risk areas.

Annualized damages for most sectors are reduced to levels comparable to or lower than 2020 levels though adaptation measures.

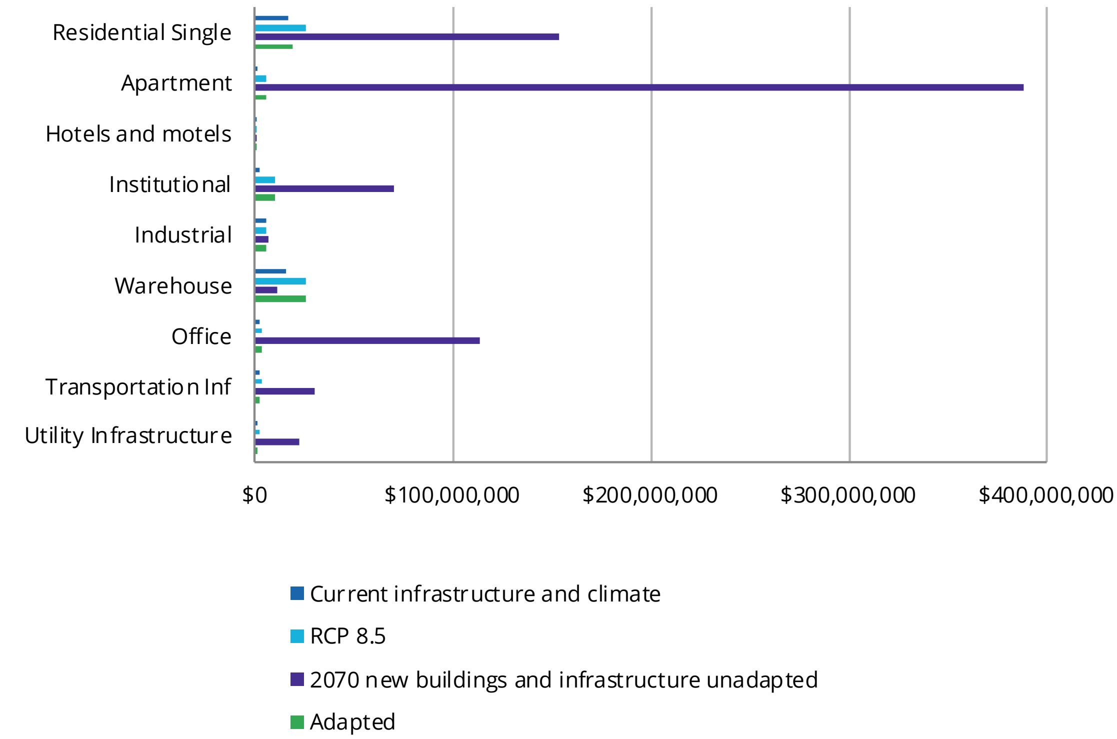


Figure 17. Annualized structure damages for existing buildings and infrastructure under current (2020) weather conditions, under future climate conditions (RCP 8.5), for new buildings and infrastructure under future climate conditions, and for adapted infrastructure and buildings.

Damages to the structure and contents of residential buildings are highest in single-family homes in 2020. Whitby is currently dominated by this type of housing, but future development is likely to shift towards apartments and townhouses. Damages to the contents of warehouses can cause significant financial losses and disrupt supply chains across the region.

By 2070, potential damages are an order of magnitude higher for most categories of infrastructure, with residential buildings (both single-family homes and apartments/condos) and their contents experiencing the largest impacts.

Floods disrupt businesses by damaging contents and causing closures for clean up and repairs.[29]

[29] Natural Resources Canada, 2021. Federal flood damage estimation guidelines for buildings and infrastructure. General Information Product 124e, 2021, 131 pages, https://doi.org/10.4095/327001

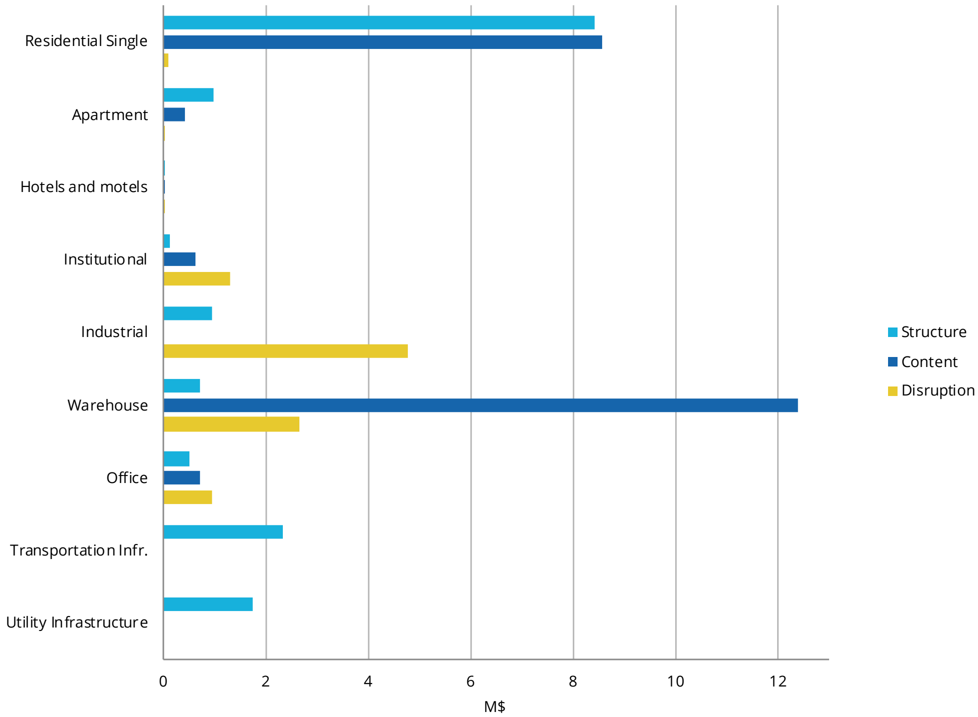


Figure 18. Annualized damages to structure and contents and damages resulting from disruption of business for 2020, averaged across all flood return periods for Whitby for coastal and riverine flooding.

Damages to structure and contents and damages resulting from disruptions in 2070 are significantly larger than in 2020. For residential buildings, damages increase by an order of magnitude, from a combined $17 million for structure and contents to $180 million in 2070. Apartments and condos experience the largest increase as a result of increased development of this type of structure and the location of these structures in high-risk areas.

The damage level in the 2070 Adapted Scenario is comparable to 2020 levels (Figure 20). Annualized damages to single homes are reduced to $17 million, and damages to apartments and condos are reduced to $5.7 million.

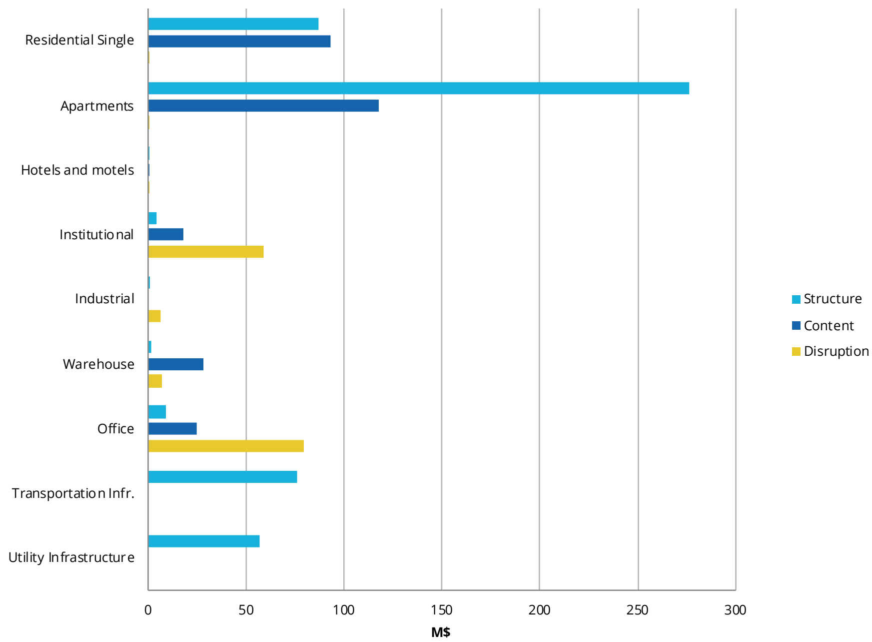


Figure 19. Damages to structure and contents and damages resulting from disruption of business for 2070 BAP, averaged across all flood return periods for Whitby, for coastal and riverine flooding.

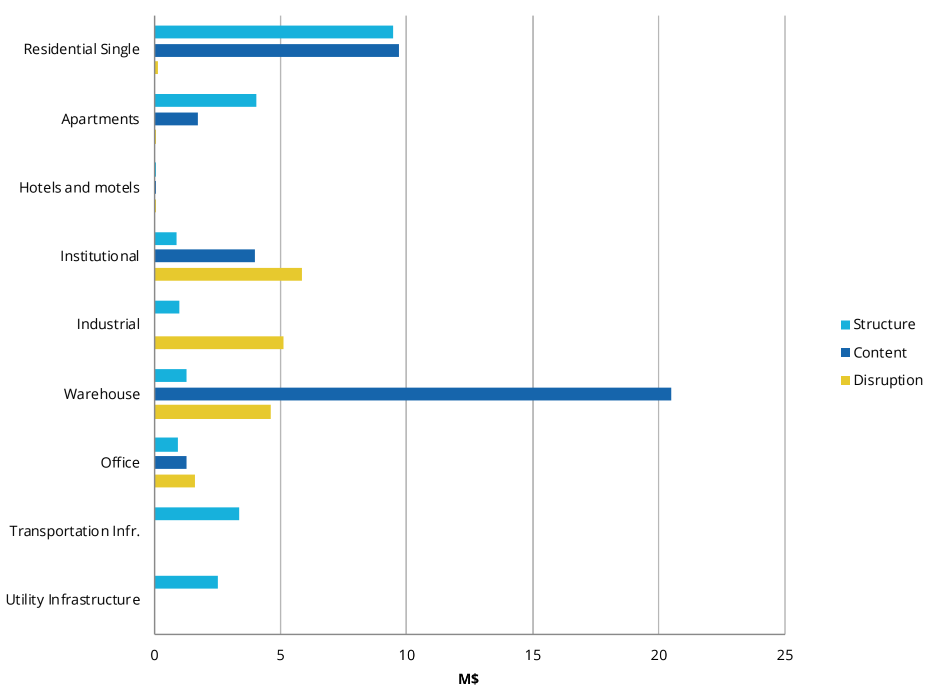


Figure 20. Damages to structure and contents and damages resulting from disruption of business for 2070 Adapted Scenario, averaged across all flood return periods for Whitby, for coastal and riverine flooding.

4.1.5 GROWTH IN WHITBY

Whitby is a growing community currently experiencing pressures to develop more housing to accommodate the expanding population. While this growth is inevitable, and comparable trends are seen across Southern Ontario, careful consideration of the location of new development will protect the safety and investments of individuals while also meeting the needs of the growing community.

The modelling for this project did not dramatically change the current trajectory of development within Whitby. All planned developments were kept within the same traffic zone, but specific parcels with an elevated flood risk were removed from consideration for future development. In the model, building types must align with development bylaws, and areas with zoning codes restricting new development (flood zones) are not assigned any new buildings. However, there are potential areas for development that are not labelled as flood zones in which flooding could occur for a given return period. The BAP Scenario does not prohibit building in these areas; however, the Adaptive Scenario restricts placing new buildings in parcels where flooding occurs in a 100-year return period storm. Figure 21, below, compares the distribution of floor space by traffic zone in the BAP and Adapted scenarios.

The implications of limitations on the location of new development was explored by looking at available space for the projected buildings on a zone-by-zone basis to ensure that the measure would not conflict with projected growth. Total projected floor space by traffic zone was divided by traffic zone total buildable area (which is restricted in the Adaptive Scenario) to obtain available space per building and to check for space sufficiency.

The flood modelling used in this project is based on unconstrained flows and the most appropriate data available at the time. A detailed in-depth hydrologic analysis of future floodplains, using future climate conditions, would be essential to ensure that any changes to development zoning are made with minimal impacts to current development plans and future community requirements.

Figure 21. Location of new floor space (residential and non-residential) in the 2070 BAP and the 2070 Adapted scenarios.

4.2 Urban Flooding

4.2.1 THE STATE OF PLAY

Urban flooding is a direct result of how we live and the cities we build. Hard, impermeable surfaces like roads, buildings, parking lots, and sidewalks reduce the ability of the ground to absorb precipitation. Instead of sinking into the ground, where it is slowly released into surface water systems or into groundwater reservoirs, the rain runs along the surface, causing flooding and erosion, and reducing the water quality in associated watersheds.

To reduce the impacts of urban flooding, cities are built with stormwater management systems designed to channel the water into pipes and culverts as quickly as possible. When these systems become overwhelmed by the flow of water, become clogged, or fail in other ways, the water builds up on the surface, resulting in localized flooding.

Table 4. Actions to reduce risk from urban flooding.

ACTION	DESCRIPTION
Upgrade stormwater sewers	• Stormwater sewers are upgraded by implementing the preferred solution described in the Town-wide Urban Flooding Study. These improvements include installing more stormwater management ponds, upgrading stormwater sewers, and installing high-inlet-capacity catch basins.

Improve culverts	• Based on the Bridge and Culvert Master Plan[30]
	  • Upgrading eight[31] culverts from highest-priority crossings listed in Table 12-1
	  • Upgrading eight culverts from lower-priority crossings listed in Table 12-2
	• Upgrading two additional culvert upgrades that lie along the same road segment as other highest-priority upgrades

Green infrastructure	• Added trees, rain barrels, rain gardens, and permeable paving across the town

4.2.2 BASEMENT FLOODING

Urban flooding can result in basement flooding in buildings that were not built to withstand the overflow from stormwater management systems. Typically, these are older buildings without backflow prevention systems. In this analysis, basement flooding is restricted to buildings that predate 1980 (Figure 22).

[30] Ecosystem Recovery Professional Engineers, 2020. The Town of Whitby Bridge and Culvert Master Plan Environmental Study Report. Final Report.

[31] Ten culverts are included in this report, but only eight of them are presented with proposed hydraulic conditions. These future conditions were used for the projected impacts of the culverts, so the two without this information were not included in this study.

Figure 22. Prevalence of basement flooding by zone in pre-1980s houses for a 100-year flood in 2020 and in the 2070 Adapted Scenario.

Damages from basement flooding vary with the intensity of the storm. Larger storm events overwhelm stormwater management systems more quickly, leading to more urban flooding issues. Figures 23 and 24 show the anticipated damages to pre-1980 buildings from a two-year, 25-year, and 100-year storm in 2020 and in 2070 after adaptation measures have been put in place.

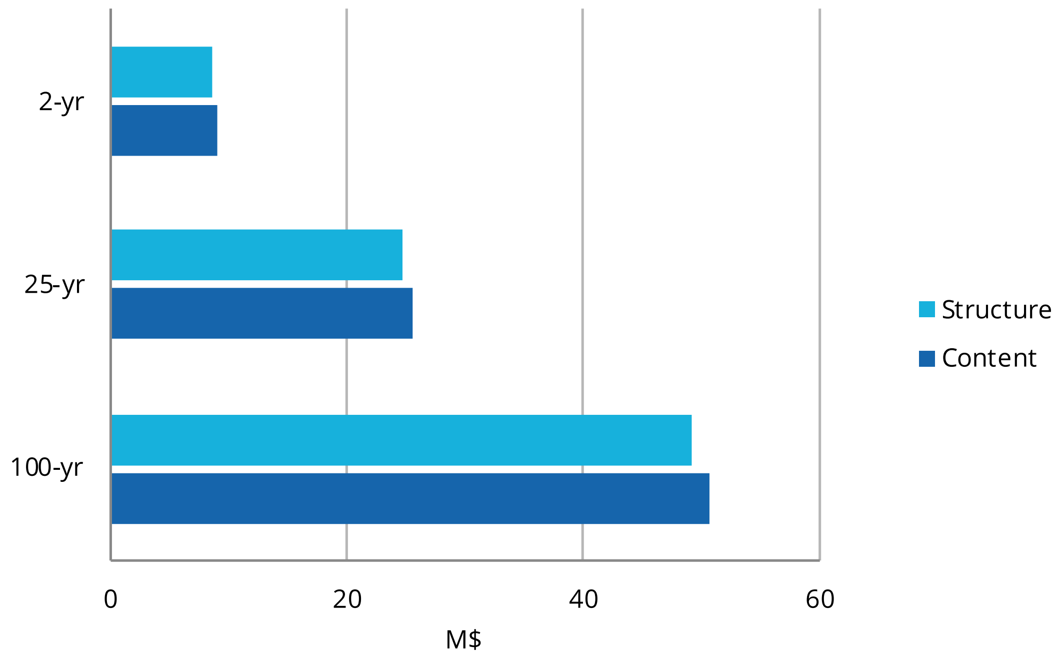


Figure 23. Damages from basement flooding for existing buildings and current weather conditions.

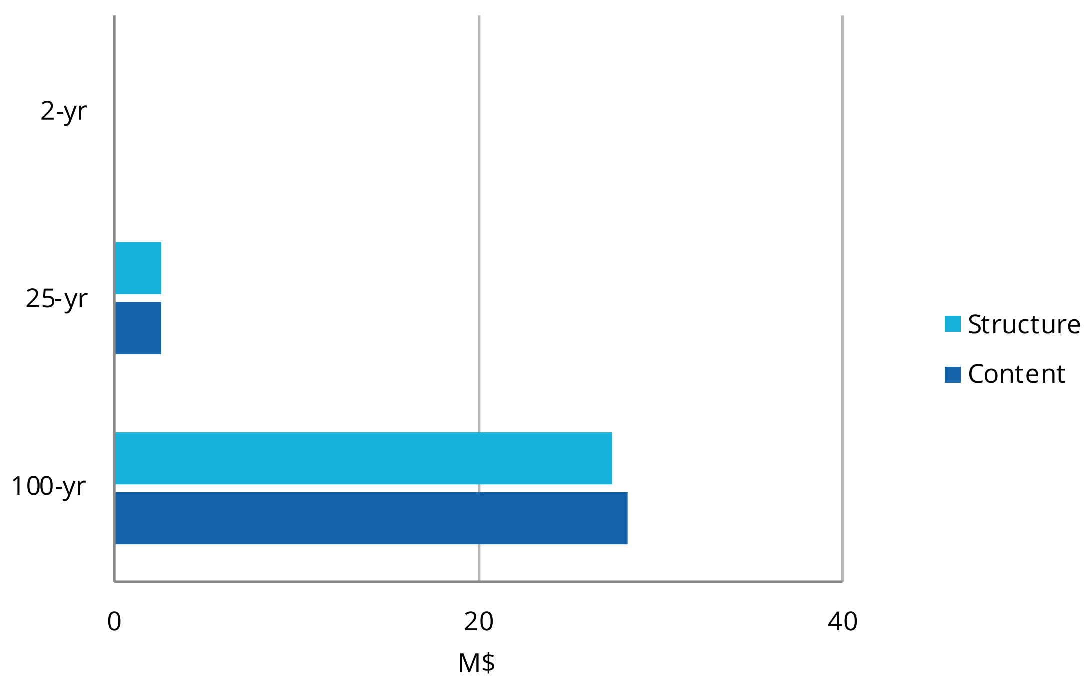


Figure 24. Damages from basement flooding in the 2070 Adapted Scenario.

Damages from two-year floods are entirely eliminated in the Adapted Scenario, and combined damages to structure and contents are reduced by 90% and 44% in the 25-year and 100-year floods, respectively.

New building standards reduce the likelihood of basement flooding, so the costs for basement flooding in the unadapted scenario increase for property owners of older buildings, without an expansion of the number of properties expected to experience flooding (Figure 25). The use of adaptation measures, such as improved stormwater sewers and green infrastructure, reduce the damages from basement flooding. Not all basement flooding is eliminated, but the damages from this flooding are greatly reduced.

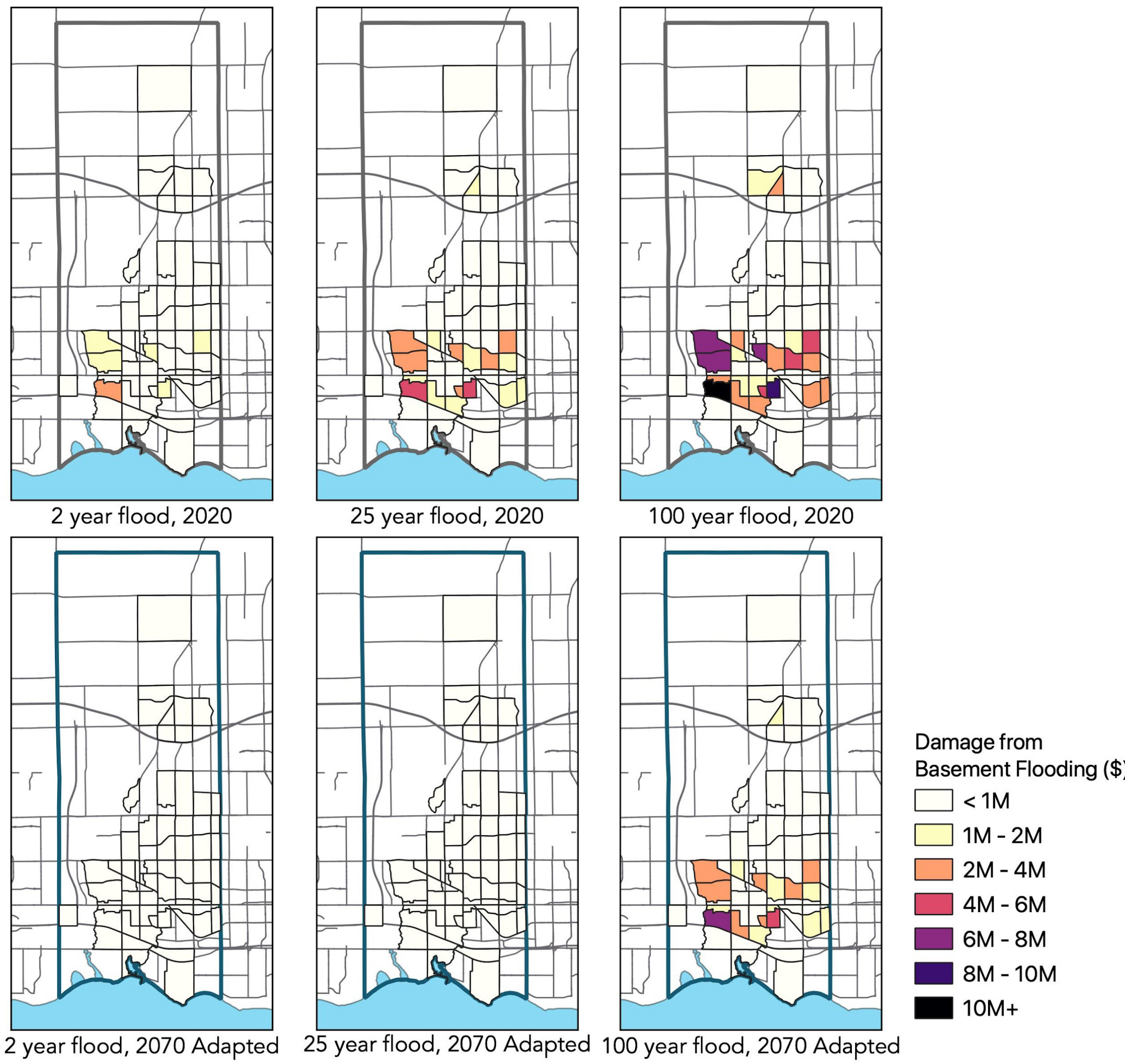


Figure 25. Damages to pre-1980 homes from basement flooding in two-year, 25-year, and 100-year floods in 2020 (top row) and in the 2070 Adapted Scenario (bottom row).

4.2.3 FLOODED ROADS

Flooding on roads is a hazard for emergency response services and for long-term road conditions. Some roads are purposely designed as stormwater conveyance systems, working to channel stormwater into pipes, culverts, and cisterns. These roads are not included in this analysis.

Knowing the location of roads prone to flooding in storms is essential for planning emergency services and facilitating broader communication to community members. Driving on flooded roads is dangerous because hazards can be hidden below the floodwaters and the integrity of the roadbed can be compromised. Furthermore, residents can become trapped in their homes, and emergency vehicles can lose the ability to reach them during flooding events.

Along with knowing the location of flooded roads (Figure 26), it is important to know how many people are put at risk by that flooding (Figure 27). Development in the northern regions of Whitby could put more people in proximity to flooded roads in the future, making this a critical consideration for all future development.

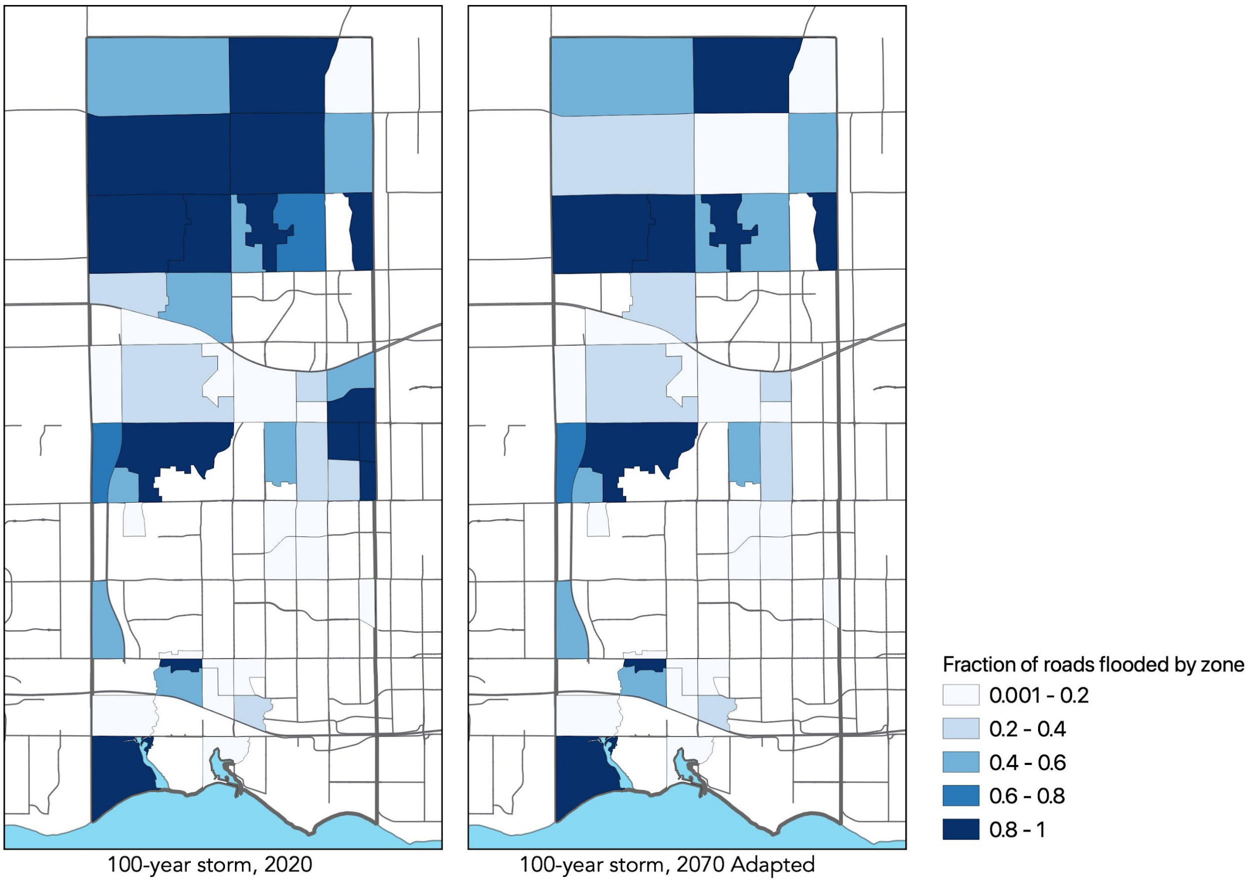


Figure 26. The fraction of roads by traffic zone overtopped in a 100-year flood in 2020.

Overtopping occurs when water levels rise above the surface of the road, leading to road flooding. Increasing the size of culverts to avoid surcharge reduces the risk of unplanned road overtopping in storm events, allowing more of Whitby to remain accessible to residents and emergency services during floods. However, the incidence of road flooding is not entirely eliminated, and the location of probable floods should be monitored closely and communicated regularly to emergency management services.

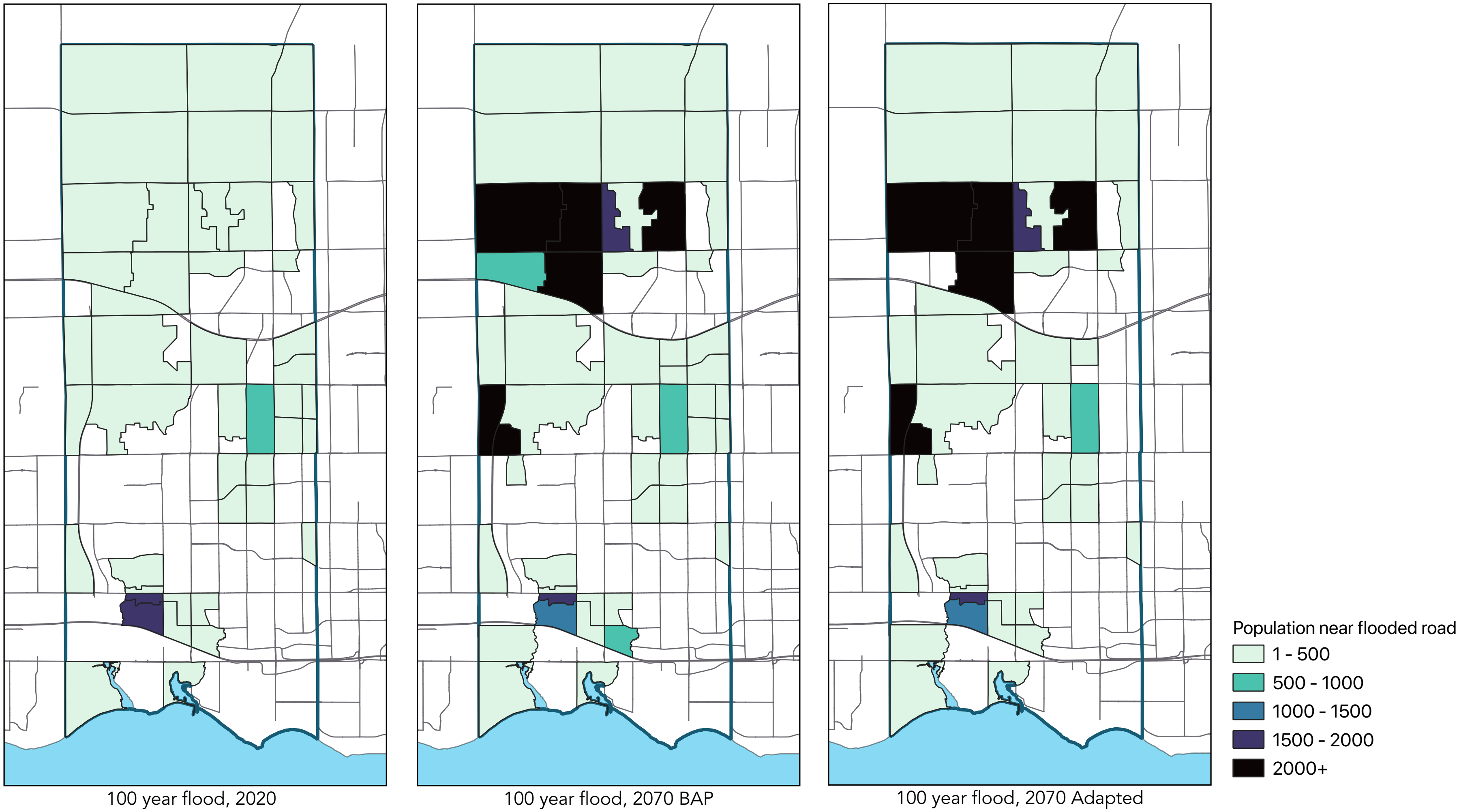


Figure 27. Number of people who live near roads prone to unplanned overtopping during a 100-year storm in 2020, in the 2070 BAP, and in the 2070 Adapted Scenario.

4.2.4 COSTS AND BENEFITS OF URBAN FLOODING ADAPTATION

Table 5 compares the damages from urban flooding with the costs of taking action to reduce the risks of urban flooding. The total capital costs and the project lifetime operations and maintenance costs show how much an action will cost to implement and maintain. The project lifetime avoided damages allow us to understand the financial impacts of the action, as well as the actions' return on investment. These are based on the future climate scenario. The number of people either fully or partially protected from urban flooding is shown for each action.

Table 5. Costs and benefits of adaptation actions.

ACTION	CAPITAL COSTS ($)	LIFETIME OPERATIONS AND MAINTENANCE COSTS	PROJECT LIFETIME AVOIDED DAMAGES WITH FUTURE CLIMATE	RETURN ON INVESTMENT WITH FUTURE CLIMATE	NUMBER OF PEOPLE WITH RISK PARTIALLY OR FULLY ELIMINATED	NUMBER OF PEOPLE AT RISK OF MORTALITY PROTECTED PER YEAR
Upgrade stormwater sewers	$537 million	$0	$1,263 million	$727 million	1,520	N/A
Improve culverts	$104 million	$0	$0	-$104 million	9,270	N/A
Green infrastructure[32]	$151 million	$34.0 million	$4 million	$423 million	31,360	522[33]

The damages avoided by installing green infrastructure only account for the reduction in damages from flooding and do not include any of the other financial and non-financial benefits of green infrastructure.

[32] This is included in the heat section as well. The costs/benefits are combined for both heat and flooding.

[33] This is from reduced risk from heat.

4.2.5 GREEN INFRASTRUCTURE

Green infrastructure is a system of measures used to reduce surface runoff during rainfall events, slow the speed of runoff, and increase the absorption of precipitation into the ground. These systems often feature natural elements, like plants and soil, but follow design guidelines like other stormwater management systems. Green infrastructure can include measures like bioswales and rain gardens, cisterns and rain barrels, and permeable paving and concrete.[34]

Green infrastructure is designed to supplement the existing grey infrastructure of pipes and culverts that is currently in place. Widespread use of green infrastructure can reduce the need to upgrade and expand grey infrastructure, and it reduces the need for water treatment, improves surface water quality, increases groundwater recharge, and can enhance biodiversity in a region.

Some green infrastructure mechanisms can also work to reduce the Urban Heat Island Effect by providing shade and facilitating evapotranspiration. Green infrastructure can be deployed on a local scale to improve the drainage and water management of a small area or on a larger scale to impact the flow of water across a watershed.

Four types of green infrastructure were included in the 2070 Adapted Scenario. The number of units of each feature installed on different property types is shown in Table 6. Rain barrels, rain gardens, and permeable paving were added specifically to zones that experience some level of flooding. These forms of green infrastructure were chosen for their ease of installation and suitability for a variety of locations and are modelled on current as well as future buildings.

Table 6. Green infrastructure additions by property type by 2070. A unit of permeable paving in this case is 3,000 m^2.

PROPERTY TYPE	NEW TREES	RAIN BARRELS	RAIN GARDENS	PERMEABLE PAVING
Urban residential building	2	0.5	0.5	0
Suburban residential building	4	0.5	0.5	0
Apartment building	2	0.5	0.5	0
Commercial building	5	0	0	0.1
Urban school property	5	0	0	0

The total number of trees, rain barrels, rain gardens, and permeable parking lots installed in the Adapted Scenario is shown in Figure 28, and the capital costs of these features, as well as the operating and maintenance costs, are shown in Figure 29. The number of 3000 m^2 permeable parking units is hard to see on this scale. There are 117 permeable parking spots, equalling 353,000 m^2 of paving.

[34] United States Environmental Protection Agency, 2022. What is Green Infrastructure? Accessed April 2022: https://www.epa.gov/green-infrastructure/what-green-infrastructure

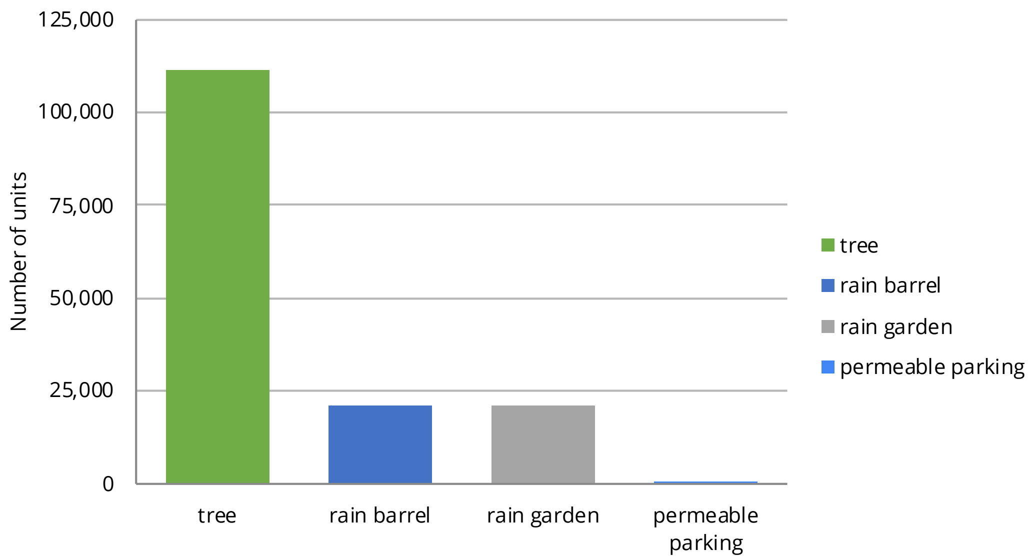


Figure 28. Number of trees, rain barrels, rain gardens, and parking lots with permeable parking (3,000 m²) included in the Adapted Scenario across all of Whitby.

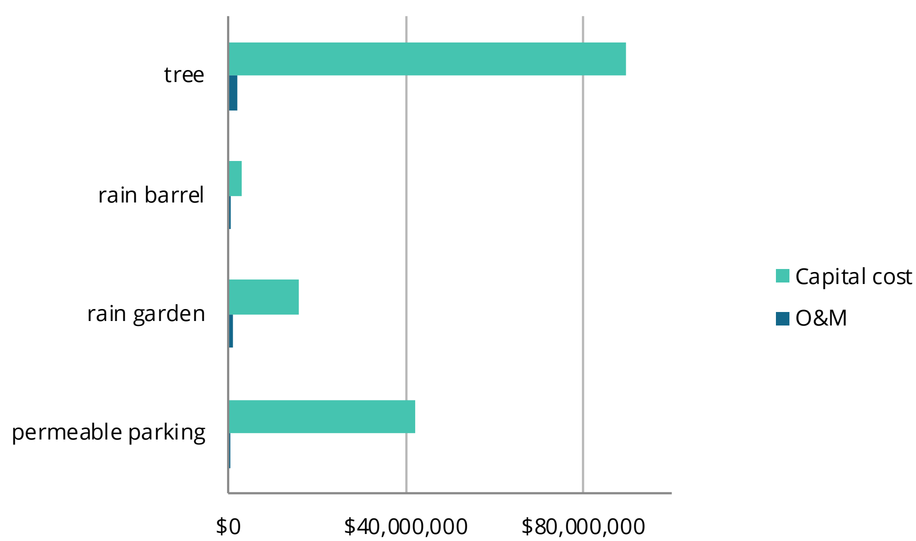


Figure 29. Capital costs and operation and maintenance costs for green infrastructure.

Trees have relatively high maintenance costs to ensure they remain healthy because monitoring and maintenance are labour-intensive. The avoided damages from flooding are highlighted in Figure 30, but the true benefit of green infrastructure comes not just from flood damage reduction, but from the co-benefits of cooling, improved air quality, property value increases, and groundwater replenishment. In 2070, green infrastructure provides $38.4 million dollars in co-benefits, with most of those benefits coming from urban trees.

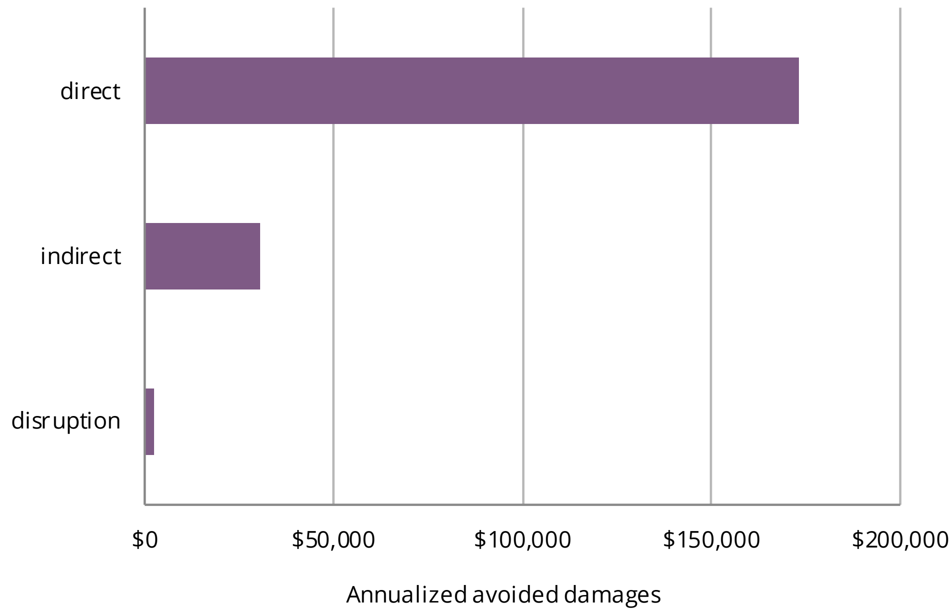


Figure 30. Annualized avoided damages from flooding as a result of green infrastructure use.

Table 7. Annual co-benefits from green infrastructure in Whitby.

CO-BENEFIT	NEW TREES	RAIN BARRELS	RAIN GARDENS	PERMEABLE PAVING
Reduced energy use	$4,011,000			
Reduced air pollutants	$20,000			
CO_2 capture	$13,000			
Property value increase	$30,640,000			
Groundwater replenishment	$25,000	$1,000	$9,000	$13,000
Reduced water treatment costs	$9,000		$3,000	$4,000

4.4 Heat

4.4.1 THE STATE OF PLAY

Along with flooding, heat is the major climate variable expected to have serious impacts on the residents of Whitby. Heatwaves, and in particular, extended periods with hot nights, have serious health consequences for at-risk people. The specific actions to reduce the exposure to high heat are shown in Table 8.

Table 8. Actions to reduce risk from heat.

ACTION	DESCRIPTION
Building retrofits	• All residential buildings within zones where 10% or more of the population was in the high-risk category (age and income) are retrofitted for energy efficiency, including building envelope improvements and improved insulation
Install heat pumps for space cooling	• As buildings are retrofit, the space heating/cooling system is replaced with heat pumps to provide efficient space cooling
Green infrastructure	• Added trees, rain barrels, rain gardens, and permeable paving across the town

The Urban Heat Island Effect means that denser and more developed areas are generally hotter, as hard surfaces retain heat, raising the ambient temperature and slowing cooling. Figure 31 shows the locations in Whitby with moderate and high temperature vulnerability, and these align closely with development density.

The very young (four years old and younger) and older people (65 years and older) are more at risk of serious consequences from high heat. Space cooling within homes can greatly reduce these risks, but household income plays a determining role in the ability to purchase and operate space cooling equipment. Figure 32 shows the number of people within the high-risk age categories who also live in low-income households. This modelling assumes that the distribution of low-income households and people within high-risk age categories stays the same but increases proportionally with the population by 2070.

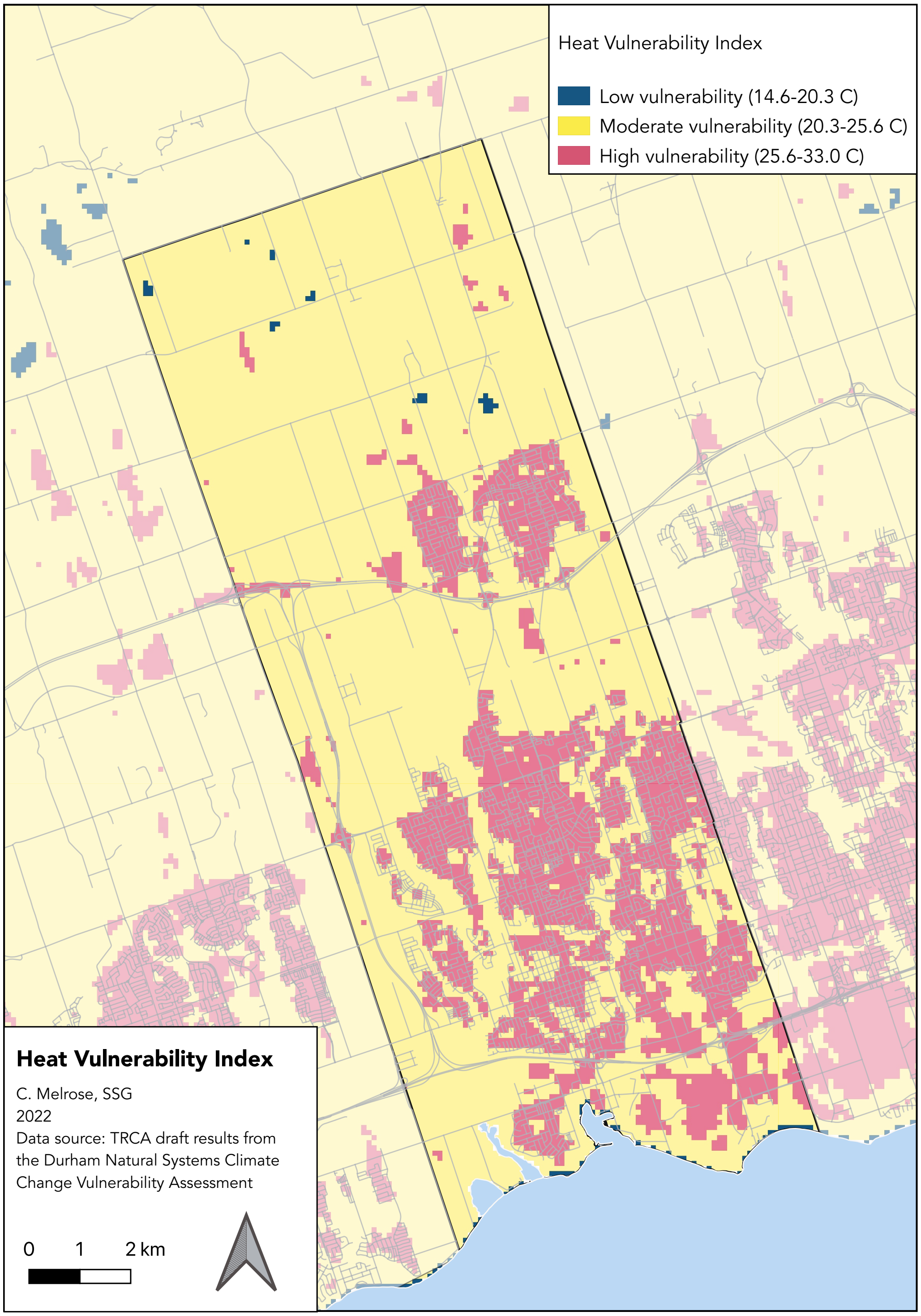


Figure 31. Current Heat Vulnerability Index in Whitby based on the TRCA's draft results from the Durham Natural Systems Climate Change Vulnerability Assessment.

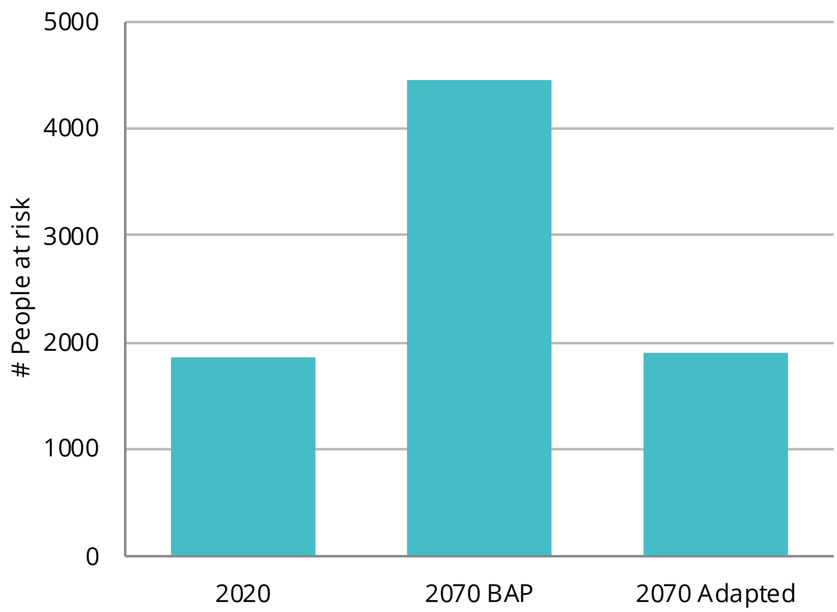


Figure 32. Number of people in Whitby in the at-risk categories of age and low income.

The number of people at risk of serious consequences from heat increases from 2020 to 2070 as the population, peak temperature, and length of heatwaves all increase. Approximately 1.4% of Whitby residents are classified as high-risk in 2020 compared to 1.3% of residents by 2070. The impact of these actions can be seen in a comparison of the number of people at risk now, in the future, and in the Adapted Scenario (Figure 33).

Knowing where high-risk people live within Whitby allows for the design and implementation of targeted strategies to reduce the heat risk in those locations (Figure 33). Building retrofits provide many benefits including improved energy efficiency and reduced GHG emissions from activities within a home, reduced energy poverty, and improved overall building condition. Retrofits such as improvements to the building envelope, insulation improvements, and the conversion to heat pumps for space heating are completed in zones where 10% or more of the population is in the high-risk category Figure 34). Heat pumps provide space cooling and dehumidification and are an efficient way to cool indoor spaces.

Tree planting is used all across Whitby but specifically works to reduce the Urban Heat Island Effect in the developed areas of the town. The number of trees planted in each zone depends on the types of buildings in that zone, but each tree casts shade and provides cooling by evapotranspiration (Figure 35).

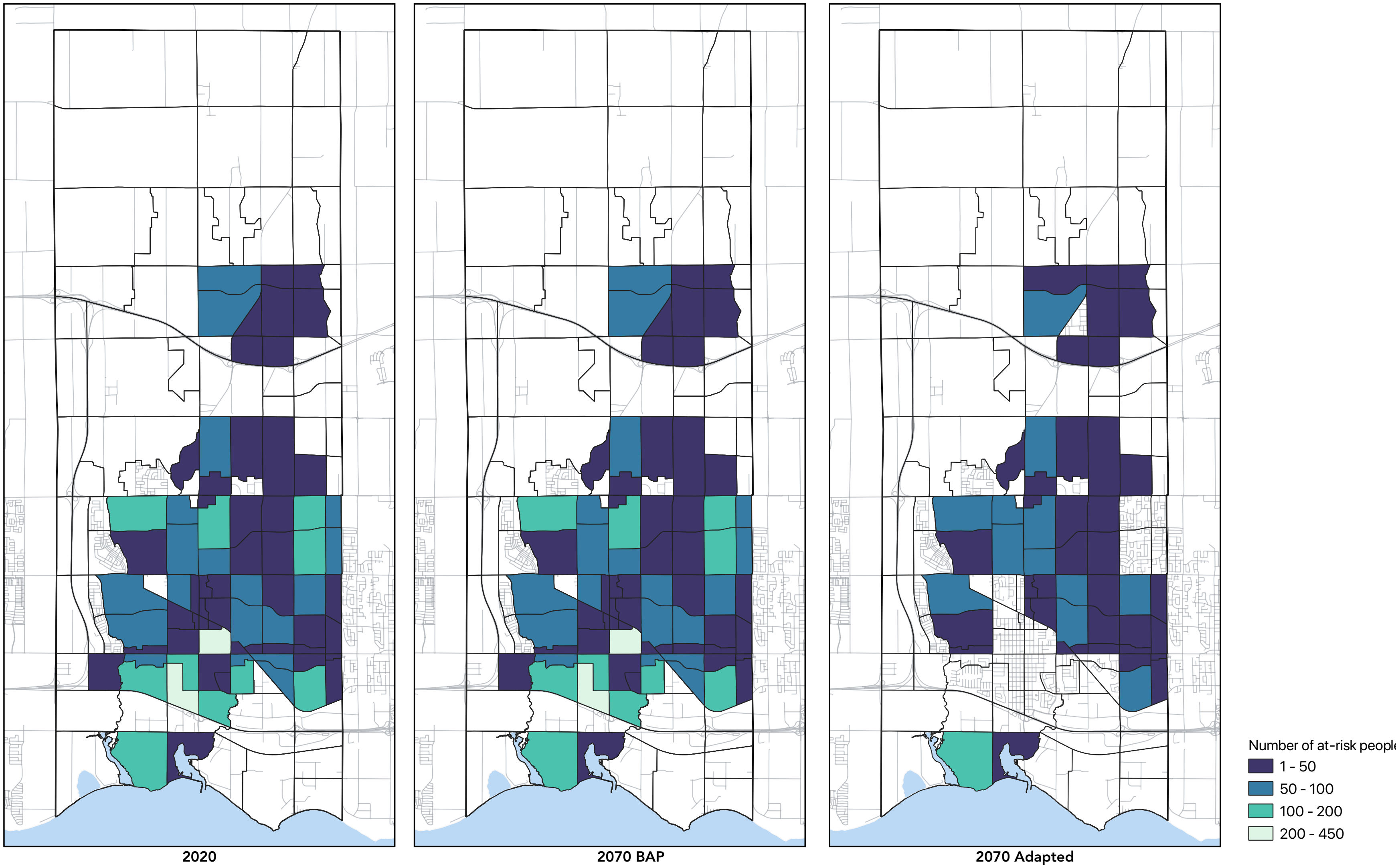


Figure 33. Population at risk of heat impacts by traffic zone in Whitby based on age and average household income in the traffic zone in 2020, in the 2070 BAP, and in the 2070 Adapted Scenario.

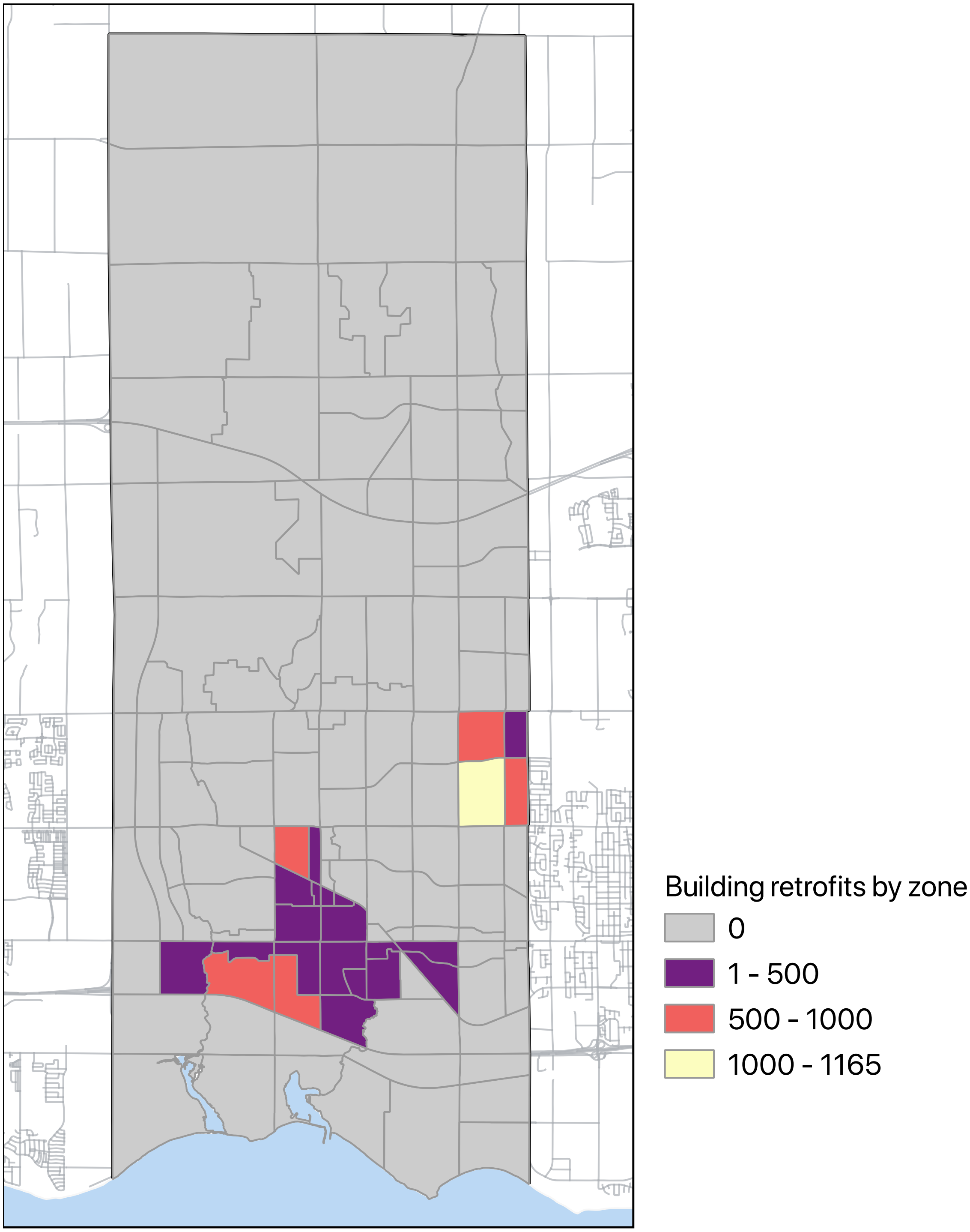


Figure 34. Number of building retrofits per zone in the 2070 Adapted Scenario.

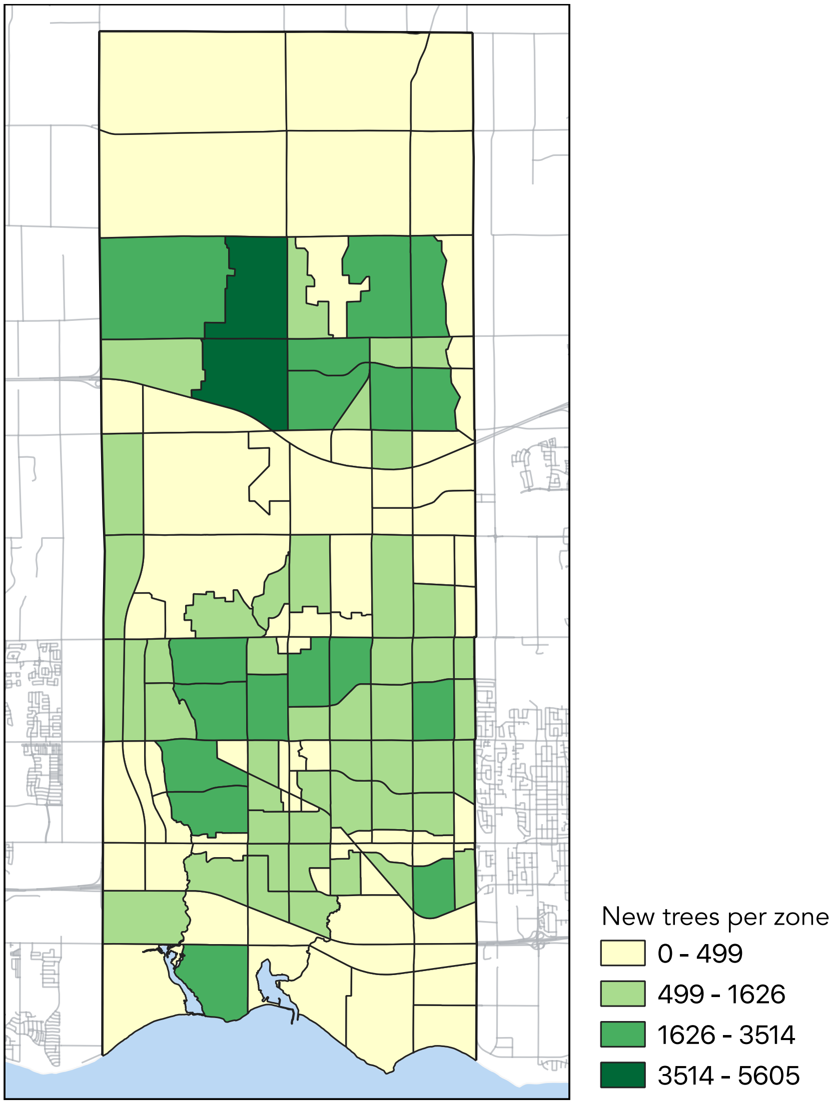


Figure 35. Number of new trees added to each zone in the 2070 Adapted Scenario.

4.4.2 COSTS AND BENEFITS OF ADAPTING TO HEAT

The costs of taking action to reduce the heat risks are summarized in Table 9 and are compared with the benefits these actions provide to the community. The total capital costs and the project lifetime operations and maintenance costs show how much an action will cost to implement and maintain. The project lifetime avoided damages allow us to understand the financial impacts of the action, as well as the return on investment of the actions. These are based on the future climate scenario. The number of people at risk of mortality from extreme heat that are protected is shown for each action. These actions are aimed at reducing vulnerable people's exposure to the risk of high heat and heatwaves, and the benefits of these actions must be measured in terms of health, comfort, and safety.

Table 9. Costs and benefits of adaptation actions.

ACTION	CAPITAL COSTS ($)	LIFETIME OPERATIONS AND MAINTENANCE COSTS	PROJECT LIFETIME AVOIDED DAMAGES WITH FUTURE CLIMATE	RETURN ON INVESTMENT WITH FUTURE CLIMATE	CO-BENEFITS	NUMBER OF PEOPLE AT RISK OF MORTALITY PROTECTED PER YEAR
Green infrastructure	$151 million	$34.0 million	$4 million	$423 million	$605 million	522
Building retrofits with heat pumps	$419 million	$0	$0	-$190 million	$229 million	2,030

The impacts of increased urban tree cover and building retrofits on the most vulnerable people are shown in Figure 36. Building retrofits will be critical for achieving low-carbon goals in Phase 2 of the Climate Change Master Plan. These results highlight the importance of designing and delivering programming that allows vulnerable people to participate in energy efficiency and building retrofit programs across Whitby.

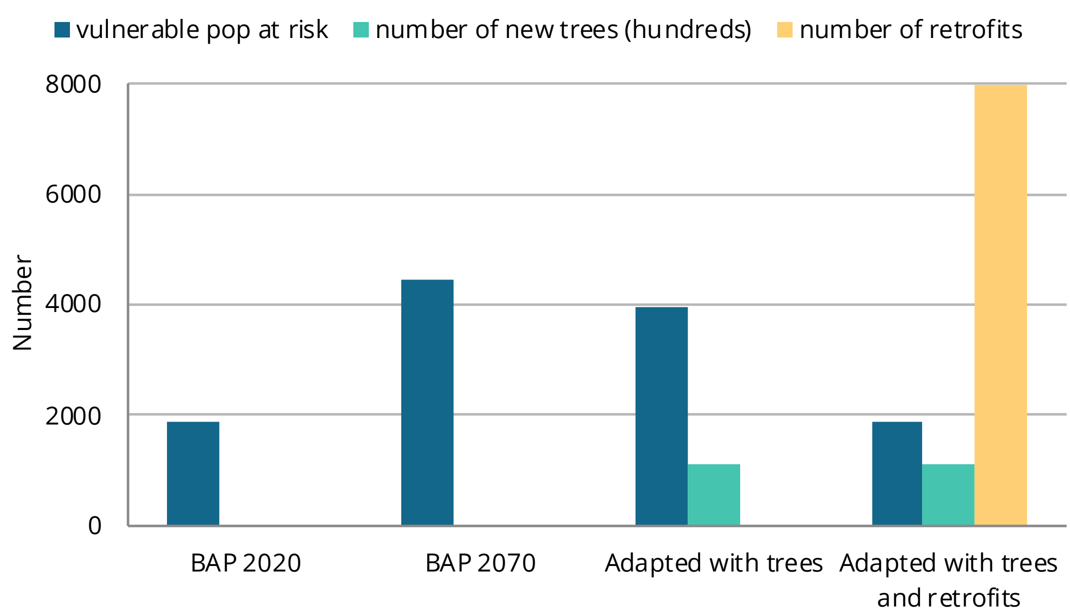


Figure 36. Number of people at risk now, in the 2070 BAP Scenario, and in 2070 compared with tree planting and building retrofits.

4.5 Non-Modelled Hazards and Sectors

Not all climate risks and hazards were included in the spatial and temporal analysis. Hazards were excluded from the analysis because of:

- A lack of spatial variance of the hazard across Whitby;
- An inability to precisely model the hazard;
- Insufficient data to accurately model the hazard;

- Stakeholder engagement; or
- Some combination of all the above.

Some assets in Whitby have not been assigned costs or values. In particular, human health and human lives have not been assigned a value.

Specific non-modelled risks and hazards included in the analysis are invasive species and agricultural impacts and the impacts of windstorms and tornadoes as they link to emergency management systems within Whitby.

A detailed species-level analysis of the urban forest and an analysis of the forest cover composition in naturalized spaces within Whitby is outside of the scope of this analysis. The impacts of urban tree canopy cover on flooding and heat management have been explored but not at a species-level. Long-term forest health requires an understanding of the species composition, the resilience of those species to climate change, and an assessment of the risk from invasive species that target individual species.

As these hazards were not included in the detailed modelling, their potential costs are not included in the analysis.

Agriculture Damages

Agricultural damages will be assessed based on the estimated values of crops and the potential loss of crops from pests or storms. The majority of agricultural land in Whitby is used for growing grain and corn. The expected current value for crops in Whitby is $7,654/acre.[35] Whitby has approximately 36,500 hectares (9020 acres) of cropland, with a combined value of $69.1 million dollars. Damage to agriculture from drought, invasive species, and other climate hazards is complicated and difficult to mitigate. Work with agriculture professionals in Whitby should be undertaken to communicate the potential impacts of climate change and identify opportunities for protecting this industry.

Extreme Wind Events

Wind modelling involves a lot of uncertainty, and projections of changes are inaccurate; therefore, structural modifications to build resilience to wind have not been specifically included in this analysis. Serious weather events, such as ice storms, tornadoes, and flash precipitation events, require preparation and planning. Plans to protect and upgrade physical structures, utilities, and essential services from the impacts of these events and to reduce service disruptions to the community must include future climate projections. Detailed, asset-level reviews of the physical infrastructure, emergency plans, and communication plans should be completed for all essential services in Whitby.

Vector-Borne Diseases

Vector-borne diseases, including West Nile virus and Lyme disease, are monitored by the Region of Durham Department of Health and Wellness. Rising temperatures and milder winters allow the vectors of these diseases to spread into new areas, and the vectors and positive cases of the diseases are monitored by the Region. Working closely with the Region to ensure safety updates and information about preventative programs are clearly communicated will help protect the people of Whitby.

Biodiversity and Species at Risk

Climate impacts on the habitat ranges and population sizes of invasive species, including insects,

[35] Farm Credit Canada, 2020. 2019 FCC Farmland Values Report.

aquatic plants, and species at risk, should be monitored carefully. Developing an invasive species management plan will allow the Town to monitor the risks climatic and biodiversity changes pose to forests, natural spaces, and environmentally sensitive areas.

5. Critical Infrastructure

5.1 Mapping Community Assets

The location of current and future critical infrastructure shapes the capacity of the community and the Town of Whitby to react to climate emergencies and adapt to long-term climate change impacts.

Understanding the location of essential infrastructure for at-risk people during heatwaves, storms, and floods allows community members to access the services they require. By communicating with residents about the location of services and the types of services available, residents can better withstand emergency events. In addition, by understanding the potential climate hazards that affect critical infrastructure, the Town of Whitby can develop management plans that prioritize the protection, adaptation, and expansion of this infrastructure.

In addition, the impacts of flooding on critical infrastructure must be considered in terms of damages and disruption of services. The location of essential electricity, water utility, hospital, and other services must be considered with a climate lens to prioritize adaptation and preparedness measures to minimize service disruptions to the town.

The location of childcare facilities and senior residences in high-heat areas should be carefully considered. Any facilities without adequate space cooling that are located within high-heat zones should be prioritized for retrofits that include efficiencies and space cooling capacity.

Adaptive measures can remove some essential services from zones that experience damages in 100-year floods in the future. These essential services should be prioritized for detailed assessment of flood risks using the future flooding extents.

Flooding presents different challenges than heat events and highlights different critical infrastructure needs. Addressing flooding in Whitby will require coordination across emergency services such as ambulance, fire, police, and emergency shelters.

5.2 The Electricity Grid

5.2.1 DECENTRALIZED GENERATION AND STORAGE

Decentralized renewable energy increases diversity and redundancy in energy systems, contributing to improved resilience to climate impacts.

Increased spatial diversification of electricity generation reduces the vulnerability of the energy supply to damage from a single event or at a single critical location.[36] It is less probable that all generating systems are affected by an extreme weather event if they are located at various points across the municipality, whereas when a considerable portion of energy comes from a single

[36] NREL. (2018). Valuing the Resilience Provided by Solar and Battery Energy Storage Systems. NREL. Retrieved from: https://www.nrel.gov/docs/fy18osti/70679.pdf

source, disruption or damage at a single point could have negative consequences for the entire system.

Decentralized renewable energy often implies multiple sources: rooftop solar, storage, waste heat systems, wind, etc. Should long-term climate changes influence the energy outputs of energy based on these sources, the consequences will be less severe if there are multiple other sources that can replace it.

In an urban context, decentralized energy,such as rooftop solar, waste heat recovery systems, etc., is often in close proximity to energy loads, minimizing the need for energy transmission infrastructure. In the case of power systems, on-site generation minimizes the need for transmission and distribution infrastructure to bring power into the city, therefore minimizing the chance ofr power outages related to transmission and distribution infrastructure damage.[37]

Solar with storage is increasingly being implemented in resilient power system designs.[38] Storage can allow a building to draw power from the battery during an outage. Without a storage system, most solar PV systems are shut down in the event of a grid outage.

For commercial and institutional buildings, storage can minimize disruptions to business and services. In an analysis by the US National Renewable Energy Laboratory, the net present value of solar with storage was assessed against potential economic losses from an outage for various buildings.[39] When comparing economic value to the potential losses in an outage, solar PV with storage was the least costly option over the systems' lifetime for a school, an office building, and a hotel.[40]

For residential buildings, on-site storage can allow occupants to remain safe in their homes during an outage. For example, the Tesla Powerwall 2 is a 13.5 kWh lithium-ion battery.[41] The Ontario Energy Board reports that the average electricity customer in the Greater Toronto Area used 715 kWh per month from 2010 to 2014, or approximately 24 kWh per day.[42] This means a home battery system could support the average electrical load for just over half the day under normal operating conditions, although it is more realistic that during an outage, only basic electrical functions would be performed. Furthermore, many home storage systems are installed with a solar PV system, which could continuously charge the home storage system for longer power backup.

Decentralized renewables can also support building function during an outage through islanding. Islanding is when a portion of the grid operates separately from the larger electrical grid on its own closed circuit.[43] To successfully island, sufficient energy resources, such as decentralized renewable energy and storage, must be present within the microgrid to supply electricity to the loads.

Islanding can improve the speed and priority of efforts to rebuild the electricity grid by focusing on the repair of strategic grids, such as those with water treatment plants, police stations, and

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[37] C2ES. (2018). Resilience Strategies for Power Outages.

[38] Opp. Cit.

[39] Ibid.

[40] Ibid.

[41] Details on the Tesla powerwall system are available here: https://www.tesla.com/en_CA/support/powerwall/faqs

[42] Ontario Energy Board. (2016). Defining Ontario's Typical Electricity Customer. Retrieved from: https://www.oeb.ca/oeb/_Documents/Documents/Report_Defining_Typical_Elec_Customer_20160414.pdf

[43] This is also known as a microgrid.

other critical infrastructure.[44] Islanding can also isolate faults in the electricity grid, minimizing the extent of power outages and decreasing the possibility for cascading outages, where a failure in one part of the system leads to widespread failure across the entire electrical grid.[45] Cascading outages were to blame for the 2003 Northeast blackout that hit Ontario and the northeastern United States. When microgrids are sufficiently supplied by local energy resources, damage to transmission lines does not necessarily mean the end users will be impacted.[46]

5.2.2 BUILDING RETROFITS

Energy retrofits reduce electricity demand in buildings, reducing strain on the electricity system and decreasing the risk of blackouts in periods of high demand.[47] During extreme weather events, electricity demand peaks. Any failure in the transmission lines further strains other lines, which can cause a blackout. Electricity operators plan for higher electricity demand and unexpected periods of loss by maintaining reserve capacity, although periods where demand exceeds supply can still happen.

Air conditioning used during heat waves can also be associated with rolling blackouts, where utilities apply planned outages to minimize overall grid strain to avoid a total electricity grid blackout, which can be detrimental to the electricity system, costly, and time-consuming to restart.[48] For example, when four electricity-generating systems in Alberta failed in the summer of 2012 during a high-electricity-demand period caused by a heatwave, rolling system blackouts occurred.[49]

Building retrofits also reduce vulnerability by reducing energy costs. Households facing energy poverty or energy insecurity face challenges such as "pay the rent or feed the kids", "heat or eat", or "cool or eat”.[50] In particular, energy insecurity disempowers low-income residents, such as single parents, the elderly, persons with disabilities, and others with low or fixed incomes,[51] resulting in stresses such as utility-related debt, shutoffs, inefficient heating systems, antiquated appliances, and extreme home temperatures with significant health impacts.[52]

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44 EDF Blogs. (November 14, 2017). Microgrids can help prevent extreme power outages, and cities are taking notice. Retrieved from: http://blogs.edf.org/energyexchange/2017/11/14/microgrids-can-help-prevent-extreme-power-outages-and-cities-are-taking-notice/

45 Hirsch, A., Parag, Y., Guerror, J. (2018). Microgrids: A review of technologies, key drivers and outstanding issues. Renewable and Sustainable Energy Reviews, 90, 402-411.

46 Ibid.

47 Ibid.

48 The 2003 Northeast Blackout was estimated to cost $4-10 billion in the United States, and caused Canada’s GDP to decline 0.7%. See NRCan, US DOE. (2006). Final Report on the Implementation of the Task Force Recommendations. Retrieved from: http://www.ieso.ca/en/Corporate-IESO/Media/Also-of-Interest/Blackout-2003.

49 Tait, C., Walton, D. (July 9, 2012). Rolling blackouts hit Alberta as power-generating stations fail in heat wave. The Globe and Mail. Retrieved from: https://www.theglobeandmail.com/news/national/rolling-blackouts-hit-alberta-as-power-generating-stations-fail-in-heat-wave/article4401831/.

50 Cook, J. T., Frank, D. A., Casey, P. H., Rose-Jacobs, R., Black, M. M., Chilton, M., … Cutts, D. B. (2008). A brief indicator of household energy security: Associations with food security, child health, and child development in US infants and toddlers. PEDIATRICS, 122(4), e867–e875. https://doi.org/10.1542/peds.2008-0286

51 Hernández, D. (2013). Energy insecurity: A framework for understanding energy, the built environment, and health among vulnerable populations in the context of climate change. American Journal of Public Health, 103(4), e32–e34. https://doi.org/10.2105/AJPH.2012.301179

52 Hernández, D., & Bird, S. (2010). Energy burden and the need for integrated low-income housing and energy policy. Poverty & Public Policy, 2(4), 5–25. https://doi.org/10.2202/1944-2858.1095

5.2.3 SAFER BUILDINGS

Improved building envelopes provide better temperature regulation, and thus, better protection for inhabitants in periods of extreme weather.[53] The US Green Building Council defines this as passive survivability or thermal safety.[54] Thermal safety is defined as maintaining thermally safe conditions during a power outage that lasts four days during peak summertime and wintertime conditions.[55] A study of buildings in New York City found that homes with efficiency upgrades could maintain indoor temperatures of over 60 degrees during a week-long power outage, whereas in average-efficiency homes with no retrofits, the temperature fell below 35°F in three days.[56]

The Durham Region Climate Resilience Standard for New Houses identifies specific actions that can be taken to reduce the risk of damages and health impacts from flooding, heat, and severe winds.[57] This Standard focuses on single-family homes and low-rise residential buildings, but similar standards for all building types, including retrofits, would increase the resilience of the building stock.

In a pilot for new LEED certification components, buildings can satisfy a thermal safety requirement by achieving Passive House certification. According to the LEED requirements, "The very high standards for energy performance with Passive House is an adequate indicator that the building will maintain passive survivability as described in this credit."[58] As indicated above, however, Passive House levels of performance are not a guarantee of increased comfort during extreme heat without this consideration as a specified design parameter. An assessment as part of an update of the Toronto Green Standard found a correlation between the achievement of higher levels of building energy performance and improved thermal resilience.[59]

Dwelling units that achieve this standard may also reduce the demand on emergency services during a power outage. Residents that are in dwellings that cannot protect them from extreme heat or cold are likely to require support from emergency services.

For example, a 2006 study in Toronto found that ambulance calls increased by 10% during periods of extreme heat.[60]

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53 Ribeiro, D., Mackres, E., Baatz, B., Cluett, R., Jarret, M, Kelly, M., Vaidyanathan, S. (2015). Enhancing community resilience through energy efficiency. Report U1508. Retrieved from: https://aceee.org/sites/default/files/publications/researchreports/u1508.pdf.

54 USGBC. Passive survivability and back-up power during disruptions. LEED BD+C: New construction. Retrieved from: https://www.usgbc.org/credits/passivesurvivability.

55 What constitutes thermally safe varies in various buildings, and can also be dependent on humidity and other factors. See LEED pilot webpage for more information: https://www.usgbc.org/node/9836068?return=/pilotcredits/all/all

56 C2ES. (2018). Resilience Strategies for Power Outages.

57 Institute for Catastrophic Loss Reduction, 2018. Durham Region Climate Resilience Standard for New Homes.

58 USGBC. Passive survivability and back-up power during disruptions. LEED BD+C: New construction. Retrieved from: https://www.usgbc.org/credits/passivesurvivability.

59 Integral Group, Morrison Hershfield, & Provident. (2017). City of Toronto Zero Emissions Buildings Framework (p. 118).

60 Dolney, T. J., & Sheridan, S. C. (2006). The relationship between extreme heat and ambulance response calls for the City of Toronto, Ontario, Canada. Environmental Research, 101(1), 94–103. https://doi.org/10.1016/j.envres.2005.08.008

6. Adaptive Actions

6.1 Adaptation Actions

Adaptation actions focus on the main climate hazards for Whitby and its residents. The primary climate hazards are increased flooding and heat. Additional hazards include the increased risk of severe storms and weather events, but adaptation and resilience actions related to these are centred around emergency response and community preparedness. These are discussed in more detail in the non-modelled actions section.

Overall, the actions work to address the highest-level climate hazards in Whitby. These include actions to reduce the risk of flooding to homes and infrastructure from coastal and riverine flooding, as well as disruptions to businesses from flooding.

Actions are taken to reduce basement flooding in homes and to reduce the number of roads that are unintentionally overtopped in storm events. This helps protect people, building contents, and structures and allows for travel and movement throughout Whitby in emergencies.

Heatwaves, and especially hot nights, lead to illness and death in at-risk people. Actions in this study focus on reducing the risk of exposure to prolonged extreme heat for those who are at risk because of health (aged 0–4 and aged 65+ years) and because of a lower household income.

6.2 Costs and Benefits

These actions, and the high-level financial costs and benefits, are shown in Table 2. The total capital costs and the project lifetime operations and maintenance costs show how much an action will cost to implement and maintain. The project lifetime avoided damages are shown for the current climate and the future climate scenarios. This allows us to understand the relative impact of the RCP 8.5 climate scenario on the scale of damage, as well as the return on investment of the action in current and future climate conditions.

The co-benefits of green infrastructure are more fully explained in Table 9. The co-benefits from building retrofits are a result of energy efficiency improvements to the buildings, reducing the energy costs associated with space heating, space cooling, and other uses within buildings.

A comparison of the annualized damages from climate hazards shows an increase from $89.6 million in 2020 to $783 million in 2070—a 770% increase (Figure 37). By implementing the adaptation actions described in Table 2, the annualized damages in 2070 are reduced to $65.8 million, representing a 27% decrease from 2020 levels all across Whitby.

Table 10. The financial return from hazard mitigation investments (2020$, discounted at 3%)

CLIMATE RISK	ACTION	HAZARD PREVENTION (CAPITAL COSTS)	HAZARD PREVENTION (LIFETIME OPERATIONS AND MAINTENANCE COSTS)	CUMULATIVE VALUE OF AVOIDED DAMAGES WITH CURRENT CLIMATE	CUMULATIVE VALUE OF AVOIDED DAMAGES WITH FUTURE CLIMATE	ADDITIONAL FINANCIAL BENEFITS	CUMULATIVE NET FINANCIAL BENEFIT OF THE INVESTMENT WITH CURRENT CLIMATE ($)	CUMULATIVE NET FINANCIAL BENEFIT OF THE INVESTMENT WITH FUTURE CLIMATE
Coastal and Riverine Flooding	**A.** New development restricted from future flood zones61	$062	N/A	$16,317 million	$17,034 million	Not assessed	$16,317 million	$17,034 million
	B. Flood berms constructed in West Lynde and along Pringle Creek	$7.7 million	$930,000	$32 million	$77 million	Not assessed	$23 million	$68 million
	C. Dry-proofing and wet-proofing buildings	$1.2 million	$0	$53 million	$60 million	Not assessed	$52 million	$59 million

[61] New development is shifted within a given traffic zone to parcels outside of the 100-year floodplain.

[62] This action is a regulatory change, so no capital costs are assigned.

CLIMATE RISK	ACTION	HAZARD PREVENTION (CAPITAL COSTS)	HAZARD PREVENTION (LIFETIME OPERATIONS AND MAINTENANCE COSTS)	CUMULATIVE VALUE OF AVOIDED DAMAGES WITH CURRENT CLIMATE	CUMULATIVE VALUE OF AVOIDED DAMAGES WITH FUTURE CLIMATE	ADDITIONAL FINANCIAL BENEFITS	CUMULATIVE NET FINANCIAL BENEFIT OF THE INVESTMENT WITH CURRENT CLIMATE ($)	CUMULATIVE NET FINANCIAL BENEFIT OF THE INVESTMENT WITH FUTURE CLIMATE
Urban Flooding	**D.** Upgrade stormwater sewers for future climate conditions	$537 million	$0	$1,263 million	$1,263 million	Not assessed	$727 million	$727 million
	E. Improve culverts for future climate conditions	$104 million	$0	$0[63]	$0	Not assessed	-$104 million	-$104 million
Urban Flooding/ Heat	**F.** Expand green infrastructure	$151 million	$34.0 million	$0	$4 million	$605 million	$419 million	$423 million
Heat	**G.** Undertake building retrofits with heat pumps	$419 million	$0	$0[64]	$0	$229 million	-$190 million	-$190 million

[63] The damages avoided are road closures from flooding, and no financial value was assigned to this. Instead, the focus was on the number of people protected.

[64] Costs associated with reducing heat risk are from reduced health care and emergency services but are not captured here.

The most impactful adaptation is shifting where new development occurs in Whitby. By shifting development out of projected 2070 100-year floodplains, but keeping it within the same traffic zone, over $17 billion in damages can be prevented by 2070. A spatial review of traffic zones showed that current planned levels of development can occur within the planned zone, but accurate floodplain mapping should inform which parcels are approved for development.

All actions, with the exception of improved culverts and building retrofits, show a positive return on investment in the millions of dollars for both current and future climate conditions. Culvert improvements are completed to reduce the risk of road flooding, improving the safety of residents. No value has been assigned to this avoided risk to residents, so the return on investment is negative. Building retrofits will be a focus of Phase 2 of the Climate Change Master Plan, where energy efficiency and building improvements will be explored in more detail. Benefits of the building retrofits include the improved health and safety of at-risk residents and their families, and no dollar value was assigned to human health.

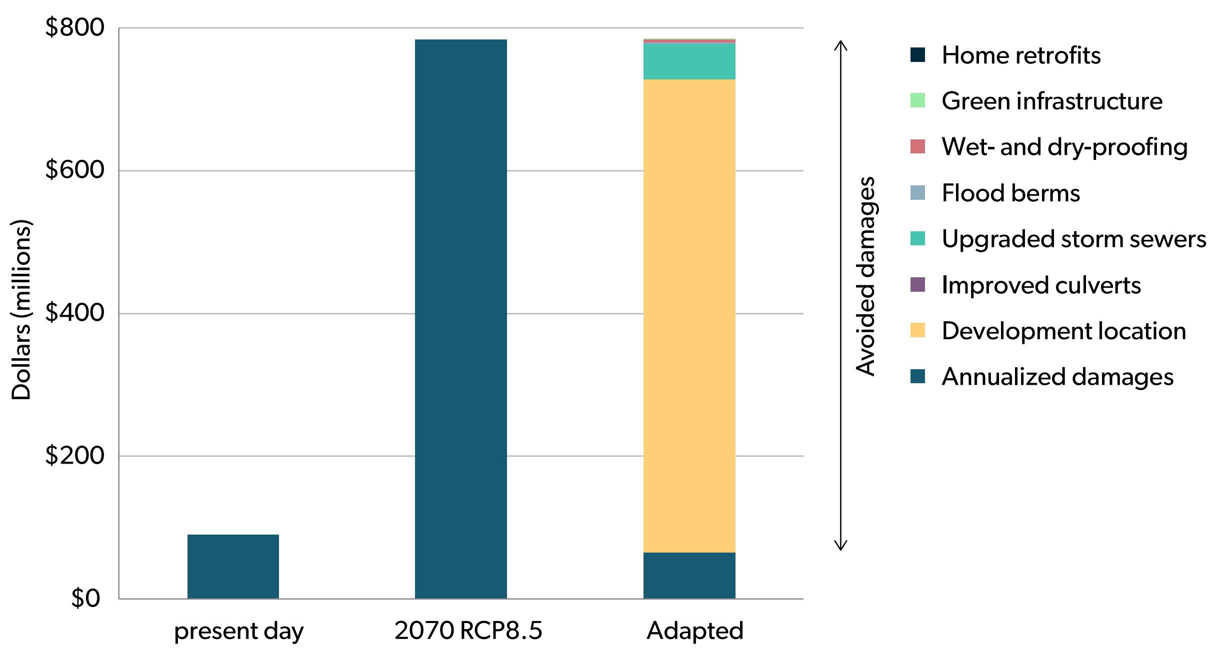

Figure 37. Annualized damages and avoided damages from each adaptation action in the three modelled scenarios.

6.3 Protecting People

The cost of damage is not the only metric by which adaptation should be measured. Figure 38 shows the changes in people at risk of climate hazards in the three modelled scenarios. People who are either partially or entirely protected from climate hazards are included in this calculation. Location of development is still the most important factor in protecting people from damage and risk, but improving culverts to control road flooding and completing home retrofits to provide space cooling are also important.

Table 11. People protected by adaptation actions.

CLIMATE RISK	ACTION	NUMBER OF PEOPLE WITH RISK PARTIALLY OR FULLY ELIMINATED	NUMBER OF PEOPLE AT RISK OF MORTALITY PROTECTED PER YEAR
Coastal and Riverine Flooding	New development restricted from flood zones65	9,060	N/A
	Flood berms constructed in West Lynde and along Pringle Creek	880	N/A
	Dry-proofing and wet-proofing buildings	200	N/A
Urban Flooding	Upgrade stormwater sewers	1,520	N/A
	Improve culverts	9,270	N/A
Urban Flooding/ Heat	Green infrastructure	31,360	522
Heat	Building retrofits with heat pumps	56,280	2,030

[65] New development is shifted within a given traffic zone to parcels outside of the 100-year flood plain. More details on this action are found in Table 4.

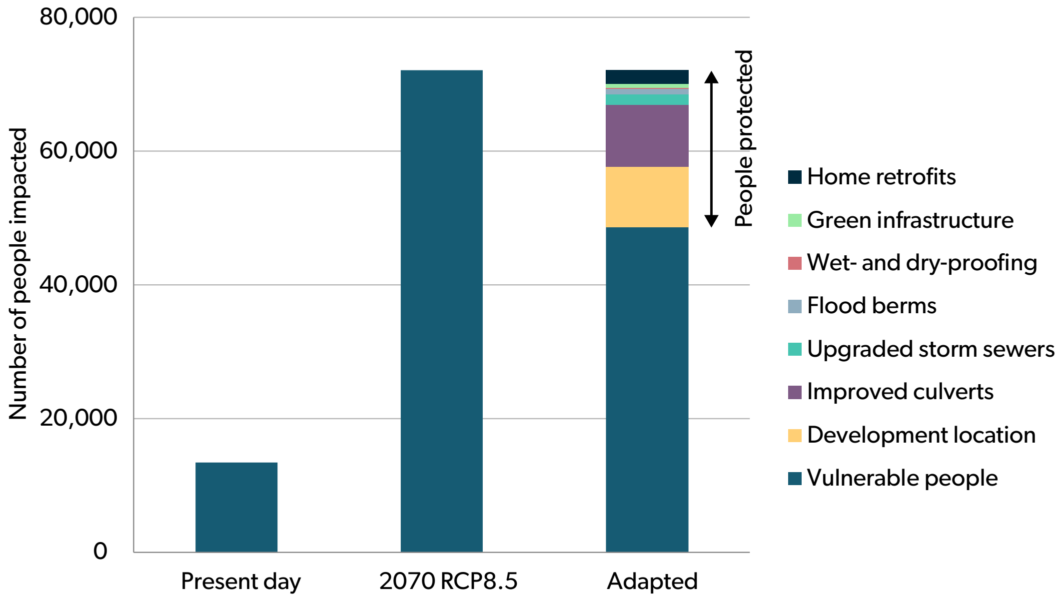

Figure 38. Number of people affected by climate change hazards in 2020 and in the 2070 unadapted scenario, the number of people who are fully or partially protected from hazards from each adaptation scenario in a 100-year event, and projected heat impacts.

7. Conclusion: An Adapted Whitby

Climate change adaptation needs to work in concert with GHG mitigation. Impacts from our changing climate are already being felt and will only increase, leading to wilder storms, less predictable weather, and hotter temperatures. Careful planning and decision-making today can prevent millions of dollars in damages in the future and can protect the people, homes, businesses, infrastructure, and natural spaces in Whitby.

The biggest change the Town of Whitby can make to protect the community against costly damages from climate hazards is to review where development occurs and ensure that no new development is allowed in floodplains. A deeper understanding of hydraulic flows, in both constrained and unconstrained flow regimes, will be essential for ensuring the safety of Whitby's growing population.

Building retrofits for at-risk people within the community will ensure their safety and comfort during prolonged heatwaves, and will reduce the energy consumption in these homes. Clearly communicating with the public about the facilities available for cooling off during these events will allow others to manage this hazard safely.

Finally, clearly and openly communicating with the public about the ways to prepare for climate emergencies and about the services available in major events will ensure as many people as possible are prepared and resilient in the face of these inevitable, serious events.

By working with the community and the many knowledgeable and connected organizations within Whitby, the Town of Whitby can be a leader in climate preparedness and resilience, making decisions today that will serve the community now and well into the future.

Appendix C: Sensitivity Analysis of the RCP8.5 Climate Scenario

Table C-1. Costs and benefits of adaptation actions with no change in future weather.

CLIMATE RISK	ACTION	CAPITAL COSTS ($)	ANNUALIZED PAYMENT (25 YEARS, 3% DISCOUNT RATE)	OPERATIONS AND MAINTENANCE COSTS (ANNUAL)	AVOIDED DAMAGES (2070)	OTHER BENEFITS
Coastal and Riverine Flooding	New development restricted from flood zones	$0	N/A	N/A	$634 million	# of people protected in 2070: 4,492
	Flood berms constructed in West Lynde and along Pringle Creek	$7.73 million	$444,000	$36,200	$ 1.25 million	# of people protected in 2070: 28
	Dry-proofing and wet-proofing buildings	$1.15 million	$66,300	N/A	$3.05 million	Number of people protected is uncalculated because properties with dry- and wet-proofing still experience flooding, but no damages occur.
Urban Flooding	Upgrade stormwater sewers	$537 million	$30.9 million	N/A	$49.1 million	# of people protected in 2070: 548
	Improve culverts	$104 million	$6.0 million	N/A	N/A	# of people protected in 2070: 2,147

CLIMATE RISK	ACTION	CAPITAL COSTS ($)	ANNUALIZED PAYMENT (25 YEARS, 3% DISCOUNT RATE)	OPERATIONS AND MAINTENANCE COSTS (ANNUAL)	AVOIDED DAMAGES (2070)	OTHER BENEFITS
Urban Flooding/ Heat	Green infrastructure	$96 million	$5.5 million	$27 million	$15,000	# of people protected in 2070: 523 Value added: $34.7 million in co-benefits
Heat	Building retrofits with heat pumps	$368 million	$22.8 million	N/A	N/A	# of people protected in 2070: 2,000

Appendix D: Sensitivity analysis of the unconstrained hydrology model

Riverine flood impacts shown in this report are based on the Regional storm model developed by CLOCA. Since the methodology recommended for Regulatory floodplain mapping is to exclude all stormwater management facilities and other man-made storage, the generated flows are unconstrained. In order to align with Regional floodplain mapping guidelines, this more conservative approach was used for the Whitby adaptation model. Alternatively, the use of constrained flows as model inputs to the Whitby adaptation model would lead to reduced impact estimates from riverine flooding events.

Table D-1 shows the difference in impacts from modeling results using constrained versus unconstrained flows for a specific area in Whitby. Although data for a townwide constrained hydrology model were not available, model outputs for constrained flows in the Michael Boulevard area were. The difference in estimated damages for this area are significant when including existing storage attenuation facilities, however it is unclear what the magnitude of difference in riverine flooding impacts would be if townwide constrained flows were used as inputs to the Whitby adaptation model. Further research would be needed to more accurately assess this impact.

Table D-1. Constrained vs. unconstrained riverine flood damages (annualized) for the Michael Boulevard area.

AREA	HYDROLOGY MODEL ASSUMPTIONS	BASE YEAR (2020)	RCP 8.5 (2070)
Michael Boulevard Area	Constrained	$167,000	$1.2 million
	Unconstrained	$867,000	$2.25 million

Appendix E: Sensitivity analysis of new zoning codes, analysis of the trained hydrology model

The location of new buildings in the model was determined by current zoning codes originally provided by the Town of Whitby. However, new zoning code updates were made available following the completion of the initial modeling and analysis. A sensitivity analysis was performed in order to determine the impact that these new zoning codes would have on future flood damage estimates. A high level estimate was done using GIS data for the updated zoning codes. Flood damage from parcels which would no longer permit the construction of new buildings under the updated codes were subtracted from total flood damage in order to assess the impact.

Table E1 compares flood damage results from both zoning code datasets. Using the updated zoning codes, which include additional restrictions for new building development in areas at flood risk, results in lower flood damage estimates for new buildings – a decrease of around 11% for total annualized damage for all return periods and 7% for a 100 year return period storm representing an extreme flooding event.

Table E1. Flood damage to new buildings using original zoning codes vs. updated zoning codes.

VARIABLE	ORIGINAL ZONING CODE RESULTS	UPDATED ZONING CODE RESULTS	% DIFFERENCE
# of parcels with flood damage to new buildings	1092	985	10%
Expected annual flood damage (annualized over all flood event return periods) (2070)	662 M$	586 M$	11%
Damage for a 100 year flood event (2070)	1,248 M$	1,155 M$	7%