Climate Change Vulnerability Assessment Tool for Drinking Water Source Quality

Version 3
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Conservation
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Natural Champions

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SOURCE PROTECTION
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Supported by Toronto and Region Conservation Authority

Ontario

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Pilot Study Participants

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- Halton Region's Burlington water intakes: Conservation Halton, Hamilton Conservation Authority, Regional Municipality of Halton.
- Seaforth Well Supply System: University of Guelph, Ausable Bayfield Conservation Authority, Maitland Valley Conservation Authority, Municipality of Huron East.
- City of Timmins River Intake: Mattagami Region Conservation Authority, City of Timmins.
- Town of Carleton Place River Intake: Mississippi Valley Conservation Authority, Rideau Valley Conservation Authority, Town of Carleton Place.

Products and Versions

The project resulted in the development of a Microsoft Excel-based assessment tool each for surface water and groundwater sources of drinking water, and an accompanying guidance document. These three products are collectively called the "assessment tool". Together, they support the consideration of climate change impacts into water quality risk assessments for drinking water source protection. The project was carried out in two phases as summarized below, and described in detail in Appendix A.

The Project Team, Steering Committee, and Academic Advisory Group worked together to develop draft products. In fall 2018, stakeholder engagement sessions were held across Ontario where Version 1 of the assessment tool was presented to participants including municipalities, source protection authorities (SPAs), and consultants. Valuable feedback were considered.

Conservation Ontario then led four pilot studies and revised the excel-based tool and guidance document accordingly, leading to Version 2 of the assessment tool. Assistance was provided by the Ontario Climate Consortium of the Toronto and Region Conservation Authority. A review was provided by the Ministry of Environment, Conservation and Parks and Conservation Halton. Conservation Ontario also developed educational materials and user templates for the benefit of the user. It is expected that with increased use of the assessment tool, additional features and improvements may be requested. These could be considered in the future.

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Acronyms

HVA: Highly Vulnerable Aquifer

IPZ: Intake Protection Zone

MOECC: Ontario Ministry of the Environment and Climate Change (now MECP)

MECP: Ontario Ministry of the Environment, Conservation and Parks (previously MOECC)

MNRF: Ontario Ministry of Natural Resources and Forestry

OCC: Ontario Climate Consortium

RCP: Representative Concentration Pathway

SGRA: Significant Groundwater Recharge Area

SPA: Source Protection Authority

SPC: Source Protection Committee

WHPA: Wellhead Protection Area

Glossary

Adaptive Capacity: The ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences (IPCC, 2007).

Assessment report: science based assessments of vulnerability and risks related to drinking water sources. These reports were developed per the *Clean Water Act, 2006*.

Climate: Climate is defined as an area's long-term weather patterns. The simplest way to describe climate is to look at average conditions (e.g., temperature, precipitation, etc.) over time. (IPCC 2012a, IPCC 2012b).

Climate Change: Refers to a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the statistical properties (e.g., mean and/or the variability) in weather and atmospheric conditions that persists for an extended period, typically decades or longer (IPCC 2007, IPCC 2012a)

Climate Change Scenario: "A climate change scenario is a description of a possible future climate based on assumptions of how the earth's climate operates, future world population levels, economic activity and greenhouse gas emissions" (NRCan, 2018). There are four main climate scenarios that are referenced in the Intergovernmental Panel on Climate Change (IPCC) reports called, Representative Concentration Pathways (RCPs): RCP 2.6, RCP 4.5, RCP 6.0, RCP 8.5.

Climate Change Vulnerability: "The propensity or predisposition [of a system, place, or human being] to be adversely affected [by climate change]. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt" (IPCC 2014). Vulnerability is a function of exposure, sensitivity, and adaptive capacity (IPCC, 2012).

Climate Condition(s): A representation or measurement of a climate driver (e.g., total daily precipitation, minimum daily temperature, 1-day maximum precipitation).

Climate Normals: "Refer to arithmetic calculations based on observed climate values for a given location over a specified time period and are used to describe the climatic characteristics of that location. Real-time values, such as daily temperature, are compared to the 'climate normal' to determine how unusual or how great the departure from 'average' they are" (Environment and Climate Change Canada, 2018a). A 30-year period is typically used to smooth out extremes, and ensure that particularly wet, dry, hot or cold years do not dominate the climate conditions overall (which may occur if only a subset of years are used as a normal period). Typically, the middle decade is used to name the climate normal, such as 2041-2070 referred to as the 2050s, 1981-2010 referred to as the 1990s (or baseline period).

Climate Projection: The term "projection" is used in two ways in climate change literature. In its general usage, a projection can be regarded as any description of the future and the pathway leading to it (e.g., World Meteorological

Organization 2007). In a more specific interpretation by the Intergovernmental Panel on Climate Change (IPCC), it refers to model-derived estimates of future climate (IPCC 2012a, IPCC 2012b).

Climate Stimuli: “Climate stimuli can include all elements of climate change, including mean climate characteristics, climate variability, and the frequency and magnitude of extremes. The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range, or variability of temperature) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to sea-level rise)” (IPCC, 2007).

Climatic and non-climatic stressors: climatic stressors include changes in temperature, precipitation, and wind patterns; while non-climatic stressors include urbanization, habitat fragmentation, and invasive species (Glick et al., 2011).

Downwelling Event: When surface water becomes denser and sinks to the bottom of a waterbody. The sinking, dense water brings dissolved oxygen to deeper waters, affecting the decomposition in bottom waters. This process is driven by wind, the Coriolis Effect, and Ekman transport (Toronto and Region Conservation Authority, 2018).

Drinking Water Threat: An activity or condition that adversely affects or has the potential to adversely affect the quality or quantity of any water that is or may be used as a source of drinking water, and includes an activity or condition that is prescribed by the regulations as a drinking water threat (*Clean Water Act, 2006*).

Exposure: “Refers to the inventory of elements in an area in which hazard events may occur” (IPCC, 2012). Exposure is primarily a function of geography (e.g., coastal communities are more exposed to sea level rise and hurricanes than an inland community).

Extreme Event: The Technical Rules defines an extreme event as described below. It is important to acknowledge; however, that based on climate change literature, an extreme event could constitute a broader meaning of the term as it is used in assessments (e.g., ice storms, heavy winds, a more or less intense rainfall than a 100-year storm event, etc.):

a) a period of heavy precipitation or winds up to a 100-year storm event;
b) a freshet; or
c) a surface waterbody exceeding its high water mark.

Greenhouse gases (GHGs): Particular gases in the atmosphere act like the glass of a greenhouse, preventing the heat from escaping. These gases absorb heat and radiate some of it back to the earth's surface, causing surface temperatures to be higher than they would otherwise be (ECCC, 2015). GHGs include carbon di oxide, water vapour, methane, nitrous oxide, chlorofluorocarbons (CFCs), hydrofluorocarbons (HFCs) and Perfluorocarbons (PFCs), as well as sulfur hexafluoride (NOAA, 2020).

Groundwater: Water originating as precipitation, runoff and snowmelt that infiltrates into the ground to the water table, where it is contained beneath the Earth's surface in soil pore space and rock formation fractures (Environment and Climate Change Canada, 2018b).

GUDI: Groundwater Under Direct Influence of surface water means groundwater having incomplete/undependable subsurface filtration of surface water and infiltrating precipitation (MECP, 2018a).

Highly Vulnerable Aquifer (HVA): An aquifer delineated per the Technical Rules, on which external sources have or are likely to have a significant effect, and includes the land above the aquifer.

(Climate Change) Impacts: Consequences of climate change on natural and human systems. Depending on the consideration of adaptation, one can distinguish between potential impacts and residual impacts:

- **Potential impacts**: All impacts that may occur given a projected change in climate, without considering adaptation." (IPCC, 2014). This is the product of climate exposure and sensitivity (see Equation 1).
- **Residual impacts:** The impacts of climate change that would occur after adaptation" (IPCC, 2014).

Intensity-Duration-Frequency (IDF) Curve: IDF curves are used in the design offlood protection infrastructure on small watersheds. They summarize the annual probability of exceedance of a volume of rainfall, in a single event of a specific duration (MTO, 2016).

Intake Protection Zone (IPZ): An IPZ is delineated per the Technical Rules, and is defined as the area on the water and land surrounding a surface water intake, where protection from surface contamination is required to safeguard the drinking water source. Three IPZs can be delineated including: IPZ-1, IPZ-2, and IPZ-3. The IPZ-1 is the closest and most vulnerable area around the intake typically based on a 1 km radius around the intake up to the land where a setback is applied. IPZ-2 is typically based on a 2-hour time of travel to the intakes, outside of IPZ-1. The IPZ-3 is the least vulnerable area around the intake based on a longer travel time in hours, outside ofIPZ-2.

Rationale: The justification, whether scientific or experiential, as to why a particular aspectof this assessment was selected or decided upon. For instance, rationales provided in the context of vulnerability indicate what they are, why they are relevant and important, and how they can be interpreted based on literature.

Representative Concentration Pathways (RCPs): There are four climate change scenarios called RCPs, that represent future total radiative forcing, a cumulative measure of human emissions of GHGs from all sources expressed in Watts per square metre pathway and level by 2100 (IPCC, 2014). Each RCP represents a different combination of economic, technological, demographic, policy, and institutional futures.

RCP 2.6: a low emissions future scenario of climate change where emissions peak by mid-century and decline through the rest of the century with substantive changes in energy use and emissions of greenhouse gases. (Sources: IPCC, 2014; van Vuuren et al. 2011).

RCP 4.5: a moderate emissions future scenario of climate change where emissions peak around 2040 before declining to 2080 and leveling off through the rest of the century. (Sources: IPCC, 2014; Thomson et al. 2011)

RCP 6.0: a second moderate emissions future scenario of climate change where emissions peak around 2060 and then decline through the rest of the century. (Sources: IPCC, 2014; Masui et al. 2011)

RCP 8.5: a high emissions, or business-as-usual, scenario where emissions continue to rise into 2100 and beyond. (Sources: IPCC, 2014; Riahi et al. 2011)

Resilience: The ability of a system and its component parts to anticipate, absorb, accommodate, or recover from the effects of a hazardous event in a timely and efficient manner, including through ensuring the preservation, restoration, or improvement of its essential basic structures and functions (IPCC 2012a, IPCC 2012b).

Seasonality: A characteristic of a time series in which the data experiences regular and predictable changes which recur every calendar year. Any predictable change or pattern in a time series that recurs or repeats over a one-year period can be said to be seasonal (e.g., summer, fall, winter, and spring).

Sensitivity: "The degree to which a system is affected by climatic stresses, adversely or beneficially, by climate stimuli" (IPCC, 2007). For example, a community dependent on rain-fed agriculture is much more sensitive to changing rainfall patterns than one where mining is the dominant livelihood.

Significant Groundwater Recharge Area (SGRA): An SGRA is an area delineated per the Technical Rules, where a relatively significant volume of precipitation recharges the groundwater source or aquifer within a source protection area, determined using criteria specified in the Technical Rules.

Source Protection Authority (SPA): A conservation authority or other person or body that is required to exercise and perform the powers and duties of a drinking water source protection authority under the *Clean Water Act* in a source protection area (*Clean Water Act, 2006*).

Source Protection Committee (SPC): Established under Section 7 of the *Clean Water Act*, and comprised of members with local knowledge from three sectors (economic, municipal, and environment/ general public/ health). SPCs are responsible for identifying significant existing and future risks to their municipal drinking water sources and developing plans to address these risks. There are 19 source protection committees in Ontario (MECP, 2018b).

Source Protection Plans: Locally driven, science-based plans, developed by Source Protection Committees, which protect drinking water supplies in communities. The plans outline the work and who will be conducting it, and include assessment reports as well as policies that require actions to reduce, eliminate or manage the identified risks. (MECP, 2018b).

Statistical downscaling: An approach that relies on historical relationships among climate parameters of various scales, and develops mathematical equations to predict future conditions. Notably, there is uncertainty as to whether these relationships will hold under evolving conditions (e.g., feedback loops, tipping points) associated with climate change.

Dynamical Downscaling: Another downscaling approach which involves running a very high resolution model once over the area of interest, driven by global climate model boundary conditions (so called 'dynamical downscaling'). In the simplest of terms one can either have 'many model runs at a coarse resolution' or 'few model runs at high resolution'. These high resolution models are called 'Regional Climate Models' (RCMs).

2017 Technical Rules under the Clean Water Act ("Technical Rules)": Technical Rules set out the science-based framework established under the *Clean Water Act, 2006* that prescribe technical approaches to assess risks and vulnerability of drinking water sources in Ontario (MECP, 2017).

Transport Pathways: Man-made features on a landscape that increase the vulnerability of raw water supplies of municipal drinking water systems. Transport pathways redirect the natural flow of water to surface water sources, or disturb the surface above an aquifer which increases the rate or quantity of flow to a groundwater source. Examples of transport pathways affecting:

a) Surface water sources may include: storm sewer lines, discharge pipes, ditches, tile drains, storm water ponds, or any other type of drain.
b) Groundwater sources may include: wells or boreholes, pits, quarries, construction activities involving deep excavations, and underground sanitary or water distribution system infrastructure.

Upwelling Event: When dense, cool, nutrient-rich water from the bottom of the lake replaces the nutrient depleted surface water in the nearshore. This process provides nutrient-rich water for biological growth in the nearshore. This process is driven by wind, the Coriolis effect, and Ekman transport (Toronto and Region Conservation, 2018).

Vulnerable Area: Per the *Clean Water Act (2006),* there are four types of vulnerable areas, related to water quality or quantity or both, as indicated below:

a) intake protection zone (IPZ) – water quality and quantity related,
b) wellhead protection area (WHPA) – water quality and quantity related,
c) highly vulnerable aquifer (HVA) – water quality related,
d) significant groundwater recharge area (SGRA) – water quantity related.

Wellhead Protection Areas (WHPA):
The WHPA is delineated per the Technical Rules, and is the area around a well where land use activities have the potential to affect the quality and quantity of water that flows into the well. The size of the water quality WHPA is dependent on how quickly water travels underground to the well, in years. Within a water quality WHPA, four zones can be delineated based on specified distance or time-of-travel including: the 100-metre zone (WHPA-A), the 2-year (WHPA-B), 5-year (WHPA-C), and 25-year (WHPA-D) time of travel zones.

1. Introduction

The climate is changing. Severe rain, ice and wind storms, prolonged heat waves and milder winters are much more common. Forests, waters and wildlife across Ontario are and will continue to be significantly impacted by these changes. People across the province and all sectors of the economy are feeling the impacts of climate change and paying more and more for the costs associated with those impacts (MECP, 2018c).

Ontario's watershed based Conservation Authorities have identified several changes and impacts to our water and land resources including (Conservation Ontario, 2020):

- Threats to water quality and supply
- Reduced river flows, warmer surface waters, more drought conditions, and more frequent severe weather from rising temperatures and changing precipitation patterns
- Increased flood and erosion problems due to more extreme rainfall
- Reduced wetlands
- Degraded biodiversity.

Climate change impacts may also affect our drinking water sources. The Government of Ontario has recognized the need to better incorporate climate change considerations into drinking water source protection planning and management, to identify and reduce the potential impacts of climate change on sources of drinking water. The assessment of the potential impacts from climate change on source water quantity is included in water quantity risk assessments, under the Drinking Water Source Protection program. The Government of Ontario has also recognized the need to do the same for drinking water source quality. To undertake an assessment at the local scale, a climate change vulnerability assessment tool has therefore been developed for surface water and groundwater source quality, along with an accompanying guidance document. Together, these three resources are called the "assessment tool".

1.1 Climate Change Impacts on Water Resources in Ontario

Ontario borders four of the five Great Lakes, and has more than a quarter of a million inland lakes, over half a million kilometres of rivers and streams, and numerous aquifers (MECP, 2016a). Overall, climate change is expected to bring a 3.6˚C increase in average annual temperatures by 2050 in Ontario (compared to the period between 1981 and 2010), along with milder and shorter winters, earlier snowmelt, a decline in ice cover on lakes, changes in precipitation intensity and frequency, and more evapotranspiration (NDMNRF, 2014). These changes can impact both the quantity and quality of water for both surface water and groundwater systems, as discussed below. .

Potential Climate Change Impacts on Surface Water

Surface water systems can be impacted by changes in the intensity, frequency and duration of drought periods; the volume and timing of runoff due to changes in precipitation patterns; increasing rates of evapotranspiration, increases in air and water temperatures; and more frequent and intense extreme weather events and storms (Bates et al. 2008).

From an ecosystem perspective, increases in air temperatures can pose significant threats to water quality as warmer air and water temperatures may alter breeding seasons, change food sources, and force native plants and wildlife to migrate northwards, thereby introducing new species to Ontario's water systems (NDMNRF, 2014). Warmer water temperatures may also cause changes to thermal regimes, streamflow and lake circulation regimes, and the chemical composition of water including salinity, pH, dissolved oxygen (Poff et al. 2002). Assuming that the pathway of emissions continue as 'business as usual' (i.e., the RCP 8.5 scenario), streams in the Lake Ontario basin have shown a projected increase of 2 to 4˚C by 2050, while it is expected that a greater effect of warming of waterbodies may occur in the more northern parts of the Great Lakes basin (Chu, 2015).

Aquatic systems deliver numerous ecosystem services such as the control of flooding and erosion, and the provision of fish habitat and recreational opportunities. Studies further indicate that freshwater ecosystems including the Great Lakes, inland lakes and rivers/streams are becoming more variable as climate continues to change (Sharma et al. 2007; O'Reilly et al. 2015), causing changes to river flows and water levels. For example, more 'higher highs' and 'lower lows' have been observed.

Ontario is also expected to experience an average increase in precipitation in the future, of up to 240 mm more precipitation annually by the 2080s (compared to the period between 1971 and 2000), with the exception of the Nelson River and Hudson Bay basins which may become drier (with up to 60 mm less precipitation than the 1971-2000 baseline level) (McDermid et al. 2015). Winters are expected to become wetter over time, whereas summers are likely to be drier on average (McDermid et al. 2015). Changes in precipitation patterns (snow and rain) will likely have a profound effect on the state of Ontario's surface water (e.g., rivers, streams, lakes, ponds, reservoirs) such as changes in shape and functions over time (Poff et al. 2002).

Potential Climate Change Impacts on Groundwater

Climate change is also expected to influence and shift the hydrological regime of Ontario's groundwater system, which is made up of shallow and deep aquifers, due to increased variability in precipitation (Allen et al. 2004). Groundwater plays a significant role in maintaining watershed health and resiliency by providing a source of cold water to surface water features, supporting natural habitat, biodiversity and potentially better water quality. Groundwater is also crucial to many municipalities in Ontario where residents depend on wells for drinking water or for the agricultural sector.

Some experts suggest that deeper and confined aquifers may be less sensitive to changes in precipitation patterns including more intense/frequent drought (Tu et al., 2017). Conversely, shallow and unconfined aquifers may be more susceptible to contamination due to shorter time of travel from the ground surface to the aquifer. If shallow and unconfined aquifers experience reduced water levels during hot, dry summers, this may lead to cascading effects including reduced discharge rates that supply baseflow and cold water inputs to surface water systems such as streams, lakes and wetlands (McDermid et al. 2015).

Other Considerations

Climate change, when coupled with other drivers such as poor land use practices and population growth can exacerbate existing risks to water resources and drinking water systems (Cheng and Basu 2017). For example, both climate change and urbanization may worsen the quality of water entering waterbodies, as heavy precipitation could cause contaminants (e.g., road salt, heavy metals, litter, rubber, microbial contaminants, and synthetic chemicals) from roads, residential areas and yards, to run off into waterbodies and/or infiltrate into the ground (Tong and Chen, 2002, Tetzlaff et al. 2010, McGrane et al. 2014, Heim and Dietrich 2007, Sullivan et al. 2007, Varca 2012, Anderson et al. 2013).

Similarly, in areas of intensive agricultural practices, heavy precipitation events can cause runoff, which can transport a variety of nutrients (e.g., nitrogen, phosphorus, manure, sewage biosolids, potassium, calcium, etc.) as well as other contaminants such as pesticides into surrounding waterbodies and into groundwater sources (MECP, 2016b). When there are sufficient levels of nutrients and conducive environmental conditions (including warm water temperatures and calm weather conditions), then naturally occurring cyanobacteria, commonly called blue-green algae, can form large “blooms” in our lakes. When they accumulate in large numbers as blooms, there can be a risk to human health from poisons called “cyanotoxins” that can be produced by the algae (MECP, 2019). The blooms can become thick, mat-like forms that can cause detrimental impacts to ecosystems and water quality. These eventually sink and decay at the bottom of a reservoir or lake, and deplete the water of dissolved oxygen, creating toxic environments for fish and wildlife known as “dead zones” (Manning et al. 2013). The causes for recent increases in blue-green algal blooms in Ontario are not fully understood, however, climate change and increases in inputs of nutrients (such as phosphorus) are likely contributors. Actions by the agricultural sector, municipalities and conservation authorities are helping to reduce phosphorus loadings and potential impacts from algae on our drinking and recreational waters (MECP, 2019).

Ontario’s population is also expected to grow by 30% or more, to over 18.2 million people by July 2041 (Ministry of Finance, 2017). This projected growth will largely be captured by the Greater Toronto Area (GTA), which accounts for half of Ontario’s population, with expectations to increase to a population of 9.6 million by 2041 (Ministry of Finance, 2017). Rapid population growth will most likely increase demand on municipal drinking water systems. The protection and management of drinking water sources are thus essential.

In light of the anticipated climate change impacts on Ontario’s water resources, along with the effects of other risk factors, climate change poses a serious concern to the public.

1.2 Drinking Water Source Protection and Climate Change

Ontario's Drinking Water Source Protection program is established under the *Clean Water Act, 2006,* which is part of Ontario's multi-barrier drinking water protection framework. This framework is based on the recommendations by Justice O'Connor in his inquiry of the Walkerton water contamination tragedy. In May 2000, the bacterial contamination of one of the Walkerton municipal drinking water wells led to the deaths of seven people within a few weeks of the contamination, while thousands of others were left with severe, long-term illnesses. Justice O'Connor conducted a comprehensive inquiry into the tragedy and made 121 recommendations on a wide range of areas related to protecting drinking water (MECP, 2018b).

The *Clean Water Act, 2006,* and its associated regulations set out the processes for protecting sources of drinking water in Ontario. Under this legislation, source protection planning is mandatory for municipal residential drinking water systems. Certain other types of systems may be brought under the program. The *Clean Water Act, 2006* requires Source Protection Committees to develop source protection plans that protect vulnerable areas around municipal wells and intakes from 22 prescribed drinking water threat activities and any other threat activities identified locally. Water quality and quantity threats are both considered under Ontario's Drinking Water Source Protection program. The source protection plans contain policies to protect existing and future sources of drinking water, and task municipalities, the provincial government, conservation authorities and others to protect drinking water sources through various tools such as land use planning, risk management plans, prohibitive orders, education and outreach, incentives, and research.

The Conservation and Source Protection Programs Branch (CSPB) of the MECP has developed the 2017 Technical Rules under the *Clean Water Act, 2006,* and updated in late 2021(herein referred to as "Technical Rules"), which are mainly overarching technical methodologies that were used during the development of science-based assessment reports. These completed assessment reports strongly support the policy framework, and form part of the source protection plans. The Technical Rules are updated as needed, sometimes resulting in updates to the source protection plans.

It is notable that Technical Rule 15.3 provide specific details which must be included in any climate change assessment in relation to a well head protection area or an intake protection zone, such as:

(1) An explanation of why specified climate data sets were used as the basis for the climate change impact assessment;
(2) A summary of the findings of the climate change impact assessment;
(3) A description of the approach used to evaluate the vulnerability of a drinking water system to climate impacts identified in the climate change impact assessment; and
(4) An explanation of the results of the evaluation under subrule (3), including whether the evaluation concluded that the drinking water system is resilient to the climate impacts identified in the climate change impact assessment.

The current Technical Rules allow local authorities to consider climate data and assess how climate change may impact the vulnerability of drinking water sources to contamination.

Source Protection Authorities (SPAs), Source Protection Committees (SPCs), the Ontario Ministry of the Environment, Conservation and Parks (MECP), and others, have acknowledged the importance of considering climate change impacts into the protection of sources of drinking water in Ontario. SPAs and SPCs indicated an interest in a more defined technical methodology to consider climate change on source water quality, as is available for water quantity.

1.3 Purpose and Benefits of the Assessment Tool

The assessment tool is one of the first of its kind in the Province of Ontario, and its main purpose it to provide science-based guidance to municipalities, source protection authorities, and source protection committees on how to conduct a climate change vulnerability assessment for drinking water source quality.

The term “climate change vulnerability” refers to the propensity or predisposition to be adversely affected by climatic or non-climatic stressor(s) or a combination of both (IPCC, 2012). In the context of the assessment tool, climate change vulnerability of source water refers to any drinking water source that will likely be adversely affected by local climate change impacts now and in the future.

The assessment tool offers instructions and examples, background information on climate change and associated terminology, and various additional resources such as climate data sources and locations. The primary benefits of the assessment tool include:

1. Providing clear guidance on how climate change science can be built into the existing source water quality risk assessment approach in Ontario;
2. Building consistency across the province in the approach used;
3. Supporting a multi-disciplinary approach leveraging local knowledge and expertise;
4. Producing information that can inform the development of source protection policies that may be required for a drinking water system; and
5. Supporting staff at the Province of Ontario as they work to develop, understand, and establish frameworks for addressing climate change within source protection plans and/or policies in the future.

The assessment tool also supports the provincial multi-barrier approach through the *Safe Drinking Water Act* and its Drinking Water Quality Management Standard. This quality management standard, specifically designed for drinking water systems, is complementary to assessing climate change impacts on the source water quality. Thus, some of the quality management standard information has specifically been built into the assessment tool as part of the criteria for the assessment, such that relevant information can be leveraged.

Worldwide, municipalities and other organizations are declaring climate emergencies. The results of the assessment tool can be used to help inform discussions around protection, management and adaptation actions at both the municipal and watershed scales. They may serve to further encourage climate change risk management of drinking water system infrastructure in Ontario and support local climate change strategies or plans. Given that the effects of climate change are currently being observed in the province, the assessment tool is crucial to build resilience and protect Ontario’s drinking water sources as we move into an increasingly uncertain and variable future.

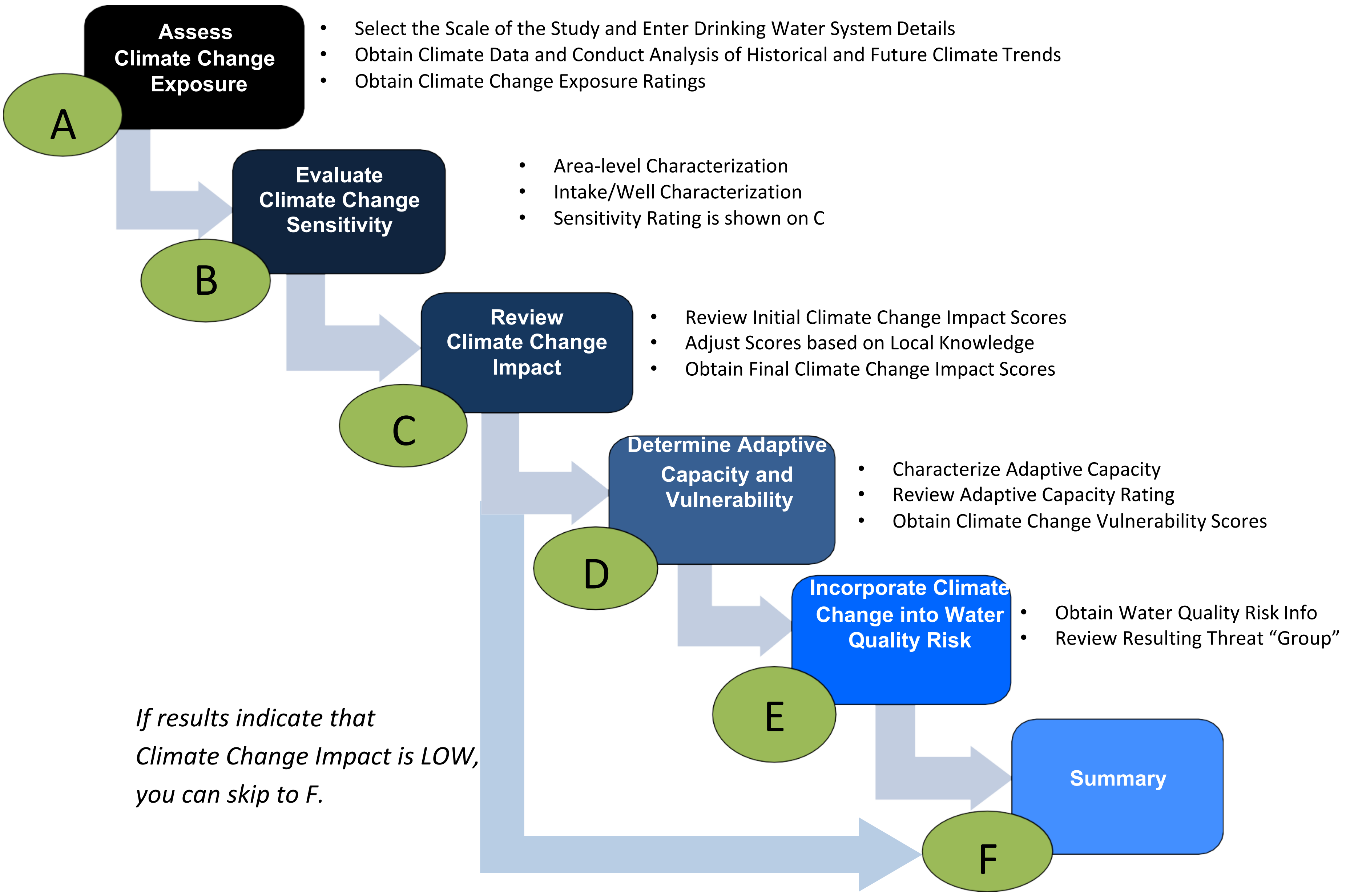
2. Overview of the Assessment Tool

The assessment tool is Microsoft Excel-based and contains a series of linked worksheets:

A. Assess climate change exposure at the area scale
B. Evaluate climate change sensitivity at the area and intake/well scales
C. Review the climate change impact scores for the area and intake/well scales
D. Determine the adaptive capacity and climate change vulnerability of the area and intake/well scales
E. Incorporate the climate change vulnerability rating into existing drinking water quality threat risk assessment
F. View a summary of the assessment results.

Figure 1 presents an overview of the assessment tool structure, along with the main objectives of each worksheet.

The assessment tool is multi-disciplinary in nature, relying on various subject matter experts likely from different organizations to provide inputs and apply their local knowledge. This follows best practices of established climate change vulnerability assessment methods, and also the multi-stakeholder source protection planning process in Ontario. During the pilot studies, this was substantiated as it was found that technical and policy/planning staff at source protection authorities, municipalities, and consultants operating municipal water treatment plants provided the inputs, local knowledge and judgement needed for the assessments. Therefore, please note that the term “user”, where used in this document, refers to more than one user.



- Select the Scale of the Study and Enter Drinking Water System Details
- Obtain Climate Data and Conduct Analysis of Historical and Future Climate Trends
- Obtain Climate Change Exposure Ratings

- Area-level Characterization
- Intake/Well Characterization
- Sensitivity Rating is shown on C

- Review Initial Climate Change Impact Scores
- Adjust Scores based on Local Knowledge
- Obtain Final Climate Change Impact Scores

- Characterize Adaptive Capacity
- Review Adaptive Capacity Rating
- Obtain Climate Change Vulnerability Scores

- Obtain Water Quality Risk Info
- Review Resulting Threat “Group”

If results indicate that Climate Change Impact is LOW, you can skip to F.

Figure 1: Overview of the Assessment Tool

2.1 Number of Assessments for a Study Area

The assessment tool is designed to be used for an individual intake or well. The user may choose to complete the assessment for as many or as few intakes or wells as they would like within the study area. However, the assessment does not need to be conducted for each and every intake or well within a drinking water system; nor does it need to be conducted for every drinking water system in the study area.

If the user only wants to conduct the assessment once, it is suggested to choose an intake or well that is most vulnerable within an area, for example, the intake or well with the most drinking water threat risks or highest vulnerability score. Consider known climate change impacts on the well or intake, based on information such as records kept by the drinking water system operators.

If there are multiple intakes or wells within the area and the user wants to minimize the number of assessments done, characteristics such as those listed below can be reviewed to decide on whether one assessment will be representative of similar intakes or wells:

- located within the same or comparable geographic areas;
- experience similar climate change conditions;
- have similar construction;
- are managed in a similar way;
- have similar source water characteristics and vulnerability, as determined under the *Clean Water Act*.

The user may choose to conduct the assessment for one intake or well for every area where the geology and/or geography changes within the area. For example, one assessment can be conducted for an intake or well in a highly elevated area, and another assessment in a low-lying area.

If an intake is reliant on a backup supply from a well, or vice versa, it is also recommended that the user conducts an assessment for both the intake and well and compare the climate change vulnerability results.

It is also important that the user applies their professional judgement and local knowledge of past events, the characteristics of the surrounding area, and the state of the intake or well when choosing which intakes or wells would be subject to the assessment.

2.2 Frequency of Assessments

Users of this assessment tool have the discretion to complete it as many times as they would like. It is recommended that users conduct this assessment as often as climate change data become updated/available, as municipalities update their municipal data, or when source protection plans are being updated, to leverage information from these documents concurrently if possible.

2.3 Scale of the Assessment

It is important to understand that the worksheets evaluate the components of climate change vulnerability at different scales.

- Worksheet A (Climate Change Exposure) evaluates exposure at the larger geographic area scale, as climate data are not available at drinking water system scales across the province.
- Worksheets B (Climate Change Sensitivity), C (Climate Change Impacts), and D (Adaptive Capacity and Climate Change Vulnerability) evaluate the components at both the area and system scales and combine information from these two scales throughout the worksheets to determine the final climate change vulnerability score.
- Worksheet E (Source Water Quality Risks) reviews risks to source water quality at the IPZ or WHPA scale, to which a climate change lens is applied.

2.4 Assessment Tool Inputs

Useful information sources that support user inputs include (but are not limited to) local source protection plans (including the science-based assessment reports), watershed characterization reports, municipal planning documents, municipal water and wastewater master plans, Drinking Water Quality Management reports, climate change studies, journal publications, and reliable climate data portals. As well, a wealth of local knowledge and expertise may be availed of from local and cross-jurisdictional organizations, agencies, working groups and committees. They include source protection authorities and committees, the Ministry of Environment, Conservation and Parks, drinking water treatment plant operators, municipal planners, consultants, and others.

That being said, the assessment tool has been designed to calculate climate change vulnerability scores with the data that has been provided by the user. Therefore, if there are missing data (e.g., the user was unable to find certain climate parameter data, or characteristic information of the area of study), the assessment tool will still calculate the climate change vulnerability of the source water quality of the drinking water system, based on available information.

The assessment tool builds upon the user's inputs to the worksheets by linking them together, and by automating the calculation of certain outputs. In the assessment tool, the cells indicated by a thick, black outline represent the areas where user input is needed. Grey boxes provide additional information to the user that may be helpful while entering information.

The user inputs information for several attributes (characteristics) in most of the worksheets. In Worksheets A, B, D (climate change exposure, sensitivity, adaptive capacity), for each attribute the user provides both quantitative (e.g.: number of intakes) and qualitative information (e.g.: assessment of low, medium, or high rating). The assessment tool assigns a corresponding score of 1, 2 or 3, for most attributes. A weight is then applied through an automated process, also on a scale of 1 to 3, to each score to better capture the attributes of most concern. This process is conducted for nearly all user inputs, to arrive at final ratings for each attribute. See Table 2 below for an example of how all of this works.

Note that since the attributes evaluated at the area scale encompass a broader area that may not have direct impacts to water quality, these attributes carry less weight than the system-level attributes.

Table 2: Example of User Input, Weight and Final Attribute Score

Intake Sensitivity Attribute	**USER INPUT**	**Internal Calculations of the Assessment Tool (not user input)**			**Description of how the Attribute is considered**
		Score Assigned to Attribute	**Weight Assigned to Attribute**	**Final Attribute Score**	
Potential clogging of intake crib	**High** *(From a choice of High, Medium or Low)*	**3** *(This is based on the user's input of "High".* *For "Low", the score assigned is 1.* *For "Medium" it is 2)*	**1** *(Weights are 1, 2 or 3 based on importance of the attribute and the scale of the assessment. A weight of 1 signifies "less concern", and a weight of 3 "most concern").*	**3** *(This is calculated by multiplying Score with Weight)*	Intake cribs may be clogged due to increased algal blooms or ice. This attribute contributes to the final climate change vulnerability score as follows: High potential for clogging is considered higher sensitivity, low potential is considered lower sensitivity.

It is also important to be aware of what unit of measurement is needed in the assessment tool. Some of the information inputs obtained from different reports and sources may need to be recalculated or units may need to be converted. For example, in Worksheet B1 (study area sensitivity), the user needs to input the percentage of the study area that is highly urbanized. Typically, this information is available in source protection assessment reports as an area unit (e.g., total number of hectares). The user would need to convert the available area unit information into the required attribute of a percentage of the study area.

The Worksheet C (climate change impact scores) uses the inputs from previous worksheets to calculate and auto populate the initial climate change impact scores for the user's review. At this point, the user may choose to alter a climate change impact score, but must provide a strong, detailed rationale in the assessment tool, explaining the change to the score.

Similarly, Worksheet D (overall climate change vulnerability rating) uses information from all previous worksheets to calculate the overall climate change vulnerability rating, which the user can review (but not change).

In Worksheet E, the user must input information on drinking water threat activities and source water quality risk assessments. This information is available from local source protection plans. This worksheet also automatically pulls the overall climate change vulnerability rating from Worksheet D and applies it to the user input.

2.5 Uncertainty Determination

As a good practice, the assessment tool allows for the user to determine the uncertainty of their inputs and analyses and assign a level of “high” or “low” uncertainty for each step of the climate change vulnerability assessment. This is consistent with the uncertainty analysis allowed for per the Technical Rules, under the *Clean Water Act, 2006* framework.

At the end of Worksheets, A through D, there is relevant information that supports the user to determine the level of uncertainty. The user may find that not all of these factors are relevant, or that additional factors should be considered. Accordingly, it is suggested that the user apply their expert judgement when conducting these uncertainty analyses. The final Worksheet F will provide an auto populated summary of all of the uncertainty ratings (by worksheet), for ease of reference.

Uncertainty can occur from climate data (both historical and future), as there may be fluctuations in the measurement instruments, and most models consist of global models that have been downscaled to a specific area, and do not take into account the local attributes and micro-climates (e.g., the lake effect snow of the Great Lakes and other lakes in Ontario).

Note that overall, the assessment tool takes a conservative approach to calculate the climate change vulnerability of source water quality of drinking water systems. This is done to account for all possibilities of climate change impacts in the future. For example, the assessment tool takes the maximum climate change exposure rating across all seasons, and multiplies this by the sensitivity scores, making the climate change impact scores the maximum that they can be, given the inputs to the assessment tool. The level of uncertainty assigned by the user can take this approach into consideration.

Uncertainty also can be a result of the assumptions made when select thresholds have been incorporated, though these have been vetted and validated to the extent possible. The majority of thresholds were developed through literature. Some thresholds that were not available were developed by the Project Team with help from the Academic Advisory Group.

The uncertainty determination at each step may influence the path forward. For example, if the user concludes that the uncertainty is high due to lack/quality of data or information to be input into any of the worksheets A-D, the user may choose not to complete the study at all until such time that appropriate inputs are available. The user could also decide to continue despite problems with data and information and assign uncertainty accordingly – which in turn influences the local actions to be taken, for example education and outreach rather than prohibitive measures.

2.6 An Overview of Incorporating Climate Change Vulnerability into Source Water Quality Risk Assessments

The incorporation of climate change impacts on water quality into the well-established drinking water source protection planning process follows widely established protocols like the Building Adaptive Resilient Communities (BARC) program for municipalities by the International Council for Local Environmental Initiatives (ICLEI) program, as shown in **Table 3**.

Table 3: Incorporating Climate Change Impacts into the Source Protection Planning Process

No.	BARC Milestone	Source Protection Planning Steps
1	Initiate	Utilize existing multi-stakeholder framework of municipalities, source protection authorities and source protection committees. Identify known climate change impacts and related source protection plan policies if any. The scope is the quality of drinking water sources of systems brought under the *Clean Water Act*.
2	Research	Use the assessment tool to assess climate change exposure, sensitivity, adaptive capacity in order to determine the overall climate change vulnerability rating of low, medium or high. This overall vulnerability rating is incorporated into the water quality risk assessment conducted under the *Clean Water Act* (available in approved source protection plans), leading to the prioritization of threat activities to be addressed.
3	Plan	Based on the prioritization of threat activities, the source protection authorities, source protection committees and municipalities will discuss source protection plan policy tool and implementer options. Monitoring policies will be discussed as well. Concurrently, local climate change plans, strategies and other tools can be reviewed. The impacts of proposed policies on persons undertaking the prioritized threat activities will be assessed. Stakeholder consultation and submission for approval by MECP will take place per *Clean Water Act* requirements.
4	Implement	Policy implementers will begin implementing per the timelines in the approved source protection plans.
5	Monitor/ Review	Monitoring policies as required under the *Clean Water Act*, will support the assessment of new information and drivers. The mandatory annual progress reporting will necessitate the tracking of policy implementation progress.

See **Appendix A** for more information.

The assessment tool has been developed to provide guidance on how climate change science can be incorporated into existing approaches under the Ontario Drinking Water Source Protection program.

The assessment tool uses a semi-quantitative, bottom-up approach to determine climate change vulnerability, based on both qualitative and quantitative data and information. This approach encourages the user to leverage local expertise to identify climate change vulnerabilities that are specific to the area surrounding the drinking water system. This is different from a quantitative, top-down approach where climate models are used to interpret climate change vulnerability.

The assessment tool effectively allows for the incorporation of climate change science into source water quality risk assessments. Using a semi-quantitative method goes hand-in-hand with how source water quality risks are rated by the Technical Rules: a risk score between 40 and less than 60 is “low”; 60 and below 80 is “moderate”; and 80 to 100 is “significant”. In the assessment tool, the overall climate change vulnerability rating is also differentiated by assigning ratings of “low”, “medium” or “high”, based on a scale ranging from 1 to 9. See **Appendix A** and the next section for more information.

While there is a lack of universal consensus on how to measure climate change vulnerability, conducting climate change vulnerability assessments is vital for adaptation and mitigation planning. Climate change vulnerability assessments can help evaluate the current and predicted state of a system (e.g., a community or source protection area) and help identify which components (e.g., population groups or intakes/wells) may be most susceptible to changing climate conditions. Vulnerability assessments can also help to explain the cumulative effects of the interactions between potential climate change impacts and existing stressors (Glick et al. 2011).

Generally, the results of the climate change vulnerability assessment in this guidance document are tailored to source protection authorities, source protection committees and municipalities, and can be used to help inform discussions around the protection, management and adaptation actions developed locally. In addition, the results may serve to further encourage climate change risk management of drinking water system infrastructure in Ontario.

3. Using the Assessment Tool

As mentioned earlier, climate change vulnerability refers to the propensity or predisposition to be adversely affected by climatic or non-climatic stressor(s) or a combination of both (IPCC, 2012). In the context of the assessment tool, climate change vulnerability of source water refers to any drinking water source that will likely be adversely affected by climate change impacts now and in the future. Climate change vulnerability is a function of exposure, sensitivity, and adaptive capacity (IPCC, 2012). The equation for climate change vulnerability has been adopted as follows:

$$\textbf{Climate Change Vulnerability} = \frac{\textbf{Potential Impact (i.e., Exposure} \times \textbf{Sensitivity)}}{\textbf{Adaptive Capacity}}$$

If users have already completed a climate change vulnerability assessment for their drinking water system infrastructure, they can compare it with the results of the source water quality assessment tool to determine if the vulnerability scores are aligned and identify whether there is any complementary information that may not have been captured or has changed over time for a particular Source Protection Area.

The following sub-sections describe each worksheet of the assessment tool and provide guidance on how to complete each of them.

3.1 Worksheet A: Assessing Climate Change Exposure

Purpose and Overview

The purpose of Worksheet A is to assess the **climate change exposure** and determine a rating, based on historical and future climate change trends. In the assessment tool, ***exposure*** refers to the degree to which an area, intake or well is exposed to climate variations, which is primarily a function of geography. The exposure analysis involves the following steps:

a) Select a scale of study
b) Select a climate change scenario (Representative Concentration Pathway)
c) Obtain climate data and published literature
d) Determine historical and future climate trends and variability of data
e) Review the climate change exposure results
f) Determine the uncertainty.

One of the first steps of a vulnerability assessment is to define the temporal and spatial scales, as well as climate parameters to be used (Tu et al. 2017). To carry out these steps, Worksheet A is comprised of two worksheets: A1 (to select scale of study) and A2 (to analyze climate parameters).

Selecting a Scale of Study

Flexibility has been provided for defining the spatial scope. In Worksheet A1, users are able to choose a specific area that best suits the scope of the assessment. For instance, the user can conduct the exposure assessment for the:

- Watershed or source protection area as a whole;
- An area within the whole area where specific geographic/geological characteristics change (e.g., above or below the Niagara Escarpment);
- An area within the whole area that represents specific climate conditions (e.g., microclimates, defined climate zones); or
- An area within the whole area that represents hydrological conditions (e.g., the subwatershed or groundwatershed scale).

This allows flexibility in the analysis, as source protection areas across Ontario differ in size and have local characteristics that may alter weather patterns within the source protection area (e.g., the Niagara Escarpment separates two areas of different geologies and elevations, which may experience climate change impacts differently).

Since comprehensive climate data are likely not available at the individual drinking water system level, the broader area scale is used to evaluate for climate change exposure in the assessment tool. The climate change vulnerability assessment then delves into greater detail and assesses the intake or well more specifically in the remaining Worksheets.

Selecting a Climate Change Scenario (Representative Concentration Pathway)

The assessment tool also requires users to obtain certain climate data, the values of which depend on "climate change scenarios" of future projections. The Worksheet A2 allows flexibility for users to choose the climate change scenario as deemed appropriate. These climate change scenarios are called "Representative Concentration Pathways" (RCPs) and are defined by the Intergovernmental Panel on Climate Change (IPCC).

The RCPs represent future total radiative forcing, which is a cumulative measure of human emissions of greenhouse gases from all sources, expressed in Watts per square metre pathway and level by 2100 (IPCC, 2014). Each RCP represents a different combination of economic, technological, demographic, policy, and institutional futures (IPCC, 2014b).

- RCP 2.6: a low emissions future scenario of climate change where emissions peak by mid-century and decline through the rest of the century with substantive changes in energy use and emissions of greenhouse gases (IPCC, 2014; van Vuuren et al. 2011). This scenario indicates global average warming levels of 0.9 to 2.3°C by 2090 (ECCC, 2018b).
- RCP 4.5: a moderate emissions future scenario of climate change where emissions peak around 2040 before declining to 2080 and leveling off through the rest of the century (IPCC, 2014;

Thomson et al. 2011). This scenario indicates global average warming levels of 1.7 to 3.2°C by 2090 (ECCC, 2018b).

- RCP 6.0: a second moderate emissions future scenario of climate change where emissions peak around 2060 and then decline through the rest of the century (IPCC, 2014; Masui et al. 2011).
- RCP 8.5: a high emissions, or business-as-usual, scenario where emissions continue to rise into 2100 and beyond (IPCC, 2014; Riahi et al. 2011). This scenario indicates global average warming levels of 3.2 to 5.4°C by 2090 (ECCC, 2018b).

It is suggested that users conduct the study for the RCP 8.5 scenario, as it is known the Earth is currently on track towards this 'business-as-usual' emissions scenario. It is recommended that a conservative approach is taken for assessing the potential climate change impacts for the specific drinking water system's source water quality. However, users are able to choose another RCP scenario if it is found to be more appropriate for the specific area of study. The user must provide a detailed rationale for the scenario selected.

Obtaining Climate Data and Published Literature

After selecting a suitable Representative Concentration Pathway (RCP) scenario, the user can download most of the climate data needed. The climate data available often spans over a hundred years including future projected data, typically to the year 2099. The climate data must be downloaded into a separate file, as described in the assessment tool. The user can see the pilot study examples in the template for climate data download and trend analysis. This template is provided to along with the assessment tool, to assist the user with climate data selection, trend graphing and analysis.

There are several climate models that project future climate conditions, based on the assumptions in the RCPs. Although climate models are based on the laws of physics, different climate models can use different methods to simulate these laws when simulating the climate. So, even for the same RCP, projections from different climate models can differ (ECCC, 2018b).

A multi-model Ensemble is created from existing model simulations from multiple climate modelling centres (IPCC, 2013b). It is recommended that the Ensemble mean be used in the assessment tool for future projections.

Modeled data can also be obtained for historical periods, which may sound confusing. However, this is an opportunity to compare the actual observed historical data to the modeled historical data to get a sense of the magnitude of the difference, if any. While it is recommended that the Ensemble mean be downloaded and used, if necessary, the user can choose to use one of the models for future projections. Alternately, the user can select another station or region for which the Ensemble mean data are more suitable to the study area. In one of the pilot studies, a comparison was done between actual historical data (from Environment and Climate Change Canada) and modeled historical data (from another data source) for the climate variable of precipitation. It was found that the modeled Ensemble mean values were considerably less than the actual mean, and therefore an alternate station was used.

Climate data can be available for specific stations or be based on regional aggregations. Some data sources offer both. When obtaining historical climate data for a specific station or location, it is important to select one that is most relevant to the study area. The World Meteorological Organization (WMO, 2007) recommends the consideration of the following factors:

- Multiple Climate Stations: using more than one station may help capture variability across the landscape. Particularly, consider using multiple climate stations if any of the following conditions apply:
    - The study area is divided by a significant geographical feature;
    - The study area is large in size; and/or
    - The study area has a climate station capturing coastal climate conditions vs. land-based weather conditions.
- Distance: The distance between the source protection area and a climate station is one of the most important variables. There is no agreed upon "maximum" distance away from any source protection area given the variability in the landscape. Generally, the closest climate station would provide the most adequate information. However, if the closest station does not provide sufficient data to determine the climate exposure of the source protection area, then select a climate station that best serves the purpose.
- Elevation: The climate station with elevation closest to the average elevation of the source protection area, can be used.

There are ten climate parameters of interest that are most relevant to source water quality. These specific parameters were selected based on literature review, consultation with subject matter experts, and considerations of data limitations and availability. Please read **Appendix B** for the rationale of including each of these parameters. The ten climate parameters are:

1. Minimum Temperature (˚C)
2. Maximum Temperature (˚C)
3. Precipitation (mm)
4. Heavy Precipitation (mm)
5. Very Hot Days (+30˚C, number of days)
6. Frost-Free Season (number of days)
7. Freeze-Thaw Cycles (number of days)
8. Maximum Length of Dry Spell (number of days)
9. Rainfall (mm)
10. Snowfall (cm).

The descriptions for each of these parameters are provided in Worksheet A and are based on the definitions and explanations available from the suggested data sources. Worksheet A includes suggested climate data sources, and detailed instructions and screenshots to assist with navigating various data portals and downloading the correct data for most of the climate parameters of interest. Users can also consider using other climate data sources if available through local monitoring networks or from analyses conducted as part of previous source protection planning. If an alternate data source is used for a parameter, note that the definition of the parameter may differ, based on the data source. The assessment tool includes suggested published literature as well, to evaluate trends for a few of the climate parameters.

Determining Climate Trends and Variability of Data

The trend analysis must be carried out for both historical and future climate periods. The period recommended for each of these analyses is at least 30-years, and this is called a "climate normal".

For the historical data, it is recommended to use a climate normal within the 1970 to 2019 range (e.g.: 1980 to 2010) to demonstrate long-term climate patterns, while representing the most recent and available historical data. The future period recommended starts from the most recent data available to at least 30 years from that point within the 2020 to 2050 range (e.g.: 2011 to 2040). The period of 2020 to 2050 has been selected as the future temporal scope for this assessment, as significant climate change is expected to be experienced within this timeframe. This period also reflects a typical 30-year climate normal period, which is widely used as a prediction of the conditions most likely to be experienced in a given location by reducing inter-annual variability, which is not necessarily representative of a climate condition (e.g., short-term fluctuations in weather patterns).

The trend analysis for each climate parameter is conducted external to the assessment tool. As mentioned above, the climate data trend template is provided along with the assessment tool, for the benefit of the user. This template is a Microsoft excel file showing real climate data downloaded for the pilot studies, climate normal periods used, climate data plotted into graphs that depict trends, and the automated statistical analysis to confirm trends.

For the trend analysis, seasonal and annual climate data are used where available, otherwise annual data will suffice. After downloading data for the climate data, the climate data are graphed as described in the assessment tool. The user can use the climate data trend template to shorten the time taken for the trend analysis. The trend is confirmed through a statistical analysis. See **Appendix C** for simple instructions on how to acquire and use the automated statistical analysis tools in Microsoft Excel, and also for various sources of literature on statistical procedures. The analysis enables the user to incorporate statistical significance, when determining historical and future climate trends of increasing, decreasing or not changing. For example, if the user determines through statistical analysis that a trend for a climate variable is not statistically significant (although it may appear to be an increasing trend when graphed), the user will identify that this trend is "not changing".

By examining these trends, the assessment tool will help determine whether the area is 'exposed' to changing climate conditions, and whether it will become 'exposed' in the future. The exposure scores for specific climate parameters are carried forward from Worksheet A to Worksheet C, based on their relevance to related attributes for the specified area and intake or well.

Table 4 shows how the user inputs climate data trends and data sources information in Worksheet A2.

Table 4: Example of Input Table for Historical and Future Climate Data

Climate Parameter	Seasonal or Annual	Historical Climate Trend	Future Climate Trend	Historical Data Source	Future Data Source	Scale
A) Minimum Temperature (˚C)	Spring					
	Summer					
	Fall					
	Winter					
	Annual					
B) Maximum Temperature (˚C)	Spring					
	Summer					
	Fall					
	Winter					
	Annual					

The exposure analysis also includes a determination of the **variability** of the historical and future data for each climate parameter. This is achieved by calculating the coefficient of variation (CV) of the data. The CV represents the ratio of the standard deviation to the mean of the data (i.e., divide the standard deviation by the mean). It indicates how a set of data is scattered around its mean or average. The higher the CV (typically 0.5 or above), the greater the exposure to climate change impacts, in the area of study. For the benefit of the user, the climate trend analysis template includes the calculation of CV for each climate parameter.

The CV is a useful statistic for comparing the degree of variation from one data series to another. It indicates how a set of data is scattered around its mean or average. The higher the CV (typically 0.5 or above), the greater the exposure to climate change impacts, in the area of study. For the benefit of the user, the climate trend analysis template includes the calculation of CV for each climate parameter.

Table 5 shows how the user can input information on climate data variability, in Worksheet A2. Where the future variability is greater than the historical variability, a flag is automatically generated (indicated by "Yes", in the Table 4 below), to indicate a potentially higher impact of climate change.

Table 5: An Example of the Input Table for Climate Data Variability

Climate Parameter	**Historical Annual Variability** *(Identify coefficient of variation)*	**Future Annual Variability** *(Identify coefficient of variation)*	**Variability Flag** *(Automatically generated)*
A) Minimum Temperature (˚C)			
B) Maximum Temperature (˚C)			
C)Precipitation (mm)			
D) Heavy Precipitation (mm)			
E) Very Hot Days			

Determining the coefficient of variation for all climate parameters is optional. If completed, the user will be provided with a summary of the climate parameters with the highest coefficients of variation and can use the information in the uncertainty analysis.

Reviewing the Climate Change Exposure Results

The historical and future trends indicate the degree to which the climate is changing at the study area scale (e.g., the source protection area, climate zone, geographical/geological area, watershed, or subwatershed area scale). Based on this information, the assessment tool automatically calculates climate change exposure ratings using the logic shown in **Table 6**. For example, if historical data shows that temperatures have been increasing, and future projections demonstrate that they will continue to increase, then a “high” climate change exposure is assigned to that particular parameter. In the same way, if a climate parameter is decreasing both historically and, in the future, the exposure for this parameter is a “low”.

Table 6: Climate Change Exposure Rating Matrix

	Future Climate Normal		
Historical Climate Normal	**No Change in Trend**	**Decreasing Trend**	**Increasing Trend**
No Change in Trend	**Low Exposure**	**Low Exposure**	**High Exposure**
Decreasing Trend	**Low Exposure**	**Low Exposure**	**High Exposure**
Increasing Trend	**Medium Exposure**	**Medium Exposure**	**High Exposure**

Final exposure ratings are calculated seasonally and annually based on the maximum values of parameters with seasonal values or parameters with only annual values. A "low" climate change exposure rating across all seasons and year would imply that not a single climate parameter was found to be worsening (or receive a "high" rating), which is rare.

As well, the Assessment Tool does not assign a "no exposure" rating, because it is not possible to conclude with absolute certainty that the area will not be exposed to changing climate conditions in the future. There is uncertainty in future climate projections and models that may not take into account local information. Furthermore, there are a limited number of climate parameters being assessed in the Tool that determine whether an area is "exposed" to climate change. That being said, the impacts have already been felt across Ontario. Severe rain, ice and windstorms, prolonged heat waves and milder winters are much more common (MECP, 2018c), and it is anticipated that all areas will continue to be exposed to some level of changing climate conditions.

Worksheet A2 also provides brief descriptions of climate exposure by season or annually for the area of study. This information is carried forward into the rest of the worksheets including the summary in Worksheet F. The overall climate change exposure rating (which accounts for significance) for the specific area, is linked with the other worksheets, providing an overall vulnerability score of the system.

Determining the Uncertainty of the Analysis

Each worksheet provides the user with the opportunity to determine and rate the uncertainty as "high" or "low", and this is consistent with the uncertainty analysis within the *Clean Water Act* technical framework. For the climate change exposure analysis, the following considerations are provided to the user to assess uncertainty:

1. The distribution (spatial and temporal), variability, quality and relevance of data used in completing this assessment
2. The ability of the methods and models used to accurately reflect local climate trends (historically and in the future) affecting the drinking water system
3. The quality assurance and quality control procedures applied

4. The extent and level of calibration and validation achieved for models used or calculations or general assessments completed.

The first, third, and fourth considerations can be linked with the quality of the historical data used for the assessment, as well as the historical coefficient of variation values. It is suggested that the user consider how the data were collected, the frequency of collection of data, the levels of calibration used in collecting the data, and if the data has been manipulated in instances when there was a lack of data. It is also suggested that the user consider the levels of uncertainty for each climate parameter, as some parameters may have more uncertainty than others (e.g., measuring precipitation may create more errors than measuring temperature).

The second consideration applies to the future data that was used in this worksheet, as models were used for all future projection data. It is suggested that the user consider the type of model used (e.g., regional or global), and how the data used were downscaled (e.g., statistically or dynamically). For example, global models that were statistically downscaled will have the highest uncertainty, whereas regional models that were dynamically downscaled will have lower uncertainty. Another consideration is the climate projection scenario that was chosen for the assessment (e.g., RCP 2.6, 4.5, 6.0, or 8.5), as each scenario comes with different levels of uncertainty (e.g., future emissions, response of the climate system, future technologies, etc.), as well as the future climate period being evaluated (e.g., the further into the future, the more uncertainty is associated with the data).

3.2 Worksheet B: Evaluating Climate Change Sensitivity

Purpose and Overview

The purpose of Worksheet B is to evaluate the **climate change sensitivity** at both the study area scale and the intake or well scale, based on relevant attributes (characteristics). ***Sensitivity*** refers to the degree to which a system is affected by climatic and non-climatic stressors.

To carry out the evaluation, there are two worksheets: Worksheet B1 for at the study area scale, and Worksheet B2 for the intake or well. The assessment is based on attributes that describe the intrinsic characteristics of the area and intake or well (e.g., general topography, geology, intake or aquifer type, etc.), as well as other characteristics that may affect the source water hydrologically (e.g., predominant land uses and land cover, history of combined sewer overflows, potential for runoff etc.). The user answers questions that help characterize the area of study and the specific intake or well based on intrinsic attributes and hydrological connections that could make the drinking water more sensitive and susceptible to the impacts of climate change.

For each intake or well within the source protection area, a score of 1 to 3 is assigned to each attribute based on user input, where 1 represents “low” sensitivity and 3 represents “high” sensitivity. A weight is then applied through an automated process, also on a scale of 1 to 3, to each score to better capture the attributes of most concern. This process is conducted for nearly all user inputs, to arrive at final ratings for each attribute. See **Table 2** for an example of these calculations. Note that since the attributes evaluated at the area scale encompass a broader area that may not have direct impacts to water quality, these attributes carry less weight than the system-level attributes. The weights for each attribute are provided in **Appendix E**.

Users are encouraged to consult municipal staff, drinking water system operators and source protection authorities to use their knowledge and experience and recent information to adequately characterize sensitivity at the area and intake or well scales. Like all other worksheets, if information is unavailable, the user may leave the specific input blank and go to the next attribute, and the assessment tool will still calculate the sensitivity scores. However, the more information that is input into the assessment tool, the more robust the assessment of climate change vulnerability will be. Information collected in Worksheet B will feed into the analysis of potential climate change impacts (Worksheet C), and the analysis of adaptive capacity and vulnerability (Worksheet D).

Evaluating Sensitivity at the Study Area Scale (Worksheet B1)

The reason for evaluating sensitivity at the area scale is because there are climate change impacts that can be seen at the larger watershed scale and could affect the drinking water system source water either directly or indirectly. For example, the impervious surfaces within the area of study coupled with an increase in extreme precipitation may likely increase the amount of runoff containing road salt, oils and grease, waste, etc. making its way into drinking water sources. Examples of area-level attributes that are evaluated in this worksheet include the size of the area, general information of current and future populations the drinking water system serves, current and future land uses (e.g., built-up area, agricultural land, areas drained by storm sewers, etc.), and historical issues with flooding, contamination, or drought events in the past.

An example of an area attribute evaluated in this worksheet is the size of the area, as larger areas would be able to capture more precipitation thus creating a higher potential for source water contamination. For this attribute, the user is asked to identify if the study area is large, medium, or small. One way to evaluate the size of a study area is by using the stream order classification system. The sizes of streams range from first order (smallest) to twelfth order (largest). First to third order streams can be classified as “small” areas, as these consist of small tributaries and headwater streams (Briney, 2018). Streams that have a stream order between 4 and 6 can be considered “medium” areas, and all streams with an order higher than 6 can be classified as “large” areas, as these are considered to be rivers (Briney, 2018). The assessment tool gives the user the ability to select which method will best determine whether the area of study is small, medium, or large for their assessment.

This worksheet also provides space for the user to add additional comments and it demonstrates how each attribute can be linked with climate change impacts (**Table 7**). Each attribute that is assessed in this worksheet has a sensitivity score based on the different answers that the user inputs. For example, for the attribute of “percentage of built-up area”, a user input of more than 50% would generate a “high” sensitivity score of 3, while a user input of less than 25% would generate a “low” sensitivity score of 1. As described above, weights are automatically assigned as listed in **Appendix E**. The user will be able to see the sensitivity scores associated with these attributes in Worksheet C (climate change impacts).

Table 7: Input Table Example for Study Area Attributes

Attribute	What to Record	Record	Comments (optional)	Why are we looking at this attribute from a climate change perspective?
Current percentage of the area of study as:				
a) Built Up area	% of study area (land surface)	*e.g.: 52*		Urban and rural settlement areas typically have increased imperviousness affecting runoff, evaporation and recharge. **Scoring:** Over 50% is considered higher sensitivity, under 25% is considered lower sensitivity.
b) Agricultural fields to which ASM, NASM, fertilizer, pesticides could be applied	% of study area (land surface)	*e.g.: 15*		Runoff from agricultural fields can result in higher nutrient, pathogen and pesticide loadings. **Scoring:** Over 50% is considered higher sensitivity, under 25% is considered lower sensitivity.
c) Surfaces to which de-icing salt could be applied	% of study area (land surface)	*e.g.: 9*		Surfaces where salt/brine can be applied can result in sodium and chloride loadings. **Scoring:** Over 8% is considered higher sensitivity, under 4% is considered lower sensitivity.

Evaluating Sensitivity at the Intake or Well Scale (Worksheet B2)

After providing inputs for study area attributes in Worksheet B1, the user is then asked to characterize the attributes of the intake or well in Worksheet B2, which is has a similar structure to that of Worksheet B1.

Examples of intake attributes include the depth below water level, distance from shoreline, percent of intake protection zone (IPZ) on land, slope of land in IPZ, and soil permeability. Examples of well attributes include depth of the top of screened interval or open borehole of well, aquifer type, direct hydraulic connection of surface water and groundwater supplying the well (“Groundwater Under the Direct Influence (GUDI) of surface water” type of well), slope of land, and soil permeability. These characteristics are important to document, as they can help determine the sensitivity of source water quality, which in turn may increase or decrease the system’s vulnerability to climate change conditions in the future.

Like Worksheet B1, each completed attribute is given a score of 3, 2, or 1, representing a “high”, “medium”, or “low” sensitivity score, based on the user’s input. Weights are automatically applied, as listed in **Appendix E**. The user will be able to see the sensitivity scores associated with these attributes in Worksheet C (climate change impacts).

Determining the Uncertainty of the Analysis

To determine the uncertainty levels of "low" or "high" for Worksheets B1 and B2, the user is asked to consider the following:

1. The distribution (spatial and temporal), variability, quality and relevance of data used in completing this assessment; and
2. The quality assurance and quality control procedures applied.

These two considerations can be associated with the quality and consistency of data that were input. For example, if the user acquired data from multiple agencies, local governments, or organizations, this could increase the uncertainty of the data as the data may have been measured differently, the data could be based on differing baseline values, and/or some data may not be as recently updated as others.

3.3 Worksheet C: Evaluating Climate Change Impacts

Purpose and Overview

The purpose of Worksheet C is to review the **climate change impact scores and rating** at the study area and intake or well scale. ***Potential climate change impact*** is any impact that may occur given projections of changing climate conditions, without any consideration of the system's adaptive capacity. It is a product of exposure and sensitivity.

Incorporating Climate Change Sensitivity and Exposure Information

To evaluate climate change impacts at the study area and intake or well scale, Worksheet C automatically brings in attributes from Worksheets B1 and B2. More than one attribute from Worksheets B1 and B2 may be combined in Worksheet C into one single attribute that is representative of a potential climate impact scenario (e.g., potential for runoff). For example, the area attribute named "potential for water quality degradation from sewage" in Worksheet C, accounts for all of the attributes used to characterize the wastewater system collected in Worksheet B1 (e.g., number of wastewater treatment plants, treatment level of plants, etc.). The maximum sensitivity score across these representative attributes would then be used for the calculation of the impact score for the single attribute in Worksheet C. By taking the maximum score of the combined attributes, the assessment takes a conservative approach in estimating potential climate change impacts. See **Appendix D** for information about which attributes from Worksheets B1 and B2 are combined in Worksheet C. Each attribute carries a specific weight as listed in **Appendix E**.

Further, the exposure scores determined for climate parameters are automatically carried forward from Worksheet A into Worksheet C, based on their relevance to each attribute for the study area and intake or well. For example, for the area attribute in Worksheet C titled, "Land Use - Percent Built-up area", the most relevant climate parameter has been identified to be heavy precipitation. The exposure score used is the maximum across all seasons. For example, if the exposure score for precipitation is highest in the spring, the assessment tool will multiply the spring exposure score by the sensitivity score. Thus, the assessment takes a conservative approach in estimating potential climate change impacts.

Initial Climate Change Impacts Scores and Adjustments

Initial scores for climate change impacts are automatically calculated in this worksheet by multiplying scores from Worksheets A and B, as seen in **Table 8**.

Table 8: Initial Climate Change Impact Score Calculations

Sensitivity Rating (Worksheet B)	**Exposure Rating (Worksheet A)**		
	Low (1)	***Medium (2)***	***High (3)***
Low (1)	Low (1)	Low (2)	Medium (3)
Medium (2)	Low (2)	Medium (4)	High (6)
High (3)	Medium (3)	High (6)	High (9)

Impacts with scores of 1-2 will have a "low" qualitative rating for climate change impact; scores of 3-4 will receive a "medium" rating; and scores of 6-9 will receive a "high" rating.

The user is then asked to review these initial climate change impact scores, and if necessary, adjust them based on their professional judgement and local knowledge. If an adjustment is made, a strong rationale must be provided. An example is described here from one of the pilot studies: in Worksheet B1 the user records that there are more than two sewage treatment plants in the study area, thus increasing climate change sensitivity. This combined with a high climate exposure rating for precipitation and a high attribute weight may result in a high initial climate change impact score. However, the two sewage treatment plants are located downstream of the intake in a fast-flowing river, and the user decides to make an adjustment for the corresponding climate change score - with the effect of lowering it. It is also prudent to consider any other climate parameters that may impact the drinking water system source water quality (e.g., evaporation, high wind speeds), and adjust the climate change impact scores accordingly. See **Table 9**.

This worksheet does not require any additional data input from the user; rather it requires the user to review and validate the calculated scores. Ultimately, a qualitative climate change impact rating of "low", "medium" or "high" is assigned, based on a scale of 1 to 9.

Table 9: An Example of a User's Review of Climate Change Impact Scores

Attribute	**Time Period**	**Climate Change Exposure Rating**		**System Sensitivity Rating**		**Initial Impact Score**	**Adjusted Impact Score**	**Rationale for Score Adjustment**	**How could climate change impact this intake?**	**Most Relevant Climate Condition(s)**
Potential for increased contaminant loadings due to size of the area	**Annual**	**1**	**Low**	**3**		**3**			Climate change could increase the transport of contaminants or cause more dilution. Loadings are influenced by the size of the source protection area	Precipitation Rainfall Snowfall
Potential for increased runoff due to percent of built-up area	**Annual**	**3**		**2**	**Mod-erate**	**6**			Larger built-up area could mean increased loading of contaminants to waterbodies due to increased runoff	Heavy Precipitation
	Fall	**2**								
	Winter	**1**								
	Spring	**3**								
	Summer	**3**								

Final Climate Change Impact Score and Rating

Worksheet C contains two tables: one for the area-level indicators, and one for the system indicators. Each attribute in these two tables has a climate change impact score, however, all of these scores need to be agglomerated into one score for the entire system and its area. The following equation shows how all the climate change impact scores in both tables are combined to give one single score:

$$Final\ Climate\ Change\ Impact =$$

$$\frac{\left(\overset{\textbf{Area Attributes}}{\frac{\sum_{i=1}^{M}(a_1w_1 + a_2w_2 + a_3w_3 + \cdots + a_mw_m)}{Sum\ of\ w_{1\ to\ M}}}\right) + \left(2 \times \overset{\textbf{Drinking Water System Attributes}}{\frac{\sum_{i=1}^{N}(b_1v_1 + b_2v_2 + b_3v_3 + \cdots + b_nv_n)}{Sum\ of\ v_{1\ to\ N}}}\right)}{\mathbf{3}}$$

Where: *a* is the adjusted climate change impact score of a specific attribute within the study area

b is the adjusted climate change impact score of a specific attribute within the drinking water system

M is the total number of attributes for the study area

N is the total number of attributes for the drinking water system

$W_{1\ to\ M}$ is the weight of the attribute associated with the study area

$V_{1\ to\ N}$ is the weight of the attribute associated with the drinking water system

This formula weighs attributes that are directly relevant to the drinking water system source water as twice the value of the attributes associated with the broader study area. This is because the attributes evaluated at the area scale encompass a broader area that may not have direct impacts to water quality, and so these attributes carry less weight than the system-level attributes, as described in section 2 of this guidance.

The adjusted impact scores of each attribute are multiplied by their corresponding weights (shown in **Appendix E**) (i.e. "a_1w_1, a_2w_2, a_3w_3,…, a_mw_m" and "b_1v_1, b_2v_2, b_3v_3,…, b_mv_m).

The sum of these adjusted scores is divided by the sum of the weights for both tables (area attributes and intake or well attributes). Then, the value for the intake or well attributes is multiplied by 2, to account for the higher weight given to intake or well attributes (as shown in the equation above). This score is then added to the area attribute score, and is divided by 3, to make the score out of 9.

The automatically calculated final climate change impact score is shown at the bottom of this worksheet with the score as a percentage value and will indicate if the source water being evaluated has a "high", "medium", or "low" climate change impact rating, as it relates to water quality. For percentages of 67% and higher, a "high" impact rating will be given, and for percentages below 33% will be given a "low" impact rating.

If the final climate change impact rating is "low", the user may choose to not pursue the rest of the assessment at that time. The user may then proceed directly to Worksheet F for a summary of their inputs. A low rating suggests that the quality of the drinking water source will be minimally affected by climate change, and existing source protection plan policies are likely sufficient to protect it. The user may revisit the assessment for reasons including the review of updated information indicating that climate change impacts are worsening, or more reliable data becomes available.

Determining the Uncertainty of the Analysis

To determine the uncertainty level of "low" or "high" for Worksheet C, the user is asked to consider the following:

- The quality assurance and quality control procedures applied
- The accuracy to which the climate change impact rating effectively represents the impact on the drinking water system.

Quality assurance and quality control could be related to how the user adjusts (changes) the climate change impact scores. For example, the collective actions of knowledgeable people will likely be more certain than the independent actions of one. It is also suggested that the user evaluate the uncertainty of the overall climate change impact score and determine if this is an accurate representation of the climate exposure and sensitivities.

3.4 Worksheet D: Determining Climate Change Adaptive Capacity and Climate Change Vulnerability

Purpose

The purpose of this worksheet is to determine the **adaptive capacity** of the study area and intake or well, and also to determine the **overall climate change vulnerability rating** for the drinking water source.

Determining Adaptive Capacity

Adaptive capacity can be defined as: the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences (IPCC, 2007). Specific factors that influence adaptive capacity include:

- **Human influences:** Ability exists to intervene and implement solutions and fixes to improve resilience.
- **Physical Changes:** new or modifications to existing infrastructure that could reduce the potential impacts of climate change (e.g., a seawall/revetment to reduce wave erosion).
- **Socio-Political System:** Adaptive capacity of the planning and policy context in which an intake/well is situated within (e.g., to provide opportunities for changes in regulation).

In the assessment tool, the analysis of adaptive capacity is based on information about the study area and intake or well (from Worksheet B), as well as additional input provided by the user to consider factors including:

- financial constraints to addressing climate change impacts
- presence or absence of a backup supply of drinking water
- existing policies and/or management procedures in place to address climate change impacts on water quality
- infrastructure that helps reduce climate change impacts
- capacity for property owners to prevent, protect against, mitigate, respond to, and recover from flooding.

Based on this information, an adaptive capacity rating is calculated, which uses an equation similar to the climate change impact equation.

This formula weighs attributes that are directly relevant to the drinking water system source water as twice the value of the attributes associated with the broader study area. This is because the attributes evaluated at the area scale encompass a broader area that may not have direct impacts to water quality, and so these attributes carry less weight than the system-level attributes.

$$\boldsymbol{Adaptive\ Capacity} =$$

$$\frac{\left(\dfrac{\overset{\textbf{Area Attributes}}{\sum_{i=1}^{M}(a_1 + a_2 + a_3 + \cdots + a_m)}}{M}\right) + \left(\mathbf{2} \times \dfrac{\overset{\textbf{Drinking Water System Attributes}}{\sum_{i=1}^{N}(b_1 + b_2 + b_3 + \cdots + b_n)}}{N}\right)}{\mathbf{3}}$$

Where: *a* is the score of a specific attribute within the area

b is the score of a specific attribute for the drinking water system

M is the total number of attributes for the area

N is the total number of attributes for the drinking water system.

The final adaptive capacity score will be given as a score out of 3 and will also be demonstrated as a percentage with the associated rating of “high”, “medium”, or “low” adaptive capacity. For a percentage of 67% or higher, a “high” adaptive capacity rating is given; and for below 33%, a “low” rating is given. It should be noted that the higher the adaptive capacity, the greater the ability the drinking water system has to adjust to impacts from climate change.

Determining Climate Change Vulnerability

The term “climate change vulnerability” refers to the propensity or predisposition to be adversely affected by climatic or non-climatic stressor(s) or a combination of both (IPCC, 2012). In the context of the assessment tool, climate change vulnerability of source water refers to any drinking water source that will likely be adversely affected by local climate change impacts now and in the future.

The assessment tool determines an overall climate change vulnerability score based on the overall climate change impact and adaptive capacity scores from Worksheet C and D. The climate change vulnerability score for the intake or well is calculated using the following equation (IPCC, 2014):

$$\boldsymbol{Climate\ Change\ Vulnerability} = \frac{Potential\ Climate\ Change\ Impact\ Score}{Adaptive\ Capacity\ Score}$$

Based on a scale of 1 to 9, a percentage is calculated which in turn results in a qualitative rating for overall climate change vulnerability as “low”, “medium” or “high”. For a percentage of 67% or higher, a “high” adaptive capacity rating is given; and for below 33%, a “low” rating is given.

Generally, a “high” vulnerability rating indicates that source water quality can be expected to be adversely affected by climate change. Some impacts could potentially be irreversible, which is a determination that the user may carry out separately. Adaptation and mitigation measures are important. A “medium” vulnerability rating indicates that source water quality could be moderately affected by climate change. Suitable adaptation and mitigation measures can be determined and applied, or planned for. With a "low" vulnerability rating, minimal impacts on source water quality can be expected due to climate change. Suitable adaptation and mitigation options can be explored for planning purposes.

The climate change vulnerability assessment tool does not assign a "no/zero climate change vulnerability" rating, because it is not possible to conclude with absolute certainty that the area will not be exposed to changing climate conditions in the future. There are uncertainties and limitations with modeled climate projections. Given the impacts that have already been felt across Ontario, it is anticipated that all areas will be exposed to some level of changing climate conditions (e.g., increasing temperature) and can be impacted by climate change to some degree either directly (through climate exposure) or indirectly (Glick et al., 2011).

Determining the Uncertainty in Analysis

To determine the uncertainty level of "low" or "high" for adaptive capacity, the user is asked to consider the following:

- The quality assurance and quality control procedures applied
- The accuracy to which the climate change adaptive capacity rating effectively represents the adaptive capacity of the drinking water system

Quality assurance and quality control could be related to the way the user responds to the yes/no questions presented in the adaptive capacity analysis. It is also suggested that the user evaluate the uncertainty of the overall climate change adaptive capacity score and determine if this is an accurate representation of the system's adaptive capacity.

3.5 Worksheet E: Incorporating Climate Change Vulnerability of the Intake or Well into Existing Source Water Quality Risk Approach

Purpose and Overview

The purpose of this worksheet is to characterize existing or future threat activities into "groups" based on the overall climate change vulnerability rating. This grouping in turn helps users consider whether additional measures are needed to address climate change impacts.

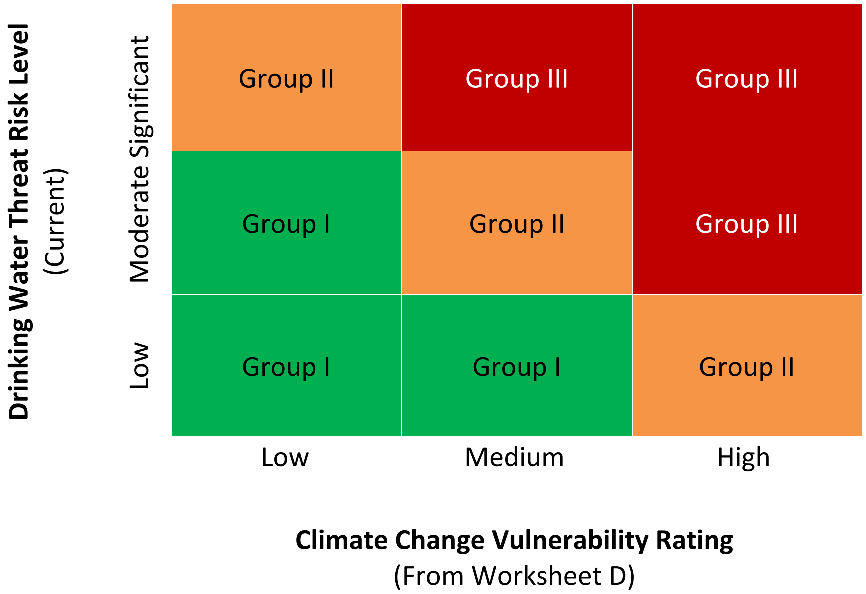
Source Water Quality Risk Assessment Inputs

The prescribed or locally specific threats to drinking water sources are identified in approved source protection plans under the *Clean Water Act*. Each identified threat activity is assigned a risk level of low, moderate, or significant based on a comprehensive risk assessment also under the *Clean Water Act* process, as described in detail in **Appendix A**.

In Worksheet E, all twenty of the prescribed threat activities that could pose risks to the quality of source waters are listed. The user is asked to identify "existing" or "future" threats that apply to the drinking water system. The worksheet also provides extra rows for the user to add any local threat activities specific to the intake or well. The user is then asked to identify the existing highest risk level within the intake protection zone or wellhead protection area for each of the identified activities. See the example provided in **Table 10**. All of the required information is available in the approved source protection plans.

Characterizing Threat Activities with Climate Change Vulnerability

The assessment tool characterizes threat activity risk levels with the climate change vulnerability rating, as shown in the logic matrix of **Figure 5**. As can be seen, the risks posed by threat activities could be exacerbated by climate change.



Drinking Water Threat Risk Level (Current)

Significant	Group II	Group III	Group III
Moderate	Group I	Group II	Group III
Low	Group I	Group I	Group II
	Low	Medium	High

Climate Change Vulnerability Rating
(From Worksheet D)

Figure 5: Characterization Matrix for Threat Risk Level and Climate Change Vulnerability Rating

The **Table 10** also shows how the user inputs are combined with the auto populated climate change vulnerability rating and the matrix results. Then the user is asked if there are policies in place to address the threat activities. As well, the user has the ability to discuss and flag if additional measures are potentially needed to address each threat activity based on local knowledge (e.g., policies or actions already in place).

Table 10: Example of Characterizing Threat Activities with Climate Change Vulnerability

	User Input	*User Input*	*Auto-populated from Worksheet D*	*Auto-populated based on Matrix*	*User Input*	*User Input*
Prescribed/ Local Threat Activity	**Existing or Future Threat**	**Existing Highest Threat Risk Level in Intake Protection Zone**	**Climate Change Vulnerability Rating**	**Character-ization (Group)**	**Local Knowledge** *(Optional), e.g., policies or actions already in place*	**Are Additional Measures Potentially Needed to Address Threat?**
The establishment, operation or maintenance of a waste disposal site within the meaning of Part V of the Environmental Protection Act						
1a. Storage, Treatment And Discharge Of Tailings From Mines	Existing	Moderate	*Medium*	**Group II**	Discuss planning	Yes
1b. Waste Disposal Site: Landfarming Of Petroleum Refining Waste	Both Existing and Future	Significant	*Medium*	**Group III**	Company recently completed a climate change plan	No

The matrix shown in **Figure 5** combines the overall climate change vulnerability score (low, medium, or high) with drinking water threat risk levels (low, moderate, significant) for any prescribed or locally-specific threat and identifies characterized groups for the user to consider moving forward. The groups are described below.

1. **Group I**: No additional measures are needed to address climate change impacts at this time. Consider creating a plan or strategy to track changes over time and incorporate new climate information into the climate change vulnerability assessments as this information becomes available.
2. **Group II**: Determine if additional measures are needed to address climate change impacts. Institute a plan or strategy to track changes over time and incorporate new climate information as it becomes available.
3. **Group III**: Consider the development and implementation of appropriate measures to address climate change impacts. For example, consider adopting changes to current policies or updating measures. Institute a plan or strategy to track the success of measures implemented over time.

As an additional resource, users can navigate to **Appendix F** for more information on how climate change can impact each of the prescribed threats. It is ultimately up to the user to decide whether additional measures will be required to address threats based on local conditions and professional judgement, and what these measures will be. If the user determines that additional measures are required, it will be important to consider how the information from this assessment may influence consultation and decisions. Worksheet E helps to set the stage for these discussions by bringing together the summary of climate change exposure (from Worksheet A), the sensitivity, adaptive capacity, and climate change vulnerability (from Worksheets B and C) as well as the risks posed by identified drinking water quality threat activities.

3.6 Worksheet F: Summary of Climate Change Vulnerability Assessment

The purpose of this worksheet is to provide a high-level summary of the assessment tool results that can then be used for reporting purposes. Notes on uncertainty and additional considerations have been included to help users interpret and share the assessment results with source protection authorities (SPAs), source protection committees (SPCs), municipalities, and other stakeholders.

The summary begins with the results from the exposure analysis (Worksheet A) to present the qualitative exposure ratings and descriptions of exposure. In addition, there is space in this worksheet for users to copy and paste their climate trend graphs from Worksheet A.

As a summary for climate change sensitivity, the assessment tool shows the total percent of “high” sensitivity scores for the area-level and intake or well attributes and lists the specific attributes leading to a higher sensitivity score. This can help users identify patterns of the type of highly sensitive attributes for their drinking water system source quality.

For the climate change impact summary, this worksheet presents the final impact score as well as its qualitative rating (high, medium, low), and the number of changes the user made to the impact scores. The summary then lists all area and intake or well attributes with “high” climate change impact scores.

The summary presents the assigned adaptive capacity score from Worksheet D, along with the qualitative adaptive capacity rating (low, medium or high). The summary also shows the area and intake or well attributes with low adaptive capacity scores. Similarly, the summary provides the overall climate change vulnerability score, and its qualitative rating.

Finally, the summary highlights the total number of threat activities that pose “moderate” risks to drinking water sources and are assigned to Group III when characterized by the climate change vulnerability rating. This indicates that measures should be considered or updated to help address climate change impacts. The summary also provides the number of threat activities that the user identified as needing measures and lists these threats. Overall, it is recommended the user consider Worksheet F similar to a ‘dashboard’ of information that can summarize key outputs for reports, presentations and for reference in future analysis.

3.7 General Recommendations

The following considerations are recommended for all users of the assessment tool, regardless of the level of climate change vulnerability or exposure identified for the drinking water system source quality, or for the study area:

a) Consider the role and value of monitoring in building resilience to climate change. Monitoring could refer to station-based monitoring of changes in climate conditions and/or changes in indicators and how they respond to changing conditions. Improving our understanding of the health or state of the watershed can enable more proactive actions to be undertaken that are based on evidence rather than high-level assumptions;

b) Leverage all information used in the climate change vulnerability assessment, as well as the outputs, within source protection plans. Begin and continue discussions among local stakeholders on building climate resilience. Through consistent use of the assessment tool, practitioners across the province can demonstrate their knowledge and the importance of ensuring that source water quality is resilient to the effects of climate change;

c) If completing other climate change assessments, consider leveraging and/or building on information from the assessment tool. For example, certain elements of the assessment such as the exposure analysis and several sensitivity attributes may help inform watershed planning, and support integrated watershed management. As well, the Ministry's update to the Drinking Water Quality Management Standard (MECP, 2016c) provides an excellent and important opportunity to produce convergent findings, collective action across the province and establishes policies and actions that build resilience on both the source protection and infrastructure side of the equation for improving water quality; and

d) Collaborate with municipal, source protection authority, and other partners, to build and strengthen local networks, to scope measures to reduce the climate change vulnerability of source water quality, based on the results of this assessment tool; and to implement measures to protect drinking water sources and improve resiliency of the watersheds (e.g., consider creating or protecting wetlands to decrease the amount of runoff flowing into drinking water sources).

4. Pilot Studies

Pilot studies were conducted using real data and information, led by Conservation Ontario in collaboration with participating municipalities and conservation authorities. The four pilot studies are listed below, along with the associated collaborations.

1. Halton Region's Burlington water intakes: Conservation Halton, Hamilton Conservation Authority, Regional Municipality of Halton Region, Conservation Ontario.
2. Seaforth Well Supply System: University of Guelph, Ausable Bayfield Conservation Authority, Maitland Valley Conservation Authority, Municipality of Huron East, Conservation Ontario.
3. City of Timmins River Intake: Mattagami Region Conservation Authority, City of Timmins, Conservation Ontario.
4. Town of Carleton Place River Intake: Mississippi Valley Conservation Authority, Rideau Valley Conservation Authority, Town of Carleton Place, Conservation Ontario.

The pilot studies cover a wide range of watershed characteristics, land uses, current population, projected growth and development and other attributes. The predominant land uses vary from urban to rural-agricultural, while different source water types include a Great Lake, inland rivers, and a groundwater aquifer. Real climate data were used in these pilot studies that span significantly different geographical/geological regions of Ontario and illustrate the diversity of climate conditions observed across Ontario.

Brief summaries of three of the pilot studies are provided. It became clear during the pilot studies that local knowledge is important to ensure that appropriate inputs are used. It is also equally important that various subject matter experts are relied on, for the same reason. It was found that the multi-disciplinary nature of the process is key to ensuring meaningful inputs and therefore outputs. The local municipal-conservation authority partnerships are a cornerstone of the assessment process.

IMPORTANT: These pilot studies were conducted for research purposes only and are not to be considered as a final assessment or report. The data, information and outputs shown are not final nor are they endorsed by any municipality, conservation authority, or other organization or agency. These pilot studies place no obligations on any organization or agency. They provide an idea for the general user about inputs needed and types of outputs produced.

4.1 Pilot Study: Burlington Drinking Water Intakes in Lake Ontario

The Burlington Water Treatment Plant is owned and operated by the Regional Municipality of Halton. This plant is located in the City of Burlington, within the Halton Region source protection area of the Halton-Hamilton source protection region (SPR). The raw water source of the plant's two intakes is Lake Ontario. Land use within the intake protection zone is urban. The treated drinking water is pumped into the South Halton Distribution System, which serves Burlington, Oakville and areas of Milton and Halton Hills.

The scale of the study area was chosen to be the source protection area, which corresponds to the Halton watershed area of over 1,000 square kilometers. The study area is characterized by its high growth and development typical of the Greater Golden Horseshoe, and at the same time influenced by the GreenBelt and Niagara Escarpment areas.

For the climate change exposure analysis in **Worksheet A**, the climate change scenario - Representative Concentration Pathway (RCP) 8.5 was chosen. Climate stations were researched by the source protection authority staff, and a suitable location determined as described here.

Precipitation depth data from Environment and Climate Change Canada (ECCC) and Climate Atlas of Canada was reviewed and compared. It is found that the Ensemble model data downloaded from Climate Atlas of Canada underestimates historical precipitation depths by 75 to 100 mm for individual stations closest to the intakes and also for the regional estimate, compared to the actual, observed historical data from ECCC. The Climate Atlas of Canada predicts future values to increase to approximately the current values measured. These facts were taken into consideration during the uncertainty analysis.

ECCC does not provide future estimated data, while Climate Atlas of Canada does. To establish a trend from historical to future, the Climate Atlas of Canada was selected as the data source for both historical and future data. The Hamilton station was selected because it most closely matched the actual measured data, albeit at lower values.

Available historical data and future projections were downloaded from various data portal sources, and trend information was extracted from published literature as follows:

- Data for six (6) of the 10 climate parameters, i.e., Minimum Temperature, Maximum Temperature, Precipitation, Very Hot Days, Frost Free Season, and Freeze Thaw Cycle, were obtained from the Climate Atlas of Canada, for the Hamilton station. The Ensemble modeled historical and future data were available for the years 1950 to 2099.
- Heavy Precipitation data was obtained from Climatedata.ca, for the Hamilton station. The Ensemble modeled historical and future data were available for the years 1950 to 2099.
- Maximum Length of Dry Spell data were obtained from the Ontario Climate Data Portal, for the Hamilton Wentworth region. The Ensemble modeled historical and future data were available for the years 1981 to 2099.
- To determine snowfall and rainfall trends, the precipitation trend information (not data) for future summer, spring and winter for the Mixwood Plains climate zone was obtained from: High resolution interpolation of climate scenarios for Canada derived from general circulation model simulations (Price et al., 2011)

Instructions in the assessment tool were followed to carry out the climate data trend analysis for climate normals for historical and future periods. The climate data for the period of 1970 to 2013 were used for the historical climate normal; while data for 2014 to 2050 were considered for the future climate normal. See the climate data trend template for the analysis for confirming a trend (i.e., increasing or decreasing), or no trend at all (i.e. no change). The outputs of Worksheet A of the assessment tool showed that the source protection area has a high exposure to climate change across the seasonal and annual periods. The level of uncertainty of the exposure assessment was found to be high, mainly due to the use of modeled data.

In **Worksheet B**, user inputs were provided to characterize the climate change sensitivity at both the study area and intake scales with two corresponding sets of attributes. A majority of assessed area-level attributes and around half of the intake-level attributes were found to be highly sensitive to climate change. The level of uncertainty of the sensitivity evaluation was found to be low, mainly due to the confidence in the definitive information and data inputs.

In **Worksheet C**, the conservation authority and municipal staff reviewed the initial impact scores (for the study area and the intake) and decided that further adjustments to the scores were not necessary. The final climate change impact rating calculated by the assessment tool was a “medium”. The level of uncertainty was found to be high, mainly due to the incorporation of the exposure assessment result which was based on modeled data.

In **Worksheet D**, some of the necessary inputs to determine adaptive capacity were auto populated based on inputs made in Worksheet B, and the remaining inputs were provided by municipal staff. The adaptive capacity was determined to be “medium”. The level of uncertainty was found to be low, mainly due to the confidence in the definitive information and data inputs. Also on Worksheet D, the overall climate change vulnerability score and rating are calculated by the assessment tool. They are 3.4 (out of 9) and a “medium” rating. These results are used in the next assessment step.

In **Worksheet E**, the conservation authority staff provided inputs on threat activities from the approved source protection plans. Combined with the climate change vulnerability rating of “medium”, one threat activity (the handling and storage of road salt) was placed in “Group II’; while two threat activities (sewage treatment plant bypass and the handling and storage of fuel) were found to be placed in “Group III”. These placements are meant to help the source protection authority, source protection committee, and municipalities determine the next steps forward in the decision-making process. For Group II, next steps include determining if additional measures are needed to address climate change impacts. A plan or strategy could be put in place, to track changes over time and incorporate new climate information as it becomes available. For Group III, it is recommended to consider developing and implementing appropriate measures to address climate change impacts. For example, consider adopting changes to current policies or updating measures. Institute a plan or strategy to track the success of measures implemented over time.

The participants did not enter any further information at the time of the pilot study.

4.2 Pilot Study: Seaforth Groundwater Well Supply

The Seaforth Well Supply drinking water system is owned by the Municipality of Huron East and is within the Maitland Valley source protection area (SPA) of the Ausable Bayfield-Maitland Valley source protection region (SPR). Land use within the wellhead protection area is predominantly agriculture. The system supplies water to the Town of Seaforth and the Village of Egmondville.

There are three municipal wells in the Seaforth well system, serving a total population of 2,900 people. The average well use is 1,260 m^3/day, and design capacity is 3456 m^3/day. An elevated storage tank and the underground reservoir are used as a supplementary supply for emergencies. The 1930 m^3 elevated storage tank water level cycles, based on demand, and provides emergency storage, fire protection and peak demand storage for the Seaforth water supply system (Seaforth Well Supply System 2018 Annual Report. Jacobs. Feb. 2019, available at: http://www.huroneast.com/index.php?sltb=reports).

The scale of the study area was chosen to be the source protection area, which corresponds to the Maitland Valley watershed area of 3, 266 square kilometers. The watershed is a fertile agricultural area, high in livestock concentration and limited natural areas.

For the climate change exposure analysis in **Worksheet A**, the climate change scenario - Representative Concentration Pathway (RCP) 8.5 was chosen. Climate stations selection, trend graphs, statistical analysis and resulting input were done by the University of Guelph, for historical data (around 1960-2008) and future projections (around 2020-2050). The choice of climate station was discussed and decided upon with source protection authority staff.

- Historical data was obtained from the Blyth weather station (Climate ID: 6120819) from Environment Canada.
- Future data was obtained as described below:
    - The Kitchener grid box of the Climate Atlas of Canada was used for all future parameters, except for Maximum Length of Dry Spell.
    - Future Maximum Length of Dry Spell data was obtained for the Huron grid box from the Ontario Climate Data Portal.
    - Rainfall/Snowfall trend information was obtained from: State of Climate Change Science in the Great Lakes Basin: A Focus on Climatological, Hydrological and Ecological Effects. pp. 29-30. McDermid et al. 2015. Accessible at: https://climateconnections.ca/app/uploads/2014/07/OCC_GreatLakes_Report_Full_Final.pdf

See the related template for climate data trends, for confirming a trend (i.e., increasing or decreasing), or no trend at all (i.e. no change). The outputs of Worksheet A of the assessment tool showed that the source protection area has a high exposure to climate change across the seasonal and annual periods. The level of uncertainty of the exposure assessment was assigned a “high” level by the user, mainly due to the use of modeled data.

Based on the user inputs to **Worksheet B**, approximately half of the assessed area-level attributes and half of the well-level attributes were found to be highly sensitive to climate change. The level of uncertainty of the sensitivity evaluation was found to be low, mainly due to the confidence in the definitive information and data inputs.

In **Worksheet C**, the conservation authority and municipal staff reviewed the initial impact scores (for the study area and the well) and decided that further adjustments to the scores were not necessary. The final climate change impact rating calculated by the assessment tool was a “medium” (with a score 5.7 out of 9). The level of uncertainty was assigned a “high” level, mainly due to the incorporation of the exposure assessment result which was based on modeled data.

In **Worksheet D**, based on user inputs the adaptive capacity was determined to be “medium”, and overall climate change vulnerability assessed to be “medium” with a score of 3.8 out of 9.

In **Worksheet E**, the conservation authority staff provided inputs on threat activities from the approved source protection plans. Combined with the climate change vulnerability rating of “medium”, threat activities of low, moderate and significant risk levels were placed in “Group I”, “Group II’, and “Group III” respectively. These groupings are meant to help the source protection authority, source protection committee, and municipalities to determine the next steps forward in the decision-making process, based on the Group placements.

4.3 Pilot Study: Mattagami River Drinking Water Intake

The City of Timmins is the owner and operator of the only municipal drinking water system in the Mattagami Region Source Protection Area. Water intake is from the Mattagami River, and the water treatment plant has a capacity to treat 54,500 cubic meters per day (www.timmins.ca/our_services/water_and_sewer/water_filtration). The plant serves a population of approximately 38,000.

The scale of the study area was chosen to be the Mattagami Region source protection area, which is over 11,000 square kilometers in size. The area around the intake within the City of Timmins provides a wide variety of institutional, commercial and industrial services, besides being comprised of urban residential areas. There are no large industrial users of the Mattagami River upstream of the Timmins water intake.

For the climate change exposure analysis in **Worksheet A**, the climate change scenario - Representative Concentration Pathway (RCP) 8.5 was chosen. Climate stations selection, trend graphs, statistical analysis and resulting input were done by Conservation Ontario, for historical data (around 1970-2013) and future projections (around 2014-2050). The choice of climate station and regions were discussed and decided upon with municipal and source protection authority staff.

Available historical data and future projections were downloaded from various data portal sources, and trend information was extracted from published literature as follows:

- Data for six (6) of the 10 climate parameters, i.e., Minimum Temperature, Maximum Temperature, Precipitation, Very Hot Days, Frost FreeSeason, and Freeze Thaw Cycle, were obtained from the Climate Atlas of Canada, for the City of Timmins station. The Ensemble modeled historical and future data were available for the years 1950 to 2095.
- Heavy Precipitation data was obtained from Climatedata.ca, for the City of Timmins station. The Ensemble modeled historical and future data were available for the years 1950 to 2099.
- Maximum Length of Dry Spell data were obtained from the Ontario Climate Data Portal, for the Cochrane region. The Ensemble modeled historical and future data were available for the years 1981 to 2099.
- To determine snowfall and rainfall trends, the precipitation trend information (not data) for future summer, spring and winter were obtained from: High resolution interpolation of climate scenarios for Canada derived from general circulation model simulations (Price et al., 2011).

See the related template for climate data trend template, for confirming a trend (i.e., increasing or decreasing), or no trend at all (i.e. no change). The outputs of Worksheet A of the assessment tool showed that the source protection area has a high exposure to climate change across the seasonal and annual periods. The level of uncertainty of the exposure assessment was assigned a “high” level by the user, mainly due to the use of modeled data.

Based on the user inputs to **Worksheet B**, approximately half of the assessed area-level attributes and half of the intake-level attributes were found to be highly sensitive to climate change. The level of uncertainty of the sensitivity evaluation was found to be low, mainly due to the confidence in the definitive information and data inputs.

In **Worksheet C**, the conservation authority and municipal staff reviewed the initial impact scores (for the study area and the intake) and decided to make an adjustment to the intake-scale impact scores for two attributes. This is because the intake is located in the fast-flowing Mattagami River, not impacted by downwelling or degraded nearshore conditions, and it is situated upstream of wastewater plants’ treated discharges. The final climate change impact rating calculated by the assessment tool was a “medium” (with a score 6 out of 9).

In **Worksheet D**, based on user inputs the adaptive capacity was determined to be “high” due to factors including the presence of a protective, permanent boom. The overall climate change vulnerability was assessed to be “low”, with a score of 2.9 out of 9.

In **Worksheet E**, the conservation authority staff provided inputs on threat activities from the approved source protection plan. The climate change vulnerability rating of “low” were combined with threat activities all of significant risk level, resulting in a placement of “Group II” for all threat activities. These groupings are meant to help the source protection authority, source protection committee, and municipalities to determine the next steps forward in the decision-making process, based on the Group placements.

4.4 Pilot Study: Carleton Place Drinking Water Intake

Background

The Town of Carleton Place is the owner and operator of one of the 12 municipal drinking water systems in the Mississippi-Rideau Source Protection Region. Water intake is from the Mississippi River, and the water treatment plant has a capacity to treat 12,000 cubic metres of water per day (Water and Sewer (carletonplace.ca). Part of the system includes a 3,180 cubic metres elevated water storage tower, with a provision for chlorine boosting with sodium hypochlorite in the summer months to maintain adequate chlorine residual in the distribution system. The plant serves more than 10,000 residents with potable water.

Characterization of Study Area

The scale of the study area was chosen to be the Mississippi Valley Source Protection Area, which is over 3,765 square kilometers in size. The land use around the intake, within the Town of Carleton Place, is a mixture of residential, commercial, industrial and other land uses. Heavy industrial land use is generally not permitted within the rural hamlets and villages of Carleton Place and vicinity. The majority of land use upstream of the Mississippi River is agricultural.

Results

For the climate change exposure analysis in **Worksheet A**, the climate change scenario - Representative Concentration Pathway (RCP) 8.5 was chosen. Climate stations selection, trend graphs, statistical analysis and resulting input were completed by Conservation Ontario, for historical data (around 1970-2013) and future projections (around 2014-2050), with some exceptions due to the availability of data. The choice of climate station and regions were discussed and decided upon with municipal and source protection authority staff.

Available historical data and future projections were downloaded from various data portal sources, and trend information was extracted from published literature as follows:

- Data for six (6) of the 10 climate parameters, i.e., Minimum Temperature, Maximum Temperature, Precipitation, Very Hot Days, Frost Free Season, and Freeze Thaw Cycle, were obtained from the Climate Atlas of Canada, for the Town of Carleton Place station. The Ensemble modeled historical and future data were available for the years 1950 to 2095.
- Heavy Precipitation data was obtained from Climatedata.ca, for the Town of Carleton Place station. The Ensemble modeled historical and future data were available for the years 1950 to 2100.
- Maximum Length of Dry Spell data were obtained from the Ontario Climate Data Portal, for the Carleton/Ottawa region. The Ensemble modeled historical and future data were available for the years 1981 to 2099.
- To determine snowfall and rainfall trends, the precipitation trend information (not data) for future spring, summer, fall and winter were obtained from: High resolution interpolation of climate scenarios for Canada derived from general circulation model simulations (Price et al., 2011, Table 14, pg. 98).

See the related excel based assessment template (**Worksheet A**) for steps taken to determine/confirm a trend (i.e., increasing or decreasing), or no trend at all (i.e. no change) in the climate data. All climate data used can be found in the companion file, *CCVAT Carleton Place Study Climate Data* Excel workbook.

The outputs of **Worksheet A** of the assessment tool showed that the source protection area has a high exposure to climate change across the seasonal and annual periods. The level of uncertainty of the exposure assessment was assigned a "high" level of uncertainty (e.g., lower confidence) by the user, mainly due to the use of modeled and scaled data (e.g. not original datasets).

Based on the user inputs to **Worksheet B**, very few (2 in total) of the assessed area-level attributes and 3 of the intake-level attributes were found to be highly sensitive to climate change. The level of uncertainty of the sensitivity evaluation was found to be high due to the confidence level in the available information, data scaling (regional to local) and data inputs.

In **Worksheet C**, conservation authority and municipal staff reviewed the initial impact scores (for the study area and the intake). Source Water Protection staff also had internal discussion about the potential influence that the low water status ratings may have on attribute #7, specifically (Potential for water quality degradation due to water quantity risks (e.g., Tier 3 assessment). It was decided that the "low" intake sensitivity rating was appropriate. The rationale for not adjusting attribute #7 is that the municipal drinking water system has been resilient when low water statuses occurred, and impacts were rarely felt. The Carleton Place drinking water system takes only a small percentage of the overall river flow. If increases in low water response conditions occur more frequently, then there may be an opportunity to review the water budgets and have a more robust discussion with the Source Protection Committee. Furthermore, the climate parameter (H) Dry Spell data analysis results showed that there was no trend in the historical or future data models.

A suggestion from conservation authority staff was to include a specific question about low water response within the Climate Change Vulnerability Assessment Tool, such as ***"Has the watershed/Region/Area ever been issued a low water status and the drinking water system been impacted quality or quantity wise"?***

The climate change impact rating for the Carleton Place Mississippi River Intake was a score of 5 out of 9 which resulted in a Qualitative Impact Rating of "**medium**".

Finally, the level of uncertainty was assessed as high due to the confidence level in the available information.

In **Worksheet D**, based on user inputs, the adaptive capacity was determined to be "high" due to factors including the ability of the water treatment to accommodate decreased raw water quality. The overall climate change vulnerability was assessed to be "low", with a score of 2.0 out of 9.

In **Worksheet E**, conservation authority staff provided input on threat activities from the approved source protection plan. Two significant threats were identified, namely the Application of Road Salt and the Sewage System or Sewage Works- Sanitary Sewers & related pipes.

The "low" climate change vulnerability rating was combined with threat activities, which all were classified as a significant risk level, resulting in placement under "Group II" for all threat activities. The resulting Group II category encourages the user to determine if additional measures are needed to address climate change impacts and institute a plan or strategy to track changes over time and incorporate new climate information as it becomes available. These groupings are meant to help the source protection authority, source protection committee, and municipalities to determine the next steps in the decision-making process.

Recommendations

Further discussion with the municipality is recommended on the potential climate change impacts in relation to the two significant threats were identified (the Application of Road Salt and the Sewage System or Sewage Works- Sanitary Sewers & related pipes) and possible adaptation strategies.

One of the limitations identified while using the CCVAT for the Carleton Place pilot study was the availability of scaled municipal data. The municipal data provided for the area sensitivity was manipulated from a regional scale dataset, this resulted in a high level of uncertainty (or low confidence) in the data. It is recommended that if more localized municipal land use data becomes available the CCVAT is re- run.

Furthermore, as a result of the recent release of the 2021 Amendments to the Director's Technical Rules under section 107 of the Clean Water Act, 2006, the Carleton Place CCVAT Pilot study may need to be updated.
Finally, consideration of building climate change resiliency, in identified areas within the study area would continue to protect existing and future drinking water sources.

Conclusion

The vulnerability rating for the Carleton Place Climate Change Vulnerability Assessment established a **medium rating** for climate change impacts (this included a flooding potential flag). The high Adaptive Capacity rating that exists for the intake, which includes the ability of the water treatment to accommodate decreased raw water quality was a positive contributor to lowering the vulnerability score.

The continued municipal-conservation authority collaboration and partnerships are essential components to the ongoing iterative assessment process and work towards building climate change resiliency for Carleton Place and the Mississippi- Rideau Source Protection Region.

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Appendices

Appendix A: Developing the Assessment Tool

In fall 2017, early discussions were initiated by the Ministry of Environment, Conservation and Parks, involving the Ontario Climate Consortium, and Conservation Ontario. Draft concepts around the project vision, scope, and goals were explored and firmed up.

The development of the assessment tool was then started through a comprehensive, multi-stakeholder process that spanned from early 2018 through spring 2020. This process was managed by the Project Coordinator Conservation Ontario, through the Ontario Drinking Water Source Protection program administered by the Ministry of Environment, Conservation and Parks.

Three groups were created for the development of the first version of the assessment tool:

- **A Project Team** to produce and develop the draft assessment tool. This team consisted of staff from the Ontario Climate Consortium (of the Toronto and Region Conservation Authority), Ministry of Environment, Conservation and Parks, and various Conservation Authorities. The Project Team Manager was from the Ontario Climate Consortium.
- **An Academic Advisory Group** to leverage existing research, support and explain relevant climate change related literature to the Project Team, and advise on the methodology presented. This group included four professors from different post-secondary institutions in Ontario, who are involved in water resources and climate science research.
- **A Steering Committee** to provide legitimacy to and accountability for the project. The Steering Committee provided comprehensive review and strategic direction throughout the development of the assessment tool. This committee was comprised of members from Engineers Canada, Conservation Authorities, Ministry of Environment, Conservation and Parks. The committee was co-chaired by Conservation Ontario and Ministry of Environment, Conservation and Parks.

The first version of the assessment tool including its methodologies was produced following substantive literature review and numerous discussions amongst these three groups, with Ontario Climate Consortium leading the Project Team, and Conservation Ontario providing overall project management. The first version was then presented to numerous practitioners and stakeholders (including source protection authorities, local municipalities, and provincial government staff) across the province, throughout the fall of 2018. This process involved three stakeholder engagement workshops held across Ontario and two webinars, organized by Conservation Ontario. The aim of the workshops was to check if the content and process resonated among stakeholders and is feasible for implementation. Valuable feedback obtained from workshop participants was incorporated into the assessment tool through edits. The main feedback around the priority need to conduct pilot studies to test the assessment tool, was addressed as described below.

Conservation Ontario led multiple pilot studies in 2019-2020 in collaboration with local municipalities and their consultants, Conservation Authorities, and academia. These pilot studies used real information and data from the participants, as well as from plans and reports including the approved source protection plans, to test the tool. The pilot studies were conducted for the:

1. Municipality of Halton Region – Burlington drinking water intakes in Lake Ontario;
2. Municipality of Huron East – Seaforth drinking water well supply;
3. City of Timmins – Mattagami River drinking water Intake; and,
4. Town of Carleton Place – Mississippi River drinking water intake.

It became clear during the pilot studies that local knowledge is important to ensure that appropriate inputs are used. It is also equally important that various subject matter experts are relied on, for the same reason. It was found that the multi-disciplinary nature of the process is key to ensuring meaningful inputs, and therefore outputs. The suggestions and feedback from participants of the pilot studies and further research conducted by Conservation Ontario, led to the revision of the assessment tool into its second version. The Ontario Climate Consortium provided in-kind assistance with edits to the back end of the assessment tool. A valuable review of the revised assessment tool was provided by Conservation Halton and Ministry of Environment, Conservation and Parks staff from the Project Team. Thereafter, Conservation Ontario provided training sessions to stakeholders (including source protection authorities, local municipalities, and provincial government staff) across the province, through January and February 2020. This process involved four training workshops and four webinars. Conservation Ontario also developed and provided new training materials for participants and climate data trend analysis templates. The entire training package includes the assessment tool, support materials and templates, and is available at Conservation Ontario.

The following sub-sections present details on the existing water quality risk assessment approach used under the *Clean Water Act, 2006* framework; climate change vulnerability assessment methods; an indication of how the current approach follows these widely accepted protocols; and lastly an introduction to the source water quality-climate change vulnerability assessment tool.

A1: Source Water Quality Risk Assessment Methods

In Ontario, the *Clean Water Act, 2006* framework provides technical approaches and methodologies to:

- Assess the vulnerability of drinking water sources to water contamination and water quantity stresses; and
- Assess activities that pose risks to the drinking water sources within drinking water vulnerable areas.

These steps, described below, are prescribed in the Technical Rules that have been established under the *Clean Water Act, 2006*. The assessment tool includes the results of the existing source water quality vulnerability and risk assessment, from approved source protection plans.

Source Water Vulnerability Assessment under the Clean Water Act Framework

In the Technical Rules, there are four **vulnerable areas** required to be mapped, and are described below.

1. **Wellhead Protection Area (WHPA)**

   A wellhead is the physical well above the ground. The WHPA is delineated per the Technical Rules and is the area around a well where land use activities have the potential to affect the quality and quantity of water that flows into the well. The size of the water quality WHPA is dependent on how quickly water travels underground to the well, in years. Within a water quality WHPA, four zones can be delineated based on specified distance or time-of-travel including: the 100-metre zone (WHPA-A), the 2-year (WHPA-B), 5-year (WHPA-C), and 25-year (WHPA-D) time of travel zones. The WHPAs can be delineated based on both source water quality and quantity considerations.

2. **Intake Protection Zone (IPZ)**

   An IPZ is delineated per the Technical Rules and is defined as the area on the water and land surrounding a surface water intake, where protection from surface contamination is required to safeguard the drinking water source. Three vulnerable zones can be delineated including: IPZ-1, IPZ-2, and IPZ-3, where IPZ-1 is the closest and most vulnerable area around the intake based on a 1 km distance to the land, IPZ-2 is typically based on a 2-hour time of travel to the intakes, and IPZ-3 is the least vulnerable area around the intake based on a longer travel time in hours. These zones are delineated to protect surface water intakes from spills and discharges and control pollutant transportation. The IPZs can be delineated based on both source water quality and quantity considerations. There are four types of intakes, which are based on their location including:

   - Type A: Great Lakes;
   - Type B: connecting channels;
   - Type C: inland rivers; and
   - Type D: all others (e.g., inland lakes) (MECP, 2018b).

3. **Highly Vulnerable Area (HVA)**
   An HVA is an aquifer delineated per the Technical Rules, on which external sources have or are likely to have a significant effect and includes the land above the aquifer. The HVAs can be delineated based on source water quality considerations.

4. **Significant Groundwater Recharge Area (SGRA)**
   An SGRA is an area where precipitation recharges the groundwater source or aquifer, with certain criteria such as the rate and volume of recharge as specified in the Technical Rules. The SGRAs can be delineated based on source water quantity considerations.

The vulnerability of each drinking water vulnerable area to contamination is assessed based on several attributes or characteristics. For surface water sources, the attributes include those at an area scale (such as land percentage, land cover, soil type, permeability, slope, rainfall, transport pathways); and at the source (such as depth of intake, length of intake from shore, history of water quality concerns). For groundwater sources, attributes considered include flow (vertical and horizontal); aquifer (depth of aquifer, types of soils); and time of travel. Vulnerability scores are calculated for each vulnerable area, based on methods prescribed in the Technical Rules. These scores range from 1 (lowest vulnerability) to 10 (highest vulnerability).

Vulnerable areas delineated under the *Clean Water Act* can be viewed at the Ministry of Environment, Conservation and Parks - Source Protection Information Atlas at the website: https://www.gisapplication.lrc.gov.on.ca/SourceWaterProtection/Index.html?site=SourceWaterProtection&viewer=SWPViewer&locale=en-US

Source Water Quality Risk Assessment under the Clean Water Act Framework

WHPAs and IPZs are areas delineated closest to the drinking water source, and they support key information inputs to the assessment tool. The remainder of this sub-section focuses on source water quality risk assessments prescribed for WHPAs and IPZs.

Within the vulnerable areas, certain activities (current or future) are identified as drinking water threats. There are 22 threat activities identified under the O. Reg. 287/07 of the *Clean Water Act, 2006*. Among these threats, 20 threat activities are related to water quality, with the remainder being water quantity related. Additional threat activities can be identified by SPCs that are specific to the local context and situations.

Three risk assessment approaches are prescribed in the Technical Rules to determine the level of risk of these prescribed and local threat activities for source water contamination. The level of risk assigned is low, moderate or significant. There are three prescribed risk assessment approaches, as described below:

1. **Vulnerability Scoring Approach**
   This approach calculates the risk score for each threat activity as follows:

   Risk score = Vulnerability score X Hazard score

   The vulnerability score is based on several characteristics of the surrounding area and of the source water, such as: land cover, soil type, depth of the intake, etc. for surface water sources; and aquifer depth, soil type, time of travel, etc., for groundwater sources. The hazard rating of the threat activity is calculated from the many factors including: toxicity, environmental fate and quantity of the contaminant; method of release of the contaminant into the environment, and impacted receivers – surface water or groundwater. A risk score between 40 and less than 60 indicates that the assessed threat activity poses a "low" risk; from 60 to below 80 indicates a "moderate" risk; and from 80 to 100 indicates a "significant" risk to the source of drinking water.

2. **Water Quality Issues Approach**
   Drinking water issues are characterized as either chemical or pathogen-related based on chemical parameters and pathogens that are known to cause deterioration to water quality at the source (e.g., *E.-coli*). The benchmarks used to identify water quality issues are typically based on the Ontario drinking water quality standards, objective and guidelines. Available at: https://www.ontario.ca/laws/regulation/030169. These guidelines in turn are based on Health Canada assessments for human health, aesthetic, and operational considerations, available at: https://www.canada.ca/en/health-canada/services/environmental-workplace-health/reports-publications/water-quality/guidelines-canadian-drinking-water-quality-summary-table.html. Where drinking water issues are identified, issue contributing areas are delineated to capture and identify the threat activities that may be the cause or may contribute to the issue identified. The risk level of activities identified through this approach is always deemed to be significant.

3. **Event-Based Areas Approach**
   This approach is used for larger surface waterbodies prescribed in the Technical Rules (e.g., the Great Lakes) and is based on the modelling of spills from threat activities under specific weather events. When models demonstrate that a spill can cause deterioration to the water quality, the risk of that activity is always deemed significant. The benchmarks applied are as described in the Water Quality Issues Approach above.

Note that the second and third approaches are used when the first approach (vulnerability scoring) does not adequately address the risk of the threat activities to drinking water sources. All three risk assessment approaches consider the magnitude and likelihood of risks to source water quality. Further, the comprehensive Table of Drinking Water Threats which is a key technical document developed by MECP under the *Clean Water Act* framework, is used in the assessment (available at: https://swpip.ca/Threats). It lists all prescribed threat activities and the specific circumstances that could constitute a significant, moderate or low risk level threat to municipal drinking water sources.

These circumstances include: vulnerable area and score (from the vulnerability assessment), contaminant of interest or pathogen, quantity of release, and other considerations. It is also important to note that local source protection plan policies **must** manage or mitigate a risk that is assigned a “significant” level. The assessment tool utilizes the source water quality risk assessment results from source protection plans.

A2: Climate Change Vulnerability and Risk Assessment Methods

The development of the assessment tool required reconciling and acknowledging key climate change concepts and terminology alongside those associated with source protection and water quality risk assessments.

Climate change is defined by the Intergovernmental Panel on Climate Change (IPCC) as a change in the state of the climate that can be identified by changes in weather and atmospheric conditions that persist for an extended period, typically decades or longer (IPCC 2007, IPCC 2012a).

The term “climate change vulnerability” refers to the propensity or predisposition to be adversely affected by climatic or non-climatic stressor(s) or a combination of both (IPCC, 2012). It is a function of exposure, sensitivity, and adaptive capacity (IPCC, 2012), as follows:

$$\textbf{Climate Change Vulnerability} = \frac{\textbf{Potential Impact (i.e., Exposure} \times \textbf{Sensitivity)}}{\textbf{Adaptive Capacity}}$$

Most risk assessment frameworks are a series of linked steps, as described by the Ontario Climate Consortium based on several resources including the International Organization for Standardization (https://www.iso.org/obp/ui/#iso:std:iso:31000:ed-2:v1:en):

1. Scoping: Setting the context, establishing a team and assessment objectives
2. Set-up: Characterizing the system and hazards
3. Risk Analysis: Estimating, characterizing and comparing the vulnerabilities; characterizing likelihoods of things happening, and consequences associated with them
4. Risk Treatment: Determining risk, researching, evaluating and selecting alternatives to manage risk or strategies to increase resilience.

Widely used climate change vulnerability and risk assessment methods are described below.

The Public Infrastructure Vulnerability Committee (PIEVC) protocol developed by Engineers Canada is a five-step process to analyze the engineering vulnerability of an individual infrastructure (e.g. a building or an infrastructure system) to current and future climate parameters such as extreme heat or extreme rainfall. Note that it is not a spatial risk assessment tool to identify areas of high, medium or low risk. See **Figure A1** below.

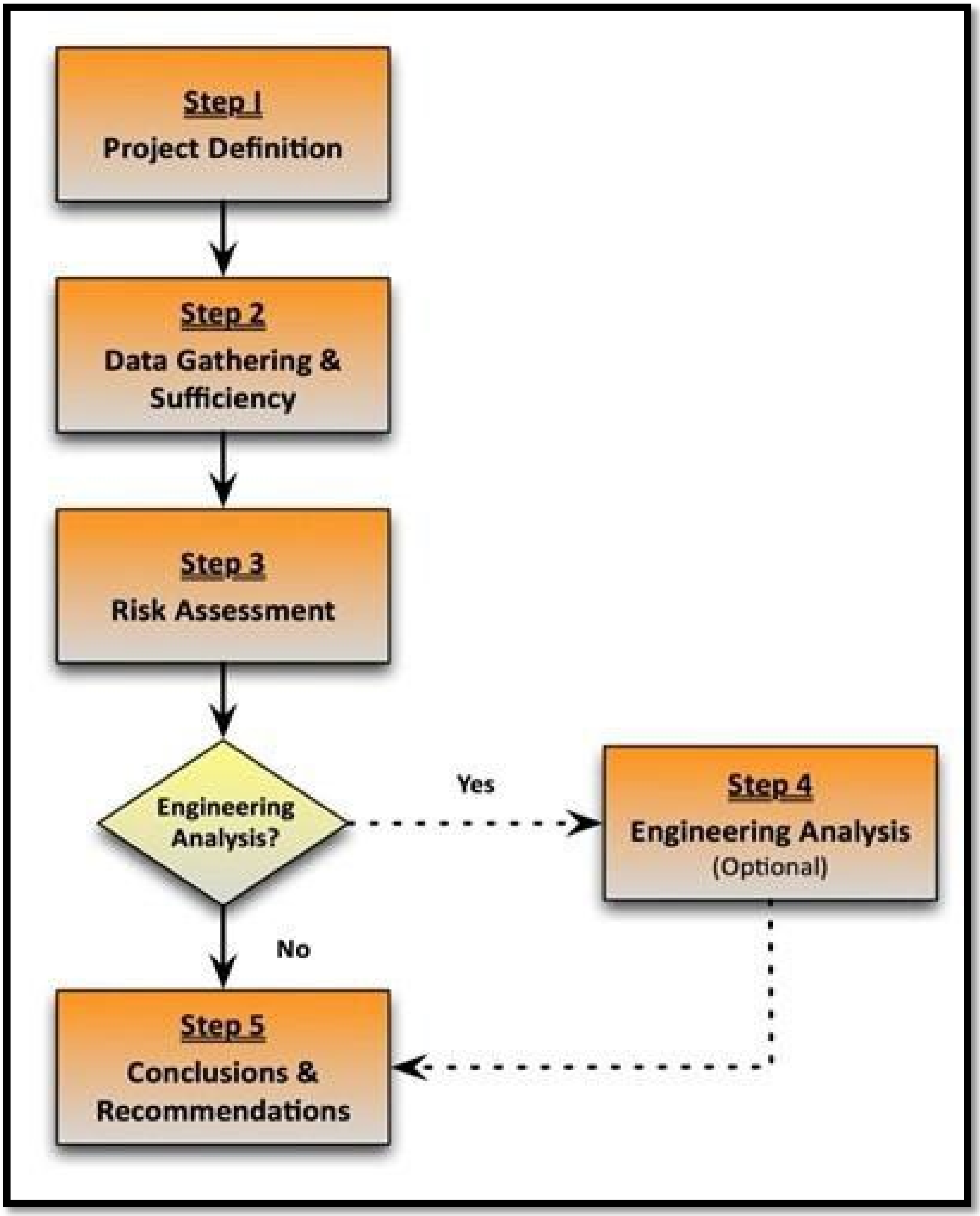

Figure A1: Public Infrastructure Vulnerability Committee (PIEVC) Protocol
(Source: https://pievc.ca/documents)

The Building Adaptive Resilient Communities (BARC) program for municipalities by the International Council for Local Environmental Initiatives (ICLEI) provides a methodology for adaptation planning, using a five-milestone approach. It starts with the initiation of adaptation efforts (by building an adaptation team and identifying local stakeholders) and culminates with a monitoring and review process that analyzes the successes and reviews the challenges of the adaptation plan and its implementation. See **Figure A2** below.

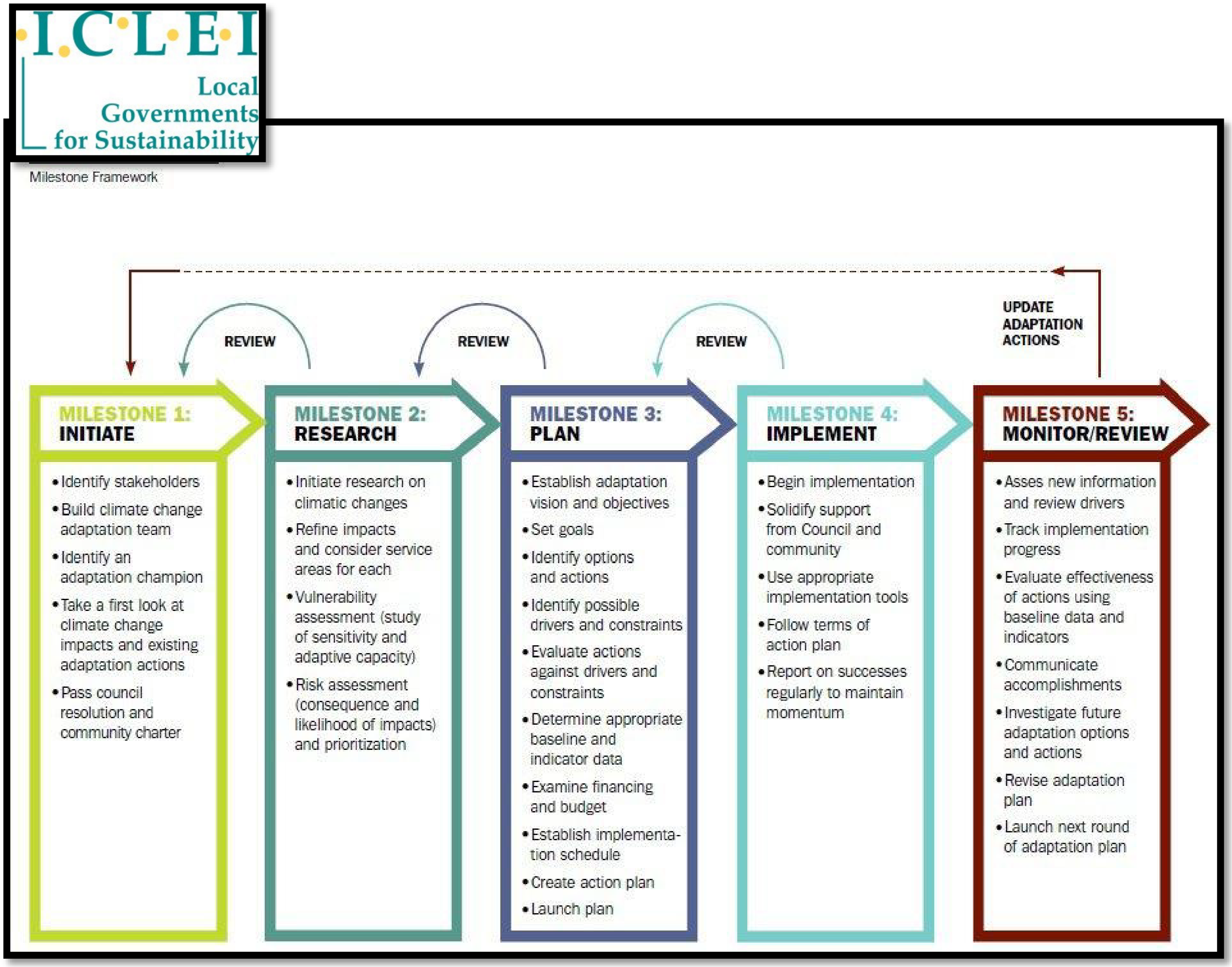

Figure A2: Building Adaptive Resilient Communities (BARC) Program by International Council for Local Environmental Initiatives (ICLEI)

(Source: https://icleicanada.org/project/changing-climate-changing-communities-guide-and-workbook-for-municipal-climate-adaptation/)

Appendix B: Climate Parameters and Relevance to Source Water Quality

Prior to establishing which climate parameters (e.g.: air temperature) and methodologies should be incorporated into the Assessment Tool, it was important to undertake an exercise among the Project Team as well as the Academic Advisory Group to document specifically how various climate conditions (e.g.: change in air temperature) could impact and/or influence surface water and groundwater processes as they pertain to water quality. Table B1 summarizes the results of this exercise, and documents a rationale for each climate condition, how it is being interpreted as part of its use in the assessment tool, potential sources of historical and future data for each, as well as the key literature and rationale from which they were adapted.

Furthermore, a suite of criteria was developed to support the selection and discussions surrounding which climate conditions to bring forward as part of the assessment tool analysis. It was important to ensure that a concise list of climate conditions was identified given that each requires significant effort to locate, interpret and analyze data as part of the assessment tool. The following were the criteria used to screen the suite of climate conditions illustrated in Table B1.

- Is there potential for this climate condition to cause contamination of drinking water sources?
- Is the climate condition relevant to surface water, groundwater, or both, as sources of drinking water supply?
- Is there a potential for the climate condition to result in increased risk, damage or impact on the landscape/vulnerable areas around the drinking water system that could affect the source of drinking water?
- Is there potential for the climate condition to cause degradation or impacts to environmental features and functions and/or terrestrial and aquatic habitats within an area (e.g., source protection area, geological area, climate zone, watershed or subwatershed)?
- Does the climate condition have available and easy-to-access data to support its use in the Assessment Tool for evaluating risk?
- Would a change in the climate condition have a direct effect on drinking water quality at the intake/well?
- Could any variation in the climate condition be significant enough to warrant additional considerations for the source of drinking water?

As described in Worksheet A of the Assessment Tool, all climate conditions included in the analysis are to be analyzed historically (for example, 1981-2010) and in the future (for example, 2021-2050) using monthly/annual resolution.

Table B1: Climate Parameters and their Relevance to Drinking Water Source Water Protection

Climate Parameter, Condition and Description	**Adapted From:**
1. Change in Air Temperature (Minimum and Maximum)	
Rationale for Including this in Guidance document: • **Surface Water:** Changes in air temperature could impact the existing water quality indirectly through its effect on the temperature of water and through its effects on the water cycle. First, the warmer the water, the less amount of dissolved oxygen will be in the water; dissolved oxygen in water is a vital molecule that allows species to live in water and is a direct indicator of water quality. Warmer water contains less dissolved oxygen as it holds more kinetic energy, which weakens the molecular attraction between water and oxygen molecules and allows the oxygen molecules to escape. Additionally, warmer water increases the rate of bacterial activities, which require oxygen for decomposition. Second, increases in air temperature can affect the hydrogeological processes as well as the water cycle, leading to an increase in evaporation that reduces flow rates/water levels in the surface waterbodies. This can further lead to reduced water quality because of reduced dilution of contaminants in the surface water sources. Third, warmer water temperatures and longer summer stratification can favour the growth of Cyanobacteria that can form algal blooms. • **Groundwater:** Depending on the depth of the groundwater system (e.g., shallow aquifers and wells will be responsive, whereas deeper aquifers may take longer to experience fluctuations in temperature), increases in average air temperature are expected to increase groundwater temperatures. Warmer groundwater temperatures could cause a reduction in assimilative capacity of surface water if baseflow support to surface features is a major contributor to flow.	Connor et al. (1989), Bedford (1992), De Groot et al. (2002), Erwin (2002), Poff et al. (2002), Eckhardt & Ulbrich (2003), Jyrkama & Sykes (2007), Kinkead (2008), Toronto and Region Conservation Authority (2008), Bovolo et al. (2009), Toronto and Region Conservation Authority (2008), Doll (2009), Hotte et al. (2009), Vincent (2009) EBNFLO AquaResource Inc. (2010), Harper et al. (2005), Mishra & Singh (2010), Browne & Hunt (2011), Gherke et al. (2011), Green et al. (2011), Tomalty & Komorowski (2011), Williams et al. (2012), Daigneault et al. (2012), Kumar (2012) Environment Canada (2013), Chu (2014), Blumberg and Toro (1990)
2. Changes in Precipitation: Rainfall and Snowfall	
Rationale for Including this in Guidance document: • **Surface Water:** The total amount of precipitation may not change significantly in the next decade or two, but the relative contributions of rainfall and snowfall to the annual amount of precipitation may change. This is important and determines the export of solutes such as nutrients, *E.coli* contamination and other waterborne pathogens, dissolved organic carbon (browning) and contaminants and algal blooms. There is also a strong link between changes in precipitation and pollutants entering the Great Lakes, as well as links between precipitation and severity of algal blooms. Not only the amounts but also the timing of runoff and associated nutrients and contaminants will change. • **Groundwater:** As changes in total precipitation occur and there is an increase in rainfall during the Winter season, this may increase the	Bedford (1992), Desplanque & Bray (1985), Erwin (2002), Poff et al. (2002), MEA (2005), Church et al. (2006), Jyrkama & Sykes (2007), Toronto and Region Conservation Authority (2008), CVC (2009), Crosbie et al. (2010), EBNFLO AquaResource Inc. (2010), Dove- Thompson et al. (2011), Gerkhe et al. (2011), Tomalty &

amount of infiltration occurring, which in turn may increase the amount of nutrients entering the groundwater system through recharge. Similar to the frost-free condition above, excessive nutrient application may increase nitrate contamination of groundwater used for drinking water, particularly for shallow wells in agricultural areas. Thus, if a groundwater system is shallow and near agricultural areas, changes in the form of precipitation may pose impacts to groundwater quality. **<u>Potential Effect of Condition on Water Cycle and Budget:</u>** Increase in precipitation could increase runoff in winter and infiltration in summer. Evapotranspiration rates could decrease	Komorowski (2011), Williams et al. (2012), Daigneault et al. (2012), NOAA (2013), Staudinger et al. (2013), Van Vliet et al. (2013), EPA (2014), Natural England & RSPB (2014), Warren and Lemmon (2014)
3. Changes in Heavy Precipitation	
<u>Rationale for Including this in Guidance document:</u> • **Surface Water:** Changes in heavy/extreme precipitation can cause flooding and impact drinking water when contaminants and pathogens are loaded into surface drinking water sources. Any pollutants that are mobilized during flooding can impact drinking water sources, for instance, an increase in total coliform (TC) concentrations could occur by suspended sediment containing coliforms in rivers or causing wastewater from flooded sewer systems to infiltrate areas used for drinking water supplies. Furthermore, high rainfall impacts the erosion process of sediment and increases turbidity of surface water. More generally, increases in future extreme precipitation could increase the likelihood of contaminant release (e.g., agricultural runoff, combined sewer overflows, salt from road application, stormwater discharges) and change the travel times of water, which in turn affect the size of the Intake Protection Zone and Wellhead Protection Area. • **Groundwater:** Changes in heavy precipitation can influence the amount of recharge that replenishes aquifer systems. A study conducted over 60 years (1950-2010) in the central U.S. demonstrated that more extreme rainfall events that represented the 95th percentile of events correlate with increased recharge rates following extreme rainfall (Zhang et al. 2016). With more extreme precipitation anticipated to occur in the future, the more likely groundwater can be contaminated through recharge.	Bolund & Hunhammar (1999), Winter (1999), Fang & Stefan (2000), Schindler, (2001), Erwin (2002), Poff et al. (2002), Vincent (2009), Harper et al. (2005), Green et al. (2011), Gerkhe et al. (2011), Williams et al. (2012), Daigneault et al. (2012), Environment Canada (2013), Zhang et al. (2016)
4. Very Hot Days (+ 30˚C)	
<u>Rationale for Including this in Guidance document:</u> • **Surface Water:** Changes in heat are expected to change water quality. A heat wave can accelerate algal and bacterial growth and promote the spread of invasive species. This is particularly true for lakes where differences in temperature cause stratification of the water column. Furthermore, heat days with high temperature could lead to more mineralization in the soils and increase leachable organic carbon. The	Bolund & Hunhammar (1999), Winter (1999), Fang & Stefan (2000), Schindler, (2001), Erwin (2002), Poff et al. (2002), Vincent (2009), Green et al. (2011), Gerkhe et al.

impact of a heat wave is different depending on the subsequent conditions. If a heat wave is followed by heavy precipitation, then an increase in browning can occur (which could make it harder to remove dissolved organic carbon and metals and other contaminants binding to dissolved organic matter). • **Groundwater:** Depending on the depth of the accessed groundwater system (e.g., shallow aquifers and wells vs. deep aquifers and wells), heat may or may not have a significant impact on water quality. If the groundwater system is shallow and there is a prolonged heat event, then there may be increases in groundwater temperature leading to similar impacts as described under the “Air Temperature” condition above and there could be more evaporation. In addition, a prolonged heat event could increase the demand for water (and pumping) and draw down groundwater levels. However, if a groundwater system is sufficiently deep or large (e.g., wells are deeper than several metres below ground) or the persistence of heat is limited, impacts to water quality would be minimal.	(2011), Williams et al. (2012), Daigneault et al. (2012), Environment Canada (2013)
5. Changes in Frost-Free Season	
Rationale for Including this in Guidance document: • **Surface Water:** The longer the frost-free season, the longer the window of time during which manure and fertilizer application may occur and contaminant exposure may increase. Nutrient export, algal blooms and dissolved organic carbon (browning) could also impact drinking water when contaminants and pathogens enter surface drinking water sources. Any pollutants that are mobilized during precipitation events (and if that season lengthens) can impact drinking water sources. For example, flooding may increase total coliform (TC) concentrations by suspending sediment containing coliforms in rivers or causing wastewater from flooded sewer systems to infiltrate and mix with drinking water. • **Groundwater:** The longer the frost-free season length, the more time there is for application of nutrients to take place and the longer period for recharge to occur. From a groundwater perspective, it has been shown that excessive nutrient application with increase nitrate contamination of groundwater used for drinking water, particularly for shallow wells in agricultural areas. Thus, if a groundwater system is shallow and near agricultural areas, increases in the frost-free season may pose impacts to groundwater quality.	Bovolo et al. (2009), Toronto and Region Conservation Authority (2008), Doll (2009), Hotte et al. (2009), Vincent (2009) EBNFLO AquaResource Inc. (2010), Mishra & Singh (2010), Browne & Hunt (2011), Gherke et al. (2011), Green et al. (2011), Tomalty & Komorowski (2011), Williams et al. (2012), Daigneault et al. (2012), Kumar (2012), Environment Canada (2013)
6. Changes in Freeze/Thaw Conditions: Number of Days Between -2^{O}C and +2^{O}C)	
Rationale for Including this in Guidance document: • **Surface Water**: This condition, mixed with increased urbanization, increases the likelihood of road salt application, which will negatively impact water quality (i.e., increase the salinity of water, and cause detrimental impacts to aquatic life in these waterbodies). Depending	Brown & Duguay (2010), McDermid et al. (2015), Minns et al. (2012), Tu et al. (2017)

on the freeze-thaw duration/cycle, this could damage or degrade infrastructure, impact fish and/or cause frazzle ice to form on lakes. In addition, sediment mobilization is more likely to occur, which in turn may require more frequent maintenance for de-clogging of intake pipes. It could also deepen frozen fields (i.e., those not thawed out in the spring for planting), which would lengthen the time for nutrients to be absorbed; therefore, increasing the runoff potential of nutrients applied to a frozen field. • **Groundwater:** Similar to the rationale provided above for “Surface Water”, changes in freeze/thaw cycles or ice conditions on land could increase the amount of road salt use, which will increase the salinity of groundwater. As ice melts (either during the spring freshet, or as a result of the increased frequency of freeze-thaw cycles due to climate change), it may have increased salinity due to road and land-based salt use, which can make its way into the groundwater and have negative impacts to groundwater quality and wells.	
7. Changes in Maximum Number of Consecutive Dry Days	
<u>Rationale for Including this in Guidance document:</u> • **Surface Water:** This condition is highly relevant in altering soil texture and characteristics. It can cause high impacts on water quality in surface waterbodies. The length of dry conditions (or droughts) is important. For example, a heavy precipitation storm is preceded by a long drought, will affect water quality. For example, when there is a dry period, geese will deposit waste over a long period of time, and eventually a large storm washes the waste into the source water with significant impact on the water quality. Increased drought conditions also create more demand for drinking water, leading to increased pumping and urban irrigation rates and correspondingly an increased size of the WHPA. These conditions may also lower the water elevation in surface water sources and thus reduce the dilution capacity. • **Groundwater:** Depending on the depth of the groundwater system (e.g., shallow aquifers and wells vs. deep aquifers and wells), dry conditions may pose a minor or more significant impact to water quality. If the groundwater system is shallow and there are prolonged dry conditions, this could increase demand for water (and pumping) hence drawing/extraction) and draw down groundwater levels. As a result, water quality may impacted/worsened due to a reduced assimilative capacity in groundwater. However, if a groundwater system is sufficiently deep or large (e.g., wells are greater than 80 m below ground) or the persistence of dry conditions is limited then impacts to water quality may be less pronounced.	Reid & Holland (1997), Eimers et al. (2007), Eimers et al. (2008), Jyrkama & Sykes (2007), Day et al. (2009), Hotte et al. (2009), EBNFLO AquaResource Inc. (2010), Green et al. (2011), Williams et al. (2012), Daigneault et al. (2012), Kumar (2012), CME (2013), Klein (2013), CRD (2014), NYSG (2014), University of Texas (n.d.), Quant (2014)

Appendix C: Statistical Analysis Tips and Resources (for Worksheet A)

Automated Statistical Analysis Feature in Microsoft Excel

If you do not already have the “Analysis ToolPak” add-in in your Excel software, then go to File -> Options -> Add Ins -> Analysis ToolPak.

Regression Method

Instructions to carry out simple statistical analysis on climate variable time series to confirm the trend to be changing (i.e., increase or decrease), or not changing, using the regression method:

Follow these steps for historical and future periods separately, after you have graphed the time series for each climate variable.

1. Data -> Data Analysis -> Regression.
2. Input Y range: select the ‘Years’ data.
3. Input X range: select the climate variable data corresponding to the same years selected for Y.
4. Select confidence level of: 95%. Leave the rest in default mode.
5. Click “ok” and you should see a statistical summary output in a new worksheet.
6. Check that the ‘R Square’ value is the same as in your graph. The closer to 1, the better the regression line (read on) fits the data.
7. Check the **Significance F value** – if it is less than 0.05, then the result is statistically significant (i.e., a trend exists). Also check all **P values** – if most of them are less than 0.05, then the result is statistically significant (i.e., a trend exists). See an example at: https://www.excel-easy.com/examples/regression.html

Other Statistical Methods

Table C-1: Options for Conducting Statistical Analyses on Climate Information

Method	Type of Method	Benefits	Caveats / Drawbacks
Graphing of Daily Climate Data (e.g., Scatter Plots, Box Plots)	Visual	Simple and quick, daily information can be used in Excel to provide a line of best fit (linear, polynomial, logarithmic, moving average, etc.)	• Focus on outliers and not on subtle changes in climate conditions • Subtle trends are difficult to determine by eye • Seasonal variation can mask trends in certain parameters

Table C-1: Options for Conducting Statistical Analyses on Climate Information

Method	Type of Method	Benefits	Caveats / Drawbacks
Statistical Time Series Analysis	Statistical (Parametric) - Regression of a Parameter Against Time (e.g., linear or non-linear regression)	• This method can help to determine if a trend is increasing, decreasing, or unchanging • Given a time series of (say) temperatures, the trend is the rate at which temperature changes over a time period. The trend may be linear or non-linear	• It is difficult to know what kind of trend analysis to complete without understanding the climate data. This method assumes the data is normally distributed • Regression methods draw a line as close to all data as possible
Statistical Time Series Analysis	Statistical (Parametric) - Student's t-Test	• This method is applied when a dataset follows a normal distribution • Typically, the null hypothesis is that there is no trend (i.e., an unchanging climate), and the results can decide whether the null hypothesis should be rejected or accepted	• It is difficult to know what kind of trend analysis to complete without understanding the climate data. This method assumes the data is normally distributed • The level of computation and expertise to conduct this approach is higher
Statistical Time Series Analysis	Statistical (Non-Parametric) - Seasonal Kendall Test	• This method can help determine if a trend is significant or not, and whether it's increasing or decreasing • The Seasonal Kendall Test compares the relationship between points at separate time periods or seasons and determines if there is a trend	• The level of computation and expertise to conduct this approach is higher
Statistical Time Series Analysis	Statistical (Non-Parametric) - Sen Slope or Kendall-Theil Test	• This method compares the change in value vs time (slope) for each data point and takes the median slope as a summary statistic describing the magnitude of the trend	• The level of computation and expertise to conduct this approach is much higher

Read more at:

Shea, Dennis & National Center for Atmospheric Research Staff (Eds). Last modified 25 Aug 2014. "The Climate Data Guide: Statistical & Diagnostic Methods Overview." **Retrieved from**

https://climatedataguide.ucar.edu/climate-data-tools-and-analysis/statistical-diagnostic-methods-overview
Click on Trend Analysis, or go to: https://climatedataguide.ucar.edu/climate-data-tools-and-analysis/trend-analysis

Appendix D: Linkages Between Climate Sensitivity and Climate Change Impact Scores

Table D1: Linkages for Area Level Indicators

Area Level Attributes in Worksheet C (Intake/Well Impact)	**Linked Area Attributes in Worksheet B1 (Area Sensitivity)**
1. Potential for increased contaminant loadings due to size of the area	• Size of the area of study
2. Potential for increased runoff due to percent of built-up area	• Current percent of the area of study as built-up area • Future percent of the area of study as built-up area
3. Potential for increased contaminant loadings due to percent of agricultural fields	• Current percent of the area of study as agricultural fields to which ASM, NASM, fertilizer, pesticides could be applied • Future percent of the area of study as agricultural fields to which ASM, NASM, fertilizer, pesticides could be applied
4. Potential for increased contaminant loadings due to percent of surfaces where salt/brine could be applied	• Current percent of the area of study as surfaces to which de-icing salt could be applied • Future percent of the area of study as surfaces to which de-icing salt could be applied
5. Existence of flood plains and potential for flooding to impact properties and infrastructure	• Existing flooding potential of water and wastewater infrastructure • Existing flooding potential of industrial/ commercial properties • Existing flooding potential of agricultural lands • Existing flooding potential of residential properties • (Stormwater system) Is there a history of flooding • General geology (dominant soil group) • Current percent of the area of study as flood plains
6. Potential for water quality degradation from sewage works	Wastewater system: • Number of wastewater treatment plants • Treatment level of plants • Usage vs capacity • Number of combined sewer overflows • Outlet proximity to the intake/well • Number of by-passes due to wet weather • Is there a noticeable relationship in the number of by-passes in recent years as the climate changes?
7. Potential for water quality degradation from storm sewers	Stormwater system: • Outlet proximity to the intake/well • System capacity

Table D2: Linkages for Drinking Water System Level for Intake(s)

Area Level Attributes in Worksheet C (Intake Impact)	Linked Area Attributes in Worksheet B2 (Intake Sensitivity)
1. Potential for increased vulnerability due to intake type	• Intake type
2. Potential for clogging of crib	• Potential clogging of crib
3. Potential for water quality degradation due to location of intake	• Zone of impact, or • Depth below average water level • Distance from shoreline
4. Potential for increased runoff within the IPZ	• Percent area of the IPZ on land • Slope of land in IPZ • Surface soil permeability
5. Potential for water quality degradation from existing or predicted future water quality issues	• Have Event Based Area (EBAs) or ICAs been delineated • Predicted future water quality issues (turbidity, pathogens, chemicals, pH levels) • If so, could source water quality be affected by higher highs in a surface waterbody • History of intake shut down because of water quality • History of: existing water quality issues (turbidity, pathogens, chemicals, pH levels) – are these issues expected to worsen under existing climate? • History of intake being affected by high intensity rainfall events
6. Potential for water quality degradation due to presence of discharges near intake	• Storm sewer outlet proximity to drinking water intakes • Waterbody discharges proximity to drinking water intakes • Wastewater treatment plant outlet proximity to drinking water intakes • Do transport pathways exist within the IPZ other than storm sewers and creeks • Have transport pathways altered the delineation of the IPZ
7. Potential for water quality degradation due to water quantity risks (e.g., Tier 3 risk assessment)	• Was a Tier 3 water quantity risk assessment completed • Predicted capacity to meet future water demands • What were the assessment results for the drought scenario? • Conversely, could source water quality be affected by lower lows in a surface waterbody
8. Water quality threats identified through a Drinking Water Quality Management Standard (DWQMS) risk assessment	• Was source water quality included in the risk assessment and threats identified?

Table D3: Linkages for Drinking Water System Level for Well/Well Field(s)

Area Level Attributes in Worksheet C (Well Impact)	Linked Area Attributes in Worksheet B2 (Well Sensitivity)
1. Potential for increased vulnerability due to well and aquifer type	• Depth of the top of screened interval or open borehole • Aquifer type • Highly vulnerable aquifers (HVA) scoring near the well • Are any of the wells Groundwater Under the Direct Influence of Surface Water (GUDI)
2. Potential for water quality degradation due to size of WHPA A-D as highly vulnerable aquifer	• Percent of WHPA-D as highly vulnerable aquifer
3. Potential for water quality degradation due to reduced recharge potential within the WHPA	• Slope of land within the WHPA • Surface soil permeability
4. Potential for water quality degradation from existing or predicted future water quality issues	• Have ICAs been delineated? • History of existing water quality issues (turbidity, pathogens, chemicals, pH levels) • History of well shut down due to water quality issues – what were those issues • History of the well-being affected by high intensity rainfall events • Predicted future water quality issues (turbidity, pathogens, chemicals, pH levels) • If so, could source water quality be affected by higher highs in a surface waterbody?
5. Potential for water quality degradation due to water quantity risks (e.g., Tier 3 assessment)	• Conversely, could source water quality be affected by lower lows in a surface waterbody? • Was a Tier 3 water quantity risk assessment completed? • What were the assessment results for the drought scenario?
6. Potential for water quality degradation due to presence of transport pathways within the WHPA	• Do transport pathways exist within the WHPA, other than storm sewers and creeks? • Has a transport pathway changed the ranking of vulnerability within the WHPA?
7. Water quality threats identified through a Drinking Water Quality Management Standard (DWQMS) risk assessment	• Was source water quality included in the risk assessment and threats identified?
8. Potential for water quality degradation due to presence of discharges near Groundwater Under the Direct Influence of Surface Water (GUDI) well	• Storm sewer outlet proximity to GUDI well • Waterbody discharges proximity to GUDI well • Wastewater treatment plant outlet proximity to GUDI well

Appendix E: Weights Assigned to the Area and System Attributes (Worksheet B and C)

Table E1: Weights for Study Area Sensitivity Attributes in Worksheet B (for both Surface Water and Groundwater Sources)

#	Study Area Sensitivity Attribute	What to record	Weight
1	**Size of the study area**	Indicate whether the area of study is large, medium or small	1
2	**General topography**	A general description of the topography of the study area	1
3	**General geology**	Dominant soil group A,B,C or D in study area	1
4	**Current population served by**		
4a	**municipal surface water systems**	Current population within the study area based on recent census	1
4b	**municipal groundwater systems**		1
4c	**private systems**		1
5	**Future population to municipal planning horizon served by:**		
5a	**municipal surface water systems**	Projected population within the study area based on municipal planning horizon	1
5b	**municipal groundwater systems**		1
5c	**private systems**		1
6	**Current percentage of the study area as:**		
6a	**built-up area**	As percent of the study area (land surface area)	1
6b	**agricultural fields**	As percent of the study area (land surface area)	1
6c	**surfaces to which de-icing salt could be applied**	As percent of the study area (land surface area)	1
6d	**drained by stormwater drainage systems**	As percent of the study area (land surface area) that is serviced by the stormwater drainage system	1

#	Study Area Sensitivity Attribute	What to record	Weight
6e	**reservoirs**	As percent of the study area (land surface area)	1
6f	**flood plains**	As percent of the study area (land surface area)	1
7	**Future percentage of the study area to municipal planning horizon as:**		
7a	**built-up area**	Projected as percentage of the study area based on the municipal planning documents (e.g., Official Plan)	1
7b	**agricultural fields**	Projected as percentage of the study area based on the municipal planning documents (e.g., Official Plan)	1
7c	**surfaces to which de-icing salt could be applied**	Based on projected land use, is the road network and parking areas expected to change? If so, please provide an estimate of the percentage of the study area based on the municipal planning documents (e.g.: Official Plan)	1
7d	**drained by stormwater drainage systems**	Based on projected changes in built-up area and population, is the storm sewer network projected to change? If so, please report projected service area based on the municipal planning (e.g.: Official Plan); as a percentage of the study area.	1
8	**Existing flooding potential of:**		
8a	**water and wastewater infrastructure**	Is there potential for flooding of these properties to occur under existing conditions (e.g., flash flooding, and 100-year floods etc.) - yes or no	1
8b	**industrial/ commercial properties**		1
8c	**agricultural lands**		1
8d	**residential properties**		1
9	**Stormwater System:**		
9a	**Outlet proximity to drinking water intakes**	Is there a stormwater outlet within an IPZ - yes or no	3

#	Study Area Sensitivity Attribute	What to record	Weight
9b	**System capacity**	Does the system have capacity to handle future storms - yes or no	3
9c	**Is there a history of flooding?**	Yes or no	3
10	**Wastewater System:**		
10a	**Number of wastewater treatment plants**	Number of wastewater treatment plants discharging in the study area	1
10b	**Treatment level of plants**	Indicate the lowest level of final treatment at the plants - primary, secondary or tertiary	1
10c	**Usage vs capacity**	Maximum usage as percentage of total capacity	1
10d	**Number of combined sewer overflows**	Maximum number of overflows that occurred within the study area in any given year	2
10e	**Outlet proximity to drinking water intakes**	Is there a wastewater outlet within an IPZ - yes or no	3
10f	**Number of by-passes per year due to precipitation**	What is the trend over the past 10 years in the data?	2
10g	**Is there a noticeable relationship in the number of by-passes in recent years as the climate changes?**	Has the municipality recorded/observed a relationship between the number of by-passes in recent years based on weather events - yes or no	2

Table E2: Weights for Intake Sensitivity Attributes in Worksheet B

#	Intake Sensitivity Attribute	What to record	Weight
1	**Intake type**	Type of intake as per technical rules A, B, C, D	3
2	**Number of intakes**	Number of intakes supplying the same population	1
3	**Potential clogging of crib**	Potential for clogging of intake crib - High (already happening), Medium or Low	1
4	**Note: Please complete either 4a or 4b and 4c.** **If 4a is completed, there is no need to complete 4b and 4c.**		
4a	**Zone of impact** (based on more advanced existing assessment), **OR:**	Vulnerability of intake's source water due to location (High, Medium or Low) based on local assessments and professional judgement	3
4b	**Depth below average water level**	Source vulnerability factor for intake depth (High, Medium or Low) based on local conditions and professional judgement	
4c	**Distance from shoreline**	Source vulnerability factor for distance from shoreline (High, Medium or Low) based on local conditions and professional judgement	
5	**Percent area of the IPZ on land**	Percentage	1
6	**Slope of land in IPZ**	Slope of land: 0 to 3% (or Class A) is considered flat; 4 to 15% (or Class B or C) is considered mild; >16% (or Class D, E or F) is considered steep.	3

#	Intake Sensitivity Attribute	What to record	Weight
7	**Surface soil permeability**	Dominant soil group A,B,C or D in the IPZ (see Additional Notes)	2
8	**Have Event Based Areas (EBAs) or Issue Contributing Areas (ICAs) been delineated under the Clean Water Act?**	Yes or no Also, please include a comment on what activity and chemical are of concern in the Comments box.	3
9	**Storm sewer outlet proximity to drinking water intakes**	Is a stormwater system outlet located within: - IPZ-1, then record 3 - IPZ-2, then record 2 - IPZ-3, then record 1 If just outside the outer-most IPZ, then record 1. In an EBA or ICA, where there is a related parameter of concern, then record 3.	3
10	**Waterbody discharges proximity to drinking water intakes**	Is a creek or river outlet located within: - IPZ-1, then record 3 - IPZ-2, then record 2 - IPZ-3, then record 1 If just outside the outer-most IPZ, then record 1. In an EBA or ICA, where there is a related parameter of concern, then record 3.	3

#	Intake Sensitivity Attribute	What to record	Weight
11	**Wastewater treatment plant outlet proximity to drinking water intakes**	Is a wastewater treatment system outlet located within (drop down list provided): - IPZ-1, then record 3 - IPZ-2, then record 2 - IPZ-3, then record 1 If just outside the outer-most IPZ, then record 1. In an EBA or ICA, where there is a related parameter of concern, then record 3.	3
12	**Do transport pathways exist within the IPZ, other than storm sewers and creeks?**	Yes or no Also, please include a comment on what transport pathways exist, natural and anthropogenic in the Comments box.	3
12a	**Have transport pathways altered the delineation of the IPZ?**	Yes or no	3
13	**History of:**		
13a	**not meeting water quantity demands**	Has the source water NOT been able to meet water quantity demands - yes or no	2
13b	**existing water quality concerns/issues (turbidity, pathogens, chemicals, and pH levels). Are these concerns expected to worsen under existing climate?**	Are issues expected to worsen under current conditions - yes or no Also, please include a comment on what issues exist in the Comments box.	3

#	Intake Sensitivity Attribute	What to record	Weight
13c	**intake shut down due to water quality concern/issues – what were those issues?**	Has the source water ever been degraded to the extent that the intake of water was stopped - yes or no? Also, please include a comment on the parameter or concern in the Comments box.	3
13d	**intake being affected by high intensity rainfall events**	How often do you experience a rain event that creates overland flooding in a year? If a high number of overland events occurred, then record 3. If a moderate number of overland events occurred, then record 2. If none, then record 1. Also, please include a comment on what impacts were experienced in the Comments box.	2
14	**Predicted future water quality issues (turbidity, pathogens, chemicals, and pH levels)**	Have studies shown that source water quality could worsen in the future - yes or no	1
14a	**If so, could source water quality be affected by higher highs in a surface waterbody?**	Have studies shown that source water quality could be affected by higher highs in surface water levels - yes or no	1
14b	**Conversely, could source water quality be affected by lower lows in a surface waterbody?**	Have studies shown that source water quality could be affected by lower lows in surface water levels - yes or no	1
15	**Was a Tier 3 water quantity risk assessment completed?**	Yes or no	2

#	Intake Sensitivity Attribute	What to record	Weight
15a	**Predicted capacity to meet future water demands**	Did the assessment show that the source water will be able to meet long-term water quantity demands - yes or no	2
15b	**What were the assessment results for the drought scenario?**	Was the intake able to meet demand during a 10-year drought under future conditions - yes or no	2
16	**Was a risk assessment completed for the water system under the Drinking Water Quality Management System (DWQMS)?**	Yes or no	1
16a	**a) Was source water quality included in the risk assessment under the DWQMS?**	Yes or no	1
16b	**b) Were threats to water quality identified? If so, please list the threats identified.**	Yes or no Please record a list of parameters identified in the Comments box.	1
17	**Can the water treatment plant accommodate decreased raw water quality (turbidity, pathogens, chemicals)?**	Does the treatment system have additional capacity for parameter removal that it currently treats for - yes or no	3

Table E3: Weights for Well Sensitivity Attributes in Worksheet B

#	Well Sensitivity Attribute	What to record	Weight
1	**Number of wells**	Number of wells supplying the same population	2
2	**Depth of the top of screened interval or open borehole**	Depth in metres	3
3	**Depth to the water table in WHPA**	Depth in metres	3
4	**Aquifer type**	Shallow-confined, shallow-unconfined, deep-confined, or deep-unconfined	3
5	**Percent Area of WHPA A-D as highly vulnerable aquifer**	Percentage	1
6	**Rating of groundwater vulnerability near the well/ well field**	Low, medium or high	3
7	**Are any of the wells GUDI?**	Yes or no	3
8	**Slope of land within the WHPA**	Low, medium or high slope	3
9	**Surface soil permeability**	Dominant soil group A,B,C or D in the WHPA (see Additional Notes)	2
10	**Have Issue Contributing Areas (ICAs) been delineated under the Clean Water Act?**	Yes or no Also, please include a comment on what activity and chemical are of concern in the Comments box.	3
11	**Storm sewer outlet proximity to GUDI well**	Is a stormwater system outlet located within: - WHPA-A, then record 3 - WHPA-B/C, then record 2 - WHPA-D/E/F, then record 1 In an ICA, where risk is always highest where there is a related parameter of concern, record 3	3

#	Well Sensitivity Attribute	What to record	Weight
12	**Waterbody discharges proximity to GUDI well**	Is a creek or river outlet located within: - WHPA-A, then record 3 - WHPA-B/C, then record 2 - WHPA-D/E/F, then record 1 In an ICA, where risk is always highest where there is a related parameter of concern, record 3	3
13	**Wastewater treatment plant outlet proximity to GUDI well**	Is a wastewater treatment system outlet located within (drop down list provided): - WHPA-A, then record 3 - WHPA-B/C, then record 2 - WHPA-D/E/F, then record 1 In an ICA, where risk is always highest where there is a related parameter of concern, record 3	3
14	**Do transport pathways exist within the WHPA, other than storm sewers and creeks?**	Yes or no Also, please include a comment on what transport pathways exist, natural and anthropogenic in the Comments box.	2
14a	**Has a transport pathway changed the ranking of vulnerability within the WHPA?**	Yes or no	2
	History of:		
15a	**not meeting water quantity demands**	Has the source water NOT been able to meet water quantity demands - yes or no	3

#	Well Sensitivity Attribute	What to record	Weight
15b	**existing water quality issues (turbidity, pathogens, chemicals, and pH levels). Are these issues expected to worsen under existing climate?**	Are issues expected to worsen under current conditions - yes or no Also, please include a comment on what issues exist in the Comments box.	3
15c	**well shut down due to water quality issues – what were those issues?**	Has the source water ever been degraded to the extent that pumping of the well was stopped - yes or no? Also, please include a comment on the parameter or concern in the Comments box.	3
15d	**well-being affected by high intensity rainfall events**	How often do you experience a rain event that creates overland flooding in a year? If a high number of overland events occurred, then record 3. If a moderate number of overland events occurred, then record 2. If none, then record 1. Also, please include a comment on what impacts were experienced in the Comments box.	1
16	**Predicted future water quality issues (turbidity, pathogens, chemicals, and pH levels)**	Have studies shown that source water quality could worsen if existing climate conditions continue - yes or no	1
16a	**If so, could source water quality be affected by higher highs in a surface waterbody?**	Have studies shown that source water quality could be affected by higher highs in surface water levels - yes or no	1
16b	**Conversely, could source water quality be affected by lower lows in a surface waterbody?**	Have studies shown that source water quality could be affected by lower lows in surface water levels - yes or no	1
17	**Was a Tier 3 quantity risk assessment completed?**	Yes or no	2

#	Well Sensitivity Attribute	What to record	Weight
17a	**a) Predicted capacity to meet future water demands**	Did the assessment show that the source water will be able to meet long-term water quantity demands - yes or no	2
17b	**b) What were the assessment results for the drought scenario?**	Was the well/well field able to meet demand during a 10-year drought under future conditions - yes or no	2
18	**Considering the risk assessment completed for the water system under Drinking Water Quality Management Standard (DWQMS)**		1
18a	**a) Was source water quality included in the risk assessment under the DWQMS?**	Yes or no	1
18b	**b) Were threats to water quality identified? If so, please list the threats identified.**	Yes or no Please record a list of parameters identified in the Comments box.	1
19	**Can the water treatment plant accommodate decreased raw water quality (turbidity, pathogens, chemicals, and pH levels)?**	Does the treatment system have additional capacity for parameter removal that it currently treats for - yes or no	3

Table E4. Weights associated with the Area Indicators in Worksheet C		
Attribute	**Weighting Score**	**How could climate change impact this intake/well?**
1. Potential for increased contaminant loadings due to size of the area	1	Climate change could increase the transport of contaminants or cause more dilution. Loadings are influenced by the size of the area
2. Potential for increased runoff due to percent of built-up area	1	Larger built-up area could mean increased loading of contaminants to waterbodies due to increased runoff
3. Potential for increased contaminant loadings due to percent of agricultural fields	1	More agricultural fields could lead to increased loading of contaminants to waterbodies due to longer growing seasons or increased runoff or tile drainage discharges
4. Potential for increased contaminant loadings due to percent of surfaces where salt/brine could be applied	1	Seasonal variations of more freeze/thaw could lead to increased application of salt/brine and high loadings, particularly in high use areas
5. Existence of flood plains and potential for flooding to impact properties and infrastructure	3	Flooding could increase release of contaminants and degrade runoff water quality
6. Potential for water quality degradation from sewage	2	Sewage treatment plants/combined sewers could discharge potentially higher loads of contaminants to waterbodies due to increased precipitation
7. Potential for water quality degradation from storm sewers	1	The size of the drainage area can influence the amount of contaminants collected and discharged to waterbodies and the location of discharges could influence impacts to source water

Table E5. Weights associated with the System Indicators for Intake(s) in Worksheet C		
Attribute	**Weighting Score**	**How could climate change impact this intake?**
1. Potential for increased vulnerability due to intake type	3	Intakes in smaller waterbodies may experience impaired water quality from climate change faster and more severely.
2. Potential for clogging of crib	1	Cribs can become clogged with algae
3. Potential for water quality degradation due to location of intake	3	The location of the intake in shallow water, close to shore or in the impact zone could mean less dilution and degraded water quality from downwellings, wave action, and influences from land.
4. Potential for increased runoff within the IPZ	3	Increased runoff (due to increased precipitation or heavy precipitation events, on top of increased urbanization, drainage/destruction of wetlands, etc.) could increase the loading of contaminants to the waterbody.
5. Potential for water quality degradation from existing or predicted future water quality issues	3	Existing water quality issues could be exacerbated or reduced by climate change.
6. Potential for water quality degradation due to presence of discharges near intake	3	Discharges from sewage works, transport pathways and surface waterbodies could have more of an impact on source water if the outlet is close to a drinking water intake
7. Potential for water quality degradation due to water quantity risks (e.g., Tier 3 assessment)	2	A changing climate could exacerbate the water quantity concerns, which could lead to degraded water quality
8. Water quality threats identified through a Drinking Water Quality Management Standard (DWQMS) risk assessment	1	A risk assessment, if completed, may provide insight into possible threats to water quality resulting from a changing climate

Table E6. Weights associated with the System Indicators for Well(s) in Worksheet C

Attribute	Weighting Score	How could climate change impact this intake?
1. Potential for increased vulnerability due to well and aquifer type	3	Shallow unconfined wells will be more responsive to changes in climate conditions that may result in deteriorating water quality conditions
2. Potential for water quality degradation due to size of WHPA A-D as highly vulnerable aquifer	1	A large vulnerable aquifer may have increased loading of contaminants from recharge
3. Potential for water quality degradation due to reduced recharge potential within the WHPA	3	Slope of land and surficial soils impact recharge potential, which could lead to changes in water quality
4. Potential for water quality degradation from existing or predicted future water quality issues	3	Existing water quality issues could be exacerbated by climate change
5. Potential for water quality degradation due to water quantity risks (e.g., Tier 3 assessment)	2	A changing climate could exacerbate the water quantity concerns, which could lead to degraded water quality
6. Potential for water quality degradation due to presence of transport pathways within the WHPA	2	Transport pathways could shorten the time of travel from ground surface to the well and impact the water quality
7. Water quality threats identified through a Drinking Water Quality Management Standard (DWQMS) risk assessment	1	A risk assessment, if completed, may provide insight into possible threats to water quality resulting from a changing climate
8. Potential for water quality degradation due to presence of discharges near Groundwater Under the Direct Influence of Surface Water (GUDI) well	3	Discharges from sewage works and surface waterbodies could have more of an impact on source water if the outlet is close to a GUDI well

Appendix F: Climate Change Considerations for Evaluating Prescribed Threats (Worksheet E)

Table F1: Climate Change Considerations to Evaluate Threats

Prescribed Threat	Impacts of Concern	Climate Factors	Source Protection Area/ System Attributes Potentially Linked to Threats	Worksheet #
1. The establishment, operation or maintenance of a waste disposal site within the meaning of Part V of the Environmental Protection Act	↑ volume of leachate ↑ strength of leachate timing of occurrence of an incident	Precipitation, heat, drought	Potential for increased runoff	C
			Land use: percent of built-up area of source protection area	C
2. The establishment, operation or maintenance of a system that collects, stores, transmits, treats or disposes of sewage	↑ volume of sewage ↑ strength of sewage discharge timing of occurrence of an incident	Precipitation, heat, drought	Potential for increased runoff	C
			Land use: percent of built-up area of source protection area	C
			Discharges near intake	C
			Potential for water quality degradation from sewage works	C
			Flooding potential	C
			Potential clogging of the crib	C
			Number of wastewater treatment plants	B1
			Wastewater treatment levels	B1
			Number of combined sewer overflows	B1
			Number of by-passes per year due to wet weather	B1

Table F1: Climate Change Considerations to Evaluate Threats				
Prescribed Threat	**Impacts of Concern**	**Climate Factors**	**Source Protection Area/ System Attributes Potentially Linked to Threats**	**Worksheet #**
			Is there a noticeable relationship/trend in the number of by-passes in recent years as climate changes?	B1
3. The application of agricultural source material to land	↑ volume of agricultural source material ↑ strength of agricultural source material timing of occurrence of an incident	Precipitation, heat, drought	Potential for increased runoff	C
			Land use: percent of built-up area of source protection area	C
			Land use: percent of agricultural area of source protection area	C
			Discharges near intake	C
			Have transport pathways altered the delineation of the IPZ?	B2
			Existing flooding potential of agricultural lands	B1
4. The storage of agricultural source material	↑ volume of agricultural source material ↑ strength of agricultural source material timing of occurrence of an incident	Precipitation, heat, drought	Potential for increased runoff	C
			Land use: percent of agricultural area of source protection area	C
			Discharges near intake	C
			Existing flooding potential of agricultural lands	B1

Table F1: Climate Change Considerations to Evaluate Threats

Prescribed Threat	Impacts of Concern	Climate Factors	Source Protection Area/ System Attributes Potentially Linked to Threats	Worksheet #
5. The management of agricultural source material	**Same as #3 and 4 above**			
6. The application of non-agricultural source material to land	↑ volume of non-agricultural source material ↑ strength of non-agricultural source material timing of occurrence of an incident	Precipitation, heat, drought	Potential for increased runoff	C
			Land use: percent of agricultural area of source protection area	C
			Discharges near intake	C
			Existing flooding potential of agricultural lands	B1
7. The handling and storage of non-agricultural source material	↑ volume of non-agricultural source material ↑ strength of non-agricultural source material timing of occurrence of an incident	Precipitation, heat, drought	Potential for increased runoff	C
			Land use: percent of agricultural area of source protection area	C
			Discharges near intake	C
			Existing flooding potential of agricultural lands	B1

Table F1: Climate Change Considerations to Evaluate Threats

Prescribed Threat	Impacts of Concern	Climate Factors	Source Protection Area/ System Attributes Potentially Linked to Threats	Worksheet #
8. The application of commercial fertilizer to land	↑ volume of commercial fertilizer ↑ strength of commercial fertilizer timing of occurrence of an incident	Precipitation, heat, drought	Potential for increased runoff	C
			Land use: percent of built-up area of source protection area	C
			Land use: percent of agricultural area of source protection area	C
			Potential clogging of the crib	C
			Have transport pathways altered the delineation of the IPZ?	B2
			Existing flooding potential of agricultural lands	B1
			Existing flooding potential of residential properties	B1
9. The handling and storage of commercial fertilizer	↑ volume of commercial fertilizer ↑ strength of commercial fertilizer timing of occurrence of an incident	Precipitation, heat, drought	Potential for increased runoff	C
			Land use: percent of agricultural area of source protection area	C
			Potential clogging of the crib	C
			Existing flooding potential of agricultural lands	B1
			Existing flooding potential of industrial/commercial lands	B1
10. The application of pesticide to land	↑ volume of pesticide ↑ strength of pesticide	Precipitation, heat, drought	Potential for increased runoff	C
			Land use: percent of built-up area of source protection area	C

Table F1: Climate Change Considerations to Evaluate Threats				
Prescribed Threat	**Impacts of Concern**	**Climate Factors**	**Source Protection Area/ System Attributes Potentially Linked to Threats**	**Worksheet #**
	timing of occurrence of an incident		Land use: percent of agricultural area of source protection area	C
			Discharges near intake	C
			Have transport pathways altered the delineation of the IPZ?	B2
			Existing flooding potential of agricultural lands	B1
			Existing flooding potential of residential properties	B1
11. The handling and storage of pesticide	↑ volume of pesticide ↑ strength of pesticide timing of occurrence of an incident	Precipitation, heat, drought	Potential for increased runoff	C
			Land use: percent of agricultural area of source protection area	C
			Discharges near intake	C
			Existing flooding potential of agricultural lands	B1
			Existing flooding potential of industrial/commercial lands	B1
12. The application of road salt	↑ volume of road salt ↑ strength of road salt timing of occurrence of an incident	Number of +2 and -2 days	Potential for increased runoff	C
			Land use: percent of surfaces of source protection area where salt/brine could be applied	C
13. The handling and storage of road salt	↑ volume of road salt	Number of +2 and -2 days	Potential for increased runoff	C

Table F1: Climate Change Considerations to Evaluate Threats

Prescribed Threat	Impacts of Concern	Climate Factors	Source Protection Area/ System Attributes Potentially Linked to Threats	Worksheet #
	↑ strength of road salt timing of occurrence of an incident		Land use: percent of surfaces of source protection area where salt/brine could be applied	C
			Existing flooding potential of industrial/commercial lands	C
14. The storage of snow	↑ volume of snow ↑ strength of snow timing of occurrence of an incident	Snowfall	Potential for increased runoff	C
			Land use: percent of built-up area of source protection area	C
15. The handling and storage of fuel	↑ volume of fuel ↑ strength of fuel timing of occurrence of an incident	Precipitation, heat, drought	Potential for increased runoff	C
			Flooding potential	C
16. The handling and storage of a dense non-aqueous phase liquid	↑ volume of DNAPL ↑ strength of DNAPL	Precipitation, heat, drought	Potential for increased runoff	C

Table F1: Climate Change Considerations to Evaluate Threats				
Prescribed Threat	**Impacts of Concern**	**Climate Factors**	**Source Protection Area/ System Attributes Potentially Linked to Threats**	**Worksheet #**
	timing of occurrence of an incident		Flooding potential	C
17. The handling and storage of an organic solvent	↑ volume of organic solvent ↑ strength of organic solvent timing of occurrence of an incident	Precipitation, heat, drought	Potential for increased runoff	C
			Flooding potential	C
18. The management of runoff that contains chemicals used in the de-icing of aircraft	↑ volume of de-icing chemicals ↑ strength of de-icing chemicals timing of occurrence of an incident	Precipitation	Potential for increased runoff	C
			Flooding potential	C
21. The use of land as livestock grazing or pasturing land, an outdoor confinement area or a farm-animal yard	↑ volume of nutrients ↑ strength of nutrients timing of occurrence of an incident	Precipitation, heat, drought	Potential for increased runoff	C
			Land use: percent of agricultural area of source protection area	C
			Discharges near intake	C
			Potential clogging of the crib	C

Table F1: Climate Change Considerations to Evaluate Threats

Prescribed Threat	Impacts of Concern	Climate Factors	Source Protection Area/ System Attributes Potentially Linked to Threats	Worksheet #
			Have transport pathways altered the delineation of the IPZ?	B2
			Existing flooding potential of agricultural lands	B1
22. The establishment and operation of a liquid hydrocarbon pipeline	↑ volume of hydrocarbon ↑ strength of hydrocarbon timing of occurrence of an incident	Precipitation, heat, drought	Potential for increased runoff	C
			Discharges near intake	C

Appendix G: Overview of Various Climate Data Sources

The following provides a high-level summary of the various climate data sources as they relate to their use in the assessment tool. All of the following portals (both historical and future) could potentially be used for Worksheet A of the assessment tool.

Table G-1: Overview of historical climate data sources

Climate Data Source	Description
1. Prairie Climate Atlas	• Almost all climate conditions referenced in the Assessment Tool are contained in this portal for historical and future information (i.e., all parameters excluding rainfall, snowfall, and consecutive dry days) • Very easy-to-use, and allows the user to visualize different climate parameters' trends, and provides climate summaries for all municipalities/regions in Canada. • Does not include data for rainfall, snowfall, or consecutive dry days. • Requires the user to download data for each season manually, rather than having all data in one excel file.
2. Environment and Climate Change Canada's: Climate Normals	• Almost all climate conditions referenced in the Assessment Tool are contained in this portal for historical information (i.e. all but consecutive dry days). • Very easy-to-use query-based website that allows the user to look up various climate stations and obtain average/total statistics over climate-normal periods (e.g., 1961-1990, 1971-2000, 1981-2010) • If daily data are desired, the user is required to download one year at a time in separate "csv" files, which then need to be combined to analyze a normal period (e.g., 1981-2010) at a detailed scale.
3. Environment and Climate Change Canada – Canadian Ice Service: Ice Tool	• Contains a very intuitive and easy-to-use query website where each Great Lake can be looked up and ice cover can be visualized on graphics for various historical periods • Flexible in which historical periods are of most interest to the user • Ice cover data are only available over the Great Lakes and larger spatial extents (e.g., not for inland lakes/ponds or other lakes).
4. NOAA's Great Lakes Environmental Research Lab – Historical Ice and Water Levels	• Contains clear and easy-to-interpret historical and current ice cover records; • Contains high quality, easy-to-visualize long term water level records • Ice cover data are only available over the Great Lakes and larger spatial extents (e.g., not for inland lakes/ponds or other lakes).

Climate Data Source	Description
5. Agriculture and Agri-Food Canada's Drought Monitor and Historical Drought Data	• Excellent query-based tool is available for different products related to historical drought across Canada and Ontario (e.g., 7-day rolling drought, meteorological dry spells, accumulated precipitation, etc.) • Data are available predominantly since the early 2000s, but do not necessarily continue further. Thus, it is recommended that data available be used as proxy in comparison to the full historical climate normal period if using this data source. A more comprehensive analysis of drought using station-based data and statistical methods (e.g., moisture indices via evapotranspiration calculations) could also be completed using Environment and Climate Change Canada's daily data as an alternative.

Table G-2: Overview of future climate data sources

Climate Data Source	Description
1. Prairie Climate Atlas	• Almost all climate conditions referenced in the Assessment Tool are contained in this portal for historical and future information (i.e., all parameters excluding rainfall, snowfall, and consecutive dry days) • Very easy-to-use, and allows the user to visualize different climate parameters' trends, and provides climate summaries for all municipalities/regions in Canada. • Data includes future data (for two different climate change scenarios – RCP 4.5 and RCP 8.5) and does not require separate downloads. • Does not include data for rainfall, snowfall, or consecutive dry days. • Requires the user to download data for each season manually, rather than having all data in one excel file.
2. Ontario Climate Data Portal (York University):	• Contains almost all climate indicators identified by academics in the project • Excellent time series available and projected for each climate station in Ontario • Can be cumbersome to download data - need to download for each climate model, then data comes in the form of ".mat" files (which require codes to open and manipulate).

Climate Data Source	Description
3. Ontario Climate Change Data Portal	- Easy to use/visualize map of Ontario with "gauge panel" to visualize data range - Climate data has been downscaled already to smaller scale grid cells (25 km by 25 km) - May be cumbersome to download all required climate data across an entire source protection area - Data downloads come in the form of .txt files (one for data and one for date/time info), so coding or data manipulation is required.
4. Ministry of Transportation Ontario's Intensity-Duration-Frequency (IDF) Curve Look up Tool	- Contains easy-to-use map of Ontario where a user can simply "click" their approximate location to look up the appropriate IDF Curve information and the future year of interest (note: Current day IDF curves are also available) - Given the scope of this project and use of climate normal to estimate trends, this website does not appear to allow the user to download multiple years at a time for statistical analysis. Thus, if this portal is used, a comparison between current and future IDF curves may be required as a "change in extreme precipitation".
5. University of Western Ontario's Intensity-Duration-Frequency (IDF) Curve Website Tool	- Contains IDF curve information for both gauged (station-based) and non-gauged (e.g., based on a gridded information across non station-based areas), which can be downloaded for multiple years (note: Current day IDF curves are also available) - Excellent visual tools of graphs, uncertainty based box plots, statistics and an interactive interface for illustrating the effects of climate change on a particular location (extreme precipitation changes in the context of this Guidance document) - Requires a log-in and password to access the website.

Table G-3: Overview of other climate portals

Climate Data Source	Description

1. Canada Climate Change Data Portal (CCCDP)	• Contains historical (1986-2005) climate data and future projected data (2020-2039, 2040-2069, and 2070-2099) for 50 km^2 grids across Canada, which can be downloaded. • Has seasonal, and monthly data on mean, maximum, minimum temperatures and precipitation. • Has multiple models to choose from. The Regional Climate Models include RegCM and PRECIS, the Global Climate Models include HadGEM2-ES. • The data are at a large scale, and does not provide localized data from weather stations in Ontario. • Does not provide any other climate indicators that are examined in the Assessment Tool, with the exception of precipitation and temperature.