Climate Change and Municipal Drinking Water Systems:

Assessment of Water Quality Impacts

December 2024

DRINKING WATER SOURCE PROTECTION
Our Actions Matter

Conservation Halton

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This report was prepared by Halton Hamilton Source Protection Region staff, in collaboration with the City of Hamilton and Halton Region staff.

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SUMMARY

Climate change has the potential to impact the availability and quality of our drinking water sources. This report documents the results of the climate change vulnerability assessment conducted for the ten (10) municipal drinking water systems in the Halton-Hamilton Source Protection Region (HHSPR) and the City of Hamilton's drinking water system in the Lynden Settlement Area to evaluate the risks climate change poses to the quality of drinking water sources.

The assessment was carried out using the Climate Change Vulnerability Assessment Tool (CCVAT) and examined surface water and groundwater systems to identify potential impacts from changing climate conditions. Climate change factors such as temperature increase, changes in rainfall patterns, and extreme weather events were considered, along with their potential influence on water systems. The assessment involved collecting and analyzing climate data for both historical and future trends, and incorporating evaluations of exposure, sensitivity, and impact for each system.

Adaptive capacity—the system's ability to mitigate or cope with these impacts—was also assessed, resulting in vulnerability scores for each of the assessed drinking water system. The final vulnerability ratings ranged from low to medium, indicating the varying degrees to which these systems might be affected by climate change. Key factors that contributed to the vulnerability rating include system attributes, such as percent of built-up areas, runoff potential, and existence of stormwater management facilities in the assessment area.

While none of the drinking water system's vulnerability was categorized as high, the results emphasize the need for municipalities to consider addressing the physical and operational aspects contributing to the system's vulnerability to climate change. This report concludes with a list of policy and management ideas that could be considered to reduce the system's vulnerability. Development and implementation of policies and management strategies provide a path to enhance the resilience of these water systems, particularly by addressing sensitive area and system attributes, such as built-up areas, flooding potential, and land use driven contaminant loadings.

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1. INTRODUCTION

Climate change has the potential to impact the availability and quality of our drinking water sources. To address this, the Ministry of the Environment, Conservation and Parks (MECP) has taken steps to enhance the integration of climate change considerations into the planning and management of drinking water sources. The objective is to identify and mitigate potential adverse effects of climate change on drinking water sources.

This report is addressing the impacts of climate change on drinking water source quality. To conduct assessments at the local level, a specialized Climate Change Vulnerability Assessment Tool (CCVAT) has been created that is designed to assess both surface water and groundwater source quality in view of a changing climate. The evaluation of potential climate change impacts on source water quantity is to some degree addressed through separate water quantity risk assessments as part of the Drinking Water Source Protection program and is not part of this report.

Within the Halton-Hamilton Source Protection Region (HHSPR) there are 10 municipal drinking water systems relying on surface water or groundwater. HHSPR received funding from the MECP to complete a climate change vulnerability assessment of areas affecting the groundwater and surface water sources of all 10 municipal drinking water systems in the HHSPR, and the City of Hamilton's groundwater-based drinking water system located in the Lynden Settlement Area.

2. CLIMATE CHANGE VULNERABILITY ASSESSMENT

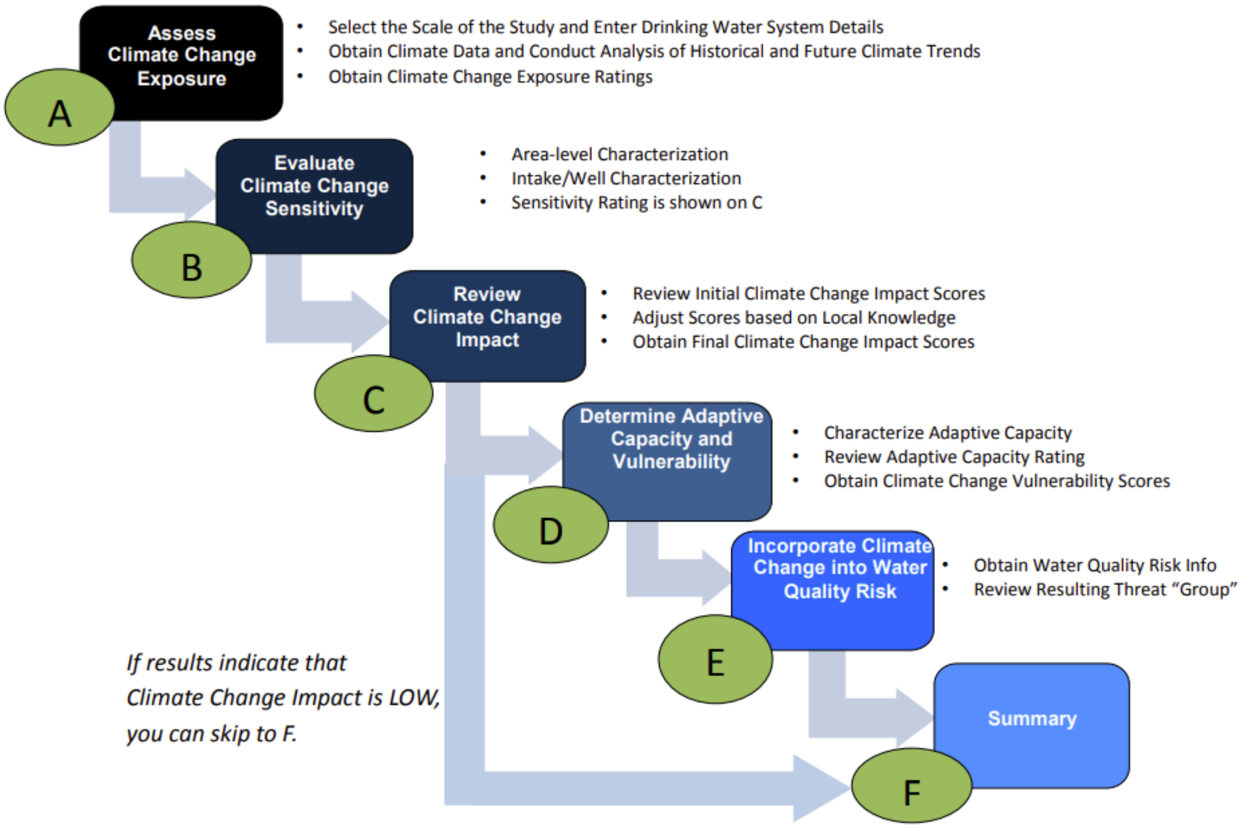
Groundwater and surface water can be impacted by rising temperatures, increased duration and frequency of drought periods, changes in rainfall amount and intensity, increased number and frequency of extreme weather events and resulting changes to the hydrologic cycle.

The 2021 technical rules under the Clean Water Act enable the inclusion of a climate change risk assessment for water quality in the assessment report (Part I.6). Rule 15.3 lays out basic requirements for a climate change risk assessment that need to be included in the assessment report, including an explanation of the data sets used, a description of the approach used to evaluate the vulnerability of a drinking water system, a summary of the findings, and an explanation of the results of the evaluation, including whether the evaluation concluded that the drinking water system is resilient to the climate impacts identified in the climate change impact assessment.

The CCVAT used for the climate risk assessment and documented in this report was developed by Conservation Ontario (CO) together with engagement of several individuals from academia and staff from the MECP, Environment and Climate Change Canada (ECCC), and various conservation authorities.

The following graphic (**Figure 1)** outlines the CCVAT steps and assessment tasks undertaken in each step.

Figure 1 Overview of the CCVAT Assessment Tool (Source: CO CCVAT Guidance)



Microsoft Excel is the platform the CCVAT is built on. Each of the steps in **Figure 1** above is a separate worksheet: Introduction, A1. Scale of Study, A2. CC Exposure, B1. Area Sensitivity, B2. Intake (or Well) Sensitivity, C. Intake (or Well) Impact, D. AdCap (Adaptive Capacity) and Vulnerability, E. Threat Activities, and F. Summary.

2.1 Climate Change Exposure

The initial phase evaluates climate change exposure and assigns a rating based on both historical and projected climate change trends. Exposure pertains to the degree or susceptibility of a region or an area to climate variations. The analysis of exposure encompasses the subsequent steps:

- Select a scale for the study and/or representative datasets
- Select a climate change scenario, as appropriate (e.g., Representative Concentration Pathway – RCP 8.5)
- Obtain historical and projected future climate data
- Determine historical and future climate trends and variability of data
- Review the climate change exposure results
- Determine the uncertainty.

2.1.1 Study Area Selection

Each lake-based system underwent an evaluation using the Source Protection Area (SPA) scale, while the assessment of groundwater systems was conducted at either the sub-watershed, catchment, or ground-watershed scale. The specific scale chosen for each system, along with the corresponding details and rationale, is outlined in the relevant sections of each assessment.

While the lake-based systems share similarities in terms of area level characterization, the initial suggestion was to assess them as one using the SPA scale. It was ultimately determined that each drinking water system should undergo its own assessment. This decision was primarily driven by the varying intake sensitivities of each system, which could lead to differences in the assessment results. **Table 1** lists the assessment area scale for each of the drinking water systems:

Table 1: Assessment Area Scale

DRINKING WATER SYSTEM	ASSESSMENT AREA SCALE
Burlington	SPA
Burloak	SPA
Oakville	SPA
Woodward	SPA
Kelso	Subwatershed
Walkers Line	Groundwatershed
Campbellville	Catchment
Carlisle	Groundwatershed
Freelton	Groundwatershed
Greensville	Groundwatershed
Lynden	Groundwatershed

Maps showing outlines of the assessment area scale for each of the drinking water systems are shown in **Figures 3** - **Figure11** in **Appendix 1 through Appendix 11**.

2.1.2 Climate Change Scenario Selection

As recommended in the CCVAT guidance document, to complete the climate change exposure analysis, the climate change scenario – Representative Concentration Pathway (RCP) 8.5 was selected. This is a high emission, or business as usual, scenario where emissions rise beyond year 2100. Selection of this scenario allows for an assessment of the potential climate change impacts and prepare for the worst-case scenario.

2.1.3 Climate Data

To conduct the CCVAT assessment, the following historical and future climate parameters were gathered: annual and seasonal data for minimum and maximum temperature and precipitation; annual data for heavy precipitation (90th percentile); the number of very hot days (days with temperatures above 30°C); the number of frost-free days; the count of freeze/ thaw cycles; and the maximum length of dry spells. Data from three online sources: Climate Atlas of Canada, ClimateData.ca, and Ontario Climate Data Portal were utilized for downloading the required information. Details regarding the scale, distribution, and the chosen data sources for each assessment are outlined in the respective sections dedicated to each system assessment. The historical data provided by the three data sources is interpolated data from multiple stations. The future climate data was statistically down sampled from multiple lower resolution Global Climate Model (GCM) outputs and bias corrected.

2.1.4 Determination of Historical and Future Trends and Data Variability

The climate data trend analyses were completed using linear regression tools incorporated into Excel. Trend analyses were necessary for both historical and future climate periods. The period recommended for each of the analyses is at least 30 years. The suggested trend analysis using the provided template relies heavily on visual trend identification and neglects the consideration of absolute values of the dataset as they relate to trends. To prevent potential misinterpretation of results, where trends may go unnoticed due to insufficient statistical support, or where trends might be incorrectly identified based solely on statistical outcomes, staff has compared the average percent change over the specified period to the corresponding absolute values. This approach highlights the significance of the change in relation to the data and allows for the use of statistical coefficients. **Appendix A** includes additional information on the enhancements to the trend analyses incorporated into this assessment.

The results of the trend analyses are populated in worksheet "A2. CC Exposure" of the CCVAT spreadsheet. In addition to the Excel-based CCVAT, an Excel spreadsheet containing all historical and future ensemble data for each system, along with the trend analysis described above, was created and is available upon request.

2.2 Climate Change Sensitivity

The subsequent phase considered various physical attributes to evaluate climate change sensitivity at both the assessment scale area and the system and vicinity scale. Sensitivity is the extent to which a system is impacted by both climatic and non-climatic stressors. Parameters related to the area, including the size of the assessment area, topography, geology, land use, and other characteristics such as the system type (groundwater vs. surface water), the existence of storm and sanitary sewer infrastructure in the wellhead protection area or intake protection zone, flooding potential, and documented or anticipated water quality issues, were assessed. The main source of data to complete this task are the assessments reports for the Halton Region, Hamilton Region, and Grand River Source Protection Areas.

Upon completing this phase, an uncertainty level was assigned. The assessment involved evaluating data quality, spatial distribution in terms of scale, accuracy, and the nature of data, whether anecdotal evidence or reported data were used. Uncertainty was then assigned as either 'low' or 'high'.

2.3 Climate Change Impact

Based on information on exposure and area and system sensitivity entered into the Excel spreadsheet, CCVAT automatically populates climate change exposure and sensitivity ratings at the area and system scale and calculates the initial impact score. CCVAT allows the score to be adjusted based on professional judgement and local knowledge. Where adjustments were made, notes are provided in CCVAT worksheet C and a brief summary is provided in the specific system summary.

The final potential climate change impact score was calculated as follows:

$$\textbf{Final Impact Score} = \frac{\textbf{Average Area Impact Score} + \textbf{2 x Average Well (Intake) Impact Score}}{\textbf{3}}$$

The final impact score was converted to percent of maximum impact score and a qualitative final impact score rating was assigned as a “high”, “medium”, or “low”. For percentages of 67% and higher, a “high” impact rating is given, and for percentages below 33% a “low” impact rating is assigned.

2.4 Adaptive Capacity and Vulnerability

Adaptive capacity is defined as the system's capability to respond to climate change, moderating potential impacts, and effectively cope with extremes. The adaptive capacity was calculated as:

$$\textbf{Adaptive Capacity Score} = \frac{\textbf{Average Area Score} + \textbf{2} * \textbf{Average Well (Intake) Score}}{\textbf{Adaptive Capacity Score}}$$

After the adaptive capacity score was calculated by CCVAT, a climate change vulnerability score was calculated as follows:

$$\textbf{Climate Change Vulnerability} = \frac{\textbf{Final Impact Score}}{\textbf{Adaptive Capacity Score}}$$

An overall climate change vulnerability rating is assigned as “low”, “medium” or “high” based on the calculated score. For a percentage of 67% or higher, a “high” climate change vulnerability rating is given; and for below 33%, a “low” rating is given. In general, a "high" vulnerability rating suggests an anticipated adverse impact on source water quality due to climate change. Some of these impacts may have the potential to be irreversible, a determination that may need to be assessed separately. Implementing adaptation and mitigation measures are necessary in such cases. A "medium" vulnerability rating indicates a moderate potential impact on source water quality from climate change. In these situations, identifying and applying suitable adaptation and mitigation measures, or planning for them, may provide longer term benefits and increase resilience. Conversely, a "low" vulnerability rating suggests minimal expected impacts on source water quality due to climate change. Exploring appropriate adaptation and mitigation options for planning purposes is advisable in such scenarios.

The final impact, adaptive capacity and vulnerability ratings for all HHSPR systems are provided in **Table 2**.

Table 2: Climate Change Impact Adaptive Capacity and Vulnerability Summary

DRINKING WATER SYSTEM	Impact Score	Impact Rating	Adaptive Capacity Score	Adaptive Capacity Rating	Final Vulnerability Score	Final Vulnerability Rating

Burlington	68%	High	63%	Medium	36%	Medium
Burloak	64%	Medium	63%	Medium	34%	Medium
Oakville	72%	High	63%	Medium	38%	Medium
Woodward	52%	Medium	66%	Medium	27%	Low
Kelso	41%	Medium	77%	High	18%	Low
Walkers Line	52%	Medium	61%	Medium	28%	Low
Campbellville	63%	Medium	57%	Medium	37%	Medium
Carlisle	69%	High	77%	High	30%	Low
Freelton	58%	Medium	77%	High	25%	Low
Greensville	59%	Medium	69%	High	28%	Low
Lynden	42%	Medium	69%	High	20%	Low

2.5 Climate Change and Water Quality Risk

In this section, the source water quality risk assessment, as summarised in the Halton-Hamilton Source Protection Plan, is combined with the established climate change vulnerability rating assigned in the previous step, for each prescribed drinking water quality threat activity. As a result, each threat activity is assigned to one of three groups. Threat activities assigned to Group I do not require additional measures to address climate change impacts. For threat activities in Group II, a determination should be made if any additional measures are needed to address climate change impacts. For threat activities in Group III, appropriate measures to address climate change impacts should be developed and implemented. **Figure 2** below shows the matrix applied to this exercise.

Figure 2 Threat Level and Climate Change Vulnerability Rating Matrix

Drinking Water Threat Risk Level	Low	Medium	High
Significant	Group II	Group III	Group III
Moderate	Group I	Group II	Group III
Low	Group I	Group I	Group II
	Climate Change Vulnerability Rating		

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 cliamte change vulnerability assessments as this information becomes available.
Group II	Determine if additional measures are needed to address climate change impacts. Institute a plan or a strategy to track changes over time and incorporate new climate information as it becomes available.
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 a strategy to track the success of measures implemented over time.

Group II threat activities exist for all drinking water systems, while Group III threat activities exist for the Burlington, Burloak, Oakville, and Campbellville systems. However, addressing climate change impacts through revisions to policies that were developed to mitigate impacts to drinking water sources from drinking water threat activities may not be practical. The Halton Hamilton Source Protection Plan includes policies to address all significant drinking water threat activities, many of which are not directly linked to climate change. For example, revisions to policies for the storage and handling of dense non-aqueous liquids (DNAPLs), organic solvents, road salt, agricultural source material (ASM) such as manure, or non-agricultural source material (NASM) such as biosolids, would do little to increase resilience of the drinking water system to the impacts of climate change. This makes the development of meaningful climate change measures or policies related to such threat activities challenging. Additionally, focusing on threat activities as they relate to climate change would address the consequences rather than the underlying issues.

Since local actions alone cannot effectively mitigate climate change, this report proposes to focus on the physical attributes of the assessment areas and drinking water systems as identified through the CCVAT. These attributes contribute to the resulting climate change vulnerability rating and may also have the potential to degrade water quality. This approach aims to reduce the overall climate change vulnerability rating, thereby declassifying identified threat activities in Groups II or III to a lower vulnerability rating group. As part of the system-specific assessments, the attributes most sensitive to and contributing the most to the climate change vulnerability rating were identified using the CCVAT. Table 3 provides a summary of these attributes for each system.

Table 3: Area and Intake/Well Sensitive Attributes

ATTRIBUTE	Area Sensitive Attribute						Intake/Well Sensitive Attribute						
SYSTEM	1. Areas to which de-icing products can be applied	2. Increased runoff due to percent of built-up area	3. Floodplain and areas where flooding can occur	4. Increased contaminant loadings due to agricultural activity	5. Stormwater management facilities within IPZ/WHPA	6. Stormwater management facilities within the assessment	7. Water quality issue at well/intake	8. Potential for water quality to worsen	9. Water quality degradation due to water quantity risks	10. Number of intakes/wells	11. Well GUDI status	12. Aquifer type and vulnerability	13. Reduced recharge
Burlington	✓		✓		✓	✓	✓						
Burloak	✓		✓		✓	✓	✓			✓			
Oakville	✓		✓		✓	✓	✓			✓			
Woodward	✓		✓		✓	✓	✓						
Kelso			✓						✓				
Walkers Line			✓					✓				✓	
Campbellville	✓							✓		✓			✓
Carlisle			✓	✓	✓						✓	✓	✓
Freelton			✓	✓						✓		✓	✓
Greensville	✓	✓								✓		✓	✓
Lynden			✓	✓			✓						

To address the sensitivity of the identified attributes and lower the overall threat vulnerability rating, the following (Table 4) are suggested ideas for policy and management measures for each of the area and well/intake sensitive attributes identified in Table 2. The list is not comprehensive and additional policy measures may be added. The intent is not to necessarily implement all of the measures listed, but rather to provide a set of tools and potential measures to choose from. Some of these measures may already be implemented by municipalities for different reasons.

Table 4: Suggested Policy and Management Measure Ideas

No	Sensitive Attribute	Policy and management measure
1	Areas to Which De-icing Products Can Be Applied	a. Best Practices: consider developing best practices manuals on the types and amounts of de-icing products used, prioritizing eco-friendly alternatives in the most sensitive areas. b. Policy Tools: explore policy for future commercial urban development to promote building multi level parking garages to reduce areas requiring application of de-icing products. c. Training Programs: enhance or develop training for public works and maintenance staff on the proper application rates and techniques to minimize runoff. d. Monitoring and Reporting: consider establishing or enhancing monitoring programs to track de-icing product usage and its environmental impacts.
2	Increased Runoff Due to Percent of Built-up Area	a. Green Infrastructure and Low Impact Development (LID): consider incentivizing or encouraging the use of green roofs, permeable pavements, rain gardens and other LID measures to reduce runoff and increase infiltration. b. Municipal Programs: explore the feasibility of developing and implementing policies, such as zoning by-laws and stormwater management plans that limit the extent of impervious surfaces in new developments. c. Stormwater Management Plans: develop or enhance comprehensive stormwater management plans to incorporate runoff reduction strategies. d. Outreach and education: consider promoting or incentivizing storm water storage and use for irrigation e.g.: use of rain barrels, developing and promoting programs to support building LID measures on private properties, such as incorporation of rain gardens, bioswales, soak away pits, promoting and supporting the use of porous pavement or other permeable products to build driveways, etc.
3	Floodplain and Areas Where Flooding Can Occur	a. Low Impact Development: enhance the implementation of green infrastructure solutions such as permeable pavements, bioswales, rain gardens, and green roofs to reduce and filter runoff. b. Wetlands Restoration: support the restoration and protection of wetlands which can act as natural sponges, absorbing floodwaters and trapping contaminants.

		c. Reforestation: accelerate the planting of trees and restoration of forested areas to enhance water infiltration and reduce surface runoff. d. Education and Outreach: enhance public education and outreach about the importance of preventing surface water contamination through proper disposal of chemicals and waste in areas vulnerable to flooding.
4	Increased Contaminant Loadings Due to Agricultural Activity and Land Use Changes	a. Agricultural Best Management Practices (BMPs): Promote BMPs such as buffer strips, cover cropping, and nutrient management to reduce runoff. b. Incentive Programs: consider providing financial incentives for farmers to adopt sustainable practices. c. Monitoring and Regulation: support extension of CH monitoring programs to identify, quantify, and track contaminant loadings from land use practices.
5	Stormwater Management Facilities within IPZ/WHPA	a. Upgraded Infrastructure: explore feasibility of upgrading existing stormwater management facilities to handle increased loads and incorporate advanced treatment technologies. b. Regular Maintenance: enhance or establish routine inspection and maintenance schedules to ensure facility effectiveness. c. Source Control Measures: implement or enhance measures to control pollution at its source before it enters stormwater systems (e.g., sewer by-laws).
6	Stormwater Management Facilities within the Assessment Area	a. Comprehensive Planning: consider enhancing the integration of stormwater management into urban planning to ensure facilities are adequately designed for future conditions. b. Nature-based Solutions: explore enhanced use of natural treatment solutions like constructed wetlands to enhance stormwater quality.
7	Water Quality Issue at well/intake	a. Monitoring and Regulation: explore implementation of robust sediment control measures and increased inspection during construction to reduce the amount of sediment entering watercourses. b. Advanced Treatment Systems: examine feasibility of advanced treatment systems at wells and intakes to address specific contaminants. c. Routine Monitoring: consider increased frequency and scope of water quality monitoring to detect issues early.
8	Water quality degradation due to water quantity risks	a. Early Warning Systems: examine opportunity to develop and implement early warning systems to detect water quality changes (e.g., periodic PGMN* and PWQMN** data assessment review and reporting). b. Adaptive Management: enhance adaptive management practices that can be adjusted based on monitoring results and emerging threats.

		c. Education and Outreach: expand public education on the importance of protecting water sources and reducing pollution.
9	Water quality degradation due to water quantity risks	a. Water Conservation Programs: explore feasibility of enhanced water conservation programs to reduce overall demand. b. Alternative Water Sources: Promote uptake of alternative water sources, such as rainwater harvesting and reclaimed water.
10	Number of Intakes/Wells	a. Diversification of Drinking Water Sources: consider diversification of water sources to reduce dependence on any single intake or well. E.g., back-up water wells should be located at different locations in case of groundwater contaminants affecting a supply.
11	Well GUDI*** Status	a. Monitoring Programs: examine increased frequency of monitoring for municipal drinking water wells classified as GUDI to quickly identify and respond to contamination.
12	Aquifer Type and Vulnerability	a. Land Use Controls: consider development and enforcement of land use controls that limit establishment of potentially contaminating activities over vulnerable aquifers within groundwater catchments of municipal systems. b. Recharge Enhancement: promote practices that enhance natural recharge and reduce contamination risks.
13	Reduced Recharge	a. Policy Tools: explore additional requirement for future development to maintain or enhance pre- to post-development infiltration. b. Land Use Planning: promote and/or incentivize land use planning that preserves recharge areas and prevents excessive surface sealing. Consider developing and promoting programs to support building LID measures on private properties, such as incorporation of rain gardens, bioswales, soak away pits, promoting and supporting the use of porous pavement or other permeable products to build driveways, etc. c. Outreach and Education: promote storm water storage and use for irrigation e.g.: use of rain barrels, developing and promoting programs to support building LID measures on private properties, such as incorporation of rain gardens, bioswales, soak away pits, promoting and supporting the use of porous pavement or other permeable products to build driveways, etc. d. Water Efficiency Measures: encourage water efficiency measures to reduce overall extraction pressure on aquifers.

* PGMN: Provincial Groundwater Monitoring Network
** PWQMN: Provincial Water Quality Monitoring Network
*** GUDI: Groundwater Under Direct Influence

By exploring and implementing some of the suggested measures, municipalities can effectively address the various climate change-related vulnerabilities that have the potential to impact source water quality and ensure good quality municipal source water in the face of changing climate.

3. CONCLUSION

The results of the CCVAT assessment provide valuable insight into understanding potential climate change impacts in HHSPR. Additionally, the results of the assessment bring attention to areas of concern that should be addressed to build resilience to a changing climate and to protect the quality of municipal drinking water sources.

The assessment highlights that while some drinking water systems in the HHSPR are more resilient to climate change impacts, others are more vulnerable and may require targeted measures to ensure water quality remains protected in a changing climate. The Burlington, Oakville, and Burloak systems were identified as having medium vulnerability, driven by factors such as increased urban runoff and stormwater management challenges. Conversely, the Kelso and Greensville drinking water systems displayed lower vulnerability due to their adaptive capacity and less sensitive area, system physical attributes and existing adaptive capacity measures.

While none of the drinking water system's vulnerability was categorized as high, the results emphasize the need for municipalities to consider addressing the physical and operational aspects contributing to the system's vulnerability to climate change. Development and implementation of policies and management strategies provide a path to enhance the resilience of these water systems, particularly by addressing sensitive attributes like built-up areas, flooding potential, and land use driven contaminant loadings. By implementing adaptive measures tailored to each system's unique vulnerabilities, municipalities can effectively mitigate risks and ensure the long-term sustainability of drinking water sources amidst a changing climate.

4. REFERENCES

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APPENDICES

APPENDIX A – SYSTEM SPECIFIC ASSESSMENTS

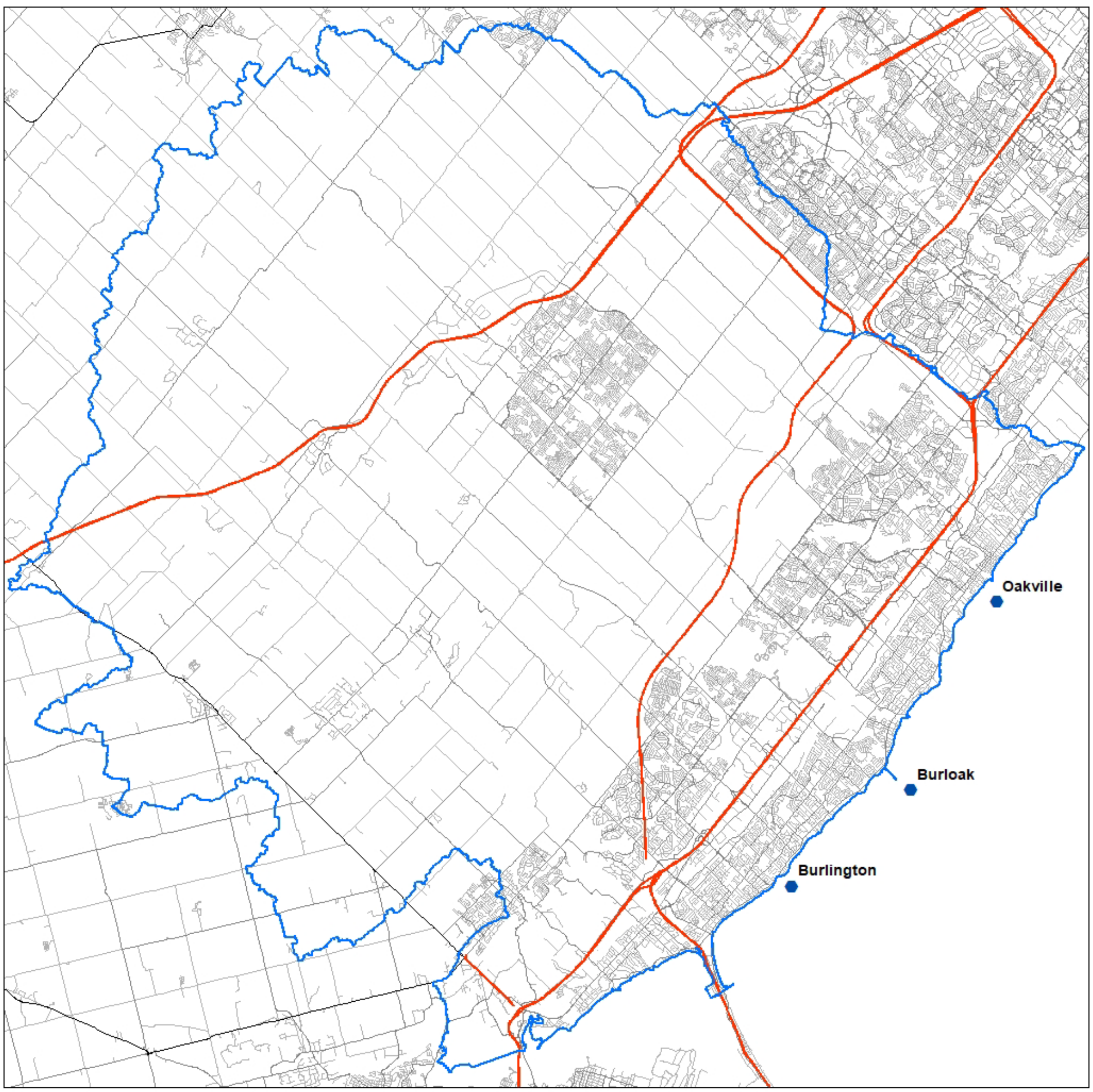
APPENDIX A1 - BURLINGTON

The Burlington Drinking Water System is one of three Lake Ontario surface water systems operated by Halton Region. The system is comprised of two intakes and a water treatment plant located in the City of Burlington.

Scale of the assessment

Taking into consideration surface water runoff from the entire watershed can affect lake water quality, the assessment was completed using the entire Halton Region SPA as the study area. **Map 1** outlines the Burlington CCVAT assessment area and shows all Halton Region Lake Ontario intakes.

Map 1: Halton Region SPA and Lake Ontario surface water intakes



Climate data description and trend analysis

The source and spatial resolution of climate data sets used in the assessment is summarised in Table 3 of worksheet A2. CC Exposure of the CCVAT Excel workbook. The following is a summary of the sources used in the study:

- Data for six (6) of the 10 climate parameters, i.e. Minimum Temperature (annual and seasonal), Maximum Temperature (annual and seasonal), Precipitation (annual and seasonal), Very Hot Days, Frost Free Season, and Freeze Thaw Cycle, were obtained from the Climate Atlas of Canada website, using the small grid for the Burlington region.
- Heavy Precipitation data was collected from climatedata.ca website using 18 small grid cells to ensure entire SPA coverage.
- The Maximum Length of Dry Spell data were obtained from the Ontario Climate Data Portal for the Halton region.
- Since future data for rainfall and snowfall are unavailable, the future trends for both parameters were based on the CCVAT Burlington pilot study conducted by CO and the study team. This approach mirrors the methodology used in the Burlington study, with one exception: the trends for summer rainfall and snowfall were changed to "Not Changing" to align with the overall trend for total precipitation.

Appendix A1.1 below shows an example of annual minimum temperature (historical and future) regression analyses. Due to the number of regression analyses which were completed, all plots and regression summary outputs are available in associated climate data regression analyses spreadsheets. The trend analyses of all parameters for both historical and future data were completed, and the results populated in worksheet A2. CC Exposure.

Area and Intake Sensitivity

The Halton Region SPA Assessment Report was the main source of data used to populate CCVAT worksheet B1-Area Sensitivity and B2-Intake Sensitivity. Spatially distributed and geographical data was integrated, visualised, analysed and summarised using geographical information system (GIS) software and the results populated in the CCVAT spreadsheet.

Future land use estimates were based on the Official Plan, or in cases of insufficient data on projected population growth. For more details, the reader is directed to CCVAT worksheet B1 notes to identify the source of information, or the method used to obtain such estimates. Recognizing the area sensitivity summary is based on the entire SPA, the Burloak and Oakville CCVAT assessments were populated using the same information as for the Burlington assessment.

Given the utilization of abundant factual data, spatially distributed data, and detailed GIS analysis to summarize data in this phase, a **low** level of uncertainty was assigned to both the area and intake climate change sensitivity assessments.

Intake Impact Assessment

Conservation Halton and municipal staff reviewed the initial impact scores for both the study area and the intake and concluded that no further adjustments were needed. The assessment tool then generated the final climate change impact score, resulting in a **medium** impact rating. A **high** level of uncertainty was assigned, stemming from the incorporation of exposure assessment outcomes, which are based on simulated future data.

Adaptive Capacity and Climate Change Vulnerability Rating

The subsequent phase in the CCVAT assessment involved allotting adaptive capacity and vulnerability (worksheet D. AdCap and Vulnerability). Certain attributes related to adaptive capacity and vulnerability are auto populated based on area and intake sensitivity data. The remaining details were supplied by Halton Region water treatment plant operating staff. Given the information and its sources utilized in this assessment, a low level of uncertainty has been assigned.

The overall climate change vulnerability score for the Burlington system is 3.2 out of 9. This corresponds to **medium** vulnerability rating.

Threat Activities

Threat activities as included in the Halton Region SPA Assessment Report were used to populate worksheet E. Three significant threats were identified. Following the threat risk level and vulnerability rating matrix these threats are categorised as Group III. These significant threats are based on event-based modelling and are not related to climate change nor can they be directly addressed through measures or policies related to climate change. However, to improve drinking water sources quality in light of changing climate, identification of area and intake sensitive attributes and potentially lowering their sensitivity scores through policy or management measures can lead to lowering the overall vulnerability rating and move the identified threats to a lower Group rating.

CCVAT Results and Sensitivity Analysis

The final climate change vulnerability rating for the Burlington system was identified as medium. Several area and intake sensitivity attributes have a deciding impact on the final climate change vulnerability rating.

The most significant area sensitive attributes influencing the final climate change adaptive vulnerability rating for the Burlington system are:

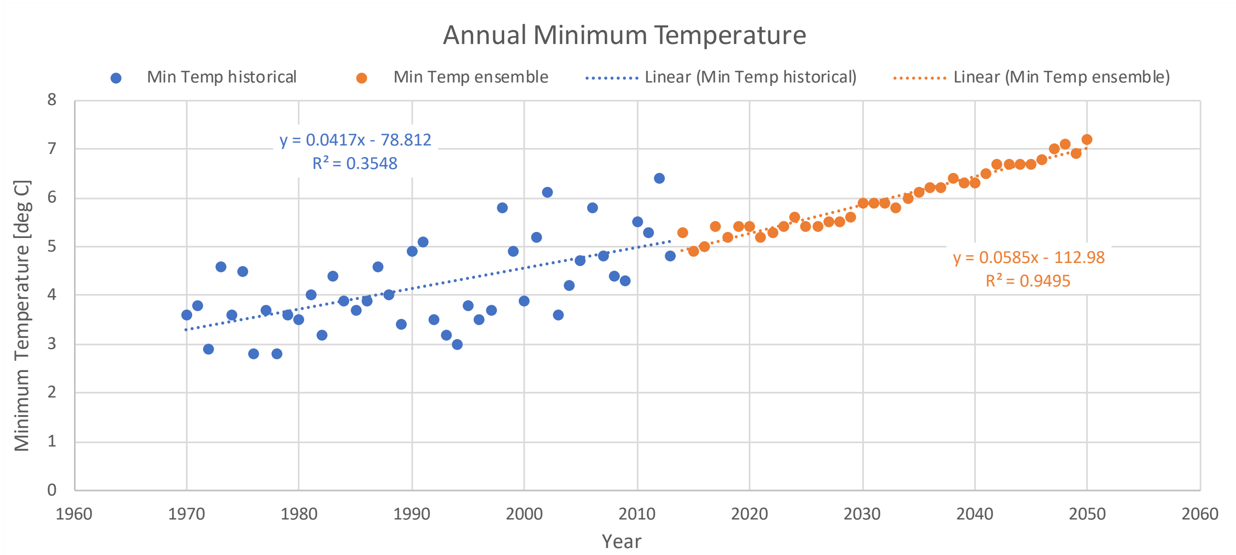
- areas to which de-icing products can be applied,
- floodplain and areas where flooding can occur,
- stormwater management facilities within Intake Protection Zones (IPZ), and
- stormwater system facilities within the assessment area.

The identified water quality issue at the Burlington intake is the only intake specific sensitive attribute influencing the final climate change adaptive capacity rating.

Recommendations:

To reduce the Burlington system's overall climate change vulnerability rating, some identified attributes can be managed through new policies aimed at lowering their sensitivities. **Table 4** policy and management measure ideas No. 1, 3, 5, 6, and 7 should be considered.

APPENDIX A1.1 – SAMPLE BURLINGTON CLIMATE PARAMETER TRENDS



HISTORICAL - ANNUAL				
Basic analysis			% DELTA	43%
Trend based on visual interpretation				**INCREASING**
Advanced analysis				
Conclusion:	The trend **IS**	statistically significant		
Std dev	0.899			
Mean	4.202			
Coeff of Var	**0.214**			

FUTURE - ANNUAL				
Basic analysis			% DELTA	35%
Trend based on visual interpretation				**INCREASING**
Advanced analysis				
Conclusion:	The trend **IS**	statistically significant		
Std dev	0.650			
Mean	5.968			
Coeff of Var	**0.109**			

SUMMARY OUTPUT - HISTORICAL - ANNUAL

Regression Statistics	
Multiple R	0.595624522
R Square	0.354768571
Adjusted R Sq	0.339405918
Standard Error	0.730649508
Observations	44

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	12.3281272	12.3281272	23.09292339	1.99678E-05
Residual	42	22.42164553	0.533848703		
Total	43	34.74977273			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-78.81198027	17.27515828	-4.562156768	4.35149E-05	-113.6746611	-43.94929942	-113.6746611	-43.94929942
X Variable 1	0.041684285	0.008674269	4.805509691	1.99678E-05	0.024178901	0.059189669	0.024178901	0.059189669

SUMMARY OUTPUT - FUTURE - ANNUAL

Regression Statistics	
Multiple R	0.974417449
R Square	0.949489366
Adjusted R Sq	0.948046205
Standard Error	0.148210898
Observations	37

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	14.45225462	14.45225462	657.9233929	2.79664E-24
Residual	35	0.768826458	0.02196647		
Total	36	15.22108108			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-112.9752489	4.63720771	-24.36277519	1.54477E-23	-122.3892811	-103.5612168	-122.3892811	-103.5612168
X Variable 1	0.058534851	0.002282059	25.65001741	2.79664E-24	0.053902025	0.063167677	0.053902025	0.063167677

APPENDIX A2 - BURLOAK

The Burloak Drinking Water System is one of three Lake Ontario surface water systems in lake systems operated by Halton Region. The system is comprised of one intake and a water treatment plant located in the west end of the Town of Oakville.

Scale of the assessment area

Similarly to Burlington and Oakville assessments, surface runoff from the entire watershed can affect lake water quality, hence the Burloak CCVAT assessment was completed using the entire Halton Region SPA as the study area.

Climate data description

The source and spatial resolution of climate data sets used in the assessment is summarised in Table 3 of worksheet A2. CC Exposure of the CCVAT Excel workbook. The climate data employed for Burloak is the same as for the Burlington and Oakville assessments. The following is a summary of the sources used in the study:

- Data for six (6) of the 10 climate parameters, i.e. Minimum Temperature (annual and seasonal), Maximum Temperature (annual and seasonal), Precipitation (annual and seasonal), Very Hot Days, Frost Free Season, and Freeze Thaw Cycle, were obtained from the Climate Atlas of Canada website, using the small grid for the Burlington region.
- Heavy Precipitation data was collected from climatedata.ca website using 18 small grid cells to ensure entire SPA coverage.
- The Maximum Length of Dry Spell data were obtained from the Ontario Climate Data Portal for the Halton region.
- Since future data for rainfall and snowfall are unavailable, the future trends for both parameters were based on the CCVAT Burlington pilot study conducted by CO and the study team. This approach mirrors the methodology used in the Burlington study, with one exception: the trends for summer rainfall and snowfall were changed to "Not Changing" to align with the overall trend for total precipitation.

Due to the number of regression analyses which had to be completed, all plots and regression summary outputs are available in associated climate data regression analyses spreadsheets. The trend analyses of all parameters for both historical and future data were completed, and the results populated in worksheet A2. CC Exposure.

Area and Intake Sensitivity

Given that Burloak and Burlington share the same area assessment scale, the data in the Burloak CCVAT spreadsheet B1 was filled out using identical information from the Burlington assessment. The Halton Region SPA Assessment Report and information provided by the municipality was used to populate spreadsheet B2-Intake Sensitivity. Spatially distributed and geographical data was integrated, visualised, analysed and summarised using geographical information system (GIS) software and the results populated in the CCVAT spreadsheet.

Given the utilization of abundant factual data, spatially distributed data, and detailed GIS analysis to summarize data in this phase, a **low** level of uncertainty was assigned to both the area and intake climate change sensitivity assessments.

Intake Impact Assessment

Conservation Halton and municipal staff reviewed the initial impact scores for both the study area and the intake and concluded that no further adjustments were needed. The assessment tool calculated a final climate change impact score, and based on the results a **medium** rating was assigned. A **high** level of uncertainty was identified, primarily attributed to the incorporation of the exposure assessment results, which relied on modeled future data.

Adaptive Capacity and Climate Change Vulnerability Rating

The subsequent phase in the CCVAT assessment involves allotting adaptive capacity and vulnerability (worksheet D. AdCap and Vulnerability). Certain attributes related to adaptive capacity and vulnerability are auto populated based on area and intake sensitivity data. The remaining details were supplied by Halton Region water treatment plant operating staff. Given the information and its sources utilized in this assessment, a **low** level of uncertainty has been assigned.

The overall climate change vulnerability score for the Burloak system is 3.0 out of 9. This corresponds to **medium** vulnerability rating.

Threat Activities

Threat activities as included in the Halton Region SPA Assessment Report were used to populate worksheet E. Three significant threats were identified. Following the threat risk level and vulnerability rating matrix these threats are categorised as Group III. These significant threats are based on event-based modelling and are not related to climate change nor can they be directly addressed through measures or policies related to climate change. However, to improve drinking water sources quality in light of changing climate, identification of area and intake sensitive attributes and potentially lowering their sensitivity scores through policy or management measures can lead to lowering the overall vulnerability rating and move the identified threats to a lower Group rating.

CCVAT Results and Sensitivity Analysis

The final climate change vulnerability rating for the Burloak system was identified as medium. Several area and intake sensitivity attributes have a deciding impact on the final climate change vulnerability rating.

The most significant area sensitive attributes influencing the final climate change adaptive vulnerability rating for the Burloak system are:

- areas to which de-icing products can be applied,
- floodplain and areas where flooding can occur,
- stormwater management facilities within Intake Protection Zones (IPZ), and
- stormwater system facilities within the assessment area.

The identified water quality issues at the Burloak intake and the number of intakes are the intake specific sensitive attributes influencing the final climate change adaptive capacity rating.

Recommendations:

To reduce the Burloak system's overall climate change vulnerability rating, some identified attributes can be managed through new policies aimed at lowering their sensitivities. **Table 4** policy and management measure ideas No. 1, 3, 5, 6, 7 and 10 should be considered.

APPENDIX A3 - OAKVILLE

The Oakville Drinking Water System is one of three Lake Ontario surface water systems operated by Halton Region. The system is comprised of one intake and a water treatment plant located in the Town of Oakville.

Scale of the assessment area

Similar to the assessments conducted for Burlington and Burloak, the Oakville CCVAT assessment took into account the entire Halton Region SPA as its study area, recognizing that surface runoff from the entire watershed can impact the quality of lake water.

Climate data description

The source and spatial resolution of climate data sets used in the assessment is summarised in Table 3 of worksheet A2. CC Exposure of the CCVAT Excel workbook. The climate data employed for Oakville is the same as for the Burlington and Burloak assessments. The following is a summary of the sources used in the study:

- Data for six (6) of the 10 climate parameters, i.e. Minimum Temperature (annual and seasonal), Maximum Temperature (annual and seasonal), Precipitation (annual and seasonal), Very Hot Days, Frost Free Season, and Freeze Thaw Cycle, were obtained from the Climate Atlas of Canada website, using the small grid for the Burlington region.
- Heavy Precipitation data was collected from climatedata.ca website using 18 small grid cells to ensure entire SPA coverage.
- The Maximum Length of Dry Spell data were obtained from the Ontario Climate Data Portal for the Halton region.
- Since future data for rainfall and snowfall are unavailable, the future trends for both parameters were based on the CCVAT Burlington pilot study conducted by CO and the study team. This approach mirrors the methodology used in the Burlington study, with one exception: the trends for summer rainfall and snowfall were changed to "Not Changing" to align with the overall trend for total precipitation.

Due to the number of regression analyses which had to be completed, all plots and regression summary outputs are available in associated climate data regression analyses spreadsheets. The trend analyses of all parameters for both historical and future data were completed, and the results populated in worksheet A2. CC Exposure.

Area and Intake Sensitivity

Since Oakville, Burloak and Burlington share the same area assessment scale, the data in Oakville's CCVAT spreadsheet B1 is a copy of the Burlington assessment. Information from the Halton Region SPA Assessment Report primarily populated spreadsheet B2-Intake Sensitivity. Utilizing geographical information system (GIS) software, spatially distributed and geographical data were integrated, analyzed, and summarized. The results were then entered into the CCVAT spreadsheet.

Due to the extensive use of factual data and detailed GIS analysis, both the area and intake climate change sensitivity assessments were assigned a low level of uncertainty in this phase.

Intake Impact Assessment

Conservation Halton and municipal staff reviewed the initial impact scores for both the study area and the intake and concluded that no further adjustments were needed. The assessment tool calculated a final climate change impact score and assigned **medium** impact rating. A **high** level of uncertainty was identified, primarily attributed to the incorporation of the exposure assessment result, which relied on modeled future data.

Adaptive Capacity and Climate Change Vulnerability Rating

The subsequent phase in the CCVAT assessment involves allotting adaptive capacity and vulnerability (worksheet D. AdCap and Vulnerability). Certain attributes related to adaptive capacity and vulnerability are auto populated based on area and intake sensitivity data. The remaining details were supplied by Halton Region water treatment plant operating staff. Given the information and its sources utilized in this assessment, a **low** level of uncertainty has been assigned.

The overall climate change vulnerability score for the Oakville system is 3.5 out of 9. This corresponds to **medium** vulnerability rating.

Threat Activities

Threat activities as included in the Halton Region SPA Assessment Report were used to populate worksheet E. Three significant threats were identified. Following the threat risk level and vulnerability rating matrix these threats are categorised as Group III. These significant threats are based on event-based modelling and are not related to climate change nor can be directly addressed through measures or policies related to climate change. However, to improve drinking water sources quality in light of changing climate, identification of area and intake sensitive attributes and potentially lowering their sensitivity scores through policy or management measures can lead to lowering the overall vulnerability rating and move the identified threats to a lower Group rating.

CCVAT Results and Sensitivity Analysis

The final climate change vulnerability rating for the Oakville system was identified as medium. Several area and intake sensitivity attributes have a deciding impact on the final climate change vulnerability rating.

The most significant area sensitive attributes influencing the final climate change adaptive vulnerability rating for the Oakville system are:

- areas to which de-icing products can be applied,
- floodplain and areas where flooding can occur,
- stormwater management facilities within Intake Protection Zones (IPZ), and
- stormwater system facilities within the assessment area.

The identified water quality issue at the Oakville intake and the number of intakes are the intake specific sensitive attributes influencing the final climate change adaptive capacity rating.

Recommendations:

To reduce the Oakville system's overall climate change vulnerability rating, some identified attributes can be managed through new policies aimed at lowering their sensitivities. **Table 4** policy and management measure ideas No. 1, 3, 5, 6, 7 and 10 should be considered.

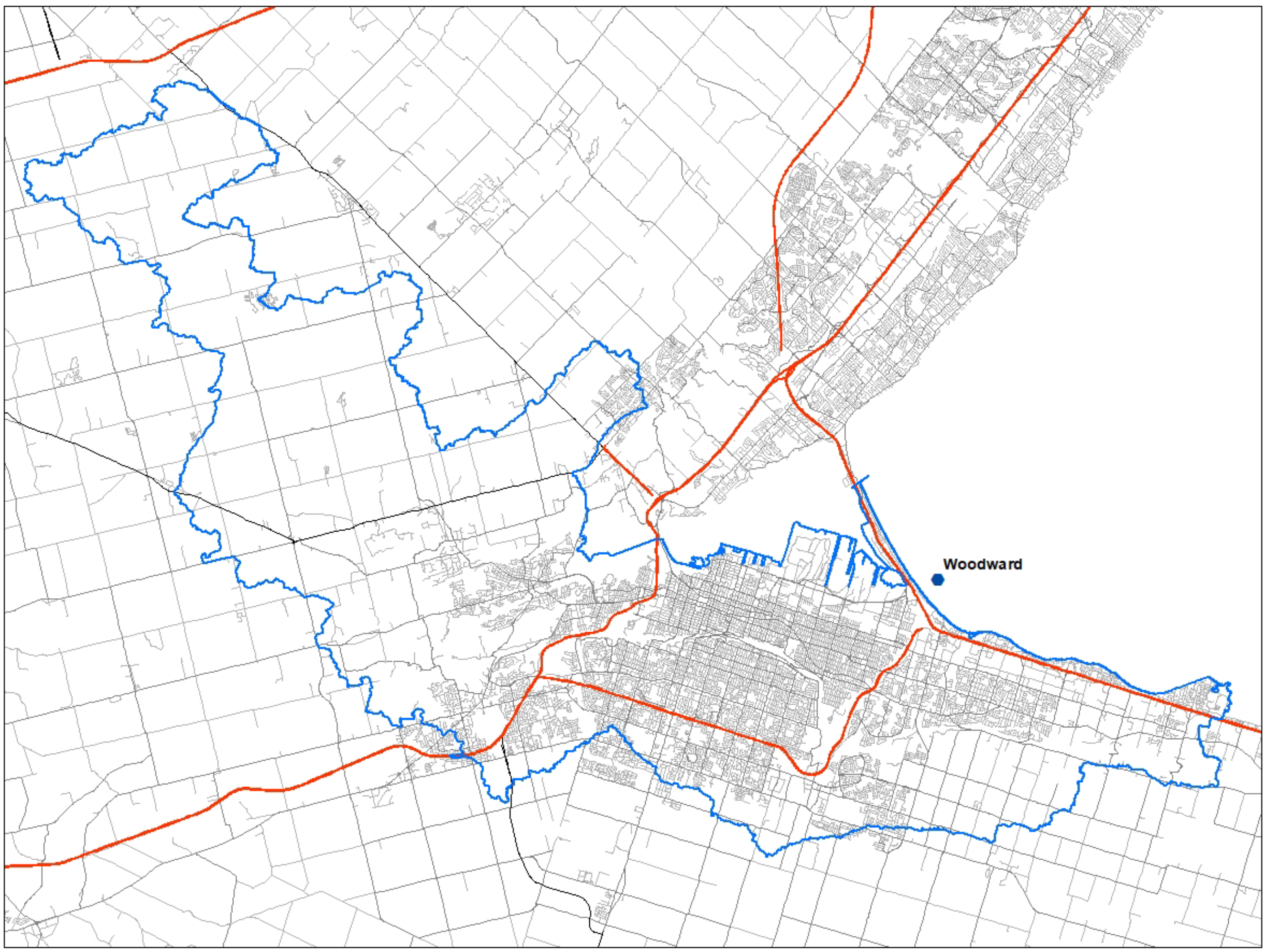
APPENDIX A4 - WOODWARD

The Woodward Drinking Water System is the only system operated by the City of Hamilton in Lake Ontario. The system is comprised of three intakes and intake pipes and a water treatment plant. Only two of the intakes are currently used for production.

Scale of the assessment area

Like the assessments conducted for the Lake Ontario based Halton Region systems, the Woodward CCVAT assessment took into account the entire Hamilton Region SPA as its study area, recognizing that surface runoff from the entire watershed can impact the quality of lake water. **Map 2** shows the Hamilton Region SPA and the Hamilton/Woodward Lake Ontario intakes.

Map 2: Hamilton Region SPA and In-lake Intakes



Climate data description

The source and spatial resolution scale of the climate data sets used in the assessment and the results of the trend analyses is summarised in Table 3 of worksheet *A2. CC Exposure* of the CCVAT Excel workbook. The following is a summary of the sources used in the study:

- Data for six (6) of the 10 climate parameters, i.e. Minimum Temperature (annual and seasonal), Maximum Temperature (annual and seasonal), Precipitation (annual and seasonal), Very Hot Days, Frost Free Season, and Freeze Thaw Cycle, were obtained from the Climate Atlas of Canada website. Considering there is no appropriate grid cell encompassing Hamilton SPA two of the small grid cells for the Burlington region and Stoney Creek region were averaged to represent the local conditions.
- Heavy Precipitation data was collected from climatedata.ca website using 36 small grid cells to ensure similar coverage to the Climate Atlas of Canada used for the assessment.
- The Maximum Length of Dry Spell data were obtained from the Ontario Climate Data Portal for the Hamilton-Wentworth region.
- Since future data for rainfall and snowfall are unavailable, the future trends for both parameters were based on the CCVAT Burlington pilot study conducted by CO and the study team. This approach mirrors the methodology used in the Burlington study, with one exception: the trends for summer rainfall and snowfall were changed to "Not Changing" to align with the overall trend for total precipitation.

Due to the number of regression analyses which had to be completed, all plots and regression summary outputs are available in associated climate data regression analyses spreadsheets. The trend analyses of all parameters for both historical and future data were completed, and the results populated in worksheet A2. CC Exposure.

Area and Intake Sensitivity

The Hamilton Region SPA Assessment Report was the main source of data used to populate CCVAT worksheet B1-Area Sensitivity and B2-Intake Sensitivity. Spatially distributed and geographical data was integrated, visualised, analysed and summarised using geographical information system (GIS) software and the results populated in the CCVAT spreadsheet.

Future land use estimates were based on the Official Plan, or in cases of insufficient data on projected population growth. For more details, the reader is directed to CCVAT worksheets B1 and B2 notes to identify the source of information or the method used to obtain estimates.

Given the utilization of abundant factual data, spatially distributed data, and detailed GIS analysis to summarize data in this phase, a **low** level of uncertainty was assigned to both the area and intake climate change sensitivity assessments.

Intake Impact Assessment

Conservation Halton and municipal staff reviewed the initial impact scores for both the study area and the intake and concluded that no further adjustments were needed. The calculated final climate change impact score corresponds to **medium** impact rating. A **high** level of uncertainty was assigned, primarily attributed to the incorporation of the exposure assessment result, which relied on modeled future data.

Adaptive Capacity and Climate Change Vulnerability Rating

The subsequent phase in the CCVAT assessment involves allotting adaptive capacity and vulnerability (worksheet D. AdCap and Vulnerability). Certain attributes related to adaptive capacity and vulnerability are auto populated based on area and intake sensitivity data. The remaining details were supplied by the City's plant operating staff. Given the information and its sources utilized in this assessment, a **low** level of uncertainty has been assigned.

The overall climate change vulnerability score for the Woodward system is 2.4 out of 9. This corresponds to **low** vulnerability rating.

Threat Activities

Threat activities as included in the Hamilton Region SPA Assessment Report were used to populate worksheet E. Three significant threats were identified. Following the threat risk level and vulnerability rating matrix these threats are categorised as Group II. These significant threats are based on event-based modelling and are not related to climate change nor can they be directly addressed through measures or policies related to climate change. However, to improve drinking water sources quality in light of changing climate, identification of area and intake sensitive attributes and potentially lowering their sensitivity scores through policy or management measures can lead to lowering the overall vulnerability rating and move the identified threats to a lower Group rating.

CCVAT Results and Sensitivity Analysis

The final climate change vulnerability rating for the Woodward system was identified as low. Several area and intake sensitivity attributes have a deciding impact on the final climate change vulnerability rating.

The most significant area sensitive attributes influencing the final climate change adaptive vulnerability rating for the Woodward system are:

- areas to which de-icing products can be applied,
- floodplain and areas where flooding can occur,
- stormwater management facilities within Intake Protection Zones (IPZ), and
- stormwater system facilities within the assessment area.

The identified water quality issue at the Woodward intake is the only intake specific sensitive attribute influencing the final climate change adaptive capacity rating.

Recommendations:

To reduce the Woodward system's overall climate change vulnerability rating, some identified attributes can be managed through new policies aimed at lowering their sensitivities. **Table 4** policy and management measure ideas No. 1, 3, 5, 6, and 7 should be considered.

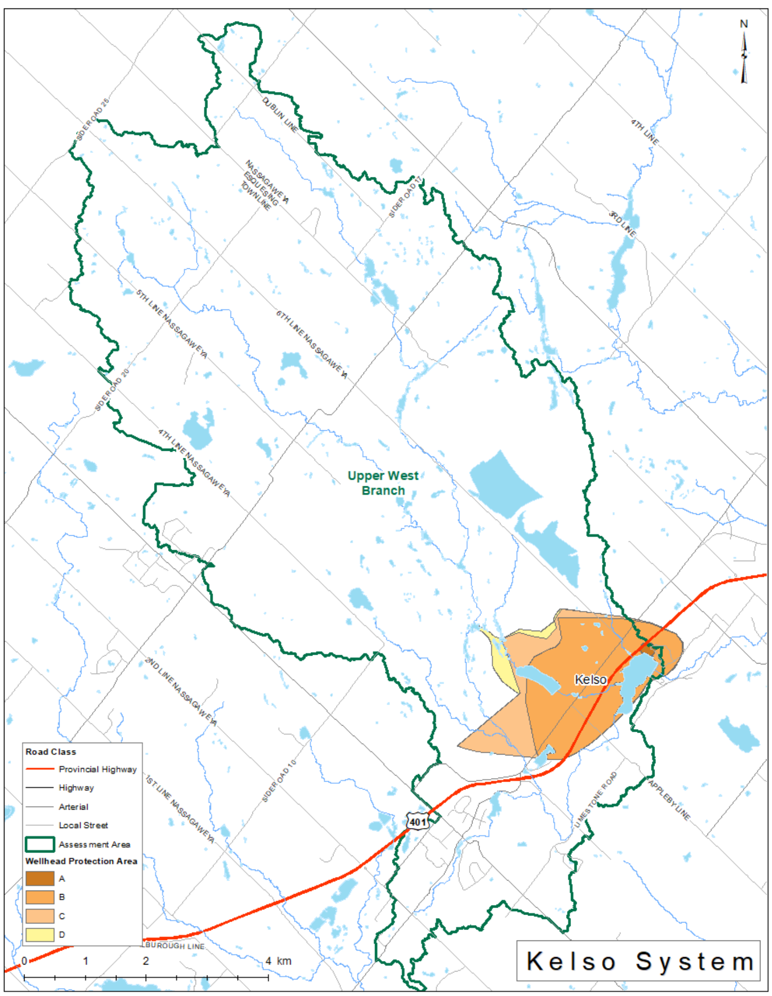
APPENDIX A5 - KELSO

The groundwater sourced Kelso Drinking Water System is one of the three groundwater-based systems operated by Halton Region within the Halton Region SPA. It is comprised of four groundwater wells completed in a confined sand and gravel bedrock valley aquifer and a drinking water treatment system located near the east end of Kelso Reservoir in the Town of Milton.

Scale of the assessment area

The Kelso groundwater wells, along with the delineated wellhead protection area (WHPA), are situated at the downstream end of the Upper West Branch of the Sixteen Mile Creek sub-watershed. Given that the Kelso system underwent a Tier 3 Water Budget assessment at the sub-watershed level and recognizing that the groundwater supplying the Kelso bedrock valley is influenced by the overall groundwater flow from the sub-watershed, the CCVAT assessment was conducted on a sub-watershed scale. **Map 3** outlines the Kelso WHPA and CCVAT assessment area.

Map 3: Kelso WHPA and CCVAT Assessment Area



Climate data description

The source and spatial resolution of climate data sets used in the assessment is summarised in Table 3 of worksheet A2. CC Exposure of the CCVAT Excel workbook. The following is a summary of the sources used in the study:

- Data for six (6) of the 10 climate parameters, i.e. Minimum Temperature (annual and seasonal), Maximum Temperature (annual and seasonal), Precipitation (annual and seasonal), Very Hot Days, Frost Free Season, and Freeze Thaw Cycle, were obtained from the Climate Atlas of Canada website, using the small grid for the Burlington region, which covers the Upper West Branch of Sixteen Mile Creek sub-watershed.
- Heavy Precipitation data was collected from climatedata.ca website using 18 small grid cells to ensure similar coverage to the Climate Atlas Canada small grid for the Burlington region.
- The Maximum Length of Dry Spell data were obtained from the Ontario Climate Data Portal for the Halton region.
- Since future data for rainfall and snowfall are unavailable, the future trends for both parameters were based on the CCVAT Burlington pilot study conducted by CO and the study team. This approach mirrors the methodology used in the Burlington study, with one exception: the trends for summer rainfall and snowfall were changed to "Not Changing" to align with the overall trend for total precipitation.

Due to the number of regression analyses which had to be completed, all plots and regression summary outputs are available in associated climate data regression analyses spreadsheets. The trend analyses of all parameters for both historical and future data were completed, and the results populated in worksheet A2. CC Exposure.

Area and Well Sensitivity

The Halton Region SPA Assessment Report was the main source of data used to populate CCVAT worksheet B1-Area Sensitivity and B2-Well Sensitivity. Spatially distributed and geographical data was integrated, visualised, analysed and summarised using geographical information system (GIS) software and the results populated in the CCVAT spreadsheet.

Future land use estimates were based on the Official Plan, or in cases of insufficient data on projected population growth. For more details, the reader is directed to CCVAT worksheets B1 and B2 notes to identify the source of information or the method used to obtain estimates.

Given the utilization of abundant factual data, spatially distributed data, and detailed GIS analysis to summarize data in this phase, a **low** level of uncertainty was assigned to both the area and well climate change sensitivity assessments.

Well Impact Assessment

Conservation Halton and municipal staff reviewed the initial impact scores for both the study area and the intake and concluded that no further adjustments were needed. The calculated final climate change impact score corresponds to **low** impact rating. A **high** level of uncertainty was identified, primarily attributed to the incorporation of the exposure assessment result, which relied on modeled future data.

Adaptive Capacity and Climate Change Vulnerability Rating

The subsequent phase in the CCVAT assessment involves allotting adaptive capacity and vulnerability (worksheet D. AdCap and Vulnerability). Certain attributes related to adaptive capacity and vulnerability are auto populated based on area and intake sensitivity data. The remaining details were supplied by Halton Region water treatment plant operating staff. Given the information and its sources utilized in this assessment, a **low** level of uncertainty has been assigned.

The climate change vulnerability score for the Kelso groundwater system is 1.6 out of 9. This corresponds to **low** vulnerability rating.

Threat Activities

Threat activities as included in Halton Region SPA Assessment Report were used to populate worksheet E. Five significant threat activities were identified. Following the threat risk level and vulnerability rating matrix these are Group II threats. These significant threat activities are not linked to climate change nor can they be directly addressed through measures or policies related to climate change. However, identifying area and well sensitive attributes and potentially lowering their sensitivity scores through policy or management measures can lead to lowering the overall vulnerability rating and move the identified threats to lower group rating.

CCVAT Results and Sensitivity Analysis

Although the final climate change vulnerability rating was identified as **low** there are several area and well sensitivity attributes which have a deciding impact on the final climate change vulnerability rating.

The most significant area sensitive attribute influencing the final climate change adaptive capacity rating for the Kelso system is:

- floodplain and areas where flooding can occur.

The identified well sensitivity attributes influencing the final vulnerability score are:

- potential for water quality issues to worsen; and
- potential for water quality degradation due to water quantity risks (Tier 3 Water Budget).

Considering the low vulnerability rating there are no necessary measures required to lower the vulnerability rating; however, to improve the conditions the following actions would benefit the Kelso system.

Recommendations:

To reduce the Kelso system's overall climate change vulnerability rating, some identified attributes can be managed through new policies aimed at lowering their sensitivities. **Table 4** policy and management measure ideas No. 3 and 9 should be considered.

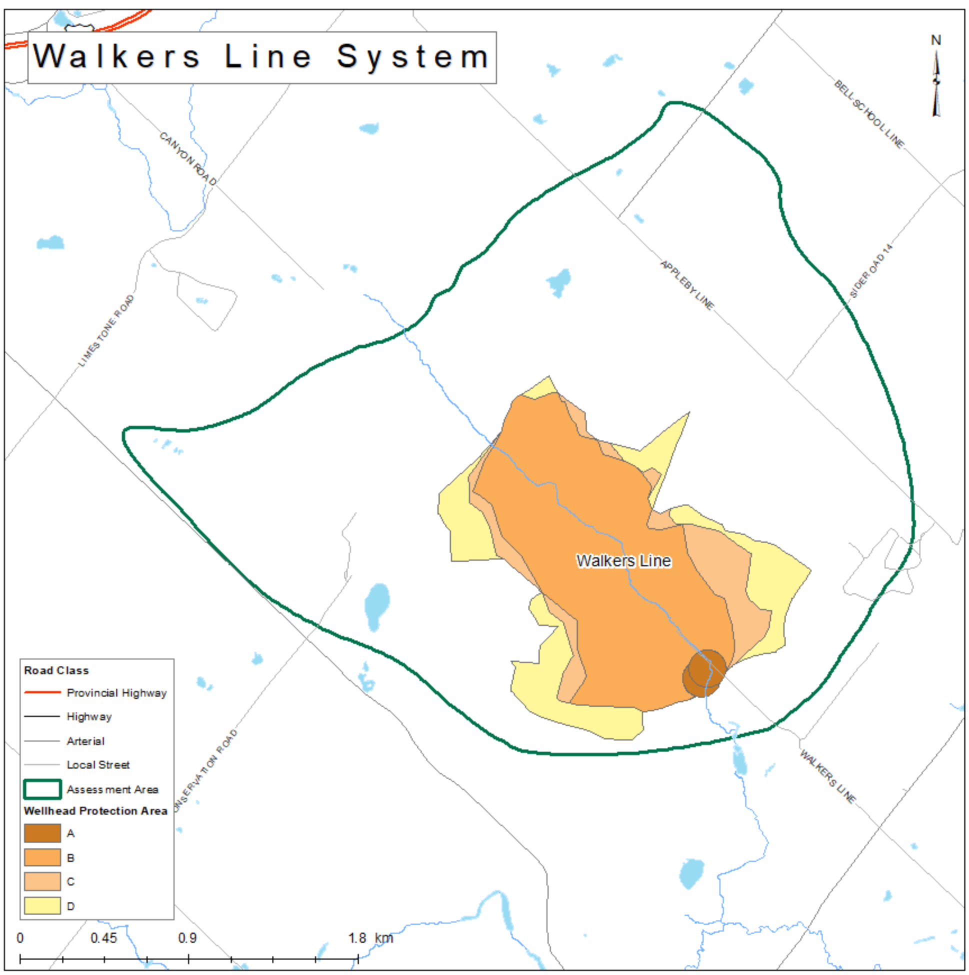
APPENDIX A6 - WALKERS LINE

The groundwater sourced Walkers Line Drinking Water System is connected to the Kelso distribution system and is one of the three groundwater-based systems operated by Halton Region within the Halton Region SPA. The system is comprised of two overburden wells and a treatment facility.

Scale of the assessment area

The Walkers Line groundwater wells are located near the southern end of the Nassagaweya Canyon. The Walkers Line wellhead protection areas (WHPA) are situated within the Limestone Creek sub-watershed, situated near its headwaters. Recognizing that the potential influence on water quality at the wells does not precisely align with surface watershed boundaries, an approximate ground-watershed was delineated to represent the contributing area. The source of water table data to delineate the ground-watershed was the 2010 Halton Region groundwater model used to delineate Walkers Line WHPA. **Map 4** outlines the Walkers Line WHPA and ground-watershed used for the CCVAT assessment.

Map 4: Walkers Line WHPA and CCVAT Ground-watershed



Climate data description

The source and spatial resolution of climate data sets used in the assessment is summarised in Table 3 of worksheet A2. CC Exposure of the CCVAT Excel workbook. The following is a summary of the sources used in the study:

- Data for six (6) of the 10 climate parameters, i.e. Minimum Temperature (annual and seasonal), Maximum Temperature (annual and seasonal), Precipitation (annual and seasonal), Very Hot Days, Frost Free Season, and Freeze Thaw Cycle, were obtained from the Climate Atlas of Canada website, using the small grid for the Burlington region, which covers the Walkers Line ground-watershed area.
- Heavy Precipitation data was collected from climatedata.ca website using 18 small grid cells to ensure similar coverage to the Climate Atlas of Canada data.
- The Maximum Length of Dry Spell data were obtained from the Ontario Climate Data Portal for the region depicted as Halton.
- Since future data for rainfall and snowfall are unavailable, the future trends for both parameters were based on the CCVAT Burlington pilot study conducted by CO and the study team. This approach mirrors the methodology used in the Burlington study, with one exception: the trends for summer rainfall and snowfall were changed to "Not Changing" to align with the overall trend for total precipitation.

Due to the number of regression analyses which had to be completed, all plots and regression summary outputs are available in associated climate data regression analyses spreadsheets. The trend analyses of all parameters for both historical and future data were completed, and the results populated in worksheet A2. CC Exposure.

Area and Well Sensitivity

The Halton Region SPA Assessment Report was the main source of data used to populate CCVAT worksheet B1-Area Sensitivity and B2- Well Sensitivity. Spatially distributed and geographical data was integrated, visualised, analysed and summarised using geographical information system (GIS) software and the results populated in the CCVAT spreadsheet.

Future land use estimates were based on the Official Plan, or in cases of insufficient data on projected population growth. For more details, the reader is directed to CCVAT worksheets B1 and B2 notes to identify the source of information or the method used to obtain estimates.

Given the utilization of abundant factual data, spatially distributed data, and detailed GIS analysis to summarize data in this phase, a **low** level of uncertainty was assigned to both the area and well climate change sensitivity assessments.

Well Impact Assessment

Conservation Halton and municipal staff reviewed the initial impact scores for both the study area and the intake and concluded that no further adjustments were needed. The calculated final climate change impact score corresponds to **medium** qualitative impact rating. A **high** level of uncertainty was identified, primarily attributed to the incorporation of the exposure assessment result, which relied on modeled future data.

Adaptive Capacity and Climate Change Vulnerability Rating

The subsequent phase in the CCVAT assessment involves allotting adaptive capacity and vulnerability (worksheet D. AdCap and Vulnerability). Certain attributes related to adaptive capacity and vulnerability are auto populated based on area and intake sensitivity data. The remaining details were supplied by Halton Region water treatment plant operating staff. Given the information and its sources utilized in this assessment, a **low** level of uncertainty has been assigned.

The climate change vulnerability score for the Walkers Line groundwater system is 2.6 out of 9. This corresponds to **low** vulnerability rating.

Threat Activities

Threat activities as included in Halton Region SPA Assessment Report were used to populate worksheet E. Only one significant threat was identified. Following the threat risk level and vulnerability rating matrix it falls into threat category Group II. Currently there is no information to confirm if the threat exists or not. However, the type of the threat is not climate change related, and therefore no measures can be incorporated to reduce its risk rating in terms of climate change. It is however possible to identify area and well sensitive attributes which have the biggest effect on the vulnerability rating to maintain a low rating.

CCVAT Results and Sensitivity Analysis

Although the final climate change vulnerability rating was identified as **low** there are several area and well sensitivity attributes which have a deciding impact on the final climate change vulnerability rating.

The most significant area sensitive attribute influencing the final climate change adaptive capacity rating for the Walkers Line system is:

- floodplain and areas where flooding can occur.

The identified well sensitivity attributes influencing the final vulnerability score are:

- potential for water quality issues to worsen; and
- aquifer type and aquifer vulnerability in the area.

Considering the low vulnerability rating there are no necessary measures required to lower the vulnerability rating; however, to improve the conditions the following actions would benefit the Walkers Line system.

Recommendations:

To reduce the Walkers Line system's overall climate change vulnerability rating, some identified attributes can be managed through new policies aimed at lowering their sensitivities. **Table 4** policy and management measure ideas No. 3, 8 and 12 should be considered.

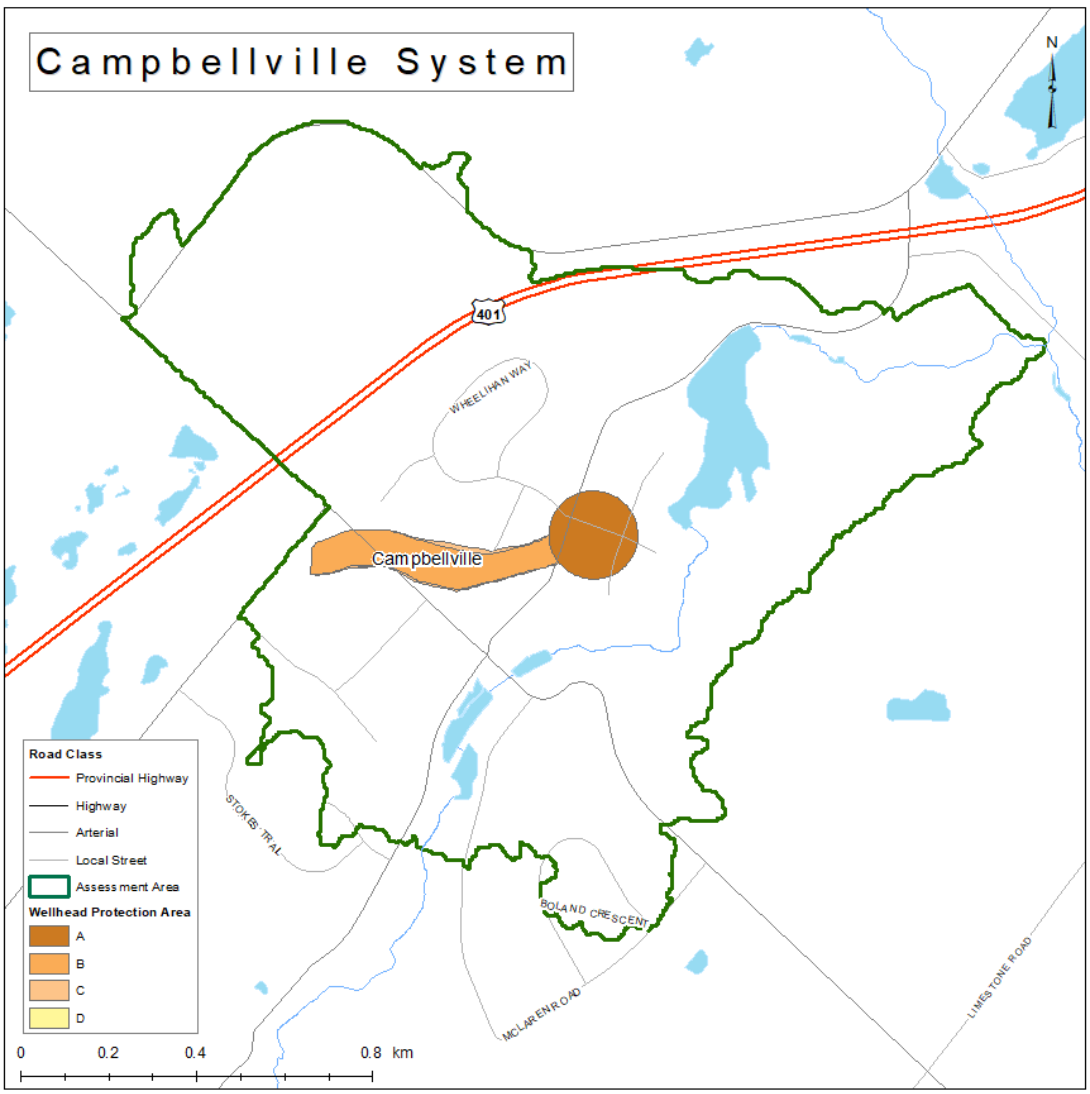
APPENDIX A7 - CAMPBELLVILLE

The groundwater sourced Campbellville Drinking Water System is one of the three groundwater-based systems operated by Halton Region within the Halton Region SPA. The Campbellville system is comprised of two overburden wells and a drinking water treatment system.

Scale of the assessment area

Similarly to Kelso, the Campbellville groundwater wells are located near the downstream end of the Upper West Branch sub-watershed. However, considering the size of the system in terms of number of users it supports and the size of its wellhead protection area (WHPA), a surface water catchment aligns more accurately with the area influencing the water quality in the system. The catchment is identified as Catchment 123. **Map 5** outlines the Campbellville WHPA and the surface water catchment used for the CCVAT assessment.

Map 5: Campbellville WHPA and CCVAT Catchment



Climate data description

The source and spatial resolution of climate data sets used in the assessment is summarised in Table 3 of worksheet A2. CC Exposure of the CCVAT Excel workbook. The following is a summary of the sources used in the study:

- Data for six (6) of the 10 climate parameters, i.e. Minimum Temperature (annual and seasonal), Maximum Temperature (annual and seasonal), Precipitation (annual and seasonal), Very Hot Days, Frost Free Season, and Freeze Thaw Cycle, were obtained from the Climate Atlas of Canada website, using the small grid for the Burlington region.
- Heavy Precipitation data was collected from climatedata.ca website using 18 small grid cells to ensure similar coverage to the Climate Atlas of Canada data coverage.
- The Maximum Length of Dry Spell data were obtained from the Ontario Climate Data Portal for the region depicted as Halton.
- Since future data for rainfall and snowfall are unavailable, the future trends for both parameters were based on the CCVAT Burlington pilot study conducted by CO and the study team. This approach mirrors the methodology used in the Burlington study, with one exception: the trends for summer rainfall and snowfall were changed to "Not Changing" to align with the overall trend for total precipitation.

Due to the number of regression analyses which had to be completed, all plots and regression summary outputs are available in associated climate data regression analyses spreadsheets. The trend analyses of all parameters for both historical and future data were completed, and the results populated in worksheet A2. CC Exposure.

Area and Well Sensitivity

The Halton Region SPA Assessment Report was the main source of data used to populate CCVAT worksheet B1-Area Sensitivity and B2-Well Sensitivity. Spatially distributed and geographical data was integrated, visualised, analysed and summarised using geographical information system (GIS) software and the results populated in the CCVAT spreadsheet.

Future land use estimates were based on the Official Plan, or in cases of insufficient data on projected population growth. For more details, the reader is directed to CCVAT worksheets B1 and B2 notes to identify the source of information or the method used to obtain estimates.

Given the utilization of abundant factual data, spatially distributed data, and detailed GIS analysis to summarize data in this phase, a **low** level of uncertainty was assigned to both the area and well climate change sensitivity assessments.

Well Impact Assessment

The initial impact scores for both the study area and the well were examined by Conservation Halton and municipal staff. Staff reduced the impact score for the attribute "Potential for water quality degradation due to water quantity risks" from 6 to 2. The Campbellville Tier 3 water budget was completed by default as the Campbellville system is in the same subwatershed as Kelso. The Campbellville system can meet allocated pumping for all the Tier 3 scenarios and therefore there is no water quantity risk to the system. No other adjustments to the impact scores were necessary.

The calculated final climate change impact score corresponds to a **medium** impact rating. A **high** level of uncertainty was identified, primarily attributed to the incorporation of the exposure assessment result, which relied on modeled future data.

Adaptive Capacity and Climate Change Vulnerability Rating

The subsequent phase in the CCVAT assessment involves allotting adaptive capacity and vulnerability (worksheet D. AdCap and Vulnerability). Certain attributes related to adaptive capacity and vulnerability are auto populated based on area and intake sensitivity data. The remaining details were supplied by Halton Region plant operating staff. Given the information and its sources utilized in this assessment, a **low** level of uncertainty has been assigned.

The climate change vulnerability score for the Walkers Line groundwater system is 3.3[1] out of 9. This corresponds to **medium** vulnerability rating.

Threat Activities

The threat activities identified in the Halton Region SPA Assessment Report were used to complete Worksheet E. Two categories of threat activities were recognized: the handling and storage of fuel, and private sewage systems. Based on the threat risk level and vulnerability rating matrix, both activities fall into Group III of threat activities. Fuel handling and storage are not related to climate change, so no additional measures are needed beyond those already included in the Source Protection Plan. For private sewage systems, there are limited options to address this existing threat. However, for future private sewage systems in the assessment area, a policy could be developed that requires maintaining or enhancing infiltration from pre- to post-development to prevent water quality impairment. Alternatively, policies and management measures could be created, for specific area and well/wellfield sensitive attributes that significantly impact vulnerability ratings, to reduce vulnerability and lower the risk rating.

CCVAT Results and Sensitivity Analysis

Although the final climate change vulnerability rating was identified as **medium** there are several area and well sensitivity attributes which have a deciding impact on the final climate change vulnerability rating.

The most significant area sensitive attribute influencing the final climate change adaptive capacity rating for the Campbellville system is:

- surfaces to which de-icing products can be applied.

The identified well sensitivity attributes influencing the final vulnerability score are:

- potential for water quality issues to worsen,
- number of wells and the aquifer type and aquifer vulnerability in the area,
- reduced recharge, and

[1] There is an error in the spreadsheet that underestimates the Area Scale adaptive capacity. The cells for stormwater and wastewater are not being populated because there are no stormwater or wastewater systems. However, the adaptive capacity calculation incorrectly divides the Area Attributes portion of the equation by 4 instead of 2. This results in an underestimated Adaptive Capacity rating.

- potential for water quality degradation due to water quantity risks (Tier 3 Water Budget).

The aquifer vulnerability in the area is **high**, according to the Halton Source Protection Area assessment report mapping.

Although the potential for water quality degradation due to water quantity risks was identified as a well sensitive attribute, the Tier 3 water budget was only required due to the presence of the Kelso system in the same sub-watershed, not because of water quantity concerns in Campbellville, and therefore the potential for water quantity risks is not a concern.

Recommendations:

To reduce the Campbellville system's overall climate change vulnerability rating, some identified attributes can be managed through new policies aimed at lowering their sensitivities. **Table 4** policy and management measure ideas No. 1, 8, 10 and 13 should be considered.

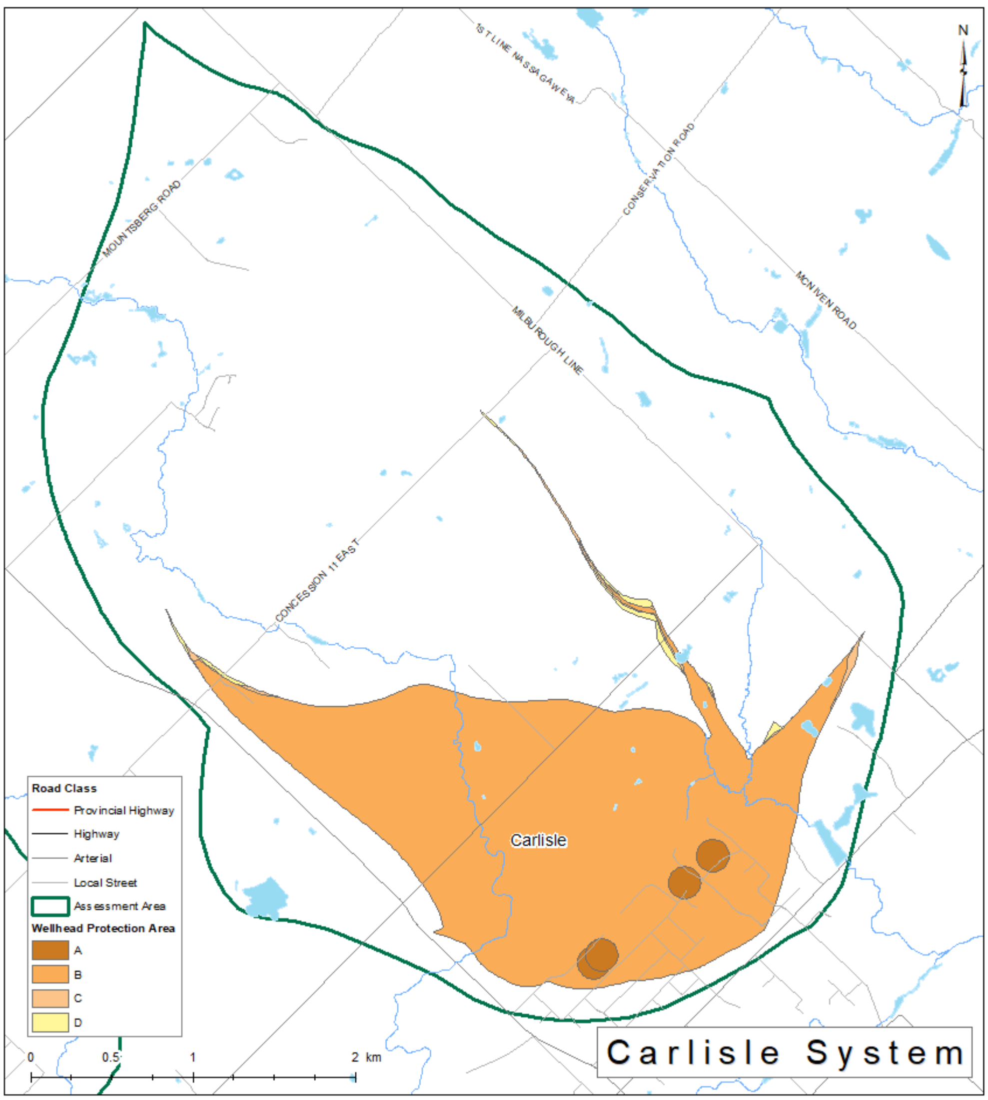
APPENDIX A8 - CARLISLE

The Carlisle Drinking Water System is one of two groundwater-based systems operated by the City of Hamilton located within Halton Region SPA. The system is comprised of four bedrock wells and a treatment system located in the community of Carlise in the City of Hamilton.

Scale of the assessment area

Although the Carlisle groundwater wells are located within the Flamboro Creek sub-watershed, the WHPA for the system extends into three different sub-watersheds. To identify areas potentially influencing water quality in the system a ground-watershed was delineated. The source of water table data for the delineation was the 2008 groundwater flow model developed to define the WHPA for the Carlisle system. **Map 6** outlines the Carlisle WHPA and the delineated ground-watershed used for the Carlisle CCVAT assessment.

Map 6: Carlisle WHPA and CCVAT Ground-watershed



Climate data description

The source and spatial resolution of climate data sets used in the assessment is summarised in Table 3 of worksheet A2. CC Exposure of the CCVAT Excel workbook. The following is a summary of the sources used in the study:

- Data for six (6) of the 10 climate parameters, i.e. Minimum Temperature (annual and seasonal), Maximum Temperature (annual and seasonal), Precipitation (annual and seasonal), Very Hot Days, Frost Free Season, and Freeze Thaw Cycle, were obtained from the Climate Atlas of Canada website, using the small grid for the region depicted as Cambridge on the CAC website.
- Heavy Precipitation data was collected from climatedata.ca website. An average of 18 small grid cells encompassing the same area as the Climate Atlas of Canada Cambridge region cell to ensure similar coverage.
- The Maximum Length of Dry Spell data were obtained from the Ontario Climate Data Portal for the Hamilton-Wentworth region.
- Since future data for rainfall and snowfall are unavailable, the future trends for both parameters were based on the CCVAT Burlington pilot study conducted by CO and the study team. This approach mirrors the methodology used in the Burlington study, with one exception: the trends for summer rainfall and snowfall were changed to "Not Changing" to align with the overall trend for total precipitation.

Due to the number of regression analyses which had to be completed, all plots and regression summary outputs are available in associated climate data regression analyses spreadsheets. The trend analyses of all parameters for both historical and future data were completed, and the results populated in worksheet A2. CC Exposure.

Area and Well Sensitivity

The Halton Region SPA Assessment Report was the main source of data used to populate CCVAT worksheet B1-Area Sensitivity and B2- Well Sensitivity. Spatially distributed and geographical data was integrated, visualised, analysed and summarised using geographical information system (GIS) software and the results populated in the CCVAT spreadsheet.

Future land use estimates were based on the Official Plan, or in cases of insufficient data on projected population growth. For more details, the reader is directed to CCVAT worksheets B1 and B2 notes to identify the source of information or the method used to obtain estimates.

Given the utilization of abundant factual data, spatially distributed data, and detailed GIS analysis to summarize data in this phase, a **low** level of uncertainty was assigned to both the area and well climate change sensitivity assessments.

Well Impact Assessment

Conservation Halton and municipal staff reviewed the initial impact scores for both the study area and the well/wellfield and concluded that no further adjustments were needed. The calculated final climate change impact score corresponds to a **high** impact rating. Also, a **high** level of uncertainty

was identified, primarily attributed to the incorporation of the exposure assessment result, which relied on modeled future data.

Adaptive Capacity and Climate Change Vulnerability Rating

The subsequent phase in the CCVAT assessment involves assigning adaptive capacity and vulnerability (worksheet D. AdCap and Vulnerability). Certain attributes related to adaptive capacity and vulnerability are auto populated based on area and intake sensitivity data. The remaining details were supplied by city of Hamilton staff. Given the information and its sources utilized in this assessment, a **low** level of uncertainty has been assigned.

The climate change vulnerability score for the Carlisle groundwater system is 2.7[2] out of 9. This corresponds to **low** vulnerability rating.

Threat Activities

Threat activities as included in Halton Region SPA Assessment Report were used to populate worksheet E. Although there were several significant threat activities identified in the assessment report, a number of threat activities were removed through field verification. The only remaining threat activity category is private sewage works. Following the threat risk level and vulnerability rating matrix the threat activity falls into Group II. There are limited options to address this type of an existing threat activity as it relates to climate change. Potentially, for future private sewage systems within the area of assessment, a policy could be developed requiring maintaining or enhancing pre- to post-development infiltration to ensure water quality is not impaired.

It is also possible to identify area and well sensitive attributes which have the biggest effect on the vulnerability rating to keep it low and reduce the identified threats risk level in terms of climate change.

CCVAT Results and Sensitivity Analysis

Although the final climate change vulnerability rating was identified as **low** there are several area and well sensitivity attributes which have a deciding impact on the final climate change vulnerability rating.

The most significant area sensitive attributes influencing the final climate change adaptive capacity rating for the Carlisle system are:

- potential for increased contaminant loadings due to agricultural activity,
- existence of flood plains and areas where flooding can occur, and
- potential for water degradation from storm sewers.

The identified well sensitivity attributes influencing the final vulnerability score are:

- water well supply GUDI status,

[2] There is an error in the spreadsheet that underestimates the Area Scale adaptive capacity. The cell for wastewater is not being populated because there are no wastewater systems. However, the adaptive capacity calculation incorrectly divides the Area Attributes portion of the equation by 4 instead of 3. This results in an underestimated Adaptive Capacity rating.

- reduced recharge; and
- aquifer type and aquifer vulnerability in the area.

It should be noted that the aquifer vulnerability is **high** in the area.

Recommendations:

To reduce the Carlisle system's overall climate change vulnerability rating, some identified attributes can be managed through new policies aimed at lowering their sensitivities. **Table 4** policy and management measure ideas No. 3, 4, 5, 11, 12 and 13 should be considered.

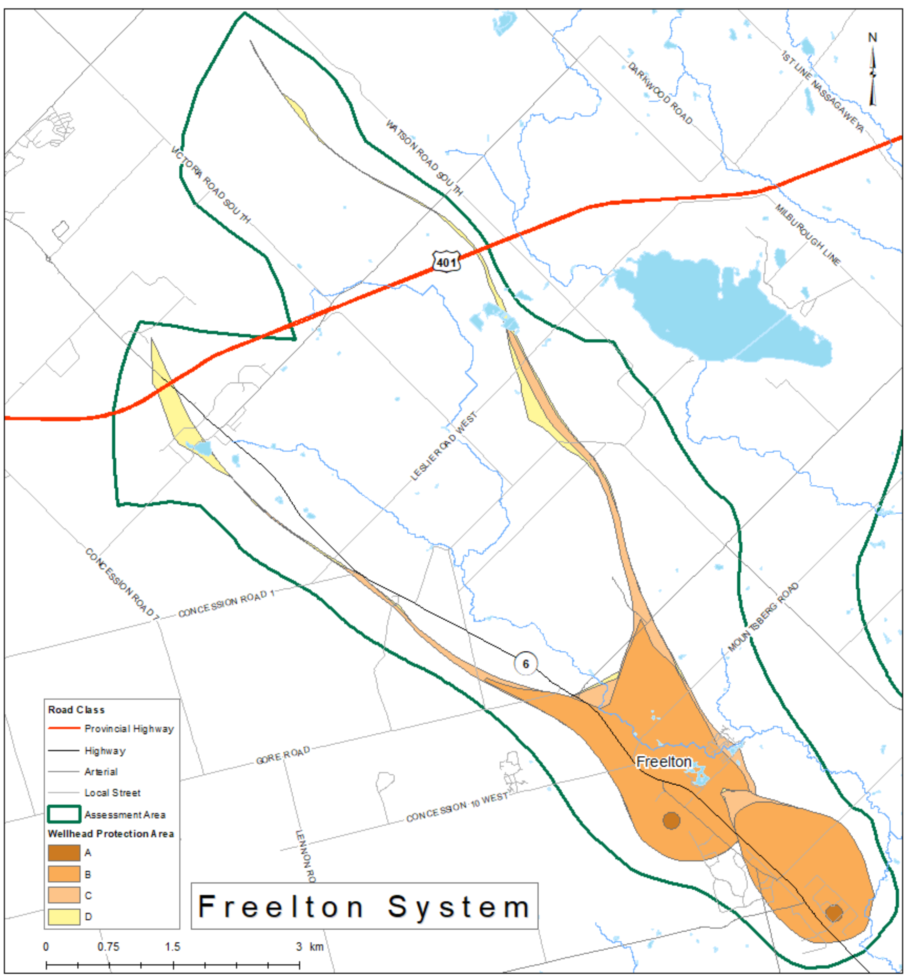
APPENDIX A9 - FREELTON

The Freelton Drinking Water System is one of two groundwater-based systems operated by the City of Hamilton located within Halton Region SPA. The system is comprised of two bedrock wells and two pump houses and treatment systems located in the community of Freelton in the City of Hamilton.

Scale of the assessment area

Although the Freelton groundwater wells are located within the Upper Main Branch of the Bronte Creek sub-watershed at least half of the sub-watershed is downgradient of the wells and has no impact on the Freelton water quality. The Freelton WHPAs extend into multiple sub-watersheds and lie within three different conservation authority jurisdictions. To identify the area potentially influencing water quality in the system a ground-watershed was delineated. The source of water table data for the delineation was the 2010 groundwater flow model developed for the City of Hamilton to define WHPAs and assign vulnerability levels. **Map 7** outlines the Freelton WHPAs and the delineated ground-watershed used for the Freelton CCVAT assessment.

Map 7: Freelton WHPA and CCVAT Ground-watershed



Climate data description

The source and spatial resolution of climate data sets used in the assessment is summarised in Table 3 of worksheet A2. CC Exposure of the CCVAT Excel workbook. The following is a summary of the sources used in the study:

- Data for six (6) of the 10 climate parameters, i.e. Minimum Temperature (annual and seasonal), Maximum Temperature (annual and seasonal), Precipitation (annual and seasonal), Very Hot Days, Frost Free Season, and Freeze Thaw Cycle, were obtained from the Climate Atlas of Canada website, using the small grid for the region depicted as Cambridge on the CAC website.
- Heavy Precipitation data was collected from climatedata.ca website. An average of 18 small grid cells encompassing the same area as the Climate Atlas of Canada Cambridge region cell to ensure similar coverage.
- The Maximum Length of Dry Spell data were obtained from the Ontario Climate Data Portal for the Hamilton-Wentworth region.
- Since future data for rainfall and snowfall are unavailable, the future trends for both parameters were based on the CCVAT Burlington pilot study conducted by CO and the study team. This approach mirrors the methodology used in the Burlington study, with one exception: the trends for summer rainfall and snowfall were changed to "Not Changing" to align with the overall trend for total precipitation.

Due to the number of regression analyses which had to be completed, all plots and regression summary outputs are available in associated climate data regression analyses spreadsheets. The trend analyses of all parameters for both historical and future data were completed, and the results populated in worksheet A2. CC Exposure.

Area and Well Sensitivity

The Halton Region SPA Assessment Report was the main source of data used to populate CCVAT worksheet B1-Area Sensitivity and B2-Well Sensitivity. Spatially distributed and geographical data was integrated, visualised, analysed and summarised using geographical information system (GIS) software and the results populated in the CCVAT spreadsheet.

Future land use estimates were based on the Official Plan, or in cases of insufficient data on projected population growth. For more details, the reader is directed to CCVAT worksheets B1 and B2 notes to identify the source of information or the method used to obtain estimates.

Given the utilization of abundant factual data, spatially distributed data, and detailed GIS analysis to summarize data in this phase, a **low** level of uncertainty was assigned to both the area and well climate change sensitivity assessments.

Well Impact Assessment

Conservation Halton and municipal staff reviewed the initial impact scores for both the study area and the well/wellfield and concluded that no further adjustments were needed. The calculated final climate change impact score corresponds to a **medium** impact rating. A **high** level of uncertainty

was identified, primarily attributed to the incorporation of the exposure assessment result, which relied on modeled future data.

Adaptive Capacity and Climate Change Vulnerability Rating

The subsequent phase in the CCVAT assessment involves assigning adaptive capacity and vulnerability (worksheet D. AdCap and Vulnerability). Certain attributes related to adaptive capacity and vulnerability are auto populated based on area and intake sensitivity data. The remaining details were supplied by City of Hamilton staff. Given the information and its sources utilized in this assessment, a **low** level of uncertainty has been assigned.

The climate change vulnerability score for the Freelton groundwater system is 2.2[3] out of 9. This corresponds to a **low** vulnerability rating.

Threat Activities

Threat activities as included in Halton Region SPA Assessment Report were used to populate worksheet E. There were 13 threat activity categories identified as significant in the assessment report. A number of threat activities were removed through field verification. Following the threat risk level and vulnerability rating matrix the threat activities fall into Group II.

Some of the threat categories as listed in the Technical Rules are not influenced by climate change and there seems to be limited options to develop additional policies and measures.

Potentially, for future private sewage systems within the area of assessment, a policy could be developed requiring maintaining or enhancing pre- to post-development infiltration to ensure water quality is not impaired.

To reduce the climate change overall impact, identification of area and well sensitive attributes which have the biggest effect on the vulnerability rating and developing policies to address them can be the most effective way to keep the vulnerability rating low and/or reduce the identified threats risk level in terms of climate change.

CCVAT Results and Sensitivity Analysis

Although the final climate change vulnerability rating was identified as **low** there are several area and well sensitivity attributes which have a deciding impact on the final climate change vulnerability rating.

The most significant area sensitive attributes influencing the final climate change adaptive capacity rating for the Freelton system are:

- potential for increased contaminant loadings due to agricultural activity, and
- existence of flood plains and areas where flooding can occur.

[3] There is an error in the spreadsheet that underestimates the Area Scale adaptive capacity. The cell for wastewater is not being populated because there are no wastewater systems. However, the adaptive capacity calculation incorrectly divides the Area Attributes portion of the equation by 4 instead of 3. This results in an underestimated Adaptive Capacity rating.

The identified well sensitivity attributes influencing the final vulnerability score are:

- number of water supply wells,
- reduced recharge,
- aquifer type and aquifer vulnerability in the area

Based on the assessment report mapping the aquifer vulnerability is **high** in the area.

Recommendations:

To reduce the Freelton system's overall climate change vulnerability rating, some identified attributes can be managed through new policies aimed at lowering their sensitivities. **Table 4** policy and management measure ideas No. 3, 4, 10, 12 and 13 should be considered to achieve this goal.

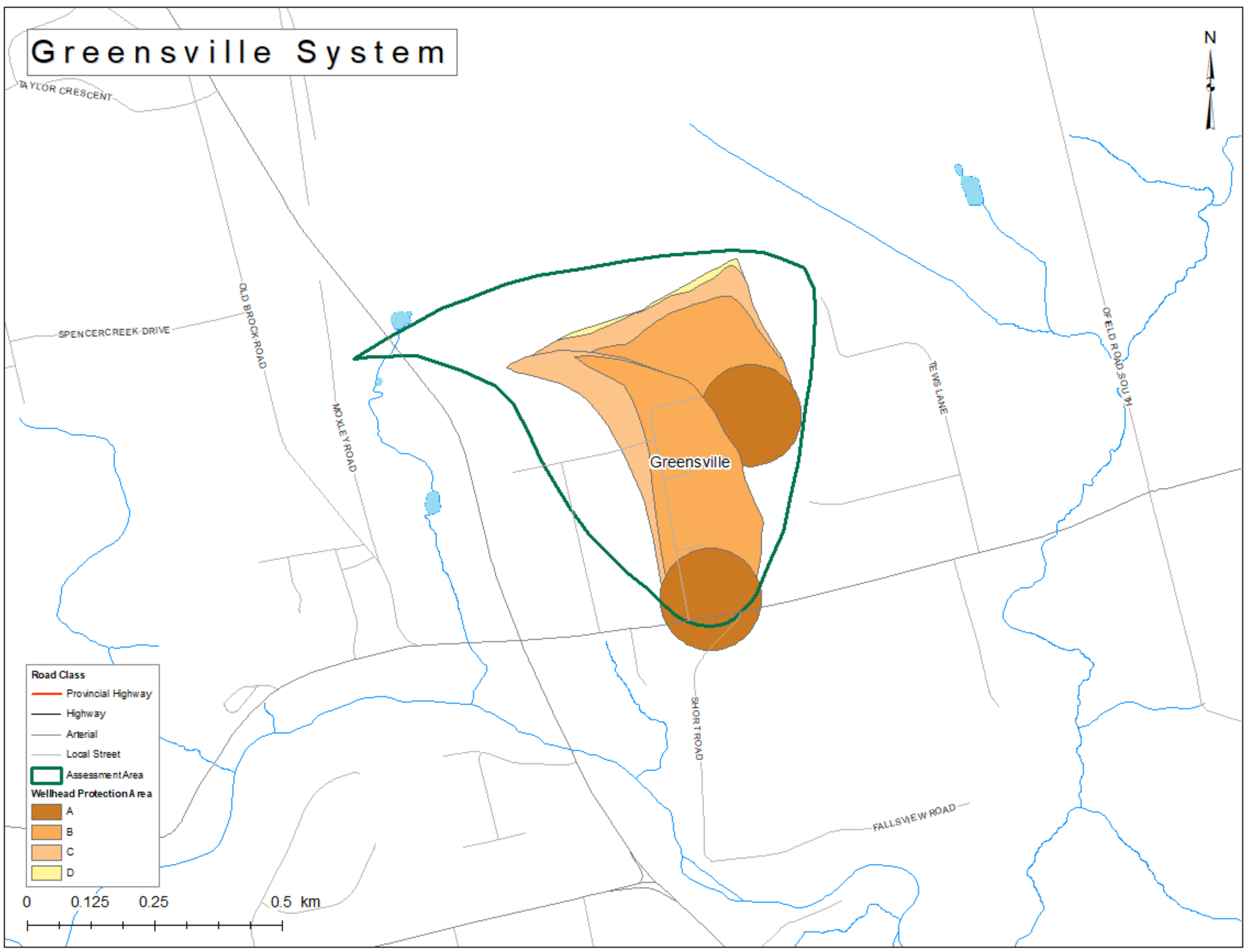
APPENDIX A10 - GREENSVILLE

The Greensville Drinking Water System is the only groundwater-based system operated by the City of Hamilton within the Hamilton Region SPA. The system is comprised of two wells, however, currently only one well is utilised for production.

Scale of the assessment area

The Greensville wells are situated at the lowermost point of a comparatively sizable sub-watershed, especially when compared to the dimensions of the Greensville WHPAs. Additionally, these WHPAs in Greensville are in proximity to the local catchment boundary and extend into multiple catchments. To identify the area potentially influencing water quality in the system, a ground-watershed was delineated. The source of water table data for the delineation was the 2017 groundwater flow model developed to define WHPAs for the City of Hamilton and assign vulnerabilities and complete a Tier 3 water budget. **Map 8** outlines the Carlisle WHPA and the delineated ground-watershed used for the Carlisle CCVAT assessment.

Map 8: Greensville WHPA and CCVAT Ground-watershed



Climate data description

The source and spatial resolution of climate data sets used in the assessment is summarised in Table 3 of worksheet A2. CC Exposure of the CCVAT Excel workbook. The following is a summary of the sources used in the study:

- Data for six (6) of the 10 climate parameters, i.e. Minimum Temperature (annual and seasonal), Maximum Temperature (annual and seasonal), Precipitation (annual and seasonal), Very Hot Days, Frost Free Season, and Freeze Thaw Cycle, were obtained from the Climate Atlas of Canada website, using the small grid for the region depicted as Cambridge on the CAC website.
- Heavy Precipitation data was collected from climatedata.ca website. An average of 18 small grid cells encompassing the same area as the Climate Atlas of Canada Cambridge region cell to ensure similar coverage.
- The Maximum Length of Dry Spell data were obtained from the Ontario Climate Data Portal for the Hamilton-Wentworth region.
- Since future data for rainfall and snowfall are unavailable, the future trends for both parameters were based on the CCVAT Burlington pilot study conducted by CO and the study team. This approach mirrors the methodology used in the Burlington study, with one exception: the trends for summer rainfall and snowfall were changed to "Not Changing" to align with the overall trend for total precipitation.

Due to the number of regression analyses which had to be completed, all plots and regression summary outputs are available in associated climate data regression analyses spreadsheets. The trend analyses of all parameters for both historical and future data were completed, and the results populated in worksheet A2. CC Exposure.

Area and Well Sensitivity

The Hamilton Region SPA Assessment Report was the main source of data used to populate CCVAT worksheet B1-Area Sensitivity and B2-Well Sensitivity. Spatially distributed and geographical data was integrated, visualised, analysed and summarised using geographical information system (GIS) software and the results populated in the CCVAT spreadsheet.

Future land use estimates were based on the Official Plan, or in cases of insufficient data on projected population growth. For more details, the reader is directed to CCVAT worksheets B1 and B2 notes to identify the source of information or the method used to obtain estimates.

Given the utilization of abundant factual data, spatially distributed data, and detailed GIS analysis to summarize data in this phase, a **low** level of uncertainty was assigned to both the area and well climate change sensitivity assessments.

Well Impact Assessment

The initial impact scores for both the study area and the well/wellfiled were examined by Conservation Halton and municipal staff. The area level indicator for existence of floodplains and potential for flooding was reduced from a score of 9 to 3 as only 1% of the most upgradient groundwater catchment is in a flood plain. The calculated final climate change impact score corresponds to **medium** impact rating. A **high** level of uncertainty was identified, primarily attributed to the incorporation of the exposure assessment result, which relied on modeled future data.

Adaptive Capacity and Climate Change Vulnerability Rating

The subsequent phase in the CCVAT assessment involves allotting adaptive capacity and vulnerability (worksheet D. AdCap and Vulnerability). Certain attributes related to adaptive capacity and vulnerability are auto populated based on area and intake sensitivity data. The remaining details were supplied by city of Hamilton staff. Given the information and its sources utilized in this assessment, a **low** level of uncertainty has been assigned.

The climate change vulnerability score for the Greensville groundwater system is 2.6 out of 9. This corresponds to **low** vulnerability rating.

Threat Activities

Threat activities as included in Hamilton Region SPA Assessment Report were used to populate worksheet E. Private sewage systems or sewage works was the only significant threat identified in the assessment report. Following the threat risk level and vulnerability rating matrix the threat falls into Group II.

There are limited options to address this type of an existing threat activity as it relates to climate change. Potentially, for future private sewage systems within the area of assessment, a policy could be developed requiring maintaining or enhancing pre- to post-development infiltration to ensure water quality is not impaired.

To reduce the climate change overall impact, identification of area and well sensitive attributes which have the biggest effect on the vulnerability rating and developing policies and/or mitigation measures to address them can be the most effective way to keep the vulnerability rating low and/or reduce the identified threats risk level in terms of climate change.

CCVAT Results and Sensitivity Analysis

Although the final climate change vulnerability rating was identified as **low** there are several area and well sensitivity attributes which have a deciding impact on the final climate change vulnerability rating.

The most significant area sensitive attributes influencing the final climate change adaptive capacity rating for the Greensville system are:

- Potential for increased runoff due to percent of built-up area, and
- potential for increased contaminant loadings due to percent of surface to which de-icing products can be applied to,

The identified well sensitivity attributes influencing the final vulnerability score are:

- number ow water supply wells,
- reduced recharge,
- aquifer type and aquifer vulnerability in the area, and

- potential for water quality degradation due to water quantity risks (Tier 3 Water Budget).

Based on the assessment report mapping the aquifer vulnerability is **high** in about half of the WHPA area.

Although, the potential for water quality degradation due to water quantity risks was recognized as a well-sensitive attribute, the results of the Greensville Tier 3 water budget demonstrate that the system can meet all scenarios required by the Technical Rules. Furthermore, the Greensville wells are completed in a different aquifer than the largest groundwater taking in the Middle Spencer Creek sub-watershed, which contributed to triggering the Tier 3 water budget assessment. Based on this analysis, water quality degradation due to water quantity risks are not considered a concern.

Recommendations:

To reduce the Greensville system's overall climate change vulnerability rating, some identified attributes can be managed through new policies aimed at lowering their sensitivities. **Table 4** policy and management measure ideas No. 1, 2, 10, 12 and 13 should be considered to achieve this goal.

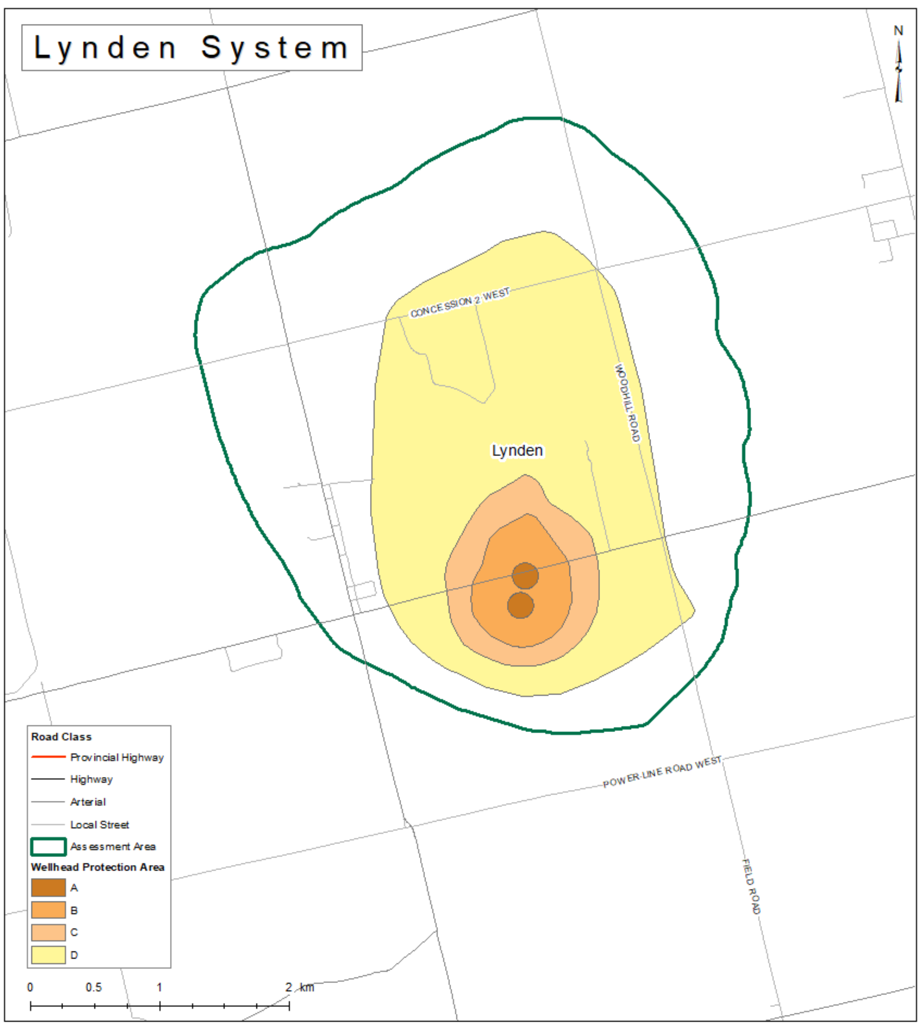
APPENDIX A11 - LYNDEN

The groundwater-based Lynden Drinking Water System is located in the Grand River SPA, but within the City of Hamilton limits. HHSPR agreed to complete the CCVAT assessment to ensure consistency for all City of Hamilton drinking water systems. The Lynden system is comprised of two overburden wells and a drinking water treatment system.

Scale of the assessment area

Based on Grand River Conservation Authority on-line mapping the Lynden wells are situated close to a sub-watershed boundary and the associated WHPA overlaps two sub-watershed boundaries. To identify the area potentially influencing water quality in the system, a ground-watershed was delineated. The source of water table data for the delineation was the 2010 groundwater flow model developed for the City of Hamilton to define WHPAs and assign vulnerabilities. A new WHPA was delineated for the Lynden system since 2010, and the ground-watershed was adjusted to ensure the new WHPA is entirely within the CCVAT assessment area. **Map 9** outlines the Lynden ground-watershed used for the Lynden CCVAT assessment.

Map 9: Lynden CCVAT Groundwater



Climate data description

The source and spatial resolution of climate data sets used in the assessment is summarised in Table 3 of worksheet *A2.* CC Exposure of the CCVAT Excel workbook. The following is a summary of the sources used in the study:

- Data for six (6) of the 10 climate parameters, i.e. Minimum Temperature (annual and seasonal), Maximum Temperature (annual and seasonal), Precipitation (annual and seasonal), Very Hot Days, Frost Free Season, and Freeze Thaw Cycle, were obtained from the Climate Atlas of Canada website, using the small grid for the region depicted as Brantford on the Climate Atlas of Canada website.
- Heavy Precipitation data was collected from climatedata.ca website. An average of 18 small grid cells encompassing the same area as the Climate Atlas of Canada Brantford region cell to ensure similar coverage.
- The Maximum Length of Dry Spell data were obtained from the Ontario Climate Data Portal for the Hamilton-Wentworth region.
- Since future data for rainfall and snowfall are unavailable, the future trends for both parameters were based on the CCVAT Burlington pilot study conducted by CO and the study team. This approach mirrors the methodology used in the Burlington study, with one exception: the trends for summer rainfall and snowfall were changed to "Not Changing" to align with the overall trend for total precipitation.

Due to the number of regression analyses which had to be completed, all plots and regression summary outputs are available in associated climate data regression analyses spreadsheets. The trend analyses of all parameters for both historical and future data were completed, and the results populated in worksheet A2. CC Exposure.

Area and Well Sensitivity

The Grand River SPA Assessment Report was the main source of data used to populate CCVAT worksheet B1-Area Sensitivity and B2-Well Sensitivity. Spatially distributed and geographical data was integrated, visualised, analysed and summarised using geographical information system (GIS) software and the results populated in the CCVAT spreadsheet.

Future land use estimates were based on the Official Plan, or in cases of insufficient data on projected population growth. For more details, the reader is directed to CCVAT worksheets B1 and B2 notes to identify the source of information or the method used to obtain estimates.

Given the utilization of abundant factual data, spatially distributed data, and detailed GIS analysis to summarize data in this phase, a **low** level of uncertainty was assigned to both the area and well climate change sensitivity assessments.

Well Impact Assessment

Conservation Halton and municipal staff reviewed the initial impact scores for both the study area and the well/wellfield and concluded that no further adjustments were needed. The calculated final climate change impact score corresponds to a **medium** impact rating. A **high** level of uncertainty

was identified, primarily attributed to the incorporation of the exposure assessment result, which relied on modeled future data.

Adaptive Capacity and Climate Change Vulnerability Rating

The subsequent phase in the CCVAT assessment involves assigning adaptive capacity and vulnerability (worksheet D. AdCap and Vulnerability). Certain attributes related to adaptive capacity and vulnerability are auto populated based on area and intake sensitivity data. The remaining details were supplied by City of Hamilton staff. Given the information and its sources utilized in this assessment, a **low** level of uncertainty has been assigned.

The climate change vulnerability score for the Lynden groundwater system is 1.8 out of 9. This corresponds to **low** vulnerability rating.

Threat Activities

Threat activities as included in Grand River SPA Assessment Report were used to populate worksheet E. Although there were several significant threats identified in the assessment report, a number of threats were removed through field verification. The two remaining threat categories are private sewage works and application of agricultural source material to land. Two properties where agricultural source material is being applied have risk management plans in place. Following the threat risk level and vulnerability rating matrix, the threats fall into Group II. There are limited options to address this type of an existing threat activity as it relates to climate change. Potentially, for future private sewage systems within the area of assessment, a policy could be developed requiring maintaining or enhancing pre- to post-development infiltration to ensure water quality is not impaired.

To reduce the climate change overall impact, identification of area and well sensitive attributes which have the biggest effect on the vulnerability rating and developing policies and/or mitigation measures to address them can be the most effective way to keep the vulnerability rating low and/or reduce the identified threats risk level in terms of climate change.

CCVAT Results and Sensitivity Analysis

Although the final climate change vulnerability rating was identified as **low** there are several area and well sensitivity attributes which have a deciding impact on the final climate change vulnerability rating.

The most significant area sensitive attributes influencing the final climate change adaptive capacity rating for the Lynden system are:

- potential for increased contaminant loadings due to agricultural activity, and
- existence of flood plains and areas where flooding can occur.

The identified well sensitivity attributes influencing the final vulnerability score are:

- water quality issues/threats identified by the municipality.

Recommendations:

To reduce the Lynden system's overall climate change vulnerability rating, some identified attributes can be managed through new policies aimed at lowering their sensitivities. **Table 4** policy and management measure ideas No. 3, 4, and 7 should be considered to achieve this goal.

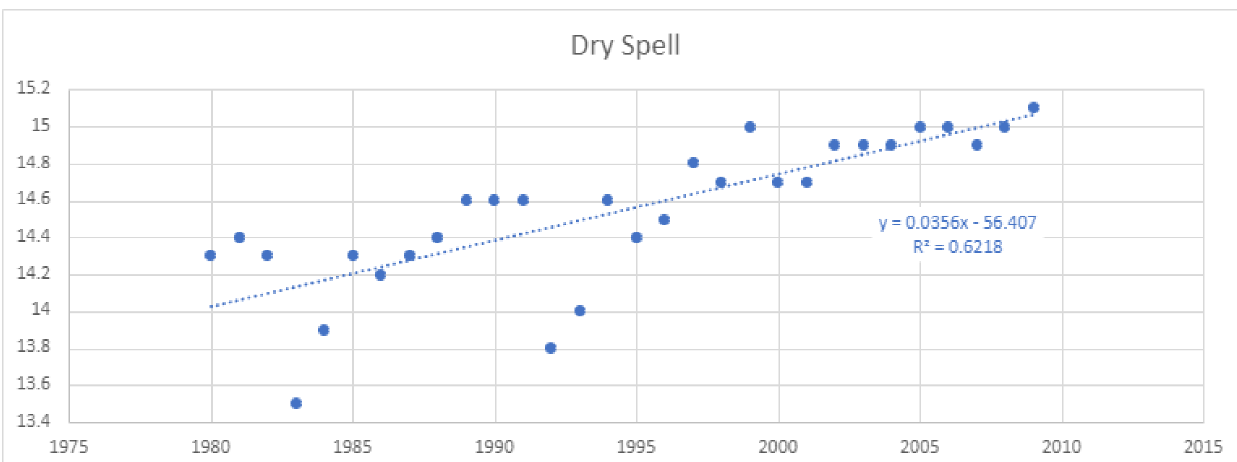
APPENDIX B - TREND ANALYSES ENHANCEMENTS

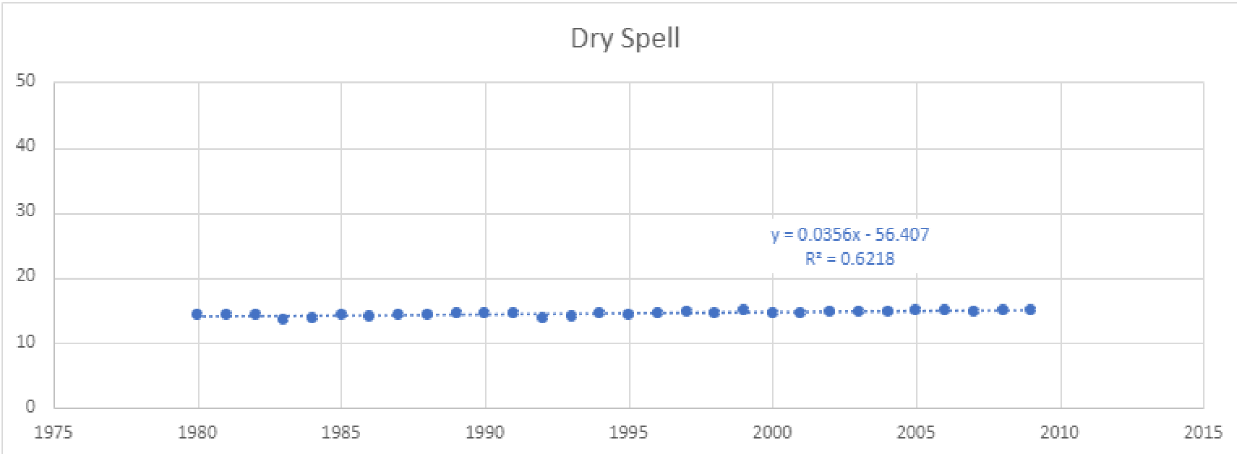
Additional information was incorporated into the given template for conducting trend analysis. This inclusion aimed to mitigate visual bias and promote consistent assessments, regardless of the absolute values of the data. Instead of visual trend identification, a threshold was established at 2.5% change in absolute values in the dataset between the start and the conclusion of the assessment period, as calculated using the linear regression equation. For instance, for historical data spanning from 1970 to 2013, a percent change exceeding 2.5% was deemed indicative of an increasing trend, while a decline of more than 2.5% indicated a decreasing trend. Percent change values falling within the range of -2.5% to 2.5% were interpreted as no discernible trend in the dataset. To confirm these results, statistical significance was considered. However, in instances of inconclusive results, especially in historical data with high variability, the percent change coefficient took precedence over the statistical significance coefficient.

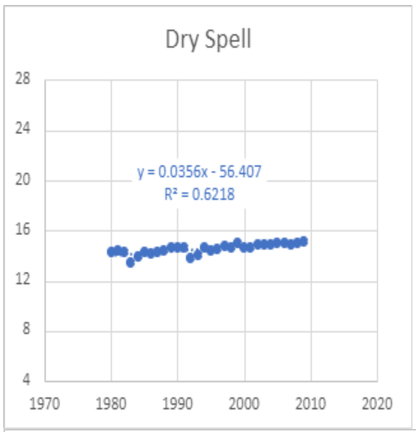
Below are a few examples to support the enhancements:

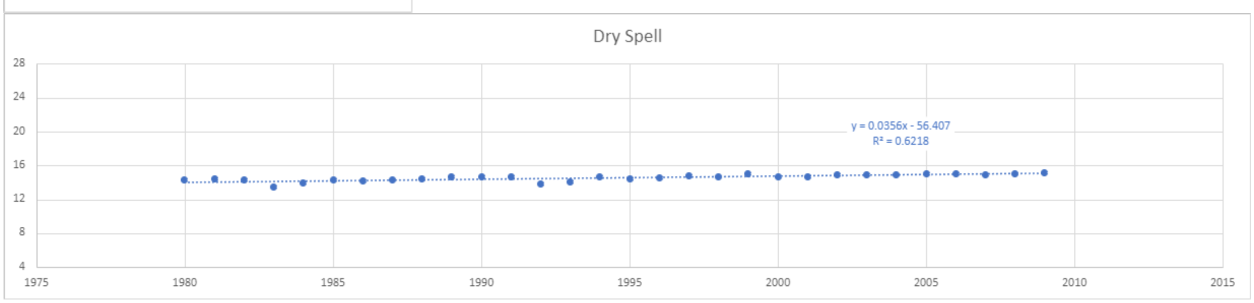
1. Visual bias

Selection of the vertical scale or range of units play an important role in visual trend analysis. As shown, although the four graphs are based on the same dataset and have the same statistical coefficients, they can be interpreted visually as having either an increasing or 'not changing' trend.









For the dataset above the linear regression summary output below suggest that the trend is statistically significant. By analysis of the percent change of the values within the given time period the trend is increasing and the change at 7% confirms an increasing trend. The visual analysis based on simple preference or odds can lead to different results.

SUMMARY OUTPUT

Regression Statistics					% DELTA	7%
Multiple R	0.788562941	Mean:	14.54			**INCREASING**
R Square	0.621831511					
Adjusted R Squ	0.608325494					
Standard Error	0.248539779					
Observations	30					

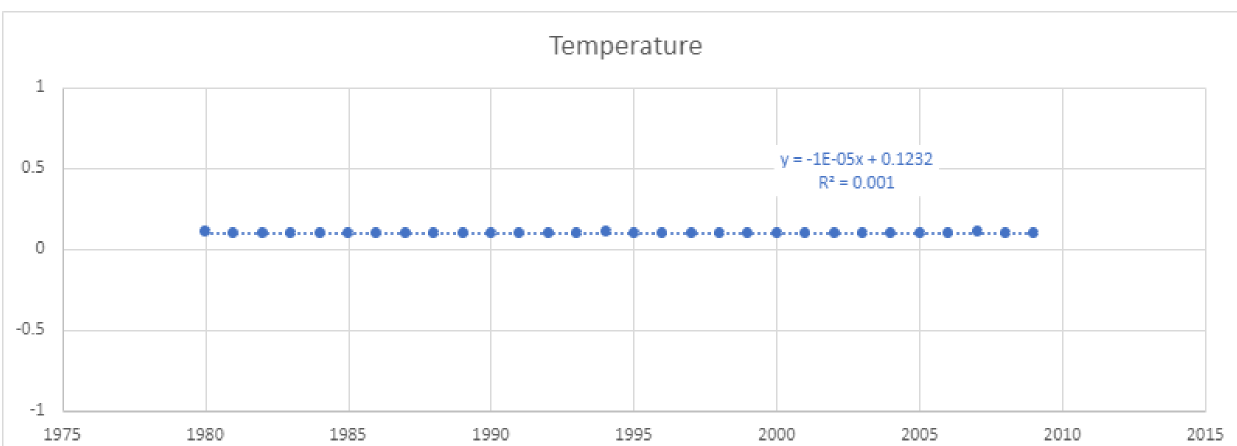
ANOVA

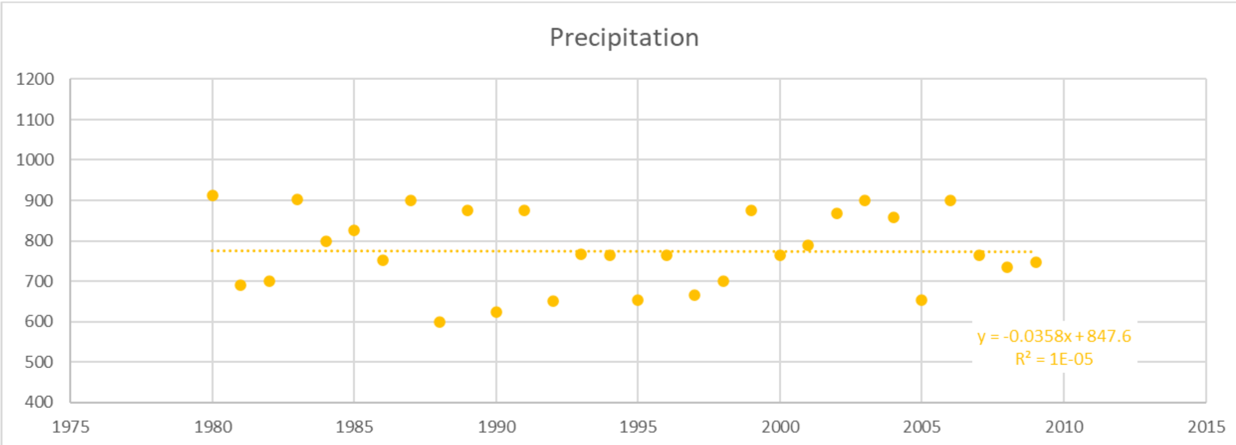
	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	2.844050056	2.844050056	46.04107121	2.27415E-07
Residual	28	1.729616611	0.061772022		
Total	29	4.573666667			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-56.40673341	10.45644814	-5.394444905	9.4437E-06	-77.82579646	-34.98767036	-77.82579646	-34.98767036
X Variable 1	0.035572859	0.005242592	6.785357117	2.27415E-07	0.024833896	0.046311822	0.024833896	0.046311822

2. Over-reliance on statistical coefficients

In a linear regression model where the measured data is constant or it oscillates around its mean, the R-squared is usually very small because the model cannot explain any of the variability in the outcome variable and the statistical significance is large because of the lack of meaningful predictive power. Discarding no change as not statistically significant based on low R-squared and high statistical significance values should not always be supported. The two graphs below show temperature and precipitation data. These trends may not be statistically significant because linear regression struggles to explain the variability in the outcome variable or there is no systemic change in the relationship between the predictor variable and the outcome. However, the lack of variability within the dataset clearly results in a ‘not changing’ visual trend. The two examples below show datasets described above with linear regression characterised by small R-squared and high statistical significance F value.





SUMMARY OUTPUT - TEMPERATURE

Regression Statistics							
Multiple R	0.032092849	Mean:	0.10	%DELTA	-0.3%		
R Square	0.001029951				**NOT CHANGING**		
Adjusted R Sq	-0.034647551						
Standard Error	0.003103695						
Observations	30						

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	2.78087E-07	2.78087E-07	0.02886836	0.86630502
Residual	28	0.000269722	9.63293E-06		
Total	29	0.00027			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.123185762	0.130577209	0.943394053	0.353548966	-0.144289525	0.390661048	-0.144289525	0.390661048
X Variable 1	-1.11235E-05	6.5468E-05	-0.169906917	0.86630502	-0.000145229	0.000122982	-0.000145229	0.000122982

SUMMARY OUTPUT - PRECIPITATION

Regression Statistics							
Multiple R	0.003311256	Mean:	776	%DELTA	0%		
R Square	1.09644E-05				**NOT CHANGING**		
Adjusted R Sq	-0.03570293						
Standard Error	96.91072537						
Observations	30						

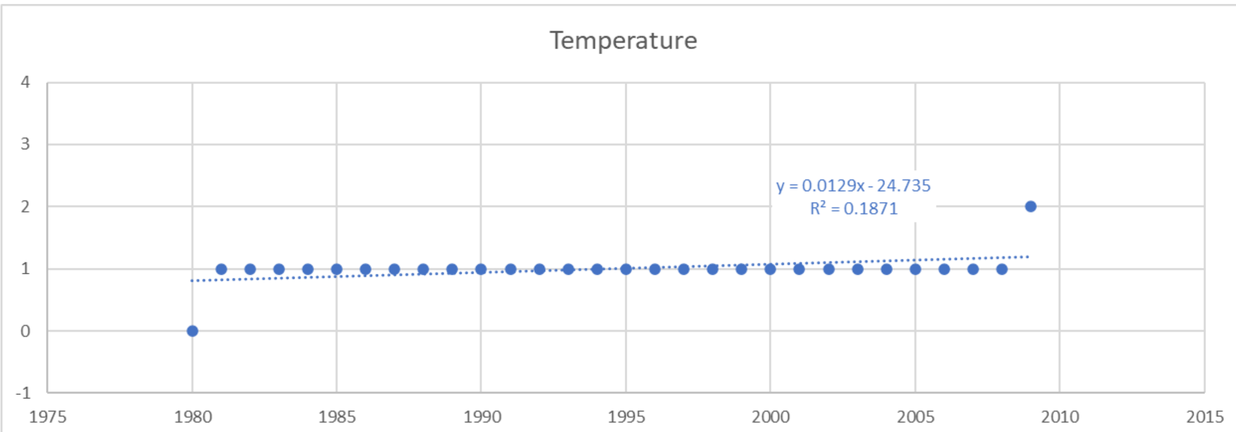
ANOVA

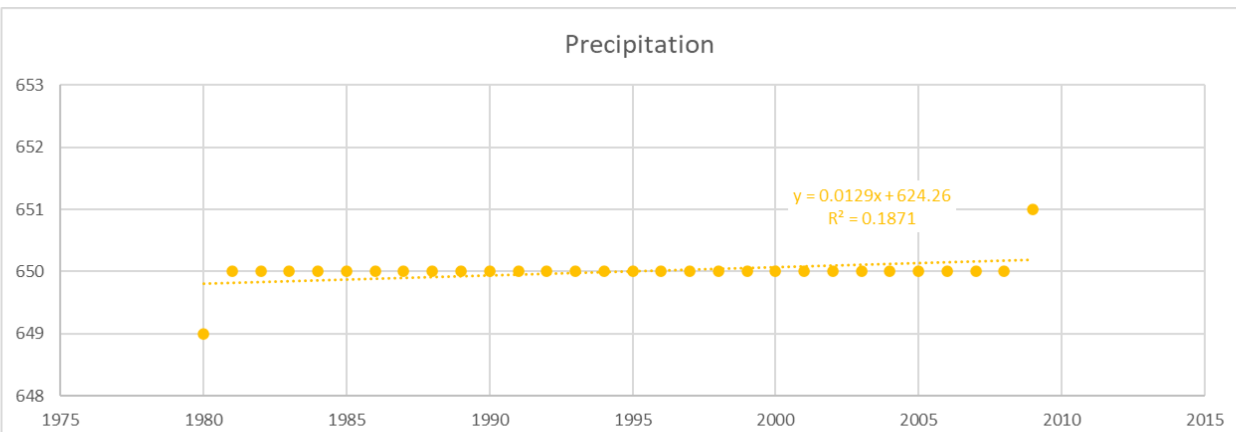
	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	2.883314794	2.883314794	0.000307007	0.986144748
Residual	28	262967.2834	9391.688691		
Total	29	262970.1667			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	847.6048202	4077.182243	0.207889854	0.836819699	-7504.124405	9199.334045	-7504.124405	9199.334045
X Variable 1	-0.035817575	2.044193458	-0.017521617	0.986144748	-4.223158053	4.151522903	-4.223158053	4.151522903

3. Visual and statistical coefficients vs percent change

To illustrate how visual analysis and reliance on statistical coefficients can bias the trend analysis results, below is an example of linear regression analysis completed on synthetic temperature and precipitation data. The statistical coefficients (R-squared and statistical significance F) and linear regression equation for both datasets are the same. The trend is visually the same, however if we analyse what this change means when we consider the absolute values of the dataset, the resulting trends are different. The change in temperature constitutes a 37% increase over the time period. Meanwhile, considering the absolute values of the precipitation dataset, the change is close to zero percent which results in a 'not changing' trend. Using the percent change method as it relates to the absolute values, the temperature trend would be considered an increasing trend, while the precipitation trend analysis result is 'not changing' regardless of the statistical coefficients.





SUMMARY OUTPUT - TEMPERATURE

Regression Statistics						% DELTA		**37%**	
Multiple R	0.432546846		Mean:	1				**INCREASING**	
R Square	0.187096774								
Adjusted R Sq	0.158064516								
Standard Error	0.240965799								
Observations	30								

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.374193548	0.374193548	6.444444444	0.01697299
Residual	28	1.625806452	0.058064516		
Total	29	2			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-24.73548387	10.13779921	-2.439926393	0.02127814	-45.50182418	-3.969143558	-45.50182418	-3.969143558
X Variable 1	0.012903226	0.00508283	2.538591035	0.01697299	0.002491521	0.02331493	0.002491521	0.02331493

SUMMARY OUTPUT - PRECIPITATION

Regression Statistics						% DELTA		**0%**	
Multiple R	0.432546846		Mean:`	650				**NO CHANGE**	
R Square	0.187096774								
Adjusted R Sq	0.158064516								
Standard Error	0.240965799								
Observations	30								

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.374193548	0.374193548	6.444444444	0.01697299
Residual	28	1.625806452	0.058064516		
Total	29	2			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-24.73548387	10.13779921	-2.439926393	0.02127814	-45.50182418	-3.969143558	-45.50182418	-3.969143558
X Variable 1	0.012903226	0.00508283	2.538591035	0.01697299	0.002491521	0.02331493	0.002491521	0.02331493