Picton
Source Protection Study
Intake Protection Zone 2 Delineation Addendum

Final Report

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Submitted by

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Section 1: Introduction

1.1 Study Background

Within the municipality of Prince Edward County land located at the crossing of County Road 5 and the Millennium Trail is used as a site for the storage of snow. The portion of this land studied measures to be approximately 1.68 hectares, and the location of the site is circled below in Figure 1:

Figure 1: Location of Storage Site

Source Protection Authority staff were contacted by the municipality, as the storage location has an incline of approximately 7.5°, encouraging a downslope travel of the snowmelt towards Picton Bay (Appendix 2) was flagged as a potential transport pathway into the Intake Protection Zone 2. A transport pathway is a human-made channel that bypasses the natural protection provided by the soil and rock layer resulting in a greater risk of contamination of the aquifer. Alterations to natural surface drainage can also result in faster or more widespread distribution of contaminants in surface water. The Intake Protection Zone 2 was originally approved as a four-hour travel time. Should runoff from the storage site take less than the four-hour time of travel to reach the drinking water intake, the portion of the property that drains into the intake protection zone 2 will be amended to be included within the zone and additional preventative measures may be required to manage the risk to the drinking water from the snowmelt.

1.2 Modelling Methods

1.2.1 Mathematical Modelling

To determine whether the snowmelt will reach the threshold of four-hour travel time, the time of concentration can be calculated. The time of concentration is a measure of the time required for runoff to travel from the hydraulically most distant point in the watershed to the outlet [1]. Upon visiting the site, it is evident that the snowmelt would experience both overland and open-channel flow. Overland flow describes surface runoff that occurs in the form of sheet flow on the land surface without concentrating in clearly defined channels [2]. Open-channel flow is the flow of a fluid through a channel with a free surface [3]. The behaviour of fluids is different under the two types of flows and their approaches to calculating time of concentration are distinct.

Overland flow can be modelled using various methods including the TR-55 method. To calculate the time of concentration for overland flow using the TR-55 method, Equation 2 can be used, where T is the overland flow time (hr), n is the Manning's Roughness coefficient, L is the flow length (ft), P_2 is the 2-year 24 hour rainfall (in), and S_f is the slope (ft/ft):

$$T = \frac{0.007\ (nL)^{0.8}}{P_2^{0.5} * S_f^{0.4}} \qquad (2)$$

While there are multiple methods to calculate the open-channel flow time of concentration, the TR-55 method for open-channel flow equation is used, as shown in Equation 3, where T_c is the time of concentration (hr), L_f is the flow length (ft), and V is the average velocity (ft/s):

$$T_C = \frac{L_f}{V} * \frac{1}{3600} \qquad (3)$$

In order to calculate the time of concentration in Equation 3, it is required to determine the average velocity, *V*, to be solving for just one parameter (T_c) . The velocity parameter can be found manually on site if there is adequate flow or by using Equation 4. In Equation 4, Q is the flow rate (m^3/s), n is the Manning's Roughness coefficient, A is the flow area (m^2), R is the hydraulic radius (m), and S is the channel slope (m/m):

$$Q = V * A = \left(\frac{1.00}{n}\right) * A * R^{\frac{2}{3}} * \sqrt{S} \qquad (4)$$

To determine the velocity in Equation 4, it is assumed that the flow runoff rate remains consistent throughout the whole study. This meaning that the overland flow runoff rate is assumed to measure to be the same as the open-channel flow rate. Therefore, the Rational Method can be used to calculate Q for the overland flow, and thus, the conclusions from this method can be inputted into Equation 4 to determine velocity, and then the velocity can be inputted into Equation 3 to determine the time of concentration. The Rational Method equation is shown below in Equation 5, where Q is the runoff rate from the drainage area (m^3/s), C is the runoff coefficient, I is the rainfall intensity (mm/hr), and A is the drainage area (ha):

$$Q = 0.00278CIA \tag{5}$$

To conclude the study, the time of concentrations for all sections are added as shown below in Equation 6, where Tc_{total} is the total time of concentration, $Tc_{overland}$ is the total time of concentration for the overland flow, and $Tc_{channel}$ is the total time of concentration for the channel flows:

$$Tc_{total} = Tc_{overland} + Tc_{channel} \tag{6}$$

1.2.2 Excel Modelling

In order to allow for ease of calculations, an Excel model is used to reflect on the calculations outlined in Section 1.2.1. This allows for quick and efficient computation of the time of concentration. Should a parameter value be changed in the equations above, this new value can be entered into Excel, and the total time of concentration will be computed and updated immediately.

Section 2: Findings

2.1.1 Flow Path

Through analysis of elevation information on GIS software and confirmation during a visit to the snow storage site, the most likely flow path of the snowmelt could be determined. The path is outlined in red in Figure 2 below:

Figure 2: Initial Path of the Snowmelt to be Analyzed

The outlined path begins at the snow storage side, moves South towards the Millennium trail, across the Millennium Trail (via a culvert underneath County Road 5), along Country Road 5 towards McDonald Drive and then along McDonald Drive to a channel that leads to a storm pond. For ease of calculations, the flow path is split into sections and a detailed analysis is done on each individual section.

The remainder of the path (the storm pond to the drinking water intake) was analyzed during a previous zone amendment, and therefore those calculations were used as to reduce duplication of efforts.

2.1.2 Section 1 of Study – Snow Storage Site

The first section of study is located at the crossing of County Road 5 and the Millennium Trail. This is the location of the snow storage site. Here, the snowmelt would undergo the behaviour of overland flow, as it travels downslope towards the Millennium Trail. The portion of this section measured to be 1.68 ha using GIS software, and the length from the top of the hill to the trail is approximately 371.88 ft (113.35 m). The elevations shown result in an approximate slope of 0.1316 (Appendix 2).

Figure 3: Section 1 Area of Study

Using Equation 2, and the information above, the overland time of concentration can be calculated. The Manning's Roughness coefficient is obtained from the Ministry of Transportation Drainage Manual under the category "pasture, no brush, high grass" with a value of 0.042. The 2-year 24-hour rainfall amount is derived from the provided Trenton IDF curves and is calculated to be 1.9843 in.

$$T = \frac{0.007\ (nL)^{0.8}}{P_2^{0.5} * S_f^{0.4}} \tag{2}$$

$$T = \frac{0.007\ (0.042 * 371.88)^{0.8}}{1.9843^{0.5} * 0.13158^{0.4}}$$

$$T = 0.1008\ hours$$

Therefore, the total time of travel for the overland flow in Section 1 is **0.1008 hours.**

2.1.3 Section 2 of Study – Along Millennium Trail

The second section of study is along the Millennium trail, as shown in Figure 4. An open-channel flow analysis is appropriate for this section, and given an abundance of vegetation in this channel, there is a considerable amount of friction prohibiting the flow. The length of this section measures to be approximately 91.22 m, with a slope of 0.00401 (Appendix 2). Due to this dense vegetation, the Manning's Roughness coefficient to be used is 0.03, being described as an "unlined, open-channel with dense weeds" in the Ministry of Transportation Drainage Manual.

Figure 4: Section 2 Area of Study

To determine the time of concentration for Section 2 of this study, the flow runoff rate must be calculated first using the Rational Method as discussed in Section 1.2.1. In Equation 5, the runoff coefficient, *C,* is 0.30 under the category "lawns, heavy soil, steep 7% slope" [4]. The rainfall intensity, I, is 7.4914 mm/hr and is obtained from the Trenton IDF curves located in Appendix 2. The area is 1.68 ha, as shown in Figure 3.

$$Q = 0.00278CIA \quad (5)$$

$$Q = 0.00278 * 0.3 * 7.4914 * 1.68$$

$$Q = 0.010496\frac{m^3}{s}$$

Therefore, the snowmelt flow rate is approximately 0.0105 m^3/s, which is assumed to remain consistent throughout the whole flow path.

The cross-section of the channel is shown below in Figure 6, which was concluded on a site visit. In correspondence with Figure 5; b = 1 m, z = 1 m, T= 4 m, and y is an unknown depth.

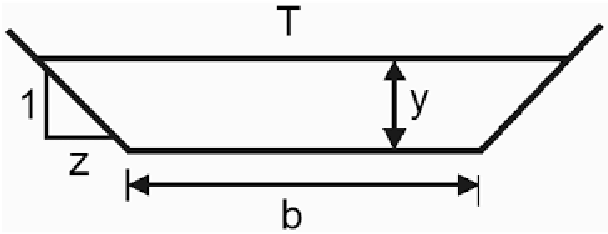

Figure 5: Channel Cross-Section Parameters [5]

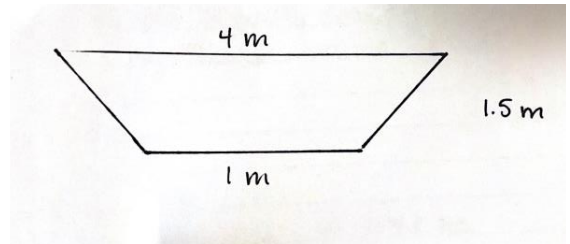

Figure 6: Section 2 Cross-Section

With the snowmelt runoff rate determined, the velocity can be found by rearranging Equation 4 to solve for the flow depth, y, (indirectly *V),* which is a required parameter in Equation 3 to solve for time of concentration:

$$Q = V * A = \left(\frac{1.00}{n}\right) * A * R^{\frac{2}{3}} * \sqrt{S} \qquad (4)$$

$$Q = \left(\frac{1.00}{n}\right) * A * R^{\frac{2}{3}} * \sqrt{S}$$

$$Q = \left(\frac{1.00}{n}\right) * (b * y + z * y^2) * \left(\frac{by + zy^2}{b + 2y * \sqrt{(1 + z^2)}}\right)^{\frac{2}{3}} * \sqrt{S}$$

$$0.010496 = \left(\frac{1.00}{0.03}\right) * (1 * y + 1 * y^2) * \left(\frac{1 * y + 1 * y^2}{1 + 2y * \sqrt{(1 + 1^2)}}\right)^{\frac{2}{3}} * \sqrt{0.0401}$$

Using trial and error methods, and confirming with the Excel model, it is concluded that the required flow depth, y, to achieve the flow rate, Q=0.010496 m^3/s, is 0.04165 m.

This y-value can then be substituted back into Equation 4 to solve for the velocity.

$$V * A = \left(\frac{1.00}{n}\right) * A * R^{\frac{2}{3}} * \sqrt{S} \qquad (4)$$

$$V = \left(\frac{1.00}{n}\right) * R^{\frac{2}{3}} * \sqrt{S}$$

$$V = \left(\frac{1.00}{0.03}\right) * R^{\frac{2}{3}} * \sqrt{S}$$

$$V = \left(\frac{1.00}{0.03}\right) * \left(\frac{(1)(0.04165) + (1)(0.04165)^2}{(1) + 2(1) * \sqrt{(1 + 1^2)}}\right)^{\frac{2}{3}} * \sqrt{0.00401}$$

$$V = 0.241954\ m/s$$

Therefore, the velocity of the snowmelt is 0.241954 m/s, which can be used to solve for the time of concentration in Equation 3:

$$T_C = \frac{L_f}{V} * \frac{1}{3600} \tag{3}$$

$$T_C = \frac{91.22}{0.241954} * \frac{1}{3600}$$

$$T_C = 0.1047\ hours$$

Therefore, the time of concentration for the open-channel flow in Section 2 is **0.1047 hours.**

2.1.4 Section 3 of Study – Along County Road 5 to McDonald Drive

The third section of study is the snowmelt path from just above the Millennium Trail up until McDonald Drive. The snowmelt travels through a culvert below the Millennium Trail and in an open-channel along County Road 5, until it reaches another culvert, taking it below McDonald Drive. The path has "dense weeds, high as flow depth" according to the Ministry of Transportation Drainage Manual, resulting in a Manning's Roughness coefficient of 0.12. The snowmelt travels for an approximate length of 144.64 m along this channel, as shown below in Figure 7:

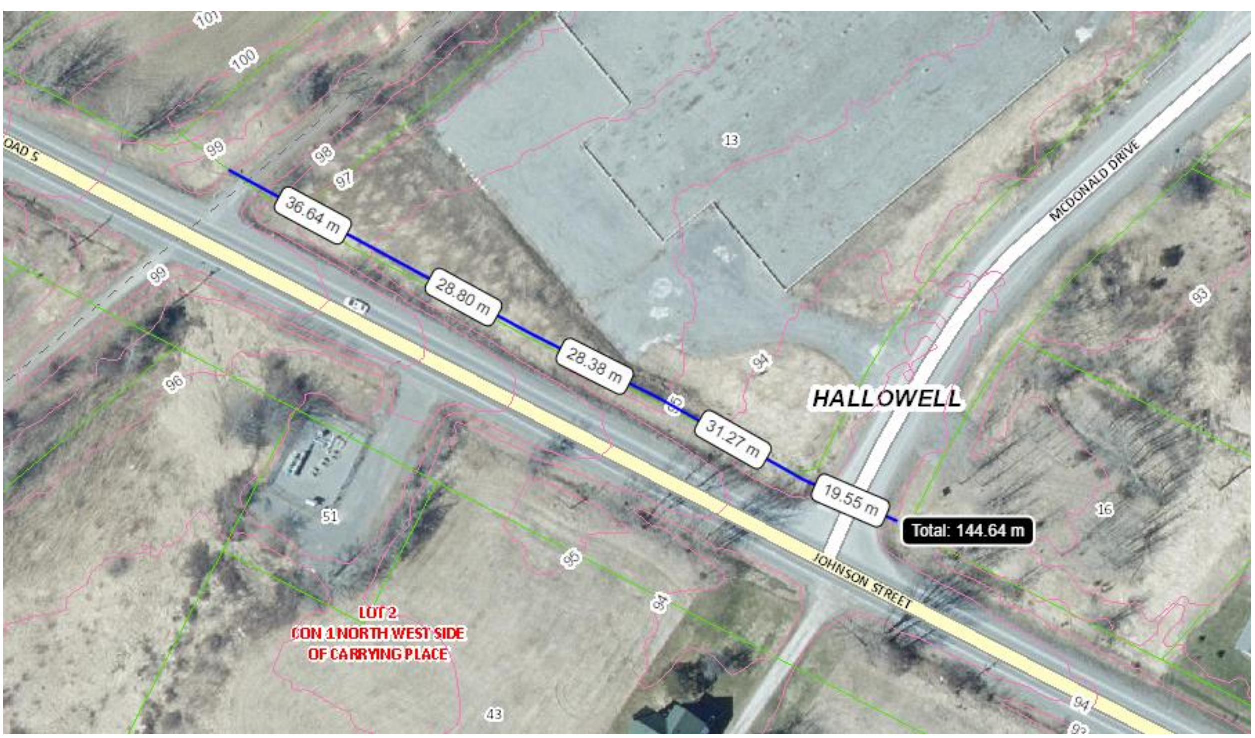

Figure 7: Section 3 Area of Study

The cross-section for the channel in Section 3 is shown below in Figure 8:

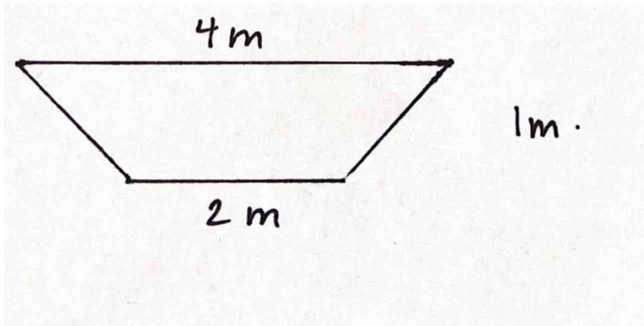

Figure 8: Section 3 Cross-Section

The same process outlined in Section 2 is done to determine the time of concentration for Section 3. The final time of concentration for Section 3 of the study **is 0.01876 hours**. The flow depth is 0.0305 m, while the velocity is 0.1697 m/s. To validate the accuracy of these conclusions, the Excel model has been run to confirm this time of concentration.

2.1.5 Section 4 of Study – Along McDonald Drive, Overgrown 1

The vegetation along McDonald Drive changes as the snowmelt flows. Initially, there is a section of very "dense weeds, high as the flow depth", giving a runoff coefficient of 0.12 according to the Ministry of Transportation Drainage Manual. This vegetation spans for approximately 149.45 m, with a slope of 0.00401. The section is shown below in Figure 9:

Figure 9: Section 4 Area of Study

The cross-section of this particular area of the study is the same as Section 2. This cross-section is shown in Figure 6**Error! Reference source not found.**. Given that this is an open-channel flow, the same process performed for Section 2 to determine the time of concentration can be done for Section 4. It is concluded that the time of concentration of the snowmelt in the section is **0.4149 hours**, given a flow depth of 0.09574 m, and a velocity of 0.10 m/s.

2.1.6 Section 5 of Study – Along McDonald Drive Maintained Channel

The channel changes from the overly dense and tall weeds to a well-maintained channel located on the property of Desjardins Insurance. This maintenance allows the snowmelt to flow with less friction that would prohibit movement through the channel. An appropriate Manning's Roughness coefficient selected for this section is 0.06, as the vegetation is defined as "Kentucky Bluegrass" according the MTO Drainage Manual. This section of the channel spans 59.35 m, with the same slope of 0.00401.

Figure 10: Section 5 Area of Study

The cross-section of this particular area is shown below in Figure 11. The 'b' value of this section is 1 m, while the 'z' value is 2.16 m. Given that this is an open-channel flow, the process performed for Section 2 to determine the time of concentration can repeated for Section 5. It is concluded that the time of concentration of the snowmelt in the section is **0.1084 hours**, given a flow depth of 0.05493 m, and a velocity of 0.15209 m/s.

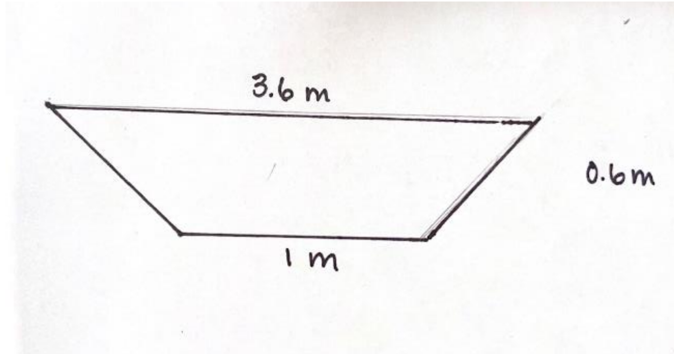

Figure 11: Section 5 Cross-Section

2.1.7 Section 6 of Study – Along McDonald Drive, Overgrown 2

The channel changes again from the well-maintained section, back to a similar overgrown section as the first. This spans for 174.27 m with the same Manning's Roughness coefficient as Section 4; 0.12.

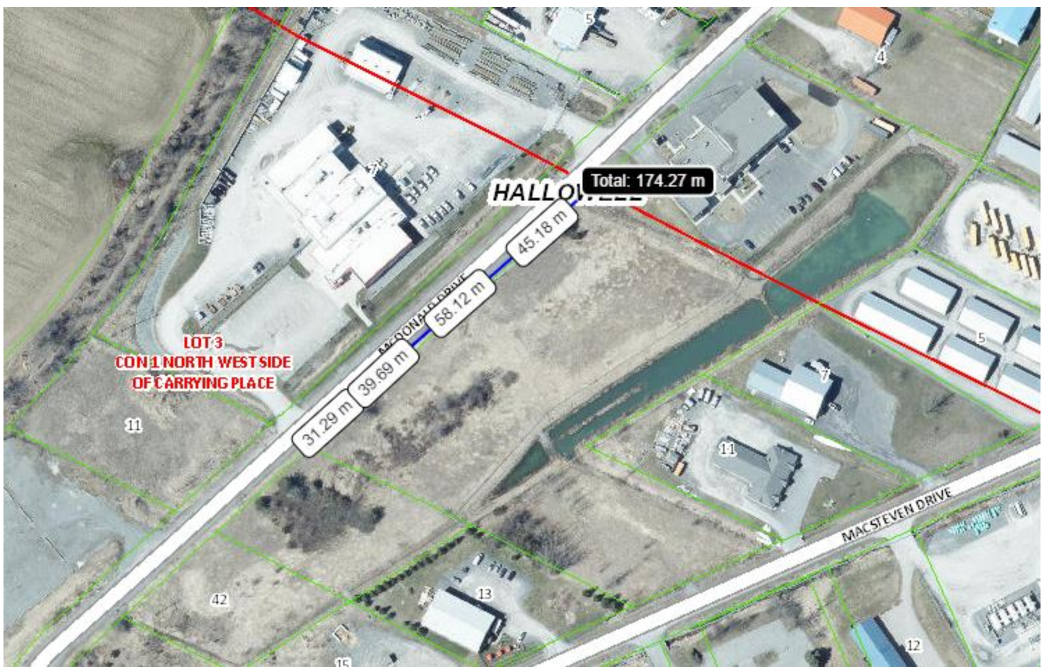

Figure 12: Section 6 Area of Study

The cross-section of this area of the study is the same as Section 2. This cross-section is shown in Figure 6. Given that this is an open-channel flow, the same process performed for Section 2 to determine the time of concentration can be done for Section 6. It is concluded that the time of concentration of the snowmelt in the section is **0.4839 hours**, given a flow depth of 0.09574 m, and a velocity of 0.10 m/s.

2.1.7 Section 7 of Study – Channel off McDonald Drive into Storm Pond

The final section of the study to be analyzed is the open-channel that leads the snowmelt off McDonald Drive to the storm pond. This is shown below in Figure 13, where the channel measures to be 97.31m, and is classified as an "unlined, open-channel, dense weeds deep channels" in the Ministry of Transportation Drainage Manual. This results in a Manning's Roughness coefficient of 0.035, and the slope of the channel is 0.019539 (Appendix 2).

Figure 13: Section 7 Area of Study

Given the difficulty of accessing and observing this channel, the cross-section provided is an estimate. This cross section is shown below in Figure 14. Given this cross-section, 'b' is 1 m, and 'z' is 0.5 m, resulting in a flow depth of 0.02581 m, velocity of 0.36174 m/s and a time of concentration of **0.0747 hours.**

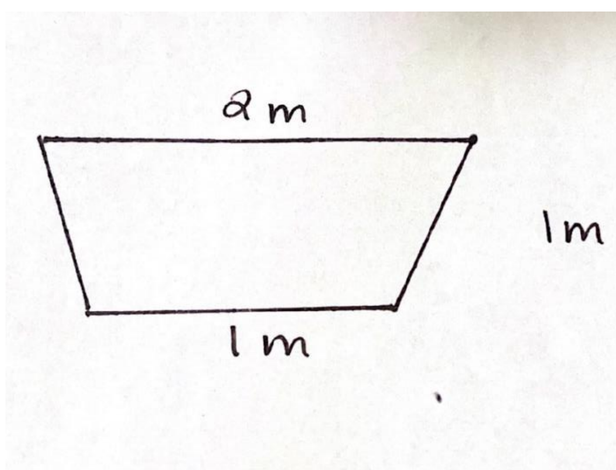

Figure 14: Section 7 Cross-Section

To determine the total time of concentration of the snowmelt from the storage site to the pond, Equation 6 can be used:

$$T_c total = T_c overland + T_c channel \quad (6)$$

$$T_c total = 0.1008 + 0.10473 + 0.1876 + 0.4149 + 0.108395 + 0.4839 + 0.0747$$

$$T_c total = 1.4751\ hours$$

Therefore, it can be concluded that the time of concentration for the snowmelt is approximately **1.475** hours following the path outlined in Figure 2.

2.1.8 Section 8 of Study – Flows from Storm Pond to Intake

Source Protection Authority staff used calculations from intake protection zone 2 delineation to determine the final flow path, from the storm pond to the intake in Picton Bay as shown in Figure 15.

Figure 15: Section 7 Storm Pond to Intake

Staff determined the remaining flows within the pond, then from the ditch to the creek and finally within Picton Bay to the intake to be 29.5 minutes for half and hour.

2.1.9 Section 9 of Study – Total time of travel

When all velocities were combined, the total time of concentration equalled 118 minutes or 1.96 hours.

Section 3: Amendment

From the calculations outlined in Section 2: Findings, it can be concluded that the snowmelt takes approximately 1.96 hours to reach the municipal drinking water intake. Thus, the runoff from the snow storage site could reach the intake within the four-hour time of travel and the intake protection zone 2 required amendments to include the land.

Source Protection Authority staff used the 2013 South Central Ontario Orthophotography (SCOOP) digital elevation model (DEM) and Arc Hydro to determine the portion of the property draining by ditch into Picton’s intake protection zone 2 and updated the zone to include this transport pathway, while maintaining the 120-meter buffer on the land as shown in Figure 16.

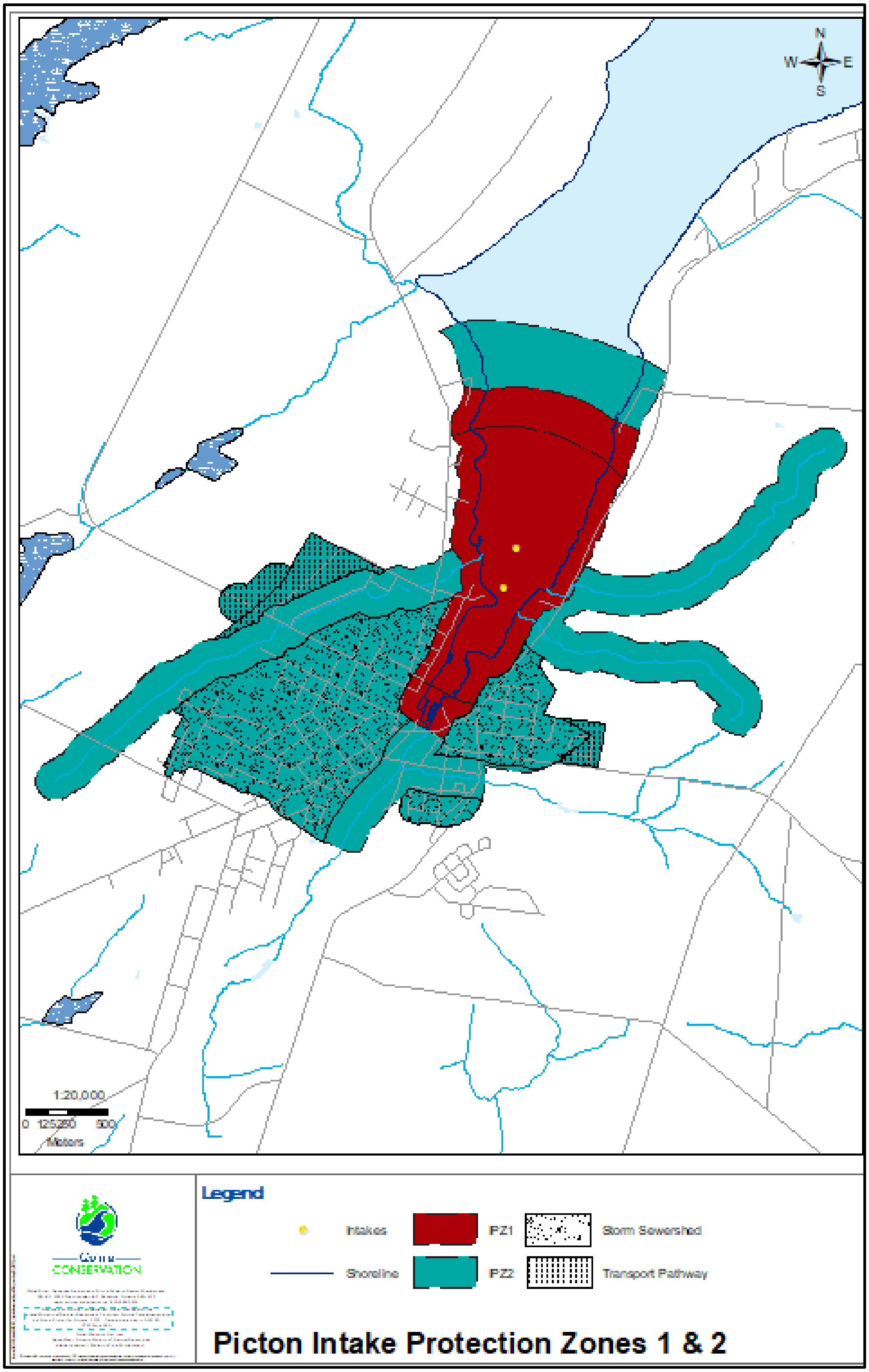

Figure 16: Picton Amended Intake Protection Zone 2

References

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[3] "What is Open Channel Flow? Types of Flow in Open Channels," 8 February 2020. [Online]. Available: https://theconstructor.org/fluid-mechanics/open-channel-flow-types-flow/37501/. [Accessed 15 August 2022].

[4] D. B. Thompson, "The Rational Method," 2006.

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Appendix 1: Relevant Data used in Equations

The table below in Figure 15 is obtained from the Trenton IDF curves and used to determine the P_2 value used in Equation 5 for Section 2.1.2:

Table 2a : Return Period Rainfall Amounts (mm)
Quantité de pluie (mm) par période de retour

Duration/Durée	2 yr/ans	5 yr/ans	10 yr/ans	25 yr/ans	50 yr/ans	100 yr/ans	#Years Années
5 min	6.9	10.1	12.2	14.8	16.8	18.7	47
10 min	10.0	13.4	15.7	18.5	20.6	22.7	47
15 min	12.0	15.9	18.5	21.8	24.2	26.7	47
30 min	15.5	20.5	23.8	27.9	31.0	34.0	47
1 h	19.6	27.5	32.7	39.3	44.2	49.0	47
2 h	24.5	34.4	41.0	49.2	55.4	61.4	47
6 h	35.3	47.5	55.5	65.7	73.3	80.8	46
12 h	43.8	57.9	67.2	79.1	87.8	96.5	48
24 h	50.4	65.9	76.1	89.0	98.6	108.1	48

Figure 15: Trenton Return Period Rainfall Amounts

The table below in Figure 16 is obtained from the Trenton IDF curves and used to determine the interpolated rainfall rate used in Equation 5 in Section 2.1.3. This calculation is shown in Appendix 2.

Table 3 : Interpolation Equation / Équation d'interpolation: R = A*T^B

R = Interpolated Rainfall rate (mm/h)/Intensité interpolée de la pluie (mm/h)
RR = Rainfall rate (mm/h) / Intensité de la pluie (mm/h)
T = Rainfall duration (h) / Durée de la pluie (h)

Statistics/Statistiques	2 yr/ans	5 yr/ans	10 yr/ans	25 yr/ans	50 yr/ans	100 yr/ans
Mean of RR/Moyenne de RR	29.5	40.7	48.1	57.4	64.4	71.2
Std. Dev. /Écart-type (RR)	28.6	40.4	48.3	58.4	65.8	73.2
Std. Error/Erreur-type	4.5	4.2	4.2	4.5	4.9	5.3
Coefficient (A)	18.6	25.2	29.6	35.2	39.3	43.4
Exponent/Exposant (B)	-0.656	-0.664	-0.668	-0.671	-0.673	-0.674
Mean % Error/% erreur moyenne	5.1	5.0	5.2	5.6	6.0	6.2

Figure 16: Trenton Rainfall Intensity Interpolation Equation

Appendix 2: Critical Values and Additional Calculations

Section 1

Below, Figure 18 demonstrates how the flow length of 113.35 m was obtained for Section 1 (overland flow). Figure 16 shows how the slope of 0.1316 was determined for Section 1:

Figure 18: Flow Length - Section 1

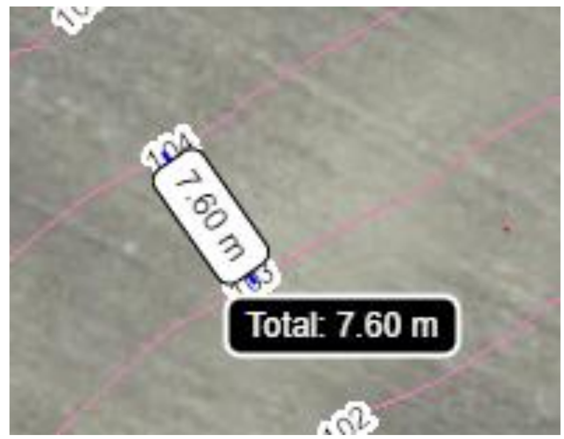

Figure 17: S1 Change in length per 1 meter of elevation

$$Slope = \frac{(104 - 103)}{7.60} = 0.1316$$

Section 2

Figure 17 shows how a slope of 0.00401 is derived for Section 2. It is critical to note that the slope for Section 2 was assumed to be the same as the slope of Section 3, Section 4, and Section 5, given there is no apparent change in elevation along Section 2 on GIS software. Therefore, the image below is used for the slope of all four sections:

Figure 19: S2 Change in length per 1 m of elevation

$$Slope = \frac{(94 - 93)}{249.43} = 0.00401$$

To calculate the Rainfall intensity used in Equation 5, the Trenton IDF curve provided in Appendix 1 is used, where R is the rainfall rate (mm/hr), A is the coefficient, T is the rainfall duration (hr), and B is an exponent:

$$R = A * T^B$$

$$R = 18.6 * 4^{-0.656}$$

$$R = 7.4914 \frac{mm}{hr}$$

Section 7:

Figure 20 below shows how the slope of Section 7 is derived to be 0.019539:

Figure 20: S7 Change in length per 1 meter of elevation

$$Slope = \frac{(93 - 92)}{51.18} = 0.019539$$