# Appendix 6-1

Vulnerability Scoring – Inland Rivers Intake Protection Zones

Mississippi-Rideau Source Protection Region

# APPENDIX D
# Wind Conditions and the IPZ-2 Delineation

## Introduction:

Wind information, collected as part of routine meteorological monitoring, may assist in defining the surface water intake conditions. Wind data were compiled for each of the study's three surface water intakes. This appendix includes: a summary of the wind data; a discussion of the potential wind effects on the limits of the IPZ-2; and, a description of the methodology used to account for wind in the IPZ-2 delineations.

## Wind, Wind Velocity and Surface Current Effects

Depending on the wind velocity, wind can cause a certain amount of mixing of the water column. The effect of wind speed on the travel time of a pollutant however is constrained to shallow depths. Lab experiments and measurements in lakes revealed that wind-accelerated water velocities decrease exponentially from a maximum at the surface down to near zero wind influence at one third of the depth of the water column (Bye, 1965; Liu and Perez, 1971).

Since wind has its greatest influence at the surface, wind-driven currents are especially significant in the transport of floating pollutants such as oil, provided that the wind speed is greater than 5 m/s. It should be noted, however, that wind-induced flow is not significant in high-current systems, and that the wind must blow in a consistent direction for a long period of time in order to have an effect (Integrated Publishing, 2007). In general terms, when wind is present, average water velocities (averaged over the entire water column) can be increased and so contaminants that mix throughout the water column will move at a greater speed than if there was no wind present.

It is therefore recommended that wind-driven currents be considered in the final IPZ-2 delineation process. The peer review of the study's preliminary IPZs indicated that surface currents could be approximated as a percentage (e.g. 3%) of wind speed. The 3% of wind speed estimate is within the range of values cited in the literature (Tsinker, 1995; Bye, 1965) and is considered to be an acceptable estimation of wind-induced water surface velocity.

## Methodology:

In order to take into account the potential maximum effect of average wind speeds on all the major pathways within the IPZ-2s, wind directions that followed the direction of the current for each tributary and main branch of the channel were used. In this way, maximum speeds from each contributing water body are taken into account simultaneously. The resulting estimate for the IPZ-2 with wind (herein referred to as the IPZ-2W), is the maximum distance that could be assigned for each intake, for the specified two-hour travel time.

Average wind speeds were calculated from data obtained from the Wind Atlas of Canada. The Wind Atlas wind speeds were measured at a height of 30 m. Since wind speeds are generally lower at lower altitudes, wind speeds at 30 m represent a conservative estimate of wind speeds at the lower elevations (e.g. 10 m above surface) (Tsinker, 1995).

The total surface velocity was calculated by adding 3% of the wind speed to the average water course velocity (without wind) calculated by the HEC-RAS model. The "with wind" calculation is as follows:

$$v_{water,\ surface} = v_{water,\ no\ wind} + 0.03 v_{wind} \tag{1}$$

where $v_{water,\ surface}$ is the surface current velocity, $v_{water,\ no\ wind}$ is the average current velocity calculated by the HEC-RAS model, and $v_{wind}$ is the wind velocity at an elevation of 30 m.

A decreasing linear relationship between depth and wind-induced water velocity was assumed and at one-third of the water column depth, wind would no longer have any effect on water velocity, such that:

$$v_{water, top\ 0.3D} = \frac{(v_{water,\ no\ wind} + 0.03 v_{wind}) + v_{water,\ no\ wind}}{2} \tag{2}$$

and

$$v_{water,\ bottom\ 0.7D} = v_{water,\ no\ wind} \tag{3}$$

where $v_{water, top\ 0.3D}$ is the average water velocity over the top 30% of the water column and $v_{water,\ bottom\ 0.7D}$ is the average water velocity over the remaining 70% of the water column. The average water velocity over the depth of the water column, $v_{water,\ avg.}$ is calculated to be:

$$v_{water,\ avg.} = 0.3 v_{water,\ top\ 0.3D} + 0.7 v_{water,\ bottom\ 0.7D} \tag{4}$$

Combining equations (2), (3) and (4) results in the following formula:

$$v_{water,\ avg.} = 0.3\left(\frac{2 v_{water,\ no\ wind} + 0.03 v_{wind}}{2}\right) + 0.7 v_{water,\ no\ wind} \tag{5}$$

Rearranging that formula:

$$v_{water,\ avg.} = 0.3 v_{water,\ no\ wind} + 0.3\frac{0.03 v_{wind}}{2} + 0.7 v_{water,\ no\ wind} \tag{6}$$

This simplifies to:

$$v_{water,\ avg.} = v_{water,\ no\ wind} + 0.3\frac{0.03 v_{wind}}{2} \tag{7}$$

This linear estimate is conservative. The relationship of wind-induced water velocity, as described in the literature (Bye, 1965; Liu and Perez, 1971), is an exponential decay curve, which would give a lower average water velocity for the entire water column.

IPZ-2W distances were calculated using the same methodology used for no wind IPZ-2 distances and substituting the average water velocity calculated in equation (7) with the water velocity obtained using the HEC-RAS model.

**Wind Data**

The Wind Atlas of Canada presents wind data for areas of 5 km$^2$. The data represent an average of wind measurements taken every 6 hours over the past 43 years.

**Wind Data for the Carleton Place Intake:**

For the Carleton Place intake area, wind speeds average 4.4 m/s and the prevailing wind direction (the mode) is 210 degrees from north or, generally from upstream. The average wind direction is 280 degrees from north, which is also generally from upstream. Figure D1 shows the wind rose calculated by Environment Canada for this area as well as a histogram of wind speeds.

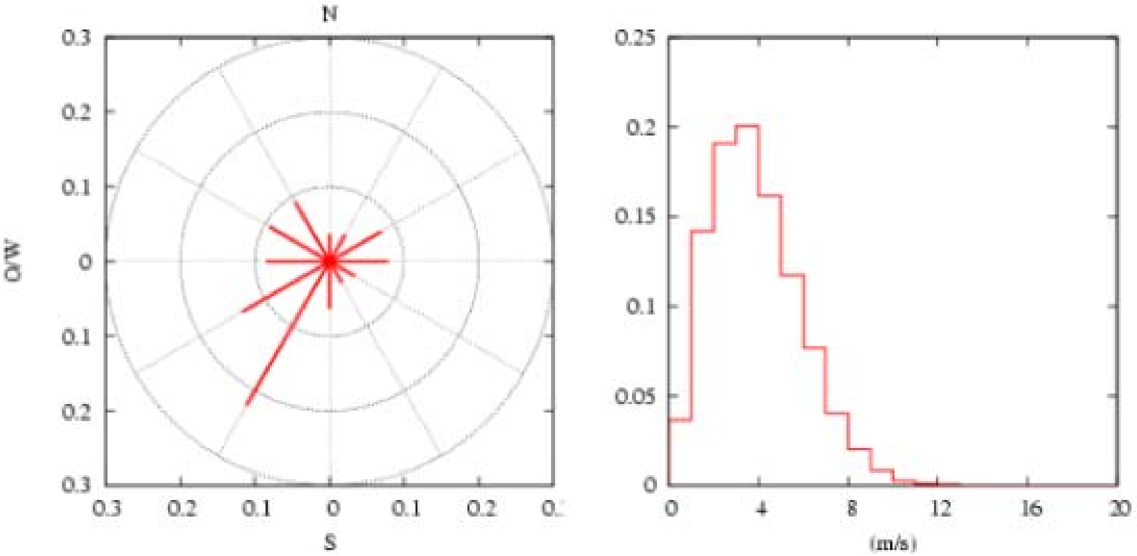

Figure D1: Wind rose and histogram for frequency of wind velocity for Carleton Place area: 45.157N, 76.162 W, measured at an elevation of 30 m. Wind Atlas of Canada. Last update: October 19, 2006. http://www.windatlas.ca/en/index.php

**Wind Data for the Perth Intake**:

For the Perth intake wind speeds average 4.6 m/s and the prevailing wind direction (the mode) is 210 degrees from north or generally, from upstream. The average wind direction is 283 degrees from north, which is also generally from upstream. Figure D2 shows the wind rose calculated by Environment Canada for this area as well as a histogram of wind speeds.

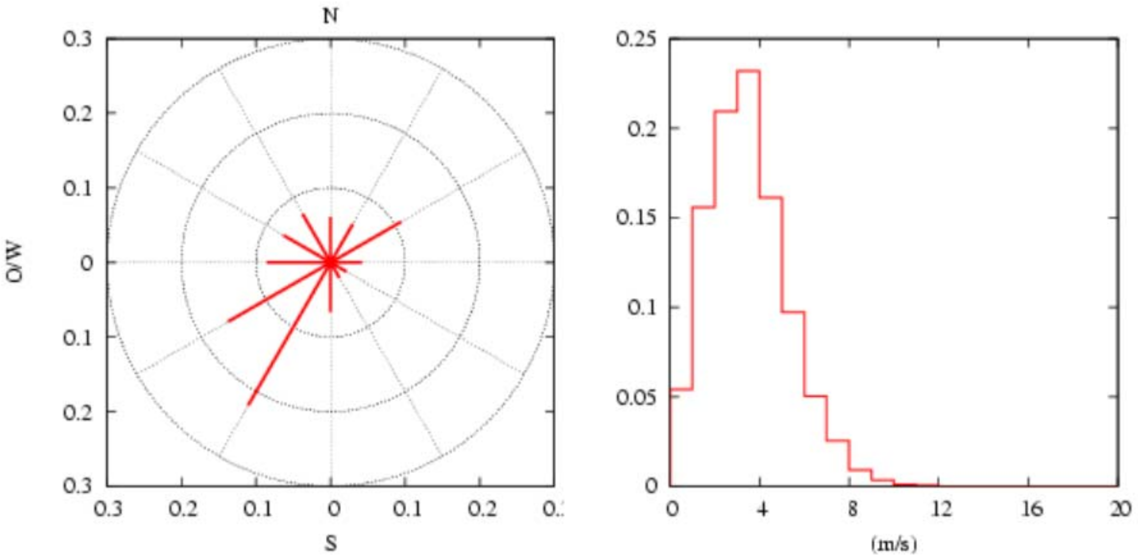

Figure D2: Wind rose and histogram for frequency of wind velocity for Perth area: 45.914N, 76.250 W measured at an elevation of 30 m. Wind Atlas of Canada. Last update: October 19, 2006. http://www.windatlas.ca/en/index.php

**Wind Data for the Smiths Falls Intakes:**

For the Smiths Falls intake wind speeds average 4.2 m/s and the prevailing wind direction (the mode) is 210 degrees from north or, generally upstream (between west and southwest). The average wind direction is 282 degrees from north (west northwest), which is also generally from upstream. Figure D3 shows the wind rose calculated by Environment Canada for this area as well as a histogram of wind speeds.

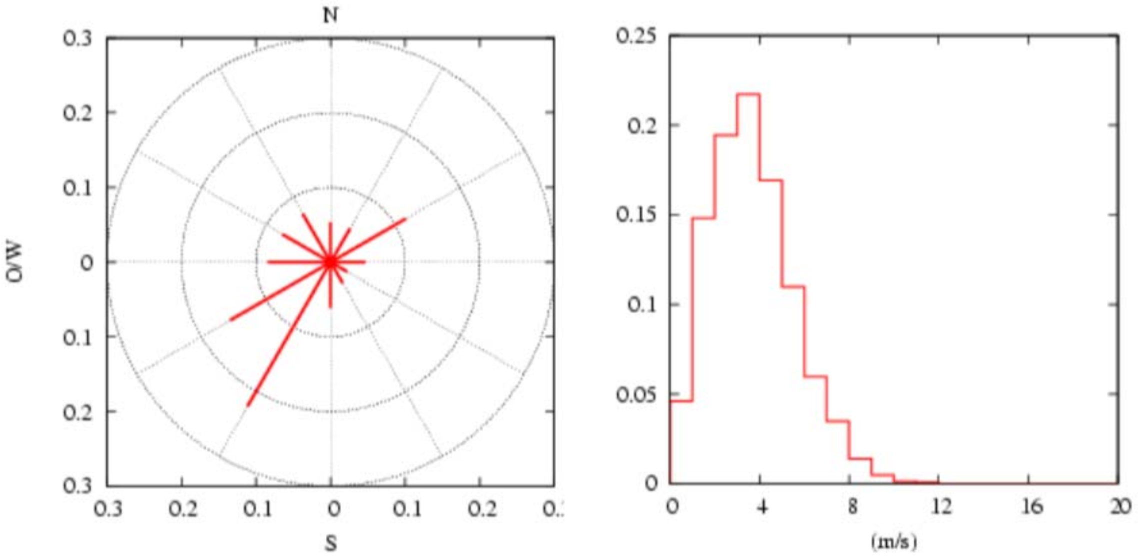

Figure D3. Wind rose and histogram for frequency of wind velocity for Smiths Falls area: 44.885N, 76.014 W measured at an elevation of 30 m. Wind Atlas of Canada. Last update: October 19, 2006. http://www.windatlas.ca/en/index.php

## IPZ-2 Extensions Due to Wind

### Carleton Place Intake:

As shown by the values in Table D1, the average velocity had a net increase of about 6.7% in the main branch when the effect of wind was taken into account. This translated to an additional distance of 142 m when calculating the IPZ-2W, which extends the IPZ further into Mississippi Lake and includes an additional tributary on the south shore of Mississippi Lake as shown in Figure C3d of Appendix C.

### Perth Intake:

As shown by the values in Table D2 (see following page), the average velocity had a net increase of about 5.8% in the main branch when the effect of wind was taken into account. This translated to an additional distance of 150 m when calculating the IPZ-2W, which extends the IPZ further upstream in the Tay River as shown in Figure C6d of Appendix C.

### Smiths Falls Intakes:

As shown by the values in Table D3 (see following page), the average velocity had a net increase of about 7.7% and 7.1% in the main branch when the effect of wind was taken into account, for the main and auxiliary intake, respectively. This translated into an additional distance of about 135 m for both intakes, when calculating the IPZ-2W, which extends the IPZ further up the Rideau River and laterally into the riverine wetlands as shown in Figure C9d of Appendix C.

**Table D1: Extensions of IPZ-2 for the Carleton Place Intake due to Wind Conditions**

| | | Main Branch | CP12 | | CP13 | |
|---|---|---|---|---|---|---|
| | | | d/s of CP12 to Intake | IPZ-2 limit to d/s of CP12 | d/s of CP13 to Intake | IPZ-2 limit to d/s of CP13 |
| Original distance within stream | (m) | 2117 | 1889 | 770 | 2035 | 280 |
| Original travel time within stream | (min) | 120 | 98.6 | 21.4 | 112.3 | 7.7 |
| $v_{water,\ no\ wind}$ | (m/s) | 0.294 | 0.319 | 0.600 | 0.302 | 0.606 |
| $v_{wind}$ | (m/s) | 4.39 | 4.39 | 4.39 | 4.39 | 4.39 |
| Wind Factor | | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 |
| $v_{water,\ surface}$ | (m/s) | 0.132 | 0.132 | 0.132 | 0.132 | 0.132 |
| Additional distributed *v* due to wind | (m/s) | 0.020 | 0.020 | 0.020 | 0.020 | 0.020 |
| $v_{water,\ avg.}$ | (m/s) | 0.314 | 0.339 | N/A | 0.322 | N/A |
| % Velocity increase | (%) | 6.72 | 6.19 | N/A | 6.54 | N/A |
| Travel time within stream with wind | (min) | 120 | 92.9 * | 27.1 | 105.4 * | 14.6 |
| New travel distance within stream | (m) | 2259 | | 977 | | 531 |
| Additional distance due to wind | (m) | 142 | | 207 | | 251 |

Note: * Interpolated travel time based on wind

## Table D2: Extensions of IPZ-2 for the Perth Intake due to Wind Conditions

| | | Main Branch | P11 | | P10 | |
|---|---|---|---|---|---|---|
| | | | d/s of P11 to Intake | IPZ-2 limit to d/s of P11 | d/s of P10 to Intake | IPZ-2 limit to d/s of P10 |
| Original distance within stream | (m) | 2594 | 2061 | 1198 | 1571 | 410 |
| Original travel time within stream | (min) | 120 | 86.5 | 33.5 | 69.5 | 50.5 |
| $v_{\text{water, no wind}}$ | (m/s) | 0.360 | 0.397 | 0.596 | 0.377 | 0.135 |
| $v_{\text{wind}}$ | (m/s) | 4.64 | 4.64 | N/A | 4.64 | N/A |
| Wind Factor | | 0.03 | 0.03 | N/A | 0.03 | N/A |
| $v_{\text{water, surface}}$ | (m/s) | 0.139 | 0.139 | N/A | 0.139 | N/A |
| Additional distributed V due to wind | (m/s) | 0.021 | 0.021 | N/A | 0.021 | N/A |
| $v_{\text{water, avg.}}$ | (m/s) | 0.381 | 0.418 | N/A | 0.398 | N/A |
| % Velocity increase | (%) | 5.80 | 5.26 | N/A | 5.54 | N/A |
| Travel time within stream with wind | (min) | 120 | 82.2 | 37.8 | 65.9 | 54.1 |
| New travel distance within stream | (m) | 2744 | | 1353 | | 440 |
| Additional distance due to wind | (m) | 150 | | 155 | | 30 |

## Table D3b: Extensions of IPZ-2 for the Smiths Falls Auxiliary Intake due to Wind Conditions

| | | Main Branch | Tributary 1 | | | Storm Sewer | | |
|---|---|---|---|---|---|---|---|---|
| | | | d/s of Trib 1 to intake | IPZ-2 limit to d/s of Trib 1 | Stream outlet to limit of IPZ-2 | d/s of Trib 1 to intake | d/s of Storm limit to d/s of Trib 1 | Storm Sewer |
| Original distance within stream | (m) | 1756.55 | 206 | 999 | 235 | 544 | 824 | Already included |
| Original travel time within stream | (min) | 120 | 15 | 105 | 24.7 | 33 | 86.6 | in buffer past 2-h limit |
| $v_{water,\ no\ wind}$ | (m/s) | 0.244 | 0.229 | 0.159 | 0.159 | 0.273 | 0.159 | |
| $v_{wind}$ | (m/s) | 4.16 | 4.16 | 4.16 | | 4.16 | 4.16 | |
| Wind Factor | | 0.03 | 0.03 | 0.03 | | 0.03 | 0.03 | |
| $v_{water,\ surface}$ | (m/s) | 0.125 | 0.125 | 0.125 | | 0.125 | 0.125 | |
| Additional distributed V due to wind | (m/s) | 0.019 | 0.019 | 0.019 | | 0.019 | 0.019 | |
| $v_{water,\ avg.}$ | (m/s) | 0.263 | 0.248 | 0.177 | | 0.292 | 0.177 | |
| % Velocity increase | (%) | 7.67 | 8.18 | 11.81 | | 6.85 | 11.80 | |
| Travel time within stream with wind | (min) | 120 | 13.9 | 106.1 | | 31.0 | 77.4 | 11.5 |
| New travel distance within stream | (m) | 1891 | | 1129 | | | | |
| Additional distance due to wind | (m) | 135 | | 130 | | | | |

Notes: * Stream all included into IPZ-2

| | | Tributary 2 | | | Tributary 3 | | |
|---|---|---|---|---|---|---|---|
| | | d/s of Trib 2 to Intake | IPZ-2 limit to d/s of Trib 2 | Stream outlet to limit of IPZ-2 | d/s of Trib 3 to Intake | IPZ-2 limit to d/s of Trib 3 | Stream outlet to limit of IPZ-2 |
| Original distance within stream | (m) | 812 | 912 | 1080 | 478 | 20 | 812 |
| Original travel time within stream | (min) | 68 | 52 | 83 | 37 | 1.5 | 68 |
| $v_{water,\ no\ wind}$ | (m/s) | 0.199 | 0.292 | 0.217 | 0.215 | 0.215 | 0.199 |
| $v_{wind}$ | (m/s) | 4.16 | 4.16 | 4.16 | 4.16 | | 4.16 |
| Wind Factor | | 0.03 | 0.03 | 0.03 | 0.03 | | 0.03 |
| $v_{water,\ surface}$ | (m/s) | 0.125 | 0.125 | 0.125 | 0.125 | | 0.125 |
| Additional distributed V due to wind | (m/s) | 0.019 | 0.019 | 0.019 | 0.019 | | 0.019 |
| $v_{water,\ avg.}$ | (m/s) | 0.218 | 0.311 | 0.236 | 0.234 | | 0.218 |
| % Velocity increase | (%) | 9.41 | 6.40 | 8.63 | 8.69 | | 9.41 |
| Travel time within stream with wind | (min) | 62.2 | 57.8 | 76.4 | 43.6 | | 62.2 |
| New travel distance within stream | (m) | | 1080 | | 612 | | |
| Additional distance due to wind | (m) | | 168 | | 134 | | |

## Table D3b: Extensions of IPZ-2 for the Smiths Falls Auxiliary Intake due to Wind Conditions

| | | Main | Tributary 1 | | | Storm Sewer | | |
|---|---|---|---|---|---|---|---|---|
| | | Branch | d/s of Trib 1 to Intake | IPZ-2 limit to d/s of Trib 1 | Stream outlet to limit of IPZ-2 | d/s of Trib 1 to Intake | d/s of Storm limit to d/s of Trib 1 | Storm Sewer |
| Original distance within stream | (m) | 1900 | 544 | 828 | 179 | 544 | 824 | Already included in buffer past 2-h limit |
| Original travel time within stream | (min) | 120 | 33 | 87 | 19 | 33 | 86.6 | |
| $v_{water,\ no\ wind}$ | (m/s) | 0.264 | 0.275 | 0.159 | | 0.273 | 0.159 | |
| $v_{wind}$ | (m/s) | 4.16 | 4.16 | 4.16 | | 4.16 | 4.16 | |
| Wind Factor | | 0.03 | 0.03 | 0.03 | | 0.03 | 0.03 | |
| $v_{water,\ surface}$ | (m/s) | 0.125 | 0.125 | 0.125 | | 0.125 | 0.125 | |
| Additional distributed V due to wind | (m/s) | 0.019 | 0.019 | 0.019 | | 0.019 | 0.019 | |
| $v_{water,\ avg.}$ | (m/s) | 0.283 | 0.293 | 0.177 | | 0.292 | 0.177 | |
| % Velocity increase | (%) | 7.09 | 6.81 | 11.80 | | 6.85 | 11.80 | |
| Travel time within stream with wind | (min) | 120 | 30.9 | 89.1 | 139 | 31.0 | 77.4 | 11.5 |
| New travel distance within stream | (m) | 2035 | | 948 | | | | |
| Additional distance due to wind | (m) | 135 | | 120 | | | | |

Notes: * Stream all included into IPZ-2

| | | Tributary 2 | | | Tributary 3 | | |
|---|---|---|---|---|---|---|---|
| | | d/s of Trib 2 to Intake | IPZ-2 limit to d/s of Trib 2 | Stream outlet to limit of IPZ-2 | d/s of Trib 3 to Intake | IPZ-2 limit to d/s of Trib 3 | Stream outlet to limit of IPZ-2 |
| Original distance within stream | (m) | 981 | 887 | 38 | 1249 | 549 | 9 |
| Original travel time within stream | (min) | 70 | 50 | 2 | 85 | 35 | 0.6 |
| $v_{water,\ no\ wind}$ | (m/s) | 0.234 | 0.296 | | 0.245 | 0.261 | |
| $v_{wind}$ | (m/s) | 4.16 | 4.16 | | 4.16 | 4.16 | |
| Wind Factor | | 0.03 | 0.03 | | 0.03 | 0.03 | |
| $v_{water,\ surface}$ | (m/s) | 0.125 | 0.125 | | 0.125 | 0.125 | |
| Additional distributed V due to wind | (m/s) | 0.019 | 0.019 | | 0.019 | 0.019 | |
| $v_{water,\ avg.}$ | (m/s) | 0.252 | 0.314 | | 0.264 | 0.280 | |
| % Velocity increase | (%) | 8.01 | 6.33 | | 7.64 | 7.16 | |
| Travel time within stream with wind | (min) | 64.8 | 55.2 | 122 | 79.0 | 41.0 | 121 |
| New travel distance within stream | (m) | | 1041 | | | 690 | |
| Additional distance due to wind | (m) | | 154 | | | 141 | |

**References:**

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# Appendix 6-2

## Uncertainty Assessment – Inland Rivers Intake Protection Zones

Mississippi-Rideau Source Protection Region

# APPENDIX B
# Methodology for the Assignment of Vulnerability Scores
## September 2010

*<u>A note regarding Technical Rules (2009)</u>:*
*The Technical Rules for the Asssessment Report were revised in 2009. The 2009 version of the Rules were approved in November 16, 2009. The methods used in this study were updated in reference to the 2008 version of the Technical Rules. The methods used are also, for the most part, in accordance with the November 2009 version of the Rules.*

Under the *Technical Rules (2009)*, a vulnerability score is assigned for each IPZ-I and IPZ-2 associated with a type A, B, C or D intake, and to each area of an IPZ-3 associated with a type C or type D intake (Rule 86). The following formula is to be used for determining the vulnerability score (V):

$$V = B \times C$$

Where:

B = the area vulnerability factor of the area of the surface water intake protection zone determined in accordance with Rules 88 to 93; and

C = the source vulnerability factor of the surface water intake protection zone determined in accordance with Rules 94 to 96 (Note: *Technical Rules (2008)* stated “rules 94 and 96”).

Under the *Technical Rules (2009)*, the values and/or range of values to be used in the vulnerability scoring for type C intakes are as follows:

**Table 1: Range of Vulnerability Scoring Values for Type C intakes**

| **Intake Type** | **(B) Area Vulnerability Factor Expressed as a whole number (Rule 93)** | | | **(C) Source Vulnerability Factor (type C Intake) (Rules 94 to 96)** | **(V) Range of Vulnerability Score for IPZ-2 and IPZ-3 is expressed to one decimal point or as whole number depending on the value of C** | | |
|---|---|---|---|---|---|---|---|
| | **IPZ-1 (Rule 88)** | **IPZ-2 (Rule 89)** | **IPZ-3 (Rule 90)** | | **IPZ-1** | **IPZ-2** | **IPZ-3** |
| Type C | 10 | 7 to 9 | 1 to 9 | 0.9 or 1 | 9 or 10 | 6.3 to 9 | 0.9 to 9 |

Area vulnerability factors that are assigned to the areas within an IPZ-3 are not to be greater than the zone vulnerability factor assigned to the intake’s IPZ-2. Rule 92 requires that the determination of the area vulnerability factor for the IPZ-2, or for areas within an IPZ-3, take the following conditions into consideration:

1) the percentage of the area of the IPZ-2 or IPZ-3, as the case may be, that is composed of land;

2) the land cover, soil type, permeability of the land and the slope of any setbacks;

3) the hydrological and hydrogeological conditions of the area where the transport pathway is located. Note: The *Technical Rules (2008)* stated “the hydrological and hydrogeological conditions in the area that contributes water to the area through transport pathways”; and

4) for IPZ-3, the proximity of the area of the IPZ-3 to the intake.

The *Technical Rules (2009)* require that the consideration of these conditions be documented and an explanation provided on how each affected the determination of the area vulnerability factor. This requirement is met by this study’s methodology and documentation.

## 1.0 Carleton Place, Perth and Smiths Falls Source Vulnerability Factor

The Source Vulnerability Factor (C) is to take into account the location of the intake on the source water body and water quality concerns at the intake. Under the *Technical Rules* the “C” for type C intakes is 0.9 or 1 (Rule 95, Table 3).

The selection of the value for C for the Carleton Place, Perth and Smiths Falls intakes took into account the following considerations identified by the *Technical Rules (2008)* (Rule 95):

1) depth of intake below the water surface (e.g. deeper the intake the lower the vulnerability factor);

2) distance of the intake from the land (e.g. further distance from shoreline the lower the vulnerability factor); and

3) number of recorded drinking water issues related to the intake, if any (e.g. no past incidences the lower the vulnerability factor).

Note: Rule 95 in the *Technical Rules (2009)* is the same as above except for consideration 3) for which it states the following: “the history of water quality concerns at the surface water intake”. The current methodology used the reported incidences as an indication of a history of water quality concerns. Additional information on the raw water quality is also provided in the main text (e.g. information on the impact on the Smiths Falls intake raw water turbidity levels, colour, taste and odour by a gate adjustment upstream in the Rideau Canal system). The source vulnerability factor results for the Carleton Place, Perth and Smiths Falls intakes remain the same under the 2009 version of the Technical Rules.

The following condition was also taken into consideration:

- presence of hydraulic structures, upstream and nearby the intake, that would cause mixing of the water column (e.g. presence of such structure(s) and resulting mixing would increase vulnerability factor).

The *Technical Rules (2009)* require that the consideration of these conditions be documented and an explanation provided on how each affected the determination of the source vulnerability factor. This requirement is met by the current study’s methodology and documentation.

**Table 2: Source Vulnerability Factor Results**

| Intake | Depth of Intake (m) | Distance from Shore (m) | Water Quality Incidences (reported for raw water) | Upstream Hydraulic Structure(s) (potential mixing of water column) | Source Vulnerability Factor (C) |
|---|---|---|---|---|---|
| **Carleton Place** | 2.2 | 48 | none | no | **1** |
| **Perth** | 2 | 4 | none | no | **1** |
| **Smiths Falls - main** | 1.8 | 30 | none | no | **1** |
| **Smiths Falls - aux** | <1 | 0 | n/a | yes | **1** |

Based on the shallowness of the intakes, their distance from shore, and the presence or absence of hydraulic structures in proximity upstream, as well as any reported water quality incidences, all three of the inland intakes were assigned a source vulnerability factor of 1.

## 2.0 Carleton Place, Perth and Smiths Falls IPZ-1 Vulnerability Factors and Scores

**IPZ-1 area vulnerability factor (B):** Set at "10" for Type C intakes by Rule 88. As the IPZ-1 vulnerability scores are a product of the source vulnerability factor C (all 1's) and the area vulnerability factor B (all 10's), the IPZ-1 vulnerability score for each of the study's three intakes is 10.

**Table 3: IPZ-1 Vulnerability Scoring Results:**

| Intake | IPZ-1 Area Vulnerability Factor (B) | Source Vulnerability Factor (C) | IPZ-1 Vulnerability Scores (V) |
|---|---|---|---|
| **Carleton Place** | 10 | 1 | **10** |
| **Perth** | 10 | 1 | **10** |
| **Smiths Falls - main** | 10 | 1 | **10** |
| **Smiths Falls - aux** | 10 | 1 | **10** |

## 3.0 Carleton Place, Perth and Smiths Falls IPZ-2 Zone Vulnerability Factors and Scores

**IPZ-2 area vulnerability factor (B):** is a moderate to high level of vulnerability for inland rivers/streams and is to be given one fixed value between 7 to 9, inclusive, for the entire zone (Rule 89).

Rule 92 requires that the determination of the area vulnerability factor for the IPZ-2 take into account the considerations listed above at the beginning of this Appendix. The following are the site specific parameters used to determine "B":

- Percent land area
- Runoff generation potential (Curve Number (CN) for land cover and permeability; slope)
- Transport pathways in the zone (extent in comparison to the length of IPZ-2 main channel)

To calculate one fixed B value, ranging between 7 and 9 for each IPZ-2, a weighted combination of these parameter results was used. The weighted combination is described here:

### 3.1 Land threat potential in the zone (land versus water body area)

The determination of the score associated with the land versus water body area (**B<sub></sub>**$\mathbf{B_{\%LA}}$) was based on two scenarios. One scenario represents the highest vulnerability where the land composes 90 % of the total IPZ-2 area (as would be the case for an intake on a narrow river with an IPZ-2 with many transport pathways) and the other scenario represents the lowest vulnerability where the land composes 10% of the total IPZ-2 area (as would be the case for an intake on a wide river with an IPZ-2 with few transport pathways).

The $\mathbf{B_{\%LA}}$ score was determined in proportion to these assumed extremes by interpolation between “7” (equal to the least vulnerability) and “9” (equal to the highest vulnerability). Note that any percentage of land versus water body area that would be greater than 90% would be assigned a value of 90% and that any percentage of land versus water body area that would be lower than 10% would be assigned a value of 10%.

**Table 4: Results for Land Area Parameter:**

| Intake | Percentage of Land Area / Total Area (%) | $B_{\%LA}$ |
|---|---|---|
| Carleton Place | 72 | **8.55** |
| Perth | 86 | **8.90** |
| Smiths Falls | 45 | **7.88** |

### 3.2 Runoff generation potential factors (surface permeability, slope)

The score associated with runoff generation potential factors of surface permeability and slope ($\mathbf{B_{CN,\ Slope}}$) was derived from the following SCS lag equation (1973), developed from agricultural watershed data:

$$t_c = \frac{100L^{0.8}\left[\left(1000/CN\right)-9\right]^{0.7}}{1900S^{0.5}}$$

Where

$T_c$ is the time of concentration (min)
*CN* is the SCS runoff curve number
$S$ is the average watershed slope (%)
$L$ is the travel length (m)

Conceptually, runoff potential is assumed to vary with the time of concentration, which is expressed as a function of the SCS runoff curve number and the slope of the terrain. The highest the *CN* and *S* values are the shorter the time of concentration will be, which results in a higher vulnerability.

The selected vulnerability scores range from 7 to 9 and may be expressed by the following formula:

$$B_{CN,Slope} = 7 + 2\left[\frac{\left(\frac{(1000/CN_{actual} - 9)^{0.7}}{1900 \times S_{actual}^{\ 0.5}}\right) - \left(\frac{(1000/CN_{\min} - 9)^{0.7}}{1900 \times S_{\min}^{\ 0.5}}\right)}{\left(\frac{(1000/CN_{\max} - 9)^{0.7}}{1900 \times S_{\max}^{\ 0.5}}\right) - \left(\frac{(1000/CN_{\min} - 9)^{0.7}}{1900 \times S_{\min}^{\ 0.5}}\right)}\right]$$

Where

$B_{CN,\,Slope}$ is based on the runoff generation potential factors (surface permeability and slope)
$CN_{actual}$ is the average SCS runoff curve number of the IPZ-2 of interest
$CN_{\min}$ is the minimum of the average SCS runoff curve number (assumed as 36)
$CN_{\max}$ is the maximum of the average SCS runoff curve number (assumed as 95)
$S_{actual}$ is the average slope of the IPZ-2 of interest (%)
$S_{\min}$ is the minimum of the average slopes (assumed as 0.25 %)
$S_{\max}$ is the maximum of the average slopes (assumed as 2 %)

Note that the minimum of the average SCS runoff curve number of 36 is based on the minimum possible value from Table 1 of Addendum A and the maximum of the average SCS runoff curve of 95 is based on impervious surface value from TableI1. The values selected for the minimum and maximum average slopes reflect local slope conditions. The minimum of average slopes is based on a low vulnerability situation of minimal slope (0.25%). The maximum of the average slopes is based on a higher vulnerability situation where the slope is great enough (2%) to induce surface runoff.

Based on the above, for a CN (actual) value of 36 (or lower) combined with an average slope (actual) of 0.25 % (or lower), the computed vulnerability score will be 7. Similarly, for a CN (actual) value of 95 (or greater) combined with a slope (actual) of 2 % (or greater), the computed vulnerability score will be 9.

The weighted averages were used in the formula described above to determine a combined value normalized to fall between 7 and 9 for the IPZ-2.

**Table 5: Results for Runoff Potential:**

| Intake | CN | Slope (%) | $B_{CN,\ slope}$ |
|---|---|---|---|
| Carleton Place | 83 | 1.42 | **8.88** |
| Perth | 85 | 1.21 | **8.88** |
| Smiths Falls | 90 | 0.42 | **8.77** |

Note that the final CN values for each IPZ are affected by the presence of wetlands and open water bodies, which are assigned high CN values.

### 3.3 Transport pathways in the zone (faster transport potential, numerous pathways including natural and anthropogenic pathways, urban or rural drainage, open drains/small streams/ditches, etc.)

The score associated with transport pathways in the IPZ-2 (**B$_{TP}$**) was based on transport pathway lengths including streams, ditches, etc. In this case, storm sewers lengths are included in the calculation if the storm sewer(s) have been identified as being part of the IPZ-2.

First, the “Discharge Length” ($L_{TP}$) was calculated as the total length of the IPZ-2 transport pathways. Then, the “Length of the IPZ-2 along the main channel” ($L_{IPZ\text{-}2\ river}$) was determined, and finally, a ratio of $L_{TP}$ over $L_{IPZ\text{-}2\ river}$ was computed as it represents a good measurement of the density of transport pathways. **B$_{TP}$** is calculated using the following equation:

$$B_{TP} = 7 + 2\left[\frac{\left(\left(\frac{L_{TP\,actual}}{L_{IPZ-2\ river}}\right)_{actual} - \left(\frac{L_{TP}}{L_{IPZ-2\ river}}\right)_{\min}\right)}{\left(\left(\frac{L_{TP}}{L_{IPZ-2\ river}}\right)_{\max} - \left(\frac{L_{TP}}{L_{IPZ-2\ river}}\right)_{\min}\right)}\right]$$

A sensitivity analysis was done to determine suitable minimum and maximum values of the ratio. The analysis used the following ratio ranges: 0 and 8; 1 and 8; 0 and 9; 1 and 9; 2 and 9; 0 and 10; 1 and 10; 2 and 10; 0 and 20; 2 and 20. It was determined from the analysis that the 0 to 9 range resulted in the transport pathway score that was the most representative of the extent of transport pathways for each of the IPZ-2s and made the most “sense” when compared to a visual examination of the transport pathway networks as compared to the length of the main river channels. Therefore the minimum and maximum values of the ratio were selected as 0 and 9, respectively. The sensitivity of the scoring results to this range was tested by determining how much the ratio would need to be adjusted to result in an area vulnerability factor of “9” for Smith Falls. The ratio range would need to be as low as 0 to 2.1 in order to change the Smiths Falls result to 9, reflecting a low sensitivity to the ratio range.

A ratio of 0 would correspond to a scenario with no transport pathways and a ratio of 9 would correspond to a scenario with a total length of transport pathways that is 9 times greater than the length of IPZ-2 along the main channel. Any ratio that would be greater than 9 would be set to 9. The above equation becomes:

$$B_{TP} = 7 + 2\left[\frac{\left(\frac{L_{TP\,actual}}{L_{IPZ-2\ river}}\right)}{9}\right]$$

The values of **B$_{TP}$** for the three intakes were, in fact, determined by interpolation between the minimum and maximum to find the corresponding value between “7” and “9” for that IPZ-2. As such, according to this equation, the lower limit or value of “7” could be given to a location with no transport pathways and a value of “9” could be given to a location with a large amount of transport pathways, more specifically when the ratio of $L_{TP}$ over $L_{IPZ\text{-}2\ river}$ is greater than or equal to 9.

**Table 6: Results for Transport Pathways in the Zone:**

| Intake | $L_{TP\ actual}$ (m) | $L_{IPZ\text{-}2\ river}$ (m) | $L_{TP\ actual}$ / $L_{IPZ\text{-}2\ river}$ | $B_{TP}$ |
|---|---|---|---|---|
| Carleton Place | 14,857 | 2115 | 7.0 | 8.56 |
| Perth | 12,250 | 2594 | 4.7 | 8.05 |
| Smiths Falls | 2,706 | 1757 | 1.5 | 7.34 |

## 3.4 Combined IPZ-2 Area Vulnerability Factor:

The “scores” for the parameters were combined for each IPZ-2 by applying a weighting of 30% to $\mathbf{B_{CN,\ Slope}}$, a weighting of 30% to $\mathbf{B_{\%LA}}$, and a weighting of 40% to $\mathbf{B_{TP}}$ as follows:

$$Combined\ IPZ\text{-}2\ Vulnerability\ Factor = \frac{30\left(B_{CN,Slope}\right) + 30\left(B_{\%LA}\right) + 40\left(B_{TP}\right)}{100}$$

The transport pathways parameter has the largest weighting since the pathways are considered to be the primary vectors for transport to the source water supply. Runoff potential and percentage of land area have a lower but equal weighting.

The minimum-maximum range for the combined valued is from 7 to 9 inclusive.

The resulting B values are noted in the following table:

**Table 7: IPZ-2 Area Vulnerability Factors**

| | | Intake B Values | | |
|---|---|---|---|---|
| **Score** | **Weight (%)** | **Carleton Place** | **Perth** | **Smiths Falls** |
| $B_{\%LA}$ | 30 | 8.55 | 8.90 | 7.88 |
| $B_{CN,\ Slope}$ | 30 | 8.88 | 8.88 | 8.77 |
| $B_{TP}$ | 40 | 8.56 | 8.05 | 7.34 |
| **IPZ-2 Area Vulnerability Factors preliminary** | 100 | **8.65** | **8.55** | **7.93** |
| **IPZ-2 Area Vulnerability Factors (B)** | As whole numbers | **9** | **9** | **8** |

Note: Rule 93: An area vulnerability factor assigned for the purpose of rule 86 or 87 shall be expressed as a whole number.

## 3.5 Final IPZ-2 Vulnerability Scoring:

**Table 8: IPZ-2 Vulnerability Scoring Results**

| Intake | (B) IPZ-2 Area Vulnerability Factor | (C) Source Vulnerability Factor | (V) IPZ-2 Vulnerability Scores |
|---|---|---|---|
| **Carleton Place** | 9 | 1 | **9** |
| **Perth** | 9 | 1 | **9** |
| **Smiths Falls** | 8 | 1 | **8** |

The GIS methods, calculations and metadata used to accomplish this IPZ-2 vulnerability scoring are described and identified in **Addendum A** (attached).

## 4.0 IPZ-3 Area Vulnerability Factors (Bs)

The IPZ-3 encompasses all the streams up to first order streams, in-stream water bodies and a 120 m buffer and the Regulation Limit area around those waterways in the entire watershed upstream from the surface water intake. Also included as potential transport pathways are wetlands contiguous with the water courses and within the watershed divides. In the case of the Smiths Falls IPZ-3 the anthropogenic transport pathways of Perth have been included.

The Technical Rules (2009) require that the following be considered in the determination of the area vulnerability factor (B) for areas within an IPZ-3 (as per Rule 92):

1) the percentage of the area IPZ-3 that is composed of land;
2) the land cover, soil type, permeability of the land and the slope of any setbacks;
3) the hydrological and hydrogeological conditions of the area where the transport pathway is located; and
4) the proximity of the area of the IPZ-3 to the intake.

There can be more than one area vulnerability factor assigned to the IPZ-3, based on differences in the characteristics noted above including distance from the intake. The IPZ-3 area vulnerability factors for the Inland River intakes were determined as follows:

An area vulnerability factor is assigned to all areas based on a time of travel. Time of travel is the time it takes for runoff to reach the intake. The time of travel is a means of defining the areas within the IPZ-3 in terms of their proximity to the intake. However the determination of the time of travel in the main channels and in the tributaries and transport pathways can also take into account the other considerations listed in Rule 92; namely: land cover, soil type, permeability of the land and the slope of any setbacks; and hydrological conditions of the area where the transport pathways are located.

The methodology used for the Inland Rivers and Ottawa intakes IPZ-3 area vulnerability factors is outlined here in brief:

The total time of travel was determined in two steps: 1) the time of travel (ToT) within the source river main channel was calculated and then 2) the time of travel within the subwatersheds to the main channel was calculated. For each area in the IPZ-3, these two travel times were added to result in the total travel time to the intake from each area. Then, a vulnerability factor was assigned to travel time intervals.

## 4.1 Time of Travel in the main channel

The ToT in the main channel was determined by using either river velocities estimated by numerical models, if the models were available, and/or by an Event Based Approach (MOE 2009b) which uses records from the source river's flow gauges. The choice of which method was used, either the modelling or the EBA method, was determined by what models and/or data were available. Velocities of the 1:2 year return period flows were used for the main river channel calculations.

Carleton Place – Mississippi River

The time of travel up to 18 hours was determined by the event based approach using data recorded at the Ferguson Falls and Appleton gauges and interpolation between the IPZ-2 upper boundary and the Ferguson Falls gauge. The interpolated distances were adjusted to account for variances in the channel width. No numerical model was available for the Mississippi River.

Perth – Tay River

The time of travel up to 18 hours was determined using data from the Rideau Valley Conservation Authority's Tay River HEC-RAS model (2010), expanded upstream using data from the RVCA's Mike 11 Tay River subwatershed model. According to RVCA staff, the models used have not been calibrated and thoroughly verified but are considered to be the best available information.

Smiths Falls – Rideau River

The time of travel up to 18 hours was determined using data from the Rideau Valley Conservation Authority's HEC-RAS Rideau River model (2010), expanded upstream using data from the RVCA's Mike 11 Rideau River watershed model. According to RVCA staff, the models used have not been calibrated and thoroughly verified but are considered to be the best available information.

## 4.2 Time of Travel in the subwatersheds

Determining the travel time in the subwatersheds required the delineation of the subwatershed boundaries. This was done using GIS mapping and GIS tools (e.g. ArcHydro). The time required for flow within the subwatershed tributaries to reach the subwatershed outlet was determined using a well known hydrologic equation called the SCS lag time of concentration formula. The time of concentration formula takes into consideration the subwatershed's land cover, soil type and land surface permeability and tributary slope conditions. As stated in MOE's Technical Bulletin: Delineation of Intake Protection Zone 3 Using the Event Based Approach (EBA) (MOE 2009b), the SCS lag formula time of concentration approach is "a good method to estimate the time of travel within the watershed in the absence of an advanced numerical model. The formula is intended for use on watersheds where overland flow dominates and was developed for non-urban watersheds of 4000 acres [approximately 1619 hectares] or less." As such, the SCS lag equation approach was selected since no numerical model was available for each tributary and since the subwatersheds are less than 4000 acres and non-urban, with the exception of one subwatershed located upstream of the Smiths Falls intake.

The procedure is summarized as follows:

1) the time of concentration is calculated at every point along the stream of the subwatershed using the SCS lag equation:

$$Tc = 0.000226789\, L^{0.8}(1000/CN - 9)^{0.7}\, S^{-0.5}$$

where
$Tc$ is the time of concentration at any specific point (min)
$L$ is the distance from point to u/s end of stream (m)
$CN$ is the average Curve Number of the subwatershed
$S$ is the slope between the specific point and the u/s end of stream (m/m)

By definition, *Tc* is the time required for a drop of water falling on the most remote part of a drainage area to reach the outlet of that drainage area. The time of concentration can be determined for any point along a stream.

2) adjustments are made where computed downstream *Tc* < upstream *Tc*. This situation occurred occasionally due to rapid change in slopes along stream paths.

3) at junctions, the higher of the tc's of the upstream branches is used (this is how the longest travel path is determined).

4) computed *Tc*'s are adjusted (*Ta*) along the branches to have a common time relative to the subwatershed outlet.

5) time of travel from any stream point to the subwatershed outlet ($ToT_{stream}$) is computed as follows:
Time of travel from any point to stream outlet = *Tc* of whole subwatershed - *Ta* at that specific point.

6) time of travel from any stream point to the intake (*ToT*) is computed as follows:
$\text{ToT}_{\text{from any point to intake}} = \text{ToT}_{stream} + \text{ToT}_{\text{stream outlet to intake}}$

7) the location of the 6-,10-,14-,18- and 22-h limits are determined from this final mapping of the ToT.

## 4.3 Area Vulnerability Factors scoring table

The IPZ-3 area vulnerability factors were determined using the total travel times and 4-hour travel time intervals. The 4-hour interval was used as it is twice the time of travel used for the IPZ-2 delineation and provides, based on local hydrological conditions, an additional "two times the IPZ-2" increase in the travel time distance from the intake.

The first 4-hour interval in the IPZ-3, which starts at the upstream IPZ-2 boundary, was assigned an area vulnerability factor value of 8. This higher value was assigned to this interval due to its proximity to the intake and to be within the range of values allowed by *Technical Rule* 91 which states that the IPZ-3 area vulnerability factor is not to be greater than the area vulnerability factor assigned to the IPZ-2. In addition, the assignment of "8" to the area of IPZ-3 closest to the intake is consistent with the progression of area vulnerability factors established by the *Technical Rules*. The *Technical Rules* dictate an area vulnerability factor of 10 for IPZ-1 and an area vulnerability factor of 9, 8 or 7 for IPZ-2. The *Rules* direct a drop of at least “1” in the vulnerability factor from IPZ-1 to IPZ-2 (10 to 9).

The area vulnerability factors assigned to the succeeding IPZ-3 areas defined by the 4-hour time of travel intervals were stepped down by 1 as the distance from the intake increased until the 18 hour time of travel was reached. (e.g. 2 hours to 6 hours would have a factor of 8; 6 hours to 10 hours would have a factor of 7, etc.). It was determined that given local conditions that the area vulnerability factor value assigned to these IPZ-3s should not be less than 4. Therefore the IPZ-3 areas beyond the 18 hour travel time limit have all been assigned a value of 4.

The following table notes the range of area vulnerability factors values for the IPZ-3s.

**Table 9: IPZ-3 Area Vulnerability Factors**

| Time of Travel (hours) | IPZ-3 Area Vulnerability Factor (B) | | |
|---|---|---|---|
| | Carleton Place | Perth | Smiths Falls |
| 2 to 6 | 8 | 8 | 8 |
| 6 to 10 | 7 | 7 | 7 |
| 10 to 14 | 6 | 6 | 6 |
| 14 to 18 | 5 | 5 | 5 |
| >18 | 4 | 4 | 4 |

## 4.4 Final IPZ-3 Vulnerability scoring table

The following table notes the range of vulnerability scores for the IPZ-3s:

**Table 10: IPZ-3 Vulnerability Scoring Results**

| Time of Travel (hours) | (B)<br>IPZ-3 Area Vulnerability Factor | (C)<br>Source Vulnerability Factor | (V)<br>IPZ-3 Vulnerability Scores |
|---|---|---|---|
| 2 to 6 | 8 | 1 | **8** |
| 6 to 10 | 7 | 1 | **7** |
| 10 to 14 | 6 | 1 | **6** |
| 14 to 18 | 5 | 1 | **5** |
| >18 | 4 | 1 | **4** |

Figures 1a through to 6b in the report show the computed IPZ-3 Area Vulnerability Factors and Vulnerability Scores for the intakes. The uncertainties and data gaps encountered in each of the applications are outlined in the main text of the report.

# ADDENDUM A:

## GIS Methods, Calculations and Metadata used in IPZ-2 Vulnerability Scoring

This addendum describes the GIS methodology and specific calculations used for the IPZ-2 vulnerability scoring. The metadata used to derive the CN and slopes values are identified.

All data used in the calculation was provided through a user agreement between the contractor and the Mississippi- Rideau Source Protection Region.

Environment:

| | |
|---|---|
| Software | ESRI ArcMap v9.2 sp5 |
| Tools | Spatial Analyst Extension |

Core Datasets:

| | |
|---|---|
| Surficial Geology: | OMNR OGS Southern Ontario Surficial Geology MRD128 in lieu of soil mapping not available in the area. This is a data gap identified by RVCA and MVCA. |
| Land Use: | SOLRIS Southern Ontario Land Resource Information System. |
| DEM: | OMNR Digital Elevation Model V.2 |
| Streams and Rivers | OBM base features; water polygons, polylines, wetlands |

Methodology for CN Values Vulnerability Calculations:

1) Create a new column in the surficial geology layer named Hydrologic Soil Group (HSG). Reclassify the layer using the permeability code to the following order:

| Impermeability | HSG |
|---|---|
| Low | A |
| Low-Medium | B |
| Medium-High | C |
| High | D |
| Variable | C |

2) Use the Union tool to combine the Surficial Geology and SOLRIS layer. Layers are also clipped to the IPZ2 zone.

- cp_cn_final
- p_cn_final
- sf_cn_final

3) Use the following table to code the CN Values from each soil group to its respective land use.

**Table 1: CN Values by land use and soil group**

| SOLRIS Land Use | A | B | C | D |
|---|---|---|---|---|
| Monoculture | 69 | 79 | 86 | 90 |
| Mixed Culture | 64 | 75 | 83 | 87 |
| Rural Land Use | 61 | 76 | 84 | 88 |
| Unclassified | - | - | - | - |
| Wooded Area | 36 | 60 | 76 | 79 |
| Hedgerow | 36 | 60 | 73 | 79 |
| Plantation | 36 | 60 | 73 | 79 |
| Wetland | 98 | 98 | 98 | 98 |
| Coastal Wetland | 98 | 98 | 98 | 98 |
| Waterbody | 100 | 100 | 100 | 100 |
| Transportation | 83 | 89 | 92 | 93 |
| Built up Pervious | 61 | 76 | 84 | 88 |
| Built-up Impervious | 98 | 98 | 98 | 98 |
| Pits and Quarries | 98 | 98 | 98 | 98 |

4) Areas are calculated for each polygon using X Tools in hectares and square metres.

5) A weighted mean is calculated for the complete area to provide the mean CN value for the entire IPZ2 zone. All data exported to .dbf to include in report.

<u>Methodology for mean slopes calculations:</u>

1) DEM was clipped to the IPZ22 extent using the Spatial Analyst Extract by Mask tool.
   - cp_dem
   - p_dem
   - sf_dem

2) Use the default calculate slope tool in Spatial Analyst to provide slope information within the IPZ2
   - cp_slopes
   - p_slopes
   - sf_slopes

3) Because the WRIP DEM has forced flow information that creates unwanted artefacts within the water segments, information as to be clipped out to remove any unwanted information that would false the final result. The waterbody polygons within the IPZ2 are used to give a 0 value and provide a clean slope landscape.
   - cp_slopes_final
   - p_slopes_final
   - sf_slopes_final

4) Calculate Grid Statistics for slopes. This provides the mean slope for the IPZ2 zone.

# ADDENDUM B:
# GIS Methods, Calculations and Metadata used in IPZ-3 Vulnerability Scoring

This addendum describes the GIS methodology and specific calculations used to generate the IPZ-3 vulnerability factors and scores.

All data used in the calculation were provided through a user agreement between the contractor and the Mississippi- Rideau Source Protection Region.

Environment:

| | |
|---|---|
| Software | ESRI ArcMap v9.3.1 |
| Tools | Spatial Analyst Extension<br>ArcHydro Tools |

Core Datasets:

| | |
|---|---|
| WRIP Flow Direction: | MNR WRIP Enhanced Flow Direction clipped to the three IPZ-3 watersheds (Carleton Place, Perth, Smiths Falls).<br>Cell size 10m |
| WRIP Stream Network: | MNR WRIP Stream Network used in the creation of the WRIP Flow direction file. This data is based originally from OBM modified to run ArcHydro tools. |
| DEM Ver. 2.0: | Latest version of the MNR DEM. |

Method Used to Delineate Subwatershed

1) Using ArcHydro and ArcGIS 9.3.1 with the MNR WRIP Enhanced Flow Direction file all base files needed to run ArcHydro tools were generated for each watershed.
    a. Flow Accumulation
    b. Segmentation
    c. Catchments
    d. Sub-catchments
2) Using the Pour Point tool, at each intersection where there was a sub watershed entering the main channel a point and code was entered up to the 18-hour limit.
3) ArcHydro tools Sub Watershed Delineation tool was used to provide a first generated boundary file of all sub watersheds. In some instances, WRIP stream do not exactly fall to the actual channel in the Flow file. The pour points were displaced to fit the Flow direction file.
4) ArcHydro tools Subwatershed Delineation tool was used again to provide a satisfactory subwatershed file.
5) Subwatersheds were adjusted in some areas where they would slightly cross the main channel.

Determination of the Average CN for each Sub Watershed

1) Same Method used as in the IPZ-2 Calculation.

## Determination of Soil Hydrologic Group for Surficial Geology Map Units

Each surficial geology map unit was matched to a soil hydrologic group (HSG – A, B, C, D) using the permeability rating that was included in the data base provided by M-R SPR as a guide. Example:

Low Runoff Potential = A = Sand, Sand and Gravel, Organic
Low-Medium Runoff Potential = B = Sand
Medium-High Runoff Potential = C = Silt Sand Clay
High Runoff Potential = D = Clay, Silt

The surficial geology unit "Variable" was classified as a "C" soil since most of the material is bedrock mixed with silt and clay cover.

**Table 1: CN Values by land use and soil group**

| SOLRIS | MTO Soil Group | | | |
|---|---|---|---|---|
| Land Use Category | A | B | C | D |
| Monoculture | 69 | 79 | 86 | 90 |
| Mixed Culture | 64 | 75 | 83 | 87 |
| Rural Land Use | 61 | 76 | 84 | 88 |
| Unclassified | No Value Provided | | | |
| Wooded Area | 36 | 60 | 73 | 79 |
| Hedgerow | 36 | 60 | 73 | 79 |
| Plantation | 36 | 60 | 73 | 79 |
| Wetland | 98 | 98 | 98 | 98 |
| Coastal Wetland | 98 | 98 | 98 | 98 |
| Waterbody | 100 | 100 | 100 | 100 |
| Transportation | 83 | 89 | 92 | 93 |
| Built Up Pervious | 61 | 76 | 84 | 88 |
| Impervious | 98 | 98 | 98 | 98 |

**Table 1: CN Values by land use and soil group (continued)**

| PLC | MTO Soil Group | | | |
|---|---|---|---|---|
| Land Use Category | A | B | C | D |
| Agriculture | 64 | 75 | 83 | 87 |
| Rural Land Use | 61 | 76 | 84 | 88 |
| Unclassified | No Value Provided | | | |
| Wooded Area | 36 | 60 | 73 | 79 |
| Wetland | 98 | 98 | 98 | 98 |
| Waterbody | 100 | 100 | 100 | 100 |
| Transportation | 83 | 89 | 92 | 93 |
| Built Up Areas | 61 | 76 | 84 | 88 |
| Bedrock | 89 | 92 | 94 | 95 |

> Note: The land use data used for the determination of the CN values were a combination of the SOLRIS and Provincial Land Cover (PLC) data bases. Large parts of the study area do not have SOLRIS land use mapping coverage.
>
> Digital soil mapping is not available for the study area. The soil group mapping was derived using the digital surficial geology mapping. Digital surficial geology mapping was not available for an area at the western end of the Carleton Place IPZ-3. For that area it was assumed that the soils were variable and Soil Group C values were used.
>
> The Bedrock land use category includes land cover with a "bedrock texture" in the source imagery and the level of infiltration varies with the ground material which may include mine tailings, quarries and bedrock outcrops.

Calculation used to determine Longest Path, Slope Length and Slopes %

1) Using ArcHydro, the Longest Path tool was used to find the longest subwatershed path.
2) The longest path segments were united to create one single polyline with a downward direction to the channel direction.
3) Using 3D Analyst, the polyline was given Z values using DEM Ver 2.0.
4) Using Easy Profiler Extension in ArcGIS, the 3D polyline was extracted to create a point profile with distance to origin and elevation. Each point also having a Unique ID could be indexed to any other branch upstream. Points were generated at each DEM cell center.
5) Information was exported to a spreadsheet where slopes and ultimately Tc could be calculated.
6) Any other branch needing to be calculated for vulnerability would go through step 1-5 but distance to main channel would be adjusted using the Unique ID at the intersection of the longest path and the channel to be calculated.
7) The spreadsheet can then be related back to the GIS for IPZ-3 scoring using the Unique ID generated in step 4.

# Appendix 6-3

Vulnerability Scoring –Ottawa River Intake Protection Zones

Mississippi-Rideau Source Protection Region

# Summary of Assessments Analysis of IPZ Delineation and Vulnerability Assessments

| **Zone** | **IPZ Delineation** | | | **Vulnerability** | | | **Overall Uncertainty Rating** |
|---|---|---|---|---|---|---|---|
| | **Factors** | **Uncertainty Level** | **Overall Rating (high or low)** | **Factors** | **Uncertainty Level** | **Overall Rating (high or low)** | |
| All IPZs | N/A | N/A | N/A | Source Vulnerability Factor | | Low | Low |
| | | | | Intake location relative to shore | Low | | |
| | | | | Water quality records | Low | | |
| IPZ-1 | Subjectivity of criteria defining the extent of the zone | Low | Low | Area Vulnerability Factor as specified in the Technical Rules to be assigned a value of 10 | Low | Low | Low |
| | Accuracy - the determination of the intake location | Low | | Appropriateness of IPZ-1 boundary | Low | | |

| **Zone** | **IPZ Delineation** | | | **Vulnerability** | | | **Overall Uncertainty Rating** |
|---|---|---|---|---|---|---|---|
| | **Factors** | **Uncertainty Level** | **Overall Rating (high or low)** | **Factors** | **Uncertainty Level** | **Overall Rating (high or low)** | |
| | Accuracy in determination of the shoreline | Low | | | | | |
| | Lack of in-river verification of current conditions | Low | | | | | |

The results of the uncertainty assessment for the Carleton Place, Perth and Smiths Falls IPZ delineation and vulnerability assessments are presented in the following tables. The “factors” listed in the tables are sources of uncertainty and the level of uncertainty - low, moderate or high - associated with each of those factors is noted. The final level of uncertainty, either high or low, takes into account the uncertainty assigned to each IPZ delineation and to the uncertainty assigned to the IPZ’s vulnerability score. If the uncertainty rating for any of the factors is greater than “low” (i.e. moderate or high), than the overall uncertainty is rated as “high”.

## Table 1: Level of Uncertainty for Carleton Place IPZs

| **Zone** | **IPZ Delineation** | | | **Vulnerability** | | | **Overall Uncertainty Rating** |
|---|---|---|---|---|---|---|---|
| | **Factors** | **Uncertainty Level** | **Overall Rating (high or low)** | **Factors** | **Uncertainty Level** | **Overall Rating (high or low)** | |
| IPZ-2 | In the application of the hydraulic model: | | High | Area Vulnerability Factor scoring is a function of the runoff generation potential (surface permeability, slope and transport pathways): | | High | High |
| | Model precision and accuracy, calibration and validation | Moderate | | Slope | Low | | |
| | Selection of representative flow (bankfull 2-year flow) | Low | | CN value is a function of land use and soil mapping | Moderate | | |
| | Uncertainty inherent to statistical model | Low | | Length of transport pathways | Moderate | | |
| | Use of the 2-year flow at all the HEC-RAS cross-sections | Low | | Length of main channel in IPZ-2 | Low | | |

| **Zone** | **IPZ Delineation** | | | **Vulnerability** | | | **Overall Uncertainty Rating** |
|---|---|---|---|---|---|---|---|
| | **Factors** | **Uncertainty Level** | **Overall Rating (high or low)** | **Factors** | **Uncertainty Level** | **Overall Rating (high or low)** | |
| | Selected method to estimate travel time in streams | Moderate | | Area Vulnerability Factor scoring is also a function of weighting of parameters: | Low | | |
| | Wind conditions | Moderate | | Selected min and max values for CN | Low | | |
| | Mapping:<br>Potential of unknown sewers and transport pathways | Moderate to High | | Selected min and max values for Slope | Low | | |
| | Incomplete information on certain drainage systems | Moderate to High | | Accuracy of Area Vulnerability Factor | Moderate | | |
| | | | | Selected min and max of ratio of transport pathway to channel length<br>Weighting | Low | | |
| | Field Methods and Data:<br>Lack of access in the field | Moderate | | | | | |
| | Difficulty to | Moderate | | | | | |

| **Zone** | **IPZ Delineation** | | | **Vulnerability** | | | **Overall Uncertainty Rating** |
|---|---|---|---|---|---|---|---|
| | **Factors** | **Uncertainty Level** | **Overall Rating (high or low)** | **Factors** | **Uncertainty Level** | **Overall Rating (high or low)** | |
| | make accurate observations and translate them to exact locations on maps | | | | | | |
| PZ-3 | Lack of field data | High | High | Data | High | High | High |
| | Mapping:<br>Potential of unknown sewers and transport pathways | High | | Time of recorded peak flows | | | |
| | | | | Land use, soils | Moderate to High | | |
| | | | | Slope | Low | | |
| | | | | Channel information | Moderate to High | | |
| | Incomplete information on certain drainage systems | High | | Methods<br>Time of Travel methods | High | | |
| | Base mapping | Low | | Accuracy of Area Vulnerability Factor s | Low to High | | |

## Table 2: Level of Uncertainty for Perth IPZs

| **Zone** | **IPZ Delineation** | | | **Vulnerability** | | | **Overall Uncertainty Rating** |
|---|---|---|---|---|---|---|---|
| | **Factors** | **Uncertainty Level** | **Overall Rating (high or low)** | **Factors** | **Uncertainty Level** | **Overall Rating (high or low)** | |
| All IPZs | N/A | N/A | N/A | Source Vulnerability Factor (modifier) | | Low | Low |
| | | | | Intake location relative to shore | Low | | |
| | | | | Water quality records | Low | | |
| IPZ-1 | Subjectivity of criteria defining the extent of zone | Low | Low | Area Vulnerability Factor as specified in the Technical Rules to be assigned a value of 10 | Low | Low | Low |
| | Accuracy in the determination of the intake location | Low | | Appropriateness of IPZ-1 boundary | Low | | |
| | Accuracy in the determination of the shoreline | Low | | | | | |
| | Lack of in-river verification of current and flow conditions including on | Low | | | | | |

| Zone | IPZ Delineation | | | Vulnerability | | | Overall Uncertainty Rating |
|---|---|---|---|---|---|---|---|
| | Factors | Uncertainty Level | Overall Rating (high or low) | Factors | Uncertainty Level | Overall Rating (high or low) | |
| | effect on structures on direction and flow of water at intake | | | | | | |
| IPZ-2 | In the application of the hydraulic model: | | High | Area Vulnerability Factor scoring is a function of the runoff generation potential (surface permeability, slope and transport pathways): | | High | High |
| | Model precision and accuracy, calibration and validation | Moderate | | Slope | Low | | |
| | Selection of the representative flow (bankfull 2-year flow) | Low | | CN value is a function of land use and soil mapping | Moderate | | |
| | Limited flow data | Moderate to High | | Length of transport pathways | Moderate | | |
| | Uncertainty inherent to statistical model | Low to Moderate | | Length main channel in IPZ-2 | Low | | |

| **Zone** | **IPZ Delineation** | | | **Vulnerability** | | | **Overall Uncertainty Rating** |
|---|---|---|---|---|---|---|---|
| | **Factors** | **Uncertainty Level** | **Overall Rating (high or low)** | **Factors** | **Uncertainty Level** | **Overall Rating (high or low)** | |
| | Use of the 2-year flow at all the HEC-RAS cross-sections | Low | | Area Vulnerability Factor scoring is also a function of weighting for parameters: | | | |
| | Selected method to estimate travel time in streams | Moderate | | Selected min and max values for CN | Low | | |
| | Wind conditions | Moderate | | Selected min and max values for slope | Low | | |
| | Mapping:<br>Potential of unknown sewers and transport pathways | Moderate To High | | Selected min and max of ratio of transport pathway to channel length | Low | | |
| | Incomplete information on certain drainage systems | Moderate To High | | Weighting | Low | | |
| | Field Methods and Data:<br>Lack of access in the field | Moderate | | Accuracy of Area Vulnerability Factor | Moderate | | |

| **Zone** | **IPZ Delineation** | | | **Vulnerability** | | | **Overall Uncertainty Rating** |
|---|---|---|---|---|---|---|---|
| | **Factors** | **Uncertainty Level** | **Overall Rating (high or low)** | **Factors** | **Uncertainty Level** | **Overall Rating (high or low)** | |
| | Lack of access in the field | Moderate | | | | | |
| | Difficulty to make reliable field observations and to translate them to exact locations on maps | Moderate | | | | | |
| IPZ-3 | Lack of field data | High | High | Data<br>HEC-RAS and Mike 11 models best available data | Moderate to High | High | High |
| | Base mapping | Low | | Land use, soils | Moderate to High | | |
| | | | | Slope | Low | | |
| | | | | Methods/Models | High | | |
| | | | | Time of Travel methods<br>Accuracy of Area Vulnerability Factors | Low to High | | |

## Table 3: Level of Uncertainty for Smiths Falls IPZs

| Zone | IPZ Delineation | | | Vulnerability | | | Overall Uncertainty Rating |
|---|---|---|---|---|---|---|---|
| | **Factors** | **Uncertainty Level** | **Overall Rating (high or low)** | **Factors** | **Uncertainty Level** | **Overall Rating (high or low)** | |
| All IPZs | N/A | N/A | N/A | Source Vulnerability Factor (modifier) | | Low | Low |
| | | | | Intake location relative to shore (for primary intake) | Low | | |
| | | | | Water quality records | Low | | |
| IPZ-1 (main and aux) | Subjectivity of criteria defining the extent of the zone | Low | Low | Area Vulnerability Factor as specified in the Technical Rules to be assigned a value of 10 | Low | Low | Low |
| | Accuracy in determination of the intake location | Low | | Appropriateness of IPZ-1 boundary | | | |
| | Accuracy in the determination of the shoreline | Low | | | Low | | |
| | Lack of in- river verification of current and flow conditions including on effect on structures on direction and flow of water at intake | Low | | | | | |

| Zone | IPZ Delineation | | | Vulnerability | | | Overall Uncertainty Rating |
|---|---|---|---|---|---|---|---|
| | Factors | Uncertainty Level | Overall Rating (high or low) | Factors | Uncertainty Level | Overall Rating (high or low) | |
| IPZ-2 | In the application of the hydraulic model: | | High | Area Vulnerability Factor scoring is a function of the runoff generation potential (surface permeability, slope and transport pathways):<br>Length of main channel in IPZ-2 | | High | High |
| | Model precision and accuracy calibration and validation | Moderate | | Slope | Low | | |
| | Selection of representative flow (bankfull 2-year flow) | Low | | CN value is a function of land use and soil mapping | Moderate | | |
| | Uncertainty inherent to statistical model | Low | | Length of transport pathways | Moderate | | |
| | Use of the 2-year flow at all the HEC-RAS cross-sections | Low | | Area Vulnerability Factor scoring is also a function of weighting selected for parameters: | Low | | |
| | Selected method to estimate travel time in streams | Moderate | | Selected min and max values for CN | Low | | |
| | Wind conditions | Moderate | | Selected min and max values for | Low | | |

| Zone | IPZ Delineation | | | Vulnerability | | | Overall Uncertainty Rating |
|---|---|---|---|---|---|---|---|
| | Factors | Uncertainty Level | Overall Rating (high or low) | Factors | Uncertainty Level | Overall Rating (high or low) | |
| | | | | Slope | | | |
| | Mapping:<br>Potential of unknown sewers and transport pathways | Moderate to High | | Selected min and max of ratio of transport pathway to channel length | Low | | |
| | Incomplete information on certain drainage systems | Moderate to High | | Weighting | Low | | |
| | Field Methods and Data:<br>Lack of access in the field | Moderate | | Accuracy - Area Vulnerability Factor | Moderate | | |
| | Difficulty to make reliable field observations and to translate them to exact locations on maps | Moderate | | | | | |
| IPZ-3 | Lack of field data | High | High | Data<br>HEC-RAS and Mike 11 models best available data | Moderate to High | High | High |
| | | | | Land use, soils | Moderate to High | | |

| Zone | IPZ Delineation | | | Vulnerability | | | Overall Uncertainty Rating |
|---|---|---|---|---|---|---|---|
| | Factors | Uncertainty Level | Overall Rating (high or low) | Factors | Uncertainty Level | Overall Rating (high or low) | |
| | Mapping:<br>Potential of unknown sewers and transport pathways | High | | Slope Methods/Models | Low | | |
| | Incomplete information on certain drainage systems | High | | Time of Travel methods | High | | |
| | Base mapping | Low | | Accuracy of Area Vulnerability Factors | Low to High | | |

# Appendix 6-4

## Vulnerability Assessment –Ottawa River Intake Protection Zones

Mississippi-Rideau Source Protection Region

## VULNERABILITY SCORING METHODOLOGY

To quantify the vulnerability score (V) of an intake, MOE has developed the following formula (MOE, 2008 – Rule 87):

$$V = B \times C$$

where;

V = vulnerability score

B = area vulnerability factor; and

C = source vulnerability factor.

Table A.1 shows the possible range in these factors for the two IPZs under consideration. Note that the analysis undertaken to calculate the vulnerability scores were based on local conditions.

**Table A.1 Vulnerability Score for Water Intakes using Surface Water Sources (MOE, 2008)**

| **Intake Type** | **Area Vulnerability Factor (B)** | | | **Source Vulnerability Factor (C)** | **Range of Vulnerability score (V)** | | |
|---|---|---|---|---|---|---|---|
| | **IPZ-1** | **IPZ-2** | **IPZ-3** | | **IPZ-1** | **IPZ-2** | **IPZ-3** |
| Type C | 10 | 7 to 9 | 1 to 9 | 0.9 or 1 | 9 or 10 | 6.3 to 9 | 0.9 to 9 |

### Area Vulnerability Factor (B)

The area vulnerability factor accounts for the susceptibility of each intake protection zone to contamination. Each zone defined around an intake is assigned an area vulnerability based on the scoring system provided in the Technical Rules (Rules 88 to 93). Higher values represent greater vulnerability. The area vulnerability factor is applied as a whole number (Rule 93).

Rule 92 identifies the key issues to be considered when assigning the area vulnerability factor to IPZ-2 and IPZ-3:

1) The percentage of area of the IPZ-2 or IPZ-3 that is composed of land.
2) The land cover, soil type, permeability of the land and the slope of any setbacks.
3) The hydrological and hydrogeological conditions in the area that contributes water to the area through transport pathways.
4) The proximity of the area of the IPZ-3 to the intake.

Each of the above factors has been considered in developing the area vulnerability factor for IPZ-2 and IPZ-3.

## IPZ-2 Area Vulnerability Factor

*Percentage of Area Composed of Land*

As guidance is not provided in the Technical Rules on the selection methodology for the area factor, two scenarios were considered that could potentially bracket the range of conditions that may exist:

1) *Low Vulnerability: A wide river not affected by transport pathways*. In such a scenario, the land portion of IPZ-2 would extend inland 120 metres (Rule 65). If it was assumed that the river was 1000 m across, then the percentage of land area in IPZ-2 would be approximately 10%.

2) *High Vulnerability: A narrow river with extensive transport pathways on both banks*. Assume in this scenario that the river is 200 m in width, and that the transport pathways extend to a maximum of 5 km inland adjacent to the intake. The 5 km range is assumed based on the potential inland extent of a sewer interceptor. In this case, the percentage of land area in IPZ-2 would be approximately 90%.

Considering these two scenarios, it has been assumed that percentage of area composed of land might range from 10% to 90%. A score was assigned for Britannia and Lemieux Island in proportion to this range, as follows:

$B_{area} = 9 – 2*(90\% - \%LA)/(90\% - 10\%)$

Where %LA is the percentage of land area associated with IPZ-2.

*Land Cover, Soil Type, Permeability, Slope*

Dominate land cover was considered in three basic categories:

- Natural land cover was scored as 7
- Agricultural, open space was scored as 8
- Mainly developed land was scored as 9

As the land portion of the IPZ-2s for both Britannia and Lemieux Island are dominated by the presence of sewersheds, the key factor considered was the percent imperviousness due to its impact on potential runoff. It was assumed that percent impervious could range from 0% for a natural region to 80% for a highly urbanized environment. A score was assigned for Britannia and Lemieux Island in proportion to this range, with a score of 7 representing 0%, and 9 representing 80%, calculated as follows:

$B_{Imp} = 7 + 2*(\%Impervious)/(80\%)$

Values greater than 80% were given a factor of 9.0.

*Transport Pathways*

Transport pathways were classified on the basis of the percentage of the IPZ-2 land area that is drained by storm sewer systems. Three categories were considered:

- <10% of the land area was scored as 7. This represented an IPZ-2 with minimal storm sewer systems.
- 10% - 50% of the land area was scored as 8. This represents an IPZ-2 with a moderate coverage of storm sewer systems.
- >50% of the land area was scored as 9. This represents an IPZ-2 with a significant coverage of storm sewer systems.

The number of storm outfalls and their respective locations to the intake were also considered in determining the score for the Transport Pathways criteria. Note that reasonable modifications to the scoring for each category would not impact the final outcome.

### IPZ-3 Area Vulnerability Factor

The issues involved in determining the area vulnerability factor (B) for IPZ-3 are similar to that for IPZ-2, except that the factor varies spatially with watershed hydrologic characteristics, and with distance from the intake. For this zone, the Time of Travel (ToT) was used to account for the hydrological criteria described in the *Technical Rules* and to support the vulnerability scoring. Time of travel is simply the time it takes runoff to reach the intake; this calculation consists of both the time of travel overland, known as time of concentration (Tc), and the travel time in the river channel.

Travel time in the rivers were estimated using a combination of numerical model results and gauged flow data. Specifically, numerical model results were used to estimate velocity on the Ottawa and Carp River systems, and a combination of numerical model results and gauged data were used on the Mississippi River.

An empirical modelling approach was used to determine the time of concentration (Tc). The equation used for this analyses is the Soil Conservation Service (SCS) Lag Formula. This method implicitly accounts for the criteria outlined in the *Technical Rules* to describe the hydrological response of sub-watersheds within IPZ-3. The time of concentration is defined as the time it takes for water in the most remote part of a watershed to contribute to the flow at the outlet. By combining Tc with the travel time in rivers, the total time of travel to the intake can be calculated.

This travel time is a means of defining the area within IPZ-3 in terms of their proximity to the intake. A scoring approach based on 4-hour travel time intervals was developed and applied once the time of travel to the intakes from each sub-watershed were determined. The following summarizes the key steps carried out to score the area vulnerability factor:

1. *Development of In-River Travel Times:* Travel times on the Ottawa, Mississippi and Carp river systems were determined for the 2 year river flow condition up to the 48 hour mark. On the Ottawa River, travel times were extrapolated from the three-dimensional model results. For the Mississippi and Carp rivers, travel time estimates were determined from HEC-II model results that were provided by the Mississippi Valley Conservation Authority
2. *Delineation of Sub-Watersheds:* Existing datasets for the region's watersheds were relatively coarse, as they were delineated to significant river systems only; that is, the Mississippi, Carp and Ottawa River. For this study, the watersheds within IPZ-3 were delineated into sub-watersheds using the ArcGIS Hydro data model (Arc Hydro) and the provincial 10m DEM. As part of this process, a sensitivity of the watershed size threshold was carried out with consideration given to the size limitations of the SCS lag equation. A watershed minimum threshold size of 200 ha was found to yield subwatersheds with sizes appropriate to the 4,000 ha recommended upper limit of application of the SCS lag equation, without yielding a lot of small watersheds that would have made subsequent analysis impractical. Gaps in the subwatersheds were infilled with subwatersheds delineated using a 50 ha threshold size.
3. *Review of Sub-Watershed Delineation:* The sub-watersheds that were derived from the Arc Hydro tool were then reviewed using datasets such as the provincial streamline database, digital elevation model and aerial imagery in order to ensure the delineation did not conflict with the other available data. In some locations, particularly in regions where the land is very flat (mostly close to the river), the utility could not delineate sub-watersheds, since the threshold size was not reached. These regions were delineated manually using the datasets stated above.
4. *Determination of Watershed Characteristics:* The primary inputs to the time of concentration formula are, slope, curve number (CN), and watershed flow length. The curve number is based on the area's hydrologic soil group and land use, and it reflects the propensity of an area to generating surface runoff. Using existing GIS datasets, average slope and CN values were calculated for each sub-watershed. The CN was determined using spatially-explicit, gridded land use and hydrologic soil group layers using a look-up table to extract the appropriate CN values. The average CN for each subwatershed was then determined as an area-weighted mean of the distributed data. The CN for select sub-watersheds were then reviewed using datasets such as land use, soil type and aerial imagery in order to ensure the averaging algorithm is generating appropriate values. The length variable is defined as the longest hydraulic path in the watershed, and this distance was calculated during the delineation of the sub-watersheds.

5. *Calculate Time of Concentration (Empirical Approach):* As previously stated, the time of concentration calculation was based on the SCS lag formula, as shown below and as presented in the *EBA Technical Bulletin* (MOE, 2009).

$$t_c = 0.00526(L^{0.8})\left[\frac{1000}{CN} - 9\right]^{0.7} S^{-0.5}$$

   Where;

   $t_c$ = Time of Concentration (min)

   L = Length of Watershed (ft)

   CN = Curve Number

   S = Slope (ft/ft)

   This equation was applied to each sub-watershed. The SCS equation was developed from agricultural watershed data and was intended for non-urban watersheds of 4,000 acres or less. However, it has been adapted to small urban basins as well, although depending on the land use, it tends to underestimate the time of concentration in the watershed. The formula predicts the time it takes for the entire watershed to be contributing to the flow at the outlet; therefore, it represents the upper limit with respect to travel time for a given watershed.

   The SCS lag formula generates an estimate of the time of travel from the farthest part of a subwatershed to the watershed outlet. It is intended to be used in small watersheds where overland flow is the main transport mechanism. The lag formula becomes less applicable once flow is concentrated into channels. For this reason, the lag formula was only used for 'headwater' subwatersheds, and the Time of Concentration of downstream subwatersheds was determined using the Manning Equation. The manning Roughness coefficient was assumed to be 0.035 for all cases. Mean subwatershed slope was determined from the DEM. For the purpose of estimating flow velocity, bankfull flow in the creeks was assumed to approximate an event with a 2-year return period. Mean channel bankfull width for each subwatershed was measured from aerial photographs. Channel bankfull depth was estimated from oblique photographs at road crossings, where available, and scaled to similar-sized creeks in the area where photographs were not available. The longest flow length in each subwatershed was then divided by the velocity estimated using the Manning Formula to determine the time of concentration.

6. *Calculate Time of Travel for each Sub-Watershed:* To get the total travel time to the intake, the time of concentration for a watershed is added to the travel time in the river. For sub-watersheds that drain into other watersheds before entering the river system, the travel time was determined by simply adding the time of concentrations together.

7. *Determine Area Vulnerability Factor:* Once the travel times to the intake have been established for each sub-watershed, the area vulnerability scores were then applied. Following discussions with the City and the MR-SPR, it was decided that the area factor for IPZ-3 would start at a value of 8 for the zone closest to IPZ-2, and drop by one every four hour

time of travel interval. The technical rules do not provide guidance with respect to the scoring intervals; the four hour interval was chosen as it represents twice the length of time used to delineate IPZ-2. The *Technical Rules* state the IPZ-2 is to be based on a two hour travel time, which is considered a sufficient amount of time for plant operators to respond to a known emergency. Given the importance of IPZ-2 and in order to provide a level of consistency in the transition of scoring between protection zones, the 2 hour travel time was doubled and used as the scoring interval for the area vulnerability factor within IPZ-3. For example, 2 to 6 hours would have a factor of 8, 6 to 10 hours a factor of 7, and so on. The area factor decreases with distance from the intake. A breakdown of the scoring for the area vulnerability factor for IPZ-3 is shown in Table A.2. Note that four is the lowest area factor assigned; therefore, the area remaining within IPZ-3, outside of the 18 hour mark, would receive a value of four. Following discussions with the City and MR-SPR, it was determined that a factor of four allowed land use activities with the highest hazard ratings to be identified as low drinking water threats, which seemed reasonable given the local land use conditions.

**Table A.2 IPZ Area Vulnerability Factors**

| Intake Protection Zone | Time of Travel (hours) | Area Vulnerability Factors | |
|---|---|---|---|
| | | Britannia | Lemieux |
| IPZ-1 | NA | 10 | 10 |
| IPZ-2 | 2 | 9 | 9 |
| **IPZ-3** | **2 to 6** | **8** | **8** |
| | **6 to 10** | **7** | **7** |
| | **10 to 14** | **6** | **6** |
| | **14 to 18** | **5** | **5** |
| | **>18** | **4** | **4** |

## Source Vulnerability Factor (C)

The source vulnerability factor (C) considers the relative location of an intake on a particular body of water. One value of C is defined and used to determine the vulnerability score (V) for each protection zone around an intake. For Type C intakes, such as Britannia and Lemieux Island, C can be either a value of 0.9 or 1, as summarized in Table A.1 (Rule 95). A factor of 1 corresponds to higher vulnerability.

The following factors may be considered in the selection of the source vulnerability factor (Rule 95):

- Depth of the intake from the water surface.
- Distance of the intake from land.
- The number of recorded drinking water issues related to the intake (if any).

A source vulnerability factor is expressed to one decimal point (Rule 96).

As with the area vulnerability factor, two potential intake scenarios were considered representing the range of designs that might be encountered in practice:

- *Low Vulnerability*: A deep water intake represents a low vulnerability scenario. Based on the provincial boundary line and the bathymetric features of the river within the study domain, an intake representing the lowest bracket of vulnerability would be located in water depths of less than 15 m, and up to 1000 metres offshore.

- *High Vulnerability*: An example of a high vulnerability within the source protection region might be a shallow intake located adjacent to the bank in a small river. Such an intake might have a depth in the order of 2 metres.

*Depth of the Intake*

It was assumed for this analysis that the minimum and maximum levels of vulnerability for the drinking water intakes might range in depth from 2 metres to 15 metres. A score associated with intake depth was calculated as follows:

$$C_{Depth} = 0.9 + 0.1*(15 - ID)/(15-2)$$

where ID is the intake depth in metres.

*Distance of the Intake from Land*

It was assumed that the degree of vulnerability for drinking water intakes based on distance from shore might range from 0 metres (ie. at the shore/bank) to 1000 metres. A score associated with intake depth was calculated as follows:

$C_{Dist} = 1.0 - 0.1*(D)/(1000)$

where D is the distance of the intake offshore in metres.

*Historical Water Quality Issue*

- A value of 0.9 was defined if there were no water quality concerns at Intake
- A value of 1.0 was defined if persistent or chronic water quality concerns were present

# Appendix 6-5

## Uncertainty Assessment –Ottawa River Intake Protection Zones

## Mississippi-Rideau Source Protection Region

# 3.0 UNCERTAINTY ANALYSIS

## 3.1 The Technical Rules

The objective of the uncertainty analysis is to assign a relative degree of uncertainty for the surface water vulnerability analysis based on considerations of completeness of information, numerical model application, quality assurance/control procedures and site-specific knowledge related to natural variation (MOE, 2008).

Rule 13 identifies that an uncertainty analysis, characterized by either 'high' or 'low' uncertainty, shall be carried out with respect to the following elements:

- The delineation of the Intake Protection Zones.
- The assessment of vulnerability associated with the IPZs.

This uncertainty assessment is to be based on the following factors (Rule 14):

- *the distribution, variability, quality and relevance of data used in the preparation of the assessment report;*
- *the ability of the methods and models used to accurately reflect the flow processes in the hydrological system*
- *the quality assurance and quality control procedures applied;*
- *the extent and level of calibration and validation achieved for models used or calculations or general assessments completed;*
- *…. the accuracy to which the area vulnerability factor and the source vulnerability factor effectively assesses the relative vulnerability of the hydrological features.*

Rule 15 states that an overall assessment of 'high' or 'low' uncertainty shall be assigned to each vulnerable area.

This report section provides a summary of the uncertainty analysis for the Lemieux Island and Britannia intakes. As many data sets are in common and the numerical modelling was carried out using the identical model, the uncertainty analysis for the two intakes is very similar and has not been separately documented.

## 3.2 Summary of Uncertainty for the Intakes

Table 3.1 below provides an overall summary of the uncertainty characterization for the intakes, while Table 3.2 gives the breakdown of uncertainty by component for the two intakes. A discussion of the individual factors follows in Section 3.3.

### Table 3.1 Uncertainty Characterization

| Intake | Factors to Consider | Uncertainty Rating | | |
|---|---|---|---|---|
| | | IPZ-1 | IPZ-2 | IPZ-3 |
| **Lemieux Island WPP** | IPZ Delineation | Low | Low | High |
| | Vulnerability Assessment | Low | Low | High |
| **Overall** | | Low | Low | High |
| **Britannia WPP** | IPZ Delineation | Low | Low | High |
| | Vulnerability Assessment | Low | Low | High |
| **Overall** | | Low | Low | High |

Note: if any of the factors was rated 'high' then the overall assessment was 'high'

### Table 3.2 Uncertainty Assessment by Factor for Both Intakes

| Uncertainty Component | Factors to Consider | Uncertainty Rating | | |
|---|---|---|---|---|
| | | IPZ-1 | IPZ-2 | IPZ-3 |
| **IPZ Delineation** | Data | Low | Low | Low |
| | Methods and Models | n/a | Low | High |
| | QA/QC | Low | Low | Low |
| | Calibration and Validation | n/a | Low | High |
| **Overall** | | Low | Low | High |
| **Vulnerability Assessment** | Data | Low | Low | High |
| | QA/QC | Low | Low | Low |
| | Accuracy of vuln. factors | Low | Low | High |
| **Overall** | | Low | Low | High |

Note: if any of the factors was rated 'high' then the overall assessment was 'high'

## 3.3 Uncertainty Considerations: IPZ Delineation

### *3.3.1 The Distribution, Variability, Quality and Relevance of the Data*

An extensive set of temporal and spatial data was used as input to the IPZ delineation process, giving a low level of uncertainty. The spatial data sets included DEMs (digital elevation models), watercourses, sewer systems, land use and soils information. Temporal datasets included meteorological information, river flow and water levels.

The largest uncertainty related to data was the limited information that existed on the bathymetric features of the river from the Deschenes Rapids to the Chaudiere Dam, as it is a non-navigable section of the Ottawa River for most watercraft. A hydrographic survey was completed in August 2007 in the regions of the river that were navigable with a small boat. The resolution of the survey varied. In the immediate vicinity of the intakes, the survey was completed with higher resolution (i.e. 10 to 20m) than in regions considered less important (i.e. 100m). However, for safety reasons, no data were collected within the river rapids.

As many of the datasets were provided by municipal and provincial sources that employ standard QA/QC procedures, they are believed to be of high quality.

The available datasets were relevant to the IPZ delineation study, and few assumptions had to be made.

### *3.3.2 Methods and Models*

*IPZ-2 Numerical Modelling*
A sophisticated state of the art numerical modelling approach was utilized to delineate IPZ-2 for the Britannia and Lemieux Island WPP. The model grid that was developed covered approximately 20 km of river; included three sets of rapids and encompassed both intakes. Grid resolution ranged from 20m to 100m. A three-dimensional hydrodynamic model called MISED was used to simulate the river hydraulics, including processes such as the spatial variation in currents throughout the water column, and the influence of wind on surface currents.

Baird's in-house Reverse Particle Tracking (RPT) model was then applied to delineate the in-river portion of IPZ-2 based on the hydrodynamic conditions predicted for six different flow and wind combinations. The RPT model was also used to generate in-river time contours in order to support the delineation of the in-land portion of IPZ-2.

As with any numerical modelling activities, uncertainties exist in the model results due to simplified assumptions inherent in the numerical techniques used to solve the governing equations, model resolution, and the quality of the data used to define bathymetric features, forcing mechanisms and initial conditions. The section of the Ottawa River that encompasses both of the City's intakes offers some unique challenges such as the existence of several sets of rapids where accelerated flows, exposed riverbed, highly turbulent conditions and variable flow regimes make these regions extremely difficult to numerically model. The following provides an overview of some of the uncertainties associated with the modeling approach used to delineate the intake protection zones for the Britannia and Lemieux Island WPPs:

*Delineation of the In-River Portion of IPZ-2*

Details on the bathymetric features in the rapids was limited; these regions were estimated during model development and adjusted until a reasonable agreement was achieved with the measured flow conditions downstream of the rapids at both the Britannia and Lemieux Island WPP.

- A two-dimensional (2D) model was initially used to support the initial model development for the three-dimensional hydrodynamic model MISED ultimately employed in the delineation of IPZ-2.
- The bathymetry in the rapids was synthesized, as no data existed in these regions. Adjustments to the bathymetry were made using the 2D model and simulated results were compared against current data, measured downstream of the rapids, and water levels at Britannia.

Despite the lack of bathymetry in the rapids areas, reasonable assumptions were made based on observations and the 2D numerical model development leading to good comparisons with measured current data.

*Delineation of the In-Land Portion of IPZ-2*

The inland travel distances for IPZ-2 calculated for sewer networks was calculated based on certain assumptions regarding state of pipe flow. Given that IPZ-2 for both Lemieux and Britannia encompassed almost the entire sewer catchment area that drains into the in-river portion of IPZ-2, these assumptions had little impact on the overall extent of the in-land portion of IPZ-2, leading to low uncertainty.

Overall, the confidence in the numerical modelling procedures and results is high, leading to an assessment of low uncertainty with respect to IPZ-2 delineation.

*Delineation of IPZ-3*

The delineation of IPZ-3 has been carried out based on discussions with the City and MR-SPR, our interpretation of the current *Technical Rules* (MOE, 2008) of the Clean Water Act, and employing the guidance of the *Technical Bulletin: Delineation of Intake Protection Zone 3 Using the Event Based Approach* (EBA, July 2009).

The EBA outlines three optional approaches for undertaking IPZ-3 delineation. In this study, Option (2), the Boundary Approach, was applied based on direction from the City. This approach requires that a time of travel be determined based on the response of the system to flood events. In these systems, the largest flows are observed during the spring freshet. For this study, the "extreme event" was defined as a river flow with a return period of 100 years.

There was not enough information to determine the time of travel through the entire Mississippi watershed, which is significant, extending over 130 km inland and containing numerous lakes and contributing tributaries. Using available model data and flow gauge information, travel times were calculated from the mouth of the Mississippi, inland to Ferguson Falls, a distance of approximately 67.5 km. Given the relatively short travel time from the Ottawa intakes to Ferguson Falls; less than 4 days under the 100 year event, and recognizing the long durations during the spring freshet, IPZ-3 was extended to the extent of the Mississippi watershed. The uncertainty associated with the delineation of IPZ-3 was defined as high, due to the lack of data upstream of Ferguson Falls.

### 3.3.3 QA/QC Procedures

Quality assurance and quality control procedures were applied to the data and the modelling approaches employed in the IPZ delineations, including the field data collected as part of this study. Where possible, sensitivity analyses and statistical measures of data uncertainty (eg. confidence limits) were employed. The uncertainty assessment was considered 'low' with respect to the QA/QC procedures implemented for this study.

### 3.3.4 Calibration and Validation

*IPZ-2 Delineation*

The 3D numerical model used in the IPZ-2 delineation was calibrated and validated against measured current speeds and directions, and recorded water levels. The following observations were made in the comparisons between the model results and the measured data:

- In general, the model slightly overestimated current speeds.
- At Lemieux Island, predicted currents around the intake compared well with measured data with the average relative error determined to be 11%. A comparison of currents north of the island between Lemieux Island and Quebec showed that the model captured the peaks in flow that occurred approximately 40 m and 255 m away from the raw water intake. The absolute difference in (depth averaged) current speeds at the two peaks was determined to be 2 cm/s and 16 cm/s, respectively.
- At Britannia, the model captured the spatial trends in the peak flows, but typically overestimated the surface currents by as much as 30cm/s approximately 500m from shore. The average absolute error just downstream of the rapids was estimated to be 18 cm/s with a maximum difference of 46 cm/s.
- The average absolute error, based on a comparison of modeled results against two current measured transects just downstream of the Britannia intake, was determined to be 2 cm/s at both locations.

The overall assessment was that the 3D numerical model provided an accurate and reliable representation of currents in this reach of the Ottawa River, leading to high confidence in the model results and low uncertainty.

*IPZ-3 Delineation*

An analytical approach was used to support the delineation of IZP-3. No calibration or validation of the time of concentration equation was conducted as the availability of existing field data was limited. Overall, the uncertainty in the analytical approach used to delineate IPZ-3 was determined to be high.

## 3.4 Uncertainty Considerations: Vulnerability Assessment

### *3.4.1 The Distribution, Variability, Quality and Relevance of the Data*

The vulnerability score established for each intake protection zone is the product of the area vulnerability factor (B) and the source vulnerability factor (C). The derivation of these values was based on professional judgment to reflect site specific conditions and historical water quality data. The following general qualitative observations provide discussion regarding the level of confidence associated with key physical datasets used to define B and C:

1. *Physical Characteristics on Intakes*: A significant amount of information was available on the raw water intakes, including: structural details, water depths, GPS positioning of the intakes, design flows and entrance velocities. Discussions with the plant operators also provided valuable information on the treatment process, general water quality conditions and any chronic concerns. The uncertainty with this data is considered low for IPZ2.
2. *Water Quality Data*: Water quality in the City of Ottawa is monitored both at the water treatment facility and throughout the distribution network in order to comply with drinking water standards as outlined under the safe water drinking act. Due to the extent of the area serviced and the number of samples collected, which generally exceeds the Ontario Drinking Water Standards O.Reg 169/03, some of the testing is outsourced to accredited commercial laboratories. The City also utilizes modern analytical and laboratory methods accredited by the Canadian Association for Environmental Analytical Laboratories (CAEAL). As such, the uncertainty associated with the river water quality data at the intakes is low.

3. The watershed data used to support the area vulnerability scoring is another point of uncertainty. Existing information as provided by the City and MR-SPR, were relatively coarse as the watershed data was limited to significant river systems only. In order to complete the scoring based on the time of concentration approach, the watersheds were delineated into sub-watersheds using GIS. Although the newly generated sub-watersheds were reviewed to ensure the regions looked correct, a more comprehensive assessment is required to validate the data; as such, this dataset was given a high uncertainty rating.

Overall, the datasets utilized to assess and define the area vulnerability factor (B) and the source vulnerability factor (C) were complete and comprehensive; therefore, the level of confidence in the data is high, resulting in 'low' uncertainty for IPZ-1 and IPZ-2. For IPZ-3 the uncertainty is high.

### 3.4.2 QA/QC Procedures

Quality assurance and quality control procedures were applied to the datasets that were utilized as part of the vulnerability scoring; a number of these datasets were assembled early on in the study and have already undergone a review. Interpretation of the *Technical rules* and the methodology developed to assign a vulnerability score went through several iterations and was reviewed internally and discussions held with the Source Protection Committee and MOE. The overall confidence in the available data and the approach used to determine the vulnerability score was high, leading to an uncertainty assessment of 'low'.

### 3.4.3 Accuracy of the Vulnerability Scoring

The vulnerability scores for both treatment facilities were derived using the criteria outlined in the *Technical Rules.* A weighted average approach was applied to the criteria in order to calculate the area vulnerability factor for IPZ-2 and the source vulnerability factor. Relationships or categories were developed for each criteria using assumed conditions that bracket the range of vulnerability experienced within the study area. As discussed in Section 3.4.1, comprehensive datasets were available to help characterize the intake and surrounding environment. It should be noted that the area factor for IPZ-2 would not change, regardless of the approach used; given that the area is highly urbanized with an extensive sewer network and numerous outfalls. The source factor could potentially vary depending on the interpretation of the distance to shore criteria. Following the calculation of the area and source vulnerability factors, a qualitative assessment was conducted to determine if the score intuitively made sense. The overall confidence in the available datasets, the approach developed, and the vulnerability scores calculated was high, leading to an uncertainty assessment of 'low' for IPZ-1 and IPZ-2.

For IPZ-3, an empirical approach was used to determine the area vulnerability factor based on time of concentration. The uncertainty of the vulnerability factors for IPZ-3 was judged high due to the potential uncertainties associated with the scoring methodology and the guidance provided in the *Technical Rules.* For example, even though it is identified that IPZ-3 should vary with proximity from the intake, the approach and assumptions to be made in this calculation are unclear (for example, should area factor start at 1 at furthest extremity of IPZ-3?). The following identifies areas of uncertainty associated with the area vulnerability scoring approach used for IPZ-3:

1. The travel time in the Ottawa River is estimated by a method similar to that addressed in Section 3.3.4 for IPZ-2. However, the travel times were extrapolated upstream beyond the model domain, based on average velocities within the model domain; therefore, the uncertainty associated with this approach was determined to be high.

2. The time of concentration (Tc) in the sub-watersheds was determined by one of two calculations. For 'headwater' sub-watersheds (those that had no channel flowing in from upstream), the SCS lag formula presented in the *EBA Technical Bulletin* (MOE, 2009) was used. This is one of many empirical formulae for estimating Tc (although note that in strict

terms, time of concentration and lag time are different). Since it was not possible to test this formula against flow data in the sub-watersheds, it is not possible to determine whether this formula is preferable to any other. In particular, these are empirical formulae developed from observations in different climatic regions, different soil types, and with different land uses, and their coefficients are specific to the area (and time) of those observations. The uncertainly level associated with applying this type of formula in a different area without data for comparison is considered high.

3. For 'channelized' sub-watersheds, the presence of a permanent channel flowing through the sub-watershed negates using the SCS lag formula (which is not intended for channelized flow), and a channel routing method must be employed. The Manning equation was used to determine flow velocities in the channelized sub-watersheds. In general, the uncertainty associated with the parameters in the Manning equation is moderate. Slope, width, and depth can be easily measured (low uncertainty), and channel roughness can be characterized according to well-documented procedures. However, it was not possible to measure depth for the channels using readily-available data, and the depth was estimated from oblique photographs of the channels. In addition, a bankfull flow condition was assumed to correspond to a flow with a 2-year return period. The uncertainty associated with this estimation should therefore be considered high.

4. Along with the uncertainty in estimating the Tc using a particular technique, there is uncertainty associated with the *choice* of technique for determining Tc. For example, we applied the SCS lag formula to a channelized sub-watershed, and found a Tc of 106 minutes, compared to 90 minutes estimated by the Manning Equation. In another channelized sub-watershed, we estimated a Tc of 173 minutes using the SCS lag formula and 23 minutes using the Manning Equation. Given that the lag formula tends to over-estimate Tc in channelized sub-watersheds, the Manning equation approach was selected for these areas since it is more conservative (i.e. has a faster travel time).

5. The time of travel intervals used to determine the area vulnerability factor (B) is the main uncertainty in the vulnerability scoring for IPZ-3. There are no agreed guidelines on how to associate a particular score with a given set of IPZ-3 attributes. For this study, the scoring approach involved dividing IPZ-3 into differently-scored zones based on the estimated travel time to the intake under a 2-year return period flow. However, the linkage of these travel times to an overall score remains arbitrary, so the uncertainty associated with these scores is high.