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North Bay - Mattawa Conservation Authority
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Attention: Francis Gallo
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Dear Francis,

Technical Assessment Report
Groundwater Vulnerability Analysis
Municipality of Powassan

1.0 INTRODUCTION

The Clean Water Act (receiving Royal Assent in October, 2006) set out a framework for the development and implementation of source protection plans in Ontario. Under Bill 43, source protection plans are being developed for all municipal drinking water systems focusing on a watershed-based approach. The lead agency for development of the present plan is the North Bay - Mattawa Conservation Authority and, to assist the Conservation Authorities, Source Protection Technical Studies Draft Guidance Modules were developed in 2006 (by the Ministry of the Environment) outlining in detail the necessary study components. These guidelines were further supplemented by the publication of the Technical Rules in 2008, which further clarified the technical reporting requirements for the lead agencies, in the publication of their assessment reports.

Several of the studies identified in the Draft Guidance Modules have already been initiated by the North Bay - Mattawa Conservation Authority. Beginning in 2007, additional funding was made available by the Ontario Government to specifically focus on three areas:

- Groundwater Vulnerability Analysis (Guidance Module 3)
- Threats Inventory and Issues Evaluation (Guidance Module 5)
- Water Quality Risk Assessment (Guidance Module 6)

This report comprises the Groundwater Vulnerability Analysis for the municipal well field in Powassan, Ontario. A combination of techniques was used to complete the Groundwater Vulnerability Analysis, with a primary aim of reflecting the unique characteristics of the watershed as it relates to the wellhead protection area of the municipal well field in Powassan. The assessment was based on the best available data, and in accordance with the objective of continuous improvement, data gaps and future data needs were identified for any follow-on study phases.

The information presented in this assessment is intended for use in the Water Quality Risk Assessment report, which has been completed under a separate cover.

2.0 MUNICIPAL WATER SUPPLY OVERVIEW

The Municipality of Powassan well field consists of two municipal wells, located on the north side of Highway 534 and west of the Highway 11 corridor, in Powassan (Figure 1). The well field is located on a gently sloping topography between Highway 534 and Genesee Creek, with both wells being located above the creek level. The UTM co-ordinates of the two municipal wells (in NAD83) are 625874 mE and 5104525 mN (Well No. 1) and 625890 mE and 5104590 mN (Well No. 2).

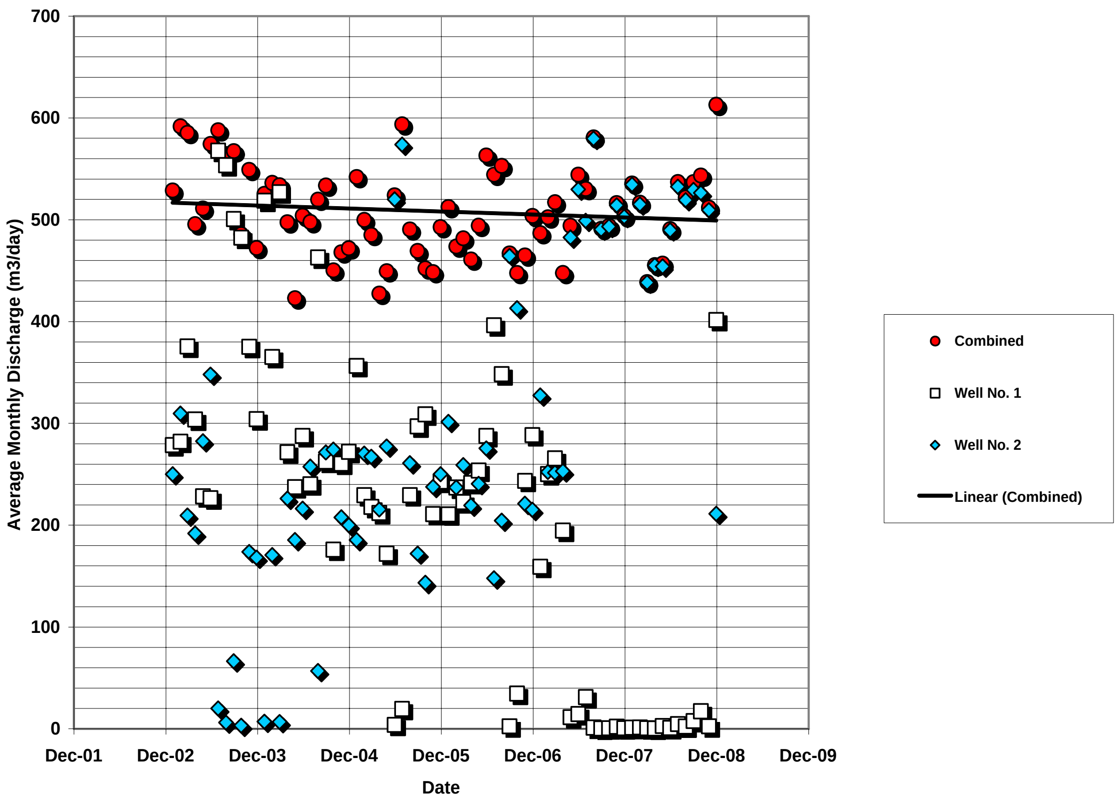
Powassan Well No. 1 was drilled in 1981, by Crowley Groundwater Limited (Dundas) to a total depth of 23.2 m below grade. The well comprises a 158.8 mm (6 1/4 inch) diameter steel casing to a depth of 19.3 m, with a 3.8 m screened interval comprising a 139.7 mm (5 1/2 inch) diameter composite screen consisting of two 0.9 m long No. 10 slot stainless steel screens over top of one 1.2 m long No. 50 slot stainless steel well screen. There is no indication of any gravel pack. The formation encountered during drilling consisted of fine brown sand (to a depth of 10.7 m), over brown layered silty clay and fine sand (to a depth of 15.2 m) which in turn overlies a coarse sand and gravel (with occasional cobbles) to the total completion depth of 24.1 m. The static water level upon completion (1981) was 5.9 m below grade. This well is not registered with the Ministry of the Environment water well record database, and the above information was obtained (by the North Bay - Mattawa Conservation Authority) from R.J. Burnside and Associates Ltd.

Powassan Well No. 2 was drilled in 1983, by Crowley Groundwater Limited (Dundas) to a total depth of 18.6 m below grade. The well comprises a 304.8 mm (12 inch) diameter steel casing to a depth of 11.0 m, with a 7.6 m screened interval comprising a 250 mm

(10 inch) diameter composite screen consisting of a 2.7 m long No. 30 slot stainless steel screen on top of 4.0 m of No. 40 slot stainless steel well screen, which overtops 0.9 m of No. 35 stainless steel screen. There is no indication of any gravel pack. The formation encountered during drilling consisted of a brown dirty sand (to a depth of 3.4 m), over clay with streaks of sand (to a depth of 10.4 m), over gravel and sand (to a depth of 18.9 m, with a partially cemented layer from 12.3 m to 12.8 m) which in turn overlies clay, gravel and sand to the total completion depth of 22.0 m. The static water level upon completion (1983) was 0.4 m below grade (and approximately at the elevation of the nearby Genesee Creek). The well construction was subsequently modified to raise the well casing above the regional flood level for Genesee Creek. This well is not registered with the Ministry of the Environment water well record database, and the above information was obtained (by the North Bay - Mattawa Conservation Authority) from R.J. Burnside and Associates Ltd.

Water consumption data were obtained from the Municipality, for the time period extending from January, 2003, to December, 2008, and are plotted below (Diagram 1):

Diagram 1 - Average Monthly Pumping Rates



Although there is a degree of scatter in the plot (attributed to some seasonal effects coupled with well maintenance activities), there was no distinct trend in total water use over the indicated period.

The highest total consumption in the records was for December of 2008, with an average daily consumption value of 613 m^3/day (402 m^3/day being taken from Well No. 1 and 211 m^3/day being taken from Well No. 2). Over the total time period for which the records were obtained, the average total daily consumption was 508 m^3/day, with an average of 208 m^3/day being taken from Well No. 1 and 300 m^3/day being taken from Well No. 2.

These values are well below the maximum permitted pumping rate (both wells combined) of 1,313 m^3/day (Permit to Take Water No. 82-P5292)(Totten Sims Hubicki, 2001). For the present analysis, the allocated quantity of water to be used in the well head protection analysis was assumed to be equal to 508 m^3/day (i.e. the average consumption for the time interval of January, 2003, to December, 2006). Also, the individual well withdrawal rates used in the capture zone assessment were set at 208 m^3/day for Well No. 1 and 300 m^3/day for Well No. 2.

Based on discussions with the North Bay - Mattawa Conservation Authority, it is our understanding that there is no committed demand surcharge associated with this municipal system. Allowance for an additional committed demand would be made if there is a proposed expansion to the water distribution system underway at the time of this assessment (or otherwise approved within the Official Plan for Powassan).

3.0 WELL HEAD PROTECTION AREA (WHPA)

Under the previous municipal groundwater studies' Technical Terms of Reference (November, 2001), each municipal well field in the groundwater study area was to be assigned a wellhead protection area (WHPA) which represents the subsurface zone of the underlying aquifer which contributes water to the public water system. While the groundwater flow in the subsurface typically can move in three dimensions, in order to present the contributing groundwater flow on a two dimensional map view, the contributing volume of aquifer was projected upwards to the ground surface. The wellhead protection area is, therefore, a two dimensional representation (or map view) of the lateral extent of the subsurface volume of aquifer which supplies water to the well field, but contains no information on the depth of the groundwater flowing to the well field.

The WHPA defines an area adjacent to a pumping well through which contaminants may enter the subsurface and ultimately reach the wells supplying the public water system. From a risk management perspective, the subsurface areas (within the WHPA) which are closest to the well intakes pose the highest risk to the public for contaminants moving in the subsurface, while the subsurface areas which are further away from the well intake carry a lesser risk from contaminant movement.

As identified in the Technical Terms of Reference (2001), the specific risks from contaminants vary throughout the WHPA. Bacterial contaminants have a limited lifespan, and the longer they take to travel in the subsurface from the point of release to the well intake, the less likely they are to remain active and at risk to human health. Similarly, some chemical contaminants can break down (degrade) over time and become absorbed into the aquifer soils as they travel through the subsurface, while others can become diluted as they flow through the groundwater system.

For these reasons, the WHPA identified for a given well field is sub-divided into various capture zones in order to reflect variations in the risk potential when moving outwards from the immediate well intake area. A total of four zones are established for each WHPA, based on the concept of “time of travel” (or TOT), or the time required for water to move from a specific location within the groundwater aquifer to the municipal well intake. If the well system is classified as obtaining groundwater under the direct influence of surface water (or a GUDI system), additional consideration must be given to the identification of the potential interactions between the groundwater system and the nearby surface water source.

The various groundwater capture zones, as defined in the 2008 Technical Rules (for a Type 1 drinking water system under the Clean Water Act, 2006), were modified slightly from the original descriptions identified in the Technical Terms of Reference (2001). However, the basic concept of establishing zones based on a time of travel distance from the well intake remained the same.

From the current definitions of the WHPA, the various sub-areas are identified as follows:

- WHPA-A - being the surface and subsurface area centred on the well with an outer boundary identified by a radius of 100 metres,
- WHPA-B - being the surface and subsurface areas within which the time of travel to the well is less than or equal to two years, but excluding the WHPA-A,
- WHPA-C - being the surface and subsurface areas within which the time of travel to the well is less than or equal to five years but greater than two years and
- WHPA-D -being the surface and subsurface areas within which the time of travel is less than or equal to twenty-five years, but greater than five years.

As indicated previously, if the well field is classified as GUDI, additional areas are defined relating to the interaction of surface water with the groundwater capture zones. Despite their close proximity to the nearby surface water course (Genesee Creek), the municipal wells in the Powassan well field have not been classified as being groundwaters under the direct influence of surface water (GUDI) in the First Engineers' Report (Totten Sims Hubicki Associates, 2001), or by present modelling efforts (Appendix A) and, therefore, there are no other additional WHPA zones associated with the well field in Powassan.

The Technical Rules (2008) also prescribe the accepted methodologies which may be used to determine the time of travel to a wellhead. In the original 2006 groundwater study (Waterloo Hydrologic Inc.), the method chosen was a three-dimensional, steady-state computer model developed using VisualMODFLOW software (Waterloo Hydrologic, Inc.). The present study continued with the use of VisualMODFLOW (using Version 4.3), however the model domain and characteristics were modified to reflect the input of additional hydrogeological data sources which were researched during this study program. Appendix A presents a detailed overview of the groundwater model development.

The groundwater model was run in a steady-state mode, which assumed that the wells were pumping at their assigned average pumping rates until steady state conditions were attained. The regions of the aquifer which contribute flow to the well head area were identified by an analysis method referred to as "particle tracking". Particle tracking is a feature within the groundwater model which allows the movement of individual particles of water to be traced (on a map view) from the point where recharge enters the groundwater flow system to the point where water leaves the groundwater flow system (at the well). The exact pathway that the water particles follow depends on the subsurface soil and rock types, and the directions of groundwater flow in the aquifer. Within VisualMODFLOW, particle tracking is performed by a sub-program called MODPATH.

By using MODPATH, several dozen particles can be tracked simultaneously as they move through the groundwater flow system being modelled. The position of each particle can be described by the time it takes to travel a fixed distance in the groundwater flow system, and therefore particle tracking is the basis for developing the WHPA zones (identified previously) using their respective time of travel (TOT) characteristics. Although this analysis is theoretical, and is based solely on a mathematical model of the real world conditions in the aquifer, it is the only way that such an analysis can be performed. Groundwater movement in an aquifer is very slow, and the use of chemical "tracers" to observe actual groundwater movement, at the scale needed for the present analysis, would take many decades to accomplish.

The use of a sophisticated groundwater model, such as VisualMODFLOW, permits the detailed analysis of such slow groundwater movement, based on assumptions of the geology and hydrogeological inputs to the groundwater flow system. Although superior to other more simplified analytical methods, the model remains only a representation of the real world and is strongly dependent upon the conceptual understanding that was used in its development (Appendix A). In the present assessment, the model was developed using the best available data, and is believed to be an accurate representation of the flow system being studied. The various input parameters and assumptions/interpretations relating to the hydrogeological model are presented in Appendix A.

The WHPA zones, as developed by the present analysis and following the methodology outlined in the Technical Rules (2008), are presented in Figure 2. On this figure, the lateral boundaries of the subsurface zones contributing groundwater to the well field are clearly defined (by the outermost perimeter of the WHPA), and the WHPA is observed to be oriented in an east-southeast to northwest direction. The wellhead itself (the well locations) are situated in the extreme northwest corner of the WHPA, and regional groundwater flow, as defined in the present model and the previous assessment (2006), is from the southeast to the northwest (towards Lake Nipissing).

4.0 INTRINSIC VULNERABILITY ASSESSMENT

A component of the Municipal Groundwater Study program was the requirement to assess the vulnerability of the groundwater aquifers to surface contamination sources. In the 2006 NBMCA Groundwater Study Report, this assessment was based on information contained within the Ministry of the Environment’s water well database, and followed a technique which resulted in an Intrinsic Susceptibility Index (or ISI value) being generated for each well record location.

In an ISI analysis, a portion of an aquifer is assigned a numerical score based on the unique hydrogeologic conditions at a particular location. The scores are based on the depth to water and soil type, and as such, the scores reflect the susceptibility to contamination of the uppermost aquifer (also referred to as the “water table”). The scoring technique is modified when confined aquifer conditions are encountered, and the methodology is described in detail in the original Technical Terms of Reference (2001).

The ISI is calculated by multiplying the thickness (in metres) of each geological unit (which overlies the water supply aquifer) by its corresponding “K-factor” (which is assigned based on the hydraulic conductivity, or permeability, of the geological unit being considered). The ISI is an index value only, and does not equate numerically to any physical characteristic of a soil or rock type. An ISI value is calculated for each geological unit, in the case of a layered sequence of materials, and the individual values are summed (added) vertically to arrive at a final ISI for that particular location.

For the 2006 study (Waterloo Hydrologic Inc.), the ISI scores were developed only at locations where there were water wells present, and the ISI values assigned to each well location were subsequently contoured across a broader area to provide a map of regions having low, medium and high Intrinsic Susceptibility Index values. While on a regional mapping scale the use of automated contouring techniques (such as kriging) is justifiable, there was a concern that this methodology may not adequately reflect the local variations in surficial conditions in the immediate well head area. The potential benefits of using local mapping and knowledge (beyond the water well database) is also referenced in the Guidance Module (2006).

As a result, a supplemental assessment of the aquifer sensitivity analysis was undertaken, in an effort to bring more local detail into the process. Building upon the 2006 groundwater study findings, and through consultation with the North Bay - Mattawa Conservation Authority, a decision was made to incorporate available surficial geological mapping to aid in interpreting the aquifer sensitivity to surficial contamination. A primary source of information used in this assessment was the local aggregate resource mapping (Ontario Geological Survey, 1984), which presents the local surficial geology at a scale of resolution of 1:50,000 (an improvement over the other surficial mapping scales used in the NOEGTS mapping and geological reports). This information was also correlated to the revised water well database (Appendix A), and the groundwater model features developed using VisualMODFLOW.

In the present analysis, a total of seven geological units were considered in the groundwater model (Appendix A), and from the Guidance Module 3 tables, the following K-factors were assigned to each unit (Table 1):

Table 1 - Representative K-Factors For Selected Geological Materials

Geological Unit	**K-factor**
sand and gravel aquifer	**1**
sandy till	**2**
silty sand	**3**
sandy silt	**4**
alluvium	**4**
clay	**8**
bedrock	**3**

For the unconfined areas of the groundwater flow system, the depth to water table values were determined from the VisualMODFLOW output, and these values were then multiplied by the respective K-Factors (above) to arrive at an ISI for the unconfined areas. For the confined parts of the flow system, the thickness of the geologic units were determined from the VisualMODFLOW output, and these values were then multiplied by the respective K-Factors (above) to arrive at an ISI for each confining layer. The ISI values were then added together to arrive at a unique ISI for each location.

ISI mapping provides a qualitative interpretation of potential areas of concern, highlighting areas where the underlying aquifer is recognized as being vulnerable to surficial sources of contamination. Surficial sources of contamination refers to contaminants released onto the ground surface, or at shallow soil depths, which have the potential to infiltrate downwards and contaminate the underlying water table aquifer.

Following the guidelines of Guidance Module 3, the various surficial soil types were assigned low, medium and high intrinsic vulnerability scores through an application of previous data, professional judgement and hydrogeological interpretation. As a result, the original ISI mapping was updated (within the WHPA) to reflect the newer information sources that have been used in the present study.

As defined in the 2008 Technical Rules,

- an area having an ISI score of less than 30 is considered to be an area of high vulnerability,

- an area having an ISI score greater than or equal to 30, but less than or equal to 80, is considered to be an area of medium vulnerability and

- an area having an ISI score of greater then 80 is considered to be an area of low vulnerability.

The intrinsic vulnerability scores assigned to a groundwater flow system can vary from location to location, depending of the changes in the geology and depth to water. By contouring the scores across the broader study area, a map of the vulnerability of an aquifer was developed for later use in the risk assessment process outlined in Guidance Module 6.

The preliminary intrinsic vulnerability mapping for the Powassan WHPA, and the surrounding model domain, is presented in Figure 3. From this figure, it can be seen that a large portion of the WHPA is assigned a low vulnerability to surficial contamination, due to the predominance of lower hydraulic conductivity silts and clays in the central portion of the WHPA. Two areas of high vulnerability occur within the WHPA-

D zone, corresponding to areas where the more permeable till deposits are interpreted to outcrop at surface (and the corresponding depth to water is shallower). The remainder of the WHPA was assessed as having a medium vulnerability to surficial contamination.

5.0 GROUNDWATER VULNERABILITY SCORING

The goal of the previous assessment methodologies is to arrive at a unique vulnerability score (or scores) for the Well Head Protection Area, that can then be used in the risk analysis of any identified contaminant sources within the WHPA. As outlined in the Guidance Document (Module 3), there are two main steps to be completed in arriving at the vulnerability scoring for the WHPA: (1) categorizing the intrinsic vulnerability of the aquifer as being either high, medium or low, and (2) mapping the various time of travel (TOT) zones within the WHPA and noting where the WHPA zones intersect with the relative vulnerability areas (on a map view).

The determination of the vulnerability scoring within the WHPA therefore involves a consideration of the flow characteristics within the aquifer (from a TOT perspective) coupled with a consideration of the relative susceptibility of the aquifer (within each TOT zone) to surficial contaminant sources. By the current methodology, and specific to the WHPA, the groundwater vulnerability scores range from the maximum value of 10 (the default setting assigned to WHPA-A) to a minimum value of 2 (encountered at the furthest distance from the well head area in a region of low intrinsic vulnerability).

The Technical Rules (2008) describe the vulnerability scoring ranges to be applied in the present analysis of the WHPA, and the scoring is outlined in the table which follows (taken from the 2008 Technical Rules)(Table 2):

Table 2 - Aquifer Vulnerability Scoring

Groundwater Intrinsic Vulnerability Category for the Area	**Location Within a Well Head Protection Area**			
	WHPA-A	**WHPA-B**	**WHPA-C**	**WHPA-D**
High	**10**	**10**	**8**	**6**
Medium	**10**	**8**	**6**	**4**
Low	**10**	**6**	**4**	**2**

The above table was applied to the mapping presented previously, and the resultant vulnerability scores are presented for the WHPA, and the adjacent modelled areas, in Figure 4. This analysis is used in the risk assessment process of Guidance Module 6.

6.0 VULNERABILITY SCORING ADJUSTMENTS

The vulnerability scores indicated on Figure 4 can be increased if a particular land use activity causes the surface conditions above the groundwater aquifer to become more vulnerable to contamination, thereby changing the intrinsic vulnerability of the aquifer in that particular area. As indicated in the Guidance Document (2006), natural preferential pathways (in the form of fractures in bedrock or larger solution cavities in karst limestone formations) are already incorporated into the K-factors used in the ISI calculations. However, certain man-made activities, such as deep open excavations, large diameter well borings or abandoned water well casings, can offer a constructed preferential pathway which may justify raising the intrinsic vulnerability to the next level in the affected areas.

In the present assessment, a large aggregate extraction operation exists marginally outside of the south corner of the WHPA-D zone. This operation effectively creates an open window to the underlying aquifer, and would justify raising the intrinsic vulnerability score in this location. However, the intrinsic vulnerability score in most of this area is already “high”, and cannot be increased any further. The only exception is a small southwest corner of the aggregate extraction operation which was originally mapped as having a “low” intrinsic vulnerability score. This zone was subsequently raised to a “medium” intrinsic vulnerability value.

Our review of the geotechnical highway construction reports for the Hwy. 11 and Hwy. 534 interchange indicates that several geotechnical boreholes were advanced into the subsoils, and were subsequently abandoned when the work was completed. The method of abandonment was identified as being “backfilled” using drill cuttings, and the date of the studies (1985 to 1993) pre-dates more recent internal policies (within the Ministry of Transportation) relating to borehole abandonment and sealing in accordance with the requirements of O.Reg. 903 (the water well regulation).

A review of the subsurface logs indicates that many of the drill holes penetrated lower permeability horizons, and that flowing borehole conditions were not encountered. As such, it is considered likely that a borehole drilled in these areas would not have remained open for any length of time if the subsurface soils comprised the more clay-rich soil types. Unfortunately, a clay unit having sufficient “plasticity” (or ability to collapse and close) was not always encountered in every geotechnical borehole, and it is considered possible that a constructed pathway from the surface to the aquifer may have been created within the identified geotechnical test areas.

Consequently, given the documented existence of several deep abandoned geotechnical boreholes in this area of the WHPA, it was considered advisable to raise the intrinsic vulnerability scores in the immediate area of the past highway construction studies. Although initially assigned an intrinsic vulnerability of “low” to “medium” (because of the various subsurface soil types encountered), the area of the former geotechnical studies has been assigned a revised intrinsic vulnerability score of “medium” near the Hwy. 11 and Hwy. 534 interchange, and a score of “high” near the Genesee Creek overpass on Hwy. 11, to account for the presence of the identified potential constructed pathways.

Similarly, the test wells installed during the Ministry of the Environment-funded study (Morrison Beatty Limited, 1981) were also abandoned upon completion. Since this work was performed by a licensed water well contractor, under supervision of a field hydrogeologist and in accordance with a work program authorized and developed by the Ministry of the Environment, it is considered likely that the abandoned test holes in this particular study were sealed in accordance with the standard of care required at the time (including the use of low permeability drilling muds to seal the open boreholes). No modification to the intrinsic vulnerability score was made for these test locations.

Private water well casings pose a potential constructed pathway from the surface to the aquifer if the construction is not properly sealed or if the well is improperly abandoned (if no longer in use). A review of the known water well locations was undertaken, with the goal of determining if higher density clusters of wells occur within the WHPA zones defined in this study. There are currently no specific criteria available to assess the significance of well clusters, and the assessment of the overall effect of clusters of wells on the intrinsic vulnerability scores is based on professional judgement.

A review of the distribution of water well records indicated, from the available information, that most of the high density well cluster groups occur in three distinct areas surrounding Powassan. These areas are located outside of the municipally-serviced area of the townsite, and in general extend beyond the WHPA identified in this study. In particular, the main central portion of Powassan (which is now municipally-serviced) has very few well casings recorded (approximately 10 records in total). Based on the low number of records, no adjustment of the intrinsic vulnerability score was made for this area.

The remaining well clusters are located in areas beyond the municipal service lines, and constitute active water well systems. These are not, therefore, considered to be abandoned and do not pose a constructed pathway to the aquifer (if they are being properly maintained). The location of these well clusters is at the farthest perimeter of the WHPA-D zones, and as such are not considered a significant reason to modify the intrinsic vulnerability score for this part of the aquifer.

The revised groundwater vulnerability mapping for the Powassan WHPA is presented in Figure 5. From this figure, the modification to the preliminary vulnerability mapping was focused on the area of the highway investigation boreholes. Again, by following the guidance in the Technical Rules (2008), a revised vulnerability score was generated for each WHPA zone which intersected the constructed pathways. The revised vulnerability scoring is presented in map view in Figure 6.

7.0 UNCERTAINTY ASSESSMENT

As identified in the Guidance Document (Module 3) each of the vulnerable areas within the WHPA will carry a degree of uncertainty, depending upon the quality of the data used in the assessment and the professional judgement skills of the analyst. The present study requirement is to designate an uncertainty level to each area having a vulnerability score assigned to it, with the uncertainty being quantified as either “high” or “low”.

In terms of the definition of the WHPA zones, the present analysis comprised a new conceptualization of the groundwater model (when compared to the 2006 Municipal Groundwater Study). The present WHPA results were compared to the 2006 study results, and when the respective WHPA zones were overlain, some areas of similarity in the results were noted. This suggests that, for those areas of common overlap, the two models were in close agreement and that, despite different conceptualizations, the final WHPA results were similar.

Therefore, these two modelling efforts effectively constitute a “multiple scenario” approach to establishing the WHPA zones, and for those areas where common overlap occurred, the uncertainty assessment is considered to be “low”. Similarly, in the present study, in those areas where no previous overlap occurred, the uncertainty is considered to be “high” (following the recommendations of the Guidance Document).

Although the present study placed some reliance upon the Ministry of the Environment’s water well database and, where practical, took steps to improve the confidence in the information contained in the WWIS, reliance was also placed on higher quality aquifer pumping test reports from several locations and detailed geotechnical borehole grainsize data. Considering all of the data reviewed in the conceptualization process, the aquifer characteristics from a groundwater hydraulics viewpoint are considered to be well understood, and so the time of travel assessments in the vicinity of the well head area are interpreted to be highly representative of the true field conditions. Consequently, the uncertainty associated with the TOT zones close to the well head area is considered to be “low”, extending from WHPA-A to WHPA-B. The only exception was in the general area of the former geotechnical boreholes, and since the status of the abandonment of these boreholes remains unknown, the uncertainty within these identified areas is considered to be “high” for both the WHPA-B and WHPA-C areas.

Data density was an issue for the broad landscape within the model domain. Due to historical and current land use development patterns, which focused on development along main roads and arteries, large areas of the model domain were (and remain) undeveloped from a groundwater perspective. In some areas the geological conditions were extrapolated based on marginal data, and reliance was placed on published geological interpretations by others. In terms of the WHPA, some portions of WHPA-D must be considered to have a “high” uncertainty for these reasons.

In accordance with the Technical Rules (2008), an uncertainty analysis was performed for each vulnerable area within the WHPA for the Powassan well field. In order to clarify the individual vulnerable areas covered in this assessment, each individual vulnerable area (which is a sub-area within each WHPA zone) was assigned a unique identification label for future referencing, and are indicated on Figure 7. The uncertainty analysis for each vulnerable area of Figure 7 is presented in spreadsheet format in Appendix B of this report.

8.0 SUMMARY

This report presents the results of a groundwater vulnerability analysis for the Powassan municipal well field. The assessment followed the methodology presented in the Guidance Module (2006) and Technical Rules (2008), and resulted in the generation of well head protection areas (WHPAs), an intrinsic vulnerability assessment of the aquifer and the assessment of vulnerability scores within the WHPAs. The information in this module is intended for use in the risk assessment procedures of Guidance Module 6.

In performing this assessment, every effort was made to use the best available data. In some cases, existing information sources (such as the WWIS) were enhanced by further research and investigation and, wherever possible, past studies were built upon and their conclusions critically reviewed in order to build confidence in the results that have been obtained. Areas of uncertainty have been identified, in the anticipation that later planning cycles may be able to supplement the interpretations presented in this document via the process of continuous improvement.

We thank you for the opportunity of working with the North Bay - Mattawa Conservation Authority on this project.

Yours truly,
WATERS ENVIRONMENTAL GEOSCIENCES LTD.

Peter A. Richards, M.Sc., P.Eng.
President

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Appendix A - Groundwater Model Development - Powassan

1.0 Background

In 1979, studies were initiated (by the Ministry of the Environment), with the goal of finding an alternative to the municipal surface water intake from Genesee Creek. Test drilling, carried out at three locations in Powassan (in 1980), failed to find a suitable municipal supply source at the in-town locations drilled (Morrison Beatty Limited, 1981), but subsequent drilling (by Crowley Groundwater Limited) in Lot 17, Concession XIII proved successful.

The resultant municipal wells are located near the floodplain area of Genesee Creek, which is a tributary of South River, and are situated approximately 300 m northwest of the corner of the intersection of Highway 11 and Highway 534. The wells were drilled in 1981 (Well No. 1) and 1983 (Well No. 2), and were subsequently connected to the municipal water infrastructure (in 1982 and 1984, respectively) (Golder Associates Limited, 1993). The UTM co-ordinates of the two municipal wells (in NAD83) are 625874 mE and 5104525 mN (Well No. 1) and 625890 mE and 5104590 mN (Well No. 2). These co-ordinates were incorrectly referenced as NAD27 in the First Engineers' Report (Totten Sims Hubicki Associates, 2001), which would otherwise have placed the wells on the north side of Genesee Creek (instead of their correct location on the south side of the creek).

The well field, comprising Well No. 1 and Well No. 2, is currently rated at a combined maximum capacity of 1,313 m^3/day (under the Ministry of the Environment's Permit To Take Water Program), although recent pumping data (obtained from the municipality) indicate that the average pumping rates have been approximately 40 % (or less) of the rated capacity of the system.

The hydrogeological setting of the Powassan well field area has been defined by a number of technical reports and maps, which were reviewed as part of the current Groundwater Vulnerability Assessment. The relevant information reviewed included the following:

- NBMCA Groundwater Study Report, January, 2006, Waterloo Hydrogeologic , Inc. and Tunnock Consulting Ltd.

- Stream Flow and Temperature Measurements For Genessee Creek, June 1 to June 15, 2004, Municipality of Powassan, 2004, Northland Engineering (1987) Limited

- Municipality of Powassan, Powassan Well Supply, First Engineer's Inspection Report for Water Works, March, 2001, Totten Sims Hubicki Associates

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These information sources were reviewed and assessed as part of the present study program, and a conceptual model of the site hydrogeology was developed. The conceptual model development was an extension of the initial work preformed previously by Waterloo Hydrologic, Inc. and Tunnock Consulting Ltd. (2006), and utilized additional hydrogeological information obtained by the North Bay - Mattawa Conservation Authority and Waters Environmental Geosciences Ltd. during the present data review process.

The 2006 NBMCA Groundwater Study Report made extensive use of the Ministry of the Environment's Water Well Information System (WWIS) well record database, and following the Terms of Reference (2001) for the groundwater studies, the well records were filtered (removed from further consideration) if location discrepancies of more than 300 m (horizontally) or 15 m (vertically) were noted. For the entire source protection area (extending from North Bay to Mattawa to Powassan), only 54% of the 5,121 water well records we deemed acceptable for modelling purposes, the majority of the records being eliminated because of missing UTM co-ordinates (Waterloo Hydrogeologic , Inc. and Tunnock Consulting Ltd., 2006). As a result of this data validation process, and specific to the Powassan area, a subset of 77 records were used to model the groundwater conditions in the wellhead area (in the 2006 study).

In order to augment the existing study information, contact was made with the Sudbury Regional Office of the Ministry of the Environment (Technical Support Section) and the available electronic spreadsheet database was compared against the original water well forms (held on-file at the Regional Office). The WWIS is limited in the amount of information that can be presented electronically and, in particular, one feature that is not available is the driller's sketch map of the well location. Through consultation with the Ministry of the Environment, and by use of available topographical mapping and airphotos of the study area, UTM co-ordinates were assigned to many of the formerly "un-verified" water well records contained in the water well database. As well, corrections were made to the database in the case where the well locations were identified as being incorrectly plotted. These records were subsequently assessed for inclusion into the present study analysis.

By this methodology, 28 water well records were provided with new (or revised) UTM location co-ordinates, and were incorporated into the present analysis of the hydrogeological setting of the Powassan municipal well field. As well, additional water well records (excluded previously) were brought into the assessment of the local hydrogeology in cases where our review of the original water well records provided sufficient information to increase the confidence in the use of the records. The total number of water well records made available for the present assessment was therefore increased from 77 (in the previous study) to 116 water well records (in the present study). The updated UTM co-ordinates for the wells were also provided to the North Bay - Mattawa Conservation Authority for use in updating their internal database records.

One shortcoming of the use of the WWIS database in the 2006 groundwater study was that no water well records were included for the two municipal wells in Powassan, because the well constructions were never reported to the Ministry of the Environment (and are currently missing from the database). Information on the well constructions was presented in the First Engineers' Report (Totten Sims Hubicki Associates, 2001), while the stratigraphic information was summarized in two as-built drawings (R.J. Burnside and Associates Ltd., 1983).

In addition, subsurface information from the area near the well field was obtained from 17 geotechnical boreholes drilled during highway work in the vicinity of the Hwy. 534 and Hwy. 11 interchange (Ministry of Transportation, 1985, 1991 and 1993, Golder Associates Ltd., 1993). These sources were not included in the previous analysis, as geotechnical boreholes are not included in the WWIS database. Therefore, this supplemental subsurface information was not referenced in the original wellhead protection analysis, and as a result of the present data review, an additional 19 stratigraphic logs were incorporated into the present study.

One feature of the WWIS database is the dominance of bedrock-constructed well records for the study area (and in Northern Ontario in general). Prior to 1984, shallow dug well constructions and owner-constructed water wells were not required to be reported to the Ministry of the Environment, and the exact number of these types of water wells in use, and their geographical distribution, is unknown and under-reported in the WWIS database. Therefore, site-specific information on shallow overburden wells is limited in the WWIS database, even though it is these overburden formations that constitute the municipal aquifers in many settings (such as Powassan).

The distribution of water well and borehole information, reviewed in the present assesment, is displayed graphically in Figure A1. The age of the records plotted in Figure A1 span 1952 to 2000 (or 48 years), and reflect the history of settlement in Powassan (from a groundwater usage perspective). In some parts of the study area, the information coverage was sparse, for example in the more central part of the townsite, where prior to 1983 the area was municipally serviced from a surface water intake on Genesee Creek.

As a result, the present conceptual model was based on a combination of the subsurface information obtained from 135 borehole/well locations within the study area of Powassan, as well as the information available from geological mapping and consultant's reports.

2.0 Municipal Aquifer Characterization

A review of available pumping test data on the municipal wells was undertaken in order to assist in identifying the hydraulic properties of the aquifer beneath the Powassan well field. Well performance data, obtained (in the 1980s) by Crowley Groundwater Limited, comprised drawdown curves appended to the consultant's reports. Raw (numeric) data were not obtained, and the historical performance curves were subsequently examined and copied to a spreadsheet to facilitate re-plotting and analysis.

The 1981 data comprised drawdown curves for a 75 hr steady-state pumping test on Powassan Well No. 1, and associated drawdown curves for a nearby observation well. The 1983 data comprised drawdown curves for a 7 hr steady-state pumping test on Powassan Well No. 2, and associated drawdown curves for two nearby observation wells. There were no other historical hydraulic test data available for the Powassan well field in the consultant's files or in the Town records.

The pumping test on Powassan Well No. 1 was carried out (date unknown) at a rate of 1,309 m^3/day, with observations of drawdowns being recorded in both the pumping well and an observation well (located 6.4 m away from the pumping well). The drawdowns reported for both wells showed an initial drop with increasing time, followed by a flattening trend (Figure A2), which is indicative of a change in aquifer conditions at a distance from the pumping well.

For the present study, the data were analysed by several techniques, including the Cooper-Jacob non-equilibrium method and the Theis type-curve method (Fetter, 2001). The results of our analysis are presented in Table 1.

Table 1 - Pumping Test Analysis for Well No. 1

Location	Analysis Method	Transmissivity (m^2/day)	Storativity (dimensionless)
Well No. 1	**Cooper-Jacob**	**185**	**not defined**
OW – 1	**Cooper-Jacob**	**185**	**7×10^{-5}**
	Theis Type Curve	**174**	**1×10^{-4}**

The pumping test on Powassan Well No. 2 was carried out (date unknown) at a rate of

2,873 m^3/day, with observations of drawdowns being recorded in both the pumping well and two observation wells (located 3.0 m and 75.9 m away from the pumping well). The drawdowns reported for all of the wells showed an initial drop with increasing time, followed by a flattening trend (Figure A3), similar to the test results for Powassan Well No. 1.

The data were again analysed by several techniques, and the results of our analysis are presented in the Table 2.

Table 2 - Pumping Test Analysis for Well No. 2

Location	Analysis Method	Transmissivity (m^2/day)	Storativity (dimensionless)
Well No. 2	**Cooper-Jacob**	**405**	**not defined**
OW - 1	**Cooper-Jacob**	**234**	**2×10^{-4}**
	Theis Type Curve	**176**	**7×10^{-4}**
OW - 2	**Cooper-Jacob**	**263**	**5×10^{-5}**
	Theis Type Curve	**208**	**6×10^{-5}**

The above transmissivity calculations were performed on the drawdown curves before the flattening trend was noted, and reflect aquifer conditions in the immediate vicinity of each well head. Based on the values obtained, the geometric mean of all of the calculated transmissivity values was 220 m^2/day, which indicates that the aquifer beneath the Powassan well field is capable of municipal well yields, based on criteria established by Driscoll (1986). The storativity values ranged from 5×10^{-5} to 7×10^{-4}, and typically indicate a confined to semi-confined aquifer setting (in agreement with the soil types reported in the well construction logs).

The observed flattening trend of the drawdown curves indicates that the aquifer conditions change at a distance from the pumping well. A flattening trend indicates either that the aquifer materials have a higher transmissivity at an increasing distance from the well, or that a source of recharge to the well was encountered when the drawdown cone expanded during pumping. Given the close proximity of Genesee Creek to the well field, it is interpreted that the flattening of the drawdown curve was due to recharge entering the aquifer from the nearby surface water source.

It should be noted that the observed flattening effect does not imply that surface water immediately enters the well intake, and that the delay in the onset of the flattening effect demonstrates that a portion of the flow to the well is carried out through the aquifer itself. This, in turn, implies that there is not an immediate “short circuiting” of surface water flow to the well screen intake. It should also be noted that the test pumping rates exceeded the typical pumping rates reported by the municipality.

The flattening of the drawdown curves was interpreted as indicating that a recharge boundary had been encountered by the drawdown cone during pumping. An analysis of the boundary conditions was undertaken, using both the Cooper-Jacob analysis and the Theis type curve method, in order to determine the approximate location of the recharge boundary (or boundaries) from each well. The methodology used involved plotting departures from the drawdown curves, and followed that presented in Heath and Trainer (1968).

The results of our analysis are presented in Table 3.

Table 3 - Recharge Source Calculations

Location	Analysis Method	Distance to Image Well from Location (m)	Inferred Distance to Recharge Source from Location (m)
Well No. 1 / OW - 1	Cooper-Jacob	327	163
	Theis Type Curve	155	78
Well No. 2 / OW - 1	Cooper-Jacob	215	107
	Theis Type Curve	78	39
Well No. 2 / OW - 2	Cooper-Jacob	537	268
	Theis Type Curve	480	240

The boundary recharge analysis values were reviewed against the various well locations and although there was some scatter in the data (due in part to the variations in the methodology), the inferred distance to the recharge zone is well within the range of distances between the various wells and the nearby Genesee Creek watercourse. Therefore, from this analysis, the cause of the flattening of the drawdown curves (during the pumping tests) is interpreted to be due to a recharge source (or several distributed sources) along the Genesee Creek watercourse.

By working with the available information, a range of hydraulic conductivity values for the municipal supply aquifer (for use in the subsequent groundwater model development) was derived from the apparent transmissivity values. Since transmissivity is equal to the hydraulic conductivity of the aquifer materials, multiplied by the aquifer thickness, the available subsurface information was used to determine a representative hydraulic conductivity of the aquifer in the vicinity of the well intakes.

For Powassan Well No. 1, the reported aquifer thickness was 8.84 m, which yields an associated aquifer hydraulic conductivity of 20 m/day (or 2.3 x 10^{-2} cm/sec). For Powassan Well No. 2, the reported aquifer thickness was 8.54 m, which yields an associated aquifer hydraulic conductivity of 31 m/day (or 3.6 x 10^{-2} cm/sec). These values are considered reasonable for the assumed conditions, and fall within the range of hydraulic conductivity values commonly reported for sand and gravel aquifers (Freeze and Cherry, 1979, Domenico and Schwartz, 1998).

Pumping test data were also obtained during the 1981 test drilling program (by Morrison Beatty Limited). The test locations were selected along the valley of Genesee Creek, nearer to the former surface water intake location and in the more central parts of the townsite. These data were also reviewed as part of the present study, and comprised constant rate pumping tests of three well locations (identified as TW4-80, TW5-80 and TW7-80).

The results of our analysis of the previous study data are presented in Table 4.

Table 4 - Pumping Test Analysis (1980 Study)

Location	Analysis Method	Transmissivity (m^2/day)
TW4-80	Cooper-Jacob	7
TW5-80	Cooper-Jacob (early)	7
	Cooper-Jacob (late)	19
TW7-80	Cooper-Jacob	12

For TW4-80, the aquifer thickness was 13.72 m, which yields an associated aquifer hydraulic conductivity of 0.53 m/day (or 6.2 x 10^{-4} cm/sec). For TW5-80, the aquifer thickness was 2.13 m, which yields an associated aquifer hydraulic conductivity of 3.2 m/day (or 3.7 x 10^{-3} cm/sec) for the early drawdown data, and 8.9 m/day (or 1.0 x 10^{-2} cm/sec) for the late drawdown data. For TW7-80, the aquifer thickness was 13.72 m, which yields an associated aquifer hydraulic conductivity of 0.89 m/day (or 1.0 x 10^{-3} cm/sec). All of these values are considered typical of the ranges of hydraulic conductivities expected for sand and gravel formations.

Because these well tests did not include observation wells, no information was obtained on the aquifer storativity at these locations. The results for TW5-80, where a break in slope was observed, are interpreted as indicating that the aquifer transmissivity increased (or improved) at a distance from the pumping well. The higher hydraulic conductivity value calculated for this zone (using the late data) approached the value observed at the municipal well field itself. TW5-80 was the closest test well to the municipal well field (located in the vicinity of the Ontario Provincial Police building on Clarke Street).These results were interpreted as indicating that the higher transmissivity zone around the municipal wells was of a limited lateral extent, and that, regionally, the aquifer had a much lower yield potential.

Therefore, by this analysis, the groundwater model assumed an aquifer hydraulic conductivity value in the range of 1.0×10^{-2} cm/sec to 3.6×10^{-2} cm/sec, in the immediate vicinity of the municipal wells, and a slightly lower range of values (6.2×10^{-4} cm/sec to 3.7×10^{-3} cm/sec) for the more regional sand and gravel till deposit, in order to best reflect local known subsurface conditions.

3.0 Bedrock Aquifer Characterization

In addition to the information from the test wells and municipal production wells, water well records were obtained from the Ministry of the Environment, and were reviewed for the pumping test information they provided on the bedrock aquifer. In total, 62 records contained sufficient data to allow analysis of the apparent transmissivities of the bedrock formations, and the analysis was carried out following an iterative procedure using the Cooper-Jacob equation, as referenced in Fetter (2001). For this analysis, the bedrock storativity was assumed to be equal to 1×10^{-4} (dimensionless), typical of fractured rock aquifers.

Of the 62 records reviewed, 33 records were from wells having diameters 127 mm or larger, with the remainder being 51 mm borehole wells. The small diameter wells were excluded from further analysis (due to concerns for non-representative water level measurement in the narrow casings), and the remaining transmissivity values were equated to an apparent hydraulic conductivity value by noting the saturated thickness of the formation at each well. The apparent hydraulic conductivity values were plotted as a function of the depth of penetration into the bedrock, and a drop in hydraulic conductivity with increasing depth of penetration into the bedrock was noted (Figure A4).

From this analysis, a variation in hydraulic conductivity of the bedrock with increasing penetration depth (from 0 m to 30 m) was noted. The variation in hydraulic conductivity ranged from 8.7×10^{-4} cm/sec to 2.2×10^{-4} cm/sec, which is well within the range of fractured igneous and metamorphic rocks (Freeze and Cherry, 1979). This range, although low, is not considered low enough (or a great enough contrast to the aquifer hydraulic conductivity above it) to exclude the bedrock zone from being part of the groundwater flow system beneath the well field. Therefore, by this analysis, the groundwater model assumed a bedrock hydraulic conductivity value in the range of 8.7 x 10^{-4} cm/sec to 2.2 x 10^{-4} cm/sec.

By way of comparison, groundwater models in overburden aquifers typically consider the bedrock to be a no-flow boundary, and are usually excluded from the model. As reported in Harrison (1972), the local bedrock is characterized as being highly weathered in some areas, which may explain the higher hydraulic conductivity estimates calculated in the present analysis.

4.0 Overburden Aquitard Characterization

Above the sand and gravel till aquifer lies a sequence of overburden soils, which become finer in composition when moving upwards through the stratigraphy (i.e. from the top of the aquifer upwards towards the ground surface). These materials are the result of glacial lake erosion and re-deposition of the original till deposits which covered the entire study area. In some places, and depending on the topography, one or more of these overburden units may be absent, resulting in the sand and gravel till (aquifer) being unconfined and exposed at surface. In other locations, the aquifer is confined by lower permeability cap (or aquitard) materials.

Stratigraphically situated above the sand and gravel till deposit lies a silty sand to sandy silt deposit. Grainsize analysis of samples recovered during geotechnical drilling along the Highway 11 corridor (by the Ministry of Transportation) indicate that the hydraulic conductivities of these deposits range from 2.5 x 10^{-7} cm/sec to 5.6 x 10^{-3} cm/sec (by Hazen's method), giving a geometric mean value of 3.6 x 10^{-5} cm/sec .

The uppermost stratigraphic unit identified in the study area was a glaciolacustrine silty clay to clayey silt. Soil grainsize analysis of representative samples from these units (by the Ministry of Transportation) indicated that the hydraulic conductivities of these deposits range from 2.5 x 10^{-9} cm/sec to 4.5 x 10^{-6} cm/sec (by Hazen's method), giving a geometric mean value of 2.3 x 10^{-7} cm/sec. The glaciolacustrine deposits were generally found at the lower topographic elevations in the study area, and were not interpreted to extend across the entire study area.

In the valley and floodplain of Genesee Creek, a silty sand alluvium deposit was identified, and soil grainsize analysis (from Ministry of Transportation reports) indicated that the hydraulic conductivities of these deposits range from 9.0 x 10^{-5} cm/sec to 6.4 x 10^{-3} cm/sec (by Hazen's method), giving a geometric mean value of 4.3 x 10^{-4} cm/sec. Based on the depth and locations of the boreholes, along the flanks of Genesee Creek, the alluvium deposits are interpreted as fully penetrating the silty clay to clayey silt capping material, and offer a “window” through the underlying clays for surface water recharge to the underlying sand and gravel till aquifer. The presence of these “windows” is interpreted as being the reason for the flattening of the drawdown curves that was observed during the pump testing of the municipal well field (discussed previously).

5.0 MODFLOW Analysis

The sequence of soils described in the preceding sections reflect a complex geological history for the well field area, and play a significant role in the generation of groundwater flow patterns from the recharge areas to the well capture zones. In the subsequent model development, the identified ranges of hydraulic conductivity were used as “known” quantities, and the recharge values assigned to each geological unit were adjusted until a reasonable fit of the flow data to the observed field conditions was made. As the model conceptualization process proceeded, minor adjustments were also made to the various hydraulic conductivity values of the geologic formations, resulting in a final calibrated model for the Powassan well field.

The Powassan groundwater model was created using a commercial software package (VisualMODFLOW, Version 3.4, by Waterloo Hydrologic Inc.). MODFLOW is a three dimensional finite-difference groundwater flow model that was initially developed by the United States Geological Survey (USGS) in the 1980s, and is used worldwide to simulate groundwater flow in simple to complex geological settings. VisualMODFLOW is an adaption of the public domain USGS MODFLOW software, and was created to run on personal computers.

The present VisualMODFLOW model comprised a variably-spaced horizontal grid of 111 rows by 113 columns, with 3 overburden layers of varying thicknesses and a bottom bedrock layer having a minimum thickness of 30 m. The model’s areal extent (or domain) is presented in Figure A5, and was based on the position of the surficial drainage divides as interpreted from 1:20,000 scale topographic mapping and DEM survey data. In Figure A5, the outer boundary of the groundwater flow model is represented by the darker shading.

A total of 7 stratigraphic units (i.e. a total of seven different hydraulic conductivity values) were incorporated into the model, reflecting the interpreted complexity of the hydrogeological setting in Powassan. Figure A5 also presents a cross-sectional view through municipal Well No. 1, as was simulated in the model. The model was run using the MODFLOW2000 engine, with a CGSTAB-P Linear Solver (Waterloo Hydrologic Software).

The level of detail applied to the modelling effort was considered reasonable for the data inputs used. However, any model is a generalization of real world conditions, and simplifications in the stratigraphy were made when required to assist in achieving a working groundwater model for this site, particularly in areas of steep topographic relief. The groundwater model, and the correctness of the conceptualization, was evaluated through a calibration process using local water well data and mapped surface water features.

Constant head boundaries were assigned to the South River (at the western edge of the modelled area, at an assigned elevation of 239 m) and to a small pond on Genesee Creek (at the southeastern edge of the modelled area, at an assigned elevation of 260 m), while Genesee Creek itself was assigned as a river boundary type, with various sections of the creek having a linear grade in slope (reflecting the assumed profile of the free water surface).

Smaller surface water tributaries to Genesee Creek were not assigned as river or drain boundaries in the model; instead, the mapped elevations of these smaller tributaries were used during the calibration process as an aid in evaluating the water table profile. By this methodology, the water table surface was not “forced” to match the smaller streams in the area (which, when modelling with numerous drain boundaries, can lead to errors in the overall model performance).

During the model calibration process, the soil properties and recharge values were adjusted manually until a close match of the water table surface and the water levels in the wells and creeks were obtained. The process followed was an iterative process, and the main constraints applied to the calibration were to keep the hydraulic conductivity values of each respective stratigraphic unit within the previously determined ranges (indicated above). In the case of the aquifer storage terms (specific yield and porosity), typical values were selected from published literature (as these were not measured in any of the field reports used in the model conceptualization).

The final calibrated parameters used in the model are listed in Table 5.

Table 5 - Model Parameters at Calibration

Zone	Material	$k_x = k_y$ (cm/sec)	k_z (cm/sec)	Recharge (mm/year)	S_s (1/m)	S_y	$n_{eff} = n_{tot}$
1	basal till	4×10^{-3}	4×10^{-4}	180	6×10^{-5}	0.24	0.35
2	bedrock	9×10^{-4}	9×10^{-4}	150	1×10^{-6}	0.04	0.10
3	alluvium	1×10^{-4}	1×10^{-5}	80	6×10^{-7}	0.18	0.25
4	clay	1×10^{-6}	1×10^{-7}	10	3×10^{-4}	0.05	0.45
5	sandy silt	9×10^{-5}	9×10^{-6}	80	1×10^{-4}	0.18	0.40
6	silty sand	3×10^{-4}	3×10^{-5}	110	1×10^{-4}	0.18	0.40
7	sand and gravel aquifer	3×10^{-2}	3×10^{-3}	n/a	6×10^{-5}	0.24	0.35

In the above table, "n/a" indicates that there is no recharge value applicable to the sand and gravel aquifer because the unit is not in the uppermost layer (i.e. recharge only applies to the uppermost layer of the model). The symbol "k" refers to the hydraulic conductivities, with the subscripts indicating the direction in which the parameter is measured (corresponding to the x, y and z axes). The symbol "S_s" refers to the specific storage, "S_y" refers to the specific yield and "$n_{eff} = n_{tot}$" refers to the effective and total porosity (set equal to each other in this case). With the exception of the bedrock unit, an anisotropy ratio of 1:10 was used for the vertical to horizontal hydraulic conductivity values.

Using VisualMODFLOW, the amount of time needed for the water "particles" to travel through the aquifer to the well field can be determined, allowing the contributing areas to be defined by their respective travel times (or time of travel values). The technique applied in this analysis is commonly referred to as a "particle tracking" method.

The calibrated model was run in a steady-state configuration, and the pathways that water takes in moving through the groundwater flow system were identified by the particle tracking analysis. The exact technique used is referred to as backward particle tracking, using the MODPATH computer code module contained in the VisualMODFLOW software package. In the present analysis, a total of 80 particles were assigned to model cells immediately surrounding each well, being distributed vertically through the screened section of the aquifer in order to fully assess the variability in the travel times that can occur due to stratification in the flow system.

Based on discussions with the North Bay - Mattawa Conservation Authority, and in recognition of the more or less constant total flow from the well field (from 2003 to 2008), Diagram 1 (refer to the main body of the report), the average pumping rates for the interval beginning in 2003 to and ending at the end of 2008 were interpreted to be representative of the future yield demands on the municipal well field. Unlike the previous Municipal Groundwater study (2006), the maximum pumping rates permitted by the Permit to Take Water for the well system were not used in the modelling exercise.

The pumping rates assigned to the municipal well field for the particle tracking analysis reflected the “allocated quantity of water” (as defined in the Technical Rules, 2008), which equalled the mean annual quantity of water presently taken by the well field (plus any additional quantity needed to meet the committed demand of the system). For this modelling exercise, the total allocated quantity of water for the Powassan well field was set equal to 508 m^3/day, assigned as 208 m^3/day for Well No. 1, and 300 m^3/day for Well No. 2.

The resultant well head protection area (WHPA) mapping is presented in Figure 2 (of the main report), which shows the WHPA-A, WHPA-B, WHPA-C and WHPA-D zones in plan view. The WHPA-A is a fixed 100 m radius zone surrounding each pumping well, while the other areas are based on 2-year, 5-year and 25-year time of travel (TOT) calculations (refer to the main text for a detailed explanation of the various WHPA zones).

On this figure, the lateral boundaries of the subsurface zones contributing groundwater to the well field are clearly defined, and the WHPA is observed to be oriented in an east-southeast to northwest direction, with the wellhead itself (the well locations) being situated in the extreme northwest corner of the WHPA. Regional groundwater flow, as defined in the present model and the previous assessment (2006), is from the southeast to the northwest (towards Lake Nipissing).

6.0 GUDI Analysis

Wells that draw all or some of their water supply from a surface water body, and have less than 50 days time of travel from the surface water to the well intake, are classified as groundwaters under the direct influence of surface water (or GUDI), and once classified require additional levels of water treatment before distribution to the public.

The Powassan well field has not been flagged as having any interaction with the nearby surface water feature (Genesee Creek), as was indicated in the First Engineers’ Report (Totten Sims Hubicki Associates, 2001), and is considered to be a non-GUDI supply under the Clean Water Act (2006). However, our review of the initial pumping test data suggested that at higher pumping rates, the area of influence of the pumping wells may extend outwards far enough to capture a portion of surface water via recharge (causing a flattening of the drawdown curve). The pumping rates used during the initial well testing far exceeded the pumping rates presently used at the Powassan well field.

Therefore, although not required under the current Guidance Module, a supplemental analysis was undertaken using the calibrated groundwater model, in order to investigate the specific pumping conditions which may lead to the conversion of the water supply from non-GUDI to GUDI status. Through dialogue with the North Bay - Mattawa Conservation Authority, this information was identified as being of value to future watershed planning exercises and, as well, would provide a sensitivity analysis of the model itself to future changes in groundwater withdrawals.

Initially, the allocated quantity of water was modelled, and particles (for particle tracking) were assigned along the Genesee Creek watercourse, from the eastern edge of the modelled area to a position downstream of the municipal lagoon outfall. If the creek was a potential source for water traveling to the well intakes, the particle tracking method (using forward particle tracking) would identify any movement from the creek to the well field.

By the present analysis, and assuming a total withdrawal equal to the presently-allocated quantity of water, the Powassan well field does not appear to be under the direct influence of surface water. Municipal Well No. 1, by our analysis, receives no surface water inputs from Genesee Creek at the allocated pumping rate. Municipal Well No. 2, by our analysis, does receive a portion of its intake from Genesee Creek under the allocated pumping rate. However, the location of this surface water input (i.e. recharge area) is approximately 1 km east of the well field area, and the associated time of travel to the well from this area (identified as Area A on Figure A6) is in the range of 30 to 40 years.

A second analysis was undertaken, by varying the pumping rates at Well No. 1 and Well No. 2, in order to determine if there is a critical pumping rate which should not be exceeded to keep the well status as non-GUDI. The practical scenario by which this type of analysis may happen involves the removal of one of the municipal wells (for servicing or repair) at a time of high demand on the water system.

Initially, an analysis was conducted assuming that one of the wells is taken out of service and the other well is pumped at the allocated quantity, or 508 m^3/day. By this analysis, the well being pumped (either Well No. 1 or Well No. 2) will receive a portion of its intake from Genesee Creek, originating at a distant source area (Area A, identified previously). Through particle tracking analysis, the time of travel values from Area A are on the order of 30 to 40 years. Therefore, when a single well is pumped at rates up to the allocated pumping rate, the Powassan well field is interpreted to remain non-GUDI (because of the large TOT values encountered during these scenarios).

A second analysis was undertaken, assuming that one of the wells is taken out of service and the other well is pumped at the maximum permitted capacity, or 1,313 m^3/day. By this analysis, the well being pumped (either Well No. 1 or Well No. 2) will receive a portion of its withdrawal from two locations along Genesee Creek, one location being close to the well field area (identified as Area B on Figure A6) and a second more distant source area (Area A, identified previously). Through particle tracking analysis, the time of travel values associated with Area B are on the order of 100 days (for the locations nearest Well No. 2) to a few years, which are greater than the minimum 50-day TOT criterion for a non-GUDI well. The time of travel values for Area A are again on the order of 30 to 40 years. Therefore, even when a single well is pumped at the maximum permitted pumping rate (under the current Permit To Take Water), the Powassan well field is interpreted to remain non-GUDI.

As a result of the forgoing analysis, the Powassan well field is interpreted to be non-GUDI for all pumping rates up to the allocated quantity of 508 m^3/day. The model also predicts that the well field will remain non-GUDI even if a single well is pumped continuously at the maximum rate permitted by the current Permit to Take Water. However, since there is a degree of uncertainty associated with any model, caution is advised in interpreting that the well field to remain non-GUDI at rates exceeding the current allocated quantity of water, and additional study is warranted to verify these findings.

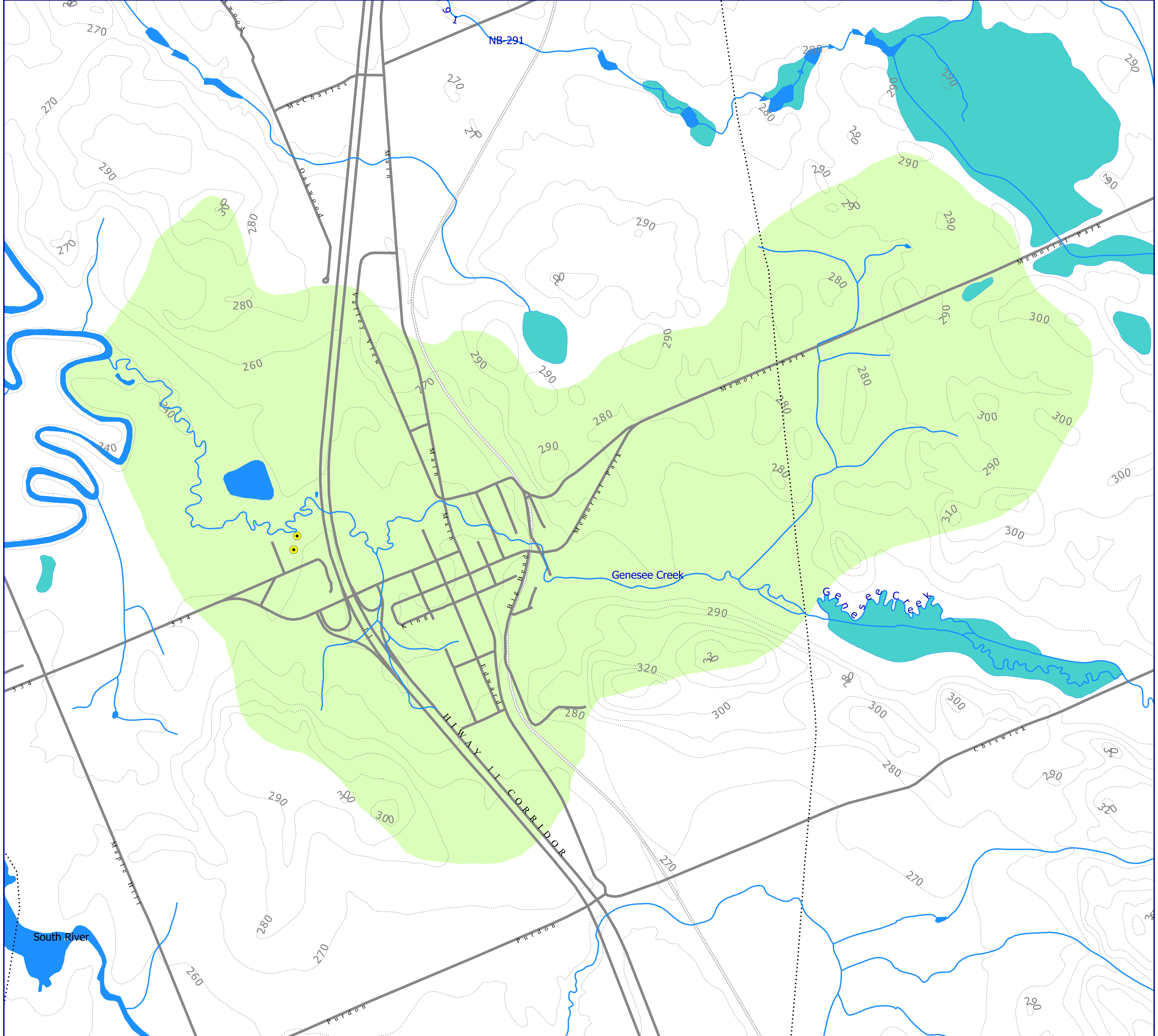
APPENDIX B - Groundwater Vulnerability Analysis , Municipality of Powassan
Uncertainty Assessment - Powassan Well Field

WHPA Zone	Vulnerable Area Designation	Intrinsic Vulnerability Category	Vulnerability Score	Uncertainty Factor	Explanation
A	A-1	low	10	low	fixed radius was applied, no hydrogeological interpretation required
	A-2	medium	10	low	fixed radius was applied, no hydrogeological interpretation required
B	B-1	high	10	high	status of abandoned geotechnical boreholes are unknown in this area
	B-2	medium	8	low	detailed modelling indicates stable capture zone close to the well head multiple scenario modelling indicates similar capture zone configuration
	B-3	low	6	low	detailed modelling indicates stable capture zone close to the well head multiple scenario modelling indicates similar capture zone configuration
	B-4	medium	8	high	status of abandoned geotechnical boreholes are unknown in this area
C	C-1	high	8	high	status of abandoned geotechnical boreholes are unknown in this area
	C-2	medium	6	low	detailed modelling indicates stable capture zone close to the well head multiple scenario modelling indicates similar capture zone configuration
	C-3	low	4	low	detailed modelling indicates stable capture zone close to the well head multiple scenario modelling indicates similar capture zone configuration
	C-4	medium	6	high	status of abandoned geotechnical boreholes are unknown in this area
	C-5	low	4	high	low density of subsurface information in this area
D	D-1	low	2	high	low density of subsurface information in the west half of this area multiple scenario modelling indicates variable capture zone configuration
	D-2	medium	4	high	low density of subsurface information in this area multiple scenario modelling indicates variable capture zone configuration
	D-3	high	6	low	sufficient density of subsurface information in this area
	D-4	medium	4	low	multiple scenario modelling indicates similar capture zone configuration
	D-5	high	6	high	low density of subsurface information in this area
	D-6	medium	4	high	status of abandoned geotechnical boreholes are unknown in this area

North Bay – Mattawa

DRINKING WATER SOURCE PROTECTION
ACT FOR CLEAN WATER

FIGURE 1: Municipality of Powassan Study Area and Well Locations



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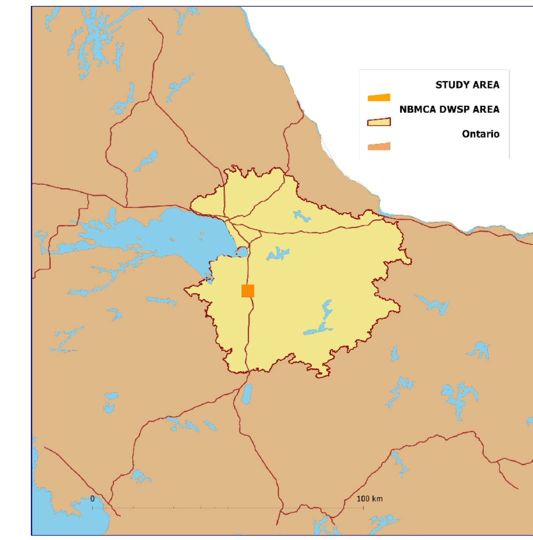

LEGEND

- Study Area
- Powassan Wells
- Roads
- Railway

Water Features

- Waterbody Segment
- Wetland Area, Permanent
- Stream/River
- Contour/Elevation

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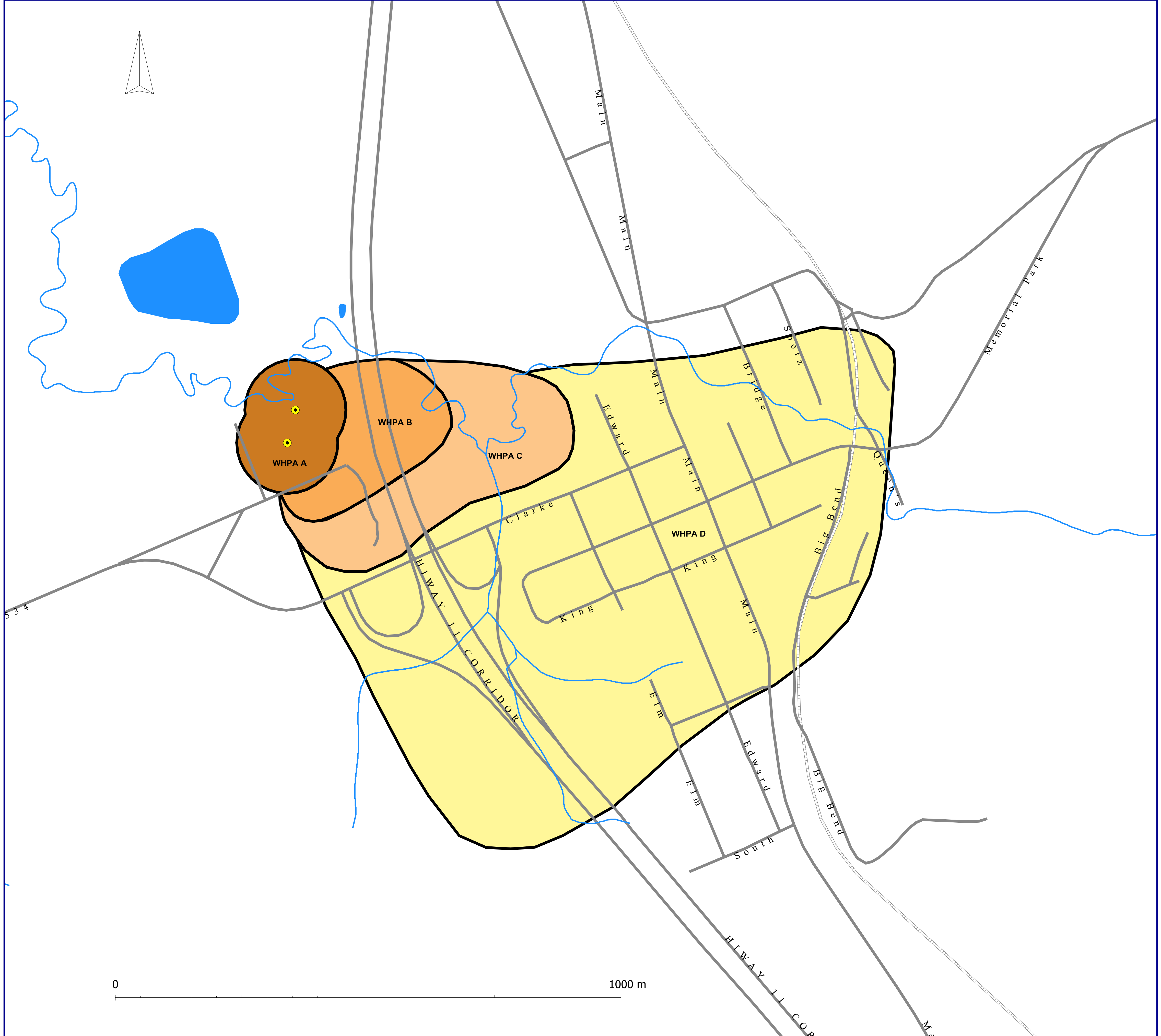

FIGURE 2: Municipality of Powassan Wellhead Protection Area (WHPA)

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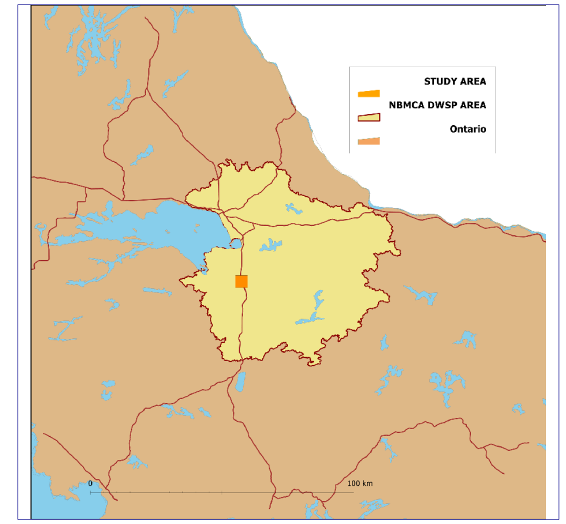

LEGEND

Powassan Well

Roads

Railway

Water Features

Waterbody

Wetland Area

Stream/River

Powassan WHPA

WHPA A

WHPA B

WHPA C

WHPA D

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ACT FOR CLEAN WATER

FIGURE 3: Municipality of Powassan Intrinsic Susceptibility Index

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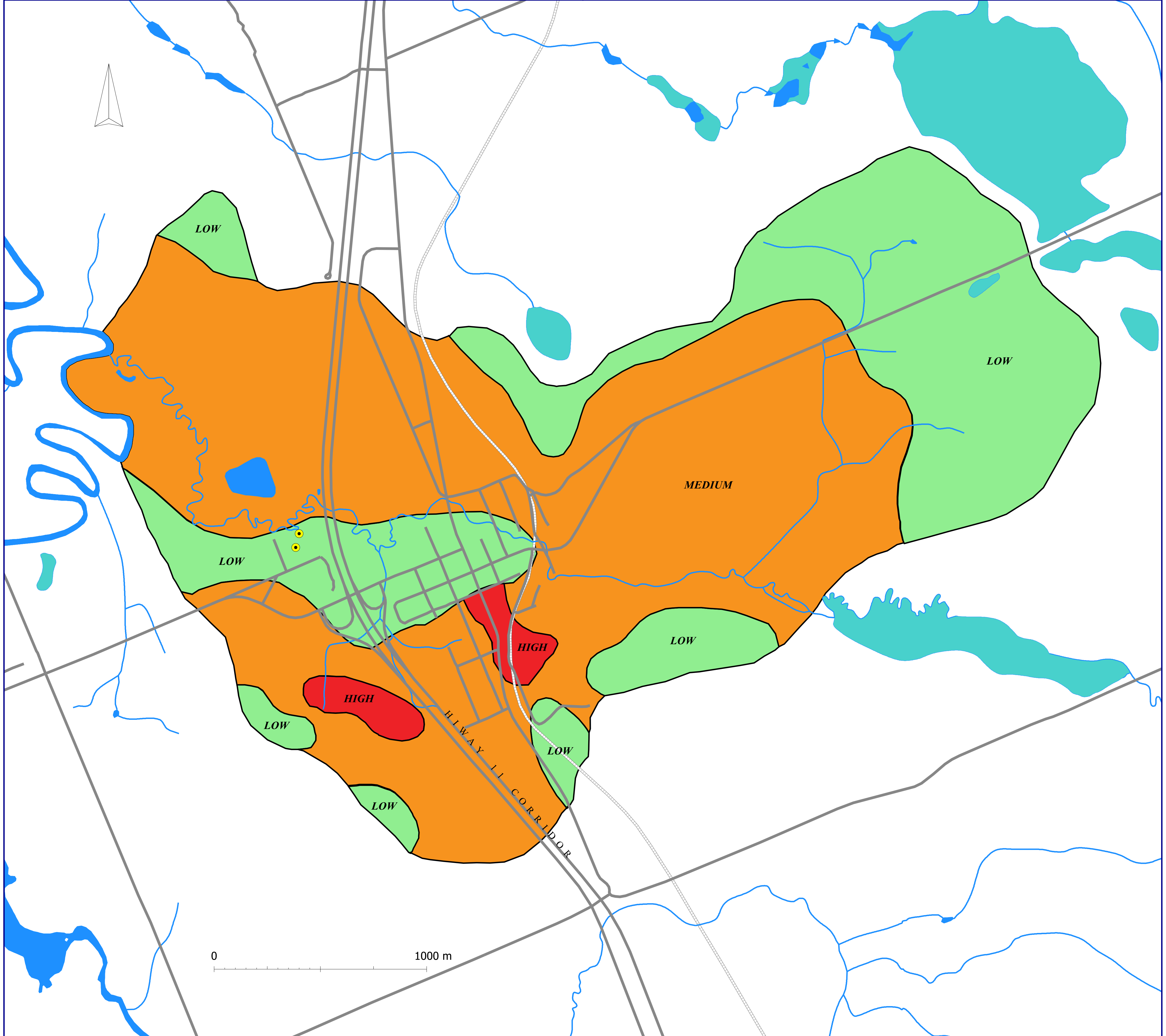

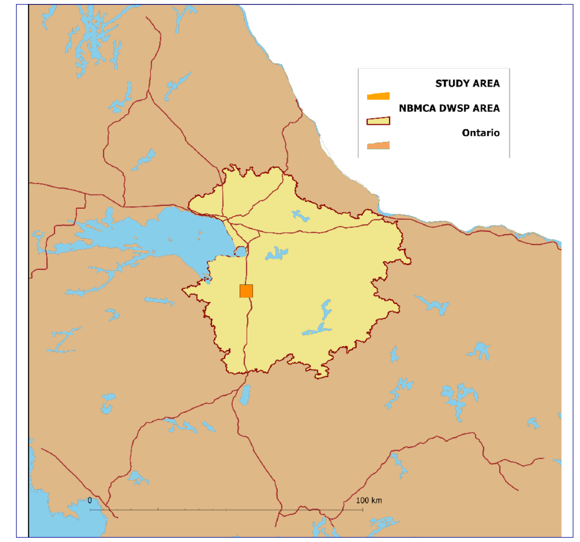

LEGEND

Powassan

Road

Rail

Water Features

Waterbody

Wetland Area

Stream/River

ISI RANKING

HIGH

MEDIUM

LOW

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ACT FOR CLEAN WATER

FIGURE 4: Municipality of Powassan Wellhead Protecttion Area and Vulnerability Scores

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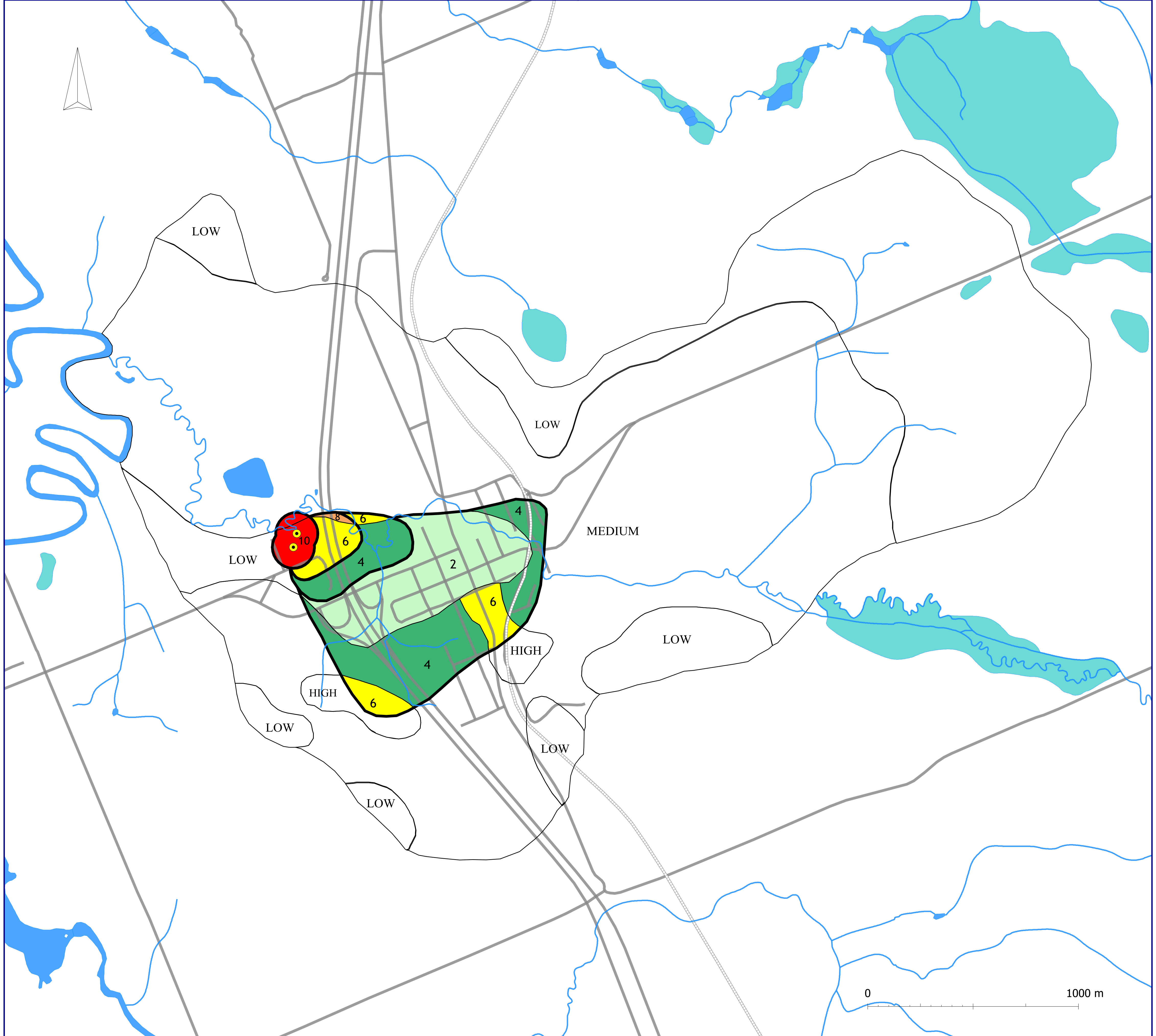

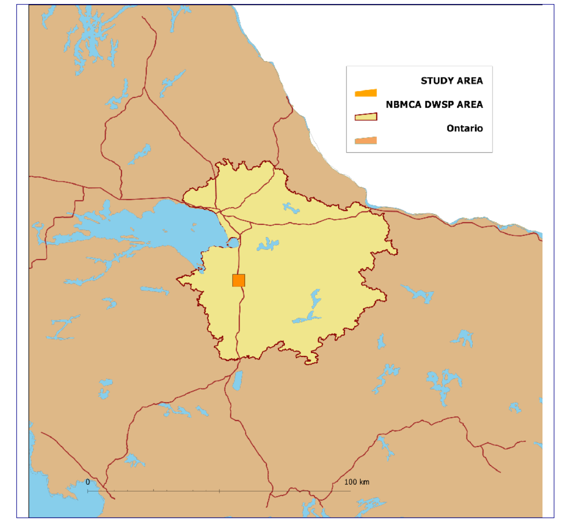

LEGEND

Powassan Well

Water Features

Streams/RIvers

Waterbody

Wetland Area

Road

Railway

Prelim. Vulner. Scoring

2

4

6

8

10

ISI RANK (Low, Medium, High)

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ACT FOR CLEAN WATER

FIGURE 5:
Municipality of Powassan Adjusted Intrinsic Susceptibility Index

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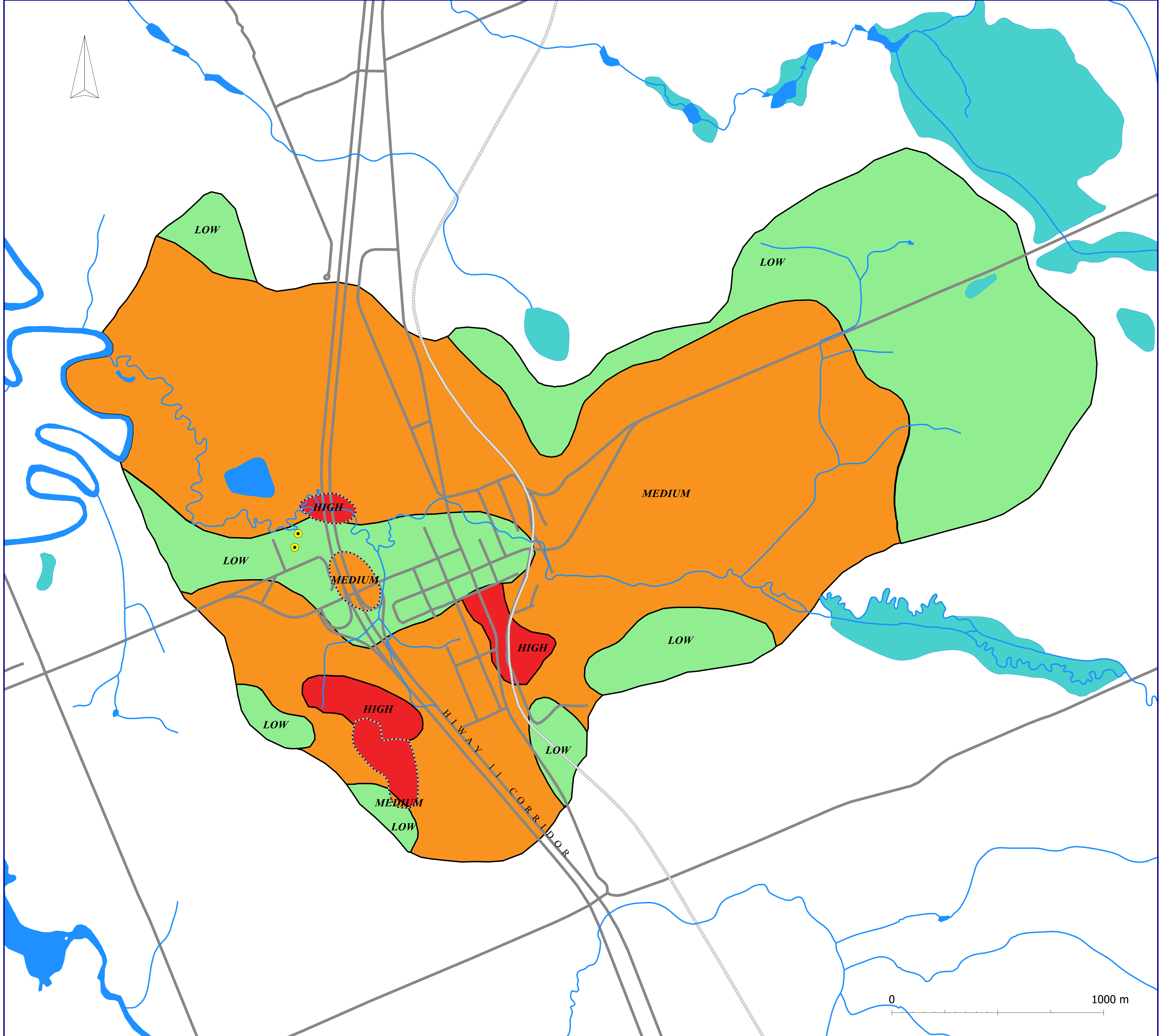

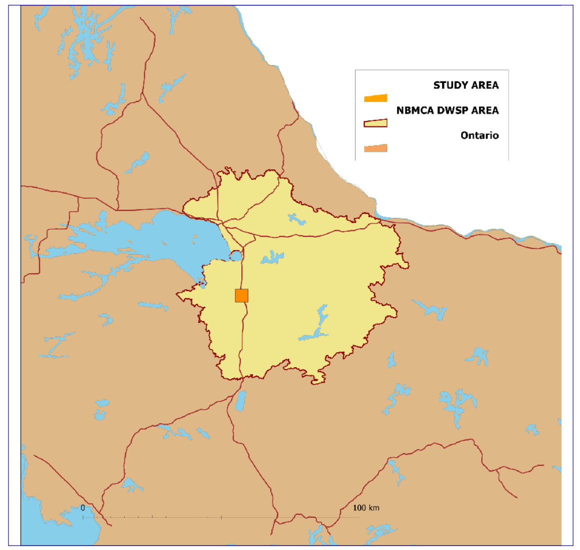

LEGEND

Powassan Well
Road
Railway

Water Features

Wetland Area
Waterbody
Streams/Rivers

Transport Pathways

Adjusted ISI Areas

HIGH
LOW
MEDIUM

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SOURCE PROTECTION
ACT FOR CLEAN WATER

FIGURE 6: Municipality of Powassan Adjusted Vulnerability Scores

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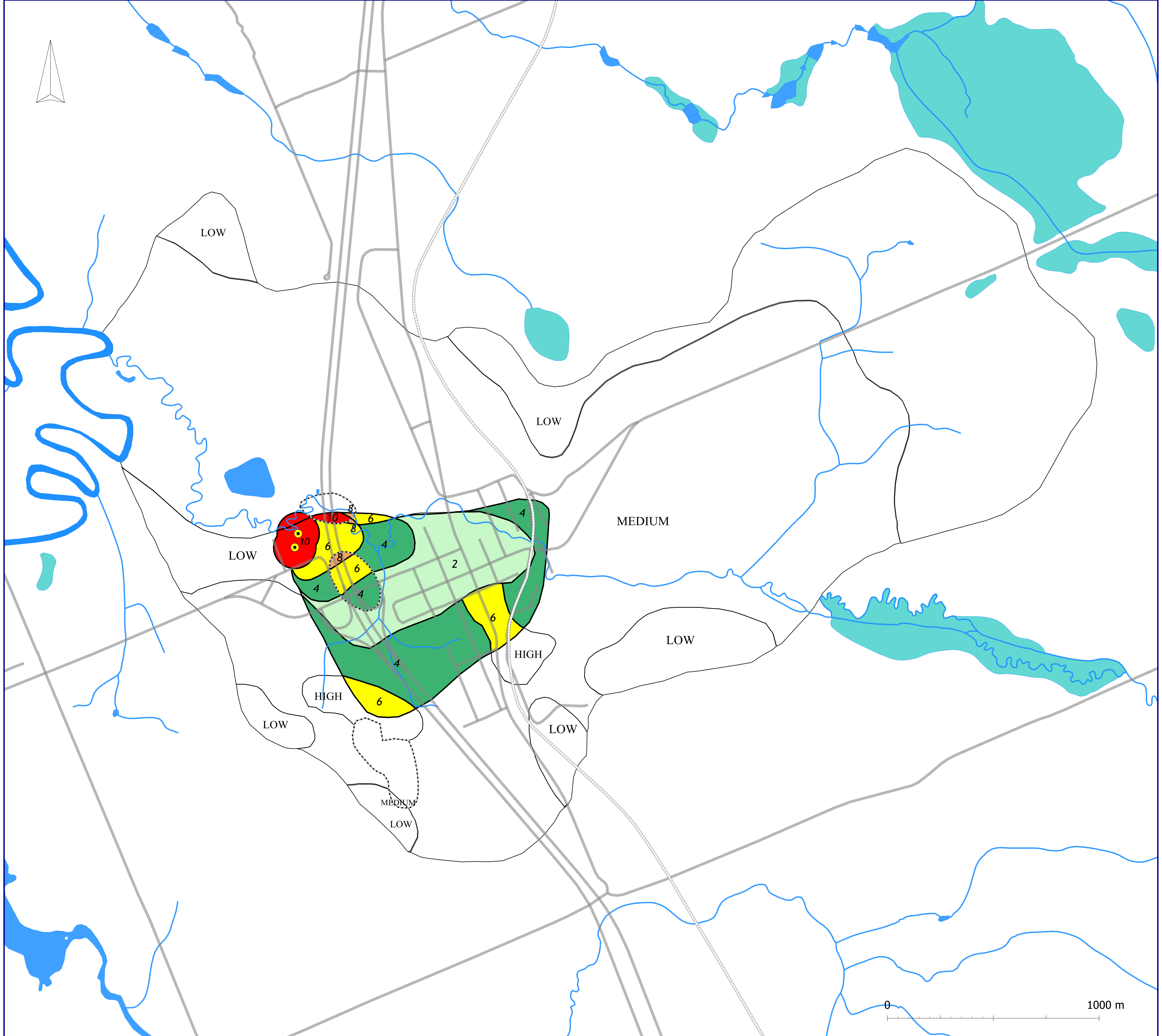

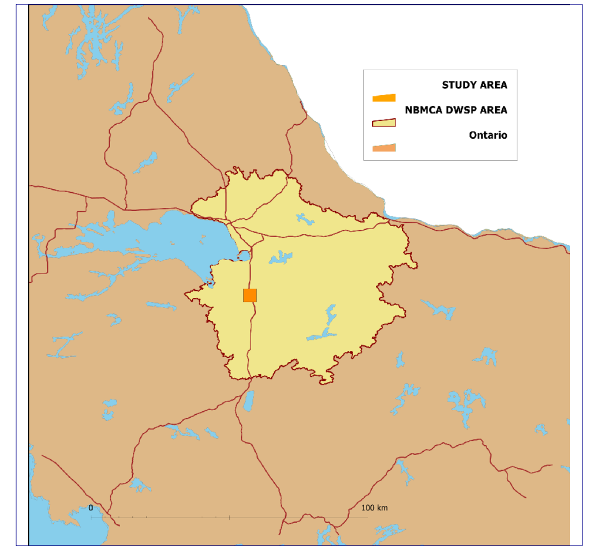

LEGEND

Powassan Well
Road
Railway

Water Features

Stream/River
Waterbody
Wetland Area

Vulnerability Scores

SCORE
2
4
6
8
10

ISI (High, Medium, Low)
Pathways

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ACT FOR CLEAN WATER

FIGURE 7: Municipality of Powassan Wellhead Protection Area and Vulnerabilty Zone Index

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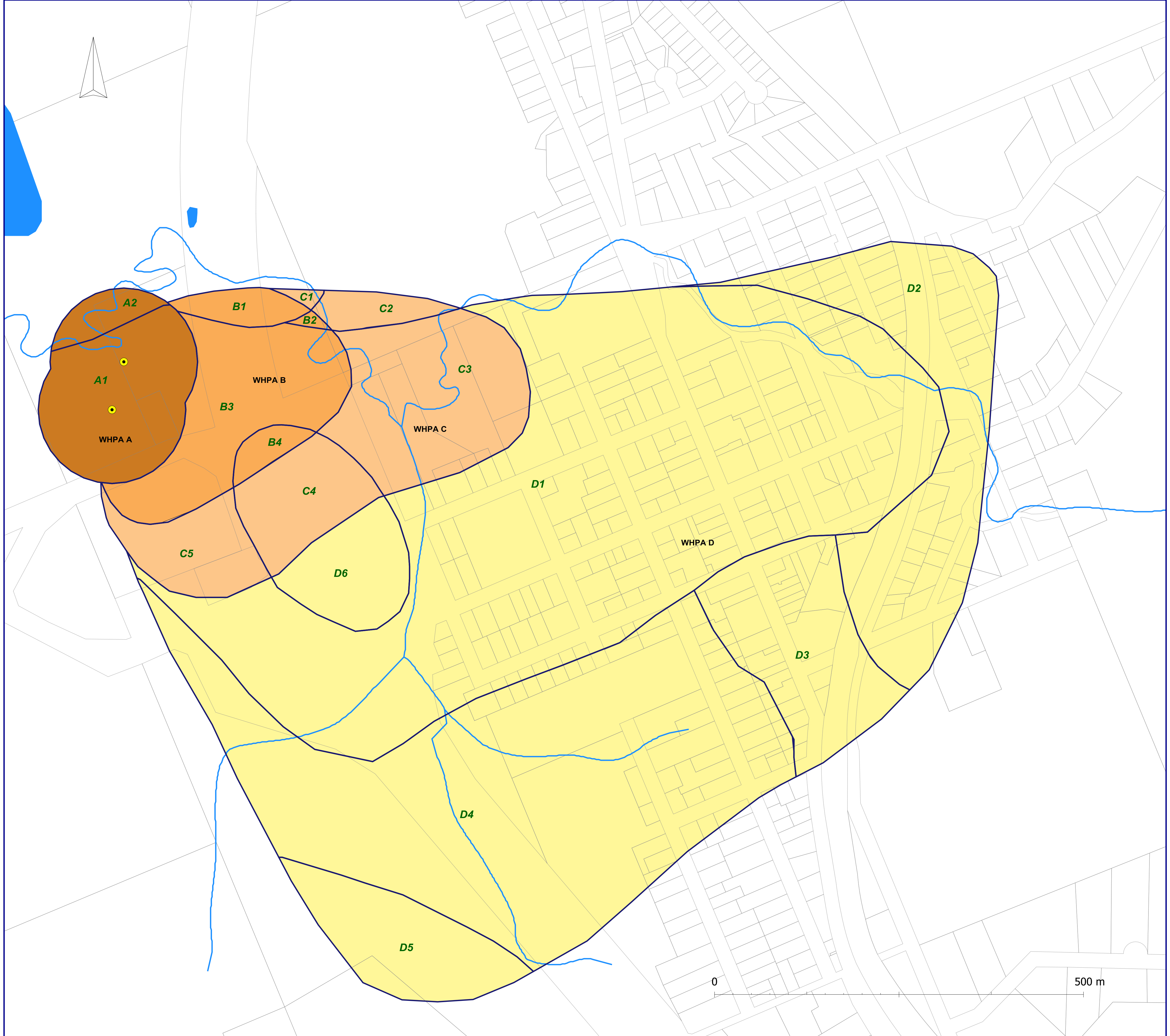

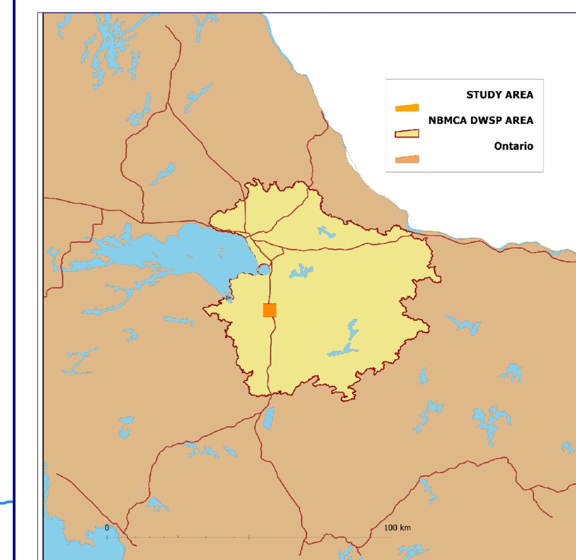

LEGEND

Powassan Wells

Water Features

Streams/RIvers

Waterbody

Wetland Area

Parcel Boundary

Vulnerability Zones

Indexed Zones

Powassan WHPA

WHPA A

WHPA B

WHPA C

WHPA D

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