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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
Town of Mattawa

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Bay - Mattawa Conservation Authority and, to assist the Conservation Authorities, Source Protection Technical Studies Draft Guidance Modules were developed in 2006 (by the Ministry of the Environment) outlining in detail the necessary study components.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Several of the studies identified in the Draft Guidance Modules have already been initiated by the North Bay - Mattawa Conservation Authority.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 Mattawa, 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 Mattawa. 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 Town of Mattawa well field consists of two municipal wells, housed in a single structure located on the northeast corner of the intersection of Bisset Street and Fourth Street, in the Town of Mattawa (Figure 1). A third well on site is not in use. The well field is located on the west side of the Mattawa River, approximately 60 m from the riverbank, and the site is elevated approximately 5 m above the river level. The UTM co-ordinates of the well building (in NAD83) are 676227 mE and 5131742 mN (Ministry of the Environment, 2008).

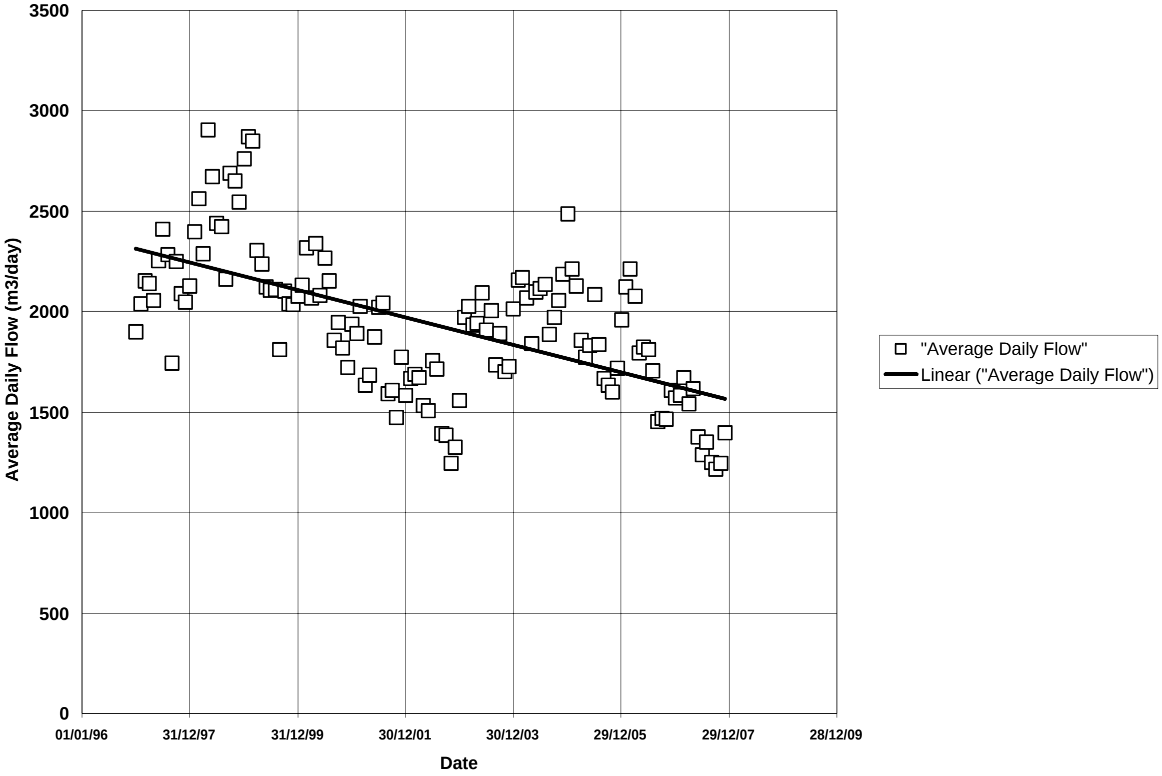
Mattawa Well No. 1 was drilled in 1958, by International Water Supply Ltd. (London) to a total depth of 26.5 m below grade. The well comprises a 406.4 mm (16 inch) diameter steel casing to a depth of 22.0 m, with a 4.6 m length of 406.4 mm (16 inch) diameter, No. 6 slot, stainless steel well screen extending to a depth of 26.4 m. The well is reported to be gravel packed, and has an outer working casing 660.4 mm (26 inches) in diameter, which extends to a depth of 18.8 m below grade. The formation encountered during drilling consisted of sand and gravel, with boulders. The static water level upon completion (1958) was 5.2 m below grade. This well is registered as Ministry of the Environment water well record 43-00581.

Mattawa Well No. 2 was drilled in 1949, by International Water Supply Ltd. (London) to a total depth of 23.6 m below grade. The well comprises a 304.8 mm (12 inch) diameter steel casing to a depth of 20.6 m, with a 3.0 m length of 304.8 mm (12 inch) diameter, No. 6 slot, stainless steel well screen extending to the final completion depth. The well is reported to be gravel packed, and has an outer working casing 558.8 mm (22 inches) in diameter, which extends to a depth of 18.6 m below grade. The formation encountered during drilling consisted of sand and gravel, with occasional boulder layers. The static water level upon completion (1949) was 5.4 m below grade. This well is registered as Ministry of the Environment water well record 43-00579.

Mattawa Well No. 3 was drilled in 1956, by Trudeau et Fils (St. Anne De Bellevue) to a total depth of 25.9 m below grade. The well comprises a 406.4 mm (16 inch) diameter steel casing to a depth of 14.6 m, with a 4.6 m length of 406.4 mm (16 inch) diameter, stainless steel well screen (slot size unknown) extending to a depth of 19.2 m. There is no indication of any gravel pack, and the well has an outer working casing 660.4 mm (26 inches) in diameter, which extends to a depth of 14.9 m below grade. The formation encountered during drilling consisted of gravel and sand. The static water level upon completion (1956) was 5.5 m below grade. This well is registered as Ministry of the Environment water well record 43-00580, and was identified as being no longer in use (Dennis Consultants, 2001).

Water consumption data were obtained from the Municipality, for the time period extending from January, 1997, to December, 2007, 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), an overall trend towards lower consumption in the recent past was noted.

The highest total consumption in the records was for May of 1998, with an average daily consumption value of 2,907 m^3/day (900 m^3/day being taken from Well No. 1 and 2,007

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 1,940 m^3/day.

These values are well below the maximum permitted pumping rate (both wells combined) of 6,546 m^3/day (Permit to Take Water No. 02-P-5059, Ministry of the Environment, 2003). For the present analysis, the allocated quantity of water to be used in the well head protection analysis was assumed to be equal to 1,940 m^3/day (i.e. the average consumption for the time interval of January, 1997, to December, 2007). Since the wells are located in very close proximity to each other (i.e. a few metres apart), the assessment of the pumping of the municipal wells on the aquifer was simulated based on a single well pumping at this combined rate.

Based on our review of the available information and through 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 Mattawa).

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 (Mattawa River), the municipal wells in the Mattawa well field have not been classified as being groundwaters under the direct influence of surface water (GUDI) in the First Engineers' Report (Dennis Consultants, 2001), or on the Certificate of Approval and, therefore, there are no other additional WHPA zones associated with the well field in Mattawa.

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 (for the data sources used). 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 a northwest to southeast direction. The wellhead itself (the well locations) are situated in the extreme southeastern edge of the WHPA, and regional groundwater flow, as defined in the present model and the previous assessment (2006), is radially from the height of land in the northwest to the southeast (towards the Mattawa River).

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, the present study included a review of available mapping and recently researched external information sources, in an effort to bring more local detail into the process. Contact was made with the original well drilling company (International Water Supply, Barrie) to determine if there were any archival records from the late 1940's and 1950's which may provide additional data on the hydraulic testing of the municipal wells. As well, Ministry of Transportation archival reports on geotechnical studies related to the former Canadian Pacific Railway overpass (in Mattawa), were obtained. Contact was also made with a knowledgeable geotechnical drilling consultant who has extensive experience in the Mattawa area (Merlex Engineering Ltd., North Bay) to determine if there was any supplemental information available which may assist in further defining the local hydrogeological setting.

Unfortunately, as discussed in Appendix A, there appears to be very little subsurface information available for the Mattawa area which would help to further refine the present understanding of the hydrogeological conditions at the Mattawa well field site. Consequently, the present study was unable to provide any supplemental analysis relating to the ISI scoring presented in the previous 2006 municipal groundwater study (Waterloo Hydrologic Inc.), and a decision was made to continue with the analysis using the previous ISI assessment results.

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. 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.

A map of the vulnerability of an aquifer was developed, based on previous assessments, for later use in the risk assessment process outlined in Guidance Module 6. The intrinsic vulnerability mapping for the Mattawa WHPA, and the surrounding model domain, is presented in Figure 3. From this figure, it can be seen that the entire study area, including the various WHPA zones, was assigned a high vulnerability to surficial contamination, due to the predominance of higher hydraulic conductivity sands and gravels, an unconfined aquifer setting, and shallow bedrock exposure over the upland portions of the site.

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, the entire study area was designated as a high vulnerability to surficial contamination, and no further adjustment to the scoring is possible (under the Technical Rules, 2008).

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 assign 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, a close similarity in the results was 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 may be considered to be “low”. Similarly, in the present study, in those areas where no previous overlap occurred, the uncertainty may be considered to be “high” (following the recommendations of the Guidance Document).

Overall, however, data density (or a lack of detailed subsurface information) was an issue for the broad landscape within the model domain. 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, therefore, it is recommended that, despite the “overlap” of various modelled zones within the WHPA, all of the interpretations presented in this analysis must be considered to have a “high” uncertainty (in order to provide a conservative analysis of the follow-on risk assessment), with the exception of the WHPA-A (which is based on a fixed 100m radius, and therefore has a “low” uncertainty). The high uncertainty rating assigned to the remaining WHPAs could be reduced if supplemental subsurface information were obtained for the groundwater system (i.e. in any follow-on investigations in the future). The results of this uncertainty analysis are presented in Appendix B.

8.0 SUMMARY

This report presents the results of a groundwater vulnerability analysis for the Mattawa 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 - Mattawa

1.0 Background

The Mattawa municipal wells are located on the west side of the Mattawa River, approximately 400 m upstream of the confluence of the Mattawa River and the Ottawa River, in the Town of Mattawa. The well head area is situated on the northeast corner of Bissett Street and Fourth Street, in a developed area of town locally known as Rosemount Valley (NBMCA, 1978).

The well head site lies approximately 5 m above the present river level, in a formation described as a gravelly sand outwash (Northern Ontario Engineering Geology Terrain Study Map 5042, 1979), and has been interpreted locally as having a significant depth of permeable overburden (Harrison, 1972). The valley of the Mattawa River defines a bedrock fault zone (the Mattawa River Fault) which is part of a regional structural feature known as the Ottawa-Bonnechere Graben. Precambrain bedrock associated with this structure rises approximately 100 m above the landscape, and defines the northern boundary of the outwash deposits, while the southern extent of the deposits lie beyond the Mattawa River, and abut a second bedrock rise which extends south and east of the Town of Mattawa.

The municipal wells are located above the floodplain area of the Mattawa River. The wells were drilled in 1958 (Well No. 1) and 1949 (Well No. 2), and were subsequently connected to the municipal water infrastructure. A third well, drilled in 1956, is no longer in use. The UTM co-ordinates of the municipal wells, located in the same building, are (in NAD83) 676227 mE and 5131742 mN (Ministry of the Environment, 2008).

The well field, comprising Well No. 1 and Well No. 2, is currently rated at a combined maximum capacity (both wells combined) of 6,546 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 25 % (or less) of the rated capacity of the system.

The hydrogeological setting of the Mattawa 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:

- 2008/2009 Inspection Report for the Mattawa Well Supply, October, 2008, Ministry of the Environment

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

- The Corporation of the Town of Mattawa, Mattawa Wells First Engineers's Report, March, 2001, Dennis Consultants

- Report on Hydrogeological Assessment of Mattawa Well Supply, Mattawa, Ontario, March, 2001, Golder Associates Ltd.

- Map 2361, Geological Compilation Series, Sudbury - Cobalt, 1991, Ontario Geological Survey

- Soils of the North Bay Area, Soil Survey Report No. 54, 1986, Agriculture Canada

- The Physiography of Southern Ontario, Third Edition, Ontario Geological Survey, Special Volume 2, 1984, L. J. Chapman and D. F. Putnam

- Northern Ontario Engineering Geology Terrain Study, Ontario Geological Survey Map 5042, Data Base Map, Mattawa, 1979, Ontario Geological Survey

- Mattawa Island Conservation Area Master Plan, 1978, North Bay - Mattawa Conservation Authority

- The Physiography of the Georgian Bay - Ottawa Valley Area of Southern Ontario, Ontario Division of Mines, Geoscience Report 128, 1975, L. J. Chapman

- Quaternary Geology of the North Bay - Mattawa Region, Geological Survey of Canada, Paper 71 - 26, 1972, J. E. Harrison

- Foundation Inspection Report at the Site of the C.P.R. Overhead Extension, Highway # 17 in Mattawa, Ontario, #65-F-47, June, 1965, Department of Highways Ontario

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 Mattawa area, a subset of 48 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, 15 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 Mattawa 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 29, focusing on the immediate area of the Mattawa well field. 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.

In addition, subsurface information was obtained from 4 geotechnical boreholes drilled during highway work in the vicinity of the Hwy. 17 - C.P. Rail overpass (Department of Highways Ontario, 1965). 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 Mattawa).

The distribution of water well and borehole information, reviewed in the present assessment, is displayed graphically in Figure A1. The age of the records plotted in Figure A1 span 1949 to 1997 (or 48 years), and reflect the history of settlement in Mattawa (from a groundwater usage perspective). In most of the study area, the information coverage was sparse, for example in the more central part of the townsite, where (based on conversations with residents at an information session) prior to the provision of municipal water infrastructure, the community relied upon shallow (un-recorded) dug well supplies.

As a result, the present conceptual model was based on a combination of the subsurface information obtained from 33 borehole/well locations within the study area of Mattawa, 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 was undertaken in order to assist in identifying the hydraulic properties of the aquifer beneath the Mattawa well field. The primary data sources comprised well performance data obtained by International Water Supply Ltd. for tests conducted in 1985 and 1988. The 1985 data were obtained from International Water Consultants Ltd. (Barrie, Ontario), and consisted of raw drawdown curves for two sets of step tests run on Mattawa Well No. 1 and Mattawa Well No. 2. Additional information was provided by the Corporation of the Town of Mattawa (M. Mathon) and consisted of a letter report and attached data detailing performance tests on Mattawa Well No. 2 carried out in 1988. The report noted that the well performance in 1988 was better than previously reported. No other historical hydraulic test data for the Mattawa well field was located in the International Water Consultants Ltd. files or in the Town records.

Through consultation with a local geotechnical drilling firm (Merlex Engineering Ltd., North Bay) it was understood that subsurface information in the Mattawa area is extremely limited due to the presence of numerous boulders in the overburden (which prohibit deep soil sampling with conventional geotechnical augering equipment). A geotechnical study report for the Canadian Pacific Railway overpass on Highway 17 (on the opposite side of the Mattawa River) was obtained from the Ministry of Transportation (dating to 1965), but was considered to be of limited value in assessing the aquifer due to its location, distance from the well field area and generally shallow depth of penetration of the boreholes.

Since the step tests reported on water levels recorded inside the well casings during pumping, the analysis of the performance data was considered to be conservative in that the drawdowns within the casing were likely greater than the drawdowns in the aquifer outside of the casing (due to well loss effects at the well screen/aquifer contact zone). The step test data were analysed by an iterative technique using the Cooper-Jacob equation, and assuming an aquifer porosity (specific yield) ranging from 0.18 to 0.30 (typical of granular overburden soils).

The results of our analysis are presented in Table 1.

Table 1 - Step Test Analysis For Well No. 1 and Well No. 2

Well	**Date**	**Pumping Rate (m^3/day)**	**Drawdown (m)**	**Assumed Porosity**	**Apparent Transmissivity (m^2/day)**
No.1	**10/10/85**	**1309**	**0.64**	**0.18**	**1602**
				0.30	**1509**
		2618	**1.64**	**0.18**	**1209**
				0.30	**1136**
No.2	**07/05/98**	**2635**	**2.06**	**0.18**	**1028**
				0.30	**920**
		4933	**5.77**	**0.18**	**605**
				0.30	**566**
Geometric Mean Transmissivity (m^2/day)					**1009**

The geometric mean of all of the calculated apparent transmissivity values was 1,009 m^2/day, which is considered a conservative value for the aquifer beneath the Mattawa well field. This value is high and indicates that the aquifer beneath the Mattawa well field is more than capable of municipal well yields, based on criteria established by Driscoll (1986).

In addition to the well performance data, the step test results indicated a depth to static water level that was more or less constant over the time interval covered by the various testing programs. Therefore, a simple average of all of the previously reported depth to static values was taken, and equaled 5.80 m. This level was assumed to be approximately equal to the water level in the Mattawa River (approximately 60 m south of the well head area), and would be consistent with a high transmissivity aquifer (as was identified in the step test pumping results). Unfortunately, there are no other pump test data available to further define the hydrogeological setting (since there are no observation wells near the well field). In addition, there is no information on the total depth of the aquifer itself, other than the maximum depth of penetration into the overburden by the municipal wells themselves.

By working with the available information, a range of hydraulic conductivity values (for use in the groundwater model development) was derived from the apparent transmissivity value of 1,009 m^2/day (geometric mean value) by assuming a range of aquifer saturated thicknesses (which are also input parameters to the model). The minimum base elevation of the aquifer was initially set equal to the bottom of the deepest well screen elevation, or a value of 134.6 m (geodetic) (for Well No. 2), which gave a saturated thickness of 20.6 m and an associated aquifer hydraulic conductivity of 49 m/day (or 5.7×10^{-2} cm/sec). This value is considered reasonable for the assumed conditions, and falls within the range of hydraulic conductivity values commonly reported for sand and gravel aquifers.

Other aquifer saturated thicknesses were also considered in the evaluation. Table 2, which follows, reports on the respective hydraulic conductivity values that were determined for each saturated thickness.

Table 2 - Hydraulic Conductivity Estimates for the Overburden Formation

Static Elevation (m)	Assumed Aquifer Base Elevation (m)	Saturated Thickness (m)	Hydraulic Conductivity (m/day)	Hydraulic Conductivity (cm/sec)
155.2	**134.6**	**20.6**	**49.0**	**5.7×10^{-2}**
	130	**25.2**	**40.0**	**4.6×10^{-2}**
	120	**35.2**	**28.7**	**3.3×10^{-2}**
	110	**45.2**	**22.3**	**2.6×10^{-2}**
	100	**55.2**	**18.3**	**2.1×10^{-2}**
	90	**65.2**	**15.5**	**1.8×10^{-2}**

As can be seen in the above table, the hydraulic conductivity values fall within a range of 5.7×10^{-2} cm/sec to 1.8×10^{-2} cm/sec for a wide range of assumed saturated thicknesses (from 20.6 m to 65.2 m total). This analysis demonstrates that the theoretical hydraulic conductivity values for the aquifer span a relatively narrow range in order to produce the observed transmissivity value seen during the step testing program, and are not particularly sensitive to the assumed saturated thicknesses used in the analysis. Therefore, by this analysis, the groundwater model assumed an overburden aquifer hydraulic conductivity value in the range of 5.7×10^{-2} cm/sec to 1.8×10^{-2} cm/sec, in order to best reflect local known conditions. 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).

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, 24 records contained sufficient data to allow analysis of the apparent transmissivity of the bedrock formation, 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 24 records reviewed, 16 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 was noted (Figure A2).

From this analysis, the variation in hydraulic conductivity of the bedrock with penetration depth (from 0 m to 30 m) was noted to range from 4.0×10^{-4} cm/sec to 9.1×10^{-5} 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 4.0×10^{-4} cm/sec to 9.1×10^{-5} 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.

Stratigraphic information in the municipal well field area is limited to the well records for the pumping wells themselves, which indicate sand and gravel from surface to full termination depth. Further to the west of the well field, in the vicinity of the Municipal lagoons, there are several private well records which indicate a continuation of the sands and gravels, and bedrock is noted to rise in this general direction. Although the area on the north side of the Mattawa River was settled before municipal services were brought to the area, it is considered likely that residential water supplies were obtained from the overburden aquifer using owner-constructed dug wells and washed well casings (which were not recorded in the water well database).

It should be noted that the municipal wells were not drilled to bedrock, so the exact elevation of the bedrock surface beneath the well field is unknown. Bedrock outcrops were observed to the north of the well field, dominating the highland area on the north side of the Mattawa River valley, and there is a possibility that bedrock rises to near surface beneath Mattawa Island (to the immediate south of the municipal well field, in the Mattawa River).

The lack of comprehensive stratigraphic information on the west side of the Mattawa River makes detailed analysis difficult. However, the unique shallow drawdown characteristics of the municipal wells, and the associated high transmissivity of the groundwater aquifer at the well field, was incorporated into the overall conceptual model development.

4.0 Water Balance and Recharge Estimation

For the purpose of the present groundwater model development, a water balance and recharge estimate was performed using VisualHELP software (Waterloo Hydrologic, Inc.). The software was used to estimate the net recharge to the water table through the unsaturated zone, and has been identified as an acceptable methodology under the current Guidance Module 3 documentation (Ministry of the Environment, 2006). The current version of VisualHELP (Version 2.2) was used in this assessment and is based on the USEPA’s HELP model (Schroeder, et al, 1983). The decision to apply the VisualHELP model in this analysis was made because of a lack of any other hydrological information which would assist in estimating and calibrating recharge values for the study area.

The HELP model solves the equations of flow in the unsaturated zone (above the water table) using a complex algorithm to estimate monthly surficial runoff (based on the SCS-curve method), and evapotranspiration (based on a modified Penman method), which are subtracted from the monthly precipitation values (input by the user) to arrive at a percolation (recharge) value through the unsaturated zone. The model also tracks changes in storage water in the unsaturated zone.

In the present analysis, the unsaturated zone was conceptualized as a single layer, with a thickness which extended from ground surface to the top of the water table (Waterloo Hydrologic, Inc., 2003). Input variables required for the model included the following parameters:

- latitude and longitude - used to calculate the net solar radiation at the study site
- soil properties - total porosity, field capacity, wilting point and saturated hydraulic conductivity
- surface water settings - type of cover and slope
- evapotranspiration settings - evaporative zone depth, maximum leaf area index, growing season start and stop days, quarterly relative humidity, average wind speed
- temperature and precipitation climate normal data - used to initiate the water balance calculation

Generic soil properties were used in the assessment, based on a compilation of information from various sources (Morris and Johnson, 1967; Johnson, 1967; Schroeder, et al, 1983a; British Columbia Ministry of Agriculture, Food and Fisheries, 2002; Kresic, 2007). The values for the saturated hydraulic conductivities were taken from Freeze and Cherry (1979).

As discussed in the HELP User's Guide (Schroeder, et al, 1983a), the relationship between total porosity, field capacity and wilting point is that total porosity > field capacity > wilting point for all modeled cases. The values which were used in the present HELP model assessment were chosen as follows, and were grouped into 6 major soil divisions (gravel, sand, sandy silt, silt, silty clay and clay) (Table 3).

Table 3 - Soil Parameters for the HELP Model Calculations

Soil Group	Total Porosity	Field Capacity	Wilting Point	Saturated Hydraulic Conductivity (cm/sec)
Gravel	**0.33**	**0.08**	**0.07**	**1.0 to 1×10^{-2} (1×10^{-1} average)**
Sand	**0.36**	**0.09**	**0.05**	**1×10^{-1} to 1×10^{-3} (1×10^{-2} average)**
Sandy Silt	**0.39**	**0.15**	**0.08**	**8×10^{-4} (geometric mean of sand and silt average values)**
Silt	**0.43**	**0.24**	**0.12**	**6×10^{-4} to 6×10^{-6} (6×10^{-5} average)**
Silty Clay	**0.45**	**0.30**	**0.15**	**3×10^{-6} (geometric mean of silt and clay average values)**
Clay	**0.46**	**0.37**	**0.18**	**1×10^{-6} to 1×10^{-8} (1×10^{-7} average)**

Within the VisualHELP model, the sensitivities of the model were assessed by varying the surficial slope conditions (in 10 x increments) from 0.05 % to 50% slope, and the surficial soil conditions were adjusted to reflect bare soil, fair grass to excellent strand of grass conditions. The soil types included in the model (comprising gravel, sand, sandy silt, silt, silty clay and clay) were assigned representative values of total porosity, field capacity, wilting point and saturated vertical hydraulic conductivity (based on typical values reported in various publications).

Included in the VisualHELP model is the capability to simulate (or synthesize) several years of climatological data (temperature, precipitation and solar radiation) using a weather generator module developed by the U.S. Department of Agriculture (Waterloo Hydrologic, Inc., 2003). The module relies upon the original climate normal data and site location (which are input to the model as “seed” data), and adjusts the mean monthly values (within a range of possible values) based on a statistical database assessment of known weather records for similar latitudes. Each set of synthesized weather data were run through the VisualHELP model, and the cumulative precipitation, evapotranspiration, runoff, percolation (recharge) and storage values were tracked.

In the present analysis, the cumulative totals were carried for a total simulation time of 100 years, yielding 100 year totals for each component of the water balance. These totals contained data for both average years and climate extremes (within the statistical limits imposed by the software), and are considered to be a fair representation of the anticipated water balance over the simulated 100 year timespan. The average annual volumes of precipitation, evapotranspiration, runoff and percolation (recharge) were determined from the 100 year cumulative volumes by dividing by 100 (the total number of years that the simulation was run).

The weather data used for this assessment were taken from published climate normal data for three nearby weather stations, since Mattawa itself did not have a weather station. The weather stations chosen for this analysis were the North Bay Airport (Ontario) weather station (which meets WMO standards for temperature and precipitation), the Barrage Temiscamingue, Quebec weather station and the Rapide Des Joachims, Quebec weather station, obtained on-line from Environment Canada (www.climate.weatheroffice.ec.gc.ca). The data spanned the interval of 1971 to 2000.

The North Bay Airport weather station is situated approximately 56 km west of Mattawa, the Barrage Temiscamingue, Quebec weather station is located approximately 54 km northwest of Mattawa and the Rapide Des Joachims, Quebec weather station is located approximately 80 km southeast of Mattawa. The Mattawa data for precipitation and temperature were determined from these three weather station locations using a linear interpolation method presented in Wang and Anderson (1982). Although the Barrage Temiscamingue and Rapide Des Joachims weather stations do not currently meet WMO standards, their use was considered justified for the present analysis (as “seed inputs” to the weather generator module) because of their relative close proximity to Mattawa when compared to other, more distant, weather stations.

A total of 72 simulation runs were performed for the study location, incorporating the above-indicated range of parameters and, from our analysis, it was observed that the percolation (recharge) values were not particularly sensitive to % slope and soil conditions, but were sensitive to the saturated vertical hydraulic conductivity values assigned to each soil group. As a result, a decision was made to analyse the 72 simulations using saturated vertical hydraulic conductivity as the master variable and, from the appearance of the plots obtained, a regression analysis was performed to arrive at a relationship between percolation (recharge) and soil type (as characterized by the saturated vertical hydraulic conductivity value).

Based on our analysis, the following relationships were obtained:

- Net Annual Recharge

Recharge (mm) = 23.751 ln (Saturated Vert K, cm/sec) + 475.26

- Net Annual Evapotranspiration

Evapotranspiration (mm) = - 14.501 ln (Saturated Vert K, cm/sec) + 241.66

- Net Annual Runoff

Runoff (mm) = - 9.170 ln (Saturated Vert K, cm/sec) + 251.93

The net annual precipitation at Mattawa, as produced by the Weather Module for 100 years of simulation time, was 969 mm.

For the range of hydraulic conductivities determined previously, and assuming an anisotropy ratio (vertical hydraulic conductivity to horizontal hydraulic conductivity) of between 1:3 and 1:10, a range of water balance values were determined for the Mattawa well head area using the VisualHELP software, and we used as preliminary data inputs in the model development (Table 4).

Table 4 - HELP Model Recharge Estimates

Geological Unit	$K_{horizontal}$ Range (cm/sec)	$K_{vertical}$ Range (cm/sec)	Recharge (mm/year)	Evapotranspiration (mm/year)	Runoff (mm/year)
Sand and Gravel Aquifer	1.8×10^{-2}	1.8×10^{-3}	**325**	**333**	**310**
	5.7×10^{-2}	1.9×10^{-2}	**381**	**299**	**288**
Bedrock	9.1×10^{-5}	9.1×10^{-6}	**200**	**410**	**358**
	4.0×10^{-4}	1.3×10^{-4}	**262**	**371**	**334**

As stated previously, the VisualHELP model results were used in the development of the Mattawa groundwater model because of a lack of calibration data from nearby water wells or surface water streams. During typical modelling assessments, recharge values are selected and adjusted during the model calibration steps, until a representative groundwater flow system is obtained. For the present analysis, the recharge values were simply assigned based on the results of the VisualHELP analysis, incorporating the interpreted geology of the surficial materials.

In terms of the bedrock uplands areas, runoff from the bedrock was considered available for recharge into the adjoining overburden soil type, and was simulated by assigning a higher recharge to a narrow strip of soil which extended along the flanks of the bedrock highlands area. The remainder of the bedrock runoff was assumed to be re-infiltrated into the remaining downgradient soils.

5.0 MODFLOW Analysis

The soil and bedrock descriptions provided in the preceding sections reflect a simplified 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 Mattawa well field.

The Mattawa 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 134 rows by 115 columns, with 2 overburden layers of varying thicknesses and a bottom bedrock layer having a typical 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 A3, the outer boundary of the groundwater flow model is represented by the darker shading.

A total of 2 stratigraphic units (i.e. two different hydraulic conductivity values) were incorporated into the model, reflecting the interpreted hydrogeological setting in Mattawa. Figure A3 also presents a cross-sectional view through the simulated municipal well. The model was run using the MODFLOW2000 engine, with a Conjugate Gradient Solver (PCG2).

The level of detail applied to the modelling effort was considered reasonable for the limited 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. Given the lack of nearby water level data, and absence of any nearby surface water features (i.e. small streams) which could otherwise be used to verify the water table interpretations, the model must be considered “un-calibrated”.

This designation does not imply that the model results are invalid, and the WHPAs developed in the present assessment were noted to be in good agreement with the regionally-calibrated model WHPAs generated during the previous 2006 municipal groundwater study. It does, however, indicate that some caution should be applied in the interpretation of the groundwater flow characteristics near to the well head area, since these have been based on very local data (i.e. developed from measurements within the well casings themselves, and not in the adjacent aquifer).

Constant head boundaries were assigned to the Ottawa River (at the eastern edge of the modelled area, at an assigned elevation of 152 m) and to the Mattawa River (at the southern edge of the modelled area, at an assigned elevation of 152 m). There were no other surface water bodies identified within the study area.

During the model calibration process, the soil properties and recharge values were adjusted manually until a reasonable fit of the water table to the known surficial conditions was attained. 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 there 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	**sand and gravel aquifer**	**4×10^{-2}**	**4×10^{-3}**	**344**	**6×10^{-5}**	**0.24**	**0.35**
2	**bedrock**	**5×10^{-4}**	**5×10^{-4}**	**295**	**1×10^{-6}**	**0.04**	**0.1**

In the above table, 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. A high recharge rate was applied to the bedrock due to the mapped steeply dipping bedrock structure reported in the local area.

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 the well head, 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 documented decline in 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 1997 to and ending at the end of 2007 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 Mattawa well field was set equal to 1,940 m^3/day, assigned to a single theoretical well (due to the close proximity of the two pumping wells in the well head area).

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 a northwest to southeast direction, with the wellhead itself (the well locations) being situated in the extreme southeastern corner of the WHPA. Regional groundwater flow, as defined in the present model and the previous assessment (2006), is radially from the bedrock highland area to the southeast (towards the Mattawa River).

North Bay – Mattawa

DRINKING WATER SOURCE PROTECTION
ACT FOR CLEAN WATER

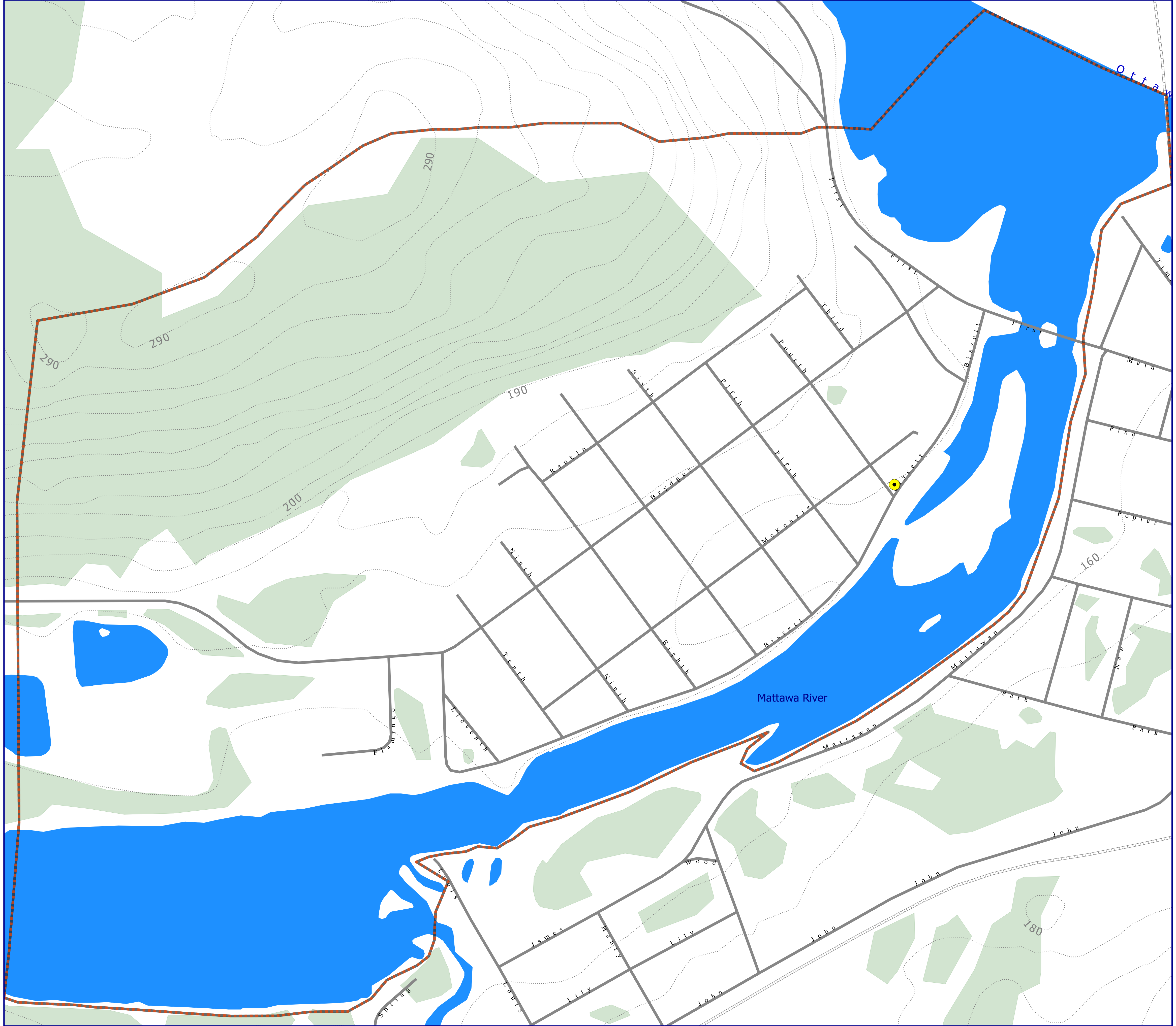
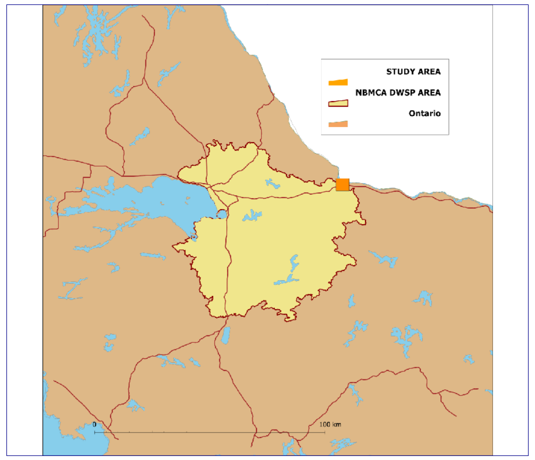


FIGURE 1
TOWN OF MATTAWA

Study Area

NORTH BAY-MATTAWA CONSERVATION AUTHORITY

Waters Environmental Geosciences Ltd.



LEGEND

● Wells

Mattawa Study Area

Roads

Rail

Water Features

Waterbody

Stream/Creeks

Wooded Area

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North Bay – Mattawa

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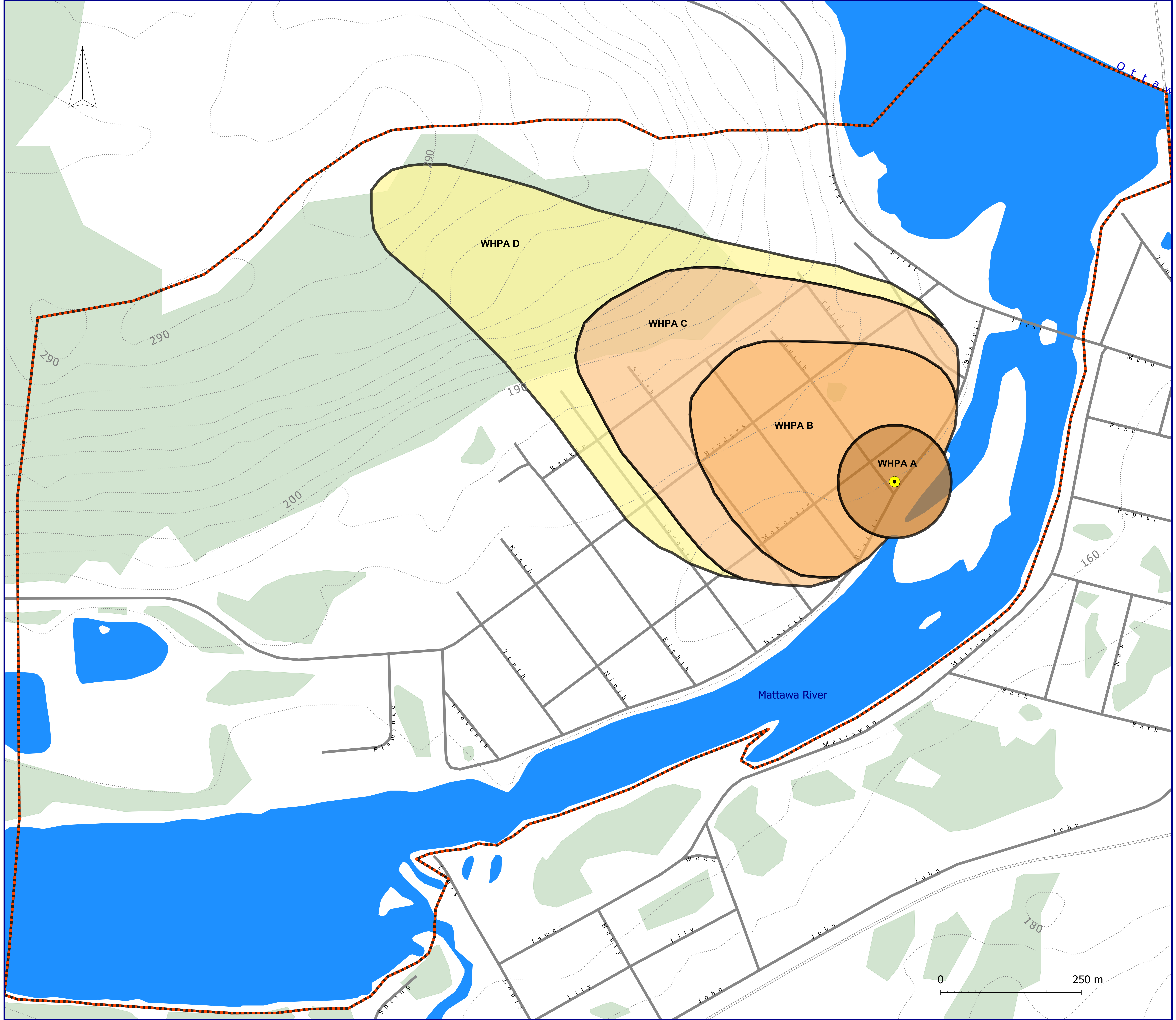
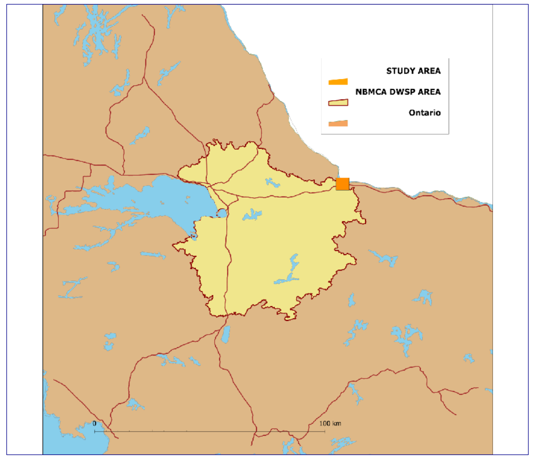


FIGURE 2:
TOWN OF MATTAWA

Wellhead Protection Area (WHPA)

NORTH BAY-MATTAWA CONSERVATION AUTHORITY

Waters Environmental Geosciences Ltd.



LEGEND

Wellhead Protection Area

▭	WHPA D
▭	WHPA C
▭	WHPA B
▭	WHPA A
⊙	Wells
⋯	Mattawa Study Area
—	Roads
┿	Rail
	Water Features
■	Waterbody
—	Stream/Creeks
■	Wooded Area

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ACT FOR CLEAN WATER

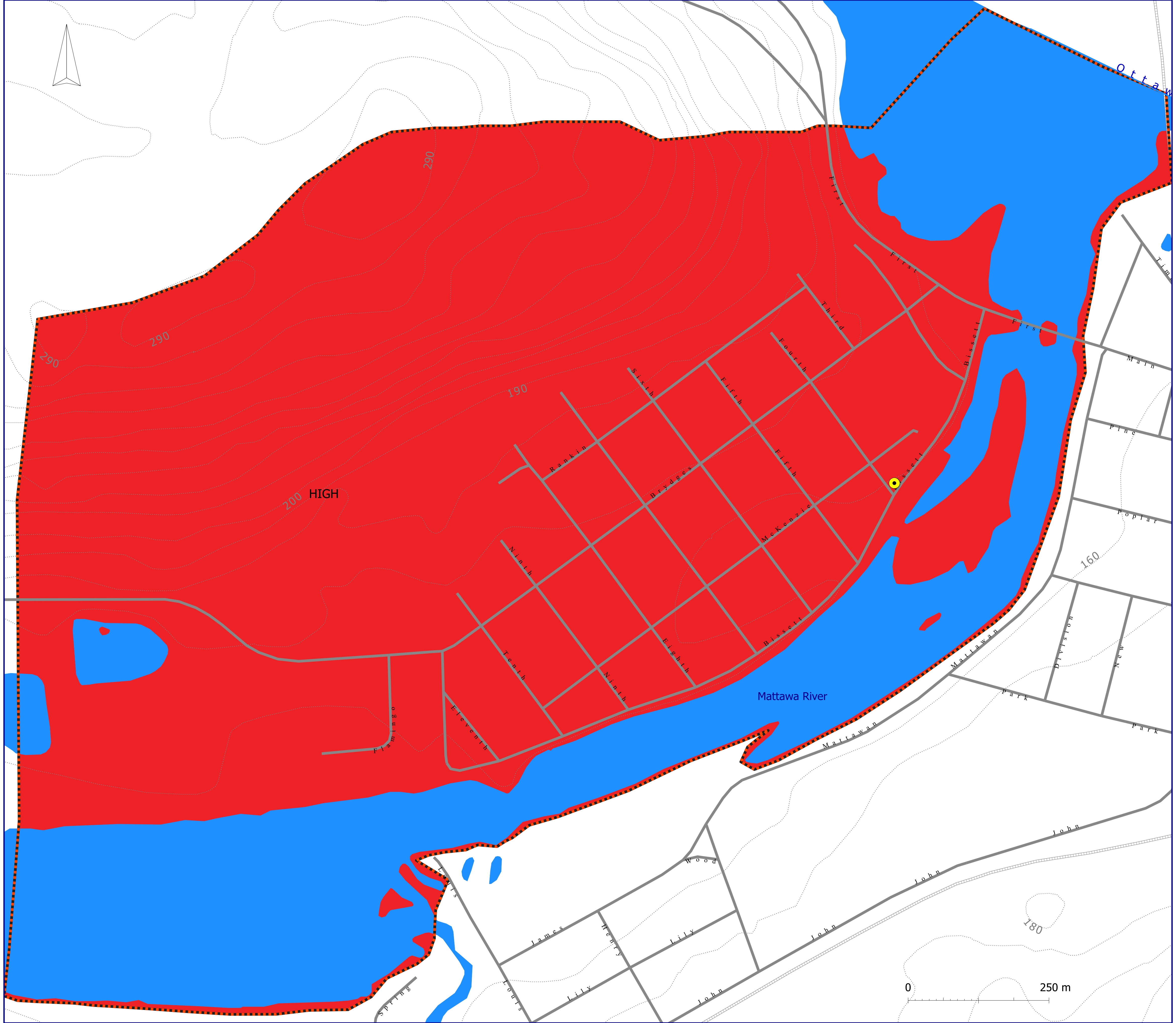
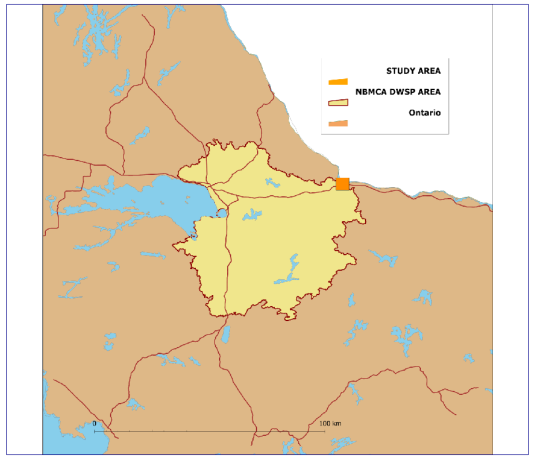


FIGURE 3:
TOWN OF MATTAWA

Intrinsic Susceptibility Index

NORTH BAY-MATTAWA CONSERVATION AUTHORITY

Waters Environmental Geosciences Ltd.™



LEGEND

● Wells

Roads

Rail

Water Feature

Waterbody Segment

Stream/Creek

Interinsic Susceptibility Index

🟥 HIGH

Mattawa Study Area

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DRINKING WATER SOURCE PROTECTION
ACT FOR CLEAN WATER

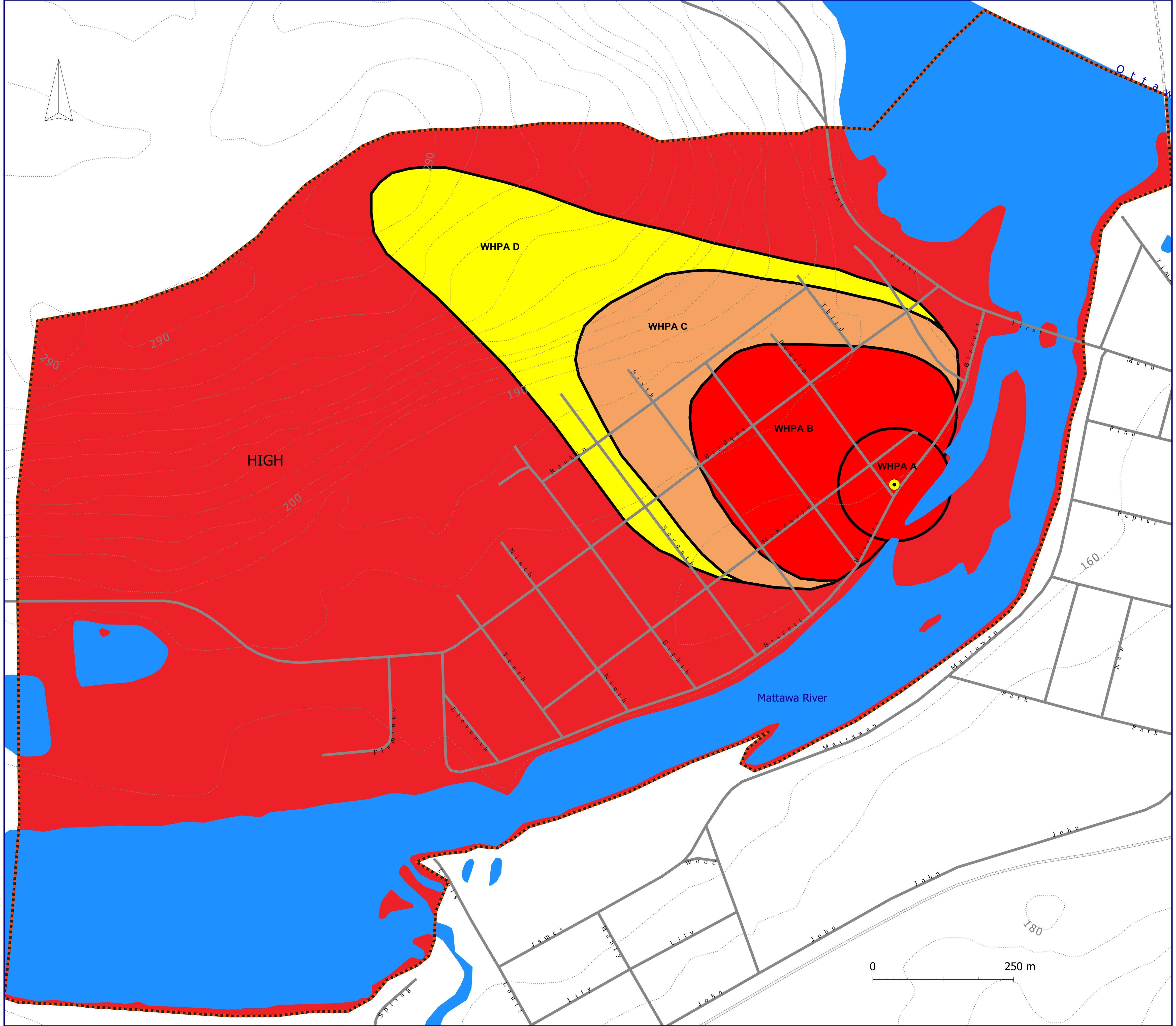
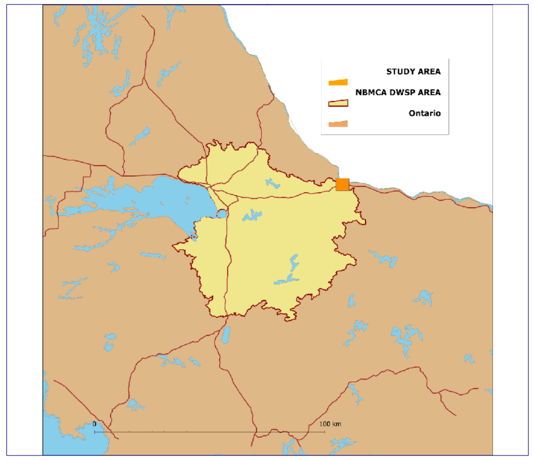


FIGURE 4:
TOWN OF MATTAWA

Intrinsic Susceptibility Index & Wellhead Vulnerablity Scores

NORTH BAY-MATTAWA CONSERVATION AUTHORITY

Waters Environmental Geosciences Ltd.™



LEGEND

●	Wells
—	Roads
┼┼┼	Rail
	Water Features
🟦	Waterbody Segment
—	Stream
	Intrinsic Susceptibility Index
🟥	HIGH
	Vulnerability Scores (WHPA)
🟥	10
🟧	8
🟨	6
▭	Mattawa Study Area

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Map Produced in Co-Operation with the Province of Ontario and Conservation Ontario

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