Updated Assessment Report

Sault Ste. Marie Region

Source Protection Area

CHAPTER 3

GROUNDWATER VULNERABILITY ANALYSIS

With Support Provided By

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ASSESSMENT REPORT
GROUNDWATER VULNERABILITY ANALYSIS

Table of Contents

LIST OF TABLES

APPENDICES

LIST OF ACRONYMS

ACR **Algoma Central Railway**
AVI **Aquifer Vulnerability Index**
CIRNAC **Crown-Indigenous Relations and Northern Affairs Canada (formerly INAC – Indian and Northern Affairs Canada)**
CWA ***Clean Water Act, 2006***
DEM **Digital Elevation Model**
DNAPL **Dense Non-Aqueous Phase Liquids**
DWSP **Drinking Water Source Protection**
GIS **Geographic Information System**
GL **Giga Litre (1 000 000 000 Litres = 1 000 000 m^3)**
GUDI **Groundwater under the Direct Influence of Surface Water**
GW **Groundwater**
GWVA **Groundwater Vulnerability Analysis**
HVA **Highly Vulnerable Aquifer**
HVA's **Highly Vulnerable Aquifers**
HYSEP **Hydrograph Separation**
IKONOS **A Commercial Earth Observation Satellite**
IPZ **Intake Protection Zone**
ISI **Intrinsic Susceptibility index**
K **Hydraulic Conductivity**
km **kilometre**
km^2 **square kilometre**
LIO **Land Information Ontario**
LSB **Local Services Board**
m **metre**
m^3/s **cubic metres per second**

MECP	**Ministry of Environment, Conservation and Parks (formerly MOE and MOECC)**
MGD	**Million gallons per day**
ML	**Mega Litre (1Million Litre =1 000 000 Litres = 1000 m^3)**
mm	**millimetre**
MODFLOW	**A Three-Dimensional Finite-Difference Ground-Water Flow Model**
MODPATH	**Advective Particle Tracking Module of visual MODFLOW model**
OGS	**Ontario Geological Survey**
PGMN	**Provincial Groundwater Monitoring Network**
PSOC	**Potential Sources of Contamination**
PTTW	**Permit to Take Water**
SAAT	**Surface to Aquifer Advection Time**
SGRA	**Significant Groundwater Recharge Area**
SPC	**Source Protection Committee**
SSM	**Sault Ste. Marie**
SSMR SPA	**Sault Ste. Marie Region Source Protection Area**
SWAT	**Surface to Well Advection Time**
TOR	**Terms of Reference**
TOT	**Time of Travel**
UZAT	**Unsaturated Zone Advection Time**
WHPA	**Wellhead Protection Area**
WTP	**Water Treatment Plant**
WWAT	**Water Table to Well Advection Time**
WWIS	**Water Well Information System**

EXECUTIVE SUMMARY

The Ontario Clean Water Act as it came into force on July 3rd, 2007, is a legislation to protect the drinking water at the source, as part of an overall commitment to human health and the environment. A key focus of the legislation is the production of locally-developed, science-based assessment report and source protection plan. The Sault Ste. Marie Region Source Protection Committee (SSMR SPC) is representative of the watershed community and includes members from municipal governments, local aggregate industry, the environmental sector, water distributors and landowners. The SPC in conjunction with the drinking water source protection staff has prepared the assessment report Chapter 3 on Groundwater Vulnerability Analysis of the Sault Ste. Marie Municipal Well Head Protection Areas. The Assessment Report will be used to develop the source water protection plan and to establish the measures to protect both the quality and quantity of sources of drinking water within the St. Marys River watershed.

The assessment report was originally developed under the 2008, 2009 and 2013 versions of the Technical Rules and where updates were made, they were carried out under amendments to the 2017 Rules and 2018 addition of pipelines circumstances to the Table of Drinking Water Threats. This report addresses the intrinsic vulnerability of the groundwater aquifer across the Sault Ste. Marie Region Source Protection Area (SSMR SPA). Groundwater vulnerability is defined as the tendency and likelihood for general contaminants to reach the water table after introduction at the ground surface. All groundwater is to some degree vulnerable and the analysis for the assessment reflects the ability of contaminants to reach the water table in groundwater aquifers across the region.

In this study, the team selected the intrinsic vulnerability analysis approach to identify the vulnerable areas. The mapping has also been done for the relative vulnerability of the aquifer within each Wellhead Protection Area (WHPA). The vulnerable areas considered in the assessment include: Wellhead Protection Areas around municipal drinking water supply wells (WHPAs); Highly Vulnerable Aquifers (HVAs); and Significant Groundwater Recharge Areas (SGRAs).

The relative vulnerability within each of these areas was characterized as high, medium or low. This categorization is intended to reflect the susceptibility of the aquifer(s) in the vulnerable areas to surface (or near surface) sources of contamination. The vulnerability score is assigned based on the intrinsic susceptibility analysis and presented in the mapping products. These results, as well as the level of confidence in the assessment, will be provided as input to the “Water Quality Risk Assessment”. The initial vulnerability score was modified after the adjustment of potential presence of transport pathways which could allow contaminants of concern at surface to bypass natural protective layers above the aquifers.

The Intrinsic Susceptibility Index (ISI) approach was selected for groundwater vulnerability analysis. The assessment was based on the existing hydrogeological data, land use and information from the provincial groundwater studies. The section on the Intrinsic Susceptibility Index (ISI) describes the vulnerability of the aquifer. The ISI was estimated by assigning the numerical score related to the hydraulic conductivity of the material in each layer overlying the water table multiplied by the thickness of that layer. Based on this analysis, the higher the ISI, the less sensitive is the aquifer.

The results indicate that the 100 m radius area around the WHPAs having a score of 10 is highly vulnerable to contamination from surface sources. Most of the area within 2-year time of travel has a medium vulnerability (IV score 6) to surface sources of contamination. Some areas within the 25-years capture zone of the Shannon and Lorna well fields have a medium vulnerability (IV score 6). It is also observed that some areas within the 5-year capture zone of Goulais wells have the medium vulnerability (IV score of 6).

Maps have been produced to provide the visualization of the vulnerability analysis of each municipal wellhead protection area. These vulnerability analysis maps are designated throughout the report as **GWVA Map #** and are presented in Appendices at the end of this report. An assessment and rating of the uncertainty associated with the vulnerability score is also provided and categorized as either high or low. Assessment results indicate that in the area of the low lands, covered by thick clay and silt deposits, the aquifer is less susceptible to contamination. The shallow water table aquifer over the Precambrian uplands, in parts of the recharge area and within the 100 m radius around WHPA’s, are areas of relatively high intrinsic susceptibility to contamination.

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1.0 INTRODUCTION

The City of Sault Ste. Marie is supplied with drinking water from both surface and groundwater. Surface water is supplied from Gros Cap (Lake Superior) and contributes approximately 50% of the supply. The remainder of the water supply to the city is sourced from four (4) groundwater well fields having six (6) wells. The wells are drawing water from deep bedrock aquifers, located within the city limits. There are three (3) groundwater basins located between the Precambrian uplands to the north of the City and the St. Marys River. These Basins are referred to as East, Central and West Basins. The basins are separated by topographic highs in the Precambrian bedrock (Burnside, 2003).

The importance of groundwater has long been recognised, but the potential to become contaminated as a result of human activities at or near the land surface has only been recognised in recent years. Groundwater can be contaminated by localized releases from sources such as hazardous waste disposal sites, municipal landfills, surface impoundments, underground storage tanks, gas and oil pipelines, back-siphoning of agricultural chemicals into wells, and injection wells. Groundwater can also become contaminated by substances released at or near the soil surface in a more dispersed manner including pesticides, fertilizers, road salt application, septic tank leachate, and contamination from other non-point sources.

As groundwater is inherently susceptible to contamination from anthropogenic activities; remediation is very expensive, often impractical and in many cases, cleanup may not be possible within a reasonable time. In addition, groundwater is the only source of drinking water for many rural areas. The cost of replacing contaminated sources with outsourced bottled water or other alternatives is high relative to that of existing groundwater resources. Prevention of contamination is critical in effective groundwater management. Aquifer vulnerability assessment aims at predicting areas, which are more likely than others to become contaminated as a result of activities at or near the land surface.

In general, groundwater vulnerability can be defined as the tendency or likelihood for the contaminants to reach a specific position in the groundwater system after introduction at some location above the uppermost aquifer.

The vulnerability could be lower where soils and substrata are thicker and more organic and clay-rich, where there is a general absence of fractures, and where the water table is deeper. These factors reduce and/or slow the amount of water moving downwards and are also important in stopping a wide range of contaminants reaching the water table.

There are a large number of activities with potential to contaminate groundwater. Examples include the use of pesticide and fertilizer in agriculture, septic tank discharge, sludge spreading and landfills. The vulnerability assessment calculation method on a broader landscape is a technique that can appropriately subdivide land areas into areas of high and low groundwater vulnerability to a range of activities and is therefore, a useful tool in identifying locations where such activities pose a higher risk of contaminating groundwater. Once identified, different areas of vulnerability can then be subjected to land use restrictions, codes of practices or targeted for more detailed assessment.

Two well fields known as Goulais and Steelton consist of three deep wells. The Goulais well field has two wells known as Goulais # 1 and #2. The Goulais and Steelton wells are located on the Central Basin aquifer. The well fields at Shannon and Lorna consists of three deep wells (one at Shannon and two at Lorna). Two wells at the Lorna well field are normally pumped simultaneously. The Shannon and Lorna wells are located within the East Basin aquifer.

In 2001, the Ministry of the Environment (MOE) initiated the Municipal Groundwater Studies program in support of groundwater source protection and management throughout Ontario. The program included a project that assessed groundwater conditions at a regional scale across Sault Ste. Marie (Sault Ste. Marie Area Groundwater Management and Protection Study 2003).

In 2005, under the new initiative from the Ministry of the Environment, a Groundwater Vulnerability study was also completed. Based on the MOE Terms of Reference (TOR) 2005, the vulnerability of municipal groundwater study has been carried out to further refine the vulnerability of the wellhead protection areas. In this study, the evaluation of the aquifer vulnerability was based on the application of advection modelling that evaluated time of travel from ground surface to the water table.

The Sault Ste. Marie Groundwater Study (2003) included intrinsic susceptibility index (ISI) mapping throughout the watershed area and the delineation of well-head protection areas (WHPA) for the municipal supply wells in the study area (including all four well fields). For the municipal wells, the WHPA was delineated using a numerical model (MODFLOW), based on an interpretation of existing information such as water well records, published geologic maps, as well as geo-technical, environmental and hydrogeological investigation reports.

In the present assessment report, the evaluation of intrinsic vulnerability of the groundwater resources of Sault Ste. Marie to contamination on a watershed basis has been carried out. The assessment is focused on the physical characteristics of the resource and is therefore independent of considerations associated with chemical use. The results of the groundwater vulnerability analysis will provide input to the Water Quality Risk Assessment Report (Chapter 6 of the Assessment Report).

The intrinsic susceptibility index (ISI) method was selected for the groundwater vulnerability assessment. This method was selected by considering the various factors, including existing vulnerability mapping, the quality and availability of data, the complexity of the hydrogeological system, the existing drinking water threats that had been inventoried, water usage and the long term planning objectives. The DWSP team selected the iterative approach for the aquifer and groundwater vulnerability. In this way, the assessment may become more detailed as additional data become available.

The assessment of aquifer vulnerability for the broader landscape across the watershed is used to identify the highly vulnerable areas both inside and outside of the WHPAs. The vulnerable areas considered in the assessment include:

- WHPAs around municipal drinking water supply wells;
- Highly Vulnerable Aquifers (HVAs);
- Significant Groundwater Recharge Areas (SGRAs); and
- Other Designated Systems, if identified in a Terms of Reference

The work carried out in this assessment includes: identification of sensitivity areas and assignment of vulnerability scores to these sensitivity areas.

In addition to using all of the available hydrogeological data and results from previous groundwater studies (Appendix 1 of the Assessment Report), the chapter was completed with data and information from other reports. The delineation of significant groundwater recharge areas was adapted from "Water Budget and Water Quantity Risk Assessment" (Chapter 2a and Chapter 2b). The inventory of transport pathways was achieved through the study Preferential Pathways Study (TSH, 2007). The data, maps and results from the previous groundwater studies were also used in the vulnerability analysis. The wellhead protection area delineation and ISI mapping was adapted for the report from the Groundwater Management Study done by Burnside in 2003.

In the vulnerability assessment scoring, the previous capture zone delineations and the existing ISI mapping for Sault Ste. Marie was considered to overlay/integrate the WHPA capture zones with the existing ISI vulnerability index mapping. The assigned vulnerability score was based on Ministry of the Environment (MOE) prescriptive procedures (Technical Rules, 2009).

1.1 STUDY AREA

The study area encompasses the Sault Ste. Marie Region Source Protection Area (SSMR SPA) (**WC Map 01**), situated within the District of Algoma, along the north shore of the St. Marys River and Lake Superior. This area includes the municipality of Sault Ste. Marie, the Township of Prince, portions of the townships of Dennis, Pennefather, Aweres, Jarvis, Duncan as well as areas of the Garden River and Batchewana First Nations. The SSMR SPA covers approximately 775 km^2 including the land and water based areas.

The City of Sault Ste. Marie is located at the south central portion of the watershed. The boundary of the SSMR SPA extends out to the international border along its entire width. Both Lake Superior and the St. Marys River are shared resources of Canada and the United States. With a population of approximately 75 000 (2006 Census Canada), the City of Sault Ste. Marie is a major regional centre for industrial, business, forestry, institutional and commercial services.

Prince Township lies to the west and north of the municipal boundaries of the City of Sault Ste. Marie. Its western boundary is comprised of a portion of the coastline of Whitefish Bay of Lake Superior while its northern boundary is shared with Dennis Township. Highway 550 runs east-west through the Township while Highway 565 extends south through the Township to connect with Pointe Des Chênes, Pointe Louise and the municipal airport all in the City of Sault Ste. Marie. The population of the Prince Township is approximately 980.

1.2 DATA SOURCES

Every effort was made to collect, compile and use the most recent data available for the groundwater vulnerability analysis according to the Technical Rules: Assessment Report.

Required datasets for the report were requested from various Provincial and Federal departments, ministries and agencies, Conservation Ontario and several Engineering Consultants. Datasets were also acquired from local PUC Inc. and City of Sault Ste. Marie Engineering Office as needed. Studies and reports within the SSMRCA and Algoma University library were fully utilized.

The following data sources have been used in the preparation of this report:

- Algoma Health Unit
- Conservation Ontario
- Environment Canada
- Kresin Engineering Corporation, Sault Ste. Marie
- Land Information Ontario (LIO)
- MacViro – GENIVAR Consultants Inc.
- Ontario's Ministry of the Environment (MOE)
- Ministry of Natural Resources
- Public Utility Corporation (PUC Inc.) of Sault Ste. Marie
- R. J. Burnside and Associates Limited
- Sault Ste. Marie Innovation Center
- The Corporation of the City of Sault Ste. Marie
- TSH Engineering, Sault Ste. Marie

1.3 PREVIOUS STUDIES

A number of reports and studies have been completed in the study area. The following reports were particularly useful in preparing this report:

- Sault Ste. Marie Groundwater Management and Protection Study, June 2003, (R. J. Burnside & Associates Ltd.)
- Vulnerability of Municipal Groundwater Study, June 2005, (R. J. Burnside & Associate Ltd.)
- Sault Ste. Marie Watershed Characterization Final Report for the Sault Ste. Marie Region Source Protection Area, June 2008 (SSMRCA)
- SSMRCA Water Budget Conceptual Understanding Final Report, November 2006 (MacViro – Genivar Ontario Inc.)
- Tier 1 and Tier 2 Water Budget and Water Quantity Stress Assessment Draft Final Report, May 2008 (MacViro – Genivar Ontario Inc.)
- Transport Pathways Study, City of Sault Ste. Marie Municipal Well Capture Zone, February 2007 (TSH and Burnside Associates).

2.0 DATA COLLECTION AND ANALYSIS

The available hydrogeological data and results from the previous groundwater studies were analyzed to develop the required mapping products and conceptual hydrogeological understanding of the groundwater flow system. The Watershed Characterization provides information on collected data and was beneficial in the preparation of vulnerability assessments. Data inputs to the groundwater vulnerability analysis include:

- Water well records and other borehole records, and mapping
- Quaternary geology and bedrock geology mapping
- Aquifer and aquitard mapping, or thickness mapping
- Aquifer parameters
- Depth to water table and piezometric surface mapping
- Overburden thickness mapping
- Geological cross-sections
- Topographic surface and surface water feature mapping

2.1 DATA COMPILATION

The groundwater vulnerability assessment was drawn largely from data compiled during the Watershed Characterization. As part of this report, all available information for the Source Protection Area (SPA) has been compiled and assessed to provide a foundation for the other Appendices. The Watershed Characterization provides a list of studies, reports and databases for the area. Previous groundwater studies were reviewed in order to identify and assemble the information/data relevant to the assessment of the intrinsic vulnerability of the aquifer.

Specific information that has been compiled includes: previously delineated WHPAs and vulnerability mapping; hydrogeological cross-sections; updated MOE Water Well Information System (WWIS) including high quality borehole data; regional scale maps illustrating the spatial distribution of aquifers; groundwater quality information;.

The groundwater data and mapping was readily available in digital format for the City of Sault Ste. Marie from the previously completed groundwater studies under the “MOE Provincial Groundwater Protection Program”. Results from the numerical models have been used for refining the vulnerability assessments.

The specific data requirement for the selected method of vulnerability assessment (including WHPA delineation) is as required in the Technical Rules: Assessment Report. Apart from compiling the overall data needed for the hydrogeological conceptualization, the following information from the other chapters and appendices of the Assessment Report is used:

- Watershed Characterization: WHPAs and Broader Landscape Vulnerability Assessment.

- Issues Evaluation and Threats Inventory Appendix: Constructed Transport Pathways Inventory.

- Water Budget and Water Quantity Risk Assessment Appendix: Recharge distribution and rates. Delineated High Volume Recharge Areas and Significant Groundwater Recharge Areas.

2.2 HYDROGEOLOGICAL CONCEPTUALIZATION

The groundwater vulnerability assessment requires the development of good conceptual understanding of the groundwater flow system for the source protection area, which is based on maximizing the reliability and level of confidence of available data. The development of a proper conceptual model is considered more critical to produce representative and useful vulnerability analysis than is the actual method used to calculate the vulnerability scores.

The development of the conceptual model of the groundwater flow system involves the collection and assessment of a wide spectrum of information related to: the hydrogeologic framework (physical dimensions) of the groundwater system, including the thickness, extent and continuity of the hydrostratigraphic unit; the hydraulic properties of each hydrostratigraphic unit; and the boundaries of the flow system (recharge/discharge areas, direction and rate of groundwater flow, distribution and rates of pumping, and changes in the flow system with time). In addition, the evaluation of the physical characteristics of the flow systems can provide information on groundwater origin and residence times. As well, this geochemical (water quality) characterization is considered an important aspect of the overall conceptualization as it can be used to provide independent verification of the results of vulnerability assessment. The following summarizes some of the important functions of the conceptual model for vulnerability assessment:

- Determination of the distribution of aquifers and appropriate target aquifers for which vulnerability assessment will be required.

- Identification of key processes controlling the groundwater flow and determine how these processes should be represented with the modelling and methods for vulnerability assessment.

- Identification of data gaps and deficiencies in the conceptual understanding of the study area hydrology.

- Data quality control since poor quality lithological logs (from water well records for example) that are inconsistent with a conceptual understanding of the geology will become apparent and can be removed from the interpretation.

- Independent evaluation of the results of the travel time vulnerability assessment methods.

The development of the conceptual model for the groundwater vulnerability was built upon and consistent with conceptualization developed in the water budget and water quantity risk assessment appendices. The following summarizes the different scales of conceptualization of the groundwater flow system that are required for vulnerability assessment.

- Regional scale, consistent with the footprint of the source protection area.

- Sub-regional scale, consistent with the footprints of the highly vulnerable aquifers, and significant groundwater recharge areas.

- Municipal wellhead protection area scale.

- Local scale, in areas of previously identified high risk land activities.

The level of detail in the conceptualization of the regional flow system is unlikely to be adequate for the local scale investigations, although it will provide an important understanding of the regional context and provide the initial basis for delineating the sub-regional scales associated with the "vulnerable areas". The vulnerability analysis can be refined as part of the continuous improvement process. In particular, the risk assessment results can be used to prioritize additional data collection efforts and refinement of the conceptual model in areas of high risk land use activities.

2.3 GAP ANALYSIS

During the review of the data requirements for the other chapters and appendices of the assessment report, and the hydrogeological conceptualization described in the above section, gaps in the spatial and temporal coverage of hydrogeological data (and deficiencies in the quality of the data) were identified. After reviewing the previous groundwater management studies for the Sault Ste. Marie area, the following data gaps have been identified:

- Because of the sparse data over the Precambrian uplands a large number of data points were introduced using the surface water body features and the same levels were assumed in the previous groundwater studies.

- ISI mapping was carried out in the groundwater study from 2003 with the assumption that water table levels in the Precambrian uplands were supposed the same as the level of surface water bodies. The Provincial Groundwater Monitoring Network installed in 2005, includes 13 monitoring wells. The water table monitoring data available from these wells will be used to refine the ISI mapping analysis.

- The hydraulic conductivity values were assumed in the Surface to Well Advection Times (SWAT) approach (Burnside, 2003) to identify time of travel (TOT) zones. The knowledge of aquifer overburden is important in developing accurate hydraulic conductivity values to be used in groundwater flow modelling.

The assessment and prioritization of additional data collection efforts required to fill the gaps will be conducted as part of the continuous monitoring and improvement process that follows the risk assessment. The gap analysis for the groundwater vulnerability assessment was built upon the gaps identified in the watershed characterization.

3.0 SELECTED APPROACH

Groundwater contamination is one of the most important environmental quality concerns. The subsurface migration of chemicals released at the surface or (in the subsurface) poses a risk to groundwater and surface water resources. The impacts from persistent chemicals can be long-lasting and impair water quality conditions over relatively large areas. The objective of the groundwater vulnerability assessment methods is to provide a quantification of the relative intrinsic vulnerability of the aquifer within the Source Protection Area and therefore as a means of providing assistance to prioritize risk management activities and implementation of effective groundwater protection programs. In this context, “intrinsic” refers to the level of protection provided by the natural physical conditions overlying the aquifers (i.e. independent of the potential contaminant or contaminant release scenario).

There are numerous approaches that have been developed over the past few decades for assessing the intrinsic vulnerability of aquifers to surface sources of contamination. These range from general qualitative hydrogeological interpretations to GIS overlays mapping, indexing methods and detailed numerical modelling. The selection of approach is dependent on local factors, available data and analysis from the previous studies. A summary of these methods can be found in U.S. Environmental Protection Agency (1993), National Research Council (NRC, 1993), Vrba & Zaporocev (1994), Foster (2002) and U.S. Geological Survey (2002). The following factors were considered in selecting the appropriate approaches for the vulnerability analysis.

- ***Existing studies of the watershed (nature, compatibility, adequacy to meet the source protection plan requirements):***

Since 1997, municipalities and Conservation Authorities have undertaken numerous groundwater management studies all across the province that have been aimed at assessing the vulnerability of aquifers to contamination, delineating wellhead protection areas (WHPAs) and completing the inventory of potential sources of contamination within the WHPA.

An aquifer vulnerability assessment was undertaken through the evaluation of intrinsic susceptibility assessment following the Technical Terms of Reference (TTOR, MOE 2001). Results of this assessment indicated that in the area of lowlands, covered by thick clay layer and silt deposits, the aquifer is less susceptible to contamination. The shallow aquifer over the Precambrian uplands and parts of the recharge area has a relatively high intrinsic susceptibility for contamination (Burnside, 2003).

Under the Ministry of the Environment (MOE) initiative (2003), a Terms of Reference (TOR) was drawn up for the completion of Groundwater Vulnerability Studies in support of Ontario’s Drinking Water Source Protection. Further vulnerability assessment was undertaken within the WHPA with the application of advection modelling that evaluate the TOT from ground surface to the water table.

- ***Purpose and scale of the analysis:***

The rationale for groundwater assessment in 2003 was two fold: one was the identification of areas of concern including an inventory of wells and fuel tanks, and the second was the assessment of the potential for contamination and groundwater vulnerability. The study also included the inventory and assessment of potential contaminant sources; aquifer vulnerability mapping; review of land use plans; and identifying potential areas of risk. The study identified wellhead protection areas and low to highly vulnerable aquifers. The analyses were carried out on a watershed scale.

The objectives of the groundwater management study in 2005 were to further assess and delineate existing wellhead protection areas. The evaluation of aquifer vulnerability was based on the application of advection modelling (time of travel from ground surface to water table). The relative vulnerability of the aquifer was evaluated by using the defined advection times. The study area included the complete watershed.

- ***Existing data, gaps, data needs, accuracy and quality:***

There was sufficient data and analysis available from the previous groundwater management studies as per the Technical Rules. The groundwater level was assumed for the aquifer vulnerability indices approach by assuming that the groundwater coincides with the numerous water bodies over the uplands. The hydraulic conductivities appeared relatively high due to the absence of sparse well data. The aerial photography, IKONOS images and the DEM data were used in the interpretations. A total of thirteen (13) groundwater monitoring locations were installed in the watershed as per suggestion from the groundwater study of 2003. Water level data from five (5) wells was used as a representative for the Precambrian uplands to verify the previous studies.

- ***Environment which includes geology, hydrogeology, complexity of aquifer system, presence of thin overburden (shallow soils), fractured/karstic bedrock environment, etc.:***

The Sault Ste. Marie groundwater study area consists of two distinct landforms. The northern portion is topographically higher, consisting of relatively rugged terrain, and underlain by Precambrian granites. This area is referred to as “Precambrian uplands”. South of this region is the relatively flat lying area adjacent to the St. Marys River. Thick sand and gravel beach deposits located along the edge of the Precambrian uplands have been identified as the main “recharge area”. The flow of streams and rivers originating in the uplands provides significant recharge due to the infiltration through these granular deposits exposed at surface to the deep overburden bedrock aquifer. Three deep overburden aquifers, identified as “*west, central and east*”, separated by bedrock highs are located in the low lands. This low land area is covered by a thick clay-rich overburden unit consisting of glaciolacustrine clays. This forms the major confining unit and acts as an effective aquitard. As a result, artesian conditions are observed over large areas in local water levels, particularly in the “central basin”. In general the groundwater flow is from north to south and follows the surface topography.

The west basin consists of an upper sand formation along the shoreline area. The aquifer is overlain by silt and clay of variable thickness and contained significant quantities of silt, which is less suitable for groundwater development. There is currently no development of groundwater resources for municipal water supply within this basin.

The central basin appears to be directly connected with the “recharge area” with a number of streams from the uplands draining into this basin. Municipal wells (Goulais and Steelton) were typically found to be very productive and artesian conditions exist over a large part of this basin.

The east basin is narrow at the upland side and widens towards the St. Marys River. The aquifer consists of a combination of sand and gravel layer of varying thickness with the upper portion of the underlying sandstone. Both municipal wells fields produce high yield from this basin.

- ***Land use activities within the watershed:***

Being situated on the Great Lakes, the land use and development within the Sault Ste. Marie area has been shaped by the area's physical setting. Within the municipal boundary of the City, land use is represented by its most current Official Plan which came into effect in 1996 and was revised in 2003. Most development and the majority of the population are in the City of Sault Ste. Marie, along the north shore of St. Marys River on the lowlands. Other small communities are found along the northern shore of Lake Superior and on the Precambrian uplands, along the Hwy 17 North corridor. The Census data taken from Statistics Canada shows that the population in the Sault Ste. Marie Region in 1996 was 83 619, in 2001 was 78 908 and in 2006 was 80 098; the decline and very slight increase in population suggests that future changes to the present land use will be limited. It is estimated that the urbanized area accounts for approximately 9.8% of the overall planning region. This includes residential, industrial, commercial and institutional uses. The remainder of the area is mainly composed of rural lots, sparsely wooded lands and scrub areas. The estimated area of woodland is 71.5% (productive woodland), the area for scrub is 6% (non productive woodland) and the area suitable for agriculture is 9% of the overall planning region (SSMR Watershed Characterization, 2007).

- ***Water usage:***

Water use within the City of Sault Ste. Marie and surrounding area can be grouped into four categories as; individual/domestic, municipal/public, commercial/industrial and agricultural. The majority of the City of Sault Ste. Marie is serviced by a public supply of water. The individual/domestic water supply system/wells located primarily outside the Urban Service Line (USL) of the City, in Prince Township, Rankin Reserve and in Sault North planning area is within the study limits. It is assumed that all identified residential lots located in areas outside of the City limit have a well. Based on the domestic well user population of 9 426, the water demand within the study area is estimated as approx. 1.2 GL (1 204 170 m^3)/annum.

The Municipal/Public supply system accounts for the largest water-consumption category within the Sault Ste. Marie Planning Area and is located completely within the Urban Service Line area of the City of Sault Ste Marie. The system is comprised of groundwater and surface water, each contributing approximately equal portions to the municipal/public system.

According to the Sault Ste Marie Public Utilities Commission's 1999 data, approximately 15.0 GL (15 000 000 m^3) of water was delivered to the municipal/public water supply system (for a population base of 75 500), with groundwater and surface water accounting for 7.1 GL (7 100 000 m^3) and 7.8 GL (7 800 000 m^3), respectively for the year.

The commercial/industrial system is primarily serviced through the municipal network. Approximately 3.2 GL (3 200 000 m^3)/annum are accounted for in the municipal category. Based on MOE Permit to Take Water records, five additional wells are used for commercial/industrial purposes that are not accounted for in the municipal system. The total permitted volume of annual water taking for these purposes is approximately 0.16 GL (160 000 m^3).

There are various Permits to Take Water (PTTW) on file at the MECP for the City of Sault Ste Marie watershed, which draw water from groundwater. These permits range from less than 0.00005 ML (50 m^3)/day to 13.64 ML (13 638 m^3)/day. These groundwater uses are characterized as research, groundwater remediation, and communal water supply. In total, the maximum permitted volume of water taking for these purposes is approximately 0.88 GL (880 000 m^3)/day. These water takings show the significance of groundwater resources within the Sault Ste. Marie Planning Area with 50% of the municipal supply and most private residents draw their drinking water from the same groundwater aquifers.

- ***Potential for addressing the data requirements of the watershed as part of the continuous improvement process.***

As indicated from the previous groundwater studies, the latest available groundwater recharge rates were calculated in 1978. Their analysis determined that the average annual groundwater recharge rate are 3.5 - 4.4 MGD (13 249 - 16 656 m^3/d), 6.3 - 6.6 MGD (23 848 - 24 984 m^3/d), and 2.0 - 3.0 MGD (7 571 - 11 356 m^3/d) for East, Central and West Basin, respectively. It is understood that science has improved since 1978 and also the methods used for calculating the recharge rate at that time are still unknown.

In the previous groundwater management study (2003), the aquifer intrinsic susceptibility index (ISI) mapping was based on the assumptions that the groundwater table coincided with the numerous water bodies over the uplands and that the hydraulic conductivities of the upper weathered and fractured rocks were relatively high. In these calculations, the water table and hydraulic conductivities over the Precambrian upland were assumed based on the absence of well data in this area. This indicates a data gap and the potential exists to collect the data as part of the future continuous improvement process.

3.1 AQUIFER INTRINSIC VULNERABILITY ASSESSMENT

This is a specific indexing approach that takes advantage of the existing water well information system (WWIS) database within the province of Ontario to produce an index or numerical score for each well in the database. The susceptibility index considers the overburden soil type and thickness above the aquifer, and the static water level in the well. This index value is then interpolated between the well locations to produce a complete spatial assessment (map) of the intrinsic vulnerability of the aquifer(s).

3.2 MUNICIPAL SUPPLY WELL INTRINSIC VULNERABILITY

For the specific case where a municipal water supply well lies within the Source Protection Area, additional methods are available for assessing the intrinsic vulnerability of the aquifer contributing groundwater to the supply well. Initially, time-of-travel (TOT) capture zones defined for the supply well using one of the methods outlined above could be used to assess the relative vulnerability within the TOT capture zones.

3.3 INTRINSIC SUSCEPTIBILITY INDICES (ISI) APPROACH

The Intrinsic Susceptibility Index (ISI) vulnerability assessment approach was selected after a qualitative review of the available data and hydrogeological conceptualization within the Source Protection Area as well as the general land use conditions in the vulnerable areas. The following factors were also considered in selecting the ISI approach:

- The distribution, accuracy and nature of the hydrogeological data, including both physical delineation of the subsurface conditions, and existing water quality characteristics of the aquifers.

- The approaches (or availability of existing numerical models) that have already been applied within the Source Protection Area.

- The general land use conditions within the vulnerable areas and inherent risk associated with the existing or potential future land uses.

- The scale of the vulnerable area in relation to the density of hydrogeological data available to define the relative vulnerability within it.

The intrinsic susceptibility of a groundwater system depends on the aquifer properties (hydraulic conductivity, porosity, hydraulic gradients) and the associated sources of water and stresses for the system (recharge, interactions with surface water, travel through the unsaturated zone, and well discharge). In this way, intrinsic susceptibility assessments do not target specific natural or anthropogenic sources of contamination but instead consider only the physical factors affecting the flow of water to, and through, the groundwater zones.

The groundwater intrinsic susceptibility index (ISI) approach takes the advantage of the existing WWIS database, available from the MOE, to produce an index or numerical score for each well in the database. The index considers the overburden, soil type and thickness above the aquifer, and the static water level in the well. This index value is then interpolated between the well locations to produce ISI map of the aquifer. The ISI approach was adopted as a general standard.

The ISI index method uses the simplified assumptions that groundwater flow is vertical from ground surface to the top of the aquifer, and the vertical time of travel is controlled by the thickness and lithological properties of the materials above the water table or above the aquifer. Although the ISI method does not provide estimates of groundwater travel time, it does provide an efficient means to assess the intrinsic vulnerability based on the hydraulic characteristics of materials overlying the aquifers of interest.

The ISI analysis yields a numerical value, the index value, allowing a comparison of the vulnerability of the aquifer across the broader landscape as well as the vulnerable areas within the Source Protection Area. In this approach, when the index value is high (>80) the aquifer has a relatively low vulnerability to surface sources of contamination. And a lower index value (<30), indicates the aquifer is highly vulnerable. The ISI values are proportional to the degree of protection provided by the strata overlying the aquifer (i.e., proportional to the time of travel from ground surface, or near ground surface, to the aquifer). Following the calculation of ISI index values, mapping of the relative vulnerability was performed.

3.3.1 ISI Calculations

The ISI was calculated by summing the product of the thickness of each geological unit overlying the aquifer with its corresponding K-Factor. The K-Factor is a dimensionless number that can be related to the exponent of the vertical hydraulic conductivity of the geological material (in m/s). In effect, the objective in assigning the K-Factor is to relate (in a relative sense) the degree of protection offered by each respective geological material that overlies the aquifer. The K-Factors were garnered from the previous groundwater management studies, conducted in other parts of Ontario.

The aquifer Intrinsic Susceptibility index (ISI) is calculated as:

$$ISI = \left(K_1 \times d_1\right) + \left(K_2 \times d_2\right) + \ldots\ldots + \left(K_n \times d_n\right)$$

Where;

K_n and d_n are the hydraulic conductivity number and thickness of nth layer.

An evaluation of the intrinsic susceptibility of the aquifer to contaminants was carried out by the intrinsic susceptibility index (ISI) approach. The method is based on assigning a numerical score to each well in the area by considering the overburden soil type, thickness above the aquifer, and the static water level in the well. This ISI value is then interpolated between the well locations to produce a complete spatial assessment (map) of the intrinsic vulnerability of the aquifers.

A determination of whether the aquifer is confined or unconfined is necessary to apply the ISI technique. For unconfined aquifers, it is reasonable to assume that contaminants from the surface may only have to migrate to the water table to cause potential impact. If the water table is located less than 4m above the top of an aquifer, the aquifer is to be considered partially saturated and is to be classified as unconfined. For unconfined aquifers, the ISI value is calculated from ground surface to the top of the water table. For confined aquifer, it is assumed that contaminants from surface must migrate through the confining layers and reach the aquifer to cause potential impact. The aquifer is considered confined if it is fully saturated with the water table located 4 m above the top of the aquifer. For the confined aquifer, the ISI value is calculated from ground surface to the top of the aquifer.

The ISI was calculated by summing the product of the thickness of each unit in the well log and a corresponding K-Factor. The K-Factor is a relative number that can be loosely related to the exponent of the vertical hydraulic conductivity values. The calculation was performed from surface to a lower limit defined by the water table configuration (MOE, 2001).

Based on this analysis, the higher the ISI, the less sensitive is the aquifer. Three classes of aquifer sensitivities have been identified (MOE, 2001).

- *Areas with ISI>80 is considered as low vulnerable;*
- *areas with ISI less than 80 but greater than 30 is classed as medium vulnerable; and*
- *all areas with ISI value less than 30 are grouped as high vulnerable areas.*

3.3.2 Selecting the Target Aquifers

3.3.2.1 Uppermost (Shallow) Target Aquifer

The broader landscape aquifer vulnerability mapping is focussed on the uppermost target aquifer. This aquifer is determined in the context of the overall hydrogeological conditions in the planning area, and consideration is given that; the use of the aquifer as a drinking water source; the linkage of the uppermost aquifer to any local surface water systems and the sensitivity of these systems; and the linkage the aquifer might have to deeper aquifers that are used for drinking water.

The approach for determining the uppermost target aquifer used well logs within the Water Well Information System (WWIS). The geological materials within the well logs must be classified as aquifer material (or not) in order to determine the thickness of the aquifer units. Table 3.1 indicates the determination of aquifer material types using the GSC classification system as mentioned earlier. The following steps are necessary to select the shallow aquifer:

- Starting from ground surface, locate the first strata unit that is greater than 2 m thick and is at least partially saturated.

- If no aquifer is detected in step 1, locate the first strata unit below ground surface that is greater than 1 m thick and at least partially saturated.

- In some cases (e.g., where no aquifer material is detected in the well log), it may be appropriate to assume the aquifer is located at the well screen, and the top of the aquifer can be set to the depth of the top of screen.

3.3.2.2 Deeper Overburden and Bedrock Aquifers

In addition to evaluating the vulnerability of the uppermost target aquifer, it is also appropriate to evaluate the vulnerability of deeper aquifers. The Sault Ste. Marie municipal water supplies utilize deeper aquifers for groundwater extraction and shallow groundwater is not used for the municipal water supply. There are significant confining layers between the deeper aquifers and the shallow aquifers. Aquifer mapping and characterization has defined distinctly separate aquifer units and the deeper aquifer systems play an important role in sustaining surface water conditions in the Source Protection Area.

The methodology for calculating the ISI described earlier remains suitable for the deeper aquifers, with the target depth becoming the top of the respective aquifer. In each of the index approaches, it is assumed that flow to the target aquifer is vertical and the validity of this assumption should be evaluated especially for deeper aquifers where there may be horizontal travel in overlying aquifers. The data included from the WWIS in the ISI calculations for deeper aquifers may need to be restricted to those locations where the aquifer has been identified.

3.3.3 Depth to Water Table

The depth to the water table (DWT) can be obtained by subtracting the water table elevation from the ground surface elevation. The water table elevation should be determined from direct measurements, sourced from one or more of the following: records with the WWIS (using the static water level information in this database); detailed studies within the Source Protection Area; and permanent water bodies that are inferred to reflect the local groundwater table. Expertise and judgment should be used to determine which wells most accurately represent the water table as opposed to those representing the piezometric surface of deeper aquifers.

Once all points have been compiled and assessed the water table surface can then be interpolated across the Source Protection Area and/or within each of the "vulnerable areas". The water table elevation can then be subtracted from the DEM (digital elevation model), to obtain the depth to the water table. Where negative values are calculated from this approach, they should be corrected to ensure that the water table surface remains, at the most, 0.5 m below the ground surface. The inferred water table elevation values can then be written to the database, for use in the ISI calculations.

3.4 VULNERABILITY ASSESSMENT

3.4.1 Highly Vulnerable Aquifers (HVAs)

The relative vulnerability of groundwater to contamination is determined within each aquifer. Vulnerability is associated with travel times of contaminants from the soil surface to the underlying aquifer. Travel times of contaminants are short in duration indicates that the aquifer well is deemed to be more vulnerable.

For the delineation of HVAs, the *Technical Rules (2009)* require:

- Assessment and delineation of groundwater vulnerability (Part IV.1, Rules 37 and 38);
- Delineation of Highly Vulnerable Aquifers (Part V.1, Rule 43);
- Assignment of vulnerability scores. Highly vulnerable aquifers outside of a WHPA area are given a score of 6 (Part VII.1, Rule 79);
- Identification of the impact of anthropogenic transport pathways (Part IV.1, Rules 39 and 40);
- Analysis of uncertainty as High or Low (Part I.4, Rules 13-15);
- Determination of threats and issues within a HVA with a score of 6 (Part X and XI);
- Calculations of Risk Score = Hazard Rating (range from a low of 1 to a high of 10) x Vulnerability (Part X and XI). A Risk Score greater than or equal to 80 is a significant threat, 60 to 79 is a moderate threat and 40 to 59 is a low threat. An

HVA can never contain a significant threat according to the proposed Risk scoring system contained within the Director's Rules.

Highly Vulnerable Aquifers (HVAs) were mapped using the Intrinsic Susceptibility Index (ISI) described in the previous section. ISI analysis and mapping were available across the entire study area from Burnside, 2003. The ISI methodology was considered to assess the vulnerability in the source protection area. Previous groundwater studies followed a consistent terms of reference, methodology and review through an MOE developed peer review process. Parameters such as bedrock elevation, overburden thickness, sand and gravel thickness and depth to water table were taken into consideration in delineating the HVAs.

The purpose of the bedrock surface elevation mapping is twofold: to identify bedrock valleys with thicker permeable overburden deposits in which potential aquifers may be located; and to define bedrock highs and lows which could control groundwater occurrence and movement. The highest bedrock surface elevations correspond to the Precambrian uplands which encompass most of the northern half of the study area. Bedrock elevations as high as 440 m occur in the uplands area and drop rapidly in areas of Cambrian sandstones. A comparison of the bedrock surface elevation (**WC Map 2B** - Chapter 1) and the ground surface elevation (**WC Map 2D** – Chapter 1) confirms that there is less overburden in the Precambrian uplands.

The overburden thickness presented in **WC Map 2E** – Chapter 1, was prepared by subtracting the bedrock surface elevation (**WC Map 2B** – Chapter 1) from digital elevation model (**WC Map 2D** – Chapter 1). From this map, it appears that the overburden thickness in the west basin reaches a depth of over 140 m. However, the recharge from the Precambrian uplands to this west basin appears to be limited since only a small number of streams drain into the upper reaches of this basin. Previous groundwater exploratory work completed in this area indicated that the groundwater resource potential is limited (IWS, 1979).

The central basin appears to be directly connected to the "recharge area". Also seen on **WC Map 5** – Chapter 1 is that a greater number of streams over the Precambrian uplands drain into this central basin. Although, the overburden thickness appears to be considerably less, particularly in the southern part of this basin, the wells in this area were found to be very productive. Artesian conditions exist over a large part of this basin because of high recharge from the streams discharging into the "recharge area" in the upper reaches of the aquifers. The east basin's recharge area is narrow on the up-gradient side and widens towards the St. Mary's River. A portion of the Root River system drains into this basin and the underlying aquifers in this basin have been found to be productive.

WC Map 2E – Chapter 1 illustrates a thin overburden varying from 0 m to 20 m covering the Precambrian uplands in the northern part of the study area. As such, overburden aquifers do not, generally, exist over the Precambrian uplands, with the exception of some areas along the Hwy 17 and railway corridor where overburden sand and gravel deposits have been mapped. South of the uplands, the majority of the area has 20 m to 60 m of overburden. Three isolated areas in the west basin have deep depressions in the sandstone and overburden of 100 m to 150 m thick.

Bedrock highs separating the three basins control the water table in the unconfined aquifer and the piezometric surface in the deeper confined aquifers. The bedrock high areas form the aquifer boundaries and the groundwater flow is generally north to south, parallel to the boundary highs. The groundwater model simulation results indicate that the upper overburden formations are thin along the bedrock highs and could potentially be drained completely under steady state conditions of continuous pumping over a long period (Burnside, 2003).

GWVA Map 02 illustrates the intrinsic susceptibility mapping of the Sault Ste Marie area. The "intrinsic susceptibility index" method (as per Technical Rule TR 37 (1)) was employed to identify the groundwater vulnerability across the source protection area. Most of the area covered by the Precambrian uplands has been assigned a high vulnerability score of < 30 due to the lack of overburden material over the bedrock areas. The aerial photography data, IKONOS images, DEM data, overburden thickness, and water table mapping were utilized in the interpretations. The resulting map (**GWVA Map 02**) shows the highly vulnerability over most parts of the Precambrian shield, with the exception of parts of the Hwy 17 corridor where relatively thick overburden materials have been mapped. Along portions of this highway, moderate vulnerability areas have been identified. Most of the area over the low lands covered by thick clay and silt deposits has been identified as having low vulnerability. Artesian flowing well conditions exist over parts of the "Central Basin" and the "East Basin", which effectively protect the deeper aquifers (Burnside, 2003).

It is noted in the Sault Ste. Marie Groundwater Management Study that the Precambrian upland is the most vulnerable area due to absence of overburden material. Overland flow from this area directly infiltrates to the Significant Groundwater Recharge Area which is connected to the all municipal groundwater wells. Review of three (3) Provincial Groundwater Monitoring Network (PGMN) well's water level data for the year 2007-2010 confirm the water table elevation presented in **WC Map 05A** – Chapter 1. It appears that there is some indication between the local PGMN well water levels and stream flow observations, there may be some shallow, fractured bedrock aquifers exist in the Precambrian Upland area. This could also be seen as some of the stream flows continuously during the winter months.

The source protection area was further divided into areas of high, medium or low groundwater vulnerability using TR 38 (1). Areas of high vulnerability are those areas with scores that are less than 30. According to the AVI methodology and Technical Rule (TR 43), an area with vulnerability score of 6 has "high" groundwater vulnerability and is therefore an HVA. This analysis assumes that the vulnerability of the aquifer increases as the relative amount of protection provided by the overlying geological materials decreases. The type and thickness of the overlying material is crucial to the scoring. As per TR 43, "an area identified as an area of high groundwater vulnerability in accordance with Part IV and the subsurface beneath that area shall be delineated as a highly vulnerable aquifer". Based on Burnside (2003) analysis, approximately 360 km^2 of the source protection area has an ISI score of less than 30. Therefore, all of this area is considered to have high groundwater vulnerability.

4.0 WELLHEAD PROTECTION AREA MAPPING

Wellhead Protection is the component of drinking water source protection that manages activities around municipal groundwater supply wells. This can be achieved by identifying the land area that recharges the well fields and then responsibly managing land use activities within those areas.

A Wellhead Protection Area (WHPA) is the land area below ground, which contributes water to the municipal wells and well fields. Under normal pumping conditions, this area is also known as the zone of contribution. Recharge zones are also known as "capture areas." A capture area defines a surface beneath where infiltrated water will be "captured" by a well or well field. When a time-of-travel (TOT) criteria is applied to capture areas, a time-related capture area is defined. This capture area is delineated as an area surrounding the well.

The wellhead protection areas for each municipal well in the Sault Ste. Marie planning region were delineated. For this assessment report, the existing delineated maps were used to assess the vulnerability. Each wellhead protection area map was sub-divided into the following four zones:

WHPA-A Pathogen Security / Prohibition Zone - 100 m radius: Wellhead protection area WHPA-A (defined as a 100 m radius around the municipal well) is mapped as one continuous sensitivity area and applies for all potential contaminants. This zone is considered a Pathogen Security / Prohibition Zone. Within this zone there is no consideration given to the results from the vulnerability assessment – the intrinsic vulnerability score will be solely based on proximity to the supply well.

WHPA-B Pathogen Management Zone - 2 year TOT capture zone: Wellhead protection area B is (defined as the 0 to 2 year TOT capture zone) the Pathogen Management Zone. Vulnerability scoring is not required for the pathogen risk assessment beyond WHPA-B unless the pathogens threats inventory identifies the need to apply a risk assessment to a specific drinking water threat or threats in these areas.

WHPA-C Dense Non-Aqueous Phase Liquids (DNAPL)/contaminant protection zone - 5 year TOT capture zone: Wellhead protection area C (generally defined as the 2 to 5 year TOT capture zone, although with respect to DNAPLs, WHPA-B is also included with WHPA-C). This is referred to as the DNAPL Contaminant Protection Zone. With respect to DNAPLs within WHPA-C, there is no consideration given to the results from the vulnerability assessment – the intrinsic vulnerability score is solely based on the area represented by WHPA-C. For all contaminants other than pathogens and DNAPLs within this zone, consideration is given to the results of the vulnerability assessment.

WHPA-D Secondary Protection Zone - 25 year TOT capture zone: Wellhead protection area D (generally defined as the 5 to 25 year TOT capture zone). This is referred to as the Secondary Protection Zone.

These zones are used to identify the varying levels of potential risks faced by a municipal supply well from pathogens and chemical contaminants.

The Time of Travel (TOT) approach to wellhead protection area mapping forms the basis of assessment for municipal supply wells. This approach is conservative, as it is based on a 2D (plan-view) projection of the time of travel of groundwater or other substances to flow from a given point within the aquifer to the wellhead location. It does not directly consider the complete time of travel from the ground surface to the well (i.e., there would be additional time of travel through the unsaturated zone and in some cases from the water table to the supply aquifer itself).

4.1 WHPA CAPTURE ZONE DELINEATION

The municipal WHPAs were delineated by using a three-dimensional regional groundwater flow model, developed through the Visual MODFLOW modelling platform. The main objective of the modelling was to delineate capture zones of the municipal wells using a calibrated groundwater model. Five time-dependent capture zones were delineated, showing 50 day, 2 year, 5 year, 10 year and 25 year capture zones. For the groundwater vulnerability assessment, the 50 day capture zone is replaced with the 100 m (WHPA-A), which is a delineation of a 100 m radius circled around the wellhead areas and independent of modelling (Burnside, 2003).

As the main purpose of this modelling exercise was to delineate the capture zones for the municipal wells, the model domain was extended to cover the City of Sault Ste Marie and surrounding areas up to the “recharge area” in the north, but did not include any part of the Precambrian uplands. The four municipal well fields (Goulais Wells, Steelton Well, Lorna Wells and the Shannon Well) in the City were included in this modelling (Burnside, 2003).

The model chosen to perform numerical groundwater flow simulations for the Sault Ste. Marie groundwater study was developed using the finite difference code MODFLOW (McDonald and Harbaugh 1988). MODFLOW was chosen for its ability to accommodate heterogeneous systems in three dimensions. This is important to accurately depict the lateral and vertical variability of overburden units, and the vertical variability of bedrock units. MODFLOW also accommodates variable recharge rates, which apply to the study area, as well as large amounts of physical data to model recharge and discharge areas, to assess the potential for contamination and to determine capture zones for pumping wells. The main advantage of MODFLOW over more complicated three dimensional finite-element models is that it is simpler to use and facilitates efficient calibration of regional-scale models. The particle tracking code MODPATH (Pollock, 1994) was designed specifically to be used with MODFLOW. MODPATH applies the groundwater flow field generated by MODFLOW and can be used to define the origin and destination of groundwater moving through the model. In this study, MODPATH was used to delineate capture zones of the municipal water wells (Burnside, 2003).

4.1.1 Data Sources

The hydrogeological analysis completed in the study provided the basic inputs to the model. Detailed model inputs were drawn where necessary from the following sources:

- MOE water well records data base, also referred as the Water Well Information System (WWIS),
- Natural Resources and Values Information System (NRVIS) database, which includes Ontario Base Map (OBM) layers,
- Quaternary geology and bedrock geology maps prepared in this study,
- MOE Permit To Take Water (PTTW) database, and
- Engineering Report pertaining to the operating groundwater supply wells.

4.1.2 Model Domain

The extent of the model domain for the Sault Ste Marie area model covered the City of Sault Ste. Marie, part of the Township of Prince (west of the City) and parts of the Batchewana First Nation-Rankin Reserve and the Garden River First Nation east of the City. This model domain was chosen so that its boundaries represent the watershed of the St. Marys River west of Little Lake George. The location of the model boundaries is sufficiently far from municipal pumping wells to minimize the effect on model predictions (Burnside, 2003).

4.1.3 Model Input Parameters

The boundaries of the Sault Ste. Marie area model were chosen to correspond to physical boundaries within the overburden and bedrock aquifer flow systems. As described above, the model comprised of 6 layers, represented by 4 layers of unconsolidated material overlying 2 bedrock layers. The lower 2 layers represent the sandstone aquifer and the underlying granite. The top and bottom elevations of the overburden and bedrock aquifers were delineated from the detailed cross-sectional analysis of the hydrostratigraphy (Burnside, 2003).

The boundary conditions that are represented in the models include vertical recharge through the upper layer of the model, rivers and lakes at the ground surface, etc. Overburden hydraulic conductivity was estimated at each interpreted borehole by assigning hydraulic conductivity values to the observed lithologies. These point estimates were then interpolated to generate a surface of a spatially distributed hydraulic conductivity field and reclassified into groups. Vertical hydraulic conductivity was assumed to be 1/10th the horizontal conductivity. Initial estimates of hydraulic conductivities were taken from representative literature values (Domenico and Schwartz 1990) based on the lithologic descriptions taken during well drilling, and from site specific data collected from well tests in the study area (Burnside, 2003).

Vertical recharge due to precipitation and runoff is specified as input to the model. Quantitative measurements for recharge to the different units are not available. Direct recharge due to precipitation is variable and depends on the geology, with the recharge considered zero for bedrock, very low for silt and clay units and higher for sand and gravel units.

Pumping wells were assigned to the grid cells nearest to the well location coordinates. Pumping well construction details were used to assign well depth, casing depth and screen interval. The four well fields in the City were included in the model. The current groundwater taking of 6.0 ML (6 000 m^3)/day from each of the four (4) well fields was simulated in the model (Burnside, 2003).

4.1.4 Model Calibration

Model calibration involved minimizing the difference between simulated and observed water levels by adjustment of the input parameters while maintaining those parameters within a feasible range. The data used to calibrate the Sault Ste. Marie groundwater model is known as “regional water level data”, which was obtained from an MOE database. Steady state calibration was based on the MOE data that was collected over many decades and may represent significant uncertainty when used to define a single unique steady-state water level configuration. Data presented in the modelling report indicates that reasonable calibration of the model was achieved (Burnside, 2003).

Calibration statistics are shown in Table 4.1. The residual mean error indicates whether the model is over-predicting or under-predicting the water levels in the system and should equal or be near zero. A value of –2.75 m for the residual mean error indicates that the simulated water levels are somewhat low, on average, but considering the regional nature of the flow system this value is reasonable. The absolute residual mean error is a summation of all the calibration residuals and gives an indication of the magnitude of total error in the calibration. The root mean square error, representing the standard deviation of error in the model, was calculated as 11 m, reflecting the high variability and large uncertainty of the MOE data. The normalized root mean square error (Normalized RMS) is the root mean square error divided by the range of observed heads and gives an indication of the root mean square error per meter of head difference within the flow system (stated as a percent), and is generally considered good if it is 15% or less. As seen from the table, the Normalized RMS is 7.77%, is considered a reasonably low value for this flow system and indicates a reasonably calibrated model (Burnside, 2003).

Table 4.1: Model Calibration Statistics

Number of Observation Points	683
Residual Mean Error (m)	-2.75
Absolute Residual Mean Error (m)	7.94
Root Mean Square Error (m)	11.00
Normalized RMS (%)	7.77

A water balance considering all model inflows and outflows was also completed in order to evaluate whether the predicted groundwater flow through the calibrated model is representative of actual flow conditions. For a numerical solution to be considered accurate, a mass balance error of less than 1.0% is desired, indicating that groundwater mass is being conserved within the flow system. The difference between total inflow and total outflow in the Sault Ste. Marie model is less than 0.001%, which indicates that there is a high degree of accuracy to the steady-state solution (Burnside, 2003).

4.1.5 WHPA Delineation

The capture zone for WHPA’s delineation was completed using the steady-state groundwater flow model described above, and MODPATH advective particle tracking. The capture zones provide insight into the source of water for each well.

Steady-state capture zones were delineated for municipal wells in the model domain using the following constraints:

- MODPATH was used to produce particle path lines;
- Reverse particle tracking from each wellhead was used to determine the general shape of the capture zone for each well;
- Forward particle tracking from recharge areas was then used to supplement the information gathered from the reverse particle tracking;
- Where two capture zones are directly adjacent to each other, professional judgment was used to determine the extent of each capture zones; and,
- Single particles, unrepresentative of other particle tracks were ignored.

The steady-state capture zones determined in this manner represent the ultimate source of water for each well based on the long-term, average pumping rates for the wells. A time-of-travel capture zone, defined as the volume of water that enters the well over a specified period of time, was determined by separating the steady-state reverse particle path lines into yearly increments. The nth year capture zone is delineated by connecting the endpoints of each n-year particle path line. The 100 m, 2 year, 5 year and 25 year TOT capture zones were delineated for the City municipal wells.

The municipal well capture zones for the City of Sault Ste Marie well fields delineated from the calibrated model simulations are shown in **GWVA Map 1**. As discussed later in this section, a sensitivity and uncertainty analysis of the modeled capture zones was completed to improve confidence in the model results. As can be expected, the capture zones incorporating the uncertainty analysis extend over larger areas. The **GWVA Map 1** presents the capture zones for the four well fields (Goulais Ave Wells, Steelton Well, Shannon Well, and Lorna Wells) in the City of Sault Ste Marie as delineated from the calibrated model.

The TOT capture zones associated with the municipal wells are stretched towards the northern area of the watershed. These capture zones are located within the East and Central basins where the wells are situated. The capture zones end at the significant recharge area (SGRA), which is located at the base of Precambrian uplands. This indicates that the SGRA is the most important recharge zone for these wells. The 25 year capture for the Shannon Well extends a small distance into the gravel deposit valley and some portion of Hwy 17 N within and beyond the City boundary. This indicates the importance of the gravel deposited unit as part of recharge zones for the municipal wells. Therefore, it is very important to protect this area from the potential sources of contamination.

5.0 VULNERABILITY ASSESSMENT

The relative vulnerability of the aquifer within each of the following vulnerable areas has been evaluated.

1) Broader landscape across the watershed (Highly Vulnerable Aquifers),
2) Wellhead Protection Areas (WHPA).

There are numerous approaches that have been developed for assessing the intrinsic vulnerability of aquifers to surface sources of contamination, ranging from general qualitative hydrogeological interpretations to basic mapping methods (including GIS-type overlays and indexing methods) to detailed numerical modelling. While many subtle variations can be found in the literature on how to apply these methods, they are all premised on the concept that the vulnerability of the aquifer decreases as the time of travel to the aquifer increases.

For this assessment, the intrinsic vulnerability indices approach was selected. This is a specific indexing approach that takes advantage of the existing Water Well Information System (WWIS) database, available within the province to produce an index or numerical score for each well in the database. The index considers the overburden soil type, thickness above the aquifer and the static water level in the well. This index value is then interpolated between the well locations to produce a complete spatial assessment in the form of maps of the intrinsic vulnerability of the aquifer(s).

The results from this approach reflect the intrinsic vulnerability of the vulnerable areas and are independent of the nature of the potential contaminants and the potential contaminant release scenario. The maps produced provide a relative indication within each “vulnerable area” of the intrinsic susceptibility of the underlying aquifer to contamination from drinking water threats. This information will not be used to assess the actual susceptibility for groundwater contamination on a specific property.

6.0 VULNERABILITY SCORE

The objective of this section is to complete the vulnerability scoring within each of the vulnerable areas. This vulnerability score will be carried forward into the risk analysis aspects of the assessment report (Chapter 6). In summary, the scoring process involved following steps:

1. Categorizing the relative vulnerability of the aquifer as" High, Medium or Low".

2. Mapping the wellhead protection areas (defined as various TOT capture zones) and intersect these areas with the intrinsic susceptibility index to assign the intrinsic vulnerability score.

3. Assigning the Tier 1 vulnerability score by considering the transport pathways within the WHPAs and assessing the uncertainty.

4. Overlaying the Highly Vulnerable Aquifer on Intrinsic Susceptibility Index and assign the intrinsic vulnerability score (to the maximum of 6).

The vulnerability scores from the above process range from 2 to 10 (representing low to high vulnerability). The thresholds (ranges) for categorization are provided in Table 6.1 and 6.2.

Table 6.1: Summary of ISI Scoring Classification Scheme (MOE, 2009)

ISI SCORE	AQUIFER VULNERABILITY
Less than 30	High
30 to 80	Medium
Greater than 80	Low

The following sections describe the detailed calculation and process of assigning the vulnerability scores and potential adjustments to the score that might arise from the presence (or potential presence) of constructed transport pathways. Such transport pathways (e.g., improperly constructed wells; pits and quarries) may serve to bypass the natural protective geologic layers above the aquifers of interest and where present they could be used to support an increase in the intrinsic vulnerability and resultant vulnerability score as part of the risk assessment. However the vulnerability score could be subsequently re-adjusted in response to local risk management activities (e.g., mitigation of constructed pathways) or refinements in the vulnerability assessment. Further details on the Tier 1 and Tier 2 water quality risk assessment process and analysis is provided in Chapter 6 of the Assessment report.

Table 6.2: Vulnerability Score within WHPAs

Capture Zone	Vulnerability Score		
	High	Medium	Low
WHPA-A 100 m (exclusive)	10	10	10
WHPA-B 2 yr TOT	10	8	6
WHPA-C 5yr TOT	8	6	4
WHPA-D 25 yr TOT	6	4	2

6.1 INTRINSIC VULNERABILITY MAPPING

An index method (ISI) has been applied across the broader landscape; the index scores were categorized and interpolated to identify the “Highly Vulnerable Aquifers”. Both the uppermost (shallow) aquifer and deeper overburden and/or bedrock aquifers were also considered in this analysis.

For ISI, the categorization as presented in Table 6.1 was followed. In this case, index values < 30 were categorized as “High”, index values ranging from 30 to 80 were categorized as “Medium”, and index values > 80 were categorized as “Low”. Following categorization, the data was interpolated across the broader landscape in order to identify the highly vulnerable areas for each aquifer of interest. It was important that completed interpolation was used in the categorized (rather than index) values. This provides a conservative approach in mapping the highly vulnerable areas. The resulted delineation is presented in the **GWVA Map 2**.

The resulting map shows a high vulnerability class (ISI value < 30) over most parts of the Precambrian shield, with the exception of parts of Hwy 17 corridor in the north, moderate vulnerability (ISI value in between 30 to 80) areas have been identified along the foot of the Precambrian shield where the slope transitions to low lands. Most of the area over the low lands covered by thick clay and silt deposits has been identified as having low vulnerability (ISI value >80).

6.2 INTRINSIC VULNERABILITY (IV) SCORES IN WELLHEAD PROTECTION AREAS (WHPAS)

As described earlier, the intrinsic vulnerability (IV) scoring in wellhead protection areas (WHPA) requires categorizing the relative vulnerability within the TOT capture zone as High, Medium or Low, and intersecting these results with the various TOT capture zones that define the WHPA. Based on the intersection, a vulnerability score was assigned as summarized in Table 6.2.

After categorizing the vulnerability results and identifying the sensitivity areas within the TOT zones, vulnerability scores ranging from 2 (low vulnerability) to 10 (high vulnerability) were assigned within the WHPA. Table 6.2 summarizes the vulnerability scores giving consideration to the methods used to complete the vulnerability and WHPA assessments, the sensitivity (TOT) areas, and the potential contaminants of interest (pathogens, DNAPLs or others).

The **GWVA MAP 1** illustrates the delineation of WHPAs time of travel zones and **GWVA MAP 2** presents the categorization of intrinsic susceptibility index. The resulting delineation of WHPA is presented in **GWVA MAP 3**, which shows the relative vulnerability score within the WHPAs. The score was assigned as indicated in Table 6.1. All areas covered by a 100 m radius around the well (WHPA-A) have been assigned a vulnerability score of 10 (high sensitivity). The relative vulnerability score of 6 to 8 assigned to 2-year time of travel (WHPA-B) indicates medium to high intrinsic susceptibility. For the 5-year TOT (WHPA-C) the relative vulnerability score of 4 to 8 has been assigned. The relative vulnerability score of 2 to 6 was assigned within the 25-year TOT (WHPA- D). As shown in **GWVA Map 3** portions of the 25-year capture zone area of Shannon and Lorna wells has a score of 6 as it intersects with the high intrinsic susceptible areas.

The same map indicates the high land use risk areas (IV score of 10) limited to (1 to 1.2 km^2) around Shannon and Lorna wells, and extends over 2.0 km^2 in an elongated shape around the Goulais Ave. and Steelton wells. The moderate land use risk area (IV score 4 to 6) is situated in the northern part of the city in the vicinity of the “recharge area”. The contaminant sources within the high and moderate land use risk areas could potentially pose a risk to the groundwater supplies if there are any spills or leakages from existing storage facilities.

The intrinsic susceptibility mapping (**GWVA MAP 2**) is indicative of the hydrogeological sensitivity (groundwater vulnerability) of the area and as such largely reflects the land use risk rating. In addition to the intrinsic susceptibility indices, the following land features have been considered; flood plains, overburden thickness over the Precambrian uplands, and distance from surface watercourses, wetlands, and environmentally sensitive areas. The land use risks ratings are defined as follows.

All areas within the Precambrian uplands where the overburden is less than 1 m is considered as a high sensitive land use area because there is a high potential for contaminants from such areas to be discharged into nearby surface water courses through surface runoff or shallow groundwater discharge. All areas within 10 m from the surface water courses and flood plains have been identified as high risk areas, because of high potential for the contaminants to be discharged in to these sensitive environments.

6.3 IV SCORES IN HIGHLY VULNERABLE AQUIFERS (HVAs)

With respect to Highly Vulnerable Aquifers, they may have originally been defined using the same thresholds shown in Table 6.2 and therefore by definition appear to be globally categorized as high intrinsic vulnerability – (with a vulnerability score of 6). The value of the intrinsic vulnerability score assigned to the identified Highly Vulnerable Aquifers outside wellhead protection areas was assigned a six (6) since these areas are Highly Vulnerable by definition.

No current technical study has been identified for any future municipal supply area delineation for the Sault Ste. Marie area. If a specific site were identified as part of the future municipal supply areas then WHPAs will be generated for these wells. The vulnerability scoring for those areas will follow the same process as for existing WHPAs. It is more appropriate to use the vulnerability mapping and scoring process to avoid placing undue restrictions on the land use or other focused risk management activities in areas where a supply well may not be commissioned.

The land use risk rating mainly addresses the risks to the groundwater source for the municipal wells and all the analysis provided above is based on the premise that no other additional municipal or private wells will be installed which would interfere with these existing wells. It should be noted that the capture zones analysis is based on the present conditions and any modifications to the groundwater withdrawal in the watershed could effectively modify the extent and shape of capture zones. As all six wells in the study area depend ultimately on the “recharge area”; any activities that could effectively reduce infiltration over the recharge area could have long-term effects on the water supply sources. As noted in the chloride impact study completed by IWC in 1995, the activities on the recharge area could affect the municipal wells in 15 to 25 years. The municipal well capture zones modelled in the study indicate that 25-year capture extends to the “recharge area” in some parts of the study area.

In order to ensure protection of the groundwater resources within the watershed, minimal risk exposure should be afforded to any future groundwater development in the Sault Ste Marie area. In this regard, the recharge area should be protected. For all practical purposes, the “recharge area” that needs to be protected could be identified as the area shown in **GWVA Map 5**. The intrinsic susceptibility over most of this recharge area was found to be high to moderate (IV Score 4 to 6).

6.4 TRANSPORT PATHWAYS ADJUSTMENT

The vulnerability of an aquifer may be increased by any land use activity or feature that disturbs the surface above the aquifer, or which artificially enhances flow to that aquifer. Transport pathways to aquifers such as large and small diameter wells and excavations can have a significant impact locally on the vulnerability of an aquifer (**GWVA Map 6**). The anthropogenic activities (e.g. drilling of domestic wells, construction of underground services, subsurface excavations, pits and quarries, etc.) could bypass this natural physical protection, thereby increasing the susceptibility, and the presence and potential impact of these features must be accounted for in the groundwater vulnerability and risk assessment process.

Natural transport pathways, such as fracturing, are accounted for in assessment of intrinsic vulnerability. Constructed transport pathways, however, are not accounted for within the assessment of intrinsic vulnerability. If these pathways are known to exist, they should be accounted for in the refined vulnerability scoring through the use of a constructed pathways modifier. The constructed pathways modifier is the increasing of the intrinsic vulnerability index by one step (i.e. from low to moderate or moderate to high) to reflect the higher vulnerability caused by the constructed pathway. The constructed pathway adjustment is part of the refined vulnerability index since it is reversible and may be removed or decreased. In extreme cases (e.g., a pit or quarry which completely breaches any low permeability layers overlying a deeper aquifer), an increase from low to high vulnerability could be considered. In either case, the resultant vulnerability score would change as a reflection of the enhanced vulnerability due to the assessed presence of transport pathways.

In some cases, it is not possible to adjust the vulnerability score for the constructed transport pathways. This applies to wellhead protection area WHPA-A, and to DNAPL threats within wellhead protection area zones B or C since those areas have already been assigned the maximum vulnerability score of 10.

The procedure to account for these pathways in the water quality risk assessment scoring involves the following components:

- **Collection of Constructed Pathways Inventory** - As part of the Issues Evaluation and Threats Assessment Chapter of the assessment report, an inventory of the constructed pathways was compiled. This inventory was collected as basic input for potential adjustment to the groundwater vulnerability score.

- **Determining the Appropriate Score Modifier** - The constructed pathways inventory was reviewed and assessed to determine an appropriate modifier value to add to the intrinsic vulnerability component of the score to account for the presence of such pathways. The bypassing of the natural protection of an aquifer will essentially increase the vulnerability index. Where an aquifer is already determined to be of high intrinsic vulnerability, no further increase is possible.

- **Modifying the Constructed Pathway Adjustment based on Risk Management Activities –** If further risk assessments are completed, the score modifier may be subsequently reduced if risk management activities have been undertaken to mitigate the impact of the constructed pathway.

6.4.1 Constructed Pathway Inventory

The constructed transport pathway inventory was taken from the Issues Evaluation and Threats Inventory Chapter, which provides the basis for the score adjustment. The following provides a general overview of the contents of the inventory for reference, Chapter 5 of the Assessment Report could be consulted for specific details on the inventory.

Examples of constructed transport pathways that may be contained in the inventory include:

- **Large Diameter Borings and Excavations -** Such as pits, quarries, mines, road cuts, ditches, other excavations and construction activities, storm water infiltration ponds, septic systems, and sanitary sewer infrastructure.

- **Water Wells and other Small Diameter Excavations -** Water wells (particularly those that are unused or improperly constructed/abandoned) and other small diameter excavations (e.g., oil and gas wells, aggregate or mineral exploration wells, test holes, field drainage tiles, etc.).

6.4.2 Determining the Appropriate Score Modifier

To account for the presence (and potential impact) of constructed pathways on groundwater quality, the intrinsic vulnerability determined from the intrinsic groundwater vulnerability assessment can be increased by the assessment to reflect (in a relative manner) an increase in the vulnerability of the aquifer of interest. The increase in the intrinsic vulnerability is to be limited (in general) to one step (from low to moderate or from moderate to high), except in extreme cases where the constructed pathway is considered to increase the intrinsic vulnerability of the aquifer from low to high. In this case (e.g., a pit or quarry which completely breaches any low permeability layers overlying a deeper aquifer) an increase from low to high vulnerability could be considered. After modifying the intrinsic vulnerability, the vulnerability score must be recalculated. The resultant vulnerability score would then reflect the enhanced vulnerability due to the assessed presence of transport pathways.

The resultant vulnerability score cannot be increased above a score of ten (10) for WHPAs or six (6) for HVAs. These are the maximum scores for these areas. In particular, this applies to WHPA-A, and to DNAPL threats within WHPA-B and C where maximum vulnerability scores of 10 have already been assigned (**GWVA Map 7**).

A study by TSH and Burnside & Associates was completed in 2007 to identify the abandoned/improperly constructed wells within the TOT zone of WHPAs. The conclusions and vulnerability score adjustment is discussed.

The initial desktop review indicated there could be as many as 458 properties with wells. The field survey confirmed 54 properties with wells and 224 properties that are unlikely to have a well. This leaves 180 properties that based on historical documentation and the presence of wells at nearby houses of the same age or older are considered as properties that may have wells. The assumption is that most if not all of these wells have not been properly decommissioned.

Lorna Well

All houses within the two year capture zone were taken out of the study due to the information gathered regarding timing of municipal servicing in area and information from residents. There were no abandoned wells found within the TOT zone of the Lorna well. Therefore, score (IV of 6) medium sensitivity is not recommended to change.

Shannon Well

Four properties were classified as having wells on their property along Trunk Road, and five properties potentially have wells. The properties with potential wells were visited during the field survey, however no further data was obtained. One of the potential properties is now a commercial plaza, another property is an abandoned public school. Therefore by considering that there is a presence of five abandoned wells within the capture zone of the Shannon well, the Tier 1 score is recommended to change as the Intrinsic susceptibility within the capture zone is modified from low to medium, so the vulnerability score is changed from low vulnerability (IV 4) to medium vulnerability (IV 6).

Goulais Well

Within the Goulais well 2-year capture zone, wells were confirmed on Chippewa Street, Walters Street, Cooper Street, Korah Road and Goulais Avenue. According to residents, the water mains were built following the amalgamation of Korah Township with the City of Sault Ste. Marie in 1965. Older homes along Goulais Avenue and Second Line built before the early 1960s, potentially have wells. Four properties on Chippewa Street have artesian wells in their front yards that were discharging water into the street's storm water ditches. There are 33 properties with confirmed wells and 10 properties that may have abandoned wells with the 2-year capture zone. It is recommended to raise the intrinsic vulnerability from low to medium for this capture zone (WHPA-B). By considering the medium ISI, the intrinsic vulnerability score for WHPA-B was changed from low (6) to medium (8) and the IV score was modified for WHPA-C from 4 to 6.

Artesian conditions exist within the 2-year time of travel (TOT) zone of the Goulais Well. When the municipal well is operated at moderate pumping rates, private wells will cease to flow. At higher pumping rates it is assumed that the water levels in the private wells drop thereby resulting in the private wells becoming transport pathways. There is anecdotal information that indicates there are some abandoned wells present below grade or in basements of homes. As a result basement flooding and flowing wells result when municipal well pumping is terminated. Therefore, the Goulais well municipal pumping is controlling artesian conditions within the 2-year TOT zone.

Steelton Well

Within the Steelton well 2-year capture zone, the water mains were installed during the 1950s and 1960s. Some wells were confirmed based on the survey results; however, there are several properties that potentially have wells for which no information is available. The Steelton area contains houses of varying ages (ranging from 1910 to 1980) and limited information to confirm time of water servicing. There are 17 properties have confirmed and potentially 165 properties may have abandoned wells. By considering the number of abandoned wells, the intrinsic vulnerability score for WHPA-B zone was modified from low (IV 6) to medium (IV 8) for the same reasons discussed in the previous Goulais well section.

6.4.3 Modifying the Constructed Pathway Adjustment based on Risk Management Activities

Where the intrinsic vulnerability ranking and resultant vulnerability score has been adjusted as part of the Tier 1 risk assessment (as described above), these adjustments can be reduced, or even eliminated, to account for risk management activities that may be completed as part of a Tier 2 risk assessment. Risk management measures could include:

- The proper abandonment of unused (or improperly constructed) domestic, exploration, monitoring and/or test wells.

- The proper infilling, sealing of excavations and/or pits.

- The management of the constructed pathways in a manner which reduces the risk of contamination via that particular pathway.

The adjustment associated with risk management may result in only reducing or removing the vulnerability ranking modifier and therefore it will return the vulnerability ranking to its original value.

7.0 UNCERTAINTY AND LEVEL OF CONFIDENCE

A scientific approach has been adopted to determine the vulnerable areas, delineation of the WHPAs, and vulnerability of the aquifers within these areas. All such approaches are subject to uncertainty. To account for uncertainty, an assessment and rating of the uncertainty associated with the vulnerability score is provided in this section. Ultimately, the uncertainty for each sensitivity area will need to be categorized as either high or low.

Wellhead capture zone uncertainty analysis has been an active research area over the past several years. A reference list and summary of approaches for uncertainty analysis for WHPA delineation is provided by W-Sahara (2005), while CREM (EPA, 2003) provides a more general discussion of uncertainty analysis methods in numerical modelling.

Uncertainty associated with the vulnerability score can be attributed to a number of factors including:

- Density of data;
- Quality and reliability of data; and
- Assumptions made when reducing or synthesizing the data

Obviously, where data quality and/or density are low, there is a high degree of uncertainty. Conversely, where data density and quality are high, there is a low degree of uncertainty. As outlined in the Technical Rules, the uncertainty associated with the risk assessment score is important, since it will be used along with the risk assessment score, to determine the need for additional data collection and/or analysis.

As outlined in the Technical Rule Assessment Report Groundwater Vulnerability section, for the purpose of this analysis, the uncertainty has involved the following steps:

- An evaluation of validity (or uncertainty) of the vulnerable areas, this includes the capture zones associated with the WHPA's, and the footprints of the SGRA's, and HVA's.
- An evaluation of validity (or uncertainty) of the relative vulnerability (i.e. high, medium or low) within each vulnerable area.
- Assignment of an uncertainty rating (high, medium or low) for each sensitivity area.

For the certainty analysis, the SSMR SPA was divided into two areas (low land area and high upland area) based on the level of the available data. Low land area is considered to have a "high" level of certainty based on the quality of data used (only those wells having high reliability rating considered from MOE well record). Conversely, the high upland Precambrian area is considered to have a low level of certainty due to the lack of high quality well record data that was used to assess the vulnerability. Accordingly, the WHPA footprints associated with all the groundwater wells are situated within a 'high" level of certainty.

For this study, one of the major challenges, given the distribution of the data within high Precambrian recharge area, was to assign the vulnerability score for that area. The study team prepared the ISI mapping using best available data and professional judgement.

7.1 UNCERTAINTY RATING FOR EACH SENSITIVITY AREA

It is concluded that the reasonably low uncertainty was achieved in this analysis by considering the following factors:

- The density of the water well data was high and the high level of confidence in the quality of the data.

- There were two previously completed groundwater studies which confirm the regional scale mapping.

- The numerical model (MODFLOW) has been sufficiently calibrated to observed data that includes aquifer testing at the well location, and water level data across the capture zone footprint, and there is a high level of confidence in the representation of the flow system (and flow system boundaries) through local hydrogeological studies.

- It is concluded from the section 1.1.4 that the normalized root mean square error (Normalized RMS) is the root mean square error divided by the range of observed heads and gives an indication of the root mean square error per meter of head difference within the flow system (stated as a percent), and is generally considered good if it is 15% or less. As seen from the table, the Normalized RMS is 7.77% and is considered a reasonably low value for this flow system and indicates a reasonably calibrated model. Therefore by considering that the model was reasonably calibrated, it is concluded that the vulnerability analysis have the low uncertainty in assigning the intrinsic vulnerability score.

8.0 CONTINUOUS IMPROVEMENT PROCESS

As part of a province wide initiative (MOE Provincial Groundwater Studies Program initiated in 2001 and 2005) most municipalities in the province, groundwater vulnerability information had been prepared and the first planning cycle is expected to make optimum use of this information. The drinking water source protection process and therefore the groundwater vulnerability assessment process are anticipated to be an ongoing management strategy. Continual improvement and development over time with assist in increasing the understanding of the overall groundwater resources in the study area and reduce uncertainty associated with its protection and effective management.

Presently, in the very sparsely populated areas within the High Precambrian upland area and the high level of uncertainty in this area associated with the current assessment is acceptable.

9.0 SUMMARY

The wellhead protection areas (WHPAs) for the municipal well fields in the Central and East Basin aquifers have been delineated based on the groundwater management study 2003. In this study numerical model (MODFLOW) was used to delineate the time of travel capture zones for the well fields.

Vulnerability scoring has been performed for the Sault Ste. Marie municipal wellhead protection areas according to the procedure described in Technical Rules. The results indicate that 100 m radius area around the WHPA having the score of 10 is highly vulnerable to contamination from surface sources. Most of the area within 2-year time of travel has a medium vulnerability (IV score 6) to surface sources of contamination. Some area with the 25-year capture zone of the Shannon and Lorna well fields has the medium vulnerability (IV score 6). It is also observed that some area within the 5-year capture zone of Goulais well has the medium vulnerability (IV score of 6).

The intrinsic vulnerability score of six (6) for the Highly Vulnerable Aquifers (HVA) outside the wellhead protection areas indicates that the aquifer is highly vulnerable to surface sources of contamination.

The Significant Groundwater Recharge Areas (SGRAs) was interpolated on the delineated intrinsic susceptibility areas and scoring was performed. The areas having the vulnerability score of six (6) were highly sensitive to surface sources of contamination. It was concluded that some of the highly vulnerable area within the SGRAs is also located with the 25-year capture zone of the Shannon and Lorna well fields. As a result of the changes to the Director Technical Rules 2017 future references to the vulnerability scoring within the SGRAs as a quality threat was to be removed. Wording in subsequent chapters and mapping has been amended to agree with the current version of the Director's Technical Rule Amendments.

The Intrinsic vulnerability score was reviewed and adjusted as per the evaluation of constructed transport pathways presence. The modified IV score of 8 (medium to high sensitive) was assigned for the 2-year TOT capture zone for Goulais and Steelton wells. IV score for 5-year TOT capture zone for Goulais well also changed from 4 to 6 (low to medium). All other scoring values were unchanged for the rest of capture zones.

There are large areas within the high recharge zone with little or no well data. This effectively limits the level of certainty for the vulnerability assessment within Precambrian area. The certainty level is found to be relatively high for the low land areas.

10.0 REFERENCES

Burnside 2003: Sault Ste. Marie Area Groundwater Management and Protection Study. R.J Burnside and Associates Limited.

Burnside 2005. Vulnerability of Municipal Groundwater Study, Sault Ste. Marie PUC. R.J Burnside and Associates Limited.

Circular 1224, by M.J. Focazio, T.E. Reilly, M.G. Rupert and D.R. Helsel. Contamination Potential Under Conditions of Uncertainty: National Academy Press. http://water.usgs.gov/pubs/circ/2002/

Doherty, J., 2002. PEST: Model Independent Parameter Estimation – 5th Edition. Watermark Computing, Brisbane, Australia.

Domenico, Patrick A. and Franklin W. Schwartz. 1990. Physical and Chemical Hydrogeology, John Wiley and Sons, New York.

Evers, S and Lerner, D N., 1998. How Uncertain is our Estimate of a Wellhead Protection Zone? Groundwater, v.36, no.1, pp.49-57.

Foster, S., Hirata, R., Gomes, D., D'Elia, M. and Paris, M., 2002. Groundwater Quality Protection: A Guide for Water Utilities, Municipal Authorities and Environment Agencies. World Bank Publication: Washington D.C., USA.

International Water Consultant Ltd., 1995. Report Investigation of Increasing Chloride Concentrations Goulais, Steelton, Shannon, and Lorna Wells, Sault Ste. Marie, Ontario.

International Water Consultants, 1997. Sault Ste. Marie Groundwater Recharge Area, Land Use Study 1997.

IWS, 1971. Report of Groundwater Investigation, Public Utilities Commission, Sault Ste. Marie.

Lerner, D.N., R. Davison, and N.G. Tait, 2004. Assessing the Potential Value of Urban Groundwater, Hydrology: Science & Practice for the 21st Century. Volume I, 293- 297.

McDonald, M.G. and A.W. Harbaugh. 1998. United States Geological Survey; A modular Three Dimensional Finite-difference Groundwater Flow Model, USGS Techniques of Water Resource Investigation, Book 6, Chapter A1.

MOE 2001. Ontario Ministry of the Environment Groundwater Studies 2001/2002 Technical Terms of Reference (TTOR).

MOE 2005. Generic Terms of Reference (TOR) for Municipal Groundwater Supply Vulnerability Pilot Studies.

MOE 2009. Technical Rules: Assessment Report, *Clean Water Act, 2006*

MECP 2018. Director's Technical Rule Amendments, 2017 – Supplemental Bulletin #3 – (August 2018)

National Research Council, 1993. Groundwater Vulnerability Assessment. http://books.nap.edu/books/0309047994/html .

Poeter, EP and M.C. Hill, 1998. Documentation of UCODE: A computer Code for Universal Inverse Modelling. U.S. Geological Survey Water-Resources Investigations Report 98-4080.

Guidelines for Delineation of Wellhead Protection Areas: Scientifically Defensible Information for Decision Makers. U.S. Geological Survey U.S. EPA, 1993. Office of Groundwater Protection, Washington, DC. EPA 440-6-87-010.

Vrba, J. and A. Zaporozec, 1994. Guidebook on Mapping Groundwater Vulnerability. International Association of Hydrogeologists. Verlag Heinz Heise. v.16. 131p.

W-Sahara, 2005. References on Topics on Well Capture Zones and Catchments. EU Consortium on Stochastic Analysis of Wellhead Protection and Risk Assessment. Available in web format at: https://cordis.europa.eu/project/rcn/52176/factsheet/en