Groundwater Vulnerability Analysis
Niagara Peninsula Source Protection Area

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1. INTRODUCTION

The Assessment Report Technical Rules (Ministry of the Environment, 2009) require vulnerability mapping to be prepared of highly vulnerable aquifers (HVAs) and significant groundwater recharge areas (SGRAs). These vulnerability maps are to account for transport pathways which can increase the vulnerability of an aquifer. For future evaluation of drinking water threats, vulnerability scores are assigned to the delineated HVAs and SGRAs. This Groundwater Vulnerability Assessment was completed to address these requirements for the Niagara Peninsula Source Protection (NPSP) Area (Figure 1.1) as described in Part IV, Part V.I, Part VII.1 and Part VII.2 of the Assessment Report Technical Rules:

- Part IV describes methods for assigning groundwater vulnerability including the identification of areas where the vulnerability may be increased due to the presence of transport pathways;
- Part V.I describes the delineation of HVAs; and
- Part VII.1 and Part VII.2 describe the assignment of vulnerability scores to HVAs and SGRAs, respectively.

1.1 Background

The Niagara Peninsula Conservation Authority Groundwater Study (Waterloo Hydrogeologic Inc., 2005) completed aquifer vulnerability mapping as part of its groundwater study. The study used two vulnerability assessment methods that are listed under the Assessment Report Technical Rules Part IV.1 Rule 37: (i) intrinsic susceptibility index (GwISI) (Figure B.5) and (ii) aquifer vulnerability index (AVI) (Figure B.9). This mapping has been presented in the NPSP Area Watershed Characterization report (Niagara Peninsula Conservation Authority, 2009) (Figure B.10).

SGRAs were mapped according to the Assessment Report Technical Rules Part V.2, as part of the Tier 1 Water Budget and Water Quantity Stress Assessment (Niagara Peninsula Conservation Authority and AquaResource Inc., 2009).

1.2 Hydrogeological Conceptualization

The regional hydrogeological setting has been summarized from other Source Water Protection studies completed for the NPSP Area.

NPSP Area aquifers can considered as four (4) main types:

(i) Surficial overburden; i.e. the Fonthill Kame-Delta Complex, the Dunnville Sand Plain and the Iroquois Sand Plain (Figure 1.2). These are unconfined aquifers consisting of coarse-grained deposits.

(ii) The Guelph/Lockport Formations (Figure 1.3), these bedrock aquifers range from (a) unconfined where they are exposed along the Niagara Escarpment, to (b) semi-confined beneath fractured/weathered overburden to (c) confined where overlain by greater than 5 m of overburden. These consist of mostly dolostone with some limestone limestone portions. Fracturing is expected to be greater where exposed at surface.

(iii) Onondaga/Bois Blanc Formations; (Figure 1.3), these bedrock aquifers also range from (a) unconfined where they are exposed along the Onondaga Escarpment, to (b) semi-confined beneath fractured/weathered overburden to (c) confined where overlain by greater than 5 m of overburden. These consist of dolostone and limestone. Fracturing is expected to be greater where exposed at surface.

(iv) "Contact zone" or the basal granular and top of bedrock aquifer (Figure 1.3), is a regional aquifer generally considered confined. It consists of granular overburden and fractured bedrock overlain by clay.

These units are also shown in regional cross-sections in Appendix A.

Although there are no current municipal groundwater systems in the NPSP Area, private water supplies serve over 77,000 people in the NPSP Area. The number serviced by aquifer units may be less, as only 6,600 private "drinking water" wells are on file in the NPSP Area Ministry of the Environment (MOE) water well information system (WWIS). However, many dug wells are not in this provincial database and cisterns are used very widely in the NPSP Area.

1.3 Technical Rules

The Assessment Report Technical Rules (MOE, 2009) provide the following instructions for the delineation of groundwater vulnerability. Rules concerning municipal wellhead protection areas were not included, e.g. rule 38.1, as there are no municipal wellhead protection areas in the NPSP Area. Assessment Report Technical Rules 13, 14 and 15 are presented separately under the Uncertainty Analysis Section 3.3.

Part IV.1 – Vulnerability Assessment and Delineation, Groundwater

37. The vulnerability of groundwater within a source protection area shall be assessed using one or more of the following groundwater vulnerability assessment methods,

(1) Intrinsic susceptibility index;
(2) Aquifer vulnerability index;
(3) Surface to aquifer advection time;
(4) Surface to well advection time, or

38. A source protection area shall be divided into areas of high, medium or low groundwater vulnerability, high corresponding to greater vulnerability as follows;

(1) Where a method described in subrule 37(1) or (2) was used to assess vulnerability;
(a) Areas of high vulnerability are those areas with scores that are less than 30,
(b) Areas of medium vulnerability are those areas with scores that are greater than or equal to 30 but less than or equal to 80, and

(c) Areas of low vulnerability are those areas with scores that are greater than 80;

(2) Where a method described in subrule 37(3) or (4) was used to assess vulnerability;
- *(a) Areas of high vulnerability are those areas with results that are less than 5 years;*
- *(b) Areas of medium vulnerability are those areas with results that are greater than or equal to 5 years but less than or equal to 25 years, and*
- *(c) Areas of low vulnerability are those areas with results that are greater than 25 years, or*

(3) Where, in accordance with rule 15.1, a method that departs from the methods specified in rule 37 has been used, to assess vulnerability, an approach shall be used that, in the Director's opinion, is comparable to the approach specified in subrules (1) and (2).

38.2 If more than one method is used to assess groundwater vulnerability, the results of both methods should be mapped separately.

Vulnerability increase, transport pathways

39. Where the vulnerability of an area identified as low in accordance with rule 38 is increased because of the presence of a transport pathway that is anthropogenic in origin, the area shall be identified as an area of medium or high vulnerability, high corresponding to greater vulnerability.

40. Where the vulnerability of an area identified as medium in accordance with rule 38 is increased because of the presence of a transport pathway that is anthropogenic in origin, the area shall be identified as an area of high vulnerability.

41. When determining whether the vulnerability of an area is increased for the purpose of rules 39 and 40 and the degree of the increase, the following factors shall be considered:

- *(1) hydrogeological conditions;*
- *(2) the type and design of any transport pathways;*
- *(3) the cumulative impact of any transport pathways; and*
- *(4) the extent of any assumptions used in the assessment of the vulnerability of the groundwater.*

Part VII.1 – Highly vulnerable aquifers

79. A highly vulnerable aquifer shall be assigned a vulnerability score of 6.

Part VII.2 – Significant groundwater recharge areas

80. *A significant groundwater recharge area shall be subdivided by the areas of groundwater vulnerability identified in accordance with Part IV rule 38.*
81. *The areas identified in accordance with rule 80 shall be assigned a vulnerability score of;*
    (1) 6, where the groundwater vulnerability for the area is high;
    (2) 4, where the groundwater vulnerability for the area is medium; or
    (3) 2, where the groundwater vulnerability for the area is low.

2. Methodology

The five (5) steps of the Groundwater Vulnerability Assessment included:

Step 1: Review and assess available data and interpretations – Section 2.1
Step 2: Assess Vulnerability – Section 2.2
Step 3: Consider Vulnerability Increase for Transport Pathways – Section 2.3
Step 4: Assign Vulnerability Score – Section 3.1 and 3.2
Step 5: Evaluate Uncertainty – Section 3.3

Information from these steps was evaluated semi-quantitatively using a methodology adapted from Jagger Hims Limited (2009). The scoring system was assigned to estimate the confidence in the available data and in each of the assessment phases.

Data sources:

- Site Selection and Assessment Reports prepared by Gartner Lee Limited in 1985 and 1987 on behalf of Ontario Waste Management Corporation
- Water Resources of the Niagara Frontier and the Welland River Drainage Basin Report prepared by Gartner Lee Limited in 1987 on behalf of the Ministry of the Environment
- Niagara Water Quality Protection Strategy prepared by CH2MHill, MacViro and Philips Engineering in 2003 on behalf of the Regional Municipality of Niagara and the Niagara Peninsula Conservation Authority
- Surficial geology and permeability mapping prepared by the Ontario Geological Survey in 1997 and 2003 for the Ministry of Northern Development and Mines
- Niagara Peninsula Conservation Authority Groundwater Study prepared by Waterloo Hydrogeologic Inc. in 2005 for the Niagara Peninsula Conservation Authority
- Hamilton Groundwater Resources Characterization and Wellhead Protection Partnership Study prepared by Charlesworth and Associates and SNC-Lavalin Engineerings and Constructors in 2006 for the City of Hamilton
- Draft Groundwater Resources Study prepared by the Hamilton Conservation Authority for the Ontario Geological Survey
- Aquifer Vulnerability Mapping prepared by EarthFx in 2008 for the Lake Erie Source Protection Region
- Significant Groundwater Recharge Areas Report prepared by the Niagara Peninsula Conservation Authority and AquaResource Inc. in 2009 for the NPSP Authority
- Ministry of the Environment Water Well Information System (2006)
- Ontario Oil, Gas and Salt Resources Library (2009)
- Ministry of Natural Resources historical pits and quarries and authorized aggregate sites

2.1 Review and assess available data and interpretations

Regional-scale NPSP Area groundwater vulnerability maps were reviewed for their suitability in the vulnerability assessment (Appendix B). From this review it was determined that the Niagara Peninsula Conservation Authority (NPCA) Groundwater Study (Waterloo Hydrogeologic Inc., 2005) mapping was most suitable basis for the groundwater vulnerability analysis. This was because:

1) It was produced using groundwater vulnerability assessment methods that are approved in the Assessment Report Technical Rules; and
2) It was the only map product which was seamless across the NPSP Area.

Waterloo Hydrogeologic Inc. assessed this groundwater vulnerability using GwISI and AVI methods, Assessment Report Technical Rules 37 (1) and 37 (2), respectively. The GwISI analysis was completed of the entire study area using MOE WWIS. The AVI analysis was only completed with respect to (i) surficial overburden and (ii) bedrock at surface aquifers, e.g. the Fonthill Kame-Delta Complex and Niagara and Onondaga Escarpments, respectively.

The final NPCA Groundwater Study groundwater vulnerability map was a conservative combination of the two methods. The GwISI results were similar to other consultants' adjacent maps in the City of Hamilton and Haldimand County where the MOE WWIS was the principal dataset (Appendix B).

2.2 Assess Vulnerability

The Groundwater Vulnerability was assessed by considering the suitability of the vulnerability as assessed by the following methods:

- Intrinsic Susceptibility Index (GwISI); and
- Aquifer Vulnerability Index (AVI) (based on regional hydrostratigraphic interpretations).

2.2.1 Intrinsic Susceptibility Index (GwISI)

As mentioned above, the GwISI map (Figure 2.1) was obtained from the NPCA Groundwater Study (Waterloo Hydrogeologic Inc., 2005). Details of the GwISI methodology are provided in Appendix B. The GwISI map is considered to reflect the vulnerability either to the water table aquifer or to the first confined aquifer layer. The vulnerability is based upon the following matrix:

GwISI/AVI Score	Vulnerability
<30 High	
30-80 Medium	
>80 Low	

Review of the GwISI against available regional hydrostratigraphic interpretations suggests that the distribution of high vulnerability is under-estimated in some areas. This is a limitation of digital contouring to map linear features, e.g. the Niagara Escarpment.

It is also a limitation of the distribution of the MOE WWIS dataset, both vertically, where there are multiple aquifers, and horizontally, between available well records. Despite these limitations the GwISI was considered a good basis for the vulnerability assessment but needing the improvement of some additional AVI mapping.

2.2.2 Aquifer Vulnerability Index (AVI)

AVI groundwater vulnerability assessments were also completed to improve the delineation of highly vulnerable aquifers. The specific aquifers considered were:

I. surficial water table aquifers (both overburden and bedrock); and
II. unconfined/semi-confined bedrock aquifers (i.e. having less than 5 metres of overburden).

The AVI groundwater vulnerability assessments were based on regional hydrostratigraphic interpretations (Section 1.2) and K-Factor assignments based on the aquifer/aquitard designation and the overburden thickness (Figure 2.2).

The AVI for the surficial water table aquifers correspond with High. The AVI for the semi-confined bedrock aquifers also correspond with High. The extent of the AVI vulnerability assessments for highly vulnerable aquifers are shown on Figure 2.3.

2.2.3 Combined Groundwater Vulnerability

The combined GwISI and AVI vulnerability assessments are presented on Figure 2.4 and tabulated in Table 2.1.

Table 2.1 GwISI/AVI Vulnerability Results

	High		**Medium**		**Low**	
Boundary (size km^2)	**km^2**	**%**	**km^2**	**%**	**km^2**	**%**
NPCA (2,409)	616	26%	740	31%	1,053	44%
Niagara Region (1,871)	541	29%	555	29%	776	41%
City of Hamilton (237)	29	12%	107	45%	101	42%
Haldimand County (302)	47	16%	79	26%	176	58%

Note: some disagreement between sum areas and individual values is caused by rounding of significant digits

The results of the mapping indicate the following as modified from the NPCA Groundwater Study (Section 3.3, Waterloo Hydrogeologic Inc., 2005):

Areas of low susceptibility occur mainly in the central portions of the NPSP Area, and correspond to thick deposits of clay and silt of the Haldimand Clay Plain. This material, below 5 m BGS, restricts the downward movement of infiltrating surface water, making the underlying groundwater much less susceptible to associated contamination.

Areas of high susceptibility:

1. *Occur mainly in the presence of high permeability overburden units with little, or no, low conductivity layers overlying the aquifer. These include the Fonthill Kame-Delta Complex, the Iroqouis Sand Plain, and the Dunnville Sand Plain.*
2. *Occur where the bedrock outcrops or is overlain by thin (i.e. <5 m) deposits.*

2.3 Vulnerability Increase for Transport Pathways

The transport pathways that were considered to have potential to increase groundwater vulnerability are (Figures 2.5a, b, c and d):

- Private water wells (including abandoned wells needing decommissioning)
- "Unknown" status oil and gas wells
- Aggregate operations; and
- Construction activities along the Welland Canal.

Other transport pathways, such as septic systems, storm water facilities and sanitary sewers, were not included as they are not likely to increase this regional groundwater vulnerability mapping. Explained further:

- Installation of in-ground septic systems only marginally increases groundwater vulnerability through removal of an upper soil layer, however they are still sources of contaminants, i.e. for potential consideration under threats and issues evaluations.
- Stormwater facilities are largely not infiltration basins in NPCA. Areas where infiltration facilities have been constructed are already classified as highly vulnerable, e.g. Fonthil Kame-Delta Complex.
- Sanitary sewers can laterally transmit contaminants however they are generally overlain by impervious surfaces. This study is primarily concerned with vertical vulnerability but they are still sources of contaminants i.e. for potential consideration under threats and issues evaluations.

2.3.1 Wells, existing

Private wells are considered to have the potential to increase groundwater vulnerability as transport pathways. Well clusters are identified as priority risks because of the high-density of wells connected to the underlying aquifer. Well clusters were defined as being six wells located within 100 m radius of each other (Jagger Hims Limited, 2009). This analysis was completed using MOE WWIS and Ministry of Natural Resources (MNR) oil and gas well records, but not including officially abandoned records. The groundwater vulnerability has been raised to high for a 30 m radius around each individual well (Figures 2.5a, b, c and d). A 30 m radius was chosen based on the recommended setback distance from contamination sources in Ontario Regulation 903 (Wells Regulation) as amended (this distance has also been incorporated in the Ontario Building Code). There were 750 wells identified in this analysis, only one was from the MNR dataset.

Wells older than 10 years old (pre-2000) were also considered transport pathways to potentially increase groundwater vulnerability. This is because newer wells are likely to be constructed to a higher standard and therefore a lower risk. The groundwater vulnerability has been raised to high for a 30 m radius around each of these 8,548 wells (Figures 2.5a, b, c and d).

In each of these cases the vulnerability was increased to high from either medium or low. This is because by its very nature a well is constructed as a pathway from the surface to the aquifer through the naturally protective layers, if present.

2.3.2 Wells, abandoned

There are 1,479 MOE WWIS records of former "water supply" wells in areas now serviced by municipal water. These transport pathways also present a high risk to the underlying aquifers. The groundwater vulnerability has been raised to high for parcels containing a well (Figures 2.5a, b, c and d). The groundwater vulnerability has been raised to high for a 30 m radius around each of the 332 well that were not located on parcels but roadways (Figures 2.5a, b, c and d).

2.3.3 Oil and Gas Wells

There are also oil and gas wells completed in the NPSP Area. Since the early 1990s, license requirements govern use and abandonment through the Ministry of Natural Resources. However the status of abandonment of some oil and gas wells prior to the 1990s is unknown. These earlier installations may not have been properly abandoned or plugged, i.e. they may not be sealed and if sealed, may not have been sealed in a method that will minimize the vulnerability of the shallow groundwater systems.

Potentially un-plugged wells, status being "unknown" and generally pre-dating 1992, have been included as transport pathways. The groundwater vulnerability has been raised to high for parcels containing these wells as they pass through the water supply aquifers. There are 1,633 unknown status wells in NPSP Area land mass while there are additional wells offshore.

2.3.4 Aggregate Operations

Aggregate operations, i.e. pits and quarries, are transport pathways reducing the amount of overlying material to filter and/or attenuate contaminants. In the NPSP Area there are 31 authorized aggregate sites, and 103 historic pit and quarry locations (Figures 2.5a, b, c and d). The vulnerability category for historic and licensed pits and quarries will be raised to high as there is no protection to the aquifer. These locations are already generally classed as highly vulnerable (Table 2.2) because they are sited where the resource is close to surface and correspond with overburden or bedrock aquifers.

Table 2.2 Aggregate Resources and Construction

GwISI/AVI Vulnerability	Transport Pathway Vulnerability	Area (km^2)	Percent (%)
High High		20.3	55
Medium High		15.8	43
Low High		0.6	2

2.3.5 Construction Activities along the Welland Canal

Construction activities can alter the natural environment through the removal of low permeability units. An example of this is the Welland Canal (Figures 2.5a, b, c and d). The canal's channel bed is directly on bedrock over two spans and acts as a source of recharge to the groundwater system (Frind, 1970), i.e. the contact zone aquifer. The St. Lawrence Seaway Management Corporation has confirmed that the two spans for which that the canal bottom is cut into bedrock are from (i) Glendale Avenue, St. Catharines to Hurricane Road, Thorold and from (ii) Ramey's Bend, south of Dain City southward to Lake Erie (Fraser Johnston, personal communication 2009). The susceptibility categories underlying these areas will be raised to high as there is no protection to the aquifer.

2.3.6 Transport Pathways Summary

Following Assessment Report Technical Rules 39, 40 and 41, medium and low groundwater vulnerabilities were modified to high. This was based upon the presence of transport pathways that have the high potential to, or actually remove, natural groundwater protection to water supply aquifers (Figure 2.6).

The overall increase in highly vulnerable aquifers from the consideration of transport pathways is 46 km^2 or about 2% of the NPSP Area (Table 2.3). Most of this increase is mapped in Niagara Region and the City of Hamilton.

Table 2.3 GwISI/AVI/Transport Pathway Vulnerability Results

	High		**Medium**		**Low**	
Boundary (size km^2)	**km^2**	**%**	**km^2**	**%**	**km^2**	**%**
NPCA (2,409)	662	27	711	30	1,036	43
Niagara Region (1,871)	557	30	544	29	77	41
City of Hamilton (237)	57	24	89	38	91	39
Haldimand County (302)	48	16	78	26	175	58

Note: some disagreement between sum areas and individual values is caused by rounding of significant digits

3. Vulnerability

3.1 Highly Vulnerable Aquifers (HVAs)

Highly vulnerable aquifers, i.e. areas of high groundwater vulnerability, were delineated for the NPSP Area based on the previously discussed analyses and are illustrated on Figure 3.1. The HVAs delineation reflects the increased vulnerability of the shallowest identified aquifers by transport pathways. As per Assessment Report Technical Rule 79, HVAs are assigned a vulnerability score of 6.

3.2 Significant Groundwater Recharge Areas (SGRAs)

Significant groundwater recharge areas (SGRAs) were previously mapped according to Assessment Report Technical Rules (Niagara Peninsula Conservation Authority and AquaResource Inc., 2009). The SGRAs cover 542 km^2 or about 22% of the NPSP Area based upon a criterion of 53 mm/year or greater (Figure 3.2). About half of the SGRAs are also mapped as highly vulnerable in the NPSP Area, as well as Niagara Region and Haldimand County (Table 3.1).

Table 3.1 SGRA Groundwater Vulnerability Distribution

Boundary (size km^2)	**SGRA size km^2 (% of Area)**	**High km^2 (%)**	**Medium km^2 (%)**	**Low km^2 (%)**
NPCA (2,409)	542 (22%)	270 (50%)	129 (24%)	144 (27%)
Niagara Region (1,871)	420 (22%)	230 (55%)	102 (24%)	89 (21%)
City of Hamilton (237)	82 (35%)	18 (22%)	21 (26%)	43 (53%)
Haldimand County (302)	40 (13%)	22 (55%)	6 (15%)	12 (30%)

Note: some disagreement between sum areas and individual values is caused by rounding of significant digits

Significant groundwater recharge areas are subdivided by the groundwater vulnerability and assigned scores of 6, 4 or 2 for groundwater vulnerabilities of high, medium and low, respectively. This is according to Assessment Report Technical Rules 80 and 81 (Table 3.2).

Table 3.2 SGRAs Vulnerability Score

Groundwater Vulnerability	Vulnerability Score
High 6	
Medium 4	
Low 2	

3.3 Uncertainty

The Assessment Report Technical Rules 13, 14 and 15 (MOE, 2009) provide the following instructions for analysis of uncertainty. Rules pertaining to surface water intake protection zones, i.e. 13(3) and 13(4) were not included.

Part I.4 – Uncertainty analysis – Water quality

13. An analysis of the uncertainty, characterized by "high" or "low" shall be made in respect of the following:

> *(1) the assessment of the vulnerability of groundwater throughout the area undertaken in accordance with Part IV;*
> *(2) the delineation of highly vulnerable aquifers, significant groundwater recharge areas and wellhead protection areas undertaken in accordance with Part V;*
> *(5) the assessment of the vulnerability of significant groundwater recharge areas, highly vulnerable aquifers and wellhead protection areas undertaken in accordance with Part VII;*

14. The following factors shall be considered in an analysis conducted for the purpose of rule 13;

> *(1) the distribution, variability, quality and relevance of data used in the preparation of the assessment report;*
> *(2) the ability of the methods and models used to accurately reflect the flow processes in the hydrological systeml*
> *(3) the quality assurance and quality control procedures applied;*
> *(4) the extent and level of calibration and validation achieved for models used or calculations or general assessments completed;*
> *(5) for the purpose of subrule 13(1), the accuracy to which groundwater vulnerability categories effectively assess the relative vulnerability of the underlying hydrogeological features; and*

15. An uncertainty factor of "high" or "low" shall be assigned to each vulnerable area delineated based on the results of the analysis conducted under rule 13.

The overall confidence in the Vulnerability Assessment as per Table 3.3 is 7 out of a possible 10. A value greater than 6 is assumed to reflect sufficient confidence that the results can be relied on for the purpose of the Vulnerability Analysis. The Uncertainty Score recommended for the NPSP Area Vulnerability Assessment based on Table 3.3 is Low. This uncertainty score reflects the combination of the confidence scoring assigned from the assessment of the quantity, quality and distribution of the available data. The uncertainty scoring suggests a high level of comfort in how representative the generated vulnerability scoring is for the NPSP area and how well it corresponds to the available data and previous work completed by others in the area.
However there are two potential areas of lower confidence within the overall assessment. These are the (i) delineation of the vulnerability of the contact-zone aquifer and (ii) including transport pathway adjustments.

The delineation of the GwISI contact-zone aquifer vulnerability is largely a function of the MOE water well records, not the actual stratigraphy. Consequently, some higher vulnerability areas where wells are not completed, may not have been mapped. Also the contouring procedure is of the well data, not the aquifer, and may not have "connected" higher vulnerability zones because of limitations of this automated process.

Both the exact location, and the status, of wells (water, oil and gas) considered to be transport pathways are unknown. However by their inclusion in the transport pathways assessment it is a conservative approach to address their potential to contaminate the aquifers.

As part of the uncertainty analysis peer review of this report was completed by two firms, Jagger Hims Limited a division of GENIVAR and Terra-Dynamics Limited. The Jagger Hims Limited peer review is located in Appendix C. Terra-Dynamics Limited comments were largely editorial and were directly incorporated into the report.

TABLE 3.3: QUALIFICATION OF UNCERTAINTY

Part 1. Assessment of Available Data

Confidence Score (x/10)	Aquifer(s) Considered:	Water Table/ Uppermost Aquifer	Target Aquifer	Other Aquifers
7	**Qualitative Assessment of Conceptual Understanding:**			
	Is the Groundwater Flow System Simple, Uniform?	Y	Yes at a regional scale assessment level	
	Does Groundwater Flow reflect topography & regional watershed drainage?	Y		
	Are there other reasonable interpretations of Groundwater Flow System?	N		
	Are watershed/surface water interactions satisfactorily represented?	Y		
	Is the Aquifer Confined?	Y		
	Is the Target Aquifer in a complex Groundwater Flow System?	Y	Predominantly	
	Is the Target Aquifer in fractured rock?	N	Yes but regional scale assessment equivalent porous media approach acceptable	

Part 2. Assessment of Vulnerability Assessment

Confidence Score	Vulnerability Method (Evaluate one method Only):	Basic Hydrogeological Evaluation	Intrinsic Susceptibility Index (ISI)	Aquifer Vulnerability Index (AVI)	WAAT/ SAAT/ SWAT	Detailed Hydrogeological Evaluation	Progressive Evaluation (more than one approach)
7.5			X	X			Y
	Based on/Considers Regional Stratigraphic Interpretations:						Y
	Based on/Considers Local (Individual Borehole) Interpretations:						N
	Does Vulnerability Assessment reasonably reflect data?						Y
	Is Vulnerability Assessment Consistent with Regional Understanding?						Y

Part 3. Uncertainty Assessment

7.0	Assessment of Available Data/Interpretation
7.5	Assessment of Vulnerability
LOW	**RECOMMENDED UNCERTAINTY SCORE**

4. Next Steps

This section describes potential future efforts to improve protection of highly vulnerable aquifers. It is recommended that improvement in the protection of groundwater supplies be a priority goal for the Source Protection Plan and Provincial Policy Statement implementation in the Niagara Peninsula Source Protection Area.

4.1 Potential Source Protection Plan Concepts

Consideration should be given to multi-agency policy development, monitoring and approvals. This is to address the complex nature of groundwater protection, supply and legislation. The following are some identified agencies and the areas of their mandate pertaining to groundwater.

- Public Health – communal and private water supplies;
- Public Works – Part 8 Building Code sewage system approvals;
- Municipal Building Officials – Geothermal approvals and some Part 8 Building Code sewage system approvals;
- Niagara Region District Office Ministry of the Environment – Wells regulation, as well as permits to take water, certificates of approval, permits to discharge and waste disposal; and
- Conservation Authority – hydrogeologic study reviews, mapping of significant and vulnerable groundwater areas.

To protect, improve and restore groundwater supplies, it is also recommended the Source Water Protection Plan include requirements for groundwater protection. Some possible approaches include:

- A multi-agency well construction improvement program. This could include for the government and the public:
    - Targeted educational programs, e.g. flush-mounted monitoring wells and flowing wells are not allowed;
    - Construction bonds with government approvals, e.g. funds secured for well decommissioning prior to construction; and
    - Active well status commenting in reporting, e.g. party commitment to annual monitoring.
- Water use surveys (e.g. private well types and/or cisterns) in highly vulnerable aquifers;
- Tertiary sewage treatment system requirements, rather than conventional systems, on highly vulnerable aquifers. This could help reduce groundwater contaminants such as nitrate.
- Analytical wellhead protection area mapping for communal water supply systems;
- Requirements for licensed drilling contractors in construction of closed loop geothermal installations; and

- Pit and quarry rehabilitation plans that meet, improve or protect pre-development groundwater vulnerability in up-gradient areas.

Some programs to reduce groundwater vulnerability for consideration include:
- Locating and confirming "unknown" status well locations;
- Water supply well-upgrade incentive funding program; and
- NPCA aquifer system hydrogeologic mapping program.

4.2 Provincial Policy Statement

Highly vulnerable aquifers are to be protected under the Provincial Policy Statement (PPS) (Ontario Ministry of Municipal Affairs and Housing, 2005). Under the PPS, the NPCA, as a planning authority is required to:

> *"protect, improve or restore the quality and quantity of water by:*
> *…d) implementing necessary restrictions on development and site alteration to:*
> *1. protect all….designated vulnerable areas; and*
> *2. protect, improve or restore vulnerable….groundwater";*

NPCA PPS groundwater vulnerability mapping should be updated to correspond with this report.

4.2.1 Contaminant Management

Recognizing the vulnerability of Highly Vulnerable Aquifers, requirements for contaminant management plans are also recommended. Contaminant management plans were recommended for Highly Vulnerable Aquifers in guidance prepared for the Conservation Authorities Moraine Coalition (CAMC) (Ogilvie, Ogilvie & Company and Anthony Usher Planning Consultant, 2005). The CAMC document recommended, under development approvals, contaminant management plans for Highly Vulnerable Aquifers and:

- High and moderate threat land uses and/or contaminant storage. Their examples of high threat land uses included but were not limited to waste management facilities, airports, lagoons for sewage treatment, and auto wrecking and salvage yards. This could include site-specific management such as double-walled fuel storage tanks with a monitoring program; and
- New or expanded agricultural uses greater than 5 nutrient units of manure per year, e.g. more than 3 milking Holstein cows.

4.2.2 Emerging Challenges

Future challenges to the protection of highly vulnerable aquifers include increased transport pathways that reduce natural protection and may increase groundwater vulnerability. Examples include:
- Priority aggregate extraction areas considered "to be important in ensuring an adequate resource base for the future", i.e. for possible resource development, and "represent*ing* areas in which a major resource is known to exist" (Ontario Geological

Survey, 1985). These include considerable areas of "select bedrock resource" in the municipalities of Grimsby, Lincoln, City of Hamilton, West Lincoln, Wainfleet, Port Colborne and Fort Erie. As well as additional areas of "primary significance for sand and gravel" extraction in the municipality of Pelham.

- Earth Energy Systems, or more commonly known as geothermal systems, may have negative implications for groundwater protection. For example, closed loop installations do not require installation by a trained licensed drilling contractor.

4.3 Future Updates – Data Gaps

Future updates of Highly Vulnerable Aquifers should be based upon:

- A three-dimensional hydrostratigraphic model, which would include mapping of aquifer and aquitard extents and incorporate golden spike datasets;
- Subwatershed-scale water table mapping including both the fractured upper clay and uppermost drilled well aquifer systems;
- Improved understanding of the number and locations of water supply systems, e.g. regulated communal systems, cisterns, dug wells and drilled wells; and
- Field inventory of transport pathways, e.g. former water supply wells requiring abandonment.

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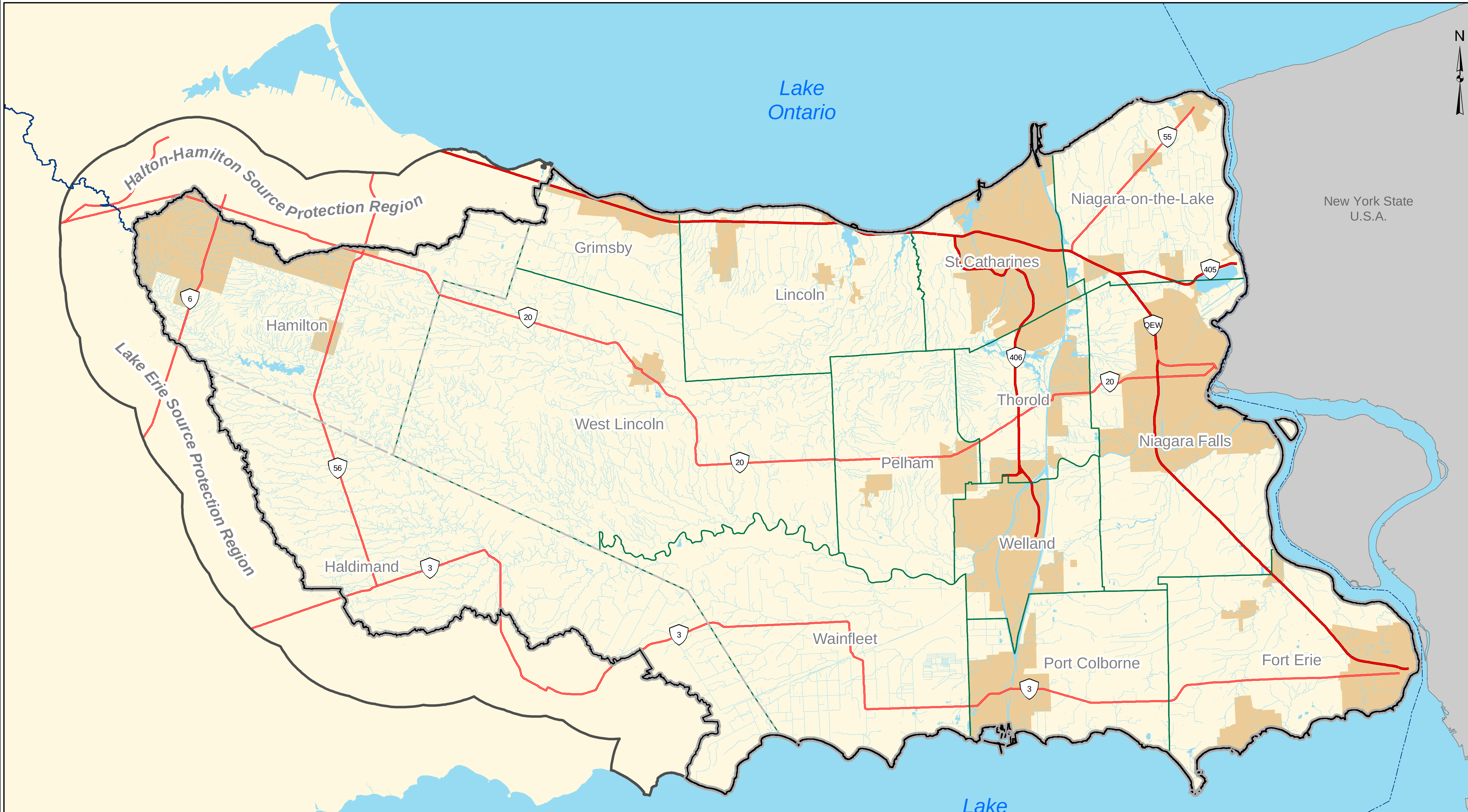
FIGURES



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Please refer to report text for digital mapping sources.
All Frames: North American Datum 1983, Universal Transverse Mercator 6° Projection, Zone 17N, Central Meridian 81° West.
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Legend

- International Boundary
- Major Highways
- Highways
- Watercourse
- Ponds, Reservoirs, Lakes
- Extended Context Area
- Source Water Protection Area
- Lower Tier Municipality
- Upper Tier Municipality
- Municipally Water Serviced Areas

Drinking Water Source Protection — Act for Clean Water

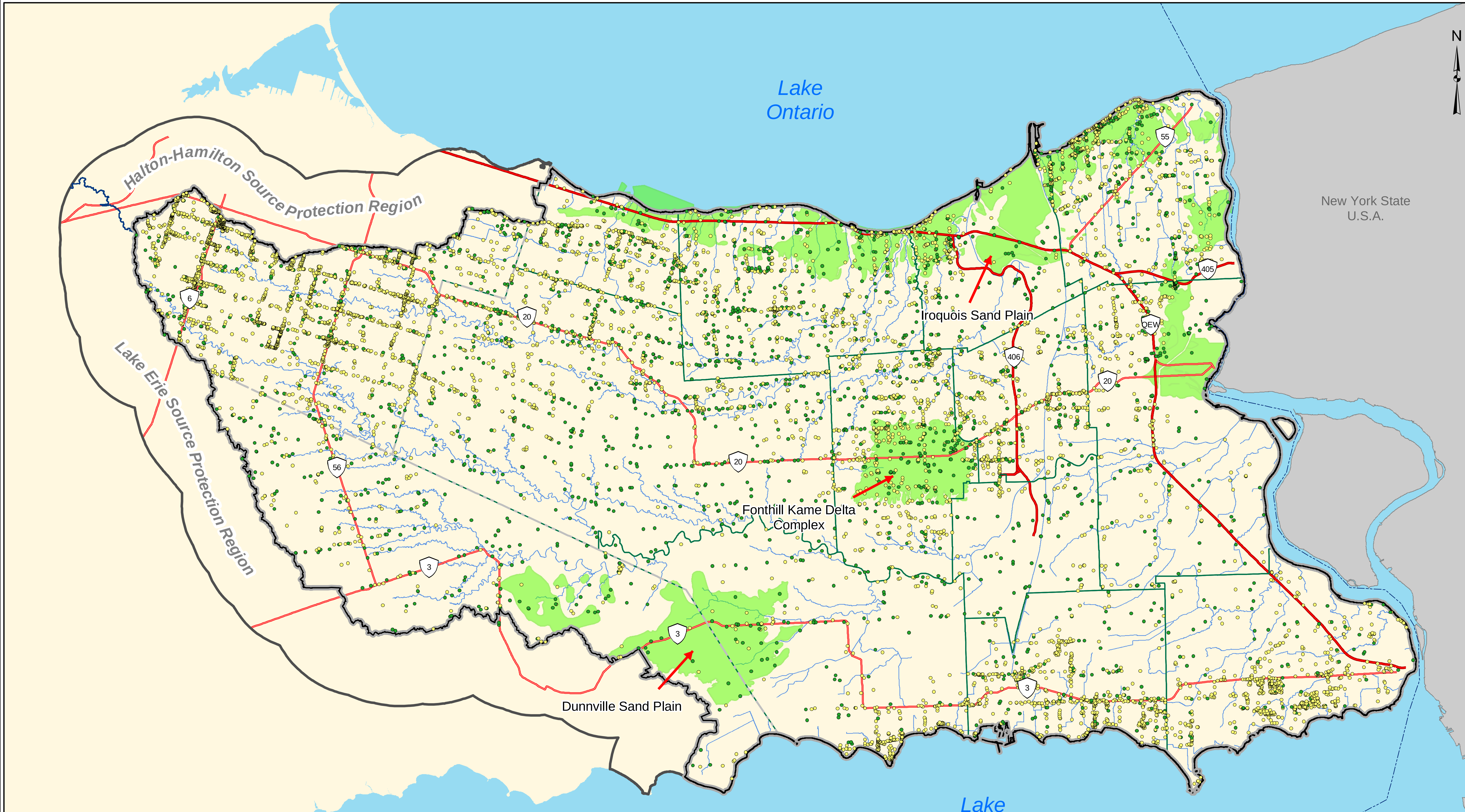
Groundwater Vulnerability Analysis

Figure 1.1: Study Area

Niagara Peninsula Conservation Authority

Friday, November 13, 2009

Ontario



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Legend

- International Boundary
- Major Highways
- Highways
- Watercourse
- Ponds, Reservoirs, Lakes
- Extended Context Area
- Source Water Protection Area
- Lower Tier Municipality
- Upper Tier Municipality
- Water Supply Wells
- Other Water Wells
- Water Supply Wells
- Surficial Overburden Aquifers

DRINKING WATER SOURCE PROTECTION
ACT FOR CLEAN WATER

Groundwater Vulnerability Analysis

Figure 1.2: NPSP Area Prominent Surficial Overburden Aquifers

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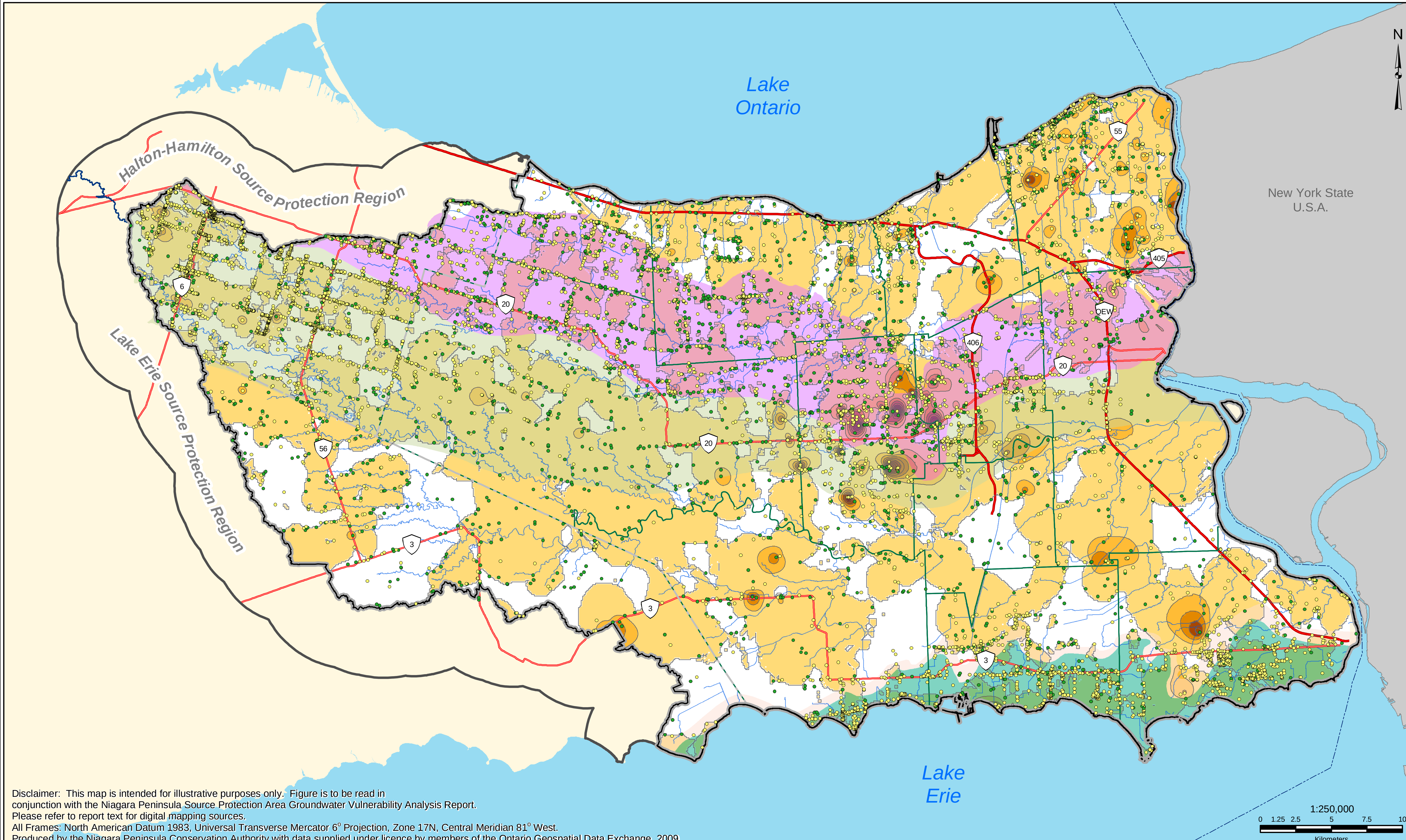
Friday, November 13, 2009

Ontario



Legend

- International Boundary
- Major Highways
- Highways
- Watercourse
- Ponds, Reservoirs, Lakes
- Extended Context Area
- Source Water Protection Area
- Contour 5 m
- Lower Tier Municipality
- Upper Tier Municipality
- Other Water Wells
- Water Supply Wells

Bedrock Water Supply Aquifers

- Bois Blanc Formation
- Onondaga Formation
- Guelph Formation
- Lockport Formation

Sand and Gravel Aquifer Thickness Above Bedrock (m)

- 0
- 0.1 - 5
- 5.1 - 10
- 10.1 - 15
- 15.1 - 25
- 25.1 - 55

DRINKING WATER SOURCE PROTECTION
ACT FOR CLEAN WATER

Groundwater Vulnerability Analysis

Figure 1.3: NPSP Area Contact-Zone and Prominent Bedrock Aquifers

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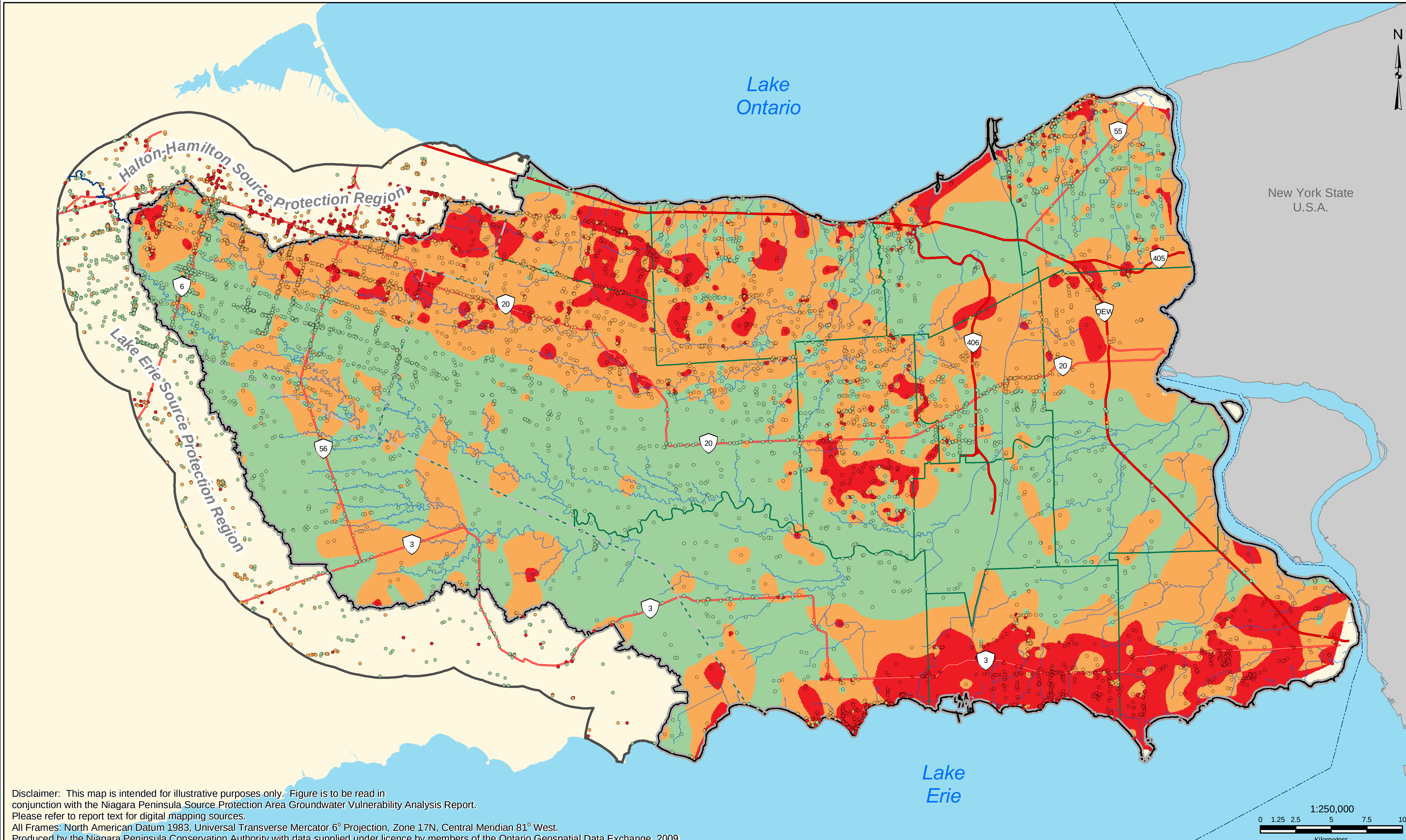

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Legend

- International Boundary
- Major Highways
- Highways
- Watercourse
- Ponds, Reservoirs, Lakes
- Extended Context Area
- Source Water Protection Area
- Lower Tier Municipality
- Upper Tier Municipality

Groundwater Susceptibility (GwISI)
- High
- Medium
- Low

GwISI Data Points
- High
- Medium
- Low

Drinking Water Source Protection — Act for Clean Water

Groundwater Vulnerability Analysis

Figure 2.1: Rule 37(1)/38(1) Groundwater Vulnerability – Intrinsic Susceptibility Index

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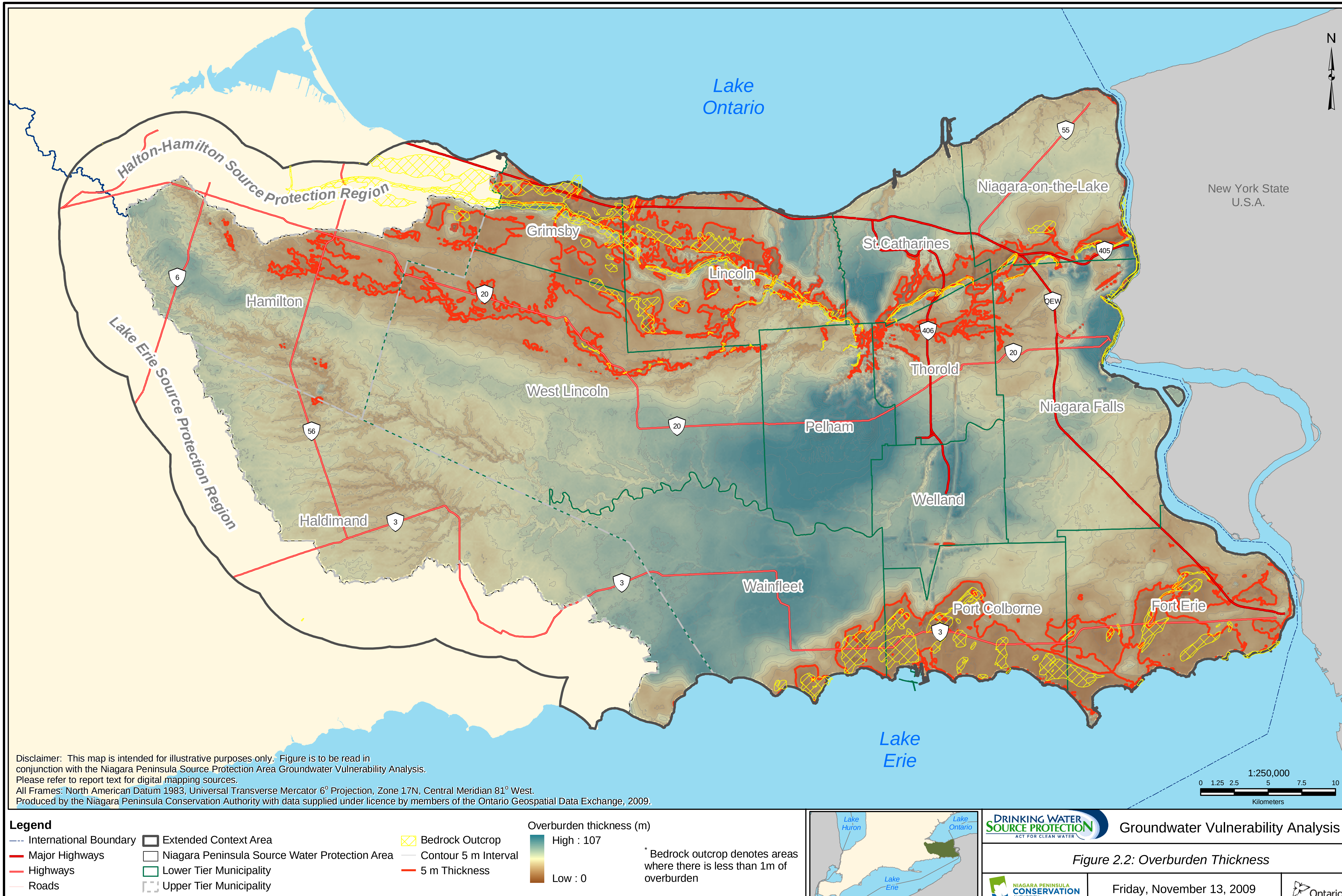
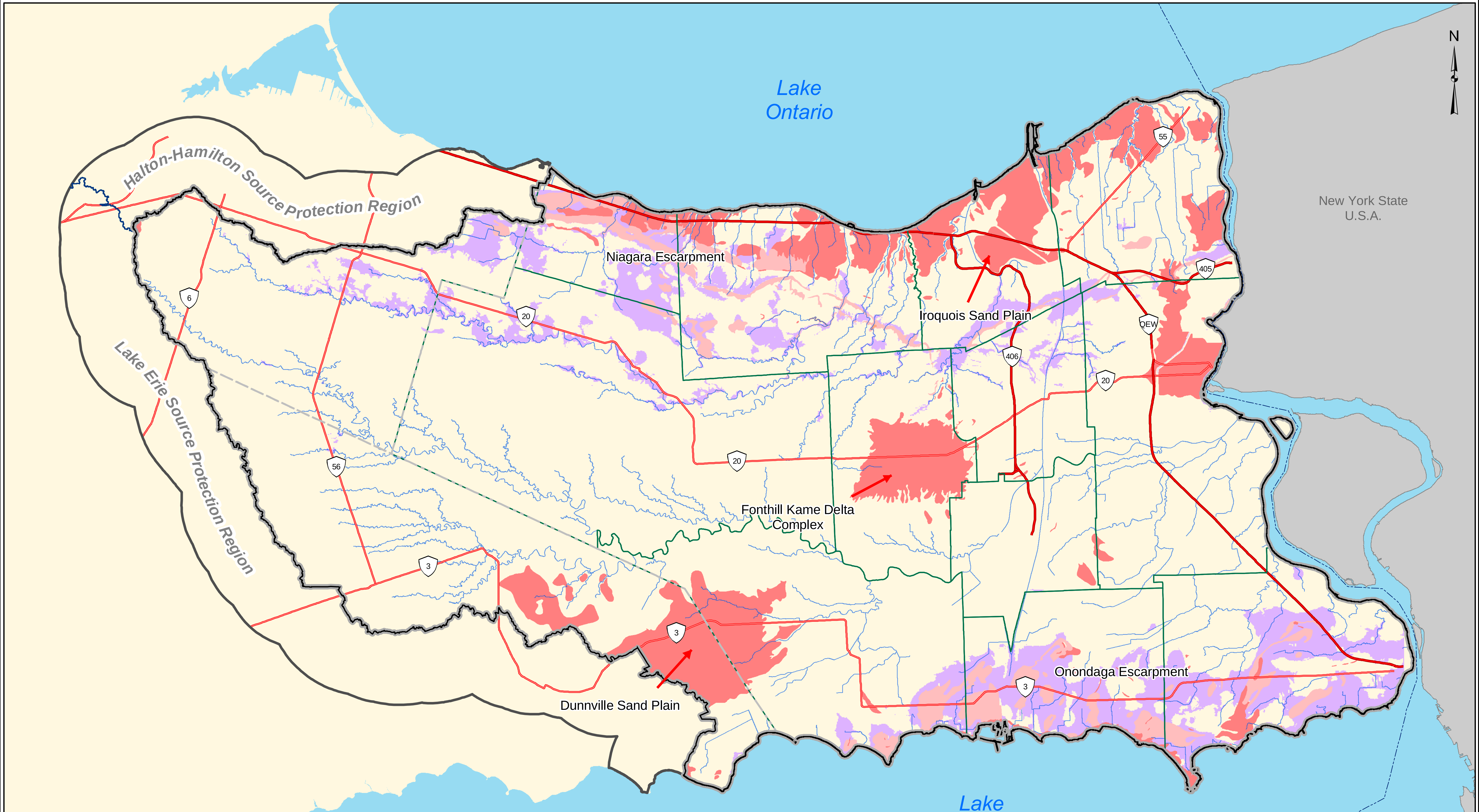


Figure 2.2: Overburden Thickness



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Legend

- International Boundary
- Major Highways
- Highways
- Watercourse
- Ponds, Reservoirs, Lakes
- Extended Context Area
- Source Water Protection Area
- Lower Tier Municipality
- Upper Tier Municipality

Groundwater Vulnerabilty (AVI)

- High (Sand and / or Gravel at Surface)
- High (Bedrock Outcrop)
- High (Karst Area)
- High (< 5 m overburden)

DRINKING WATER SOURCE PROTECTION — ACT FOR CLEAN WATER

Groundwater Vulnerability Analysis

Figure 2.3: Rule 37(2)-38(1) Groundwater Vulnerability – Aquifer Vulnerability Index

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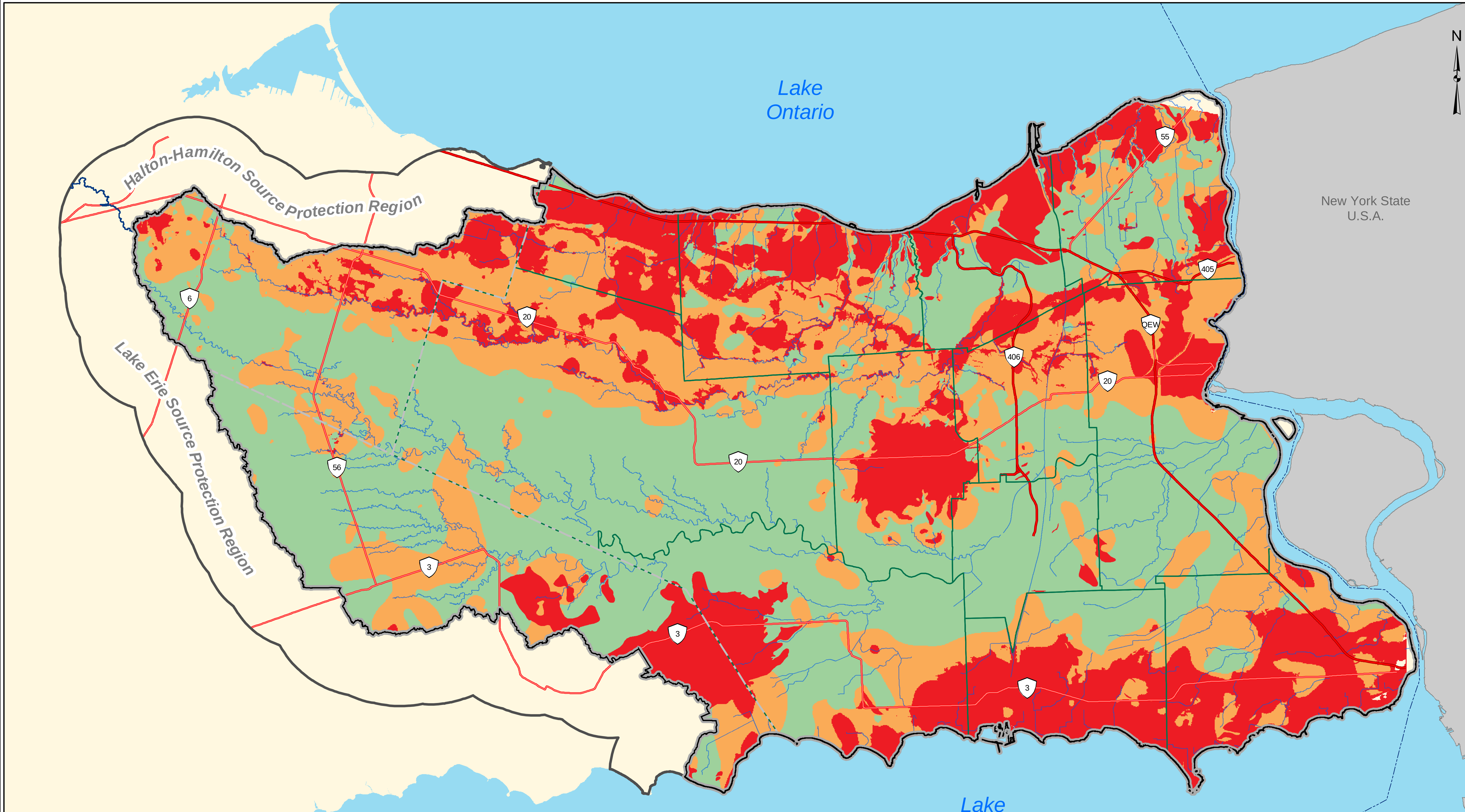

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Legend

- International Boundary
- Major Highways
- Highways
- Watercourse
- Ponds, Reservoirs, Lakes
- Extended Context Area
- Source Water Protection Area
- Lower Tier Municipality
- Upper Tier Municipality

Groundwater Vulnerability
- High
- Medium
- Low

Drinking Water Source Protection — Act for Clean Water

Groundwater Vulnerability Analysis

Figure 2.4: Groundwater Vulnerability Rules 37(1)/37(2)/38(1)

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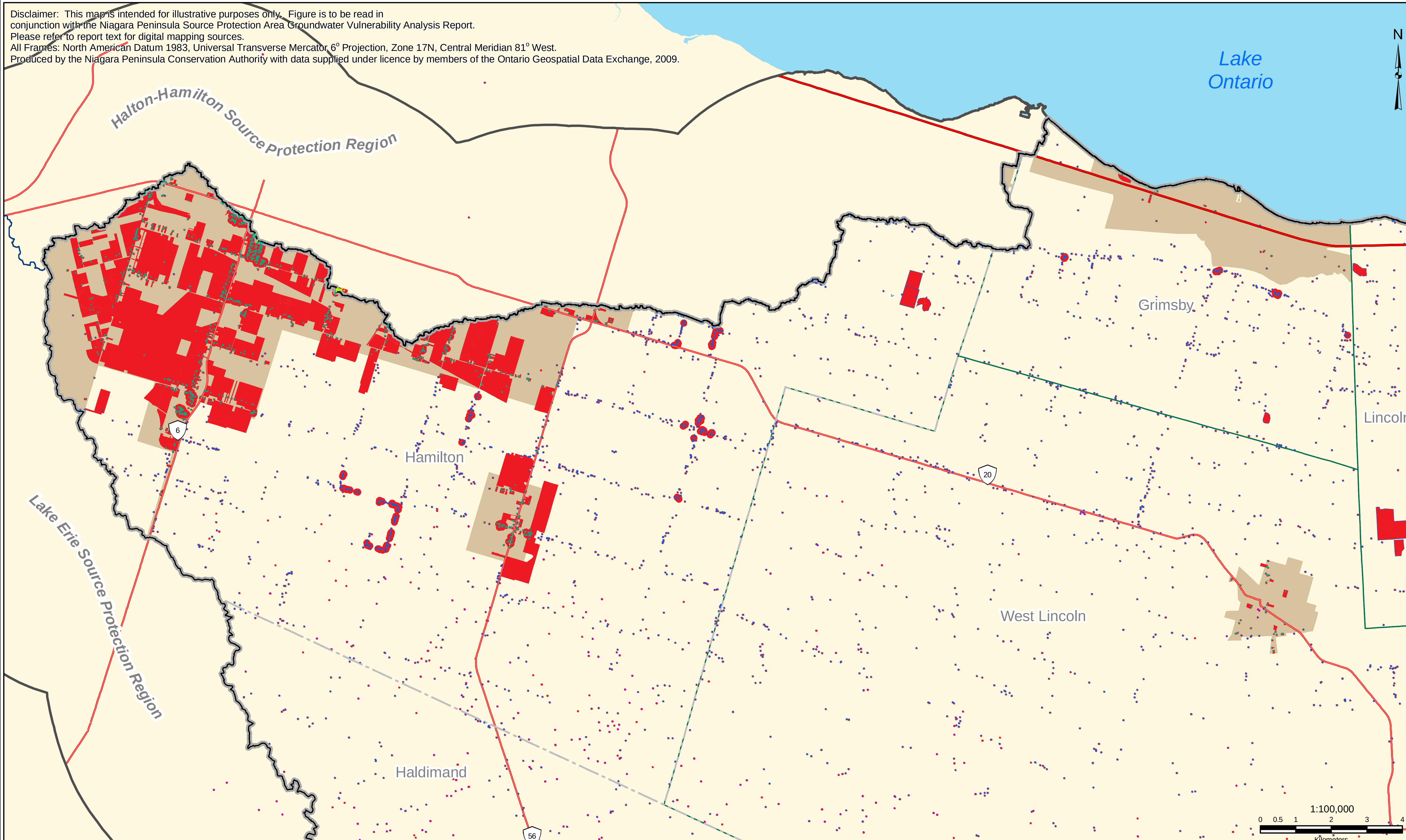

Legend

- International Boundary
- Major Highways
- Highways
- Watercourse
- Ponds, Reservoirs, Lakes
- Extended Context Area
- Source Water Protection Area
- Welland Canal on Bedrock
- Lower Tier Municipality
- Upper Tier Municipality
- Municipally Serviced Water Areas
- Aggregate Operations
- Cluster Wells (>= 6 Wells in 100 m Radius)
- Unknown Status Oil and Gas Wells
- Municipally Serviced Areas WWIS Wells
- MOE WWIS pre-2000
- Groundwater Vulnerability (High)

Lake Huron
Lake Ontario
Lake Erie

DRINKING WATER SOURCE PROTECTION
ACT FOR CLEAN WATER

Groundwater Vulnerability Analysis

Figure 2.5a: Transport Pathways

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Friday, November 13, 2009

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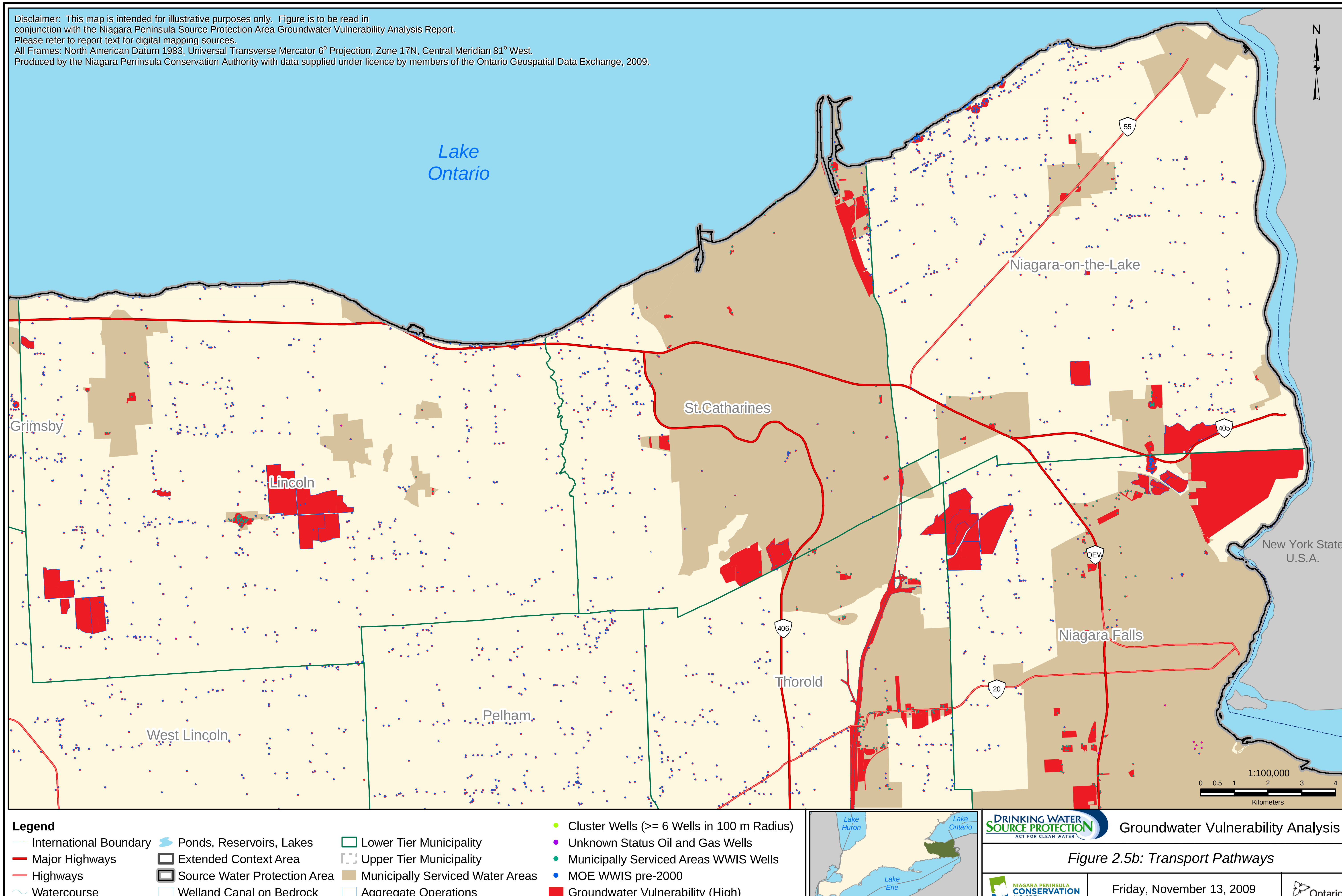


Figure 2.5b: Transport Pathways

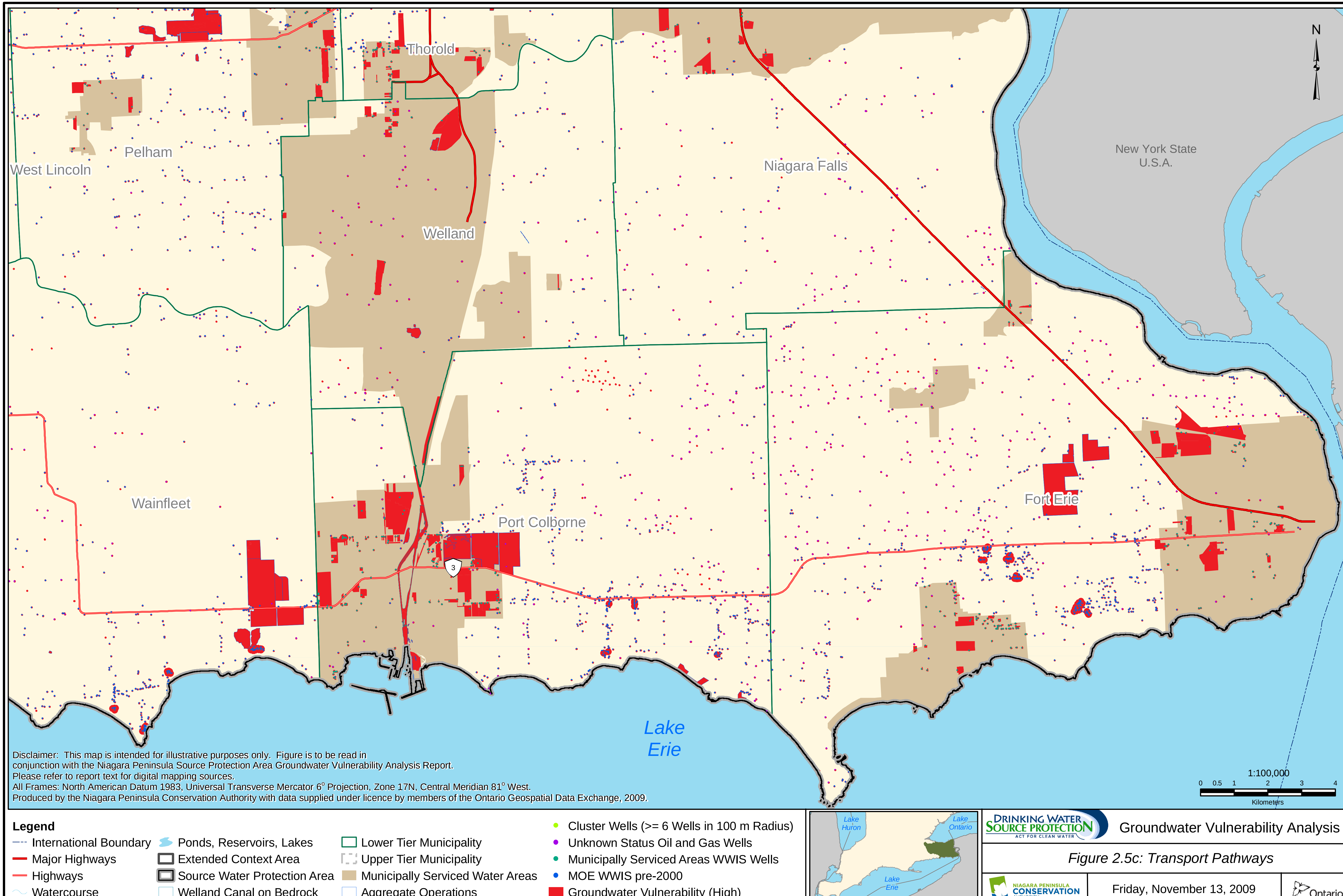
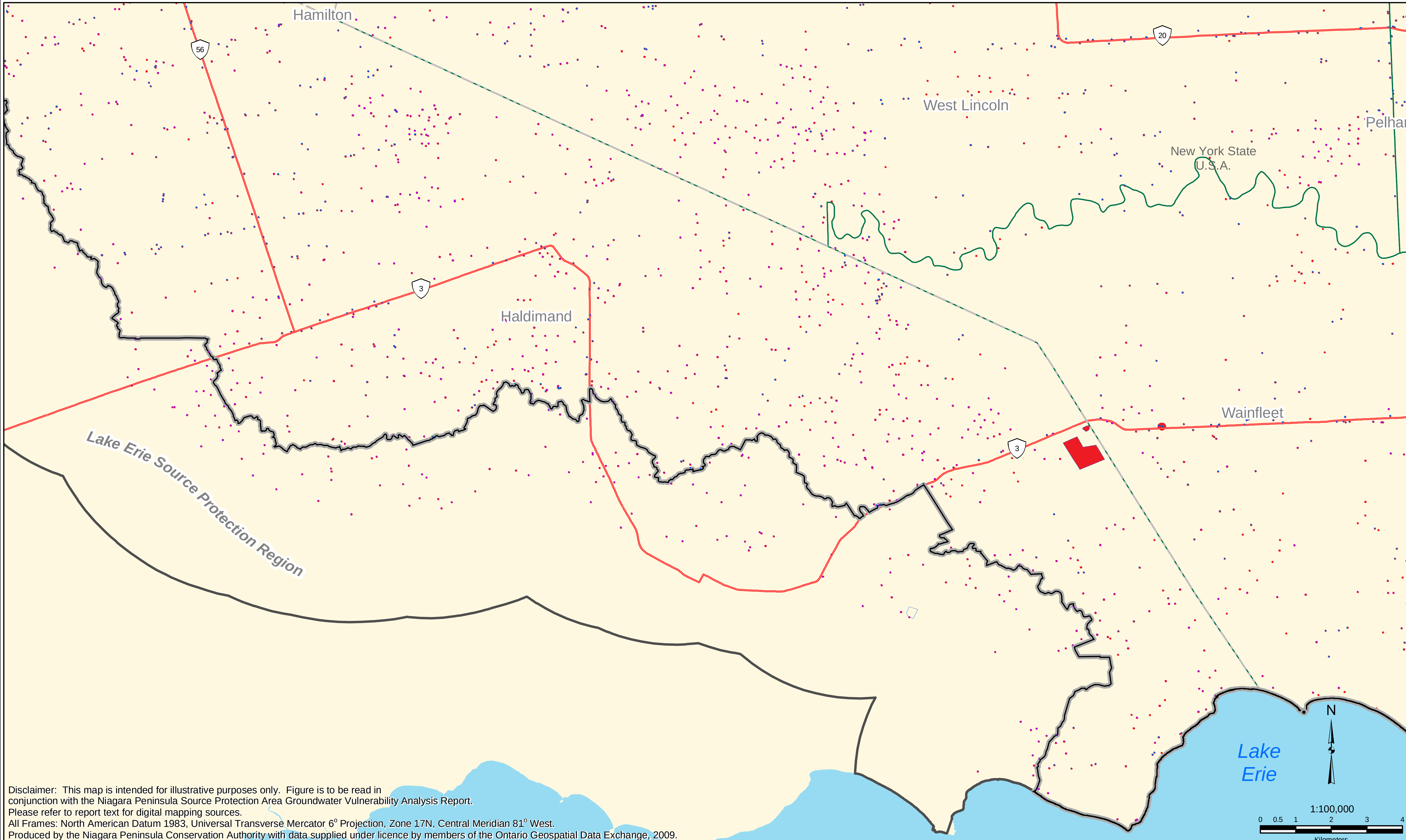


Figure 2.5c: Transport Pathways



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Legend

- International Boundary
- Major Highways
- Highways
- Watercourse
- Ponds, Reservoirs, Lakes
- Extended Context Area
- Source Water Protection Area
- Welland Canal on Bedrock
- Lower Tier Municipality
- Upper Tier Municipality
- Municipally Serviced Water Areas
- Aggregate Operations
- Cluster Wells (>= 6 Wells in 100 m Radius)
- Unknown Status Oil and Gas Wells
- Municipally Serviced Areas WWIS Wells
- MOE WWIS pre-2000
- Groundwater Vulnerability (High)

Drinking Water Source Protection – Act for Clean Water

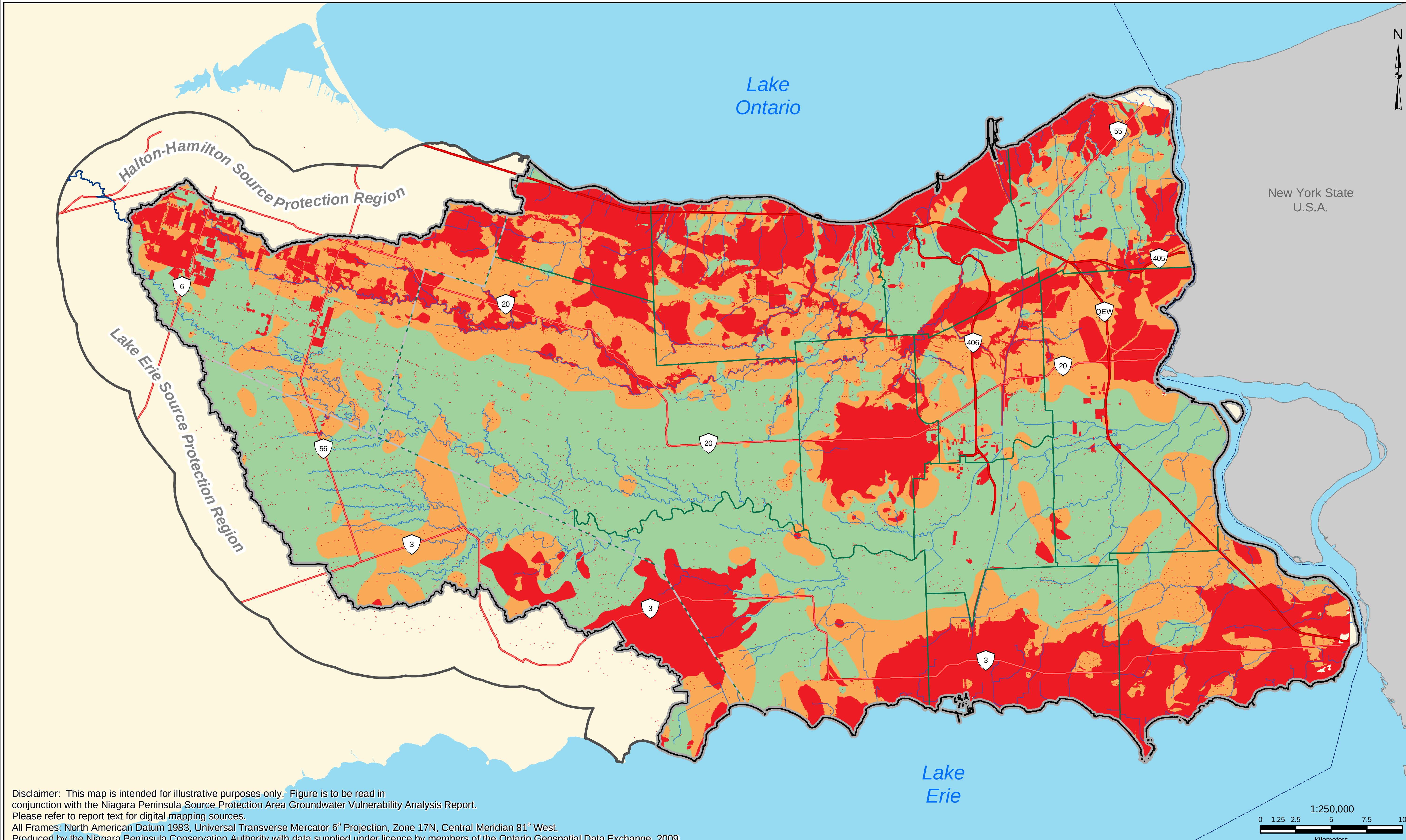
Groundwater Vulnerability Analysis

Figure 2.5d: Transport Pathways

Niagara Peninsula Conservation Authority

Friday, November 13, 2009

Ontario



Legend

- International Boundary
- Major Highways
- Highways
- Watercourse
- Ponds, Reservoirs, Lakes
- Extended Context Area
- Source Water Protection Area
- Lower Tier Municipality
- Upper Tier Municipality

Groundwater Vulnerability

- High
- Medium
- Low

Drinking Water Source Protection – Act for Clean Water

Groundwater Vulnerability Analysis

Figure 2.6: Groundwater Vulnerability Rules 37,38,39 and 40

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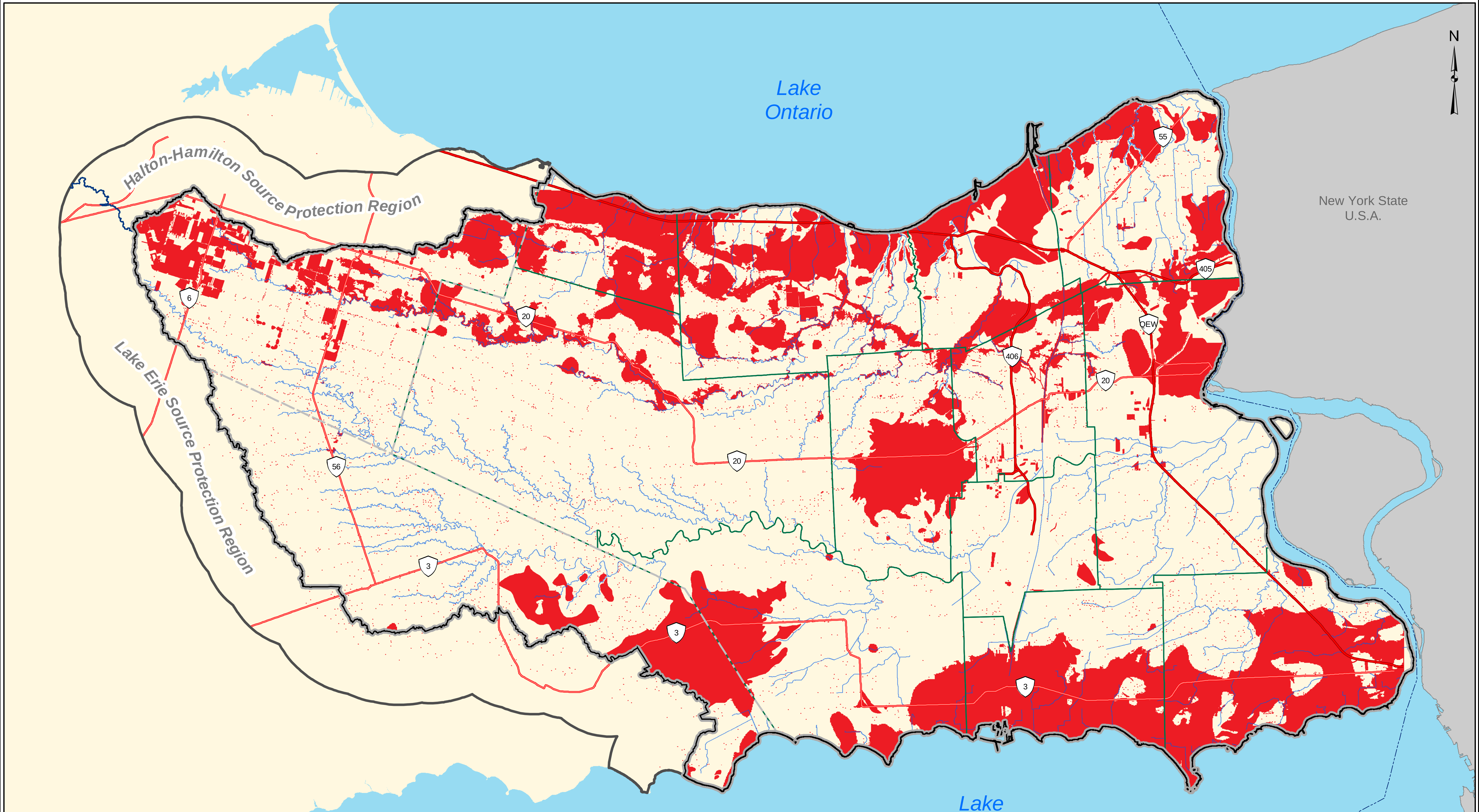

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Legend

- International Boundary
- Major Highways
- Highways
- Watercourse
- Ponds, Reservoirs, Lakes
- Extended Context Area
- Source Water Protection Area
- Lower Tier Municipality
- Upper Tier Municipality

Groundwater Vulnerability
- High - Vulnerability Score 6

Drinking Water Source Protection — Act for Clean Water

Groundwater Vulnerability Analysis

Figure 3.1: Highly Vulnerable Aquifers

Niagara Peninsula Conservation Authority

Friday, November 13, 2009

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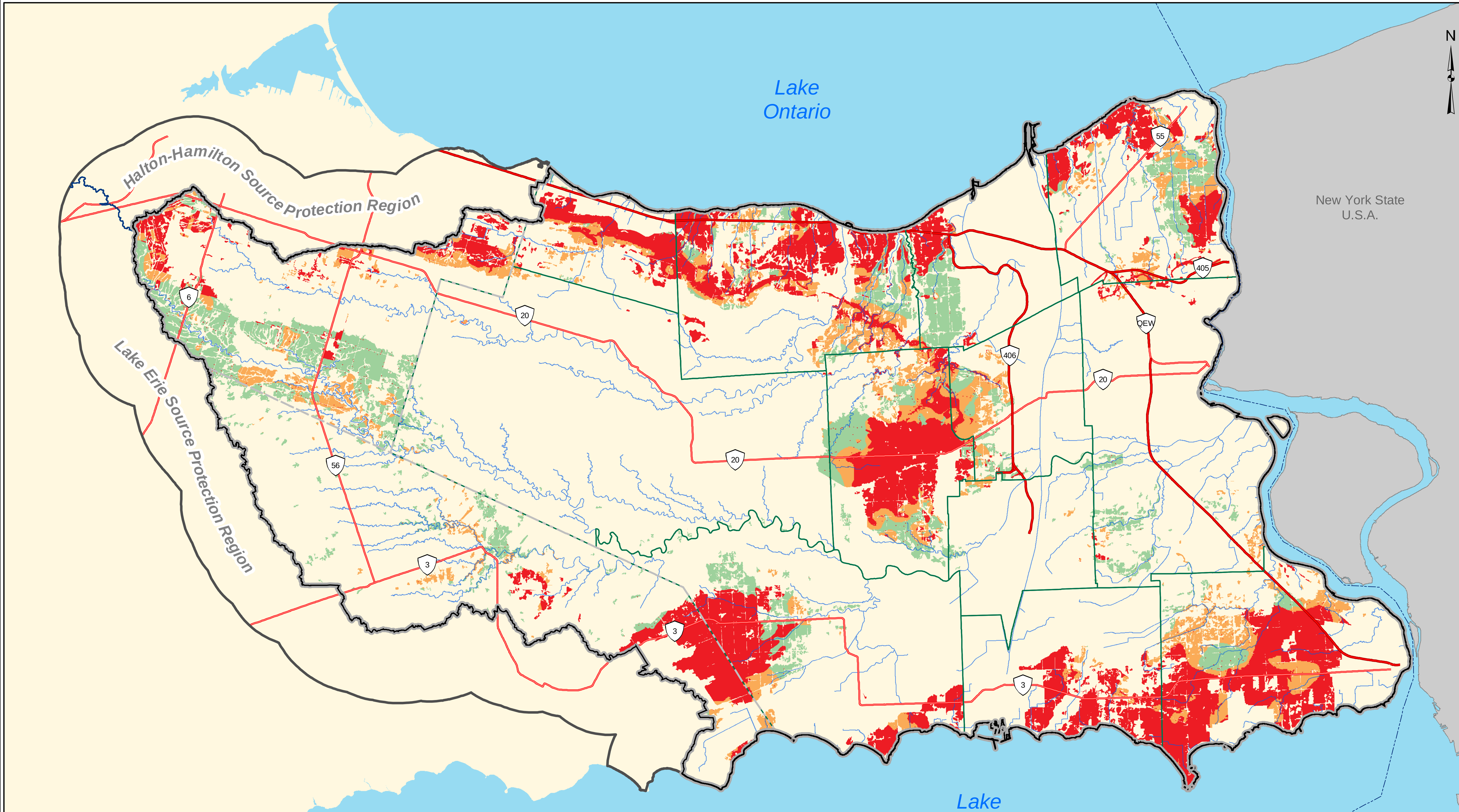

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Legend

- International Boundary
- Major Highways
- Highways
- Watercourse
- Ponds, Reservoirs, Lakes
- Extended Context Area
- Source Water Protection Area
- Lower Tier Municipality
- Upper Tier Municipality

Groundwater Vulnerability and Score

- High - 6
- Medium - 4
- Low - 2

DRINKING WATER SOURCE PROTECTION ACT FOR CLEAN WATER

Groundwater Vulnerability Analysis

Figure 3.2: Significant Groundwater Recharge Area Vulnerability

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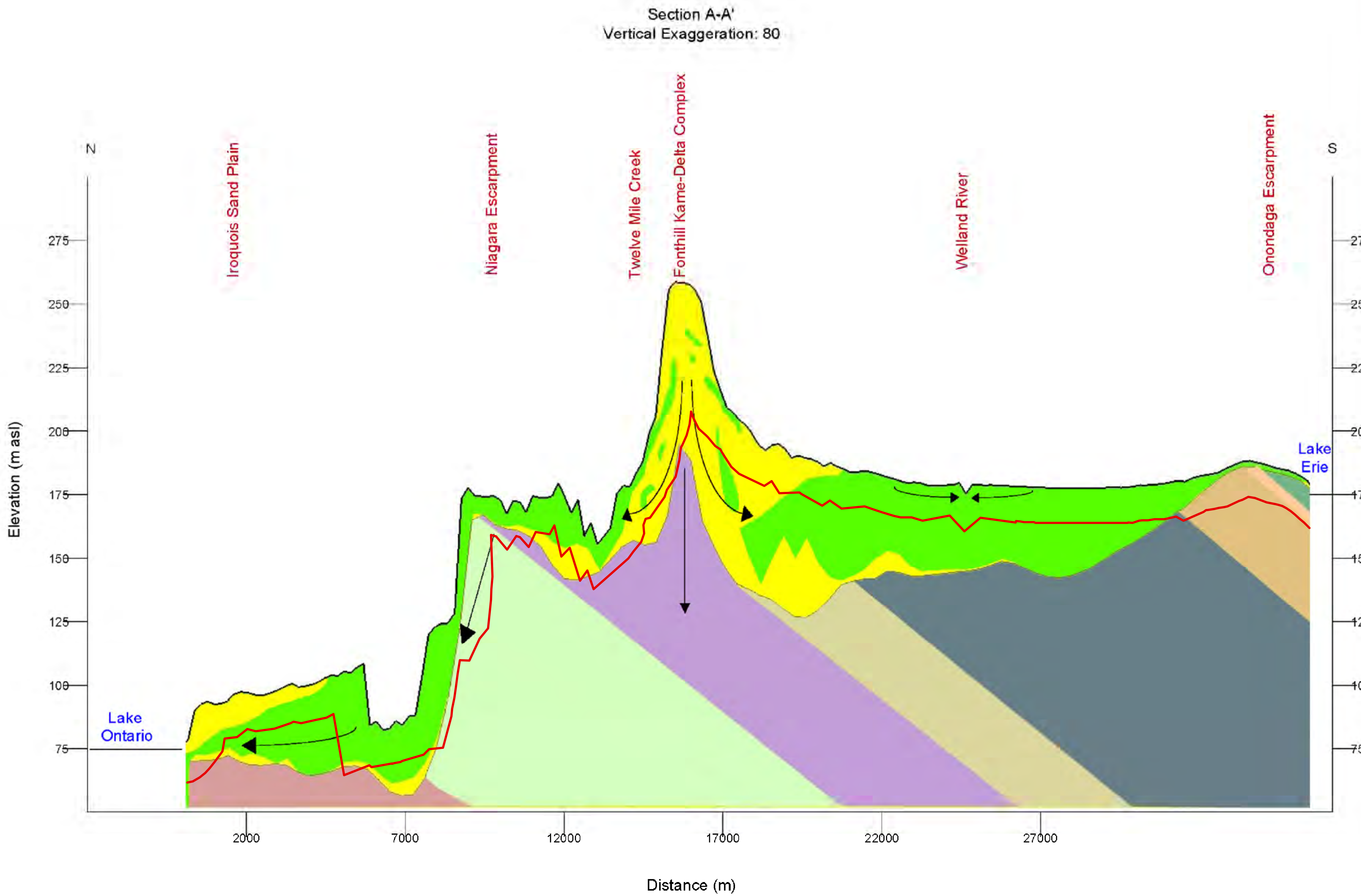
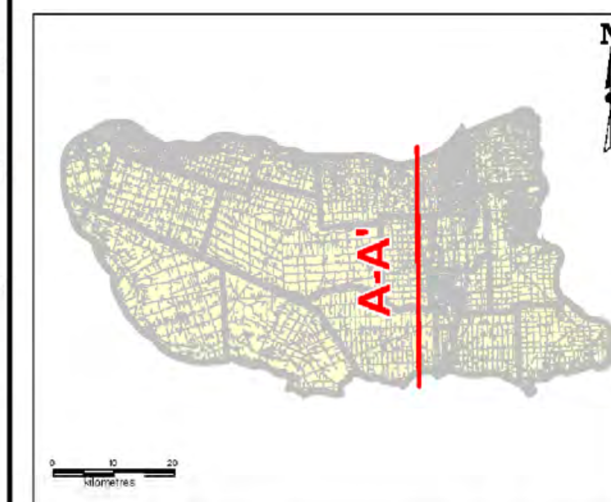
Appendix A

NPCA Groundwater Study



Legend

- Glaciolacustrine (fine)
- Lacustrine (coarse)
- Queenston Formation
- Clinton Group
- Lockport Formation
- Guelph Formation
- Salina Formation
- Bertie Formation
- Bois Blanc Formation
- Onondaga Formation
- Interpreted Groundwater Flow Directions
- 15m Below Ground Level



Disclaimer: This map is intended for illustrative purposes only. This figure is to be read in conjunction with the Niagara Peninsula Conservation Authority Groundwater Study

Digital Mapping Sources: Base Mapping features - Ministry of Natural Resource
Water Well Information: Ministry of the Environment.

Date: February, 2005

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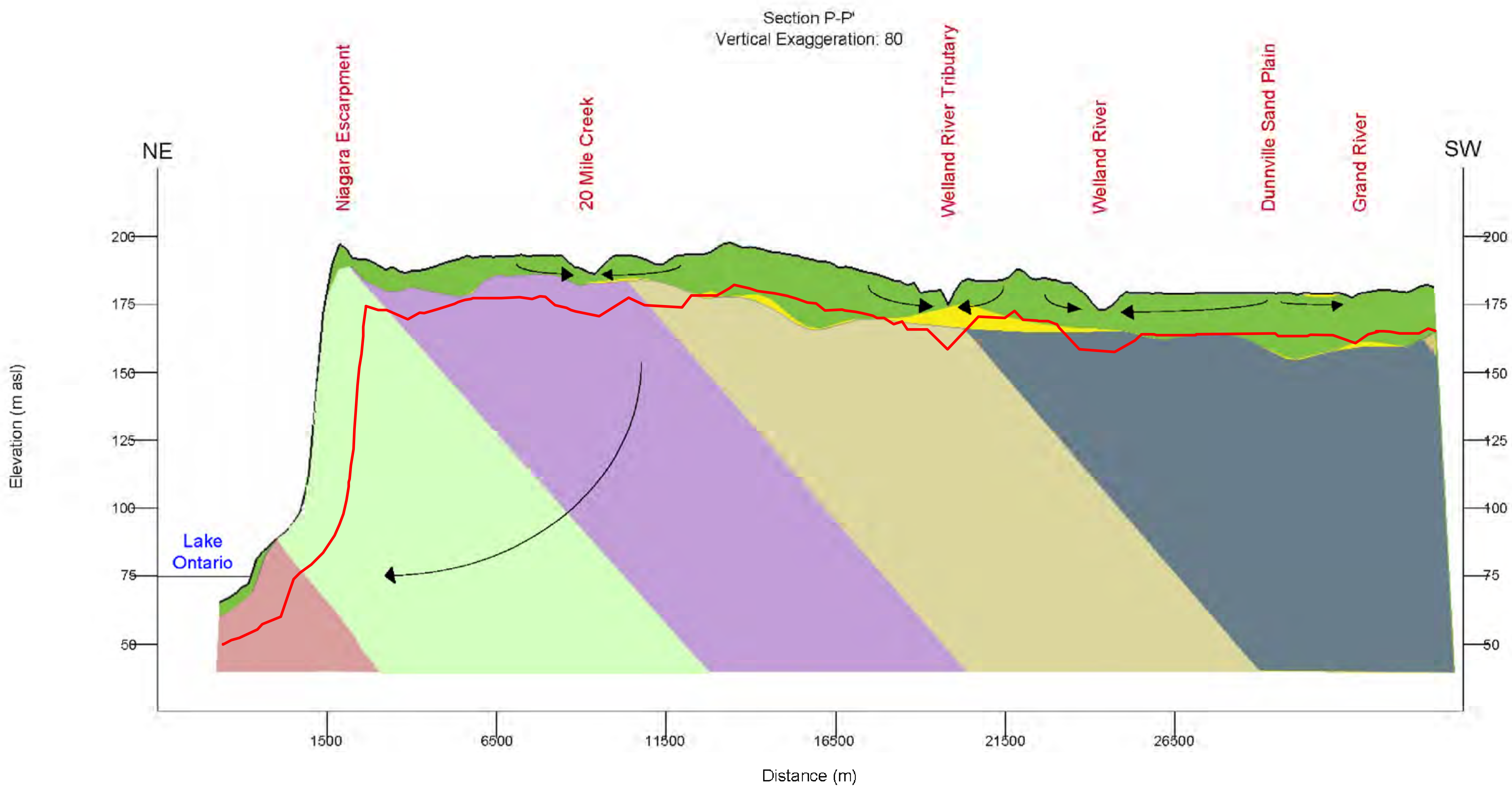
Figure 2-53: Regional Conceptual Model (A-A')

NPCA Groundwater Study



Legend

- Glaciolacustrine (fine)
- Lacustrine (coarse)
- Queenston Formation
- Clinton Group
- Lockport Formation
- Guelph Formation
- Salina Formation
- Bertie Formation
- Bois Blanc Formation
- Onondaga Formation
- Interpreted Groundwater Flow Directions
- 15m Below Ground Level

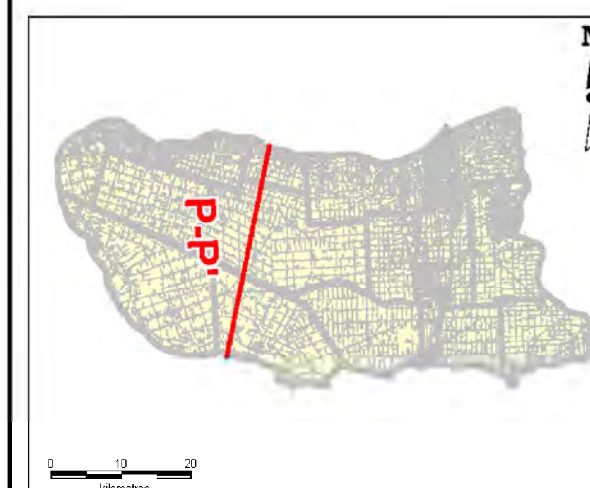


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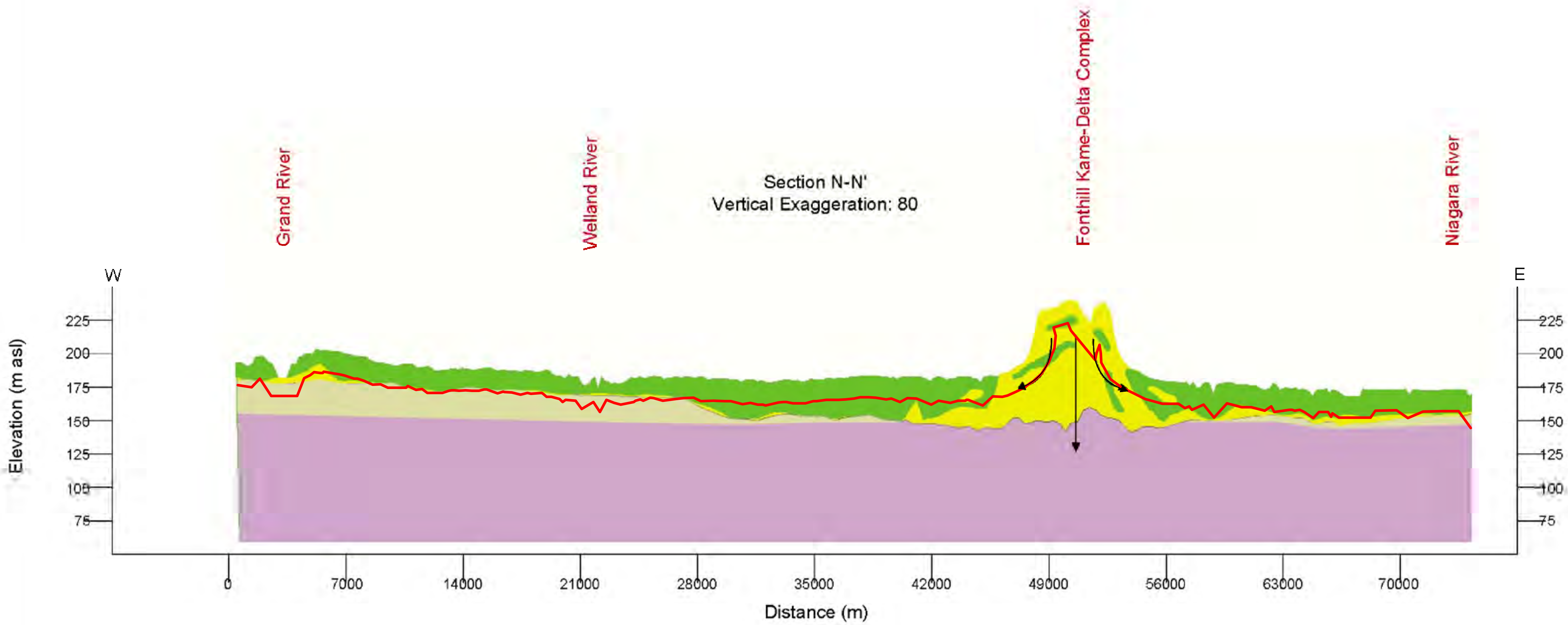
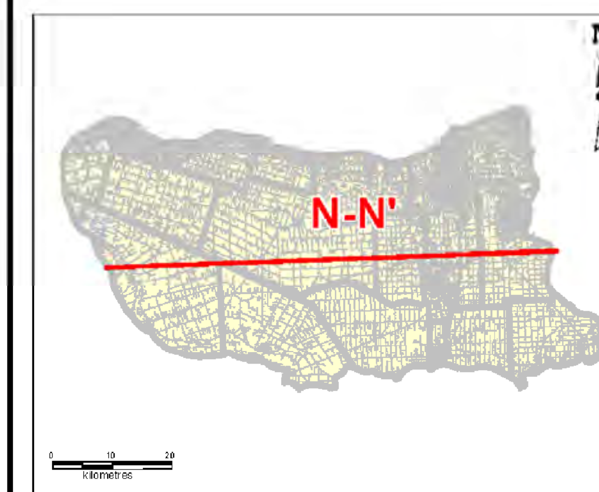
Figure 2-54: Regional Conceptual Model (P-P')



NPCA Groundwater Study

Legend

- Glaciolacustrine (fine)
- Lacustrine (coarse)
- Queenston Formation
- Clinton Group
- Lockport Formation
- Guelph Formation
- Salina Formation
- Bertie Formation
- Bois Blanc Formation
- Onondaga Formation
- Interpreted Groundwater Flow Directions
- 15m Below Ground Level



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Water Well Information: Ministry of the Environment.

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Figure 2-55: Regional Conceptual Model (N-N')

Appendix B

MEMO

NIAGARA PENINSULA CONSERVATION AUTHORITY
250 Thorold Road West, 3rd Floor, Welland, Ontario L3C 3W2
Telephone 905.788.3135 | Facsimile 905.788.1121 | www.npca.ca

DATE: **November 30, 2009**

FROM: Jayme Campbell

RE: **Existing Vulnerability Mapping Review**

1.0 OBJECTIVE:

To complete a review of existing regional-scale Niagara Peninsula Source Protection (NPSP) Area groundwater vulnerability maps for their suitability in the Source Water Protection Groundwater Vulnerability assessment.

2.0 OVERVIEW:

Groundwater protection became a high-priority issue in Ontario since the Walkerton tragedy in 2000. However, provincial mapping of groundwater susceptibility to contamination began at least two decades before (Ministry of the Environment, 1980). In the three decades since, regional scale mapping of groundwater vulnerability has been completed a number of times in the Niagara Peninsula Source Protection (NPSP) Area. This has been done using both qualitative and quantitative methods (Gartner Lee Limited 1987, CH2MHill MacViro and Philips Engineering 2003, Ontario Geological Survey 2003 and Waterloo Hydrogeologic Inc. 2005) and across NPSP Area boundaries (Charlesworth and Associates and SNC-Lavalin 2006, Hamilton Conservation Authority 2006 and EarthFX 2008).

The Niagara Peninsula Conservation Authority (NPCA) reviewed the above mentioned studies as part of preparing the NPSP Area Source Water Protection (SWP) Assessment Report. The Ministry of the Environment (MOE) Assessment Report Technical Rules (MOE, 2008) require such an analysis that includes identification of high, medium and low aquifer vulnerability as specific types of vulnerable areas that will be protected under the Clean Water Act (2006).

Three types of groundwater vulnerability studies were reviewed:

1. Basic Hydrogeological Assessments (BHA)
2. Intrinsic Susceptibility Index (GwISI)
3. Aquifer Vulnerability Index (AVI)
4. Surface to Aquifer Advection Time (SAAT)

2.1 Basic Hydrogeological Assessments:

A Basic Hydrogeological Assessment (BHA) can be defined as:

> "…*a qualitative approach where consideration is given to the available hydrogeological information and the relative vulnerability of the aquifer(s) assessed…not directly involv(ing) numerical calculations or modelling.*" (MOE, 2006a)

This method is not explicitly mentioned in the Technical Rules (MOE, 2008) but may be considered acceptable by the Director in some cases under Rule 15.1. Three sets of these BHA maps are available in the NPSP Area and they are discussed below.

2.1.1 Ministy of the Environment – Gartner Lee Limited (1987)

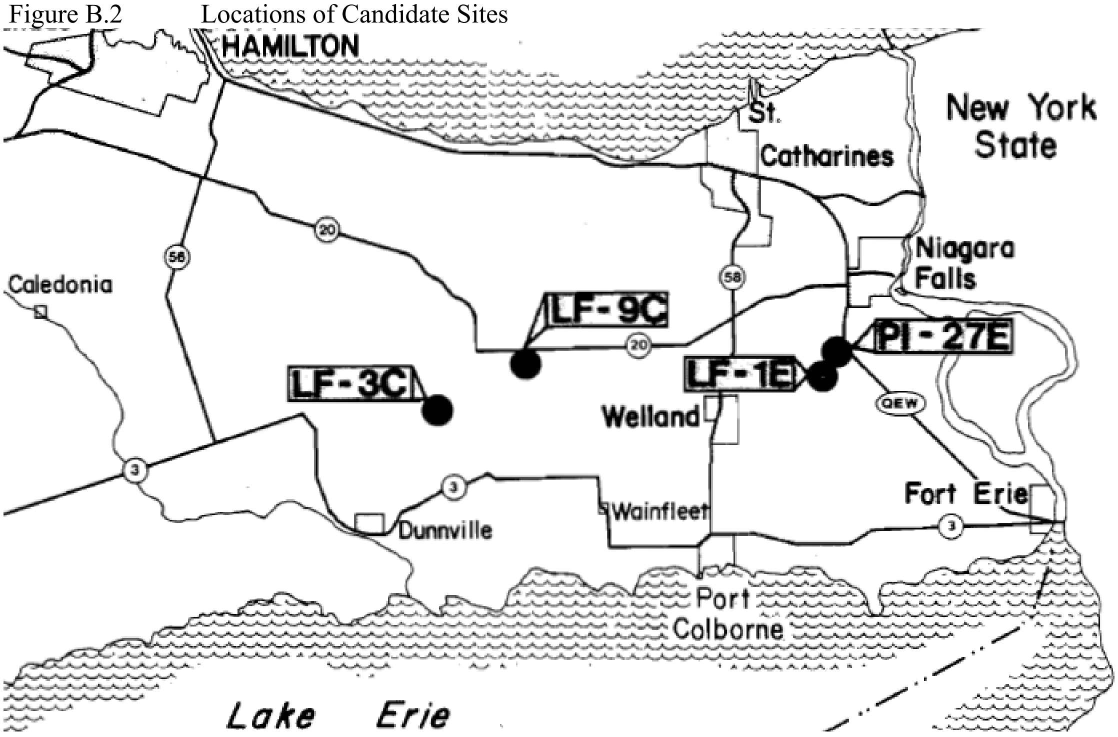
In the late 1980s, the Ministry of the Environment (MOE) inventoried surface and groundwater resources in the Niagara River and Welland River drainage basins (Gartner Lee Limited, 1987a). A series of maps were prepared entitled "Ground Water Susceptibility to Contamination" based upon a qualitative consideration of (i) the permeability of near-surface materials, (ii) groundwater movement and (iii) the presence of an aquitard and a major shallow bedrock aquifer less than 10 metres below ground surface (m bgs). Groundwater susceptibility categories included high, low and variable (Figure B.1). The initial mapping effort completed with respect to the boundaries of the Welland and Niagara River basins included 24% of these basins as highly susceptible.

The 10 mbgs criterion may seem overly conservative but was reasonable based on the consultant's experience in the Haldimand Clay Plain. Gartner Lee Limited had been working on a site selection process in Southern Ontario for "facilities for the treatment and disposal of liquid industrial and hazardous wastes" (Gartner Lee Limited, 1985). As part of the candidate site selection process, they had completed a number of very detailed hydrogeologic investigations on the thickness and competence of clay-based aquitards Niagara (Figure B.2) (Gartner Lee Limited, 1987b).

Gartner Lee Limited determined that the at-surface, fractured portion of the clay plain, which they called the upper glaciolacustrine fractured zone, may extend to depths which range up to several metres. They described the upper 1 to 3 m as intensely weathered and the most severely fractured. Fracture frequency in this "fractured zone" decreased rapidly with depth and fractures were present but infrequent below 5 m, while occasional, individual fractures were noted at greater depths ranging from 6 to 12 m (Gartner Lee Limited, 1985). These results agree with information determined as part of Niagara Region landfill investigations (Jamie Kristjanson Niagara Region, personal communication 2009).

Freeze and Cherry (1979) had also previously noted that deposits of clayey or silty till and glaciolacustrine deposits in southern Ontario contain networks of hairline fractures which are essentially vertical and which are responsible for hydraulic conductivities one to three orders of magnitude greater than in unfractured materials. Gartner Lee Limited assigned this upper glaciolacustrine fractured zone a hydraulic conductivity of 10^{-8} m/s, two orders of magnitude greater than in the underlying unfractured materials. This higher hydraulic conductivity was conservatively applied over an interval of 5 m. The estimate of vertical groundwater velocities in the fractured zone was about four orders of magnitude greater than in the underlying unfractured materials. Vertical flow velocities of between 10^{-6} and $8x10^{-7}$ m/s were calculated. Based on less than 5 m of overburden, the time of travel to the underlying aquifer could be less than a year.

Figure B.2 Locations of Candidate Sites



While movement in the surficial shallow fracture clay flow system is essentially lateral, dug and bored wells were reported to obtain water supplies from this portion of the clay plain. Saturated fracture systems and silt or granular laminations within the lacustrine deposits are considered to be the source of water to such wells. In view of the fine-textured character of the deposits and the limited porosity of the fractures, yields to most shallow dug and bored wells are expected to be low and users likely rely on well-bore storage for periods of peak use. (Gartner Lee Limited, 1985)

2.1.2 Niagara Water Quality Protection Strategy CH2MHill MacViro and Philips Engineering (2003a, 2003b)

Using a somewhat similar qualitative approach, the Niagara Water Quality Protection Strategy (NWQPS) extended the Gartner Lee Limited (1987) maps to the extent of NPCA watershed (Figure B.3). Unfortunately, a new medium vulnerability category was added through a re-classification of previously classified (i) highly vulnerable bedrock aquifers (ii) highly vulnerable bedrock aquifers beneath <10 m overburden.

It is the opinion of the NPCA, that this re-classification is not appropriate and misses the understanding previously gained about the vulnerability of fractured clay environments (Gartner Lee Limited, 1985). The NWQPS text (CH2MHill MacViro and Philips Engineering, 2003a) also appears to support the same approach as previously advocated by the MOE (Gartner Lee Limited, 1987) and not the new mapping for the Local Management Areas' groundwater susceptibility to contamination (CH2MHill MacViro and Philips Engineering, 2003b).

2.1.3 Ontario Geological Survey (OGS) – Permeability (2003)

Surficial Geology of Ontario digital mapping includes a classification of "permeability" (OGS, 2003). Permeability can be defined as the capacity of a porous medium to transmit water under a hydraulic gradient. In the NPSP Area, the OGS assigned one of three permeability categories to surficial geology units: (i) high, (ii) low and (iii) variable (Figure B.4). There were also some limited areas of "medium-high" and "low-medium" permeability which were very small and grouped to "high" and "low", respectively.

Comparing the OGS "high permeability" category to the MOE mapping prepared by Gartner Lee Limited (1987) for "high susceptibility" to contamination, the Fonthill Kame-Delta Complex and the Dunnville Sand Plain were mapped as high in both cases. Similarily, "low permeability" compared well to the mapped "low susceptibility" in cases where there is greater than 10 m thickness of overburden. However, OGS mapped bedrock at surface as "variable permeability" rather than "high" and also included in this "variable permeability" category "fill", e.g. clay and silt from the Welland Canal.

It is the opinion of the NPCA, that this mapping does not supersede the earlier MOE work (Gartner Lee Limited, 1987) as overburden thickness was not considered and bedrock at surface was not classified as highly susceptible to contamination.

However none of these three mapping efforts are allowed under the Assessment Report Technical Rules (2009).

2.2 Intrinsic Susceptibility Index (GwISI):

The Groundwater Intrinsic Susceptibility Index (GwISI) is the second approach described in the Guidance Module (MOE, 2006a) and the first listed in Technical Rule 37 (1) (MOE, 2008). MOE have defined it as:

"a specific indexing approach that takes advantage of the existing Water Well Information System (WWIS) database within the province 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 a complete spatial assessment (map) of the intrinsic susceptibility of the aquifer(s)."

Three sets of these GwISI maps are available in the NPSP Area, however only one covers the entire NPSP Area.

The GwISI is a calculated value that estimates the susceptibility of the groundwater to contamination at a given point, e.g. determined on a well-by-well basis. The GwISI methodology for assessment is intended to be linked to the time of travel (ToT) of a contaminant to the water table and/or the shallowest aquifer. Two key attributes of the GwISI methodology are the depth to the water table or target aquifer, and the assignment of a K-Factor (a surrogate of time of travel to the aquifer) to the geological material in the unsaturated zone.

These two key attributes are further explained by Earthfx (2008) for the the Grand River Conservation Authority:

"The target aquifer depends on whether the well is screened in an unconfined or confined aquifer. For wells in unconfined aquifers, the GwISI value is calculated from ground surface to the top of the water table. For wells screened in confined aquifers, the GwISI value is calculated from ground surface to the top of the confined aquifer. MOE Guidelines (2006a) recommend that a 3-D geologic model be used where available to delineate the target aquifer. A 3-D aquifer model is superior to a rule-based approach but is time-consuming to construct. In the absence of 3-D models, an automated rule-based procedure is to be relied upon. The automated procedures are limited in their ability to accurately interpret complex geologic conditions and thereby introduce a measure of error and uncertainty into the results. For instance it was found a significant number of wells were classified as "no aquifer unit"."

"K-Factors are related (but not always equal) to the negative log of a representative hydraulic conductivity of the geologic material. K-Factors are generally assigned based on the lithologic classification scheme developed for the Oak Ridges Moraine area by the Geological Survey of Canada (GSC). The GSC scheme simplified the three-material descriptions in the MOE WWIS database into a single classification. The K-factor values in Guidance Module 3 were meant as a general guide however they can be modified using professional judgement and local knowledge."

Despite the prescriptive nature of the GwISI approach, there are quite a number of procedures within the GwISI approach subject to professional judgement (as mentioned above), such as (i) depth of water table wells (e.g. 15 vs 20 m bgs), (ii) assignment of K-factors, (iii) dealing with wells assigned "no aquifer unit", (iv) interpolation approach and algorithm settings, etc. These different judgement calls can produce different results.

2.2.1 NPCA Groundwater Study (Waterloo Hydrogeologic Inc., 2005)

In 2005, the NPCA Groundwater Study as prepared by Waterloo Hydrogeologic Inc. (2005) mapped groundwater vulnerability using GwISI and AVI. The use of GwISI was prescribed according to the provincial groundwater study technical terms of reference (MOE, 2001). Only MOE water wells records were used for this GwISI analysis. However, the GwISI map was further improved using AVI for surficial overburden and bedrock aquifers to delineate additional highly susceptible areas at the direction of the NPCA Groundwater Study Steering Committee. This is discussed later in Section 2.3.

According to Waterloo Hydrogeologic Inc. (2005), the geology of each well was evaluated to determine the "*first significant aquifer*". The water table map and potentiometric surface maps developed as part of the study were also used as references for determining these aquifers. The GwISI value was then calculated at each well as a sum of the unit thicknesses multiplied by the K-Factor that represented the geology type. MOE Technical Terms of Reference K-Factors were used (MOE, 2001). The GwISI values were classified into three groupings, (i) high susceptibility (<30 GwISI), (ii) medium (30 to 80) and (iii) low (>80). GwISI susceptibility groups were then assigned unitless values to complete "indicator" interpolation likely using krigging; high as 1, medium as 2 or low as 3 (Figure B.5). However, the interpolation settings, e.g. variogram, search radius, standard error etc. were not described making numerical calculations of uncertainty difficult. Following the interpolation the divisions between the three susceptibility groupings were defined as high < 1.55, medium >1.55 to <2.55, and low >2.55.

2.2.2 City of Hamilton Groundwater Resource Characterization Study (Charlesworth and Associates and SNC-Lavalin, 2006)

The City of Hamilton Groundwater Resource Characterization and Wellhead Protection Study also evaluated the groundwater vulnerability to contamination based upon the GwISI methodology. Their GwISI mapping was based upon an "improved dataset" that included some high quality golden spike data from boreholes drilled as part of engineering projects, hydrogeological studies and sub-surface site investigations (Figure B.6). In general, the results are very similar to the NPCA Groundwater Study (Waterloo Hydrogeologic Inc., 2005) in overlapping areas. For instance, approximately 23 km^2 of the City of Hamilton 237 km^2 portion of the NPSP Area (or 10%) was mapped as highly susceptible versus 22 km^2 or 9% by Waterloo Hydrogeologic Inc. (2005). However, one discrepancy is that the City of Hamilton did not complete an AVI analysis of the Niagara Escarpment surficial bedrock aquifers.

2.2.3 Hamilton Conservation Authority (2006)

Further improvement in groundwater vulnerability mapping was subsequently pursued by the Hamilton Conservation Authority under contract to the OGS. This effort (Figure B.7) re-visited the GwISI mapping and is expected to be the Groundwater Vulnerability mapping used for the Hamilton-Halton Assessment Report. It is understood that this subsequent effort included considerably more golden spike databases to augment the MOE WWIS. These included both the above noted study database as well as Ministry of Transportation, Oil Gas and Salt Resources, OGS City of Hamilton urban geology, City of Hamilton scanned reports and Hamilton Conservation Authority geotechnical databases. In general, in the area adjacent to the northwestern section of the NPCA, the results contain many more highly vulnerable areas compared to both the NPCA Groundwater Study (Waterloo Hydrogeologic Inc., 2005) and City of Hamilton Groundwater Resource Characterization and Wellhead Protection Study. This may be as a result of the GwISI being more of an AVI analysis through the inclusion of additional shallow data such as geotechnical results. The mapping was completed to the extent of the HCA boundary.

2.2.4 Grand River Conservation Authority – City of Hamilton and County of Haldimand

The Grand River Conservation Authority (GRCA) has been performing pioneer work in aquifer vulnerability since the late 1990s. They most recently commissioned and completed a comprehensive review of the GwISI method and its associated uncertainty (Earthfx, 2008). This work was peer reviewed by S.S. Papadopulos & Associates, Inc. (2009). Although completed for the Lake Erie Source Protection Region, the study area included Long Point, Catfish and Kettle Creek Conservation Authorities, and parts of Grand River, Hamilton and Niagara Peninsula Conservation Authorities.

GwISI assessments were completed following a data compiltation and database update, and where possible, statistical and geostatistical techniques to quantify the uncertainty in the results (Figure B.8). Their results reasonably match those completed by Waterloo Hydrogeologic Inc. (2005) and Charlesworth and Associates and SNC-Lavalin (2006). However no AVI analysis was completed of Niagara Escarpment surficial bedrock aquifers. Also, Earthfx used a cutoff for the water table of 20 mbgs rather than 15 mbgs as used by Waterloo Hydrogeologic Inc. and Charlesworth and Associates and SNC-Lavalin. However there does not appear to be direct affect of this differing criterion on the results. Overall GwISI results are similar, despite different consultants, where the MOE WWIS was the principal dataset.

Earthfx's geostatistical evaluation of their GwISI dataset variance indicated that one (1) standard error (S.E.) of the GwISI values was 47 GwISI units. This indicates a 68% certainty that the GwISI value is within +/- 47 units (1 S.E.) of the calculated values and a 96% certainty that the actual GwISI value is within +/- 141 GwISI units (3 S.E.). The significance of this is shown in a comparison to the threshold values whereby 47 GwISI units nearly exceeds the medium susceptibility category range of 30-80. An exercise was then completed to removed outliers from the dataset and this modestly reduced the S.E. to 35 GwISI units.

It is understood however, that GRCA will not be using these GwISI results for their groundwater susceptibility mapping. They are expected to use Surface to Aquifer Advective Time mapping (SAAT) which they recently completed. They are expected to complete an AVI analysis of highly susceptible surficial bedrock aquifers but are not expected to include an overburden thickness less than 5 m above bedrock as highly susceptible.

The NPCA Groundwater Study GwISI mapping was chosen for use in the Source Protection Study of Groundwater Vulnerability for the Assessment Report. This is because (i) it is complete across the NPCA, (ii) was completed according to the Assessment Report Technical Rules (2009) and (iii) matches well with similar GwISI efforts in City of Hamilton and GRCA.

2.3 Aquifer Vulnerability Index (AVI):

The Aquifer Vulnerability Index (AVI) is calculated in a similar way as the GwISI. The difference is that the AVI is calculated as the sum of the K-Factor and thickness for each soil layer above the aquifer of interest with no consideration of the water table. Surficial aquifers are automatically classified as highly vulnerable because there is no overlying protection. Use of an AVI approach is a more conservative estimate of vulnerability.

2.3.1 NPCA Groundwater Study (Waterloo Hydrogeologic Inc., 2005)

Waterloo Hydrogeologic Inc. completed an AVI analysis of two sets of highly vulnerable aquifers (Figure B.9):
(i) bedrock at surface – along the Niagara and Onondaga Escarpments; and
(ii) surficial overburden – this included the Fonthill Kame-Delta Complex, the Dunnville Sand Plain and the Iroquois Shoreline.

This improved the delineation of these high susceptibility areas using mapping of surficial geology. This AVI analysis was needed because:

- Interpolation of the GwISI individual well values did not adequately delineate susceptible linear features such as the Niagara Escarpment. However, the high susceptibility of the Onondaga Escarpment was generally well represented by the GwISI results.
- The vulnerability of surficial overburden aquifers was under-predicted and not well represented by the GwISI alone. These aquifers included the Fonthill Kame-Delta Complex, Dunnville and Iroquois Sand Plains. The regional water table surface under-predicted the vulnerability of the Fonthill Kame-Delta Complex. And the dug well supplies in the Dunnville and Iroquois Sand Plain aquifers are not in the MOE WWIS and were consequently not part of the rule-based GwISI analysis (John Warbick OMFRA, personal communication 2009).

Overall the 2005 NPCA Groundwater Study results (Figure B.10 - GwISI and AVI) for the assessment of groundwater vulnerability generally correspond well with those from the 1987 MOE Study.

The NPCA AVI results were chosen to be included in the Source Water Protection Study of Aquifer Vulnerability because (i) they represent a conservative approach for improvement of the GwISI results and (ii) were completed according to the Assessment Report Technical Rules (2009).

2.4 Surface to Aquifer Advection Time (SAAT):

Surface to Aquifer Advection Time (SAAT) calculations consist of two (2) components, the sum of which defines the total SAAT:

1. The unsaturated zone arrival time (UZAT), which defines the time of travel through the unsaturated zone to the water table;
2. The water table to aquifer arrival time (WAAT), which defines the time of travel from the water table to the aquifer of interest (required for confined aquifers).

For unconfined aquifers, SAAT and UZAT are assumed to be identical.

2.4.1 Grand River Conservation Authority – City of Hamilton and County of Haldimand

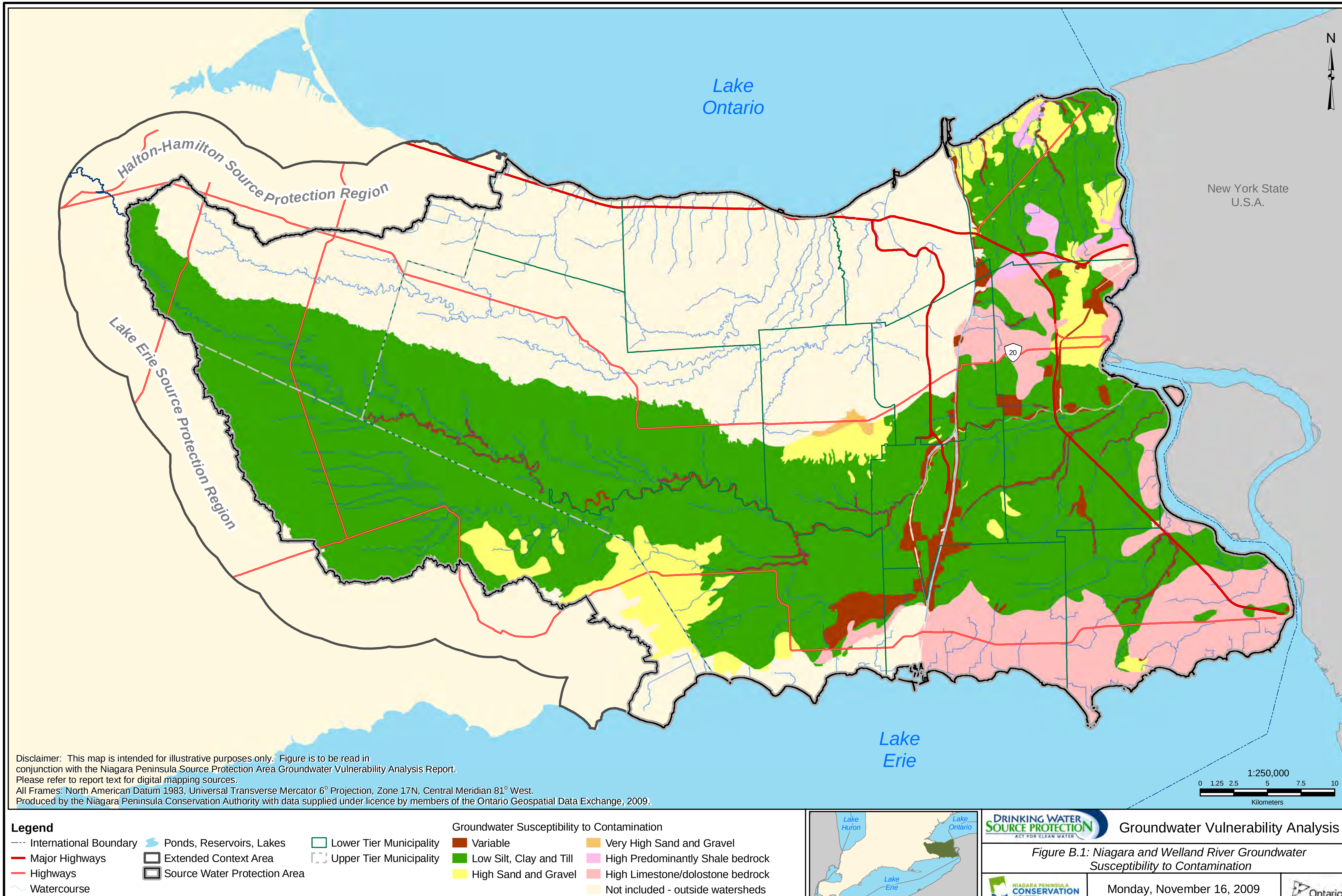
An alternative vulnerability assessment was also completed by Earthfx (2008) using SAAT (Figure B.11). This assessment was intended to improve upon the GwISI analysis through:

- Updated geologic reclassifications and methods to remove potential Oak Ridges Moraine K-Factor bias;
- Improvements in the assumptions about unsaturated zone travel; and
- Better estimates of travel time based on vertical gradient and moisture content.

It is our understanding that the SAAT results shown in Figure B.11 may be used by GRCA for their Assessment Report delineation of HVAs in the Lake Erie Source Protection Region.

SAAT values are classified into high, medium and low susceptibility based upon SAAT less than 5 years, between 5 and 25 years and greater than 25 years, respectively. While GRCA's SAAT modelling extent included all of Haldimand County and the City of Hamilton they are not currently recommended to be used in the NPSP Area. A number of reasons include, but are not limited to:

- The results appear overly un-conservative in the NPSP Area with respect shallow bedrock aquifer systems. This may be as a result of not including the potential for fracture flow in weathered overburden systems, i.e. overburden less than 5 m thick;
- Increased uncertainty associated with the SAAT approach - "*the alternative vulnerability evaluation (i.e. SAAT)…represents, in theory, an improvement over the GwISI approach…Although the approach is conceptually more satisfying, it is not clear whether the results are more defensible. The uncertainty in the results seems to outweigh any increase in rigour."* (S.S. Papadopulos & Associates, 2009).
- There is the appearance of potential krigging artifacts along the border with City of Hamilton; and
- Assumed parameters were used in the calculation of UZAT rather than NPSP Area Tier 1 Water Budget and Significant Recharge Area modelling results.


Lake Ontario
Lake Erie
New York State U.S.A.
Halton-Hamilton Source Protection Region
Lake Erie Source Protection Region
N
20
1:250,000
0 1.25 2.5 5 7.5 10
Kilometers
Disclaimer: This map is intended for illustrative purposes only. Figure is to be read in conjunction with the Niagara Peninsula Source Protection Area Groundwater Vulnerability Analysis Report.
Please refer to report text for digital mapping sources.
All Frames: North American Datum 1983, Universal Transverse Mercator 6° Projection, Zone 17N, Central Meridian 81° West.
Produced by the Niagara Peninsula Conservation Authority with data supplied under licence by members of the Ontario Geospatial Data Exchange, 2009.
Legend
International Boundary
Major Highways
Highways
Watercourse
Ponds, Reservoirs, Lakes
Extended Context Area
Source Water Protection Area
Lower Tier Municipality
Upper Tier Municipality
Groundwater Susceptibility to Contamination
Variable
Low Silt, Clay and Till
High Sand and Gravel
Very High Sand and Gravel
High Predominantly Shale bedrock
High Limestone/dolostone bedrock
Not included - outside watersheds
Lake Huron
Lake Ontario
Lake Erie
Drinking Water Source Protection
Act for Clean Water
Groundwater Vulnerability Analysis
Figure B.1: Niagara and Welland River Groundwater Susceptibility to Contamination
Niagara Peninsula Conservation Authority
Monday, November 16, 2009
Ontario

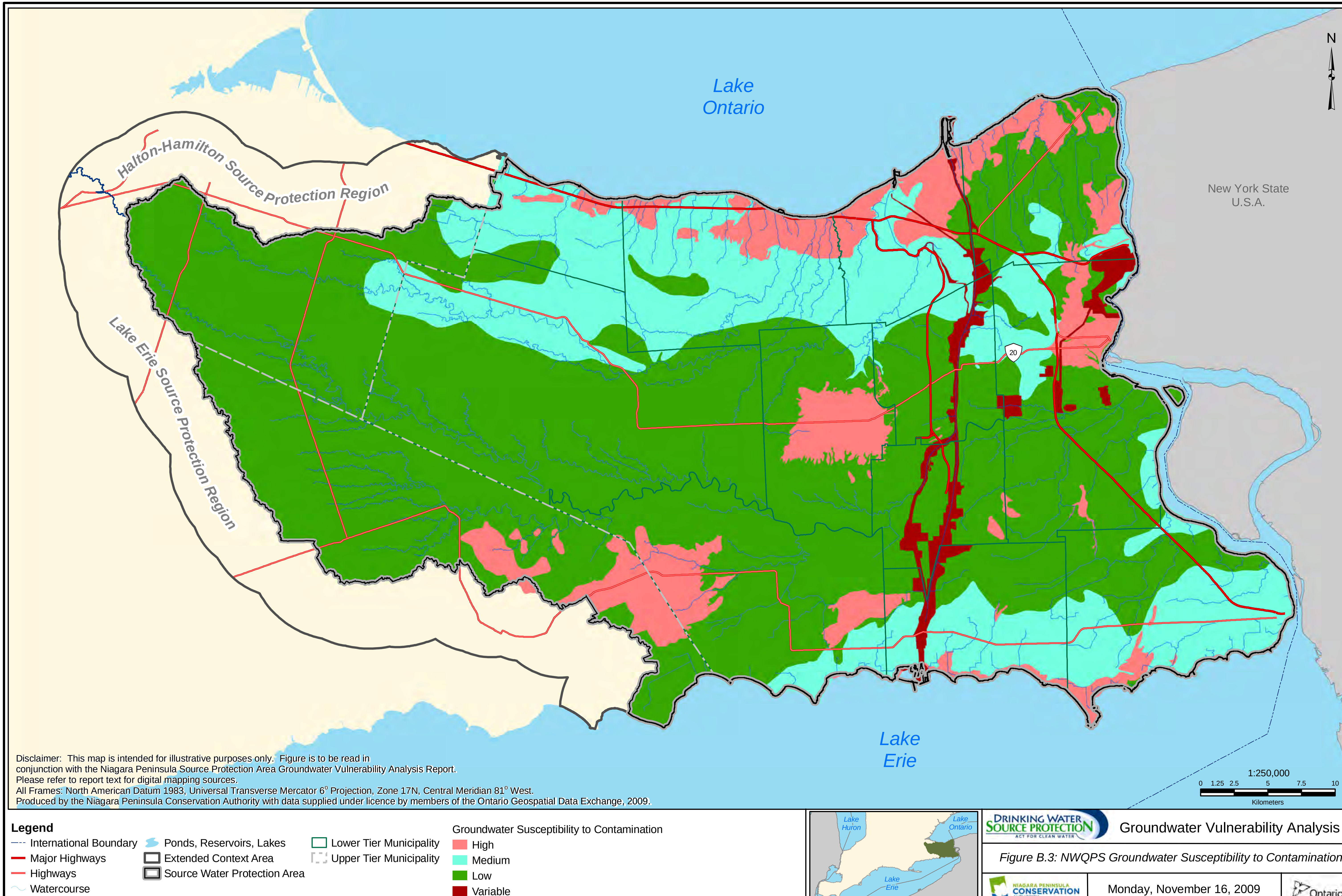
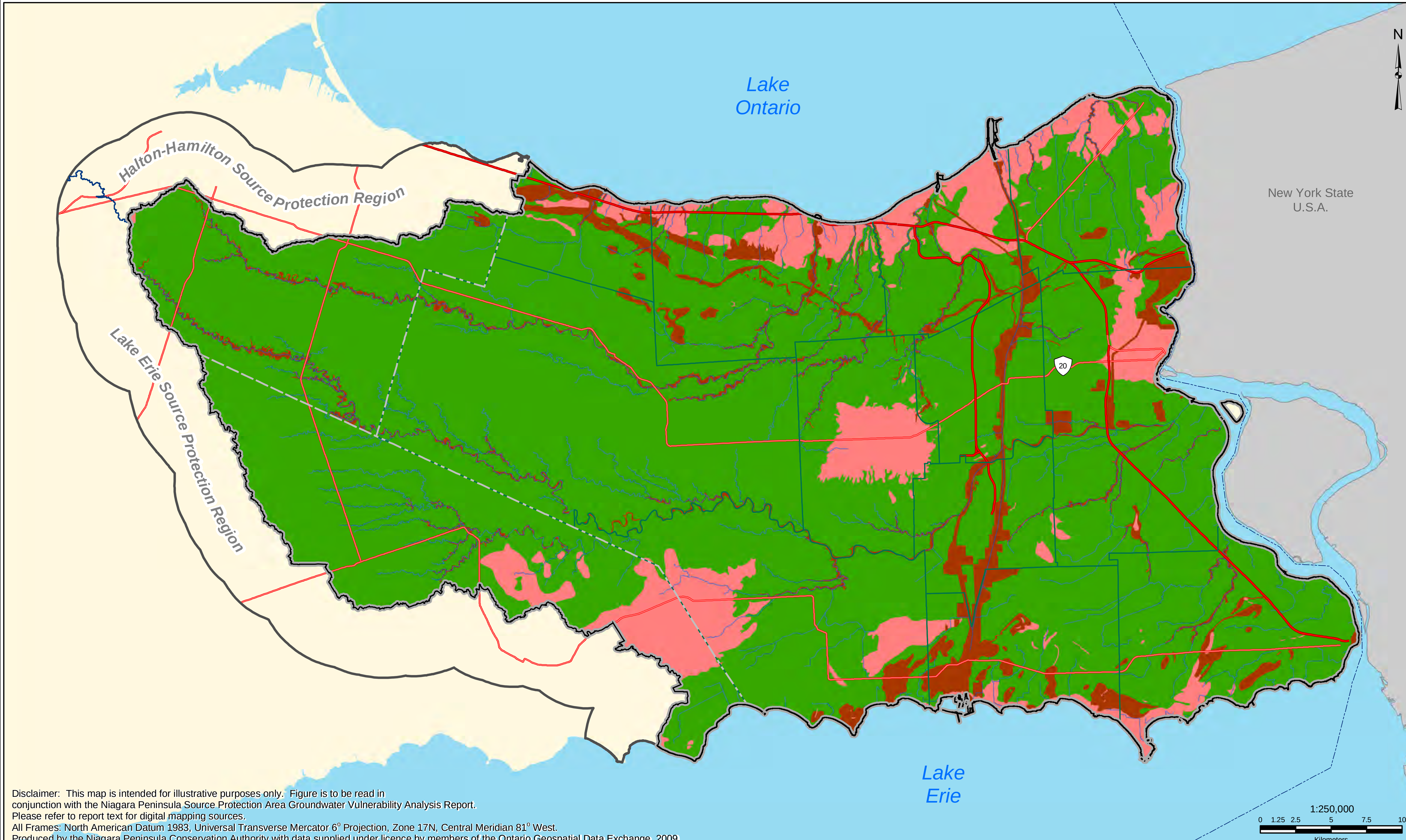


Figure B.3: NWQPS Groundwater Susceptibility to Contamination



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Legend

- International Boundary
- Major Highways
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- Lower Tier Municipality
- Upper Tier Municipality

Groundwater Permeability
- High
- Low
- Variable

DRINKING WATER SOURCE PROTECTION ACT FOR CLEAN WATER

Groundwater Vulnerability Analysis

Figure B.4: OGS Groundwater Permeability

NIAGARA PENINSULA CONSERVATION AUTHORITY

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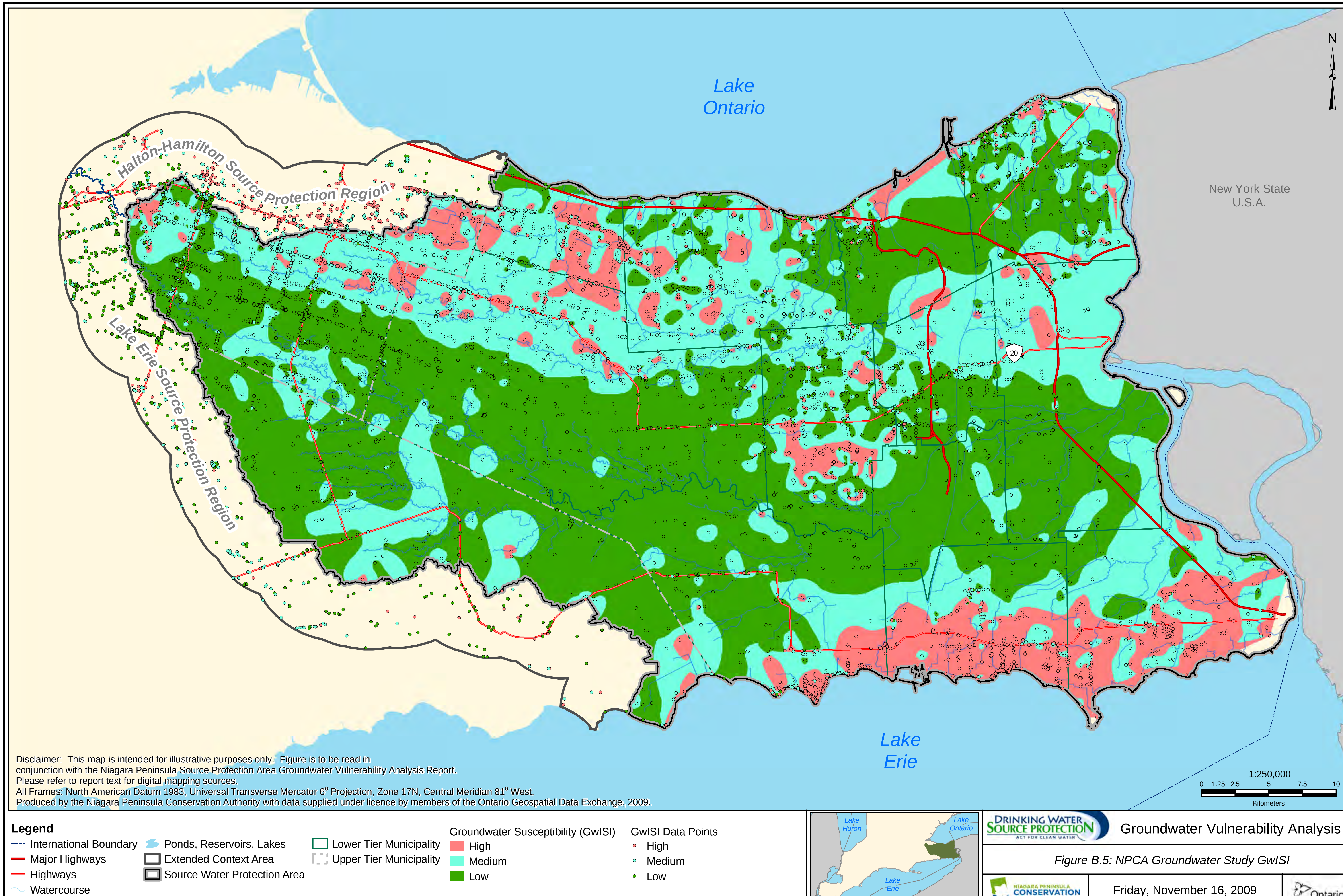
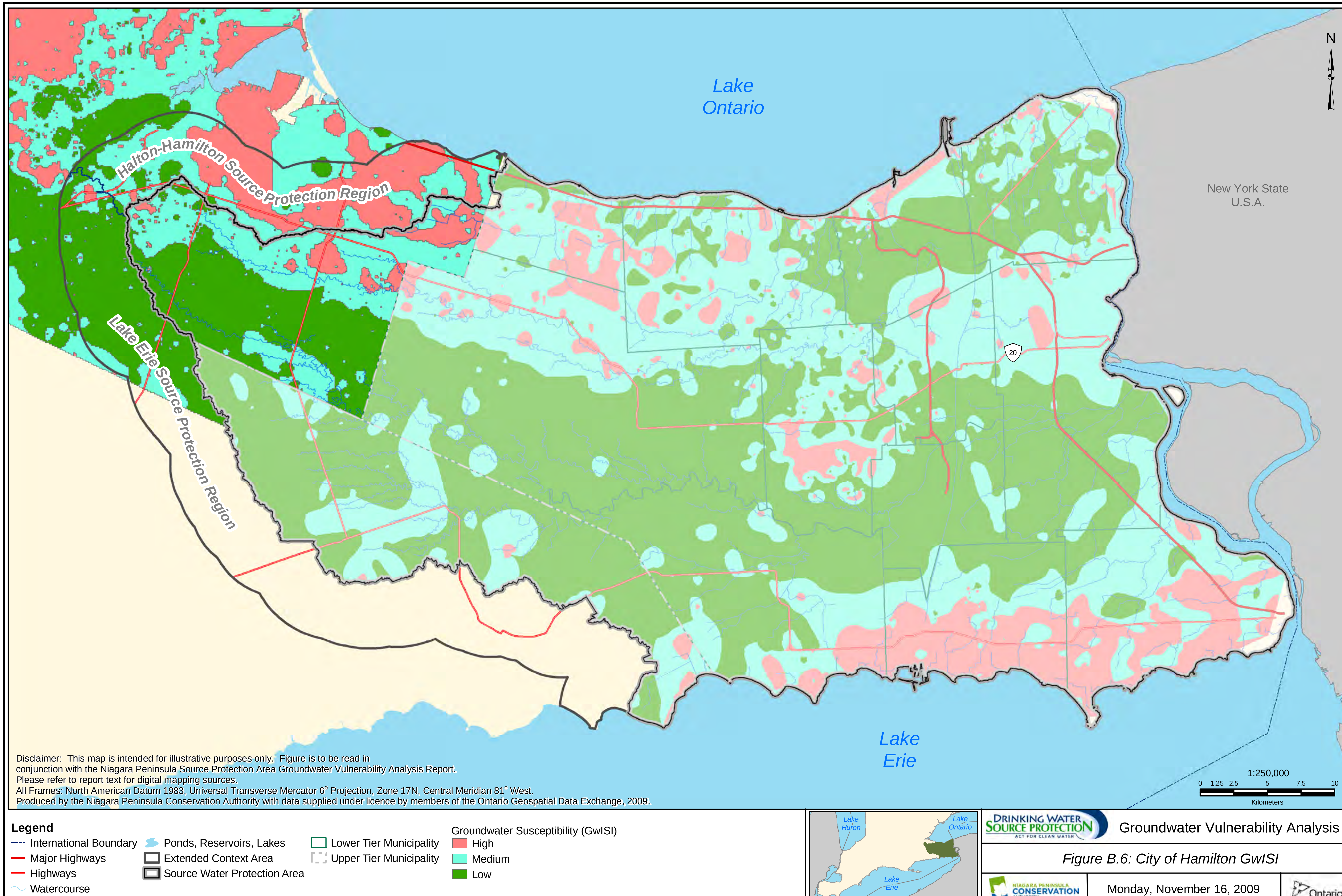
Ontario



Groundwater Vulnerability Analysis

Figure B.5: NPCA Groundwater Study GwISI

Friday, November 16, 2009


N
Lake Ontario
Lake Erie
New York State U.S.A.
Halton-Hamilton Source Protection Region
Lake Erie Source Protection Region
20
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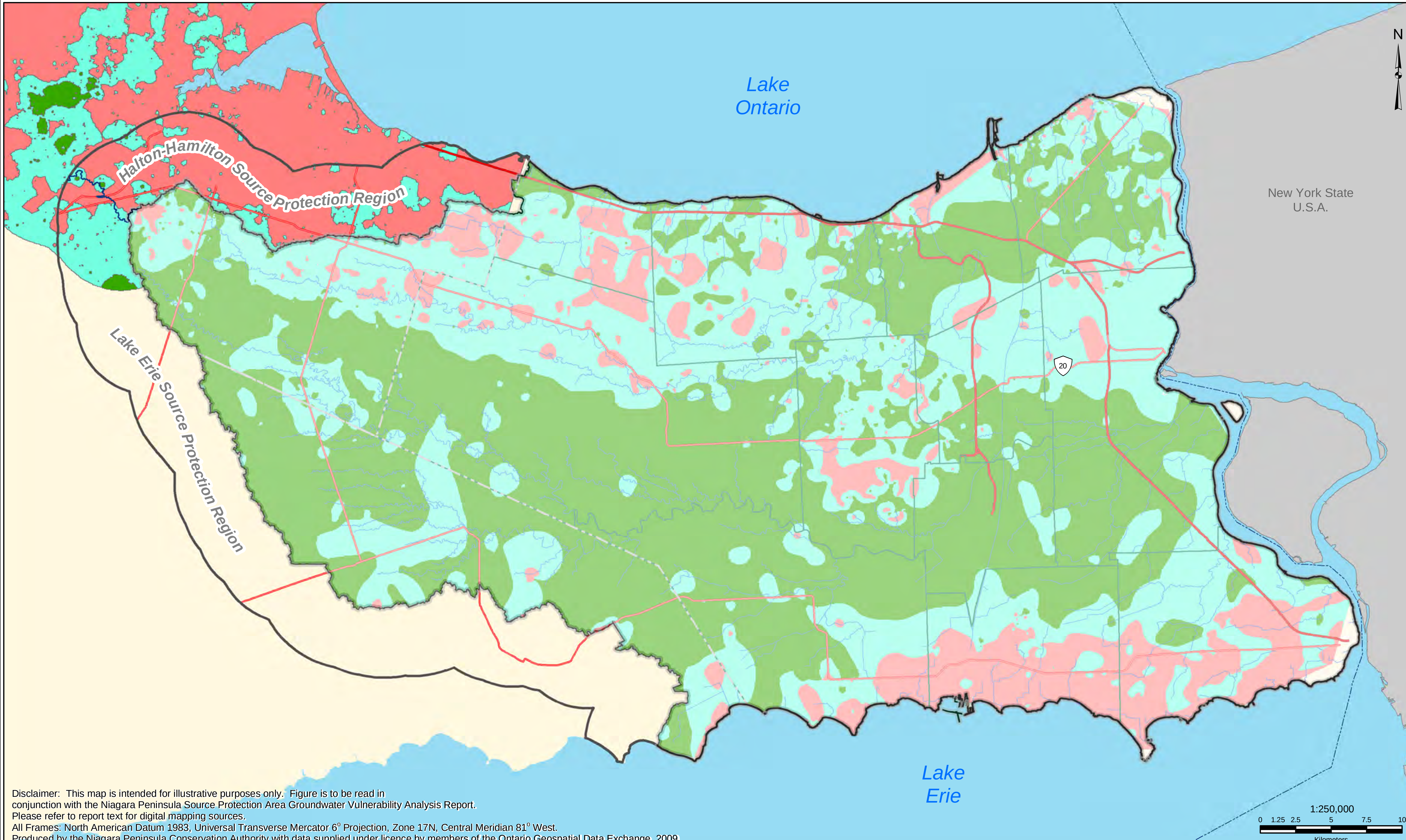
Groundwater Susceptibility (GwISI)
High
Medium
Low
Lake Huron
Lake Ontario
Lake Erie
DRINKING WATER SOURCE PROTECTION
ACT FOR CLEAN WATER
Groundwater Vulnerability Analysis
Figure B.6: City of Hamilton GwISI
NIAGARA PENINSULA CONSERVATION AUTHORITY
Monday, November 16, 2009
Ontario



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Legend

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- Source Water Protection Area
- Lower Tier Municipality
- Upper Tier Municipality

Groundwater Susceptibility (GwISI)
- High
- Medium
- Low

DRINKING WATER SOURCE PROTECTION
ACT FOR CLEAN WATER

Groundwater Vulnerability Analysis

Figure B.7: Hamilton Conservation Authority GwISI

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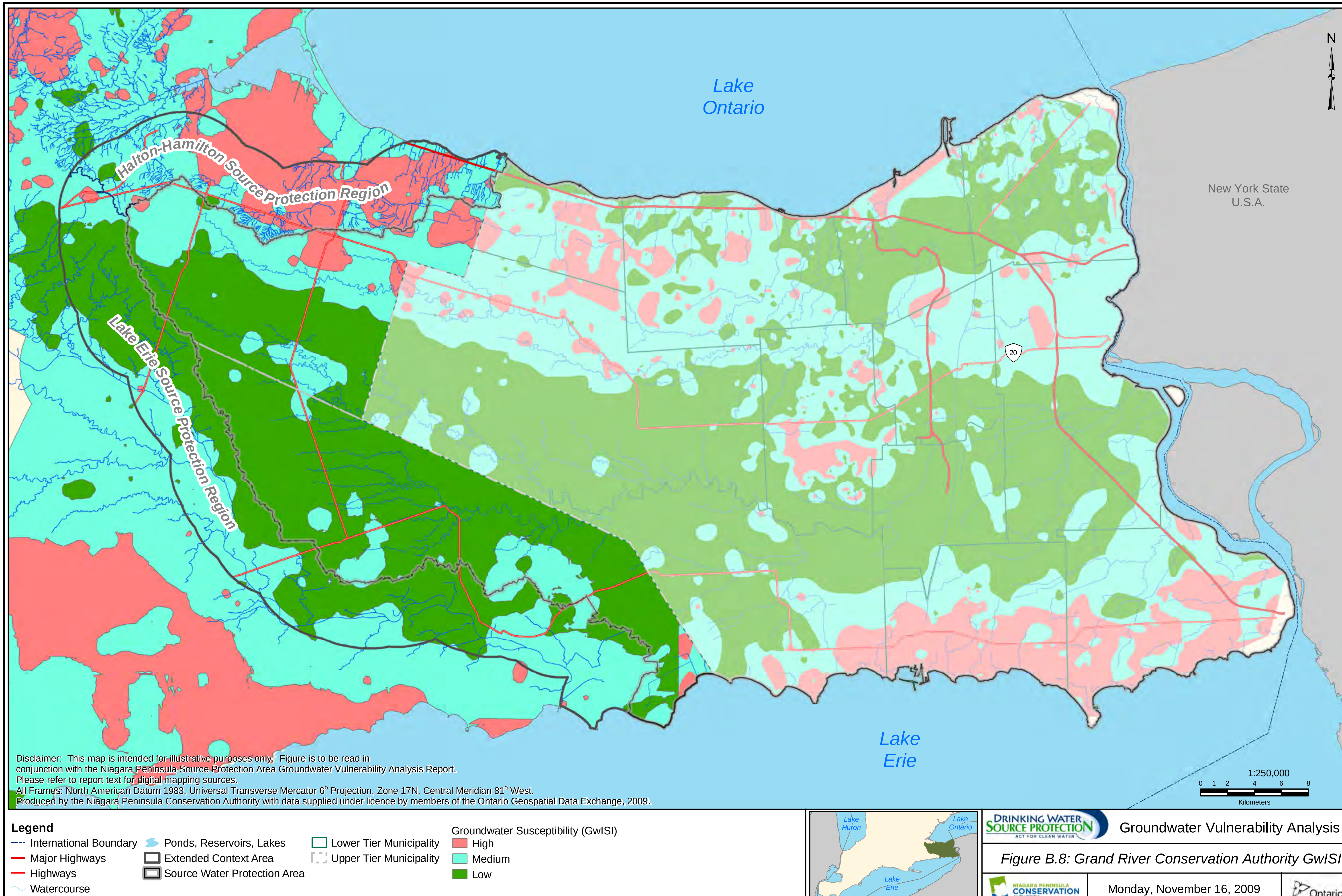
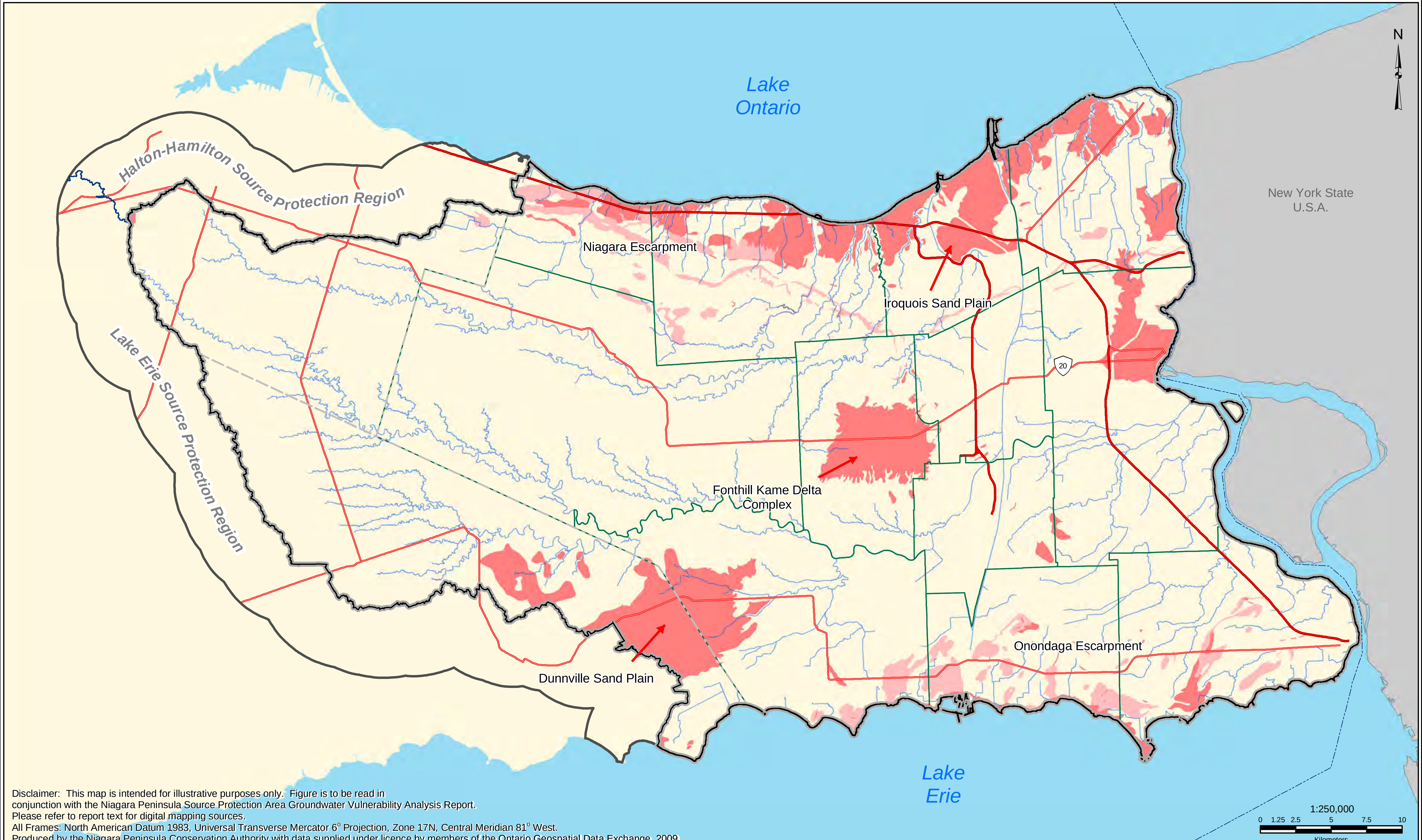
Ontario



Groundwater Vulnerability Analysis

Figure B.8: Grand River Conservation Authority GwISI



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- Source Water Protection Area
- Lower Tier Municipality
- Upper Tier Municipality

Groundwater Vulnerabilty (AVI)

- High (Sand and / or Gravel at Surface)
- High (Bedrock Outcrop)
- High (Karst Area)

Drinking Water Source Protection — Act for Clean Water

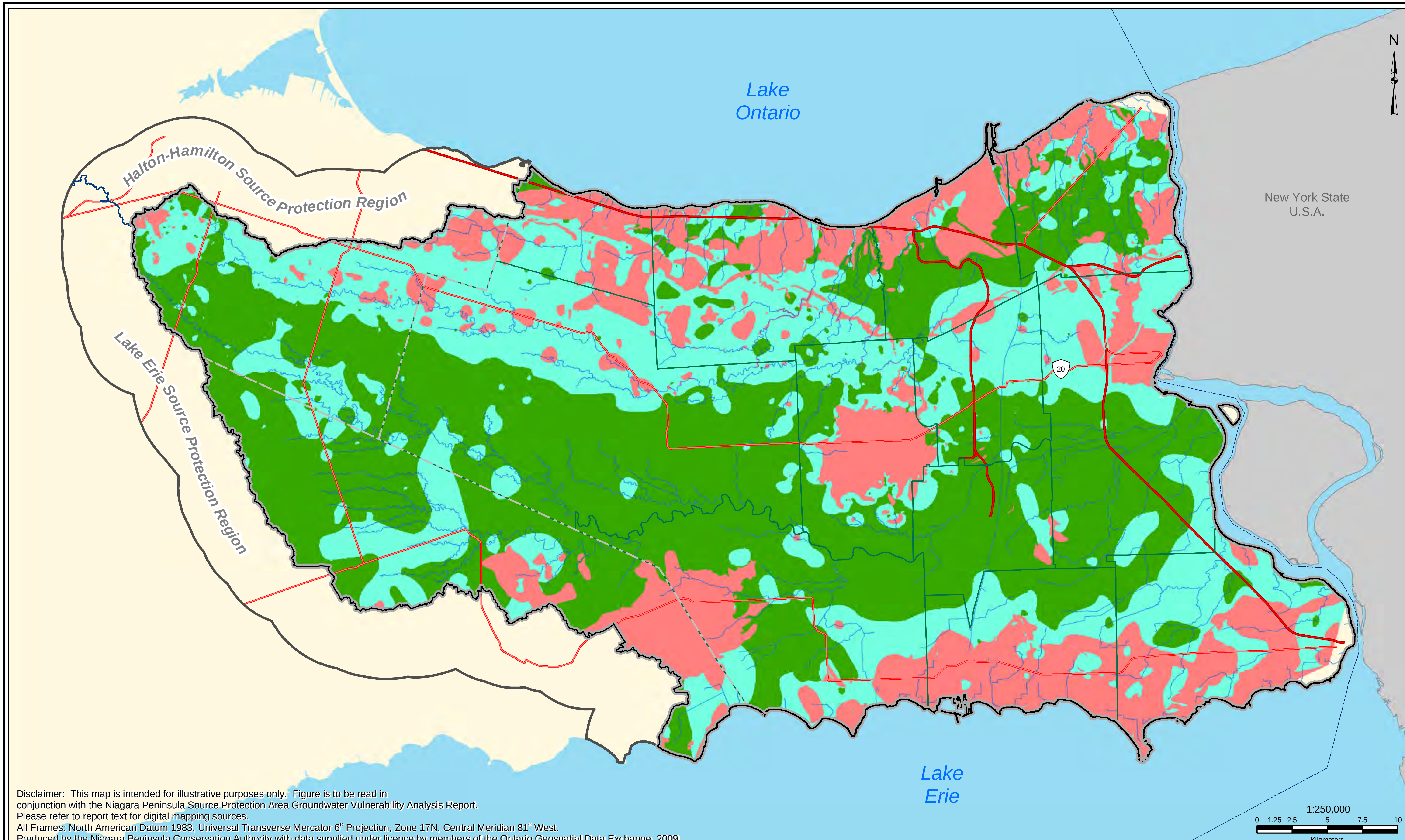
Groundwater Vulnerability Analysis

Figure B.9: NPCA Groundwater Study Aquifer Vulnerability Index

Niagara Peninsula Conservation Authority

Friday, November 16, 2009

Ontario



Legend

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- Extended Context Area
- Source Water Protection Area
- Lower Tier Municipality
- Upper Tier Municipality

Groundwater Vulnerability
- High
- Medium
- Low

DRINKING WATER SOURCE PROTECTION — ACT FOR CLEAN WATER

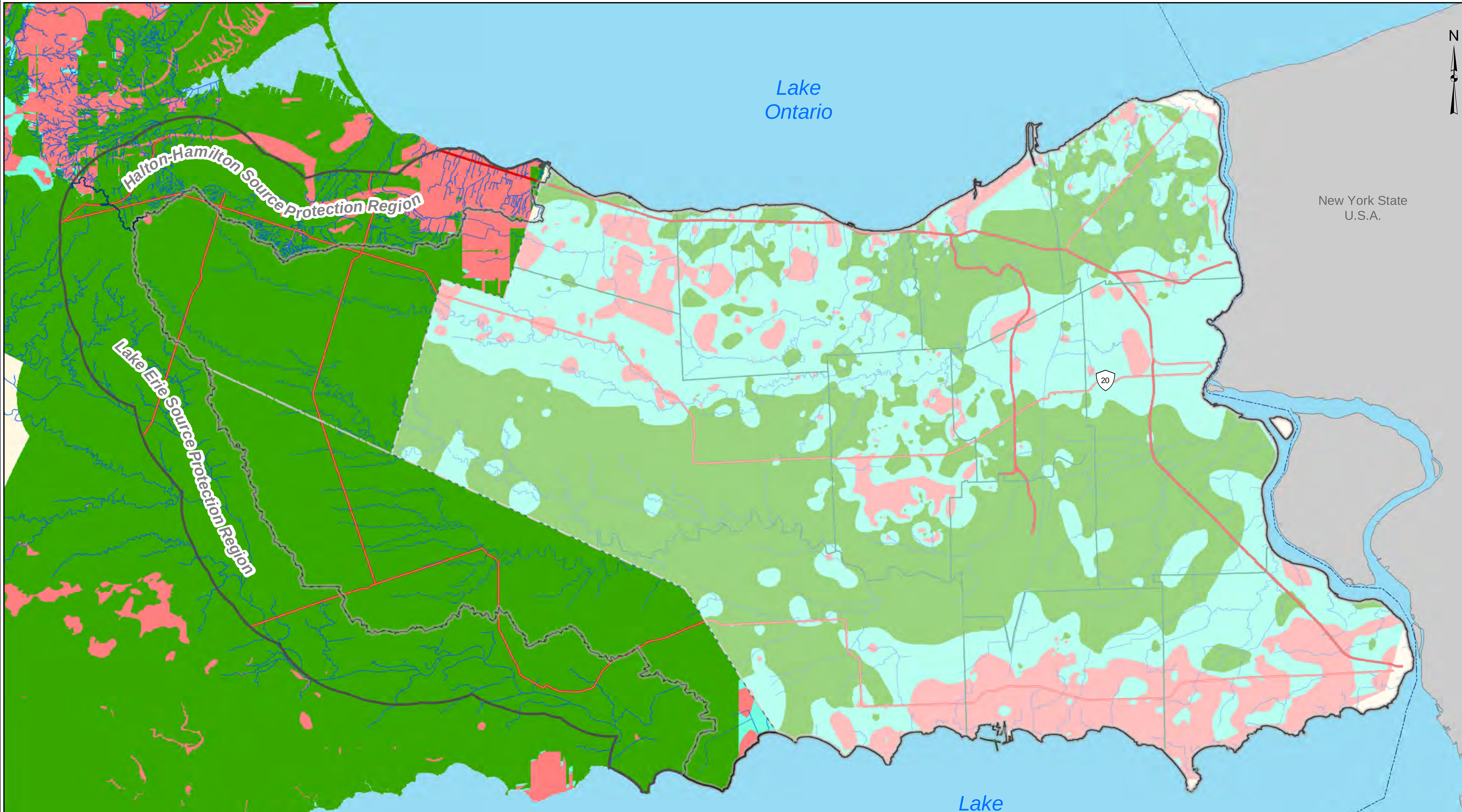
Groundwater Vulnerability Analysis

Figure B.10: NPCA Groundwater Study GwISI and AVI

NIAGARA PENINSULA CONSERVATION AUTHORITY

Friday, November 16, 2009

Ontario



Disclaimer: This map is intended for illustrative purposes only. Figure is to be read in conjunction with the Niagara Peninsula Source Protection Area Groundwater Vulnerability Analysis Report.
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Groundwater Susceptibility (GwISI)
- High
- Medium
- Low

Drinking Water Source Protection — Act for Clean Water

Groundwater Vulnerability Analysis

Figure B.11: Grand River Conservation Authority SAAT

Niagara Peninsula Conservation Authority

Monday, November 17, 2009

Ontario

Appendix C

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November 27, 2009

Mr. Jayme Campbell
Source Protection Hydrogeologist
Niagara Peninsula Conservation Authority
250 Thorold Road West, 3rd Floor
Welland, Ontario
L3C 3W2

Dear Jayme:

Re: Technical Peer Review of Groundwater Vulnerability Analysis
Niagara Peninsula Source Protection Area
File 080377.04

Jagger Hims, a Division of GENIVAR Consultants Limited Partnership (Jagger Hims) are pleased to provide Technical Peer Review comments on the draft report titled "Groundwater Vulnerability Analysis – Niagara Peninsula Source Protection Area" as prepared by the Niagara Peninsula Conservation Authority (NPCA) on November 17, 2009. The report will be referred to as NPCA Draft Report. The NPCA Draft Report presents required components of the Assessment Report to be prepared for the Niagara Peninsula Source Protection Area under the authority of *The Clean Water Act, 2006*.

The objectives of the peer review are to confirm that the work performed to delineate Highly Vulnerable Aquifers (HVAs) and to provide Vulnerability Scores for Significant Groundwater Recharge Areas (SGRAs) meets the requirements of the Technical Rules: Assessment Report document as prepared by the Ontario Ministry of the Environment. The original version of the Technical Rules was released in December 2008 and amendments were recently released in November 2009. The changes to the Technical Rules are not significant for the delineation of HVAs and the assignment of Vulnerability Scores to SGRAs.

The Technical Peer Review comments are presented in the following order:

1) Overall comments and impressions.
2) Responses to a series of questions as provided by NPCA.
3) Specific Comments related to the report content.

The November 17, 2009 version of the NPCA Draft Report was prepared to reflect input from Jagger Hims on re-organization and improvements to the clarity of an earlier draft report. draft report on the Groundwater Vulnerability Analysis.

OVERALL COMMENTS

The report provides a thorough documentation of the approach taken to map groundwater vulnerability in the NPCA and to prepare a map of Highly Vulnerability Aquifers (HVA) as required by the Technical Rules. The report contains a review of previous work and describes how these products and insights were incorporated into the draft report. The report is presented in an organized format and provides the necessary technical support for the proposed map products.

The specific comments provided below include some minor concerns with respect to using clear terminology and for improving documentation of decisions for the benefit of those who may not have technical backgrounds or may not be well-versed in the Technical Rules.

RESPONSES TO NPCA QUESTIONS

This letter report addresses the following questions:

1) Are the findings and conclusions logically derived and proven through the analysis presented in the report?
2) Was appropriate technical methodology used in developing the conceptual understanding?
3) Does the report appear to meet the requirements of the MOE AR Technical Rules?
4) Are the analysis and presentation of findings provided in sufficient detail to satisfy the MOE Source Protection requirements?

1. Are the findings and conclusions logically derived and proven through the analysis presented in the report?

Yes. The findings and conclusions were found to follow a logical pattern and are generally well documented. In a few instances, which are outlined in more detail below, comments are provided where some clarification could improve the understanding of the work conducted, particularly to a non-technical reader.

2. Was appropriate technical methodology used in developing the conceptual understanding?

Yes. Many studies have been previously conducted to assess groundwater vulnerability within the Niagara Peninsula Conservation Authority jurisdiction with differing results. As the method and/or mapping product chosen was required to conform to the MOE Technical Rules, each of the methods was examined and evaluated within this context. This process and the findings are well documented.

3. Does the report appear to meet the requirements of the Ontario Ministry of the Environment Technical Rules?

Yes. The primary evaluation criteria used in the process was the MOE Technical Rules. As each mapping product was evaluated against this criteria with documentation included in the NPCA Draft Report and a method selected that complies with one of the options outlined in the Technical Rules, the map products and documentation appear to meet the requirements of the MOE Technical Rules.

4. Are the analysis and presentation of findings provided in sufficient detail to satisfy the MOE Source Water Protection requirements?

Yes. The Vulnerability method selected for use for the HVA mapping is acceptable under the MOE Technical Rules and the decision-making was thoroughly documented and is defensible from a technical standpoint, therefore the analysis and findings satisfy the MOE Source Water Protection requirements.

SPECIFIC COMMENTS

The following comments have been prepared to identify specific features of the report that can be considered by NPCA in finalizing the NPCA Draft Report.

Report Section 1.0 - Introduction

Section 1.1

a) There is a reference made to ISI and AVI mapping that was previously completed, but no figure reference has been provided. If this mapping is presented in the report, a reference should be provided, or a statement provided that states that it is not present in the report if that is the case.

Section 1.2

b) Suggest using "considered" in place of "loosely be generalized".
c) Each of the aquifer formations listed should include basic geologic descriptions for the benefit of anyone reading the report who is not already intimately familiar with these systems. This should include brief discussion of the aquifer materials, whether unconfined or confined, and fracturing and connectivity in fractures.

Section 1.3

d) Update the reference provided to the Technical Rules to the latest version (December 2009) and ensure that quoted text matches this latest version.

Report Section 2.0 - Methodology

Section 2.2.3

e) Table 2.1 might be more easily read if the areas and percentages were clearly placed in individual columns with separating lines (also Table 2.3).

Section 2.3

f) Consider some clarification to Paragraph 2 that speaks to why other transport pathways were not considered. The potential for transport pathways, such as septic systems and stormwater and sanitary sewers to not influence the groundwater vulnerability is typically a function of the depth to the target aquifer. Typically in the NPSPA the areas where these types of infrastructure exist are typically already recognized as High Vulnerability. In this case, no further increase to the vulnerability is possible under the Technical Rules.

Section 2.3.3

g) Suggest to use the wording "The status of abandonment of Oil and Gas Wells prior to 1990s is unknown and these may not have been sealed in a method that will minimize the vulnerability of the shallow groundwater systems.

Section 2.3.4

h) The Technical Rules do not use the concept of "susceptibility" except in the context of the Intrinsic Susceptibility Method. Consider changing "susceptibility" to "vulnerability" to minimize confusion by the readers.

Section 2.3.6

i) The Vulnerability Increase for Transport Pathways, particularly those for private wells, has been increased by two steps, from Low to High instead of Low to Medium. This decision should be defended. This choice results in many small occurrences of high vulnerability within the backdrop of the low vulnerability areas and the usefulness of these areas will be directly dependent on the accuracy of the well locations used in the study. If the vulnerability is only increased by one step, the area of high vulnerability would be reduced and the corresponding maps and tables would need to be regenerated.

The approach to raise the vulnerability to from low to high for Private Wells may be beneficial for supporting the needs to develop procedures to better protect the aquifer systems for private wells. It may be appropriate to increase the vulnerability by two steps in areas where the natural protective cover has been removed, such as aggregate operations or beneath the Welland Canal.

Report Section 3.0 - Vulnerability

Table 3.3

j) This Table has been prepared to assess the entire dataset used in the study. It may be more appropriate to generate a separate table for each of the aquifer formations as there cannot be a clear answer for these questions when referring to the entire region. For example, there are fractured rock aquifers that maintain inherent uncertainty in predicting groundwater response. Similarly there are both confined and unconfined aquifers. The concept of the table is good but some of the questions may need to be adjusted to be appropriate for evaluating the uncertainty that contributed to the Vulnerability Analysis.

A Low Uncertainty may be reasonable. High Uncertainty could be considered for the areas designated by way of Transport Pathway unless clearly due to removal of soil or rock cover.

Report Section 4.0 – Next Steps

k) Consider adding programs for locating and confirming "unknown status" well locations, decommissioning unused wells, and providing upgrade incentive programs for wells that are degrading or not in compliance with current well regulations.

l) Consider programs that will obtain, compile and store data that could better characterize the aquifers, their connectivity to each other and surface water systems and flow characteristics. All of this data could go into constructing and calibrating a 3-D regional groundwater flow model. Examples of data types include detailed drilling logs, pumping test data, groundwater and surface water monitoring, etc.

Appendix A – Figures

m) Confirm that the figure colours selected conform to the standards as provided by the MOE.

Appendix B– Technical Memo

n) There is no conclusion provided in this memo as to which method was chosen for use in the current study. The assessments provided in some, but not all, of the sections outlining whether the mapping product is appropriate or not for use under the Technical Rules, should be incorporated into a concluding discussion at the end of each section with a clear statement as to which product was chosen and why.

o) Some of the descriptions provided on the mapping products and the work conducted in the studies that generated them are clear and concise as to what work was done and what the results were. As the audience reading this report will include non-technical people that may not be very familiar with these studies and what their findings mean, some of these descriptions require some clarification as to what some of the terminology included in the product means (an example being what the permeability classifications included in the OGS Permeability study mean).

Thank you for the opportunity to conduct this Peer Review on your behalf. We look forward to continuing our work with you and your partners in reaching your goals for drinking water source protection. Please contact us if you have any questions or wish to discuss these comments.

Yours truly,
JAGGER HIMS,
A DIVISION OF GENIVAR CONSULTANTS LIMITED PARTNERSHIP

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