



March 16, 2026

File No.: 4020-E-0010-09

Ministry of Transportation Ontario
Engineering Program Delivery East
1355 John Counter Blvd
Kingston, Ontario
K7L 5A3

Thurber File No.: 46611

Attention: Jerry Wang

DISAGGREGATION OF CANADA'S 6TH GENERATION SEISMIC HAZARD MODEL FOR TRANSPORTATION APPLICATIONS IN ONTARIO

Dear Jerry,

We are pleased to submit this report for the Ministry of Transportation Ontario that provides disaggregation values from the 6th generation seismic hazard model for use on transportation projects in Ontario.

1. BACKGROUND AND UNDERSTANDING

Natural Resources Canada (NRCAN) developed Canada's 6th Generation seismic hazard model to generate seismic design values for the 2020 National Building Code of Canada (NBCC2020). The seismic hazard generated by this model is also relied upon by other codes and standards, including the Canadian Highway Bridge Design Code S6:19 (CHBDC) and the soon to be released update; S6:25.

The Ministry of Transportation Ontario's Structural Manual (MTO 2024) identifies that the "2020 National Building Code of Canada Seismic Hazard Tool shall be used" to generate seismic hazard for the design of transportation structures. This seismic hazard is used to generate structural demands, to assess the likelihood of ground liquefaction, and to assess the impacts of ground liquefaction or seismically induced ground deformations.

Seismic hazard is quantified using different intensity measure types, including peak ground acceleration (PGA), peak ground velocity (PGV), and 5% damped spectral accelerations ("SA(0.5)" for example). The levels of these intensity measures (typically in g's for acceleration) are a function of the earthquake fault characteristics, the distance from the fault to the site of interest, the design probability of exceedance, and the local site conditions (for example, the V_{s30} of the soils). Different spectral accelerations are often presented together for a site as a Uniform Hazard Response Spectrum, or UHRS. The site UHRS provides spectral acceleration values having equal probabilities of exceedance (typically reported as percentage probability of exceedance in 50 years). These spectral acceleration values are used as demands for structures that have different fundamental periods.

For any site, any given combination of intensity measure level and probability of exceedance has an associated mean earthquake magnitude. For simplified analyses that are sensitive to earthquake duration (such as seismic deformation analyses of embankments or liquefaction triggering analyses), earthquake magnitude is often used as a proxy for effective earthquake duration. Like the UHRS, the mean earthquake magnitude is an output of the seismic hazard model. The process of developing the mean magnitude attributable to a specific intensity measure level is called ‘disaggregation’ (or ‘deaggregation’).

For previous generations of the National Building Code of Canada Seismic Hazard Model (including the 5th Generation model), NRCAN provided seismic disaggregation services upon request. For the current (6th) generation seismic hazard model, NRCAN no longer provides seismic disaggregation services.

The Ministry of Transportation Ontario (MTO) has retained Thurber Engineering Ltd. (Thurber) to develop a mean earthquake magnitude map for the Province of Ontario. This work will benefit geotechnical practitioners using the current generation seismic hazard model when conducting routine seismic analyses for transportation structures in Ontario.

The analyses and the results of these analyses are summarized in this document.

2. SEISMIC HAZARD DISAGGREGATION AND RESULTS

Seismic hazard disaggregation was completed using Global Earthquake Model’s (GEM) OpenQuake Engine version 3.18.0 (GEM 2024).

Seismic disaggregations are specific to an intensity measure level, site, and probability of exceedance. For example, given a specific site and probability of exceedance, the mean magnitude associated with the PGA will be different than the mean magnitude associated with the spectral acceleration at 0.5 s (SA(0.5)).

Earthquake magnitude is typically relied upon for simplified geotechnical analyses and not for developing structural demands. For simplified geotechnical analyses, the intensity measure of interest is typically the PGA. Therefore, we adopted PGA as representative for assessing the disaggregation grid resolution and for generating the mean magnitudes.

2.1 Model and Verification

We used the ‘final’ input files for NRCAN’s 6th generation seismic hazard model (‘Canada SHM6’) to generate PGAs and to conduct the associated disaggregations (Kolaj, Halchuck, and Adams et al 2023a). Canada SHM6 is documented by Kolaj et al (2019, 2020a, 2020b).

To verify the model and our process, we completed a disaggregation for Montreal City Hall and compared the results to a disaggregation of the same site completed by Kolaj et al (2023b).

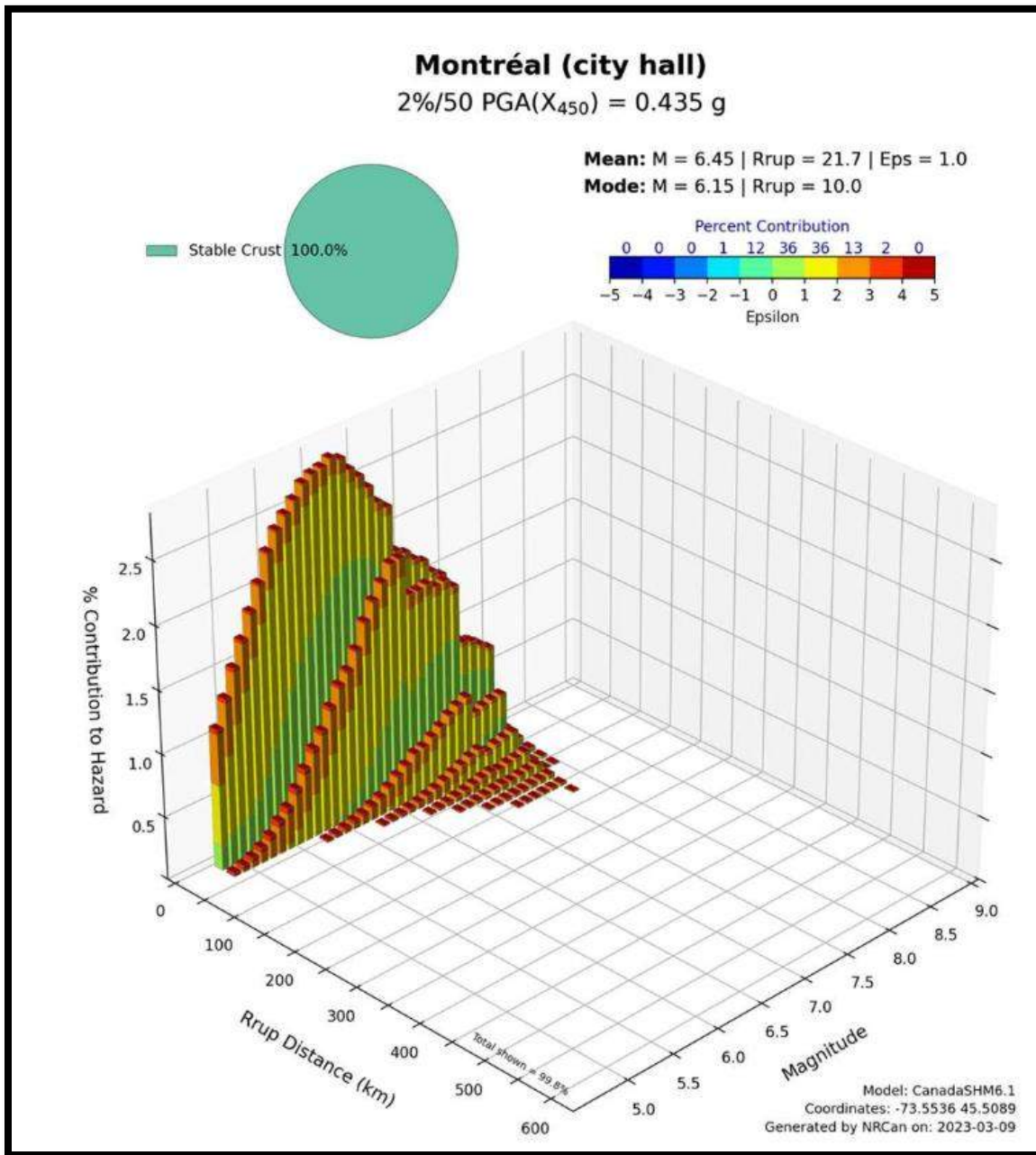


Figure 2.1: Reference Disaggregation conducted by Kolaj et al (2023b) for Montreal City Hall

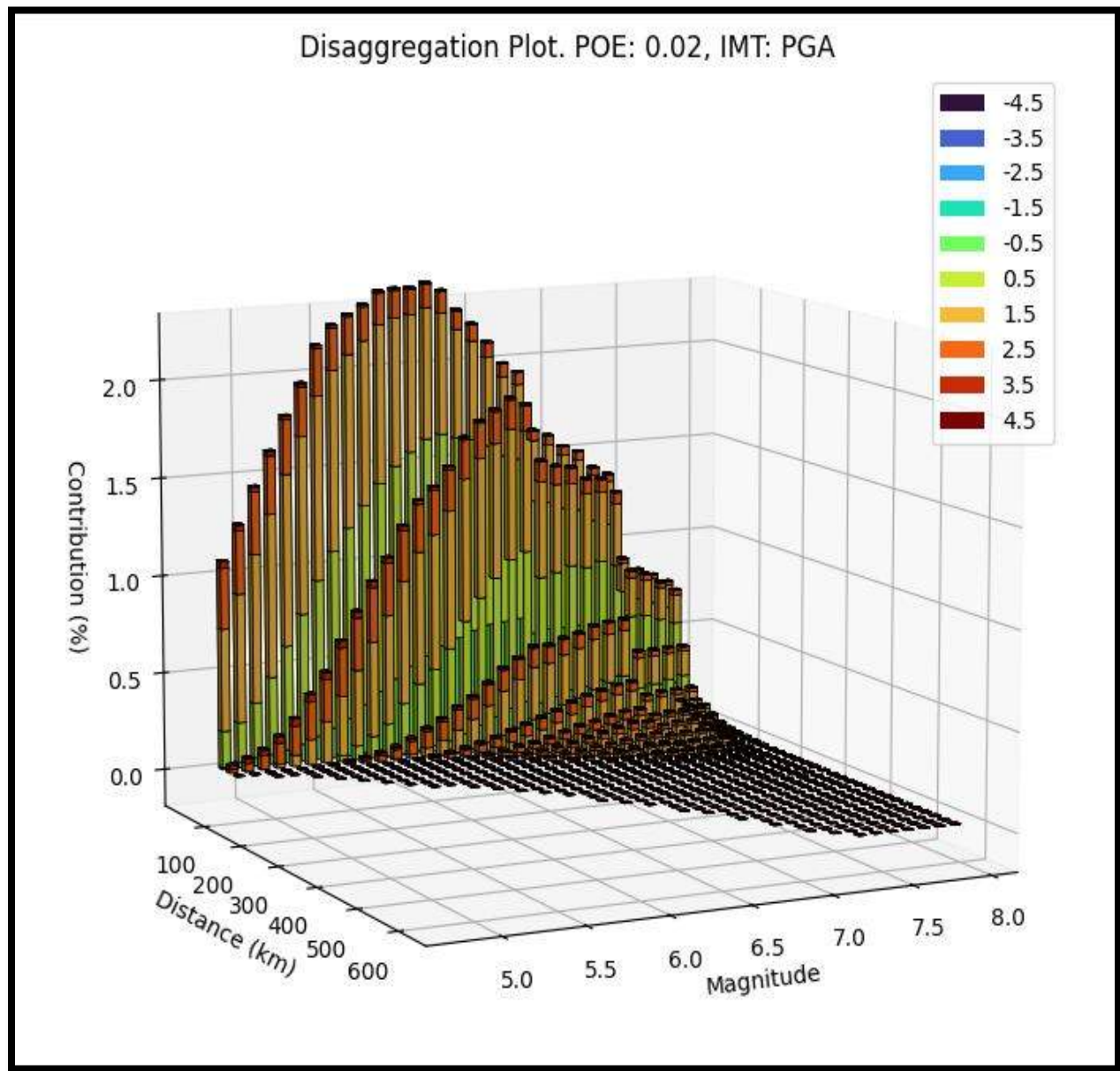


Figure 2.2: Disaggregation conducted by Thurber for Montreal City Hall for Verification Purposes

Table 2.1: Comparison of Kolaj et al Model Output and Thurber Model Output for Verification Purposes

Probability of Exceedance (% in 50 year)	Reference Mean Magnitude	Mean Magnitude Calculated by Thurber
2	6.45	6.46
5	6.26	6.28
10	6.14	6.16

We consider the difference in results to be insignificant (well within the expected uncertainty of these analyses given different versions of OpenQuake were used). The disaggregation plots are also in agreement.

2.2 Shear Wave Velocity Selection

Site amplification (which differs based on site characteristics) is accounted for in SHM6 by adjusting the intensity measures using relationships that are a function of the shear wave velocity of the upper 30 m of soils at a given site (V_{s30}). The ground motion models (GMMs) adopted for eastern sources do not have ‘built-in’ site terms to account for site amplification. SHM6 uses several different ‘non-native’ amplification functions (i.e., sourced from other GMMs) to account for site variability (Kolaj et al 2019).

We completed a parametric analysis to study the effects of shear wave velocity on mean magnitude. Three sites were selected for the comparison: Ottawa City Hall, Toronto City Hall, and Sudbury. The results are depicted in Figure 2.3 and Figure 2.4 for 2% in 50 year and 5% in 50 year probabilities of exceedance, respectively.

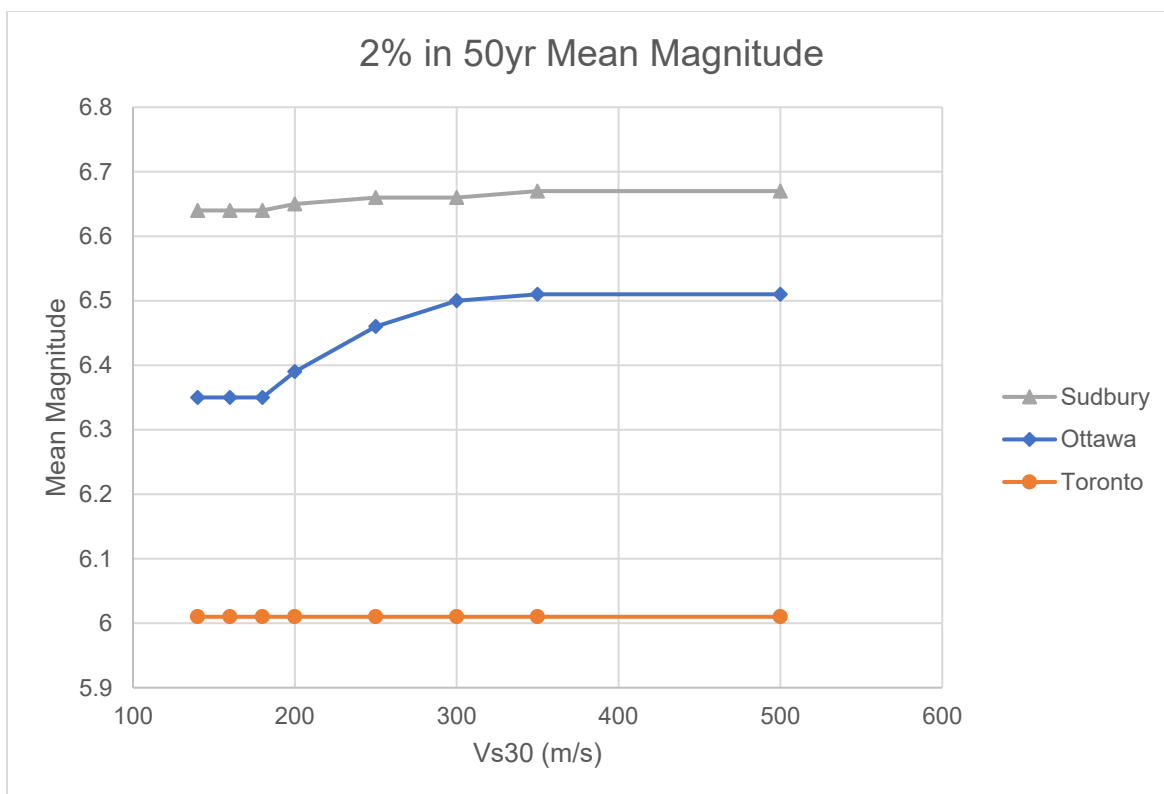


Figure 2.3: Shear Wave Velocity vs Mean Magnitude for 2% in 50 yr Probability of Exceedance

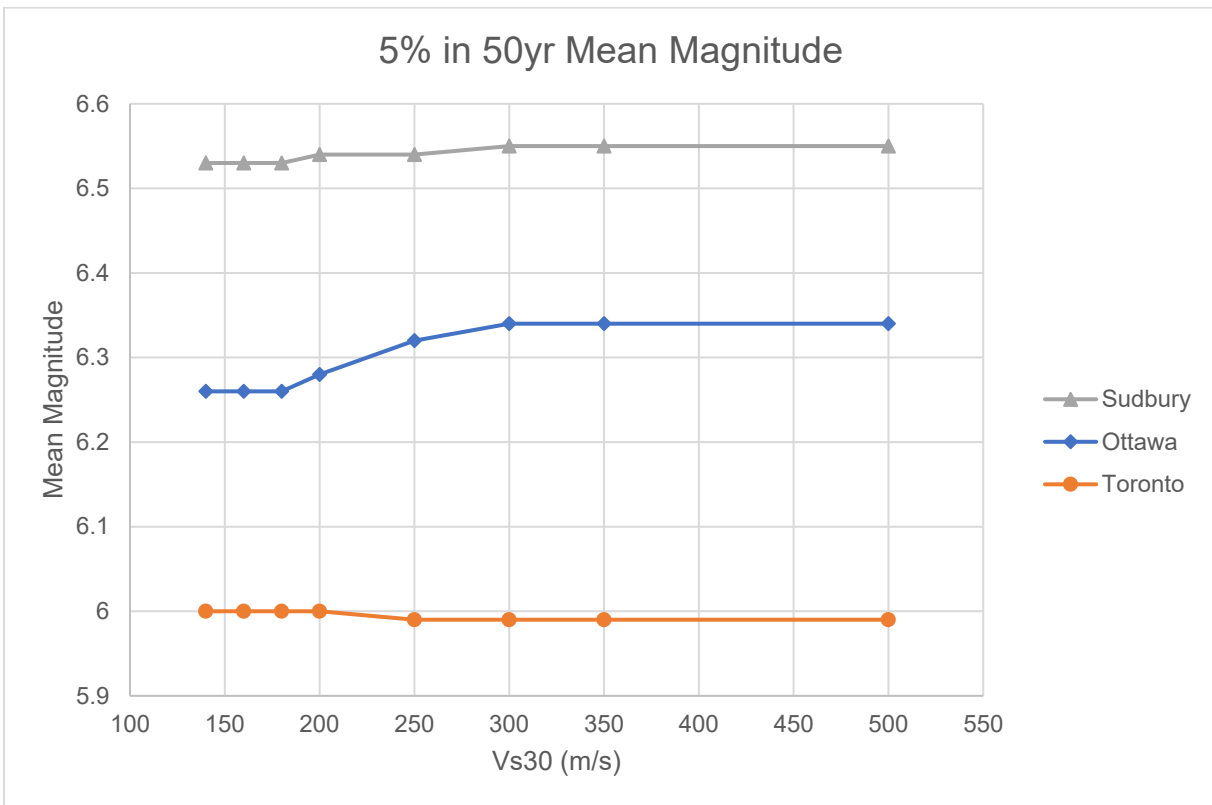


Figure 2.4: Shear Wave Velocity vs Mean Magnitude for 5% in 50 yr Probability of Exceedance

Below $V_{s30} = 180$ m/s, the mean magnitudes remain consistent because the site amplification functions for the stable crust (i.e., southeast Canada) GMMs are effectively governed by amplification relationships that use a minimum V_{s30} of 180 m/s (Boore and Atkinson 2008).

Above $V_{s30} = 300$ m/s, the magnitudes become near-constant.

For the purposes of this task, we adopted three different site conditions for each disaggregation grid point:

1. $V_{s30} = 180$ m/s
2. $V_{s30} = 250$ m/s
3. $V_{s30} = 300$ m/s

These selected values also cover the most likely range of soil conditions where the magnitude is likely to be sensitive to the site conditions. For example; soil profiles with a V_{s30} of greater than 300 m/s are stiff enough that they are less likely to liquefy; and soil profiles with a V_{s30} of less

than 180 m/s are typically soft enough to be problematic from a performance-based perspective regardless of the magnitude.

2.3 Disaggregation Grid Development

We developed a grid of points throughout the Province of Ontario and completed disaggregations at each point. To limit processing time, we only considered grid points if they were within 100 km of Ontario's major road network.

In general, where the 5% in 50 year PGA for a site with a $V_{s30} = 250$ m/s equaled or exceeded 0.05 g (generally the southeast of the Province), we set the grid point spacing at 0.45 degrees latitude and longitude (50 km north to south and 32 km to 37 km east to west). Where the PGA was less than 0.05 g, we doubled the spacing distances to limit processing time.

We manually adjusted the grid density in selected areas where we found the magnitude to be location-sensitive and near critical transportation infrastructure (such as near Toronto and along Highway 401).

We completed disaggregations for 272 distinct sites. This included Montreal City Hall, which was used for verification of the model (see Section 2.1).

2.4 Results, Output, and Quality Checks

We completed quality checks by comparing selected grid point PGA values obtained as part of the disaggregation process to the PGA values from NRCAN's seismic hazard calculator (NRCAN 2021).

For each probability of exceedance and V_{s30} pair, we used the disaggregation grid to generate a triangulated irregular network (TIN) mesh. The TIN was manually adjusted using engineering judgement in selected zones to produce a realistic and 'smooth' output. The resulting TIN was rasterized and discretized to 0.1 of a magnitude.

A spatial GIS data file was produced for each of the following conditions:

- 2% in 50 year probability of exceedance, $V_{s30} = 180$ m/s (Mean_Mag_2pc50Vs180.tif)
- 2% in 50 year probability of exceedance, $V_{s30} = 250$ m/s (Mean_Mag_2pc50Vs250.tif)
- 2% in 50 year probability of exceedance, $V_{s30} = 300$ m/s (Mean_Mag_2pc50Vs300.tif)
- 5% in 50 year probability of exceedance, $V_{s30} = 180$ m/s (Mean_Mag_5pc50Vs180.tif)
- 5% in 50 year probability of exceedance, $V_{s30} = 250$ m/s (Mean_Mag_5pc50Vs250.tif)
- 5% in 50 year probability of exceedance, $V_{s30} = 300$ m/s (Mean_Mag_5pc50Vs300.tif)
- 10% in 50 year probability of exceedance, $V_{s30} = 180$ m/s (Mean_Mag_10pc50Vs180.tif)
- 10% in 50 year probability of exceedance, $V_{s30} = 250$ m/s (Mean_Mag_10pc50Vs250.tif)
- 10% in 50 year probability of exceedance, $V_{s30} = 300$ m/s (Mean_Mag_10pc50Vs300.tif)

The spatial GIS data files have been assigned spatial data using WGS 84 (EPSG 4326), to match the SHM6 spatial data.

The disaggregation results are depicted in the attached Figures 01 through 18. These figures are included for quick reference and to provide a general overview. We do not recommend that they be used to determine the mean magnitude of a site. We recommend that the mean magnitude be extracted from the provided spatial GIS data files.

3. MINIMUM MAGNITUDE SENSITIVITY REVIEW

The minimum magnitude of earthquakes contributing to the hazard “can have a significant effect on the calculated hazard values” (Kolaj et al 2023, Halchuck and Adams 2010).

The seismic hazard values generated by NRCAN's 6th generation seismic hazard model generally use a minimum magnitude (M_{min}) of 4.8 (i.e., the seismic hazard model ignores sources that have a magnitude of less than 4.8). Other hazard maps use different values (the USGS, for example, generally uses an M_{min} of 5.0; Petersen et al 2024).

To study the effects of M_{min} , we conducted a sensitivity analysis on the location of Toronto City Hall.

Toronto City Hall PGA Hazard Curves Assuming Different M_{min} Truncations

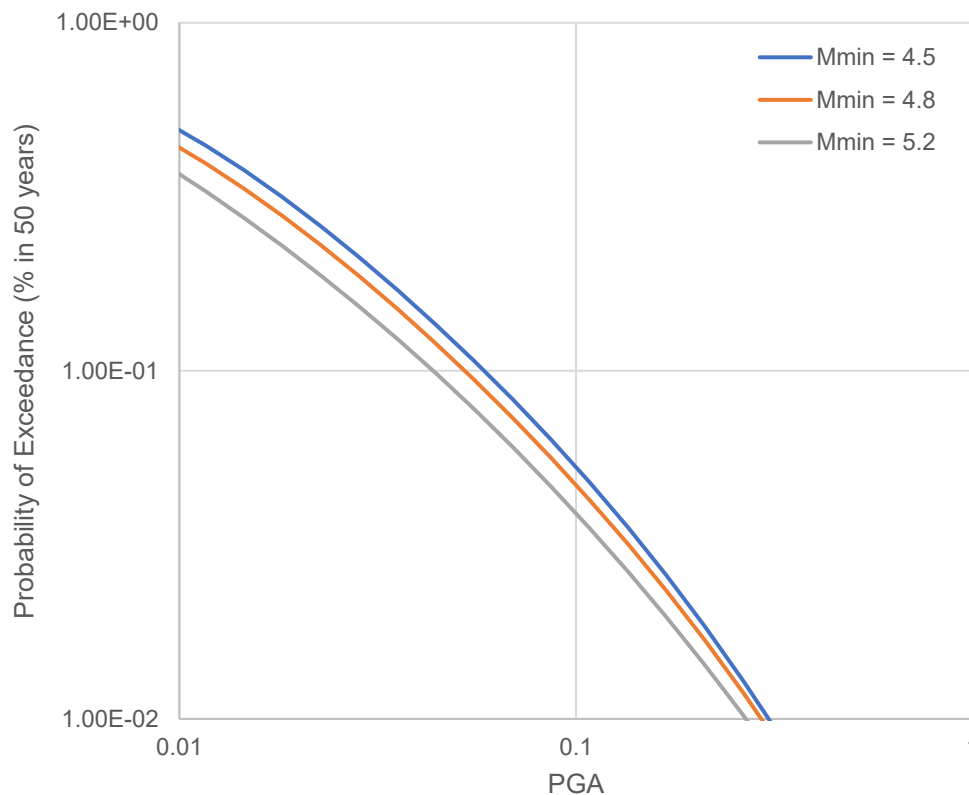


Figure 3.1: PGA Hazard vs Probability of Exceedance from Disaggregation for Different M_{min} Values

Table 3.1: Mean Magnitude as a function of M_{min} and Probability of Exceedance

Mmin	Probability of Exceedance in 50 Years		
	2%	5%	10%
4.5	5.9	5.8	5.8
4.8	6.0	6.0	6.0
5.2	6.2	6.2	6.2

In general, decreasing the M_{min} results in a higher hazard but a lower mean magnitude.

We note that adjusting the minimum magnitude of the seismic hazard model is complex and would result in inconsistencies with other analyses conducted using SHM6. For general

purposes (i.e., for any application that would be using this report and the associated data), we recommend that the default value (a minimum mean magnitude of 4.8) be adopted. For high-consequence and very-high-capital-cost structures that are judged to be sensitive to magnitude and seismic hazard (where the high cost of these analyses may be justifiable from a risk basis, a cost basis, or both), we suggest that MTO study and rationalize the default value, or any alternative value that is adopted.

4. RECOMMENDATIONS

4.1 Shear Wave Velocity

Mean magnitude values are provided for three site conditions: $V_{s30} = 180$ m/s, $V_{s30} = 250$ m/s, and $V_{s30} = 300$ m/s.

For sites with a V_{s30} of less than 180 m/s, we recommend adopting a magnitude based on a V_{s30} of 180 m/s. For sites with a V_{s30} of greater than 300 m/s, we recommend adopting a mean magnitude based on a V_{s30} of 300 m/s. For values in between, we recommend that the mean magnitude be selected using linear interpolation between the provided V_{s30} values.

4.2 Limitations and Applicability of Results

We judge that these recommendations and disaggregation values are appropriate for simplified liquefaction triggering analyses and for semi-empirical displacement analyses (i.e., non-rigorous Newmark style analyses) applicable to typical transportation infrastructure in Ontario.

The mean magnitudes are appropriate for PGA intensity measure levels obtained using NRCAN's 2020 National Building Code of Canada Seismic Hazard Tool (NRCAN 2021) and are not appropriate for other intensity measure types.

Where a site spans a zone that has multiple magnitudes within the appropriate spatial GIS data file, we recommend adopting the higher mean magnitude value for the entire site. We note that large project sites are likely to have similarly varying seismic hazards when the seismic hazards are obtained from NRCAN's online seismic hazard tool. We also recommend adopting the higher hazard value for the site and using it in combination with the higher mean magnitude. In general, this will be conservative.

5. INTERPRETATION AND USE OF THIS REPORT

This report and the associated GIS data files are intended to be used by the Ministry of Transportation Ontario, and their approved delegates, for engineering purposes associated with Ministry of Transportation Ontario infrastructure for the benefit of the Ministry of Transportation Ontario.

Use of this report or the associated GIS data files are subject to the attached Statement of Use and Interpretation of report.

6. CLOSURE

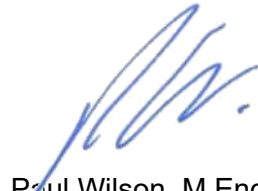
We trust this letter meets your current needs. Please contact the undersigned if you have any questions.

Yours truly,



Jonathan Foote, M.Eng., P.Eng.
Senior Geotechnical Engineer
Thurber Engineering Ltd.

Reviewed by:

A handwritten signature in blue ink, likely belonging to Paul Wilson.

Paul Wilson, M.Eng., P.Eng.
Review Engineer
Thurber Engineering Ltd.

JF/PW

Attachment:

- Statement for Use and Interpretation of Report
- Figures 01 through 18

REFERENCES

Globel Earthquake Model (GEM). 2024. *OpenQuake Engine*. V3.18.0. PC.

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Boore, David M., and Gail M. Atkinson. 2008. "Ground-Motion Prediction Equations for the Average Horizontal Component of PGA, PGV, and 5%-Damped PSA at Spectral Periods between 0.01 s and 10.0 s." *Earthquake Spectra* 24 (1): 99–138.
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STATEMENT FOR USE AND INTERPRETATION OF REPORT

1. STANDARD OF CARE

This Report has been prepared in a manner consistent with that degree of care and skill ordinarily exercised by members of the same profession currently practicing under similar circumstances at the same time and in the same or similar locality and in compliance with all applicable laws.

2. COMPLETE REPORT

All documents, records, data and files, whether electronic or otherwise, generated as part of this assignment, including this Statement For Use and Interpretation of Report, are a part of the Report, which is of a summary nature and is not intended to stand alone without reference to the instructions given to Thurber by the Client, communications between Thurber and the Client, and any other reports, proposals or documents prepared by Thurber for the Client relative to the specific site described herein, all of which together constitute the Report.

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The Report has been prepared for the specific site, development, design objectives, and purposes that were described to Thurber by the Client. The applicability and reliability of any of the findings, recommendations, suggestions, or opinions expressed in the Report, subject to the limitations provided herein, are only valid to the extent that the Report expressly addresses proposed development, design objectives and purposes, and then only to the extent that there has been no material alteration to or variation from any of the said descriptions provided to Thurber, unless Thurber is specifically requested by the Client to review and revise the Report in light of such alteration or variation.

4. USE OF THE REPORT

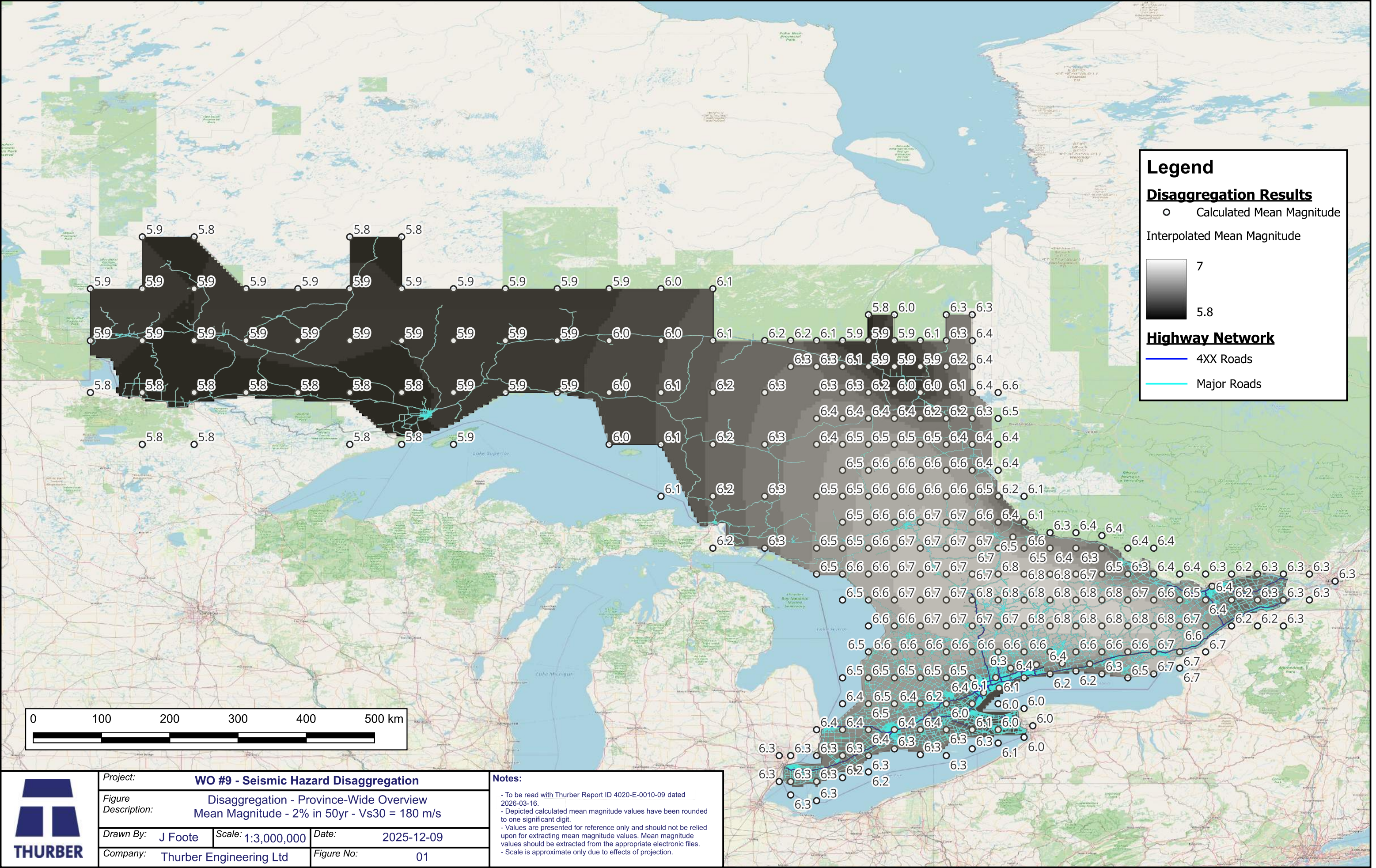
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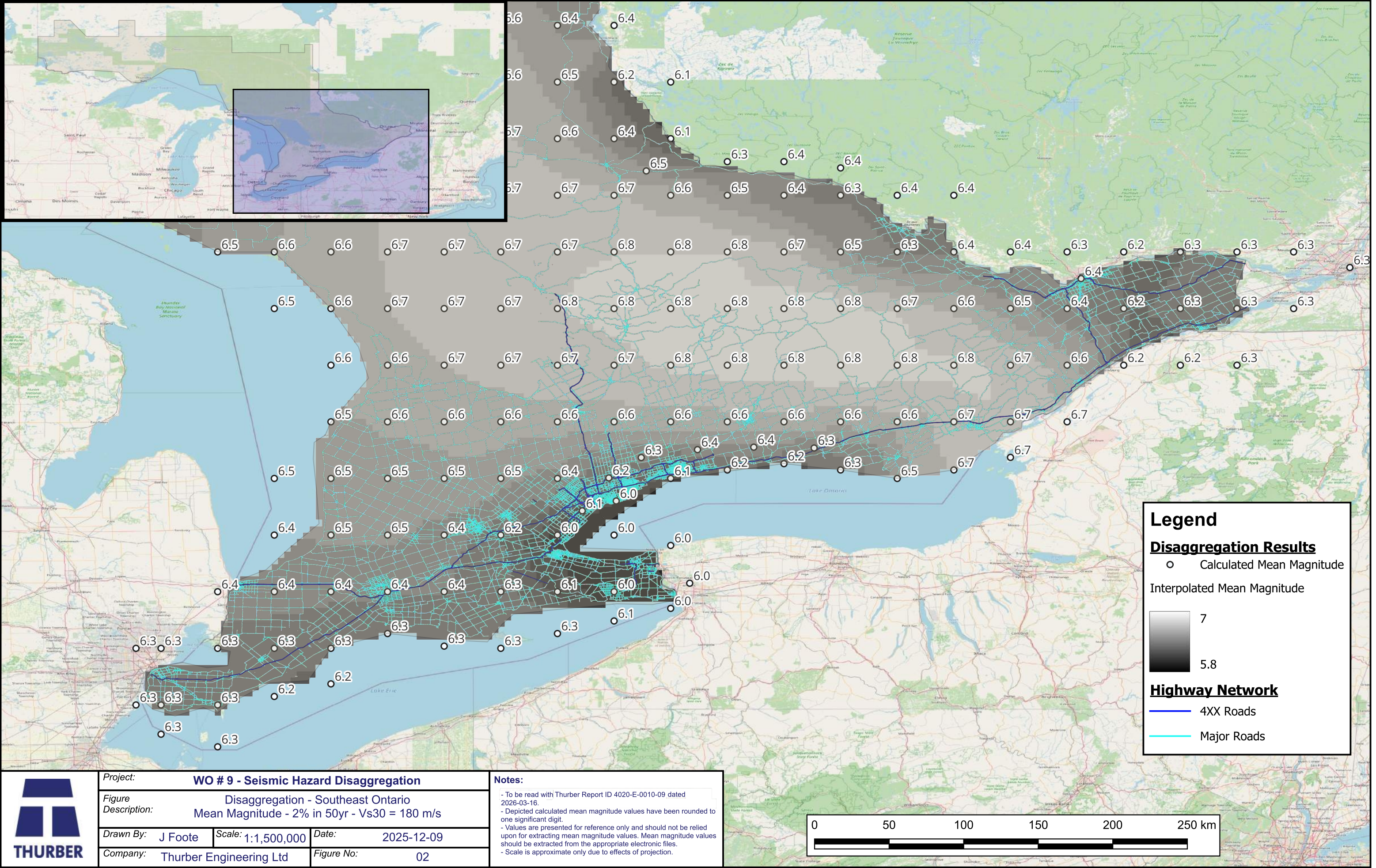
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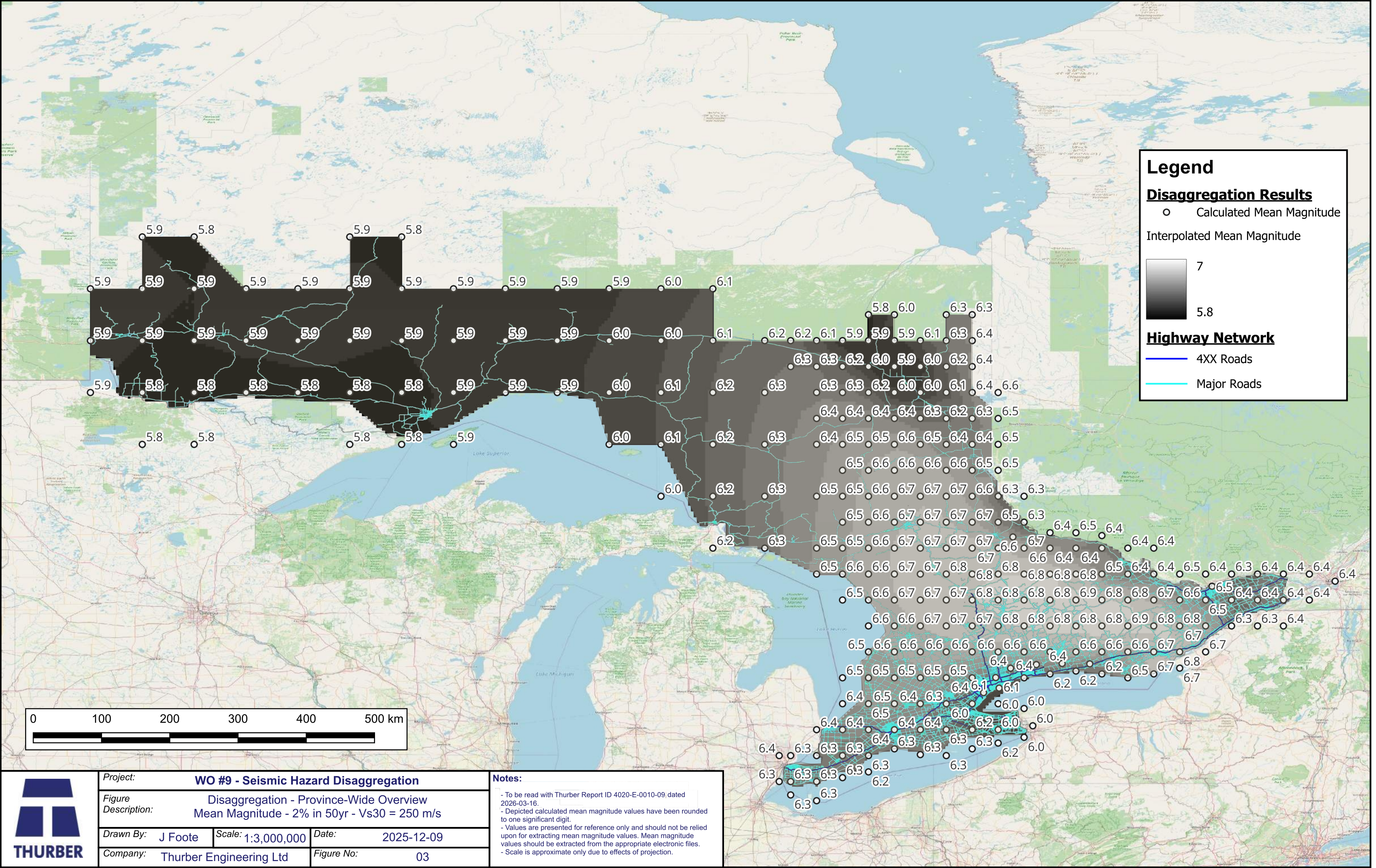
6. INDEPENDENT JUDGEMENTS OF CLIENT

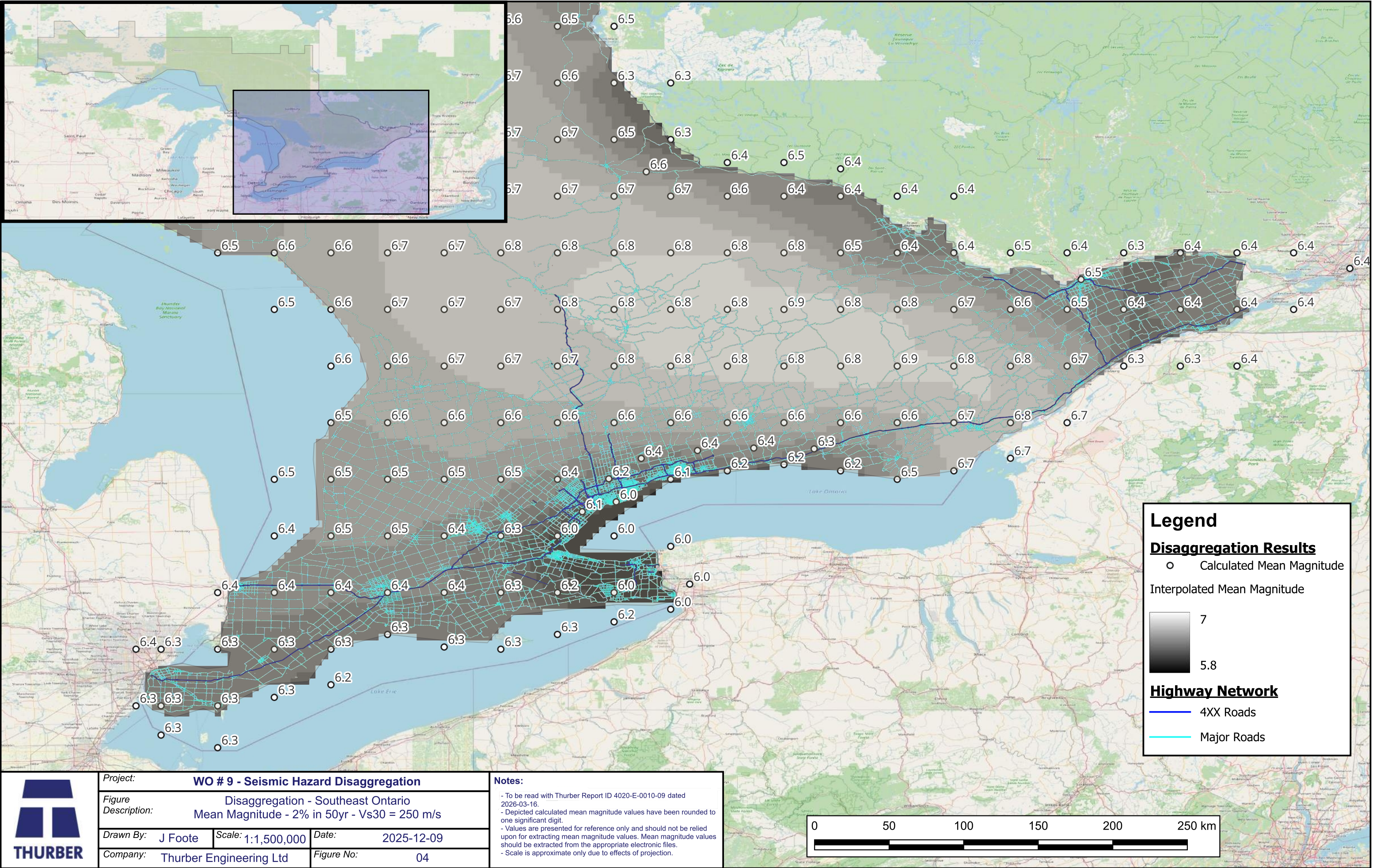
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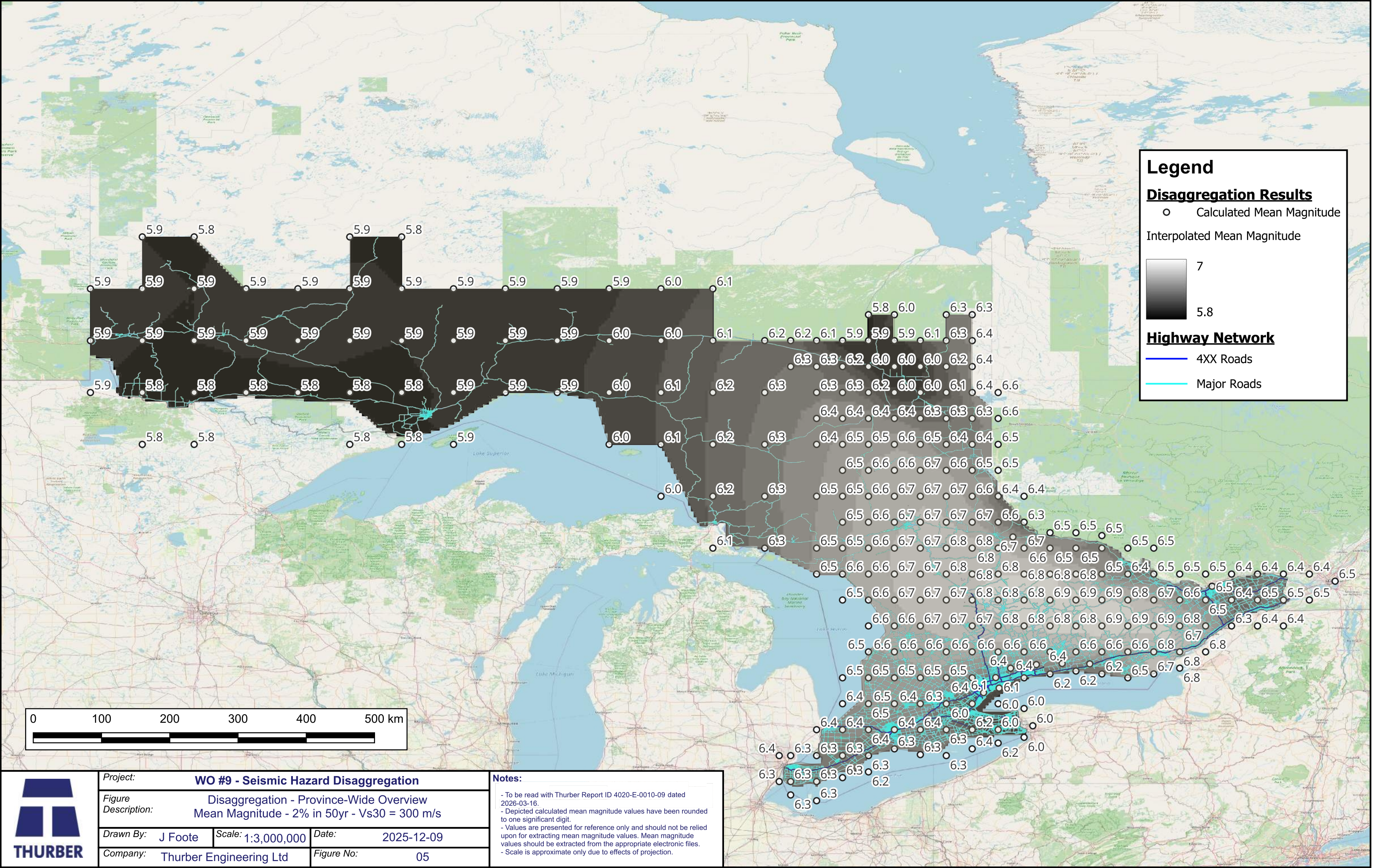


Project:		WO #9 - Seismic Hazard Disaggregation	
Figure Description:		Disaggregation - Province-Wide Overview Mean Magnitude - 2% in 50yr - Vs30 = 180 m/s	
Drawn By:	J Foote	Scale:	1:3,000,000
Date:	2025-12-09		
Company:	Thurber Engineering Ltd		
Figure No:	01		

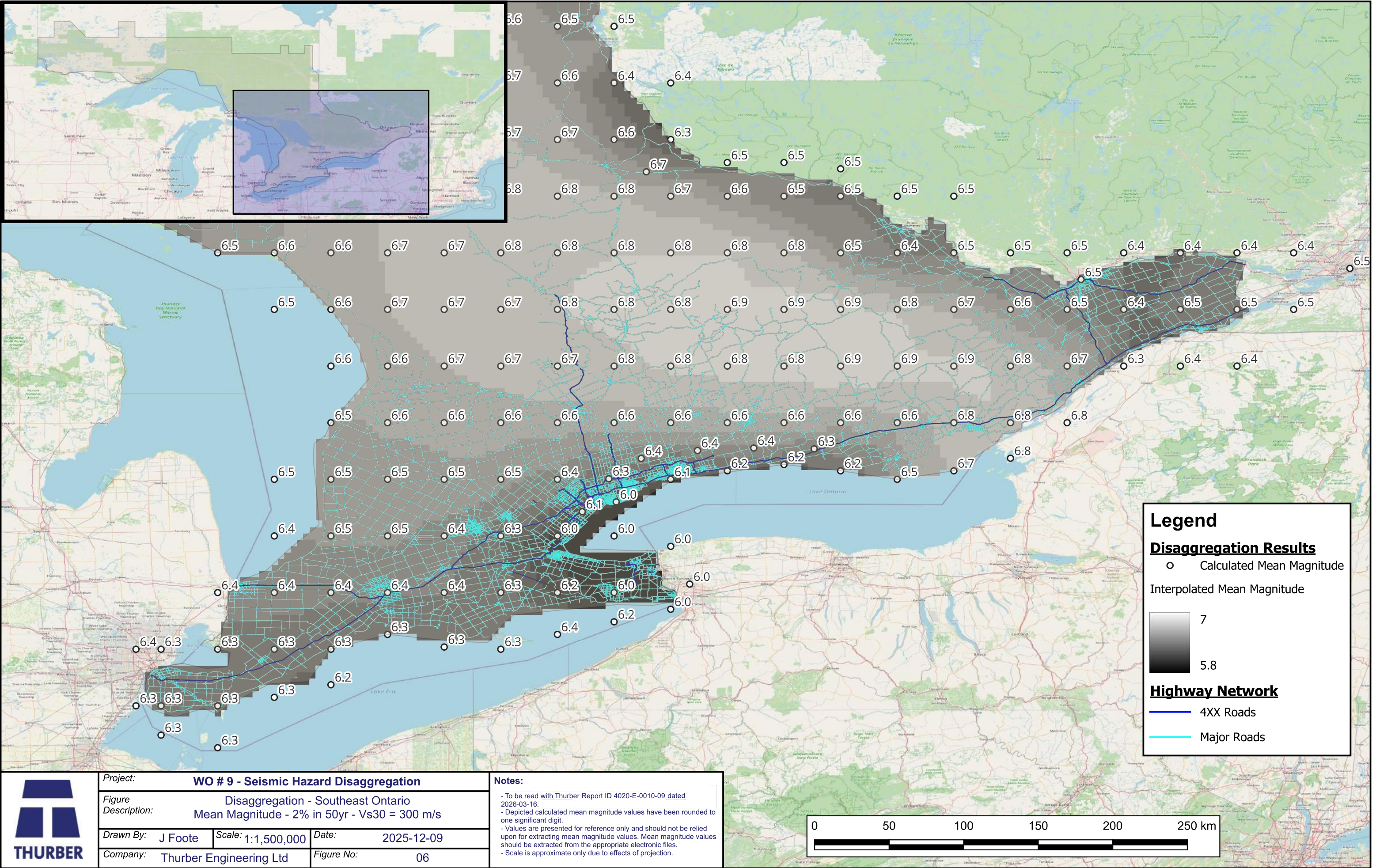


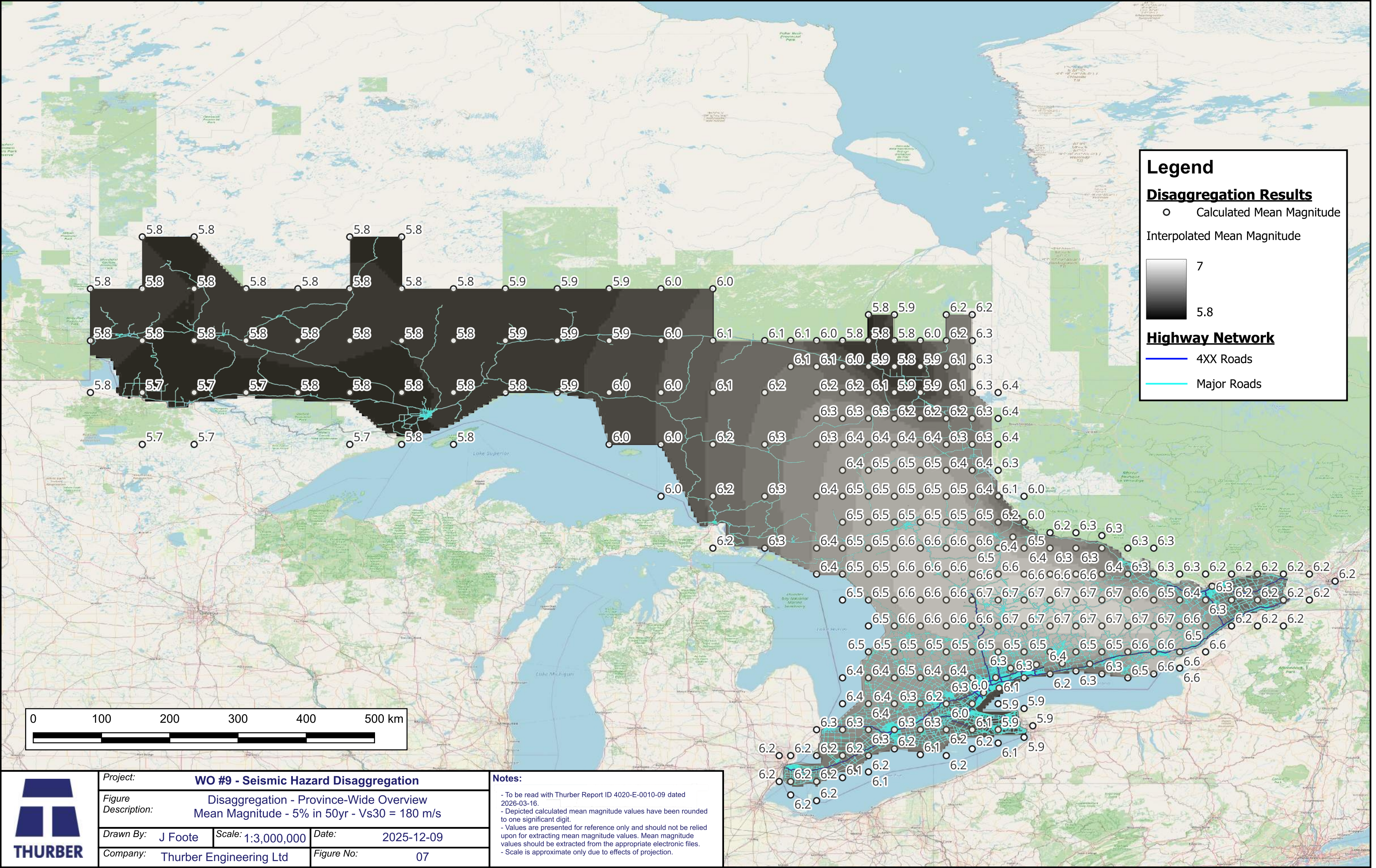






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	Drawn By: J Foote	Scale: 1:3,000,000	Date: 2025-12-09
	Company: Thurber Engineering Ltd		Figure No: 05





Legend

Disaggregation Results

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Calculated Mean Magnitude

Interpolated Mean Magnitude

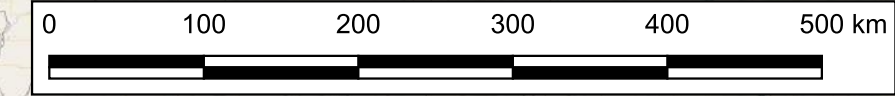
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5.8

Highway Network

4XX Roads

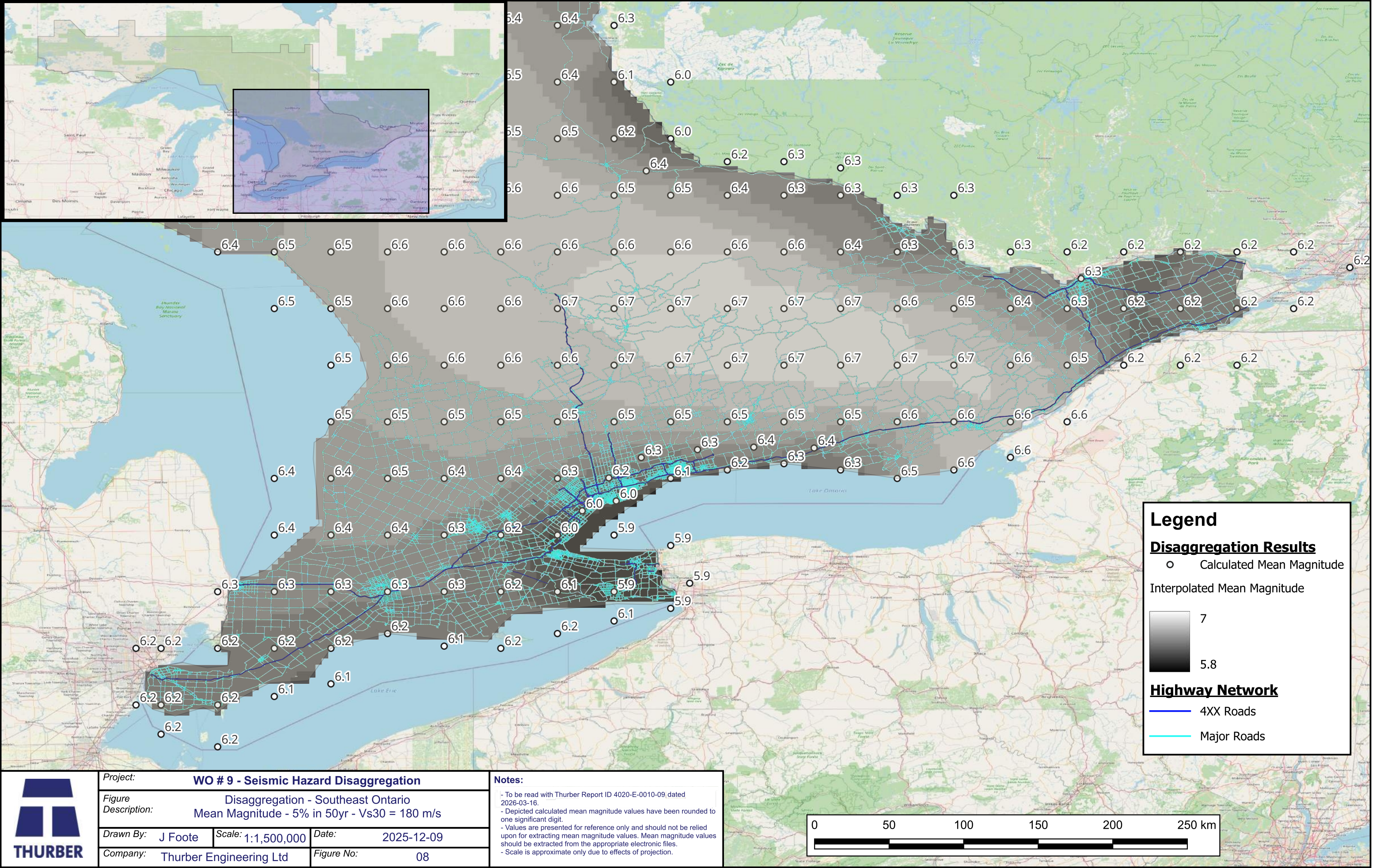
Major Roads

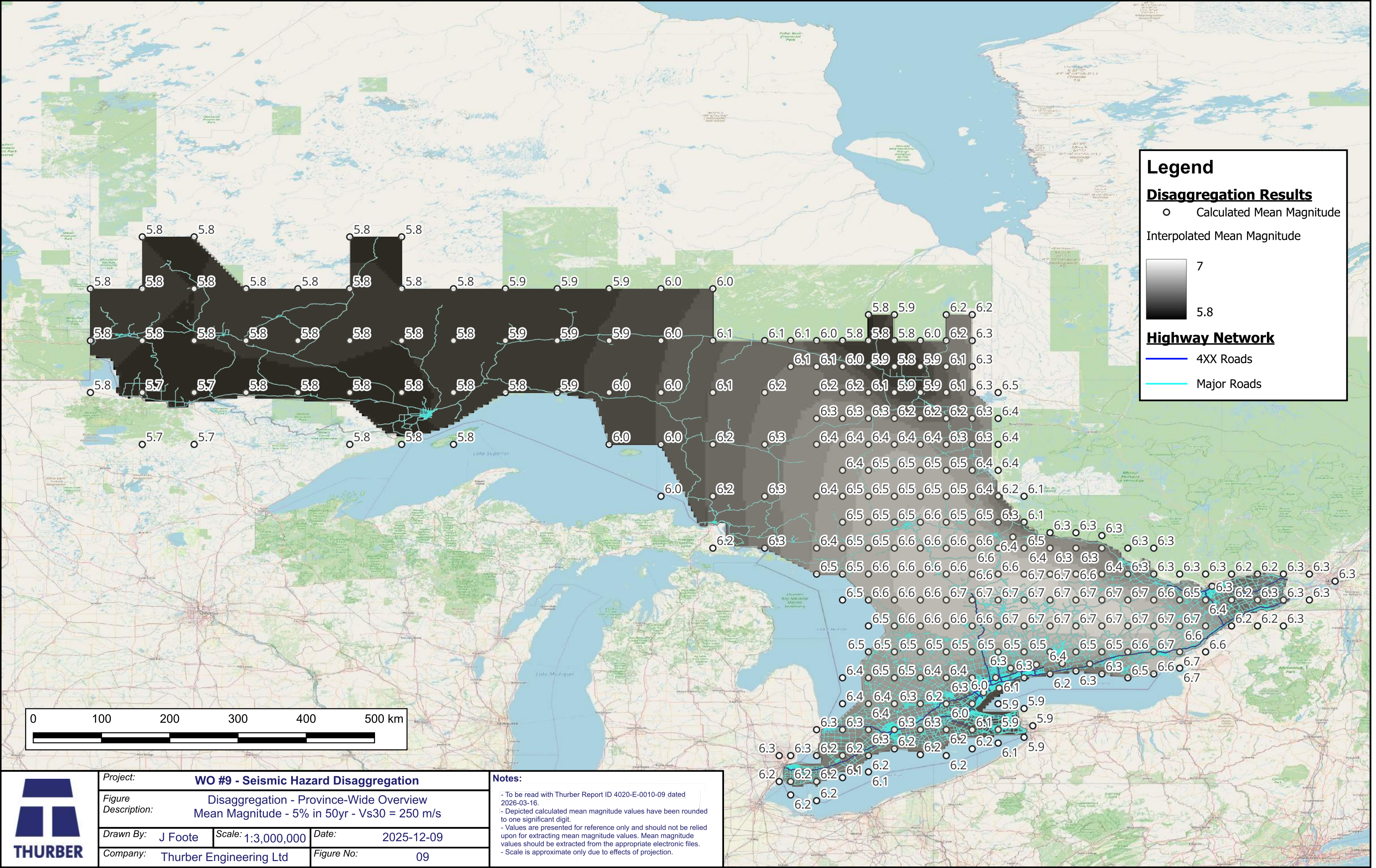


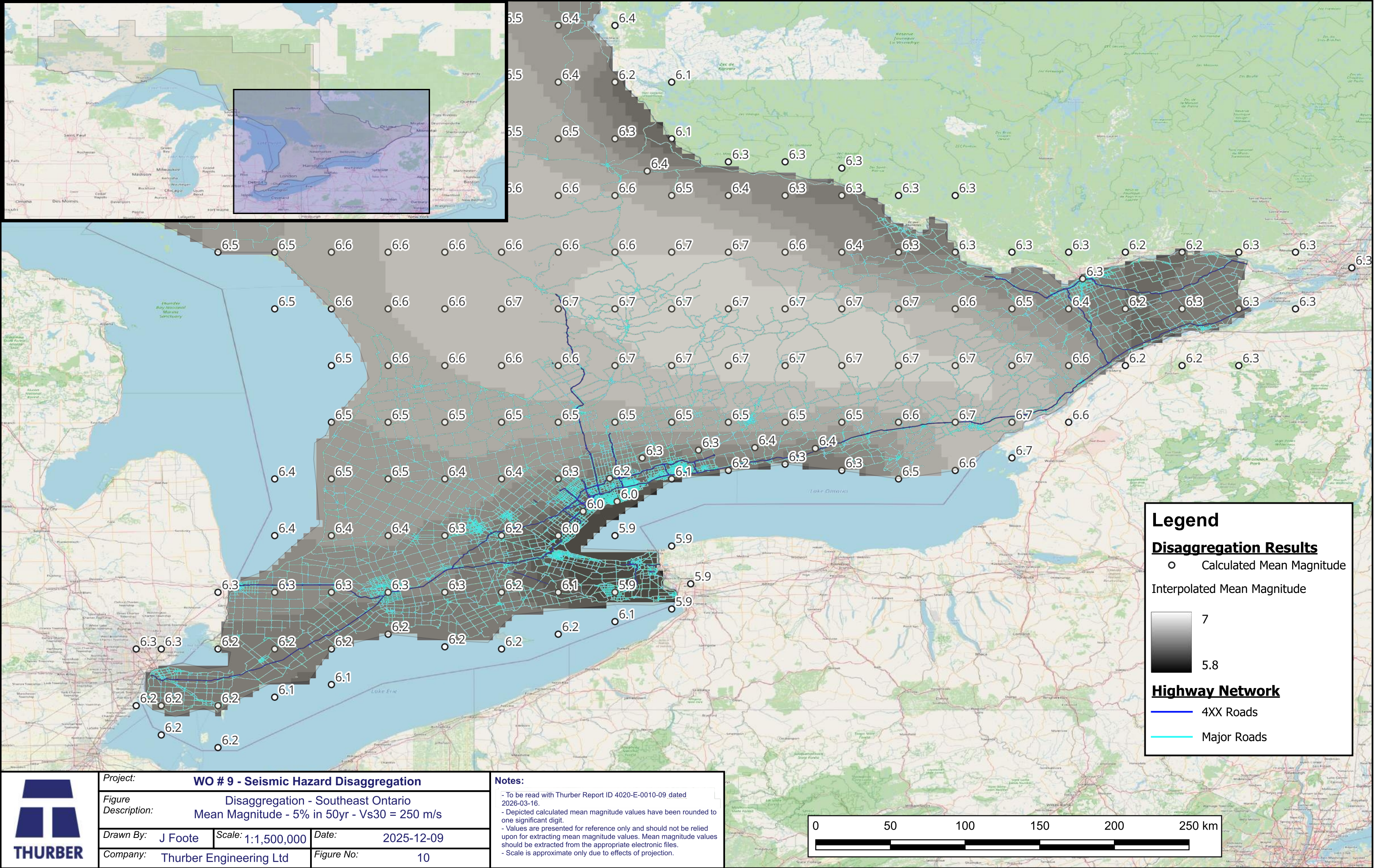
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Drawn By:	J Foote	Scale:	1:3,000,000
Date:	2025-12-09		
Company:	Thurber Engineering Ltd		Figure No:
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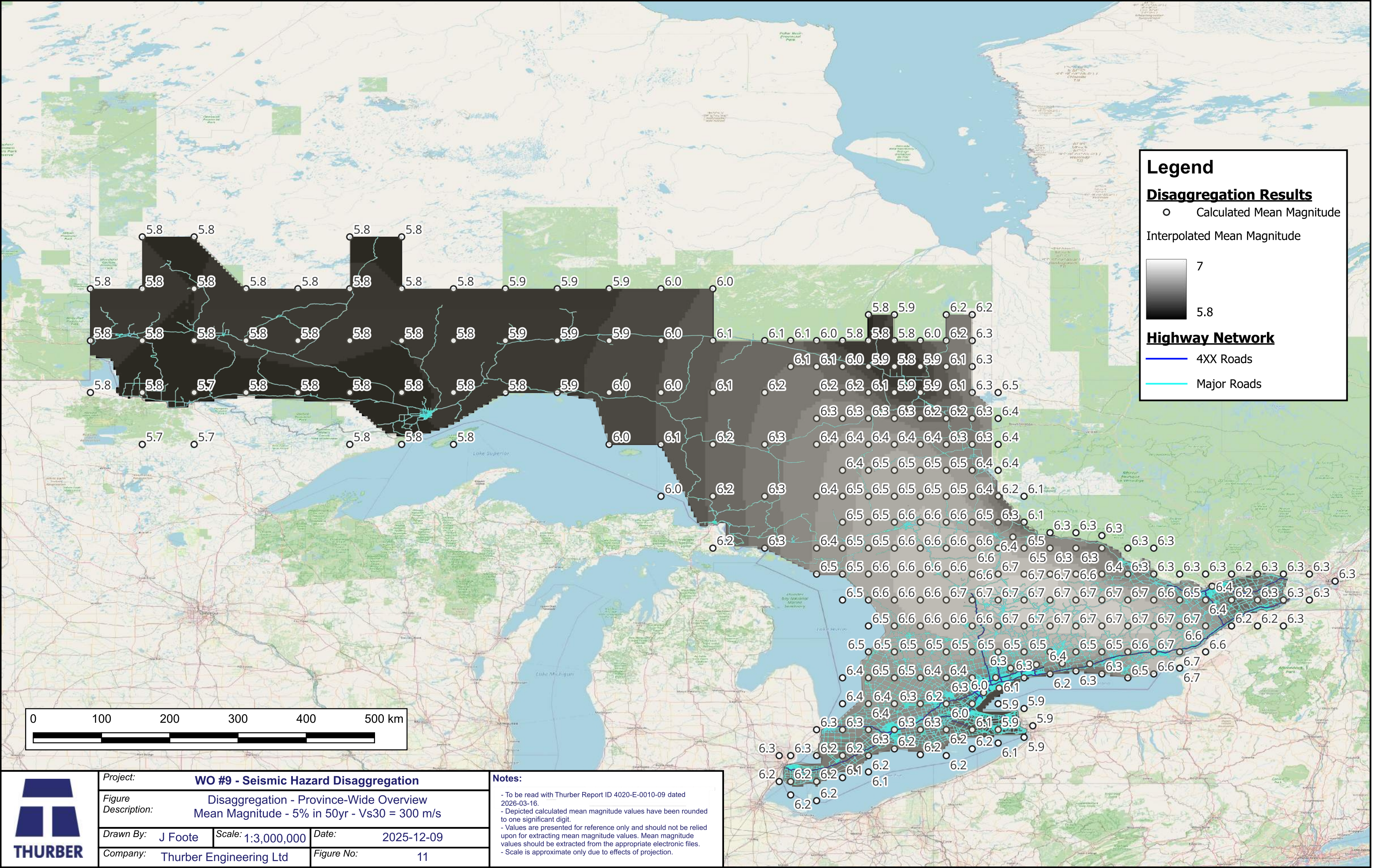
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- To be read with Thurber Report ID 4020-E-0010-09 dated 2026-03-16.
- Depicted calculated mean magnitude values have been rounded to one significant digit.
- Values are presented for reference only and should not be relied upon for extracting mean magnitude values. Mean magnitude values should be extracted from the appropriate electronic files.
- Scale is approximate only due to effects of projection.









Legend

Disaggregation Results

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Calculated Mean Magnitude

Interpolated Mean Magnitude

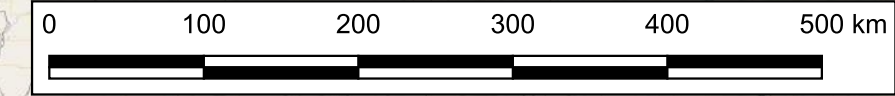
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5.8

Highway Network

4XX Roads

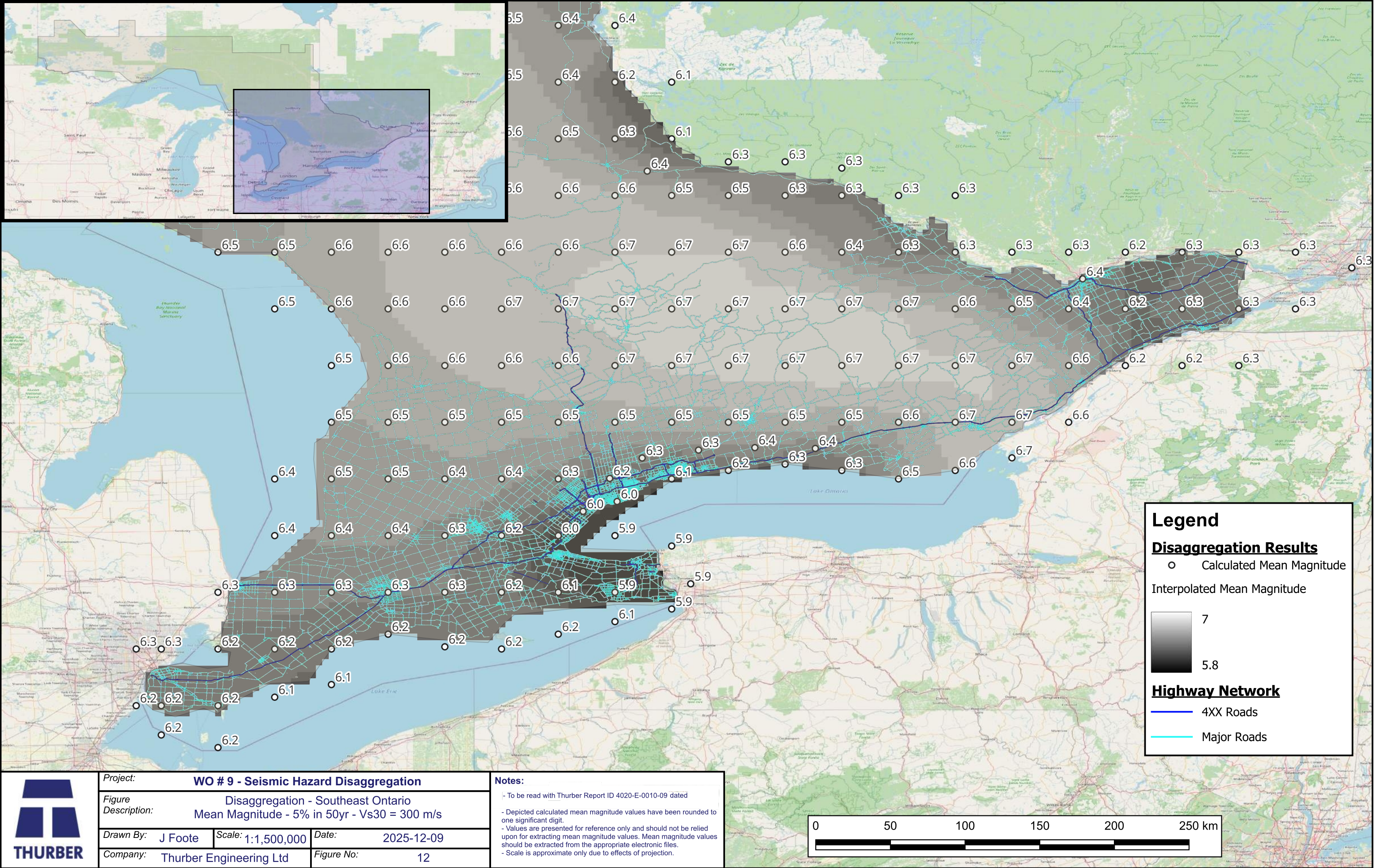
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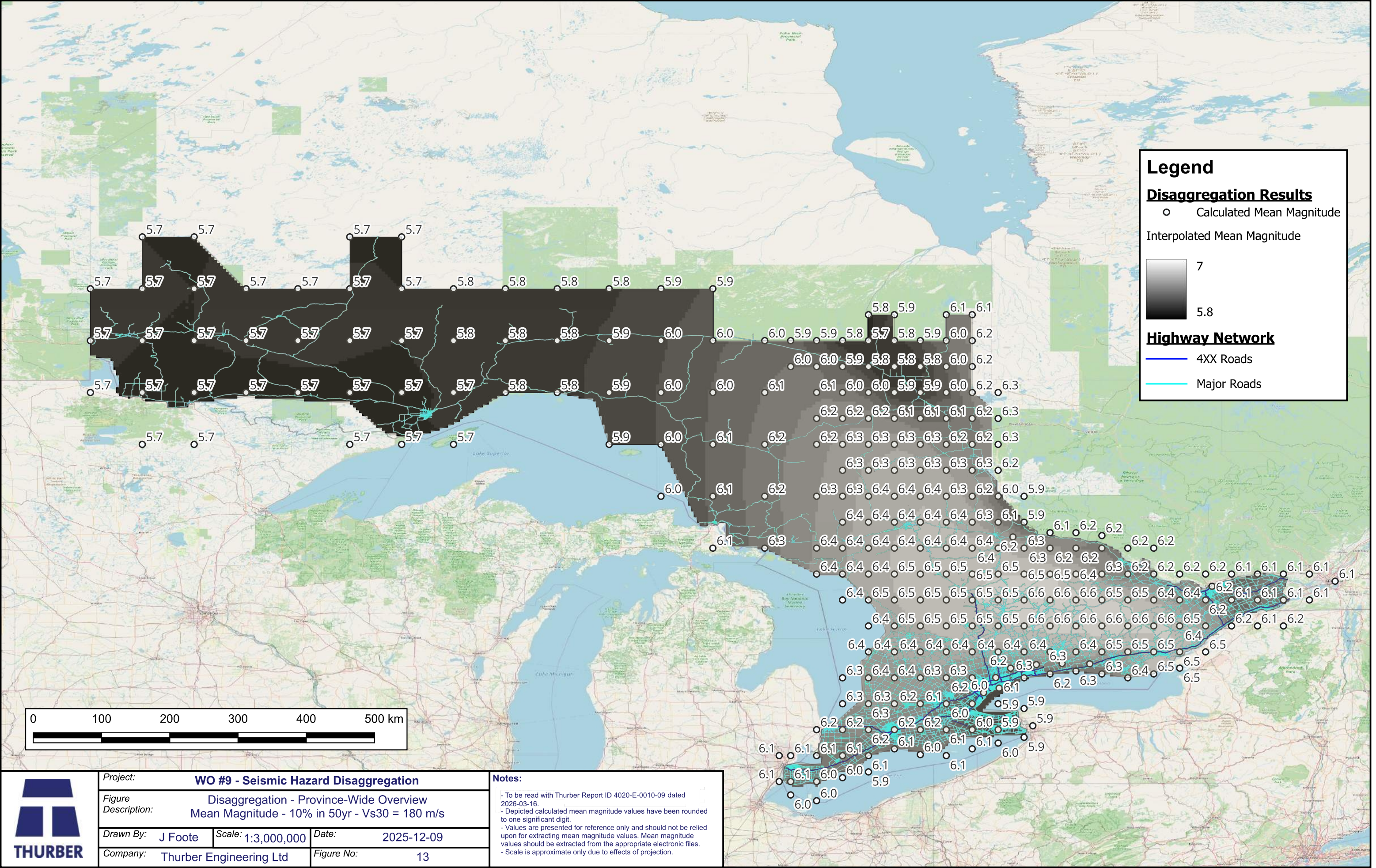


Project:	WO #9 - Seismic Hazard Disaggregation		
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Drawn By:	J Foote	Scale:	1:3,000,000
Date:	2025-12-09		
Company:	Thurber Engineering Ltd		Figure No:
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Disaggregation Results

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Calculated Mean Magnitude

Interpolated Mean Magnitude

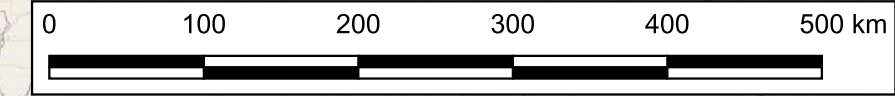
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5.8

Highway Network

4XX Roads

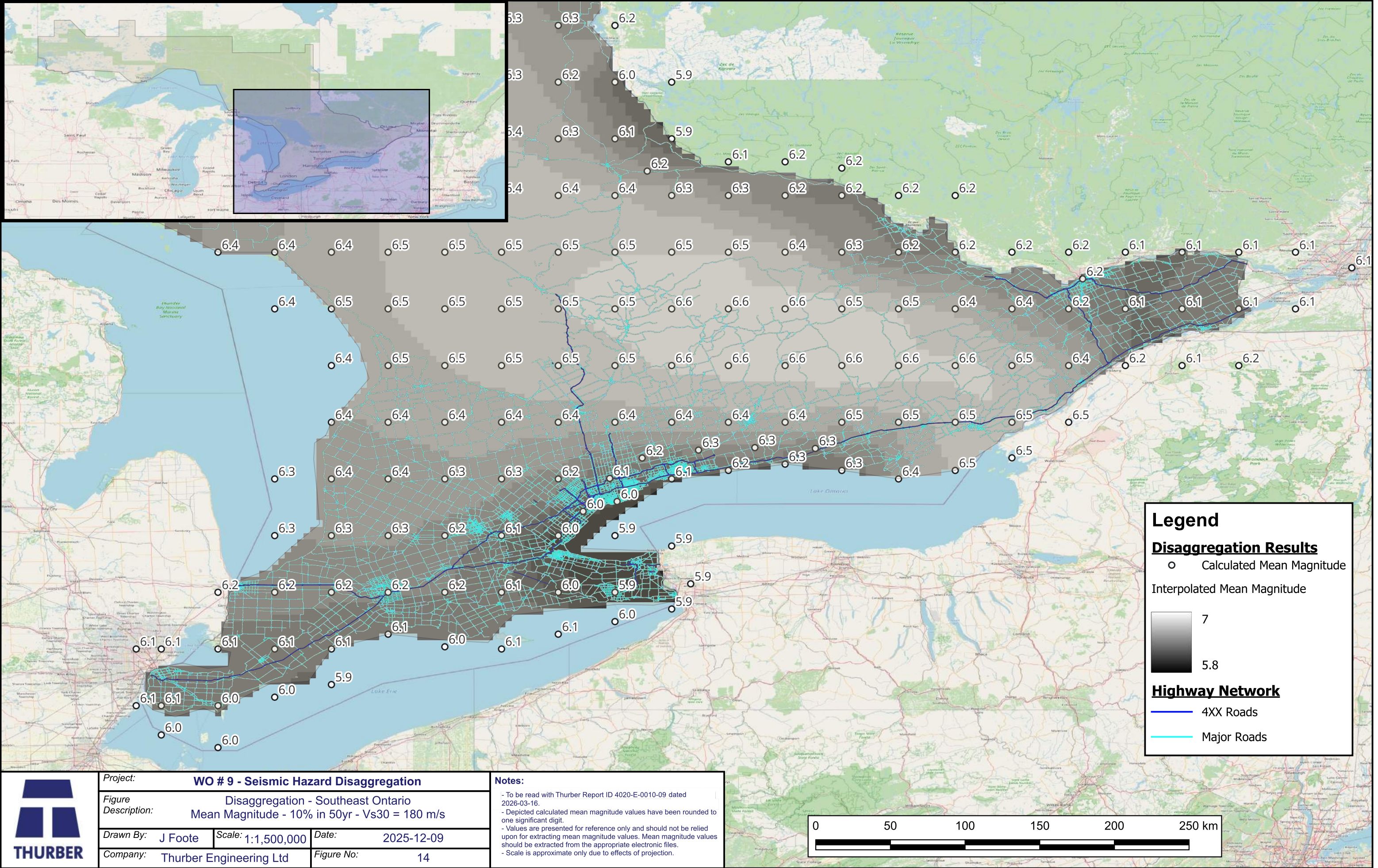
Major Roads

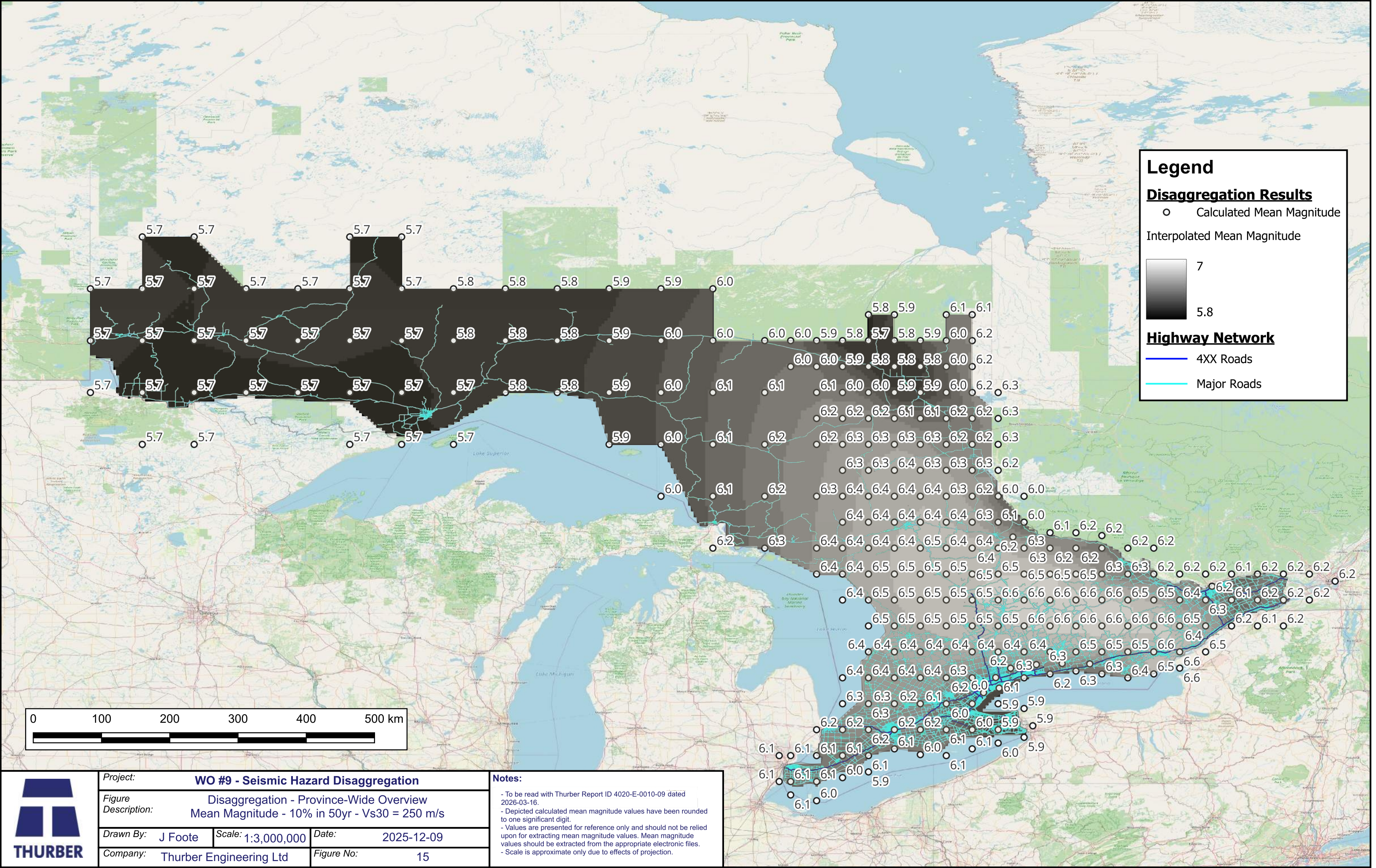


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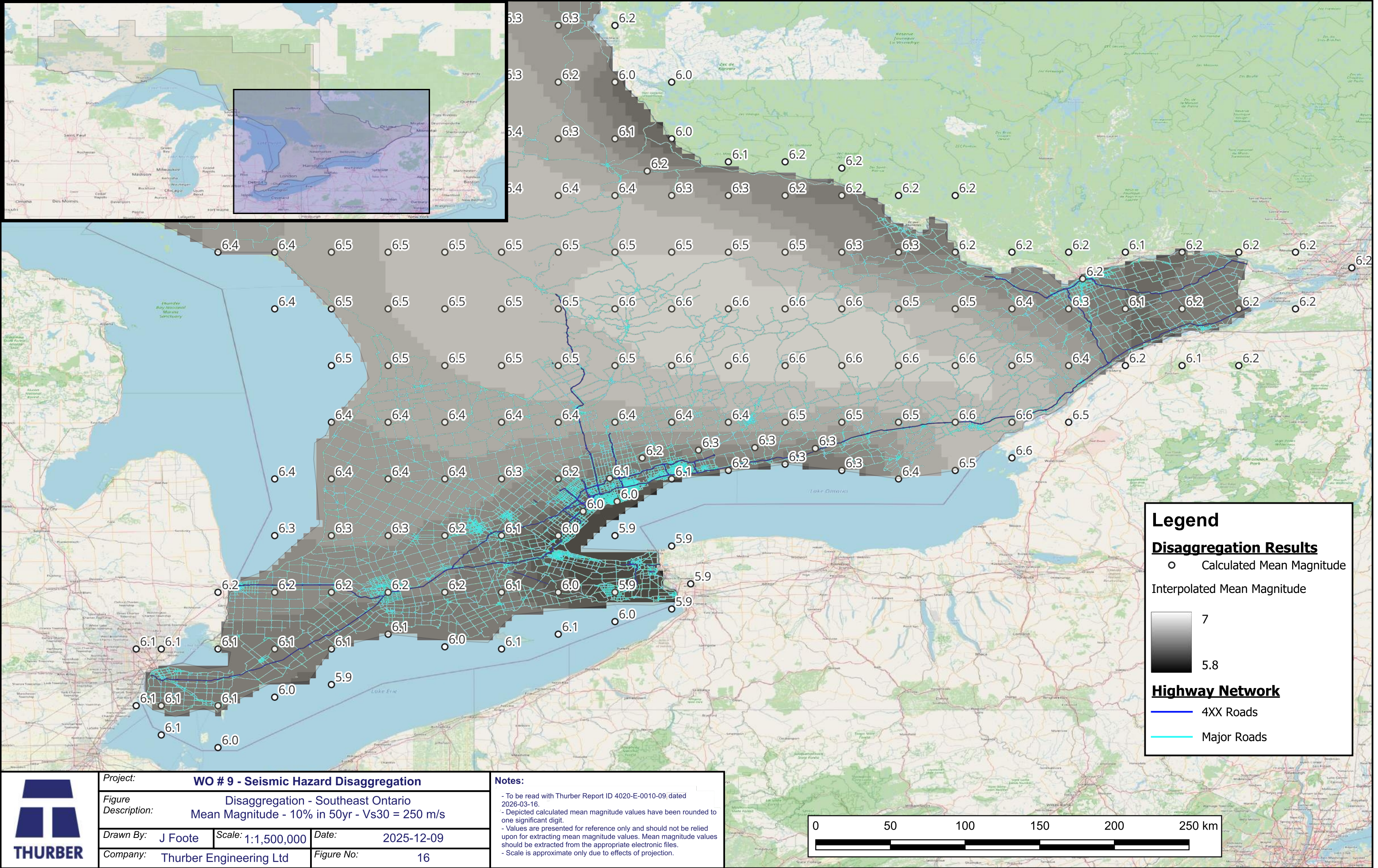
Notes:

- To be read with Thurber Report ID 4020-E-0010-09 dated 2026-03-16.
- Depicted calculated mean magnitude values have been rounded to one significant digit.
- Values are presented for reference only and should not be relied upon for extracting mean magnitude values. Mean magnitude values should be extracted from the appropriate electronic files.
- Scale is approximate only due to effects of projection.

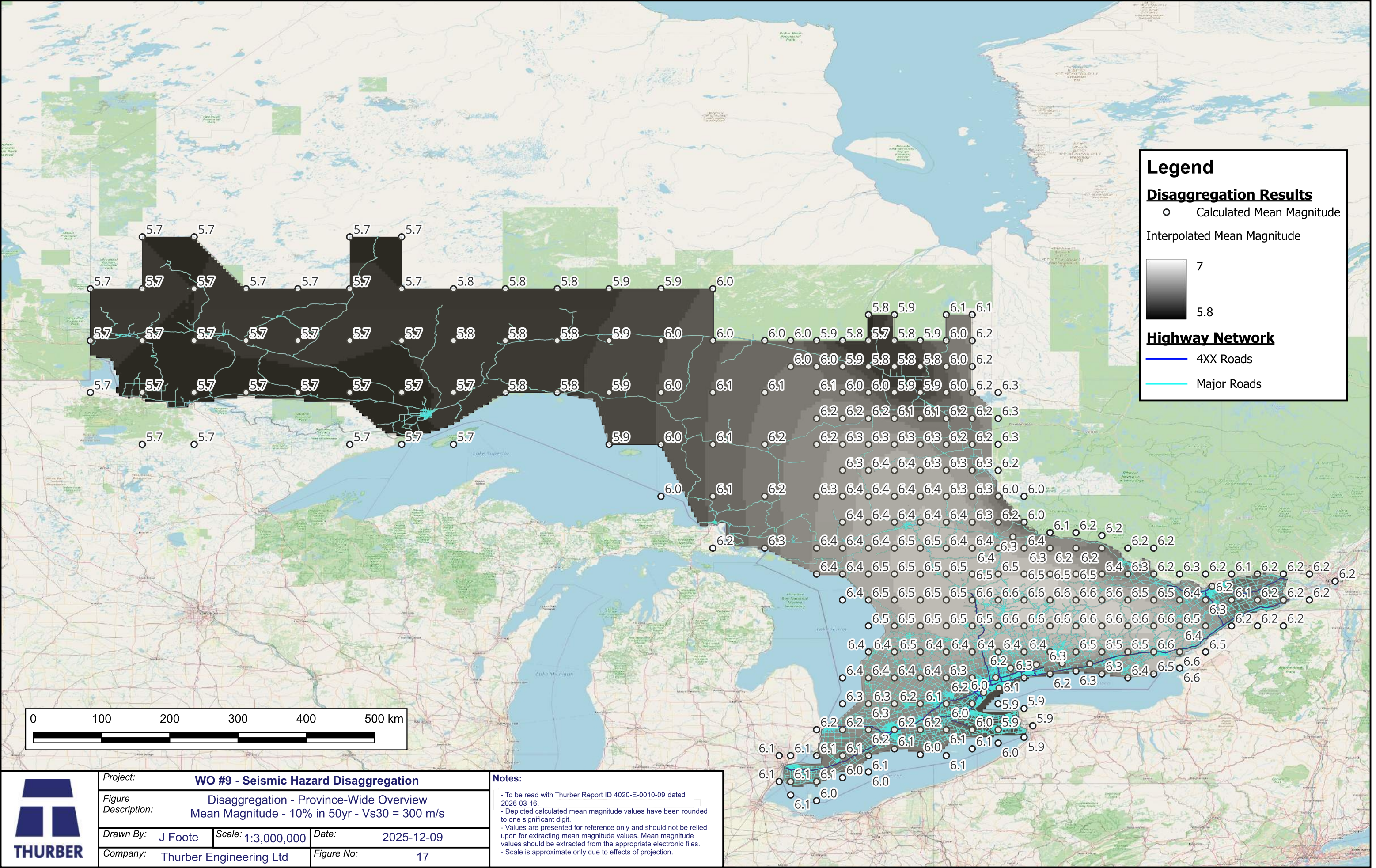




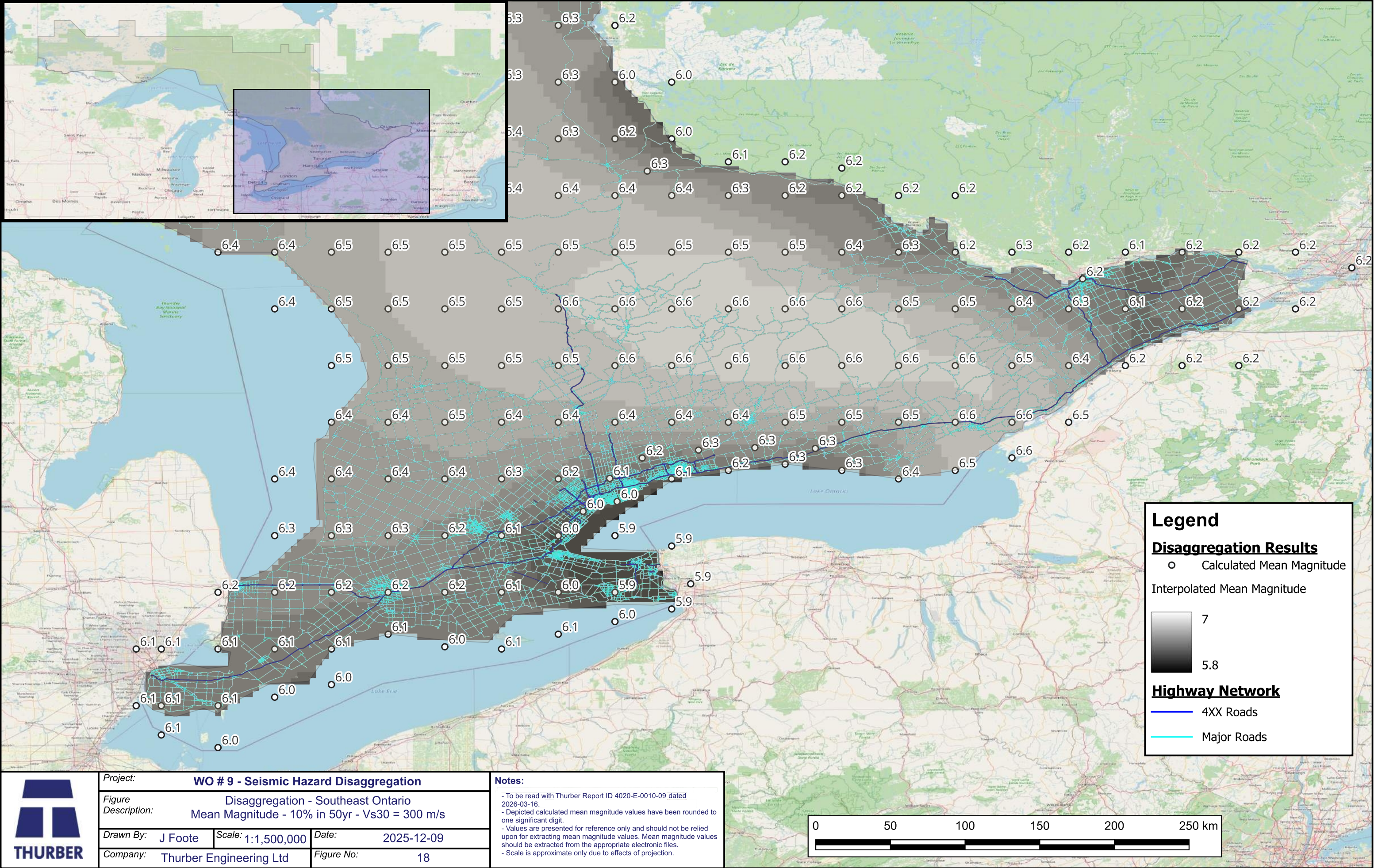
Project:		WO #9 - Seismic Hazard Disaggregation	
Figure Description:		Disaggregation - Province-Wide Overview Mean Magnitude - 10% in 50yr - Vs30 = 250 m/s	
Drawn By:	J Foote	Scale:	1:3,000,000
Date:	2025-12-09		
Company:	Thurber Engineering Ltd		
Figure No:	15		



	Project: WO # 9 - Seismic Hazard Disaggregation		
	Figure Description: Disaggregation - Southeast Ontario Mean Magnitude - 10% in 50yr - Vs30 = 250 m/s		
	Drawn By: J Foote	Scale: 1:1,500,000	Date: 2025-12-09
	Company: Thurber Engineering Ltd		Figure No: 16



Project:		WO #9 - Seismic Hazard Disaggregation	
Figure Description:		Disaggregation - Province-Wide Overview Mean Magnitude - 10% in 50yr - Vs30 = 300 m/s	
Drawn By:	J Foote	Scale:	1:3,000,000
Date:	2025-12-09		
Company:	Thurber Engineering Ltd		
Figure No:	17		



	Project: WO # 9 - Seismic Hazard Disaggregation		
	Figure Description: Disaggregation - Southeast Ontario Mean Magnitude - 10% in 50yr - Vs30 = 300 m/s		
	Drawn By: J Foote	Scale: 1:1,500,000	Date: 2025-12-09
	Company: Thurber Engineering Ltd		Figure No: 18

Notes:

- To be read with Thurber Report ID 4020-E-0010-09 dated 2026-03-16.
- Depicted calculated mean magnitude values have been rounded to one significant digit.
- Values are presented for reference only and should not be relied upon for extracting mean magnitude values. Mean magnitude values should be extracted from the appropriate electronic files.
- Scale is approximate only due to effects of projection.