

# Earthquake iso-nuisance and iso-damage maps for the risk management of induced seismicity: preliminary application in Alberta

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## Summary

We generate earthquake iso-nuisance and iso-damage maps for Alberta. These maps show the earthquake magnitudes necessary at any given location to exceed a particular threshold of nuisance and damage, considering human exposure factors and surficial geological conditions. For this analysis, we generated three levels of nuisance and damage: (1) 50% probability of causing nuisance to 30 000 households and damage to 3 households; (2) 50% probability of causing nuisance to 20 000 households and damage to 2 households; (3) 50% probability to cause nuisance to 10 000 households and damage to 1 household. The iso-nuisance and iso-damage maps provide the basis for defining the red-light magnitude thresholds in Traffic Light Protocols (TLPs) that are used to limit the seismicity risk associated with industrial activities. By defining an adequate trailing seismicity factor, which accounts for subsequent seismicity after a substantial change or end of the seismogenic operations, we derive example red-light maps for hydraulic fracturing and disposal activities in Alberta. These maps are the first step to defining the magnitude threshold from induced seismicity, enabling consistent tolerance levels throughout the province.

## Theory and Method

This presentation is part 2 of a series, where the method is described more thoroughly in part 1 (see Reyes Canales et al., 2024a, this volume). We follow a similar methodology described by Schultz et al. (2021a, 2021c) to generate iso-nuisance and iso-damage maps, with the variation that we do not include, initially, the trailing seismicity factor for the generation of the map. This factor is later included to define the red-light maps for different operational activities (E.g., hydraulic fracturing and disposal operations). For this analysis, we define an impact grid size of 3 km by 3 km and an earthquake node spacing of 10 km by 10 km. The impact cells contain information related to human exposure and surficial geological conditions; specifically, Vs30 modeling (time-averaged shear wave velocity of the upper 30 m) from surficial geological data defines the seismic amplification component, and LandScan 2020 data (Rose et al., 2021) to define population density.

For each earthquake node, a range of synthetic earthquakes is defined (magnitudes and depths). In this analysis, we simulate 100 realizations per earthquake node, each realization containing events in a magnitude range between M=2 to M=5. Impact cells up to 400 km and 40 km from the earthquake location are considered for the nuisance and damage calculations, respectively. We consider an earthquake depth distribution of 2, 5, and 7 km, with weights of 0.3, 0.5, and 0.2, respectively. For the ground motion component, we use the GMPEs defined by Schultz and Nanometrics (2021). Finally, for the nuisance and fragility functions, we refer to Schultz et al.

(2021b) and FEMA (2015). For this analysis, we use a community decimal intensity (CDI) of 3 for the nuisance, equivalent to a perceived “light shaking.” For the damage, we use a Damage State (DS) of 1, which is equivalent to cosmetic damage in zones with low seismic hazard.

## Results

Figure 1 shows the iso-nuisance (A), iso-damage (B), and combination (C) maps in Alberta using a level of 50% probability of causing a nuisance to 30,000 households and 50% probability of causing damage to 3 households. For instance, if an earthquake  $M=3$  occurs in Edmonton, there is a 50% probability that approximately 30,000 households will experience light shaking (nuisance level at  $CDI=3$ ). However, for an event in the northern parts of the province, an earthquake  $M=5$  or larger is required to cause the same level of nuisance (50% probability that 30,000 households will get nuisance at a level of  $CDI=3$ ). A similar trend is observed in the iso-damage maps; the lower magnitudes tend to match the more populated areas. Figure 2 shows the iso-nuisance (A), iso-damage (B), and combination (C) maps in Alberta, including the trailing seismicity factor for hydraulic fracturing activities. As in the previous example, we use a nuisance and damage level of 50% probability to cause nuisance to 30,000 households and 50% probability to cause damage to 3 households, respectively. For instance, if a red light of  $M=2.5$  for hydraulic-fracturing activity is defined in Edmonton, there is a 50% probability that approximately 30,000 households will perceive a light shaking (nuisance level at  $CDI=3$ ). In contrast, a red light equal to or larger than  $M=5$  is required to cause the same level of nuisance (50% probability that 30,000 households will get nuisance at a level of  $CDI=3$ ).

## Conclusions

We show a preliminary set of iso-nuisance and iso-damage maps for Alberta, using different tolerance levels. These maps estimate the probability of nuisance and damage from hypothetical earthquakes that might result from industrial operations. We also included the adequate trailing seismicity factor to derive red-light maps for hydraulic fracturing and disposal activities in Alberta. These maps are an important consideration when defining magnitude thresholds for induced seismicity Traffic Light Protocols, enabling consistent tolerance levels throughout the province. Future research should include more advanced modeling of the trailing seismicity, particularly for other operations, and incorporating other factors beyond the population distribution, such as critical infrastructure, which may warrant a different tolerance level.

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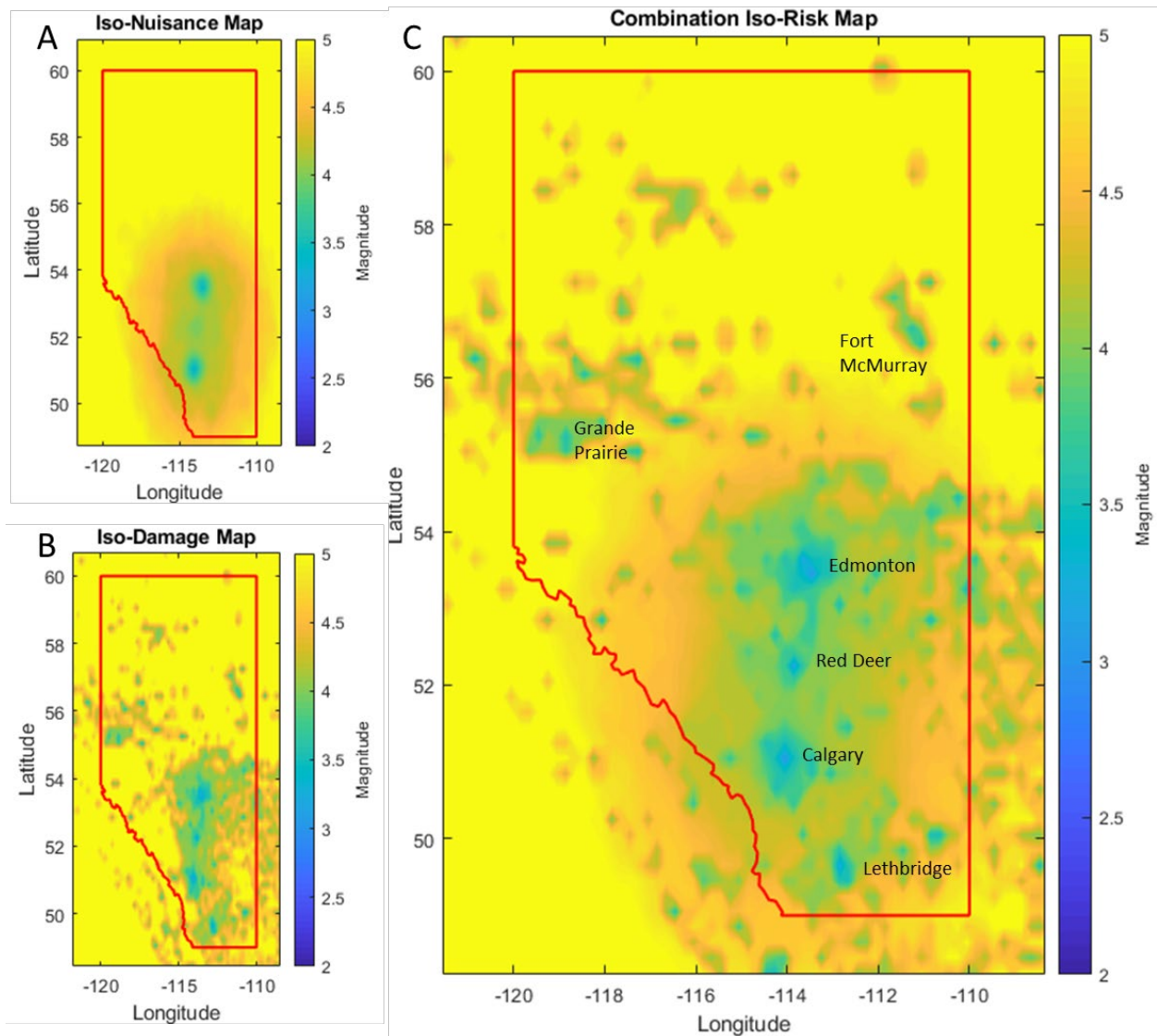


Figure 1. Iso-Nuisance map (A), using equivalent magnitudes for a tolerance level of 50% probability to cause nuisance to 30,000 households (CDI=3, equivalent to light-perceived shaking). Iso-Damage Map (B), using equivalent magnitudes for a tolerance level of 50% probability to damage 3 households (DS=1, equivalent to slight/minor cosmetic damage). Combination Iso-Risk Map (C), merging of the Iso-NUISANCE (50% probability to cause nuisance to 30,000 households) and Iso-DAMAGE maps (50% probability to damage 3 households).

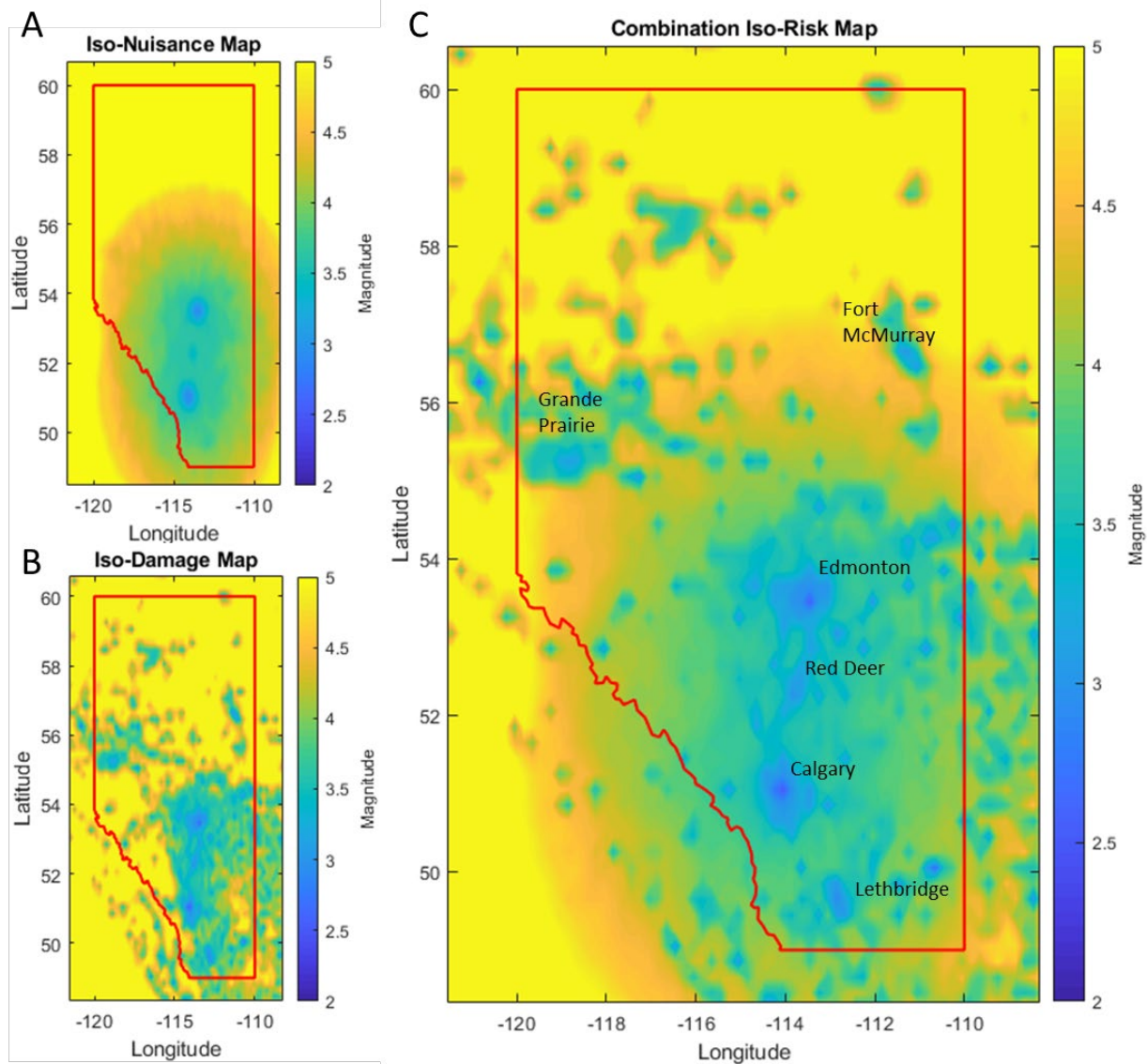


Figure 2. Iso-Nuisance map (A), including the trailing seismicity factor for hydraulic-fracturing activities, and using equivalent magnitudes for a tolerance level of 50% probability to cause nuisance to 30,000 households (CDI=3, equivalent to light-perceived shaking). Iso-Damage Map (B), including the trailing seismicity factor for hydraulic-fracturing activities, and using equivalent magnitudes for a tolerance level of 50% probability to damage 3 households (DS=1, equivalent to slight/minor cosmetic damage). Combination Iso-Risk Map (C), merging of the Iso- nuisance (50% probability to cause nuisance to 30,000 households) and Iso-damage maps (50% probability to damage 3 households).

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