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Guidance on Traffic-Light Thresholds and Magnitude Estimation for Induced Seismicity Management

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Abstract

Induced seismicity associated with hydraulic fracturing and fluid disposal has notably increased the seismic hazard in Alberta since the early 2010s. The Alberta Energy Regulator manages this hazard through area-specific subsurface orders for hydraulic fracturing and, more recently, through updated provisions in Directive 065 for fluid disposal operations, both of which rely on traffic-light protocols (TLPs) with earthquake magnitude thresholds. This Information Series provides guidance on two key aspects of implementing a TLP: the selection of magnitude thresholds and the consistent estimation of earthquake magnitudes. For threshold selection, we present the Magnitude Threshold for Acceptable Seismicity (MTAS) maps, derived from earthquake iso-nuisance and iso-damage maps for Alberta, as a minimum reference for establishing red-light thresholds, complemented by guidance on setting yellow-light thresholds. Two versions of the MTAS maps are provided, reflecting the different treatment of trailing seismicity for hydraulic fracturing and long-term injection activities. For magnitude estimation, we summarize the local magnitude relation of Yenier (2017), calibrated for the Western Canada Sedimentary Basin, and outline its practical implementation to promote consistent magnitude reporting across operators and monitoring networks.

1 Introduction

The seismic hazard in Alberta has increased notably since the early 2010s in association with subsurface energy development (Reyes Canales et al., 2022). Notable examples include hydraulic-fracturing-induced earthquakes in the Duvernay play near Fox Creek and Red Deer (Schultz et al., 2017; Wang et al., 2020), as well as disposal-induced seismicity in the Peace River region, where a M_L 5.6 earthquake in November 2022 ranks among the largest injection-induced events in Canada (Reyes Canales et al., 2026). While most induced events are not felt at the surface, larger events can produce ground motions capable of causing nuisance to residents and, in some cases, damage to structures in localized areas.

To manage this hazard, the Alberta Energy Regulator (AER) has developed a regulatory framework that addresses injection related induced seismicity. Seismic monitoring and response requirements for hydraulic fracturing operations were first introduced through area-specific subsurface orders, including Subsurface Order No. 2 (Fox Creek area; later updated to 2A), Subsurface Order No. 6 (around the Brazeau Dam) and Subsurface Order No. 7 (Red Deer area), which established magnitude-based reporting and mitigation requirements. More recently, the AER updated Directive 065: Resources Applications for Oil and Gas Reservoirs (AER, 2026) to include provisions for managing disposal-induced seismicity. Under the revised Directive 065, applicants for new disposal wells must conduct a seismic hazard assessment that, at a minimum, reviews seismicity within a 10 km radius of the well using public earthquake catalogues. If the hazard assessment indicates that the area is prone to induced seismicity, or if an operating well is deemed seismogenic by the AER, the operator must identify the risk associated with the induced seismic hazard and submit a Monitoring, Mitigation, and Response (MMR) plan that includes real-time seismic monitoring (Schultz et al., 2020), event magnitude thresholds, and a traffic-light protocol (TLP). Operators are also required to transmit real-time seismic data to the AER and submit waveform data to the EarthScope Consortium (AER, 2025).

This Information Series provides guidance on two aspects of induced seismicity management: the selection of traffic-light magnitude thresholds and the consistent estimation of earthquake magnitudes. First, it presents the Magnitude Threshold for Acceptable Seismicity (MTAS) maps, derived from earthquake iso-nuisance and iso-damage maps for Alberta (Reyes Canales et al., 2024), which can serve as a reference when selecting traffic-light thresholds; these maps are intended to complement, not replace, localized and more detailed site-specific risk identification and, if conducted, the resulting assessment. Second, it describes the local magnitude relationship of Yenier (2017), developed specifically for the Western Canada Sedimentary Basin (WCSB), and its practical implementation, with the aim of promoting consistent magnitude reporting across operators and monitoring networks.

2 Traffic-Light Threshold Guidance

The TLP is a risk management tool central to both the subsurface orders No. 2A, 6, and 7, and the induced seismicity component of Directive 065. It defines three response levels (green, yellow, and red) based on two earthquake magnitude thresholds: a low (yellow-light) and a high (red-light) threshold. Events below the yellow-light threshold fall within the green level and require no action beyond routine monitoring. Events with magnitudes between the yellow- and red-light thresholds require reporting to the AER and implementation of mitigation measures to reduce the magnitude and frequency of subsequent events. Events at or above the red-light threshold require the operator to immediately report the event and return the well to a safe state, with AER approval required before affected operations can resume.

For hydraulic fracturing operations, magnitude thresholds are prescribed through area-specific subsurface orders. Two orders focus on operations in the Duvernay Formation, near Fox Creek (Subsurface Order No. 2A; AER, 2024) and Red Deer (Subsurface Order No. 7; AER, 2019b). A third order establishes an exclusion zone within 3 km of the Brazeau Dam, where no hydraulic fracturing is permitted, and a second zone between 3 and 5 km of the dam, where hydraulic fracturing is permitted only in formations above the Duvernay (Subsurface Order No. 6; AER, 2019a). Under these orders, operators must monitor seismicity near their operations and follow the TLP defined for the area. Operators must report any event at or above the yellow-light threshold ($M_L \geq 2$ for Subsurface Order No. 2A; $M_L \geq 1$ for Subsurface Order No. 6 and Subsurface Order No. 7) and implement mitigation strategies to avoid larger events. If a red-light event occurs ($M_L \geq 4$ for Subsurface Order No. 2A; $M_L \geq 2.5$ for Subsurface Order No. 6; $M_L \geq 3$ for Subsurface Order No. 7), operators must immediately stop operations and return the well to a safe state. The variation in thresholds across the orders reflects differences in local exposure: lower thresholds are applied near population centres (Red Deer) and critical infrastructure (Brazeau Dam).

In contrast to the subsurface orders, Directive 065 does not prescribe fixed magnitude thresholds for disposal operations. Instead, thresholds are defined in the operator's MMR plan and should reflect the conditions of each area, including nearby population, essential infrastructure, private property, and site amplification conditions, which may be characterized by V_s30 (the average shear-wave velocity of the upper 30 m from surface). Low-V_s30 sites (e.g., soft sediments and valley fills) can experience stronger shaking than high-V_s30 bedrock sites. After the risk identification, operators may conduct site-specific seismic risk assessments to inform these thresholds; however, as a minimum, **red-light thresholds should be checked against the MTAS** maps developed for Alberta (Reyes Canales et al., 2024). The MTAS maps provide a spatially continuous reference for the maximum earthquake magnitude that can be tolerated at a given location before exceeding predefined nuisance or damage criteria. They were generated by combining ground-motion modelling with information on population density and site amplification conditions across Alberta, producing two intermediate products: an earthquake iso-nuisance map (magnitude with a 50% probability of causing nuisance to 30,000 households) and an earthquake iso-damage map (magnitude with a 50% probability of damaging 3 households). The MTAS corresponds, at each location, to the more restrictive of the two criteria. Because the maps are based on generalized exposure data, they do not account for specific critical infrastructure (e.g., dams, pipelines, or industrial facilities), which should be addressed through additional site-specific analysis where relevant.

Two versions of the MTAS maps are presented here, reflecting differences in how trailing seismicity is treated. Trailing seismicity refers to earthquakes that continue after injection has been reduced or stopped, and it is incorporated in the maps as a statistical factor (R_f) that accounts for the possibility of a larger event occurring after mitigation actions are taken. For hydraulic fracturing operations (Figure 1), trailing seismicity tends to be short-lived, and a factor of $R_f = 1.2$ is applied. For long-term injection activities such as fluid disposal (Figure 2), post-operational seismicity can persist for months to years, and a larger factor of $R_f = 2$ is applied, resulting in more conservative (lower) magnitude thresholds.

While the MTAS maps provide a reference for red-light thresholds, the selection of the yellow-light threshold, which marks the start of active mitigation, also depends on risk tolerance, particularly the consideration of large magnitude escalations, or 'jumps,' during mitigation operations. Studies such as Schultz et al. (2021) suggest that setting the **yellow-light threshold two magnitude units below the red-light threshold** is appropriate to minimize the number of green-to-red jumps observed in hydraulic fracturing cases.

For instance, consider an operator preparing an MMR plan for a proposed disposal well southeast of Edmonton (e.g., Township 50, Range 20W4). Because the well is a long-term injection operation, the MTAS map for long-term injection activities (Figure 2; $R_f = 2$) applies. At the proposed location, the map indicates an MTAS of approximately M_L 3.5, which serves as the reference for the red-light threshold; if the seismic risk identification finds nearby critical infrastructure (e.g., a dam or major pipeline), a more detailed site-specific risk assessment could support a lower, more protective value. Following the guidance of Schultz et al. (2021), the yellow-light threshold is set two magnitude units below, at M_L 1.5. These thresholds have direct implications for monitoring network design: under Directive 065, the seismometer network must reliably detect events at the yellow-light threshold within the assessment radius, which the operator should demonstrate through a magnitude of completeness analysis accounting for station spacing, instrument sensitivity, and background noise. In practice, lower yellow-light thresholds require denser or closer station coverage, so the selection of thresholds and the design of the monitoring network should be developed together as part of the MMR plan.

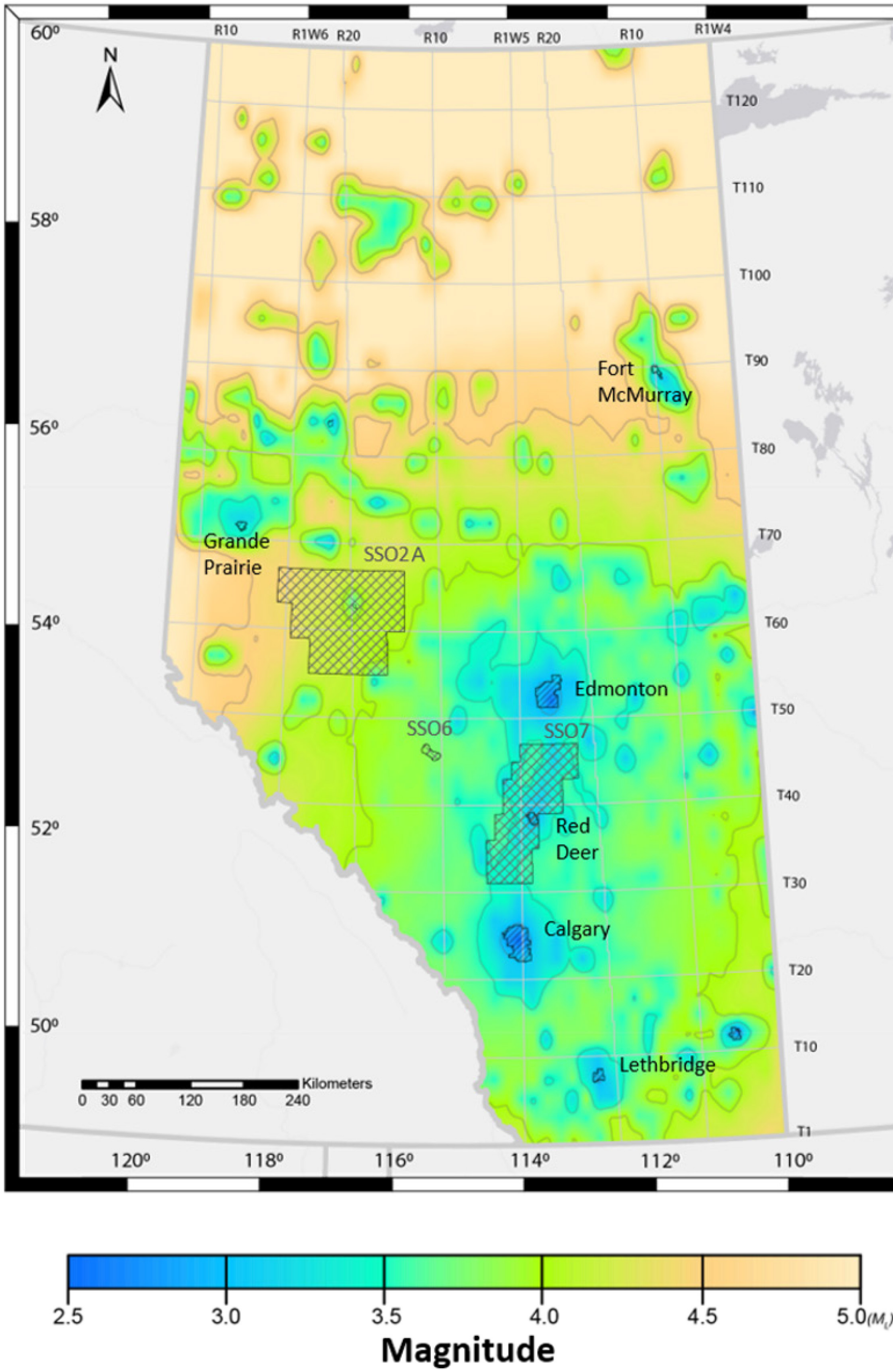

Figure 1. Magnitude Threshold for Acceptable Seismicity (MTAS), merged from iso-nuisance (50% probability of nuisance to 30,000 households) and iso-damage (50% probability of damage to 3 households) maps, both with trailing seismicity factor R_f = 1.2 (hydraulic fracturing activities). Modified from Reyes Canales et al. (2024).

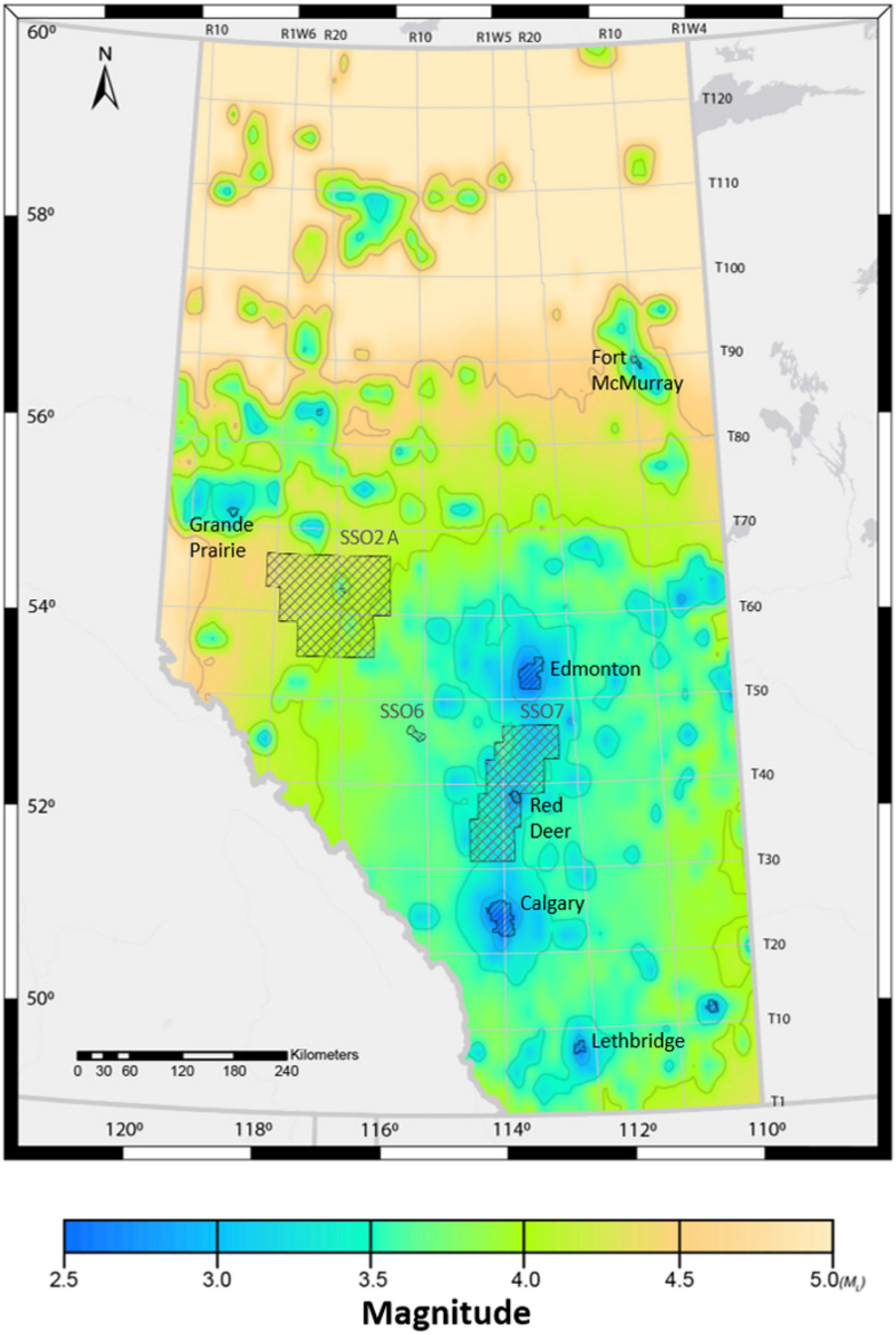

Figure 2. MTAS, merged from iso-nuisance (50% probability of nuisance to 30,000 households) and iso-damage (50% probability of damage to 3 households) maps, both with trailing seismicity factor R_f = 2 (long-term injection activities). Modified from Reyes Canales et al. (2024).

3 Magnitude Estimation Guidance

Local magnitude (M_L) is the most widely reported magnitude scale in earthquake catalogues and is the scale used to define traffic-light thresholds in Alberta's subsurface orders and MMR plans. Consistent M_L estimation is therefore essential: if operators and monitoring networks compute magnitudes differently, the same earthquake could fall in different traffic-light bands depending on the reporting agency. Standard M_L relations developed for California (Hutton and Boore, 1987) do not reflect the attenuation characteristics of the WCSB and have been shown to overestimate event magnitudes in the region by approximately 0.3 to 0.6 magnitude units, with larger bias for small events recorded by local networks (Yenier, 2017). To promote consistency, the AER recommends the regionally calibrated M_L relation developed by Yenier (2017) for the WCSB, summarized below.

3.1 Formulation

The local magnitude of an event at a given station is computed as:

$$M_L = \log(A) + (-\log A_0) + S \tag{1}$$

where A is the peak amplitude (in millimetres) measured on a horizontal-component synthetic Wood–Anderson seismogram, $-\log A_0$ is the regional distance correction evaluated at the hypocentral distance R (in kilometres), and S is a station correction accounting for local site effects. Individual station magnitudes are combined to obtain a final event magnitude.

The distance correction model for the WCSB is a trilinear function of hypocentral distance:

$$-\log A_0 = 1.399 \log(R) + 0.001R + 0.102 \text{ for } R \leq 100 \text{ km} \tag{2a}$$

$$-\log A_0 = -0.727 \log(R) + 0.001R + 4.354 \text{ for } 100 \text{ km} < R \leq 220 \text{ km} \tag{2b}$$

$$-\log A_0 = 1.806 \log(R) + 0.001R - 1.579 \text{ for } R > 220 \text{ km} \tag{2c}$$

The three distance segments reflect the attenuation behaviour observed in the WCSB: direct-wave attenuation at close distances, a flattening between 100 and 220 km caused by postcritical reflections from the Moho joining the direct waves (the 'Moho bounce'), and steeper attenuation beyond 220 km. The relation is calibrated to preserve Richter's original definition of a zero-magnitude earthquake (an amplitude of 0.001 mm at 100 km) and provides unbiased magnitude estimates over hypocentral distances from approximately 2 to 600 km, allowing consistent results from both local and regional networks.

3.2 Practical Implementation

The recommended procedure for computing ML is as follows:

1) Deconvolve the recorded station-components ground motions with instrument response; the instrument response files are provided on EarthScope's webpage as XML metadata.
2) Convert the corrected records to synthetic Wood–Anderson seismograms in the frequency domain, using a transfer function defined by a free period of 0.8 s, a damping constant of 0.8, and a static magnification of 2080 (Uhrhammer and Collins, 1990; International Association of Seismology and Physics of the Earth's Interior, 2013).
3) Measure the maximum Wood–Anderson amplitude on each horizontal component. Amplitude picks should have adequate signal-to-noise ratio to ensure reliable measurement. The final station value

should be taken as the larger of the two horizontal components and manually reviewed where practical; measurements associated with periods longer than 2 s should be excluded to avoid contamination by low-frequency noise.

4) Compute the hypocentral distance R (including focal depth) for each station. Only stations within the calibrated distance range of the relation (approximately 2 to 600 km) should be used in the analysis. It is further recommended to restrict the dataset to stations within 1.5° hypocentral distance to avoid complications from differing P- and S-wave phases. Evaluate the corresponding $-\log A_0$ term from the trilinear model above.
5) Compute a station magnitude for each horizontal component using the M_L equation, applying the station correction S where available. Yenier (2017) provides correction factors for stations in the region; for stations without a published correction, S = 0 may be assumed, recognizing this introduces additional scatter.
6) Compute the event M_L by taking the arithmetic mean of the magnitudes across all qualifying stations.

4 References

Alberta Energy Regulator (2019a): Subsurface order no. 6. URL <https://www.aer.ca/documents/orders/subsurface-orders/SO6.pdf> [August 2026].

Alberta Energy Regulator (2019b): Subsurface order no. 7. URL <https://www.aer.ca/documents/orders/subsurface-orders/SO7.pdf> [August 2026].

Alberta Energy Regulator (2024): Subsurface order no. 2A. URL <https://static.aer.ca/prd/documents/orders/subsurface-orders/so2a.pdf> [August 2026].

Alberta Energy Regulator (2025): Manual 032: how to submit seismic waveform data. URL <https://static.aer.ca/prd/documents/manuals/Manual-032.pdf> [August 2026].

Alberta Energy Regulator (2026): Directive 065: resources applications for oil and gas reservoirs. URL <https://static.aer.ca/prd/documents/directives/Directive065.pdf> [August 2026].

Hutton, L.K. and Boore, D.M. (1987): The ML scale in southern California; Bulletin of the Seismological Society of America, v. 77, p. 2074–2094.

International Association of Seismology and Physics of the Earth's Interior (IASPEI) Working Group on Magnitudes (2013): Summary of magnitude working group recommendations on standard procedures for determining earthquake magnitudes from digital data. URL <http://download.iaspei.org/commissions/CSOI/Summary_WG_recommendations_20130327.pdf> [August 2026].

Reyes Canales, M., Galloway, E., Pawley, S., Yusifbayov, J. and Hartman, G. (2024). Earthquake iso-nuisance and iso-damage mapping for Alberta: applications for choosing magnitude thresholds to manage induced seismicity; Earth's Future, v. 12, p. e2024EF004985, doi:10.1029/2024EF004985.

Reyes Canales, M., Hauck, T.E., Yusifbayov, J.A., Bui, H. and Goerzen, C. (2026): Discerning between natural and induced seismicity by using evidence-scoring tools designed to evaluate proposals of induced earthquakes: application to the Reno and Kakwa earthquake sequences, northwestern Alberta; Alberta Energy Regulator / Alberta Geological Survey, AER/AGS Open File Report 2025 05, 29 p.

Reyes Canales, M., Yusifbayov, J. and van der Baan, M. (2022): Evolution of short-term seismic hazard in Alberta, Canada, from induced and natural earthquakes: 2011–2020; Journal of Geophysical Research: Solid Earth, v. 127, no. 2, p. e2021JB022822, doi:10.1029/2021jb022822.

Schultz, R., Beroza, G.C. and Ellsworth, W.L. (2021): A risk-based approach for managing hydraulic fracturing–induced seismicity; Science, v. 372, no. 6541, p. 504–507, doi:10.1126/science.abg5451.

Schultz, R., Wang, R., Gu, Y., Haug, K. and Atkinson, G. (2017): A seismological overview of the induced earthquakes in the Duvernay play near Fox Creek, Alberta; Journal of Geophysical Research: Solid Earth, v. 122, p. 492–505, doi:10.1002/2016JB013570.

Schultz, R.J., Yusifbayov, J. and Shipman, T.C. (2020): The scientific induced seismicity monitoring network (SCISMN); Alberta Energy Regulator / Alberta Geological Survey, AER/AGS Open File Report 2019-09, 10 p.

Uhrhammer, R.A. and Collins, E.R. (1990): Synthesis of Wood-Anderson seismograms from broadband digital records; Bulletin of the Seismological Society of America, v. 80, no. 3, p. 702–716.

Wang, J., Li, T., Gu, J., Schultz, R., Yusifbayov, J. and Zhang, M. (2020): Sequential fault reactivation and secondary triggering in the March 2019 Red Deer induced earthquake swarm; Geophysical Research Letters, v. 47, no. 22, p. e2020GL090219, doi:10.1029/2020GL090219.

Yenier, E. (2017). A local magnitude relation for earthquakes in the Western Canada Sedimentary Basin; Bulletin of the Seismological Society of America, v. 107, no. 3, p. 1421–1431, doi:10.1785/0120160275.