

Assessment of the Gold Creek and Kakwa Seismic Clusters in Relation to Disposal Activities in the Leduc Formation

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Summary

Water disposal into the Leduc Formation has been associated with seismic activity south of Grande Prairie, Alberta. In this assessment, we examine two main seismic clusters: (1) Gold Creek and (2) Kakwa. In both cases, events larger than magnitude $ML > 4$ have been observed, including the $ML = 4.03$ event in early October 2024 (Kakwa) and the $ML = 4.50$ event in late October 2024 (Gold Creek). No damage has been registered from these events, although nuisance from nearby population centers has been reported. Given these significant events, we conduct a re-assessment of these cases in terms of event relocation, causation, and current seismic hazard trends. In both cases, we found an increase in the seismic hazard, peaking in 2023 for Gold Creek and in 2024 for Kakwa. A similar trend of increasing frequency of earthquakes is found, peaking in the year 2024 for both clusters. This increase in seismic hazard correlates with increasing disposal activities in the Leduc Formation.

Data and Methods

We use the Alberta Geological Survey earthquake catalogue (Alberta Geological Survey, 2025) for the analysis of both Gold Creek and Kakwa clusters. Over 420 events have been detected in the Gold Creek cluster since 2019, with a magnitude range between $M = [1.0-4.50]$. On the other hand, over 1920 events have been recorded in the Kakwa cluster since 2021, with a magnitude range between $M = [1.0-4.50]$. Figures 1a and 1b show the location of the events for the Kakwa and Gold Creek clusters, as well as the location of the disposal wells injecting into the Leduc Formation considered to be causing the events. Double-difference relocation (HypoDD, Waldhauser and Ellsworth, 2000) was applied to each cluster to refine the earthquake locations, which was necessary for analyzing the spatio-temporal correlation with the industrial activity in the region. Operational data from disposal activities were also used in the spatio-temporal analysis to identify induced seismicity (Davis and Frohlich, 1993). An annual seismic hazard analysis was conducted for these three clusters, following the approach outlined by Reyes Canales et al. (2022).

Results

Figures 2a and 2b show the monthly frequency of events and injection volumes from the corresponding disposal activities in the Kakwa and Gold Creek clusters, respectively. Figure 3a and 3b show the annual probability of events larger than magnitude $M > 4$ for both the Kakwa and Gold Creek clusters, respectively.

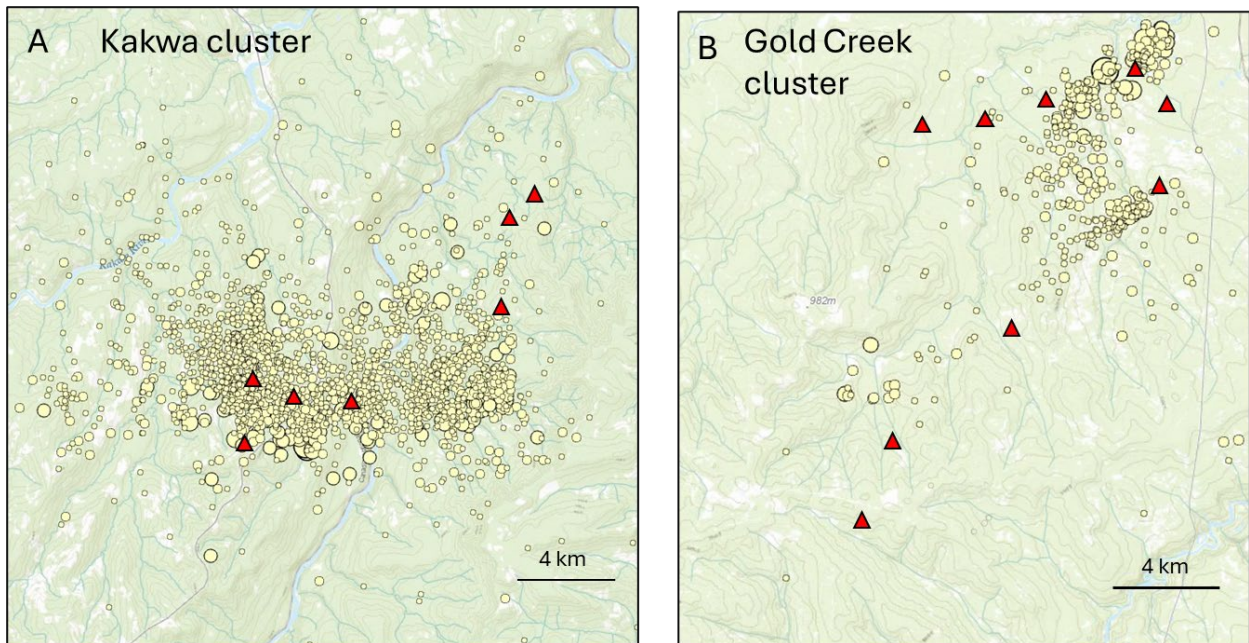


Figure 1. Location of the events for the Kakwa (a) and Gold Creek (b) clusters, as well as the location of the positively correlated disposal wells injecting into the Leduc Formation (red triangles).

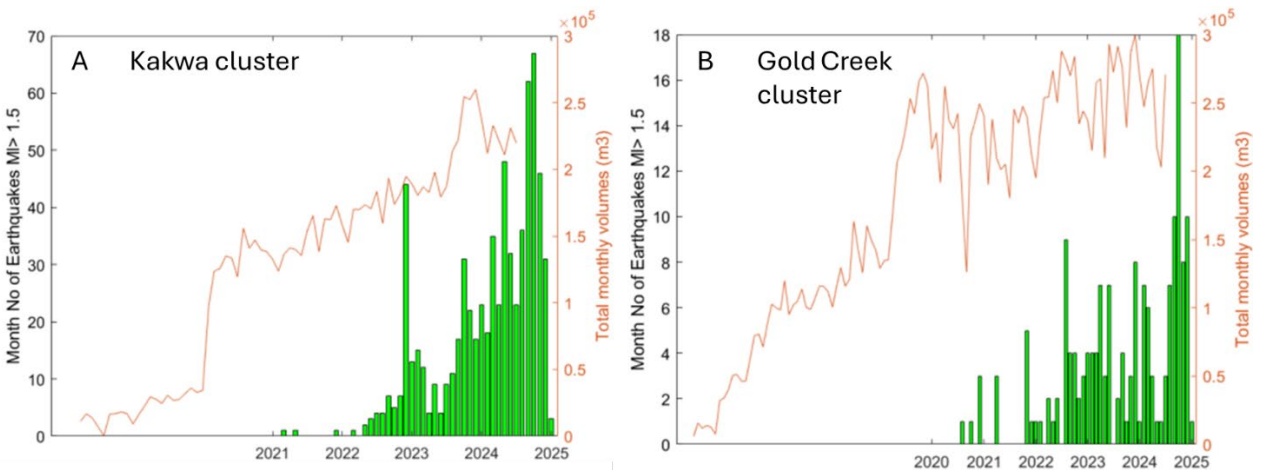


Figure 2. Monthly number of earthquakes (green bars) and monthly injection rates (orange curve) from seismicogenic disposal activities in the Kakwa cluster (a) and Gold Creek cluster (b).

From the seismic hazard analysis, the annual likelihood of events larger than magnitude $M > 4$ in the Kakwa cluster has increased over time, from 10% probability in 2022 to 24% in 2023, and peaking in 2024 to 35% (mean case scenarios, blue curve in Figure 4). Additionally, the annual likelihood of events larger than magnitude $M > 4$ in the Gold Creek cluster increased from $< 1\%$ in

2021 to 4% in 2022 and 37% in 2023 (mean case scenarios). There is an apparent reduction in 2024 to 8% probability; however, if bimodality observations in the magnitude frequency distributions are considered (e.g., Igonin et al., 2018), we estimate an alternative probability of 38% to reach earthquakes larger than magnitude $M > 4$ in the Gold Creek cluster. In terms of earthquake frequency, the largest number of events larger than $M > 1.5$ were observed in 2024, with 445 and 75 for the Kakwa and Gold Creek clusters, respectively. The rise in the frequency of events is associated with the growing disposal activities in the Leduc Formation in both the Gold Creek and Kakwa cluster areas.

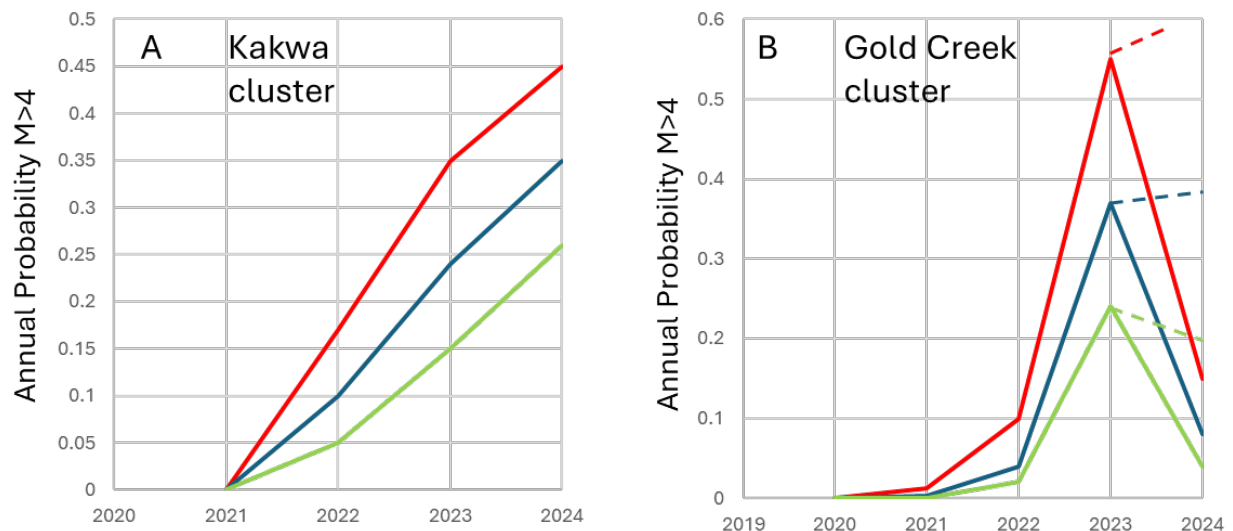


Figure 3. Annual probability of events larger than $ML > 4$ for Kakwa (a) and Gold Creek (b) seismic clusters. The blue curve corresponds to the mean case scenario, whereas the red and green curves correspond to the high and lower probability scenarios. The dash lines in 2024 for the Gold Creek cluster correspond to alternative probabilities when considering bimodality in the magnitude frequency distribution (Igonin et al., 2018).

Discussion

The Gold Creek and Kakwa seismic clusters show an overall increase in the frequency of events and seismic hazard. This observation contrasts with other clusters in the same region, specifically the central Musreau Lake cluster, which has been related to disposal activities in the Winterburn Group (Li et al., 2021). From an operational perspective, a remarkable difference between the Gold Creek and Kakwa cases with respect to the central Musreau Lake cluster is the overall reduction in injection rates. In the central Musreau Lake cluster, we observed that the seismic hazard has declined since the peak in 2022, which is in line with decreasing injection rates in the area. In contrast, there are growing disposal activities in the Leduc Formation in both the Gold Creek and Kakwa cluster areas. Seismic activity related to water disposal activities in the Leduc Formation has surged in other places in Alberta. Clusters in the Peace River region, related to disposal activities in the Leduc Formation (Schultz et al., 2023), have led to some of the highest magnitude anthropogenic earthquakes recorded in Alberta, including the 29 November 2022 $ML = 5.59$ event near Reno.

References

- Alberta Geological Survey. (2025). *Alberta Earthquake Dashboard*. Retrieved from <https://ags.aer.ca/data-maps-models/interactive-mapsand-apps/ae>
- Davis, S. D., and C. Frohlich (1993). Did (or will) fluid injection cause earthquakes? Criteria for a rational assessment, *Seismol. Res. Lett.* 64, 207–224.
- Igonin, N., Zecevic, M., & Eaton, D. W. (2018). Bilinear magnitude-frequency distributions and characteristic earthquakes during hydraulic fracturing. *Geophysical Research Letters*, 45, 12866–12874.
- Li, T., Gu, Y. J., Wang, J., Wang, R., Yusifbayov, J., Reyes Canales, M., & Shipman, T. (2021). Earthquakes induced by wastewater disposal near Musreau Lake, Alberta, 2018-2020. *Seismological Research Letters*, 93(2A), 727-738. <https://doi.org/10.1785/0220210139>
- Reyes Canales, M., Yusifbayov, J., & 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*, 127(2), e2021JB022822. <https://doi.org/10.1029/2021jb022822>
- Schultz, R., Woo, J.-U., Pepin, K., Ellsworth, W. L., Zebkar, H., Segall, P., et al. (2023). Disposal from in situ bitumen recovery induced the ML 5.6 Peace River earthquake. *Geophysical Research Letters*, 50(6), e2023GL102940. <https://doi.org/10.1029/2023gl102940>
- Waldhauser, F., & Ellsworth, W. L. (2000). A Double-difference Earthquake location algorithm: Method and application to the Northern Hayward Fault, California. *Bulletin of the Seismological Society of America*, 90(6), 1353–1368. <https://doi.org/10.1785/0120000006>