2024 Brings Record Number of Magnitude ≥3.0 Earthquakes to British Columbia's Peace River Region

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2024 brought a record high number of magnitude 3.0 or larger earthquakes (M≥3.0) to the Montney Trend in British Columbia's Peace River Region (**Figure 1**).

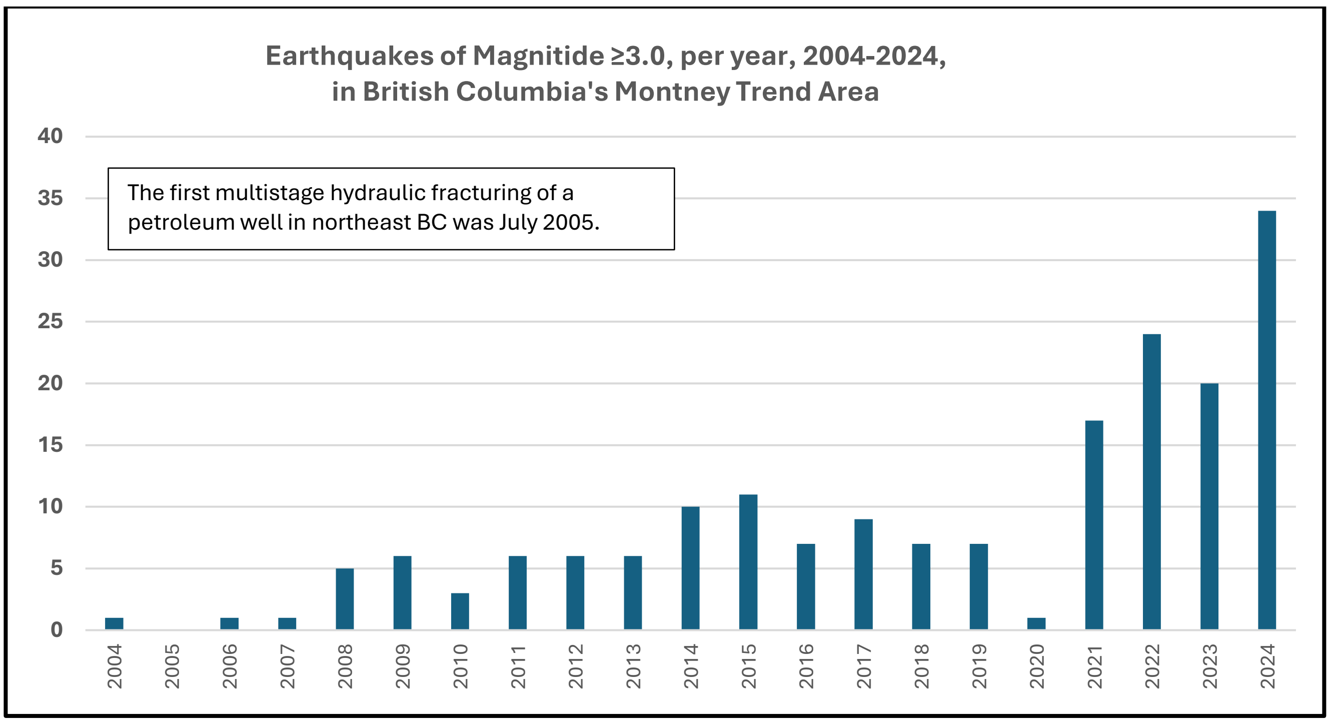

Figure 1. Magnitude 3.0 or larger earthquakes in the Montney Trend of northeast BC, 2005-2024. The earthquake data are from the Natural Resources Canada catalogue.

Multi-stage hydraulic fracturing (HF, or fracking) began in northeast British Columbia (NEBC) in July 2005, almost twenty years ago. Since then, many thousands of wells have been drilled and fracked. By 2009 or 2010, it was evident from seismicity monitoring that hydraulic fracturing was inducing earthquakes. Thousands of earthquakes have resulted from hydraulic fracturing, most small, but some sufficiently large to result in public safety and infrastructure risk (**Figure 2**). Earthquakes of M≥3.0 are generally felt on the ground surface, and so are a useful threshold through which to examine long-term trends in earthquake frequency[1].

Before 2008, earthquakes of M≥3.0 were rare. With the onset of hydraulic fracturing, however, the frequency of M≥3.0 earthquakes increased substantially. During 2008-2019 there were around 5-10 per year (2020 was anomalously low, with only one M≥3.0 earthquake). The frequency of M≥3.0 earthquakes then increased to 17-24 per year for 2021-2023. **For 2024, the year just ended, the frequency increased even further, to 34 M≥3.0 earthquakes. This is the largest number of M≥3.0 earthquakes ever recorded in British Columbia's Montney Trend in a single year and is a concerning harbinger of the future for BC's Peace River region.**

These M≥3.0 earthquakes are likely all, or almost all, human-caused, with hydraulic fracturing being the primary cause and wastewater disposal into deep wells being a secondary culprit[2]. **Figure 3** shows the rate of M≥3.0 earthquakes per year as a percentage of the wells hydraulically fractured each year[3].

What are the factors that might be associated with the substantial increase in the frequency of M≥3.0 earthquakes during 2021-2024? As hypotheses:

1. Not all geographic parts of the Montney Trend are equally seismogenic. If a significant increase in the rate of well drilling and hydraulic fracturing in the most seismogenic portions of the Montney occurred in 2021-2024, more earthquakes and possibly larger earthquakes would be anticipated. The data suggest this at least partially explains the increase in M≥3.0 earthquakes. The years 2021-2024 had more HF wells in the more seismogenic North Montney than in the 5 years prior. But, it should be noted that the 2021-2024 HF well count was still less than that of 2014 and 2015, which experienced substantially lower earthquake rates.
2. The Montney formation is considered to contain three layers, which are targeted separately with horizontal well bores. There are differences in seismogenicity among the layers, with the lowest layer, sitting above the basement rock, believed to be more seismogenic than upper portions of the formation. If the horizontal well bores hydraulically fractured in 2021-2024 were more concentrated in the lower Montney layer, more earthquakes would be anticipated. I have not examined this aspect of the data to test this hypothesis.

[1] In some circumstances, earthquakes of smaller magnitude can also be felt, depending on proximity to the epicentre and amplification of ground shaking from near-surface soil conditions.

[2] Investigations have suggested that 10-15 percent of earthquakes induced by petroleum activity result from wastewater injection into deep wells. Because hydraulic fracturing and wastewater disposal operations are occurring at the same time in the same geographic space, it is difficult to disentangle their relative earthquake effects, and so they are usually lumped together.

[3] Some of the earthquakes will have been induced by wastewater injections, but injection wells are not included in the well count shown in Figure 3.

3. There is the cumulative effect associated with antecedent fluid injection from hydraulic fracturing and wastewater disposal. Portions of the Montney Trend are highly faulted and fractured, with some of these faults and fractures creating high permeability pathways through which injected fluids can migrate over months and years to locations distant from the location of initial injection. This potentially alters the seismogenic characteristics of zones to where fluids have migrated, making them more susceptible to future earthquakes. This cumulative effect from antecedent fluid injection has not been well studied, but was discussed in Chapman (2021).
4. Other in-well factors that are part of the hydraulic fracturing process are involved, such as increases in injected water volumes per well over time and increases in the mass of proppant injected per well. The volume of injected hydraulic fracture fluid per well in the BC Montney Trend has risen consistently year-over-year, to almost 24,000 m^3 per well in 2024 (equivalent to the volume of ten Olympic-sized swimming pools), and the mass of injected proppant has also increased year-over-year to almost 5,000 tonnes per well (**Figure 4**). These 2024 rates are an increase of 3X from 2012. In the US, these large water and large proppant fracks are sometimes referred to colloquially as “monster fracks”.

The total volume of injected hydraulic fracture fluid per year has consequently also increased steadily year-over-year (**Figure 5**). During the 2005-2024 period, a total of 98 million m^3 of hydraulic fracture fluid has been injected into the subsurface in BC's Montney Trend. This is the equivalent of almost 40,000 Olympic-sized swimming pools. This large fluid volume has largely stayed underground, either by the initial hydraulic fracturing operation or by the reinjection of frack flowback wastewater into disposal wells.

British Columbia’s grand experiment in unconventional petroleum development and hydraulic fracturing may have untethered the seismic demons. Can they be controlled?

Data and Analysis

The earthquake data analyzed for this report were extracted from Natural Resources Canada’s Earthquakes Canada catalogue. Data on hydraulically fractured wells for 2005-2011 were extracted from the BC Energy Regulator’s Wells database; and data on hydraulically fractured wells for 2012-2024 were extracted from the BC Energy Regulator’s FracFocus database. All geospatial analysis was done with QGIS.

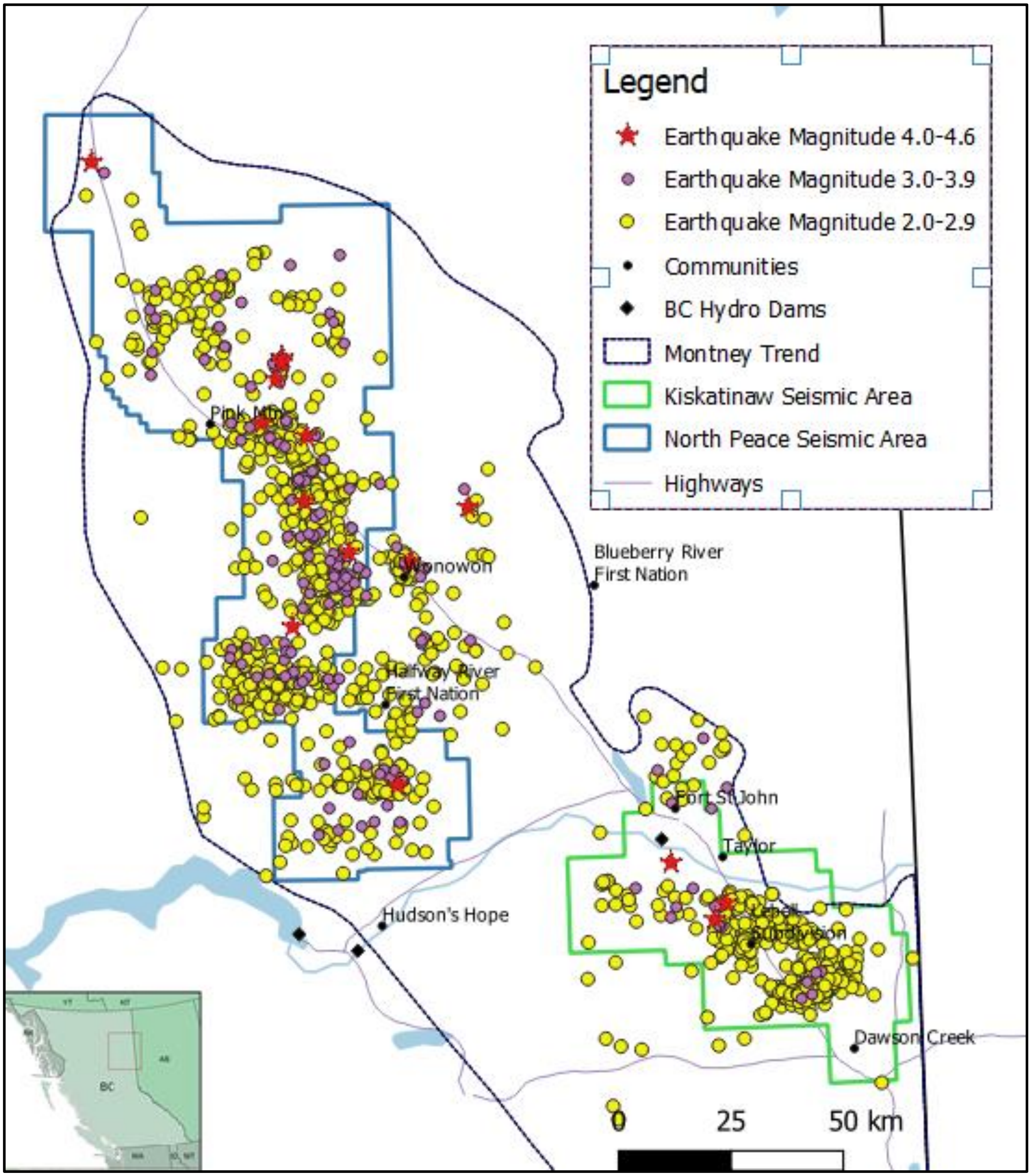

Figure 2. Induced earthquakes in British Columbia's Montney Trend, showing Magnitude 2+, 3+ and 4+ earthquakes, key communities, and the Kiskatinaw Seismic Monitoring and North Peace Seismic Monitoring areas.

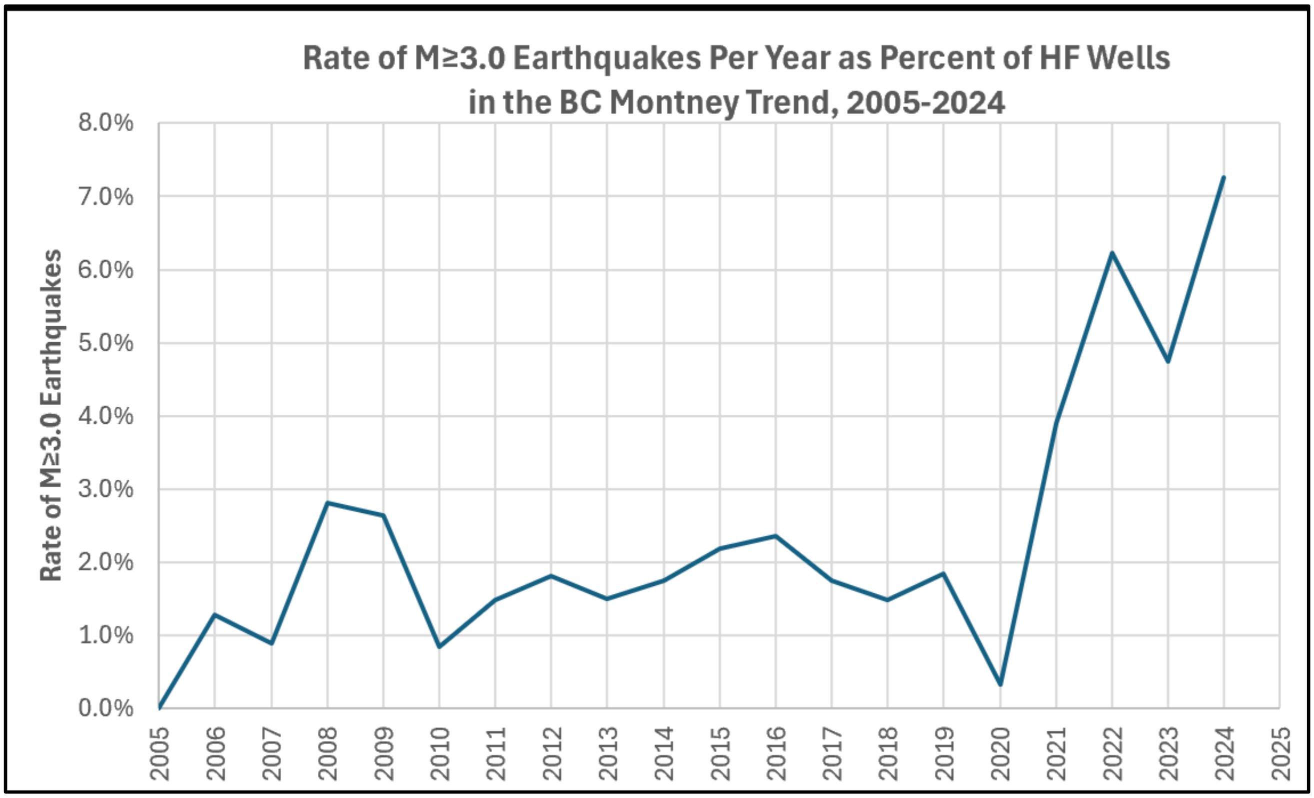

Figure 3. The annual rate of M≥3.0 earthquakes as percent of fracked wells in the Montney Trend of northeast British Columbia (2005-2024).

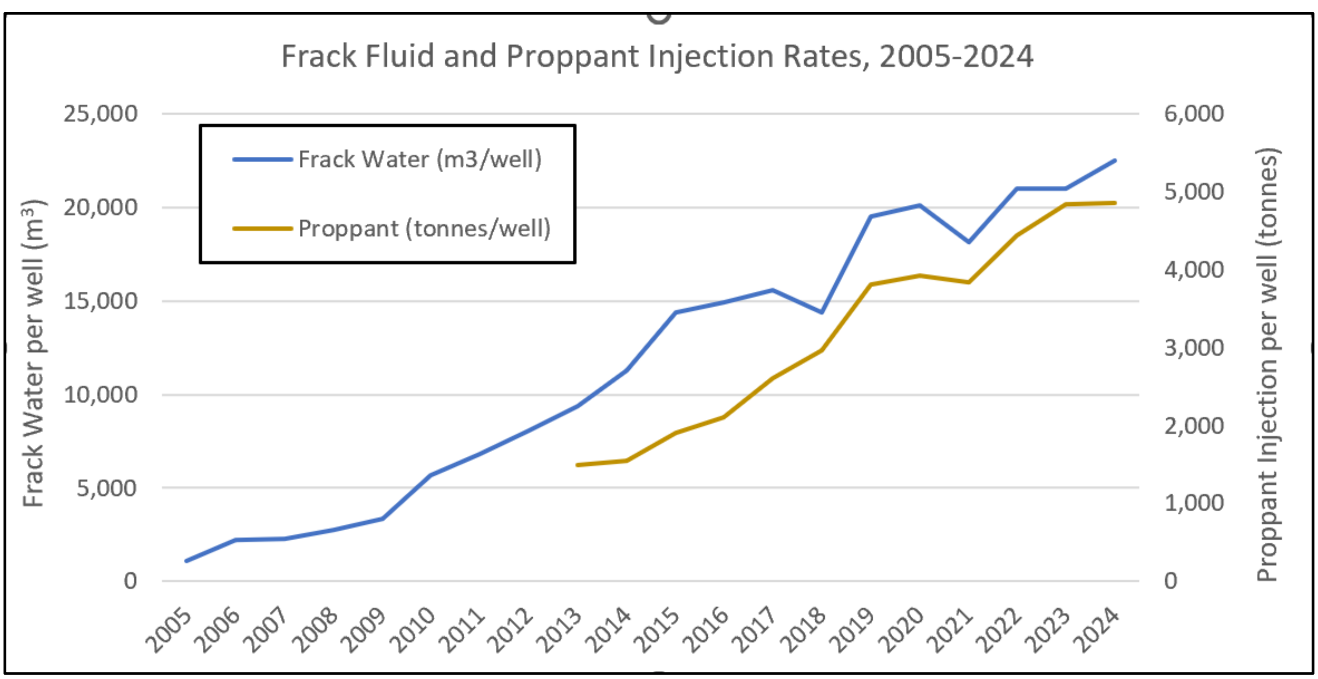

Figure 4. Changes in frack fluid and proppant injection rates per well in the BC Montey Trend, 2005-2024.

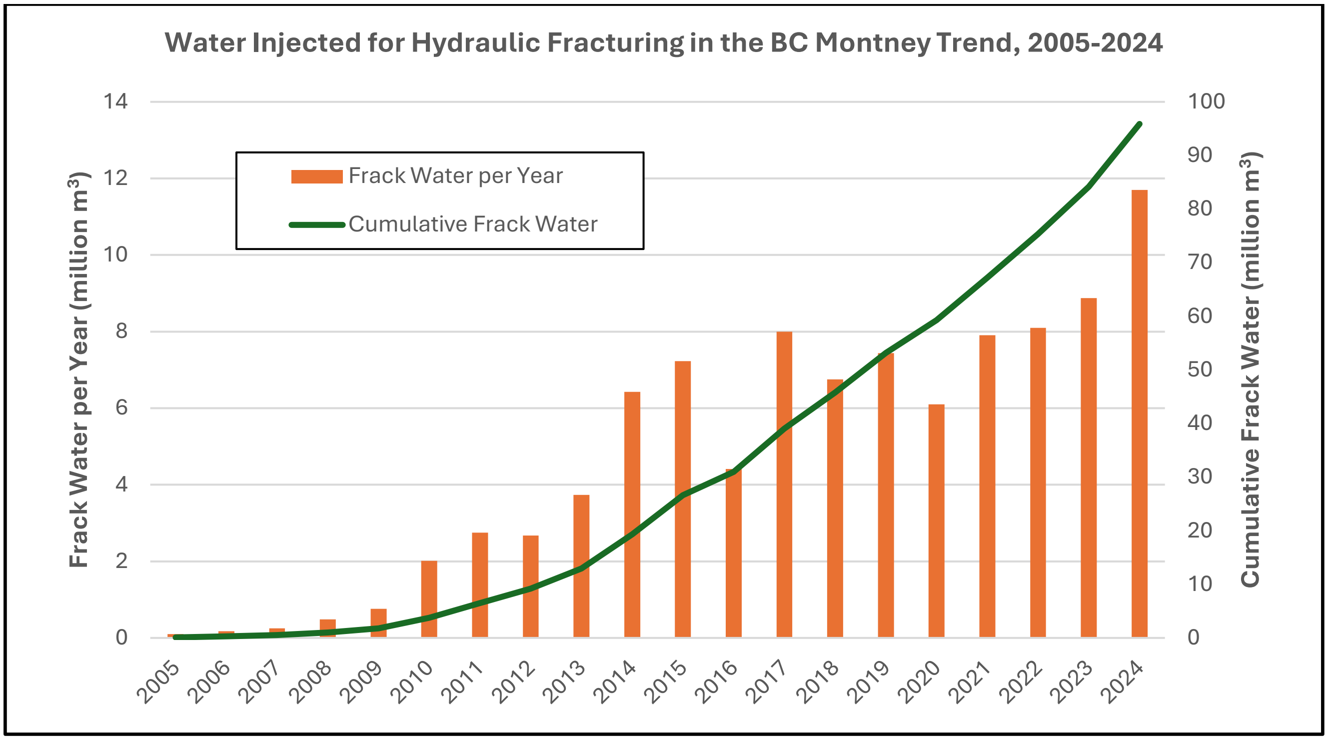

Figure 5. Annual frack fluid injection volumes, and cumulative frack fluid injection, 2005-2024.