# INTEVENTION AS FRIEND OF THE COURT

Honorable Supreme Court of Justice of the Nation:

I, **RYAN SCHULTZ,** a Canadian citizen (******), seismologist, and senior researcher at the Swiss Seismological Service at ETH Zürich (Eidgenössische Technische Hochschule Zürich**),** with current residency in Switzerland, with legal representation of *****, constituting legal domicile for the effects of this presentation at **** in the case titled **"FUNDACION AMBIENTE Y RECURSOS NATURALES (FARN) Y OTROS c/ PROVINCIA DE NEUQUÉN s/ ACCIÓN DE AMPARO" Exp. 1109/2025,** I respectfully present myself to your Honors and declare:

## 1. PURPOSE

I come before you in this proceeding as a Friend of the Court ("AMICUS CURIAE") to provide technical and scientific opinions regarding earthquakes caused by hydraulic fracturing for oil and gas in the Neuquén Basin of Argentina and good practice guidelines for managing these risks. Earthquakes caused by human activity, known as 'induced seismicity,' pose serious risks. Shaking caused by hydraulic fracturing is often strong enough to be felt, and in some cases causes damage or injuries. The full extent of impacts from induced seismicity can vary, but the hazards and risks are similar to those caused by moderate magnitude earthquakes (M2-M5) in tectonic settings. In some cases, public concern over the perceived risks of these earthquakes has led to subsurface development moratoriums.

I begin by reviewing the latest scientific evidence, which definitively shows that numerous human activities can create changes in the subsurface significant enough to trigger earthquakes, including hydraulic fracturing for oil and gas also causes seismicity.

Next, I outline recommended policies that are available to manage the risks of induced seismicity. These recommendations draw from good practice guidelines developed to address hydraulic fracturing cases in North America. Broadly, these recommendations for effective risk management and mitigation can be reduced to two major components: (i) a risk-based traffic light protocol (**TLP**), and (ii) robust and transparent earthquake monitoring.

Finally, I examine evidence on the case of hydraulic fracturing-induced seismicity within the Neuquén Basin of Argentina. Based on a recent, peer-reviewed study that I conducted with other experts, I concluded that hydraulic fracturing operations are likely inducing earthquakes there, to a high-degree of confidence (Schultz et al. (2024). Chasing the ghost of fracking in the Vaca Muerta Formation: Induced seismicity in the Neuquén Basin, Argentina. *Seismica*, 3(2)). Specifically, a large portion (~42%) of the earthquakes that occurred in the Neuquén Basin between 2014-2024 were related to hydraulic fracturing, with at least ~0.5% of all operations inducing seismic events. These events reached up to M4, which is a moderate magnitude event with the potential for damage to homes. It is important to highlight that the scope of these conclusions was limited by a lack of data availability because the province has not followed good practices for seismic monitoring or data transparency.

Based on this evidence, I recommend that the Province of Neuquén implement a TLP and ensure that their earthquake monitoring system is transparent. The government of Neuquén currently does not have either a TLP or an adequate monitoring system in place. Although the government has made initial steps to establish a monitoring network, the network is currently insufficient and there are restrictions to data availability. I conclude this brief by summarizing recommendations for a TLP and earthquake monitoring system in the Neuquén Basin.

## 2. STANDING AND QUALIFICATIONS

The role of the Friend of the Court was established by Agreement 28/2004 within the scope of the Supreme Court of Justice of the Nation (CSJN) and was later regulated by Agreement 7/2013 of the CSJN. In this regard, and with respect to the role of the Friend of the Court in the proceedings, Article 4 of the aforementioned Agreement states: "*The purpose of* *the Friend of the Court is to enrich the deliberation on institutionally relevant issues with well-founded legal, technical, or scientific arguments related to the issues under debate*."

On the topic of induced seismicity, I am an internationally recognized expert. Currently I am a senior researcher and co-lead the Induced Seismicity Group within the Swiss Seismological Service at ETH Zürich. I conduct fundamental research on induced seismicity, including identifying cases of induced seismicity, understanding the conditions/physics leading to fault reactivation, modelling/forecasting seismic response, examining operational procedures for mitigating seismic risk, building risk-informed control systems, and guiding best practices. Ultimately, this research is aimed at better managing the risks of these earthquakes.

My first professional role was as a seismologist at the Alberta Geological Survey in Canada, starting in 2012 and continuing for approximately 8 years. During this time, I was responsible for the creation of Alberta's seismic monitoring network, cataloguing earthquakes, identifying induced seismicity cases, understanding the operational and geological factors driving these earthquakes, and developing regulations. This work responded to the Alberta Energy Regulator's concerns over induced seismicity in Alberta, where earthquakes were predominantly induced by hydraulic fracturing for oil and gas. Following this endeavour, I completed my Ph.D. at Stanford University. My thesis entailed the creation of a risk-based design for TLPs, which has since been adopted within good practice guidelines, including by regulators improving their decision-making processes, and industry groups concerned with earthquake risks.

I have recently applied my expertise to the Neuquén Basin and am familiar with the local monitoring and scientific landscape; my opinions and recommendations are informed by this understanding. Furthermore, I have no conflicting interest in the outcome of this decision, no financial ties to industry in Argentina, or any other vested interests. My recommendations are motivated by a desire to resolve the problem of induced seismicity and to help those impacted by its consequences.  Opinions expressed are solely my own and do not express the views or opinions of my employer.

## 3. Fully accepted scientific evidence shows that hydraulic fracturing can induce earthquakes

Natural earthquakes predominantly occur at the tectonic boundaries or ‘faults,’ which are large pieces of the Earth’s crust that are slowly moving against one another. When stress between these plates builds up, the stored energy is released in a sudden and violent event: an earthquake. That said, earthquakes can also occur well within these plate boundaries (*i.e.*, intra-cratonic), since the Earth’s crust is abundant in faults. Induced seismicity is a type of intra-cratonic earthquake that is caused by human activity.

Thousands of cases of induced seismicity have been identified, from multiple types of human activity (Foulger et al. (2018). Global review of human-induced earthquakes. *Earth-Science Reviews*, 178, 438-514), including from mining, reservoir impoundment, ground water extraction, conventional petroleum production, wastewater disposal, underground storage of gases, enhanced geothermal systems, and hydraulic fracturing. Effectively, any operation that has the potential to change stresses or forces in the subsurface also has the potential to reactivate faults to produce an earthquake (Moein et al. (2023). The physical mechanisms of induced earthquakes. *Nature Reviews Earth & Environment*, 4(12), 847-863).

Operations that inject fluids underground can cause earthquakes (Ellsworth (2013). Injection-induced earthquakes. *Science*, 341(6142), 1225942). As an operation injects fluids, it causes pore pressure increases in the subsurface. This pressure increase can migrate laterally, diffusing through permeable rock and potentially reaching great distances (tens of kilometers from the original injection site). Pressure increases may travel far enough to encounter a fault., which can reactivate it: the increase of pressure acts against the forces clamping a fault closed, effectively moving the fault closer to slipping or sliding. The reactivation of a fault can be expressed as an earthquake. Pressure increases required for reactivation can be small: in fact, even gravity-fed injection wells, which are relatively low-pressure, have been documented to cause earthquakes (Rubinstein y Mahani (2015). Myths and facts on wastewater injection, hydraulic fracturing, enhanced oil recovery, and induced seismicity. *Seismological Research Letters*, 86(4), 1060-1067).

Hydraulic fracturing is an operation that injects fluids underground at pressures high enough to break nearby rock. The build-up of fluid pressure splits the rock, creating new fractures. This technique has been used for the extraction of hydrocarbons that are trapped in impermeable (or 'tight') rocks. If these growing fractures encounter a fault, then this pressurization mechanism can also reactivate a fault, potentially producing an earthquake.

It is well-established that hydraulic fracturing for oil and gas causes earthquakes (Atkinson et al. (2016). Hydraulic fracturing and seismicity in the Western Canada Sedimentary Basin. *Seismological Research Letters*, 87(3), 631-647). A non-exhaustive list of hydrocarbon basins where hydraulic fracturing has induced seismicity includes the Horn River Basin (Canada), Bowland Shale (UK), Duvernay Formation (Canada), Montney Formation (Canada), Utica Shale (USA), Marcellus Shale (USA), Eagle Ford Formation (USA), Delaware Basin (USA), and Sichuan Basin (China). There are likely more basins where hydraulic fracturing is causing earthquakes than currently recognized, since seismological monitoring is often lacking within the intra-cratonic settings where hydraulic fracturing occurs.

Research has identified factors that indicate when and how often hydraulic fracturing will induce seismicity (Schultz et al. (2020a). Hydraulic fracturing-induced seismicity. *Reviews of Geophysics*, 58(3), e2019RG000695; Atkinson et al. (2020), Developments in understanding seismicity triggered by hydraulic fracturing. *Nature Reviews Earth & Environment*, *1*(5), 264-277). At the basin scale, only a minority (less than approximately 1%) of hydraulic fracturing wells tend to cause earthquakes, although this fraction can be larger – up to tens of percent in earthquake prone regions.  Despite this low chance for any individual well to trigger an earthquake, the overall likelihood of encountering substantial earthquakes remains high for the whole basin: in a typical basin where tens of thousands of wells may be stimulated, it is common for hundreds of wells to cause earthquakes.

Hydraulic fracturing operations can generate relatively large events. For example, basins where seismic activity is linked to hydraulic fracturing have reported events up to M4 or larger.  Moreover, in many seismogenic basins around the world, hydraulic fracturing-induced earthquakes have become the dominant source of seismicity. Earthquakes induced by hydraulic fracturing tend to be close to the wells that cause them (within hundreds of meters), as stimulated fractures need to connect to reactivatable faults. The furthest published case is approximately 1.5 km for hydraulic fracturing (Schultz y Wang (2020). Newly emerging cases of hydraulic fracturing induced seismicity in the Duvernay East Shale Basin. *Tectonophysics*, 779, 228393) and approximately 4.0 km for an analogous geothermal system (Schmittbuhl et al. (2021). Induced and triggered seismicity below the city of Strasbourg, France from November 2019 to January 2021. *Comptes Rendus. Géoscience*, *353*(S1), 561-584), although undocumented cases at further distances may exist.

## 3.1. Fully accepted scientific evidence shows that induced earthquakes have the potential to cause nuisance, damage to buildings, injuries, and fatalities

Hazards and risks from induced seismicity can be similar to those resulting from comparable tectonic earthquakes. Damage to buildings from induced events in the Netherlands from gas extraction (up to $M_L$ 3.6) resulted in the company NAM (an operation of Shell and ExxonMobil) being liable for hundreds of millions of euros of compensation to affected homeowners and businesses (van der Voort y Vanclay (2015). Social impacts of earthquakes caused by gas extraction in the Province of Groningen, The Netherlands. *Environmental Impact Assessment Review*, 50, 1-15). In another example, earthquakes induced by hydraulic fracturing for geothermal energy in Pohang, South Korea resulted in a $M_W$ 5.5 earthquake (Grigoli et al.

(2018). The November 2017 Mw 5.5 Pohang earthquake: A possible case of induced seismicity in South Korea. *Science*, *360*(6392), 1003-1006); consequences there included at least ~$75M USD in damages, 1,124 displaced residents, 82 injuries, and 15 hospitalizations (Ellsworth et al. (2019). Triggering of the Pohang, Korea, Earthquake (Mw 5.5) by Enhanced Geothermal System Stimulation. *Seismological Research Letters*, 90(5)). Specific to earthquakes caused by hydraulic fracturing for oil and gas, the 16 December 2018 earthquake ($M_L$ 5.7) in the Sichuan Basin of China resulted in 17 injuries and up to ~$7M USD in direct economic losses, and triggered landslides and rock collapses (Lei et al. (2019). The December 2018 $M_L$ 5.7 and January 2019 $M_L$ 5.3 earthquakes in South Sichuan basin induced by shale gas hydraulic fracturing. *Seismological Research Letters*, 90(3), 1099-1110). In many cases, subsurface projects have been terminated due to earthquake risks encountered during the operation (Foulger et al., 2018, op. cit.). Note that earthquake magnitude measures the relative size of an earthquake on a logarithmic scale. This means that each magnitude unit increase represents an exponential—not linear—growth in shaking intensity and energy release (United States Geological Survey (2025; last accessed). Earthquake Magnitude, Energy Release, and Shaking Intensity, *USGS Website*). For example, an M5 earthquake would generate 10 times as much ground shaking and release 32 times as much energy as an M4 event.

## 4. Frameworks to manage the risks of hydraulic fracturing induced seismicity

Proper risk management plans are needed for any basin in which hydraulic fracturing creates a likely risk of induced seismicity, to ensure that earthquake risks are either avoided or effectively mitigated.

While there is no ‘silver bullet’ to entirely prevent earthquakes, there are ‘good practice’ guidelines for management. These guidelines are based on state-of-the-art science that governments should implement in regions encountering induced earthquakes (Zhou et al. (2024). Managing induced seismicity risks from enhanced geothermal systems: A good practice guideline. *Reviews of Geophysics*). For hydraulic fracturing-induced seismicity, the two core elements are: (1) the implementation of a traffic light protocol (TLP); and (2) the deployment of a robust and transparent monitoring system. There are useful examples of detailed risk-reduction plans for induced seismicity that adhere to these good practices, such as operational plan for the Utah FORGE geothermal hydraulic fracturing experiment (Pankow et al. (2023). Utah FORGE Induced Seismicity Mitigation Plan. *University of Utah Report*, DE-EE0007080, p 224).[1]

### 4.1. The design and implementation of a risk-based traffic light protocol (TLP)

Traffic light protocols (TLPs) are the most common framework used to reactively mitigate induced seismicity caused by hydraulic fracturing (Schultz et al., 2020a, op. cit.). Typically, the TLP establishes three thresholds labeled as red-, yellow-, and green-lights, based on the current level of seismic activity in a region of hydraulic fracturing activity. Usually, these three thresholds are pre-defined magnitude values. While within the green-light, an operator is allowed to proceed uninhibited. If an operation triggers the yellow-light threshold, the operator must execute mitigation strategies to reduce the frequency and magnitude of induced earthquakes, for example, by limiting injected fluid or pausing operations in a set time period. The red-light threshold is the last possible stopping-point before exceeding an intolerable amount of risk. Operators triggering the red-light threshold are subject to regulatory intervention; often, requiring the operator to abandon any further fracturing in a given area.

To date, many jurisdictions have implemented TLPs for a variety of induced seismicity causes. For hydraulic fracturing, TLPs have been implemented in Alberta (Canada), British Columbia (Canada), Ohio (US), Oklahoma (US), and the UK (Schultz et al. (2020b). Risk-informed recommendations for managing hydraulic fracturing–induced seismicity via traffic

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[1] Geothermal hydraulic fracturing is analogous to hydraulic fracturing for oil and gas, and this example can therefore serve as a comprehensive template for oil and gas hydraulic fracturing operations to follow.

light protocols. *Bulletin of the Seismological Society of America*, *110*(5), 2411-2422). Red-light thresholds have varied between 0.5-4.0 $M_L$, depending on the jurisdiction.

The regulator must first explicitly define what is an intolerable level of risk and set the red- and yellow-light thresholds that follow and then enforce safe and responsible development. Regulators should also ensure compliance via a mandatory system of industry reporting, verification, and audits. The responsibility of executing an operation within the TLP bounds lies first with the operator. Often, the operator is also responsible for detailing yellow-light mitigation strategies, since they are most knowledgeable about the particulars of their operation and the local subsurface.

While there are different ways to decide on TLP thresholds, a growing body of research is showing the benefits of grounding TLP designs in seismic risk principles. Under these principles, regulators should first explicitly define acceptable tolerances to risks of nuisance, damage to buildings, or human losses before operations begin. Then, seismic risk modelling can be used to define magnitude-based red-light thresholds (Schultz et al. (2021a). A risk-based approach for managing hydraulic fracturing–induced seismicity. *Science*, *372*(6541), 504-507), relying on information on ground shaking estimation, site amplification, hazard exposure, and asset vulnerability to appraise and model seismic hazards and risks (Bommer (2022). Earthquake hazard and risk analysis for natural and induced seismicity: towards objective assessments in the face of uncertainty. *Bulletin of Earthquake Engineering*, 20(6), 2825-3069). Crucial to this process is adequately capturing the potential for trailing seismicity: aftershock-like earthquakes that continue to occur after an operation has stopped (Verdon y Bommer (2021). Green, yellow, red, or out of the blue? An assessment of Traffic Light Schemes to mitigate the impact of hydraulic fracturing-induced seismicity. *Journal of Seismology*, *25*, 301-326; Schultz et al. (2022). Statistical bounds on how induced seismicity stops. *Scientific Reports*, *12*(1), 1184). To account for the effects of trailing seismicity, operators will need to stop before encountering an intolerable risk.

The choice of the yellow-light threshold can then be set based on the red-light threshold. The intention of the yellow-light threshold is to serve as a buffer to ultimately avoid encountering a red-light event. Typically, pre-existing TLPs for hydraulic fracturing have differences of 1.0-2.0 $M_L$ between red/yellow-light thresholds to account for potential jumps in magnitude (Schultz et al. (2021b). A strategy for choosing red-light thresholds to manage hydraulic fracturing induced seismicity in North America. *Journal of Geophysical Research: Solid Earth*, *126*(12), e2021JB022340). It is noteworthy that jumps in magnitude greater than 2.0 $M_L$ have been observed for hydraulic fracturing induced seismicity before (Schultz y Wang (2020), op. cit.).

The yellow-light threshold provides the opportunity for an operator to enact their mitigation strategies, to avoid encountering a red-light while still conducting injection activities. Typical mitigation strategies entail defining a new injection plan that reduces injection rates and/or pressures, ensuring that changes to the injection rate are made gradually rather than quickly, pausing operations, reorganizing the stage schedule, changing injection designs, allowing for flowback between stages, reducing total injection volume, skipping problematic stages, or ultimately pad/well abandonment (Canadian Association of Petroleum Producers (2019). Anomalous Induced Seismicity due to Hydraulic Fracturing, *Industry Shared Practices Report 2019-0026*, p. 18).

Unfortunately, there is little information on the relative efficacy of any mitigation strategies. Nonetheless, the implementation of some kind of mitigation strategy, with adequate supervision by the regulator, is far better than requiring no mitigation strategy at all. Ultimately, this deficiency highlights the need for open and transparent datasets – and the importance of interaction between industry, regulators, and academics to quantify the effectiveness of mitigation strategies to guide future best practices.

### 4.2. Effective earthquake monitoring for ensuring compliance

Effective earthquake monitoring is vital to ensuring safe and responsible operations, properly executing a TLP, reducing subsurface uncertainties, reporting to authorities, enforcing compliance, and building trust with impacted communities. Proper reporting and enforcement also need well-calibrated and verified catalogues of earthquakes that perform at least well enough to execute the TLP.

At a minimum, the regulator must have access to a 'backbone' monitoring network. Backbone monitoring provides coarse, basin-scale monitoring of earthquakes. This backbone monitoring network should be used to establish a baseline of natural seismicity before any hydraulic fracturing operations commence. After operations commence, this monitoring system serves the dual purpose of identifying new regions of induced seismicity and for the regulator to independently ensure industry compliance. Thus, this backbone monitoring system must be sensitive enough to detect all yellow-light events while also be precise enough to unambiguously attribute them to the correct source (Zhou et al. (2024), op. cit.). Accomplishing this attribution task requires data from hydraulic fracturing operations, including well locations and their subsurface trajectories, as well as locations of individual stages and corresponding timings of injection rates and volumes. All of this information should be openly accessible to the public.

Operators, meanwhile, are responsible for the deployment and maintenance of a 'local' seismic monitoring network, independent from the backbone. Data collected from the local network is used to create a real-time catalogue of earthquakes of sufficiently fine scale to inform the operator of how they must change their operations to stay within the definitions of the TLP. In many cases, this requires attribution of earthquakes to individual stages and the delineation of faults (CAPP (2019), op. cit.; Zhou et al. (2024), op. cit.). Because of these requirements, the local network typically requires greater sensitivity and resolution than the backbone network. Data from the local network should also be accessible to the public.

Broad participation from independent expert groups, interested stakeholders, and the impacted public help ensure the effectiveness of monitoring (Zhou et al. (2024), op. cit.). For example, independent expert groups like geological surveys, national monitoring agencies, or research institutions can provide input for guiding decision-making or risk-reduction strategies, while also providing new research insights. Transparency is key to fostering trust amongst different actors and with the impacted public, so that everyone can make informed decisions about ongoing operations and because many unanswered questions around the physical process and risk management of induced seismicity still linger. All monitoring networks and data should thus be shared openly using FAIR (Findability, Accessibility, Interoperability, and Reusability) principles (Wilkinson et al. (2016). The FAIR Guiding Principles for scientific data management and stewardship. *Scientific Data*, *3*(1), 1-9), requiring that data are permanently stored in a repository that can be easily found and then shared in an automated and readily accessible fashion (*i.e.*, without the need for human interaction or data requests).

To exemplify how split responsibilities and transparency worked in reality, we can look to Alberta, Canada, where the regulator and operators have followed these practices to both manage and learn from induced seismicity caused by hydraulic fracturing. The Alberta Geological Survey performs regional backbone seismic monitoring, as an expert group in support of the Alberta Energy Regulator. Alberta's provincial seismic network (RAVEN: https://doi.org/10.7914/SN/RV) spans the entire province, in order to identify new cases of induced seismicity and to independently ensure that operators are complying with regulations (Schultz y Stern (2015). The regional Alberta observatory for earthquake studies network (RAVEN). *CSEG Recorder*, *40*(8), 34-37; Schultz et al. (2015). Detection threshold and location resolution of the Alberta Geological Survey earthquake catalogue. *Seismological Research Letters*, *86*(2A), 385-397). All data from RAVEN is immediately made publicly available, via online access portals that are standard practice in seismology. For finer-scale monitoring, operators subscribe to data from 'local' networks managed by private vendors. As part of the regulator's commitment to transparency, all local seismological data required for regulatory compliance must be openly shared: immediately with the regulator and after one year with the public. To facilitate this, a seismological network (SCISMN: https://doi.org/10.7914/eeh3-2y80) was created to house the data; there, anyone can access this information (Schultz et al. (2020c). The Scientific Induced Seismicity Monitoring Network (SCISMN). *AER/AGS Open File Report 2019-09* (16 p). Edmonton, Canada: Alberta Geological Survey/Alberta Energy Regulator).

## 5. Evidence that hydraulic fracturing in the Neuquén Basin is causing earthquakes

The potential to use hydraulic fracturing to exploit oil and gas in the Vaca Muerta Formation was first recognized in 2010 by Repsol-YPF. By 2019, operations were injecting 10,000-100,000 $m^3$ of fluid per well. These injected volumes are comparable to those resulting in induced seismicity in other basins (Schultz et al. (2018). To date, there have been more than 4,000 unconventional wells stimulated in the Neuquén Basin.

Correspondingly, the Neuquén Basin has increasingly encountered earthquakes following the development of hydraulic fracturing. Similar to other basins, seismic monitoring coverage in the Neuquén Basin has historically been poor; monitoring improvements started in 2014 (Correa-Otto et al. (2018). Intraplate seismicity recorded by a local network in the Neuquén Basin, Argentina. *Journal of South American Earth Sciences*, *87*, 211-220; Correa-Otto (2021). Experimento sismológico en la cuenca neuquina, la región de mayor explotación de hidrocarburos por métodos no convencionales de la Argentina, *PhD Thesis*, Universidad Nacional de San Juan, p. 219; Correa-Otto et al. (2024). Seismotectonic and gravimetric analysis of the central Neuquén Basin. *Journal of South American Earth Sciences*, 105036). Geophysical studies have suggested that the events here are likely induced (Tamburini-Beliveau et al. (2022). Assessment of ground deformation and seismicity in two areas of intense hydrocarbon production in the Argentinian Patagonia. *Scientific Reports*, *12*(1), 19198). In

Sauzal Bonito, ground shaking from earthquakes has been regularly felt, and homes have sustained damage (Surma (2024). Fracking-induced earthquakes are menacing Argentina as regulators stand by. *Inside Climate News*). Consequently, in 2022, the province committed to the construction of 56 new basic earthquake-resistant homes (12 delivered to date) which were 50% funded by one of the operating companies (Se entregaron viviendas antisísmicas para vecinos de Sauzal Bonito, *LM Neuquen* (2024)).

A recent study of the Neuquén Basin used rigorous criteria established for the identification of induced seismicity to build on these past studies (Schultz et al. (2024), op. cit.), determining when and where earthquakes followed operations. This study concluded that hydraulic fracturing was most likely responsible for some of the earthquakes in the Neuquén Basin. This conclusion was supported by observing that earthquakes corresponded with the locations/timings of operations. Specifically, ~0.5% of operations were found to induce earthquakes. Despite the low association rate, induced earthquakes were as large as M4. Statistical testing indicated a >99.99% confidence that these earthquake-operation associations were not coincidental.

However, the study was unable to resolve some additional points: for example, some events were not well-associated with any specific operation. Whether these events are truly induced by hydraulic fracturing (but lacking an association due to incomplete data), induced by other human activities, or part of the natural background seismicity is unclear. Further conclusions were hampered by the authors' lack of access to additional data that is critical to resolving these questions. For the full details of this analysis, I direct readers to the original study (Schultz et al. (2024), op. cit.).

## 6. Recommendations for addressing gaps in current management of induced seismicity in the Neuquén Basin.

Given the evidence produced in the above study and experience with induced seismicity related to hydraulic fracturing in other basins, I recommend that the Neuquén government implement a TLP and a transparent monitoring system, as outlined by good practices in the sections above. Presently, there does not exist any regulatory framework for a TLP in the Neuquén Basin.

Current induced seismicity monitoring and management efforts in the Neuquén Basin stem from Official Bulletins published by the Government of Neuquén in 2021 (*Boletin Oficial*, Edición N° 3895, Provincia de Neuquén, Argentina; *Boletin Oficial*, Edición N° 3899, Provincia de Neuquén, Argentina Republic of Argentina). These bulletins describe the creation of a seismic network in the Neuquén Basin. The National Institute of Seismic Prevention (INPRES) is designated as the monitoring authority. The bulletins further describe the spatial extent of recording, criteria for expansion, public dissemination of information, and data sharing contributions from private companies. These Official Bulletins provide a legal mechanism for the creation of a monitoring network, but leave unaddressed gaps that are important for effective risk management, including establishing a risk-based TLP, clear delineation of monitoring standards, and requirements for transparent reporting, sharing, and publication of data.

Given this regulatory environment, which contrasts with previously outlined good practice requirements (§ 4), I provide the following recommendations to fill these gaps:

1. Implement a TLP in the Neuquén Basin
    a. Determine the regulatory authority responsible for enforcing the TLP.
    b. Provide clear thresholds (*i.e.*, yellow- and red-lights) for when operators need to change and halt operations.
    c. Red-light thresholds should be informed by risk-based principles; the regulator should explicitly define acceptable and unacceptable risk tolerances that the red-light threshold can be derived from.

    d. Yellow-light thresholds should be informed by best practices and account for 'magnitude jumps' (*i.e.*, sudden increases in the largest event).
    e. Define exclusion zones around critical infrastructure, such as dams.
    f. Require operators to develop and submit to the regulator their binding mitigations plans for when yellow- and red-light thresholds are reached.
    g. The regulator should assess the proposed mitigation plans to ensure they will meet the goals of the TLP, prior to the start of operations.
    h. The regulator should enforce operator compliance with the pre-approved mitigation plans, with penalties for noncompliance.

2. Create an effective monitoring network to detect seismic events
    a. The regulator should establish clear monitoring performance metrics, in terms of both detectability and spatial resolution.
    b. The monitoring system should be able to detect seismic events at or lower than the yellow-light threshold.
    c. Spatial resolution should be able to unambiguously attribute yellow- and red-light earthquakes to their source.
    d. The regulator should be responsible for ensuring these monitoring performance standards are met for the backbone network and then adjusting the existing network, as necessary.
    e. The purpose of the regulator’s monitoring network is to independently ensure that operators are complying with the TLP and to identify new regions of induced seismicity.
    f. Operators should be responsible for maintaining these monitoring performance standards for local networks during the following periods: prior to the initiation of injection, during injection, and for a reasonable period afterwards (*i.e.*, at least until seismicity returns to background rates).

   g. Mechanisms should be in place to independently verify that these monitoring performance metrics are being met, and to independently verify the attribution of an event as induced or natural.

3. Create transparent and open sharing mechanisms for all scientific data from the existing monitoring network
   a. Clear, publicly available, and easily accessible reporting mechanisms to publicize yellow- and red-light events.
   b. This includes all raw waveform data from seismometers, as well as derived products (*e.g.*, catalogues).
   c. Data sharing should follow FAIR (Findability, Accessibility, Interoperability, and Reusability) principles.
   d. Clear and simple mechanisms should be available for the impacted public to report nuisance, damage to buildings, or personal harm.

Following the publication of articles appraising the propensity of induced seismicity in the Neuquén Basin (Tamburini-Beliveau et al. (2022), op. cit.; Schultz et al. (2024), op. cit.), an independent group of experts based in Argentina proposed an updated framework for induced seismicity management (Observatorio de Sismicidad Inducida. Ley Provincial para la prevención de la sismicidad inducida por la práctica de la fracturación hidráulica en Neuquén: Una propuesta del Observatorio de Sismicidad Inducida (mayo 2025). This proposal provides a policy framework for prior seismic risk assessment, mandatory seismic monitoring, affected radius definitions, best operational practices, a TLP, and transparent communication. It also outlines the purpose of recommendations, their scope, and their guiding principles. Furthermore, this document also describes the enforcement authority, their role, and a regime for sanctions. Last, it offers the mechanisms for citizen participation. This document is detailed, comprehensive, and provides pertinent recommendations for the safe management of induced seismicity. Many of the proposed changes fill the currently unaddressed gaps for the management of induced seismicity in the Neuquén Basin.

Current monitoring efforts in the Neuquén Basin [*Boletin Oficial*, Ediciones N° 3895 y 3899] provide a start to the management of induced seismicity. The improvements proposed in this *Amicus Curiae* are my recommendations of still-needed changes – to ensure the safe and responsible development of hydraulic fracturing for oil and gas in Argentina.

## 7. PETITION

In light of the foregoing, I request that I be admitted as Amicus Curiae and that the scientific evidence presented herein be taken into consideration.

Provided accordingly,

LET JUSTICE PREVAIL