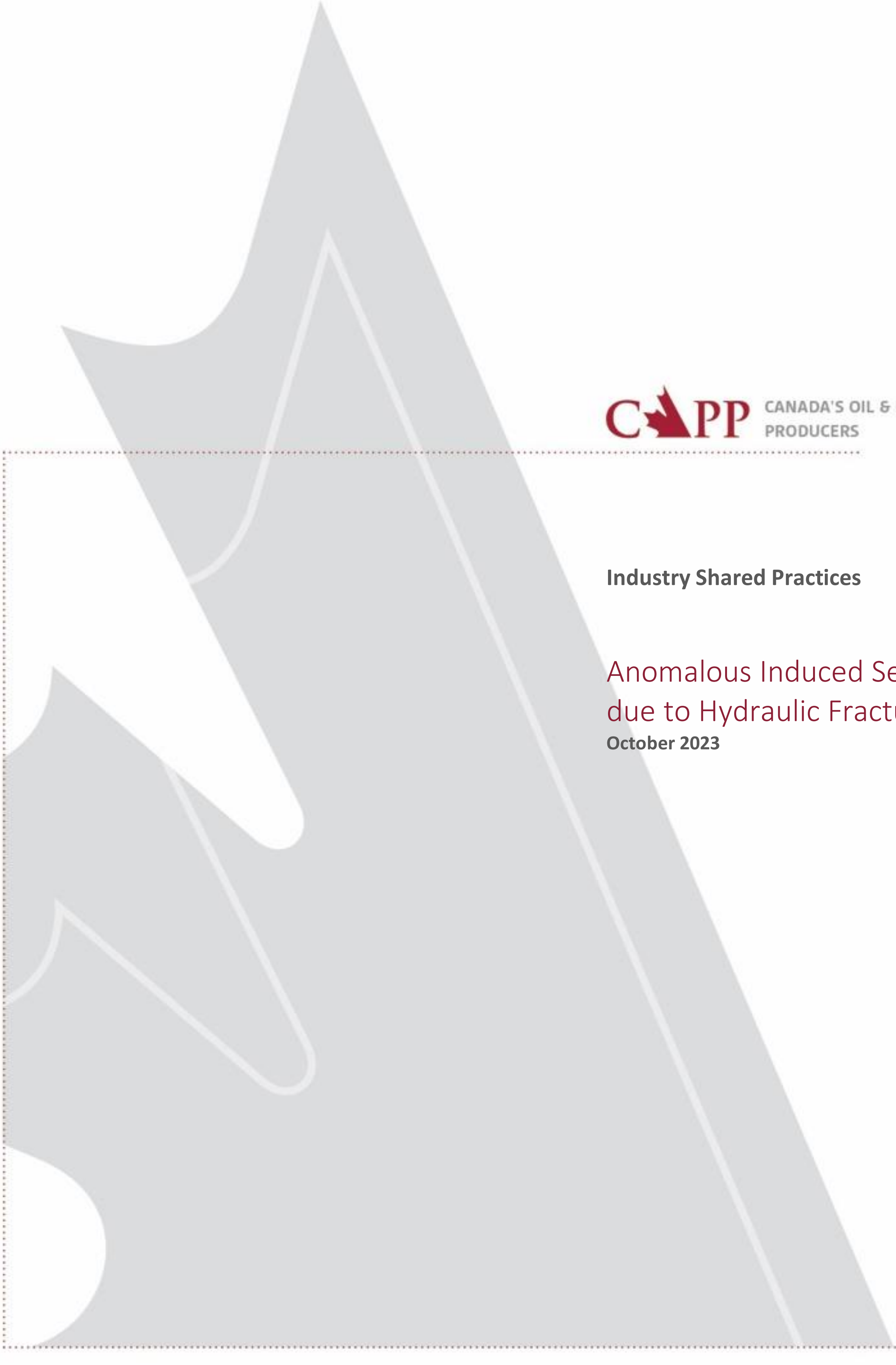

CAPP CANADA'S OIL & NATURAL GAS PRODUCERS

Industry Shared Practices

Anomalous Induced Seismicity due to Hydraulic Fracturing

October 2023

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1 Overview

CAPP and its member companies encourage approaches to managing potential seismic risk that are based on science, taking into account the local public exposure to felt events, operational factors, geological setting and historical baseline seismicity levels.

Seismicity is a normal part of hydraulic fracturing. Typically, seismic events in the Western Canadian Sedimentary Basin are deep, near the reservoir interval and small, too small to be felt at the surface. In rare cases, seismic events are large enough to be felt at the surface. Seismic events felt at the surface and linked to human activities are referred to as anomalous induced seismicity. This is the case in some areas in Alberta and northeast British Columbia where felt seismic events associated with hydraulic fracturing have been reported.

2 Definitions

Seismicity is a natural phenomenon and refers to energy released when rocks break and slip along a fault in the Earth. Seismic waves radiate out from the “source” and can cause ground shaking at surface. Seismicity resulting from human activities is called “induced” seismicity. Most induced seismic events are extremely small (micro earthquakes) and only measurable using very sensitive instruments (seismometers).

3 Purpose

Operators in CAPP’s Induced Seismicity Committee have shared their experiences and knowledge to produce this document. It describes current recommended practices for risk appraisal and risk mitigation approaches. Operators are encouraged to follow this guide voluntarily.

These shared practices reflect current knowledge, and take into account ongoing research to advance understanding and evolve mitigation strategies. This document is therefore a “shared” rather than “best” practice. Any recommendations herein are superseded by regulatory requirements in specific areas of operations.

Operators will need to adapt the shared practices to their specific situation. It is the responsibility of each operator to conduct their operations safely and in accordance with the circumstances of their operation.

4 Pre-Completions Assessment

While most hydraulic fracturing operations do not trigger anomalous induced seismicity, it has occurred under certain conditions. This section highlights factors that should be considered when designing and assessing hydraulic fracturing operations. As with all aspects of oil and natural gas operations, risks exist and should be evaluated to manage and mitigate the hazards. Like any other risk assessment, both likelihood of occurrence and impact of an event should be risked.

4.1 Subsurface Hazard Assessment and Seismicity Characterization

A comprehensive assessment to understand the potential for induced seismicity in areas where hydraulic fracturing is planned should include evaluating potential hazards related to the subsurface. Operators may choose to assess the following factors.

Historical seismicity: Understanding historical seismicity will identify whether there has been natural or induced seismicity near an area of operations. Previous seismic activity indicates whether the geologic system may be critically stressed. This may raise the likelihood of seismic activity from hydraulic fracturing, particularly if the historical seismicity is known to come from the depth near the planned operations. In addition, it is useful to identify the locations, spatial clustering/trends and focal mechanisms. These attributes provide insight into the seismogenic character of the area. The absence of seismic activity does not necessarily mean the geologic system is not critically stressed, as the dataset may suffer from sparse array monitoring that may not have detected the seismicity. Sources for historical data include Natural Resources Canada, Alberta Geological Survey, B.C. Energy Regulator and the U.S. Geological Survey. In most cases, these sources are complemented by the operators' private monitoring arrays that provide insight into past hydraulic-fracturing operations.

In situ stresses: The subsurface stress state is a key factor in assessing the likelihood of seismicity in a region. Local estimates of in situ stress magnitudes and azimuths (principal stresses and pore pressure) at the target depth should be made using available data. This may provide insight into how close the system is to failure for an optimally orientated fault and for any other fault orientations identified. Diagnostic fracture injection tests are a useful tool for estimating in situ stresses, and world stress mapping is publicly available.

Geological fault mapping: Induced seismic events typically occur along existing faults in the subsurface. Faults that provide a pathway between the stimulated formation and brittle underlying formations and basement are of particular concern due to their potential to generate larger seismic events. Faults and structural features should be mapped within the target formation, as well as above and below the area of planned hydraulic fracturing. It may also be useful to map faults at deeper levels (e.g., crystalline basement). Basement features may help to identify controlling faults that have been nearly healed at the reservoir depth but may still exert a local influence. Gravity and magnetic data can be useful in identifying some of these larger basement features that may be difficult to resolve on most industry surface seismic data. 2D and 3D seismic data are useful diagnostic tools for mapping fault features, and public fault layers can be used when seismic data are not readily available.

4.2 Surface Hazard Assessment

A field-level risk assessment helps operators to understand the impact of potential induced seismicity on infrastructure and people in an operating area. This could include identifying critical infrastructure such as dams, gas plants, power facilities and water towers, as well as nearby residents and population centres. Operators may consider using a ground motion prediction equation that relates earthquake magnitude to ground motion versus distance for a given region. This allows operators to set magnitude thresholds appropriate to the risk associated with the pad being hydraulically fractured, along with thresholds required by regulation. It also allows operators to set more stringent magnitude thresholds than those required by regulations.

5 Monitoring and Response During Hydraulic Fracturing

5.1 Monitoring and Early Detection

In areas of higher risk, it is important to establish an appropriate monitoring procedure based on the risk assessment for anomalous induced seismicity. Monitoring often uses a public national or regional seismic network for detecting and locating seismic events. In some cases, public monitoring is supplemented with a local network installed to have same-day or near real-time notification of seismic activity.

High-density monitoring involves a localized array of seismographs, also known as a dense array, that provides more detailed and accurate event location due to the tighter spacing than public arrays. These industry-owned arrays are used for monitoring before, during and after hydraulic-fracturing operations. The data can help map seismogenic complex fault networks, particularly those that may not be visible on seismic, and help implement mitigation strategies.

If a near real-time seismic monitoring program is scheduled for the well operations, the service provider should be instructed to immediately notify the operator’s onsite representative, consistent with their response protocol.

Monitoring for induced seismicity serves three main purposes:

- Allow operators to identify elevated levels of seismic activity or clustering before an anomalous event occurs so that proactive operational changes can be implemented to mitigate the risk.
- If an anomalous seismic event occurs, real-time monitoring allows the operator to implement reactive operational changes quickly.

- Improve mitigation measures and adjust hydraulic-fracture design for future operations.

5.2 Examples of Mitigation Strategies

Strategies to mitigate seismicity induced by hydraulic fracturing depend on the site-specific geology and individual operational factors. It is important to note that there is no single effective mitigation strategy – what may prove effective for one operator in a particular area may not be as effective in another operational setting and area.

Proactive strategies involve planning and geoscientific assessment prior to hydraulic-fracturing operations, which can be effective in avoiding induced seismicity. The purpose of proactive strategies is to avoid induced seismicity or to try to keep seismicity below a certain level. Reactive strategies can be used when seismicity is induced during hydraulic-fracturing operations. The purpose of proactive strategies is to prevent induced seismicity from escalating.

5.2.1 Proactive Mitigation Strategies

Well location and orientation: Locating a well a moderate distance away from a high-risk fault has, in some cases, reduced the number of induced seismic events. Well orientation relative to a high-risk fault can also be a factor. For example, orienting a well perpendicular to a high-risk fault where this is possible has proven an effective mitigation strategy by reducing the number of stages that might activate the fault. In extreme cases, wells crossing a risked fault may be drilled short to avoid the hazard.

Completion scheme selection: Common completion schemes are simultaneous fracking or zipper fracking, also known as sequential fracking. While simultaneous hydraulic fracturing creates efficiency gains, zipper fracking or even single well operations may prove more effective in mitigating induced seismicity when hydraulically fracturing near a high-risk fault by allowing pressure to dissipate between stages. Fracturing a well next to a high-risk fault first may help subdue further activation with trailing wells or creating a well separation between two actively fracked wells can also help mitigate induced seismic activity in specific cases.

Avoiding concurrent operations: Communication among operators and scheduling adjustment to avoid concurrent completion in close proximity, especially for high-risk operations. Where concurrent operations cannot be avoided, establishing a communication protocol between operators before operations start has proven useful.

5.2.2 Reactive Mitigation Strategies

Reduced rate, pressure and volumes: During hydraulic fracturing, direct operational controls for mitigating induced seismicity primarily concern pump rates, volume and pressure. If seismicity is detected during operations that requires initiating a response plan (yellow light event under the various regional traffic-light protocols), temporarily reducing one or several of these parameters has proven effective in some cases to avoid induced seismic events from escalating in number or magnitude of events.

Increase distance between subsequent stages: This allows for hydraulic-fracture energy to be dispersed along a larger surface area of the lateral, decreasing the intensity of impacts to adjacent faulting.

Stage pausing and skipping: These two options can be considered as part of a staggered mitigation strategy in cases of persistent induced seismicity. Stage pausing (also called relaxation), followed by fracking in intervals, should be a first step in cases of persistent elevated induced seismicity. Operational pauses can also be implemented by designing the well completions with lower-risk wells available to fracture after anomalous seismicity. If elevated seismicity persists, the operator should consider skipping stages to avoid further escalation of induced seismicity. Skipping stages is most effective in conjunction with a high-density array that can provide accurate seismic-event locations. This allows operators to identify if skipping stages would move the operation closer to or farther from an active seismic cluster.

Operation suspension: This is a method of last resort in cases where induced seismicity has reached red-light magnitudes as prescribed in regional traffic-light protocols. Operations are only allowed to resume with permission from the regulator.

The examples in this section reflect operator experiences in specific geological settings and under specific operational circumstances. Open communications with the regulator and among operators to share experiential learnings is critical. It is important to emphasize that different mitigation options are specific to individual operational circumstances and real-time monitoring – no single mitigation option applies to all circumstances.

5.3 Thresholds and Triggers

Regulators in B.C. and Alberta use magnitude thresholds to manage induced seismicity and help prevent magnitudes from escalating. These regulated magnitude thresholds are referred to as traffic-light protocols. They are prescribed in seismic monitoring and mitigation area special project orders (B.C.) or subsurface orders (Alberta), which apply to specified regions deemed moderate to high-risk areas based on population and infrastructure.

The table below provides an example operational response system for seismicity detected in the vicinity of hydraulic fracturing well operations. It is based on the AER's Subsurface Order No. 2.

Response Level	Observed Seismicity[1]	Operational Response
Level A	Local conditions may vary, but typically seismicity would be less than magnitude 2.	• Continue with regular operations and monitoring. • Track potential trends in the location and magnitude of events. • Consider initiating yellow-light mitigations if trends indicate the potential for higher risk.
Level B	Seismic events between magnitudes 2 and 4 are observed, or there is a trend toward events of larger magnitude.	• A response plan on-site prior to beginning operations. • Meet with engineers and subsurface geological and geophysical staff to evaluate next steps. Urgency on meeting with the team is subject to the level of seismicity observed. • Consider operational changes to mitigate further seismicity.
Level C	Seismic events greater than magnitude 4 are observed, or ground motion is felt at surface.	• Execute a controlled well shutdown and suspend further operations until an appropriate course of action is determined and approved by the operating company decision maker and the regulator as required.

The rationale for the specific threshold is as follows: events below magnitude 2 are too small to be felt at surface; events between magnitudes 2 and 4 can be felt at surface; and events larger than magnitude 4 can be felt at large distances and could cause surface damage.

6 Communication and Stakeholder Engagement

Maintaining effective communication with operating-area stakeholders, communities and residents, regulators and other operators, is prudent practice of responsible operations. This includes transparently sharing information about potential risk, how risk is managed and addressing any concerns or questions regarding induced seismicity.

7 Continuous Improvement

Over time, sharing knowledge with industry peers, service companies and research consortia helps to improve understanding of induced seismicity and how to manage it. It is part of how industry continuously improves.

Operators new to an area are encouraged to speak with nearby operators who have experience with and knowledge of hydraulic fracturing and induced seismicity.

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[1] Seismicity levels in this table are provided as an example. Traffic light protocols in B.C. and Alberta have shutdown magnitudes depending on the specifics of the given area. Regulations are also in place for some hydroelectric dams and gas storage facilities. If regulations are not in place, operators are encouraged to consult with regulators and other operators regarding appropriate magnitude thresholds for a given region. Operators should set response levels based on local operational conditions, regulatory requirements and internal protocols.

Operators are encouraged to share experiences and provide information about practices.

CAPP members are conducting and supporting several research efforts to improve how risk from anomalous seismicity is identified and mitigated. Work is undertaken through research organizations and academic/industry consortia. CAPP members also contribute data and technical knowledge to support academic research. It is important to understand and identify knowledge gaps, and show regulators how operators are supporting consortium research on anomalous induced seismicity.

Lastly, it is important to regularly review and update risk management frameworks based on new scientific research, technological advancements and operational experiences. This ensures the framework remains robust and reflective of the latest understanding of induced seismicity.