CANADA'S OIL & NATURAL GAS PRODUCERS

**Industry Shared Practices**

# Anomalous Induced Seismicity due to Fluid Disposal

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The Canadian Association of Petroleum Producers (CAPP) is a non-partisan, research-based industry association that advocates on behalf of our member companies, large and small, that explore for, develop, and produce oil and natural gas throughout Canada. Our associate members provide a wide range of services that support the upstream industry.

CAPP's members produce nearly three quarters of Canada's annual oil and natural gas production and provides more than 400,000 jobs in nearly all regions of Canada. In 2022 across Canada, our industry contributed $111 billion to the Gross Domestic Product (GDP) and paid $45 billion in taxes and royalty payments.

CAPP is a solution-oriented partner and works with all levels of government to ensure a thriving Canadian oil and natural gas industry. We strive to meet the need for safe, reliable, affordable, and responsibly produced energy, for Canada and the world. We are proud to amplify industry efforts to reduce GHG emissions from oil and gas production and support Indigenous participation and prosperity.



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# 1 Overview

CAPP and its member companies encourage approaches to managing potential induced 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. We also support the consideration of applicable engineering codes and standards related to seismic hazards and structural integrity.

Evidence suggests that any induced seismicity caused to date by fluid disposal in the Western Canadian Sedimentary Basin (WCSB), while occasionally felt at surface, is rare, generally deep, located in or near the disposal reservoir interval and poses no risk to health, safety or the environment.

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 incidents of felt seismic events associated with fluid disposal have been reported.

# 2 Definitions

Seismicity is a common natural phenomenon and refers to earthquakes associated with energy released when rocks slip along a fault in the Earth. Seismicity resulting from human activities is called induced seismicity. Alterations to the environment that create or alter stresses in deep rock formations, such as dams, mining, disposal, hydraulic fracturing and geothermal, have the potential to induce seismicity. Most seismic events induced by fluid disposal are extremely small (micro earthquakes) and only measurable using very sensitive instruments (seismometers).

# 3 Purpose and scope

Operators in CAPP's Induced Seismicity Committee have shared their experiences and knowledge to produce this document. It describes current practices for induced seismicity risk appraisal related to fluid disposal 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 improve understanding of induced seismicity and evolve mitigation strategies. This document is therefore described as a "shared" rather than "best" practice. Any recommendations herein are superseded by regulatory requirements that exist in specific areas of operations.

The scope of this document is based on operator experience in the WCSB, where fluid disposal is typically performed into geologic formations capable of accepting large quantities of fluids (such as reefs). While deep, these formations are typically laterally and vertically confined and are located hundreds of meters or more above basement rocks. The geologic situation in the WCSB therefore differs to some extent from U.S. states such as Oklahoma, where disposal into laterally extensive formations immediately above basement rocks leads to seismicity that can occur far from the disposal well. Also, while this document broadly applies to seismicity from any disposal operations, it does not specifically cover seismicity from disposal of $CO_2$ into deep saline aquifers, geothermal operations, hazardous waste disposal or acid gas disposal.

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

# 4 Pre-completions assessment

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

## 4.1 Subsurface hazard assessment and seismcity characterization

When short-term human activity, such as fluid disposal, impacts a geological system, the ability to predict the number and magnitude of seismic events is challenged. However, there are factors that can be considered when assessing the risk of induced seismicity caused by fluid disposal, as identified in the following subsections.

**Historical seismicity:** Understanding historical seismicity within 20 km will help identify whether there has been natural or induced seismic activity near an area of operations. Previous seismic activity indicates the geologic system may be critically stressed, meaning a structure is optimally oriented in the geologic stress conditions and susceptible to slip from small changes in subsurface pressure. This may raise the likelihood of seismic activity resulting from fluid disposal, particularly if the historical seismicity is known to come from the depth near that of planned disposal operations. It is also useful to identify the locations, spatial clustering/trends, focal mechanisms and the maximum magnitude of events that occurred. These attributes provide further insight into the seismogenic character of the area. The absence of seismic activity does not necessarily mean the geologic system is not critically stressed, since the pore pressure may not yet have been sufficiently raised to the point of initiating slip, or the seismicity dataset may suffer from sparse array monitoring and may not have detected the seismicity. If an area has not been previously targeted for development, fluid disposal operations may induce events for the first time as natural seismicity often occurs on larger time scales that may not yet have been captured during any monitoring. Sources for historical data include Natural Resources Canada, Alberta Geological Survey, BC Energy Regulator and the U.S. Geological Survey.

**Geological fault mapping:** Induced seismic events typically occur along existing faults in the subsurface. Faults and structural features should be mapped within the target formation, as well as above and below the area of planned fluid disposal. 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. Regional gravity and magnetic data can be useful in identifying some of these larger-scale 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. However, while identifying faults near the area of fluid disposal operations is good practice, industry experience on the use of fault mapping in B.C. and Alberta has been mixed. Seismicity with anomalous magnitudes tends to appear or cluster in zones. These zones may not correlate to areas of mapped faults, suggesting a fault may exist but is not easily discernable or below the resolution of geophysical data.

**In situ stresses:** The subsurface stress state is a key factor in assessing the likelihood of seismicity in a region. Activation of existing faults only occurs when optimally oriented and under specific stress states of the geological system. Local estimates of the in-situ stress magnitudes and azimuths (principal stresses and pore pressure) at the target level 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. Also, disposal and injection fracture gradient maps for the formation fluids are being disposed into can be found in various data services (for B.C., these can be found online from the BC Energy Regulator).

### 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, pipelines, 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 a disposal operation, along with thresholds required by regulation. It also allows operators to set more stringent magnitude thresholds than those required by regulation.

## 5 Monitoring and response during fluid disposal operations

### 5.1 Monitoring and early detection

In areas of higher risk, it is important to establish an appropriate seismic monitoring plan based on the risk assessment for anomalous induced seismicity. Options for monitoring include publicly available regional data and a spectrum of local private monitoring solutions. Prior to fluid disposal operations, the risk assessment should be incorporated into a documented monitoring and response plan. Monitoring should also consider timely access to relevant injection data for analysis with the seismicity data. Since seismicity can result from the combined impact of multiple injections contributing to pressure increases, injection data should be integrated from multiple potential operators. It is also important that roles and responsibilities are defined within the monitoring team and communication exists among operators.

Monitoring for induced seismicity serves three main purposes:

- Identify elevated levels of seismic activity or clustering before an anomalous event occurs so that proactive operational adjustments can be implemented to mitigate the risk of damage.
- Allows the operator to implement reactive operational changes quickly if an anomalous seismic event occurs.
- Learn more about the occurrence and behavior of anomalous induced seismicity to improve mitigation measures.

Monitoring will often use a national seismic network for detection and location of seismic events. National networks can be supplemented with a local private network installed to have same-day or near real-time notification of small magnitude, background seismic activity. Several applications are available that provide real-time notifications of events that can be used to monitor public arrays.

If an event is detected as part of a real-time seismic monitoring program within an agreed area surrounding the disposal well, the service provider should contact the agreed representative, consistent with their response protocol.

For fluid disposal wells in areas where seismicity has been demonstrated and the operator chooses to monitor, it is recommended to monitor prior to and during disposal operations, and for a period thereafter.

## 5.2 Examples of mitigation strategies

Mitigation strategies are implemented to reduce potential impacts prior to anomalous seismicity (such as pre-spud disposal well planning) and during injection. The purpose of proactive strategies is to avoid induced seismicity or try to keep seismicity below a certain level. Reactive strategies can be used when anomalous seismicity is detected during disposal operations to prevent induced seismicity from escalating. Response strategies to anomalous seismicity are somewhat limited when compared to operational-change options for hydraulic-fracturing induced seismicity.

Strategies to mitigate seismicity induced by fluid disposal depend on the site-specific geology, field operations and regional operating 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.

### 5.2.1 Proactive mitigation strategies

**Well location and disposal targeting:** The simplest pre-construction mitigation is to locate a disposal well a moderate distance from a high-risk fault to avoid a significant increase in pressure at the fault. Also, areas where faults intersect or branch have been shown to be more prone to induced seismicity, making it challenging to identify an optimal stand-off distance. Locating a disposal well accordingly can, in some instances, reduce the occurrence of seismic events. Similarly, the depth of disposal relative to potential seismogenic faults can be used to avoid pressurizing deep basement-rooted faults in cases where shallower injection zones are available that might provide stratigraphically isolated disposal.

**Communication protocols:** Open internal communication across departments within an operator company is required. External communication among operators in a particular area has also proven effective. This can include regular meetings to review seismicity and injection data, and developing a common response plan for that area. Also, scheduling adjustments to avoid concurrent operations in close proximity by establishing a communications protocol before disposal operations start has proven useful. Initiating communication protocols prior to the occurrence of seismicity is effective to establish lines of communications and ensure relevant data sources are identified early.

### 5.2.2 Reactive mitigation strategies

**Reduced rate, pressure and volumes:** During fluid disposal, direct operational controls for mitigating induced seismicity primarily concern pump rates, volume and pressure. Injection surface pressure can be impacted by both instantaneous injection and total injection volume into a particular well, such that reducing the disposal rate will also lower surface and reservoir pressures. For example, subsurface formation pressure changes can be controlled by reducing injection rates. In all cases, injection pressure should be kept below fracture gradients to avoid unintentional hydraulic fracturing. If seismicity is detected during fluid disposal 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.

**Depth of disposal:** Experience has shown that in some geological settings, the depth of the formation into which fluids are injected has proven a control factor. In some cases, disposal into a shallow formation with hydraulic isolation from seismogenic faults has resulted in less frequent and lower-magnitude seismic events. In such cases, and where possible, operators are encouraged to adjust operations accordingly.

**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. When disposal is halted, however, injection rates should be slowly reduced to avoid water-hammer effects associated with a rapid shut-in.

The examples in this section reflect operator experiences in specific geological settings and under specific operational circumstances. Open communication 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.

# 6 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.

The table below provides an example operational response system for seismicity detected in the vicinity of fluid disposal well operations. Operators may modify their thresholds and metrics (e.g., ground motion) to suit local operations. Note that traffic-light systems often use a two-level yellow-light, with a lower level resulting in an early warning of escalating seismicity and a higher level triggering operational changes.

| 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.<br>• Track potential trends in the location and magnitude of events.<br>• Consider initiating yellow-light mitigations if trends indicate the potential for higher risk. |

[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.

| Response Level | Observed Seismicity[1] | Operational Response |
|---|---|---|
| **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.<br>• 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.<br>• 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 typically too small to be felt at surface; events between magnitudes 2 and 4 can potentially be felt at surface; and events larger than magnitude 4 can be felt at large distances and could potentially cause surface damage.

# 7 External communication and stakeholder engagement

Maintaining effective external 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.

# 8 Continuous improvement

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 fluid disposal and induced seismicity. 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. Ground-motion studies that correlate seismicity magnitude with surface effects are an example of research with a practical application to risk management. 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.