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Industry-funded Monitoring of Induced Earthquakes

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Abstract

Human activity can trigger earthquakes to strike sooner than they may naturally occur. Some well known examples of this phenomenon are reservoir-triggered seismicity and “fracking” (hydraulic fracturing).

A recent example of earthquakes due to fracking is in Texas where the success of new drilling and fracturing techniques increased the need for saltwater disposal. The frequency and magnitude of basement-depth earthquakes accelerated in 2019 when deep injection was increasing, culminating with two magnitude 5.4 earthquakes in late 2022.

The Texas oil and gas regulator introduced an incentive program to allow individual operators to maintain higher daily injection volumes by installing and operating seismic stations, and by developing an earthquake response plan for their area of interest. The permit conditions also required that live data from the stations was fed to the University-operated public seismic network, TexNet.

This cooperative industry-funded seismic monitoring approach is how the Seismology Research Centre (SRC) established its network since the late 1970s. Individual water authorities, who could not afford to fund a network to monitor their areas of interest, were brought together and contribute proportionately to the operation of a broader network. This local-scale monitoring and data management workflow developed by the SRC is now a package that has been adopted by several privately operated seismic arrays in Texas.

An industry-funded seismic monitoring model would require government policy and regulation, but could be used in Australia to incentivise those operators to consider earthquakes in their emergency plans, and to make more data available for research into the trigger mechanisms of induced earthquakes.

Keywords: induced, earthquake, monitoring, fracking, reservoirs, research, regulation

Induced Seismicity

Earthquake location has a significant influence on how shaking can impact population and infrastructure. Earthquake activity forms the landscape and can create habitable environments, as well as bring resources to the surface, attracting population and industry. Humans then use these natural features to enhance our way of life, for example building dams in the valleys created by uplift and erosion, or mining minerals that were trapped by millions of years of geological formation and deformation.

Some of these activities that humans undertake can trigger earthquakes to occur on an accelerated time schedule due to changes in stress in the crust. By their nature these human-related events are more likely to impact the structures and the populations the activities serve. A few examples are earthquakes triggered by: the creation of dams & reservoirs; mining through the mechanical or explosive removal of material; and fluid injection for oil and gas recovery, often referred to as “fracking” due to the practice of using fluid to fracture underground rocks.

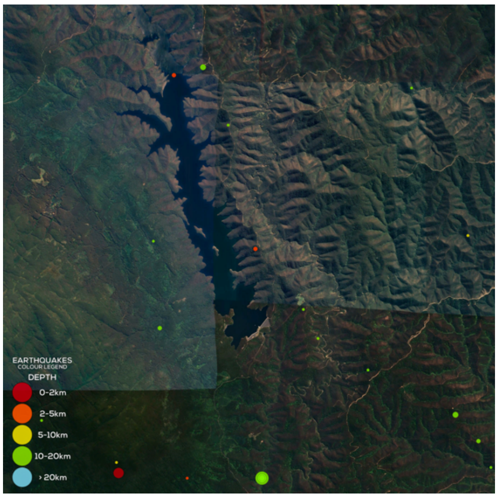
1 Reservoir Triggered Seismicity

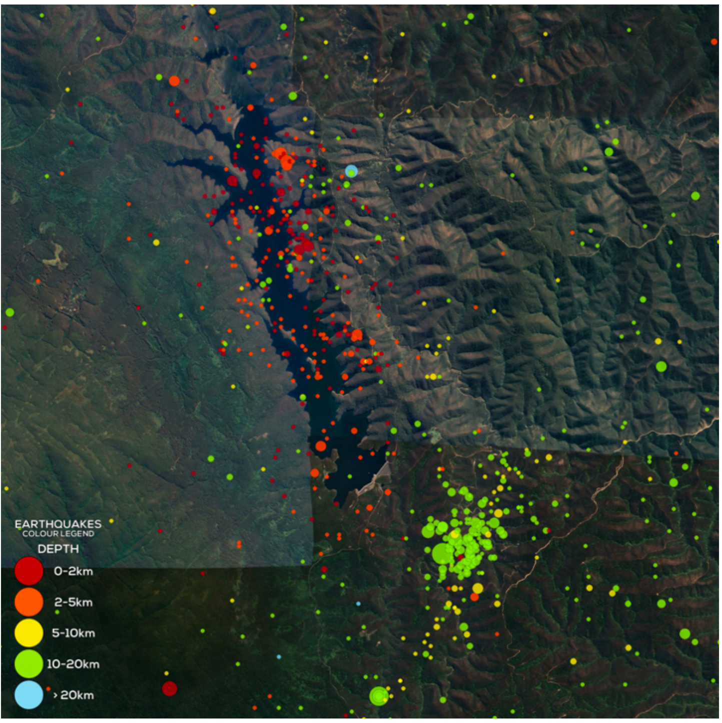
There have been a number of documented cases of reservoir-triggered seismicity in Australia, the more well-known recent examples being Eucumbene, Warragamba, and Talbingo reservoirs in New South Wales in the 1950s, 60s and 70s (Gibson, 1997) and Thomson Reservoir in Victoria in the 1980s (Allen, 2000). The construction and filling of a dam creates a new large mass of static water, increases overburden pressure, and allowing the water the permeate more broadly into crust than it naturally would, increasing the pore pressure and lubricating faults which can then slip and cause earthquakes.

In several of the above-mentioned cases, the magnitude of the largest earthquakes in the triggered sequences were in the range of ML 5.0 to 5.5, occurring at a typical depth (for southeast Australia) of 10-20km below the surface. Reservoir-triggered seismic activity typically does not begin for a few years after impoundment of the reservoir begins, but can last for decades before seismicity returns to pre-impoundment levels.

Figure 1: Earthquakes prior to reservoir impoundment (below) and since impounded in 1983 (right).

Note: colour indicates earthquake depth





2 Mining & Blasting

Removing material from a section of earth will change the stress field of a region, which can trigger faults to slip from the removal of pressure and friction, or from blast vibrations changing how well a fault plane is coupled until it slips. Recent earthquakes triggered by blasting have been documented in Victoria (Fosterville Gold Mine, 2023), acknowledging induced earthquakes as part of mining operations.

An underground long wall coal mine near Appin NSW (South32 Illawarra Metallurgical Coal, 2023) has been monitoring seismic activity in their operational area to better understand the relationship between mining and earthquake activity, engaging seismologists to analyse and report on significant events. Seismic monitoring was a conditional requirement for the approval of ongoing mining operations. This area has also been monitored for earthquakes related to coal seam gas activity (Glanville 2020).

As is often the case, these mines are located near populated areas, so the impacts of vibrations from blasting, subsidence, and induced earthquakes can affect structures and the public. The largest earthquakes near these mining operations have been in the ML 3.5 to 4.5 range.

3 Fluid Injection & Hydraulic Fracturing

There are several processes in oil and gas production that use the injection of fluid into the ground (USGS, web). The first is usually the “fracking” where fluid is injection into rocks to open up paths to allow the flow of trapped oil & gas to a production well. This injection of pressure creates fractures, and if this occurs across a fault it can lubricate that fault plane and result in a slip event.

Related to this process is production injection, where fluid is injected into a well at one end of the fractured field to push oil/gas towards the production well. This constant pressure can also induce earthquakes on nearby faults if stress fields are being significantly altered.

The most common oil production process that can trigger earthquakes on otherwise inactive faults is saltwater disposal, where the waste fluid recovered during oil production is reinjected into the ground, usually at a nearby well that leads to a naturally sealed underground storage reservoir. The change in the stress field of these storage areas is significant compared to its natural state, and has resulted in frequent and large earthquakes in areas with historically little to no seismic activity.

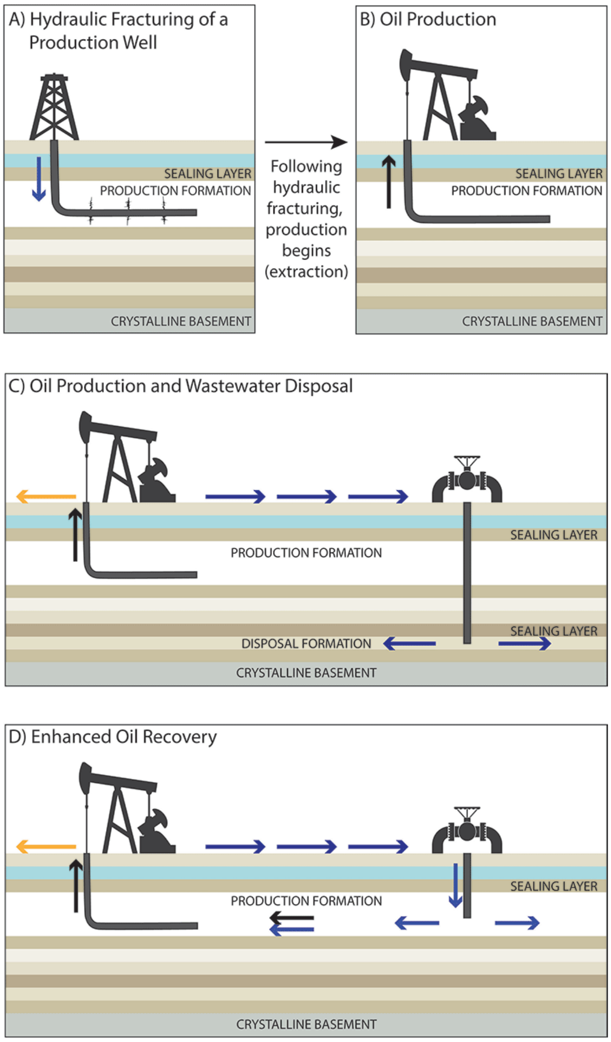


Figure 2: Oil production using fluid injection and fracturing. Source: USGS public domain

As Australian states and territories start to lift moratoriums on hydraulic stimulation (Shamsalsadati, 2021), policies need to be defined to ensure the monitoring of induced seismicity from such activities is implemented as per recommendations (IESC, 2014).

There are a number of well documented cases of induced earthquake activity in the USA from oil and gas related activities. The figures below show the change in activity rates in the last two 10-year windows, with the cluster of events in the top right of the images showing earthquakes in Oklahoma, and the activity in western Texas in the Permian Basin (Savvaidis, 2020).

The largest earthquake related to a fracking process was a magnitude 4.0 event in Texas in 2018 (USGS, web), but larger and more frequent events are caused by the wastewater injection process. The largest earthquake from wastewater injection to date was in 2011 in Oklahoma, a magnitude 5.7 earthquake that buckled a national highway and destroyed 14 homes in the nearby town of Prague (Keranen, 2013).

After deep saltwater injection operations increased in the Permian Basin from 2019, so did the rate of induced earthquakes. In 2022 alone, over 8000 earthquakes were detected in the Permian Basin production fields, including two of magnitude 5.4 in late 2022.

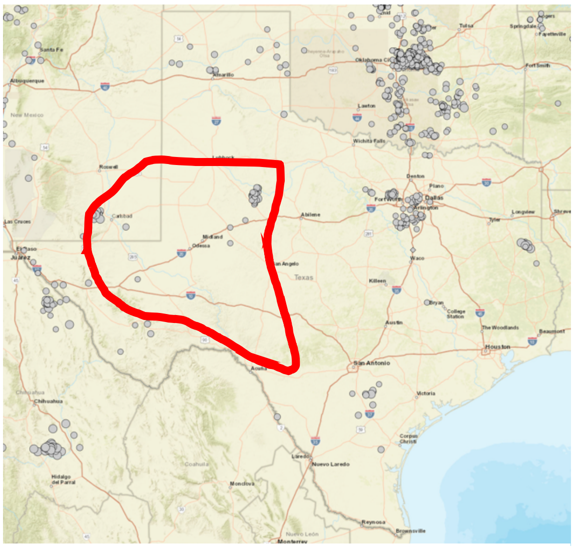


Figure 4: Magnitude 2+ earthquakes in the Permian Basin from 2004 to 2013

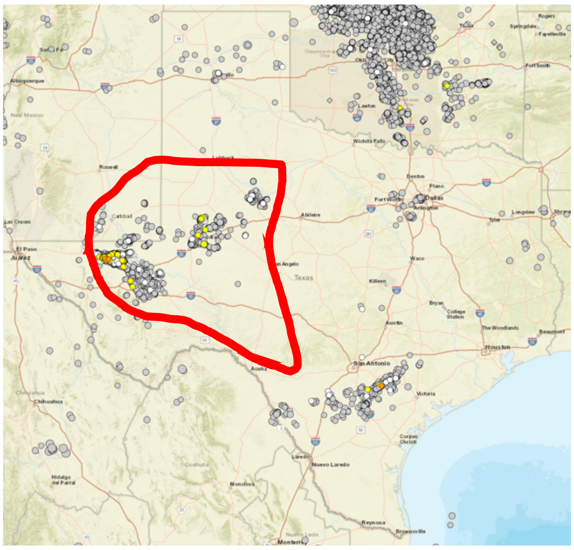


Figure 3: Magnitude 2+ earthquakes in the Permian Basin from 2014 to 2023

4 Regulations

The State of Texas established funding for TexNet in 2015 to improve the state's seismic network, growing from 18 stations to nearly 150 stations by mid-2020, increasing resolution and accuracy to help characterise seismic activity near wells in the vicinity of faults.

The Texas oil and gas regulator introduced an incentive program to allow operators to maintain higher daily injection volumes by installing seismic stations to feed additional data to TexNet, and by developing an earthquake response plan for their area of interest.

Individual production facilities often do not have the in-house expertise and resources to install and operate the seismic equipment required by the Regulator, so private seismic network operators are installing and operating instruments on their behalf. Each operator can have multiple clients and are effectively creating a cooperative industry-funded seismic network, optimising instrument coverage. Operators provide major event alerts and daily seismic activity reports to the facilities, and to manage data transmission to TexNet.

5 Parallels in Australia

This is a similar cooperative model that led to the current the earthquake monitoring network operated by the Seismology Research Centre (SRC) observatory, which was established in the late 1970s. It started by monitoring seismic activity in the area around the planned Thomson Reservoir and Dam, a program initiated by what is now Melbourne Water, who engaged the SRC to perform baseline seismicity monitoring of the area. Monitoring continued after the construction of the dam to see if the reservoir-triggered seismicity phenomenon occurred in the area as water began to be impounded.

Over the years the services expanded to include provision of near real-time earthquake alerts and routine activity reports, and then expanded to include other water authorities and catchment areas. The individual water authorities, who could not afford to fund a network to monitor their areas of interest, were brought together and contribute proportionately to the operation of a broader network. The data was centrally processed by SRC, and the authorities provided with bespoke information in near real-time for emergency response.

The SRC's local seismic monitoring workflow and data management system lent itself perfectly for operators in Texas to establish and manage private seismic arrays to determine earthquake locations and magnitudes. The data from these operator-managed networks is also streamed to TexNet's public network in real time as a permit condition of the regulator's incentive program. Between 40 and 50 stations have been added to TexNet through this program, providing greatly increased capabilities for seismic event management and emergency response.

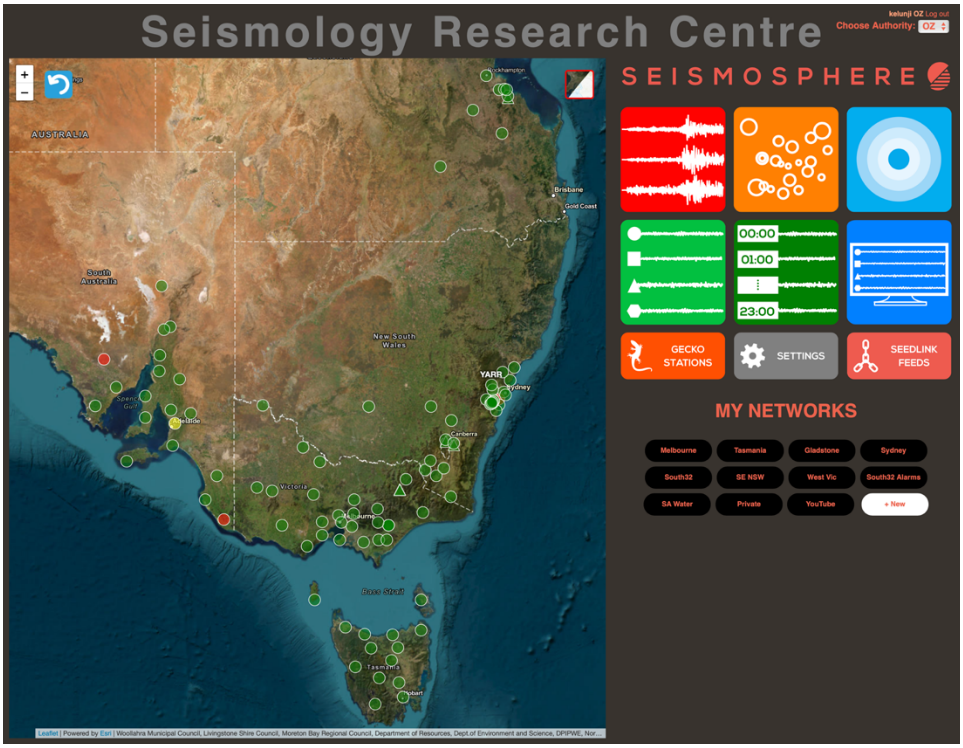


Figure 5: The SRC's earthquake monitoring network, made possible by coordinating and collaborating with a majority of water authorities in southeast Australia

Other authorities in Australia have established seismic monitoring networks specifically for understanding the natural seismicity prior to potential resource recovery operations. One example a coloration between the Government of Western Australia, Geoscience Australia, and CSIRO (DMIRS, 2022) installed stations in the Canning Basin in northwest Western Australia.

6 User Pays

Seismic monitoring of particular regions cannot always be funded by government agencies or university research programs. If the establishment and operation of a monitoring network can be funded by private organisations that can also benefit from the data in the short term (to regulate their own activities, or for emergency response), then long term benefits can be reaped by research organisations if that data is properly managed.

It is rare that private industry would voluntarily choose to undertake seismic monitoring in Australia, so the participating organisations in our water industry that have contributed to earthquake research resources should be commended for their recognition of earthquakes as a real hazard, and for their long-term vision and commitment.

Private organisations that benefit from using the earth's resources and whose operations can potentially induce earthquakes are encouraged to fund seismic data collection, but industry "recommendations" are often viewed as an optional cost and overlooked, so the only way to ensure seismicity is monitored is by creating policies and enforceable regulations. These need to be issued by the bodies that approve the use of the land, and like in Texas, the raw data must be made available to research organisations for independent assessment and analysis. AusPASS is an established data repository and would be an ideal long-term archive for seismic data collected from around the country.

7 Ground Motion

Another example of distributing the cost of seismic data collection to private industry is building monitoring. In several countries and regions, it is required by law that buildings of a certain classification have at least one strong motion sensor to record ground motion from earthquakes. Taller buildings can require at least three instruments to monitor motion of the middle and top floors during an earthquake.

Some places where these regulations exist, such as California and the Philippines, have high levels of seismicity. Other places may have lower seismicity, like Singapore, but have densely populated cities with many high-rise structures that may be exposed to large regional earthquakes that generate low frequency motion that can affect tall buildings.

The main point of legislated building monitoring is to provide earthquake alarms to assess whether occupant evacuation is necessary, and to triage potentially hundreds of structures. The California Building Code (2022) states:

> *"After every significant seismic event, where the ground shaking acceleration at the site exceeds 0.3g or the acceleration at any monitored building level exceeds 0.8g as measured by the seismic monitoring system in the building, the owner shall retain a structural engineer to make an inspection of the structural system."*

Monitoring systems, particularly those streaming data to a remote monitoring system, can easily report peak ground motion and peak building motion, allowing a building to be evacuated or reoccupied without the need for visual inspection. This can be invaluable following a large earthquake that affects hundreds of buildings within a city.

A side benefit of these instruments is a massive data set showing ground motion attenuation across a city or country at a resolution, an exercise that would otherwise be cost prohibitive. This only happens with there are enforced regulations, a distributed cost model, and the requirement to supply data on demand to research organisations.

Policies and Engagement

Australia needs policies for mandatory seismic data collection for resource-based industries, and for the monitoring of critical structures that may be affected by earthquakes. These policies should be tailored for the country – the Philippines guidelines (Singson, 2015) or the Californian standards on which they are based may not be appropriate for Australia, but local guidelines should be developed and adopted nonetheless.

Research cannot be done without data. Often this is raised as a need after a major event occurs, but interest dies off quickly and the cycle starts again. The fact that Australia doesn't have earthquakes as often means that it is even more important that these systems are established and operational to catch these rare events.

Passing extra costs onto private industry is rarely met with enthusiasm, but rather than this being an extra box to begrudgingly tick to comply to carry out their business activities, these industries need to be encouraged to remain engaged to understand how the monitoring systems benefit them.

When industry takes ownership of the process (e.g. creating and routinely reviewing earthquake action plans based on earthquake data) it becomes part of their routine operations and creates a long term commitment. We see this level of engagement in the water industry in Australia, and in the oil production industry in Texas, and with the larger building management and construction companies in the Philippines who recognise the benefits of structural health monitoring.

Incentives worked in Texas, and in Australia the insurance premiums for one water authority reduced by more than the cost of performing the insurer-specified seismic monitoring. Consistent policies in the insurance industry could play a part in encouraging structural monitoring. If structural response data means that insurer risks are reduced, lower premiums could be an incentive for building owners to implement seismic monitoring.

Australia's natural resources are a major part of our economy, and any organisation that wants to use that resource should have a duty to monitor the effects of their activity, particularly when their actions can induce earthquakes that impact on other infrastructure and our population.

8 Coordination

The existing programs have one thing in common – a central organisation that is motivated to coordinate the various organisations within an industry, that provides services to the industry stakeholders for their benefit, and acts as custodian of the data for future research. There is an opportunity for this to be established for industries that use Australia's natural resources, but it needs the support of policy-makers, legislators, and earthquake engineering researchers.

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