Trusted Regulation for Geothermal Resource Development (Including Induced Seismicity Associated with EGS Operations)

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Abstract

Operations need be managed to reduce material risks to acceptable levels and as low as reasonably practical to meet community expectations. Public trust in both industry and regulators to deliver safe outcomes fosters investment and enables efficient land access and activity approvals. These principles and practices are especially important for Engineered Geothermal System development which may pose uncertain risks from induced seismicity

The objective based, one-stop-shop, regulatory framework in South Australia (*Petroleum and Geothermal Energy Act 2000*) and the behaviour of the regulator, Primary Industries and Resources – South Australia (PIRSA) are recognized as “a relatively straightforward regulatory system, which could be considered a benchmark for other jurisdictions” (Australian Productivity Commission, 2009).

The regulatory instruments that deliver trust and efficiency in South Australia are: non-prescriptive; allow for innovation while ensuring that operators demonstrate their ability to manage all possible risks to an acceptable level; and entail extensive stakeholder consultation to set standards which are aligned with community expectations.

Operations in South Australia include internationally significant Enhanced Geothermal Systems (EGS) developments. Recognizing EGS is (at least to the public) a new technology with uncertain risks, PIRSA has taken account of international developments, commissioned research and is supporting national cooperation to increase certainty in relation to risk management for EGS operations.

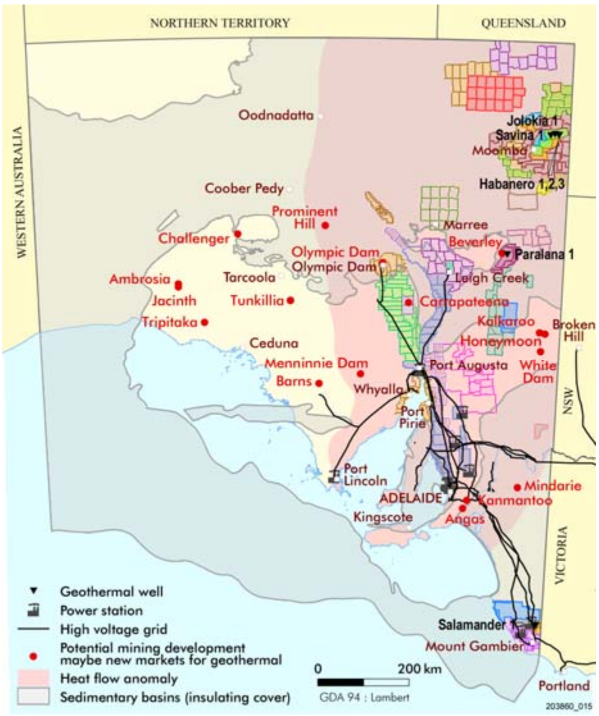
This paper describes practices and technologies that can help to inform activity approvals for EGS operations anywhere.

Efficient Co-regulation through Statements of Environmental Objectives (SEOs) and Environmental Impact Reports (EIRs)

The South Australian geothermal licenses shown in figure 1 are governed by the Petroleum and Geothermal Energy Act 2000 (P&GE Act).

In the context of the P&GE Act, the legal standards set for the protection of natural, social, heritage and economic environments are agreed through a robust, open and transparent research and consultation process that culminates in P&GE Act license operators owning and abiding by SEOs and associated EIRs (Laws, et al, 2002). EIRs detail potential impacts of proposed operations and specify strategies to mitigate risks to as low as reasonably practical (ALARP). SEOs set standards for area and operation specific compliance with co-regulatory objectives for the sustainability of natural, social, heritage and economic environments. Hence, SEOs enable PIRSA to act as a first-line, one-stop-shop for co-regulation for the full-cycle of geothermal, upstream petroleum, high pressure pipelines and gas storage operations in the State of South Australia.

Figure 1: Figure 1.Geothermal licenses in South Australia and the South Australian Heat Flow Anomaly (adapted from Neumann, et al 2000)



Trust Underpins Efficient Co-regulation

Embedding relevant local, State and Federal objectives and standards into SEOs make a breach of co-regulatory standards a breach of the P&GE Act.

Stakeholders are engaged during the development of EIRs and draft SEOs and usually in a staged process that entails face-to-face meetings. The process for SEO consultation with stakeholders can take 3 months or more depending on the level of impact of the activity, and stakeholder consultation requirements. Given potential for relatively low environmental impacts and sufficient prior publicly developed and disclosed criteria, the Minister (who is an elected Parliamentarian) may agree public consultation may be restricted to a time after a relevant SEO is fully developed for consideration. Public consultation is undertaken for the development of other EIRs and draft SEOs.

Final SEOs, final EIRs and annual statements of licensees' performance against SEOs and the Minister's determinations of the level of environmental impact of proposals are freely available to the public on PIRSA's website. PIRSA also proactively participates in public forums to enable well-informed consideration of risk management strategies put in place to protect natural, social and economic environments.

This openness and transparency underpins trust in PIRSA's roles as first-line regulator for: the integrity of plant and equipment; the protection of: water; air; flora; fauna; landscape; heritage; native (aboriginal) title; and as an interlocutor for disputes between P&GE Act licensees and stakeholders in multiple land use. In addition to the first-line roles listed above, PIRSA also works closely with South Australia's lead agency for the regulation of occupational health, safety and welfare (SafeWorkSA) matters.

Formal agreements and policies explicate mutual expectations and underpin both the efficiency and effectiveness of co-regulation. Hence, licensees have a one-stop-shop for regulation.

Australia's Productivity Commission (2009) review concludes that PIRSA "has a clear mandate, clear regulatory responsibilities, good processes to engage with other agencies, and checks and balances that apply in high risk situations" and "is widely seen as a model for other jurisdictions to emulate".

Geothermal SEOs and EIRs

The P&GE Act requires that any activity can only be conducted if it is covered by an approved SEO for the region and/or land system within which it will be carried out. Hence, geothermal operators must develop appropriate EIRs and SEOs or conclude a bridging assessment to make plain the practicality of adopting and then abiding by pre-existing SEOs for analogous operations in analogous areas. When adopting pre-existing SEOs, the bridging assessment must satisfy relevant co-regulators that location-specific risks are adequately covered in adopted SEOs. If location-specific risks are not already adequately covered, then a new relevant SEO is drafted by the operator for stakeholder consultation. In some instances, SEOs developed for petroleum license activities are adopted for analogous geothermal operations.

EIRs underpin the relevance and contents of SEOs. All licensed field activities must be covered by an SEO approved by relevant Minister(s).

When considering EIRs, PIRSA makes a determination whether proposed activities should be characterized as low-, medium or high-level environmental impact. For activities characterized as:

- Low-impact – PIRSA consults with relevant co-regulatory government agencies.
- Medium impact – PIRSA undertakes public consultation with support from the operator; and
- High impact – an Environmental Impact Statement process is instigated under South Australia's Development Act 1993.

In this way – final SEOs cover all material concerns raised by stakeholders.

Licensees are required to report annually and by exception on their performance against SEOs. Five-yearly reviews consider the efficacy of SEOs and, following the principle of transparency, these reports are available to the public from PIRSA's website.

Table 1 provides examples of EIRs and SEOs that illuminate potential risks, strategies to mitigate risks to as low as reasonably practical and standards for outcomes for geophysical survey and well operations (including drilling) used to date for deep geothermal well operations.

Table 1. Examples of Environmental Impact Reports and Statements of Environmental Objectives (SEOs)

Geophysical Surveys

- State-wide EIR for non-seismic geophysical surveys
  www.pir.sa.gov.au/__data/assets/pdf_file/0003/50844/EIR_GeoOps_NonSeis.pdf
- State-wide SEO for non-seismic geophysical surveys
  www.pir.sa.gov.au/__data/assets/pdf_file/0004/50845/SEO_GeoOps_NonSeis.pdf
- Cooper Basin EIR for geophysical operations
  www.pir.sa.gov.au/__data/assets/pdf_file/0011/27398/cooper_basin_geophysical_operations_eir.pdf
- Cooper Basin SEO for geophysical operations
  www.pir.sa.gov.au/__data/assets/pdf_file/0010/27397/cooper_basin_geophysical_operations_seo.pdf

Drilling and Well Operations

- Cooper Basin EIR for drilling and well operations
  www.pir.sa.gov.au/__data/assets/pdf_file/0004/27409/drilling_and_well_operations_eir_february_2003.pdf
- 5-Year Review of Operations, Addendum to Cooper Basin EIR for drilling and well operations
  www.pir.sa.gov.au/__data/assets/pdf_file/0009/123030/Santos_-_Drilling__and__Well_Ops_EIR_Addendum_-_November_2009_Final.pdf
- Cooper Basin SEO for drilling and well operations
  www.pir.sa.gov.au/__data/assets/pdf_file/0010/123031/Santos_-_Drilling_and_Well_Operations_SEO_-_November_2009_Final.pdf
- Habanero Well Operations EIR
  www.pir.sa.gov.au/__data/assets/pdf_file/0018/27441/habanero1_eir_sept2002.pdf
- Habanero EIR and SEO for circulation
  www.pir.sa.gov.au/__data/assets/pdf_file/0007/27439/habanero_circulation_eir_seo_oct2004.pdf
- Jacaranda Ridge 2 EIR
  www.pir.sa.gov.au/__data/assets/pdf_file/0010/52588/Adelaide_Energy_PEL_255_Region_EIR.pdf
- Jacaranda Ridge 2 SEO
  www.pir.sa.gov.au/__data/assets/pdf_file/0010/52597/Final_Adelaide_Energy_PEL_255_SEO.pdf

Geodynamics demonstrated the existing Cooper Basin SEO for drilling and well operations was relevant, and adopted that SEO for its operations in the Habanero, Jolokia and Savina wells.

Petratherm also adopted the Cooper Basin SEO for its Paralana 2 drilling and well operations.

Panax Geothermal has adopted the Otway Basin (Jacaranda Ridge) SEO for its Salamander 1 drilling and well operations.

Responsible Operator's Need to Know Best (Practice)

P&GE Act's non-prescriptive requirements for risk management enable experienced geothermal operators to easily deploy their existing corporate governance standards for risk management for use in South Australia. New entrants to geothermal operations do sometimes express a sense of uncertainty while documenting their own standard operating (including risk management) procedures. This uncertainty leads some relatively new entrants to ask to be told how to operate, as a perceived easier path to attaining competence in managing operational risks. In such cases, PIRSA willingly (and often does) 'hold-the-hand' of new entrant operators ascending learning curves that result in licence-holders adopting or developing their own activity- and area-specific SEOs and EIRs. Operator ownership of activity outcomes (and potential liabilities) also satisfies the government's policy objective that the public is protected from insufficiently managed risks. Additionally, South Australia's non-prescriptive approach allows operators to innovate and manage risks so efficiently as practical to attain standards set for outcomes. Sustainable operations and benign outcomes elicit community trust in both the regulator and industry. This is a virtuous cycle.

Activity Approvals

Local issues for particular field operations are addressed case-by-case during activity approval processes. In the activity approval process, PIRSA reviews: operator capabilities; fitness-for-purpose of plant and equipment; risk assessments concluded by licensees; and site specific environmental impacts. License operators who have demonstrated capabilities that consistently achieve regulatory compliance require low-level surveillance and only need to notify the regulator of activities, rather than seeking case-by-case activity approval.

Advance Notice of Entry

License operators must provide 21 days notice in writing to users of the land that may be affected by specific regulated activities to relevant stakeholders, including PIRSA. Land users have 14 days to raise access-related concerns with the license operator and have the option of raising the concern directly with the regulator, and the final dispute resolution is a Warden's Court proceeding.

Induced Micro-seismicity

The most advanced engineered geothermal system (EGS) projects in Australia are remote from population centers, so experience in Australia will be gained while potential risks of induced micro-seismicity are effectively managed. This experience will be of great value in showing the extent and magnitude of induced micro-seismicity, the reliability of pre-stimulation forecasts, and providing a logical basis for predicting safe distances from fracture stimulation operations in built-up areas.

Regulatory Research for EGS Operations

Many of the geothermal resources in South Australia are expected to be hydraulically fracture-stimulated to achieve optimum (high) rates of heat flow from well-bores. Fracture stimulation of reservoirs inevitably induces seismic events of some measurable magnitude. Proper planning and management of EGS operations can ensure that risks to people, buildings and infrastructure are reduced to as low as reasonably practical and acceptable levels.

To inform regulation, mitigate potential risks and address concerns raised by stakeholders, in 2005, PIRSA contracted University of Adelaide researchers to address a critical uncertainty shared by all geothermal licensees planning to demonstrate EGS in South Australia. That research (Hunt and Morelli, 2006) assessed induced seismicity within the context of local geologic conditions in the Innamincka area of the Cooper Basin, and concluded:

- Granite basement in the Cooper Basin in South Australia is ideally suited to EGS activities in terms of its compressive stress regime (prone to sub-horizontal fracture propagation), low levels of natural background seismicity and the availability of extensive high quality reflection seismic to illuminate faults and fracture trends;
- Reactivation of faults in the vicinity of the Habanero site is unlikely. This is due to the nearby faults being beyond the reach of the induced seismicity associated with EGS activity.
- Induced seismic events at the Habanero well site in the Cooper Basin could reasonably be expected to fall below a ground acceleration of 0.05 g, which is a safe level for the Habanero location and its surrounds.

These findings informed the regulator and stakeholders that the fracture stimulation of geothermal wells in the Innamincka area of the Cooper Basin could be safely managed so that micro-seismic events induced during the fracture stimulation:

- would be well below potentially damaging levels;
- were unlikely to induce slip and consequent, larger seismic events on larger geological faults; and
- were unlikely to create hydraulic communication between the stimulated granite (basement) zones below 4,000 metres and the overlying sedimentary Cooper Basin above 3,700 metres.

This last finding is based on:

- the prevailing, natural, highly compressive stress regime acting to constrain fracture propagation to sub-horizontal intervals;
- acceleration attenuation is at least one order of magnitude greater in soft rocks and soils than in crystalline rocks; and
- high frequency motion is attenuated more quickly with distance than low frequency

motion and the seismic events induced during fracture stimulation and pumping into Hot Fractured Rocks (HFR) are characteristically high frequency (100–500 Hz).

Indeed, fracture stimulation and injection programs in Geodynamics' Cooper Basin Habanero wells were both conducted safely and were successful in the enhancement and flow testing of EGS reservoirs.

Risk Management for Induced Seismicity

Given the results in the Cooper Basin, and looking forward to many additional EGS projects in Australia (and South Australia, in particular), PIRSA commissioned the development of risk management protocols for induced seismicity associated with EGS reservoir development in 2007. The findings (Morelli and Malavazos 2008) are fully consistent with the findings of Majer, Baria and Stark (2008) and are summarized in Table 2.

Running Ahead of the Frac Crew

An informed risk assessment for EGS operations starts with an analysis of:

- historical (monitored) earth movements magnitude and location; and
- geophysical survey data to relate earth movements to faults and fracture trends.

The adequacy of seismic monitoring arrays has a bearing of the certainty of seismic event magnitudes, locations and sense of motion, and hence the usefulness of recorded (historical) base-line information. Equipment capable of sensing seismicity (detectability) may only provide complete records of all movements at a higher level (completeness), because instrumentation maybe insufficient to detect many small events. The seismic monitoring stations in South Australia are depicted in Figure 2. Additional seismic monitoring stations are located in adjacent jurisdictions. The locations of four additional stations in South Australia have been agreed between State and Federal Government agencies (as shown in Figure 2) and the equipment to be deployed will enhance both the completeness and accuracy of measuring seismic events.

The detection limits of the existing seismograph network in and around South Australia is variable (as shown in Figure 2, based on Dent, 2009), and this array is reliably locating all events above Richter magnitudes of 3.5 (e.g. recording is complete for events >3.5) and is more resolute (complete for events above Richter magnitudes of 2.0) for settled areas. This is considered sufficient to manage public safety under current circumstances. If required, existing networks can be augmented to provide higher resolution of the location and depth of hypocentres.

Table 2 Information that can most help to inform activity approvals (or otherwise) for the fracture stimulation of geothermal reservoirs includes:

- Characterization of the local environment, infrastructure and population for vulnerability to ground movements and loss modeling (taking account of design standards)
- High-quality records of seismicity waveforms, magnitude and location;
- Thickness and shear velocity of soil and weathered cover over bedrock. Measuring shear velocities to 30 metres depth is a generalized suggestion;
- Reservoir data for characterization – including:
  - Orientation and magnitude of stress fields;
  - Location, extent of faults and fracture trends;
  - Mechanical, thermal and chemical rock properties, and
  - Hydrologic parameters (extent, pressure, chemistry and nature of confining aquitards)
- Conclude loss modeling (taking account of design standards and infrastructure that pre-dates design standards)

Non-exhaustive protocols for credible risk management for geothermal operations that may induce seismicity

- Apply national or international standards for risk management
- Proponent to demonstrate adequate assessment of potential consequence of induced seismicity for sites selected for hydraulic stimulation or large scale injection.
- Stakeholder engagement to start as soon as is practical
- If required, augment the existing seismic monitoring network to detect and gather seismic events of magnitudes (Richter scale) less than 3. It will be advantageous to deploy seismic monitoring stations to:
  - Continuous digital high sample frequency (≥ 100 htz) recording;
  - Attain adequate network to accurately locate seismic events and measure attenuation; and
  - Geophysical surveys to calibrate regolith response models at EGS locations.
- Maintain the seismic monitoring network for the life of the project.
- As practical, deploy at least one sub-surface seismic monitoring station (below regolith if possible) prior to hydraulic stimulation or large scale injection.
- Deploy down-hole and near surface monitoring stations to determine attenuation and regolith amplification.
- Sustain an evergreen watching brief so new information is assessed and considered for induced seismicity risk management.

The location and magnitude of historical, recorded earth movements in South Australia are depicted in Figure 3. This map does not express the uncertainty of epicenter locations, but this uncertainty is a factor considered when assessing potential risks posed by EGS operations.

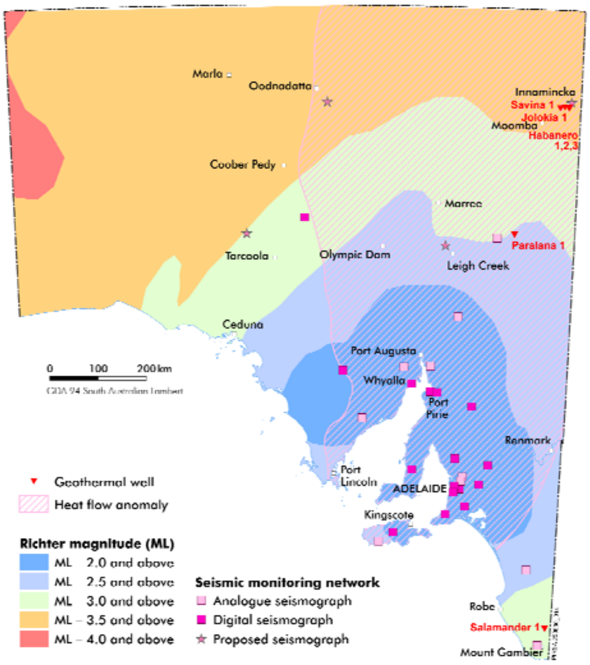
The most advanced EGS projects in Australia are those of Geodynamics (Habanero, Jolokia and Savina wells – see figure 1) and Petratherm (Paralana 2 – see figure 1). Only Habanero wells have been fracture stimulated by year-end 2009.

High resolution seismic monitoring arrays have been installed at Habanero and Paralana to better measure both background seismicity and seismicity induced during stimulation, production and circulation operations. The array positioned at Habanero can detect and locate events as low as -2.5 (Richter scale) at a depth of 5 km, with a 3D locational accuracy of about 30metres, but the completeness of accurately computing all events is probably limited to -1 (Richter scale). Networks can be augmented as required to provide greater resolution and completeness of the epicenter locations.

Hot Sedimentary Aquifer projects that do not require fracture stimulation and entail well operations largely analogous to petroleum well operations do not necessarily need to deploy seismic monitoring arrays.

Reflection seismic is useful to optimize drilling locations for EGS targets. Figure 4 depicts vast areas in the South Australian Heat Flow Anomaly that are remote from population centers, and covered with at least some modern reflection seismic information.

Figure 2. Locations and approximate capability of seismograph network in South Australia (including use of seismographs in adjacent States and the Northern Territory. Adapted from Dent, 2009. The South Australian Heat Flow Anomaly is also shown (adapted from Neumann, et al 2000).



Tools of Trade in Assessing Attenuation

Standards for attenuation for induced seismicity need be locally appropriate. The largest recorded magnitude seismic event associated with EGS operations at Habanero in the Cooper Basin determined to be of magnitude 3.7 on the Richter scale e.g. an event felt but one that would rarely cause damage, and which had no significant negative impacts on local social, natural or economic environments.

Analysis of natural and induced seismicity (associated with EGS operations in the term 2003-5) in the Innamincka region in the Cooper Basin, Hunt and Morelli (2006) found:

- natural seismicity can be expected to range between Richter magnitudes of 3.5 and 4.0 once every 50 to 167 years;
- the largest event in the area prior to 2003 was in 1979 with magnitude 2.9;
- the Australian Building Code AS 1170.4 - (1993) characterizes this region as having a 10% chance in 50 years of experiencing a peak ground acceleration of 0.05g, and
- the calculated maximum peak ground acceleration from EGS operations in the Habanero wells is 0.041g, which for this location.

Figure 3 Location and magnitude of historical earth movement epicenters in South Australia. The South Australian Heat Flow Anomaly is also shown (adapted from Neumann, et al 2000).

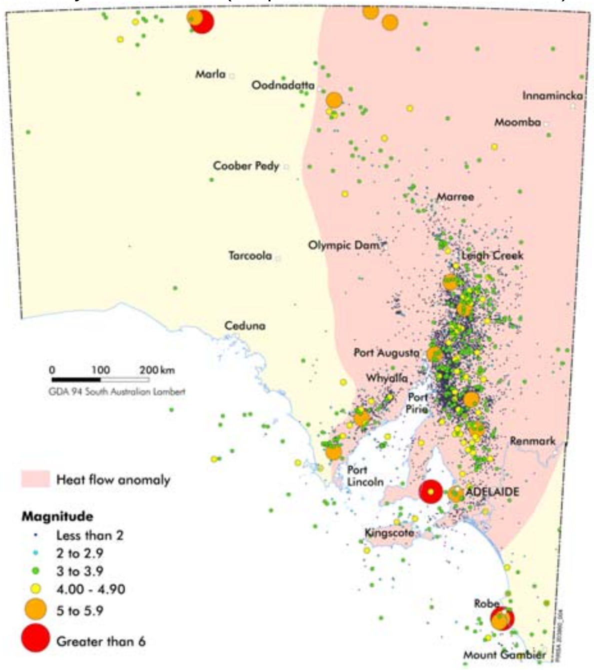
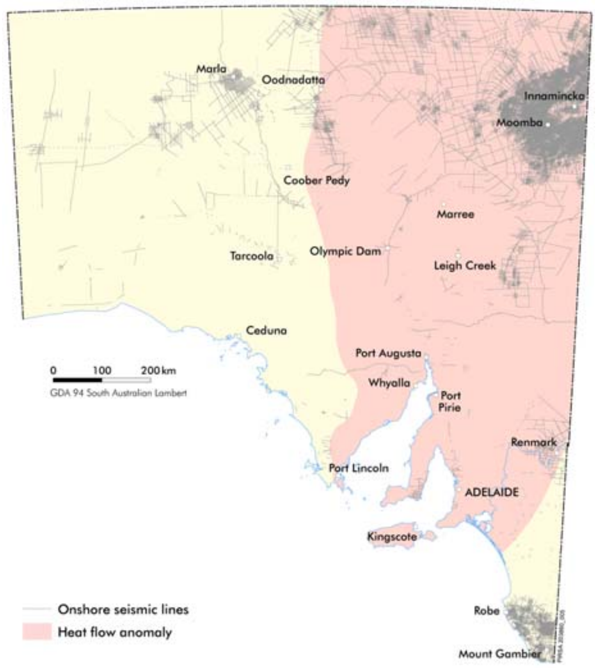


Figure 4. Reflection seismic lines (2D and 3D surveys) onshore South Australia. The South Australian Heat Flow Anomaly is also shown (adapted from Neumann, et al 2000)



Using Toro's (1997) relationships, Hunt and Morelli (2006) mapped the attenuation distance of peak ground acceleration in units of gravity (g) and distance (in kms) from the Habanero site as redisplayed here in figure 5.

Figure 5. Toro (1997) relationship calculation of attenuation distance of peak ground acceleration in units of gravity (g) and

distance (in kms) generated at the Habanero well locations near Innamincka in the Cooper Basin. From fig.8 in Hunt and Morelli, 2006)

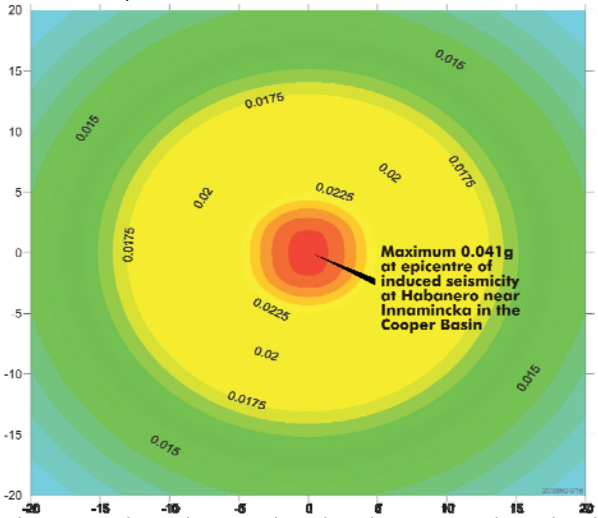
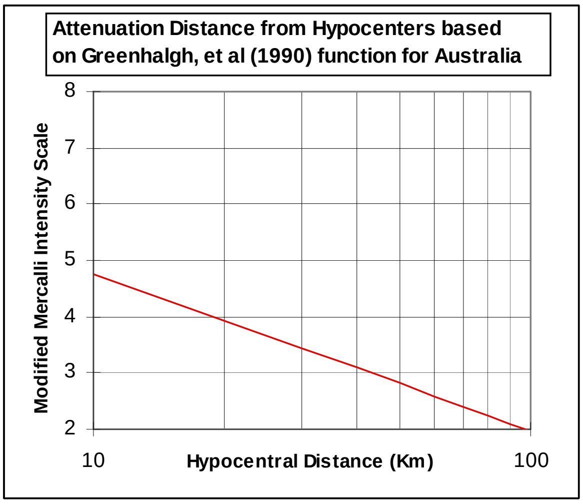


Figure 6. Estimated attenuation of earth movement intensity of a Richter scale 3.7 magnitude seismic event with distance from an event hypocenter in northeast South Australia.



Another approach is illustrated with Figure 6, which is output from a spreadsheet tool developed by PIRSA (Love, 2009) that uses estimates of earth movement (seismic wave) velocities to forecast modified Mercalli scale intensity attenuation with distance from hypocentres. This spreadsheet tool estimates intensity attenuation based on five functions published in: Bierbaum, et al, 1994; Gaull, et al 1990; Greenhalgh, et al, 1990; and Greenhalgh, et al 1994. The Greenhalgh, et al (1994) function for Australia is considered the best approximation of these five correlations to characterise seismicity induced during EGS operations in the Cooper Basin in South Australia. More detailed analyses (akin to the analysis illustrated in figure 5) are expected to be concluded by EGS operators to optimise fracture stimulation programs, assess potential hazards, and underpin consultation with stakeholders. Based on this correlation (figure 6), the maximum (3.7 on the Richter scale) recorded event at Habanero is characterised as having attenuated to a modified Mercalli scale intensity of 4.8 at 10 km distance from the hypocenter and diminished to a slight intensity at a distance 20 km from the hypocenter e.g. <4 on the modified Mercalli scale, similar to vibration from the passing of a truck. Further experience in remote locations will provide calibration for predictive modeling of EGS operations.

Perfect predictions?

One of the best predictors of large seismic events (as geo-hazards) are Gutenberg-Richter plots of Richter scale magnitude (on a linear scale x-axis) versus the number of recorded events (for a given area) exceeding Richter scale magnitude (on a log scale y-axis). Gutenberg-Richter plots can be interpreted to define maximum magnitudes in a given area, but those interpreted maximum magnitudes are generally too high to be of much practical use. More usefully, Gutenberg-Richter plots define predictable potentially harmful events where not-so-harmful (moderately-sized) earth movements are relatively frequent, and are used to inform risk management standards. It seems intuitively obvious that low levels of modest magnitude natural seismicity corresponds to a lower probability of more harmful events, but there is not yet enough empirical calibration of this hypothesis to draw associated categorical conclusions.

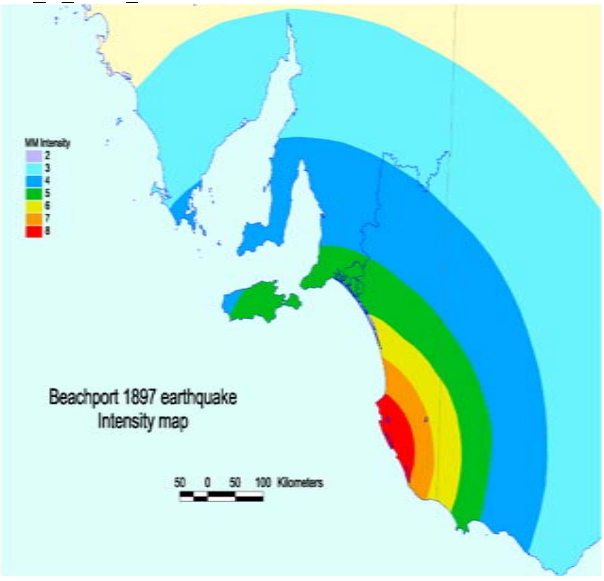
Acknowledging the need for further calibration, as proposed by Majer, et al (2006), real-time analysis of induced seismicity provides an opportunity to set thresholds and gain experience from 'traffic light' risk management during fracture stimulation (pumping) and production of geothermal reservoirs. Experience gained in geohazard risk management associated with dams and mine operations can also provide insights for EGS operations.

Pre-stress tested regions?

The extent of influence of seismic events can be mapped in terms of intensity (and also velocity and acceleration) to levels of accuracy enabled by monitoring systems. Figure 7 illustrates Modified Mercalli intensity based on newspaper reports of damage caused by the largest (6.5 Richter scale magnitude) earthquake documented in South Australia since 1837. This earthquake in southeast South Australia caused significant damage at Kingston, Robe and Beachport, and caused minor damage 312 kilometres to the north in Adelaide. It was felt as far away as Port Augusta (592 kilometres north from Beachport) and Melbourne (437 kilometres east from Beachport). Several cases of liquefaction were recorded and it is thought that the epicentre was offshore. No tsunami was reported, but aftershocks continued for months.

Trustworthy modeling methods and operational protocols to mitigate potential risks of induced seismicity remain high priority research objectives.

Figure 7. Intensity map of the Beachport (South Australia) earthquake of 10 May 1897 based on print media reports from http://www.pir.sa.gov.au/minerals/earthquakes/major_earthquakes_in_south_australia.



Better Baseline Data

A unique opportunity arises for cooperation to efficiently meet multiple objectives for public safety, and exploration for EGS, unconventional gas reservoir sweet-spots and geosequestration.

This would entail cooperation of: government agencies responsible for assessing geo-hazards associated with earth movements; proponents of developing fractured reservoirs for the production of heat energy (e.g. EGS); proponents of developing coal bed methane, shale gas and tight gas reservoirs; and proponents of subsurface greenhouse gas storage

In particular – it will be advantageous for companies exploring for reservoir sweet-spots related to tensile rock fabrics and seismically quiescent storage reservoirs and relevant government agencies to coordinate plans in the context of:

- publically managed seismic monitoring networks, so those networks are augmented with multiple objectives in mind;
- privately installed monitoring stations become public assets, post-decommissioning of industry's projects; and
- national and international forums to foster interoperability of databases and software applications (input and output).

Cooperation will advance both knowledge of induced seismicity risks and reservoir development opportunities.

Conclusions

1. Co-regulatory efficiency and effectiveness for geothermal operations can be delivered with an objective-based and transparent one-stop-shop approach as applied in South Australia.
2. PIRSA's research into potential risks posed by EGS operations has informed regulatory approvals for fracture stimulation operations in geothermal wells in areas that are remote from population centers.
3. The magnitude and extent of micro-movement induced by fracture stimulation and injection at Habanero in the Cooper Basin were largely as predicted e.g. EGS reservoirs were created and circulated without adverse impacts.
4. Calibration of predictive models for the risk management of induced seismicity in remote locations will provide benchmarks for the regulation of EGS projects nearer to populated locations.
5. Australia is becoming a globally important laboratory for EGS operations.
6. Given enough experience – risk management strategies for fracture stimulating and injecting into geothermal reservoirs are expected to evolve and EGS operations are expected to become predictably profitable and reliably safe. The outcome will be wide-spread community and investor trust in EGS development.

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