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# A Review of Traffic Light Protocol for Induced Seismicity and Its Effectiveness in Canada


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NATURAL RESOURCES CANADA - INVENTIVE BY NATURE

# Outline

- Definition of a Traffic Light Protocol (TLP)
- Historical development of the TLP for induced seismicity (IS-TLP).
- IS-TLP in Canada.
- Case studies of red-light events in BC and AB.
- Summary and implications.

# What is a Traffic Light Protocol?

- A TLP is a site-specific, real-time, risk management system with multiple discrete response levels.
- Each TLP level is determined using observable criteria and invokes specific actions designed to mitigate the associated risk.
- Most IS-TLPs work by providing a feedback system that allows for an operational response to the nearby occurrence of seismic events exceeding a prescribed set of criteria.

# IS-TLP from Regulator's Perspective

- Identification, analysis, and treatment of seismic risk associated with induced seismicity.
- IS-TLP is considered a reactive risk management tool in the "treatment" catagory.
- In general, seismic damage starts when peak ground acceleration (PGA) exceeds 5–10% of Earth's gravity (g).
- Ultimate goal: To ensure a quick and effective reduction in both the number and size of induced earthquakes.

# IS-TLP from Operator and Service Provider's Perspective

- *CAPP Publication 2012-0024* "CAPP Hydraulic Fracturing Operation Practice: Anomalous induced seismicity: assessment, monitoring, mitigation and response"
- IS-TLP is part of the "monitoring, mitigation and response" category.
- For the industry, IS-TLP is part of the decision-making process. Thus, it must be easy to understand, communicate, develop, and implement.
- Ultimately, the economic reality is the bottom line.

# The First IS-TLP

- Proposed for the operations of hydraulic stimulations of enhanced geothermal systems in eastern El Salvador, Central America *(Bommer et al. 2006).*
- Based on peak ground velocity (PGV).
  - Green: Ground motion below the threshold of general detectability, or the occurrence rate of seismicity lower than the already established background level.
  - Amber: Ground motion can be felt, but damage is unlikely.
  - Red: Damage to buildings is expected to set in.

# IS-TLP in Europe

- Enhanced Geothermal System, Basel, Switzerland (*Haring et al., 2008*).
  - Green: PGV <0.5 mm/s, $M_L$ <2.3, no felt report (Proceed as planned)
  - Yellow: PGV ≤2.0 mm/s, $M_L$ ≥2.3, few felt report (Inform regulators, stop increasing rate)
  - Amber: PGV ≤5.0 mm/s, $M_L$ ≤2.9, many felt reports (Reduce pumping rate)
  - Red: PGV >5.0 mm/s, $M_L$ >2.9, generally felt (Stop pumping, bleed wells)

- Hydraulic Fracturing of Shale Gas, UK (https://www.gov.uk)
  - Green: $M_L$ ≤0.0 (Proceed as planned)
  - Amber: $M_L$ between 0 and 0.5 (Proceed with caution, lower rates, intensify monitoring)
  - Red: $M_L$ >0.5 (Suspend injection immediately)

# IS-TLP in USA

- CO (*Wong et al.*, 2015)
  - Yellow: Felt at the surface (Modify operations)
  - Red: $M_L$ ≥4.5 (Suspend operations)
- OK (Stoplight System, http://earthquakes.ok.gov)
  - Escalating review of operator's mitigation procedures as $M_L$ ≥2.5, ≥3.0. Suspend operations when $M_L$ ≥3.5.
- OH (*Brudzinski et al.*, 2017; *Dade*, 2017)
  - $M_L$ <1.5 (Proceed as planned)
  - $M_L$ ≥1.5 (Inform regulator)
  - $M_L$ between 2.0 and 2.4 (Modify operations)
  - $M_L$ ≥2.5 (Temporary halt completions on lateral)
  - $M_L$ ≥3.0 (Suspend operation)

# IS-TLP in AB, Canada

- Subsurface Order #2, issued on February 19, 2015.
  - Applicable to the Duvernay Zone within the Fox Creek area.
  - Green: $M_L$ <2.0 (Proceed as planned)
  - Yellow: $M_L$ between 2 and 4 within 5 km of an injection well (Immediately report to AER, implement mitigating plan)
  - Red: $M_L$ ≥4 within 5 km of an injection well (Immediately report to AER and cease hydraulic fracturing operations)

# IS-TLP in BC, Canada

- Section 21.1 of the Drilling and Production Regulation (since June 2015, presented as site-specific permit condition since October 2012).
  - A stoplight system, no escalating levels.
  - Applicable to all injection operations in BC.
  - Red: $M_L$ ≥4 within 3 km of the drilling pad, or a ground motion felt on the surface by any individual within the 3 km radius (Suspend operations).

# Major Deficiencies of Magnitude-based IS-TLP

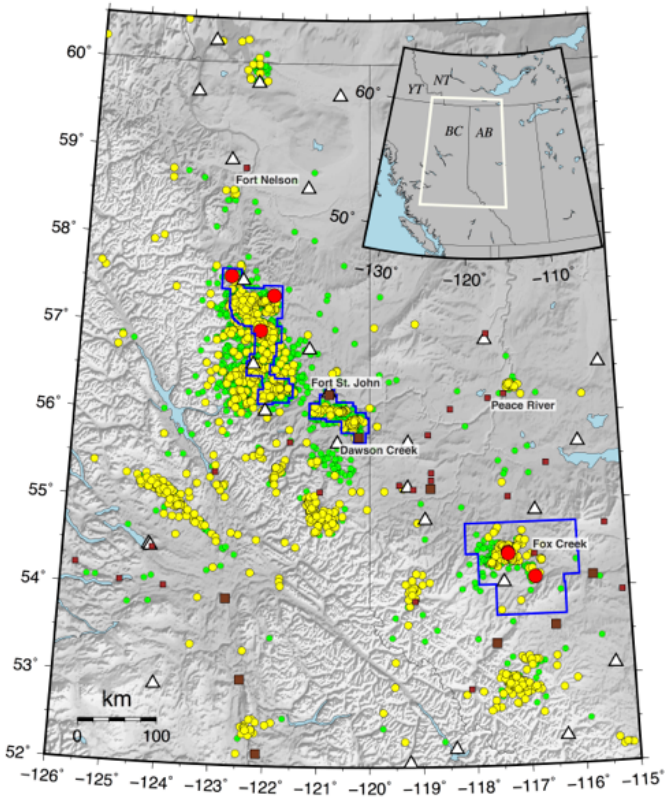
- Possible confusion due to magnitude uncertainty.
  - Different scales and/or methodology ($M_L$, $M_w$, $M_n$, etc.)
  - Different choice/availability of data (local array vs. regional networks)
  - Different source characteristics (moment scaling, stress drop, focal mechanism)
  - Different attenuation/distance corrections
  - Different site effects
- Not linked to the impact/consequences of reported events.
- Completely ignore other potential useful indicators (e.g., change of earthquake occurrence rate, migration of hypocenters, correlation with geological structures).

# Designated Ground Motion Monitoring Areas in BC

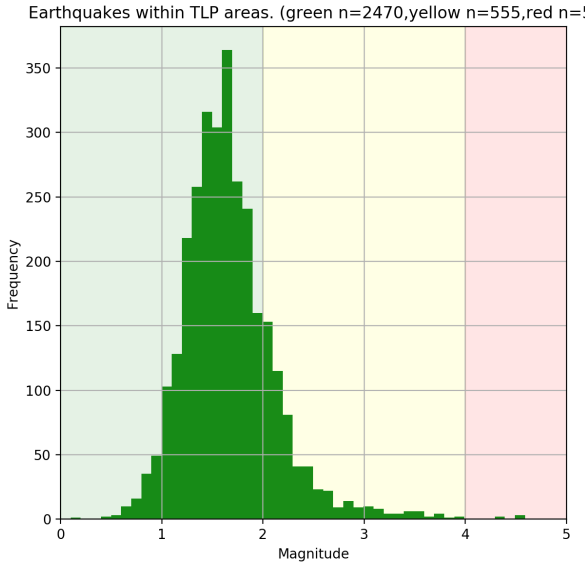
- New permit condition for wells in two designated areas.
- Require presence of adequate monitoring of ground motion during hydraulic fracturing.
  - Minimum of 1 ground motion monitor within 3 km of the common drilling pad.
  - Instrument with a dynamic range of +/-2g and a minimum detectability of 0.02g.
- Submit ground motion monitoring report within 30 days of completion.
- Seismic data for any ground motions exceeding 0.02g must be submitted.

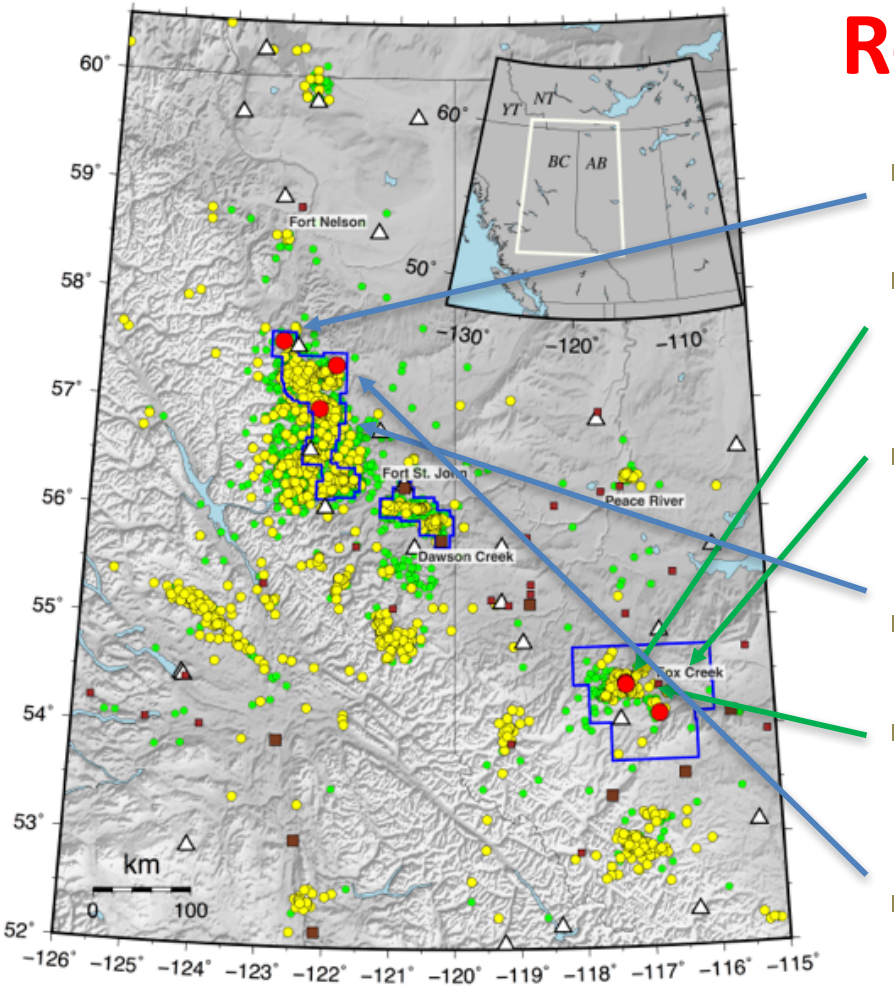
(*BC OGC Industry Bulletin 2016-19*)

# Distribution of Regional Seismicity in northeast BC and west AB




- 4919 events in total.
- 3030 (~62%) occurred in the designated monitoring areas.
- Green: ~81.5%, Yellow: ~18.3%, Red: <0.2%





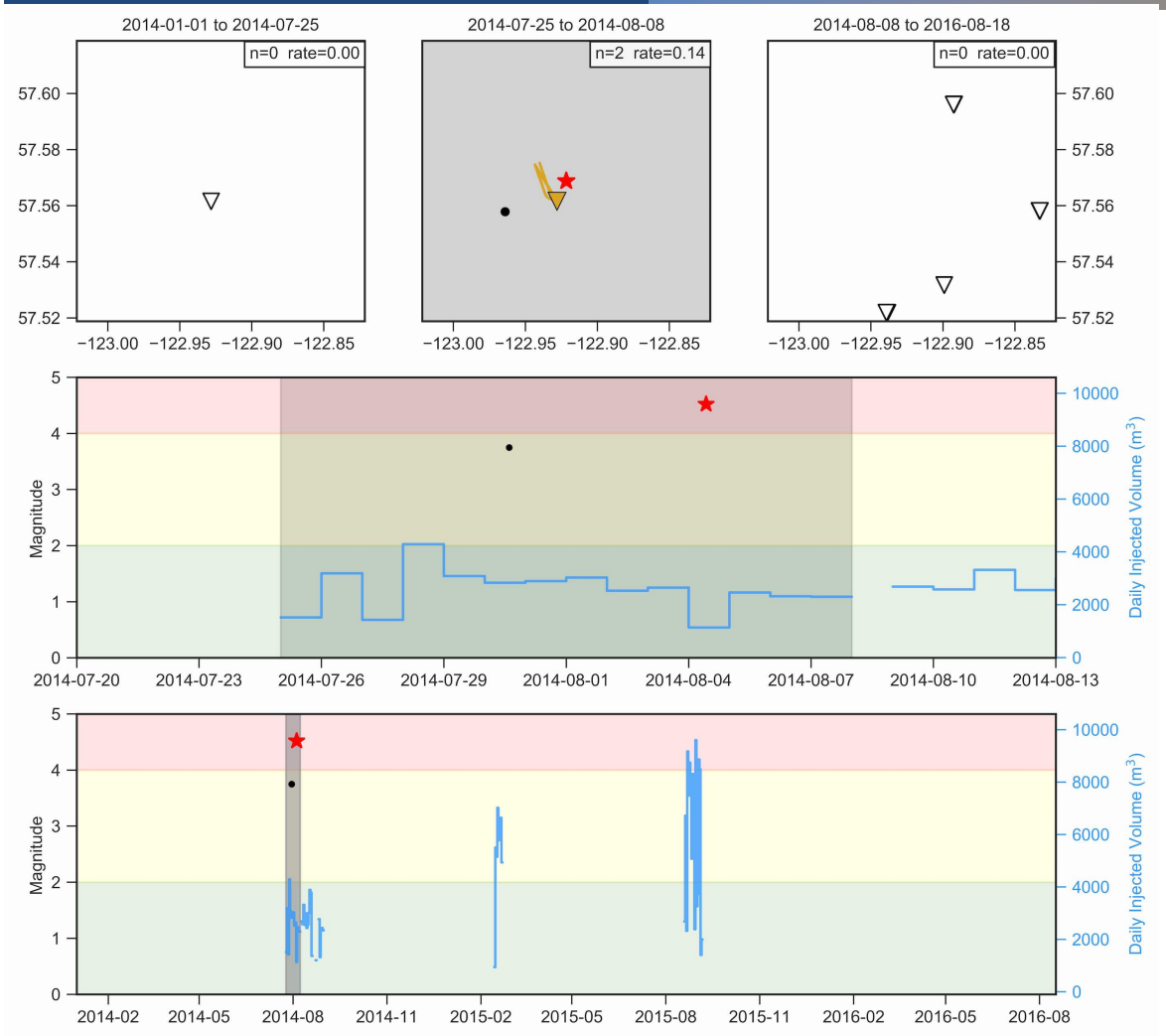

# Red-Light Events in BC and AB

- 1. August 4, 2014, $M_w$ 4.5 ($M_L$ 4.1)
- 2. January 23, 2015, $M_w$ 4.4 ($M_L$ 4.1)

  * $M_w$ 3.6 (Schultz et al., 2017).
- 3. June 13, 2015, $M_w$ 4.6 ($M_L$ 4.3)

  * $M_w$ 3.9 (Wang *et al.*, 2016), $M_L$ 4.4 (AGS).
- 4. August 17, 2015, $M_w$ 4.6 ($M_L$ 4.9)
- 5. January 12, 2016, $M_w$ 4.4 ($M_L$ 4.6)

  * $M_w$ 4.1 (Schultz *et al.*, 2017), $M_L$ 4.8 (AGS).
- 6. July 12, 2016, $M_w$ 3.9 ($M_L$ 4.0)

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# Event 1, $M_w$ 4.5 ($M_L$ 4.1) August 4, 2014 northern Montney, BC

- Active HF and WD during 7/25 – 8/07.
- One yellow-light ($M_w$ 3.8) event occurred on 7/30.
- The red-light event occurred with reduced injection rate and pressure.
- Prior, during, and post-injection earthquake rates are 0, 0.14, and 0 event per day, respectively.
- No more *M*4+ event afterwards.

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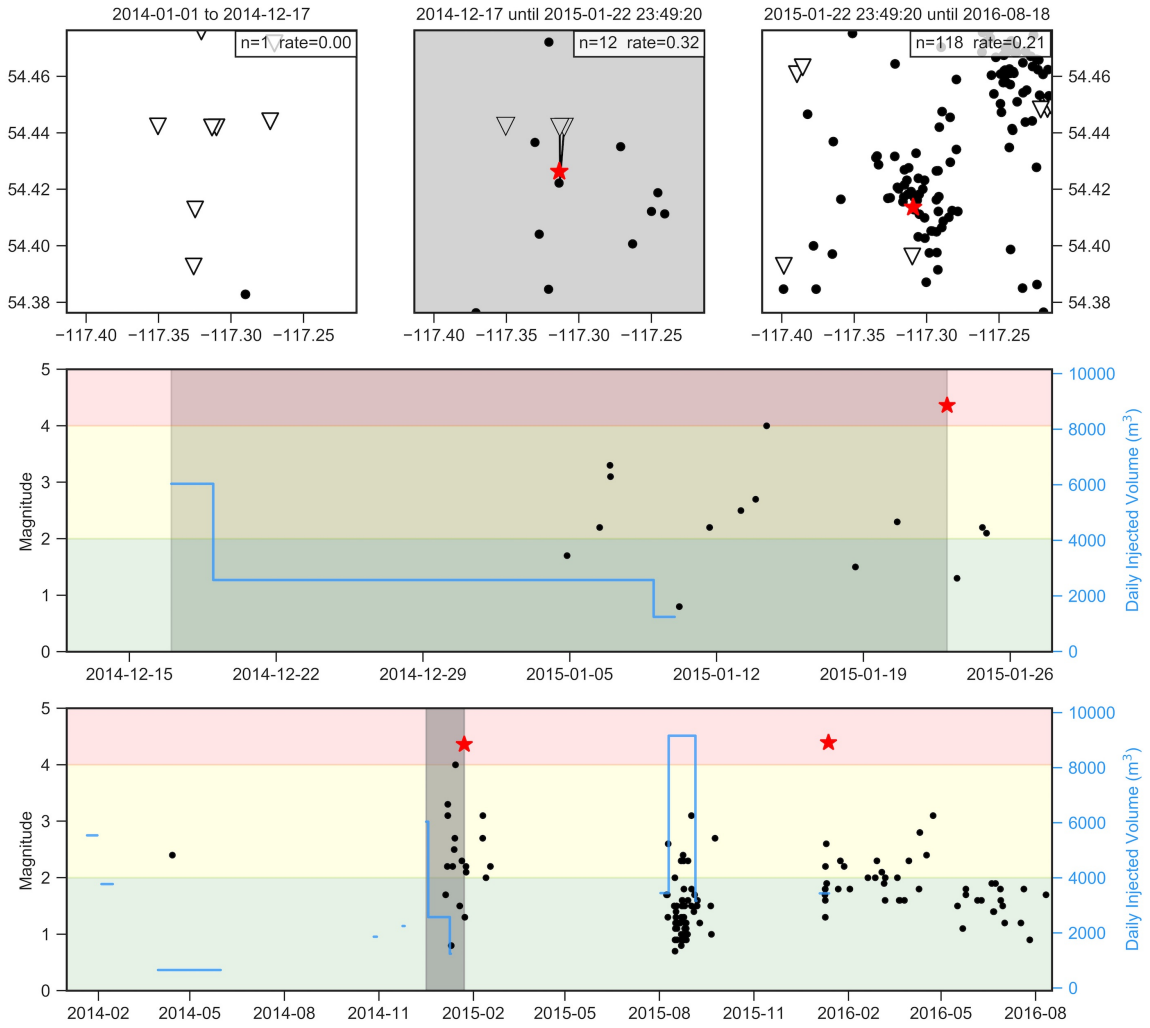
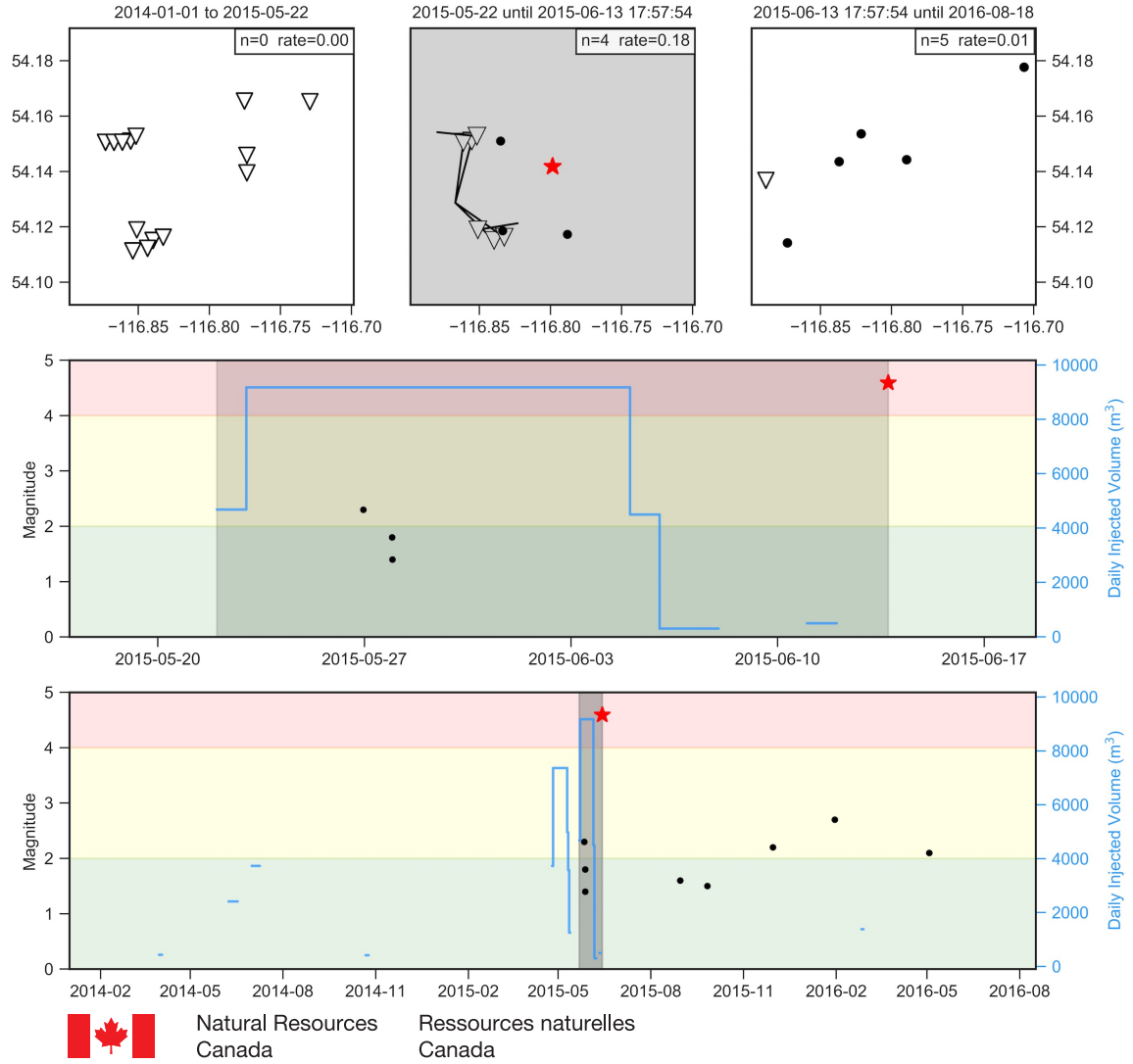



# Event 2, $M_w$ 4.4 ($M_L$ 4.1)
# January 23, 2015
# Fox Creek, AB

- Active HF during 12/17 – 1/10.
- 1 green- and 3 yellow-light events during the last 5 days of injection.
- Seismicity continued after the completion of HF for 2 more weeks.
- Prior, during, and post-injection earthquake rates are <0.01, 0.32, and 0.21 events per day, respectively.
- Another *M*4+ event about a year later.
- A clear case of "delayed" triggering.

(*Schultz et al., 2017; Wang et al., 2016*)

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## Event 3, $M_w$ 4.6 ($M_L$ 4.3)
## June 13, 2015
## Fox Creek, AB

- Active HF during 5/22 – 6/07 at 6 nearby wells.
- Among the highest daily injection volume.
- One yellow-light event occurred on 5/27.
- Prior, during, and post-injection earthquake rates are 0, 0.18, and 0.01 event per day, respectively.
- No more *M*4+ event afterwards.
- Another example of "delayed" triggering.

(*Schultz et al., 2017*)

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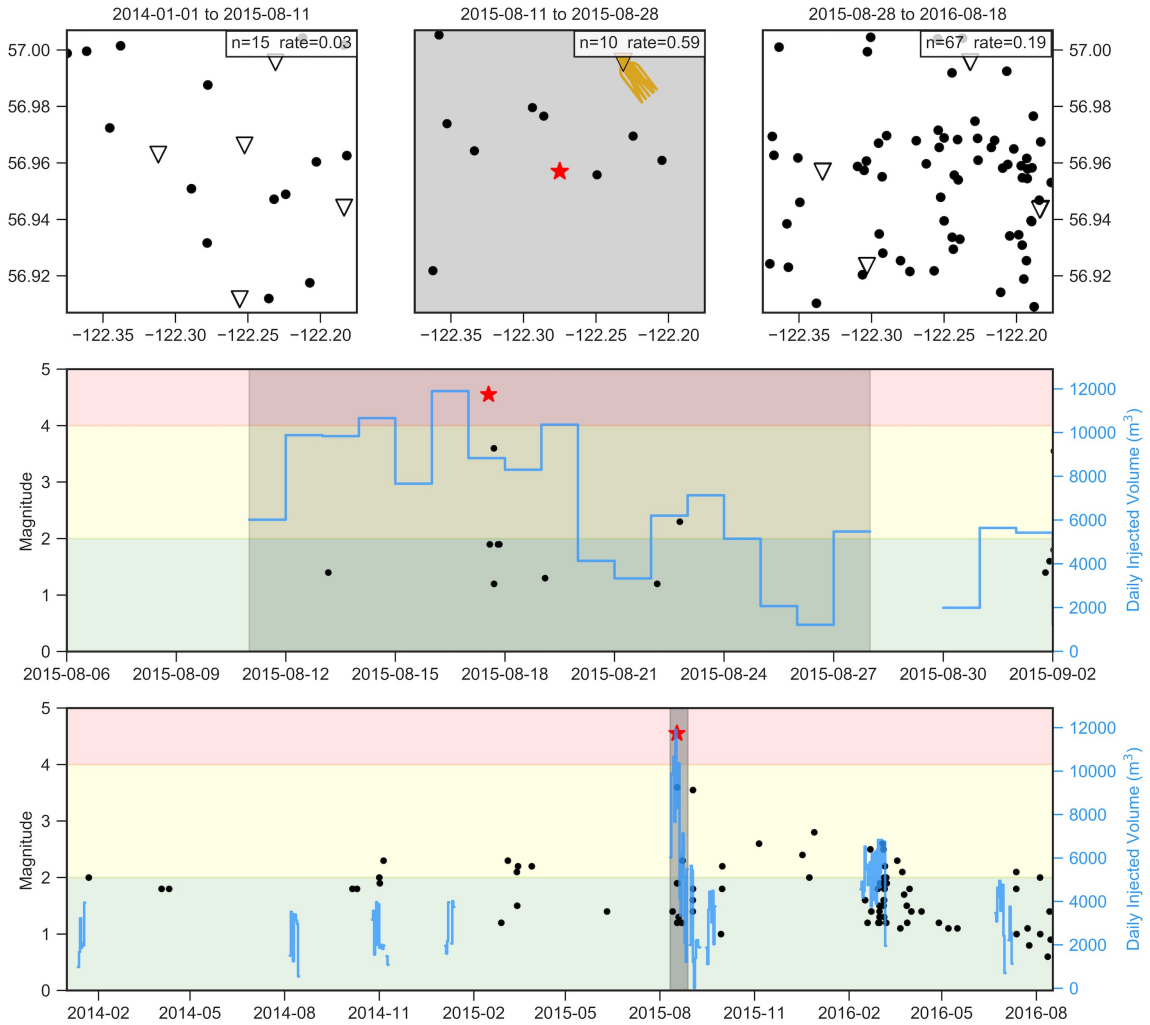
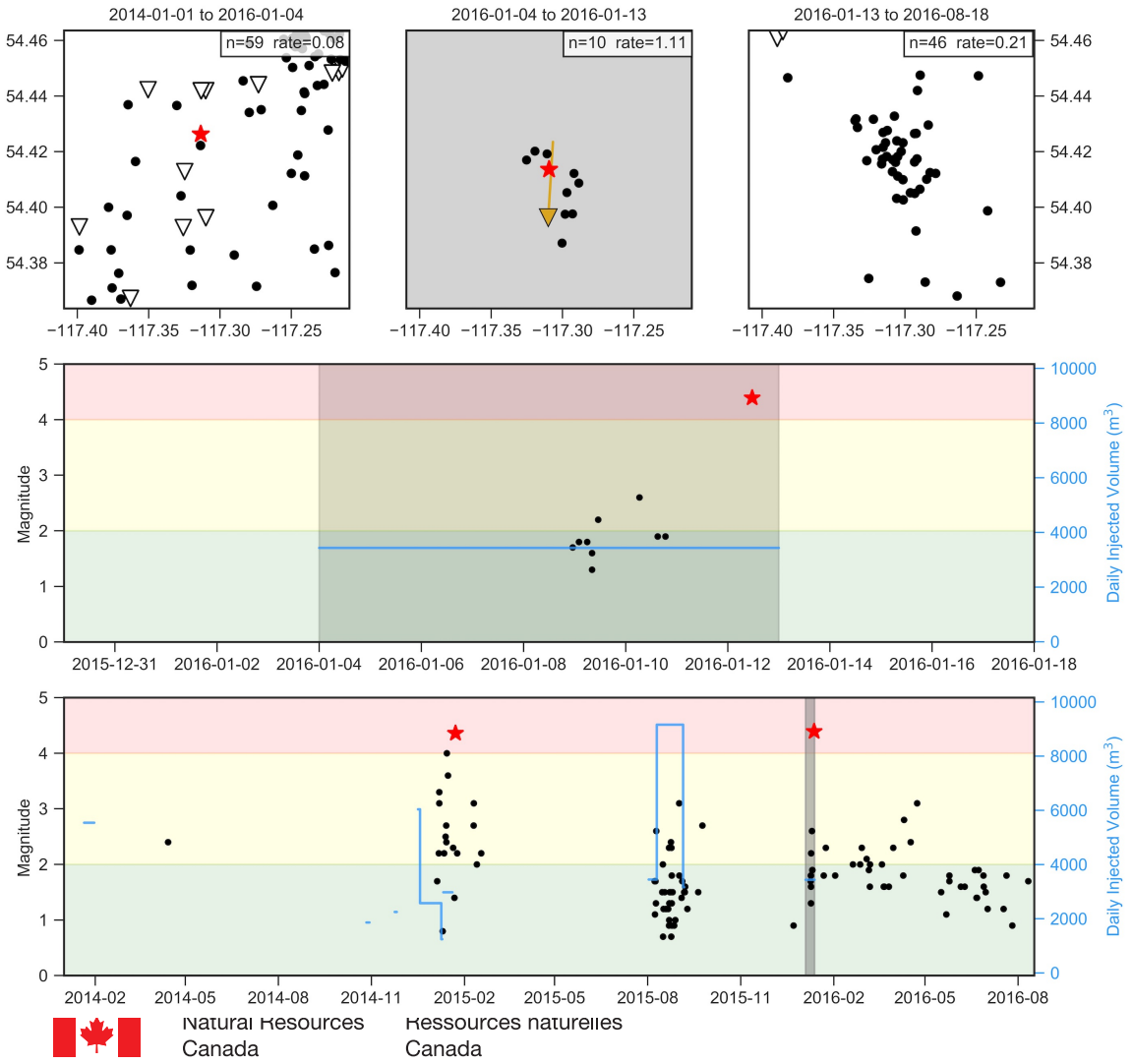



## Event 4, Event 4, $M_w$ 4.6 ($M_L$ 4.9)
## August 17, 2015
## northern Montney, BC

- Active HF and WD during 8/11 – 8/28.
- One green but NO yellow-light event occurred since the injection began before the $M_w$ 4.6 event.
- Seismicity continued for ~one week.
- Prior, during, and post-injection earthquake rates are 0.03, 0.59, and 0.19 events per day, respectively.
- No more *M*4+ event afterwards.

(*Babaie Mahani et al., 2017a, 2017b*)




# Event 5, $M_w$ 4.4 ($M_L$ 4.6) January 12, 2016 Fox Creek, AB

- Same general area of the January 23, 2015, $M_w$ 4.4, red-light event.
- Active HF started on 1/04, stopped right after the red-light event, never resumed.
- Two yellow-light events occurred on 1/09 and 1/10.
- Prior, during, and post-injection earthquake rates are 0.08, 1.11, and 0.21 events per day, respectively.
- No more *M*4+ event afterwards. But scattered *M*<4 seismicity continued till the end of our study period.

(*Schultz et al., 2017; Wang et al., 2017*)

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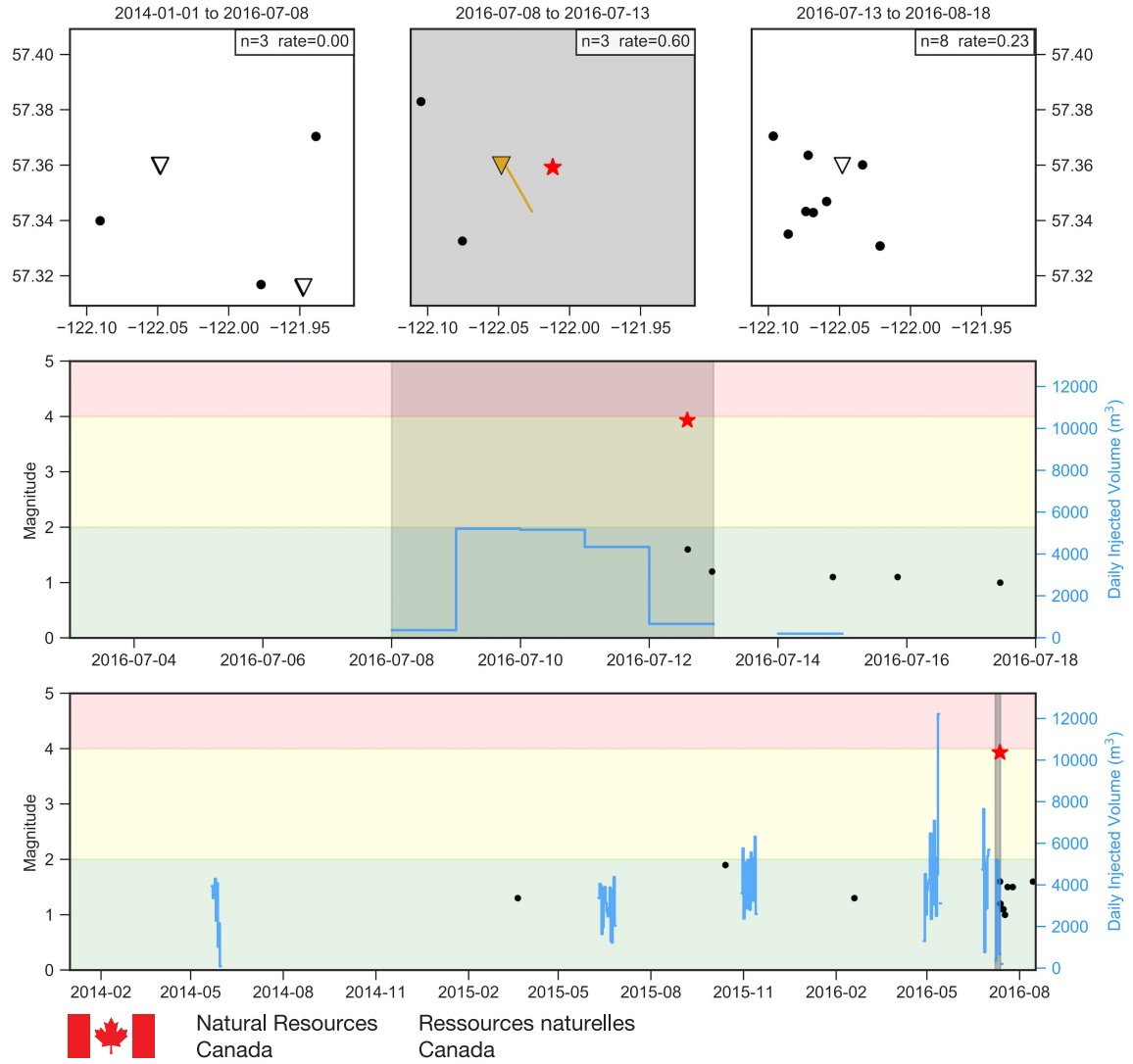


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## Event 6, $M_w$ 3.9 ($M_L$ 4.0)
## July 12, 2016
## northern Montney, BC

- Initially reported $M_L$ = 4.0, later revised to $M_w$ = 3.9
- Active HF started on 7/08.
- No event occurred before this red-light event.
- Prior, during, and post earthquake rates are <0.001, 0.6, and 0.23 events per day, respectively.
- No more *M*4+ event afterwards.

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# Key Observations About Red-Light Events in BC and AB

| Key Features | Event 1 (BC) | Event 2 (AB) | Event 3 (AB) | Event 4 (BC) | Event 5 (AB) | Event 6 (BC) |
|---|---|---|---|---|---|---|
| Total number of events during injection stage | 2 | 12 | 4 | 10 | 10 | 3 |
| Precursory seismicity during injection stage | YLE | YLE+GLE | YLE+GLE | GLE | YLE+GLE | None |
| Rate of seismicity before the start of injection | 0.00 | <0.01 | 0.00 | 0.03 | 0.08 | <0.01 |
| Rate of seismicity during the injection | 0.14 | 0.32 | 0.18 | 0.59 | 1.11 | 0.60 |
| Rate of seismicity after the injection | 0.00 | 0.21 | 0.01 | 0.19 | 0.21 | 0.23 |
| Seismicity responding to injection adjustment | Yes | N/A | N/A | Yes | Yes | Yes |
| Followed by a larger event causing damage | No | No | No | No | No | No |

# Summary and Implications

- An IS-TLP based on escalating magnitude (green –> yellow –> red) is more applicable to AB than BC.
- Background seismicity may be a useful reference in forecasting the overall seismic response to injections.
  - Low pre-injection seismicity rate ~ Low seismicity rate during injection
- A clear jump in the seismicity rate from the pre-injection period to the injection period, especially after 2015.
- The phenomenon of "delayed triggering" (two red-light events in AB) can be a problem for the effectiveness of the IS-TLP and should be carefully considered
- Existing IS-TLP for induced seismicity in both BC and AB appear to be working in the sense that it prevents any damaging earthquakes (*M*>5.5) from happening.

# Questions or Comments?

- Send your questions or comments to

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