Risk Treatment

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Induced Seismicity Workshop, Yellowknife NWT

Risk Management Approach to Induced Seismicity

Establishing the Context:

What are the potential outcomes (negative or positive) of induced seismicity?
-safety to people and infrastructure, groundwater impacts, social perception/security, economic realities.

What can be tolerated by induced earthquakes? Where? Why?

Hazard Identification

Where is induced seismicity occurring?

What are the factors that could lead to induced seismicity? Geologic conditions or operational behavior?

What are the best predictors of induced seismicity?

Hazard Analysis

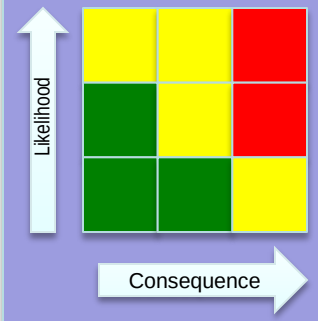
If geological associated, then what is the regional distribution of susceptibility?

If an operational association, then; What parameter is most associated with triggered events?

How should this be mitigated?

Risk Evaluation

Evaluation of risk using a heat map, common risk framework, bounded by acceptable risk.



Risk Treatment

Decisions: develop regional strategies for management with allowances/threshold /avoidance areas

Compliance: monitoring and improved reporting

Policy for long term planning.

Risk Treatment

- Process to modify risk. Can involve avoiding the risk, taking or increasing the risk in order to pursue an opportunity; removing the risk source, changing the likelihood; changing the consequences, sharing the risk with another party or parties, and retaining the risk by informed decision

How is induced seismicity different, as related to impact?

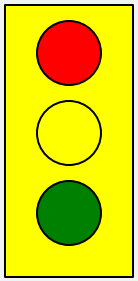
- Hydraulic fracturing **IS**; ~1Km near the well bore, no lag
  - Short term issues, commonly managed with TLP
  - Geospatially ephemeral
- Disposal **IS**; ~50Km from well bore, ~3 year lag
  - Long term issues, commonly managed with TLP reacting to cumulative effects.
- Relationship to critical infrastructure
  - Ground motion, PSHA, Shake Maps
- Intensity of magnitude of induced seismic events
  - Largest IS 4.7 Mw from HF
  - Largest IS 5.8 Mw from Disposal

Risk Treatment

Reactive

Proactive

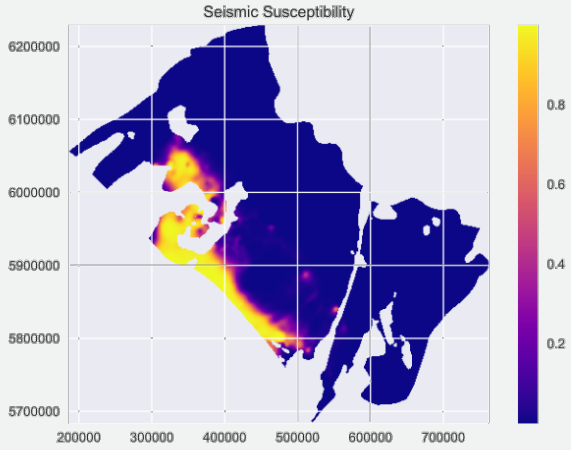
Predictive

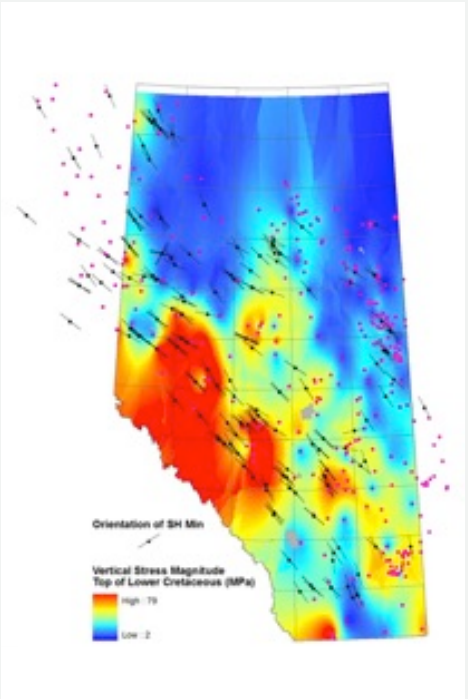


Suspend Operations

Modify Operations

Normal Operations

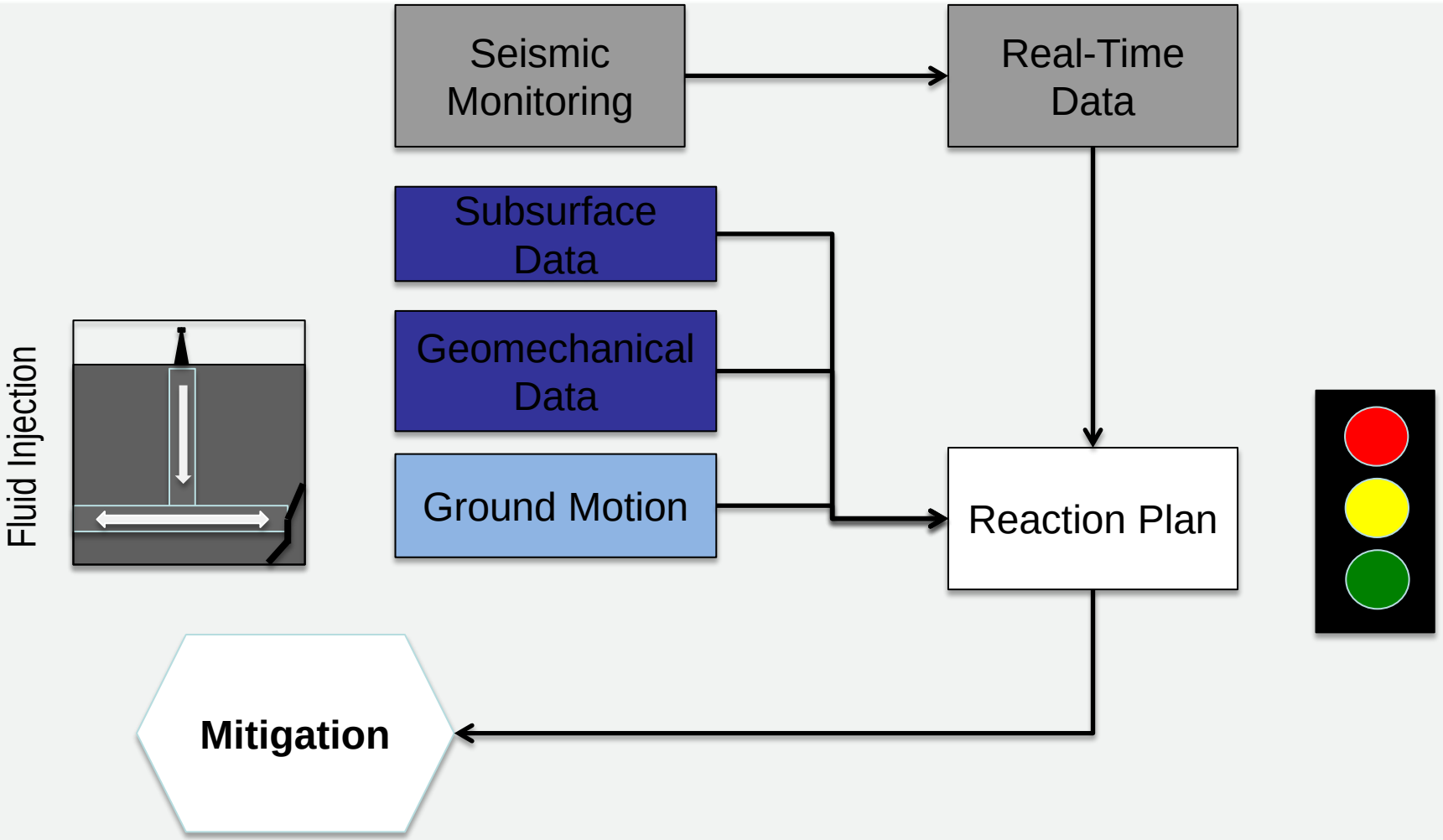




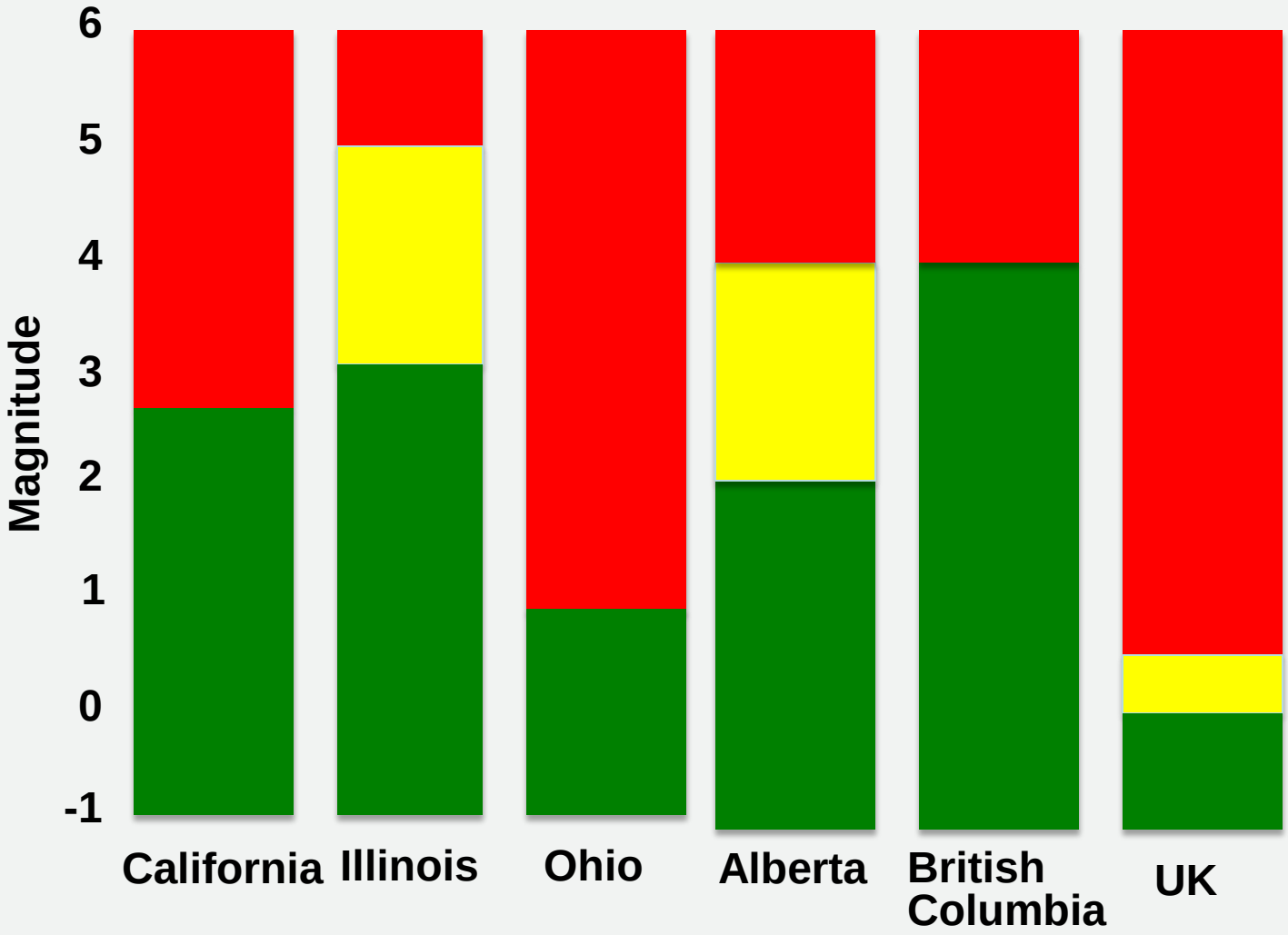
Reactive Risk Treatment

- Risk treatments that allow for non-damaging induced seismic events to occur with a threshold based zone of enforcement
- React to these with a mitigation strategy which allows for the reduction of risk.

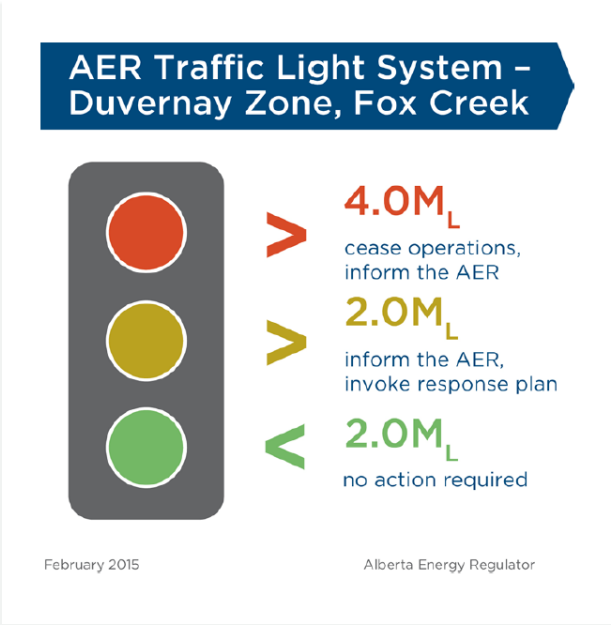
Typical Traffic Light Protocol



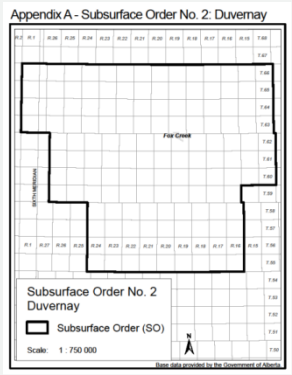
Examples of Traffic Light Protocols



Subsurface Order #2, Traffic Light Protocol for Induced Seismicity



- Issued February 19, 2015
- Applies to hydraulic fracturing operations in Duvernay Zone in Fox Creek area
- Requires an assessment of induced seismicity, a plan to respond to induced seismicity, and seismic monitoring
- Uses a Traffic Light Protocol for response to seismic events



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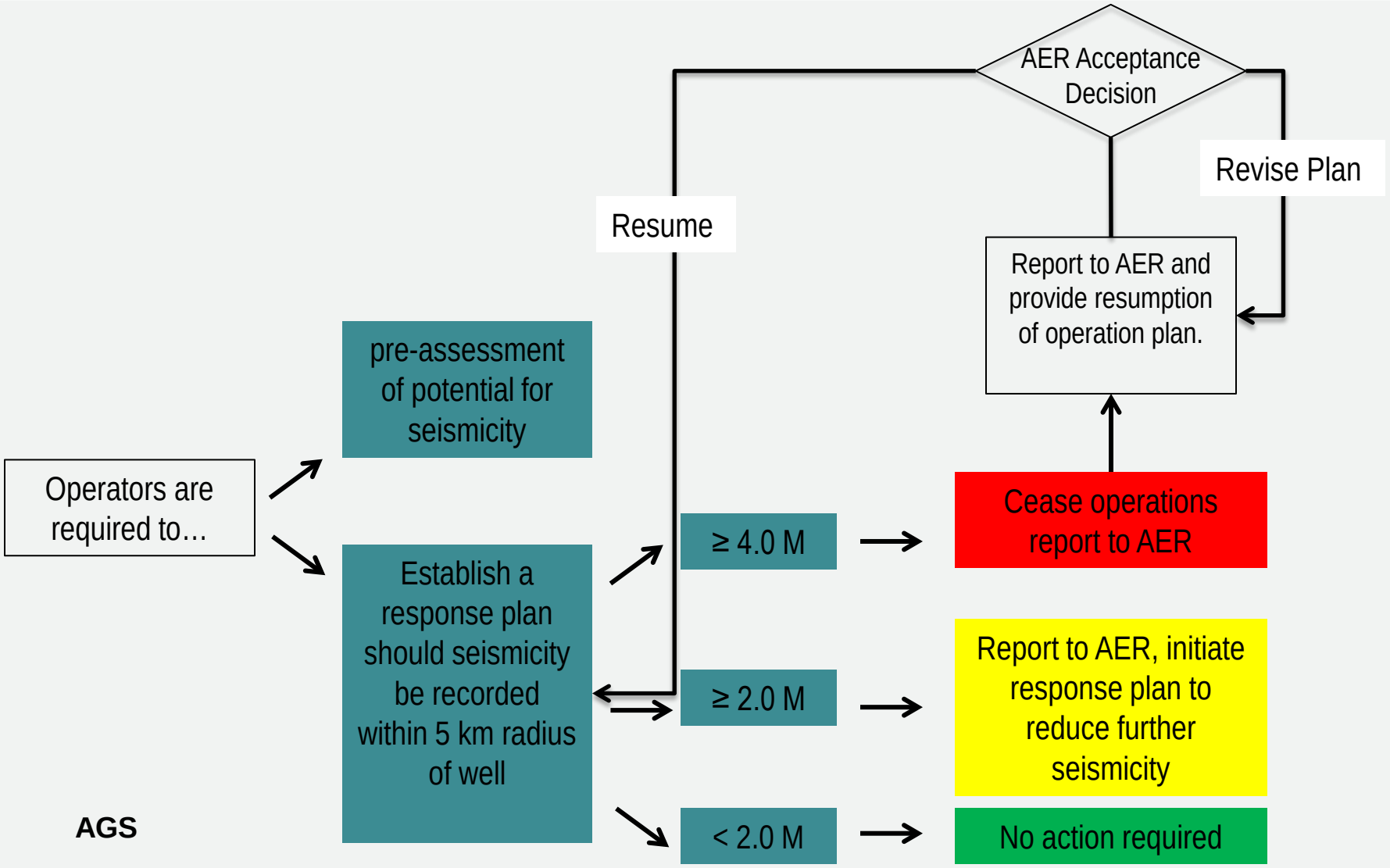
AER's Subsurface Order No. 2



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BCOGC's Regulation Surrounding Injection and Induced Seismicity

Reporting of any event of 4.0 ML or greater with in 3km near fracking operations

Suspend fracturing operations

Operations Continue if

- Plan developed to reduce seismicity
- Commission is satisfied with the plan
- Operator implements plan

Disposal Injection

- Meter to Kilometers of well
- 3 months to 1 year of the event
- Controlled by injection rate and pressure
- Reduce rates/Suspend

Hydraulic Fracturing

- 300m to 1 km of well
- Hrs to days of injection
- Stops at the end of fracking
- By pass stages/Lower pump rate/flowback

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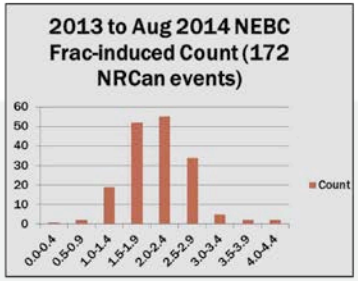
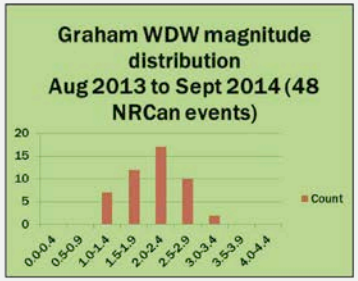
PERMIT CONDITIONS TO ADDRESS INDUCED SEISMICITY

1. During fracturing operations on this well, the operator shall immediately report to the Commission Emergency Contact 1-800-663-3456 any seismic event
   a. recorded by the operator or any source available to the operator as being magnitude 4.0 or greater and within a 3 km radius of the drilling pad, or
   b. felt on surface within a 3km radius of the drilling pad.
2. In the event that a pad well is identified, either by the operator or the Commission, as being responsible for the seismic event described in section 1(a) above, the operator, subject to section 3 below, will suspend fracturing operations on this well immediately.
3. Fracturing operations at this well, suspended under section 2 above, may continue if:
   a) the operator presents to the Commission a plan for mitigation aimed at reducing the seismicity or eliminating well operations related to the induced seismicity,
   b) the Commission is satisfied with this plan, and
   c) the operator implements this plan.





DISPOSAL-INDUCED SEISMICITY

- Can occur within metres or kilometres of injection point - (injection point remains)
- In NEBC Disposal IS has occurred within 3 months to 1 year of injection initiation (all cases continuous injection)
- Frequency of events controlled by injection rate (pressure)
- Some evidence of breakout into adjacent zones

MITIGATION

- Injection rate reduction
- Pressure limit 120% original Fm pressure
- Suspend operations

FRAC-INDUCED SEISMICITY

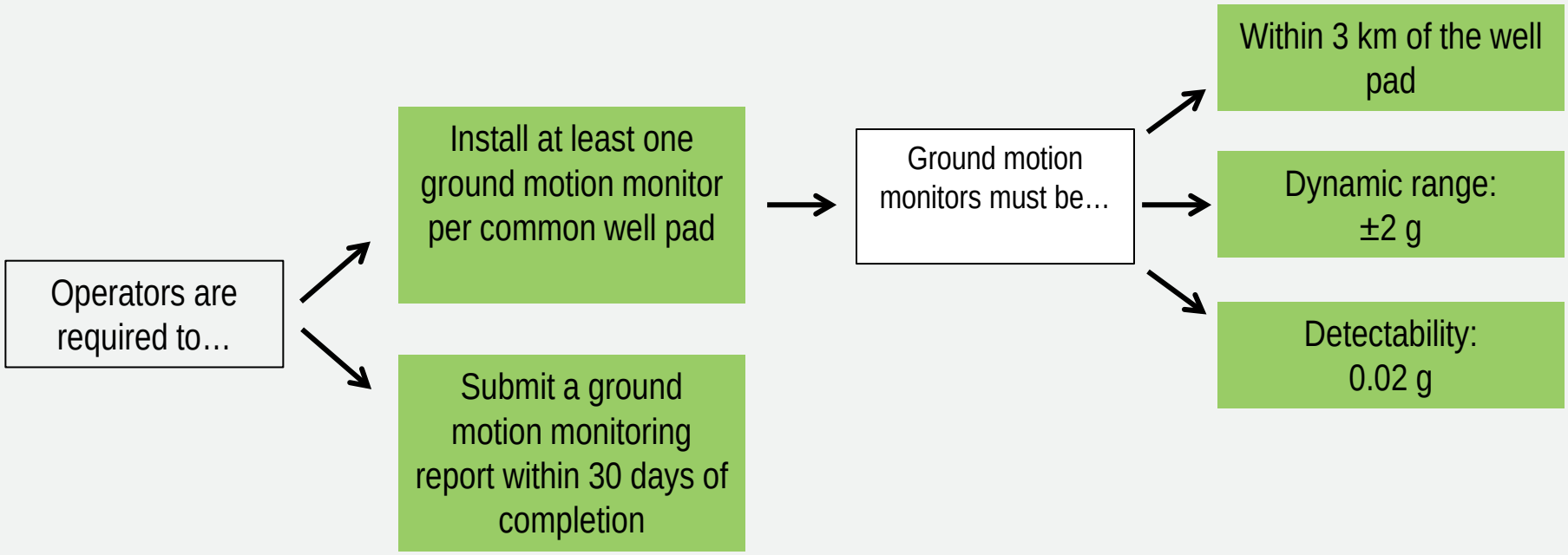
- Occurs within 300 metres to 1km of injection point - (injection point travels)
- Usually occurs within minutes to 24hrs of injection
- Stops with end of fracing
- Confined to re-activation zones
- Not triggered from distant injection points
- Mostly in target zone

MITIGATION

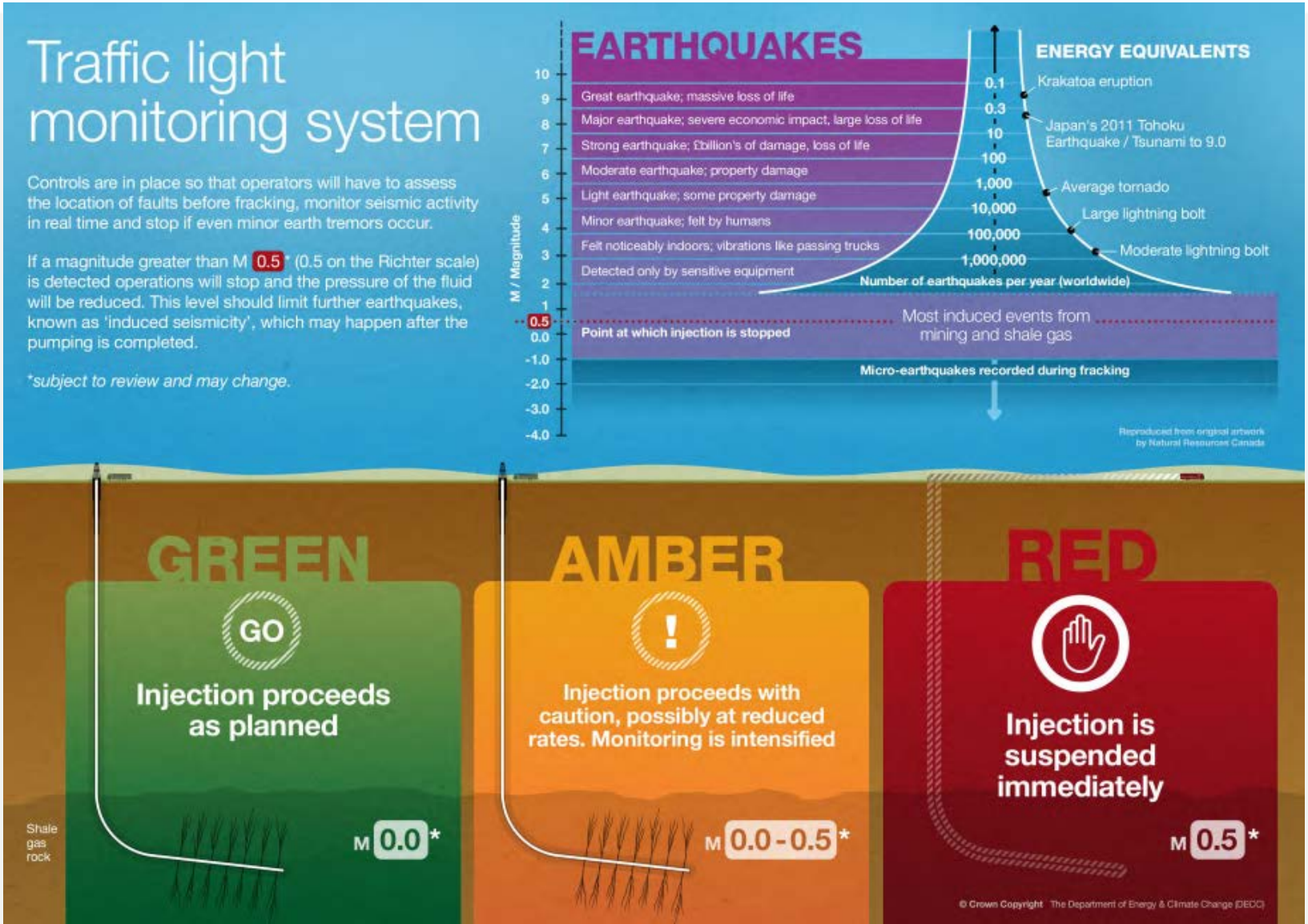
- Lower pump rates
  - Etsho
  - Kiwigana
  - Tattoo
- Bypassing stages
- Exit re-activation zone
- Flowback

After BCOGC

BCOGC's Ground Motion Regulations



DECC's Traffic Light Protocol



Proactive Risk Treatment

- Risk treatments prevent risky activity through avoidance.
- This includes implementation of operational changes, quantifying susceptibility of areas, and/or moratorium

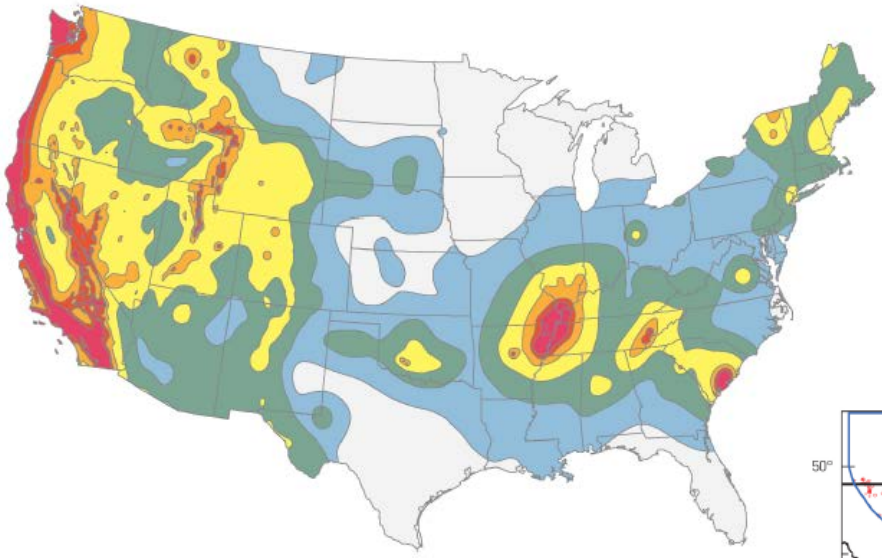
What options are there for managing the risk for induced seismicity?

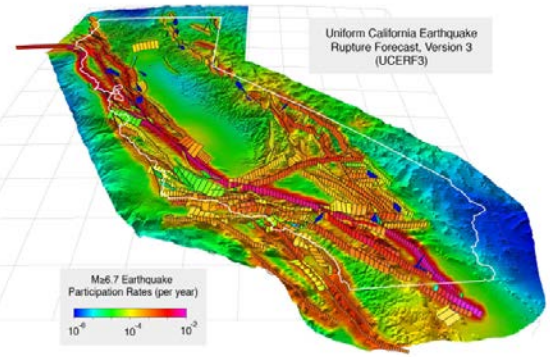
- Avoidance/Quantification
  - Geological susceptibility- effective stress, structures
  - Infrastructure-measured ground motion, distance activity, PSHA, Shake Maps
- Moratorium
  - Activity driven- disposal, conventional extraction, HF
  - Depth driven- prevent all operations near formations that are known to cause IS
  - Location driven- near susceptible areas, such as faults, zone where induced seismicity is more likely

What Set Backs are Currently Done for Induced Seismicity/Oil and Gas Activity?

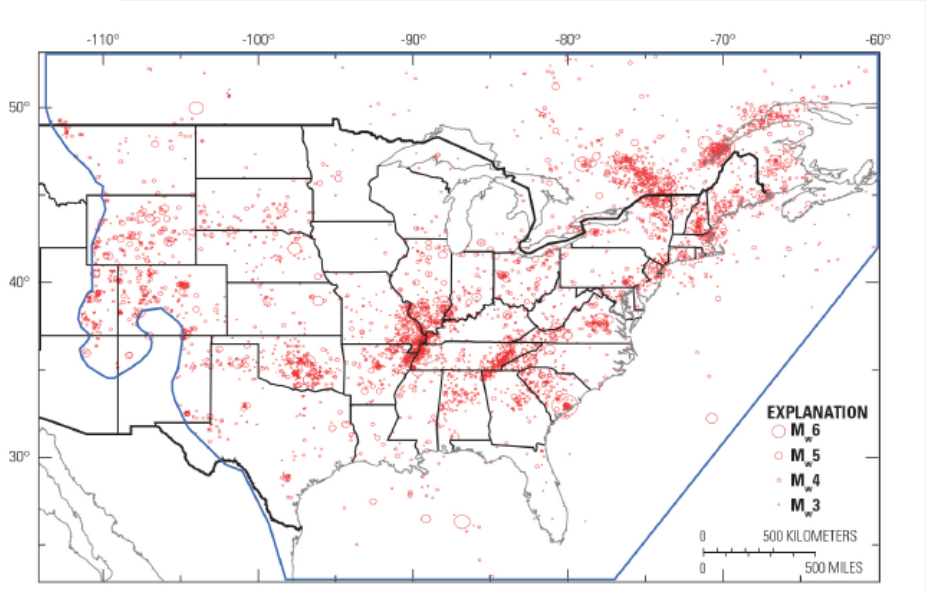
- Joe Pool Dam
  - 4000 ft exclusion zone set around the dam
  - Possible restriction of disposal wells within 3 to 5 miles
- Post Oklahoma 5.6 M event
  - 0-5 miles managed shut-in of wells currently authorized to inject, within a 7 days
  - 5-10 miles managed shut-in of authorized injection wells, within 10 days
  - With ongoing seismicity Oklahoma regulator instigated 40% reduction in disposal volumes.
- Moratoriums in jurisdictions.

Seismic Susceptibility





Are there other underlying geological factors which we can correlate to induced seismicity?



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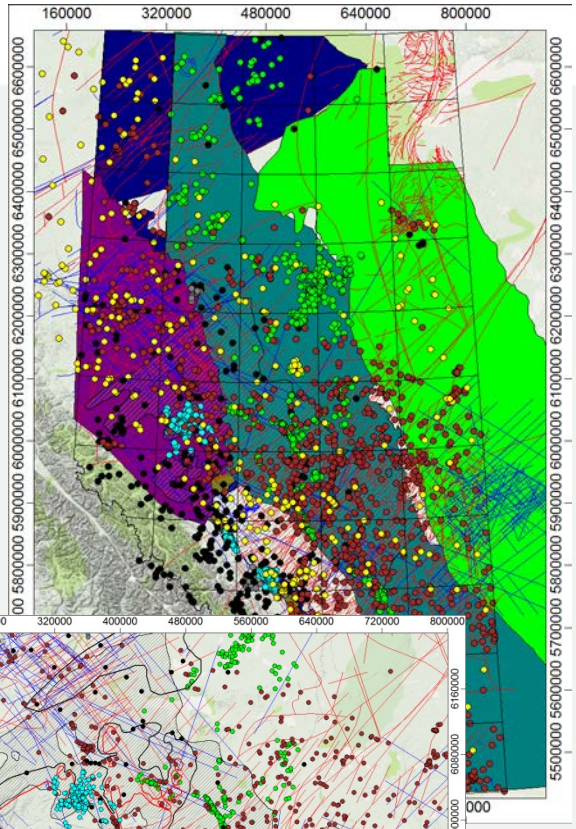
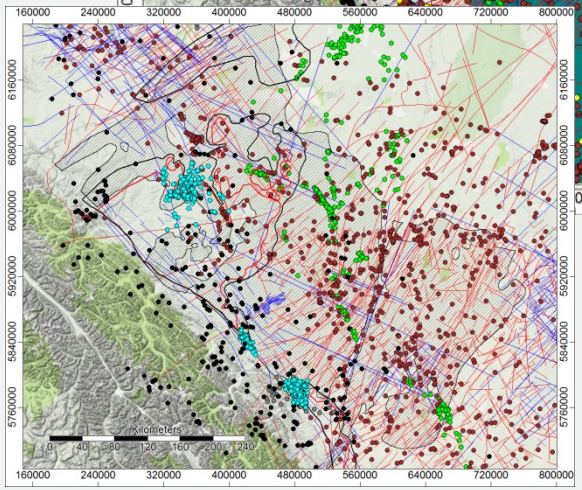
After USGS

Geological Predictors

- Faults/Reef Edges
- Formations of Interest, including influence of temp and pressure (present/not present)
- Dolomite occurrence
- Li and Sr concentrations (indication of basement involvement)
- Pressure and Stress data
- Natural earthquake occurrence
- Basement structure

Overall Picture





Duvernay Formation

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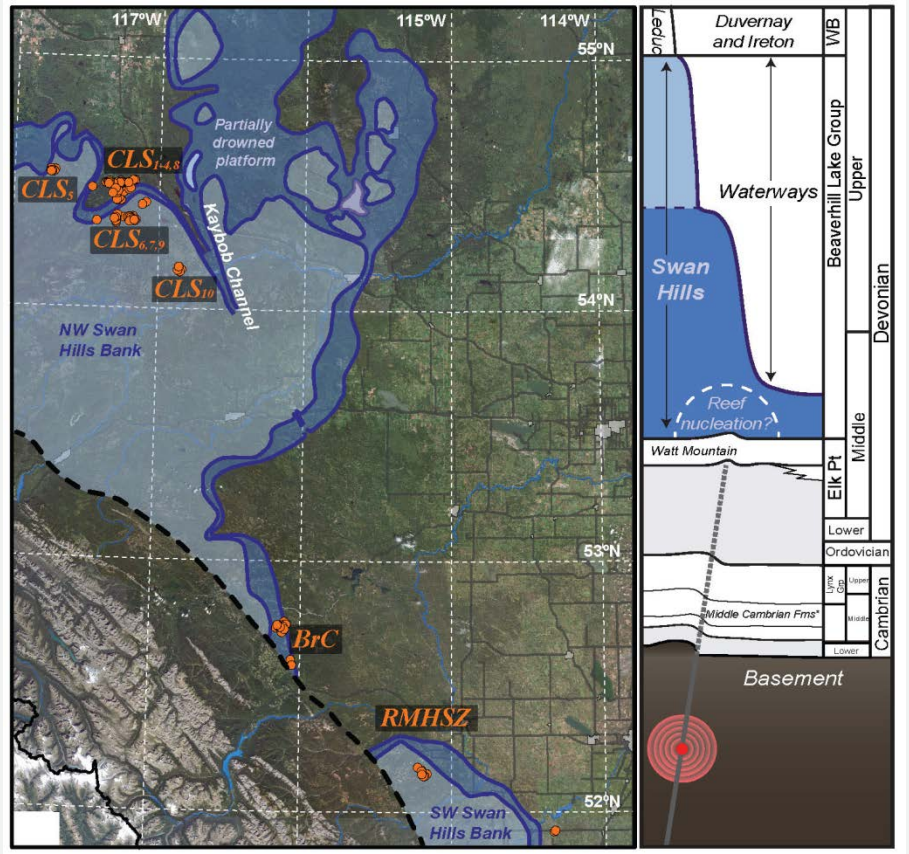
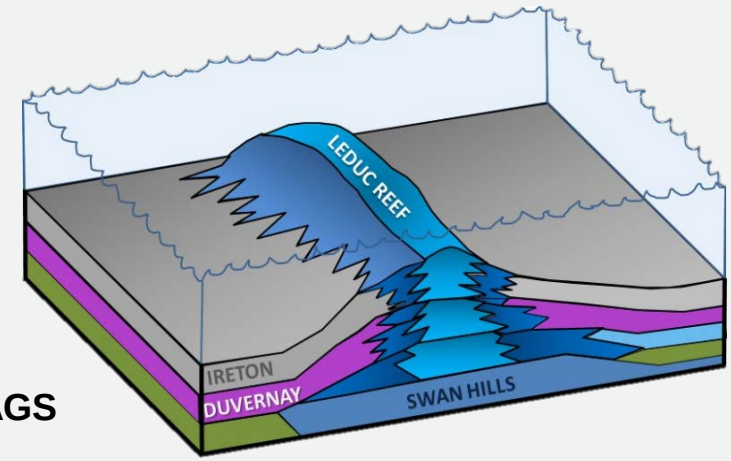
Geospatial Association

Geological features may be used to infer areas with faults that could be prone to reactivation; seismic events near Fox Creek and central Alberta follow a trend along an ancient fossil reef (Schultz et al., 2016)





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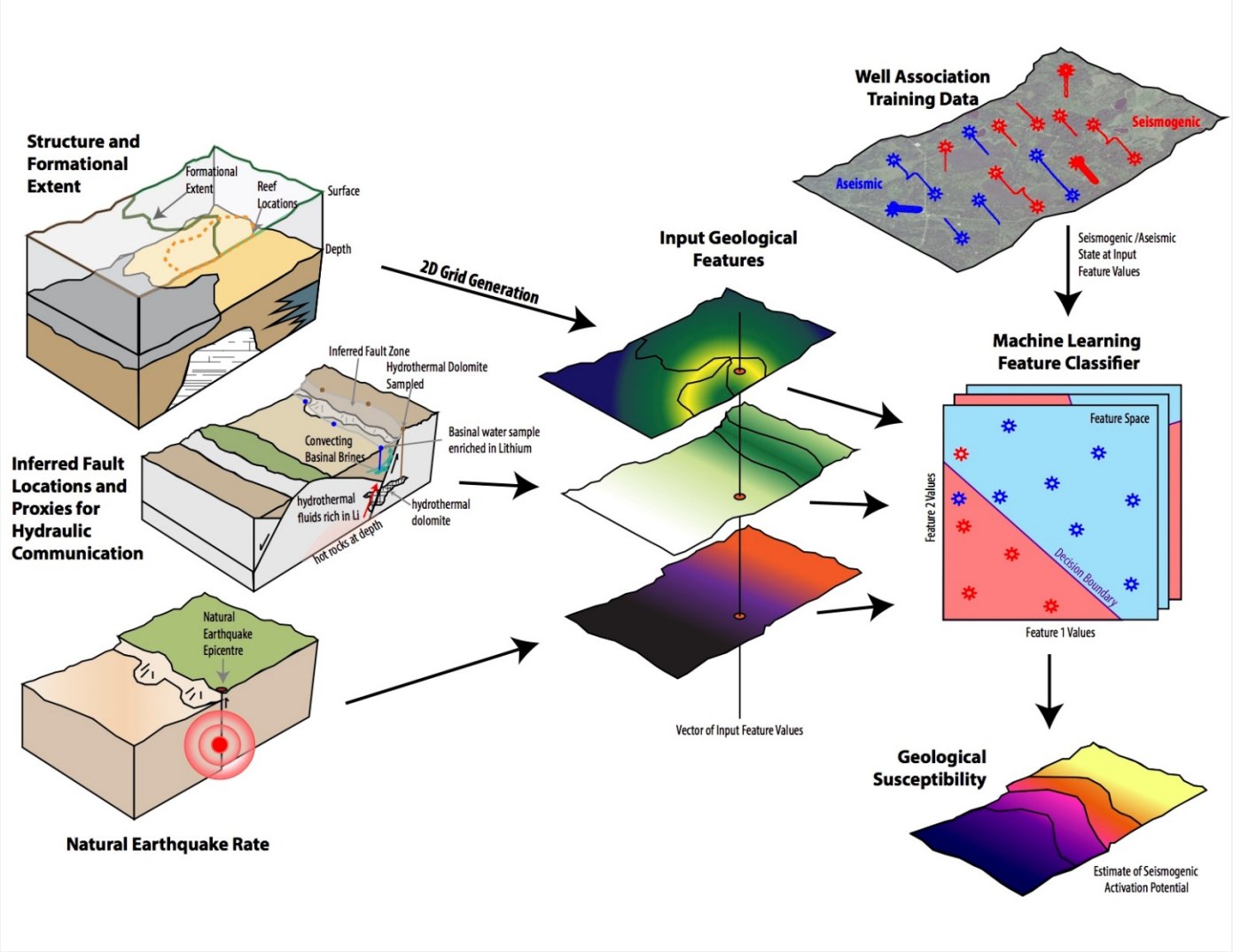
Susceptibility Modeling



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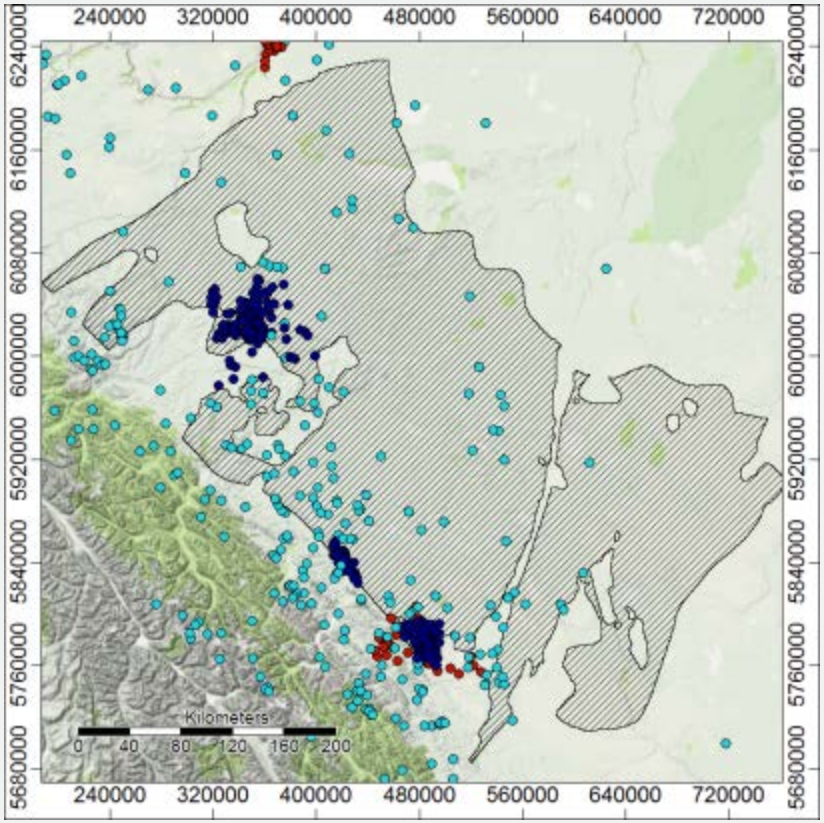
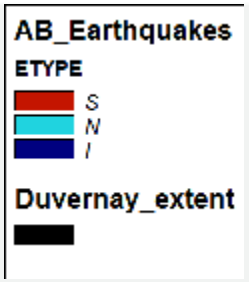
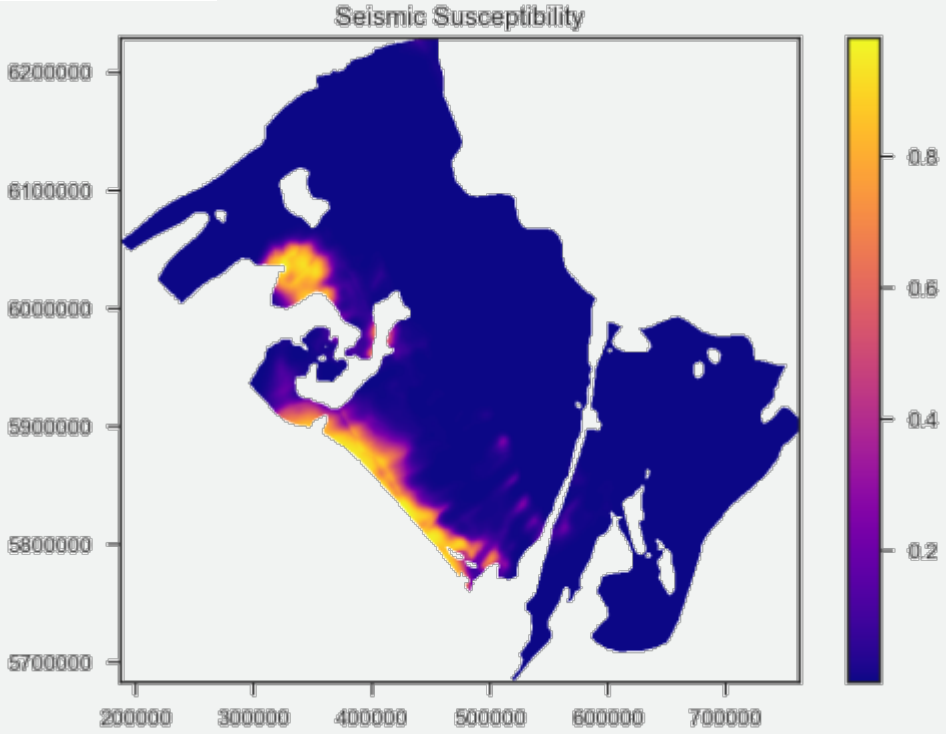
Induced Seismicity Susceptibility

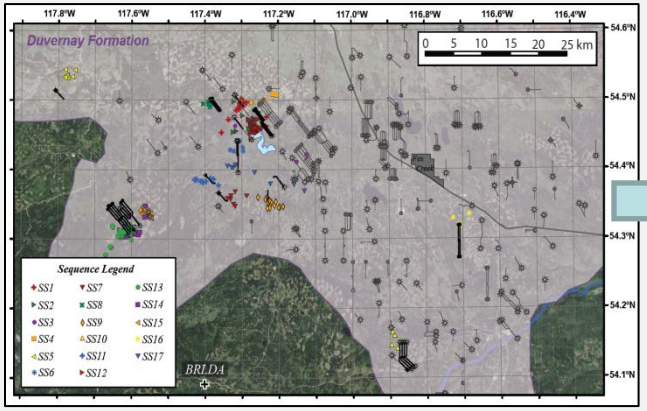




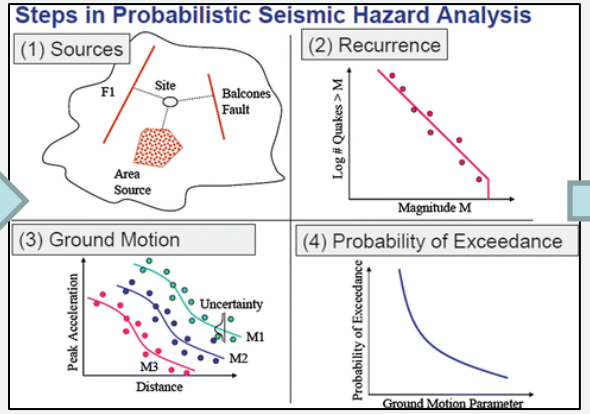


So What? How Does GS Help?

1. Identify & Understand Hazard



2. Quantify Hazard



3. Assess Risk

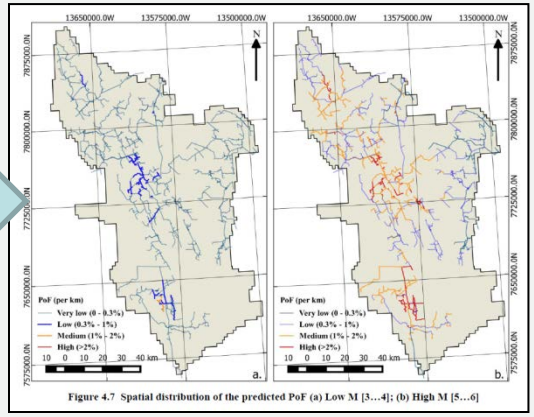


Figure 4.7 Spatial distribution of the predicted PoF (a) Low M [3…4]; (b) High M [5…6]

Allows jurisdictions to make science-informed decisions regarding policy & regulation.

- E.g., Building codes with respect to background seismic hazard.

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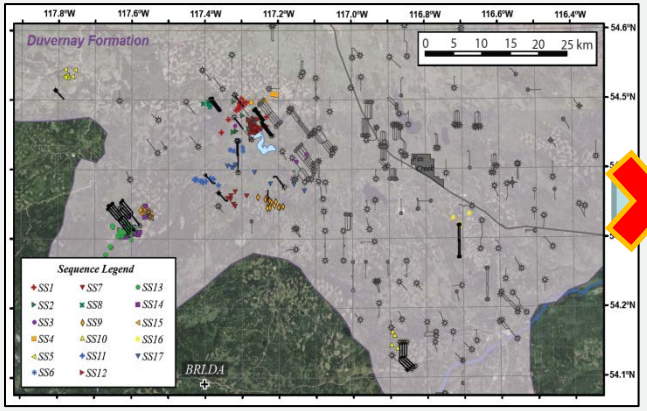

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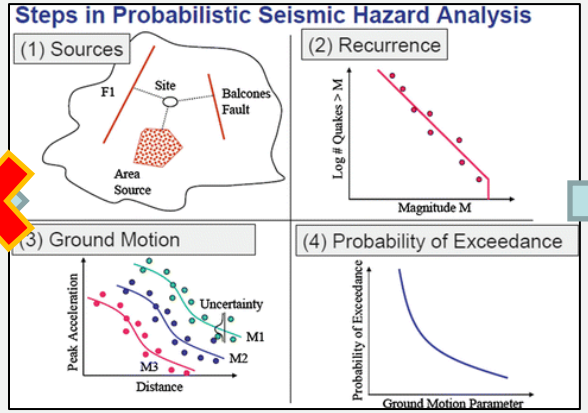

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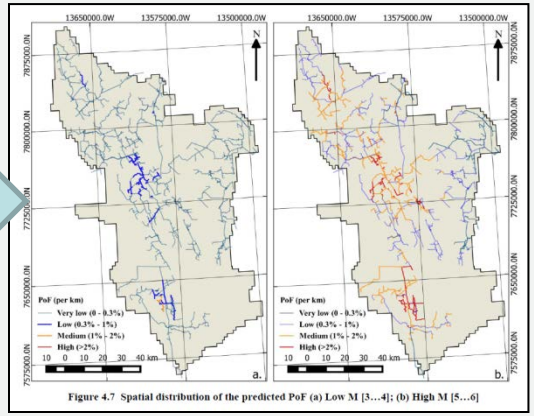


Allows jurisdictions to make science-informed decisions regarding policy & regulation.

- E.g., Building codes with respect to background seismic hazard.

Well defined means to quantify natural seismic hazard, but not induced…

The Problem:

$$N_M = 10^a 10^{-bM}$$

EQ Location Models

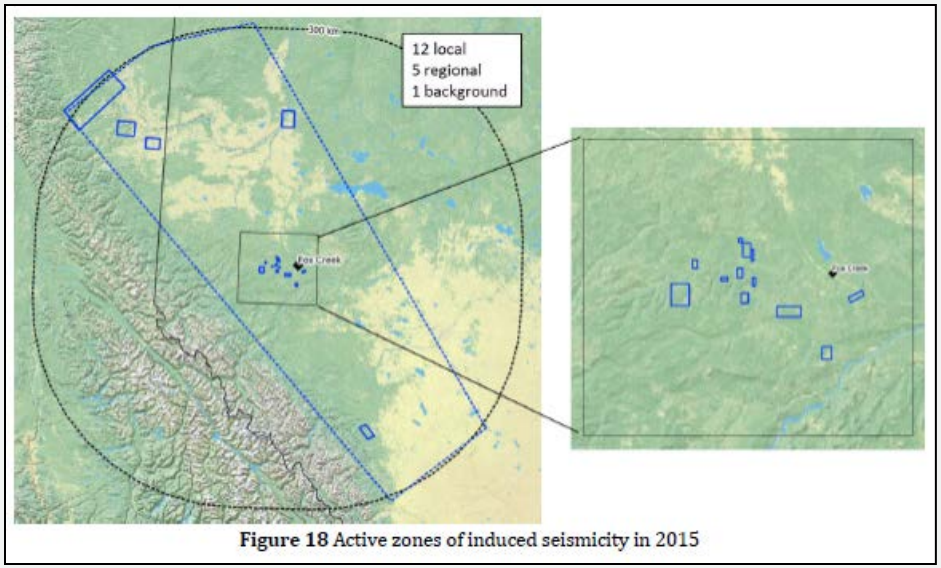
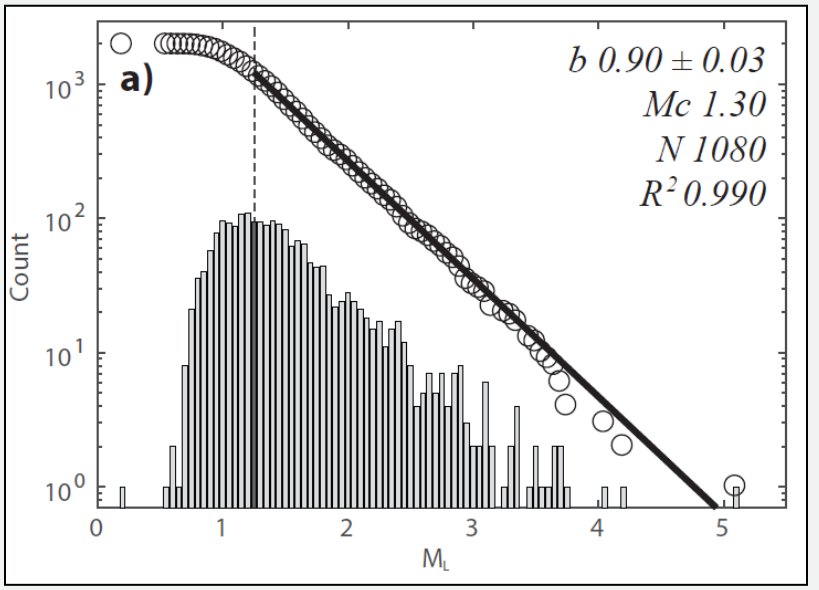


Figure 18 Active zones of induced seismicity in 2015

1. Natural EQs always come from the same place/area

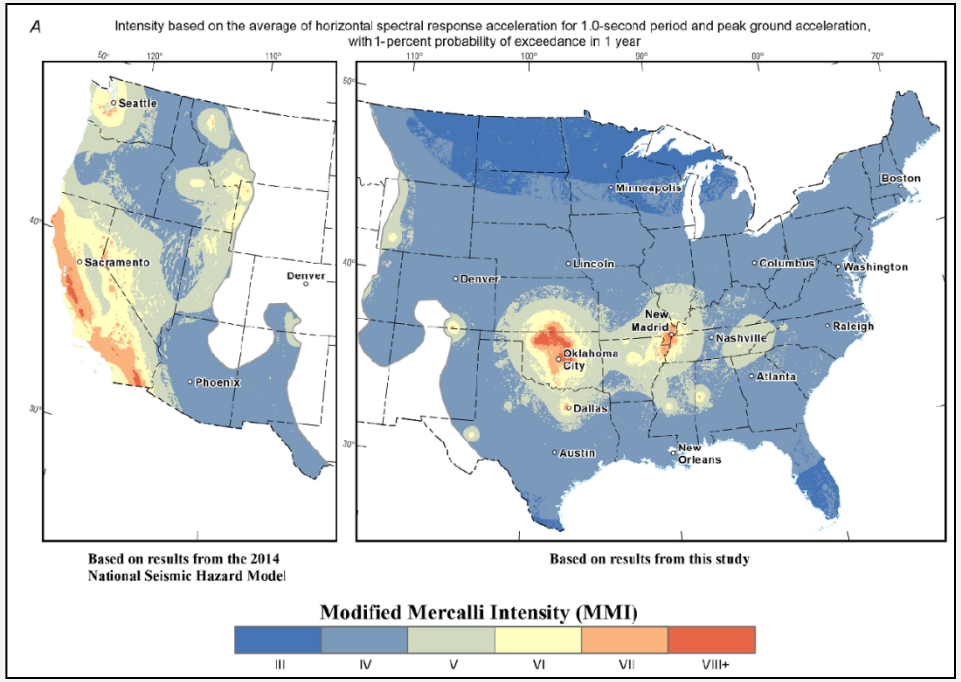
EQ Rate Models



2. Natural EQs are a Poisson process in time.

Current Work-Around

- No one knows how to reconcile this problem.
- Just ignore non-stationarity, assume it holds on small time scales of ~ 1 year.
- Philosophy of recent USGS PSHA IS updates.



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- Similar approach used by AGS for Fox Creek.

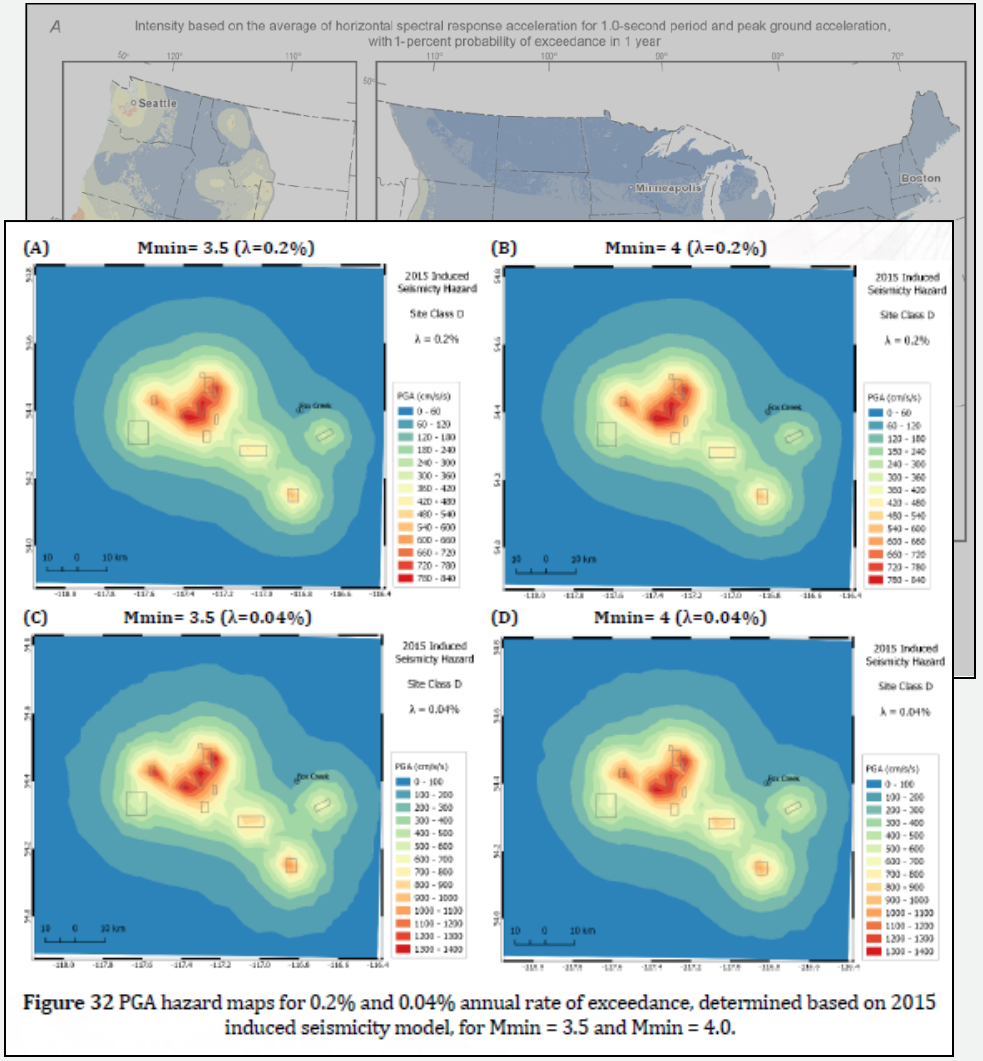

Figure 32 PGA hazard maps for 0.2% and 0.04% annual rate of exceedance, determined based on 2015 induced seismicity model, for Mmin = 3.5 and Mmin = 4.0.

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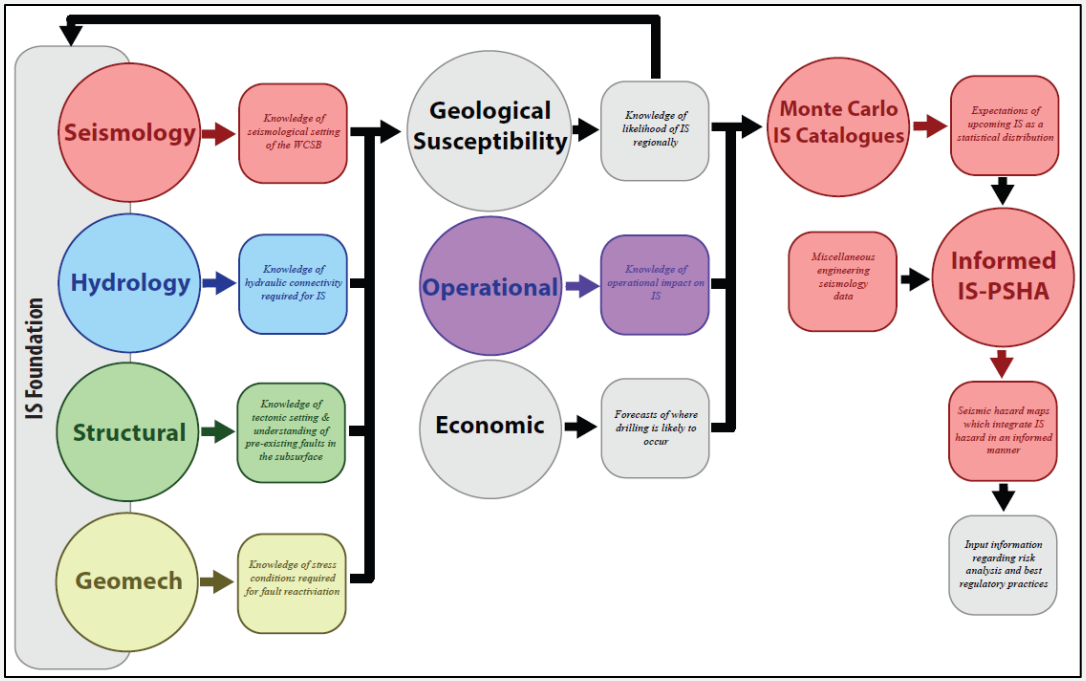
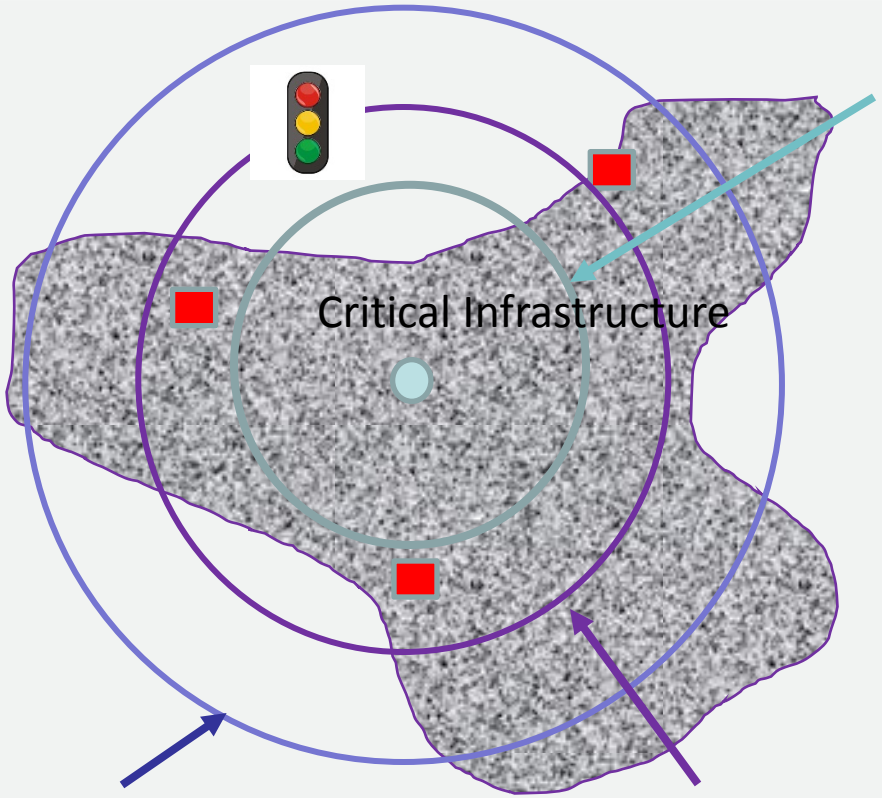
GS in an IS Hazard Framework

- Upcoming work casts GS into an IS hazard framework.
- Geology controls where IS occurs, operators control when it occurs.
- Quantify hazard moving forward.

$$N_M = V(t) \cdot \delta(\bar{r}) \cdot 10^{\Sigma} 10^{-bM}$$



Induced Seismicity Near Critical Infrastructure



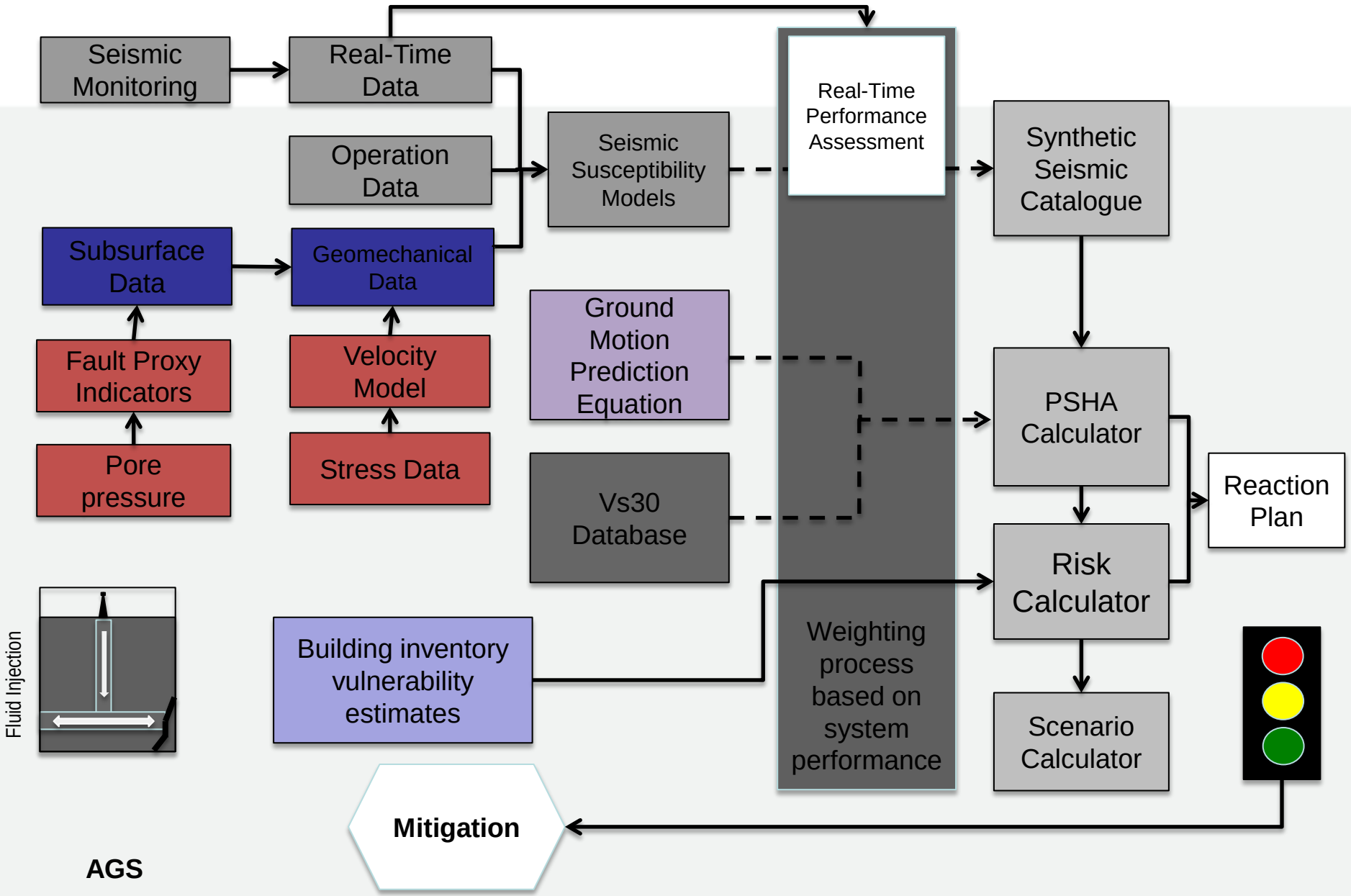
Area of restricted oil and gas development

Resources under application

Well

Site-specific mitigation strategy, traffic light, etc. to restrict potentially damaging ground motion from any susceptible play

Concept of an Adaptive Traffic Light Protocol



Predictive Risk Treatment

- Risk treatments that predict where there is risk and forecast it in order to mitigate it.
- This is a combination of a reactive and proactive treatment, which allows for activity in high risk areas and reacts to change in risk in order to avoid any damaging induced seismicity

Questions

- **Send your questions or comments to:**

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Alberta Geological Survey

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Thank you