Risk Evaluation

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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

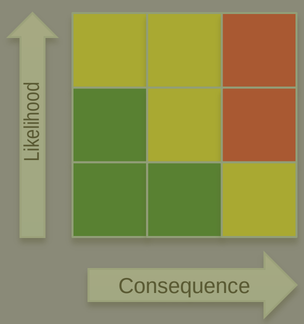
If geological associated, then what is the regional distribution of susceptibility?

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 Assessment

Risk = Consequence X Probability of Hazard

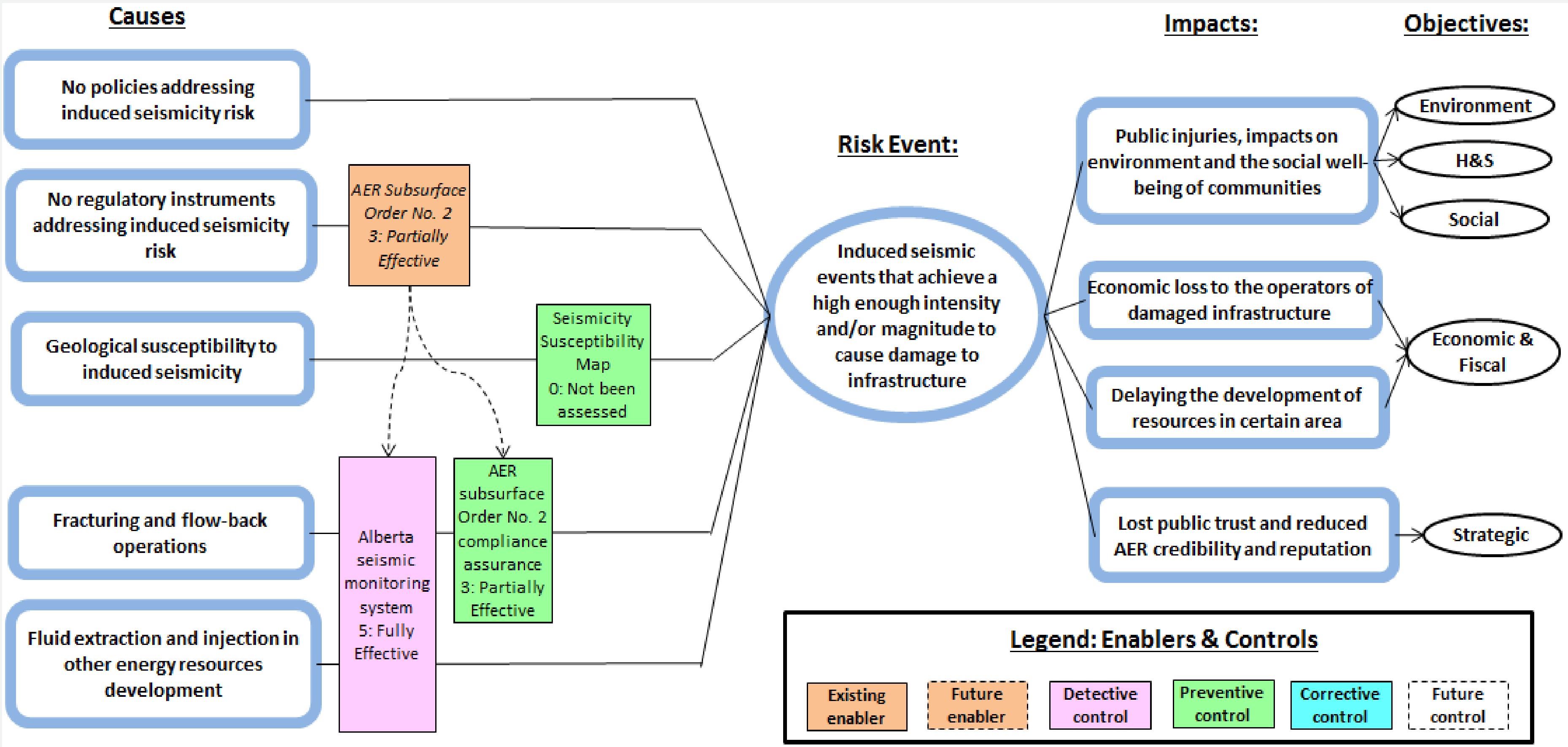
- *Consequence* of failure for extreme, very high, and high consequence infrastructure unacceptable (all agree even though controls could be put in place to reduce consequence)
- *Probability* of IS (induced seismicity) varies based on a number of factors, therefore risk also depends on probability of inducing an event of sufficient magnitude to cause a failure
- Use probability factors to determine risk of IS and identify those regions and zones of higher probability for IS
- Determine if high consequence critical infrastructure occur in these regions
- If yes, then consider risk mitigation options

GOA Common Risk Framework

COMMON RISK MANAGEMENT FRAMEWORK
RISK CRITERIA AND MATRIX

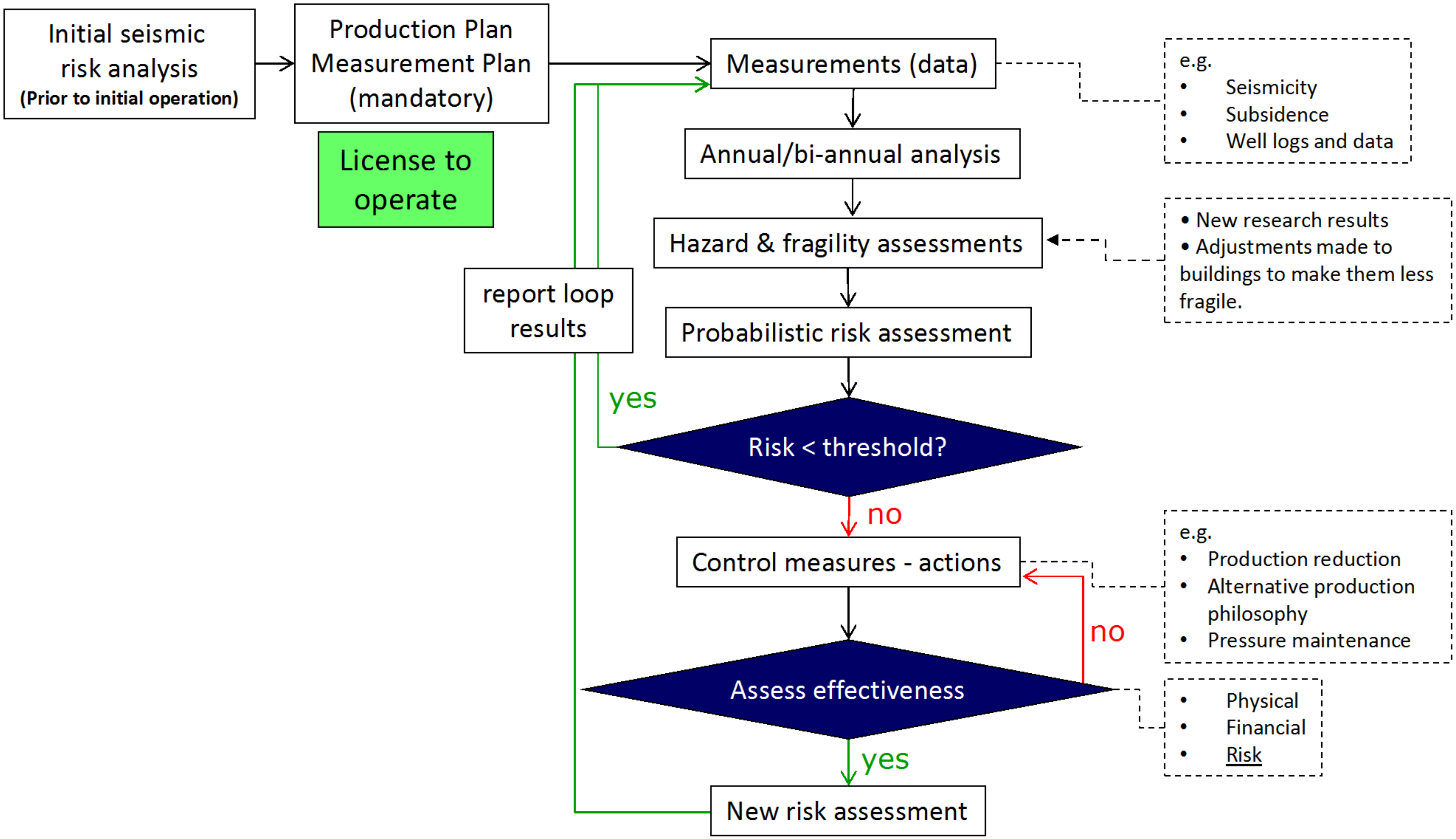
Consequence Categories												
Environmental Impacts	Economic and Fiscal Impacts	Social Impacts	Health Impacts	GOA / AER Operational Impacts	Strategic Impacts							
[Air, Land, Water, and Biodiversity]	[Revenues, Hydrocarbon Development, Investment and Operator Financial Health]	[Disputes and Relationships, Aboriginal Rights, and Community Viability]	[Injuries and Fatalities, Health-Related Limits]	[Business Continuity, Health and Safety, Assets, Budgets, and Information]	[Reputation and Media, Government Objectives, Legal Challenges, and Jurisdictional Issues]							
						Catastrophic	C5					CRITICAL RISK
						Major	C4				HIGH RISK	
						Moderate	C3			MEDIUM RISK		
						Minor	C2		LOW RISK			
						Insignificant	C1					
								L1	L2	L3	L4	L5
								Occurs once in 100 years or more	Occurs once in 30-100 years	Occurs once in 10-30 years	Occurs once in 3-10 years	Occurs once every 3 years
								There is almost no chance this level of impact would be seen	While there is a chance this level of impact would be seen, the odds are small	The chance of this level of impact occurring are roughly 50/50	There is a high likelihood that this level of impact will occur	One can assume this level of impact will occur
								Rare	Unlikely	Possible	Likely	Almost Certain
								Likelihood Levels				

Risk Evaluation Bowtie

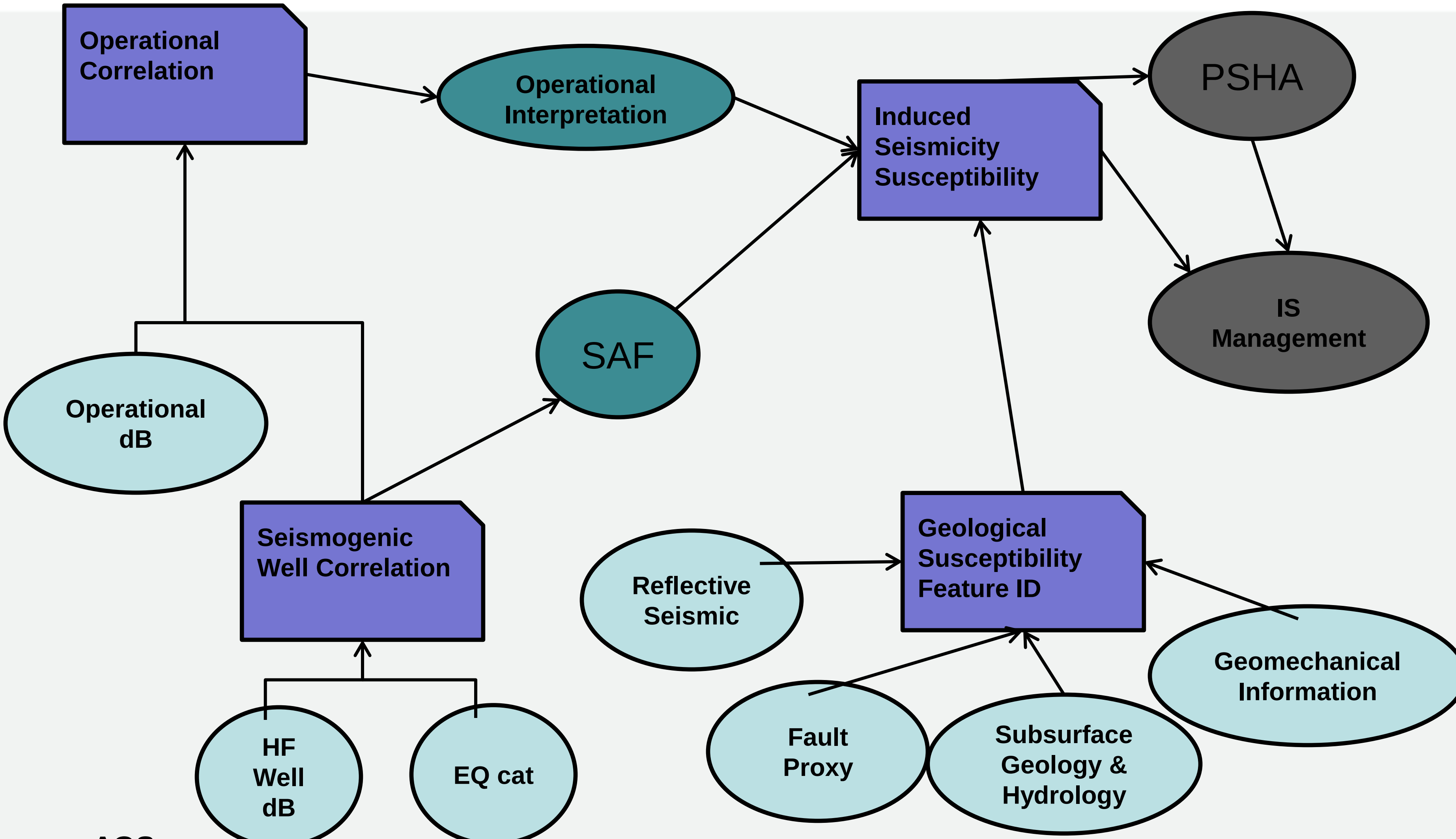


Risk Matrix

Consequence Level	Rare	Unlikely	Possible	Likely	Almost Certain
Catastrophic		Current State		CRITICAL RISK	
Major			HIGH RISK		
Moderate		MEDIUM RISK			
Minor	LOW RISK				
Insignificant					


Initial seismic risk analysis
(Prior to initial operation)
Production Plan
Measurement Plan
(mandatory)
License to operate
Measurements (data)
e.g.
• Seismicity
• Subsidence
• Well logs and data
Annual/bi-annual analysis
Hazard & fragility assessments
• New research results
• Adjustments made to buildings to make them less fragile.
Probabilistic risk assessment
report loop results
yes
Risk < threshold?
no
Control measures - actions
e.g.
• Production reduction
• Alternative production philosophy
• Pressure maintenance
no
Assess effectiveness
• Physical
• Financial
• Risk
yes
New risk assessment

Risk Identification and Analysis Work Flow



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IS Probability of Hazard Factors

Geologic

- Geography - Proximity to foothills/mountains
  - Proximity to historic natural earthquake events
  - Proximity to critically stressed faults
  - Size and orientation of faults
- Geological formation / rock type (lithology) being targeted
  - Unconventional rocks – shales and tight rock higher risk
  - Conventional rocks – sandstones and carbonates low risk
  - Over pressured zones
  - Depth of target zone (distance above basement)

Operations

- Volume of fluid injected
- Injection rates
- Type of hydraulic fracture fluid
- Orientation of wellbore and induced fractures

Probability of Inducing Seismicity

Risk factors (probability of IS)	Risk level	Rationale
1 – deep (near basement), over pressured, ***shale***, close to critically stressed fault, western part of province, large volumes of fracture fluid injected (> 10,000m3)	High	• Only HF operations in ***shales*** in Alberta, B.C., U.K., and the U.S. are known to induce seismic events • In Alberta, IS has occurred in some instances in the Duvernay and Exshaw shales. Shales targeted since 2013 (200 – 300 wells) and have induced events in a few cases. • **These are the only documented HF examples of IS in Alberta**
2 – mid to shallow depth shale or shale east of naturally occurring seismic events	low	• There is a low level of certainty because there are very few of these wells. There are some shallow wells in the Colorado, but not recorded seismic events. Wells were targeting gas and therefore currently uneconomic.
3 – deep, tight rock, western part of province, high volumes of fracture fluid injected	very low	• The Doig and Montney Formations are an example. The Montney is a shale in BC and is associated with IS. It transitions to a siltstone in Alberta and has not been associated with IS. Over 2000 wells completed in the Alberta Doig and Montney and no IS
4 – deep carbonates in western part of province	remote	• No evidence of any IS
5 – all HZ HF sandstone reservoirs regardless of depth or geography	extremely remote	• > 10000 wells in this category with no IS reported at any magnitude • Injected fluid volumes low (~1000 – 4000 m3)
6 – vertical HF wells, all lithology's	extremely remote	• These have been drilled and completed for decades with no IS. Over 180,000 wells

Unconventional

Conventional

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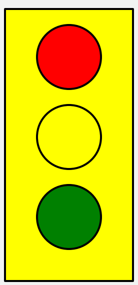
Risk Treatment

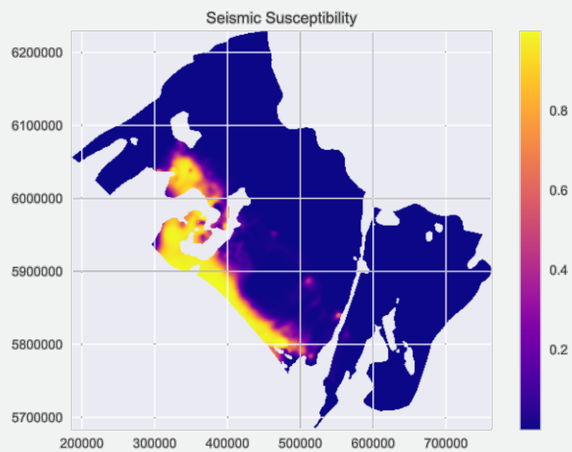
Reactive	Proactive	Predictive

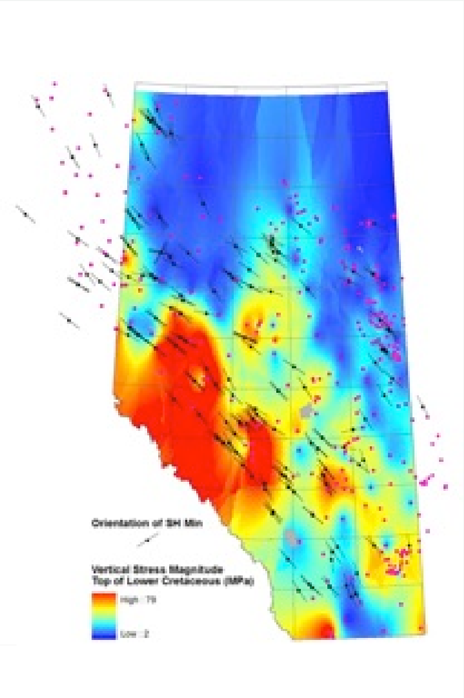


Suspend Operations

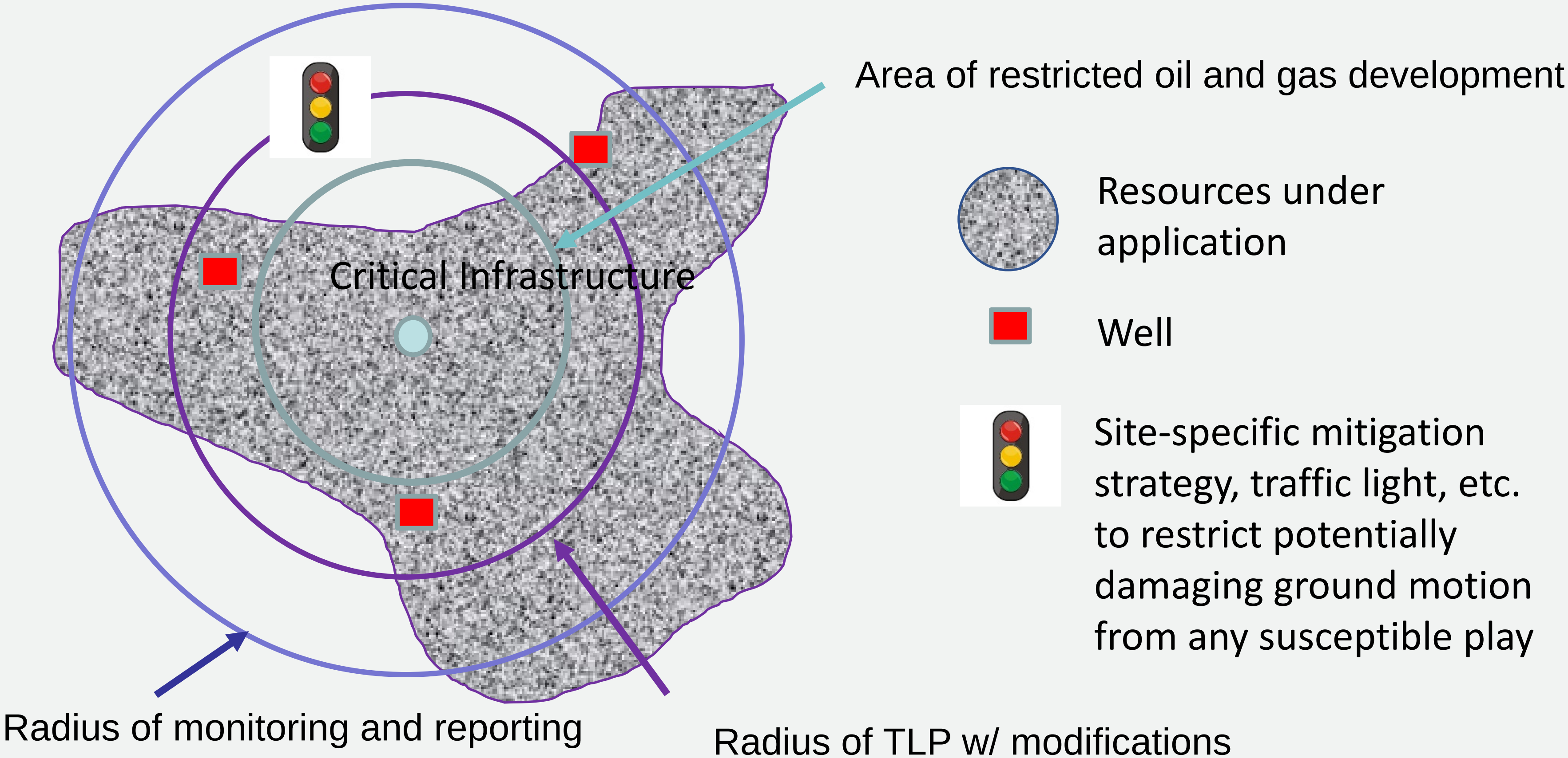
Modify Operations

Normal Operations





Induced Seismicity Near Critical Infrastructure



Questions

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

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Thank you