

Tool Box

Subsurface Assessment Tools

Seismicity

Historic seismic activity

Current seismic activity

Mapping of private & public data - 10 km radius

Reservoir

Area operating records

Well geologic & hydrologic characteristics

Well logs and cores

Well completion & test data

Modeling and Interpretation

Map location of faults

Map basement rock and basement rock faults

Map location of seismic events

Characterize in-situ tectonic stress fields

Characterize injection zone hydrologic parameters

Perform rock and fluid mechanics modeling

Surface Assessment for Potential Risk

Assess seismic event that may be or was felt.

Assess relationships between surface movements, Modified Mercalli Index (MMI), event magnitude and possible scale of fault movement.

Assess potential impact based on population density, infrastructure, and building codes.

Community Relations & Intangible

Goodwill, trust & reputation

Planning Considerations

Define issues to be addressed in plan

Historical & current seismicity

Proximity to faults & fault conditions

Area injection activity & reservoir characteristics

Population density & structures and infrastructure

Monitoring plan / Response plan / Outreach plan

Monitoring Opportunities

Reservoir engineering

Rates, volumes & pressures

Diagnostic analyses

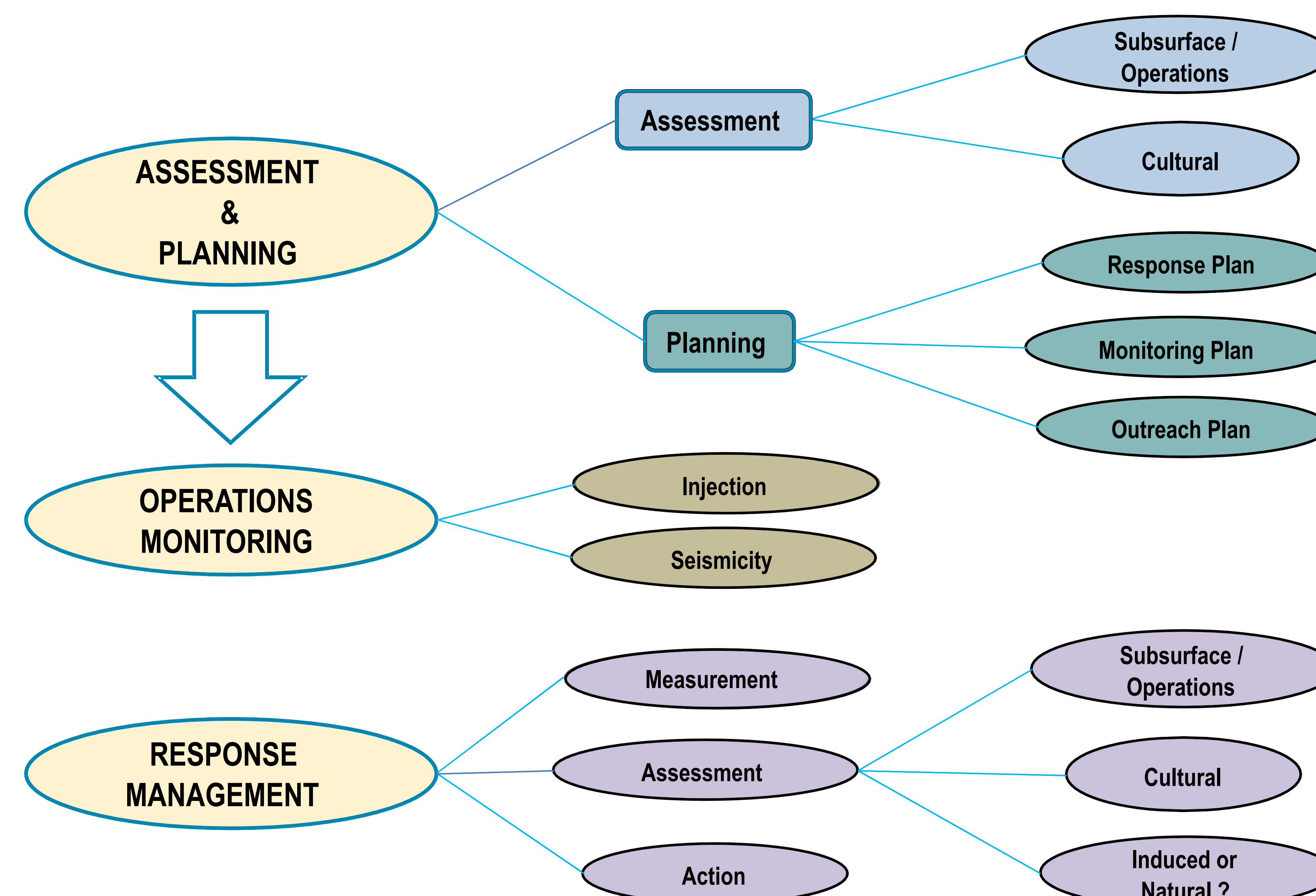
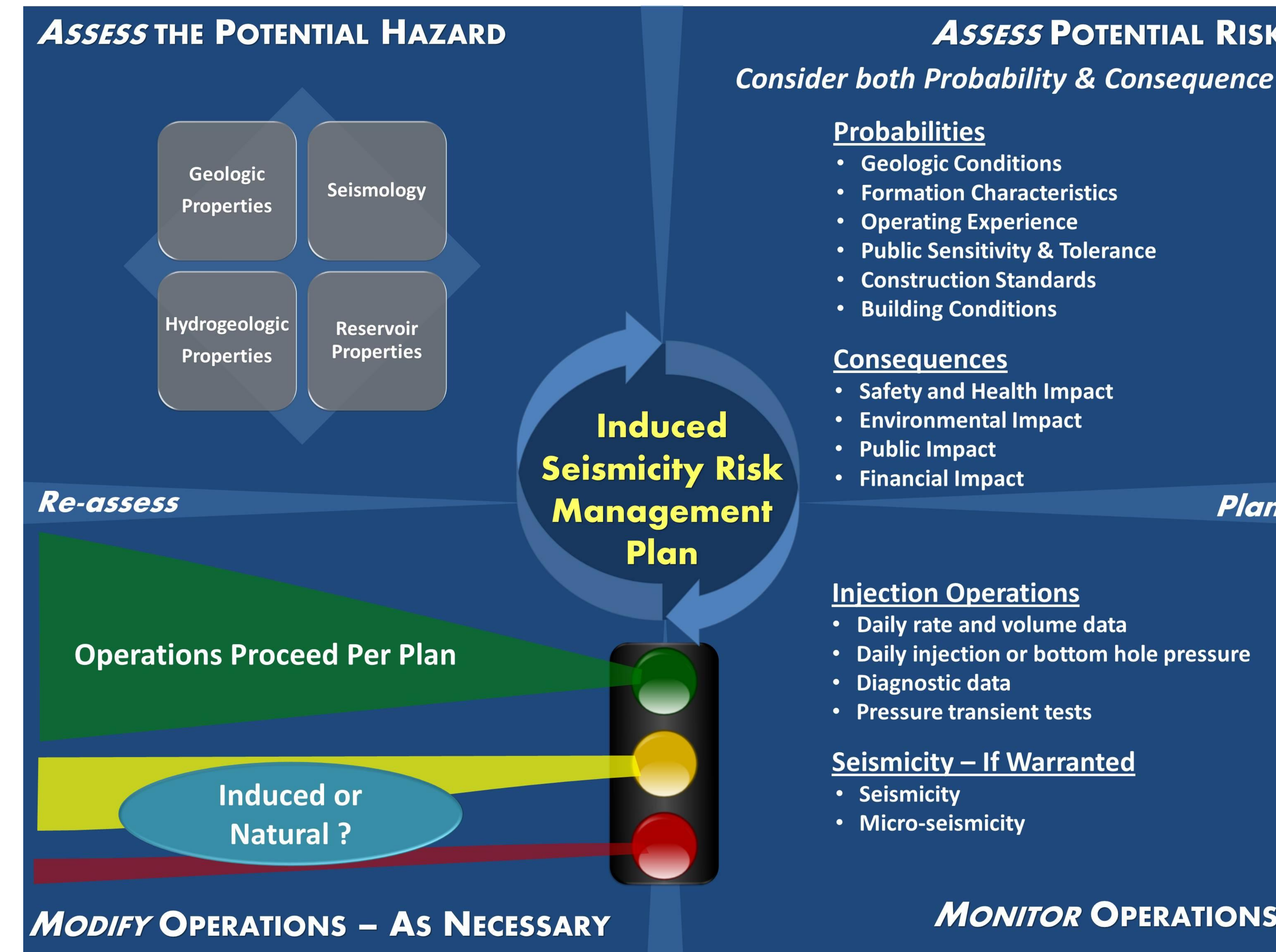
Pressure transient tests

Current seismicity activity

Engineering, geologic, spatial & temporal relationships

Monitoring data: National / Regional arrays, accelerometer, local arrays, buried near-surface receivers, borehole micro-seismic tools.

Injection wells: minimizing the risk of induced seismicity



Traffic Light System

green light: If no potential induced seismicity is observed*, operations proceed as per operations plan. The vast majority of wells will fall in this category.

yellow light: If anomalous low-level seismicity is recorded* that plausibly appears to be spatially and temporally correlated with injection, events and local conditions should be studied to determine whether they are natural or induced. Supplemental monitoring may be initiated.

red light: If moderate-level seismicity is recorded* (e.g. magnitude, ground shaking or recurrence) that plausibly appears to be spatially and temporally correlated with injection, operations should be suspended pending further investigation and discussion with stakeholders.

*Data reported by U.S. National Earthquake Information Center (NEIC) or similar national agency.

Discussion Points

The vast majority of wells will operate in the "Green Light" based on extensive operating experience globally; only under extremely rare conditions may a "Yellow Light" or "Red Light" condition exist. Induced seismicity is not readily or quickly distinguished from naturally occurring seismicity – local geologic conditions must be assessed.

Setting seismicity thresholds for Yellow and Red Lights should be based on local conditions and experience:

- Local relationship between MMI, ground shaking (PGA/PGV), and seismic magnitude
- Rate, intensity, and risk of natural seismicity (based on historical experience)
- Formation Characteristics, Tectonics & Faulting
- Local history of injection experience
- Population density / public sensitivity
- Local Construction Standards / Existing Building Conditions

Possible Cause of Induced Seismicity from Underground Injection

Fluid injection raises pore pressure in subsurface. Region of elevated pore pressure reaches nearby critically-stressed fault. Fault movement in brittle formation, especially in basement rock, causes seismic event(s). Moderate ground motion may result at surface. Very rare occurrence

