Geohazard Assessment for Underground Natural Gas Storage

April 2018

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Executive Summary

For underground natural gas storage ("UNGS"), a geohazard is any natural force or event that can compromise mechanical or functional integrity of the reservoir, wells or surface support that is needed to maintain well control.

Geohazards is one of several different categories of risk assessment and integrity management in API RP 1170/1171 — two guidance documents for UNGS that were adopted as mandatory requirements by the Pipeline and Hazardous Materials Safety Administration ("PHMSA") in the Interim Final Rule ("IFR") for gas storage safety, effective on January 18, 2018.

Pending the PHMSA Final Rule, suitable assessment of geohazards for UNGS facilities can be accomplished through focus on "Weather related and ground movement" geohazards that are called out in API RP 1171.

A storage operator can usefully begin geohazard assessments — and reduce compliance gaps relative to the PHMSA IFR — by taking the following steps:

- **Identify the Weather-Related Hazard that Would Most Seriously Compromise Well Control.** The issue is potential impacts on surface support operations, including the ability to remotely or directly maintain well control through wellhead systems. For many facilities, that geohazard might be flooding, tornados or other types of severe weather.

- **Identify the Ground Movement-Related Hazard that Would Most Seriously Compromise Reservoir or Well Integrity.** The issue is jeopardy to below-ground gas containment, including the ability to monitor reservoir pressure and measure gas migration. For many facilities, that geohazard would be earthquakes or subsidence.

- **For Each Main Geohazard, Develop a Plan to Evaluate Likelihood, Consequence and Detectability into a Risk Priority Number (RPN).** By applying numerical scales to the three key assessment elements, the geohazard can be communicated to regulators in standard terms as:

  \[
  RPN = (\text{Likelihood}) \times (\text{Consequence}) \times (\text{Detectability})
  \]
What is a Geohazard?

A geohazard — also known as a natural hazard — is a natural force or event that can disrupt, damage or destroy human infrastructure or quality of life\(^1\).

Many geohazard events are not predictable while some types of events can be anticipated with warning lead times of a few hours or more. Vulnerability to a geohazard depends on the natural setting and history of a particular facility.

The most commonly recognized geohazards are:

- Earthquakes
- Landslides
- Floods
- Severe weather (including hurricanes)
- Subsidence (including sinkholes)
- Wildfires
- Volcanic eruptions

For underground natural gas storage ("UNGS"), a geohazard is any natural force or event that can compromise mechanical or functional integrity of the reservoir, wells or surface support that is needed to maintain well control.

Not all geohazards are relevant to all UNGS facilities but event types with significant recurrence will require risk assessments in updated operational safety regulations.
Regulation of Underground Gas Storage

Regulation of Underground Gas Storage

UNGS operations in the U.S. historically were the purview of state regulatory agencies with relatively few exceptions — until 2018. Based on a new interim final rule ("IFR") that became effective on January 18, 2018, all UNGS facilities in the U.S. must comply with federal safety requirements promulgated by the Pipeline and Hazardous Materials Safety Administration ("PHMSA").


Data compiled by the Energy Information Administration ("EIA") as of 2016 indicate a total of 415 individual UNGS facilities with a total working gas capacity of 4,812 billion cubic feet ("Bcf") (Table 1). Both by number and by aggregated working capacity, the large majority of UNGS facilities use depleted oil or gas reservoirs (80%) with the remainder apportioned between aquifer reservoirs (10%) and salt cavern reservoirs (10%).

All UNGS facilities and all reservoir types are affected by the PHMSA IFR.

Each storage operator must establish a plan to achieve compliance with the PHMSA rules — even as state regulators adjust to the new PHMSA authority. The PHMSA rules include, but are not limited to, assessment of above- and below-ground geohazards that might affect UNGS facilities.

Table 1. UNGS Facility Inventory in the U.S. as of 2016

<table>
<thead>
<tr>
<th>Reservoir Type</th>
<th>Number of Facilities</th>
<th>Working Gas Capacity (Bcf)*</th>
<th>Total Gas Capacity (Bcf)*</th>
<th>Deliverability (Bcf/d)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depleted Oil or Gas Reservoir</td>
<td>329 (79%)</td>
<td>3,864 (80%)</td>
<td>7,017 (77%)</td>
<td>73.0 (63%)</td>
</tr>
<tr>
<td>Aquifer</td>
<td>47 (11%)</td>
<td>452 (10%)</td>
<td>1,447 (16%)</td>
<td>9.7 (8%)</td>
</tr>
<tr>
<td>Salt Cavern</td>
<td>39 (10%)</td>
<td>496 (10%)</td>
<td>679 (7%)</td>
<td>33.9 (29%)</td>
</tr>
<tr>
<td>TOTAL</td>
<td>415 (100%)</td>
<td>4,812 (100%)</td>
<td>9,143 (100%)</td>
<td>116.6 (100%)</td>
</tr>
</tbody>
</table>

All data summarized from U.S. Energy Information Administration (EIA).
* 1 Billion cubic feet (Bcf) = 0.02832 Billion cubic meters (Bcm).
To establish technical criteria for rule compliance, the PHMSA IFR adopted by reference two
Recommended Practices (RPs) published by the American Petroleum Institute (API) — API RP
1170\(^4\) for salt caverns and API RP 1171\(^5\) for depleted oil or gas reservoirs and aquifers. Both of
the API RPs included abundant “shall” and “should” statements that were distinguished by API as:

- **Shall** — Denotes a minimum requirement in order to conform to the specification.
- **Should** — Denotes a recommendation or that which is advised but not required in order to conform to the specification.

The PHMSA IFR made all “shall” and “should” statements equally mandatory but, after receiving
considerable feedback from storage operators, PHMSA declared a limited grace period on
compliance with “should” requirements\(^6\). “Shall” requirements remained mandatory and enforceable
as of January 2018 but “should” requirements will not be enforced until one year after publication of
the PHMSA Final Rule — which is expected before the end of 2018.

Because they apply to different reservoir types, API RP 1170 and API RP 1171 identify a variety of
compliance criteria for operational and functional integrity of reservoirs, wells and essential surface
support — the appropriate set of criteria for an individual facility depends on the reservoir type
that pertains to the facility.

Geohazards is one of several different categories where risk assessment and integrity management are addressed in API RP 1170/1171. The remainder of this paper focuses only on geohazards.
Geohazards Relevant to Gas Storage

Table 2 summarizes the PHMSA IFR adopted-by-reference identification of geohazards by reservoir type, including classification of assessment criteria as “shall” or “should” statements as they relate to existing or prospective PHMSA safety rules for UNGS.

Table 2. Geohazard Considerations per PHMSA IFR

<table>
<thead>
<tr>
<th>Reservoir Type</th>
<th>Geohazard Description</th>
<th>API RP Standard — Section(s)*</th>
<th>“Shall” or “Should” Statement**</th>
</tr>
</thead>
</table>
| Depleted oil / gas reservoir or aquifer | Outside force — natural causes  
Weather related and ground movement  
- Heavy rains, floods, lightning, earth movements, groundwater table changes, subsidence, etc. that could result in:  
- damage to facilities/impact to service reliability | 1171 — 8.4.2                  | “The operator **shall** evaluate the potential threats and hazards impacting storage wells and reservoirs.”  
“The operator **should** estimate risk from potential events that could occur related to potential threats and hazards to individual facilities, such as wells, and by region when considering the reservoir.”  
“The operator **should** perform periodic evaluations of hazards, threats, and risks related to potential events in order to account for changes in perception of likelihood or consequence in event potential.” |
| Salt Cavern                        | Elements of uncertainty that pose particular risks in salt include but are not limited to the edge of salt, shear zones, faults, high impurity zones, K-Mg salts, weak zones, zones with high creep potential, dissolution or collapse zones, nearby wells or other subsurface activities. | 1170 — 5.4.3.2 | “Additional buffer **should** be assessed on a site by site basis by a qualified geologist to account for uncertainty in locating the exact edge of salt and to allow for the possibility that salt quality with regard to geomechanical strength properties and impurity content tends to degrade towards the edge of salt.” |

* “1170” refers to API RP 1170 (see Reference 4); “1171” refers to API RP 1171 (see Reference 5).  
** Quoted from Standard but with emphasis added on “shall” and “should” as they occur
At the top level of comparison, it is apparent that specification for geohazard assessment is a “shall” requirement only for depleted oil or gas and aquifer reservoirs, per API RP 1171. Indeed, prescription of formalized risk assessments appears only in API RP 1171. In contrast, the corresponding standard for salt cavern reservoirs, API RP 1170, does not include formalized risk management and expresses only more generalized references to hazards. Until the PHMSA Final Rule is published, it is arguable that geohazard assessment is required only for UNGS facilities that use depleted oil or gas and aquifer reservoirs.

A major unresolved issue is whether the PHMSA Final Rule will require geohazard assessments for salt cavern reservoirs as the Interim Rule already does for depleted oil or gas and aquifer reservoirs. Resolving that question will require clarification from PHMSA as to which “should” statements are mandatory and whether the two adopted-by-reference standards — API RP 1170 and API RP 1171 — are to be applied separately or together for the purpose of UNGS integrity management.

Fortunately, the geohazard assessment approaches as recommended in this paper can be applied to any UNGS facility. Tailoring of the assessments may still be necessary by reservoir type but data and documentation can follow similar templates. By making early adoption of geohazard assessment methods, a storage operator can substantially reduce the gap between current or anticipated regulations and current facility practices.
The most actionable geohazard assessment criteria under the PHMSA IFR relate to “Heavy rains, floods, lightning, earth movements ...” (Table 2) as named in API RP 1171.

Severe weather and floods can be evaluated using historical storm data. Likewise, earth movements can be evaluated through historical data for earthquakes (sudden movements) and subsidence (gradual sinking of the ground).

**Example: Floods and Earthquakes**

Top-level assessment of geohazards can be illustrated by comparing geographic distribution of flood events (Figure 2) with distribution of earthquake events (Figure 3).

Flood hazards are significant for UNGS facilities because floods can either disable or destroy surface support systems that are needed to maintain well control, including wellheads or SCADA connections to wellheads, or prevent access to those control systems by covering roads with high water.

Earthquake hazards are significant for UNGS facilities because ground shaking can potentially degrade reservoir integrity — possibly affecting gas containment — or damage well tubing, casing or other hardware.

Figure 2 shows the geographic distribution of UNGS facilities relative to recurrence of flood events as documented in the U.S. National Weather Service Flash Flood Observation Database. The density of flood-event polygons (red squares) indicates the relative frequency of floods by location.

Figure 3 shows the geographic distribution of UNGS facilities relative to the U.S. Geological Survey’s Seismic Long-Term Risk Map. The prospective recurrence of earthquake hazards is indicated by the contoured spacing of potential peak ground movements (red lines) — as a percentage of gravitational acceleration (approximately 32.2 feet per second-squared) — over a period of 50 years. Increasing tightness in contour spacing indicates increasing likelihood for stronger ground shaking.
The main takeaways are that (a) flood hazards may be significant for many UNGS facilities in the eastern half of the conterminous U.S. but less so in the west; (b) earthquake hazards may be significant for many UNGS facilities in the western half of the U.S. but also in the U.S. Midwest — with minimal earthquake hazards along the Gulf Coast.

Figure 2. UNGS Facilities Relative to Flood Hazards

Figure 3. UNGS Facilities Relative to Long-Term Seismic Hazards
Pending the PHMSA Final Rule, suitable assessment of geohazards for UNGS facilities can be accomplished through focus on “Weather related and ground movement” geohazards that are called out in API RP 1171 (Table 2).

A storage operator can usefully begin geohazard assessments — and reduce compliance gaps relative to the PHMSA IFR — by taking the following steps:

- **Identify the Weather-Related Hazard that Would Most Seriously Compromise Well Control.** That geohazard would be the one to most significantly impact surface support operations, including the ability to remotely or directly maintain well control wellhead systems. For many facilities, that geohazard would be flooding — but for other facilities it might be tornados or other types of severe weather.

- **Identify the Ground Movement-Related Hazard that Would Most Seriously Compromise Reservoir or Well Integrity.** That geohazard would be the one to most significantly threaten below-ground gas containment, including the ability to monitor reservoir pressure, measure gas migration and verify inventory. For many facilities, that geohazard would be earthquakes — but for other facilities it might be subsidence or associated aquifer changes.

- **For Each Main Geohazard, Develop a Plan to Evaluate Likelihood, Consequence and Detectability into a Risk Priority Number (RPN).** Historical data are excellent starting points for establishing event likelihood whereas facility or industry experience usually serves to inform on severity of consequences. Detectability depends on the nature of the event — for example, floods often are predictable hours or days ahead whereas earthquakes typically occur with no actionable warnings.

By applying numerical scales to the three assessment elements, the geohazard can be communicated to regulators in standard terms as:

\[
RPN = (\text{Likelihood}) \times (\text{Consequence}) \times (\text{Detectability})
\]
References and Notes


7. **SCADA.** Supervisory control and data acquisition (SCADA) or equivalent electronic systems for remotely operating wellheads or other equipment that controls gas flow.


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Geoclime, LLC
P.O. Box 13
1600 Main Street
Seabrook, Texas 77586 USA

Telephone: +1 281-451-8375
Website: https://www.geoclime.com
E-mail: info@geoclime.com