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Bayesian Benchmarking of Off-Normal Occurrence Frequencies for US Underground Natural Gas Storage Facilities

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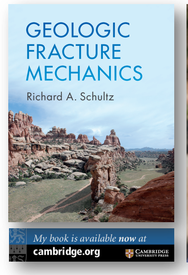
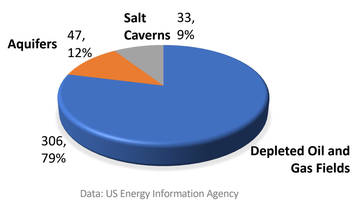
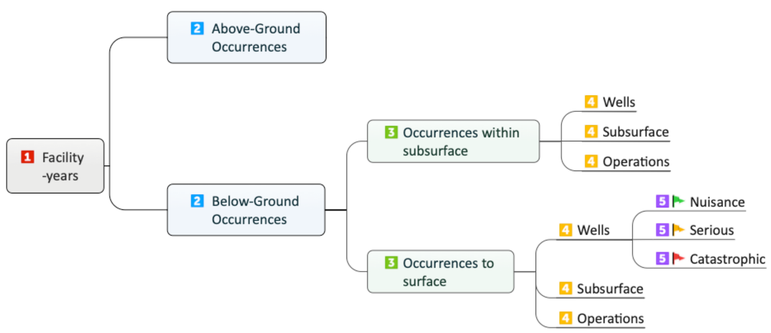


Types of UGS Storage Facilities (US): 386 ±



Data: US Energy Information Agency



Overview

Natural gas (methane) is a critically important component to the energy economies of the United States and other countries. Because storage capacity in the above-ground pipeline network is insufficient to meet demand, natural gas is stored in large underground (UGS) facilities.

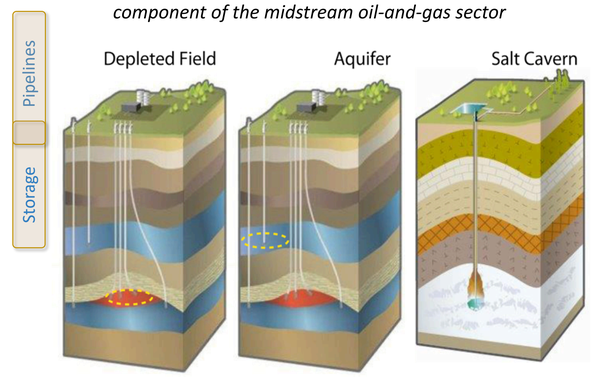
Defining a baseline for the frequency of reported and documented *off-normal occurrences* (≡ any reported or documented issue, event, incident, accident, or failure with or without leakage arising during routine operations at any given facility, of any cause or magnitude of severity, that may have involved human error, process safety, mechanical or operational issues, or natural events) at UGS facilities is critical to maintaining safe operation and to the development of appropriate risk management plans and regulatory approaches.

A Bayesian probabilistic analysis characterizes the historical US occurrence frequencies. Frequencies for the three main UGS facility types are 3 to 9 x 10^{-2} occurrences per facility-year, of all causes and severities. Loss of well integrity is associated with many, but not all, occurrences.

Well integrity loss contributes to
- 72% of occurrences within the geologic subsurface, all severities
- 91% of occurrences to the ground surface, all severities

Operators and regulators can
- Choose risk tolerance (e.g., 1%) and identify frequency reductions that can achieve this
- Quantify probabilities for occurrences by cause, field type, degree of severity
- Assess success of Risk Management Plans by comparing targets to baseline

3 main types of UGS facilities showing the underground storage component and the transport (pipeline) component of the midstream oil-and-gas sector



Calculated Bayesian occurrence frequencies to surface per facility-year for increasing severity magnitude group, wells and subsurface causes combined. Note reversed scale for occurrence frequency, decreasing toward top of figure. Small filled symbols, scalar arithmetic mean frequencies of number of occurrences to surface per facility-year; larger filled symbols are Bayesian occurrence frequencies for each facility type with P5, P50, and P95 exceedance probabilities shown by error bars. Values for aquifer mean occurrence frequencies of zero are not plotted.

Arithmetic Averages

$$\text{Frequency} = \frac{(\text{Number of Occurrences})}{(\text{Number of Facilities})(\text{Number of Years})}$$

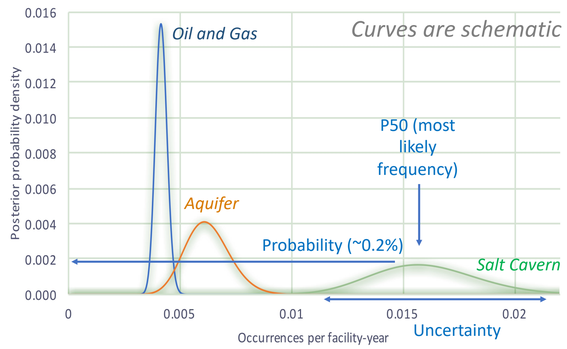
$$\text{or} = \frac{(\text{Number of Occurrences})}{(\text{Number of Wells})(\text{Number of Years})}$$

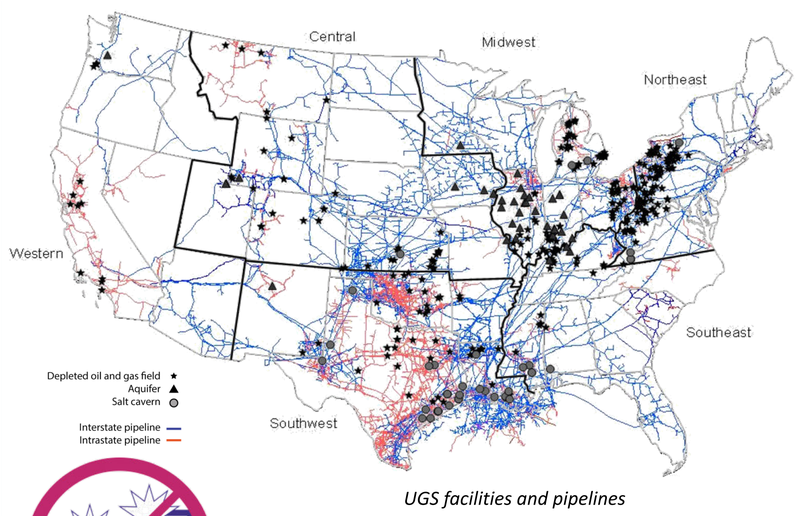
Example: 0.005 or 5 x 10^{-3}
- Increases with number of occurrences, decreasing number of facilities
- Decreases with increasing years of operation
- Uncertainties rarely calculated
- New estimates made in isolation from previous ones

Bayesian inversion was used to calculate the probability of an occurrence frequency that was incompletely sampled by the historical occurrence data. The frequency of occurrences was modeled by a binary choice (occurrence/no occurrence) per facility-year, corresponding to a Bernoulli trial and calculated using the BETAINV and BINOM.INV functions in Excel™

Bayesian Statistics: Binomial Distribution

- Models occurrence frequency relative to a random number of (yes/no) occurrences
- Provides probability (likelihood) of occurrences at given frequencies
- Compares new data against prior values to update frequencies using new numbers for facilities, wells, years of operation, and occurrences





UGS facilities and pipelines

Material was drawn from a paper by the same authors that has been accepted for publication in *Risk Analysis*