Defining Metrics for Reliability of Hydraulic Fracturing Operations in Shale Gas

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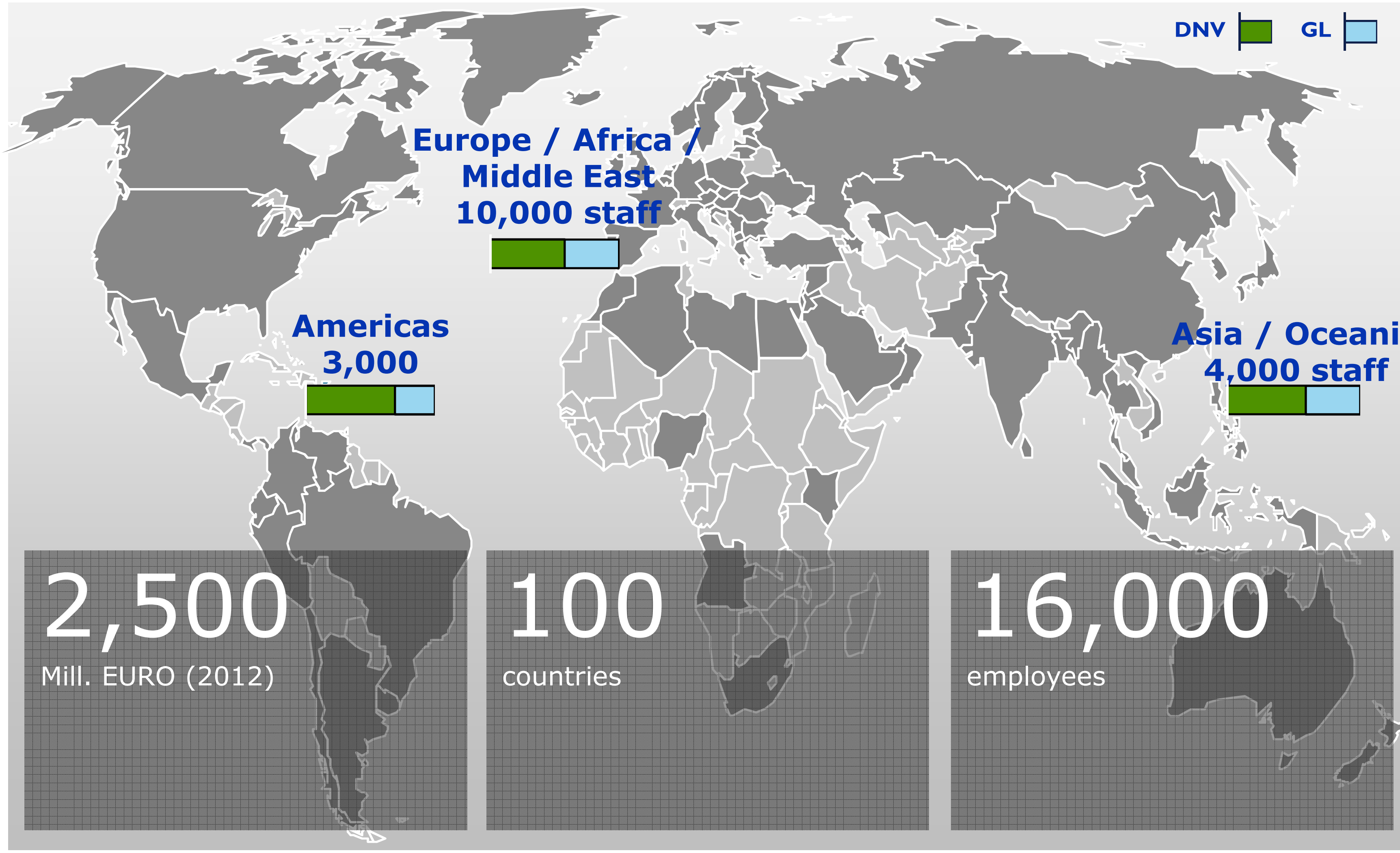
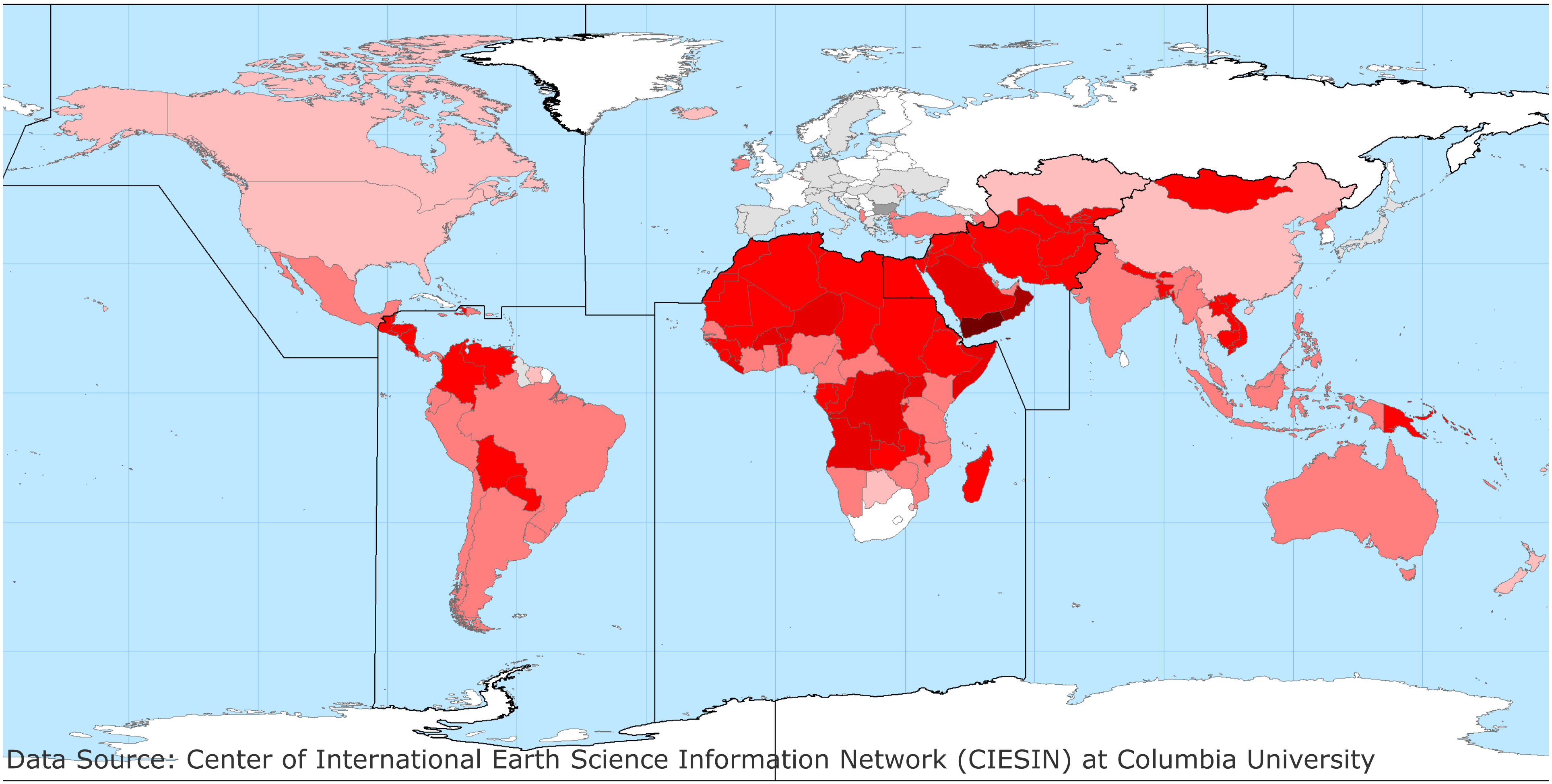


DNV
GL
Europe / Africa / Middle East
10,000 staff
Americas
3,000
Asia / Oceania
4,000 staff
2,500
Mill. EURO (2012)
100
countries
16,000
employees

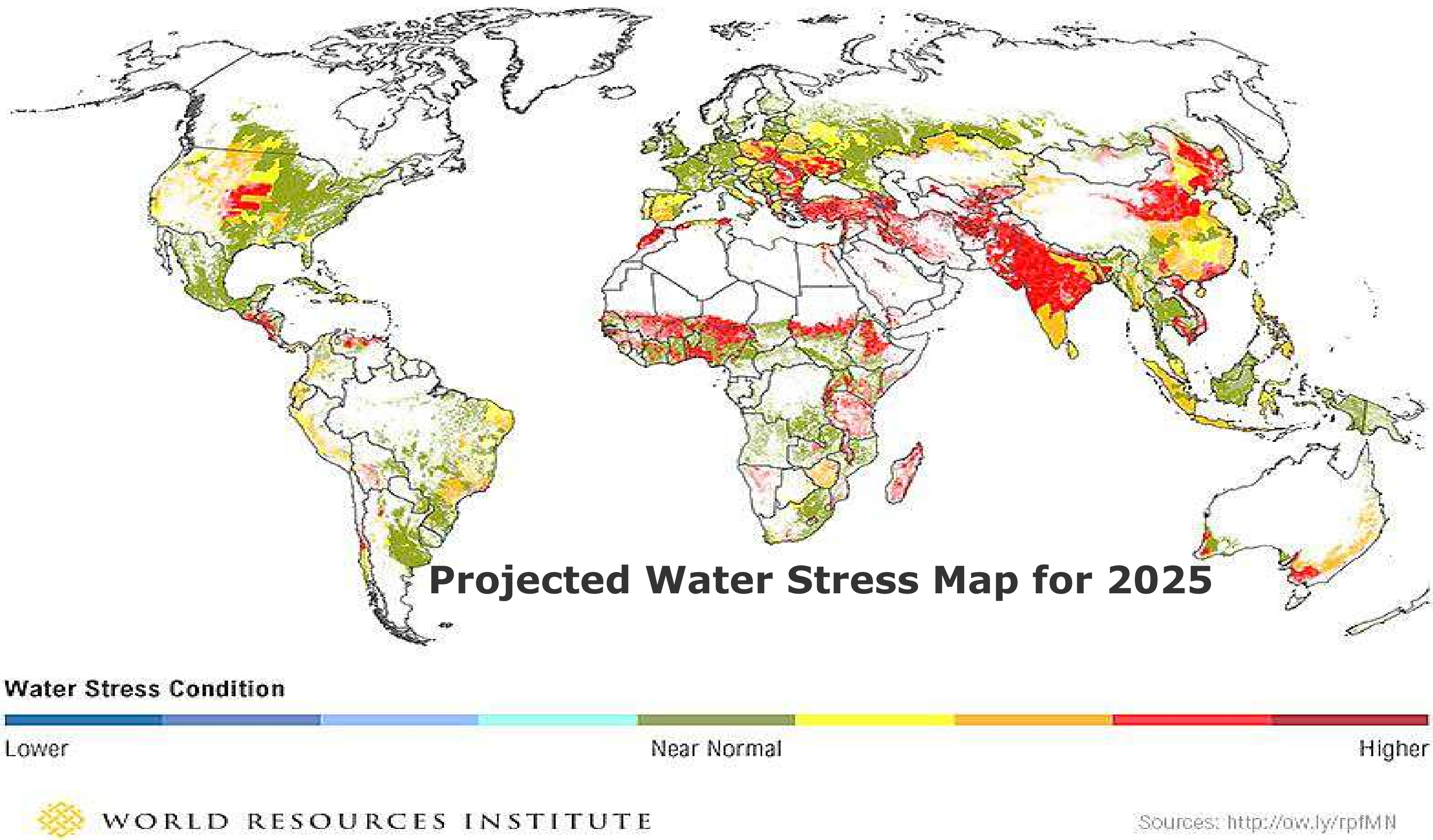
Motivation

Projected Change in Population from 2000- 2050



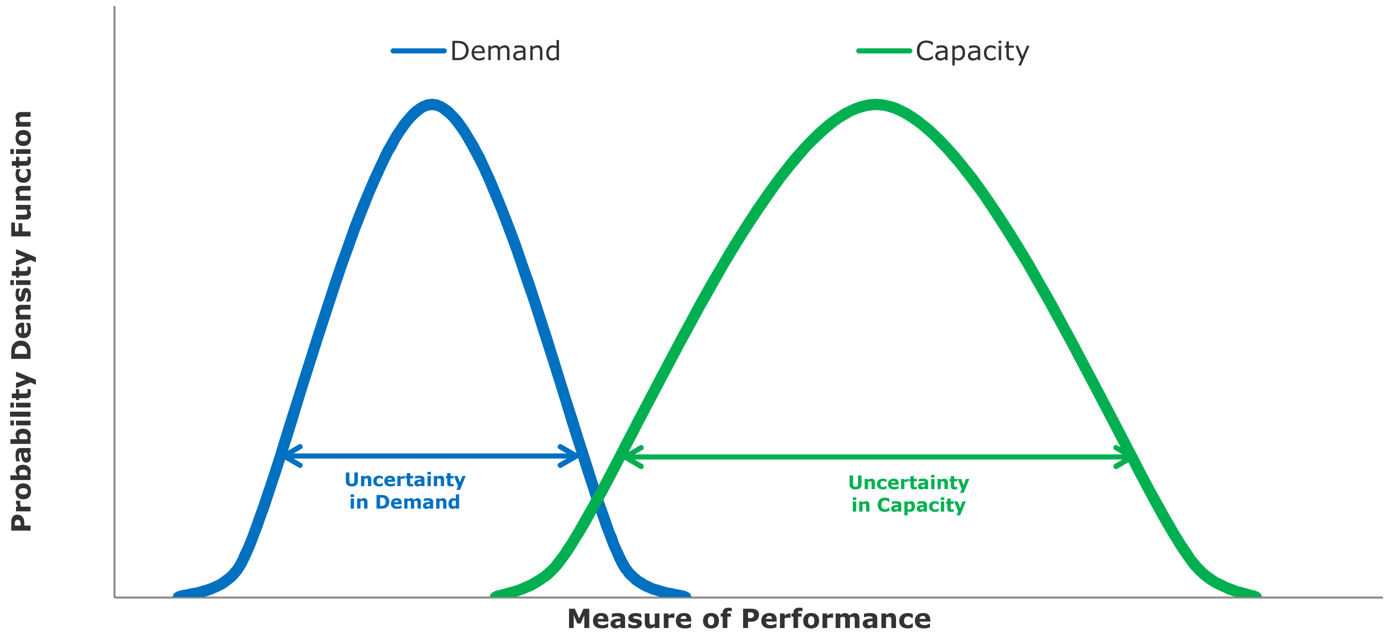
Data Source: Center of International Earth Science Information Network (CIESIN) at Columbia University

Motivation

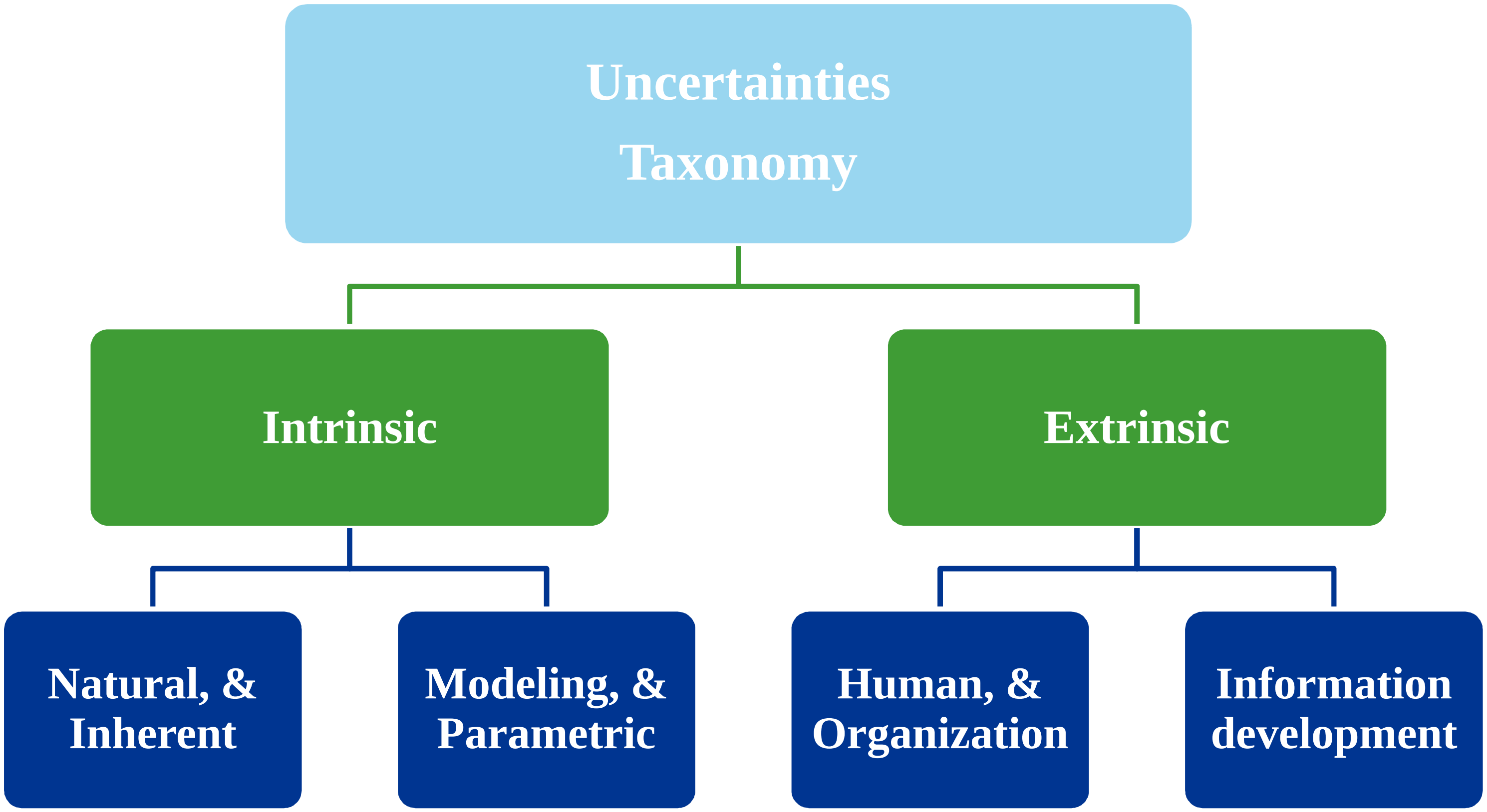

Projected Water Stress Map for 2025
Water Stress Condition
Lower
Near Normal
Higher
WORLD RESOURCES INSTITUTE
Sources: http://ow.ly/rpfMN

How to explore and produce oil and natural gas

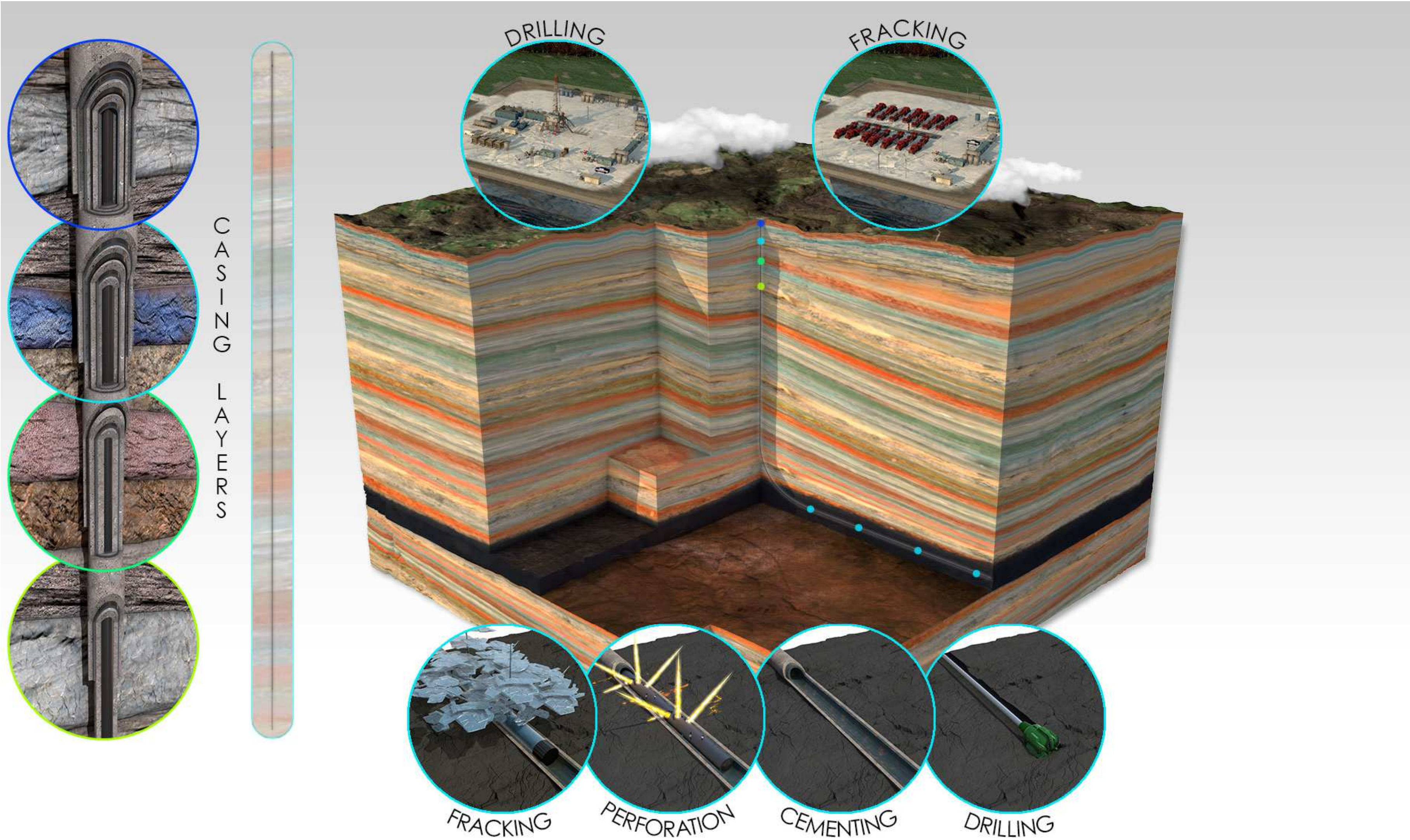
- For the particular case of a shale gas hydraulic fracturing operation, acceptable performance means that the fracturing operation maintains a desirable serviceability, safety, compatibility and durability during the expected life of the system.
- Risk is defined as Likelihood of loss or injury



"Safety Factors" are only meaningful when uncertainty is included and when acceptance criteria are given



Ground Beneath our Feet

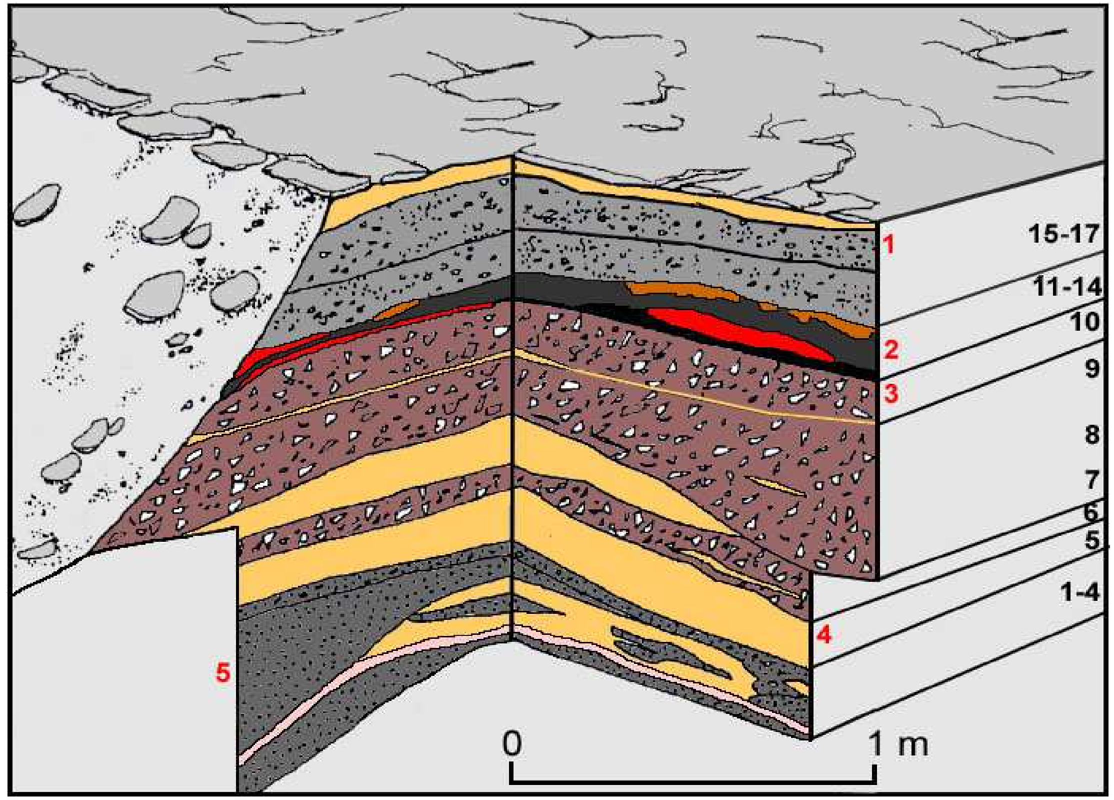


Definitions of Intrinsic Uncertainty

- Type I, Aleatory: uncertainty inherent to a physical process or property
  - Spatial variability of Rock properties
  - Cannot be reduced with additional data/knowledge
- Type II, Epistemic: uncertainty associated with incomplete or imperfect knowledge
  - Shortcoming of calculation, e.g., limitations of 1-D ground response model
  - Can be reduced with research (development of additional data, better models)

Examples of Type I Inherent Variability

- Clay Content
- Shear strength Rock
- Fluctuation in groundwater Elevation
- Non-Uniformity Stratigraphy
- Defects in Cement Materials and Workmanship



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CATEGORIES OF DATA QUALITY

- **CONCRETE (f_{cu})** (ACI 1965)
  - COV < 10% EXCELLENT
  - COV = 10 – 15% GOOD
  - COV = 15 – 20% SATISFACTORY
  - COV > 20% BAD

10 - 20%

- **Rock (s_u)** (EPRI TR105000)
  - COV = 10 – 30% LOW
  - COV = 30 – 50% MEDIUM
  - COV = 50 – 70% HIGH

10 - 70%

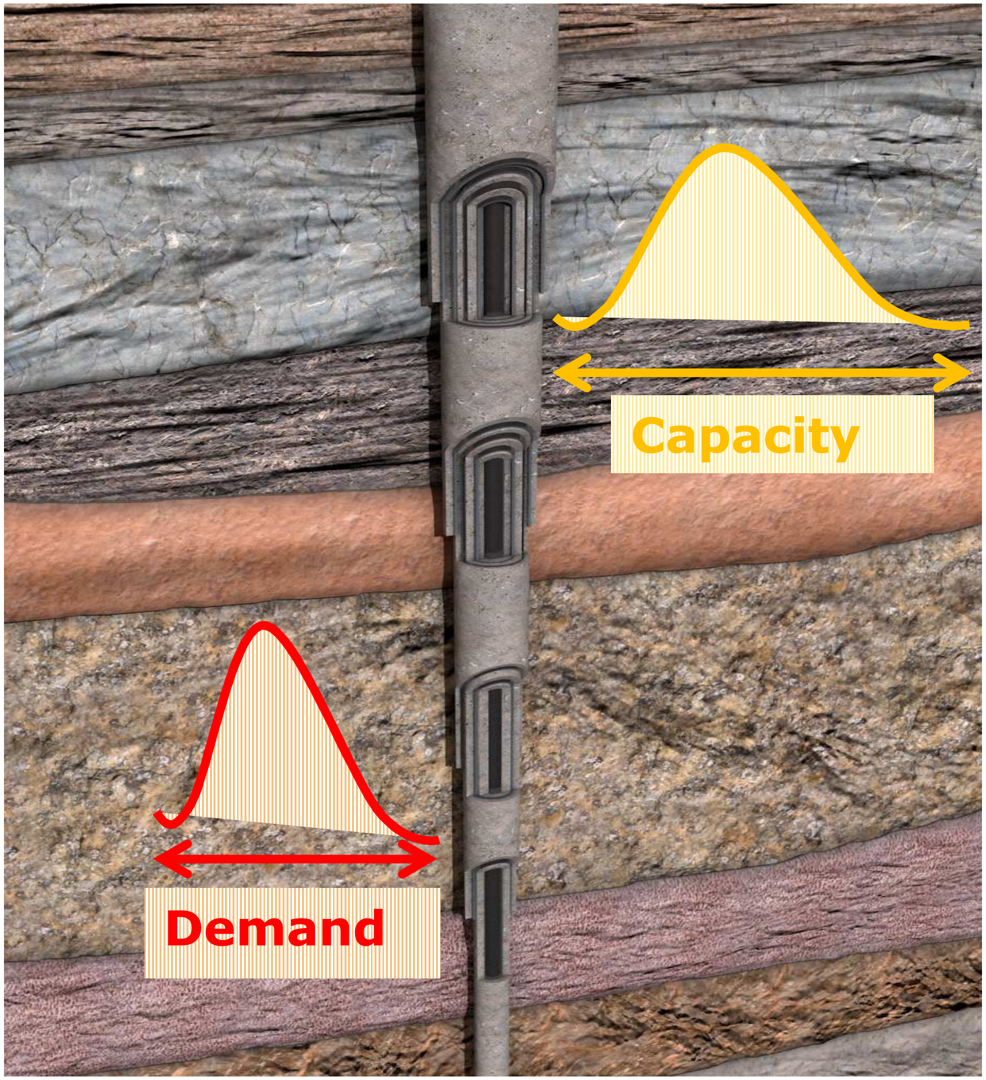
Preventing Unwanted Locations of Induced Fractures
The 3 main failure modes

A Failure of well casing cement sheath and allows fracturing fluid, and Methane to flow to shallow zones, including protected aquifer

B Induced fracture intercepts a larger, natural, pre-existing fault and causes a noticeable induced seismic event

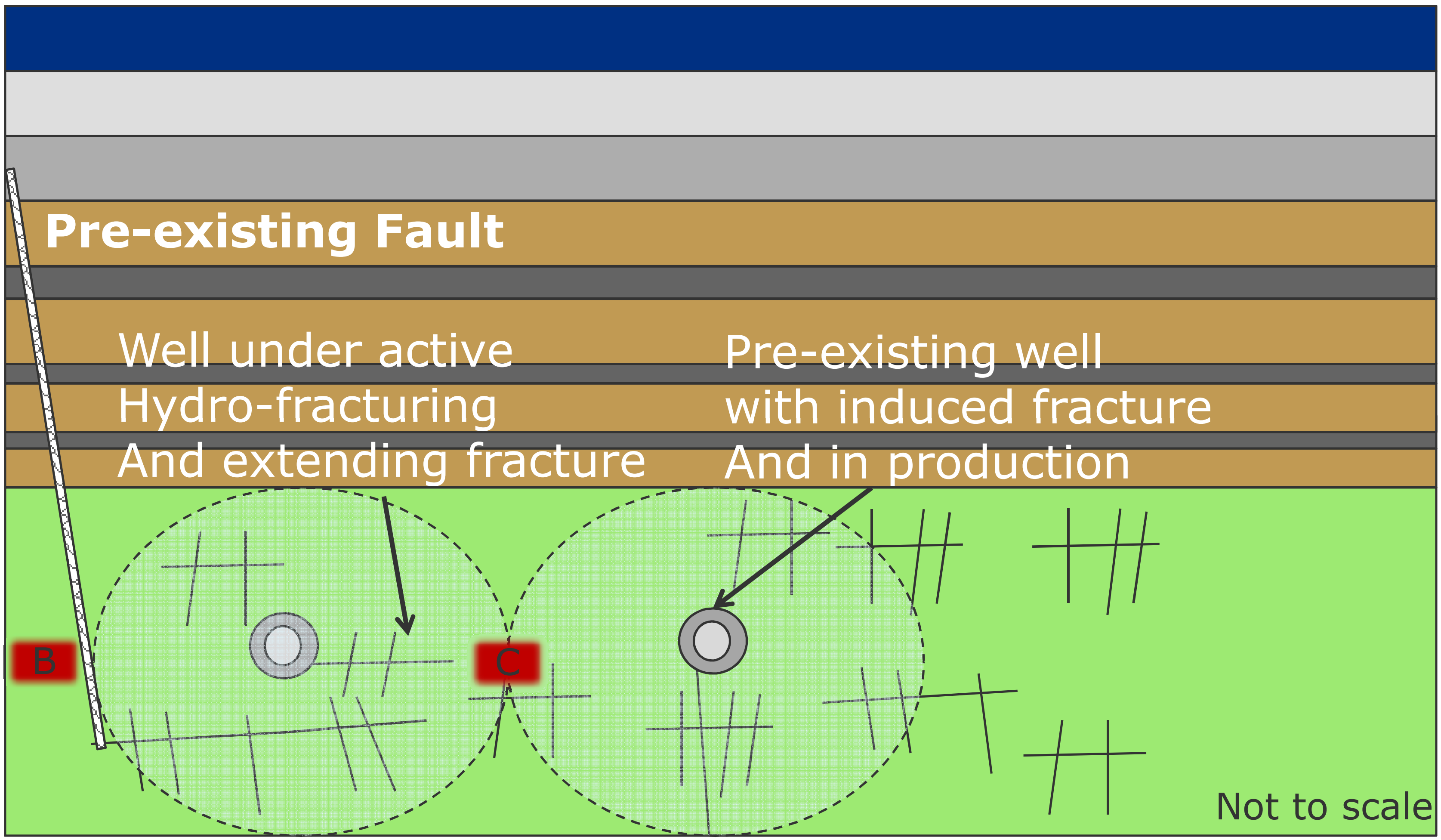
C Induced fracture intercepts the fracture network of a nearby well already drilled, fractured **and in production**, causing high pressure fluid to enter the nearby wellbore and potentially a blow-out in the nearby well

Case A



- Groundwater Elevation
- Conductor Casing
- Surface Casing
- Intermediate Casing
- Production Casing

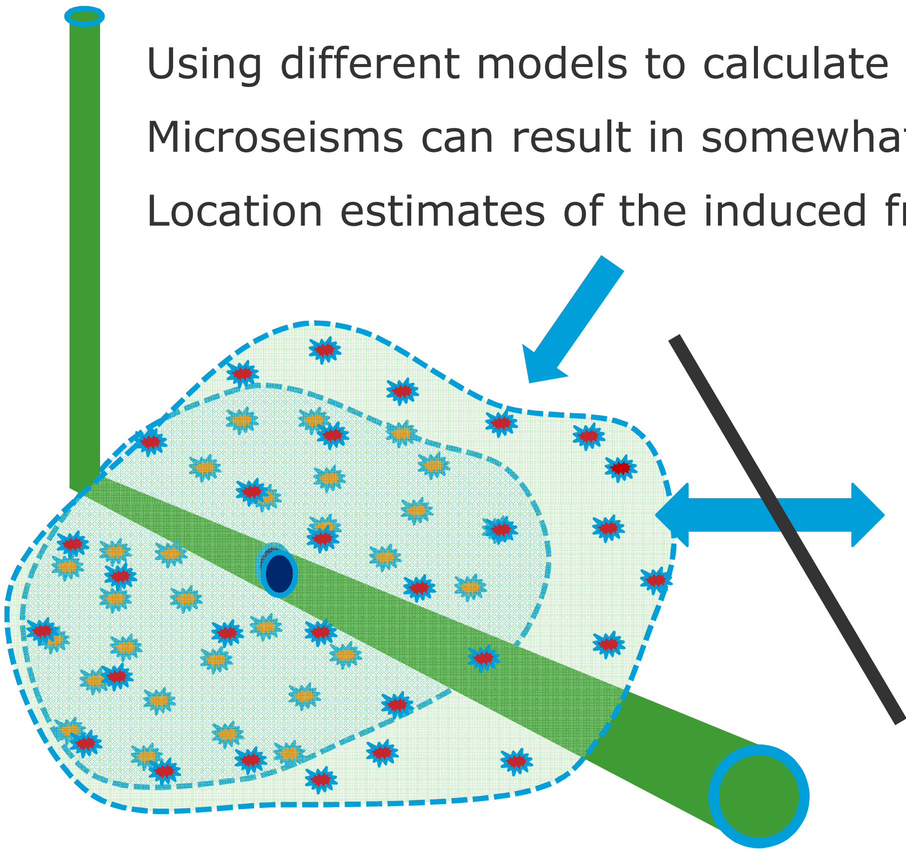
Potential "Failure modes" During Fracturing B and C



Horizontal wellbore entering the page

Example of Type II uncertainty in locations of subsurface features:

Using different models to calculate location of
Microseisms can result in somewhat different
Location estimates of the induced fracture



Failure mode B:
Pre-existing fault, also with somewhat uncertain location, which might be reactivated if in contact with pressurized fracture fluid
Note that a proper site-specific baseline mapping is required to assess Failure mode B probability and risk

This might be important for estimating probability of the induced fracture intersecting a feature in a way that increases risk

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Type II Uncertainties

-

- $$Bias = \frac{\Psi(\text{true or measured value})}{\Psi(\text{nominal or predicted value})}$$

- Determined by comparing "Measured" data with proposed analytical model
- Extremely important part of determining probabilities of failure

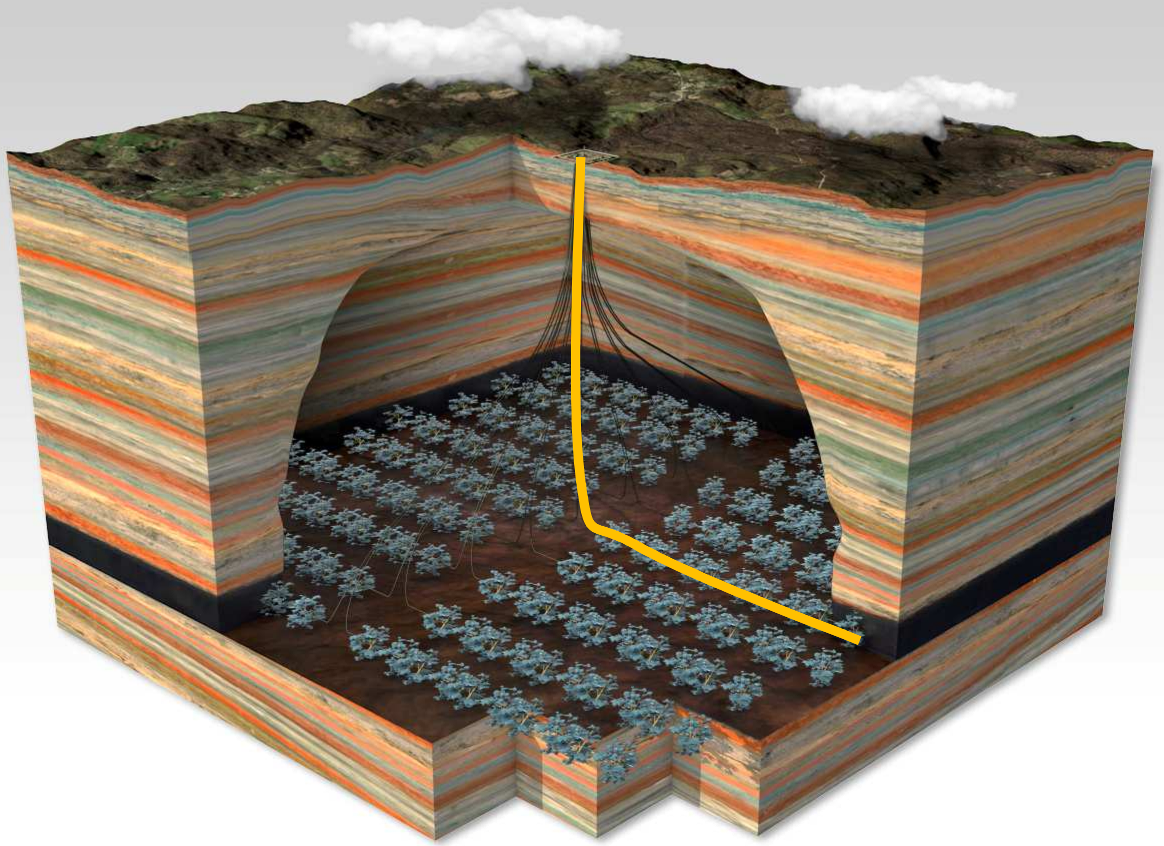
Evaluation of Probability of Failure

-

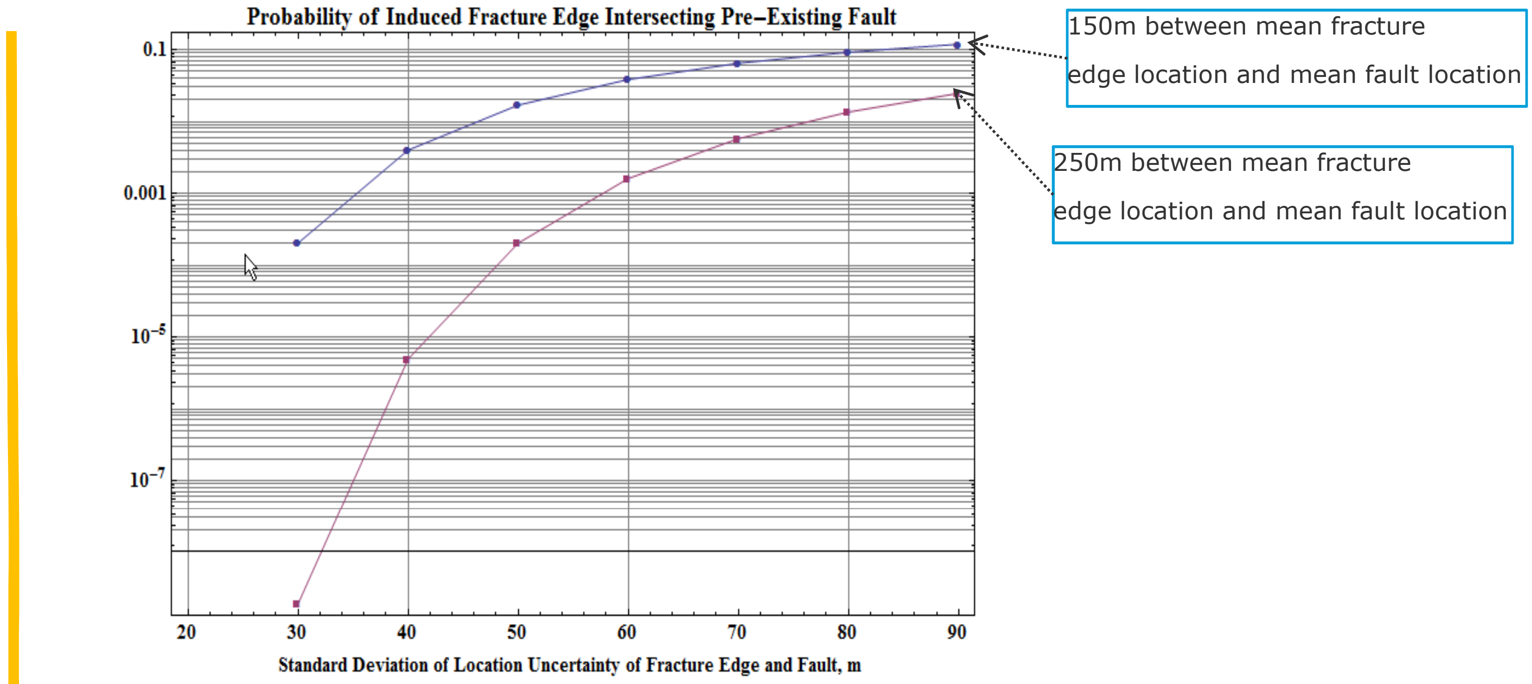
- $$\beta = \frac{ln({}^{C_{50}}/_{D_{50}})}{\sqrt{\sigma^2_{I\,ln\,C} + \sigma^2_{I\,ln\,D} + \sigma^2_{II\,ln\,C\&D}}}$$

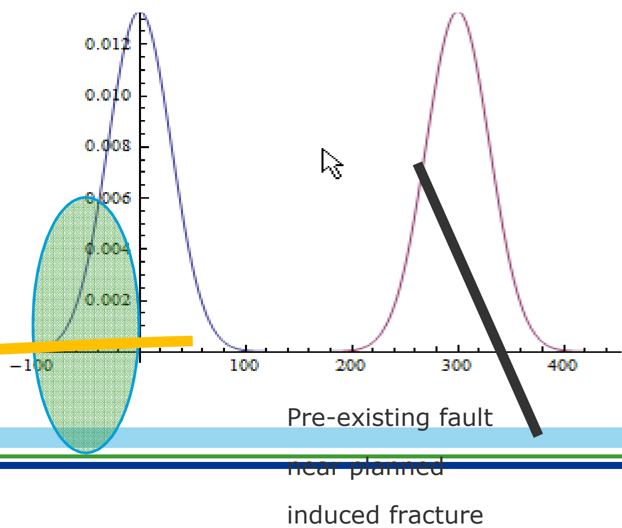
- $P_f = 1 - \Phi\ (\beta)$

Geohazards and Large Geographically Distributed Systems



Failure Mode B : A simplified example with probabilities of occurrence





Uncertainty in location expressed as Normal distributions, 2 parameters, mean and standard deviation

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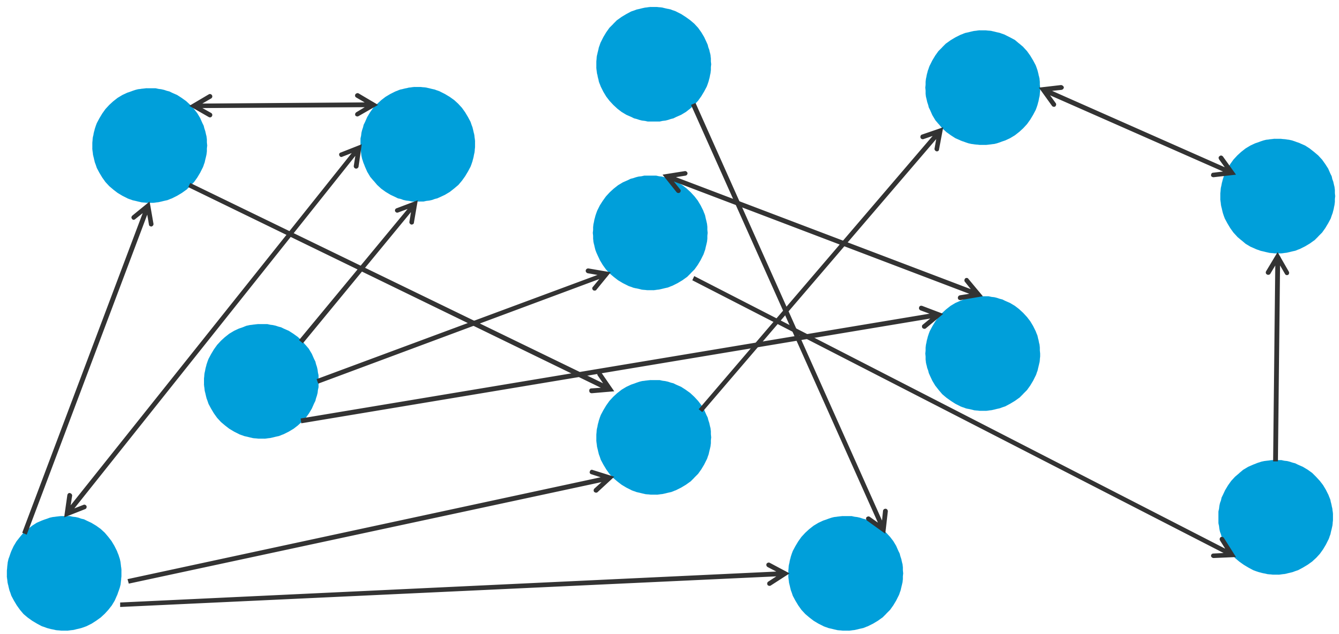
$P(F_i) = P(D_i > C_i)$

- **i=1 Serviceability (days available for service)**
- **i=2 Safety (…)**
- **i=3 Durability (expected life of system)**
- **i=4 Compatibility (expected initial and future cost)**



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Conclusion

- Provide and assessment process for the four levels of uncertainty comprising risk
- Provide all stakeholders with quantitative measures of the risk of contaminating groundwater resources
- Evaluate the effects of shale play uncertainties on geographically distributed drilling operation
- Assist in characterizing potential hazards to groundwater resources by modeling spatial and temporal risk variability
- Define methods for making risk-based decisions under conditions of uncertainty
- Gain an understanding of potential impacts of hydraulic fracturing operations on ground water resources

Questions?

Thank you

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