What can performance assessment and M&V tell us about risks and how do we know?

Richard Metcalfe, Alan Paulley

Quintessa

www.quintessa.org

CO 2 REMOVE
research monitoring verification

Outline

- Definitions of
  - risk
  - Performance Assessment (PA)
  - Monitoring & Verification (M&V)
- Requirements of legislation
- Risks of concern / informed by CO2ReMoVe
- Aspirations and challenges for risk assessment
- Tools for evaluating risk
- Role of PA and M&V

What needs to be achieved?

How do we achieve it?

What is Risk?

‘The potential for realization of unwanted, adverse consequences to human life, health, property, or the environment’

Society for Risk Analysis

Risk = Probability x Consequence

Probability:

- Sometimes impossible to estimate from prior knowledge
- Expert judgment needed

Consequence:

- Subjective:
  - consequences of interest
  - mapping to numerical scale
- Context-dependent

Risk ≠ Uncertainty

What is Performance Assessment?

- PA defined differently by different authors

- *Most generally*:

  The evaluation of the performance of a specified system or sub-system relative to some criterion or criteria of interest to particular stakeholders

- Not (necessarily) the same as 'risk assessment', unless a risk criterion is also the performance criterion of interest

- For CO2ReMoVe, primary performance indicators:

  - containment
  - injectivity
  - capacity

What is Monitoring and Verification?

- Monitoring:
  - observing what happens to the stored CO_2
- Verification:
  - determining that the CO_2 is effectively stored, involving particularly:
    - establishing that stored CO_2 behaves as expected
    - establishing that stored CO_2 evolves to a state of greater stability

OSPAR Requirements

- OSPAR – Cooperation among 15 countries & EC to protect NE Atlantic
- OSPAR (2007): Guidelines for Risk Assessment and Management of CO_2 storage - OSPAR 07/24/1-E, Annex 7
- Storage licence must contain a **risk management** plan, including:
  - **monitoring** & reporting requirements
  - mitigation and remediation options
  - site closure plan
- **Monitoring** programmes should be linked to impact scenarios
- **PA** contributes to determining plausible impacts

Note: impact assessment not a primary goal of CO2ReMoVe, but PA similar to that carried out in CO2ReMoVe could be part of an impact assessment

EC Storage Directive Requirements

- Article 18, point 1 requires it to be shown that:
  - *'all available evidence indicates that the stored CO_2 will be completely and permanently contained'*
- Article 19, point 2 requires the operator to demonstrate conformity to the previous point and, before handing responsibility to a 'competent authority', at least:
  - conformity of actual & modelled behaviour of injected CO_2
  - absence of detectable leakage
  - storage site is evolving towards long-term stability

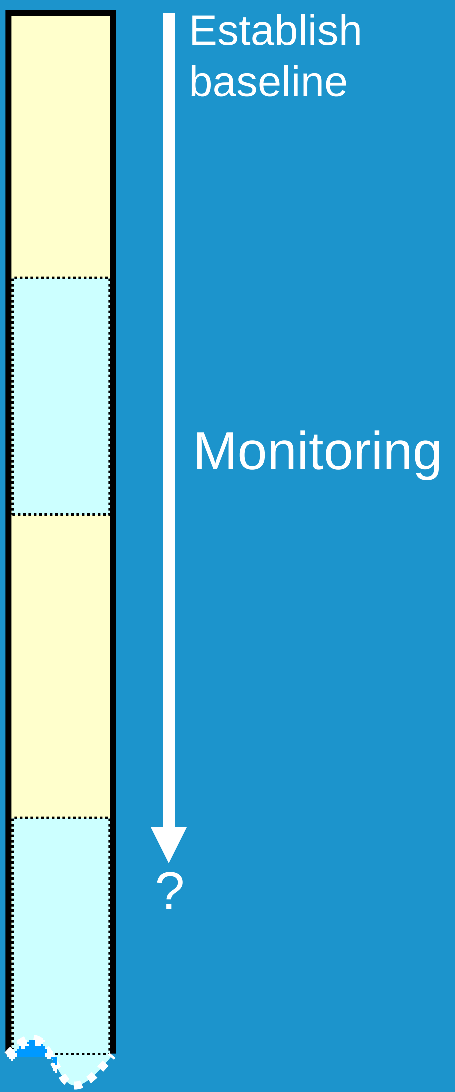
Risks of Concern to CO2ReMoVe

- Risk that stored CO_2 will not be contained
  - risk of borehole leakage
  - risk of caprock failure
  - risk of reservoir overfilling
- Risk that injectivity will be insufficient
- Risk that storage capacity will be insufficient
- Risk that it won't be possible to demonstrate progression towards long-term stability of the stored CO_2.

Phases of a CO_2 Storage Project

- Site characterization
  - likely a few years
- Operations (CO_2 injection)
  - a few 10’s of years (probably 20 y -30 y)
- Post-closure, pre-transfer of responsibility
  - several 10’s of years (at least 20 y in EC Directive)
- Post-transfer of responsibility
  - likely several 1000 years to consider

> - Risks different at each stage
> - Perception of risk different at each stage



PA, M&V and Risk Perception

- People tend to ignore ‘unknown unknowns’
- Increase in knowledge (e.g. from M&V) causes increased understanding of variability (informed by PA)
- People often mistake increased recognition of uncertainties for increased risk
- Solution
  - recognize that there will be ‘unknown unknowns’ from the start
  - communicate information and understanding openly and transparently
  - develop multiple arguments based on varied information
- Implies expert judgments essential
- Risk assessment NOT just about numerical calculations

Aspirations and Challenges

- Overall aims are to:
  - ***bound*** risks over time
  - ***present risks*** to stakeholders so they can decide whether acceptable
- ***Don't*** aim to predict the future in detail, i.e
  - predictions like 'The CO_2 will stay with the storage complex' useful
  - predictions like 'The margin of the CO_2 will be 5.25 km from the injection point after 102 years and 6 months' not needed, maybe unhelpful
- Develop robust arguments based on multiple lines of reasoning, e.g.
  - risk estimate supported by different kinds of models
  - past experience
  - natural analogues etc
- Important challenges are:
  - identify uncertainties and establish their significance
  - develop whole-system understanding
  - communication of risks and uncertainties

Information to Judge Risks

Varied information needs to be considered

PA is part of the process for integrating information

Need to combine various types info.

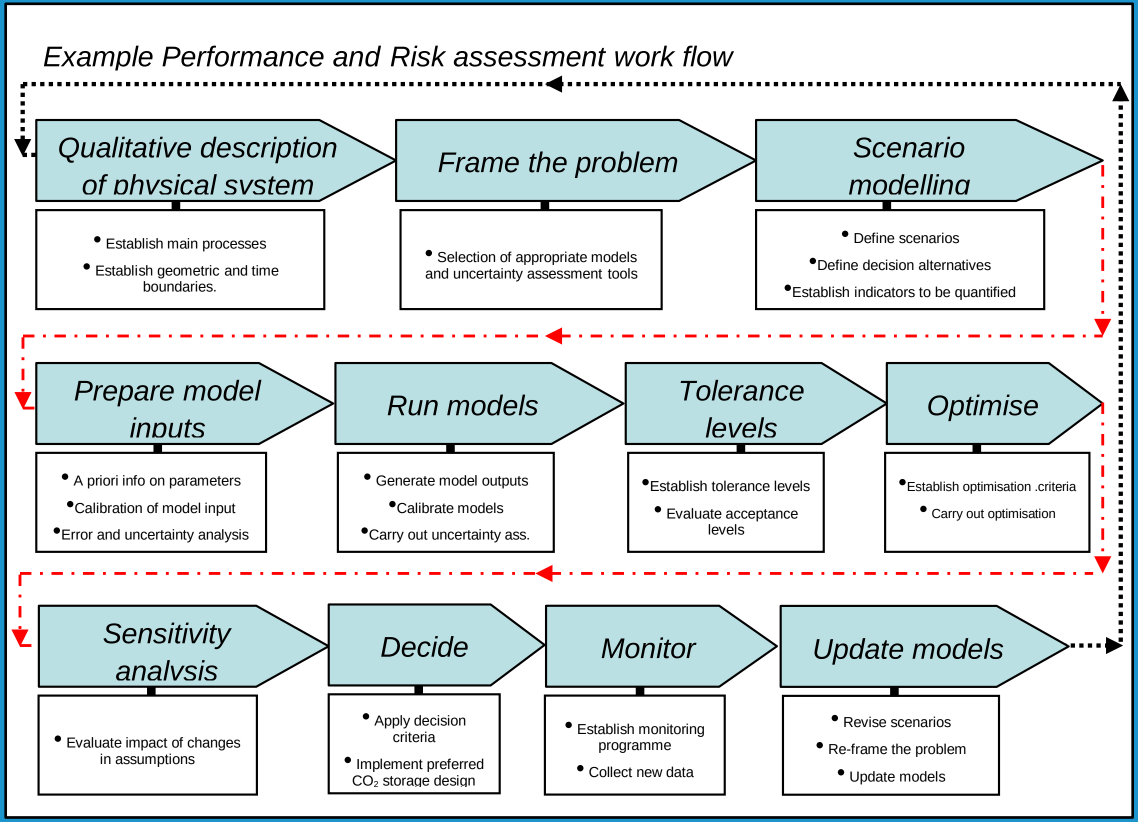
Quantitative

Qualitative

- Field data, e.g.
  - Seismic
  - Formation water analyses
- Modelling, e.g.
  - Short term detailed models (reservoir, geochemistry)
  - Long term performance assessment models
- Expert judgment / reasoning, e.g.
  - Likelihood of undesirable events
  - Likelihood of undetected features
  - Economic viability
- Value judgments of stakeholders, e.g.
  - ‘Not in my back yard’
  - ‘You haven’t demonstrated that it’s safe’
  - …

Tools for Risk Assessment

- Structured scenario development process
- FEP databases
- Sensitivity analysis tool
  - e.g. well scale
  - e.g. reservoir scale
- Prototyping tool to:
  - test models rapidly
  - communicate results rapidly
- Other tools:
  - reservoir simulators
  - geomechanical, geochemical tools etc



After Korre et al. 2008 (D2.2.1A)

- Decision-support tool to integrate information from other tools
  - provide an audit trail
  - demonstrate to stakeholders relevant issues have been judged

Structured Scenario Development

A scenario is:

A plausible description of the potential evolution of a system according to the nature of the FEPs that might act within and upon it.

FEPs are used to build scenarios, consisting of:

Features - Components of a system, e.g. a reservoir, a fault

Events - Transient phenomena that may affect the system, e.g. earthquakes

Processes - Phenomena that affect the system over unspecified, typically long periods e.g. groundwater flow

Scenario building by expert judgment within a structured, recorded process

Aims of Scenario Development

- Take into account conceptual uncertainty by alternatives
- Identify 'base case' or 'expected evolution' scenario
- Identify *plausible* (but usually very unlikely) alternative scenarios
  - borehole leakage scenario
  - fault leakage scenario
  - over-filling scenario

  Very unlikely at a well-chosen and managed site, but
  - regulators (+ other stakeholders) usually require to show considered
  - must consider to develop monitoring and mitigation plans
- Cover range of possibilities (most likely and worst cases)
- Develop a model ('knowledge' in database can help)

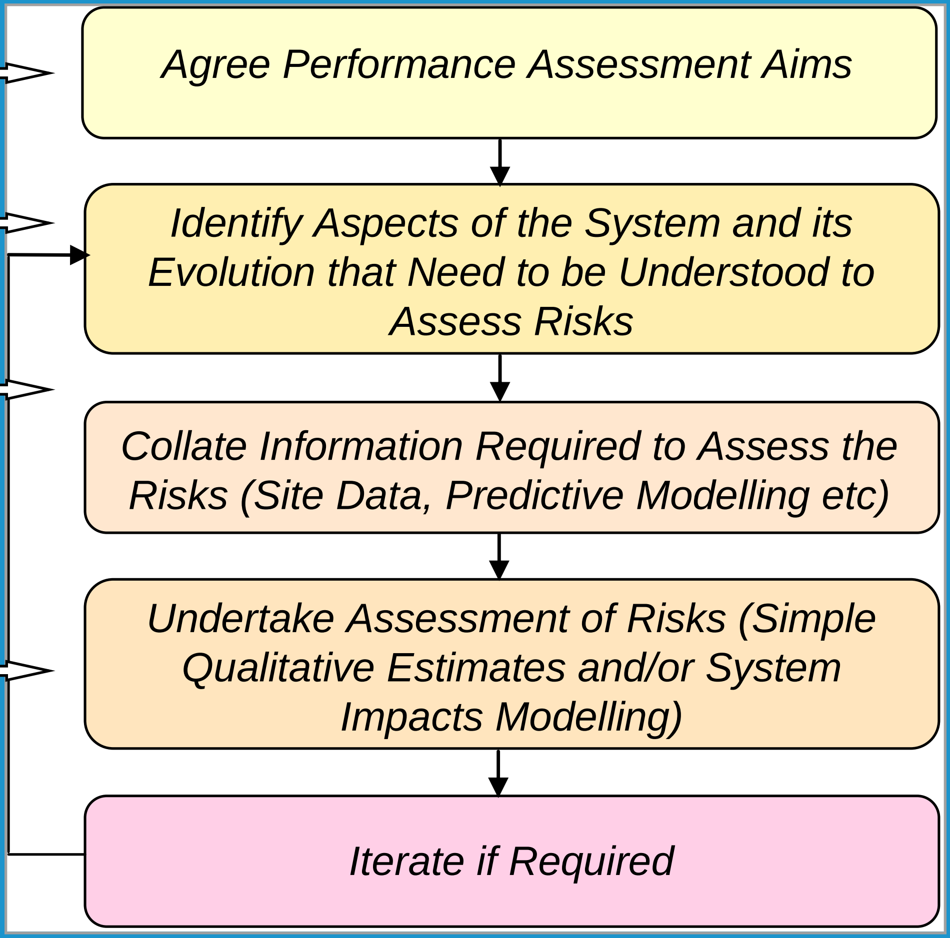
Framework Applied to In Salah (1)

Framing discussions at FEP & scenario expert workshops

FEP identification and PA assessment at expert workshops

Site data and reservoir models are key inputs; supplemented by systems modelling

Integration of PA outcomes using a decision support tool



Framework Applied to In Salah (3)

Outcomes

- Identification of 'best estimate' description for the site and its evolution ('Normal Evolution Scenario')
- Where uncertainties were identified regarding the overall evolution of the system, alternative scenarios or variants were identified to bracket the envelope of potential performance.
- No quantification of the relative likelihood of occurrence of alternative scenarios. A key PA aim is to prove that scenarios representing loss of containment will be very unlikely to occur and/or that leakage rates will be extremely low even if they do occur.

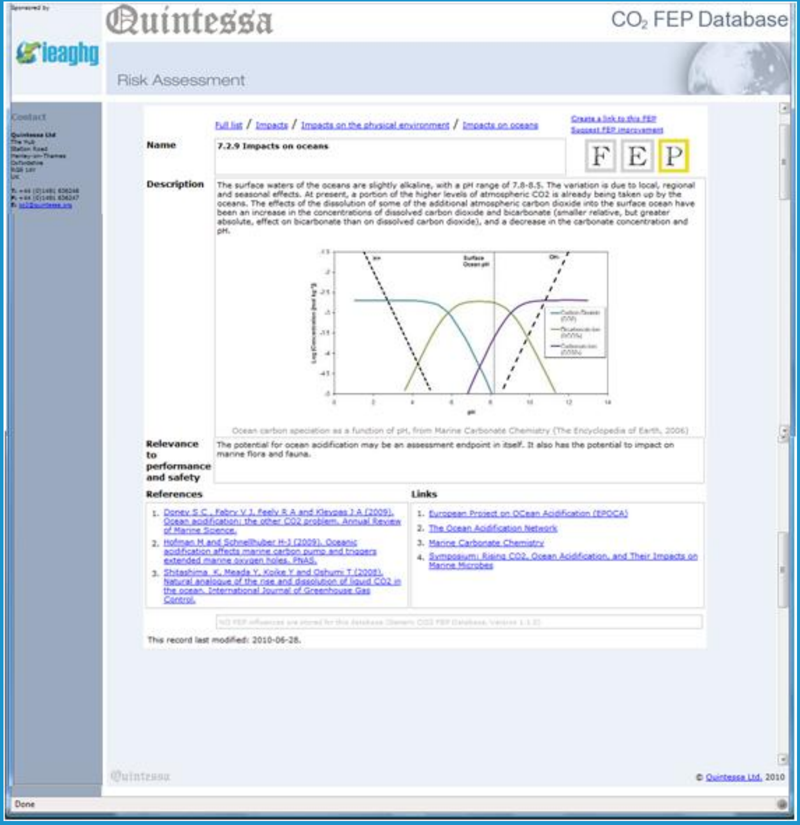
In addition to 'Normal Evolution', scenarios identified included

- Well seal failure scenarios
- Improvements in site understanding lead to design/operation changes
- Filling to over present design capacity
- Seismic effects
- Additional extraction of water from aquifers

FEP Databases

- Use as:
  - audit tools, to check nothing missed
  - aids to discussion among experts
  - ‘top-down’ scenario development
  - ‘bottom-up’ scenario development

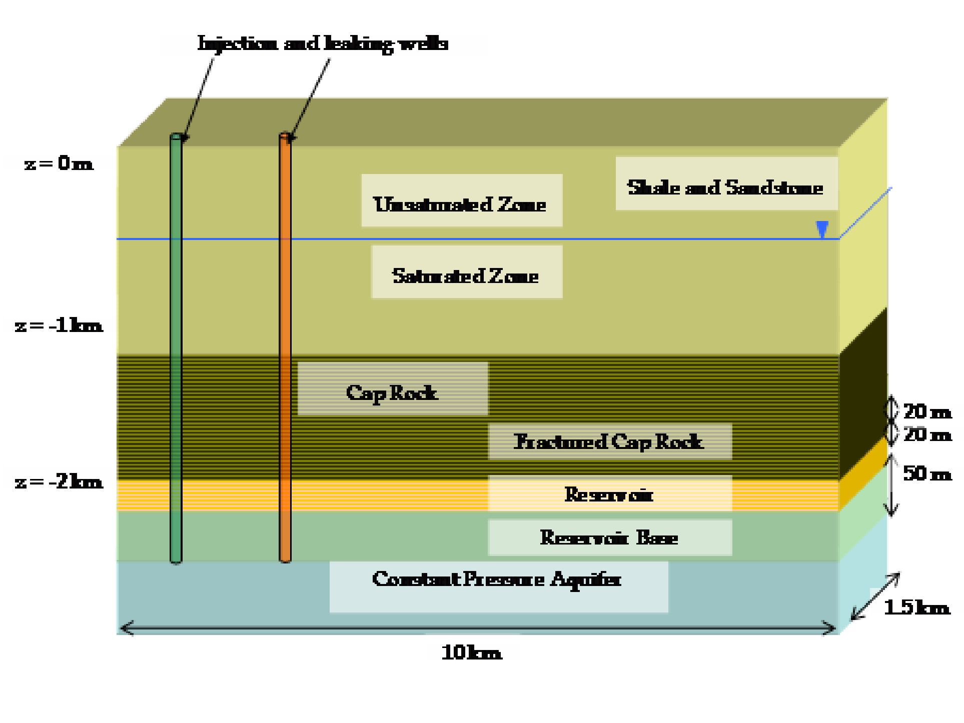
- Two developed +/or enhanced in CO2ReMoVe:
  - Quintessa’s on-line Generic CO2 FEP Database (enhanced during CO2ReMoVe)*
  - TNO’s CASSIF (developed in CO2ReMoVe)



* At http://www.quintessa.org/co2fepdb/

Sensitivity analysis / prototyping tool (1): System model

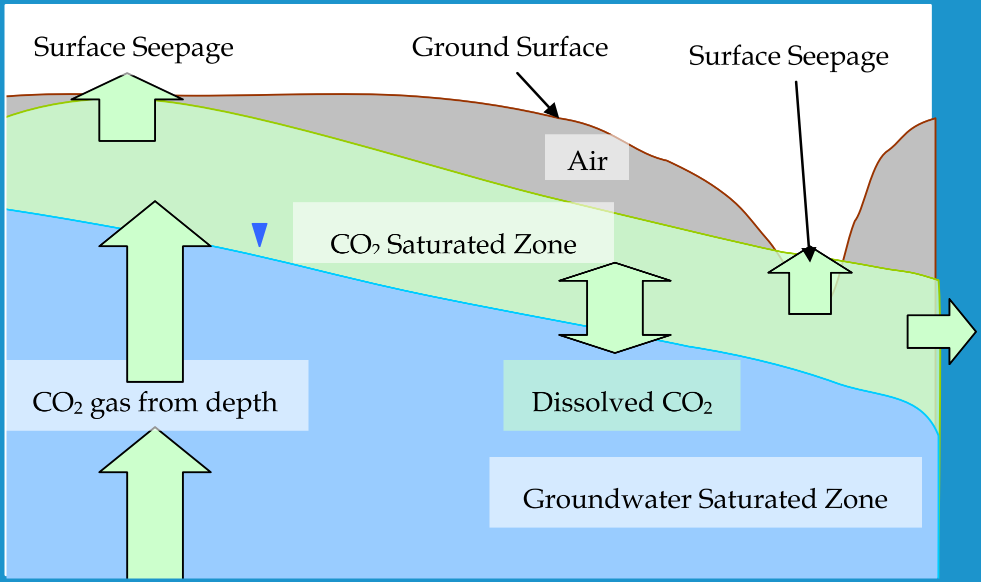
- Near-surface sub-system:
  - un-saturated zone (air-saturated)
  - CO_2-saturated zone
  - groundwater-saturated zone



- Deep sub-system:
  - aquitard beneath reservoir
  - reservoir
  - fractured cap-rock
  - cap-rock
  - injection well and a leaking well

Sensitivity analysis / prototyping tool (2): Modelled processes

- Near-surface sub-system:
  - Darcy flow of water & CO_2
    - distinct layered phases
  - CO_2 dissolution & transport in groundwater
  - CO_2 surface seepage via advection & diffusion
  - indicative pH changes to groundwater



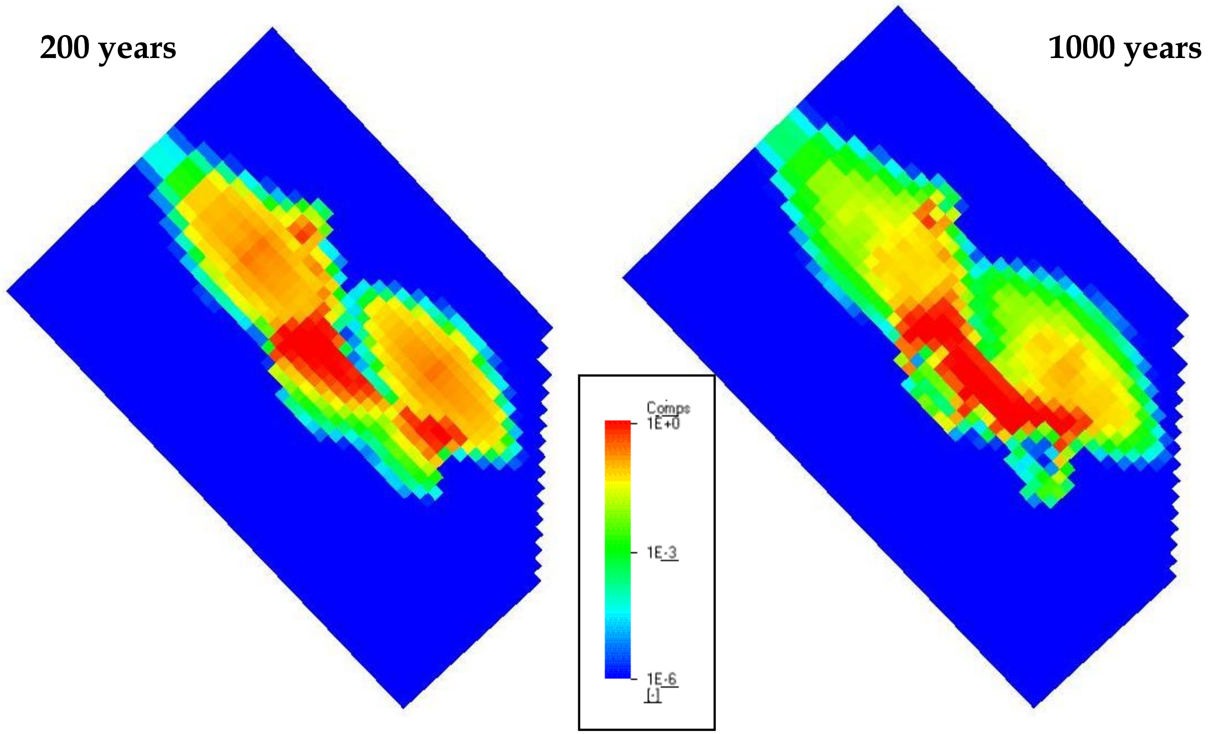
- Deep sub-system:
  - multi-phase flow of water & CO_2
  - CO_2 dissolution in water
  - well injection and migration around leaky wells
  - geochemical processes that may immobilize CO_2

‘What if’ Scenarios Evaluated Using a Systems Model

The tested simplified model was used to efficiently investigate areas of uncertainty and sensitivity associated with Alternative Evolution scenarios for In Salah.

1. Exploration of implications of pressure evolutions within the system as a result of different operations scenarios over operational through to long-term time periods.
2. Robustness of CO_2 storage under different conditions (normal evolution, over-filling, well failure). Prediction of high probability of containment due to under-pressurisation, geological trapping and progressive dissolution in groundwater.
3. Over-pressurisation (to above hydrostatic) plus well failure the only mechanism by which any significant leakage to near-surface encountered.
4. Exploration of effect of adding or removing different geological structures (system found to be robust to model representations).

In Salah Systems Model Application

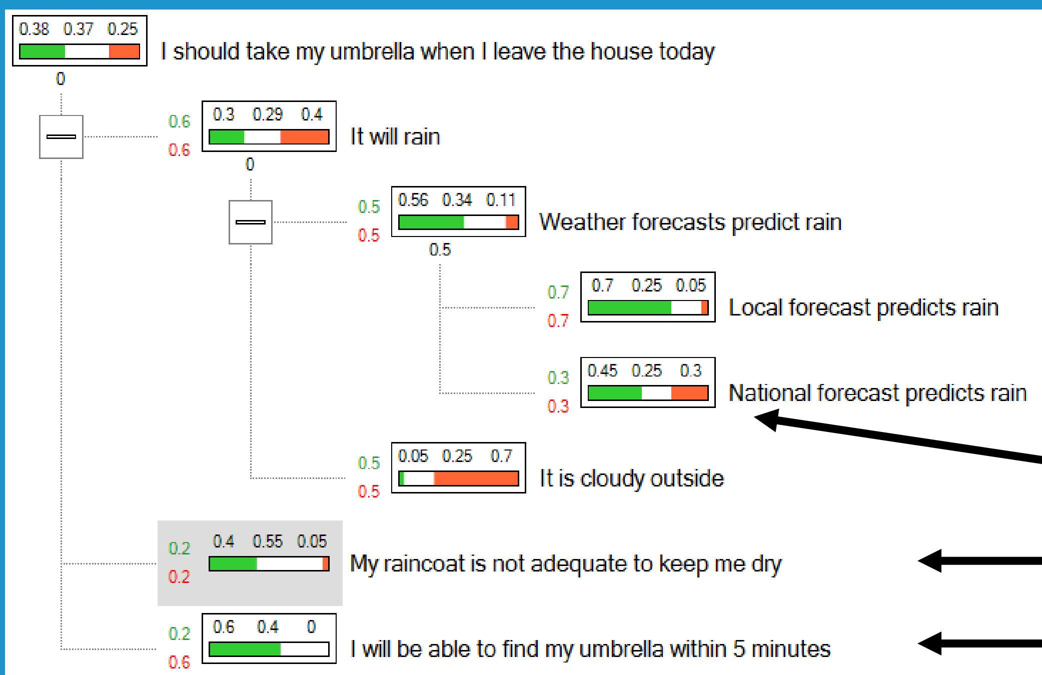


CO_2 saturation in the lower reservoir (logarithmic scale) at 200 years (left) and 1000 years (right) for the overfilling case (AES3).

Very Low Risk = Low Probability (expert judgment) x Low Impact (very small CO_2 quantities calculated to leave the reservoir in extreme cases)

Decision Support / Integration tool (1): ESL

- Evidence-based uncertainty analysis using Evidence Support Logic (ESL)
- Balancing multiple kinds of evidence for and against multiple hypotheses
- Hypotheses arranged in a decision tree, with main one of interest at the top
- Lower hypotheses support / refute higher ones, according to weights



Confidence for

Confidence against

Uncertainty represented, recorded

User inputs confidence values, based on evidence to lowest level

CO2 REMOVE
research monitoring verification

Decision support / integration tool (2): Decision tree

- Decision Tree Structured to reflect:
  - requirements of the EC CO2 Storage Directive (2009/31/EC)
  - kinds of information actually produced by CO2ReMoVe
- Integrates varied information
- Presents multiple arguments
- PA and M&V results inform many hypotheses at the lower levels
- Records audit trail (see next slide)

CO2 REMOVE
research monitoring verification

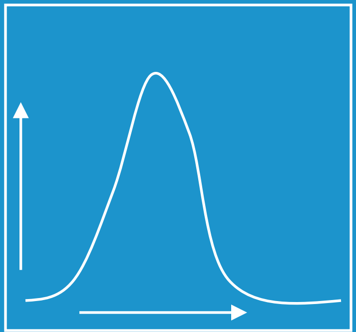
What can PA and M&V tell us about risks?

Risk = Probability x Consequence

Expert Judgment

Stochastic PA Simulation

Frequency



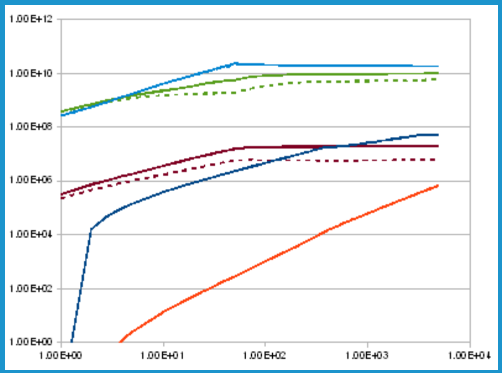
Time (years)

Expert Judgment

Expert Judgment

PA Simulation

Quantity of CO_2 (Kg)



Time (years)

Expert Judgment

- Often cannot estimate probability reliably e.g. probability of fault reactivation
- Then, determine hypothetical consequence if occurs
- If very low impact, then risk low too

M&V

\+ / or other information e.g. site characterisation data

CO2 REMOVE
research monitoring verification

Conclusions

- Risk assessment not just numerical calculations, also
  - use qualitative and quantitative information
  - multiple lines of reasoning
  - expert judgments always important

- PA and M&V inform expert judgments of risk, but don't tell us risks directly

- Presenting risk judgments requires
  - clarity and traceability
  - honesty about uncertainties

- Framework developed in CO2ReMoVe consisting of:
  - hierarchy of models (complex → simplified)
  - detailed modelling tools
  - systems modelling approach and tools
  - a decision-support tool
  - a linked FEP database (knowledge base and audit tool)