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Risk Assessment: The True Story

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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 (subjective)

Consequence:

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

Risk ≠ Uncertainty

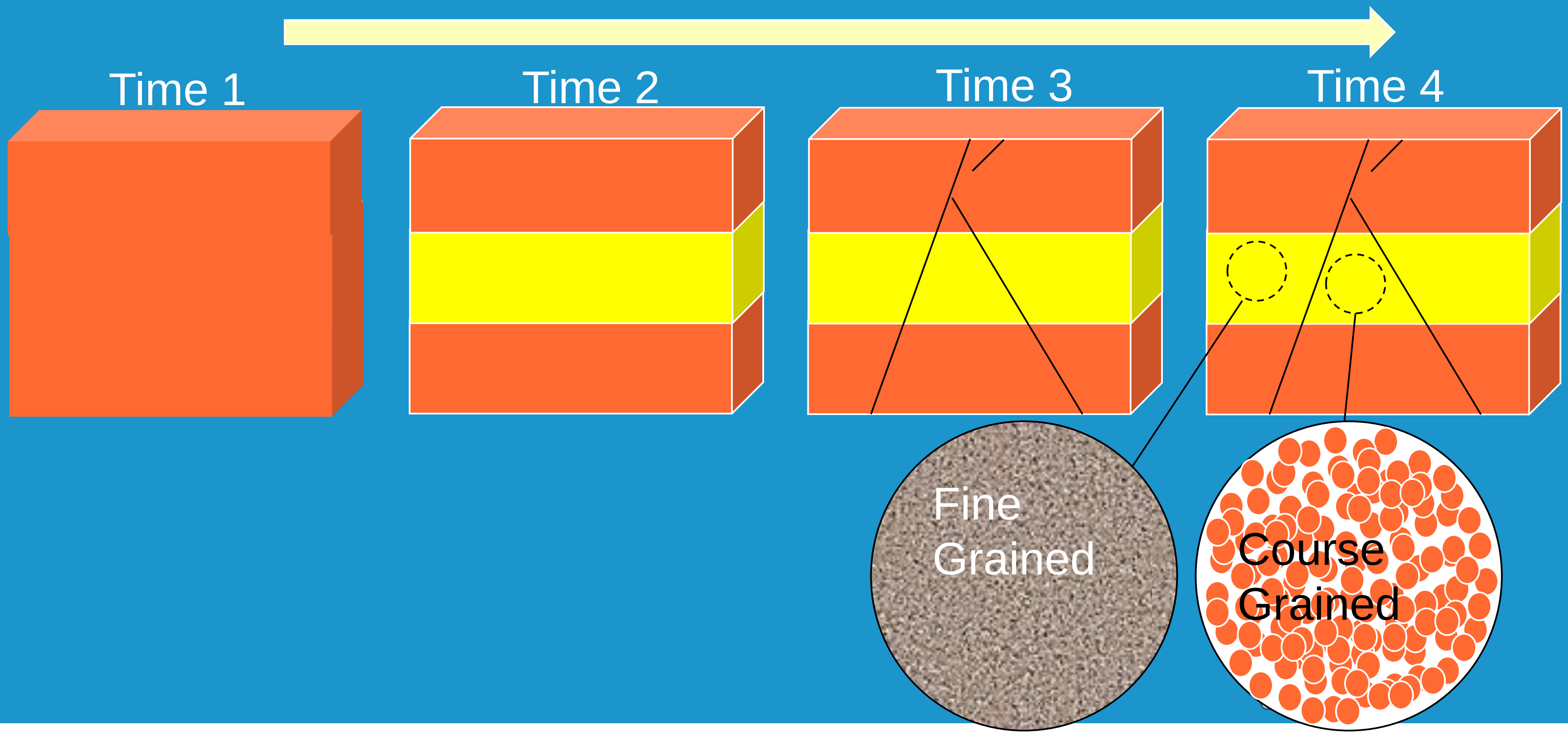
*Of some phenomenon, e.g. well seal failure, earthquake etc

Risk Perception

- People tend to ignore ‘unknown unknowns’
- Increase in knowledge (e.g. from Monitoring) causes increased understanding of variability (informed by Performance Assessment models)
- 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

Knowledge Change

- Expect increasing recognition of complexity
- Expect increasing recognition of uncertainties
- Risks don't actually increase!

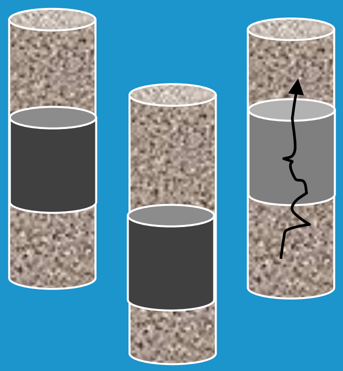


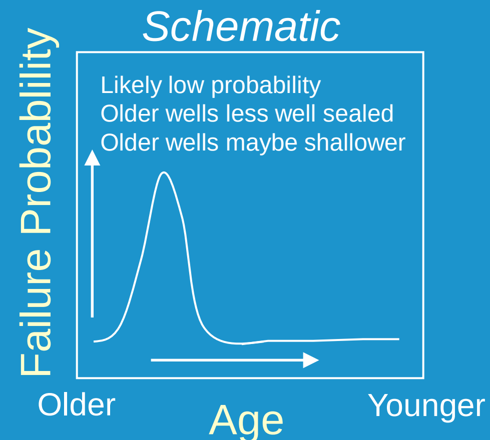
Estimating Probabilities

Risk = Probability x Consequence

Measure / observe some phenomena → Determine probability distribution → Estimate future probability

e.g. examine lots of well seals





Probability of future failure

- In natural systems, often cannot measure or observe, because
  - phenomenon very infrequent (e.g. often fault reactivation)
  - impossible / undesirable to obtain data (e.g. need to drill lots of boreholes to determine rock variability fully, with associated risk of creating leakage paths?)
- In these cases cannot estimate future probability by numerical calculation

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Estimating Consequences

Risk = Probability x Consequence

- If probability of adverse event (scenario) sufficiently low, consequences may be of little concern, but
  - probability often needs to be expressed qualitatively
  - need *discussion* with stakeholders about what probability is acceptable
  - may need to take steps to reduce probability (e.g. planning etc)
- When probabilities cannot be estimated reliably:
  - develop hypothetical 'what if' scenarios for extreme events (scenarios)
  - model consequences
  - *discuss* implications of consequences with stakeholders
  - if agree consequences acceptable, then risk acceptable
  - if no agreement, take steps to reduce consequences (e.g. planning etc)

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

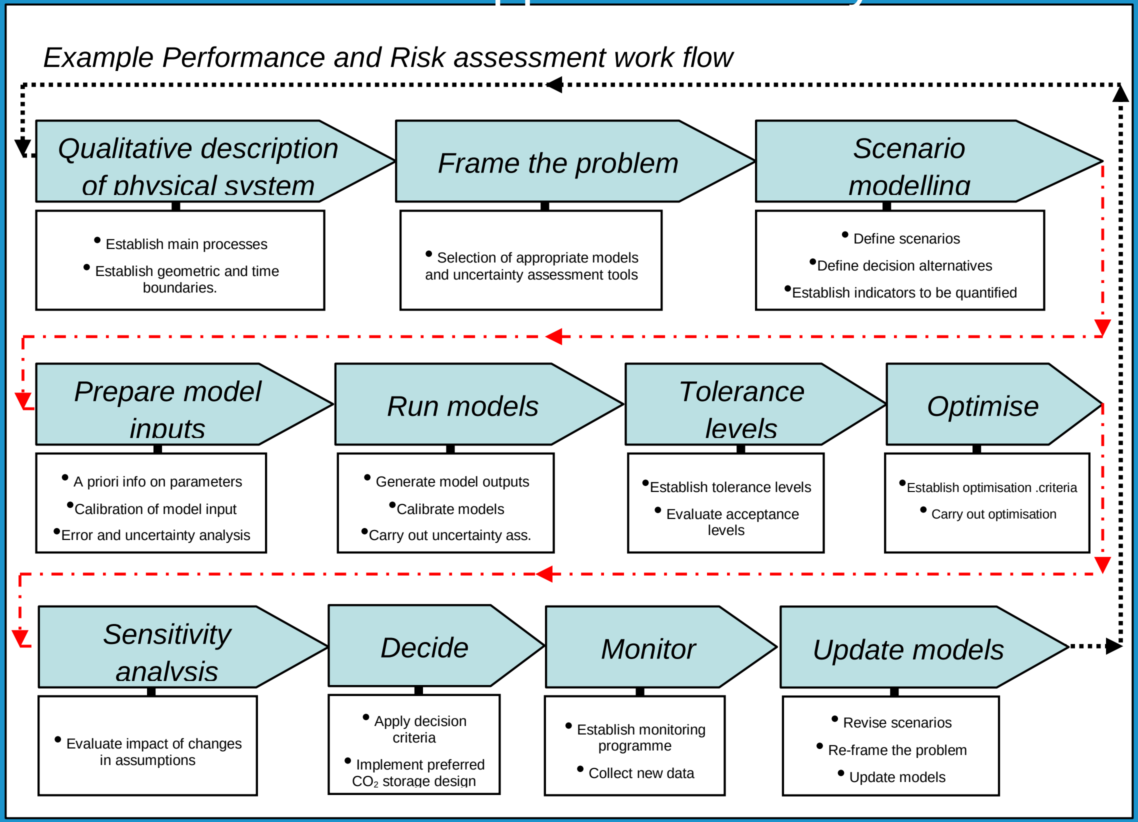
Qualitative

- 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
- Databases of important issues (Features, Events, Processes)
- Sensitivity analysis tools
  - 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

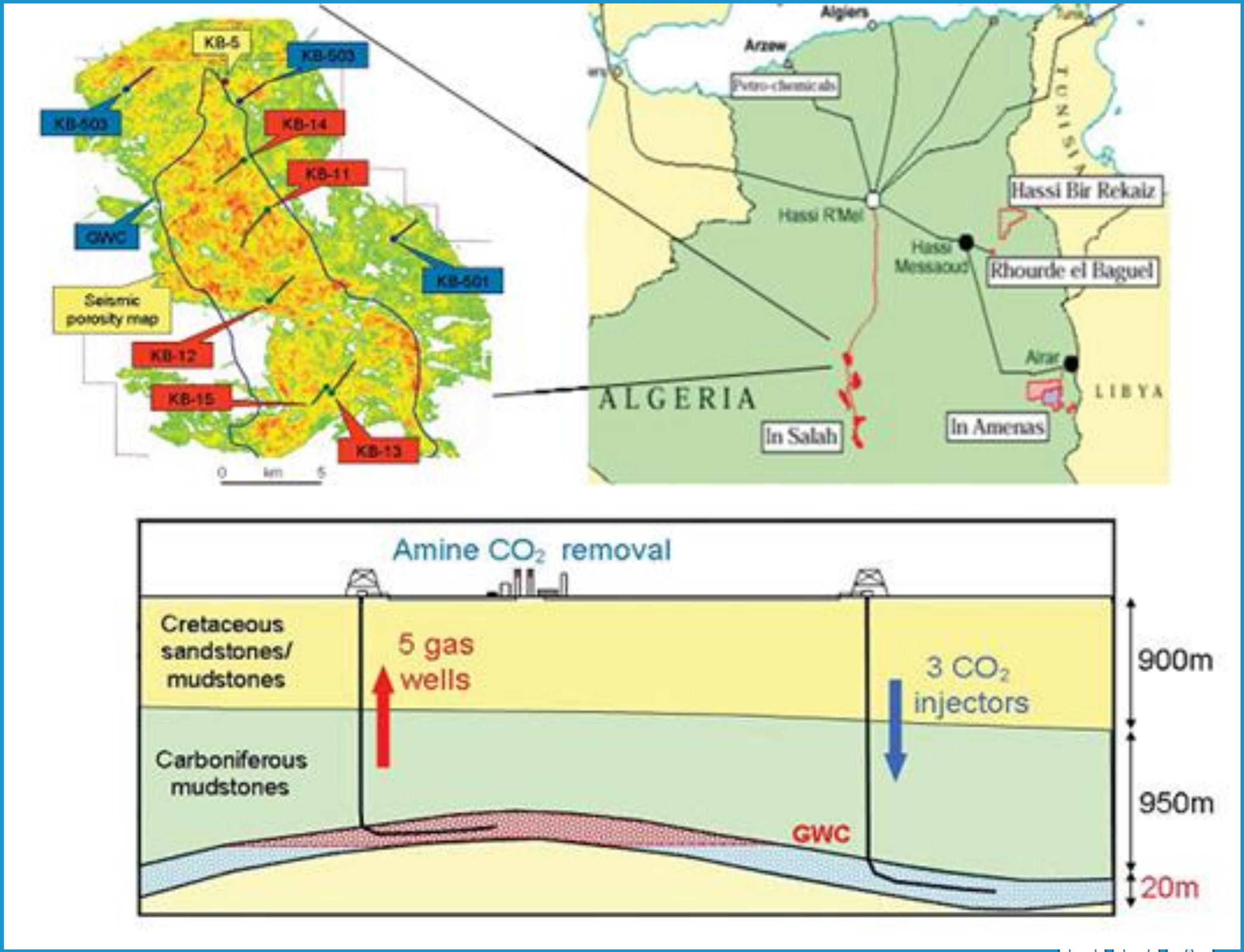
Tools applied iteratively



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

Example: In Salah



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Framework Applied to In Salah

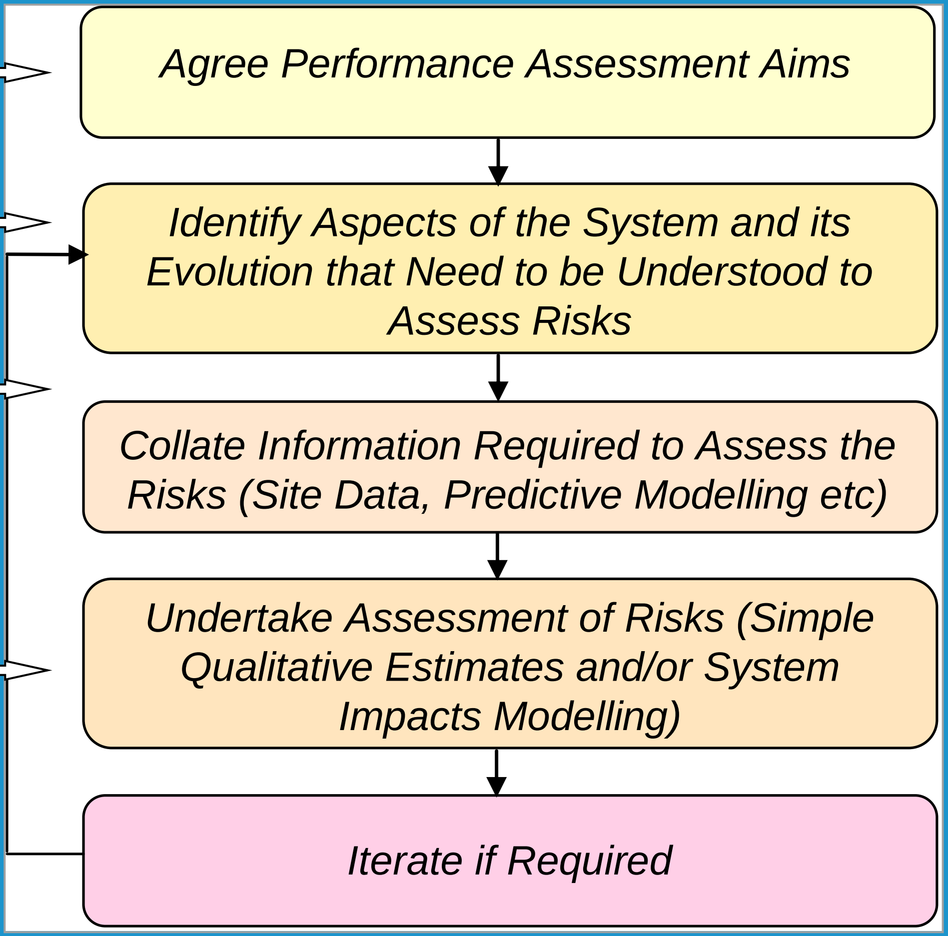
Structured process for defining scenarios

Framing discussions at expert workshops

Identify issues (Features, Events, Processes) at expert workshops

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

Integration of outcomes using a decision support tool



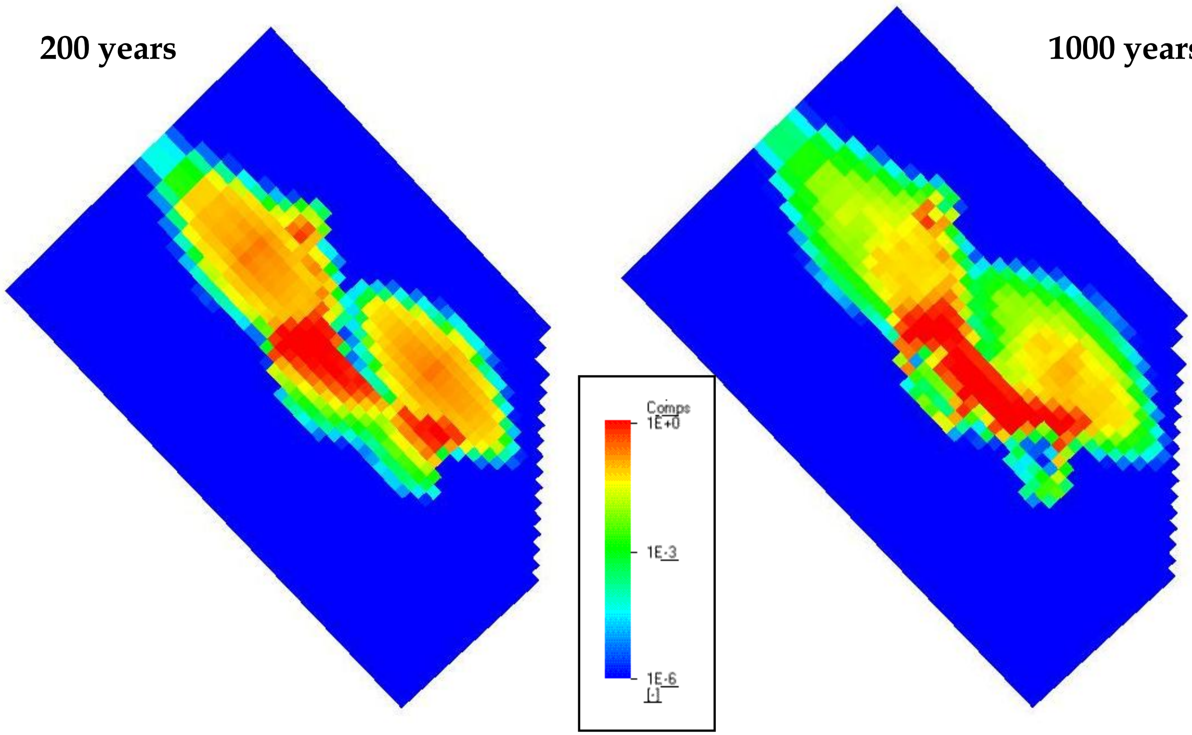
In Salah: Expected Evolution Scenario

CO_2 injection:	• operations will be in line with current site operator plans; • will achieve a defined temperature and pressure.
CO_2 transport:	• lateral extent of the CO_2 will remain within the lateral extent of the caprock; • 2-phase transport within storage system plus CO_2 migration into/within faults and fractures; • transport in faults and fractures will enhanceCO_2 dissolution and diffusion into rock matrix.
Caprock:	• will be tight against vertical transport, with permeability as currently estimated; • will behave in the same manner as for the methane reservoir; • will provide a measure of secondary containment following diffusion.
Well seals:	• will behave 'as designed'; • older wells will be re-sealed if necessary such that performance is as for 'new' wells; • will degrade, but slowly over the long term.
Monitoring:	• well seals will be monitored in line with regulations, and remediated if seepage occurs; • monitoring of the primary and secondary geological containment systems will continue.
The biosphere:	• will be as currently observed and will not evolve significantly.

In Salah: Alternative (Unlikely) Evolution Scenarios

- **Well seal failure**
  - absence of legacy well seals, poor quality future well seals etc
- **Operational changes**
  - improvements to design/operation, overfilling
- **Seismic effects**
  - to show unlikely that seismic activity will disrupt the system
- **Changes to local human habits**
  - including water abstraction from shallow aquifers

In Salah: Exploration of Consequences of Alternative (Unlikely) Evolution Scenarios

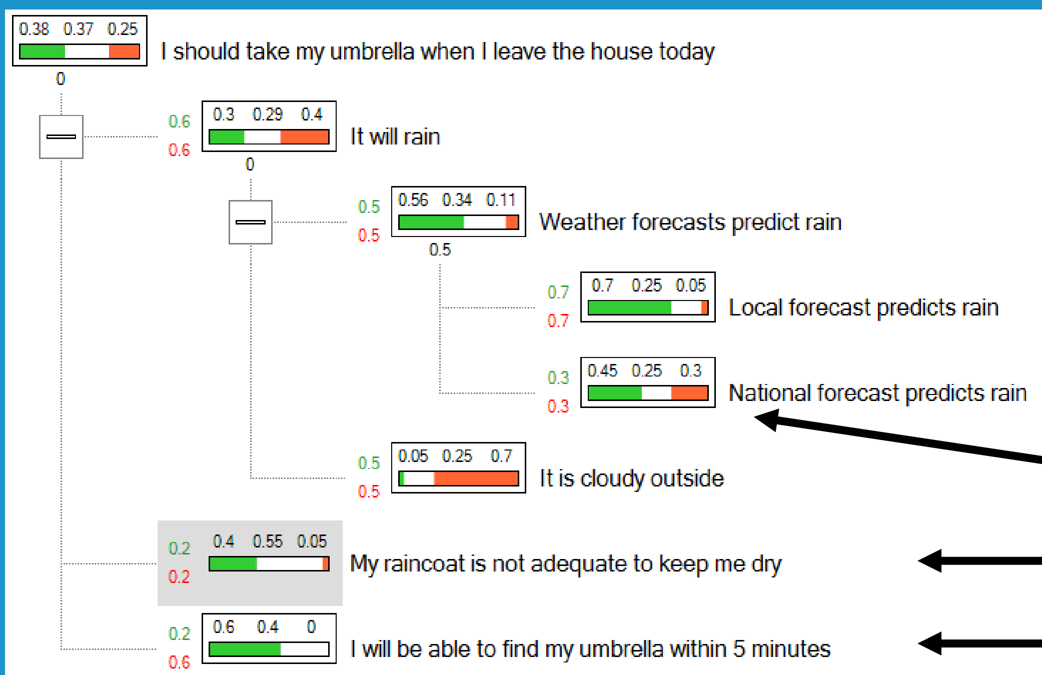


CO_2 saturation in the lower reservoir (logarithmic scale) at 200 years (left) and 1000 years (right) for the overfilling case (AES3).

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

Structuring / Recording Decisions

- Subjective judgments inevitable / essential
- Need structured framework for conversation among experts / stakeholders
- Balancing multiple kinds of evidence for and against multiple hypotheses
- Here illustrate approach using decision trees



Confidence for

Confidence against

Uncertainty represented, recorded

User inputs confidence values, based on evidence to lowest level

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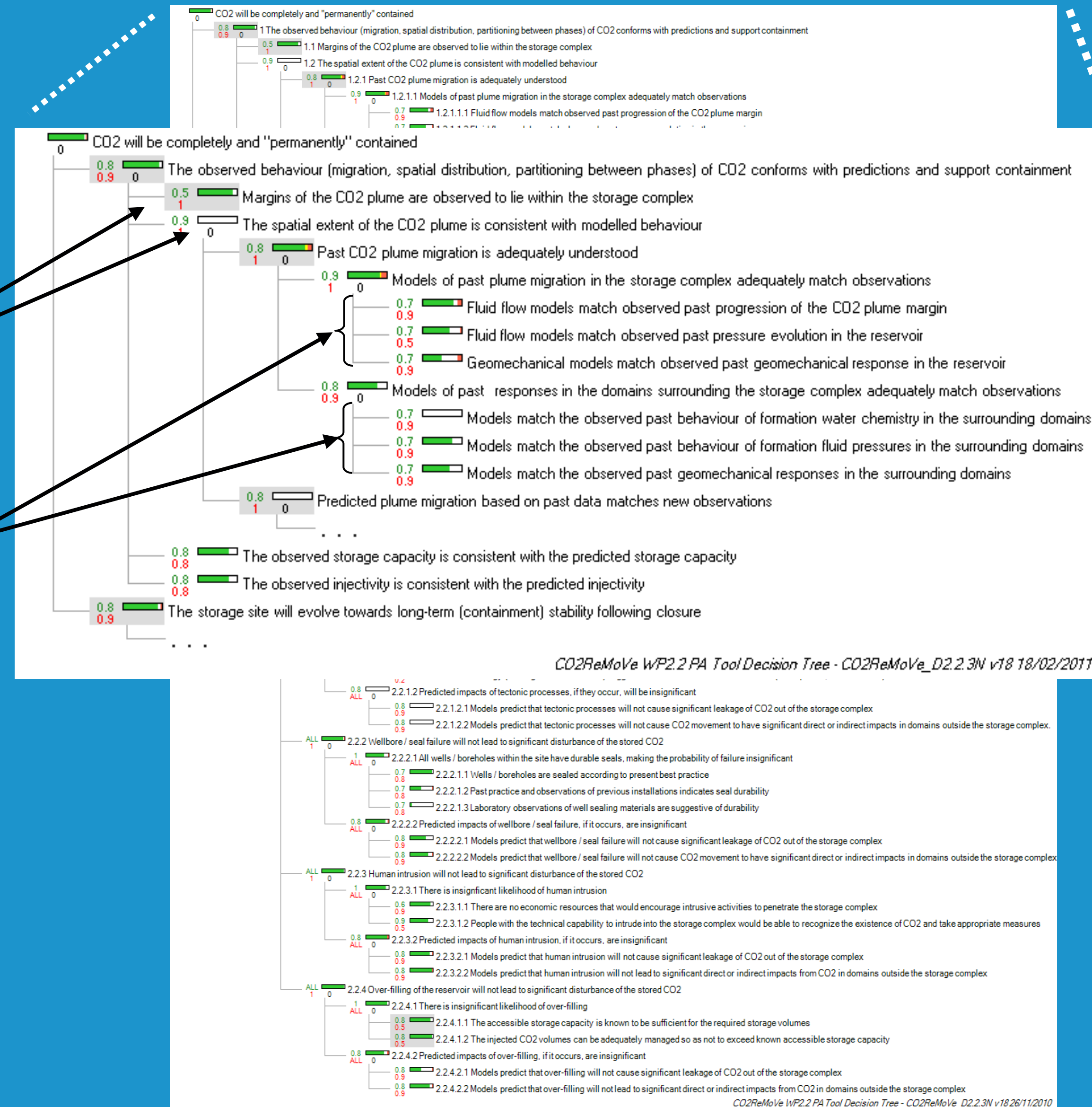
Example: In Salah Decision tree

- 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
- Assessment models & monitoring results inform many hypotheses at the lower levels
- Records audit trail



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Conclusions

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

- Varied numerical models and monitoring 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)