CO_2 Storage: Approaches to risk assessment and methodologies

Richard Metcalfe

Technical workshop on carbon dioxide capture and storage in geological formations as clean development mechanism project activities

Abu Dhabi, United Arab Emirates
7–8 September 2011

Quintessa

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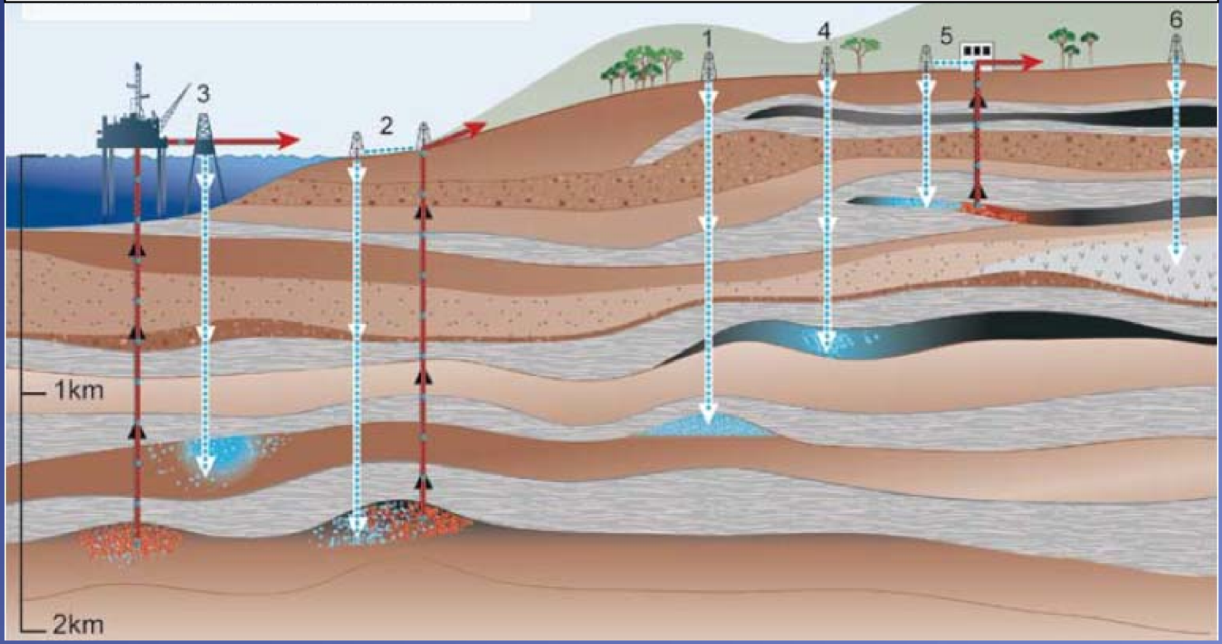
Geological Storage Options

- Different kinds of sites
- Different kinds of storage options

1. Depleted oil and gas reservoirs
2. Use of CO_2 in enhanced oil recovery
3. Deep unused saline water-saturated reservoir rocks
4. Deep unmineable coal seams
5. Use of CO_2 in enhanced coal bed methane recovery
6. Other suggested options (e.g. basalts, oil shales, cavities)

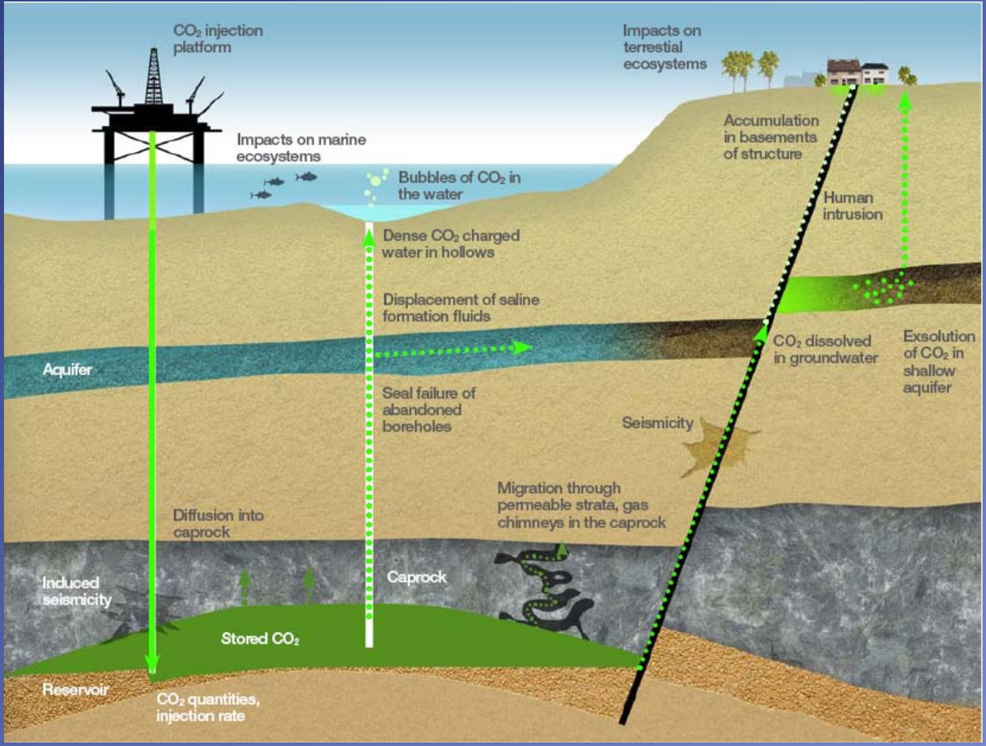


After Cook (1999), as reproduced in IPCC Special Report on CCS (2005)

Site / project dependency of risks

- Different balance of processes influence risks in different sites / projects:
  - different balance of physical processes (rock properties, driving forces etc)
  - different balance of chemical processes (salinity, temperature, rock reactivity)
- Non-technical site / project – specific factors also influence
- Risk assessment needs to be matched to a site / project
- Can define general principles / steps
- Cannot be too prescriptive

Examples of processes to be considered



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 cannot estimate from prior knowledge
- Expert judgment needed (subjective)

Consequence

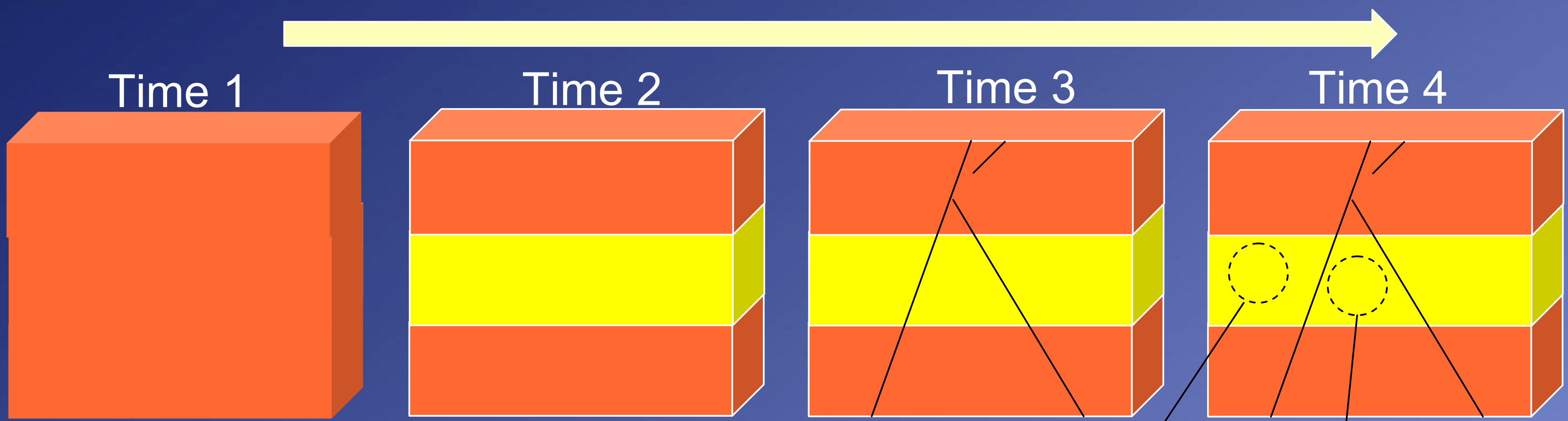
- Subjective:
  - consequences of interest
  - mapping to numerical scale
- Context-dependent

Risk is not uncertainty

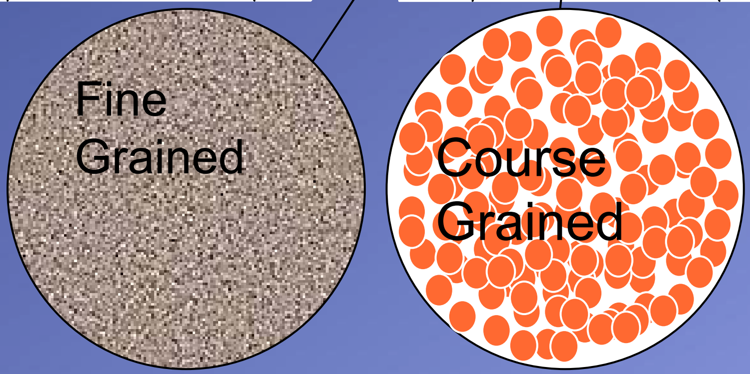
*Of some phenomenon, e.g. well seal failure, earthquake etc

Risk Perception

- Increasing recognition of complexity
- Increasing recognition of uncertainties
- People tend to mistake increased recognition of uncertainties for increased risk
- But risks don't actually increase!



- Solution
  - recognize from start that there will be 'unknown unknowns'
  - communicate information & understanding openly, transparently

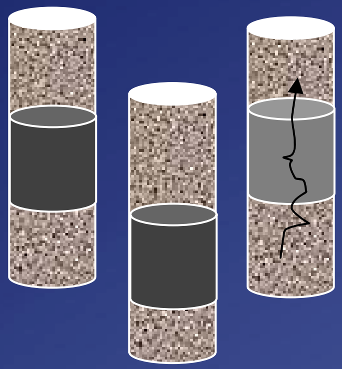


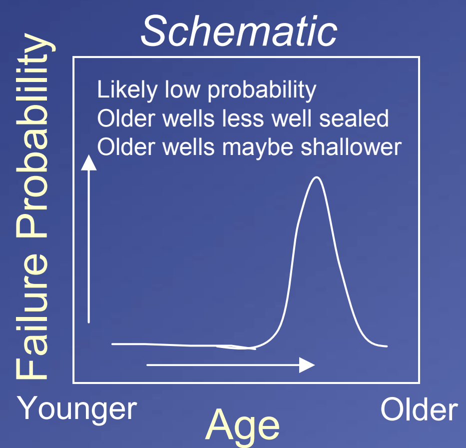
Estimating Probabilities

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 probability distribution 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)
- In these cases cannot estimate future probability by numerical calculation
- Use scenario approach to explore "what if" situations

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
  - 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)

Steps in Risk Assessment

- Several slightly different approaches
  (e.g. DNV / CO2Qualstore, EC Directive, ISO31000)
- General themes / steps can be identified:

Iterate

1. Frame the problem – context definition
2. Acquire information / data
3. Identify potential hazards
4. Identify potential receptors / sensitive domains
   (who / what would be affected if CO_2 leaked)
5. Assess possible impacts

Communication

- Iterations matched to milestones in project lifecycle
  (e.g. initially, pre-closure, pre-transfer of responsibility etc)
- But, must not be too prescriptive (allow for additional cycles)

Information to Judge Risks

Varied information needs to be considered

Qualitative ↔ Quantitative

- 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'*
  - *…*

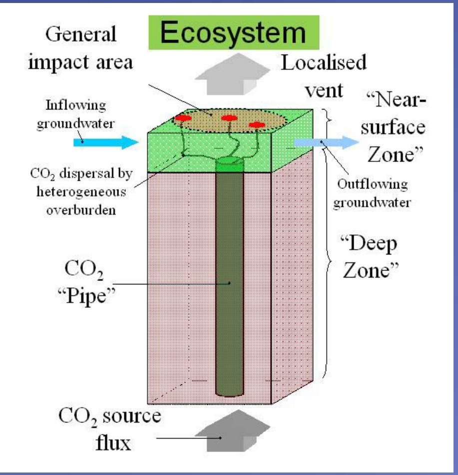
Tools for Risk Assessment: Models

- Wide variety of models used – helps quantify uncertainty
- Use to complement one another
- Match applications to needs of a particular:
  - site
  - project
  - stage in lifecycle

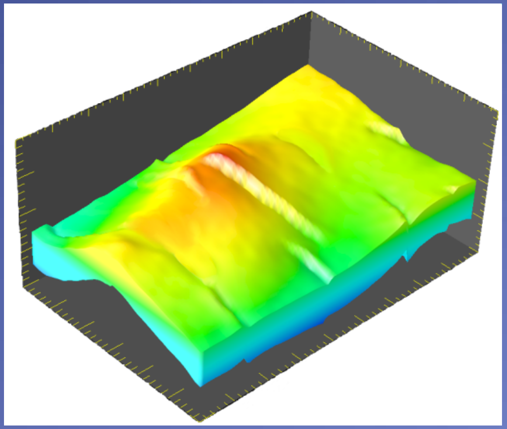
More processes, more coupling

Finer discretization

e.g. system models



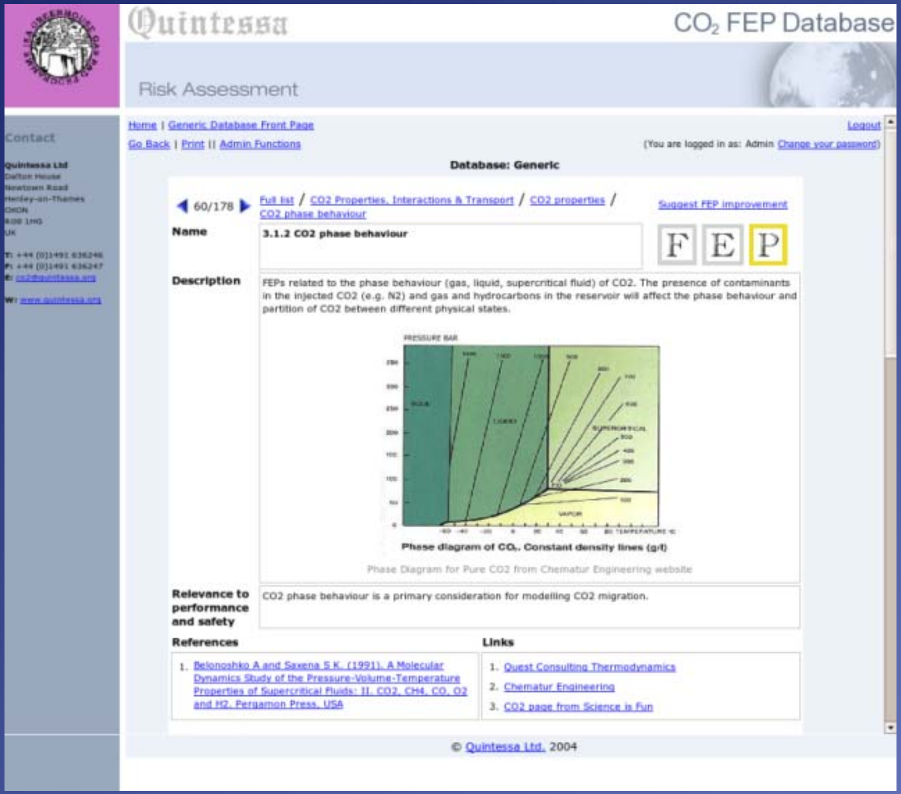
e.g. reservoir simulators

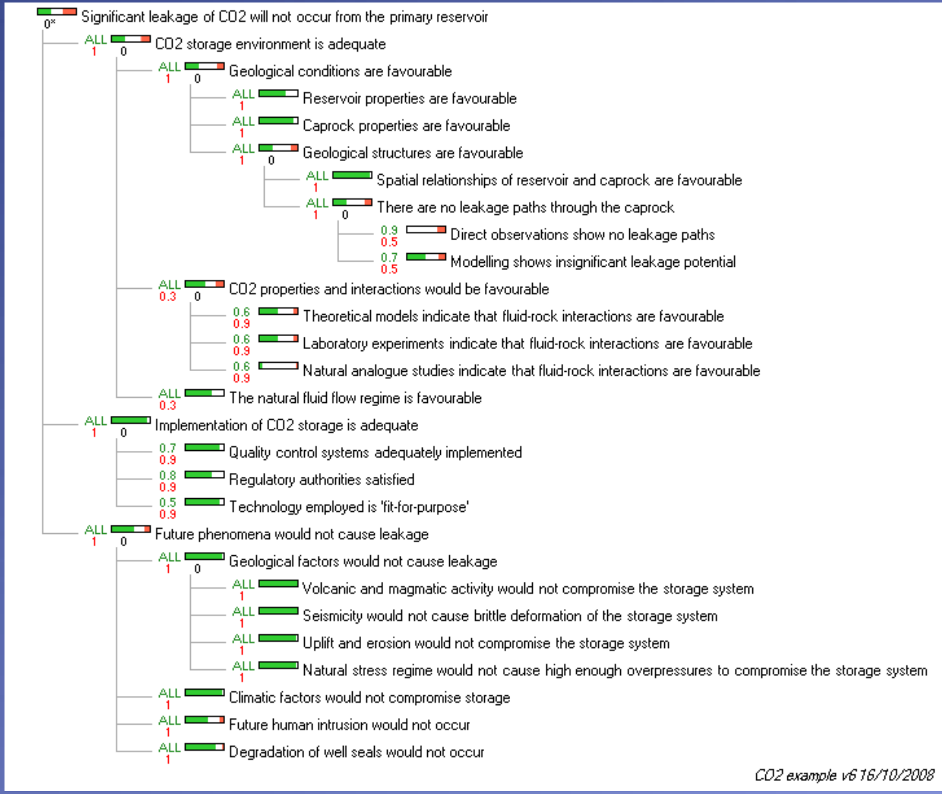


Tools for Risk Assessment: Audit & Decision Making

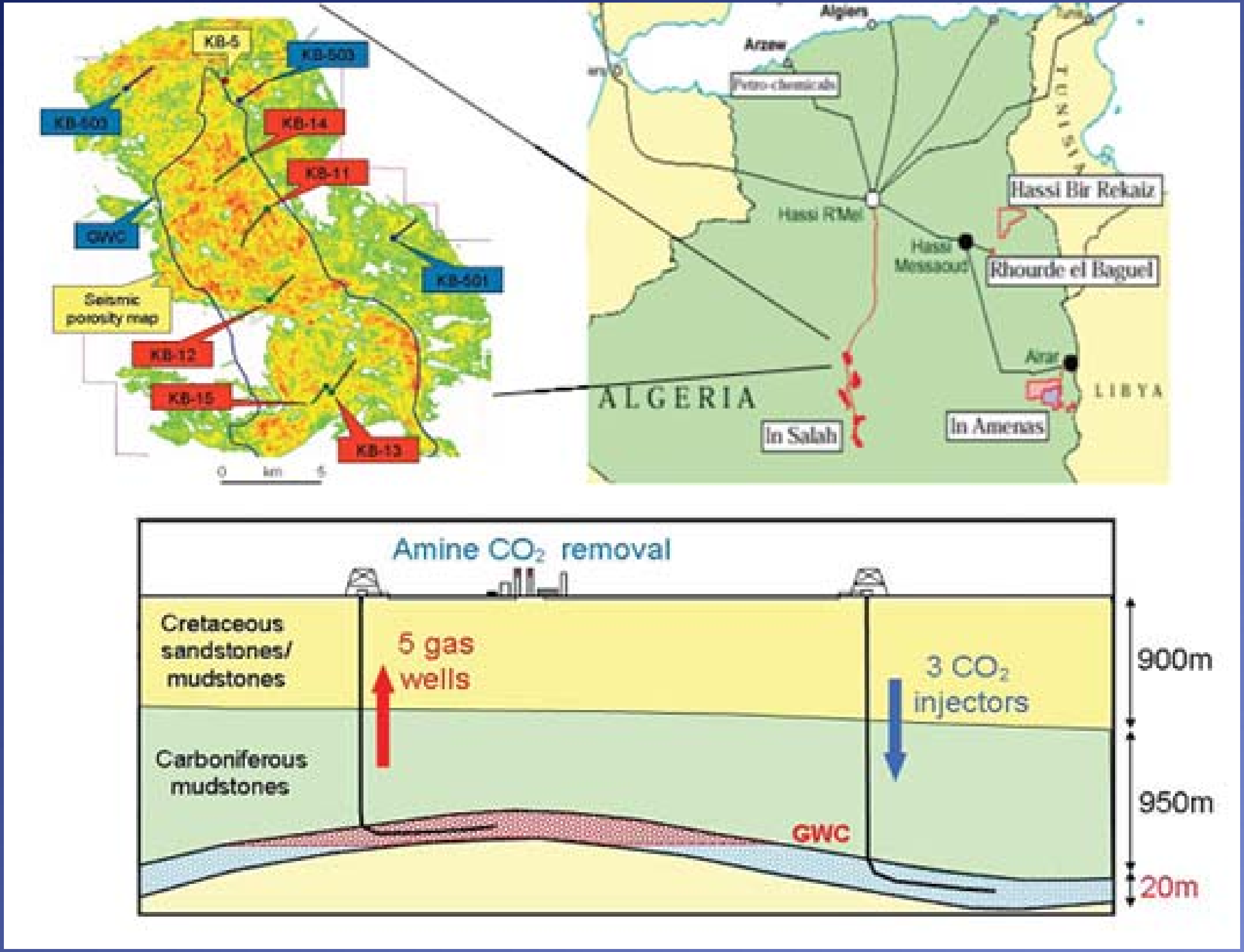
- Databases of important issues (Features, Events, Processes)
  - audit tool
  - support discussion

- Decision-support / integration tools
  - provide audit trail
  - Identify important issues
  - demonstrate relevant issues have been judged





Example: In Salah



Scenario Development: Example In Salah

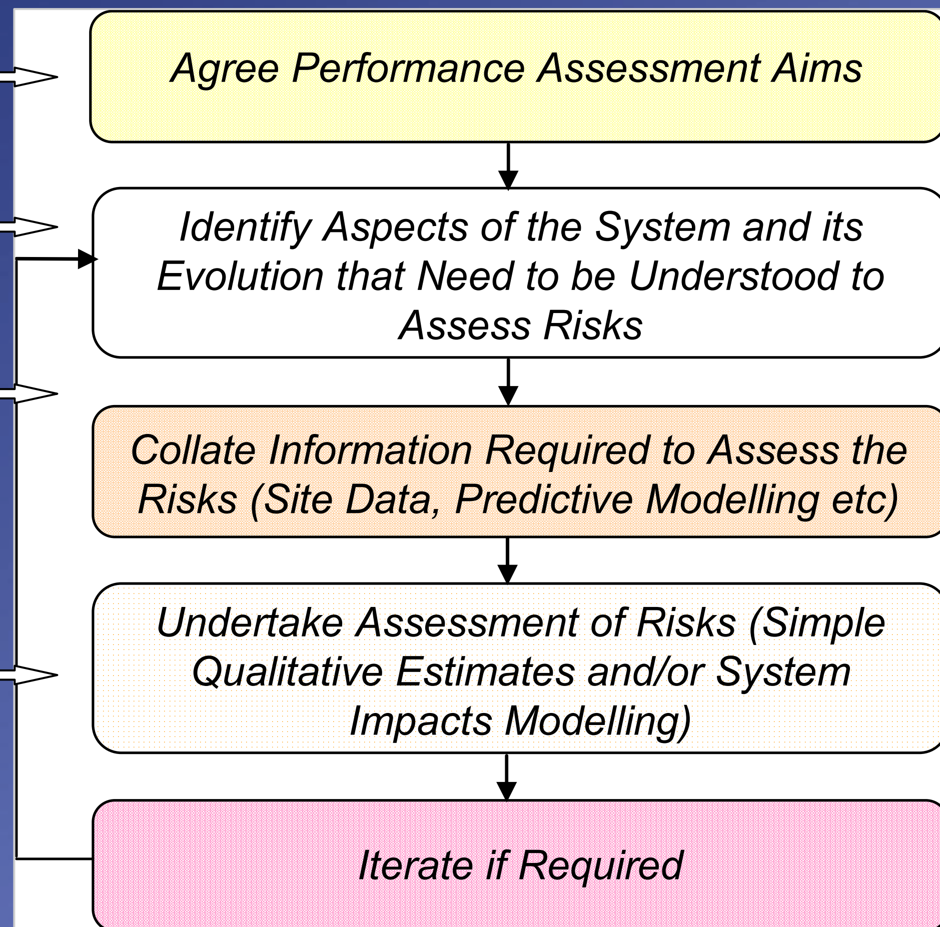
Approach taken in CO2ReMoVe Project

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



After Paulley et al. 2010: GHGT10 Proceedings

CO2 REMOVE research monitoring verification

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.

After Paulley et al. 2010: GHGT10 Proceedings

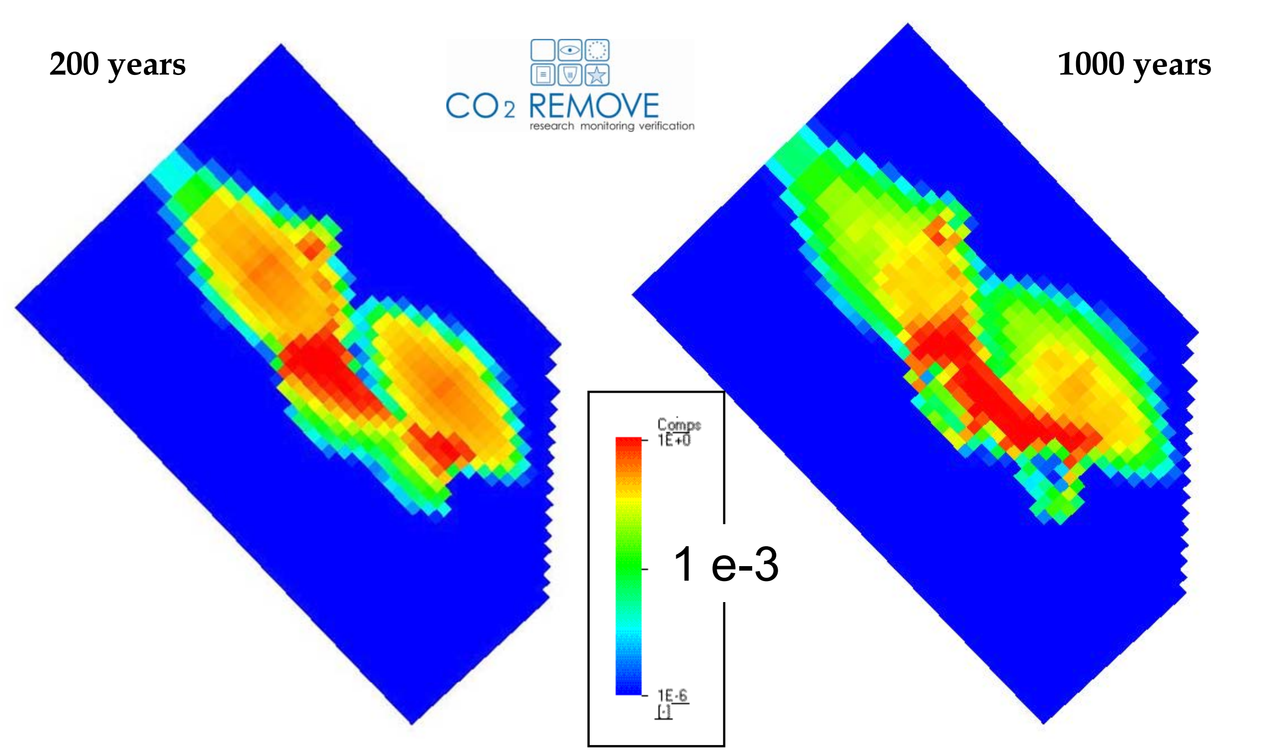
In Salah: Alternative (Unlikely) Evolution Scenarios

- **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

CO2 REMOVE research monitoring verification

Explore Consequences of Alternative (Unlikely) Evolution Scenarios – Example In Salah

- Effects of hypothetical injection for c. 10 x planned period
- Even this extreme case causes little CO_2 loss from reservoir
- Shows large safety margin for present operations
- Robust against uncertainty



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)

Impact Simulations

- Sophisticated biosphere / impact models possible
- Models need further development, but rapid progress already
- Natural CO_2 seeps provide insights into seepage processes
- Can be used to develop / test impact models

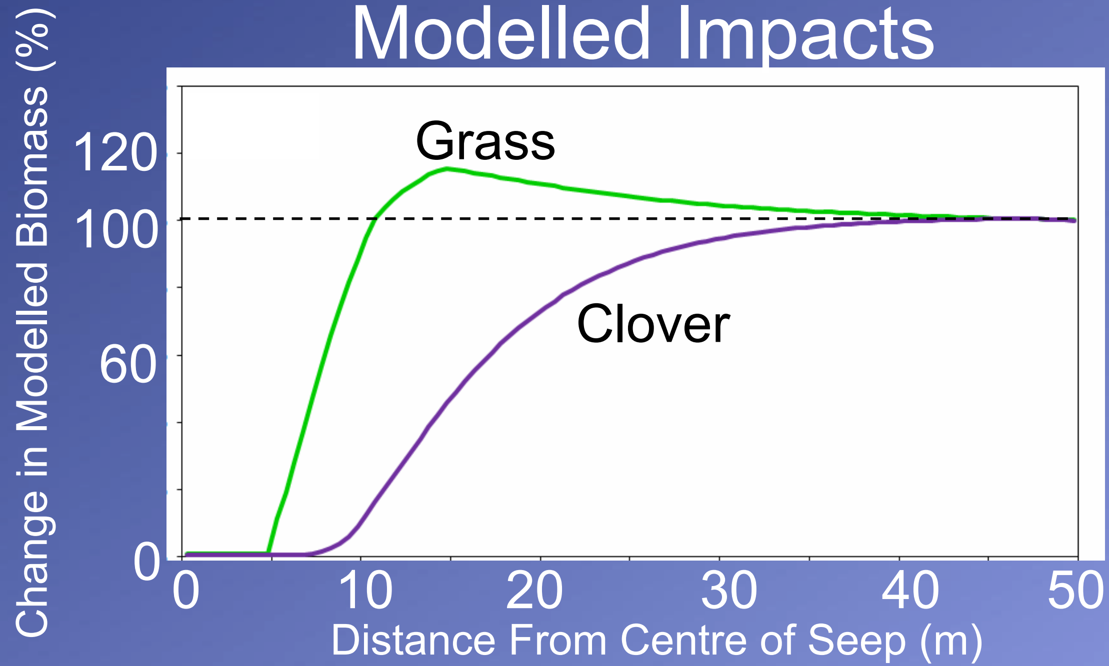
Example: Latera, Italy

Observations

Peak CO_2 flux c. 3000 $g/m^2/day$

After Beaubien et al. (2008), IJGCC

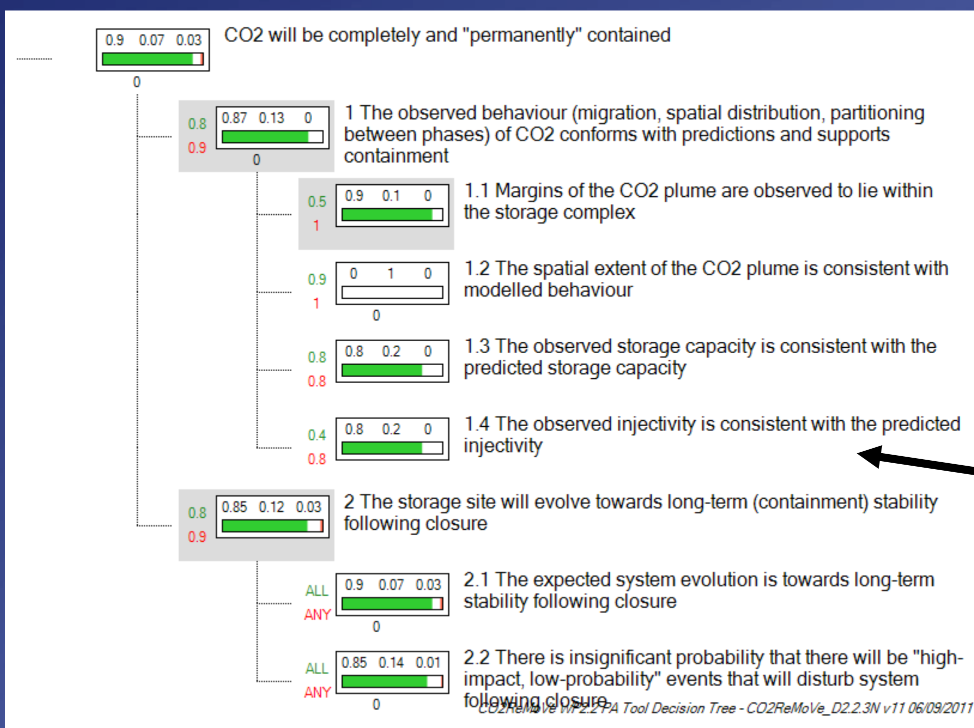
Modelled Impacts



After Maul et al. (2009), DECC Report R318

Structuring / Recording Risk Decisions

- Confidence-building is key
- Need to understand uncertainties – identify / address those that are significant
- Need structured framework for conversation among experts / stakeholders
- Balancing multiple kinds of evidence for and against multiple hypotheses
- Here illustrate approach using decision trees (example developed in CO2ReMoVe)



Uncertainty represented, recorded

User inputs confidence values to lowest level
(Full tree larger than shown)

Conclusions

- Risk assessment not just numerical calculations, also
  - use qualitative and quantitative information
  - multiple lines of reasoning (never rely on one model)
  - expert judgments always important
- Risk-influencing processes are amendable to modelling
- Modelling as much to improve understanding as for prediction
- Risk and uncertainty are not the same thing
- Presenting risk judgments requires
  - clarity and traceability
  - honesty about uncertainties
- Site- and project- specific factors influence how a risk assessment will be done – general principles, not details can be defined
- Carry out risk assessments iteratively, link to project lifecycle