Estimating CO_2 Storage Capacity of UKCS Deep Saline Aquifers

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RPS Energy

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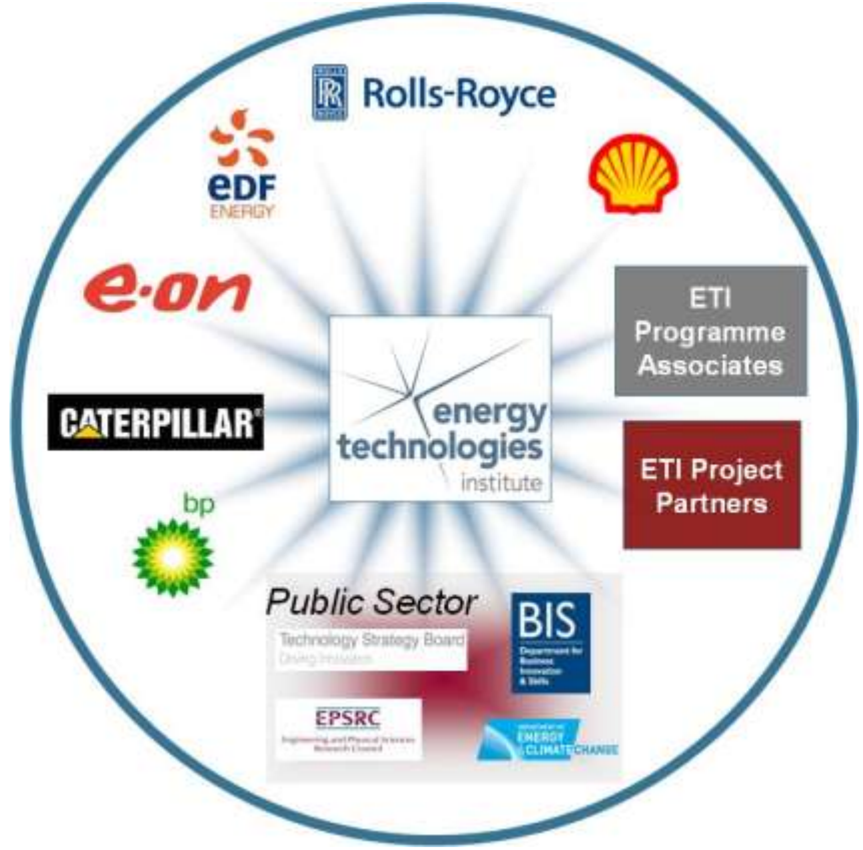
UK CO_2 Storage Appraisal Project (UKSAP)

- **10 organisation consortium**
  - British Geological Survey
  - Durham University
  - Element Energy Ltd
  - GeoPressure Technology Ltd
  - Geospatial Research Ltd
  - Imperial College, London
  - Heriot-Watt University
  - RPS Energy Ltd
  - Senergy Alternative Energy Ltd
  - University of Edinburgh
- **Objective - defensible and auditable estimate of the potential for geological storage of CO_2 on UKCS**
  - No engineering optimisation
- **Technically accessible ('dynamic') storage capacity takes account of:**
  - Pressure constraints
  - Injectivity
  - CO_2 migration when potentially important



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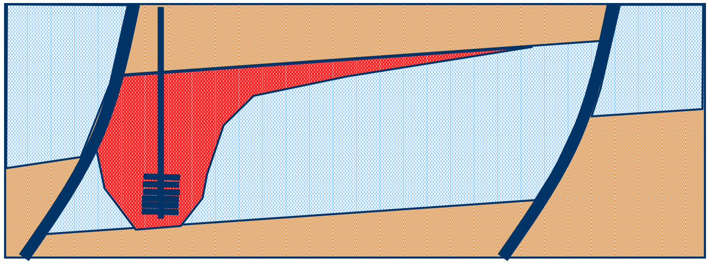
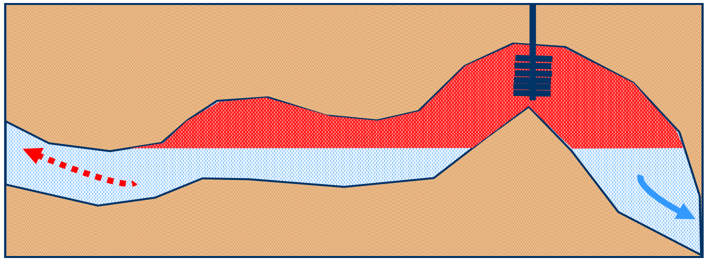
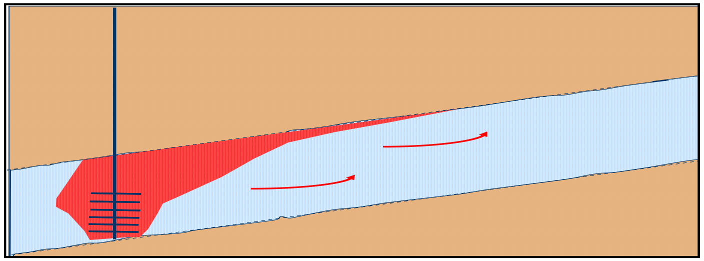
UKSAP Deep saline aquifer storage types



‘Closed’ – behaves as if fully structurally confined – capacity depends on available ‘pressure space’



Structural Trap – partial confinement, capacity depends on spill points, but pressure can bleed off



‘Open’ - overlying seal does not provide significant structural confinement – CO_2 can migrate laterally updip

Outline

- **Deep saline ‘open’ aquifers**
  - Typical behaviour of injected CO_2
  - How to define when an ‘open’ aquifer is full?
  - Estimation of technically accessible CO_2 storage capacity
  - Summary of key points

Numerical simulation of simple dipping open aquifer - typical CO_2 behaviour

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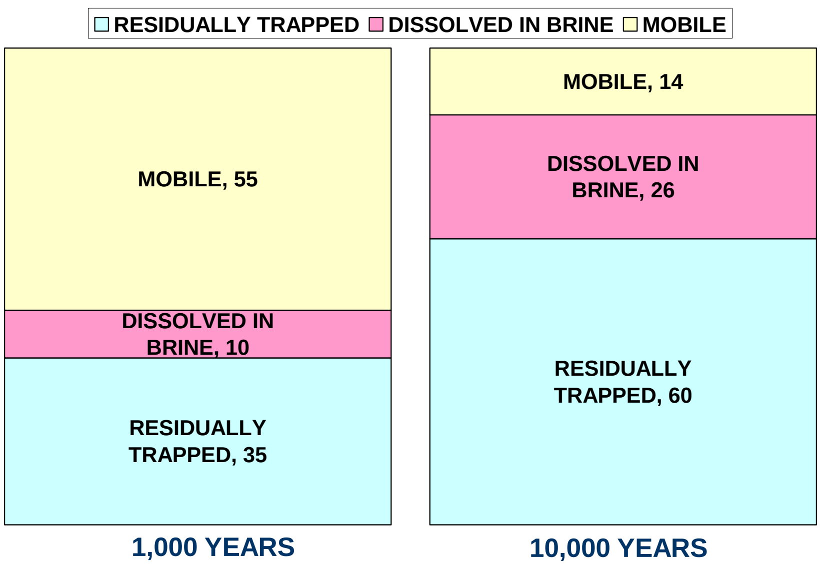
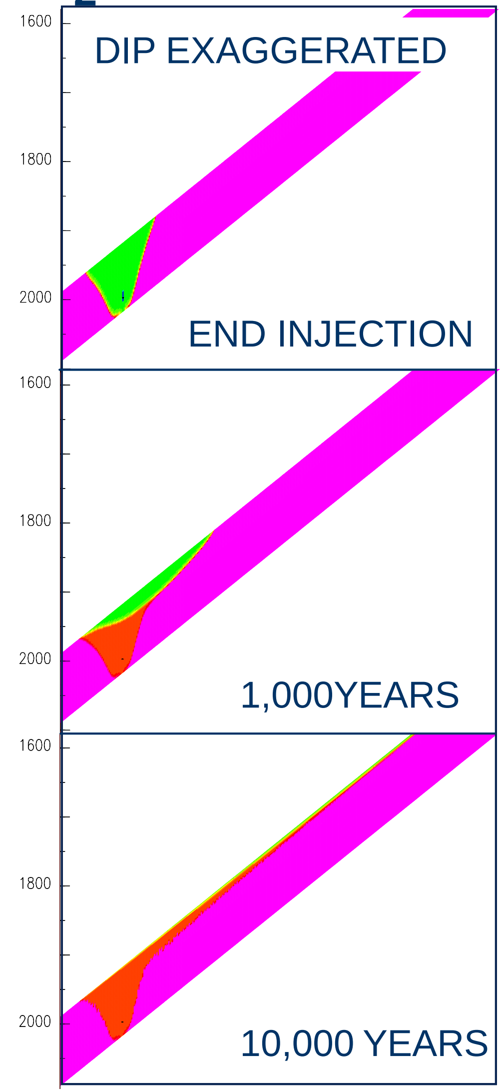
- **Both simple homogeneous and detailed heterogeneous models**
  - Include dissolution, residual (capillary) trapping, but not mineralisation
  - Several hours to run
- **Generic example case**
  - Permeability 300 mD, dip 0.5º
- **Typical CO_2 behaviour**
  - After CO_2 injection ceases, CO_2 local to well and brine redistribute under gravity
    - Promotes residual trapping of CO_2 through hysteresis of relative permeabilities
    - Typically most CO_2 may be residually trapped or dissolved by 10,000 years, but some remains free
    - Bulk of CO_2 eventually trapped near injector
  - Unstable CO_2/brine displacement may cause thin tongue of CO_2 to move updip under the overlying seal
    - May travel tens of kms in thousands of years



TRAPPING MECHANISM DISTRIBUTION (%)



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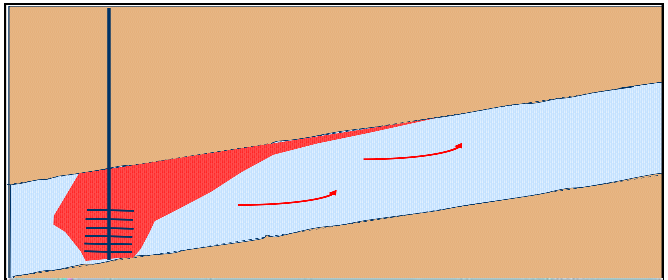
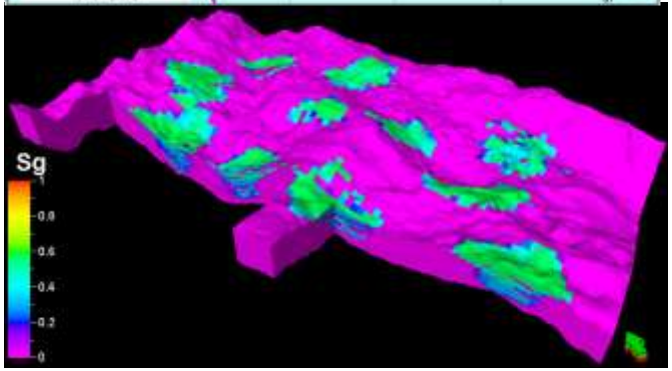
Dipping open aquifer - conclusions

- **Mean dip and representative permeability key factors**
  - For high permeability (100s of mD)
    - CO_2 migration velocities at 1000 years >> 10 m/ yr and increasing
  - For intermediate permeabilities (~100 mD) & low mean dips ~< 1°
    - CO_2 migration velocities at 1000 years < 10 m/ yr and decreasing
  - For low permeability (~10 mD)
    - CO_2 remains localised near injector, no override
    - But injectors typically strongly constrained by pressure limits
- **Detailed modelling of an actual potential storage site confirms sensitivity of storage security to dip and permeability**
  - Undulating top structure can increase (structural trapping) or decrease (locally higher dip) storage capacity



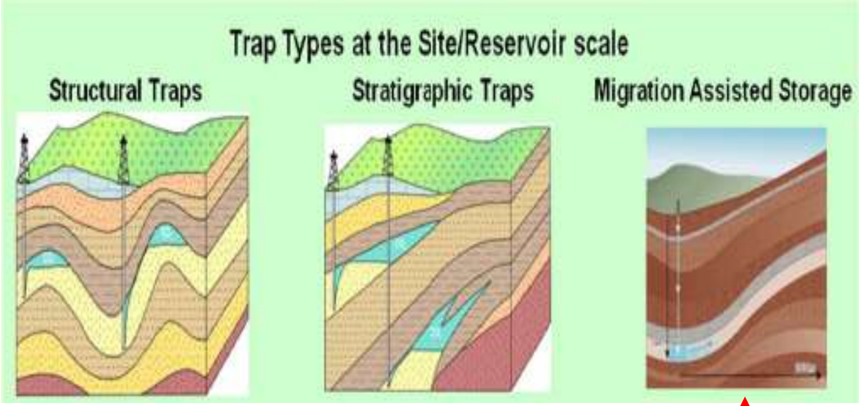


Deep open saline aquifers

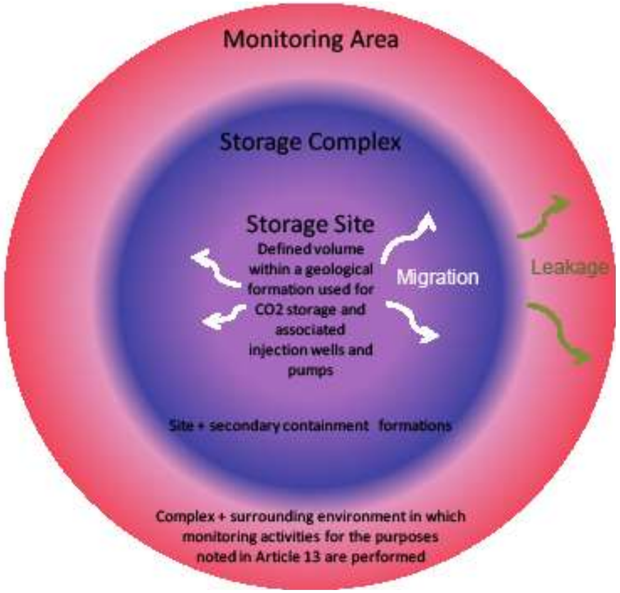
- Typical behaviour of injected CO_2
- **How to define when an ‘open’ aquifer is full?**
- Dynamic capacity estimation
- Summary of key points

2009/31/EC Directive Guidance on the Geological Storage of CO_2

- **Structural/stratigraphic trapping not essential**
  - CO_2 may be dissolved, residually trapped or even mobile in some circumstances
- **CO_2 may leave the storage *site* but not the storage *complex***
  - 'Leakage' means CO_2 leaving the storage complex
- **The storage site must evolve towards a situation of long-term stability indicated when:**
  - models project the plume will be completely and permanently contained with no expectation of future leakage
  - key monitored parameters are within a predetermined range to the future predicted stable values
  - the rate of change in key monitored parameters is small and declining (e.g. lateral plume migration up to metres per year)
  - backcasted values from the modelling are within the confidence intervals of the historical monitored parameters



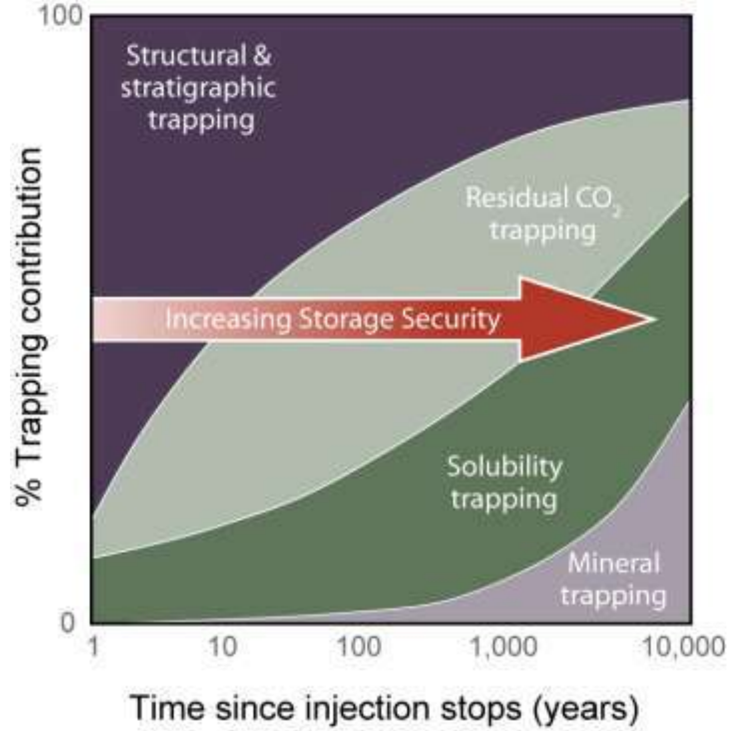
Trap type figure from GD1



Key terms schematic from GD2

Limiting constraints for UKSAP dynamic modelling estimates of open aquifer storage capacity

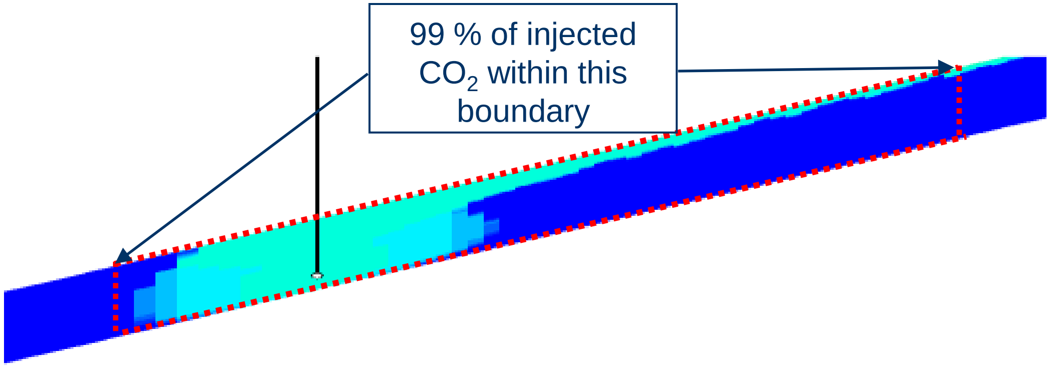
- **Pressures**
  - Standard UKSAP assumption that pressures do not exceed 90% of the minimum of estimated fracture and overburden pressures
- **Time of storage capacity estimation**
  - Choose 1000 years
  - Sufficient to gauge ultimate plume dynamics
- **Confinement tolerance**
  - Target 99% of injected CO_2 to be within storage site after 1000 years
  - Presume that 1% of injected CO_2 outside storage site after 1000 years can remain within storage complex (ie no leakage)
- **Actual storage in specific sites**
  - Appraisal data gathering and detailed modelling should better define appropriate timescale and demonstrate leakage unlikely

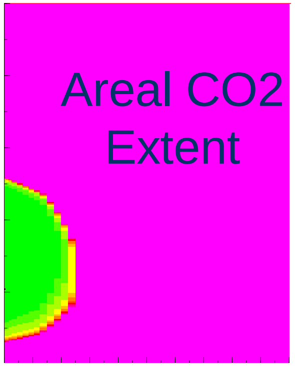


With proper geologic selection and project management, 99% of injected CO_2 will "likely" be retained for 1000 years" (IPCC Special Report on CCS, 2005)

UKSAP storage assumptions for open saline aquifers

- **The extent of the storage *site* boundary in the dip direction is that boundary encompassing 99% of injected CO_2 (by mass) after 1000 years**
  - providing the maximum CO_2 migration velocity at 1000 years is less than 10 metres/year and declining
  - providing pressures remain less than 90% of the estimated fracture pressure limit
- **NB For actual *site* storage not to be interpreted as indicating any expectation of CO_2 *leakage* from the *storage complex***
- **Pragmatic assumptions to facilitate estimation of UKCS storage potential from many sites using simple models**
  - Not suggesting directive should always be interpreted with these assumptions





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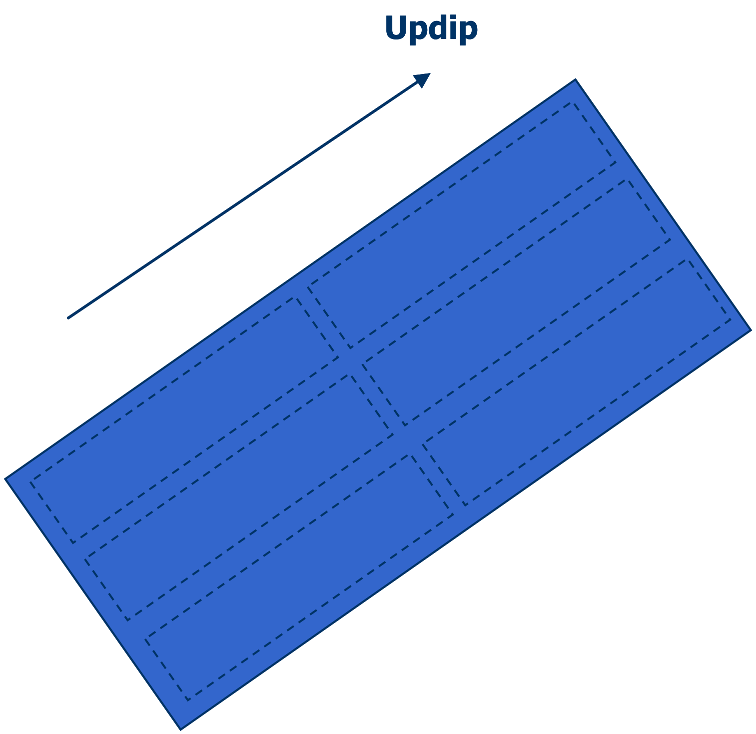
Deep open saline aquifers

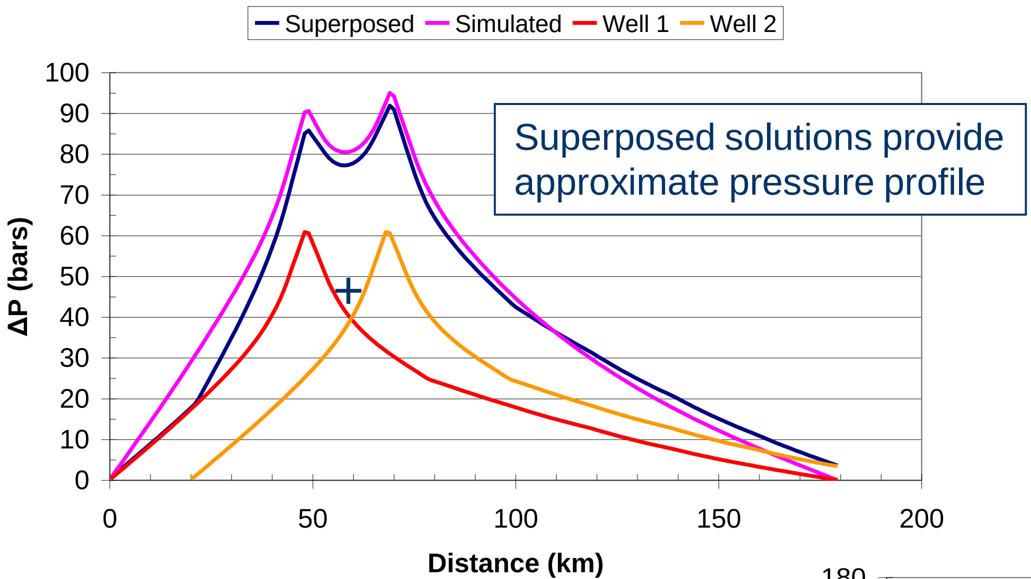
- Typical behaviour of injected CO_2
- How to define when an ‘open’ aquifer is full?
- **Dynamic capacity estimation**
- Summary of key points

Packing of injection sites into open aquifer

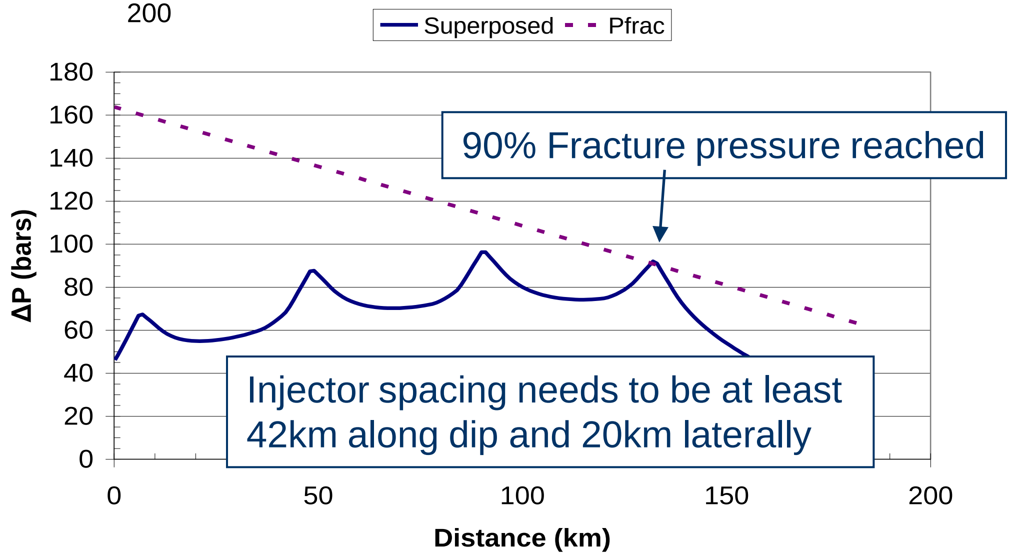
- **Simulated single injector sites rectangular so assume open aquifer also rectangular**
- **Injection site**
  - Length updip determined by 99% rule or pressure footprint after injection ceases
  - Width determined by extent of pressure footprint after injection ceases
    - larger than CO_2 extent
- **Require procedure for estimating extent of pressure footprint**



Estimating pressure footprint



- **Superposition and Method of Images used to approximate multi-injector pressure footprint from single injector simulation**
- **Post processing programme calculates best arrangement for maximum packing of injector sites ensuring**
  - $P < 90\% \ P_{fracture\ press}$



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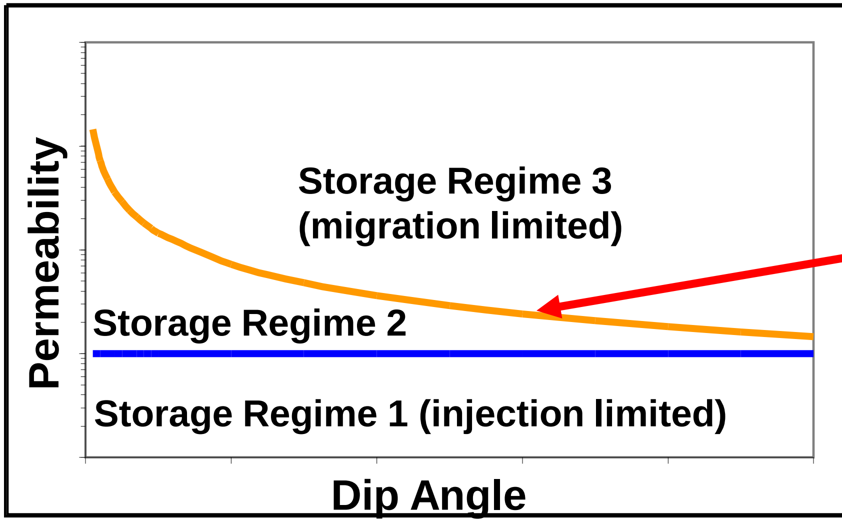
Open aquifer storage regimes

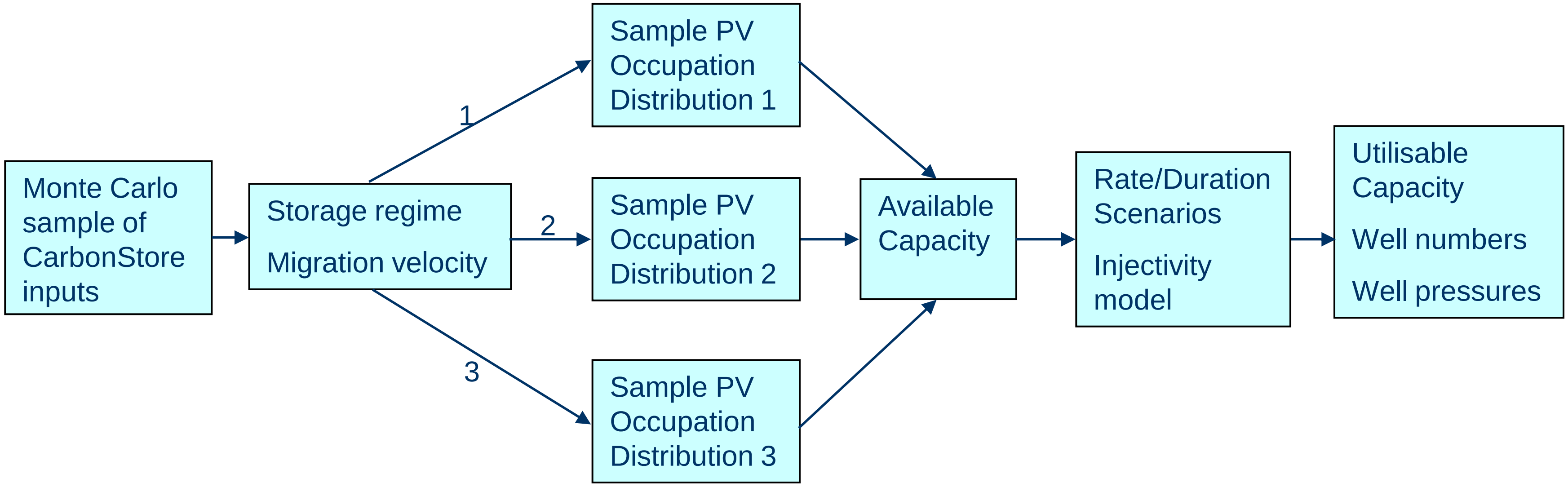


CO_2 Migration Velocity at plume tip after 1000 years = 10 m/year

$$v = \frac{k k_{rCO2} (\rho_w - \rho_{CO2}) g \sin\theta}{\mu_{CO2} (1 - S_{wirr}) \phi}$$

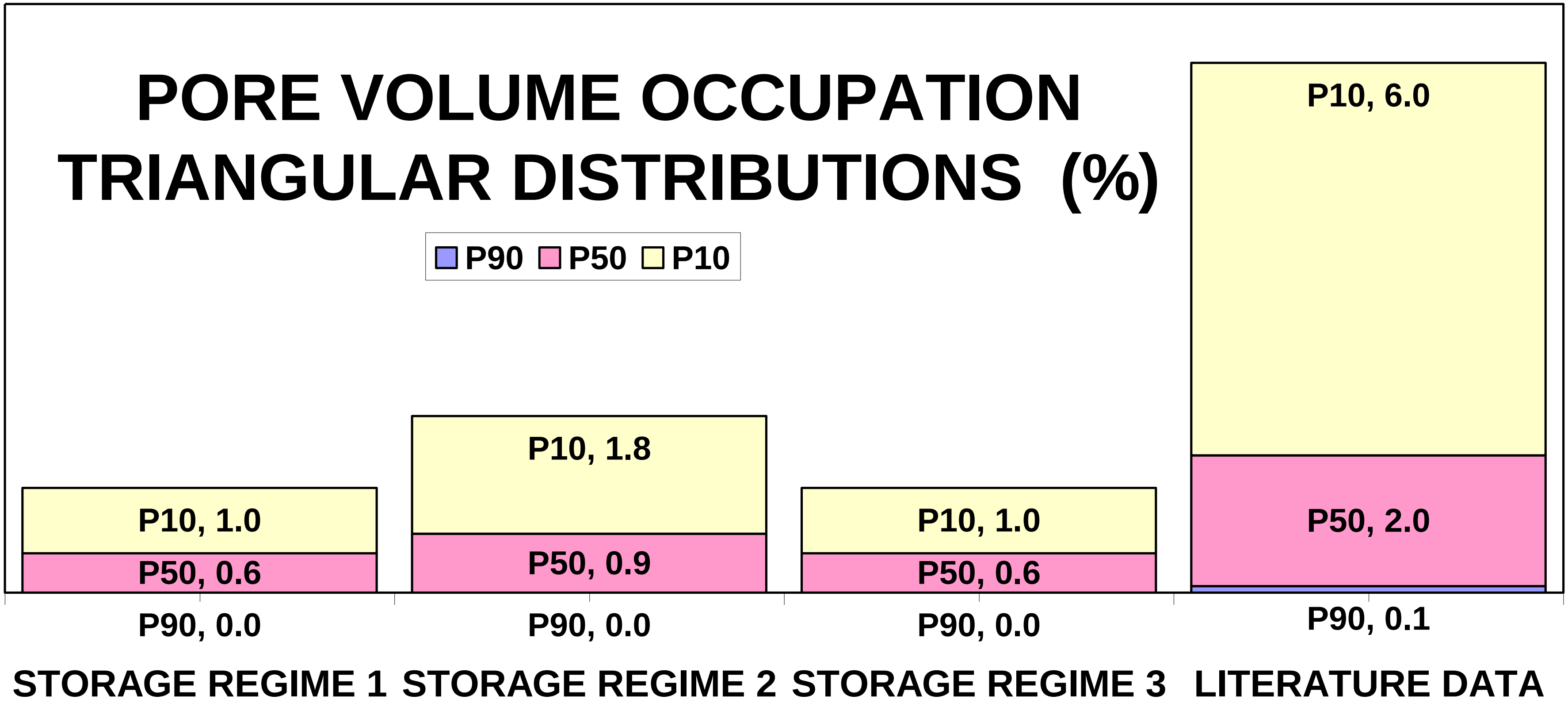
- **~100 Cases**
  - Various input data sensitivities
  - Additional cases informed by properties of CarbonStore units
- **Defined three storage regimes for capacity estimation from simple models**
- **For regime 1, CO_2 remains local to well, so storage is secure but injection limited**
- **For regime 3, migration velocities do not satisfy velocity storage criterion, *so all stored CO_2 in this regime must be residually trapped or dissolved***
  - Injection into regime 3 stores limited to prevent CO_2 being mobile at 1000 years

UKSAP open aquifer capacity estimation



CarbonStore open aquifer Monte Carlo loop

UKSAP open aquifer capacity estimation



- **Pore volume occupations (storage efficiency) lower than for other studies**
    - Limited by pressure footprint

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Summary of key points

- **Typical behaviour of injected CO_2 illustrated**
  - Residual trapping around injector, but CO_2 migration updip
  - Key factors influencing storage security identified (permeability and dip)
- **Three storage regimes defined for simple models**
- **UKSAP procedure for estimation of open aquifer technically accessible CO_2 storage capacity presented including:**
  - Pragmatic estimation assumptions
  - Method for estimation of pressure footprint from single injector simulation
- **Estimated pore volume occupations (storage efficiencies) typically at lower end of literature values**