SEVENTH FRAMEWORK PROGRAMME

Characterisation of European CO_2 storage

Developing a storage permit for an onshore aquifer

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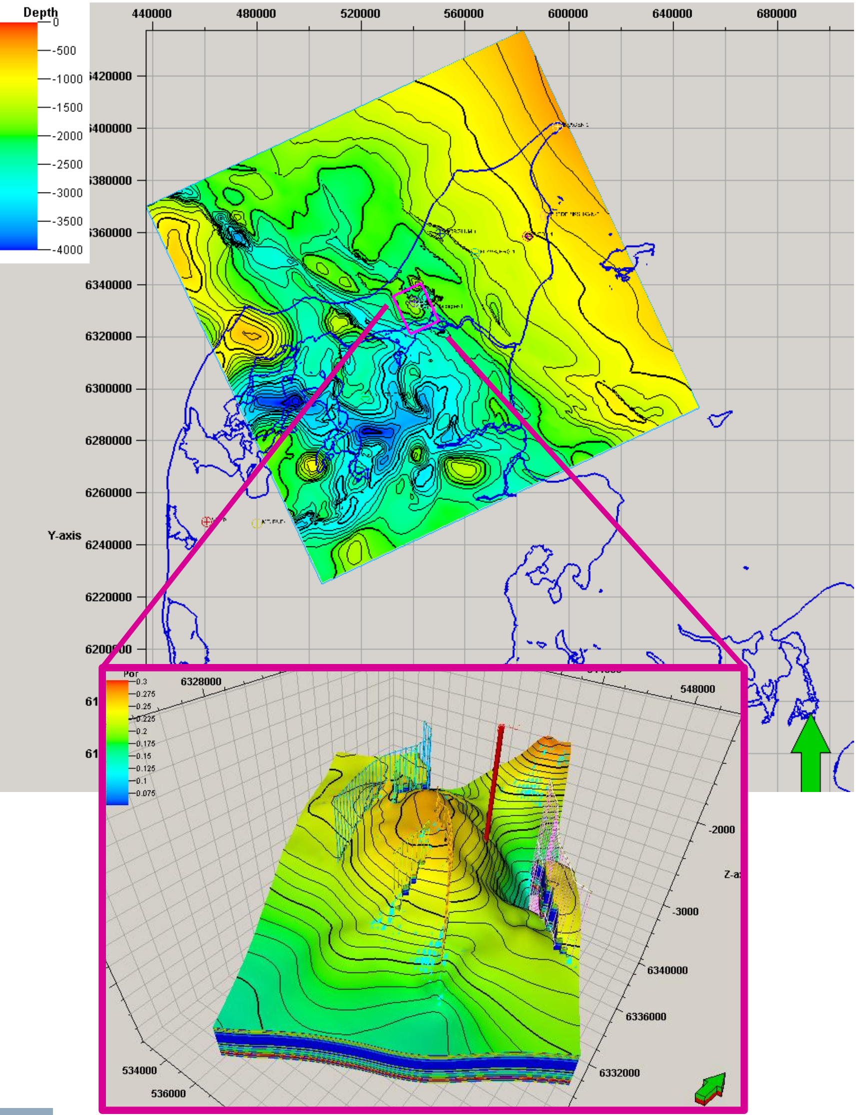
Outline

- Introduction to the Danish site
- Objectives for the work
- Sparse data set for characterisation
- Dynamic modelling and pressure development
- Risk assessment, monitoring and baseline survey
- Key learnings and recommendations

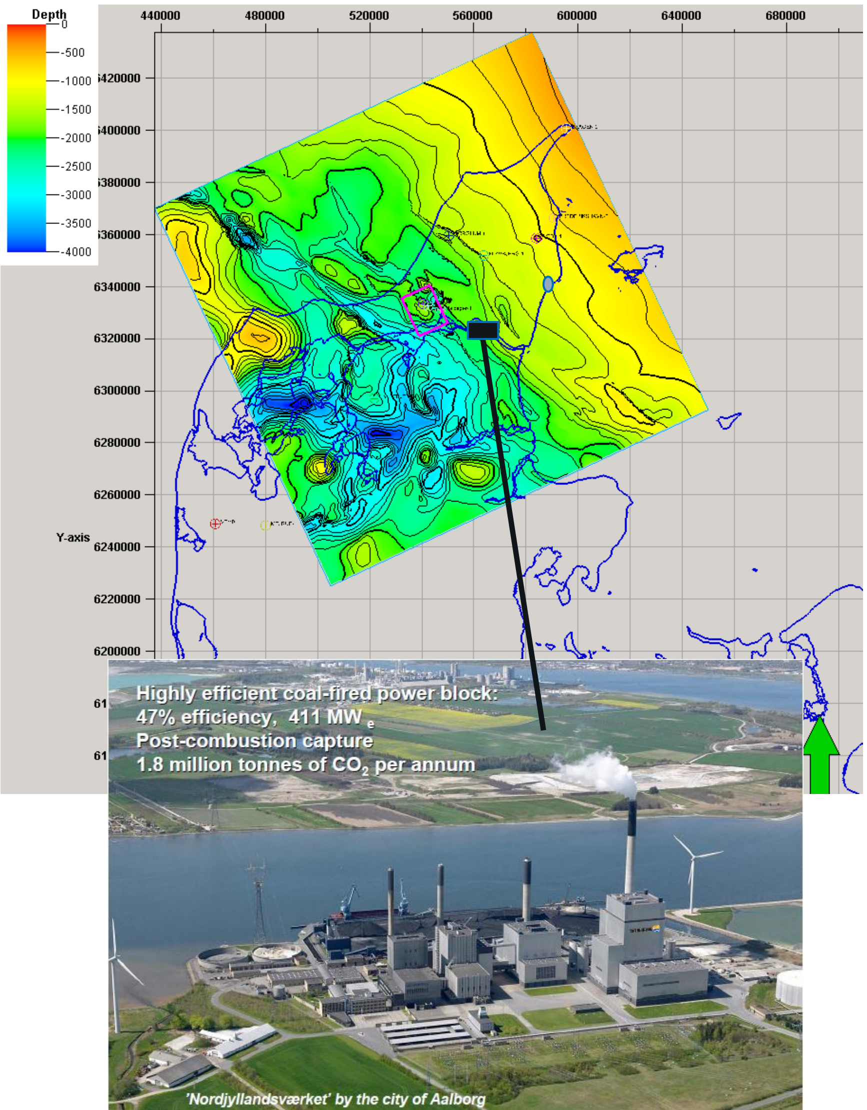
The Danish site – Vedsted



Vedsted storage site

- Onshore aquifer
- Upper Triassic – Lower Jurassic Ss. (1. Gassum Fm., 2. Haldager Fm.)
- Trap: Anticlinal closure in a major fault system
- Reservoir @ 1800 – 1900 m depth
- Identified by hydrocarbon exploration campaign in the late 1950-ties
- Identified as candidate for CO_2 storage by GEUS in 2003 (GESTCO)
- Sparse data set
  - One legacy well, vintage 2D seismic surveys (1967 and 1983), new 2D seismic survey 2008

The Danish site



Project concept

- 2007-2011 Vattenfall plan to develop a full-scale demonstration project
- Safely store captured CO_2 from coal fired power plant: CO_2 emission ~ 2 Mt/y
- Vedsted structure situated approx. 30 km from power plant (transport by pipeline)
- Additional CO_2 source from cement industry: CO_2 emission ~ 1 Mt/y
- 40 years injection operation
- 1 to 3 injection well(s)
- Phased development
  - 1. inj. well down flank of structure

Objectives for the Vedsted site in SiteChar

- To complete a site characterisation comprehensive enough to fulfil a 'dry-run' storage permit application
- Investigate different ways to supplement a sparse data set
- Exploring and mitigating impacts on the surrounding area from the storage operation – especially undesirable pressure footprint
- Set up a monitoring strategy for best risk management – including relevance of baseline survey(s)
- Old well integrity assessment

Scope of the dry-run permit

- Not all issues in the EC storage directive addressed
  - Abandonment, EIA, financial security, reporting plan
- Limited resources for acquiring new data and very comprehensive studies
- Lack of production data for history matching dynamic modelling
- Baseline surveys performed in analogue area

➢ But, an actual permit application produced with lessons learned through process

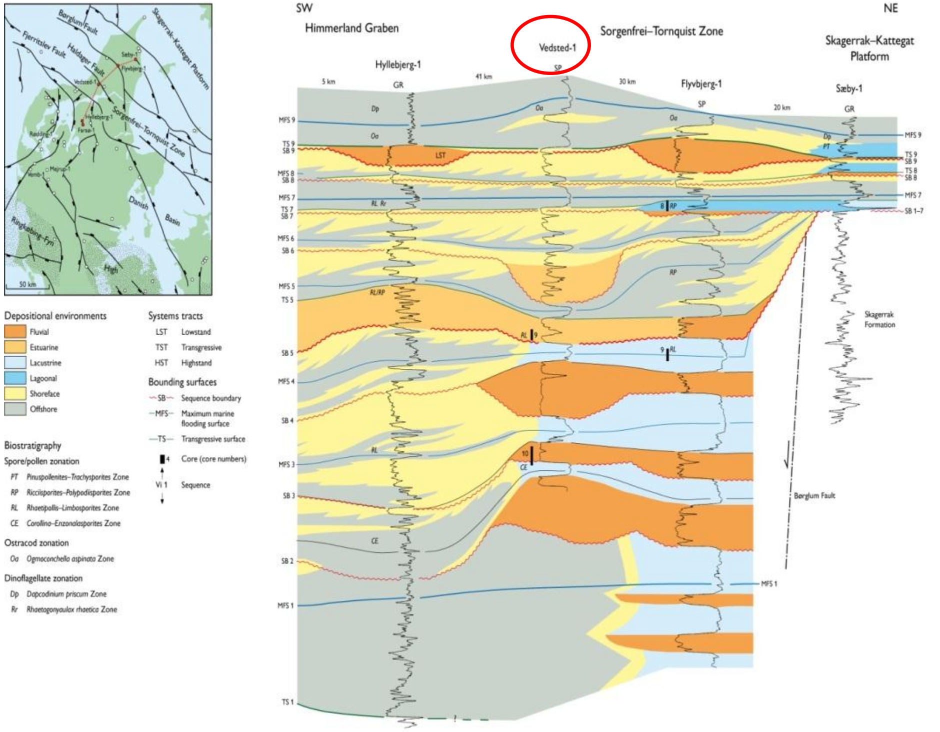
Handling a sparse data set for characterisation

- Regional geological interpretation used to guide site specific modelling

- Resolution and variability issues (only one case constructed)

- Use of analogue settings and data (wells, core data and similar structures/sites)

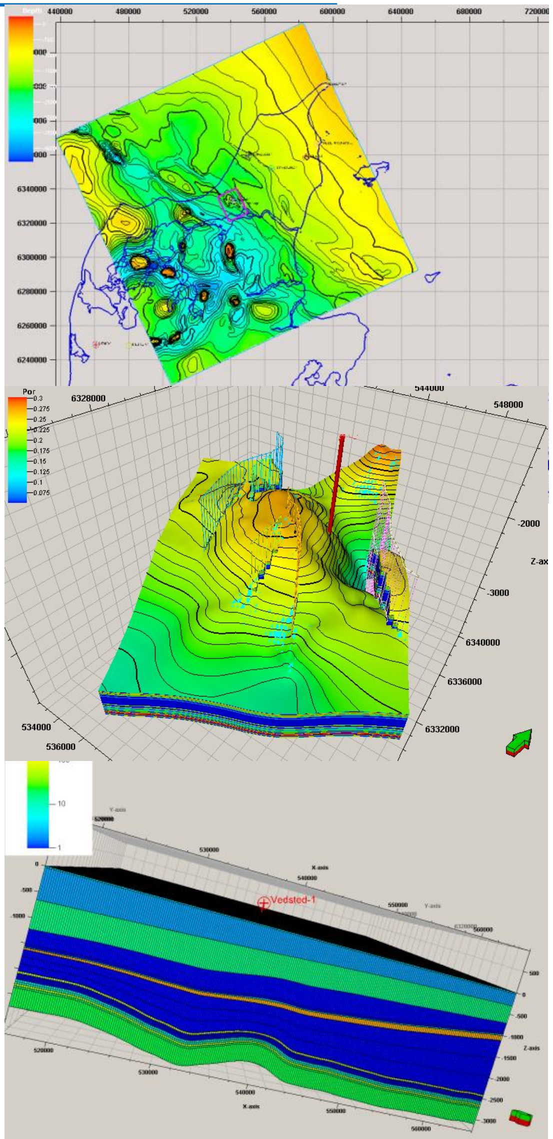
- Iterative modelling procedure and phased development
  - 3D seismic, appraisal well, inj. test etc…



Static and dynamic modelling

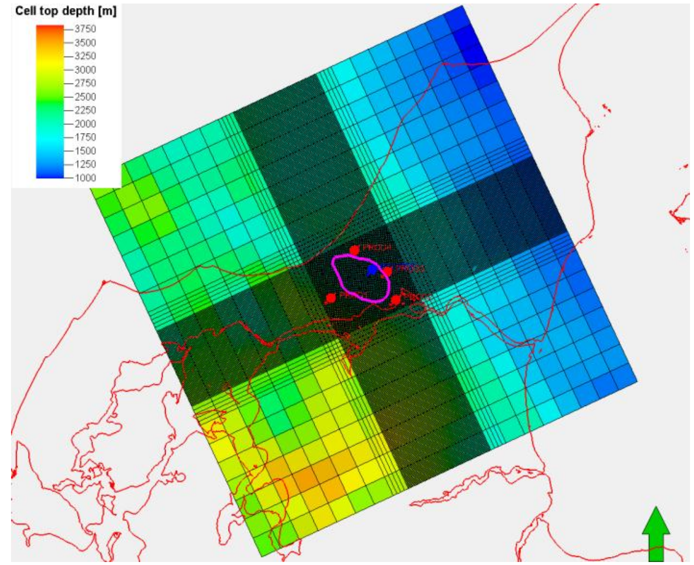
Model construction at different scales

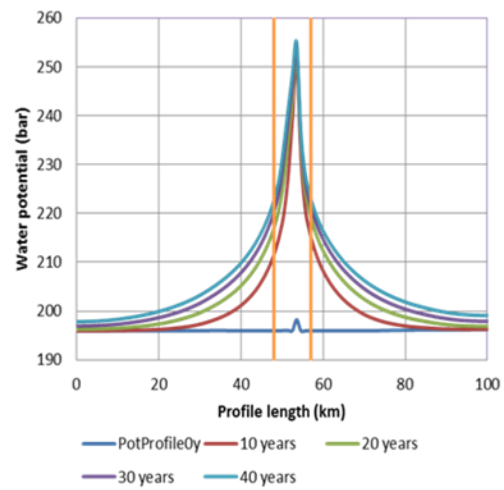
- Regional model for pressure and boundary conditions study (160km x 160km)
- Site specific model for plume distribution and injection strategy (12km x 16km)
- Intermediate size model for geomechanical study (50km x 50km) – overburden included
- Iterative modelling procedure

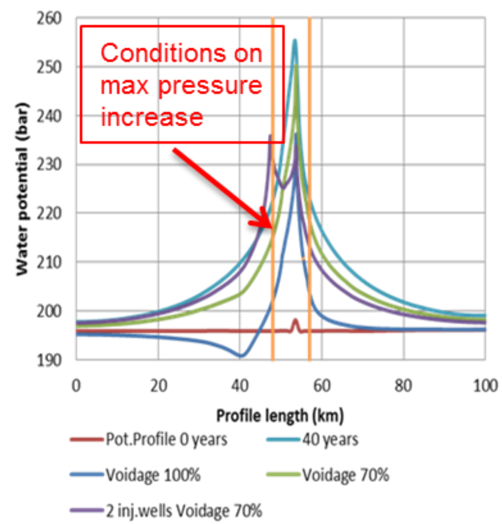


Regional pressure development and mitigation

- Regional pressure development
- Boundary conditions impact on evaluation of filling efficiency and capacity estimation
- Pressure release through water production (eg. 4 prod. wells outside the closing contour)

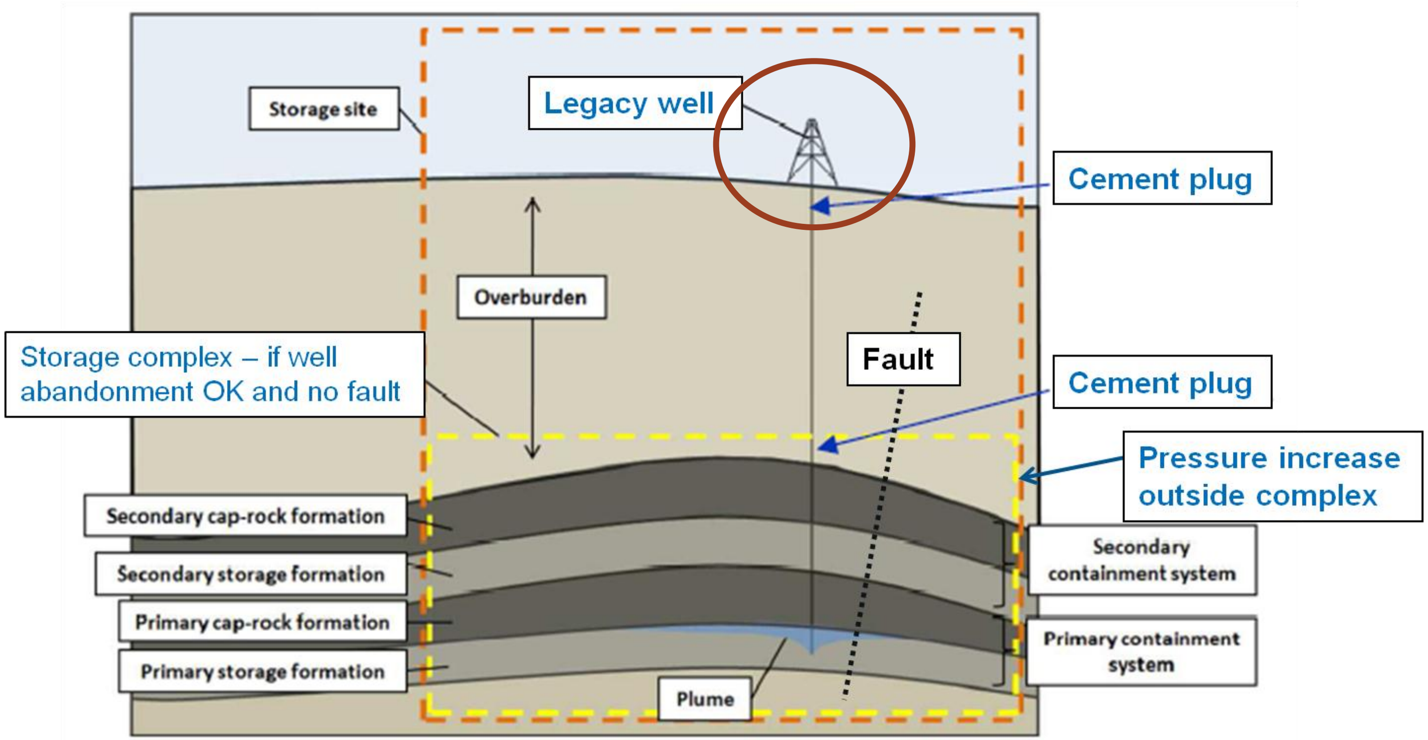






Regional pressure development and definition of the storage complex

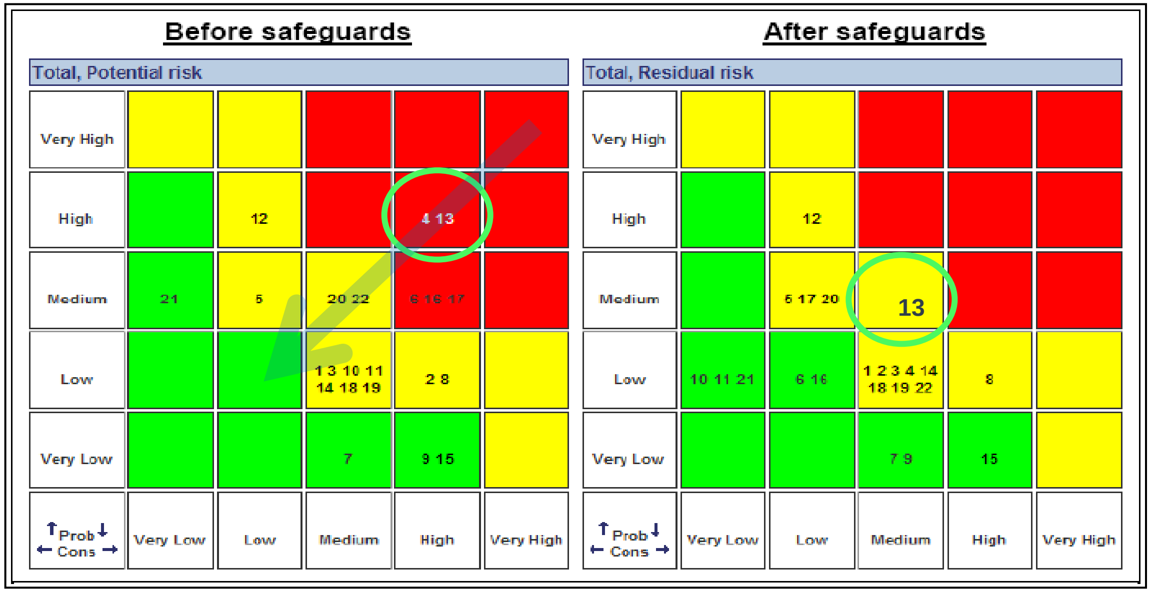
- Constraints on regional pressure development?
- EC storage directive provides no clear definitions for pressure increase



Monitoring to ensure the best risk management

Risk driven and site specific

- Site specific <u>risk assessment</u> to guide a meaningful monitoring plan
- Onshore and offshore sites have different challenges for choice and deployment of monitoring techniques
- Monitoring plan deployed at all the main stages of a storage project
  - Baseline, operational and post-injection stages



Before safeguards

Total, Potential risk

↑Prob↓ / ←Cons→	Very Low	Low	Medium	High	Very High
Very High					
High		12		4 13	
Medium	21	5	20 22	6 16 17	
Low			1 3 10 11 14 18 19	2 8	
Very Low			7	9 15	

After safeguards

Total, Residual risk

↑Prob↓ / ←Cons→	Very Low	Low	Medium	High	Very High
Very High					
High		12			
Medium		5 17 20	13		
Low	10 11 21	6 16	1 2 3 4 14 18 19 22	8	
Very Low			7 9	15	

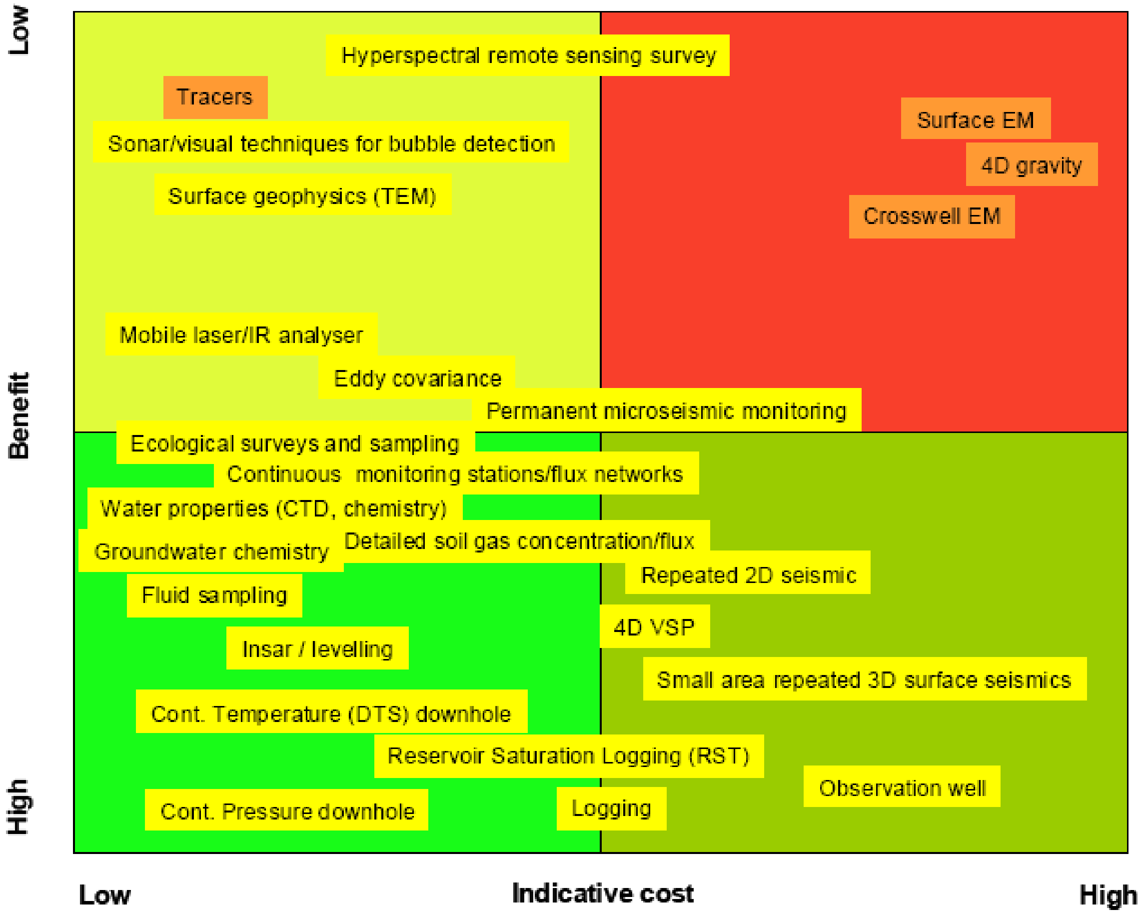
Risk matrix – before and after implementation of safeguards

Ex.: “13” old Vedsted-1 well

Monitoring plan

Comprehensive study assessing all relevant monitoring techniques for the Vedsted site (CO_2GeoNet)

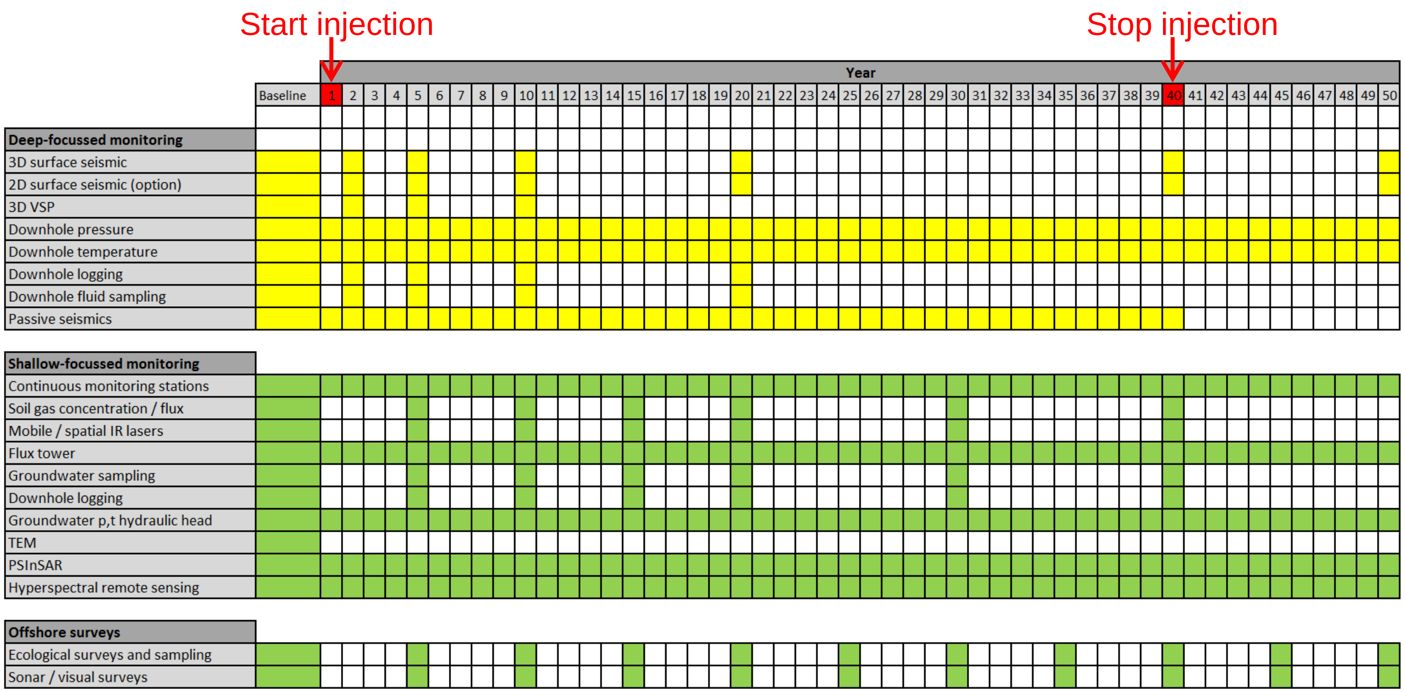
- Surface (4D seismic) and downhole (VSP, pressure, temp.) sensor deployment



Monitoring plan

Dynamic document

- Operator must update monitoring plan and strategy if any irregularities are discovered
- Update 3D models – monitoring surveys tied to appropriate modelling procedures and interpretations



N.B. Includes surveys which will be considered but might not actually be deployed, depending on circumstances - see text for details

N.B. Subject to review and modification through operational phase as monitoring data becomes available and predictive models are updated

Regulatory requirements for monitoring

EC Storage Directive (monitoring plan)

- Monitoring throughout the project lifetime
- Member state authority controls the operators monitoring activity

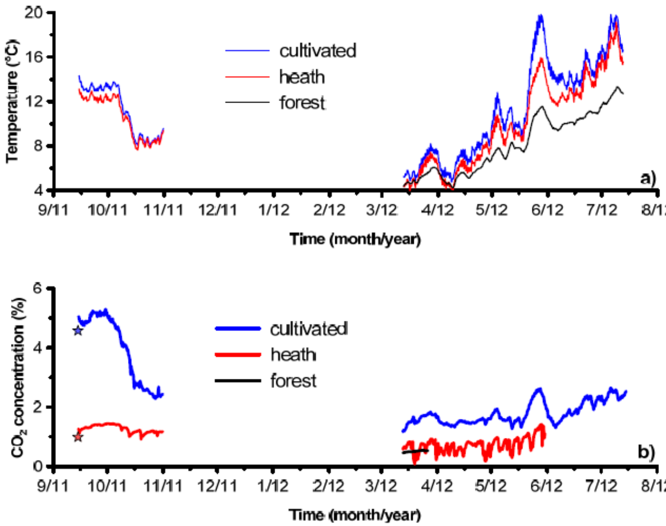
Monitoring objectives

- Site performance (predicted *vs*. observed behaviour)
- Leakage detection
- Detection of significant irregularities (pressure -, plume development)
- Adverse environmental impacts
- Assists in deployment of any corrective measure
- Verify long-term storage stability and permanent containment
- Update site performance assessment
- Update risk assessment for the site every 5 years

Baseline surveys

Experimental field work

- Test site shifted from the Vedsted site to the ”Hobe test-site” (agriculture research site)
- Three main land-use types;
- Plantation (conifer), cultivated field, heath/moor
- Two monitoring campaigns;
- Sept. 2011; soil gas monitoring and deploying
- measurement probes for baseline program
- May 2012; soil gas and CO_2 flux sampling
- CO_2 concentration higher in cultivated fields, CO_2 flux almost constant in heath/moor, CO_2 flux varies with surface temperature variation for cultivated fields



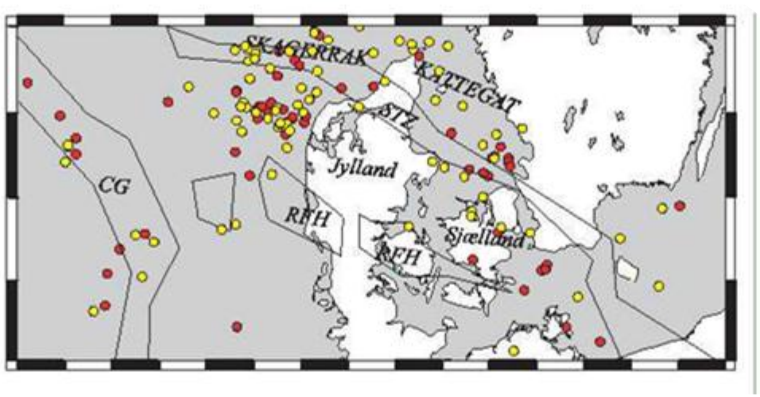
Baseline monitoring

Objectives for baseline data

- ○ Pre-injection dataset for all proposed monitoring techniques
- ○ Pre-injection dataset for any operational induced irregularities

Challenges for baseline data

- ○ All natural variability must be captured
  - Background or natural soil gas fluxes, seasonal variation, weather conditions, non-operational seismicity, “unexpected events”, …



Earthquakes 1970-1990
Earthquakes 1990-2010

Key learnings from the SiteChar experience

- Very instructive to build the model framework as early as possible in the characterisation process as this helps guide the risk assessment, even that the model might be simple, complexity can be added after key findings

- Iterative process adjusting models as the project progresses and at different scales

- The risk assessment controls the individual elements of a storage permit application/project

- Regional pressure development is not fully defined in the EC storage directive, and this complicates the definition of the storage complex

Remaining issues/Challenges

- Production data / well test for calibration of the dynamic models not available
- Sensitivity/uncertainty analysis not carried out – due to lack of calibration data (low and high cases should be constructed)
- Optimised injection strategy not carried out (compartmentalization, filling efficiency, plume migration)
- Geochemical analysis (caprock integrity, injectivity)

Recommendations

- For the modelling part; start simple and introduce more complexity as the project experience/knowledge progresses
- For onshore (offshore as well??) sites with sparse data coverage an incremental development can reduce risks and costs
- Baseline survey(s) are essential
- Pressure footprint on the surrounding areas from the injection operation must be assessed and potentially mitigated through water production

Acknowledgments

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