4TH RISK ASSESSMENT WORKSHOP

Report No. 2009/07

November 2009

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ACKNOWLEDGEMENTS AND CITATIONS

The IEA Greenhouse Gas R&D Programme supports and operates a number of international research networks. This report presents the results of a workshop held by one of these international research networks. The report was prepared by the IEA Greenhouse Gas R&D Programme as a record of the events of that workshop.

The fourth international research network on Risk Assessment was organised by IEA Greenhouse Gas R&D Programme in co-operation with the CO2CRC. The organisers acknowledge the hospitality provided by the hosts Rendezvous Hotel, Melbourne, Australia.

A steering committee has been formed to guide the direction of this network. The steering committee members for this network are:

Tim Dixon, IEA GHG (Chairman)
John Kaldi, CO2CRC
Rick Chalaturnyk, University of Alberta / IPAC
Jonathan Pearce, British Geological Survey
Malcolm Wilson, University of Regina / IPAC
Claudia Vivalda, Schlumberger
Lisa Bacanskas, US EPA
George Guthrie, NETL
Charles Jenkins, CO2CRC
Brendan Beck, IEA GHG

The report should be cited in literature as follows:

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Further information on the network activities or copies of the report can be obtained by contacting the IEA GHG Programme at:

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Summary Report of 4th Risk Assessment Network Meeting

Date: 16 – 18 April 2009
Rendezvous Hotel,
Melbourne, Australia.

Organised by IEA GHG and CO2CRC.

FOURTH WORKSHOP OF THE INTERNATIONAL RESEARCH NETWORK ON RISK ASSESSMENT

Executive Summary

The fourth IEA GHG Risk Assessment Network Meeting was held on the 16th—17th April 2009 in Melbourne, Australia, and hosted by CO2CRC.

Cliff Kavonic of Victorian Department of Primary Industries gave the official welcome. The Victorian Government was that day publishing a report by Geoscience Victoria on the storage potential in the Gippsland basin in south Victoria.

The fifty six attendees enjoyed the discussions based around the six sessions. These were on reports from other initiatives, leakage impacts, combining monitoring with modelling and risk assessment, insurance and risk, risk communication, and updates from real projects.

Of particular note were Australian presentations on impacts of CO_2 storage on groundwater, putting potential effects of CO_2 into context with other effects, and showing that there may be positive effects in terms of drinking water re-pressurisation. Work from the US and Canada was also heard on groundwater impacts.

Also, in terms of risk communication, the community engagement for two successful projects in Germany and Australia were presented, highlighting the importance of the engagement process itself as much as the information communicated.

The workshop also included a presentation and discussion of risk assessment and insurance. This included discussion of the CCS liability policies offered by Zurich Insurance, and the role of ETS in setting a price for CO_2. This is discussed in more detail in Session 4 of this report.

The workshop concluded with breakout groups to identify the gaps, recommended actions, and key learning points. In considering the future role of the Risk Assessment Network, the overall conclusion was that it continues to be necessary, but level of openness in the future may not be a great as members' desire because of increasing commercial sensitivities around real projects. In terms of what are the boundaries of the Risk Assessment Network's mission – the conclusions from most participants were that it should remain technically focused, although its results are use in the context of economic, political, social and other risks assessments.

The meeting was followed by a trip to the CO2CRC Otway project to see first-hand the site and work that had been described during the Network meeting.

Contents

Welcome and Introduction,

Tim Dixon and John Kaldi opened the meeting, and reminded all of the remit of the Network which was established in 2005.

Cliff Kavonic of Victorian Department of Primary Industries gave the official welcome. The Victorian Government, coincidentally, that day released a report by Geoscience Victoria on the storage potential in the Gippsland basin in south Victoria. Questions followed around funding for CCS, the role of CCS within emissions trading schemes, and CCS and biomass. Cliff and Tim Dixon responded.

Neil Wildgust of IEA GHG gave a presentation on the results of the previous Risk Assessment Network meeting and the relevant conclusions from the Joint Network meeting.

Session 1: Reports from Other Initiatives, Chair: Malcolm Wilson

1.1 Modelling Network; Neil Wildgust, IEA GHG

Neil Wildgust of IEA GHG gave a presentation on the first meeting of the new IEA GHG network on modelling of CO_2 storage, held in Orleans, France, Feb. 10-13. Part of the aims of that meeting was to identify technical knowledge gaps and provide an international forum to try to identify means to address those gaps. Questions followed on whether this network had considered how it would interface with the risk assessment process. This had been discussed but without reaching a conclusion. It was suggested that each network should have its own risk assessment.

1.2 Wellbore Integrity Network; Rick Chalaturnyk, University of Alberta

Rick Chalaturnyk of the University of Alberta gave a presentation on the results of the last Well Integrity Network (WIN) meeting. This included reviews of experiments on Portland based cements. The WIN identified the need to evaluate CO_2 resistant cements and to get information on frequency of failure of oil and gas wells and CO_2 EOR wells, in order to model leakage rates, so as to input to risk assessment. The network is working towards a risk based assessment of wellbores. Questions followed on whether it was possible to measure CO_2 flux in wellbores.

1.3 IPAC; Rick Chalaturnyk, University of Alberta

Rick Chalaturnyk of the University of Alberta gave a presentation on the International Performance Assessment Centre (IPAC). IPAC is proposed as an international independent evaluating body benchmarking risk technologies. It is to be based in Regina, but to have nodes & “networked” stakeholders elsewhere in the world. Comments included that IPAC may only be needed if existing risk assessments were not sufficient; that it had to do assessments with transparent indicators, including frequency and severity and type of loss. Rick responded that IPAC would not take-on liability if its assurance was wrong, as it won’t review risk quantification but only risk assessment procedures.

1.4 Risk Assessment Terminology Study; Anna Korre, Imperial College

Anna Korre gave a talk on the IEA GHG funded study on Risk Assessment Terminology. This focussed more on the risk processes than the definitions. This draft report has been peer reviewed. Further comments are welcomed by IEA GHG and IPAC will input to this report and adopt and share. The need for a standard definition of risk assessment was raised.

1.5 CSLF Risk Assessment Taskforce; Claudia Vivalda, Schlumberger

Claudia Vivalda gave a brief overview of the work of the CSLF's Risk Assessment Taskforce and its forthcoming report on an overview of risk assessment for CCS (to be finalised May, 2009). Their recent meeting in Oslo this month had recognised the need of undertaking a gap assessment on tools and methodologies to be encouraged by PIRT, and recommended to the CSLF Policy Group to consider the link between risk assessment and liability and to put the use of risk assessment in the context of stakeholder outreach and communication.

1.6 Facilitated Discussion Session 1

The discussion was around whether additional "general guidelines" were needed, suggesting there was more impetus for specific case-by-case guidelines rather than more general ones. IPAC are looking at this.

Session 2: Quantification of Leakage Impacts, Chair: Claudia Vivalda

2.1 Environmental Impacts Workshop; Jonathan Pearce, BGS

Jonathan Pearce of BGS gave a presentation on the outcomes from the IEA GHG workshop on Environmental Impacts of Leakage (EIL), with its recommendations including research needs. Specifically, there is a need for credible (post injection) leakage scenarios (how much/how long) so as to define scope of environmental impact assessments and to put leakage into context and scope the scale of experimental releases and how these might impact modelling. The workshop also considered industry needs, regulator needs and public awareness needs. Studies on analogues are recommended, and work on target indicator species. Questions followed on experiments on injecting CO_2 into groundwater, though this wasn't included at the EIL workshop. Ensuing discussion included agreement that we must engage the public, but what is communicated must match level of audience understanding; i.e. be aware of terminology and of how much of our uncertainty to discuss.

2.2 Potential Impacts on Ground Water: An Australian Perspective I; Jim Underschultz, CO2CRC / CSIRO

Jim Underschultz of CSIRO/CO2CRC gave a presentation on their work in Australia on impacts of CO_2 storage on groundwater in the Gippsland basin. This was in terms of the effects on the freshwater/brine boundaries moving and flux through cap rocks. The freshwater/brine boundary movement has to be looked at in the context of significant movements caused by mine dewatering, oil and gas extraction, water extraction for irrigation and the natural flows that exist going to offshore.

2.3 Potential Impacts on Ground Water: An Australian Perspective II; Greg Leamon & Andrew Feitz, Geoscience Australia

Greg Leamon and Andrew Feitz gave a presentation on Geoscience Australia's work on groundwater impacts. Greg described their assistance to the Commonwealth Government with the offshore acreage releases. Andrew talked about their work in the Great Artesian Basin (Queensland) looking at potential impacts in the Surat / Gallilee Basins. This region has 3,100 artesian wells deeper than 1,000m and 35,000 sub-artesian wells around 100m deep. This extraction has caused the water level to drop by 100m, and more pumping required at existing wells. Methane also exists in the water and degassing causes a risk as well as being a GHG. The main risk of CO_2 storage in this region is of contaminating the freshwater and of leakage of the CO_2. However, on the positive side, it could also boost the pressure in the depleted water reservoirs and so assist freshwater extraction. There are no proposals at present to use the Great Artesian Basin for CO_2 storage. Questions included the potential conflict in permitting different resources.

2.4 Potential Impacts on Ground Water: Weyburn Perspective; Rick Chalaturnyk, University of Alberta

Rick Chalaturnyk of the University of Alberta gave a talk on the Weyburn project's work on potential geochemical impacts on shallow potable water, looking at wellbore leakage scenarios. The in situ geochemistry was sampled and tested with CO_2 in laboratories. The results suggest that formation of precipitates could actually have a leakage plugging effect, and that a drop in pH was caused which itself caused other geochemical changes but not at levels that would affect drinking water. Questions followed on the precipitates formed (siderite vs. iron oxide), site specific behaviour, and equilibrium in laboratory tests compared to in situ.

2.5 Potential Impacts on Ground Water: A US Perspective; Lisa Bacanskas, US EPA

Lisa Bacanskas of the US EPA gave the US perspective, reporting out on work lead by Jens Birkholzer (LBNL) on the potential impacts of CO_2 leakage on groundwater. The talk focused on research that investigated water quality changes that resulted from increased acidification, for example contaminants released from mineral sources within the shallow aquifer (release either from dissolution of minerals such as galena, a lead sulfide; from desorption, or from ion exchange sites). Results from the ZERT work were shown. Questions followed on how long the baseline data had been gathered and that rainfall was the main driver of baseline data.

2.6 Facilitated Discussion Session 2

Extensive discussion followed. Experimental data is used to build models, but models should be built first then tested with real results, this would provide more learning. In terms of well leakage, what are credible leakage scenarios for 1,000 years when no-one may be around? It was suggested that model well bores as just open to create worst case scenario. On well plugging, currently this is done to EOR standards which may not be enough for CO_2. BRGM are working on a simulation of CO_2 leakage into the Paris basin aquifer, but no results available yet.

Is model software development sufficient? It was suggested that reservoir simulators should have geochemistry added. Geomechanical effects are more for short-term, but geochemical effects are longer-term except for effects on injectivity.

From the insurance perspective, models are missing effects on groundwater. The risk assessment should happen by operational stages to reflect available tenure. Whilst there isn't the case history for actuaries to have data to build on, there are insurance-analogues to work from and other new activities don't have such data and are able to be insured.

Session 3: Combining MMV, Modelling and Risk Assessment, Chair: Rick Chalaturnyk

3.1 US Regional Partnerships; Ken Knottavange-Telleen, Schlumberger / MGSC

Ken Knottavange-Telleen of Schlumberger US gave a presentation on the work of the US regional partnerships in general and the Midwest Geological Storage Consortium in particular (MGSC) with their Decatur Project in Illinois. This used Features Events & Processes (FEP)-based risk matrix approach. Most discussion to date has been how to bring quantification to the risk assessment, and Schlumberger's work has brought risk assessment to modelling. Discussion on this approach suggested that it doesn't calculate probability of events, but is semi-quantitative in nature. It provides information to project managers for prioritisation of resources. The FEPs were looked at in isolation and weren't aggregated.

3.2 Combining MMV, Modelling and Risk Assessment at the Otway Project; Charles Jenkins, CO2CRC

Charles Jenkins of CO2CRC gave an extensive presentation on combining MMV, modelling and risk assessment at the Otway project. This covered the range of monitoring techniques, verification of predicted behaviour and development of key performance indicators. This work generates many research questions, such as what to measure, how sensitive, spatial and temporal coverage, how to interpret measurements. Questions were on whether the risk assessment drove the monitoring selection. The modelling to predict breakthrough used full deterministic modelling, and the actual breakthrough to the monitoring well was at the early end (just over 4 months) of the range predicted (4-8 months).

3.3 The TESLA Risk Assessment Tool and System Modelling; Richard Metcalfe, Quintessa

Richard Metcalfe of Quintessa gave a presentation on the TESLA risk assessment tool and system modelling. This provides whole system modelling and is a decision support tool driven by uncertainties based on value judgements by humans. Simon James of Shell (India) gave a presentation of Shell's experience in using the TESLA methodology. They have used this several times now on different projects. Their learning's were that it compliments other risk assessment methodologies. Its main benefit is in highlighting areas of insufficient evidence and where evidence is conflicting. Questions covered how the value of this approach was in the discussions it prompted between experts rather than the numbers coming out. A point was made that expert opinions still rely on experts, who are subject to human values. Benefit came from testing the results from one group of experts on another group of experts. It also creates benefit in getting focus on the evidence base.

3.4 Facilitated Discussion Session 3

The discussion that followed continued the themes in the questions on TESLA. Such an approach has its main benefits in assisting resource decisions and not in risk quantification. Consideration was given to group dynamics in terms of consensus views versus individual views, and the benefits therein of bring in external experts from outside project teams.

Session 4: Insurance and Risk Assessment, Chair: Jonathan Pearce

4.1 Setting the Scene; Lindene Patton, Zurich

A panel session was held on insurance and risk assessment. Lindene Patton of Zurich (USA) gave the scene setting presentation, and the panel consisted of Lindene, Andy Nicol of GNS New Zealand, and Simon James of Shell. Lindene highlighted the principles of public good and private asset protection and risk profile of CCS projects (increasing with time) that underlie the CCS liability policy provided by Zurich. This policy includes risks of pollution (air and groundwater etc), business interruption, well integrity and geomechanical liability. Simon focussed on the need for enough information to make business decisions. For them risk assessment includes technical, economic, commercial, organisational and political risks. Ways of managing risks are demonstrated in their proposed CDM methodology. Andy raised questions on the interface between insurance and technical risk assessment which is mostly qualitative and dominated by judgements of experts with the primary focus being on containment. He thought that economic, political and social risks should be dealt with separately. To prompt discussion he asked: what range of activities should be included; should economics be integrated; what risk metrics should be used (e.g. dollars, human safety); how to value consequences and estimate uncertainty.

4.2 Panel Discussion

The discussion started with the price on CO_2 and the role of ETS in providing that. The question of "Who are 'We' in the Risk Assessment Network was asked, seeking definition of the group whose participants include technologists, regulators and project developers. The insurance industry thought that there was a reluctance to deal with the conflicts of resources issue, which is controlled by regulatory bodies. There was acknowledgement that the Risk Assessment Network was technology orientated. It was also highlighted that transport networks would be required as companies moved from single-source-sink to a portfolio approach of multiple hubs, including other mitigation options.

Consideration was given to mitigation of deep leaks or migration. However, it was although thought that the system failing in such a way would trigger regulatory action, and that this group's focus was primarily driver by regulatory requirements and frameworks. There was celebration that this group included regulators as well as technologists and project developers. There was also a question whether the group should broaden from risk assessment to risk management, without conclusion in the discussion.

Session 5: Risk Communication, Chair: Tim Dixon

5.1 Risk Communication; Peta Ashworth, CSIRO

Peta Ashworth of CSIRO (Australia) gave a scene setting talk on risk communication in the context of public communication and consultation around CCS. She covered both theory and real-life practice and results from Australia and world-wide, including the work of the US Regional Carbon Sequestration Partnerships around their CCS projects. Essential elements in project's consultation with the public are to build trust, understand perceptions and moral acceptability, and ensure the benefits outweigh the risks.

5.2 Communication and Public Perception for the Otway Project; Sandeep Sharma, CO2CRC

Sandeep Sharma of CO2CRC (Australia) gave a presentation on the communication and public perception around the Otway project. One of the project's goals is to build public support for CCS. They created a local Stakeholder Reference Group which meets regularly. He emphasised that you need the local community to make projects happen. Key principles are: for the public to hear from the project directly and not via the media; address concerns quickly; use scientists to communicate; if can't provide data then explain why; start early; and involve government staff.

5.3 Risk Communication – A Government Perspective; Namiko Ranasinghe, Victorian State Government

Namiko Ranasinghe of Victoria Department of Primary Industries gave a talk from a government perspective, including the overlapping regulatory regimes for Otway. She got audience participation in a risk rating exercise. Frank Schilling of University of Karlsruhe (KIT) (Germany) gave a presentation on the public engagement in the CO_2Sink project at Ketzin. He emphasised their success was down to establishing trust, honesty and providing a good and direct point of contact.

5.4 Facilitated Discussion Session 5

The discussion considered the results from these and other projects, and the importance of the right terminology, e.g. "catastrophic" should be used with caution. A key conclusion was drawn that these examples of successful projects in public communication were successful essentially because of their process of communication and not just because of the actual risk answers that were provided.

Session 6: Updates from Real Projects, Chair: John Kaldi

6.1 CO_2Sink; Frank Schilling, GFZ-Potsdam

Frank Schilling of the University of Karlsruhe (KIT) gave an update on the CO_2Sink project at Ketzin. This has injected 12k t of CO_2 to date. He described the extensive regulatory approvals process, and that they will reapply for approvals when they get to 20k t CO_2 injected.

6.2 Vattenfall German Demonstration; Claudia Vivalda, Schlumberger

Claudia Vivalda of Schlumberger (France) gave an update on the Vattenfall demonstration project at Janschwald. The preliminary risk assessment used DNV's draft guidelines for site qualification. Storage is intended to start in 2014/2015, both storage options are onshore. DNV used Structured What If (SWIFT) workshops to identify hazards and evaluate the risks in a qualitative way, and a Screening and Ranking Framework (SFR) to assess containment integrity.
As the results from these exercises were confidential, this prompted a discussion about whether confidentiality was going to get in the way of future discussions in the Risk Assessment Network.

6.3 Weyburn; Adrian Bowden, URS

Adrian Bowden of URS gave an update on the risk assessment work at Weyburn. This work uses the RISQUE method developed under GEODISC, and is being extended from the technical risk around the reservoir/geological aspects to include environmental and stakeholder risks.

6.4 The Otway Project; Lincoln Paterson, CO2CRC

Lincoln Patterson of CO2CRC gave an update on the Otway project. This started injecting in April 2008 and has injected 46kt CO_2 to date. Stage 2 injection will look at non-structural (e.g. residual) trapping in the saline aquifer Paaratte formation using a second injection well.

6.5 Facilitated Discussion Session 6

Discussion continued about whether confidentiality issues are going to impede future network meetings. It seems there is no way of avoiding it as projects become more commercial, even though it might cause the public to get suspicious. There is also the question of timing, i.e. when to release information, e.g. after, rather than before, a problem is solved?

Session 7: Key Outcomes and Conclusions

7.1 Key Outcomes

Participants were then divided into three breakout groups to identify outcomes and conclusions from the Risk Assessment Network meeting, in terms of gaps, recommendations for further actions, and key learning's. These are compiled here into one set of outcomes. The individual outputs of each group are provided in Appendix 3.

GAPS:

- Projects risk (financial, social, organisational & etc)
- Data for ACQ not poss./access rights
- Benefit/cost analysis $ CO_2 stored versus project cost
- Social Charzen (?)
- Systems approach: e.g.: risk reviews, risk management, optimisation
- Public policy: need info base? Policy drives risk ID, applying tech RA results to meeting policy goals
- List of tools, attributes
- Prioritise gaps per timing
- Understand phys, chem., coupling
- Not quant., regulators role, data, calibration of models & validation
- Evaluation of existing models including procedures
- Pressure front
- Brine movement
- Geostatistics – distribution?
- How does the risk scale?
- Understanding EQ rupture in a reservoir
- EOR - CO_2 Induced seismicity, worst case scenarios
- Consideration of effects on other resources
- Human error – well operation/included in modelling
- ERM (enterprise)
- Biosphere (deep)
- Mitigation – risk management
- Induced seismicity
- Expert elicitation process
- Acceptability limits
- Impact assessment & severity

TO DO:

- Formalise objectives for network
- Answer "who are we?"
- Selectively broaden scope & population of R.A.N. & structure
- Set problem statements, propose mission
- Rank CCS generic risks that deserve work
- Define R.A.N.
- Define our audience
- Sharing of data
- Broaden the network? Economists, political risk
- Biosphere
- Interaction with stakeholders
- Non-tech summary/guides
- Raise public awareness
- Involvement of wider audience (other disciplines)

Regulator involvement
IEA regulator network feedback
Co-network meetings
Support to international standards
IPAC Involvement
Explosion
Encourage wider participation (discussions)
Informal discussions (SPE/ATW forum)
Very generalised conclusions

LEARNINGS:

Chat room/blog (restricted access)
Produce documents to publish
Collect references
IPAC
Repository for methods & data sets
Network must take care describing what it does (i.e.: performance assessment of reservoir etc)
Provide info to mitigators & decision makers (sub surface mitigation)
Need a formal definition of that the R.A. is for the network
Think tank for R.A.
IPAC relationship

7.2 Conclusions

It was concluded that this meeting of the Risk Assessment Network had addressed the key topics and technical gaps as recommended by the 3rd Risk Assessment Network and the Joint Network meetings.
In terms of the rationale, scope and objectives of the network, it was concluded that the Risk Assessment Network continues to be necessary, however recognizing that the level of openness in the future may not be as great as members' desire because of commercial sensitivities. In terms of the scope of the Risk Assessment Network's mission – the conclusions from the majority of participants was that it should remain subsurface i.e. technical, in its focus. The overall objectives for the Network as described at the beginning (and are included in Appendix 4) have been followed well to date, but should these be revisited in the light of this meeting and wider developments, for example regulation did not exist in 2005 and increasingly does now. More time can be devoted to discussion of these overall objectives by including them on the agenda for the next meeting.

Presentations are available on the Risk Assessment Network website:
www.co2captureandstorage.info/networks/riskassess.htm. IPAC offered to host the next Risk Assessment Network workshop.

Day 2 (17th April 2009)	
Session 4: Risk Assessment and Insurance, Chair: Jonathan Pearce	
08.30 to 08.45	Setting the scene; Lindene Patton, Zurich
08.45 to 10.00	Panel session involving: Lindene Patton, Zurich Andy Nicol, GNS Simon James, Shell
10.00 to 10.30 Break	
Session 5: Risk Communication, Chair: Tim Dixon	
10.30 to 11.00	Risk Communication: Peta Ashworth, CSIRO
11.00 to 11.20	Communication and public perception for the Otway project: Sandeep Sharma, CO2CRC
11.20 to 11.40	Risk Communication - a government perspective: Namiko Ranasinghe, Victorian State Government
11.40 to 12.30	**Discussion**
12.30 to 13.30 Lunch in the Grill Restaurant	
Session 6: Updates from Real Projects, Chair: John Kaldi	
13.30 to 14.00	CO_2 Sink: Frank Schilling, GFZ-Potsdam
14.00 to 14.30	Vattenfall German Demonstration; Claudia Vivalda, Schlumberger
14.30 to 15.00	Weyburn; Adrian Bowden, URS
15.00 to 15.30	The Otway Project; Lincoln Paterson, CO2CRC
15.30 to 16.40	**Discussion**
16.40 to 17.00 Break	
17.00 to 17.30	Key learning for other networks and summing-up including topics for next meeting; Tim Dixon, IEA GHG, John Kaldi, CO2CRC
Close Day 2	

Appendix 1: Original Network Objectives

The objectives of the Risk Assessment as set out in 2005:

- *Overall aim:* To bring together key groups working on risk assessment for CO_2 storage from around the world to share knowledge and experiences. Emphasis on potential regulatory requirements with regard to CCS safety and impact assessment.
- *Specific aims and objectives:*
    - Develop an open and transparent process to allow different risk assessment approaches and associated results to be understood;
    - Provide a forum where different approaches to risk assessment can be compared;
    - Provide an ‘umbrella group’ for international collaboration;
    - Identify knowledge gaps and determine actions required to close these gaps;
    - Act as an informed body on risk assessment and to maintain dialogue with regulators and NGO’s

Appendix 2: Breakout Group Results by Group

Group 1

GAPS:

Projects risk (financial, social, organisational & etc)
Data for ACQ not poss./access rights
Benefit/cost analysis $ CO_2 stored versus project cost
Social Characterisation
Systems approach: e.g.: risk reviews, risk management, optimisation
Public policy: need info base? Policy drives risk ID, applying tech RA results to meeting policy goals
List of tools, attributes
Prioritise gaps per timing
Understand phys, chem., coupling

TO DO:

Formalise objectives for network
Answer "who are we?"
Selectively broaden scope & population of R.A.N. & structure
Set problem statements, propose mission
Rank CCS generic risks that deserve work
Define R.A.N.
Define our audience

LEARNINGS:

Chat room/blog (restricted access)
Produce documents to publish
Collect references

Group 2:

GAPS:

Not quant., regulators role, data, calibration of models & validation
Evaluation of existing models including procedures
Pressure front
Brine movement
Geostatistics – distribution?
How does the risk scale?
Understanding EQ rupture in a reservoir
EOR - CO_2 Induced seismicity, worst case scenarios
Consideration of effects on other resources
Human error – well operation/included in modelling

TO DO:

Sharing of data
Broaden the network? Economists, political risk
Biosphere
Interaction with stakeholders

LEARNINGS:

IPAC
Repository for methods & data sets
Network must take care describing what it does (i.e.: performance assessment of reservoir etc)
Provide info to mitigators & decision makers (sub surface mitigation)
Need a formal definition of that the R.A. is for the network

Group 3

GAPS:

- ERM (enterprise)
- Biosphere (deep)
- Mitigation – risk management
- Induced seismicity
- Expert elicitation process
- Acceptability limits
- Impact assessment & severity

TO DO:

- Non-tech summary/guides
- Raise public awareness
- Involvement of wider audience (other disciplines)
- Regulator involvement
- IEA regulator network feedback
- Co-network meetings
- Support to international standards
- IPAC
- Explosion
- Encourage wider participation (discussions)
- Informal discussions (SPE/ATW forum)
- Very generalised conclusions

LEARNINGS:

- Think tank for R.A.
- IPAC relationship

Appendix 3: Site Visit

The meeting was followed by a trip to the CO2CRC Otway project, kindly organized and hosted by CO2CRC, to see first-hand the site and work that had been described during the Network meeting. Delegates saw the CO_2 production well, the injection well, the monitoring well and the visitor centre, and had good discussions with the CO2CRC staff at Otway.

Photo 1: The Network attendees checking out a different source of CO_2, close to Otway.

Photo 2: Attendees viewing Otway Project's CO_2 production well.

Photo 3: Rainbow over the Otway visitor centre.

IEA GHG 4th Risk Assessment Network Meeting

16th-17th April 2009

Rendezvous Hotel, Melbourne, Australia

Grant Arnold	Dept of Primary Industries	Peta Ashworth	CSIRO
Scott Ayash	Energy & Environmental Research Center	Olivier Bouc	BRGM
Lisa Bacanskas	USEPA	Cirilo Bernardo	CO2CRC/CanSyd
Adrian Bowden	URS Australia Pty Ltd	Hannah Brackley	GNS Science
Mark Bunch	CO2CRC	Rick Causebrook	Geoscience Australia
Rick Chalaturnyk	University of Alberta	Brian Davey	Dept of Primary Industries
Tim Dixon	IEA GHG	Sevket Durucan	Imperial College
Andrew Feitz	Geoscience Australia	John Gale	IEA GHG
Matt Gerstenberger	GNS Science	Louise Goldie Divko	GeoScience Australia
Rick Hogan	AIG Australia	Ken Knottavange-Tellen	Schlumberger
Kenshi Itaoka	Mizuho information & Research Institute	Simon James	Shell Technology India
Charles Jenkins	CO2CRC	Hironobu Komaki	RITE
John Kaldi	CO2CRC	Aleksandra Kalinowski	Geoscience Australia
Anna Korre	Imperial College	Greg Leamon	Geoscience Australia
Yannick Lefebvre	Schlumberger Carbon Services	Ian McKay	ExxonMobil
Jason McKenna	Woodside Energy Ltd.	Terry McKinley	Dept of Primary Industries
Richard Metcalfe	Quintessa Ltd	Andy Nicol	GNS Scisnce
Lindene Patton	Zurich Financial Services	Jonathan Pearce	BGS
Namiko Ranasinghe	Dept of Primary Industries	Richard Rhudy	EPRI
Dave Ryan	CanmetEnergy	Sohei Shimada	University of Tokyo
Frank Schilling	Universität Karlsruhe - KIT	Willie Senanayake	Dept. of Resources, Energy & Tourism
Sandeep Sharma	CO2CRC (Schlumberger)	Atsuko Tanaka	AIST
Steve Tantala	Dept. of Resources, Energy & Tourism	Peter Tingate	GeoScience Victoria
Kate Townsend	Dept of Primary Industries	Jim Underschultz	CO2CRC and CSIRO
Sandrine Vida-Gilbert	CO2CRC	Claudia Vivalda	Schlumberger
Charlie Voss	Golder Associates	Klaus Udo Weyer	WDA Consultants Inc
Neil Wildgust	IEA GHG	Malcolm Wilson	University of Calgary
David Wong	Dept of Primary Industries		

River, downtown Melbourne

4th Risk Assessment Network Meeting

16th—17th April 2009

Rendezvous Hotel, Melbourne, Australia

Organised by

IEA Greenhouse Gas R&D Programme and CO2CRC

Hosted by

CO2CRC

CO2CRC

16th April 2009 Day 1

08.15 to 08.30 Registration

08.45 to 09.00	Welcome Address: Tim Dixon, IEA GHG and John Kaldi CO2CRC
09.00 to 09.30	Welcome: Peter Batchelor, Victorian State Minister for Energy and Resources
09.30 to 10.00	Report from the 3rd Risk Assessment Meeting and the Joint Network Meeting; Neil Wildgust, IEA GHG

10.00 to 10.30 Coffee Break in The Vestibule

Session 1: Reports from Other Initiatives Chair: Malcolm Wilson, University of Regina

10.30 to 10.50	Modelling Network: Neil Wildgust, IEA GHG
10.50 to 11.10	Well Integrity Network: Rick Chalaturnyk, University of Alberta
11.10 to 11.30	IPAC: Rick Chalaturnyk, University of Alberta
11.30 to 11.50	Risk Assessment Terminology Study: Anna Korre, Imperial College
11.50 to 12.00	CSLF Risk Assessment Taskforce: Claudia Vivalda, Schlumberger
12.00 to 12.30	Discussion

12.30 to 13.30 Lunch at the Grill Restaurant

Session 2: Quantification of Leakage Impacts Chair: Claudia Vivalda, Schlumberger

13.30 to 13.45	Environmental Impacts workshop: Jonathan Pearce, BGS
13.45 to 14.00	Potential Impacts on Ground Water: An Australian Perspective 1: Jim Underschultz CO2CRC/CSIRO
14.00 to 14.15	Potential Impacts on Ground Water: An Australian Perspective 2: Greg Leamon and Andrew Feitz, Geoscience Australia
14.15 to 14.30	Potential Impacts on Ground Water; Weyburn Perspective: Rick Chalaturnyk, University of Alberta
14.30 to 14.45	Potential Impacts on Ground Water; A US Perspective: Lisa Bacanskas, US EPA
14.45 to 15.30	Discussion

15.30 to 16.00 Coffee Break in The Vestibule

Session 3: Combining MMV, Modelling, and Risk Assessment Chair: Rick Chalaturnyk, University of Alberta

16.00 to 16.20	US Regional Partnerships: Ken Hnottavange-Telleen, Schlumberger/MGSC
16.20 to 16.40	Combining MMV, Modelling and Risk Assessment at the Otway Project: Charles Jenkins, CO2CRC
16.40 to 17.00	The TESLA Risk Assessment Tool and System Modelling: Richard Metcalfe, Quintessa
17.00 to 18.00	Discussion

Close Day 1

19.30 Dinner in the Ballroom

17th April 2009 Day 2

Session 4—Risk Assessment and Insurance: Chair: Tim Dixon, IEA GHG

08.30 to 08.45 Setting the Scene: Lindene Patton, Zurich

08.45 to 10.00 Panel Session involving:
Andy Nicol, GNS
Simon James, Shell
Pat Concessi, Deloitte &Touche
Lindene Patton, Zurich

10.00 to 10.30 Coffee Break in The Vestibule

Session 5—Risk Communication: Chair: Tim Dixon, IEA GHG

10.30 to 11.00 Risk Communication: Peta Ashworth, CSIRO

11.00 to 11.20 Communication and Public Perception for the Otway Project: Sandeep Sharma, CO2CRC

11.20 to 11.40 Risk Communication - a Government Perspective: Namiko Ranasinghe, Victorian State Government

11.40 to 12.30 Discussion

12.30 to 13.30 Lunch at the Grill Restaurant

Session 6– Updates From Real Projects: Chair: John Kaldi, CO2CRC

13.30 to 14.00 CO2 Sink: Frank Schilling, GFZ-Potsdam

14.00 to 14.30 Vattenfall German Demonstration: Claudia Vivalda, Schlumberger

14.30 to 15.00 Weyburn: Adrian Bowden, URS

15.00 to 15.30 The Otway Project: Lincoln Paterson, CO2CRC

15.30 to 16.00 Discussion

16.00 to 16.30 Coffee Break in The Vestibule

16.30 to 18.00 Workshop Conclusions: Key learning for other networks and summing-up including topics for next meeting: Tim Dixon, IEA GHG, Neil Wildgust, IEA GHG, John Kaldi, CO2CRC

Close Day 2

18th April 2009 Day 3

Itinerary for the Otway Project Tour

08.00	Bus departs Rendezvous Hotel
12.00	Arrive Boggy Creek Pub for lunch
13.30	Depart Boggy Creek Pub
14.00 to 16.30	Tour of the Otway CCS Project Site
20.00	Bus arrives back at the Rendezvous Hotel via Melbourne Tullamarine Airport.

IEA Greenhouse Gas R&D Programme

4th Risk Assessment Network Meeting

Co-organisers and hosts: CO2CRC

Melbourne – 16-18 April 2009

IEA Greenhouse Gas R&D Programme

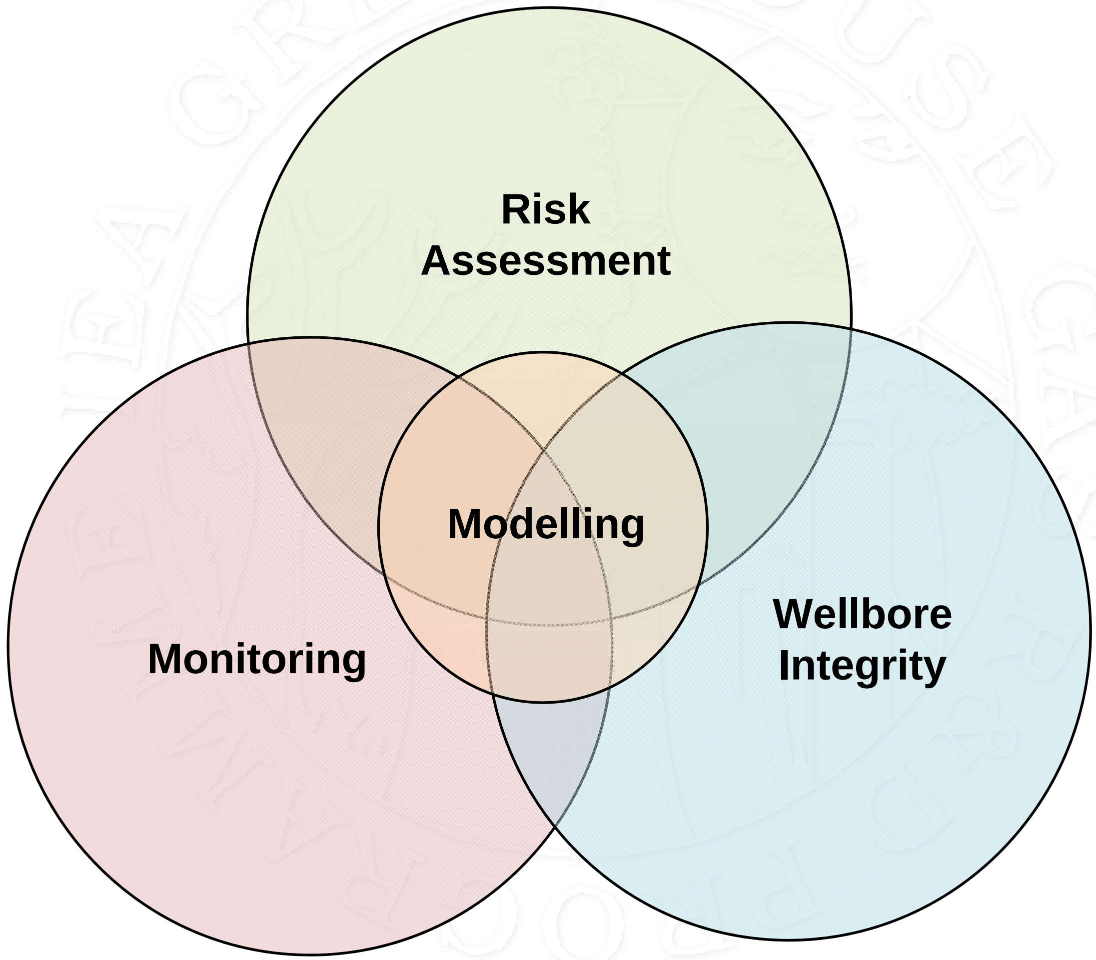
- A collaborative research programme founded in 1991
- Aim: *Provide members with definitive information on the role that technology can play in reducing greenhouse gas emissions.*
- Producing information that is:
  - Objective, trustworthy, independent
  - Policy relevant but NOT policy prescriptive
  - Reviewed by external Expert Reviewers
  - Subject to review of policy implications by Members
- Activities: Studies (>120); R&D networks :- Wells, Risk, Monitoring, Modelling, Oxy, Capture, Biofixation; Communications (GHGT9, IJGGC, etc); facilitating and focussing R&D and demonstration activities

Contracting Parties and Sponsor Organisations of IEA GHG

R&D Networks

- Bring together international key groups of experts to share knowledge and experience
- Identify and address knowledge gaps
- Act as informed bodies, eg for regulators
- CO_2 geological storage – assessing and managing risks
- Started in 2004/5
  - Risk Assessment Research Network
  - Monitoring Research Network
  - Wellbore Integrity Research Network
  - Modelling Network (2009)
- Benefit experts and wider stakeholders
- Depend on experts' time and inputs – valuable and widely appreciated

Storage Networks Overlap



4^{th} Risk Assessment Network Meeting CO2CRC, Melbourne 2009

- 3^{rd} Imperial College, London, 2007
- 2^{nd} LLNL, California, 2006
- 1^{st} TNO, Netherlands, 2005

Risk Assessment Network

- *Overall aim:* To bring together key groups working on risk assessment for CO_2 storage from around the world to share knowledge and experiences. Emphasis on potential regulatory requirements with regard to CCS safety and impact assessment.
- *Specific aims and objectives:*
  - Develop an open and transparent process to allow different risk assessment approaches and associated results to be understood;
  - Provide a forum where different approaches to risk assessment can be compared;
  - Provide an ‘umbrella group’ for international collaboration;
  - Identify knowledge gaps and determine actions required to close these gaps;
  - Act as an informed body on risk assessment and to maintain dialogue with regulators and NGO’s

4th Risk Assessment Meeting Agenda

1. Reports from other initiatives
2. Leakage Impacts
3. Combining Monitoring, Modelling and Risk Assessment
4. Insurance and Risk Assessment
5. Risk Communication
6. Updates from Real Projects
7. Workshop Conclusions and Key Points for other Networks

CO2CRC Otway Project Site Visit

IEA Greenhouse Gas R&D Programme

4th Risk Assessment Network Meeting

Co-organisers and hosts: CO2CRC

Melbourne – 16-18 April 2009

IEA GHG Risk Assessment Research Network Meeting

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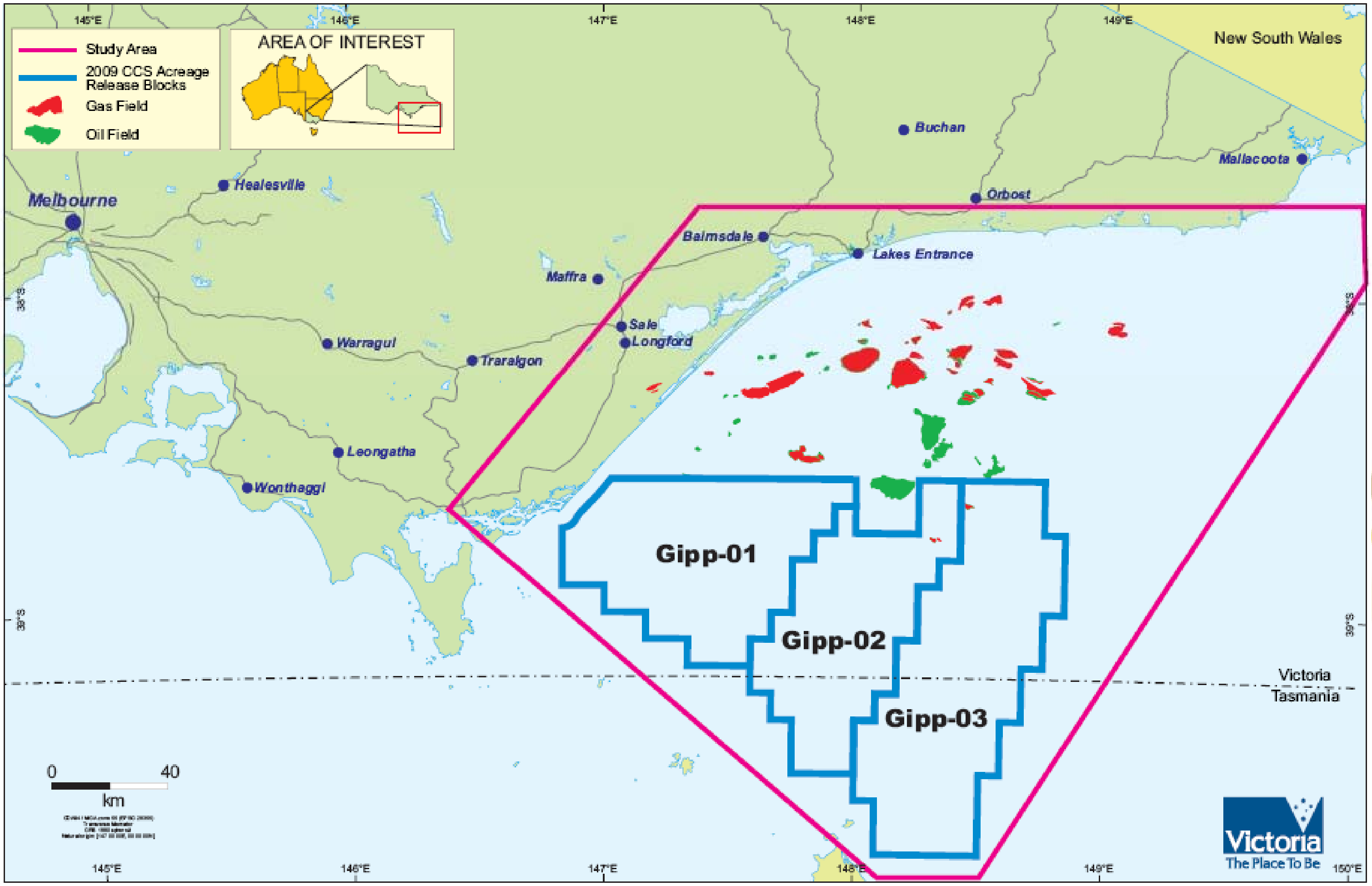
Study Area and 2009 CCS Acreage Release Blocks



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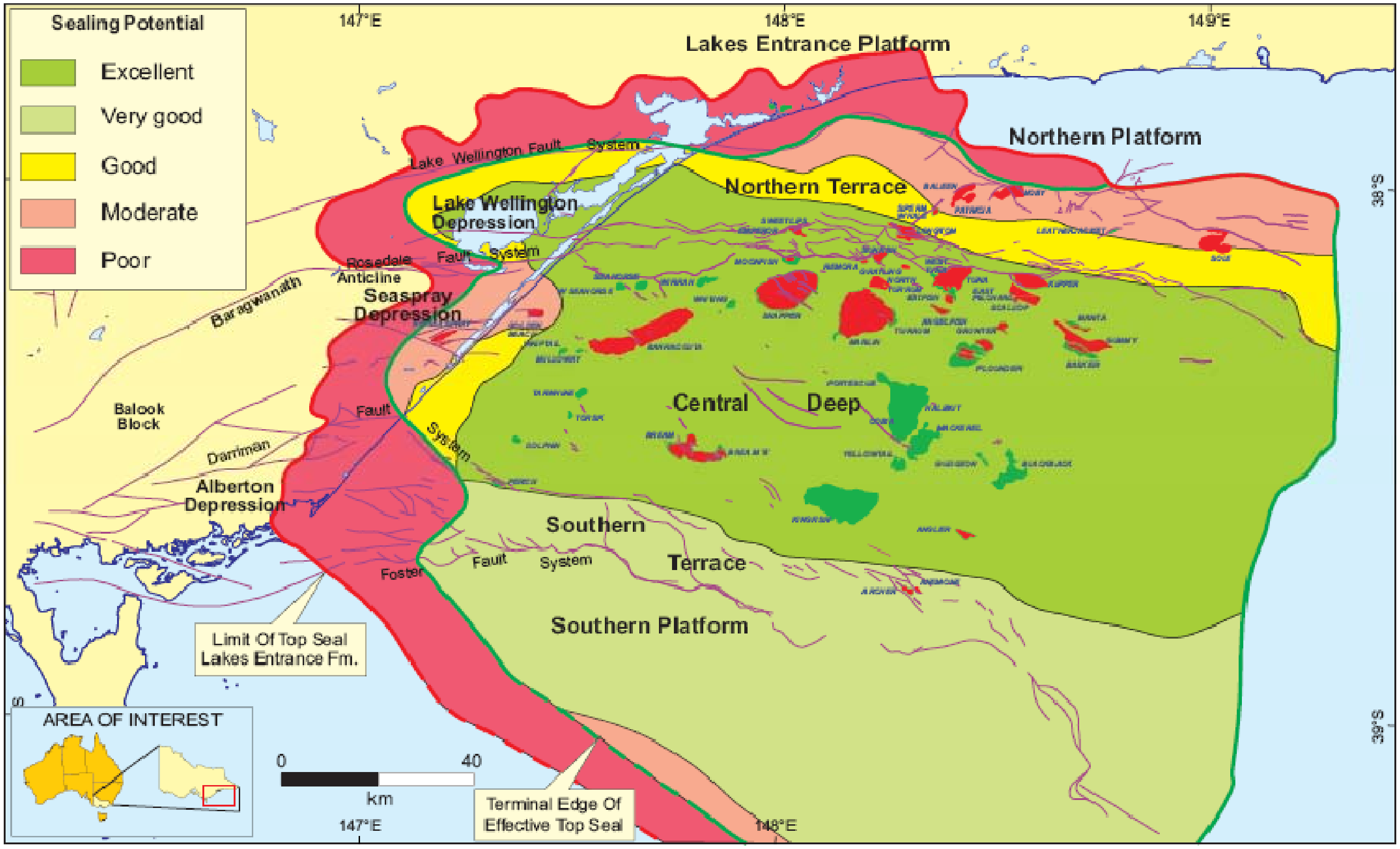
Seal Capacity of the Gippsland Basin



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CO2CRC Otway Project Launch

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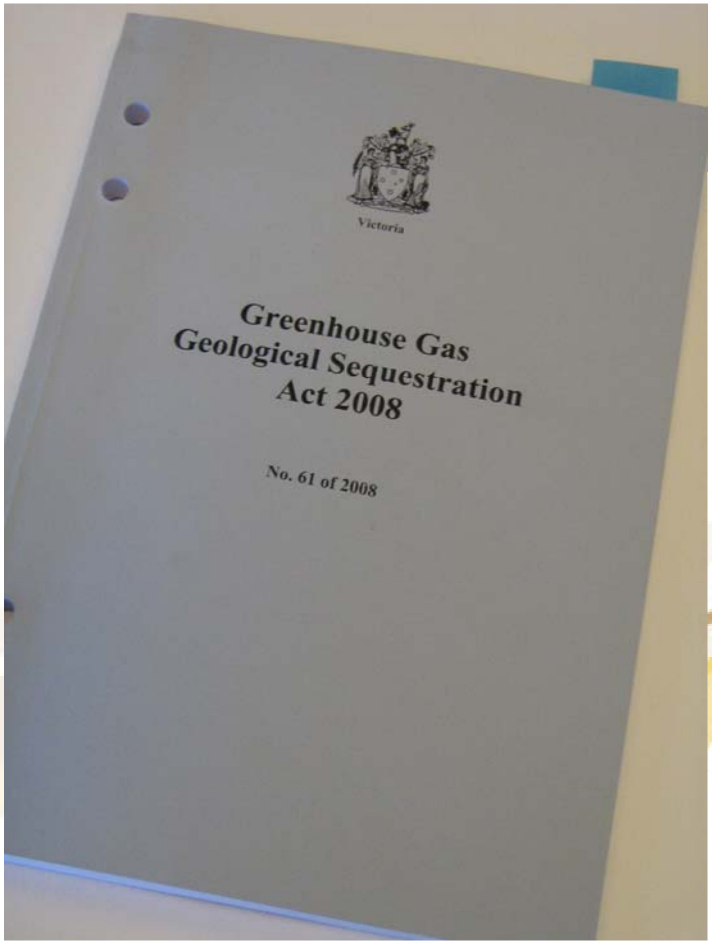
Monitoring Equipment at the Naylor-1 Well

Victorian Legislation



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Energy Technology Innovation Strategy

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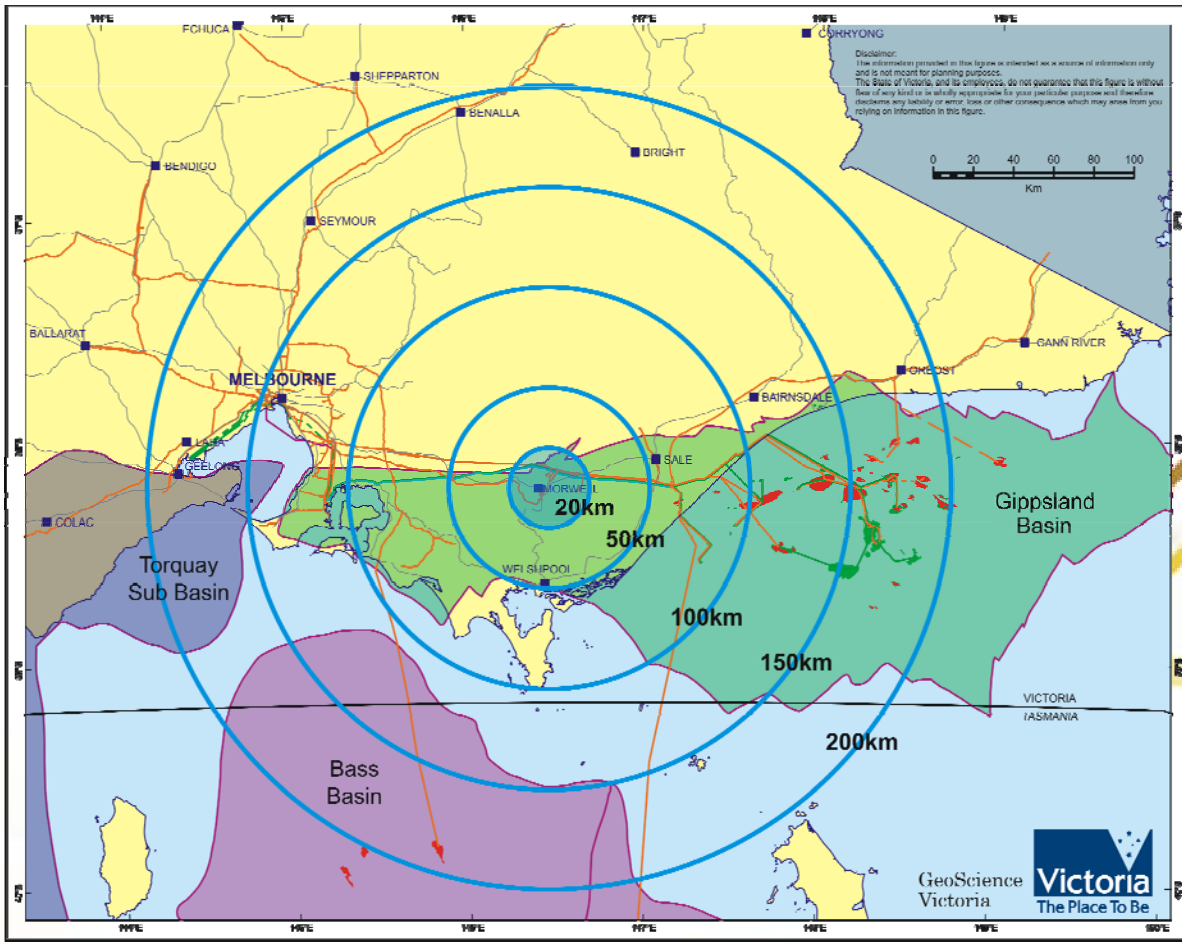
Transport Distances from the Latrobe Valley



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Report from the 3rd Risk Assessment Network & 1st Joint Network Meeting

IEA Greenhouse Gas R&D Programme

4th Risk Assessment Network Meeting

Melbourne 16-17 April 2007

3rd Risk Assessment Network

- London
- August 2007
- Hosted by Imperial College

- Results in two parts:
  - Agenda and outcomes
  - Further issues/questions raised

3rd Risk Assessment Network

- Topics discussed and outcomes:
  - Risk assessment terminology
    - Final report being presented here
  - How much site characterization is enough?
    - Not able to answer this yet
  - Quantitative vs. qualitative risk assessment
    - We can currently only achieve semi-quantitative at best
  - The FEP risk assessment process
    - One tool of many, best suited to an auditing tool

3rd Risk Assessment Network

- Further issues/questions raised:
  - Do we require risk assessment guidelines?
  - How can we best incorporate expert judgement into the risk assessment process?
  - How confident are we of the modelling results?
  - How long do you need to monitor for?
  - Can the accident/worst case scenario approach work for CCS risk assessment?
  - How can we better communicate risk?

1st Joint Network Meeting

- New York
- June 2008
- Hosted by the US Environmental Protection Agency

- Results in two parts:
  - Technical gaps
  - Operational or Network Gaps

1st Joint Network Meeting

- Technical Gaps
  - There is a need to better identify the regulators for a CCS project
  - We need more information about leakage through the wellbore – statistics, classification, causes
  - What are the impacts of leakage into shallow marine environments and potable aquifers?
    - How do we quantify the impacts
  - What are the differences between risk assessment modelling and front end process modelling

1^{st} Joint Network Meeting

- Technical Gaps cont.
  - We need to benchmark existing projects
  - How do you incorporate M&V into RA process (and vice versa)
  - How is public confidence linked to risk assessment
  - How do we better engage insurers, regulators and NGO's
  - How do we perform risk screening for site selection
  - What are the risks associated with co-contaminants

1^{st} Joint Network Meeting

- Network gaps:
  - Risk and monitoring networks are not sufficiently integrated
  - Need to communicate with new IEA regulator network

IEA GHG Modelling Workshop and New Network

- Formation of IEA GHG modelling network debated at JNM in June 2008
- Agreed first step to hold modelling workshop
- Aims of workshop:
  - Examine approaches to modelling
  - Discuss confidence in current approaches
  - Debate input to risk assessments and regulatory aspects
  - Identify current knowledge gaps and limitations
  - Discuss potential aims and next steps for formation of a modelling network

Workshop Details

- Workshop hosted by BRGM in Orleans, France, 10th to 12th February 2009
- Co-organised by IEA GHG, BRGM, Schlumberger and CO2GeoNet
- Sponsored by IFP and Total
- Over 100 registered delegates from 14 different countries, representing industry, consultants and academia

Social events

Civic reception

Gala dinner

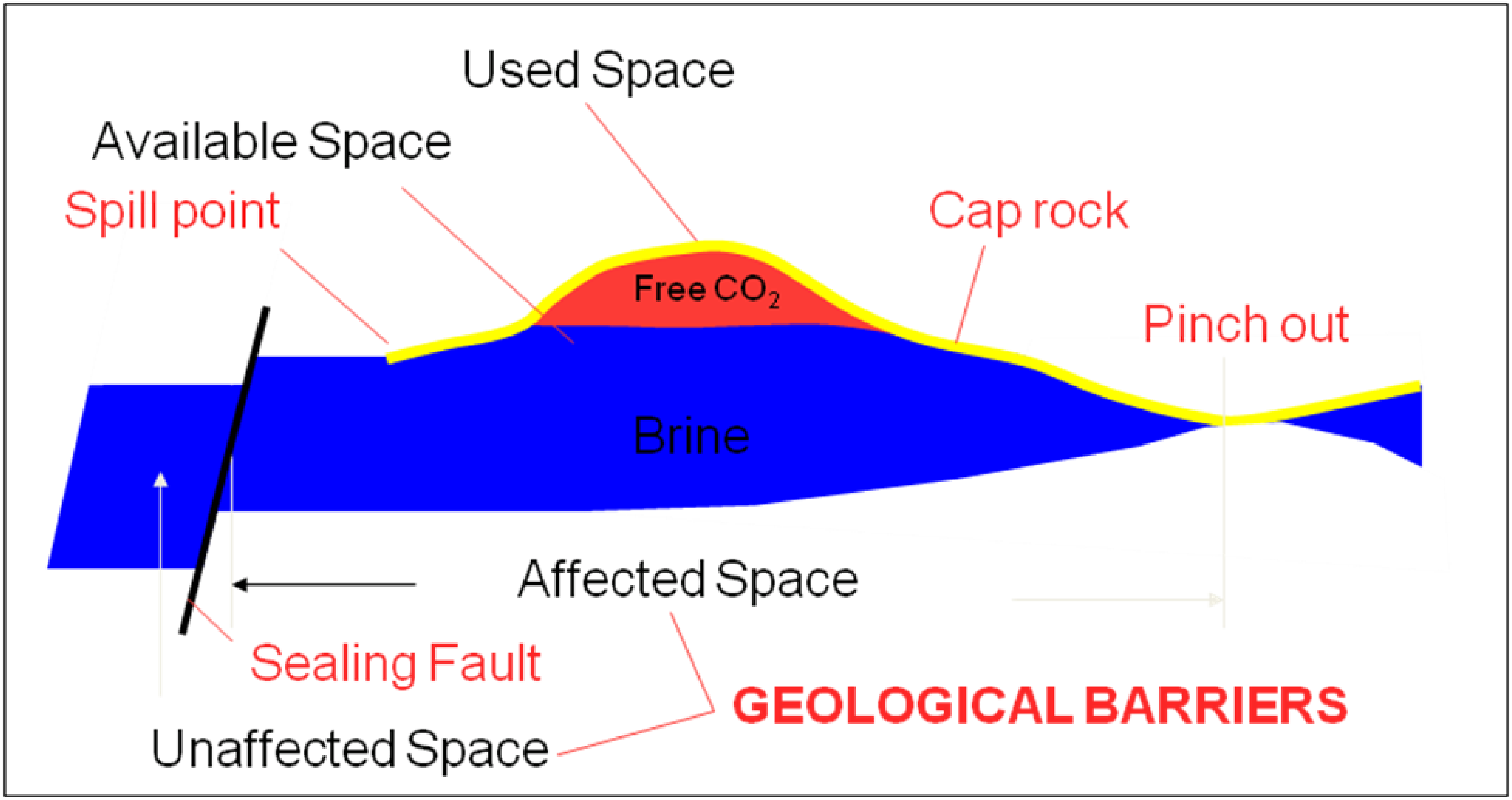
Workshop Structure

- Introductory session included an overview of CO_2 storage modelling (Isabelle Czernichowski) and regulatory perspective (IEA GHG)
- Sessions on modelling objectives, processes, special issues and formation of network
- Presentations from invited speakers followed by breakout discussions and plenary feedback

Modelling Objectives Session

- Presentations:
- Storage capacity (Bert van der Meer, TNO)
- Injectivity (Yann le Gallo, Geogreen)
- Caprock integrity (Brian McPherson, Utah Uni)
- Plume evolution (Sylvain Thibeau, Total)
- Leakage through wellbores (Mike Celia, Princeton)
- Leakage through faults (Andrew Cavanagh, Permedia)

'Affected space' concept



Discussions on Objectives

- Discussions focussed on current models in relation to reservoirs, caprock and leakage
- Considerable work remains
- Modelling of potential leakage uncertain
- Divergence of approaches
- Sharing of information and benchmarking

Processes Session

- Presentations:
- Geological models (Peter Frykman, GEUS)
- Multiphase flow (Suzanne Hurter, Schlumberger)
- Geochemistry (Mohammed Azaroual, BRGM)
- Geomechanics (Jonny Rutqvist, LBNL)
- Thermal effects (Jens Birkholzer, LBNL)

Discussions on Processes

- Significant knowledge gaps:
- General issues include coupling of processes, up-scaling from pore to field scale, heterogeneity, input data availability
- Many specific knowledge gaps highlighted e.g. relative permeability, reaction kinetics, fault properties and reactivation, stress fields, formation compressibility

Special Issues Session

- Presentations:
- Code comparisons (Holger Class, Stuttgart Uni)
- Model comparisons (Jens Birkholzer, LBNL)
- Numerical tools (Anthony Michel, IFP)
- Modelling and monitoring (Susan Hovorka, University of Texas)
- Modelling and risk assessment (Rajesh Pawar, LANL)

Discussion on Special Issues

- Discussions centred on how modelling relates to monitoring and risk, also confidence in current modelling capabilities
- Iterative nature of storage assessment
- Current model reliability may be hampered more by lack of input data than understanding?
- Modelling predicts distribution of free phase CO_2 – main risk source

Formation of Network

- Agreement that an international modelling network would be worthwhile and could make significant contribution
- Recognition that modelling is a distinct specialisation feeding into risk assessment
- RA network could form ‘over arching’ risk management network with inputs from modelling, wellbore and monitoring networks

Modelling Network Aims and Objectives

- Aim: provide an international forum for experts to share knowledge and promote collaboration
- Some specific objectives:
  - Online discussion forum and reference material
  - Guidance documents for practitioners
  - Guidance to non-technical specialists
  - Identification of knowledge gaps
  - Support to RA network

Modelling Network Next Steps

- Workshop report to be issued in May, following circulation of draft to steering committee
- Summary presentation of workshop outcomes to RA and monitoring networks
- Modelling network website:
  - Online discussion forum
  - Links to benchmarking studies
- First network meeting planned for February 2010 (University of Utah)

Overview of Well Integrity Network

Wellbore Integrity Network

(Summary Presentation from JNM in New York)

Bill Carey (Los Alamos National Lab)
Craig Gardner (Chevron Energy Technology Company)

Rick Chalaturnyk
University of Alberta

April 16, 2009

Network Charter

- The long-term ability of wellbores to retain CO_2 has been identified as a significant potential risk for the long-term security of geologic storage facilities
- Assess and communicate the state of knowledge, nature of research programs, and the research needs to understand the long-term integrity of wellbore systems in CO_2-rich environments

Steering Committee Members

- Toby Aiken, IEA GHG
- Idar Akervoll, SINTEF
- Stefan Bachu, Alberta Energy Resources Conservation Board
- Bill Carey (chair), LANL
- Mike Celia, Princeton University
- Walter Crow, BP
- Rich Chalaturnyk, University of Alberta
- John Gale, IEA GHG

Network Objectives

- Determine impact of CO_2 interaction with wellbore materials on long term storage
- Bring together experts working on CCS
- Assess current level of understanding
- Develop R&D priorities
- Facilitate collaborative research efforts
- Collect and develop field experience
- Provide recommendations of field monitoring and integrity evaluation
- Provide recommendations for remediation
- Foster and provide leadership for experimental and numerical studies
- Provide guidance on policy and regulations

Wellbore Integrity Focus Areas

1. Field studies of CO_2 in the wellbore environment including EOR and natural CO_2 reservoirs
2. Field monitoring and evaluation methods
3. Remediation approaches
4. Experimental studies on cement-CO_2 interactions including new cement formulations
5. Numerical modeling of CO_2 in the near-wellbore environment and in field-scale studies of multiple-well interactions
6. Risk, Best Practices, and Policies and Regulations

Summary of Key Issues (from JNM) - 1

- Wellbore integrity problems exist in oil and gas operations (e.g., SCP). We need to develop a basis for evaluating leakage potential from legacy wells
- Laboratory experiments on CO_2-cement need to reconcile effects of key variables: confining pressure, fluid flow, matrix vs. interface flow, and effect of reservoir rock
- New approaches to wellbore remediation and methods to evaluate the potential costs of remediation are needed

Summary of Key Issues (from JNM) - 2

- New CO_2-resistant cements are in development and methods for evaluating their performance and determining their suitability are needed
- Casing and tubular corrosion may be more rapid than cement degradation but their role in integrity is unclear
- More sensitive and diagnostic logging and field monitoring tools are needed

Summary of Key Issues (from JNM) - 3

- Numerical models of wellbore geochemistry and geomechanics need additional development for providing long-term predictions
- Numerical models incorporating realistic permeability distributions for wells are needed to evaluate the leakage potential of fields with multiple wells
- Integrated geomechanical and geochemical experiments/numerical models are needed to capture full range of wellbore behavior

Summary of Key Issues (from JNM) – 4

- Integrated field evaluations in fields with long CO_2 exposure are needed to develop logging/monitoring methods, understand mechanisms of CO_2-induced degradation, and assess effective permeability of the wellbore
- Data mining of the rich resources available in private companies and regulatory bodies should be a priority for developing a statistical basis for evaluation of wellbore performance

Needs (as Identified from JNM)

- Information on frequency of failure
  - Well failure in new CO_2-EOR fields
  - Help in modeling potential leak rates
  - Informs Risk Assessment activities
- Assessment of steel and elastomer interactions with CO_2 and the likely effect on long-term isolation
- Costs and impacts of remediation
- Long-term numerical modeling grounded in enhanced field and experimental data

Interface with Other Networks

- Risk
  - We are working toward the development of risk-based assessments of wellbore performance
  - We are interested in the approaches being used by the Risk Network
- Monitoring
  - Our monitoring efforts are primarily for evaluation of wellbore integrity—less emphasis on detecting leaks

Network Future Goals

- Develop consensus (?) document on the potential impact of wellbore behavior on storage site performance

Wellbore Integrity Meeting in Calgary, Alberta on May 13 and 14, 2009

Session 2: Risk and Regulatory Environment for Wellbore Integrity

- *Well blowout rates and consequences in California Oil and Gas District 4 from 1991 to 2005,*

  Preston Jordan, Lawrence Berkeley National Lab
- *CO2 Storage--Managing the Risks of Wellbore Leakage over Long Timescales,*

  Rabih Chammas, Olivier Poupard, Oxand
- *Qualitative and semi-quantitative risk assessment methods to evaluate potential CO2 leakage pathways through wells,*

  Claudia Vivalda, Schlumberger
- *Regulatory practices in Alberta,*

  Tristan Goodman, ECRB
- *Well Abandonment Practices Study,*

  TNO

Session 3: Field Studies of Wellbore Integrity

Wellbore integrity in the North Sea

Tor Harald Hanssen, StatoilHydro

CO_2 Capture Project results from Buracica, Brazil

Walter Crow

Salt Creek EOR experience

Ken Hendricks, Anadarko

Wellbore Database at Weyburn, Canada

Rick Chalaturnyk, U. of Alberta

Measuring and understanding CO_2 leaks in injection wells: experience from MovECBM

Matteo Loizzo, Schlumberger

Effective Zonal Isolation for CO_2 Sequestration

Ron Sweatman, Haliburton

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Session 4: Wellbore Remediation, Leakage and Alternative Practices

- CO_2 injection well conversion and repair
  - Mark Woitt, RPS Energy
- Use of alternative cement formulations in the oilfield
  - Don Getzlaf, Cemblend
- Microseismic studies revealing leakage pathways,
  - Marco Bohnhoff, Stanford University
- Long term sealing of GHG sequestration wells,
  - Homer Spencer

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Session 6: Experimental studies of Wellbore Processes

- Experimental studies on wellbore cements,
  - Karoosh Ashgari, University of Regina
- Experimental assessment of brine and/or CO_2 leakage through well cements at reservoir conditions
  - Brant Bennion, Hycal
- Impact of CO_2 on Class G cement, static and dynamic long term tests
  - Francois Rodot and André Garnier, Total

Session 7: Modeling of Wellbore Processes

- Simulating leakage through well cement: coupled reactive flow in a micro-annulus
  - Laure Deremble, Schlumberger
- Modelling of wellbore cement alteration as a consequence of CO_2 injection in exploited gas reservoirs
  - Claudio Geloni, Saipem

Session 8: Quo Vadis: Future Direction of the Wellbore Integrity Network

Status Report Issued by the Wellbore Integrity Network: Elements and Outline

Wellbore Integrity Network

- Risk
  - We are working toward the development of risk-based assessments of wellbore performance
  - We are interested in the approaches being used by the Risk Network

Rick Chalaturnyk
University of Alberta

April 16, 2009

Overview of IPAC CO_2 – an International Performance Assessment Centre for Geological Storage of CO_2

IEA GHG R&D Network Meeting - Risk Assessment
Melbourne, Australia
April 16 & 17, 2009

Rick Chalaturnyk
University of Alberta

What is IPAC-CO2?

- *"IPAC-CO2 is an international panel for the independent evaluation and advancement of risk and performance assessment of geological storage of carbon dioxide"*
- *IPAC-CO2 provides and advances global expertise to independently benchmark, evaluate and provide advice on geological storage. It responds to the needs of the public, policymakers, regulators, developers and others." Statement of Intent, Paris, 2009*

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A Role for IPAC-CO2

- IPAC-CO2 was founded to provide standards and guidelines for verification of CCS.
- IPAC-CO2 will not compete with private sector risk assessment companies.
- It will instead provide the overarching level of confidence that will be needed by the public, regulators and those looking to store CO2 that the appropriate standards are in place and have been adhered to in the development of risk assessment for geological storage.
- Without an independent group—displaying transparency in undertaking the necessary oversight, conducting research to fill gaps in knowledge and benchmarking to understand predictive outputs of long-term storage—there will always be questions about the validity of risk assessment for geological storage and the establishment of a value on liability.
- Geological storage of CO2, globally, will face significant challenges without an independent organization like IPAC-CO2 conducting the evaluation of risk assessment and providing assurance of standards being met.

- IPAC-CO2, established with $5 million each from the Government of Saskatchewan and Royal Dutch Shell, is an independent research organization affiliated with the University of Regina.
- The core team of IPAC-CO2 scientists from multiple Canadian universities was instrumental in conducting the research for the IEA's "Weyburn-Midale CO2 Monitoring & Storage Project," which is North America's most significant CCS research undertaking.
- IPAC-CO2's business model will expand upon what is commonly found at many leading research institutions in that it will provide the overview services needed by industry, regulators and the public.
- IPAC-CO2's technical leadership and far-reaching institutional relationships will allow it to build a networked organization which harnesses best-in-class skill sets—and makes those skills available to CCS development around the world.
- Nodes are planned for Canada, USA, Europe, Australia, Brazil, China, India and South Africa.
- IPAC-CO2's organizational framework is designed to flexibly address a wide range of technical challenges and commercial concerns. This will be done by bringing some of the best minds in risk assessment to work within a collaborative framework, to advance specific CCS development and acceptance.
- Diversified participation and funding without undue influence from any special interest or market segment will allow IPAC-CO2 to operate in an environment that is transparent, impartial and technology-neutral.

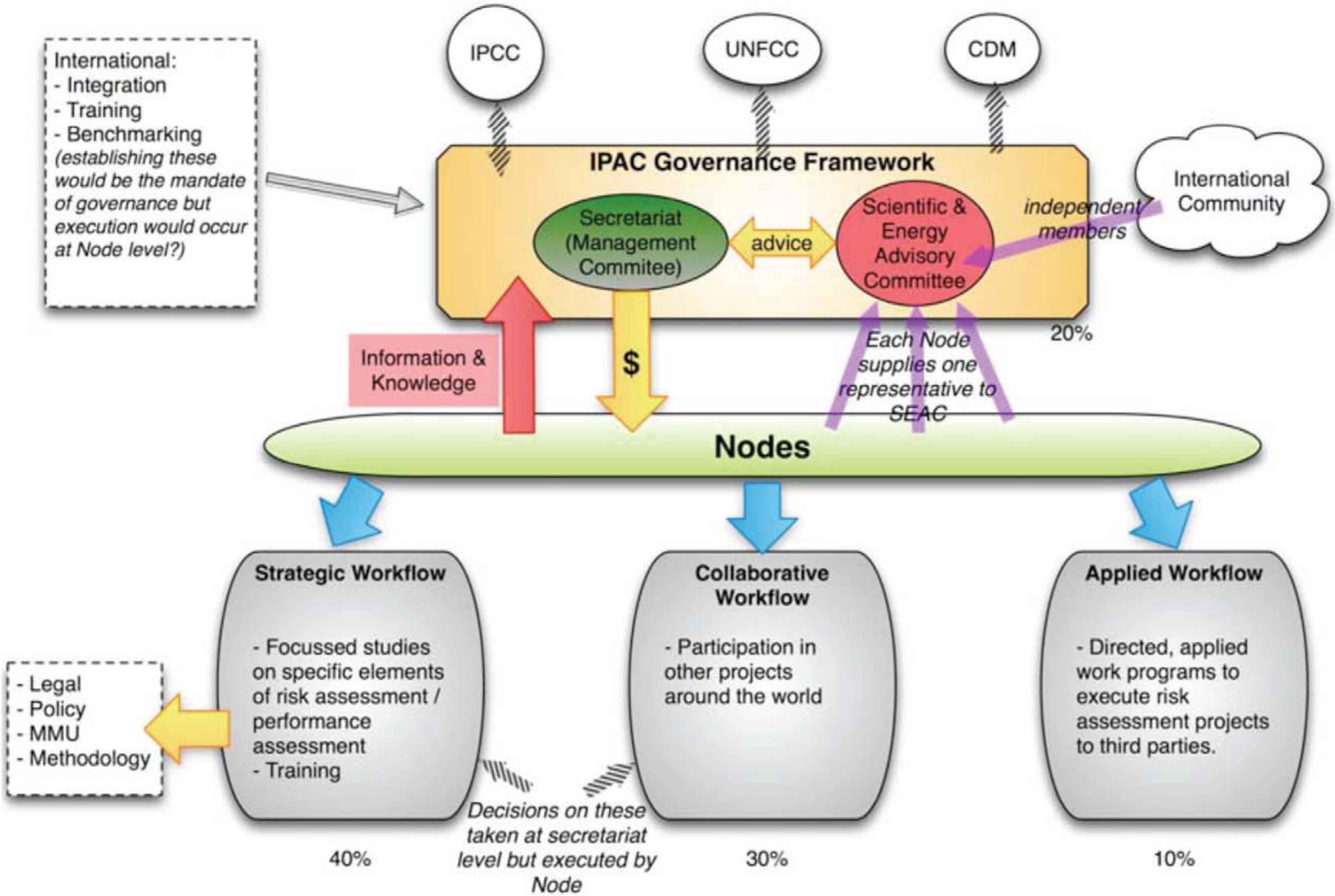
Early Structure for IPAC-CO2

IPAC Framework

Key goals:
1. assess CCS project risk and advise as to appropriate risk management
2. answer technical and other questions to enable CCS projects to proceed
3. engage with and educate various stakeholders and publics re: CCS to increase acceptance
4. network internationally to ensure learnings from other researchers are built upon and/or utilized

Parties using IPAC	Centre Activities	Centre Outputs
Companies with CCS projects	Risk Assessment	Risk mgmt plans Project advancements
Government regulators & agencies	Applied Research	Improvements to models, increased understanding of subsurface
Universities, other researchers	International Networking	International & Cdn. projects advanced; shared learnings, more HQP
Concerned publics, NGOs, local residents	Communication, Education	Community workshops, educational materials, greater understanding of and support for CCS

Current Potential Governance Structure



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Overview of IPAC CO_2 – an International Performance Assessment Centre for Geological Storage of CO_2

Rick Chalaturnyk
University of Alberta

IEA GHG R&D Network Meeting - Risk Assessment
Melbourne, Australia
April 16 & 17, 2009

CO_2 Storage Risk Assessment Terminology Study

Anna Korre, Sevket Durucan
Department of Earth Science and Engineering
Imperial College London

MERG

Outline

- Objectives of the work
- Review of the international state of the art in risk assessment and management guidelines
- Risk assessment and management for CO_2 storage projects
- Example extract from the terminology database
    - Data oriented terms
    - Action oriented terms
- What happens next …

Objectives

The objective of this work has been to develop and propose internationally harmonised terminology for CO_2 storage risk assessment.

It is not a goal to standardise risk assessments globally. Instead, harmonisation is thought of as an effort to strive for consistency among approaches

- to enhance understanding of the various approaches to CO_2 storage risk assessment worldwide
- facilitate the mutual use and acceptance of the assessment of CO_2 storage projects between countries, saving resources for both governments and the industry.

Target groups of users of the harmonised terms are CO_2 storage and environment professionals and political actors at all levels.

Review of the international state of the art in risk assessment and management guidelines

In providing this harmonising terminology, it was considered essential to review

- the international literature and regulations on risk assessment and management (EU, US EPA, AS/NZ Standards, US NAS/NRC) and
- key glossaries and terminology compilations developed by international organisations, regulatory agencies and authoritative associations (e.g. WHO, EU, US EPA, US NRC, IPCC).
- The recent guidance, technical support documentation and proposed regulations for CO_2 geological storage
  - OSPAR Framework for Risk Assessment and Management of Storage of CO_2 Streams in Geological Formations (2007)
  - EC Directive for CO_2 storage projects (2008)
  - US EPA Vulnerability Evaluation Framework for Geologic Sequestration of Carbon Dioxide (July 2008)
  - US EPA Federal Requirements under the Underground Injection Control Program for Carbon Dioxide Geologic Sequestration Wells (July 2008)

Fields of Risk Assessment

Historically, risk assessment has been dominated by two parallel methodological developments:

public-health risk assessment, focus on the health effects of chronic exposures to chemicals, contaminants, and pollutants in the water, the air and the food.

engineered-systems risk assessment, focus on immediate and delayed effects due to the failure of systems, (e.g. aerospace vehicles, chemical process plants, and nuclear power plants).

More recently there has been heightened interest in other risks including

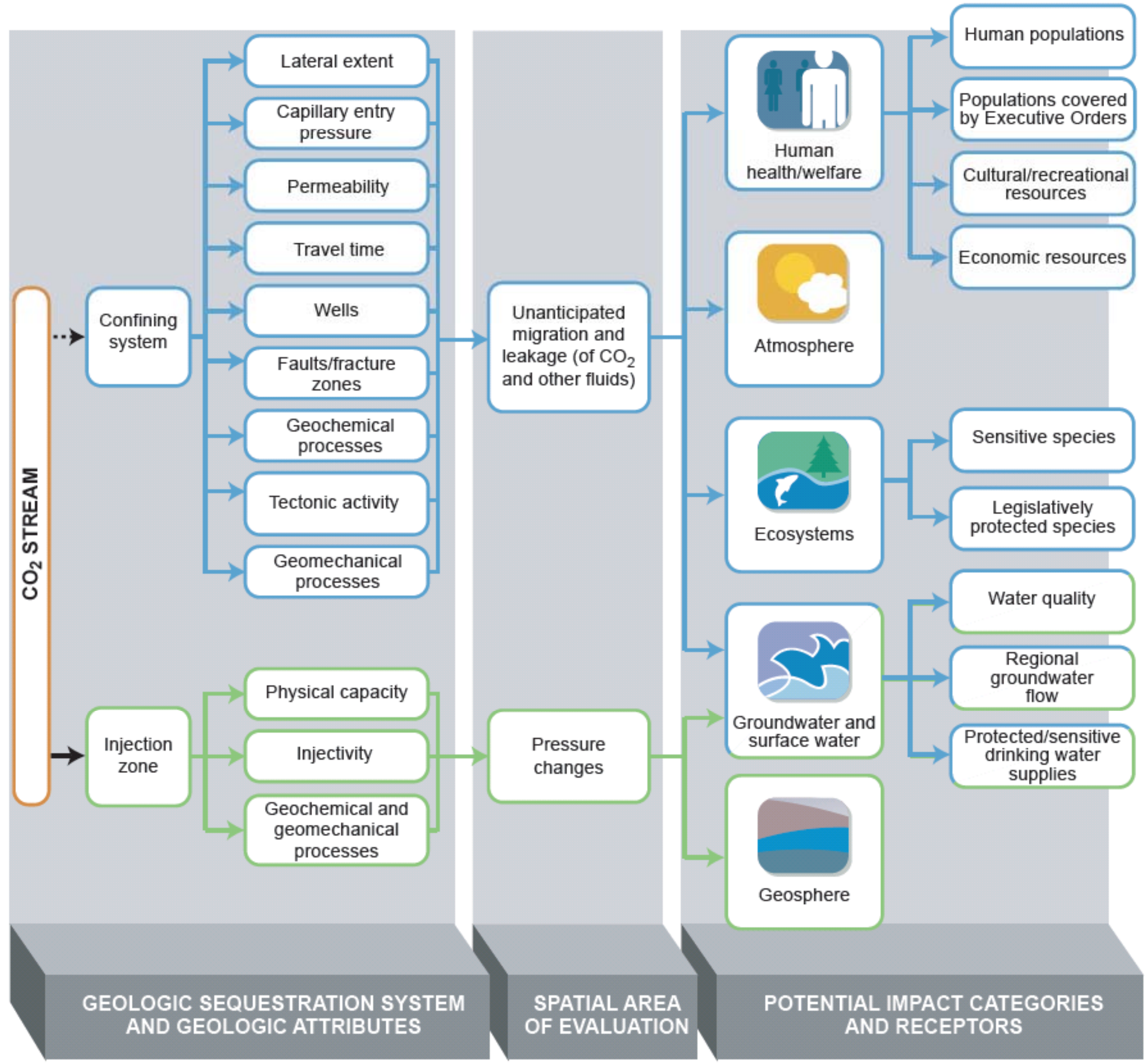
ecological risks (e.g. the degradation of ecological systems due to nonnative invasive species, global warming, and genetically modified organisms);

risks related to severe natural phenomena (e.g. hurricanes, earthquakes, fires, and floods); and

risks associated with malicious human acts (terrorism).

Which impact categories/receptors should be included in risk assessment for CO_2 geological storage

- Human health/welfare
- Atmosphere
- Ecosystems
- Groundwater and surface water
- Geosphere



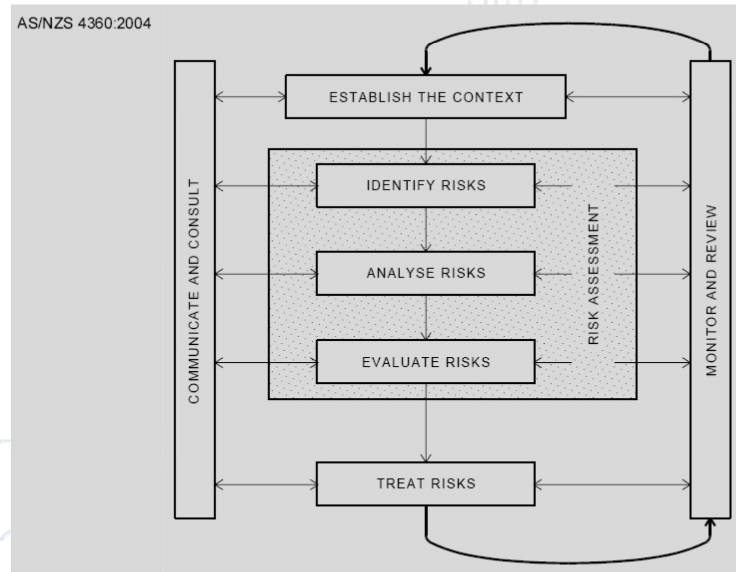
US EPA, Vulnerability Evaluation Framework conceptual model, 2008

How do the Risk Assessment steps relate with Risk Management and Risk Communication

Regulatory actions are based on two distinct elements:

Risk assessment is the use of the factual base to define the effects of exposure of individuals or populations to hazardous materials and situations.

Risk management is the process of weighing policy alternatives and selecting the most appropriate regulatory action, integrating the results of risk assessment with engineering data and with social, economic, and political concerns to reach a decision.



Risk management process overview (AS/NZS 4360:2004)

OSPAR Framework for Risk Assessment and Management

	Problem formulation	Site selection & characterisation	Exposure assessment	Effects assessment	Risk characterisation	Risk management (monitoring & mitigation)
Planning	☑	☑	☑	☑	☑	☑
Construction		☑	☑	☑	☑	☑
Operation		☑	☑	☑	☑	☑
Site-closure			☑	☑	☑	☑
Post-closure			☑	☑	☑	☑

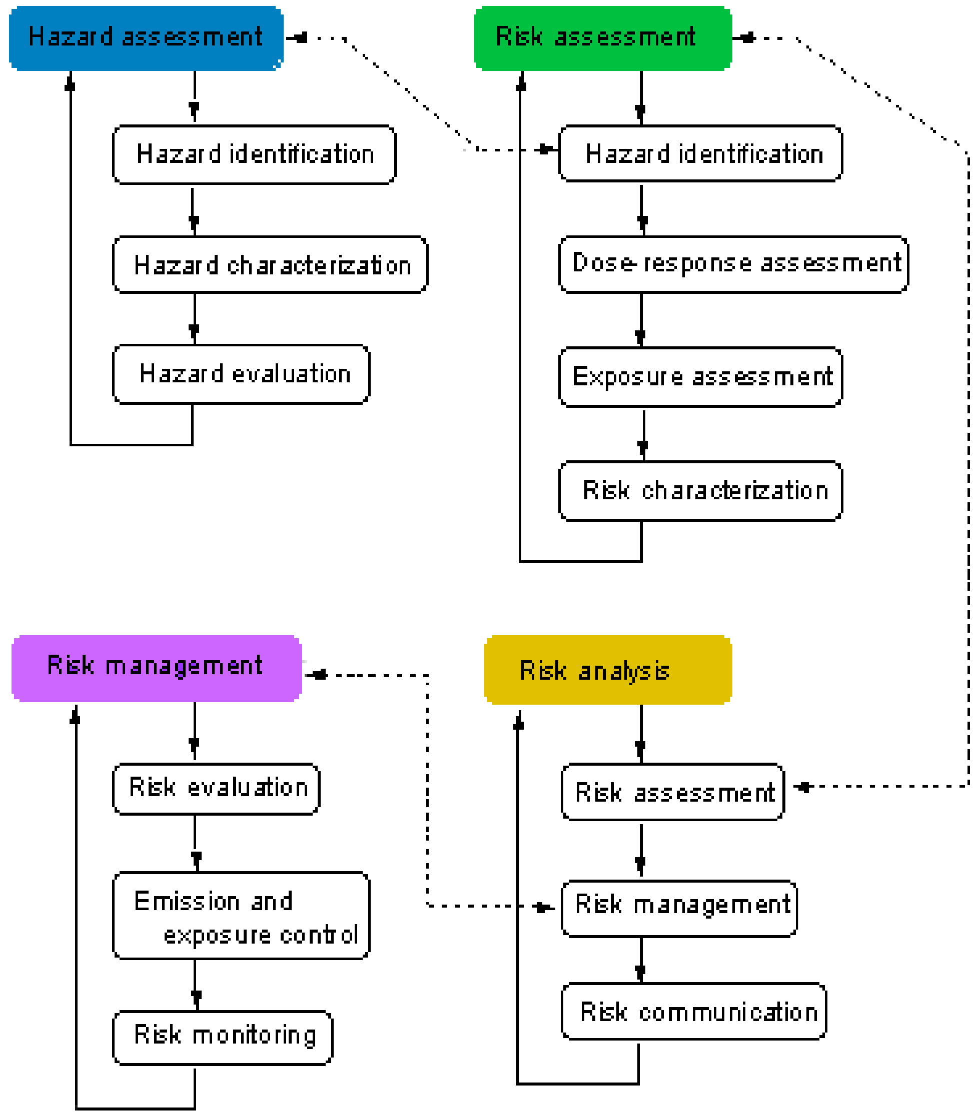
- Problem Formulation: critical scoping step, describing the boundaries of the assessment
- Site characterisation: collection and evaluations of data concerning the site (capacity, integrity, leakage pathways, monitoring options, surrounding area)
- Exposure assessment: characterisation and movement of the CO_2 stream (properties of CO_2 stream, exposure processes and pathways, likelihood, scale)
- Effects assessment: assembly of information to describe the response of receptors
- Risk characterisation: integration of exposure and effect data to estimate the likely impact (impact hypothesis with performance criteria, qualitative or quantitative)
- Risk management: including monitoring, mitigation and remediation measures

How do the Risk Assessment steps relate with Risk Management and Risk Communication

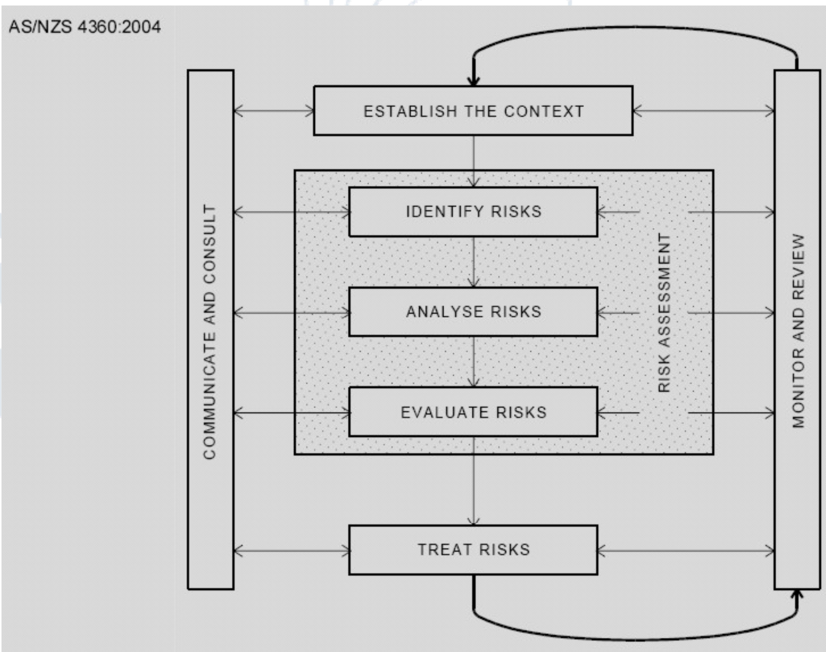
Risk assessment is the use of the factual base to define the effects of exposure of individuals or populations to hazardous materials and situations.

Risk management is the process of weighing policy alternatives and selecting the most appropriate regulatory action, integrating the results of risk assessment with engineering data and with social, economic, and political concerns to reach a decision.

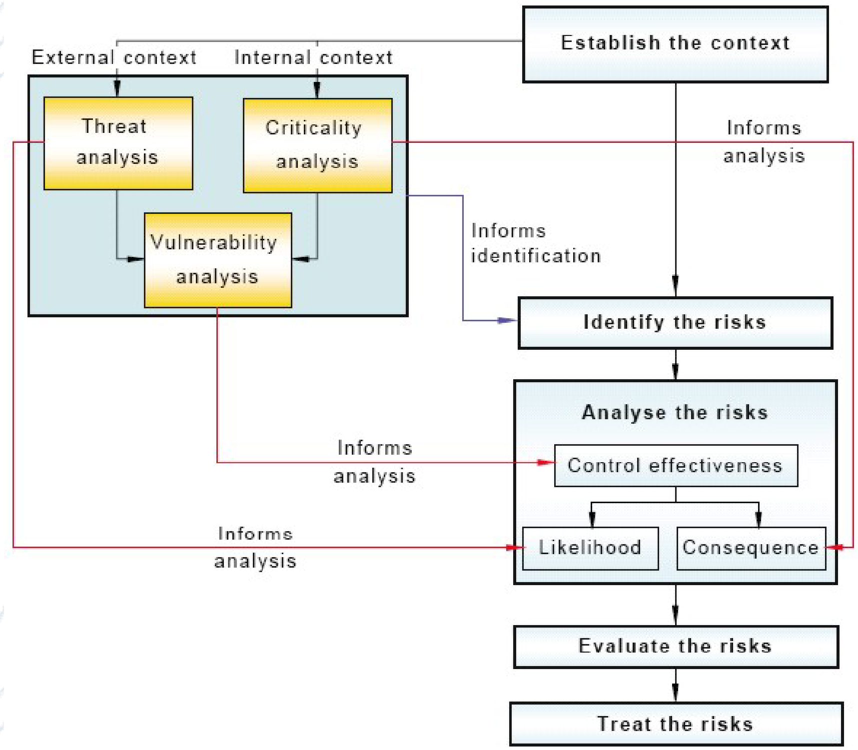
International Program on Chemical Safety/ Organization for Economic Cooperation and Development, 2004



Level of detail required in risk analysis

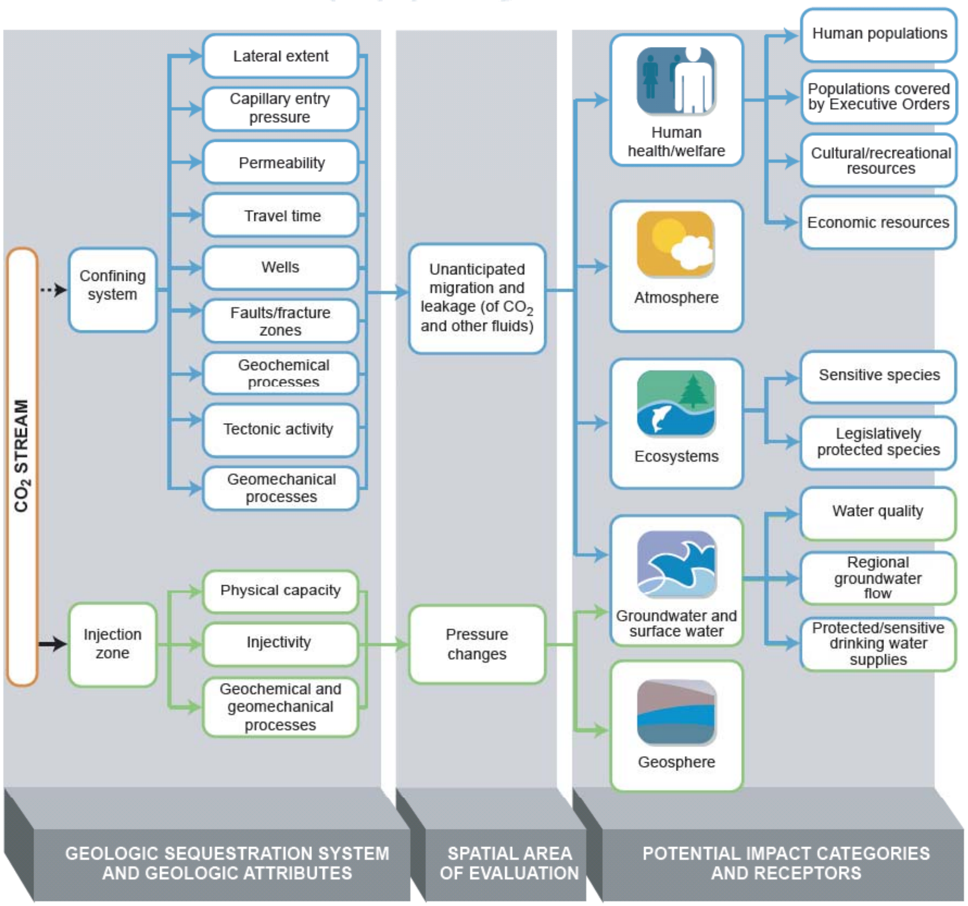


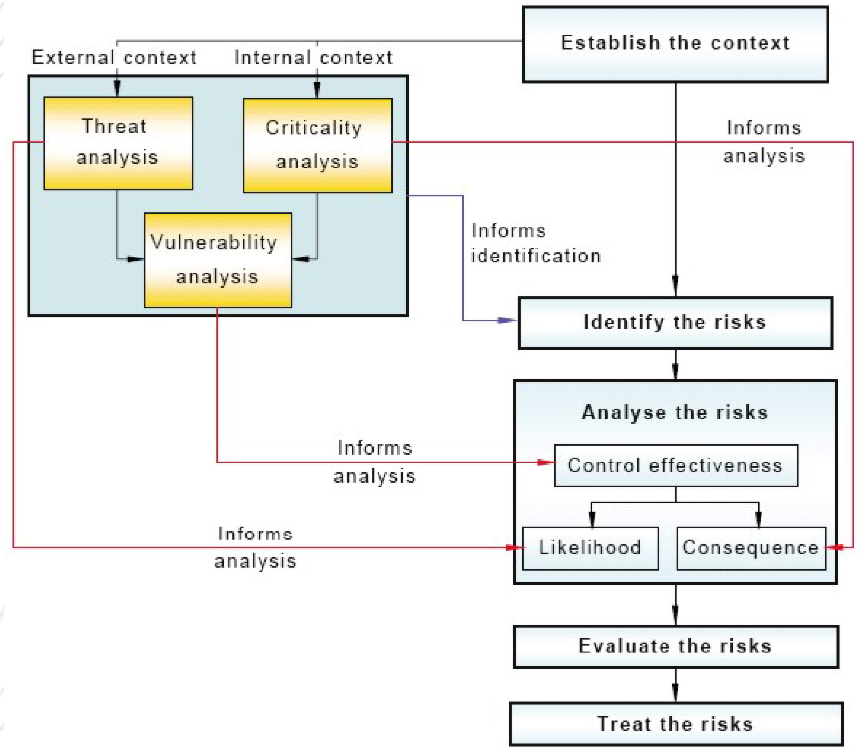
Risk management process overview (AS/NZS 4360:2004)



Using threat, criticality and vulnerability to inform risk analysis (AS/NZS HB 167:2006)

Level of detail required in risk analysis

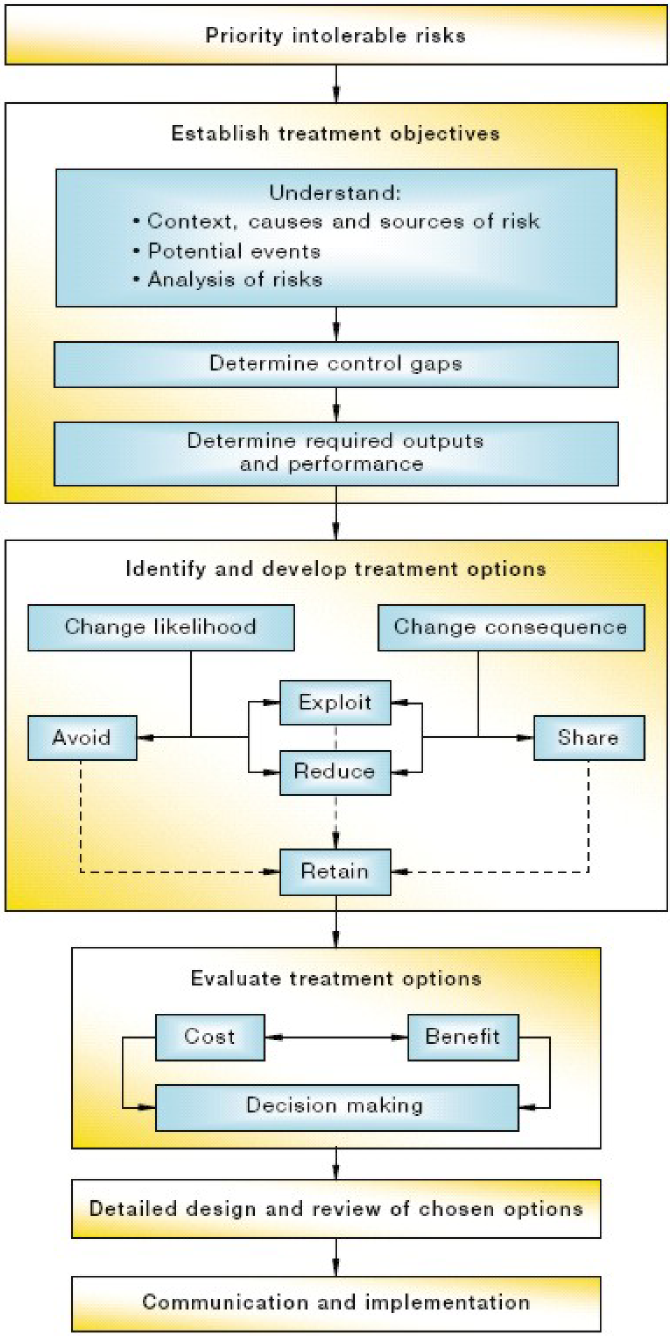




Using threat, criticality and vulnerability to inform risk analysis (AS/NZS HB 167:2006)

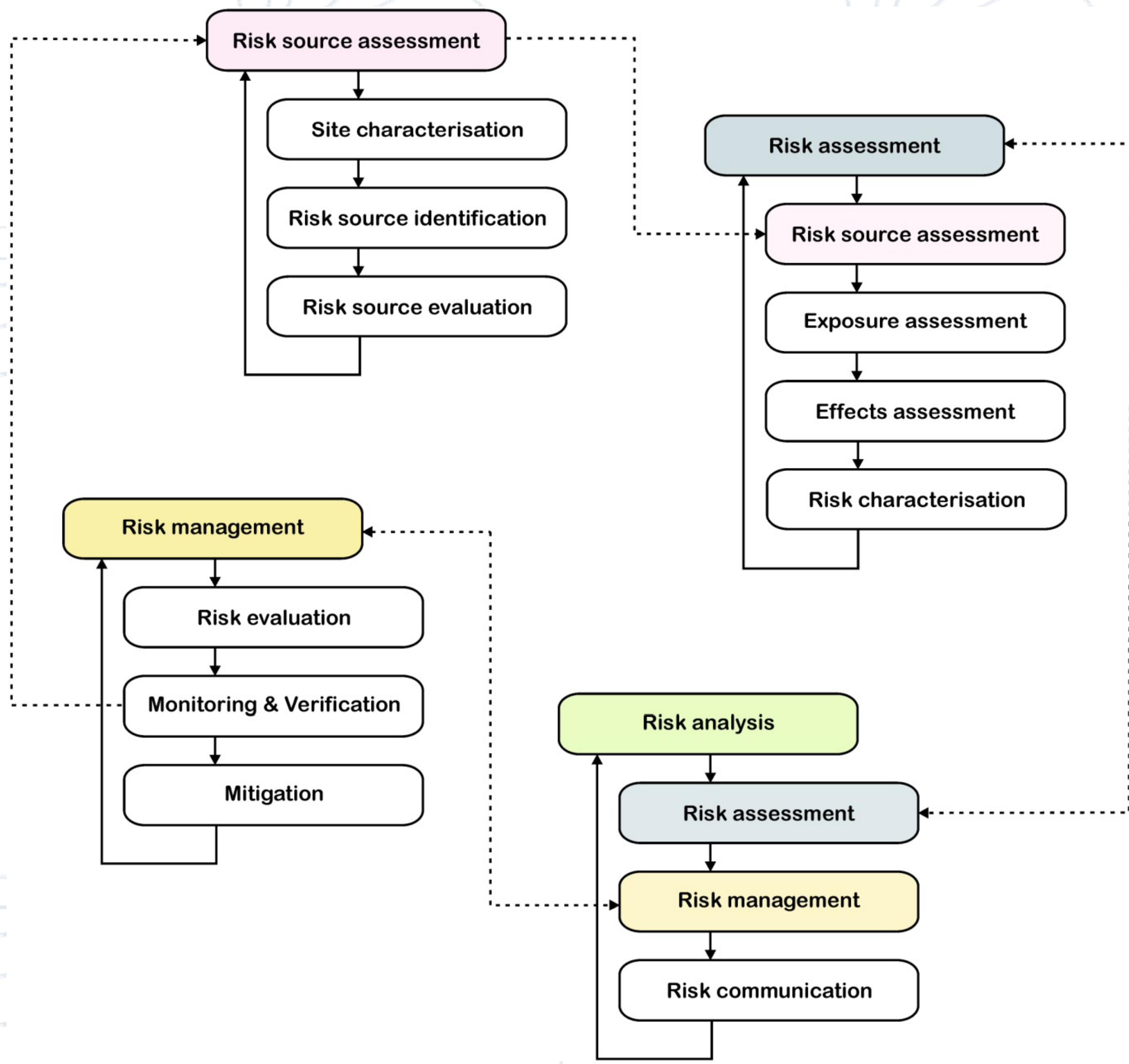
US EPA, Vulnerability Evaluation Framework conceptual model, 2008

Treatment of risk



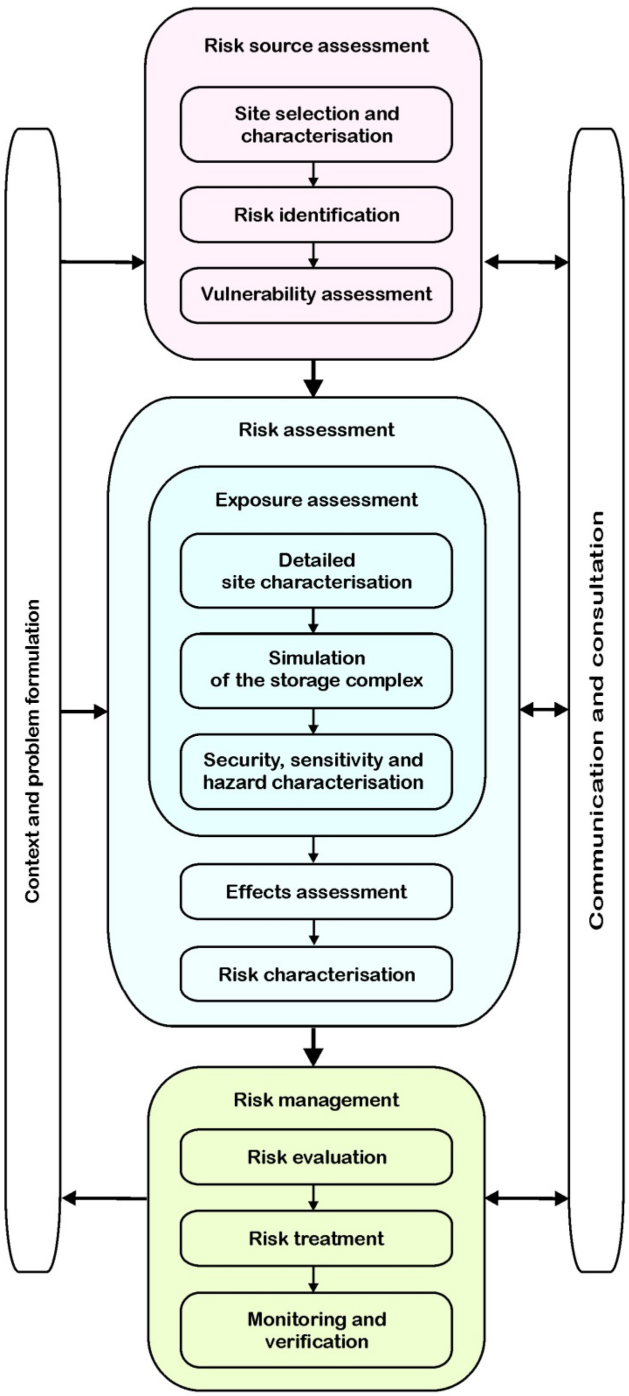
Key stages of treating risk (AS/NZS HB 167: 2006)

Framework for Risk Assessment, Management and Communication for CO_2 storage projects



Risk assessment, management and communication framework for CO_2 storage projects

- OSPAR Framework for Risk Assessment and Management of Storage of CO_2 Streams in Geological Formations (2007)
- EC Directive for CO_2 storage projects (2008)
- US EPA Vulnerability Evaluation Framework for Geologic Sequestration of Carbon Dioxide (July 2008)



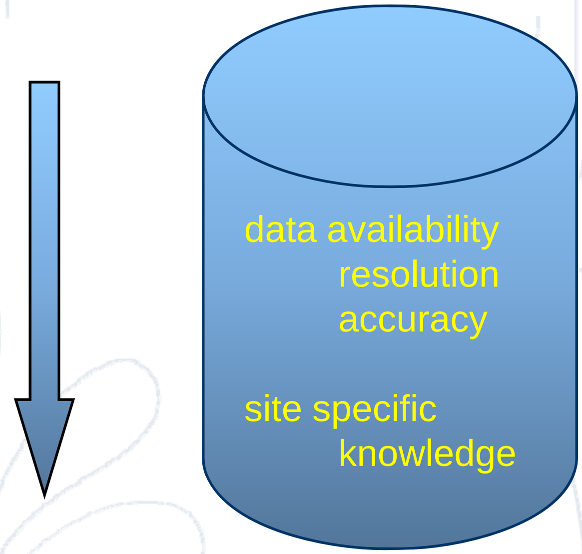
Relevance of risk assessment to the lifetime stages of a CO_2 storage project

A. Site Selection

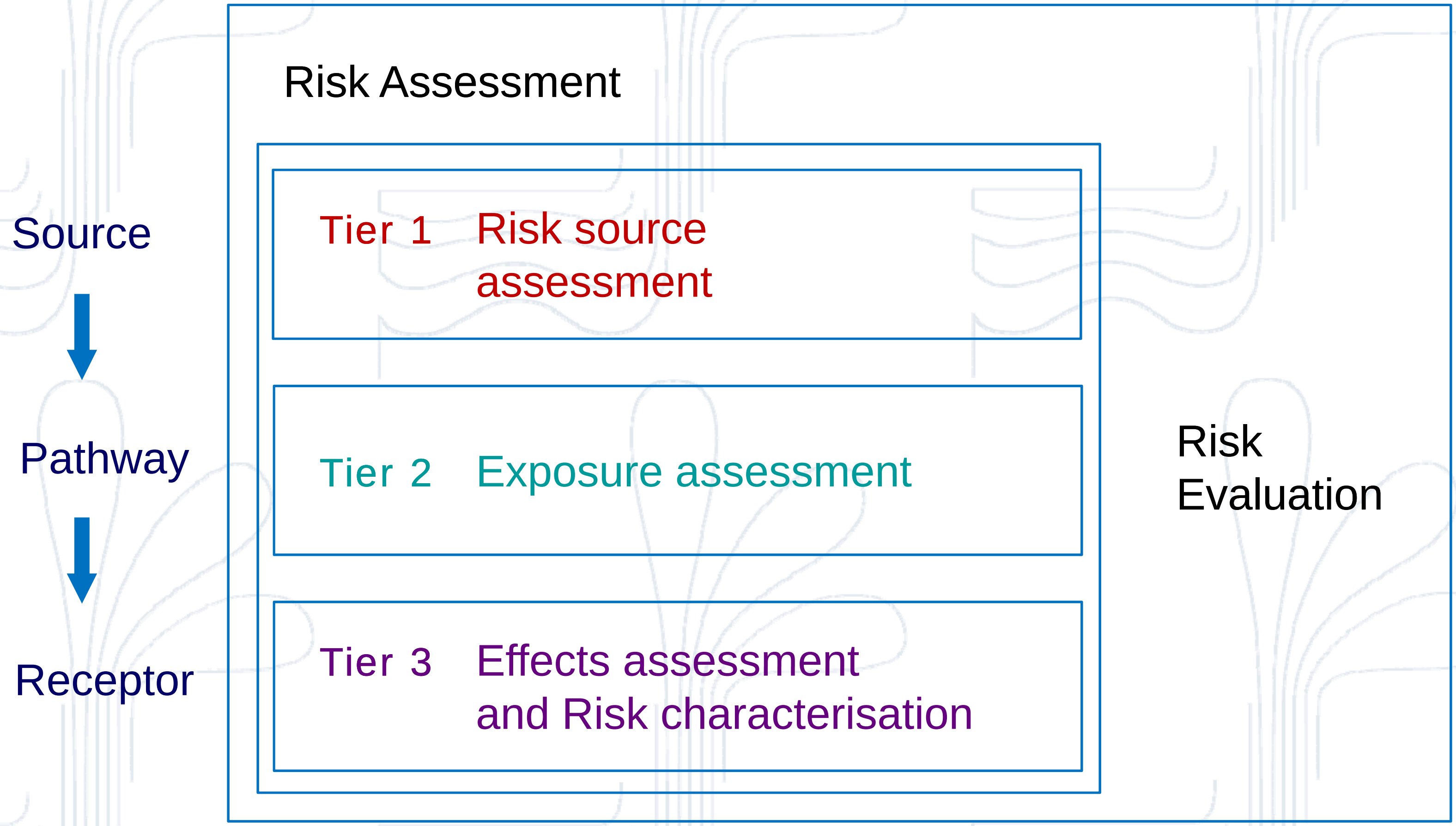
B. Storage Licensing

C. Operation, Closure

D. Post-closure



Framework for Risk Assessment, Management communication for CO_2 storage projects



Framework for Risk Assessment, Management communication for CO_2 storage projects

A. Site Selection
B. Storage Licensing
C. Operation, Closure
D. Post-closure

Tier 1
Risk Source Assessment

Scenario analysis tools
FEPs analysis tools
VEF analysis
Conceptual model development tools

Data requirements:
modest, use of generic data

Risk evaluation

Risk likelihood
(likely, …, unlikely) and
Significance
(negligible, marginal, significant)

Framework for Risk Assessment, Management and Communication for CO_2 storage projects

A. Site Selection
B. Storage Licensing
C. Operation, closure
D. Post-closure

Tier 1
Risk Source Assessment

Scenario analysis tools
FEPs analysis tools
VEF analysis
Conceptual model development tools
Treatment of uncertainties
System level modelling

Data requirements:
generic data
coarse site specific data
(aggregation, audit)

Risk evaluation

Risk and significance
qualitative,
semi-quantitative

Performance: CO_2 flux
Ecosystem acceptable
levels(?)

Framework for Risk Assessment, Management and Communication for CO_2 storage projects

A. Site Selection
B. Storage Licensing
C. Operation, Closure
D. Post-closure

Tier 2
Exposure assessment

Process level modelling tools
fluid flow codes; geochemical codes; geomechanical codes, …
ecosystem modelling codes(?)
System level models
Treatment of uncertainties,
natural heterogeneity (geological model)

Data requirements:
site specific data,
surrogate data from analogue sites
(data audit)

Risk evaluation

Risk and significance
quantitative

Performance: CO_2 flux
(volume, timescale)
Receptor based thresholds (?)

Framework for Risk Assessment, Management and Communication for CO_2 storage projects

A. Site Selection
B. Storage Licensing
C. Operation, Closure
D. Post-closure

Tier 3

Effects assessment and Risk characterisation

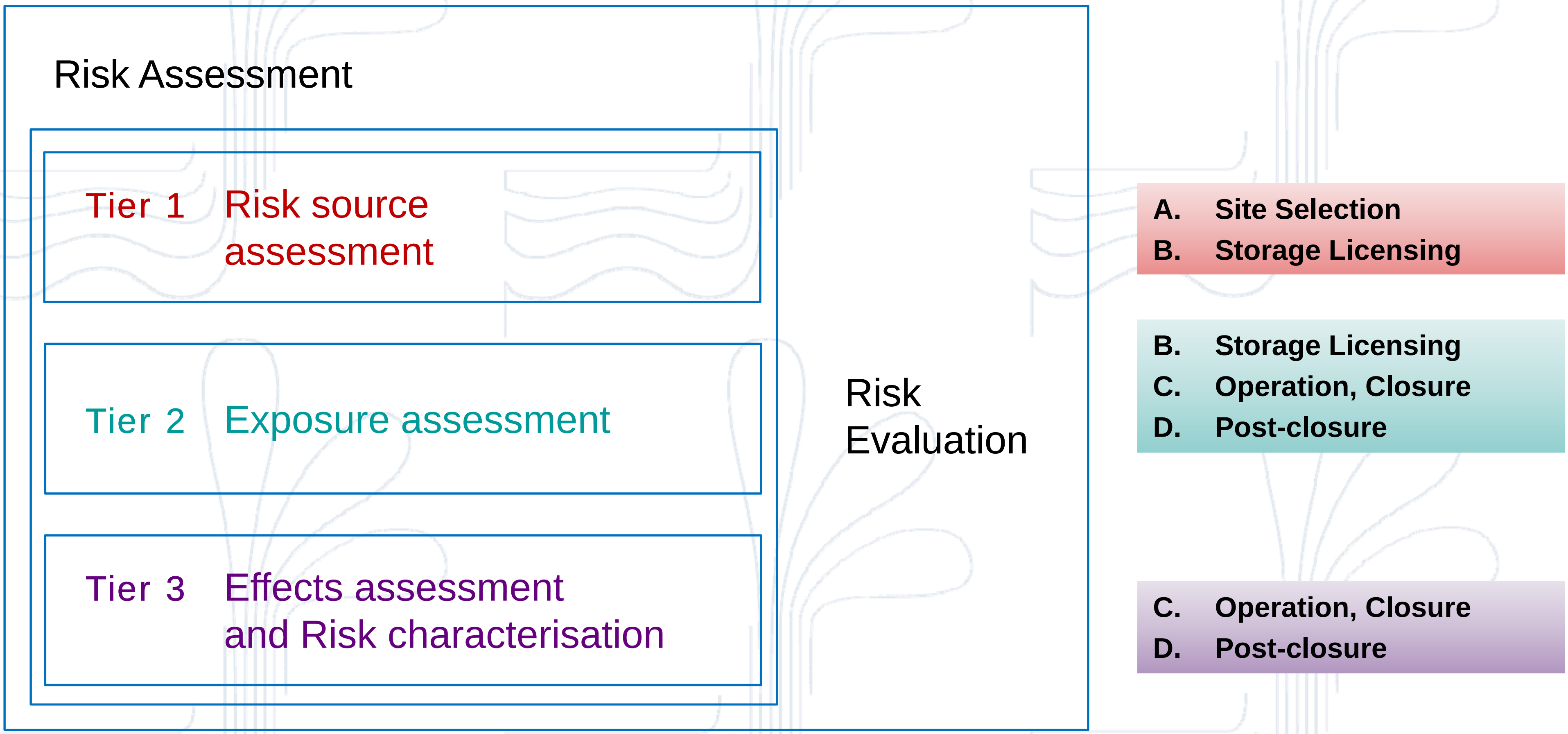
Ecosystem modelling
- ecotoxicity assessment,
- biodiversity impact assessment,
- dose - response curves

Data requirements:
- experimental data from laboratory and field studies

Risk evaluation

Receptor based thresholds (?)

Framework for Risk Assessment, Management communication for CO_2 storage projects



CO_2 storage RA terminology development: What happens next …

The definitions for the higher-priority generic and specific terms extracted from the "key documents and sources" has been circulated (e.g., through IEA GHG RA network, the research community and industry) for review and comments.

Once the report is finalised it will be made available widely in a wikipedia style database as a live document with respondents able to:

- identify or provide their preferred definition for each term
- identify terms considered as synonyms
- indicate whether any important key documents or sources should be included as they become available.

Contact details:

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Imperial College London

MERG

Carbon Sequestration Leadership Forum

www.cslforum.org

IEA-GHG Risk Assessment Network Meeting

Melbourne - April 16th-17th, 2009

Report from:

CSLF Risk-Assessment Task Force

Carbon Sequestration Leadership Forum

www.cslforum.org

Task Force History and Mission

- **At the joint meeting of the CSLF Technical and Policy Groups in London (November 14th–15th 2006), the CSLF Technical Group formed a Task Force (TF) to examine risk assessment standards and procedures.**
- **This TF was formed to address a need identified in the CSLF strategic plan.**
- **In phase I of its activities, this Task Force was expected to examine risk-assessment standards, procedures, and research activities relevant to *unique risks* associated with the injection and long-term storage of CO_2**

Carbon Sequestration Leadership Forum
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Task Force Membership

- Australia
- Canada
- France
- India
- Japan
- Netherlands
- Norway
- United Kingdom
- United States, chair
- IEA Greenhouse Gas Programme

Carbon Sequestration Leadership Forum

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Phase I Status

- Phase I draft report edited and revised
- Summary of ongoing risk assessment activities expanded
- Recommendations finalized at the CSLF Technical Group meeting in Oslo (April 1st-2nd 2009)
- Final draft to Secretariat mid-April for circulation to the Technical Group for review

Potential Impacts Considered

- Impingement on pore space not covered under deed or agreement;
- Impingement on other subsurface resources;
- Change in local subsurface stress fields and geo-mechanical properties;
- Impact on the groundwater and/or surface water;
- Elevated soil-gas CO_2 in terrestrial ecosystems;
- Accumulation in poorly ventilated spaces or in low lying areas subject to poor atmospheric circulation;
- CO_2 or other displaced gases (such as methane) return to the atmosphere.

Carbon Sequestration Leadership Forum

www.cslforum.org

Summary of Ongoing Risk Assessment Activities/Projects

Project Title:
Include a short title or description of the project.

Lead Organization(s) and Point(s) of Contact (w/e-mail):
Focus on lead; the intent is to provide a point of contact as opposed to be inclusive on participants.

Duration:

State and completion dates (if applicable): ???

Injection and monitoring dates (if applicable): ???

Dates & short description of key risk assessment milestones: ???

Scale of Injection (if applicable):
For example, XXX tons per year for YYY years. Please spell "million" as applicable.

Risk Assessment Methodology:
Include a brief description of the approach and tools used for risk assessment.

Brief Summary:
Include a short narrative on the project, discussing key goals and key milestones.

If the project includes a field effort, include a brief site description (and/or reference).

Key Risk Assessment Findings (if applicable)
Include a short description of key findings and publications/documents from the project, as they relate to risk assessment.

Note any lessons learned.

If there is a website link to project summary, please provide.

- **Form circulated by Secretariat**
- **Current Summaries**
  - Australia
  - Canada
  - France
  - France-Germany
  - Japan
  - USA
  - IEA

Issues requiring further action

- *A **gap assessment** to identify CCS-specific **tools and methodologies** that will be needed to support risk assessment.*
- *The feasibility of developing **general technical guidelines for risk assessment practices** that could be adapted to specific sites and local needs, and subsequently development of such guidelines.*

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Recommendations to consider passing to the Policy Group

- *The link between **risk assessment** and **liability** should be recognized and considered.*
- *The use of **risk assessment** to ensure successful performance at storage sites should be considered in the context of stakeholder **outreach and communication**.*

Defining R&D Needs to Assess Environmental Impacts of Potential Leaks from CO_2 Storage, IEA GHG / BGS Workshop, Nottingham, UK, 15-17th September, 2008.

Julie West, Jonathan Pearce, Toby Aiken, Tim Dixon

Kingsley Dunham Centre
Keyworth
Nottingham NG12 5GG
Tel 0115 936 3100

British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL
www.bgs.ac.uk

Objectives

- **To bring together experts from research communities not necessarily already involved in CCS**
- **To review the potential impacts on both terrestrial and marine ecosystems of (post-injection) leaks from CO_2 storage sites.**
  - **Reviewing existing knowledge and current research**
  - **Identifying gaps in knowledge of possible concern to regulators**
- **To identify future research and demonstration needs**

Agenda

- **Selected viewpoints of different stakeholder groups were presented**
  - **Regulators**
  - **Industry**
  - **Public**
  - **Research**
- **Recent and current research activities presented**
  - **IEAGHG Terrestrial and marine impact reviews**
  - **Field-based research:**
    - experimental
    - analogue systems
- **R&D needs were identified and prioritised**

Industry needs

- Leakage rates must be realistic and quantified to allow credible scenarios to be defined
- A defined scope for Environmental Impact Assessments is needed
  - To include costs and priorities
  - Demonstrate ability to 'learn by doing',
  - Extrapolation of lessons from specific research
- Database of analogue sites, both leakage and non-leakage
- Database of experimental sites
- Monitoring guidelines;
  - Timescale issues – how long to monitor for? Over what period should EIAs be considered?
  - Access to baseline data
  - What monitoring techniques should be used?

Regulator needs

- **Strategic overviews of potential storage locations**
- **Database of experimental and analogue sites, to include an interpretation of data and figures**
- **Decision tools / frameworks, such as GIS based tools, to support site leasing and licensing**
- **Real project data is needed to understand environmental risks**
- **Identified indicator species and reference ecosystems**
- **Sensitivity thresholds of indicator species and ecosystems**

Public needs

- **Involvement of local interest groups,**
- **Consultation would include consideration of**
  - **The needs of the general public / local communities?**
  - **What level of detail is appropriate?**
    - Education;
    - Knowledge of natural leaks,
    - Knowledge of the characteristics of CO_2
- **Need to identify those issues of greatest importance to the public:**
  - **examples might include groundwater and marine protection**
- **Terminology is an issue that was raised repeatedly throughout the workshop**
  - **For example: EC Storage Directive terms such as ‘significant’ and ‘limited’ which will require definition.**

Research needs

- Environmental impacts at ecosystem level;
- Impacts of chronic exposure and physiologic responses,
- Identify reference / target species
- Groundwater quality issues;
  - Validation of models,
- Formation of a database for natural analogues,
- Timescales for future performance assessments;
  - Definition of operational period / monitoring period,
- Pathways between reservoirs and the surface;
- Rates of leakage and associated impacts
  - Effects of coupled or multiple stressors on individual ecosystems,
  - Definition of spatial scale of impact / monitoring regime;
- Development of appropriate scenarios

Prioritised gaps to be addressed

- **An understanding of the consequences, both positive and negative, of CO_2 and other co-released species or substances,**
- **Likely impact, and extent of impact of pH changes, mobilisation of heavy metals and brine intrusion on groundwater quality,**
- **Effects of brine displacement**

Other gaps to be addressed

- Local environmental impacts at ecosystem level
- Impact on surface freshwater ecosystems
- Identification of target and key indicator species
- Thresholds of exposure and definition of "acceptable" flux rates
- Distinctions between acute versus chronic effects
- Analysis of the reaction rates involved in the processes
- Development of monitoring techniques, for specific issues
- The effects of multiple or coupled stressors

Monitoring and EIA

- **Collaboration between the monitoring and risk assessment communities is needed for development of monitoring techniques.**
- **Monitoring should be directed to address EIA's as well as CO_2 storage security.**
  - **For discussion by the IEA GHG International Research Network on Monitoring.**
- **Risk assessment should give the end points that monitoring programmes will be designed to address.**
- **There must be clarity between monitoring for risk assessment and for risk management.**

Monitoring and EIA

- **The size and location of areas to be monitored will be site-specific.**
- **Similarly the frequency, density and types of monitoring will reflect site-specific conditions and local regulations.**
  - **E.g. Protected habitats, groundwaters, target species**
- **While effects of leaks at some natural analogue sites suggest impacts could be reasonably localised, the location of leak may be less predictable.**
- **The potential for leaks into groundwaters used as public water supplies may prevent some storage projects receiving approval.**

Addressing issues identified

- **Identification of reference species:**
  - **Should include commercially important species.**
  - **Assessment should include multiple stressors (fishing, acidification & pollution)**
  - **Marine reference species could include corals (strongly susceptible?), shellfish and nematodes (more tolerant?).**
  - **Terrestrial reference organisms could include legumes (more susceptible), grasses (cereals), and possibly worms.**
- **For validation of groundwater models purposeful injection into aquifers is unlikely to be permitted**
  - **So could use natural analogues if appropriate systems can be identified.**
- **A combination of laboratory, mesocosm, field-scale leakage experiments, analogue studies and modelling can be used.**

Summary

- Credible leakage scenarios need to be defined
  - to put leakage into context
  - to enable experimental studies to be appropriately constrained
  - to define scope of EIAs
- An analogues database was proposed
- Target species and threshold levels are needed
- Responses of ecosystems and target species to multiple stressors (including co-released species) is a key gap
- Monitoring will need to assess potential impacts
- A combination of laboratory, mesocosm, field-scale leakage experiments, analogue studies and modelling would address gaps
- Some opportunities for funding were noted.
- Meeting report by Toby Aiken available from IEAGHG

IEA: 4th Risk Assessment Network Potential Impacts on Groundwater: An Australian Perspective

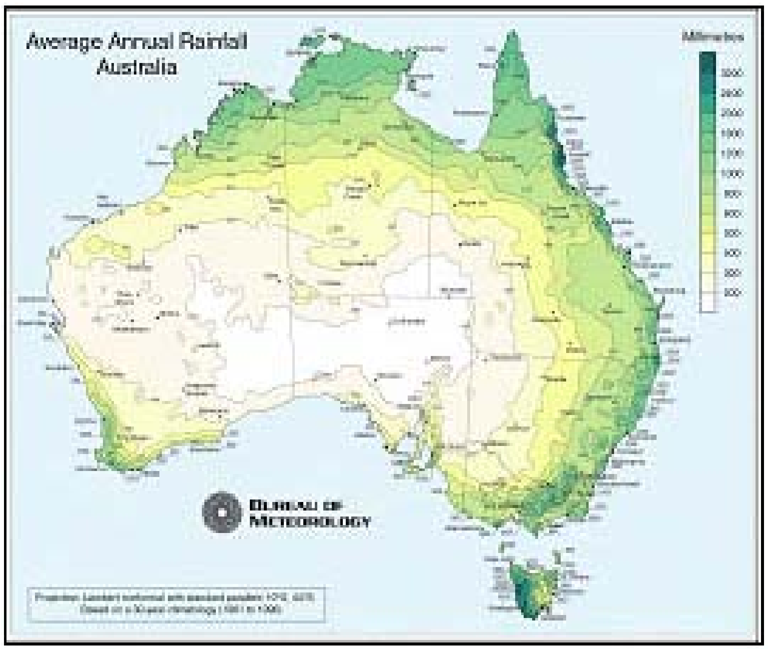
Jim Underschultz

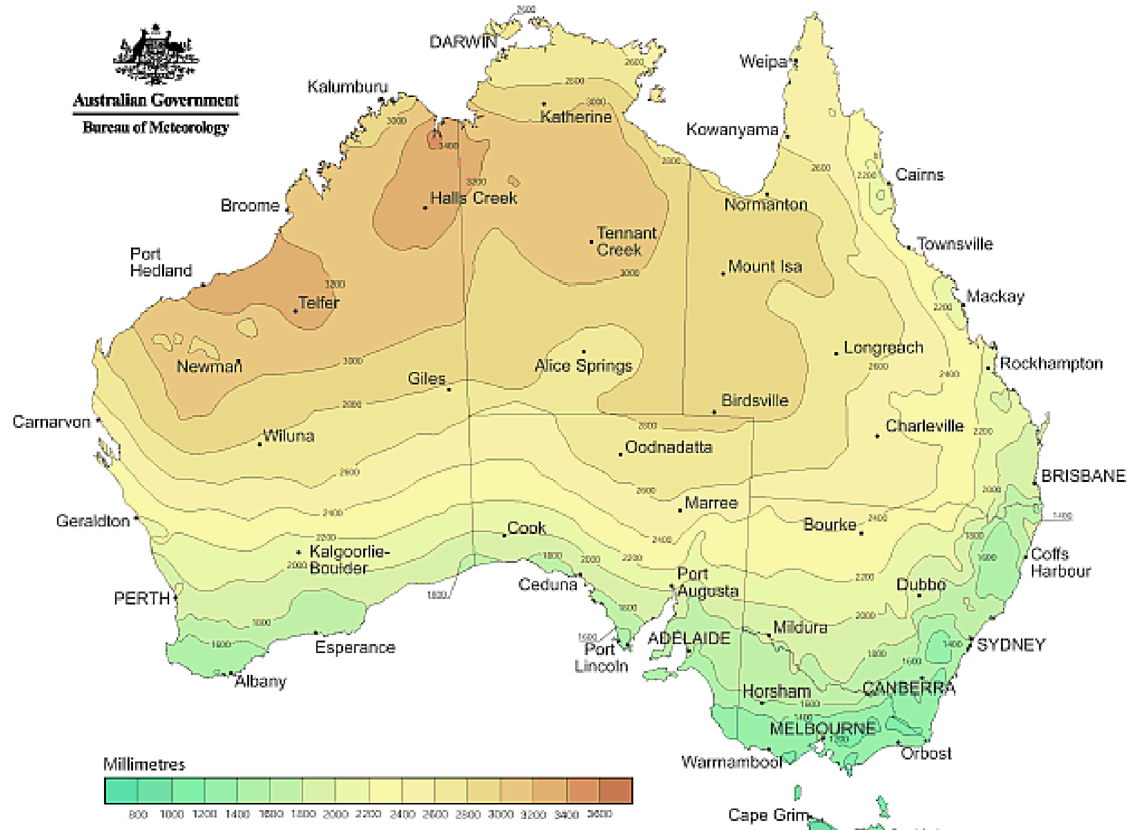
(CSIRO Petroleum and CO2CRC)

Issues

Australia is dry, we are in drought, our population is growing.

Average Rainfall





Evapotranspiration

CSIRO

CO2CRC

Issues: Water Resources are Crucial

- Off-shore
  - injection may shift the Freshwater-Saltwater interface on-shore

- On-Shore
  - Fault seal and top seal containment security and leakage into shallow groundwater resources
  - Very deep brackish groundwater resources
  - Great Artesian Basin
  - Induced saline leakage (flux) from the top seal

Related Issues: Ground heave and infrastructure security

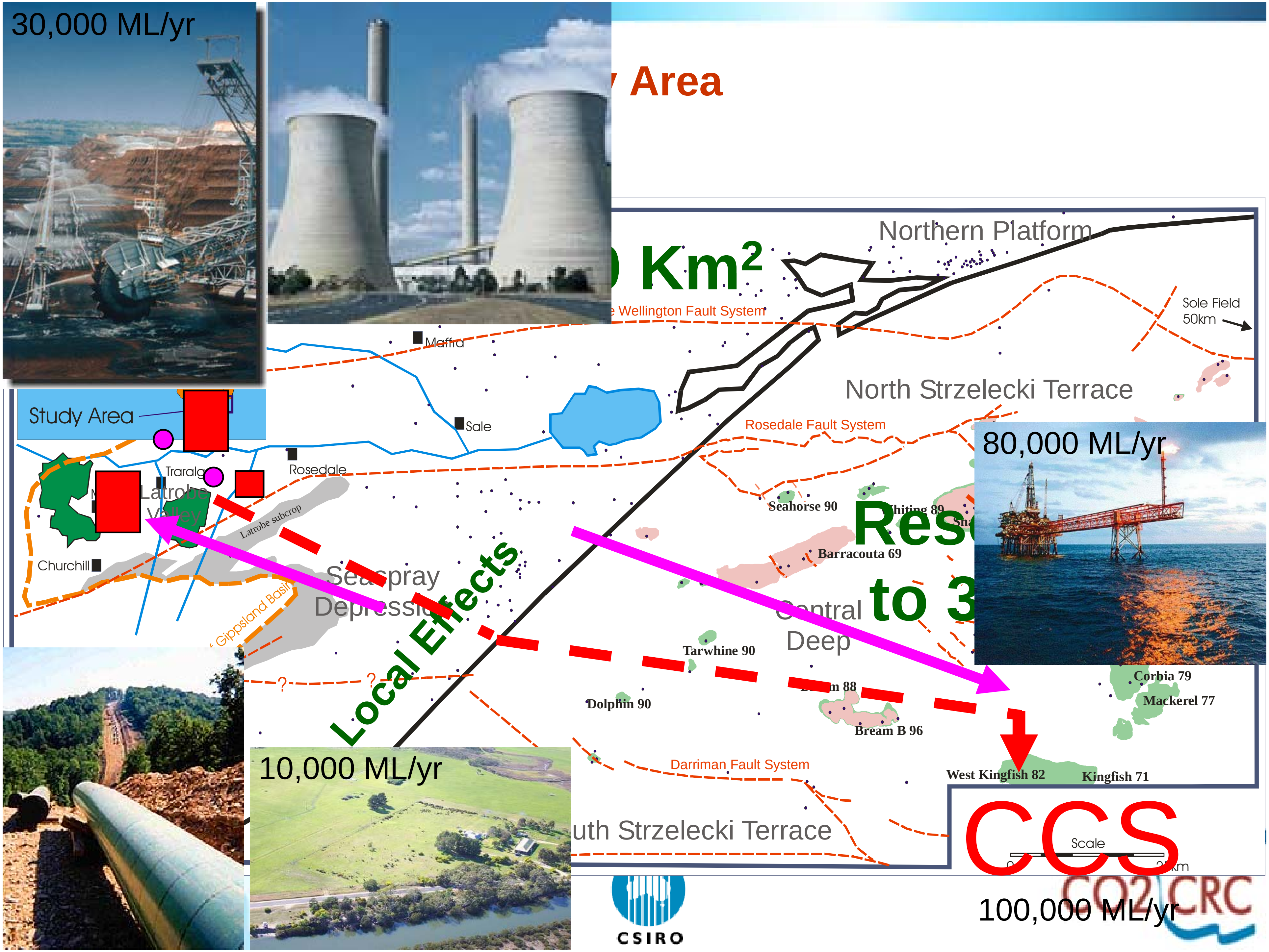
Commercial Scale Volumes

Eg. Latrobe Valley in Victoria

- **New Power Stations designed for CCS plus some retro-fit**

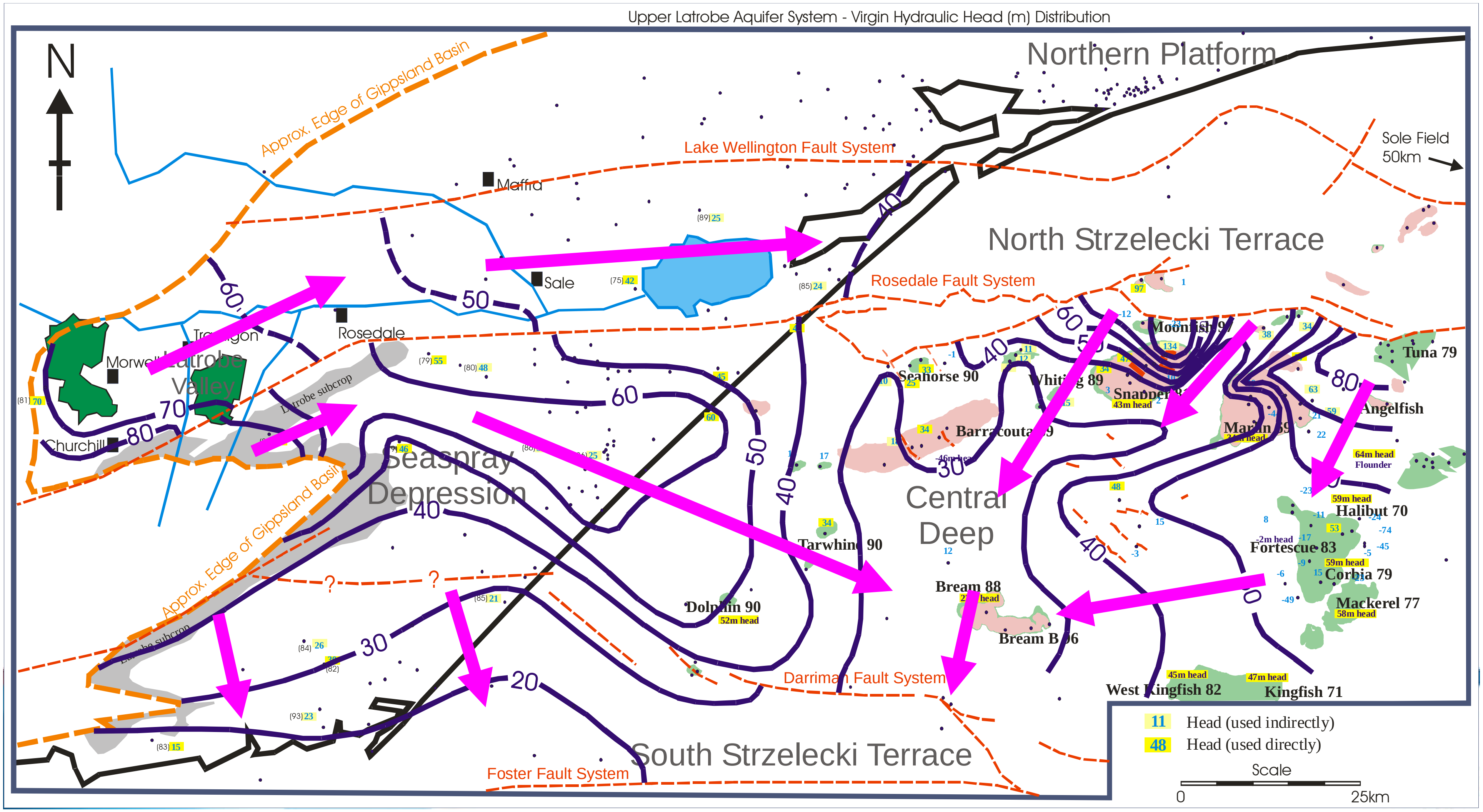
~50 Mt/yr for 30 years = 1500 Mt total

- **Do we have anything comparable to use as an analogue of how the basin framework and contained fluids will respond?**

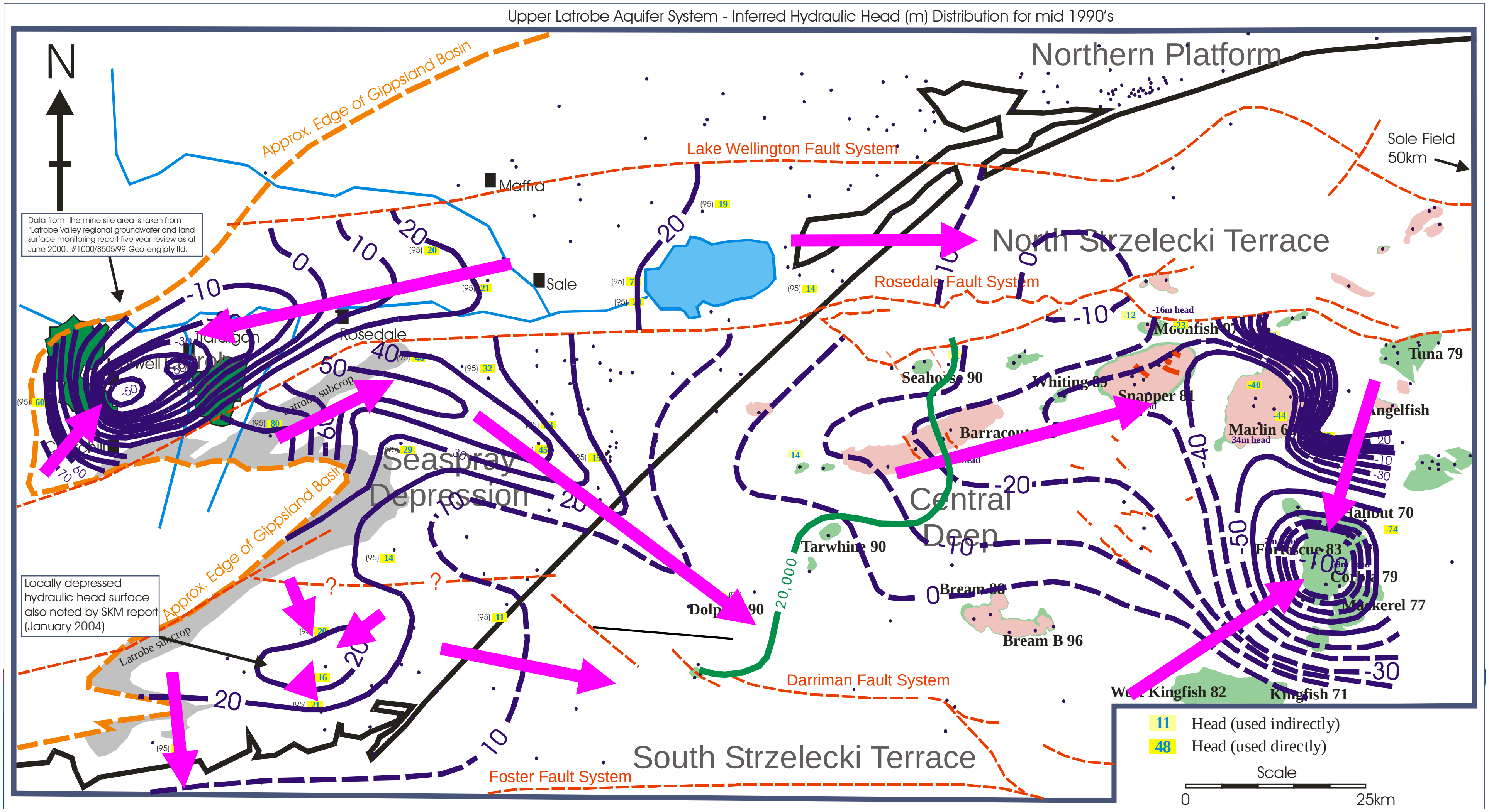


30,000 ML/yr
Area
Km²
Northern Platform
Wellington Fault System
Sole Field
50km
Maffra
North Strzelecki Terrace
Study Area
Sale
Rosedale Fault System
80,000 ML/yr
Rosedale
Traralg
Latrobe
Valley
Latrobe subcrop
Seahorse 90
Barracouta 69
Churchill
Seaspray
Depressio
Local Effects
Gippsland Basin
Central
Deep
Tarwhine 90
Dolphin 90
Bream B 96
Corbia 79
Mackerel 77
10,000 ML/yr
Darriman Fault System
West Kingfish 82
Kingfish 71
CCS
Scale
uth Strzelecki Terrace
CSIRO
100,000 ML/yr
CO2CRC

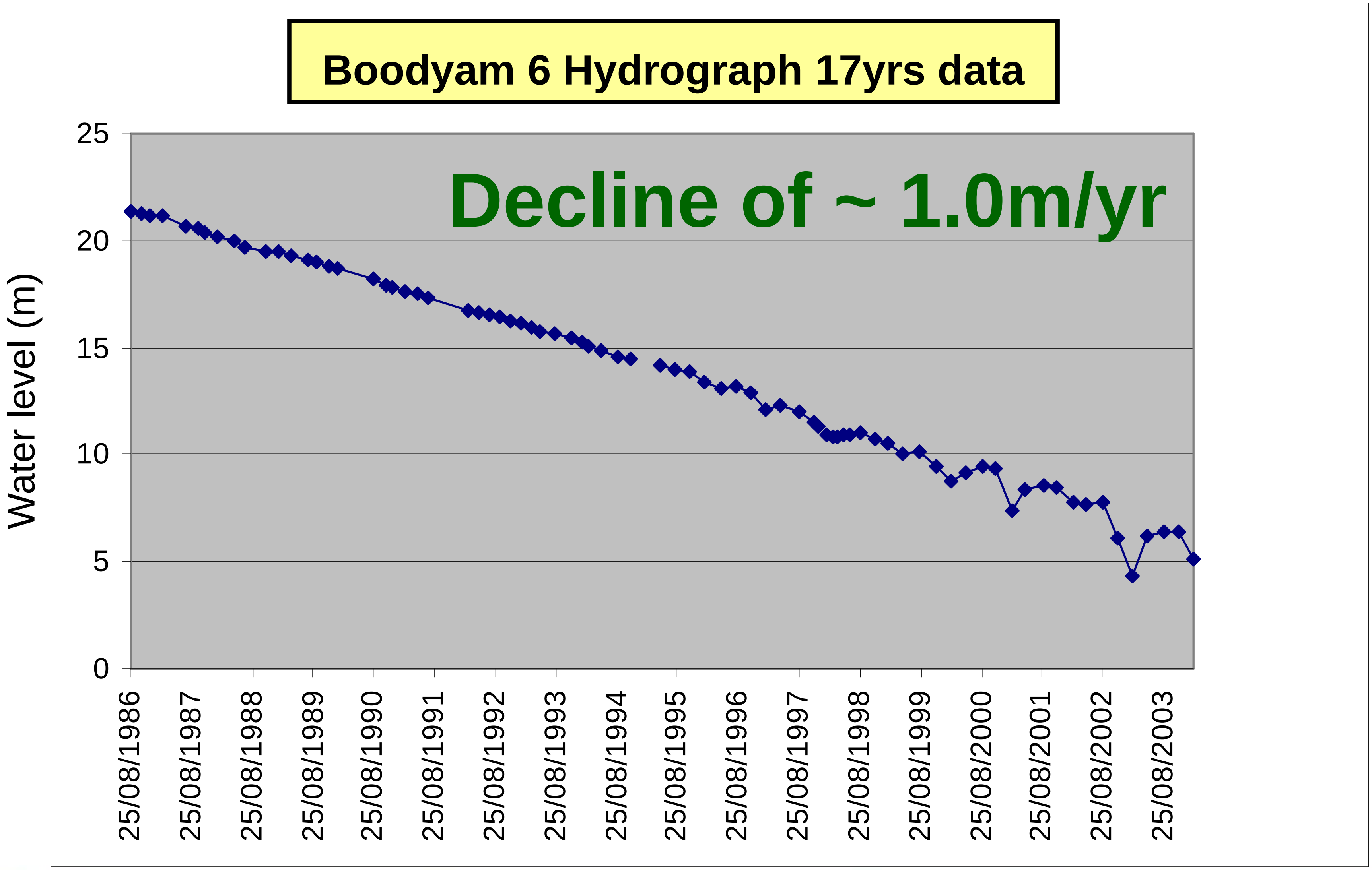
Virgin Hydraulic Head (mSS)



Mid 1990's Hydraulic Head (mSS)

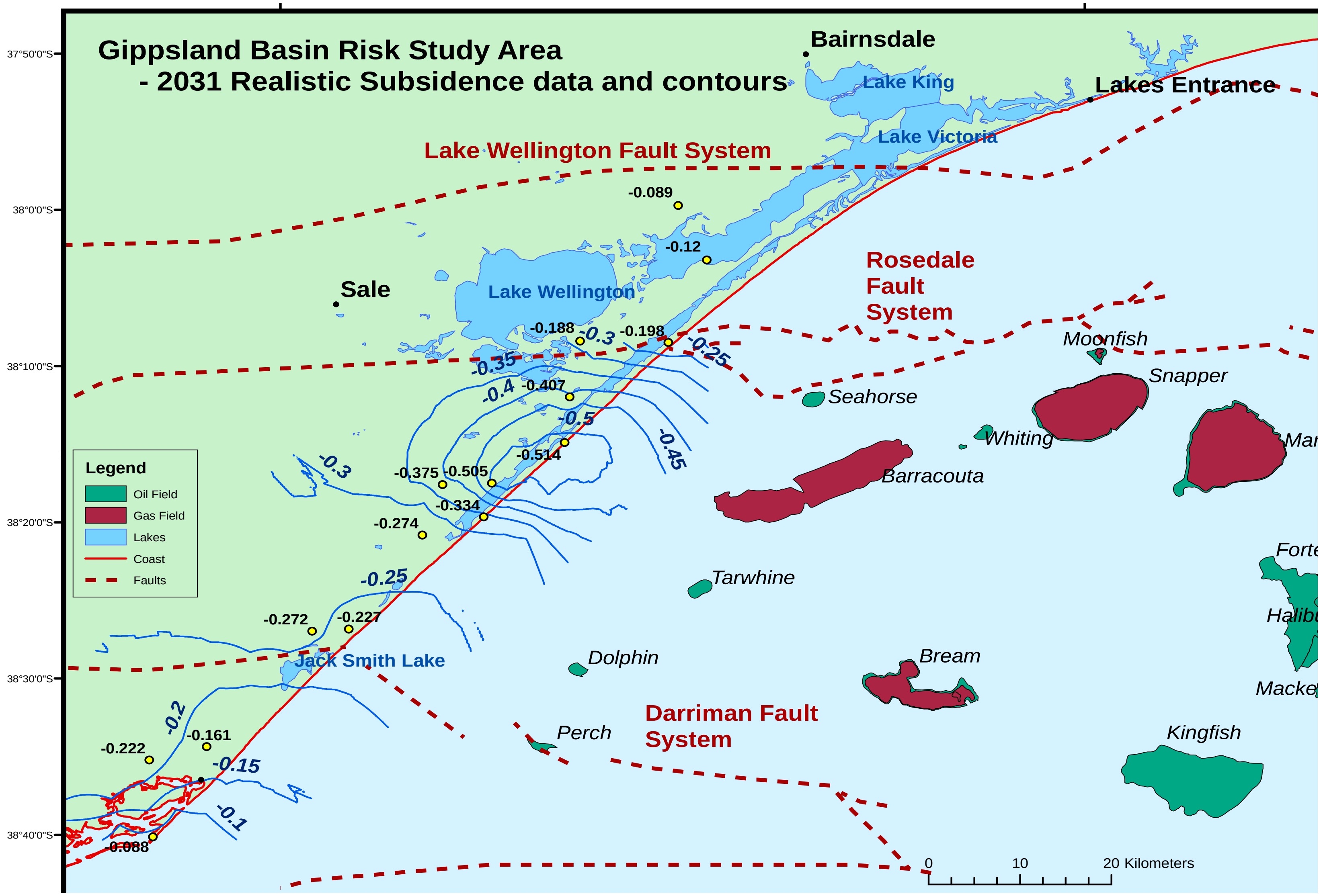


Gippsland Basin Victoria



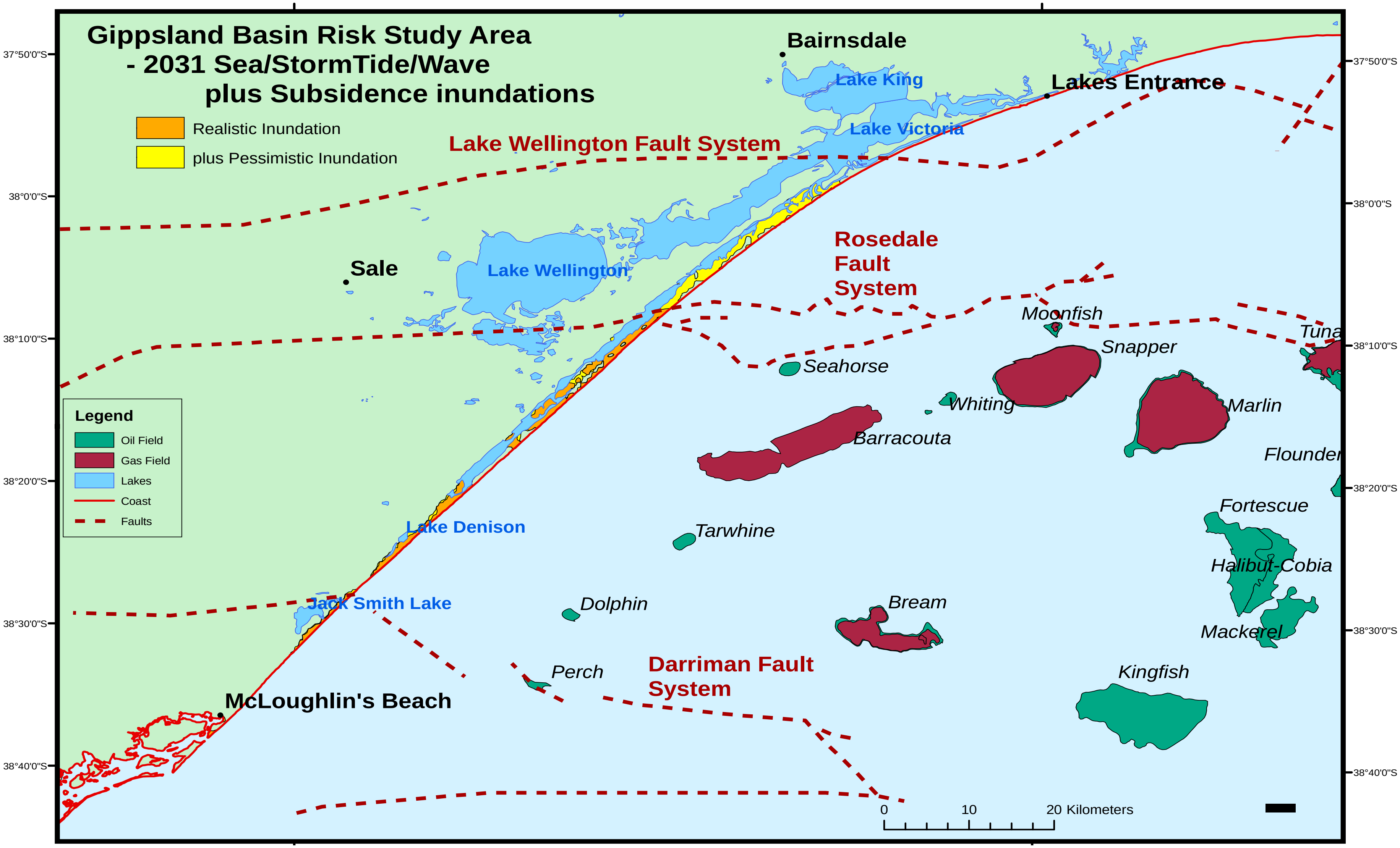
Subsidence

Predicted realistic subsidence year 2031



Inundation risk maps

Year 2031

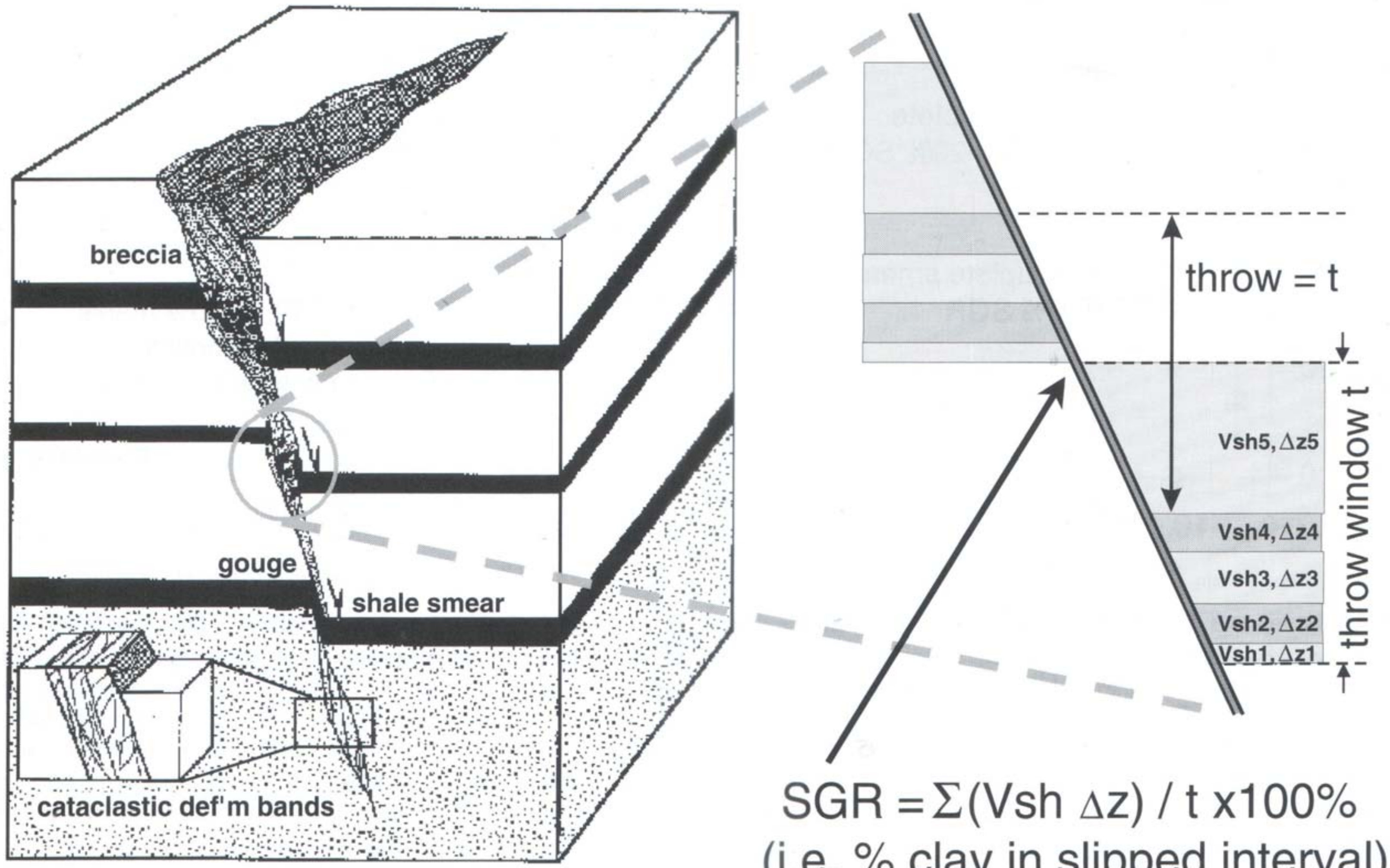


Potential vertical leakage

- **Leaking Wells**
- **Leaking Top Seal**
- **Leaking Faults**
- **Reactivated Leaking Faults**

Can we understand the Fluxes?

- **Some examples of our research on Fault Leakage**

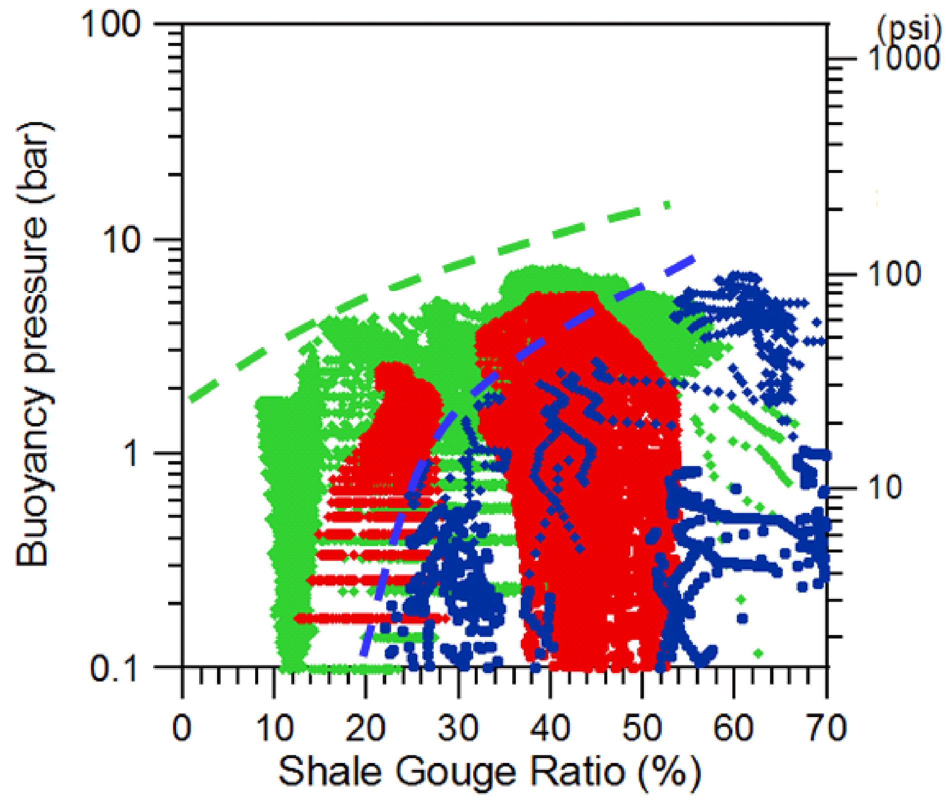


$$SGR = \Sigma(Vsh\ \Delta z) / t \times 100\%$$

(i.e. % clay in slipped interval)

SGR-Buoyancy Pressure Calibration

Calibrating Seal Capacity vs SGR

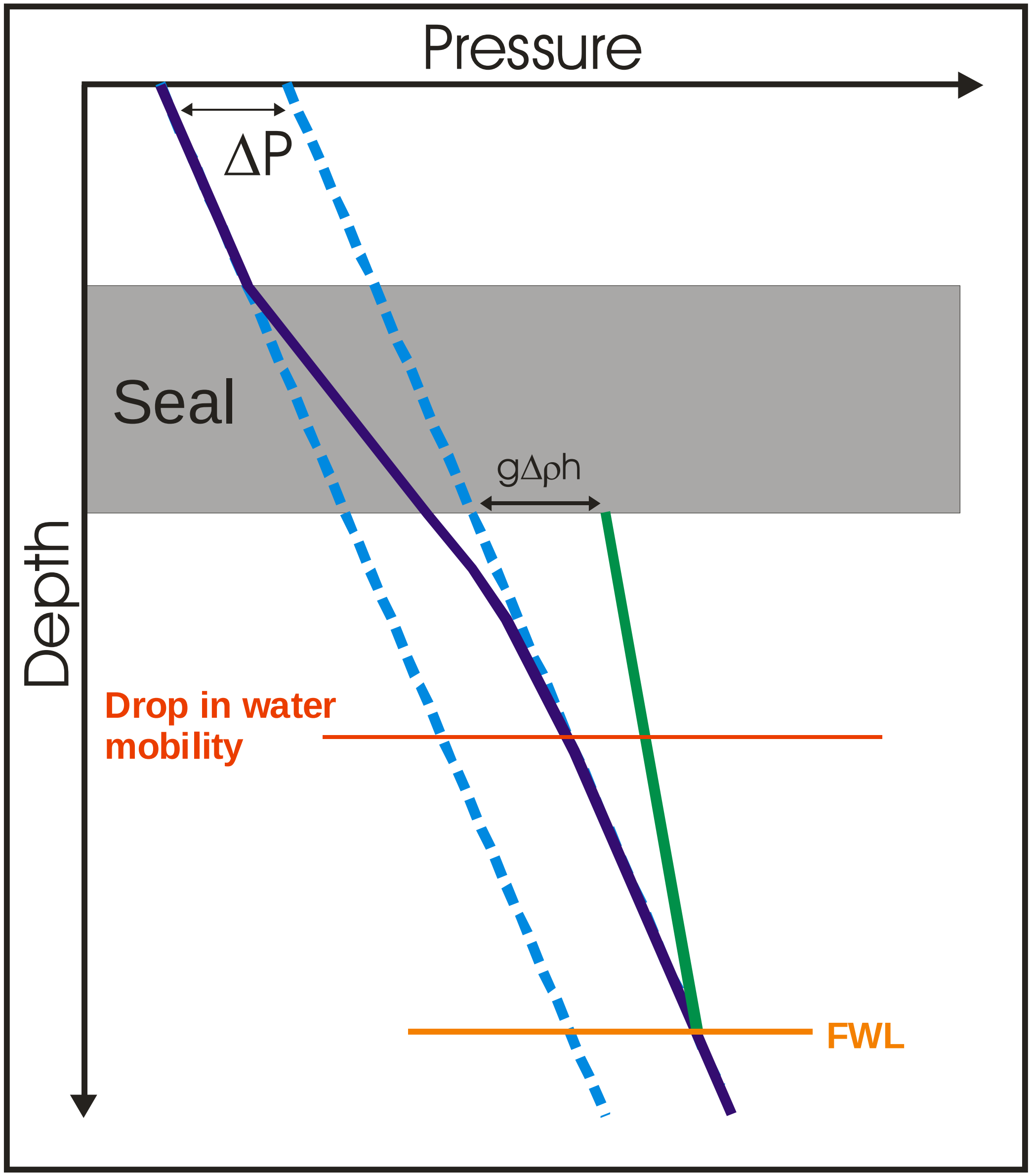


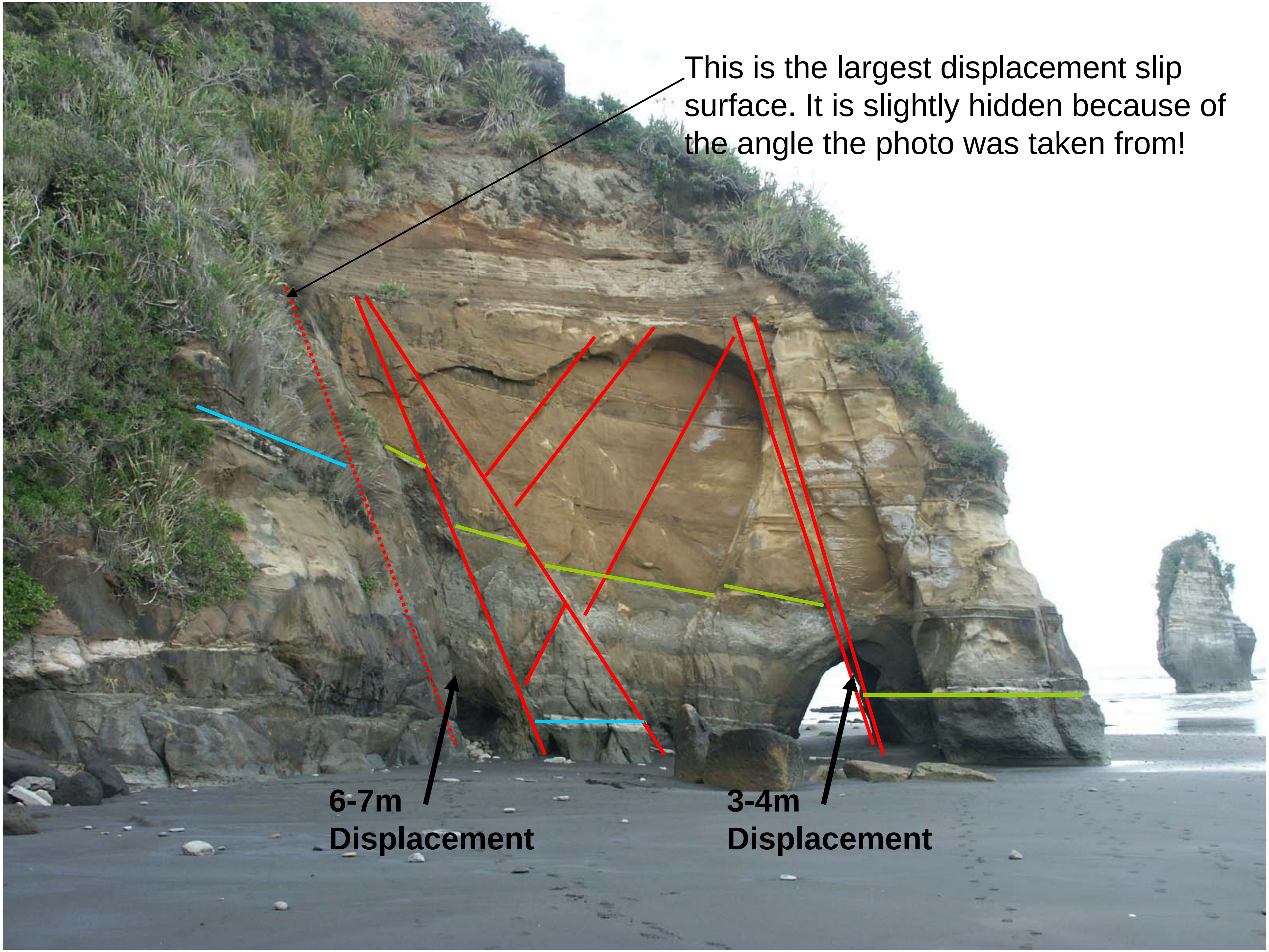
Seal failure envelopes at stable hydrocarbon traps

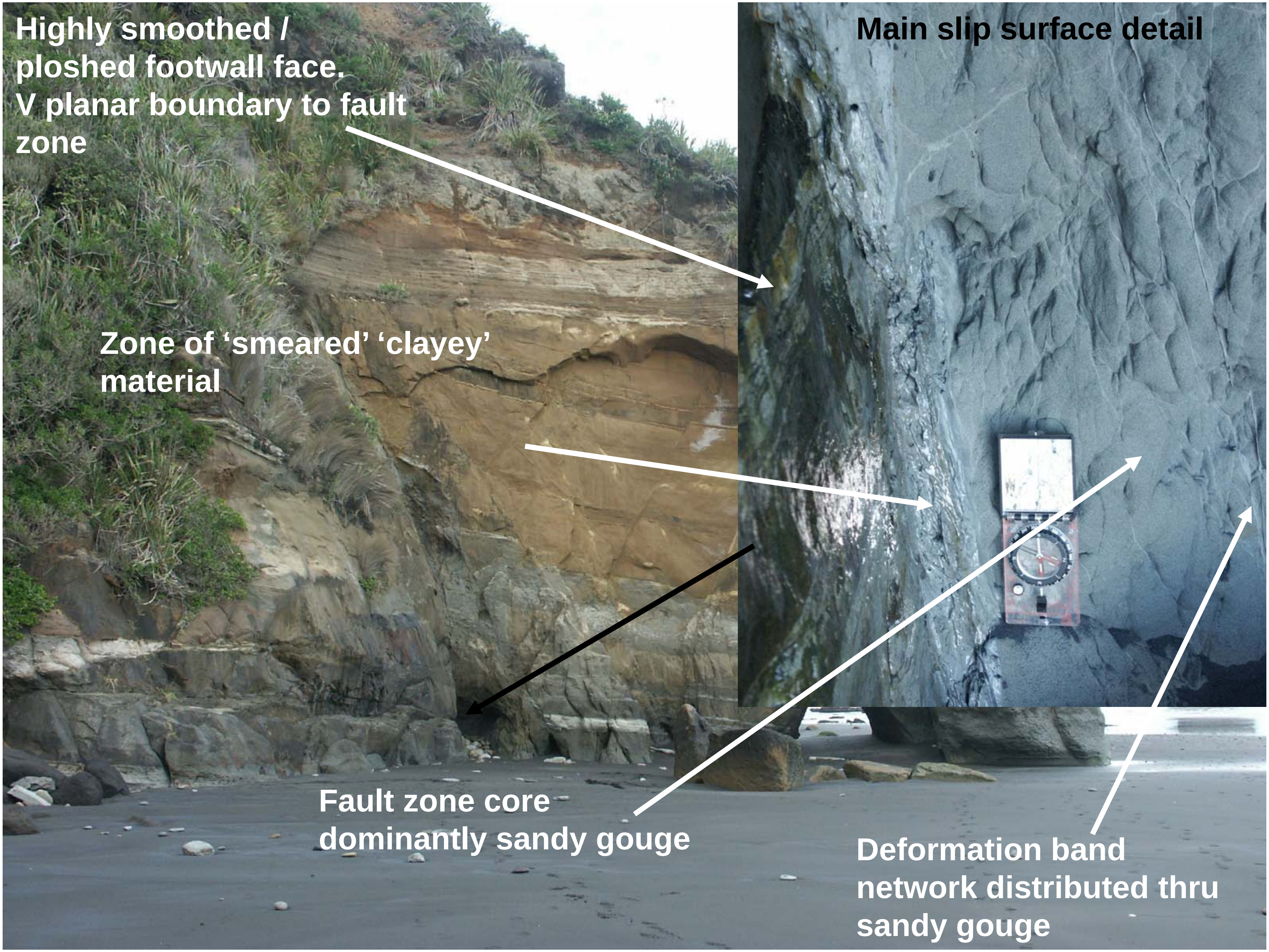
CSIRO

CO2CRC

$$C_{Tp} = \Delta\rho g H - \Delta P$$

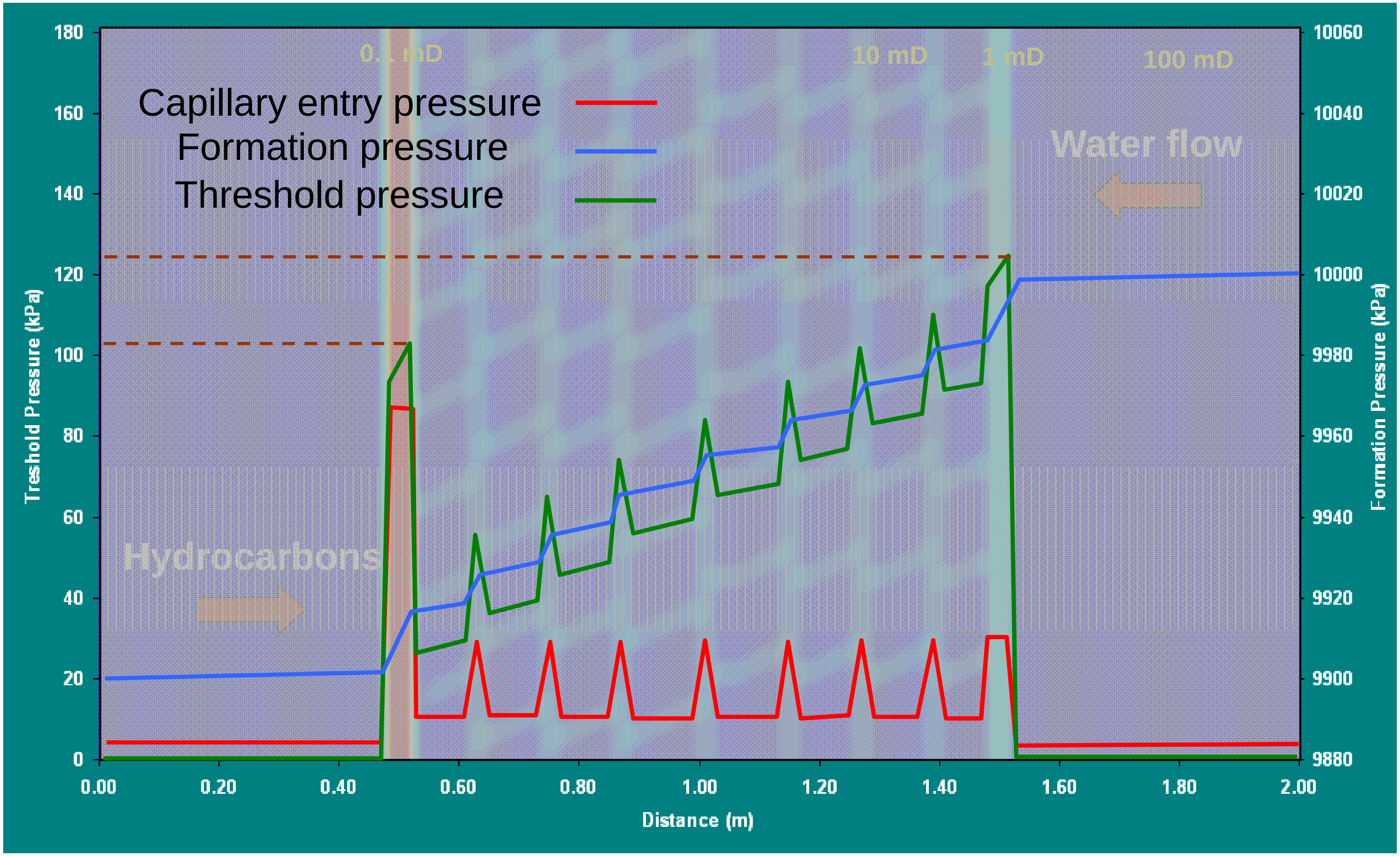



This is the largest displacement slip surface. It is slightly hidden because of the angle the photo was taken from!
6-7m Displacement
3-4m Displacement



Highly smoothed / ploshed footwall face. V planar boundary to fault zone
Main slip surface detail
Zone of 'smeared' 'clayey' material
Fault zone core dominantly sandy gouge
Deformation band network distributed thru sandy gouge

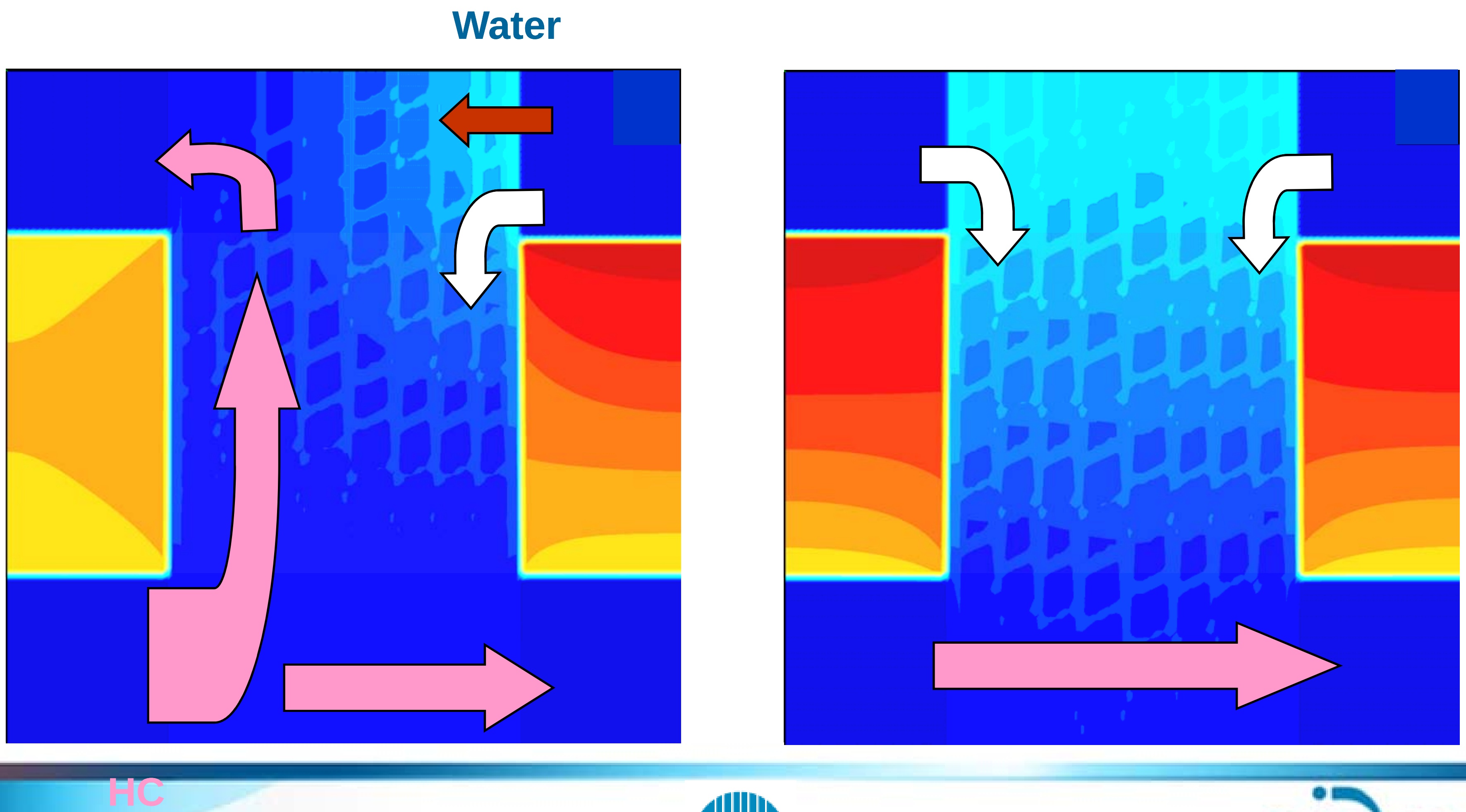
Fault zone heterogeneity



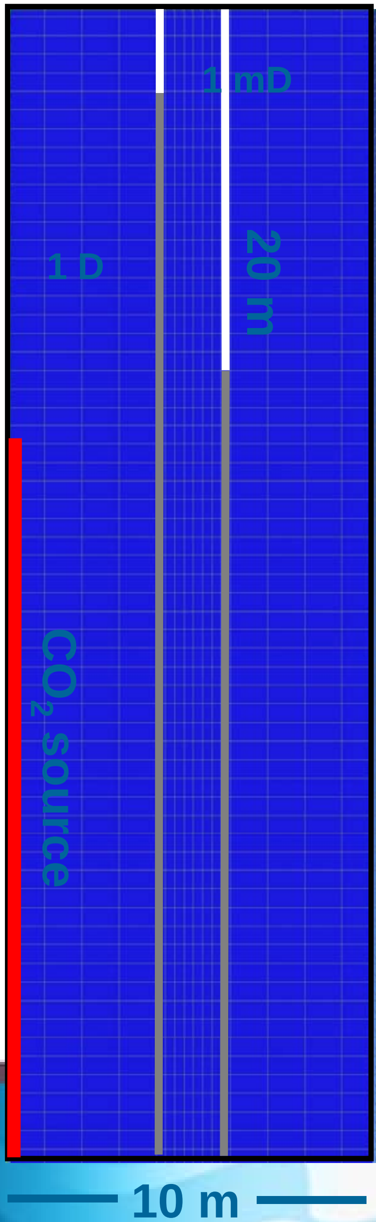
CSIRO

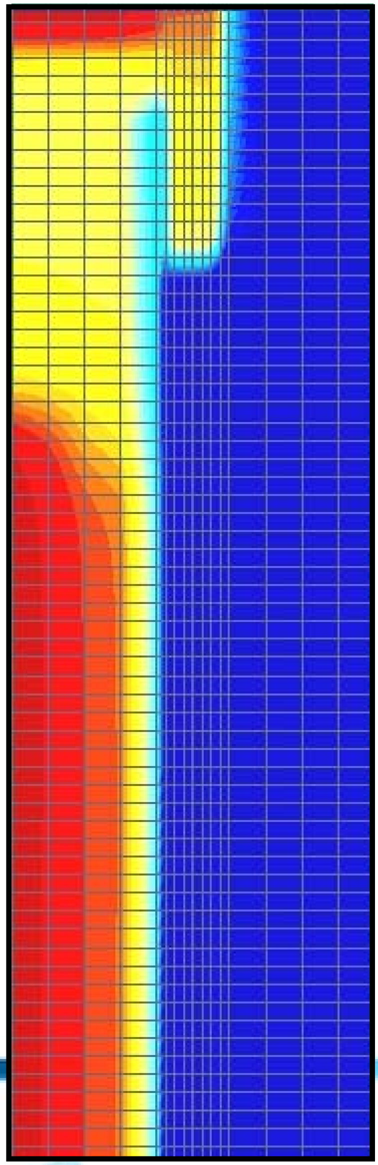
CO2CRC

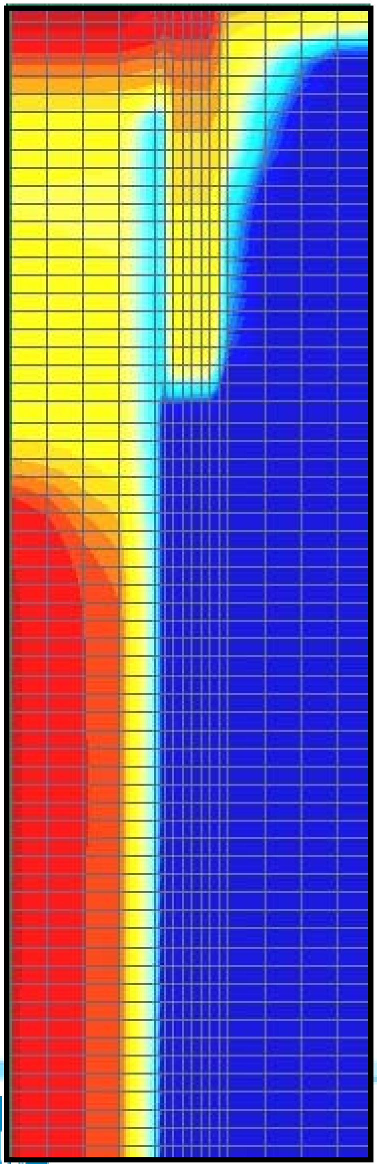
Vertical versus lateral fault leakage

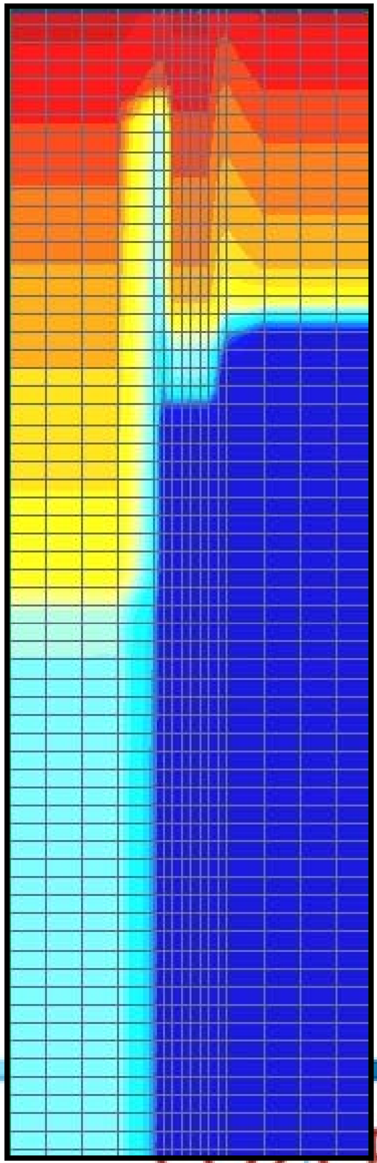


Two-phase flow modelling





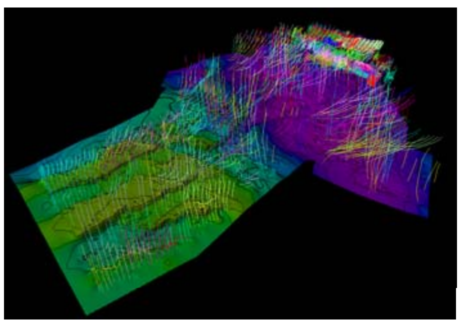


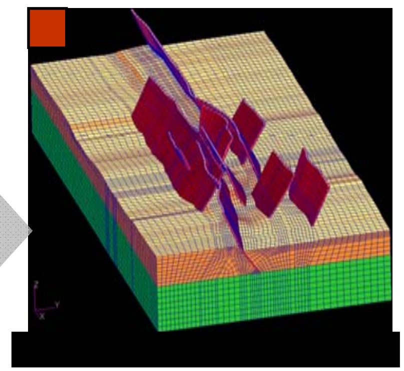


Fault Zone Architecture and Fault Reactivation Risk

Objective: to model deformation and fluid flow and constrain the behaviour of fault structures and assess structural permeability variation and trap integrity

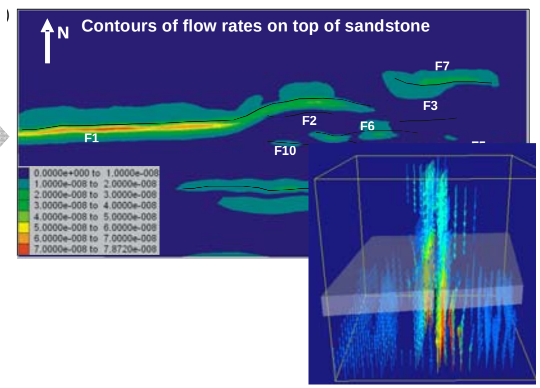
Strati. & structural interp.



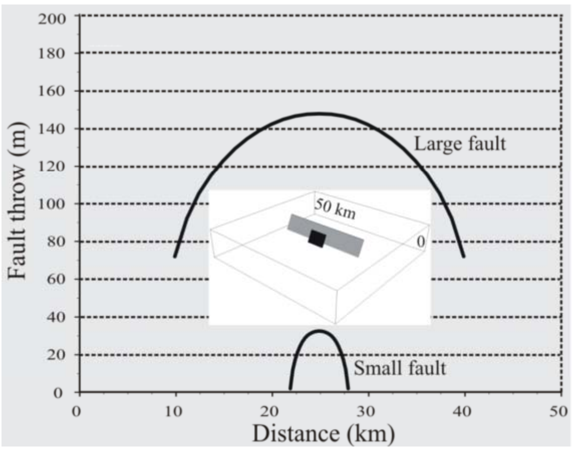


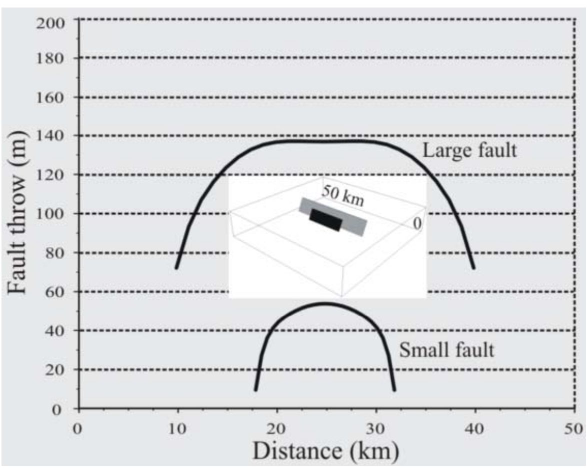
Model strategy & development

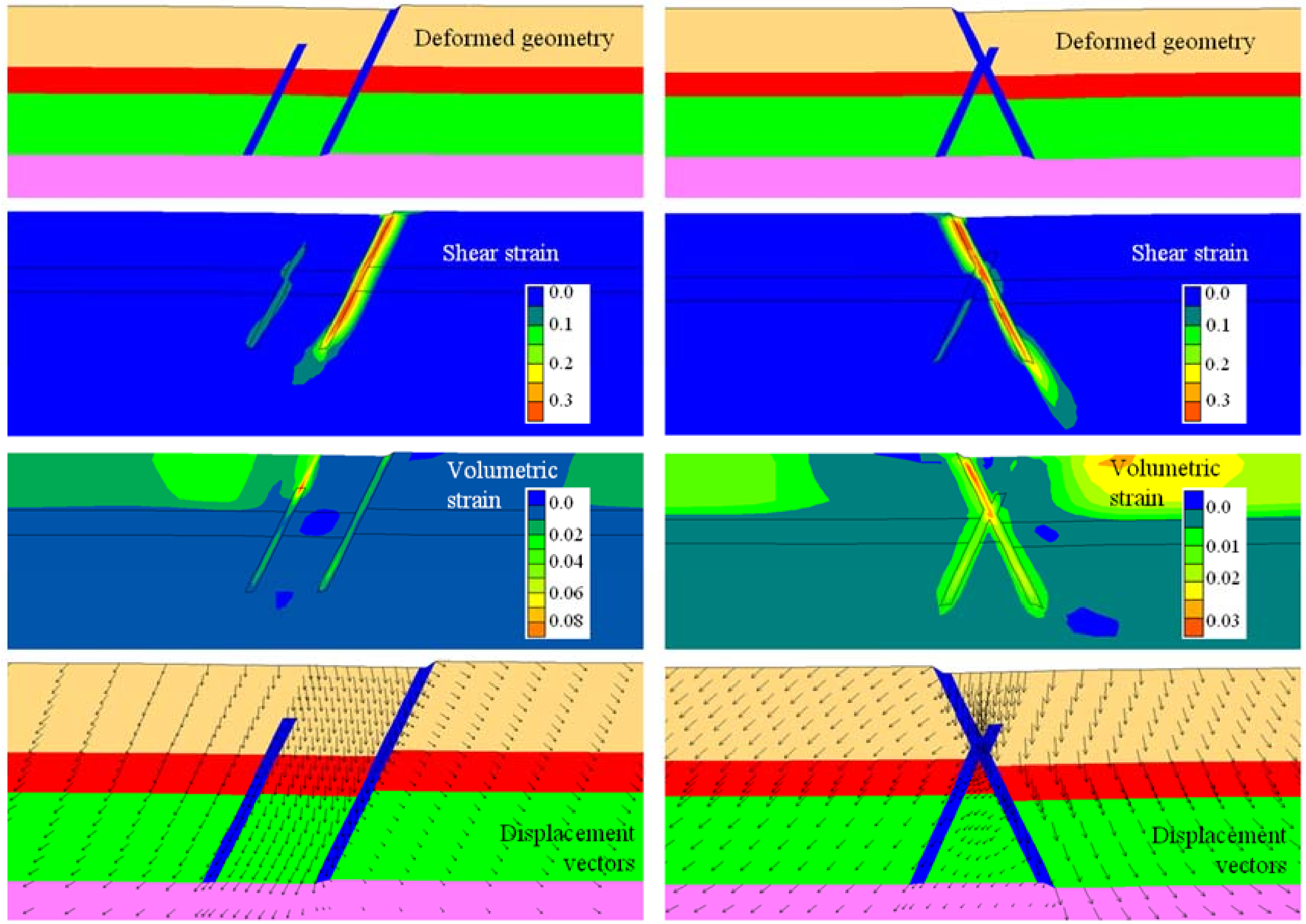
Strain-stress & struct. perm. distribution



Key control – fault length



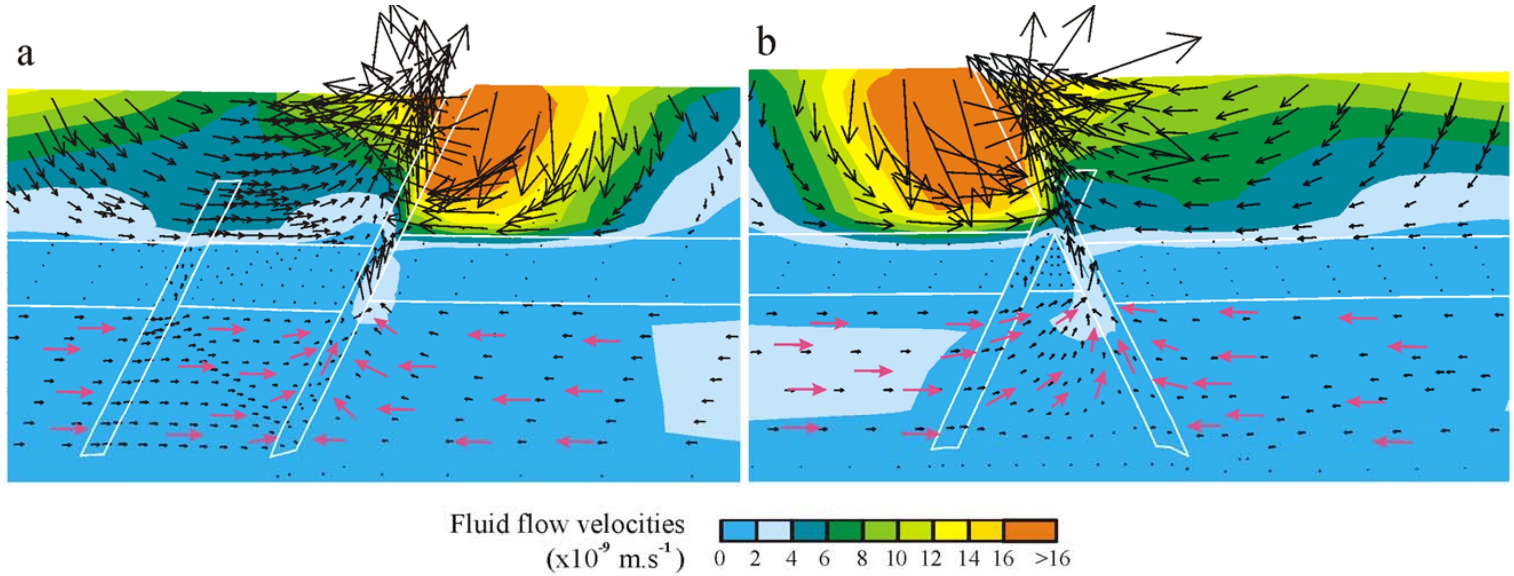




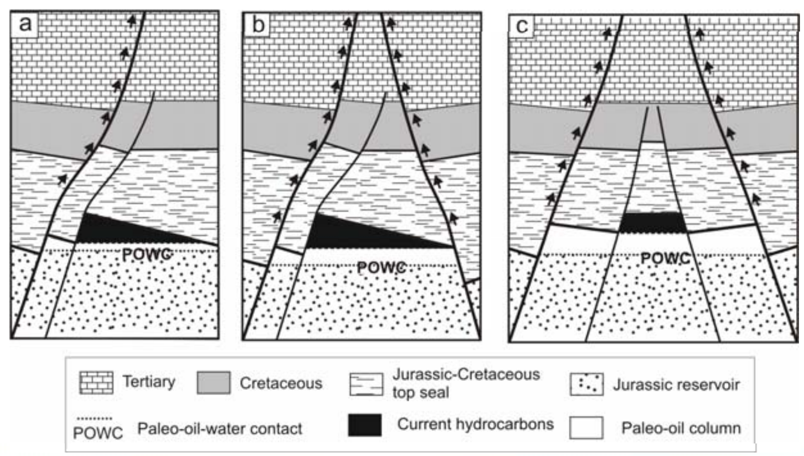
CSIRO

CO2CRC

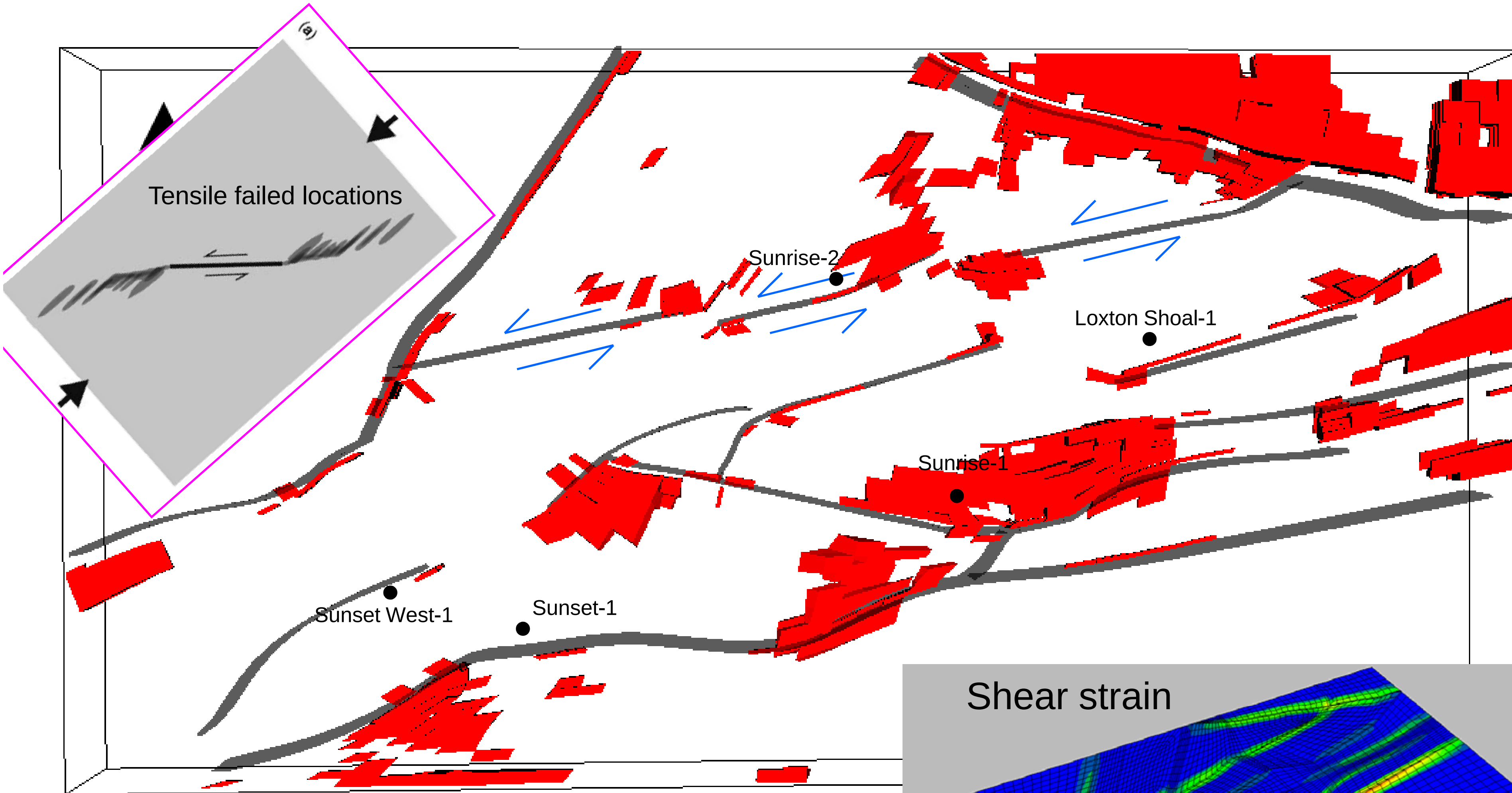
Key control – large faults and fluid flow

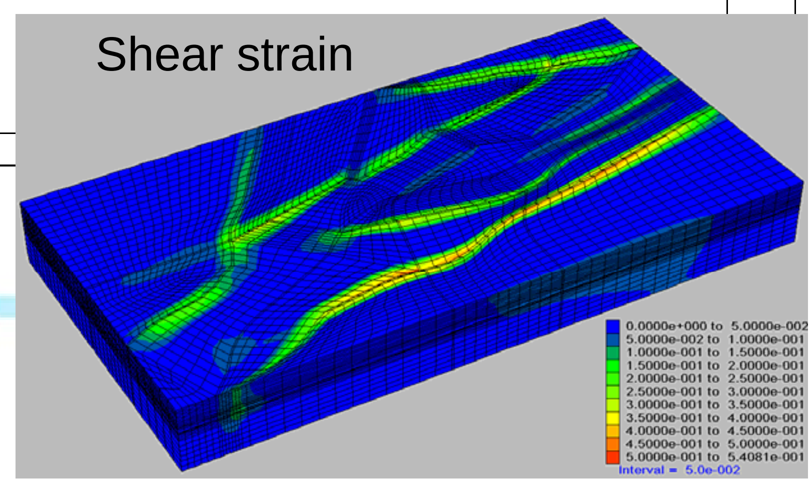


Consistent with and support a hydrocarbon preservation model for the Timor Sea: hydrocarbons tend to be preserved in the traps bound by smaller faults with low post-rift displacements, commonly overlapped by larger high displacement faults



Complex fault population – Sunrise Field





- Strain distribution and partitioning
- Fluid flow patterns
- Tensile failure distributions

Potential Impacts on Groundwater

We are directing R&D to reduce uncertainty in characterisation of groundwater contamination risks associated with carbon storage, including:

- **Shifting the saltwater – freshwater interface**
- **Ground heave**
- **Top Seal leakage**
- **Fault Seal leakage – Across Fault**
- **Fault Seal Leakage – Up Fault**
- **Fault Reactivation – Transient flux**

CO2CRC Participants

Supporting participants: Australian Greenhouse Office | Australian National University |
| CANSYD | Meiji University | The Process Group | University of Queensland |

Australian Government

Geoscience Australia

Potential Impacts on Ground Water

An Australian Perspective

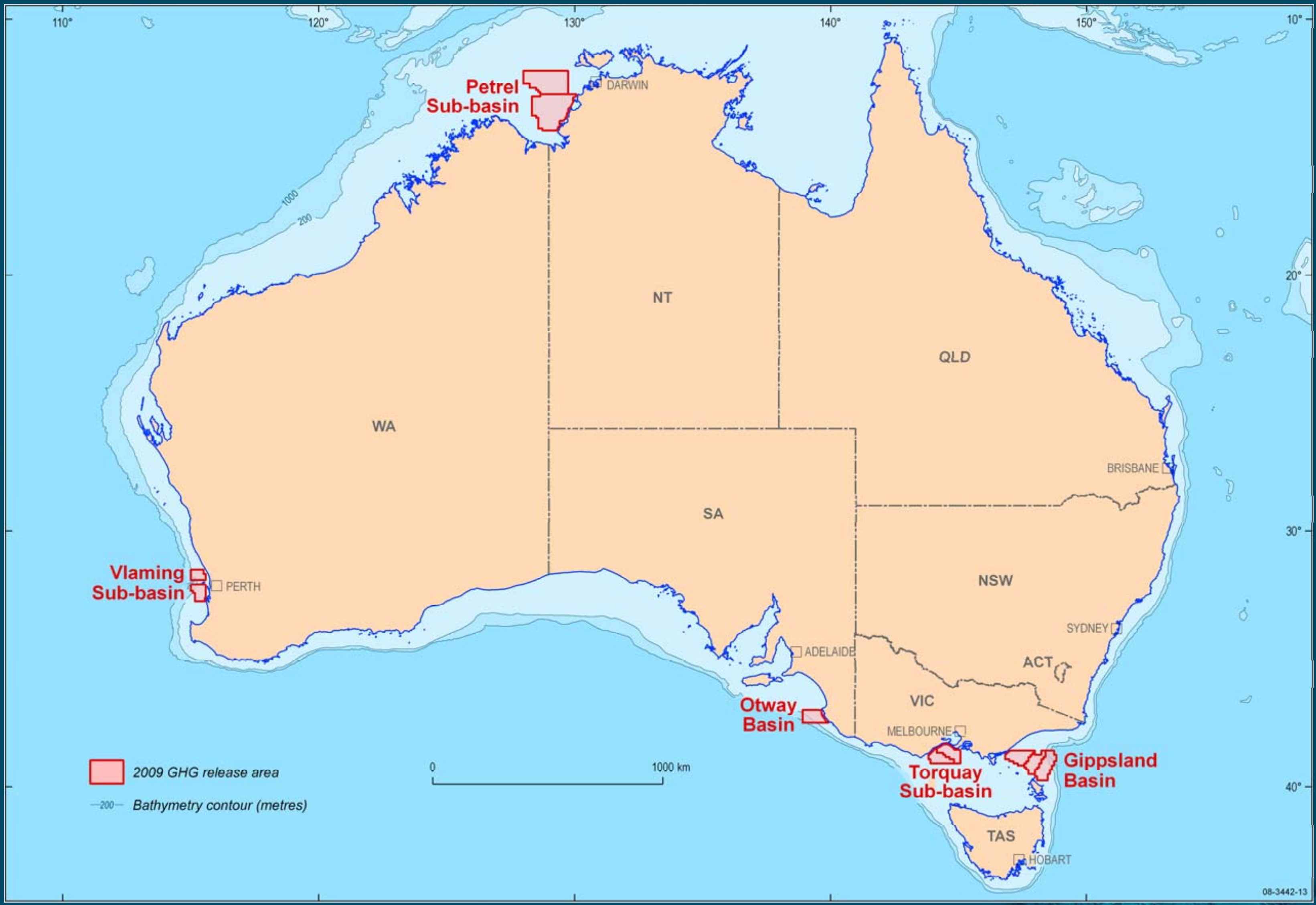
Andrew Feitz, Tim Ransley

Greg Leamon

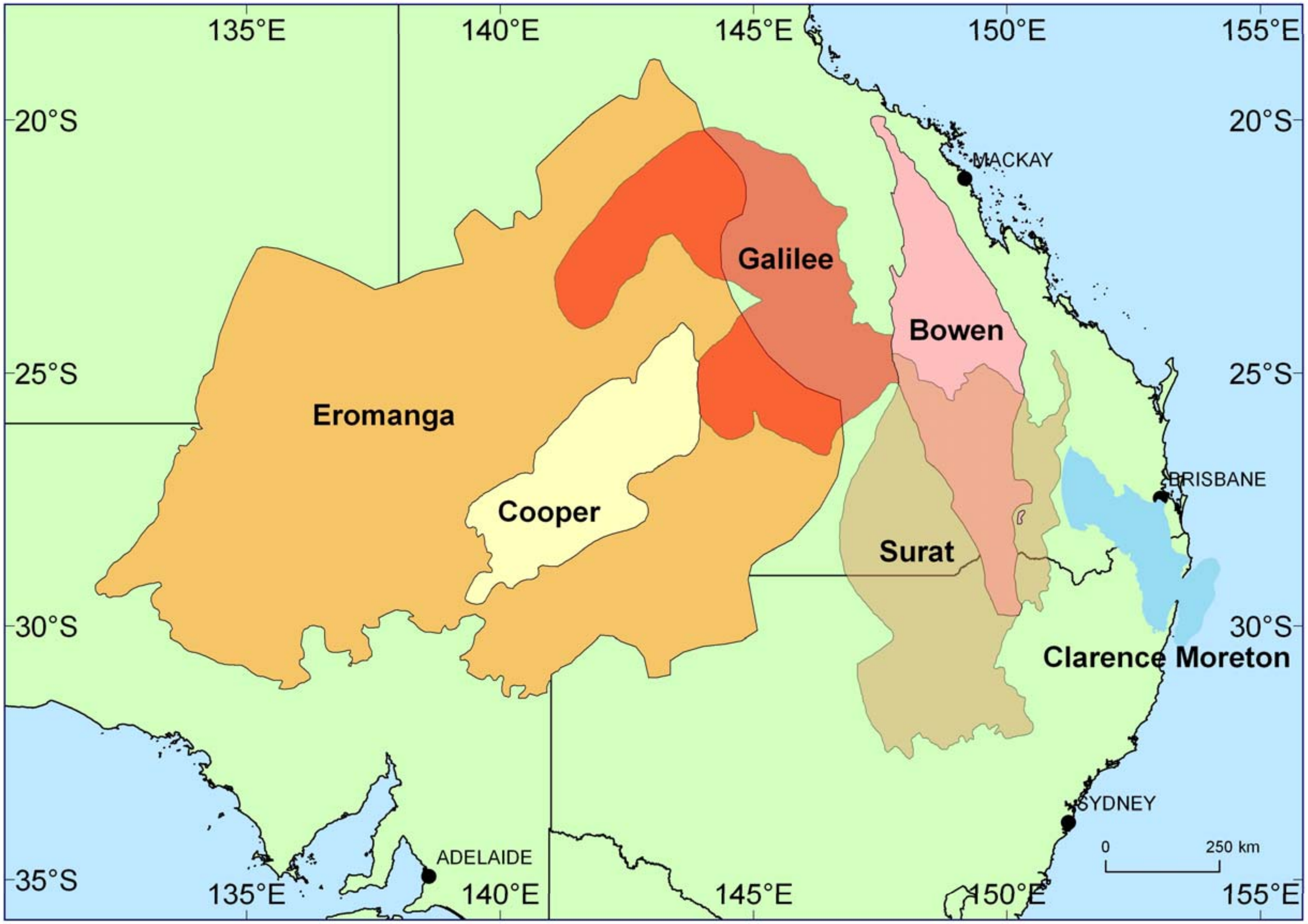
Geoscience Australia

Geoscience Australia - Canberra

2009 offshore release areas for GHG storage

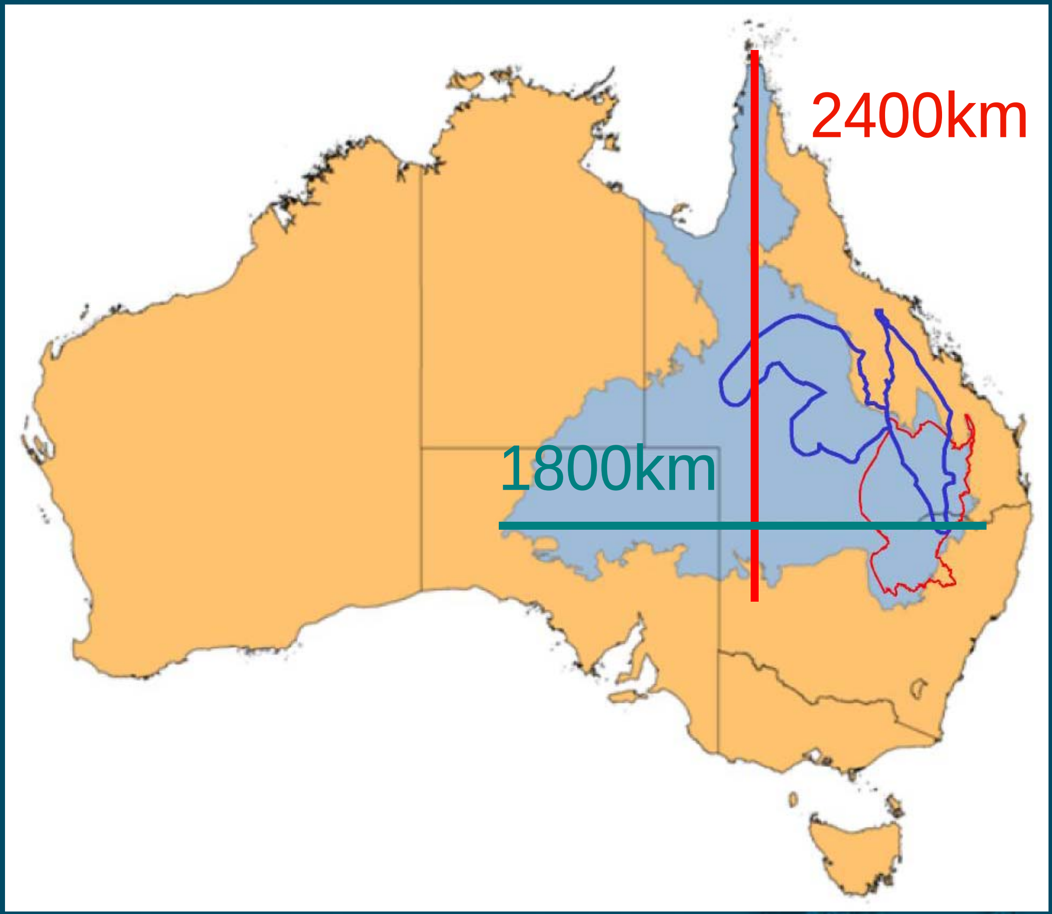


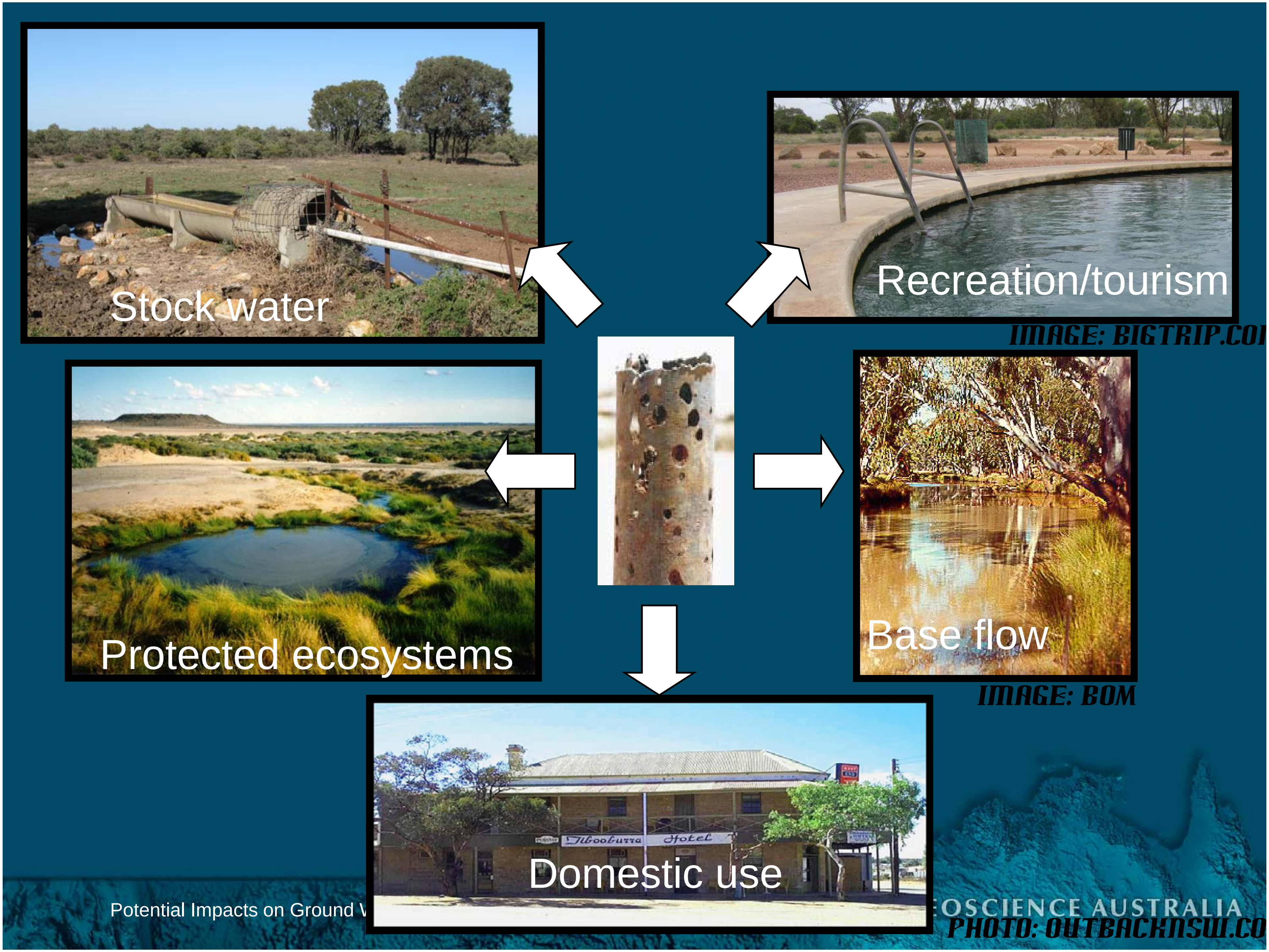
Basins for onshore CO_2 storage



Great Artesian Basin

- 1.7 million km^2
- 100 – 3000m deep
- 30 - 100°C
- 65,000,000 GL (100,000 Sydney harbours)
- Extraction 570 GL/yr
- Mostly freshwater
- 0.5 – 2.5 m/yr
- Value $4+ billion/yr

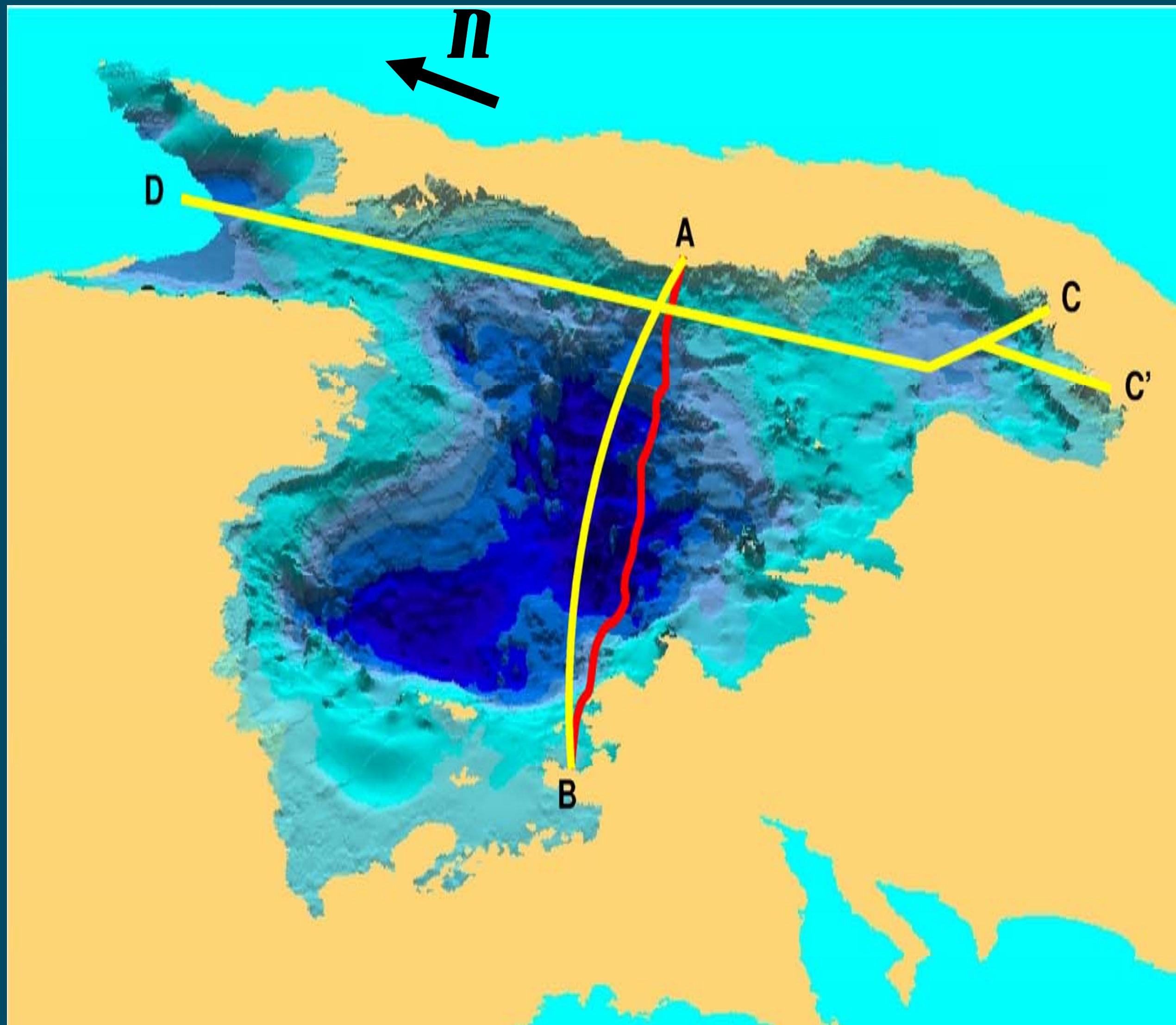



Stock water
Recreation/tourism
IMAGE: BIGTRIP.CO
Protected ecosystems
Base flow
IMAGE: BOM
Tibooburra Hotel
Domestic use
Potential Impacts on Ground V
EOSCIENCE AUSTRALIA
PHOTO: OUTBACKNSW.CO

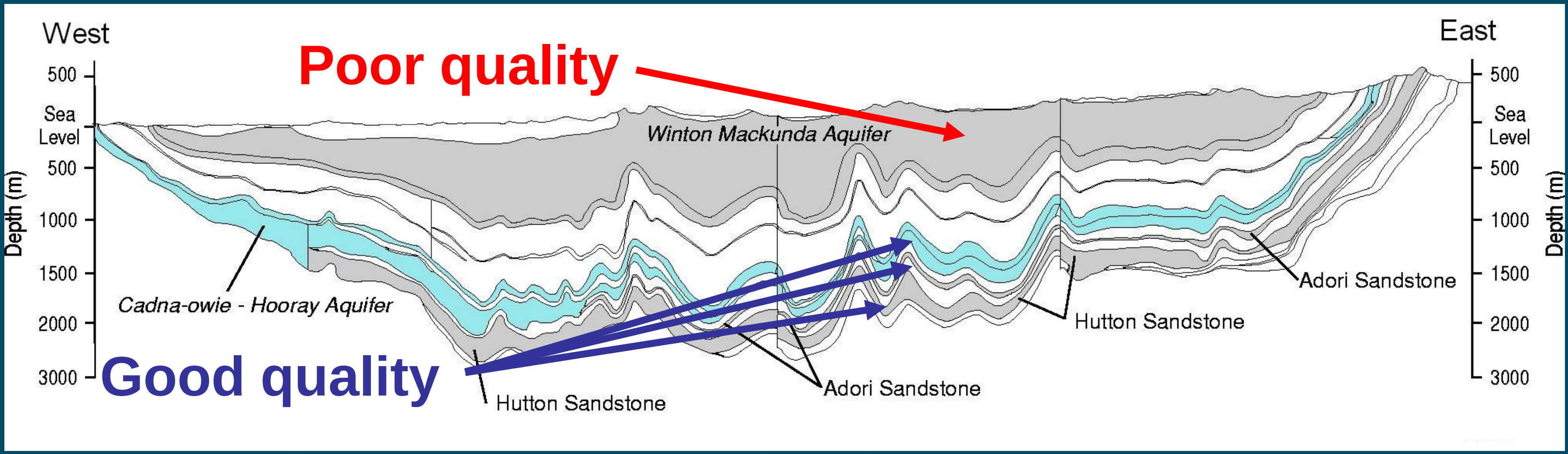
Natural analogues

- Properties of groundwater chemistry in high CO_2 environments
- Regional variations in water quality
- Environmental impacts, e.g. coal seam gas
- Well bore integrity

Great Artesian Basin

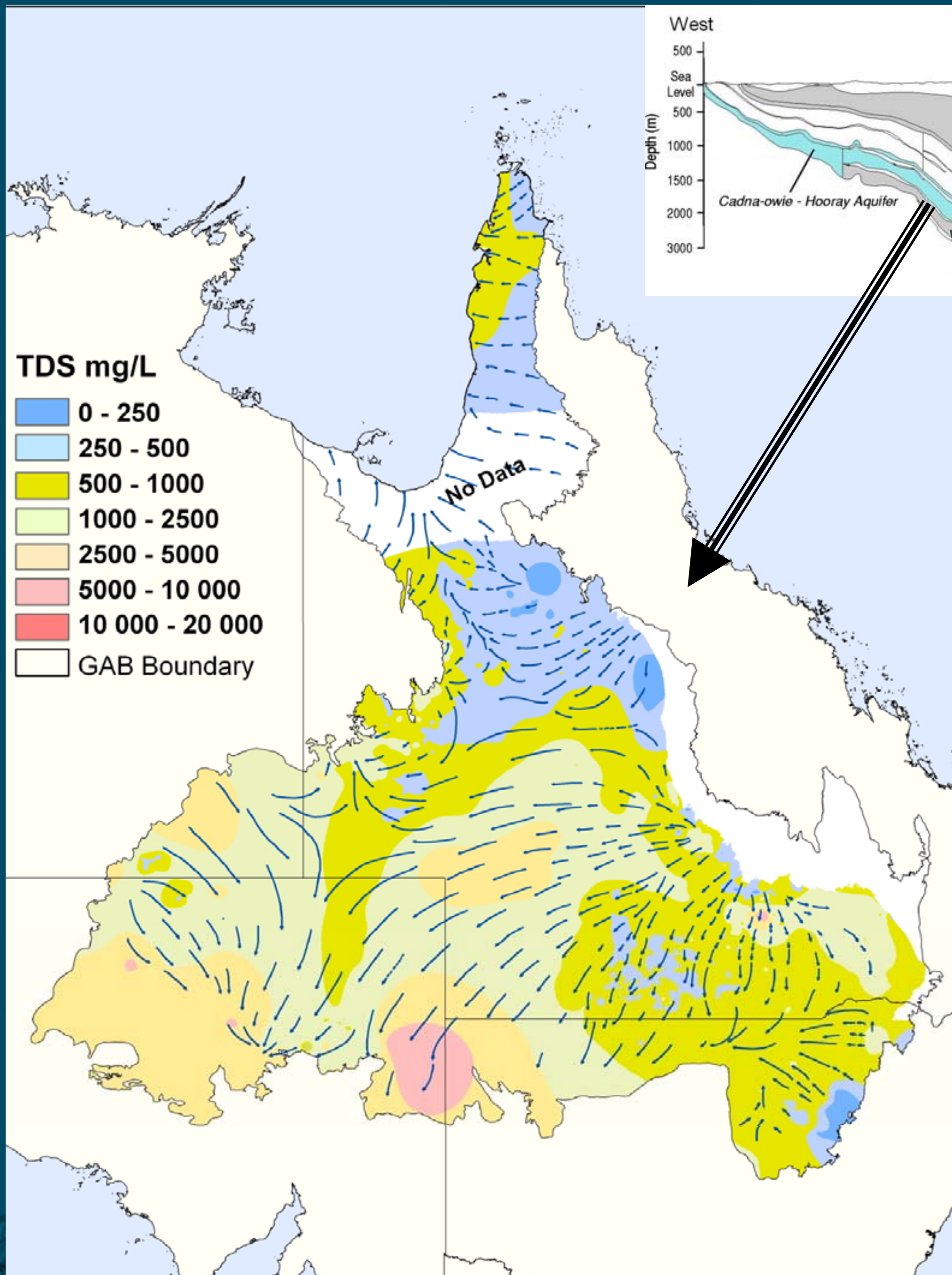


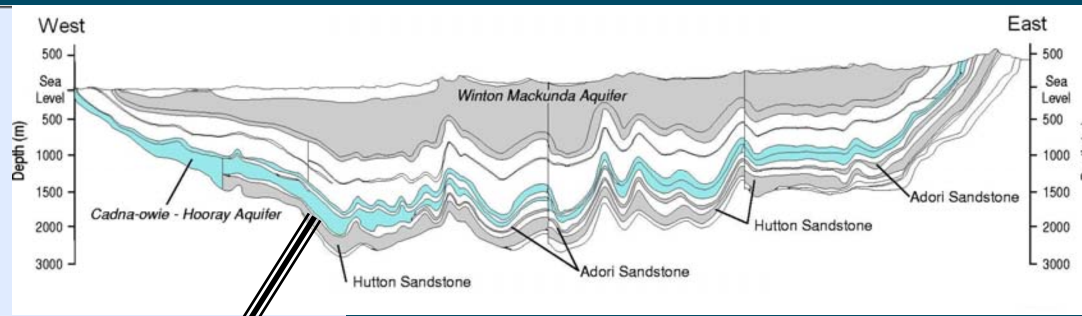
Great Artesian Basin cross-section



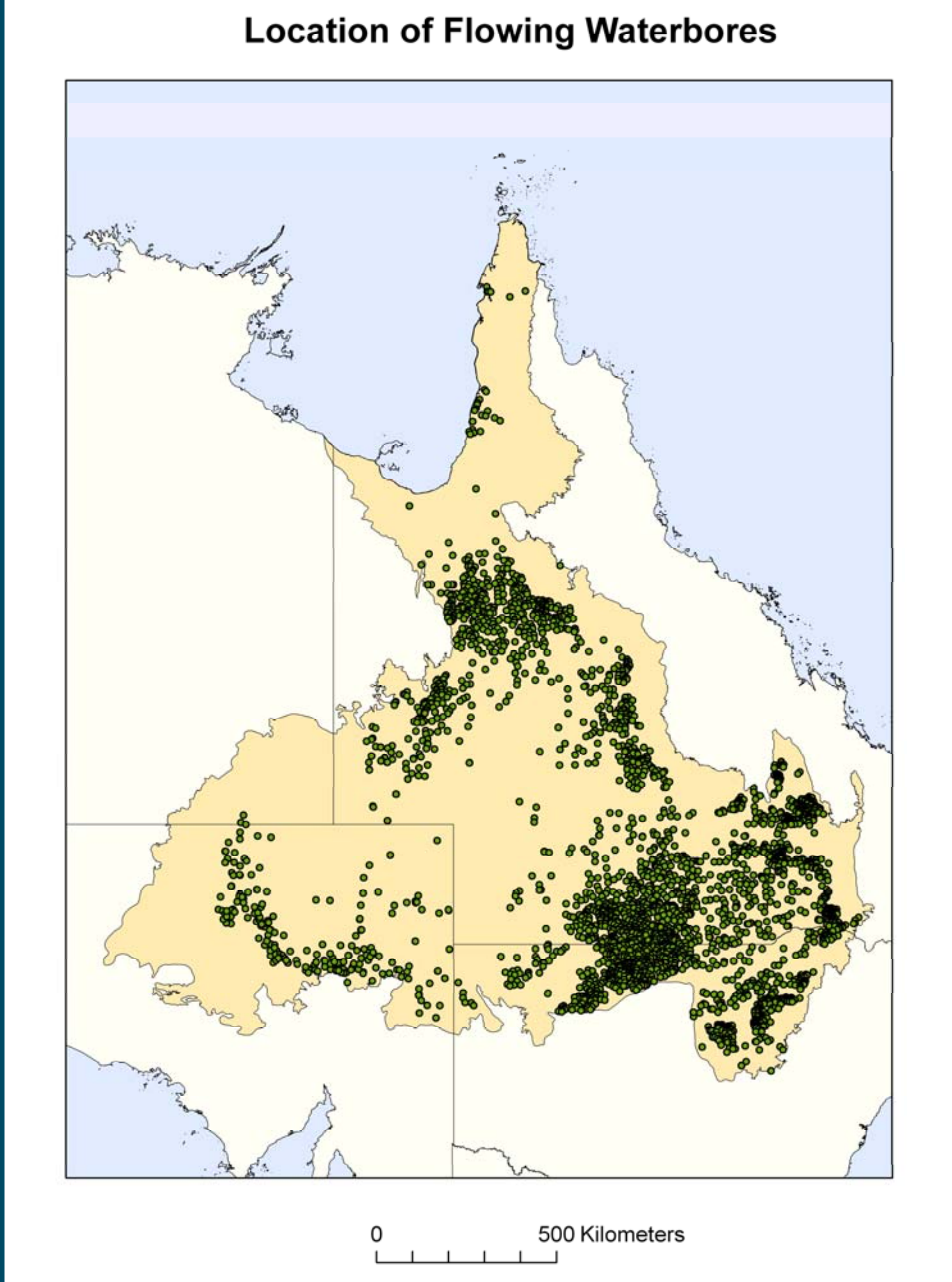
Poorest quality aquifers are typically the shallowest

Cadna-owie Hooray Aquifer



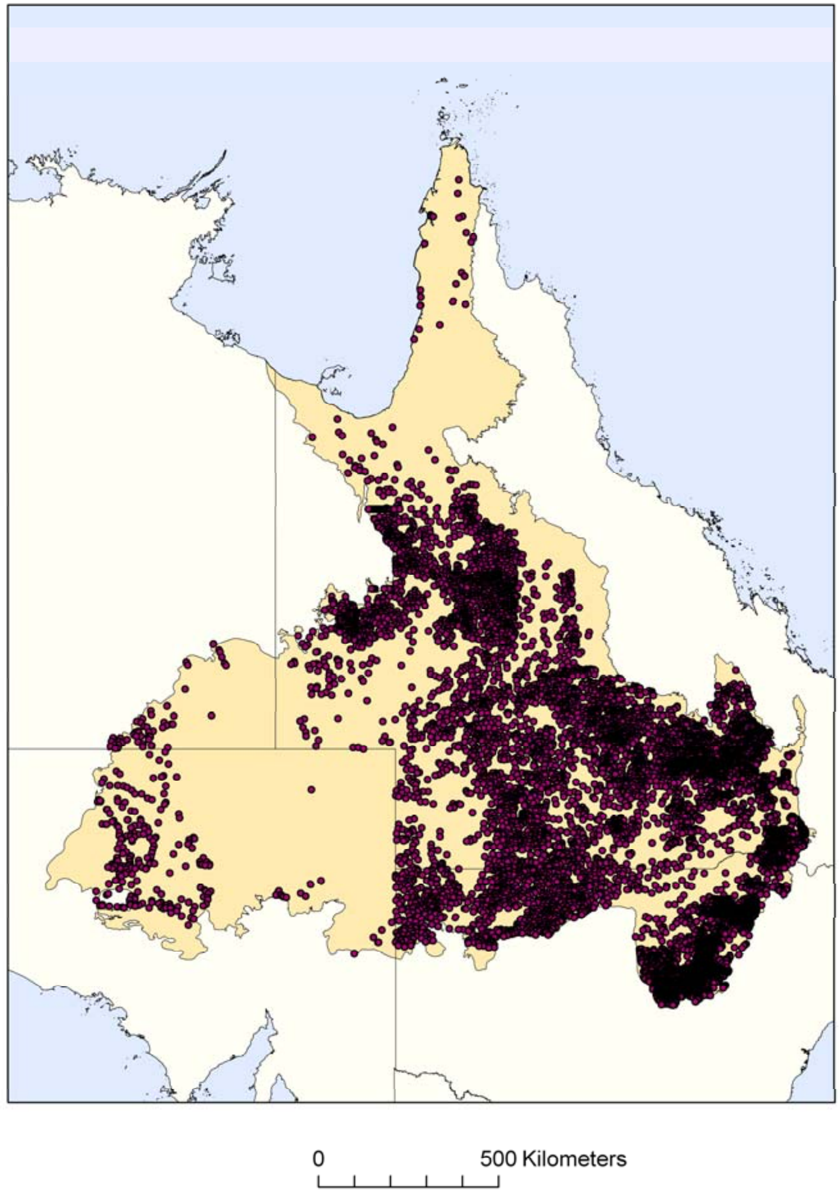


3,100 artesian wells



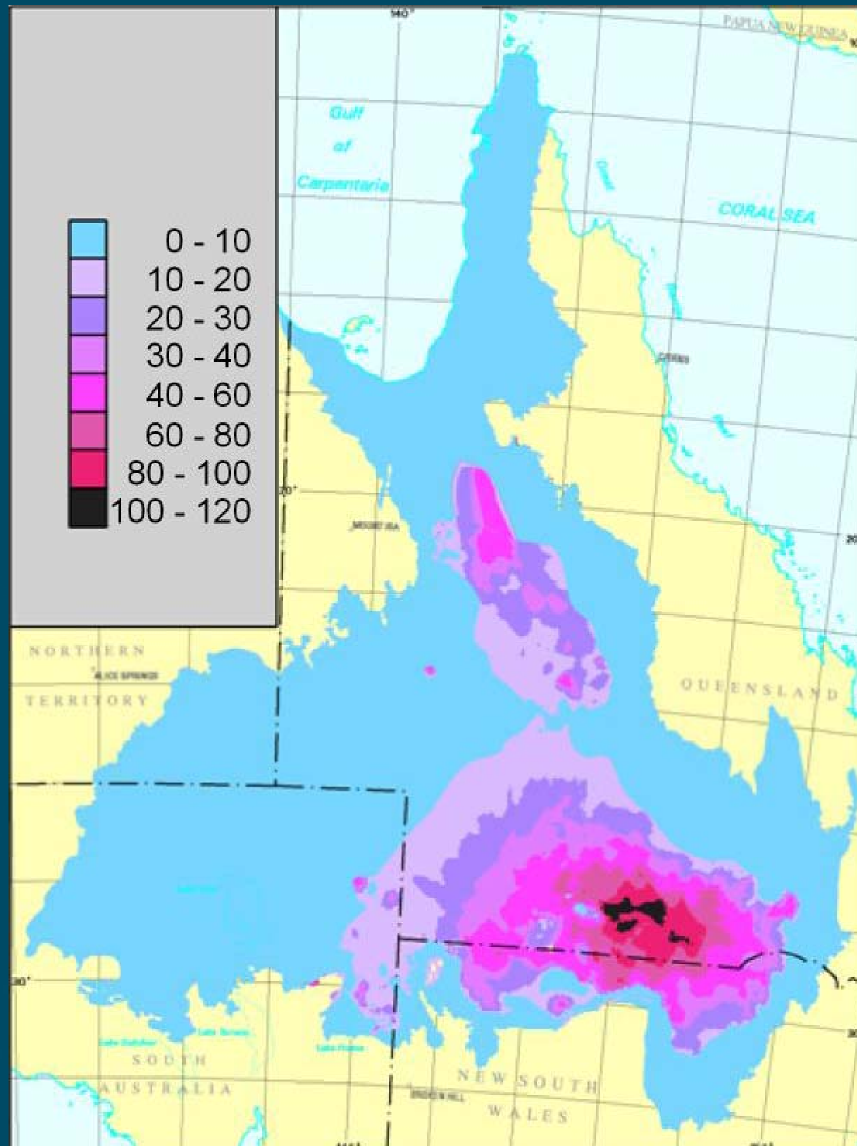
35,000 sub-artesian wells

Location of Non-Flowing Waterbores

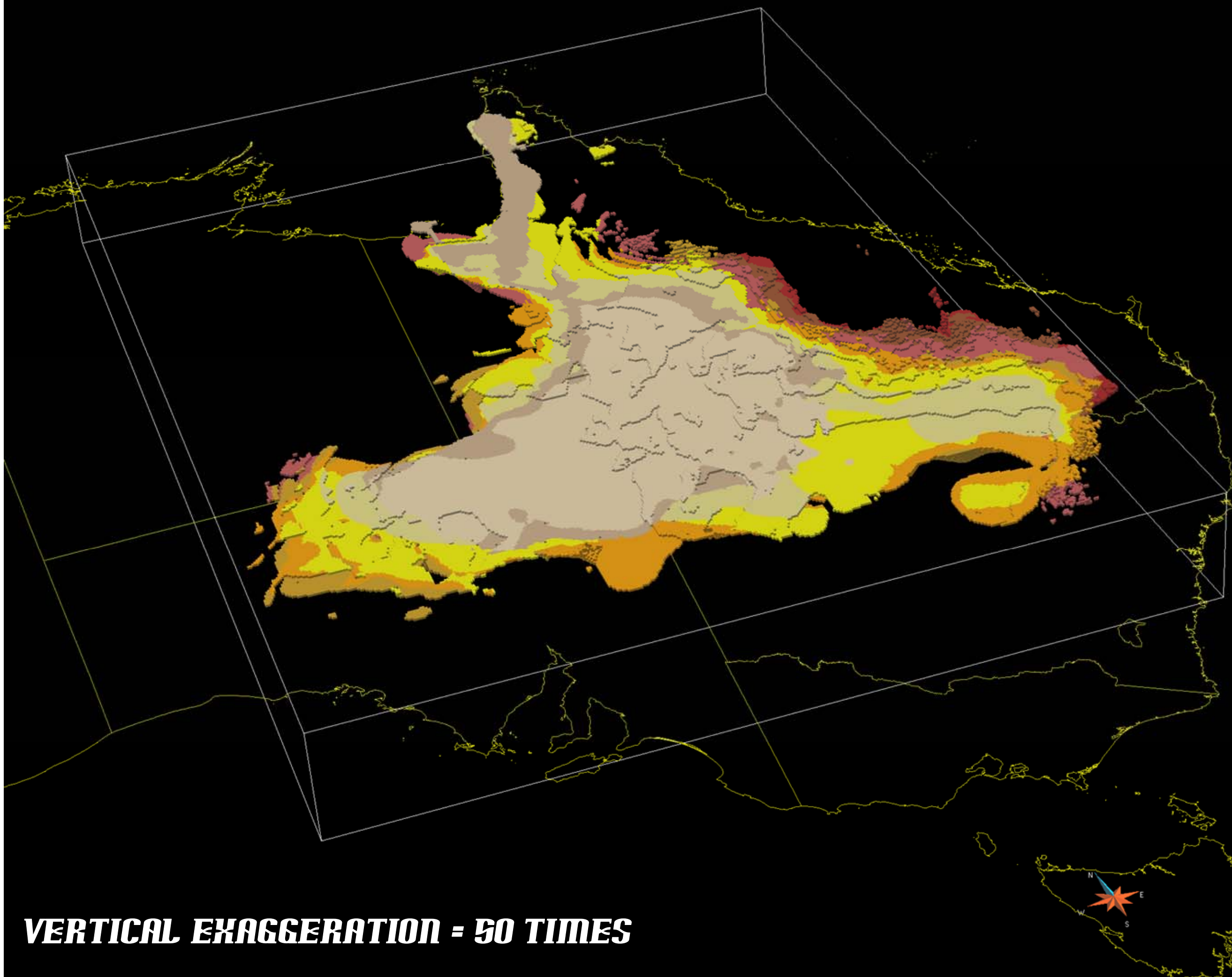


Decrease in water level

Regional drawdown (m) of the potentiometric surface (1880-1970)



RADKE ET AL, 2000

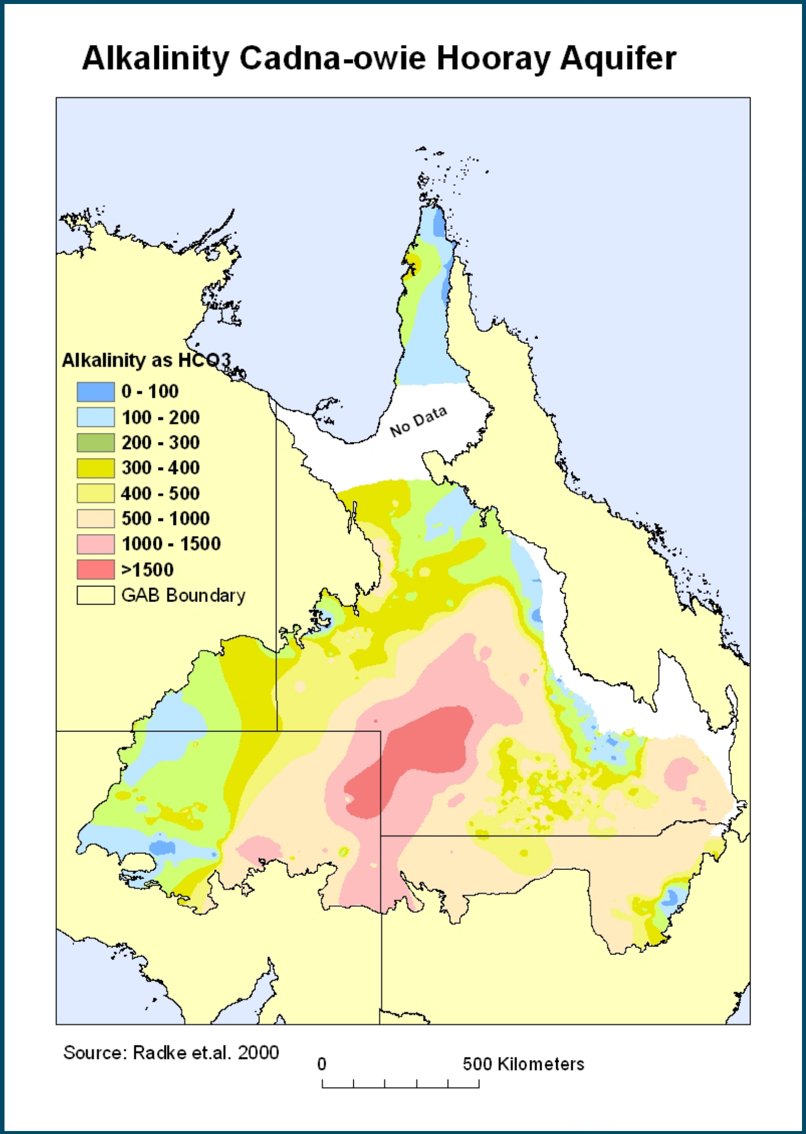


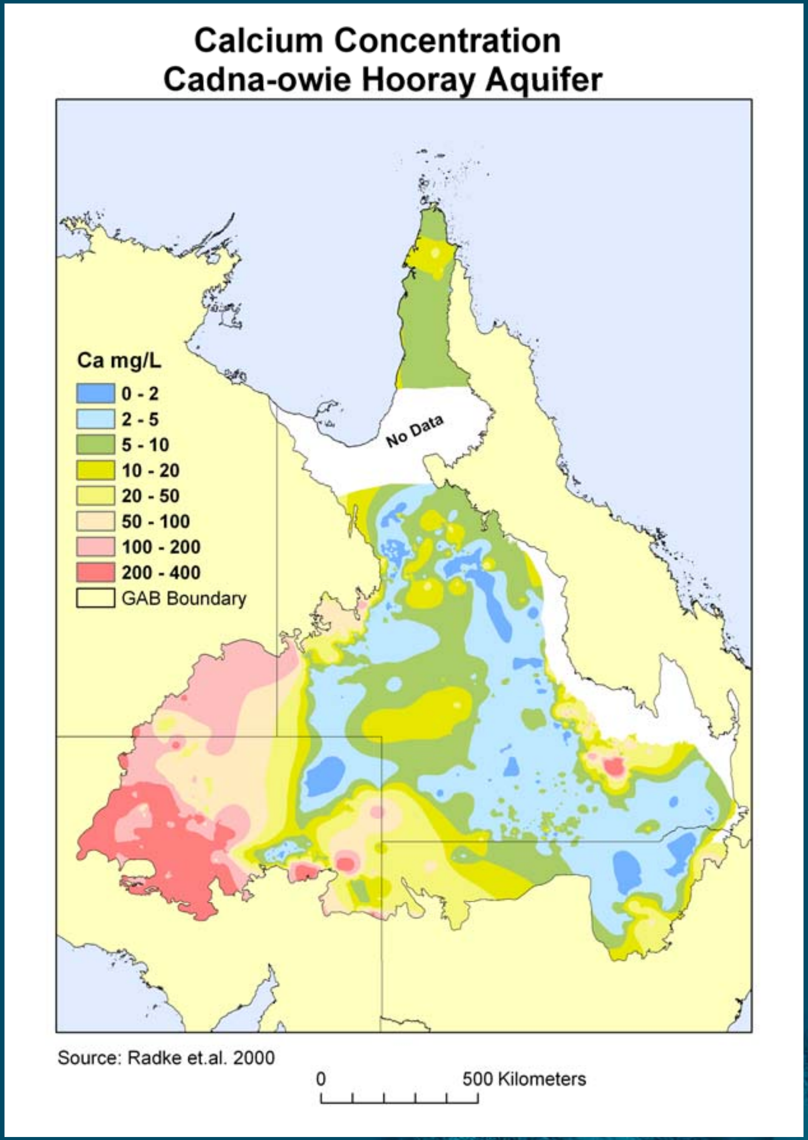
Production of a 3D Geological Block Model (gOcad voxet)

01_KSRW (WINTON)
02_KSRM (MACKUNDA)
03_KLRO (TOOLEBUC)
04_KSR (ROLLING DOWNS)
05_KSCO (CADNA-OWIE)
06_JSYH (HOORAY)
07_JSBH (HUTTON)
08_RSMO (MOOLAYEMBER)
09_RSL (CLEMATIS)

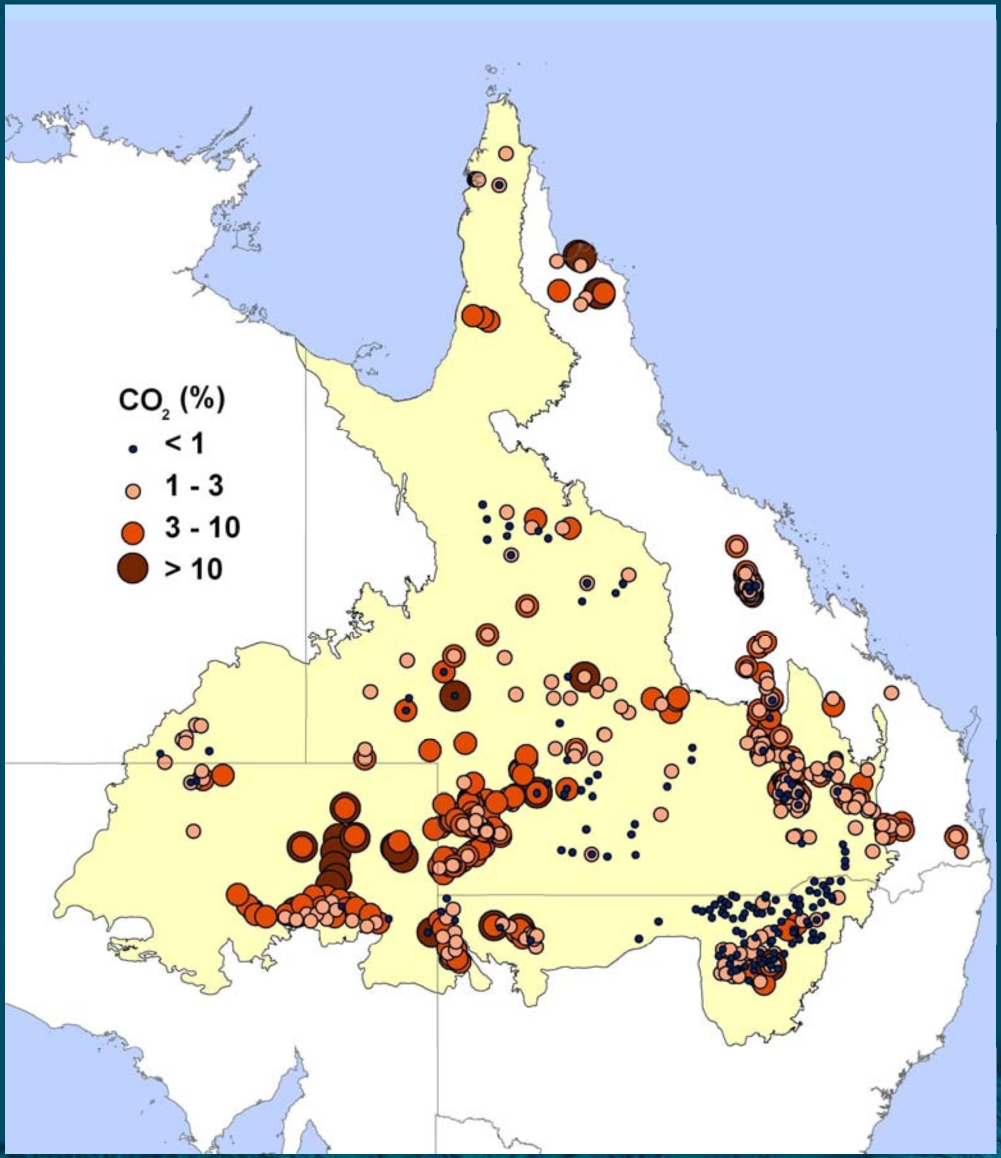
VERTICAL EXAGGERATION = 50 TIMES

FIGURE COURTESY OF GA URANIUM SYSTEMS PROJECT


Alkalinity Cadna-owie Hooray Aquifer
Alkalinity as HCO3
0 - 100
100 - 200
200 - 300
300 - 400
400 - 500
500 - 1000
1000 - 1500
>1500
GAB Boundary
No Data
Source: Radke et.al. 2000
0
500 Kilometers


Calcium Concentration
Cadna-owie Hooray Aquifer
Ca mg/L
0 - 2
2 - 5
5 - 10
10 - 20
20 - 50
50 - 100
100 - 200
200 - 400
GAB Boundary
No Data
Source: Radke et.al. 2000
0
500 Kilometers

Reported CO_2 levels in wells



Water chemistry data for the GAB

- Approx. 90,000 water chemistry records for GAB (<15,000 suitable)
- >1000m depth, only have ~1000 data points (1.7 million km^2)
- Only 20 data points for arsenic

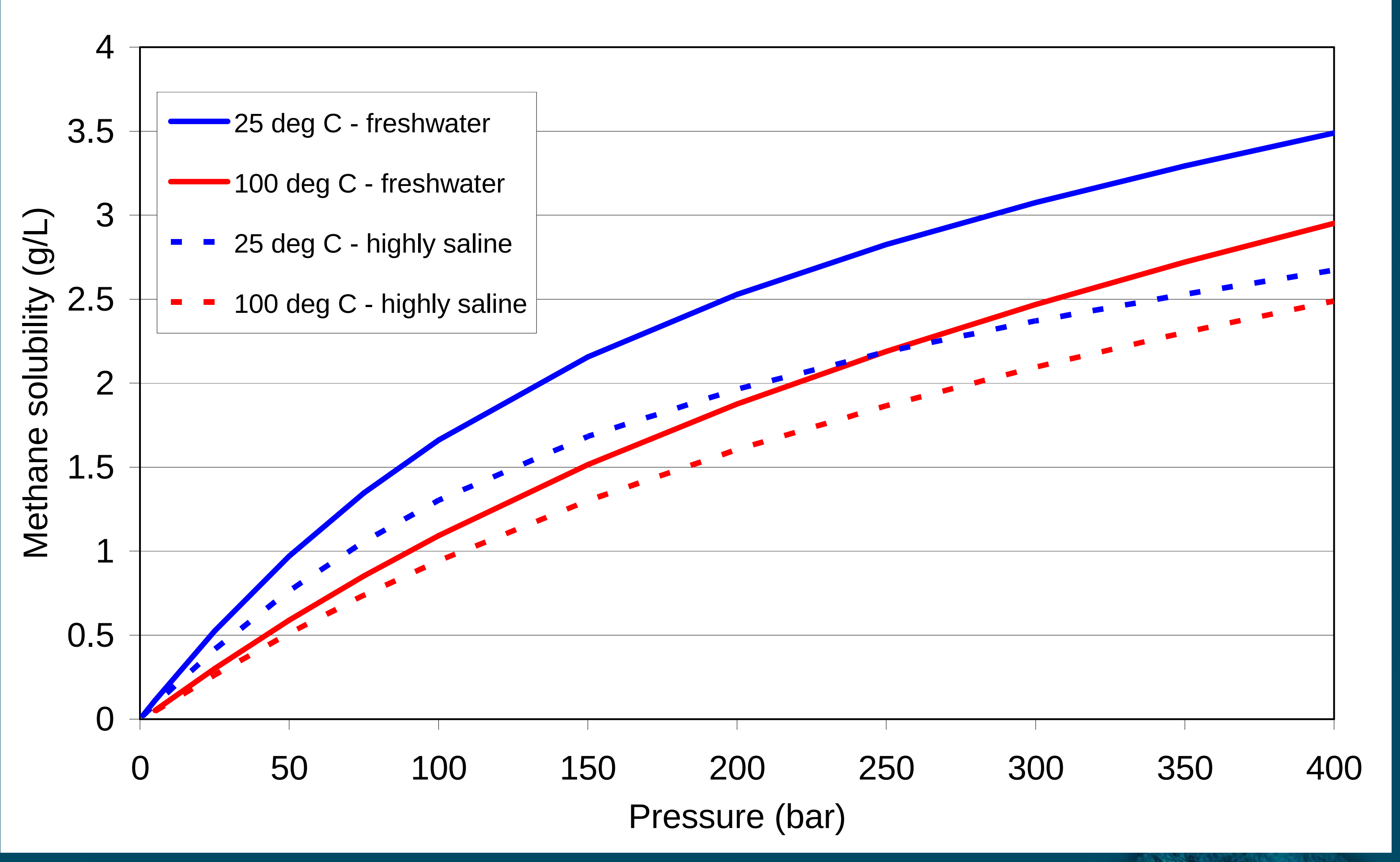
Gases in production water

Source: CSIRO Petroleum (Glyn Corona11, NSW)

Impacts of GHG storage on groundwater

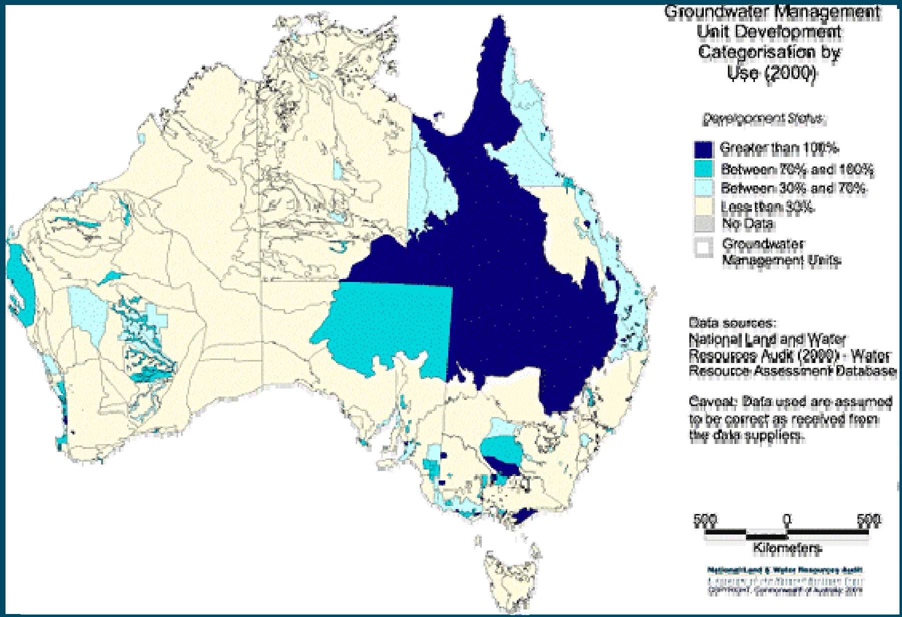
- Potential contamination of freshwater resources
- Release of gases from produced waters
- Boosting pressure in depleted groundwater reservoirs
- Balancing existing and future water resource needs against GHG injection

Methane solubility



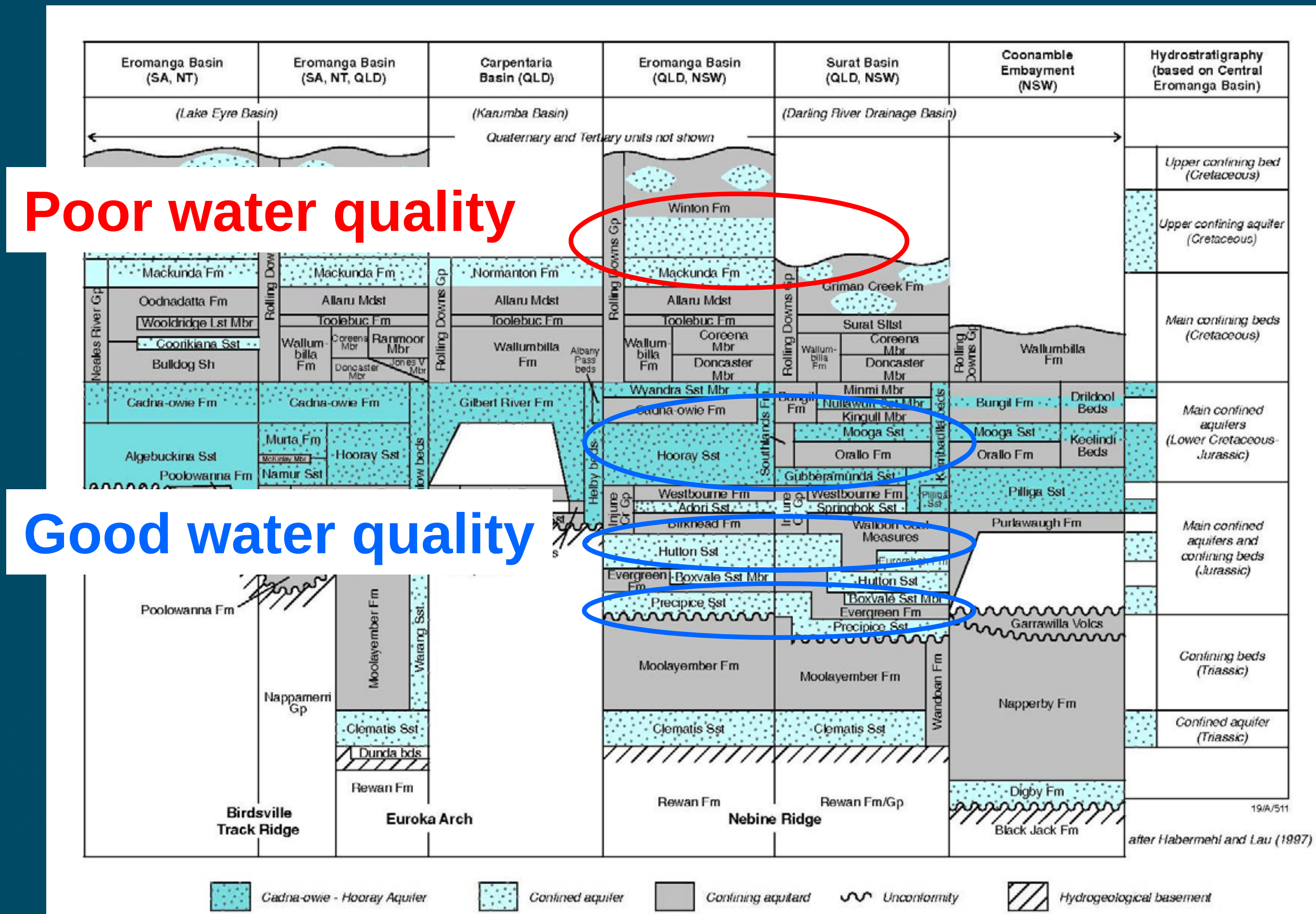
Groundwater in Australia

- 5,600 GL/yr used
- Supports 500 cities and townships
- Primarily used for agriculture
- Provinces of overuse



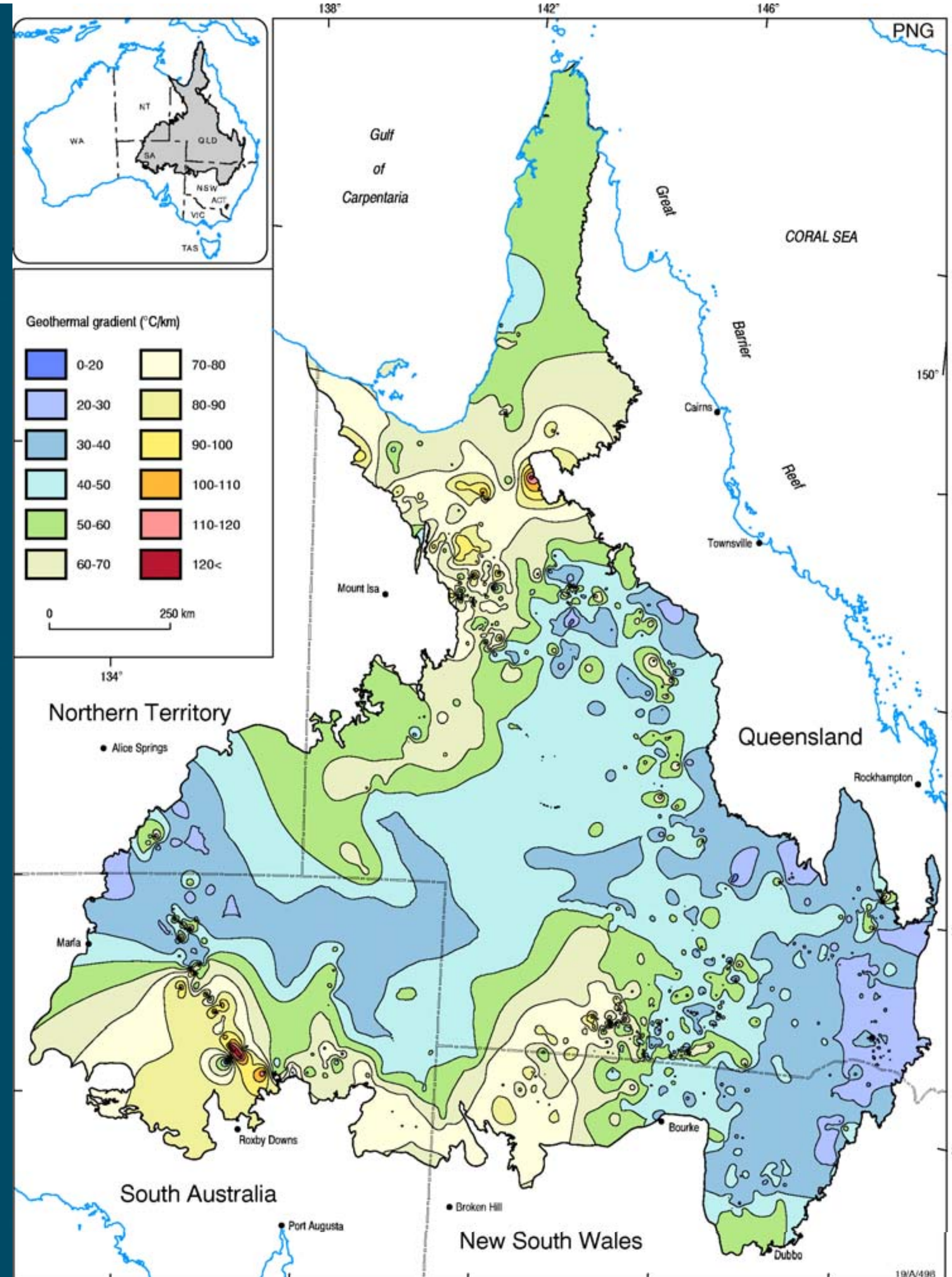
ARNA, 2009

GAB hydrostratigraphy



Geothermal Gradients within the GAB

- Gradients Range between ~15^0 C/Km to ~ 100^0 C/Km



Geochemical response of a potable aquifer to leakage from geologically sequestered carbon dioxide

Kris Draude, R. Donahue, R. Chalaturnyk

IEA GHG R&D Network Meeting - Risk Assessment
Melbourne, Australia
April 16 & 17, 2009

K. Draude, 2004. *Geochemical response of a potable aquifer to leakage from geologically sequestered carbon dioxide.* MSc. Thesis, University of Alberta.

Environmental Concerns

- **The impact of a sudden release CO_2 on public safety is typically of greater concern than the impact on the environment of a slow release.**
- **Consequences to the environment must be better defined and understood.**
- **The process of sequestering CO_2 must be less damaging to the environment than its continued release to the atmosphere.**

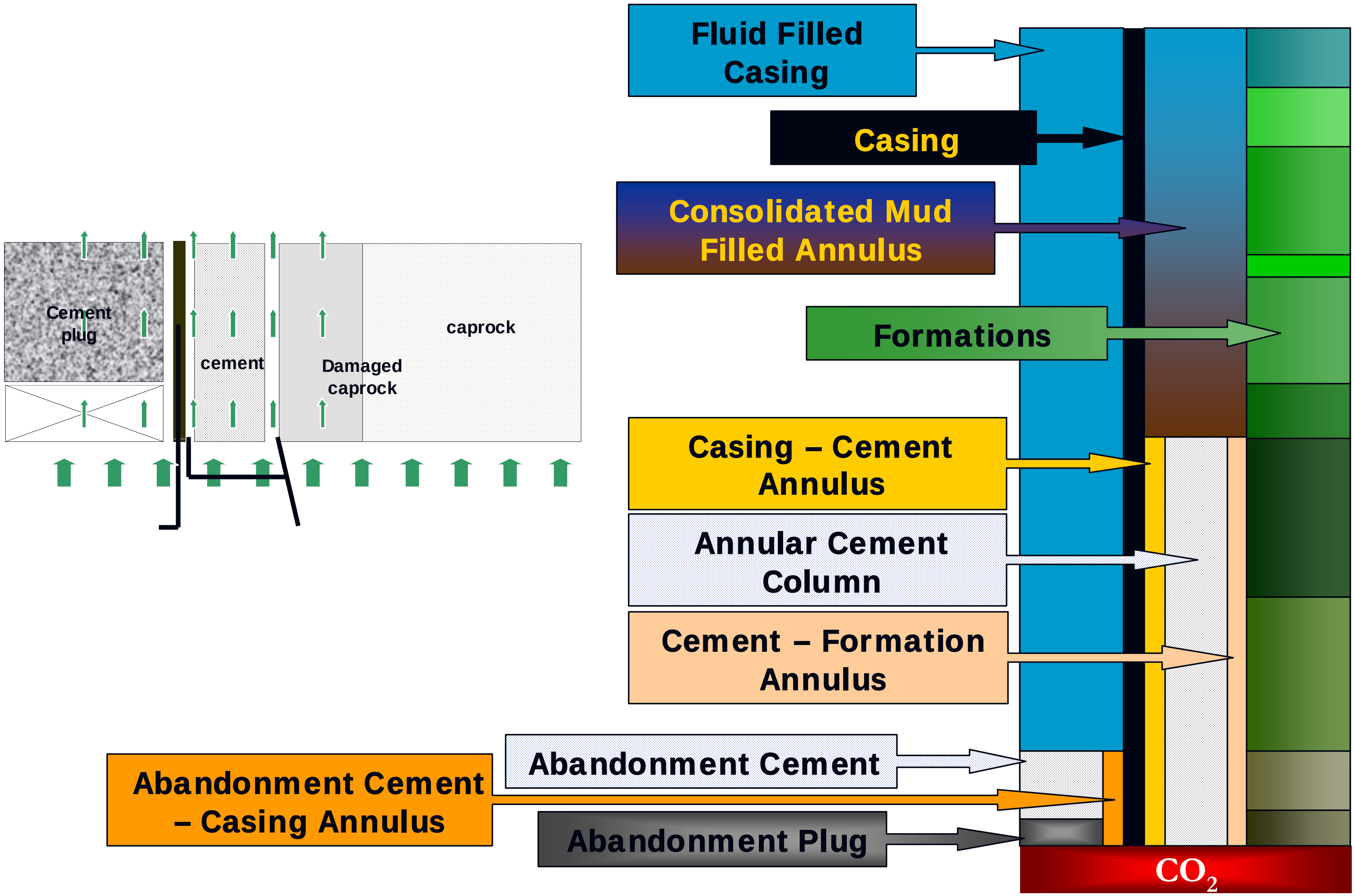
K. Draude, 2004. *Geochemical response of a potable aquifer to leakage from geologically sequestered carbon dioxide.* MSc. Thesis, University of Alberta.

Research Objective

- **To characterize the geochemical reactions that may occur in an aquifer as a result of leakage from a CO2 injection well used for the geologic sequestration of carbon dioxide.**

K. Draude, 2004. *Geochemical response of a potable aquifer to leakage from geologically sequestered carbon dioxide.* MSc. Thesis, University of Alberta.

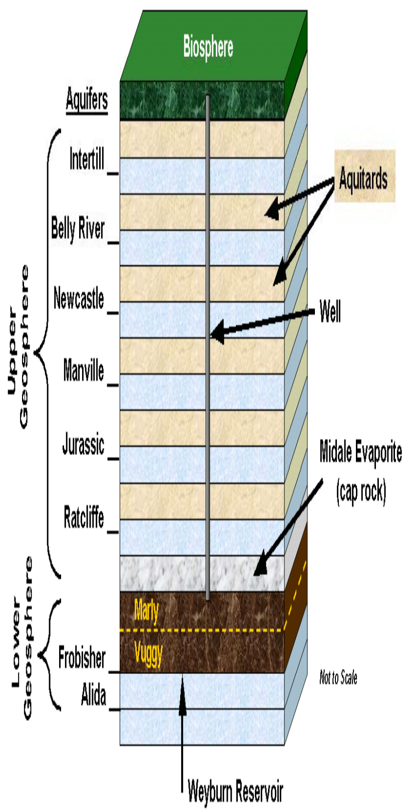
Context for Research

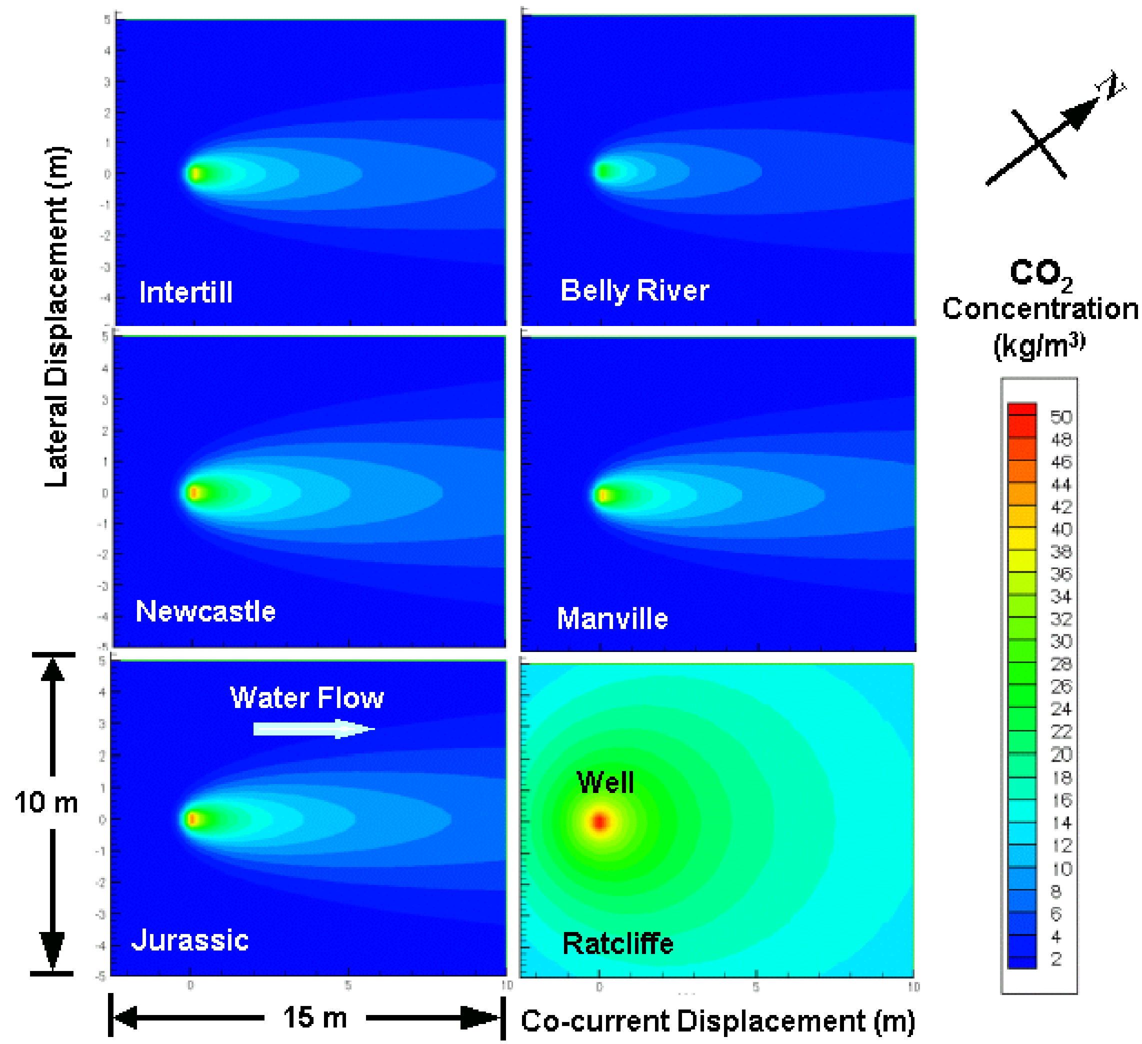


K. Draude, 2004. *Geochemical response of a potable aquifer to leakage from geologically sequestered carbon dioxide.* MSc. Thesis, University of Alberta.

CO2 Leakage from Wells in Overlying Aquifers

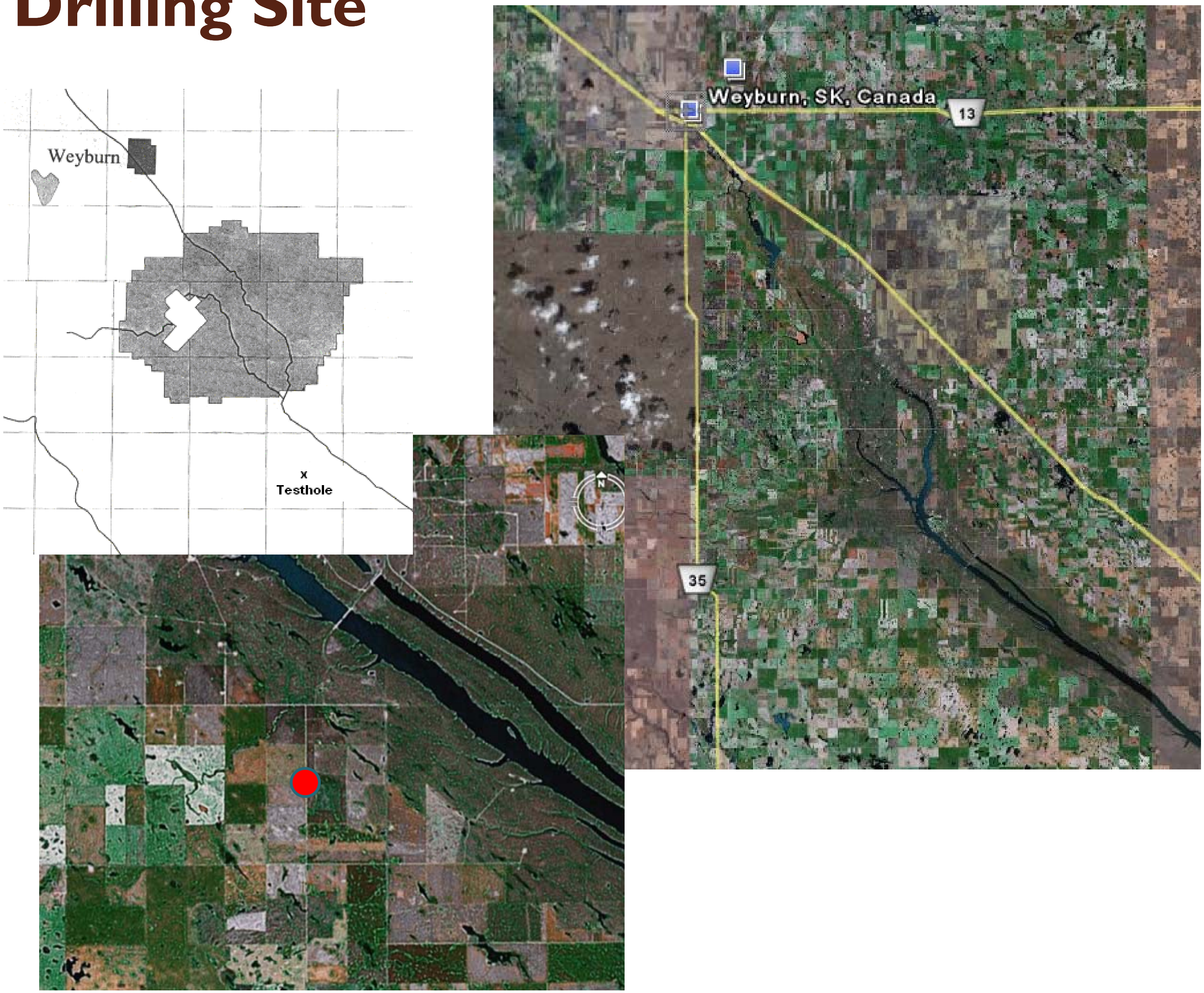
K. Draude, 2004. *Geochemical response of a potable aquifer to leakage from geologically sequestered carbon dioxide.* MSc. Thesis, University of Alberta.





(from Phase I of IEA GHG Weyburn Project)

Drilling Site



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Drilling Site

K. Draude, 2004. *Geochemical response of a potable aquifer to leakage from geologically sequestered carbon dioxide.* MSc. Thesis, University of Alberta.

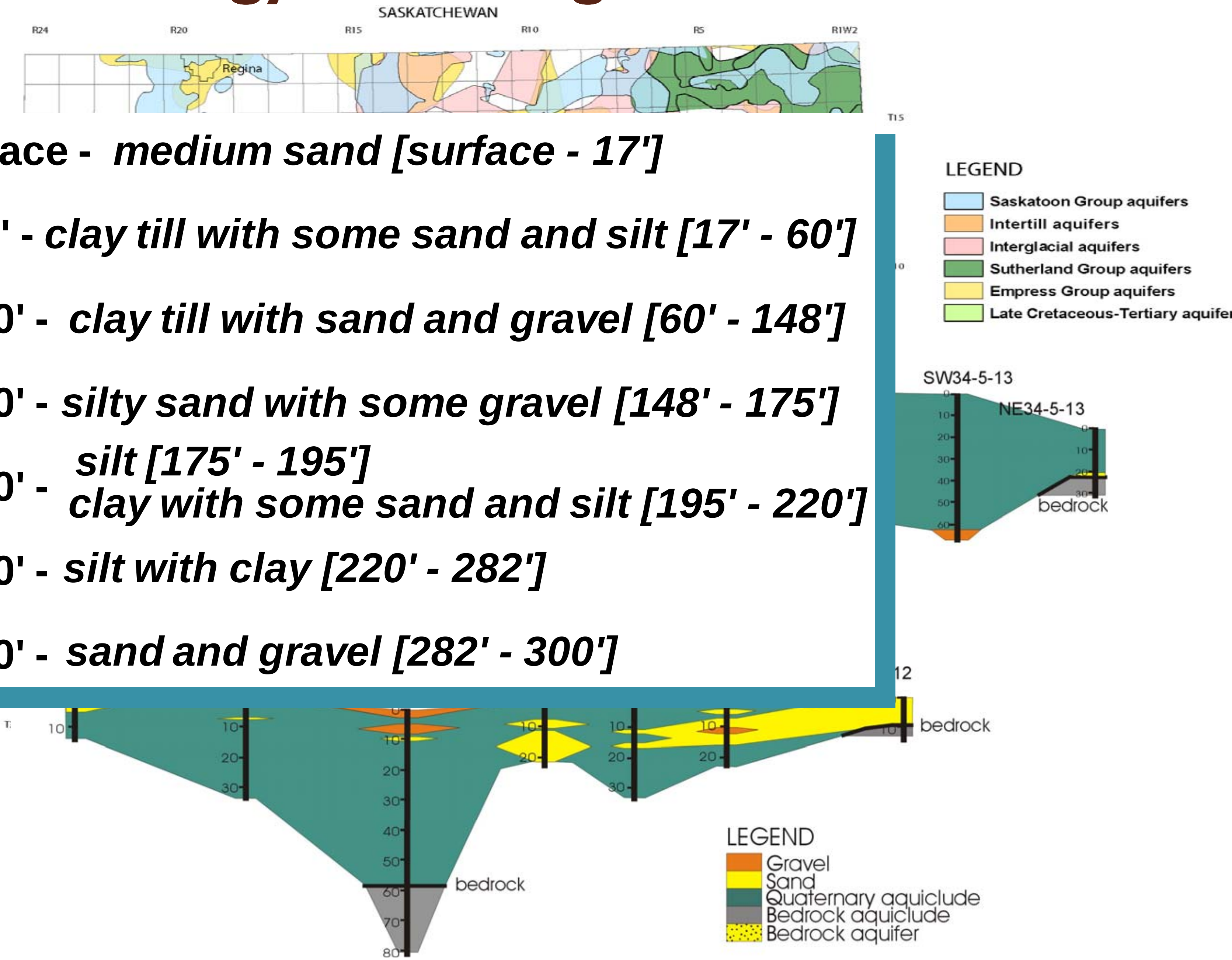
Drilling Site

K. Draude, 2004. ***Geochemical response of a potable aquifer to leakage from geologically sequestered carbon dioxide.*** **MSc. Thesis, University of Alberta.**

Drilling Site

K. Draude, 2004. ***Geochemical response of a potable aquifer to leakage from geologically sequestered carbon dioxide.*** **MSc. Thesis, University of Alberta.**

Lithology of Drilling Site



surface - ***medium sand [surface - 17']***

50' - ***clay till with some sand and silt [17' - 60']***

100' - ***clay till with sand and gravel [60' - 148']***

150' - ***silty sand with some gravel [148' - 175']***

200' - ***silt [175' - 195']***
clay with some sand and silt [195' - 220']

250' - ***silt with clay [220' - 282']***

300' - ***sand and gravel [282' - 300']***

K. Draude, 2004. *Geochemical response of a potable aquifer to leakage from geolog*
MSc. Thesis, Universi

Sample Collection

K. Draude, 2004. *Geochemical response of a potable aquifer to leakage from geologically sequestered carbon dioxide.* MSc. Thesis, University of Alberta.

Sample Collection

K. Draude, 2004. ***Geochemical response of a potable aquifer to leakage from geologically sequestered carbon dioxide.***
MSc. Thesis, University of Alberta.

Groundwater Chemistry

routine water properties		***average***
pH		8.07
electrical conductivity	[uS/cm @ 25˚C]	3052.5
calcium	[mg/L]	65.96
magnesium	[mg/L]	26.7
sodium	[mg/L]	584.3
potassium	[mg/L]	6.59
chloride	[mg/L]	632.8
carbonate	[mg/L]	<6
bicarbonate	[mg/L]	848.6
T-alkalinity	[mg/L]	696.0
iron	[mg/L]	<0.05
manganese	[mg/L]	0.20
arsenic	[mg/L]	0.0036
strontium	[mg/L]	0.54

K. Draude, 2004. *Geochemical response of a potable aquifer to leakage from geologically sequestered carbon dioxide.* MSc. Thesis, University of Alberta.

Sediment Composition

extractable elements	***concentration***
	[μg/g]
calcium	27011
magnesium	7073
iron	8942
aluminum	3650
manganese	231.6
phosphorus	223.7
sulfur	866.1
silicon	215.0

K. Draude, 2004. *Geochemical response of a potable aquifer to leakage from geologically sequestered carbon dioxide.* MSc. Thesis, University of Alberta.

Sediment Composition

trace metals	***concentration*** *[ug/g]*
titanium	130.8
barium	81.52
strontium	32.01
zinc	25.54
vanadium	14.78
nickel	10.29
chromium	7.34
cobalt	4.90
copper	4.68
lead	4.18
arsenic	3.70

K. Draude, 2004. *Geochemical response of a potable aquifer to leakage from geologically sequestered carbon dioxide.* MSc. Thesis, University of Alberta.

Mineralogy

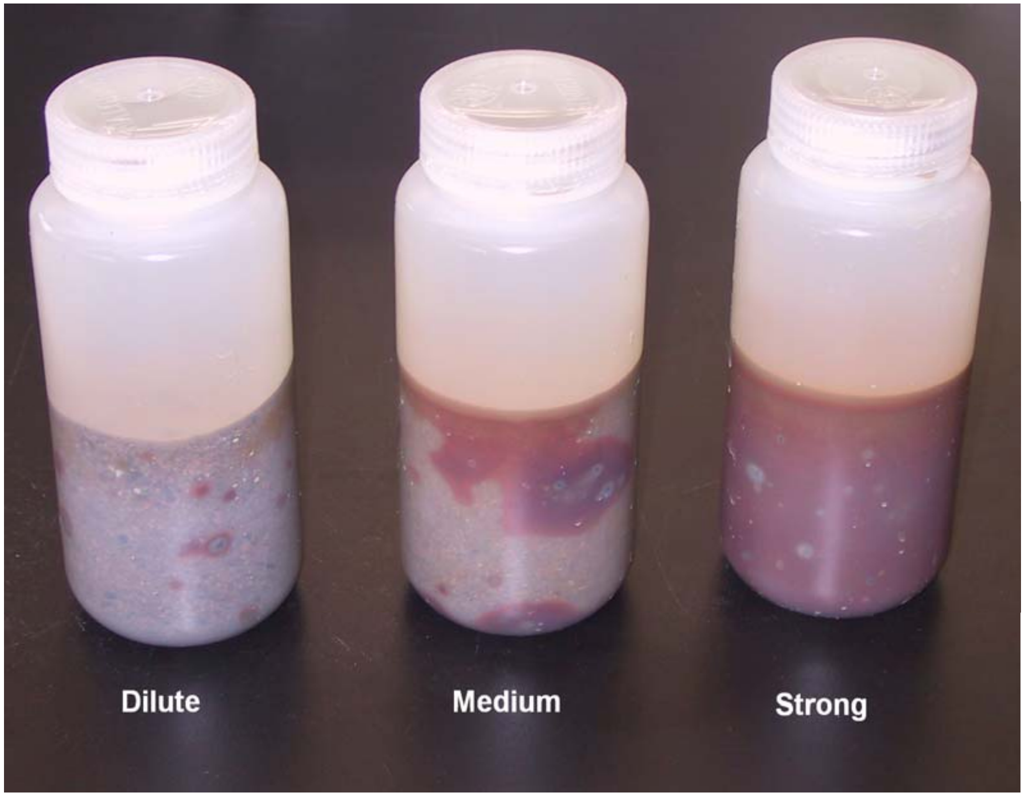
Fines *(<75μm)*	**Sand** *(<2000μm)*	**Gravel** *(>2000μm)*
Quartz	Quartz	Quartz
Calcite	Calcite	Calcite
Dolomite	Dolomite	Dolomite
Feldspar	K-Feldspar	K-Feldspar
Smectite	Na-Feldspar	Na-Feldspar
Illite		Granite
Kaolinite		Chert
Chlorite		Coal

Mineral	**Composition** *[%]*
Smectite	44
Illite	20
Kaolinite	19
Chlorite	17
Total CEC	*38.6 meq/100g*

K. Draude, 2004. *Geochemical response of a potable aquifer to leakage from geologically sequestered carbon dioxide.* MSc. Thesis, University of Alberta.

Leaching Test

- **preliminary test conducted in order to determine the potential for mineral dissolution, ion exchange, and desorption reactions on the sediment phase due to elevated carbon dioxide levels in water.**



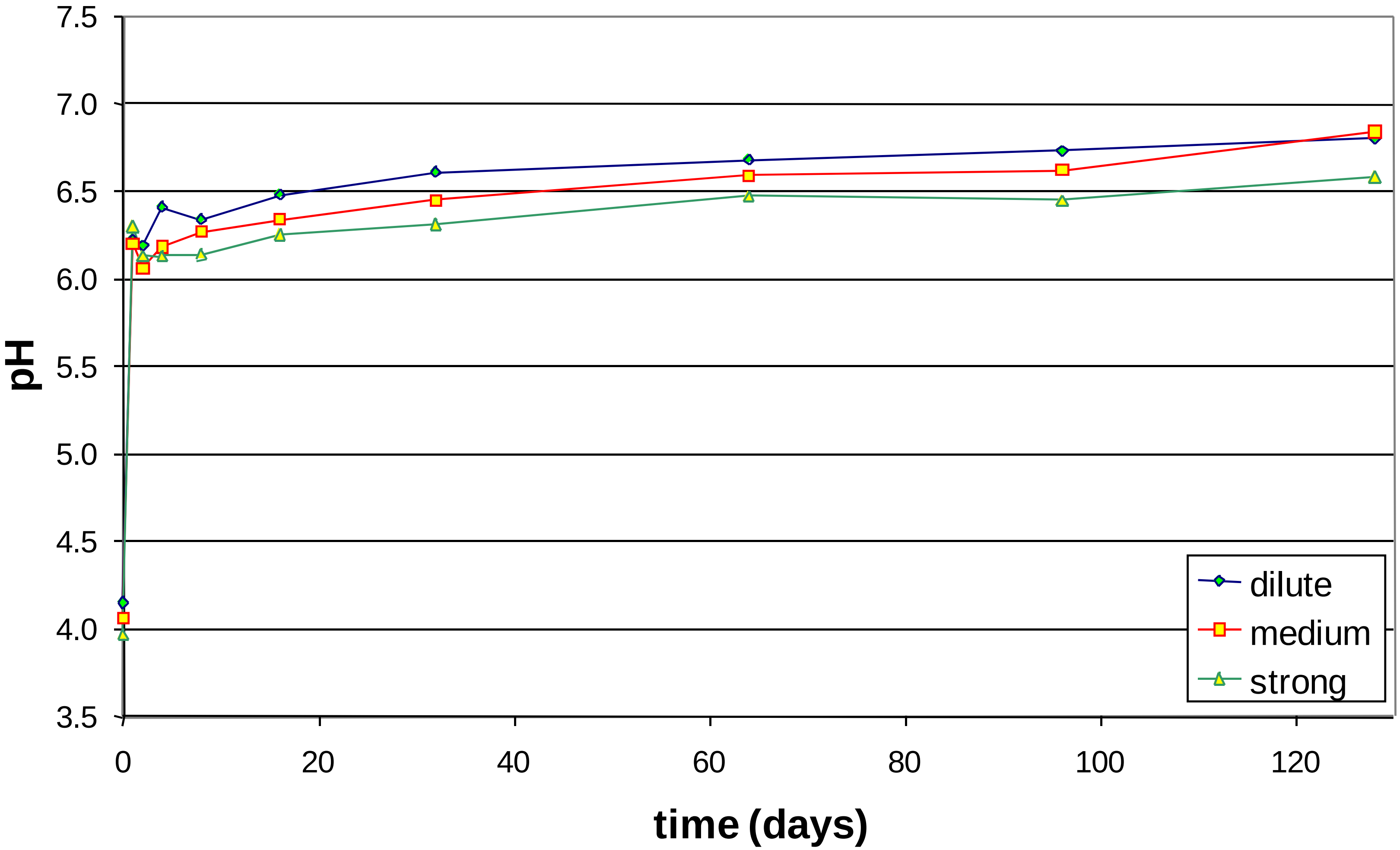
K. Draude, 2004. *Geochemical response of a potable aquifer to leakage from geologically sequestered carbon dioxide.* MSc. Thesis, University of Alberta.

Leaching Test

- **Experimental:**
  - Experimental variables included time and [H_2CO_3].
  - Sampling intervals were 1, 2, 4, 8, 16, 32, 64, 96 & 128 days.
  - Three concentrations of H_2CO_3 were prepared: 600, 1200 & 1800 mgCO_2/L.
  - The bottles were filled with a known mass of sediment and topped up with the desired concentration of H_2CO_3 and left for the time corresponding to the sampling interval.
- **Analysis:**
  - pH, Electrical Conductivity, Alkalinity, [H_2CO_3], Ion Chromatography, ICP/MS

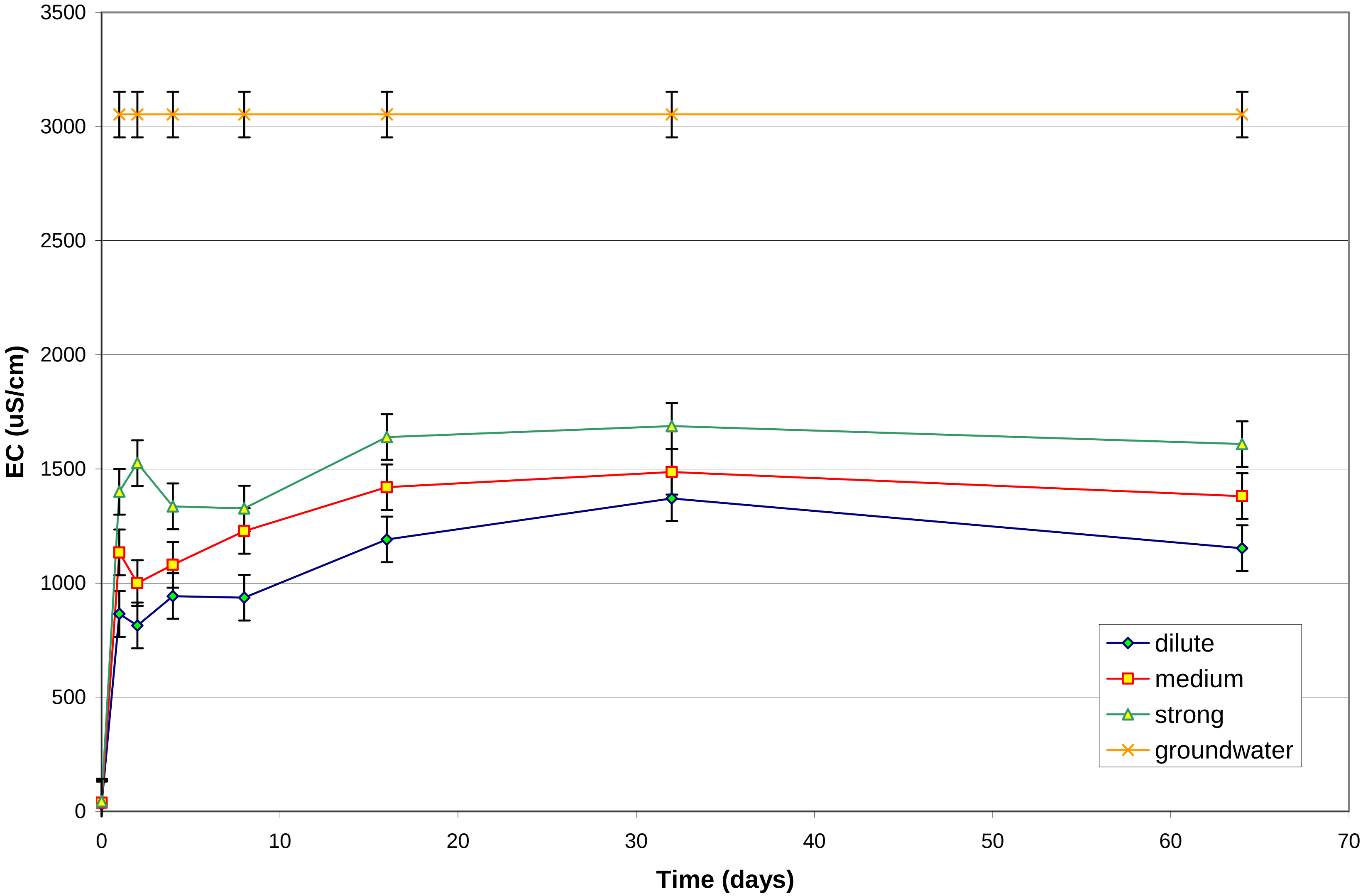
K. Draude, 2004. *Geochemical response of a potable aquifer to leakage from geologically sequestered carbon dioxide.* MSc. Thesis, University of Alberta.

Leaching Test -pH



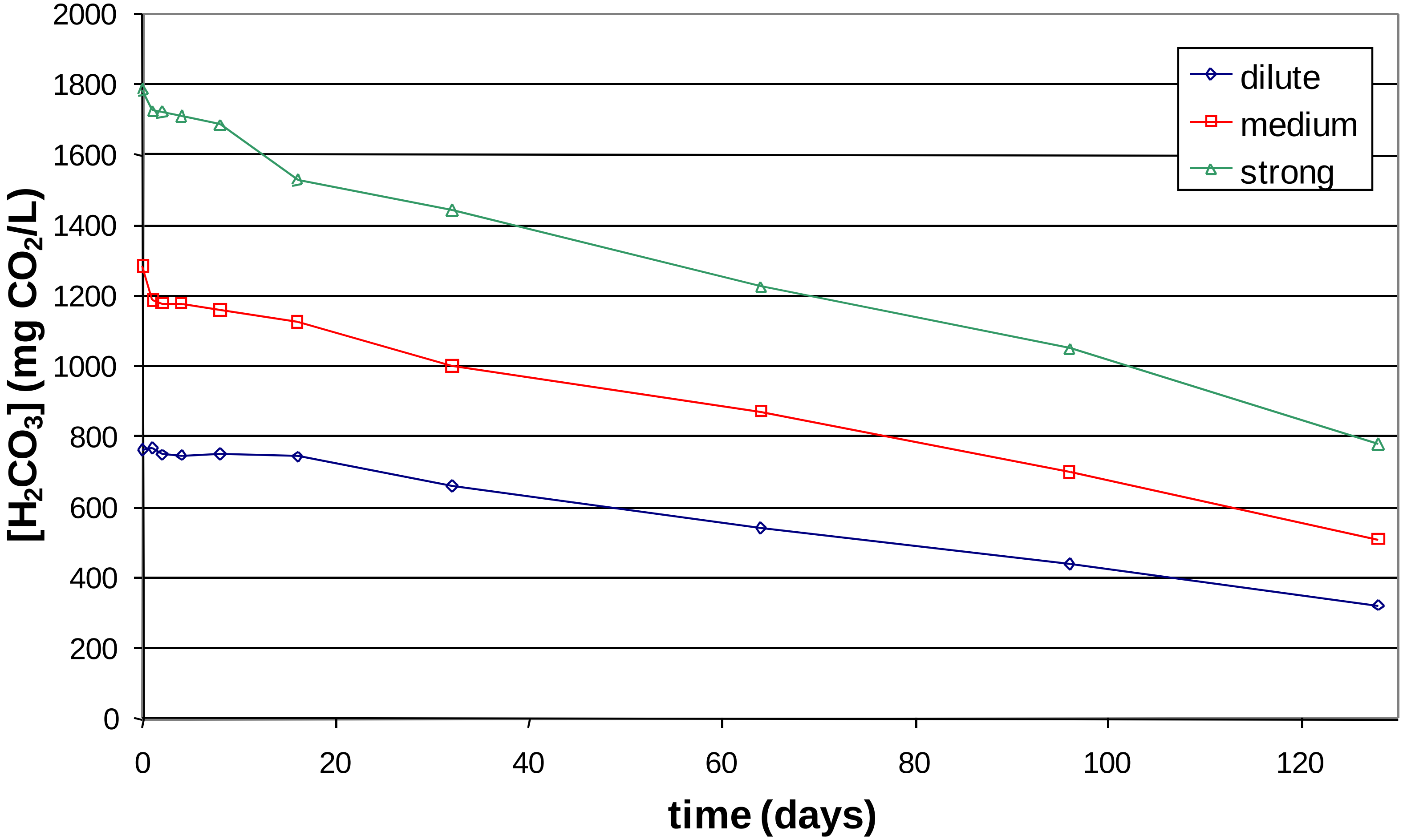
K. Draude, 2004. *Geochemical response of a potable aquifer to leakage from geologically sequestered carbon dioxide.* MSc. Thesis, University of Alberta.

Leaching Test – Electrical Conductivity



K. Draude, 2004. *Geochemical response of a potable aquifer to leakage from geologically sequestered carbon dioxide.* MSc. Thesis, University of Alberta.

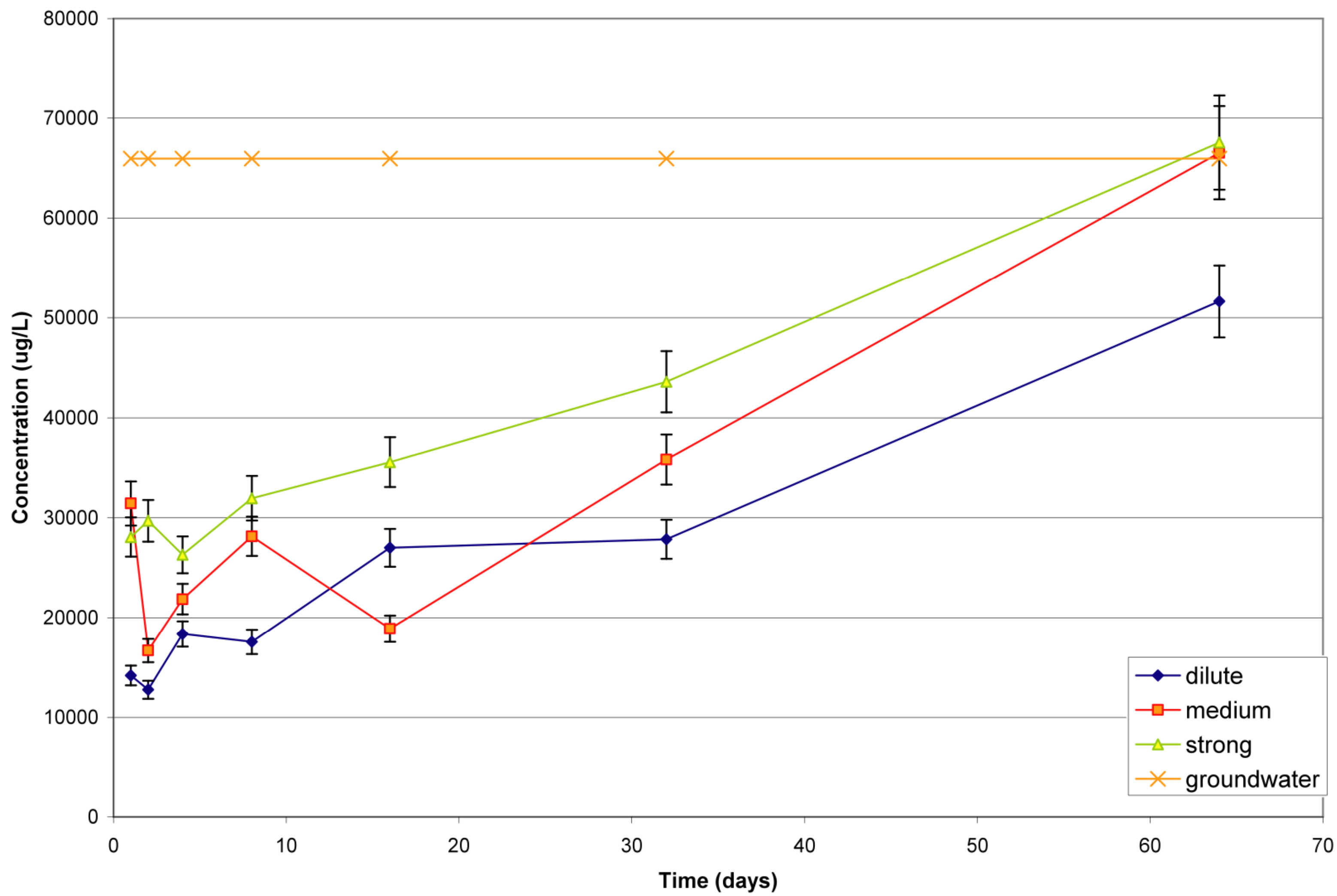
Leaching Test – Bicarbonate Ion



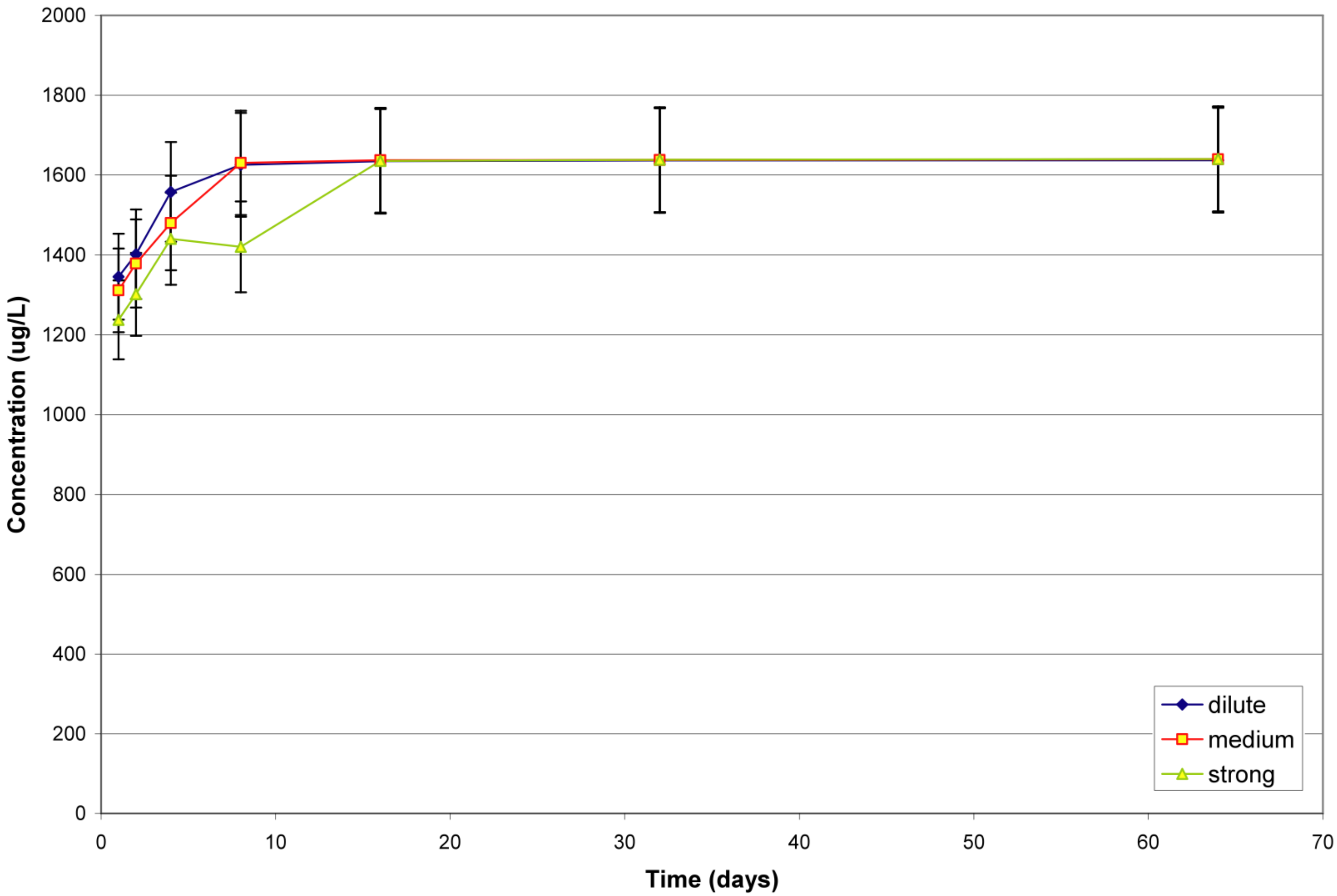
K. Draude, 2004. *Geochemical response of a potable aquifer to leakage from geologically sequestered carbon dioxide.* MSc. Thesis, University of Alberta.

Calcium Concentration (in Solution) during Leaching Test

K. Draude, 2004. *Geochemical response of a potable aquifer to leakage from geologically sequestered carbon dioxide.* MSc. Thesis, University of Alberta.



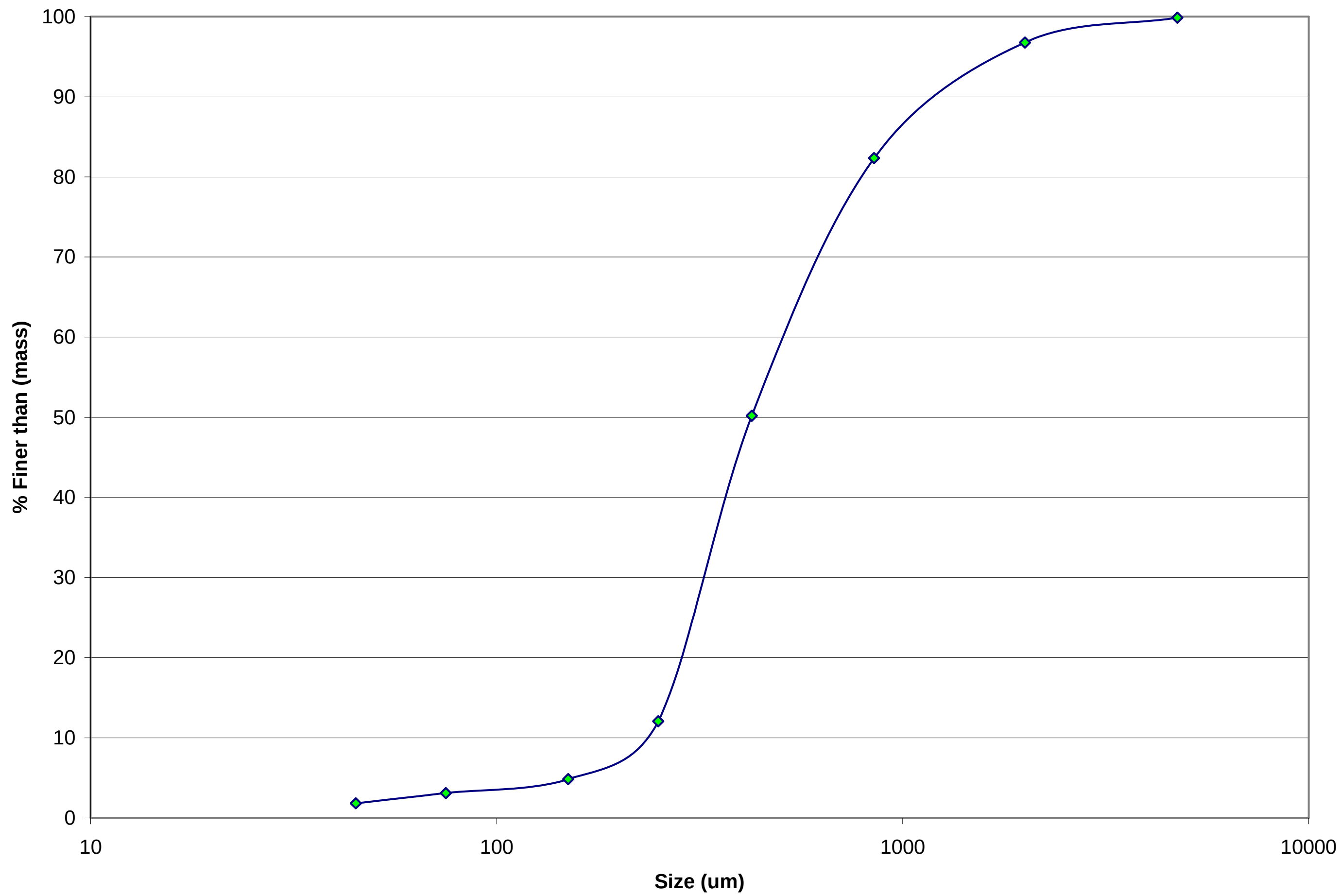
Iron Concentration (in Solution) during Leaching Test



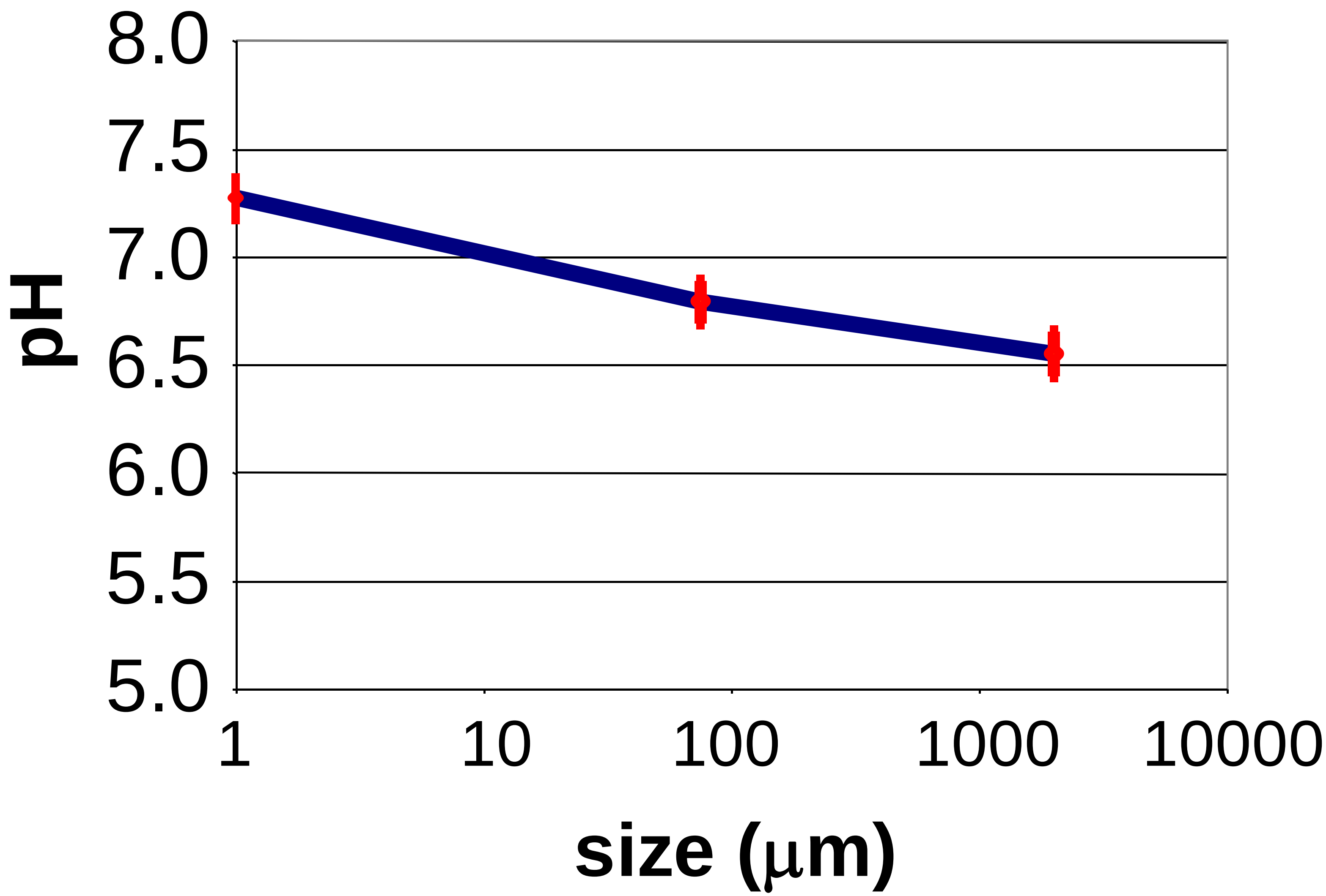
K. Draude, 2004. *Geochemical response of a potable aquifer to leakage from geologically sequestered carbon dioxide.* MSc. Thesis, University of Alberta.

Particle Size Distribution

K. Draude, 2004. ***Geochemical response of a potable aquifer to leakage from geologically sequestered carbon dioxide.*** **MSc. Thesis, University of Alberta.**



Size Fraction Effects



K. Draude, 2004. *Geochemical response of a potable aquifer to leakage from geologically sequestered carbon dioxide.* MSc. Thesis, University of Alberta.

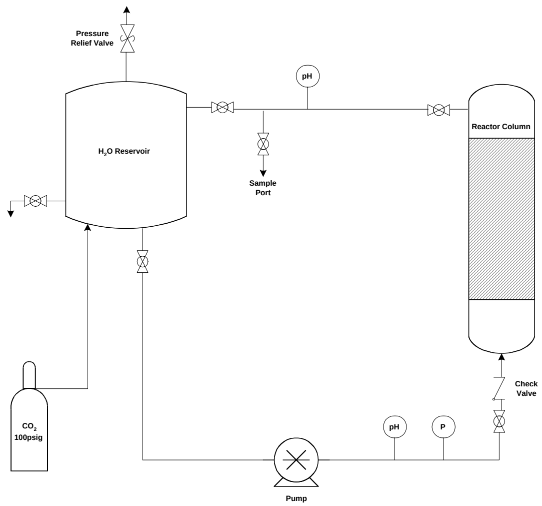
Column Study

- **generate information on the mineral-water-carbon dioxide interactions under more representative conditions of those found in situ as compared with the leaching study.**

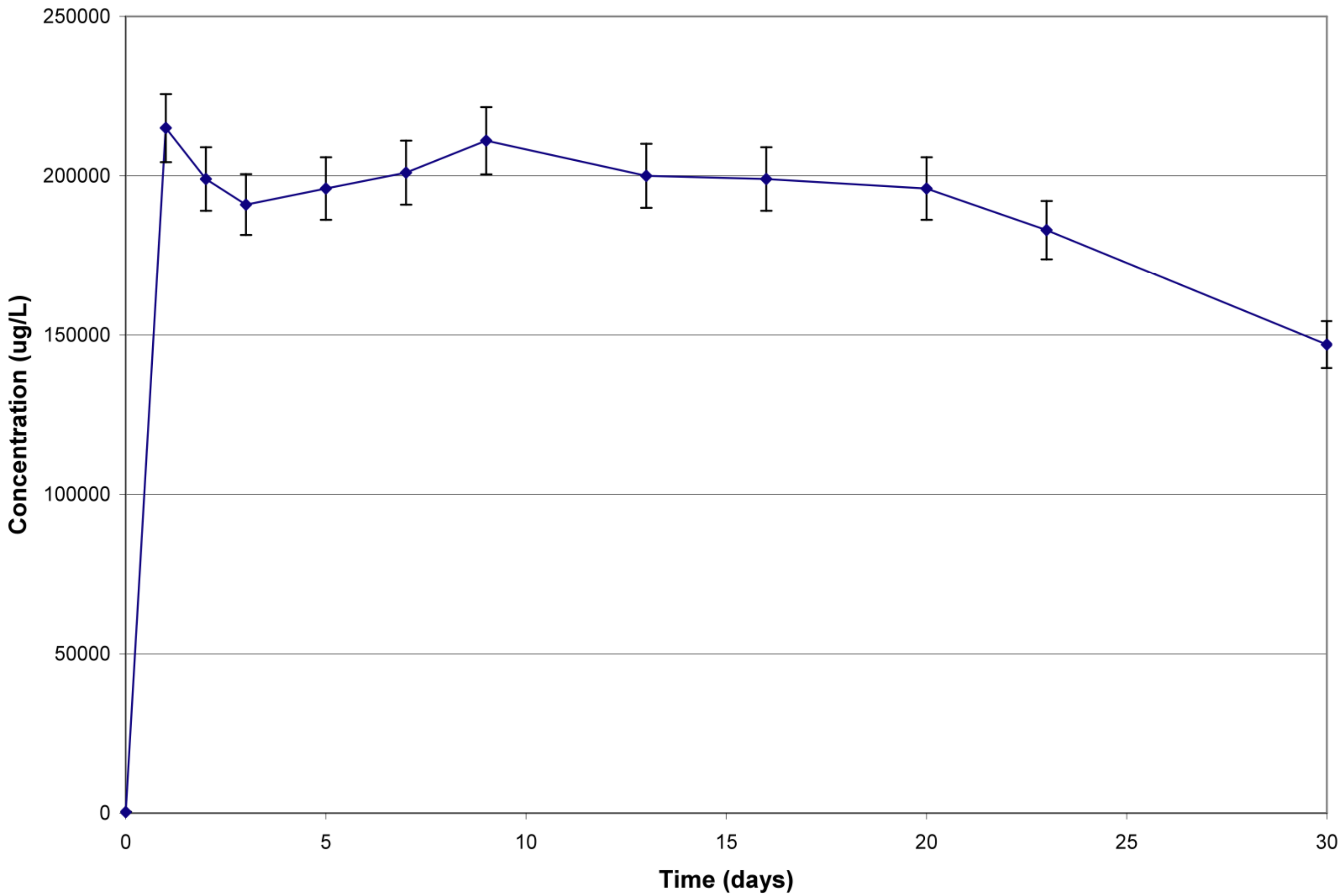
K. Draude, 2004. *Geochemical response of a potable aquifer to leakage from geologically sequestered carbon dioxide.* MSc. Thesis, University of Alberta.

Column Study

K. Draude, 2004. *Geochemical response of a potable aquifer to leakage from geologically sequestered carbon dioxide.* MSc. Thesis, University of Alberta.



Change in Iron Concentration



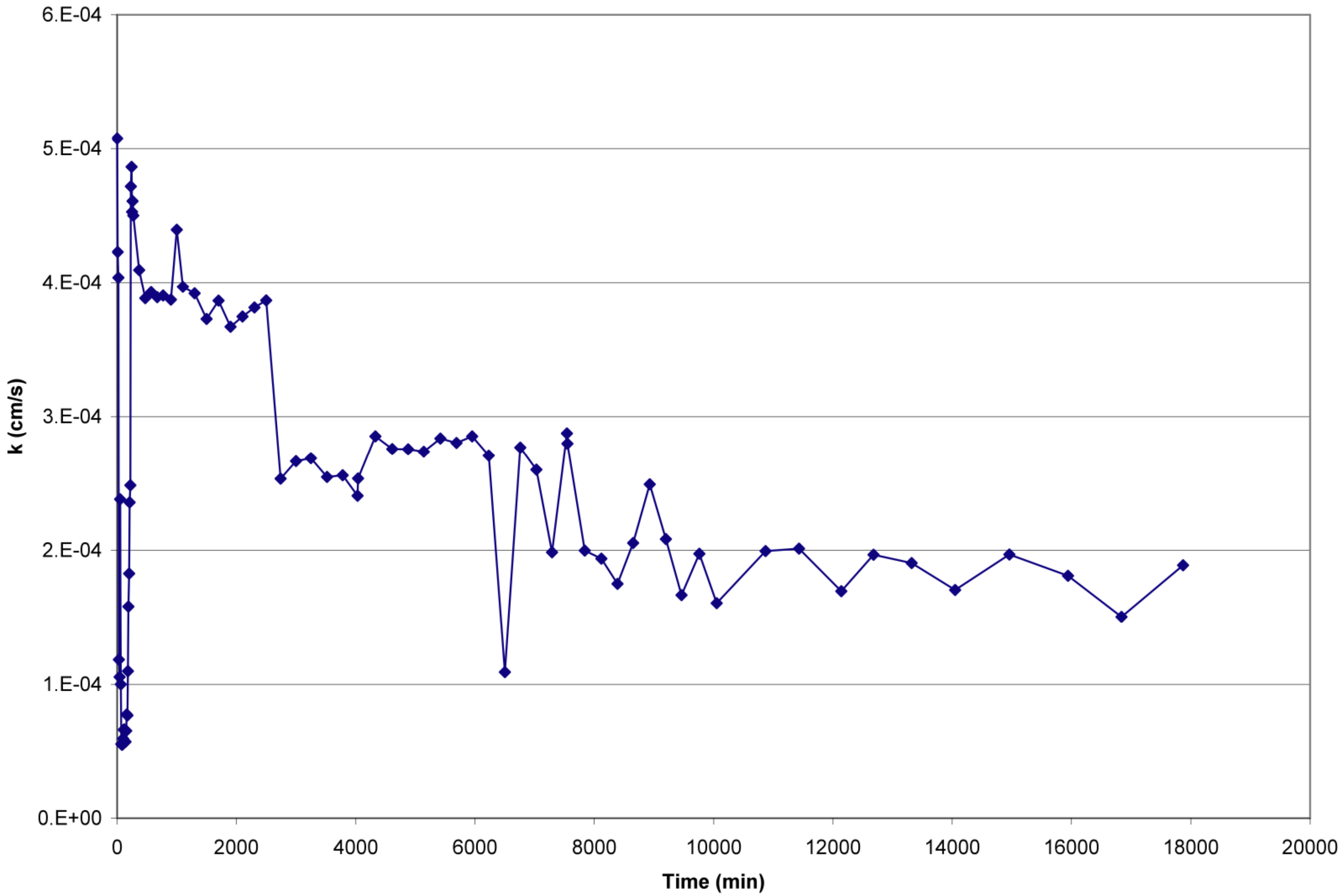
K. Draude, 2004. *Geochemical response of a potable aquifer to leakage from geologically sequestered carbon dioxide.* MSc. Thesis, University of Alberta.

Siderite Precipitate formed at Column Inlet

K. Draude, 2004. ***Geochemical response of a potable aquifer to leakage from geologically sequestered carbon dioxide.*** **MSc. Thesis, University of Alberta.**

Change in Hydraulic Conductivity

K. Draude, 2004. *Geochemical response of a potable aquifer to leakage from geologically sequestered carbon dioxide.* MSc. Thesis, University of Alberta.



Summary of Results

- Elevated carbon dioxide levels introduced to the aquifer water resulted in a drop in pH, despite the buffering effects of the carbonate minerals which converted the dissolved carbon dioxide to bicarbonate ions.
- The lowered pH caused other geochemical changes, including the solubilization and precipitation of various mineral phases present in the sediment.
- Elements most affected include calcium, magnesium, nickel, iron, strontium, and barium, all of which underwent a net dissolution, increasing their concentration in the groundwater.
- The elevated bicarbonate levels caused the groundwater to become oversaturated with respect to several carbonate minerals, allowing for precipitation. Most notable of these was the formation of siderite.
- The formation of precipitates reduced the porosity of the sediment, resulting in a decrease in hydraulic conductivity.
- Other metals that were dissolved did not approach the Drinking Water Quality Guidelines outlined by the CCME, for the short-term duration of this experiment.

K. Draude, 2004. *Geochemical response of a potable aquifer to leakage from geologically sequestered carbon dioxide.* MSc. Thesis, University of Alberta.

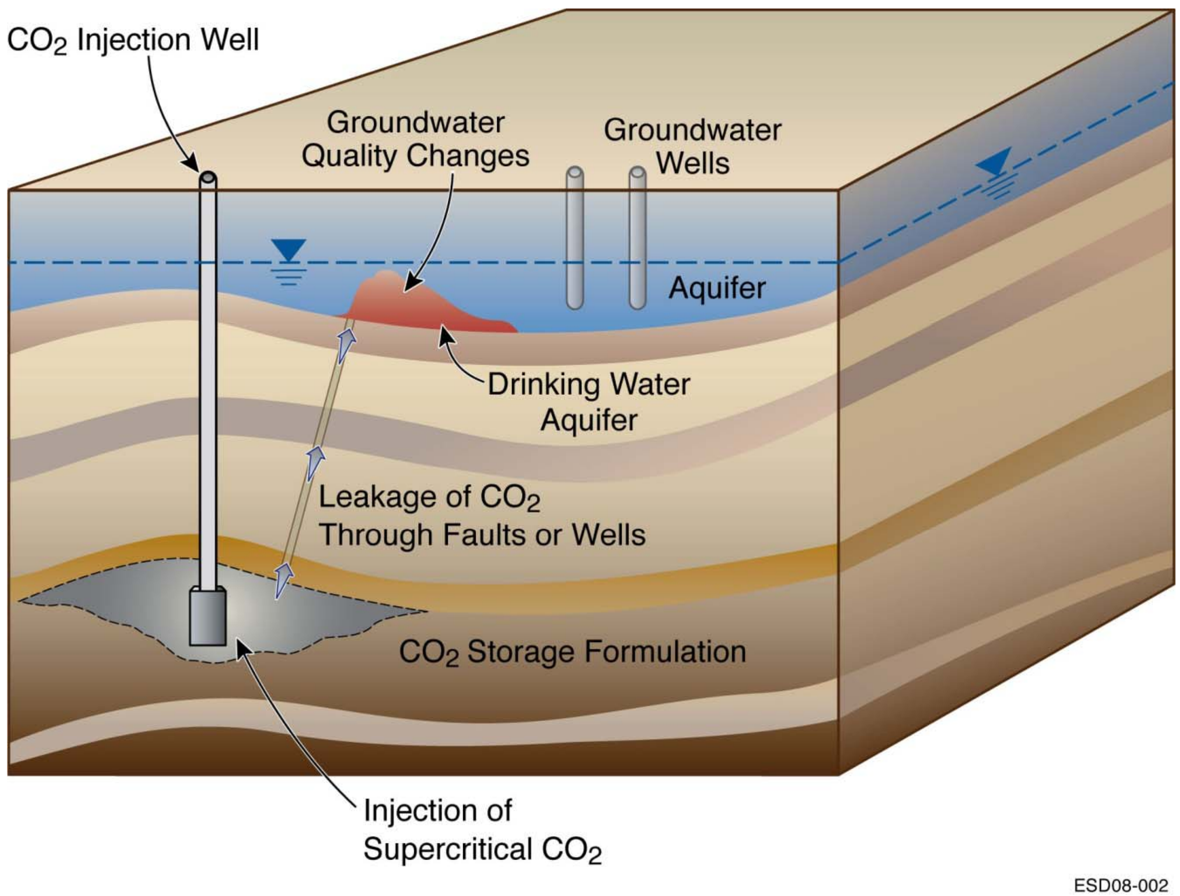
K. Draude, 2004. ***Geochemical response of a potable aquifer to leakage from geologically sequestered carbon dioxide.*** **MSc. Thesis, University of Alberta.**

Groundwater Quality Changes in Response to CO_2 Leakage from Deep Geological Storage

Lisa Bacanskas (USEPA) and Jens Birkholzer (LBNL)

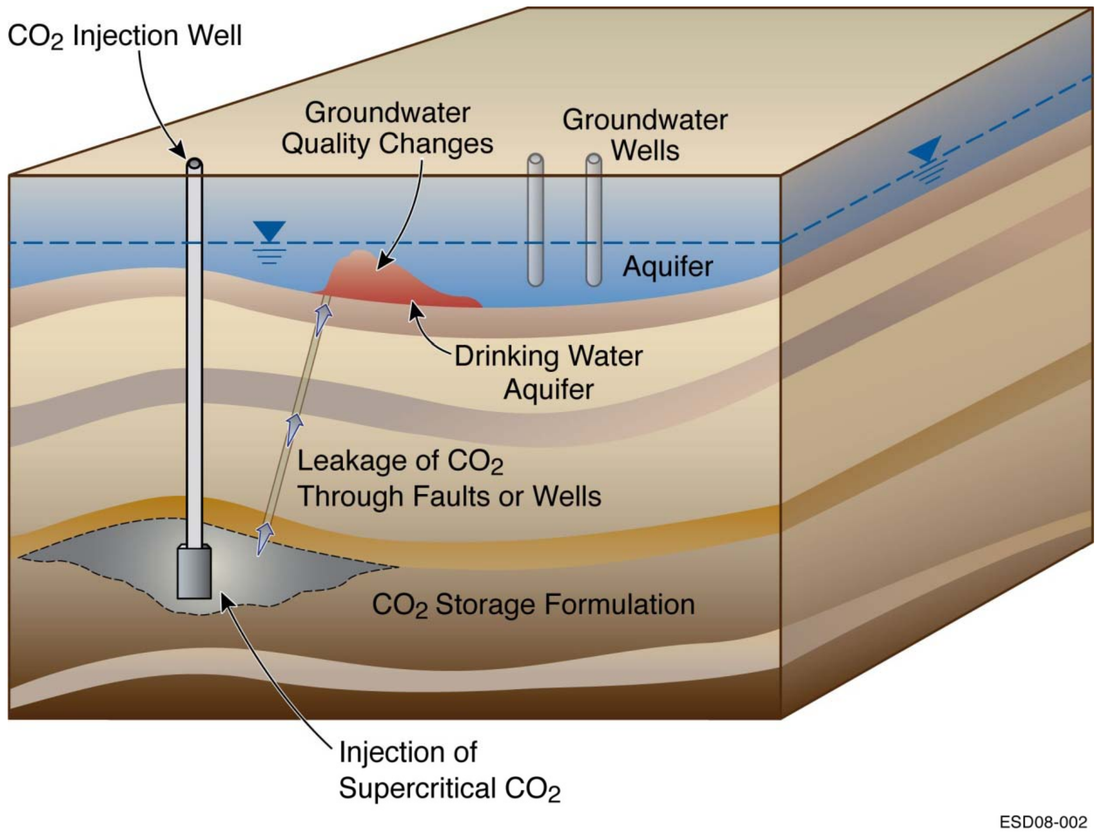
With contributions from:
John Apps, Liange Zheng, Nic Spycher, Yingqi Zhang, Tianfu Xu (LBNL)
Yousif Kharaka, Jim Thordsen, Evangelos Kakouros (USGS)

CO_2 Leakage from Geologic Storage and Possible Impact on Groundwater



Main Concern: **Increased acidity in response to CO_2 leakage into aquifer may mobilize hazardous trace elements**

Two Recent or Ongoing Research Projects



- **Project A: Systematic prediction of CO_2-related mobilization of hazardous trace elements in groundwater using reactive-transport model**
- **Project B: Field experiment with shallow CO_2 release and measurements of geochemical changes**

Project A: Systematic Quantification of Leakage Impacts

- **Part 1: Geochemical Model Development**

  1a. Literature and Data Survey

  - How widely are hazardous trace elements distributed in aquifer rocks? What are the likely mineral hosts for hazardous trace elements?

  1b. Evaluation and Thermodynamic Equilibrium Analysis of 38,000 Groundwater Samples from USGS NWIS Database

  - What are typical geochemical conditions in U.S. aquifers? What is the initial abundance of hazardous trace elements in most groundwaters? Which minerals control the initial aqueous concentrations of these elements?

- **Part 2: Equilibrium Analysis of Water Quality for High P(CO_2)**

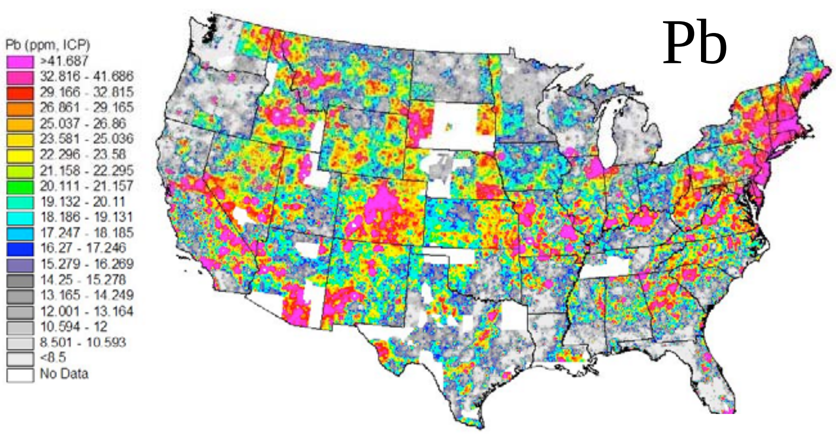
  - Which trace element concentrations are most sensitive to CO_2 intrusion?

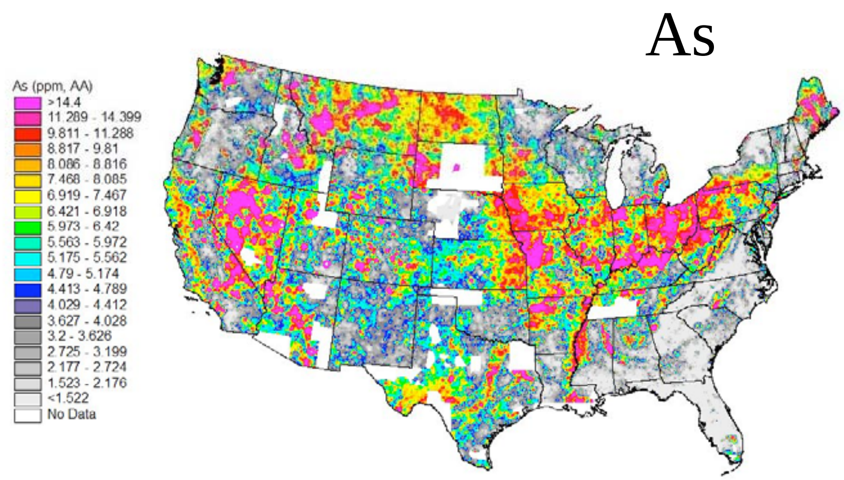
- **Part 3: Systematic Reactive Transport Model Analysis**

  - What is the possible impact of CO_2 intrusion on water quality, considering a wide range of hydrogeological and geochemical conditions?
  - Will drinking water standards be exceeded, and under which conditions?

As and Pb Distribution in Soils

Concentrations in Soils and Surficial Sediments

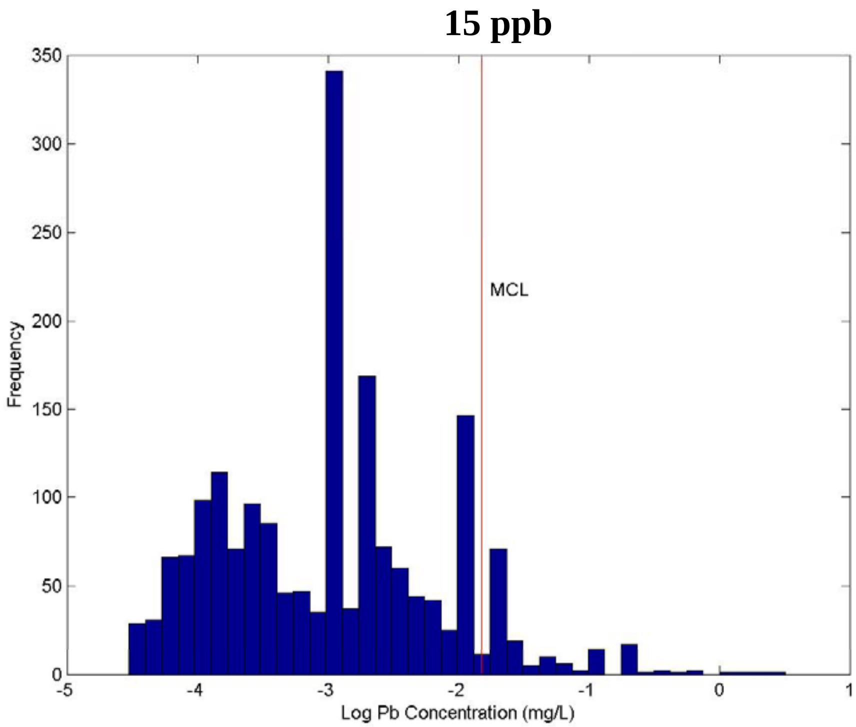




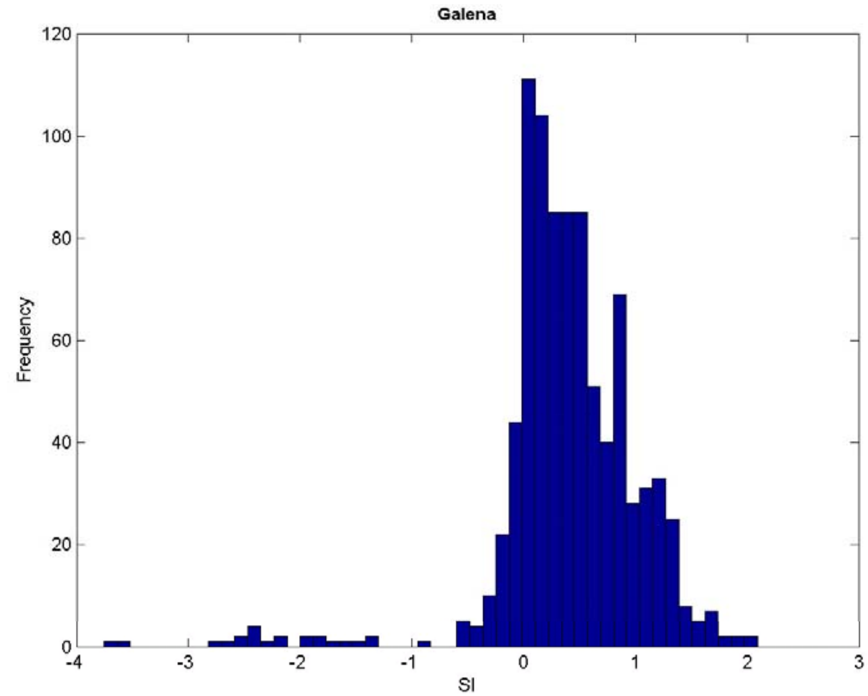
Source: National Geochemical Survey Database, USGS (2008)

Example of Thermodynamic Controls in US Aquifers: Lead

Aqueous Lead Concentration



Saturation Index for Galena



– Samples shown were analyzed with ICP-MS (some analytical artifacts)
– Of all ICP-MS samples, about 50-80% had detectable lead concentrations
– Galena (and/or clausthalite) appear to control aqueous lead concentrations in most samples

Thermodynamic Controls Summary

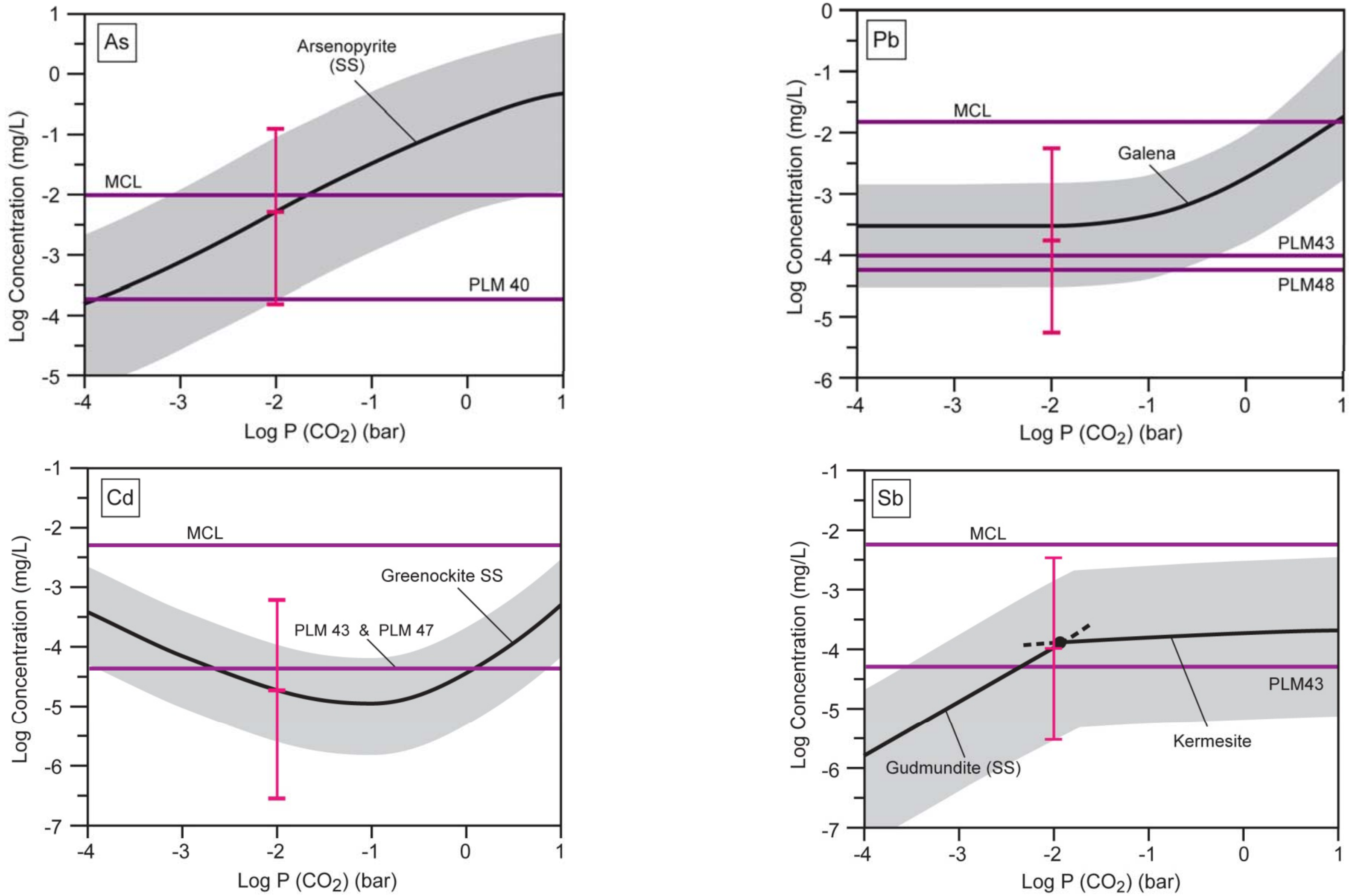
Likely Thermodynamic Controls in Reducing Conditions

Hazardous Trace Element	Solid Solution Component	Discrete Mineral
Arsenic (As)	in Pyrite	Arsenopyrite (SS)
Barium (Ba)	-	Barite
Cadmium (Cd)	in Sphalerite	Greenockite (SS), Cadmoselite
Mercury (Hg)	in Pyrite	Cinnabar (SS), Tiemannite
Lead (Pb)	-	Galena, Clausthalite
Antimony (Sb)	in Pyrite	Gudmundite (SS), Kermesite
Selenium (Se)	in Pyrite	Dzharkenite, Cadmoselite, Tiemannite, Clausthalite,
Uranium (U)	-	Uraninite, Coffinite
Zinc (Zn)	-	Sphalerite

Part 2: Equilibrium Analysis

Aqueous Concentrations at Elevated CO_2 Concentrations

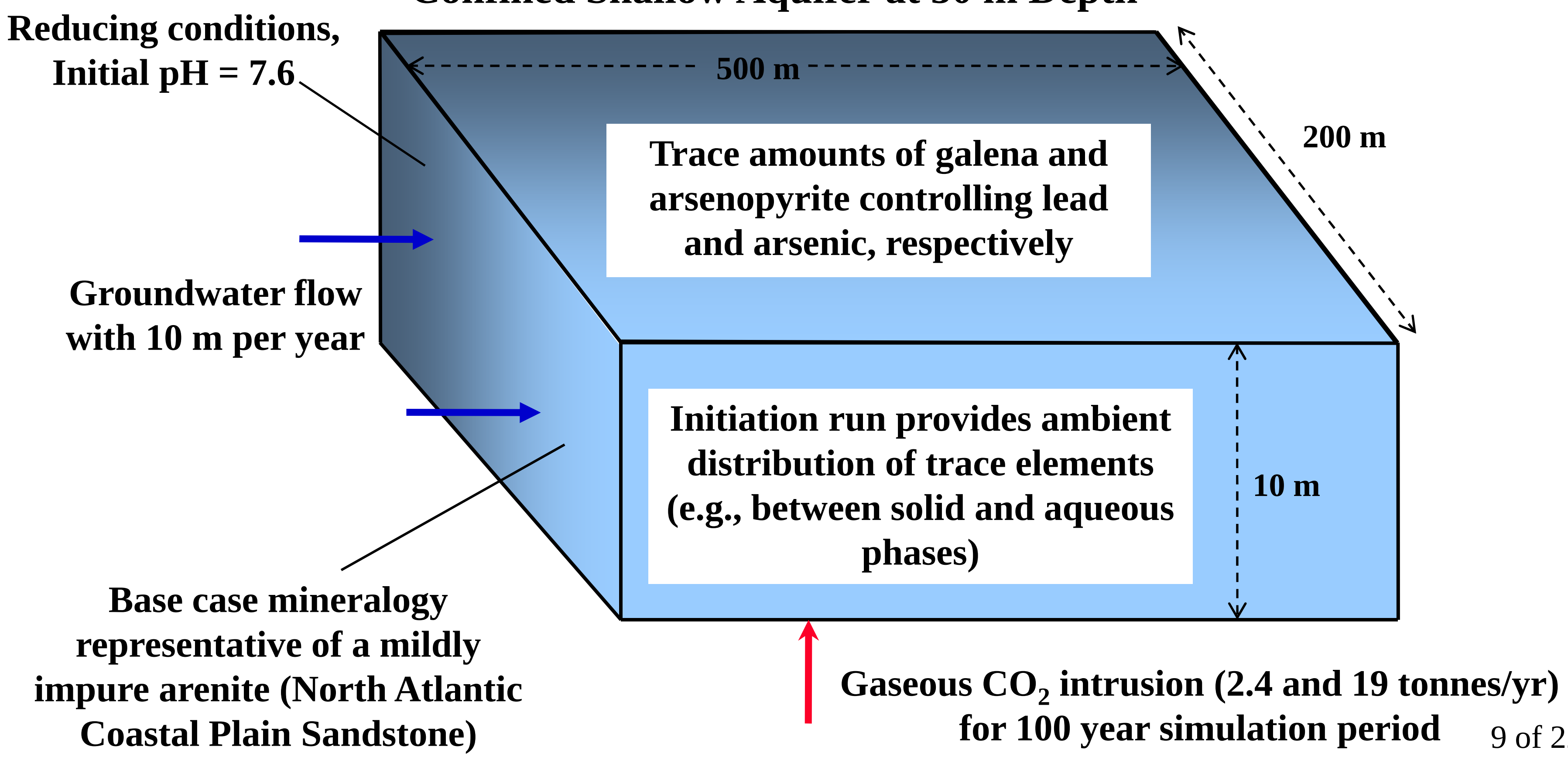
(initial pH = 7.6, reducing conditions, calcite saturation)



Part 3: Reactive Transport Modeling

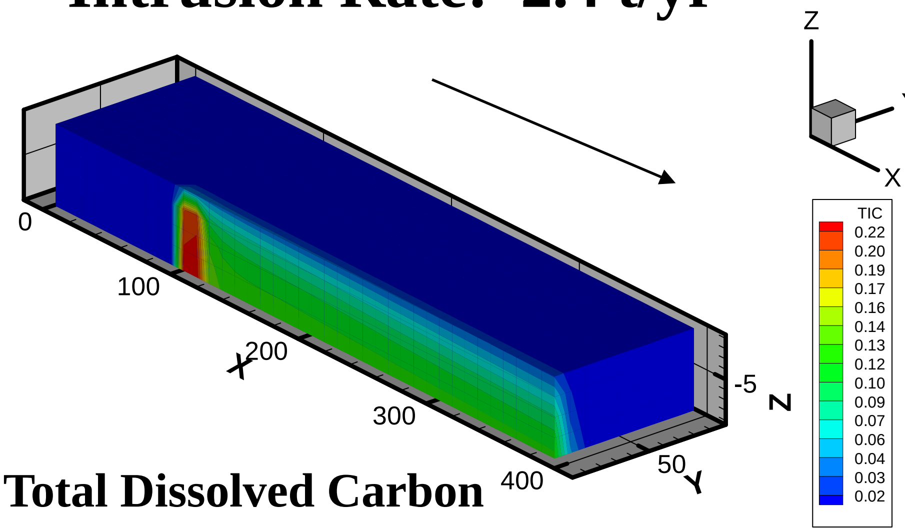
- Simulator TOUGHREACT is used to predict impact of CO_2 intrusion into fresh water aquifer (multiphase flow plus reactive transport)
- Geochemical model based on groundwater analyses and geochemical evaluation
- Various sensitivity cases

Confined Shallow Aquifer at 50 m Depth



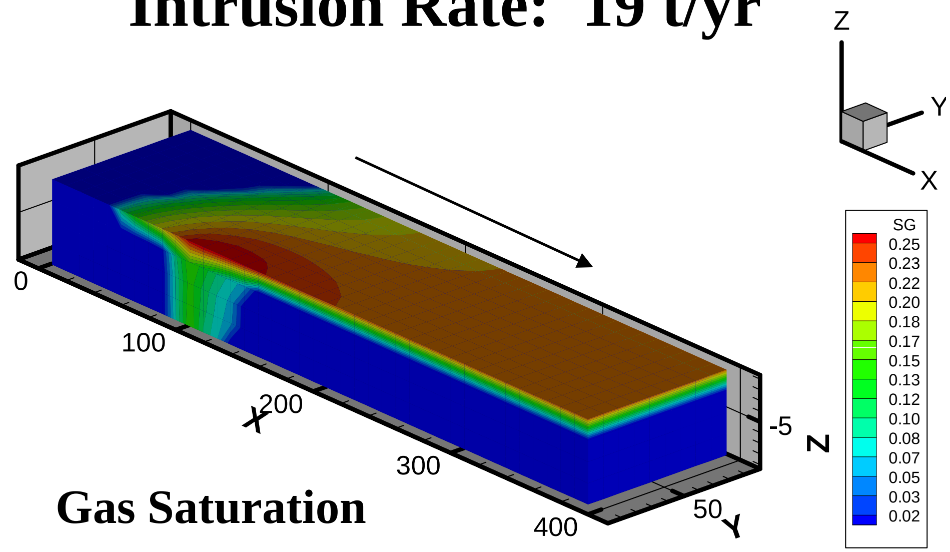
CO_2 and pH at 100 years

Intrusion Rate: 2.4 t/yr

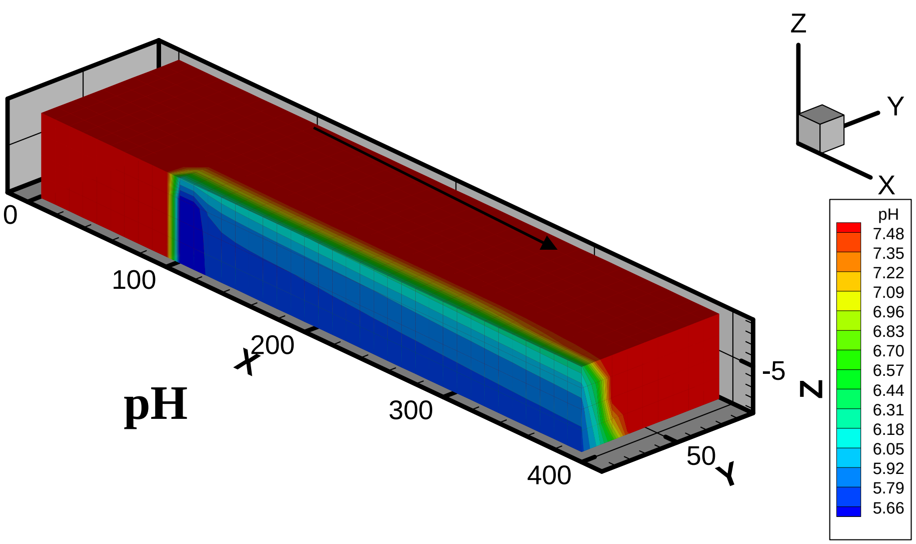


Total Dissolved Carbon

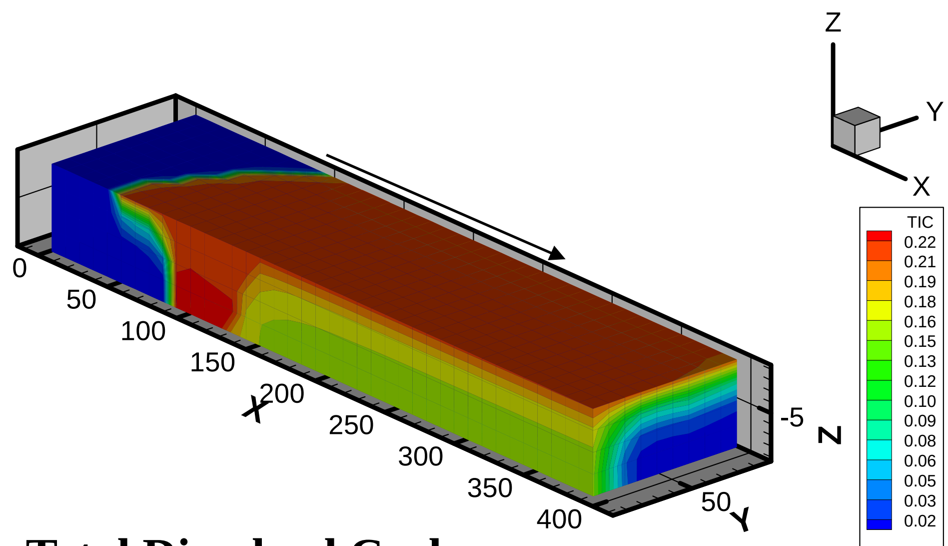
Intrusion Rate: 19 t/yr



Gas Saturation



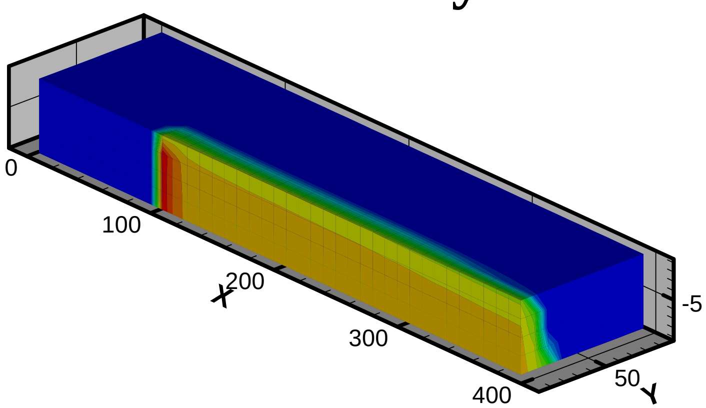
pH



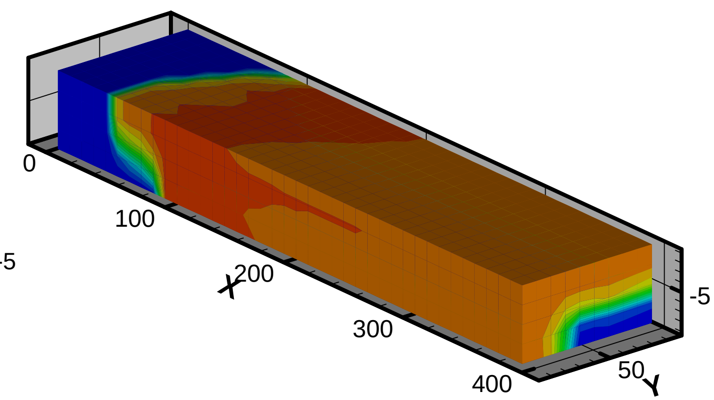
Total Dissolved Carbon

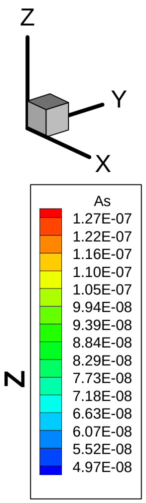
Aqueous Arsenic Concentrations

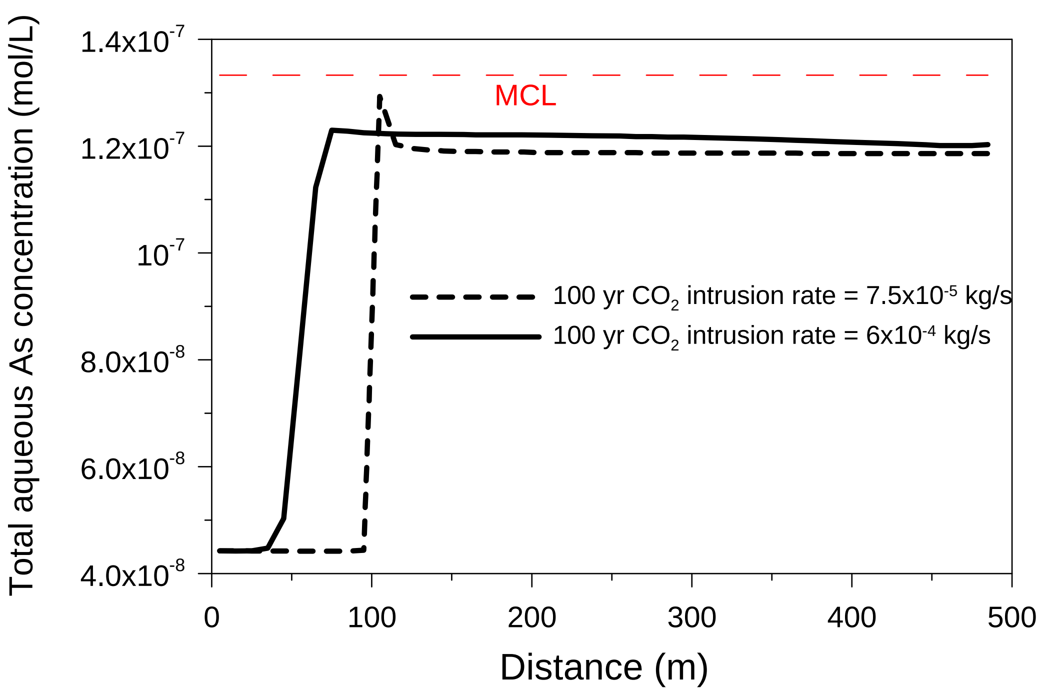
2.4 t/yr



19 t/yr

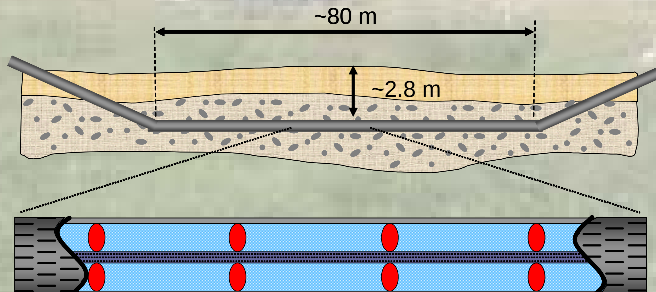






Arsenic Concentration at 100 years

Project B. Field Experiment at ZERT Shallow Release Facility in Montana



Slotted Stainless Pipe With Internal CO_2 Pipe & Packer System for Even Gas Distribution

Facility Goals, Rationale, and Design

- Develop a well–characterized site
- Apply known CO_2 injection rates for testing near-surface monitoring
- Use this site to establish detection limits for monitoring technologies
- Use this site to improve flow and transport models
- Develop a site that is accessible and available for multiple seasons / years

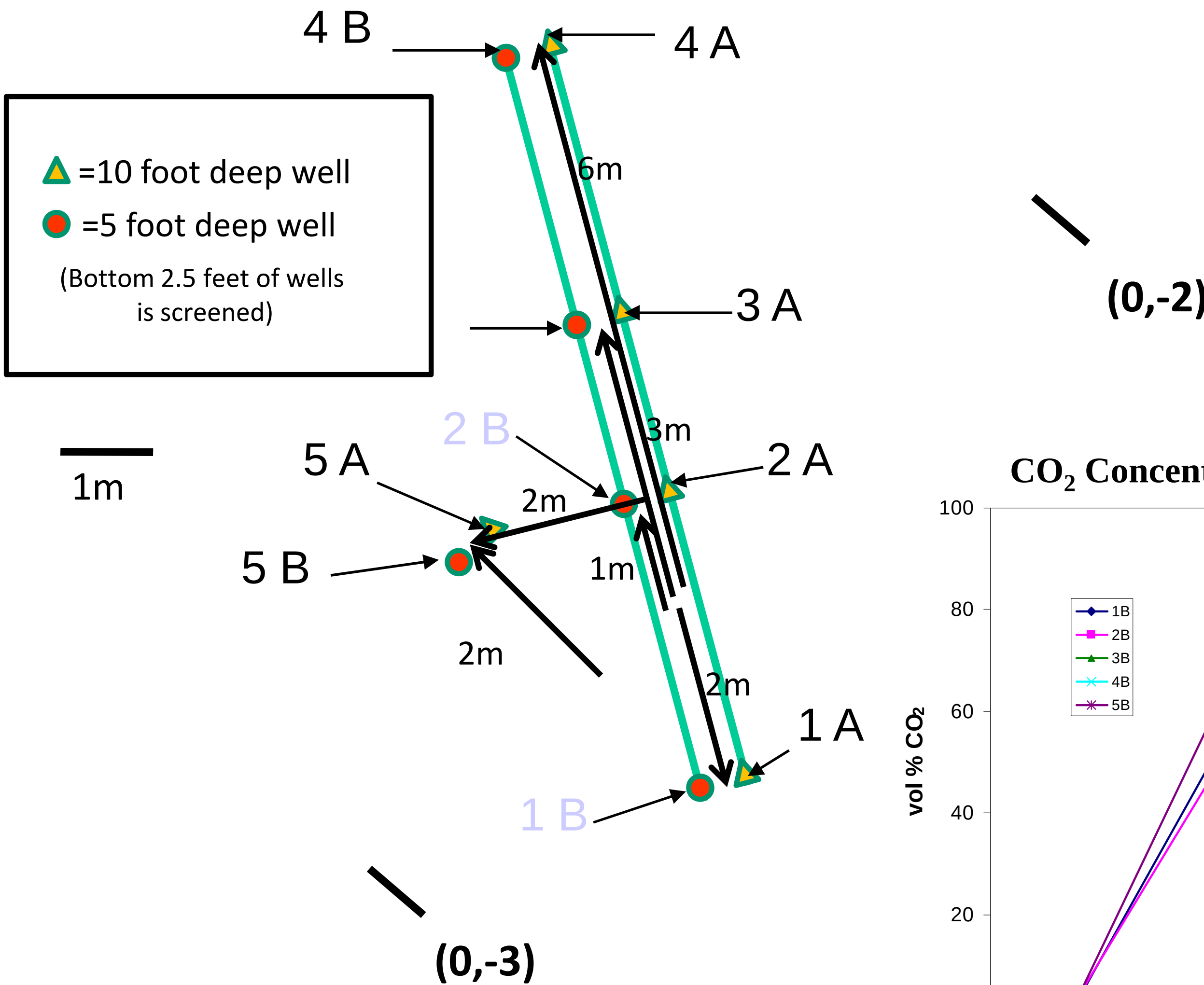
Activities to Date

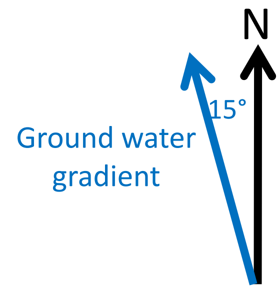
- 2006—Characterization, vertical-well injections, horizontal well installation
- 2007—Year 1 Shallow-release
  - Ph. 1 100 kg/day for 10 days
  - Ph. 2 300 kg/day for 7 days
- 2008—Year 2 Shallow-release
  - Ph. 1 300 kg/day for 30 days

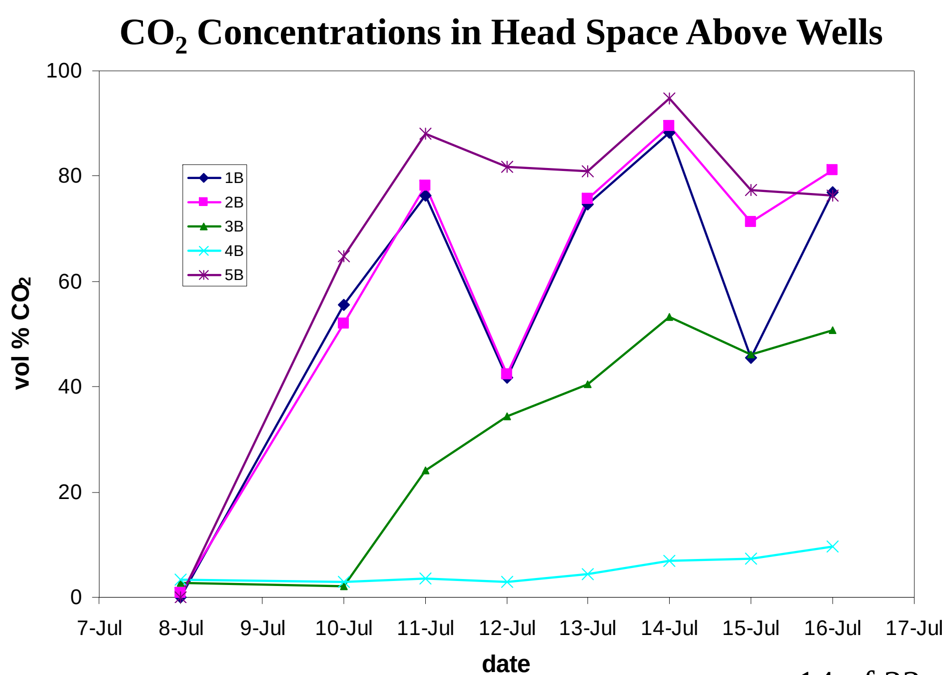
Courtesy of Lee Spangler, MSU

Chemical composition of shallow groundwater at ZERT before, during and following 2008 CO_2 injection: Collaborative effort by LBNL and USGS

Shallow Monitoring Wells

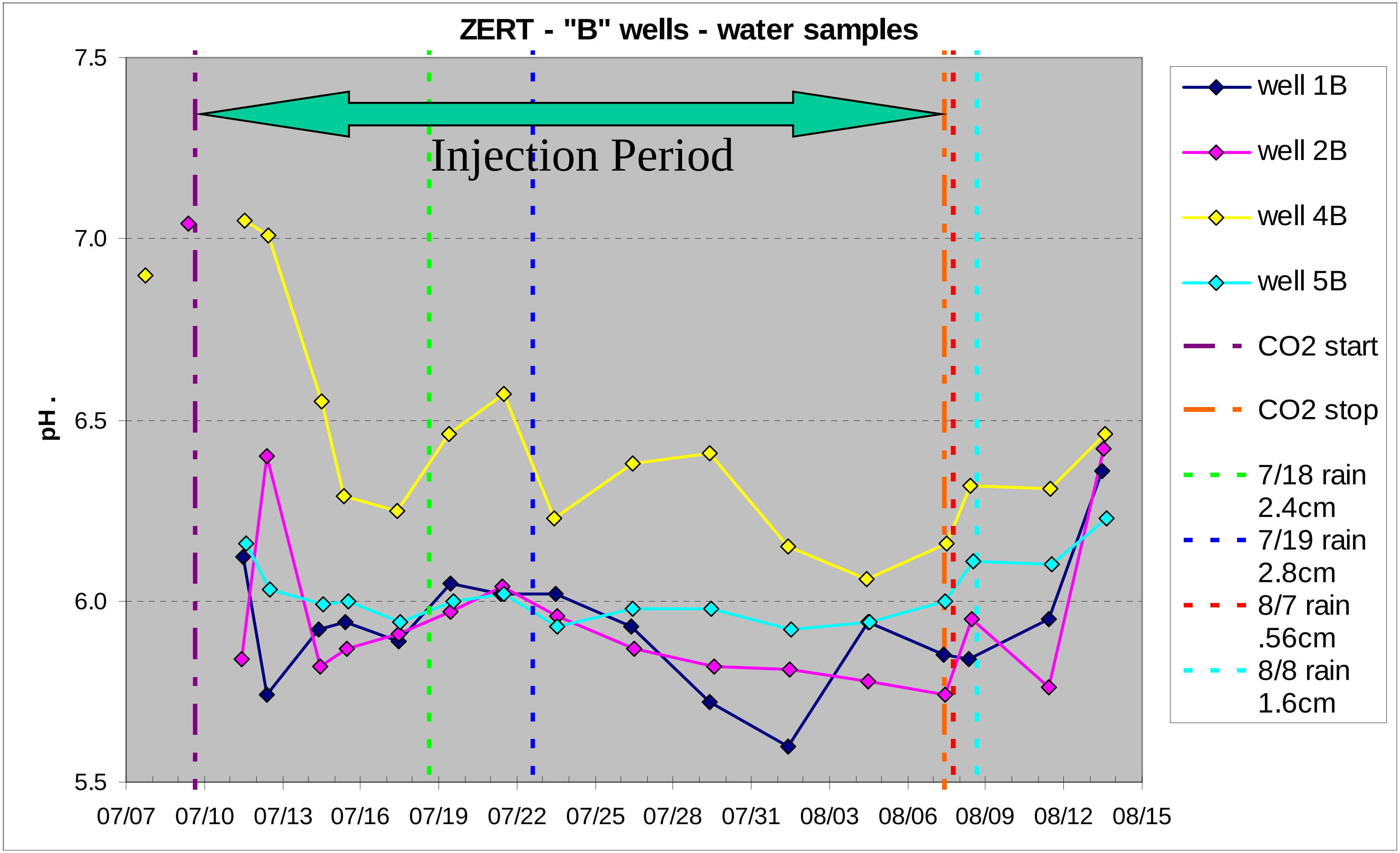






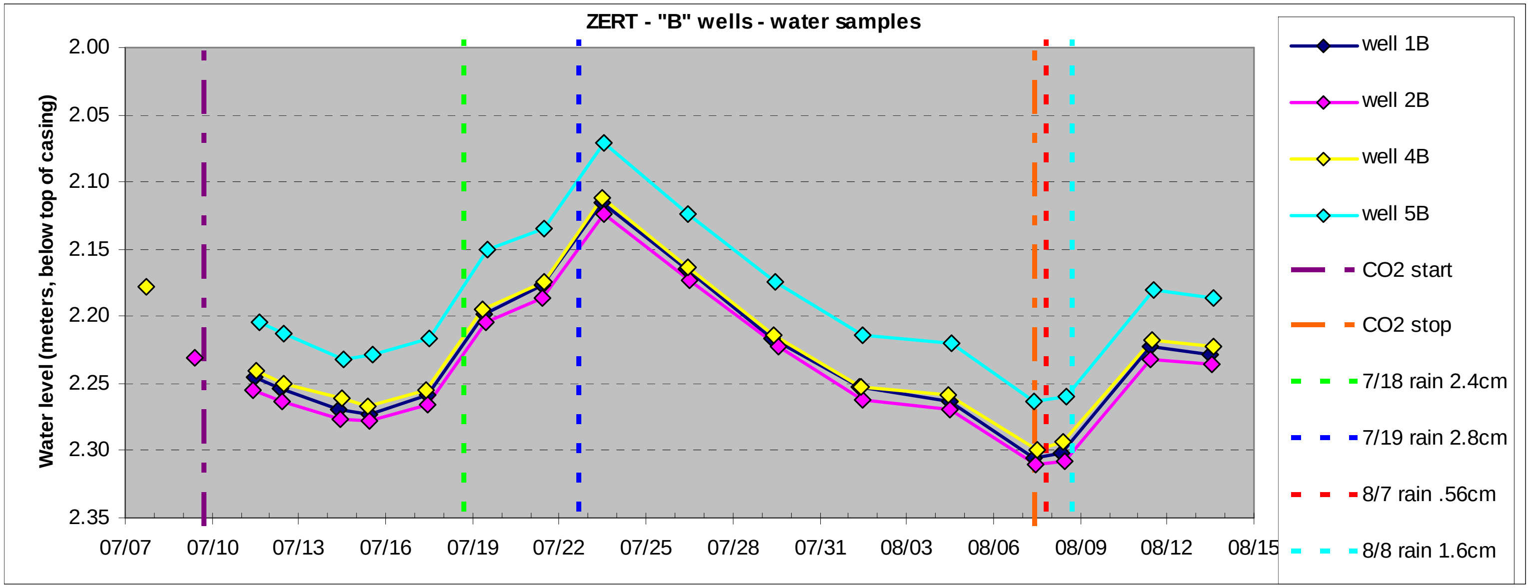
Courtesy of Lee Spangler, MSU

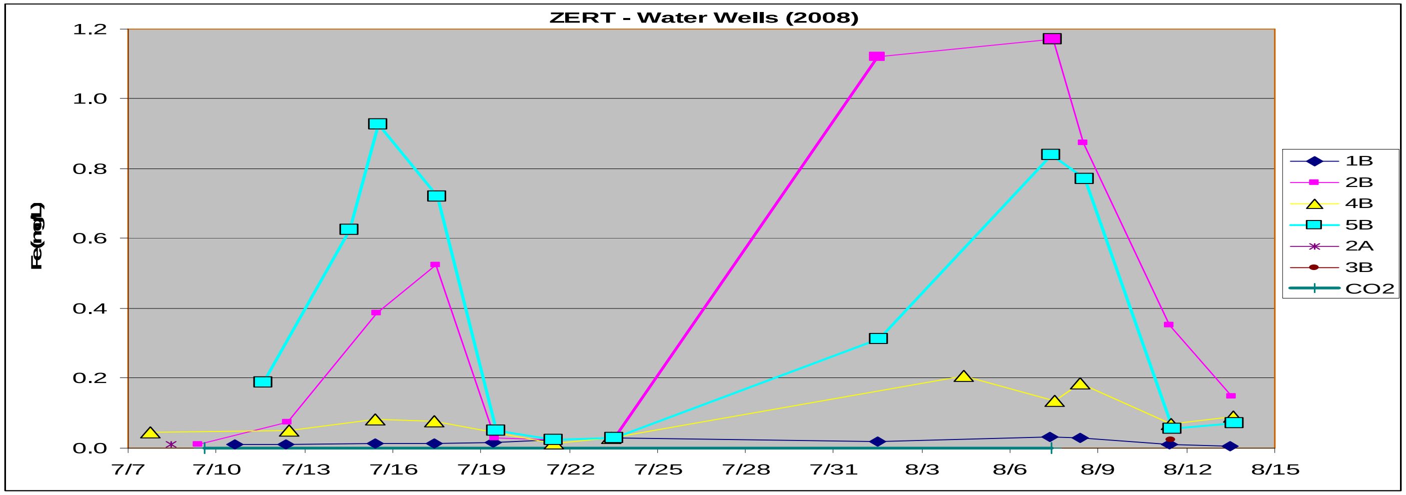
Evolution of pH



Courtesy of Yousif Kharaka, USGS

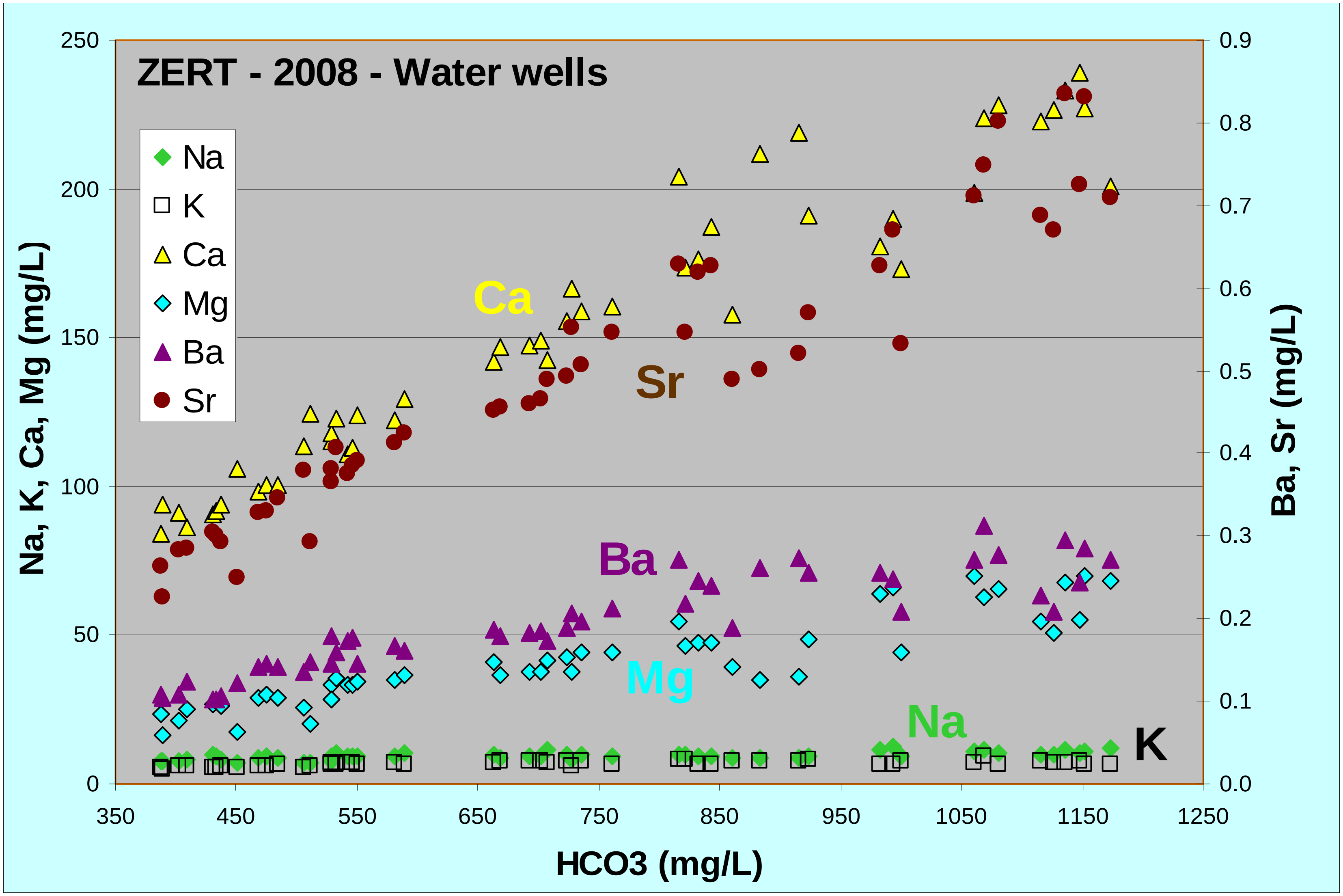
Water Levels and Fe versus Time





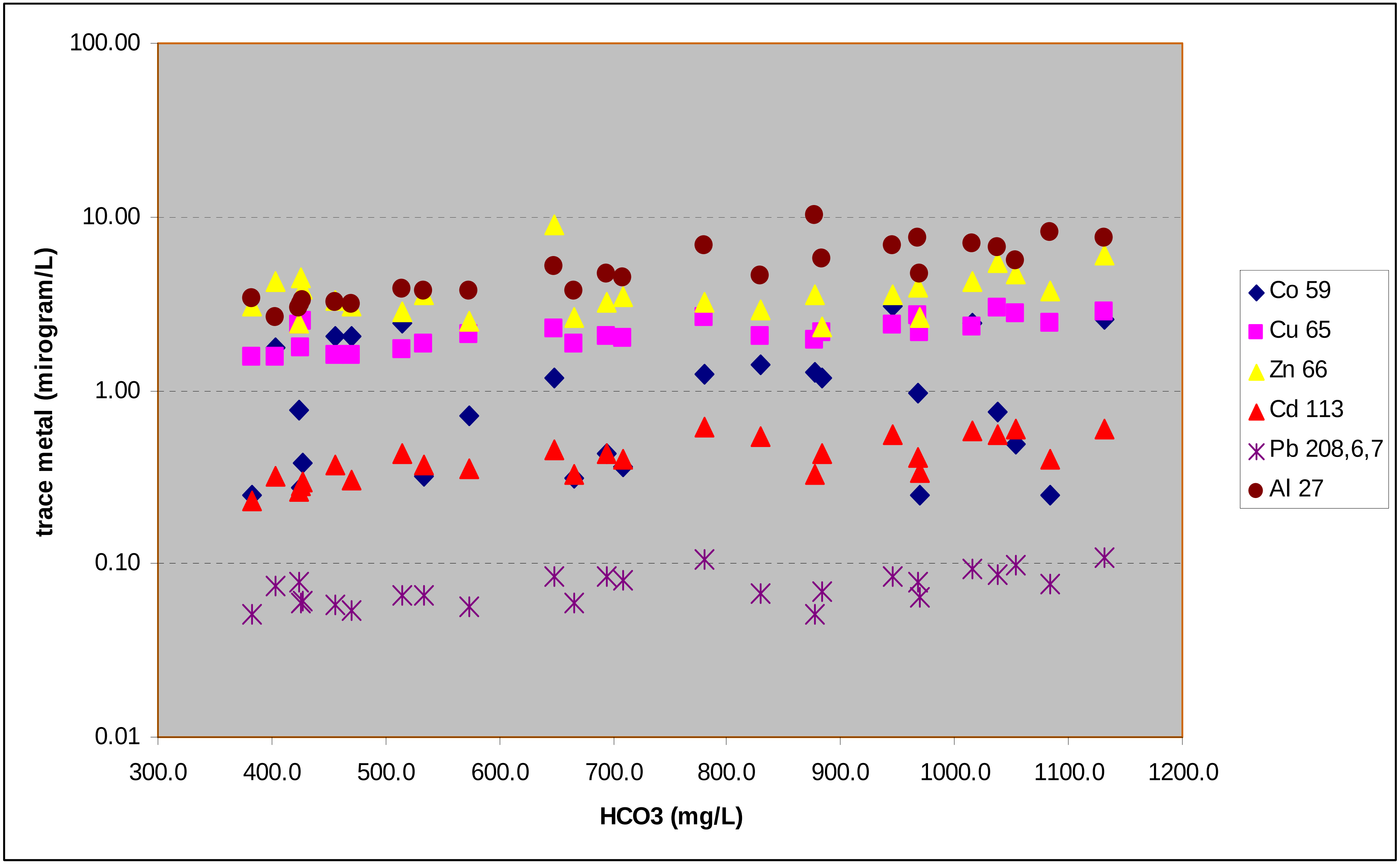
Courtesy of Yousif Kharaka, USGS

Major Cations vs HCO3



Courtesy of Yousif Kharaka, USGS

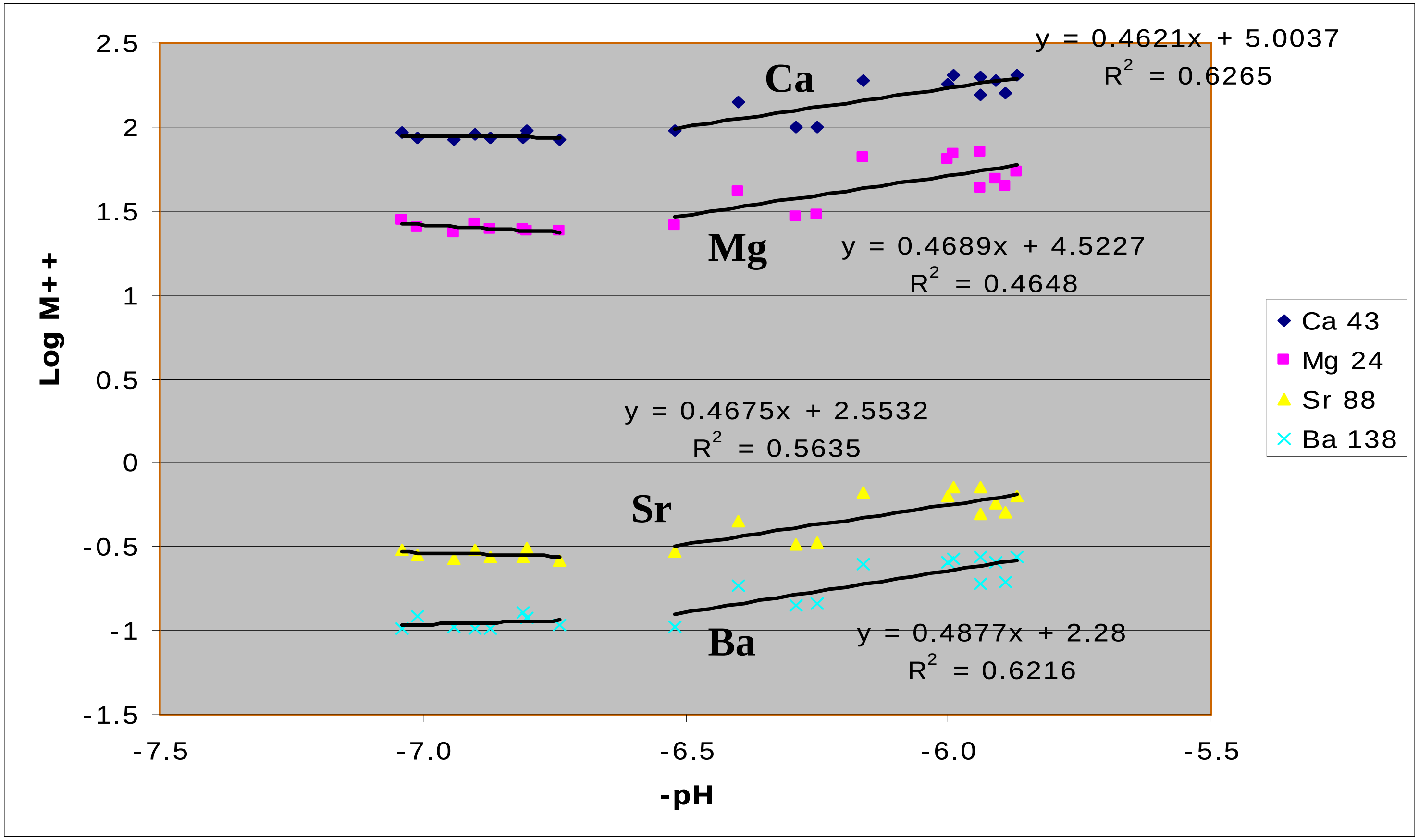
Trace Metals vs HCO3



Courtesy of Yousif Kharaka, USGS

Metals vs pH

Short-Term Response Suggest pH Controlled Desorption Below pH of 6.7



- Data analyzed are from early period before first rainfall
- Adsorption reaction with about 0.5 log-slope suggests desorption of bivalent metals
- Same correlation seen for Cadmium and Lead

Conclusions on Groundwater Impacts

Conclusions from Systematic Evaluation

- Many aquifers in the United States and worldwide contain trace amounts of hazardous trace elements that can be mobilized in the case of CO_2 intrusion.
- CO_2-related mobilization can increase aqueous concentrations of hazardous trace constituents in shallow groundwater resources. However, in reducing environments, drinking water standards should be not be exceeded in most cases. Stronger impact may be seen in oxidizing environments.
- Predictions of water quality changes have wide uncertainty and variability ranges.

Conclusions from ZERT Experiment

- CO_2 injection caused fast and systematic changes in pH, resulting in strong increases in the concentrations of major cations.
- Increases were also seen in most hazardous trace elements, but drinking water standards were not exceeded (possibly because duration of experiment was too short).
- Desorption/ion exchange are likely processes responsible for observed concentration increases.

Some Background on Possible Groundwater Quality Impacts

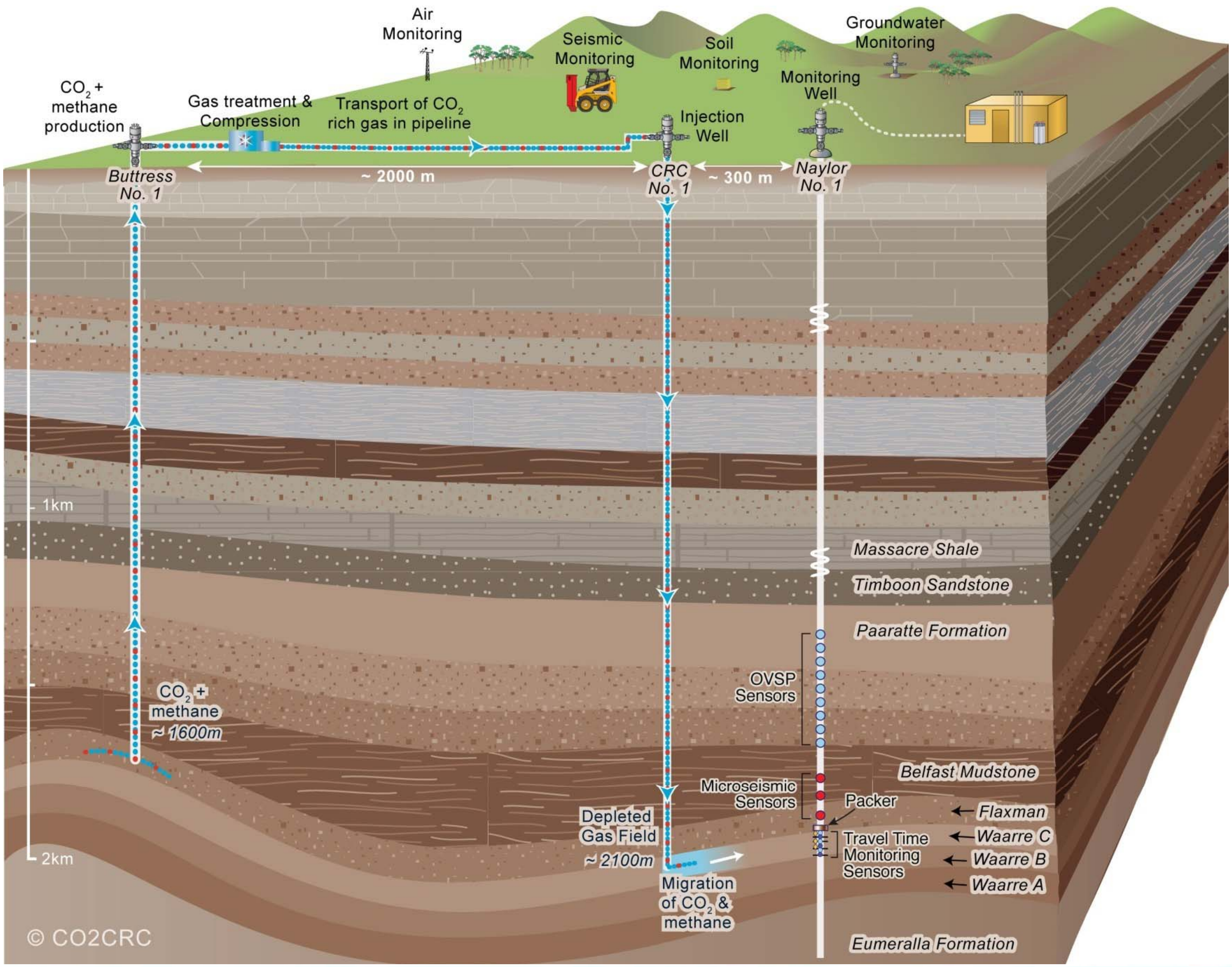
- **Wang and Jaffe, Energy Conversion and Management, 45, 2004**
  - Simulation of CO_2 intrusion into shallow groundwater shows increase in lead concentrations, for very simplified host rock mineralogies
- **Kharaka et al., Geology, 34, 2006**
  - Strong increases in trace metal concentrations following CO_2 injection in a deep storage formation at Frio
- **Lewicki et al., Environmental Geology, 52, 2007**
  - Natural analogs show acidification of groundwater and changes in chemical composition, but waters remain potable in most cases
- **McGrath et al., Ground Water Monitoring & Remediation, 27, 2007**
  - Increase in cadmium concentrations in shallow groundwater (above drinking water limits), related to CO_2 releases from a municipal landfill
- **Smyth et al., Proceedings GHGT-9, 2008**
  - Increases in cation concentrations measured in laboratory batch experiments of diverse aquifer rocks exposed to CO_2-water mix
  - Comparison of water samples from aquifers in SACROC region show no trend of degradation below drinking water standards

CO2CRC
The Otway Project

Charles Jenkins,
Manager, Monitoring & Verification

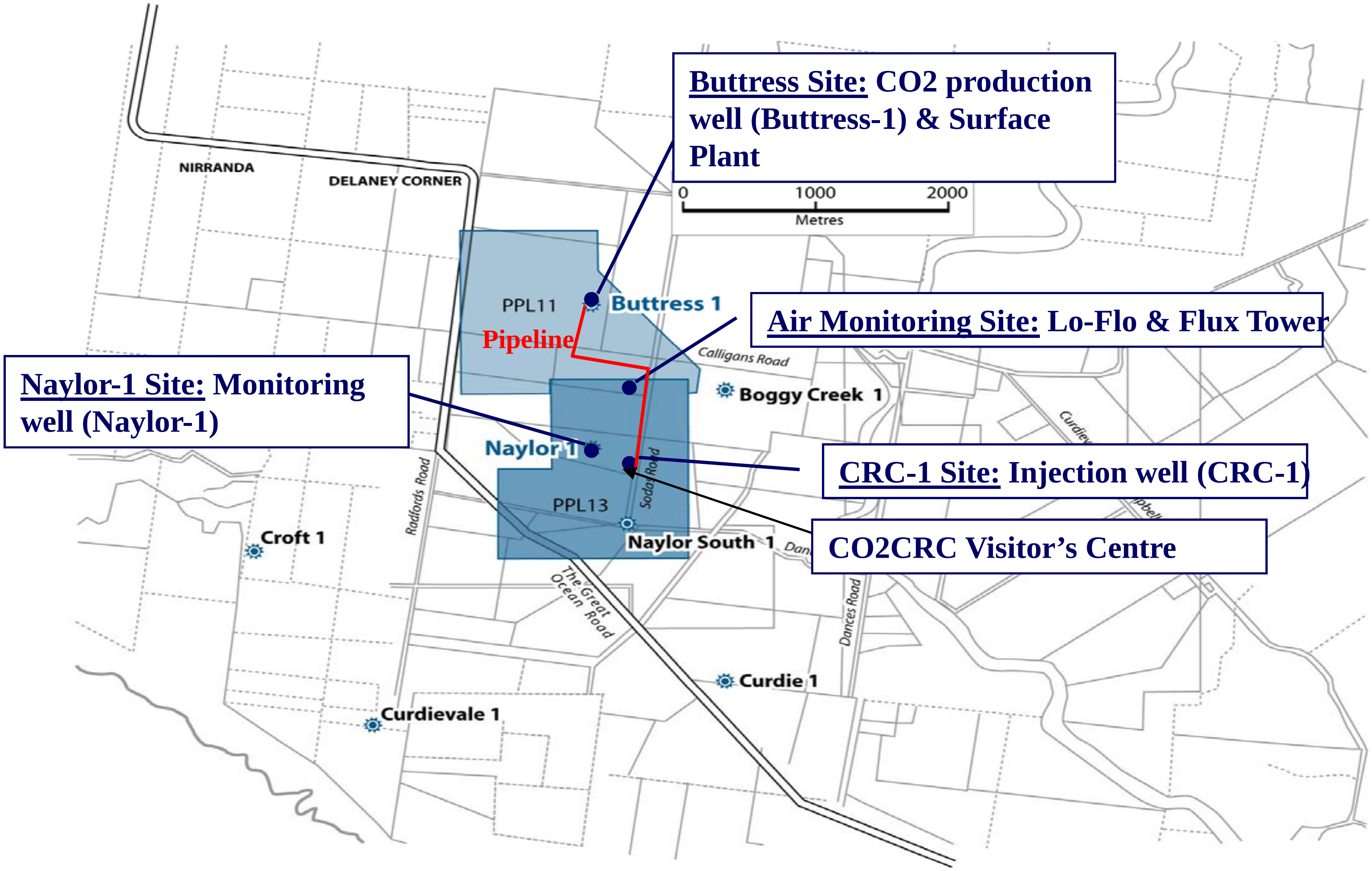
CO2CRC

The Otway storage project

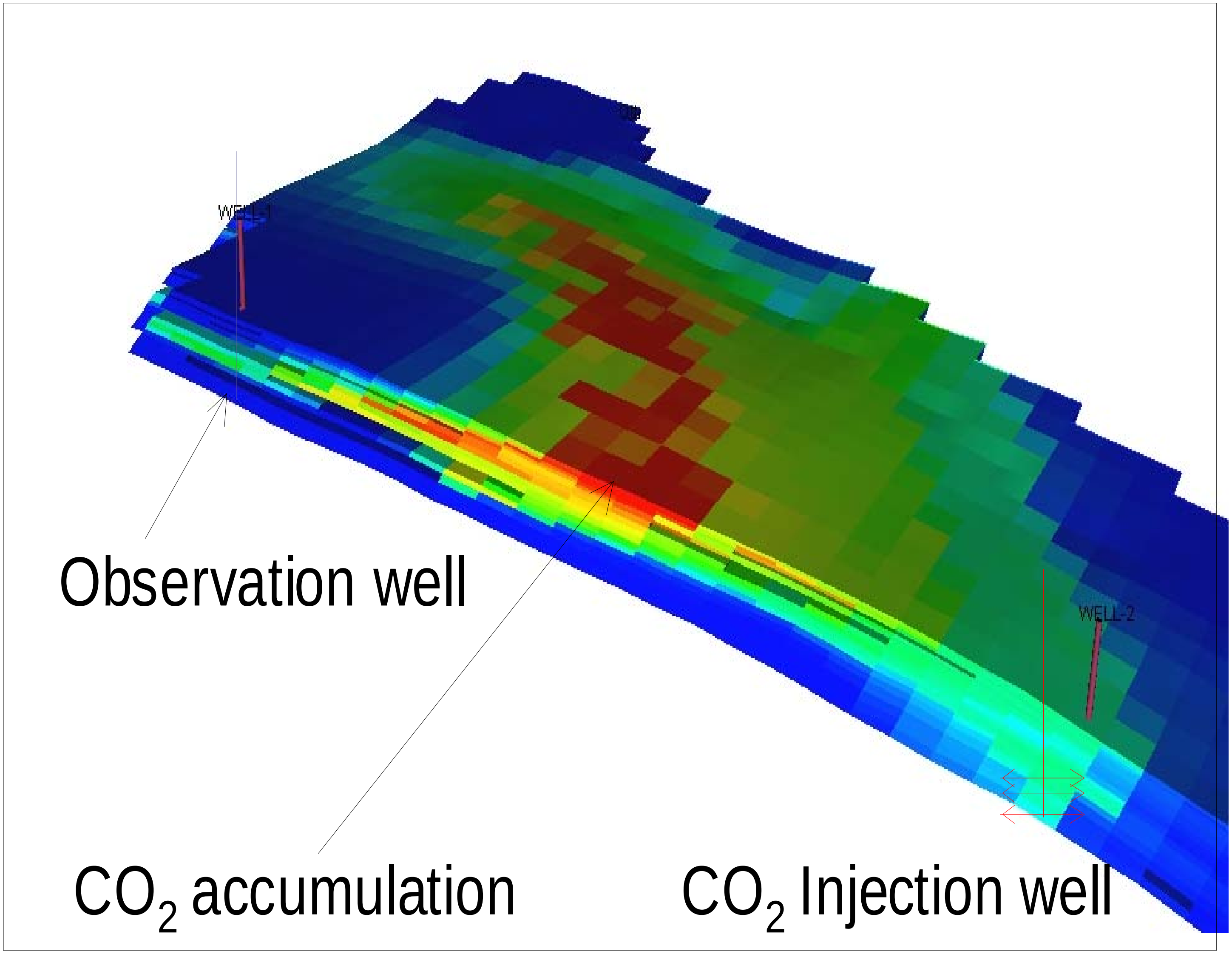


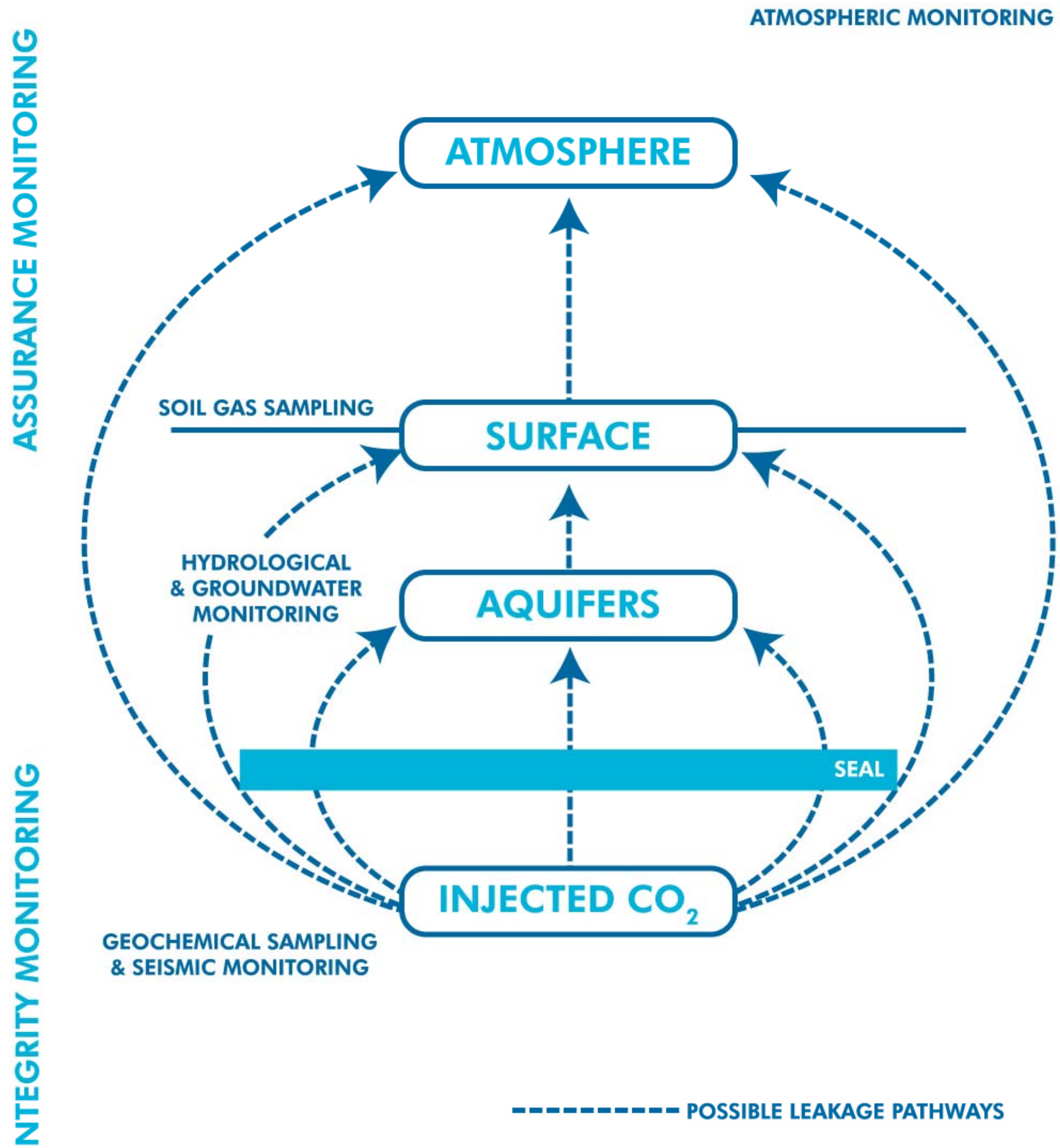
Air Monitoring
Seismic Monitoring
Soil Monitoring
Groundwater Monitoring
CO_2 + methane production
Gas treatment & Compression
Transport of CO_2 rich gas in pipeline
Injection Well
Monitoring Well
Buttress No. 1
~ 2000 m
CRC No. 1
~ 300 m
Naylor No. 1
1km
2km
Massacre Shale
Timboon Sandstone
Paaratte Formation
OVSP Sensors
CO_2 + methane ~ 1600m
Belfast Mudstone
Microseismic Sensors
Packer
Flaxman
Waarre C
Waarre B
Waarre A
Travel Time Monitoring Sensors
Depleted Gas Field ~ 2100m
Migration of CO_2 & methane
Eumeralla Formation
© CO2CRC

CO2CRC Otway Project facilities



The conceptual model





ASSURANCE MONITORING
INTEGRITY MONITORING
ATMOSPHERIC MONITORING
ATMOSPHERE
SOIL GAS SAMPLING
SURFACE
HYDROLOGICAL & GROUNDWATER MONITORING
AQUIFERS
SEAL
INJECTED CO_2
GEOCHEMICAL SAMPLING & SEISMIC MONITORING
POSSIBLE LEAKAGE PATHWAYS

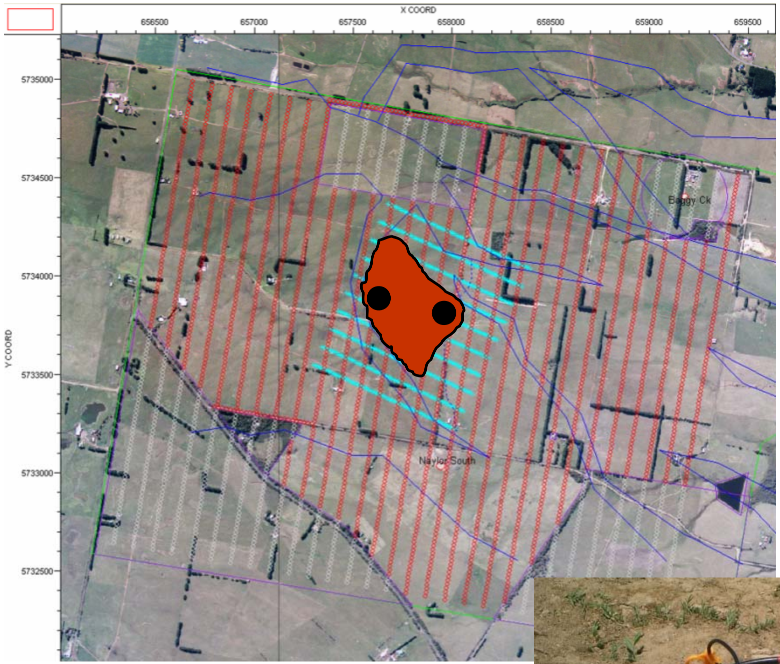
- Gregory (Scotland Yard detective): "Is there any other point to which you would wish to draw my attention?"
- Holmes: "To the curious incident of the dog in the night-time."
- Gregory: "The dog did nothing in the night-time."
- Holmes: "That was the curious incident."

- *From "Silver Blaze” by Sir Arthur Conan Doyle*

3D surface seismic monitoring (Subsurface)

GEOPHYSICS
ASSURANCE MONITORING/
STORAGE INTEGRITY MONITORING

Objective: **to map the migration path of CO_2 plume from injector to producer**



Methods: **4D or time-lapse surveys**

Repeatability of surveys before, during and after the CO_2 injection is very important for every aspect of acquisition (source and receivers positioning; source signal; hardware; time of year; processing)

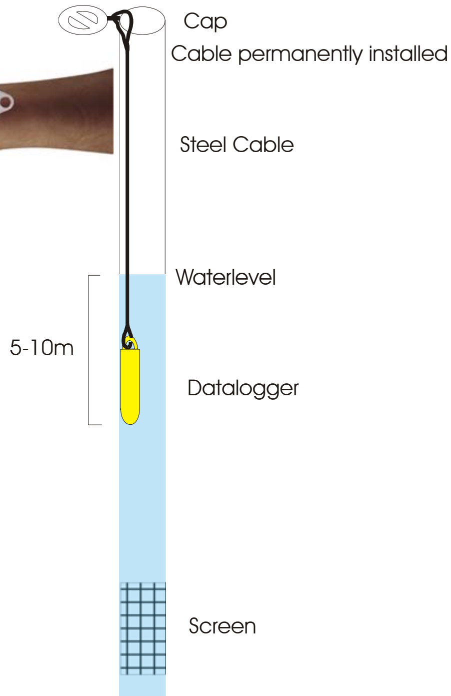
Hydrodynamics & groundwater Monitoring (Near-Surface)

GEOCHEMISTRY
ASSURANCE MONITORING

Objective:
- Monitor water levels to determine seasonal variation, flow rate and direction
- Identify any chemical changes associated with possible CO_2 leakage

Methods:
- Dataloggers
- Water chemistry

Aquifers monitored:
- Shallow unconfined Port Campbell Limestone,
- Deep confined Dilwyn aquifer



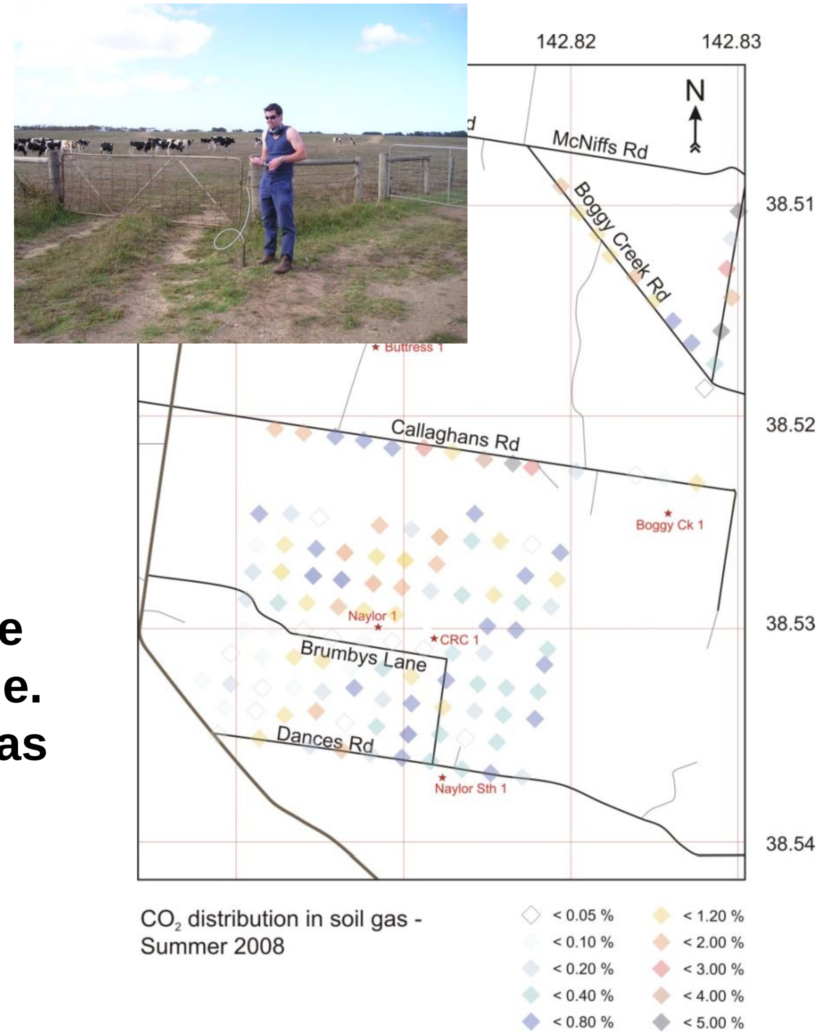
Soil Gas Monitoring (Surface)

GEOCHEMISTRY
ASSURANCE SURFACE MONITORING

Objective:
- **Establish CO_2 variations within the extended area beyond the CO2CRC tenements**
- **Determine the likely source of origin**
- **Differentiate natural from injected CO_2.**

Methods:
- **The soil gas program extracts air from the unsaturated soil zone above the water table.**
- **Samples are analysed on site (portable gas chromatograph) and in the laboratory for CO_2, CH_4 and isotopes.**

Frequency
- **Baseline: Four surveys**
- **Once a year during and after the injection**

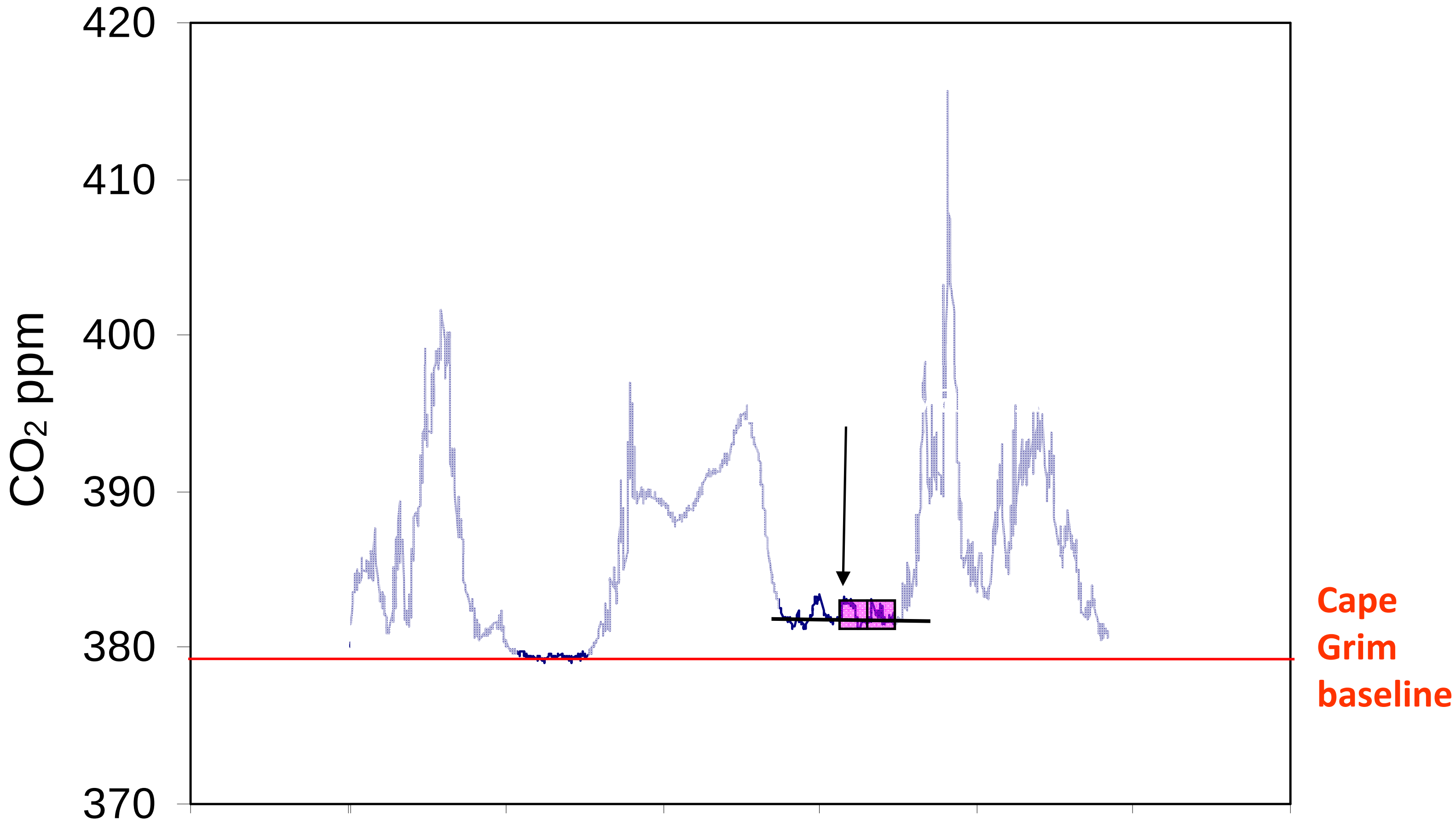


CO_2 distribution in soil gas - Summer 2008

Atmospheric Monitoring

Objectives:
To verify that injected CO2 stays underground; or in the unlikely event of leakage to surface, demonstrate the capacity to detect and quantify surface leakage

Atmospheric monitoring

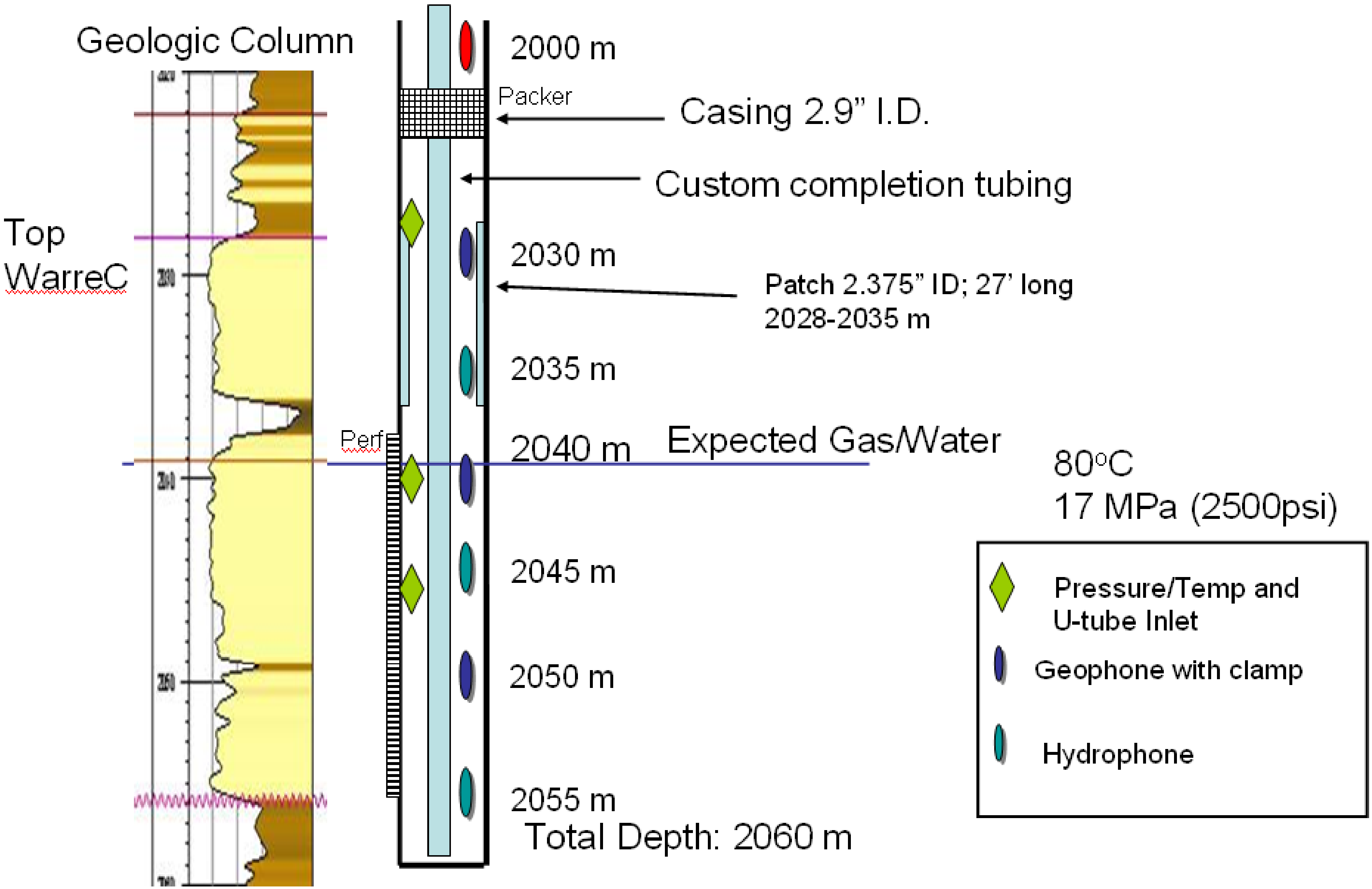


Downhole fluid sampling

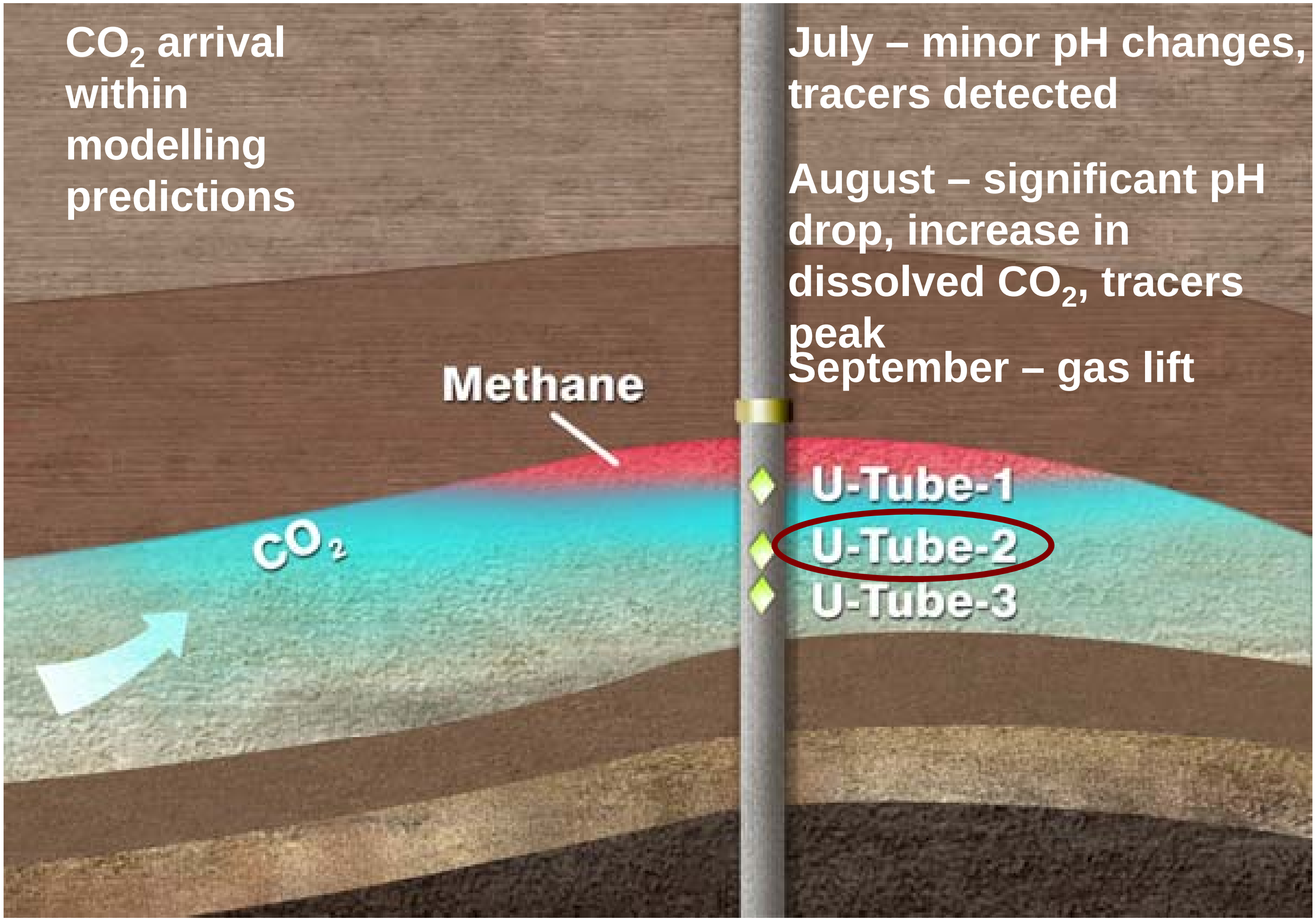
Figure X – U-tube surface facility (yellow container) – above

Figure X – Isotube sample cylinder – left

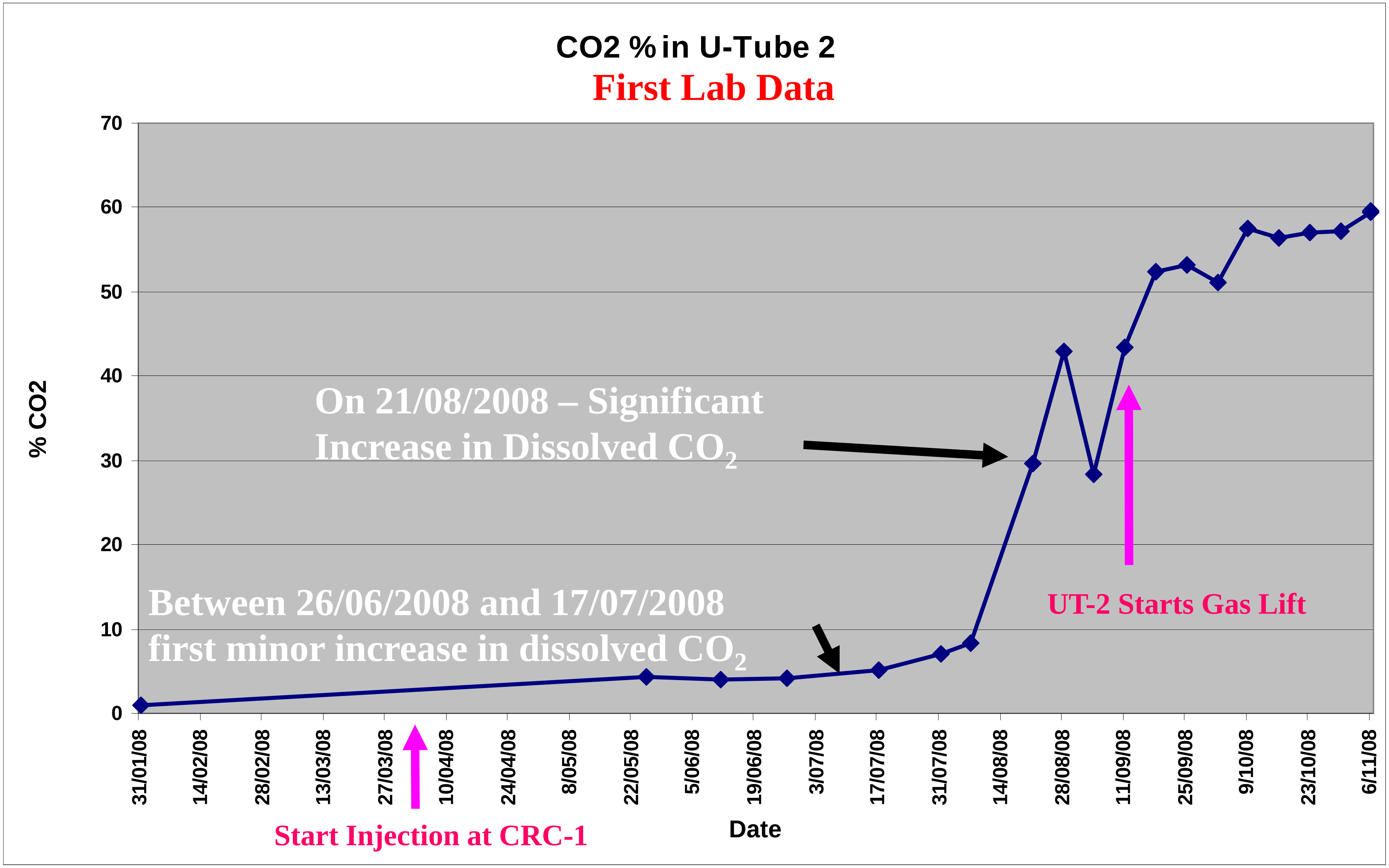
Figure X – Inside the u -tube surface facility - right


Geologic Column
Top
WarreC
Perf
2000 m
Packer
Casing 2.9" I.D.
Custom completion tubing
2030 m
Patch 2.375" ID; 27' long
2028-2035 m
2035 m
2040 m
Expected Gas/Water
80°C
17 MPa (2500psi)
2045 m
2050 m
2055 m
Total Depth: 2060 m
Pressure/Temp and
U-tube Inlet
Geophone with clamp
Hydrophone

Injection phase: U-Tube-2 results



Initial Results of U-Tube Sampling



What does the “V” in M&V refer to?

•*Phase 1A*

•1. Establish injection and migration models and uncertainties.

•*Phase 1B*

•2. Environmental impacts within SEPP bounds.

•3. Injection/Migration within model prediction bounds.

•*Phase 2*

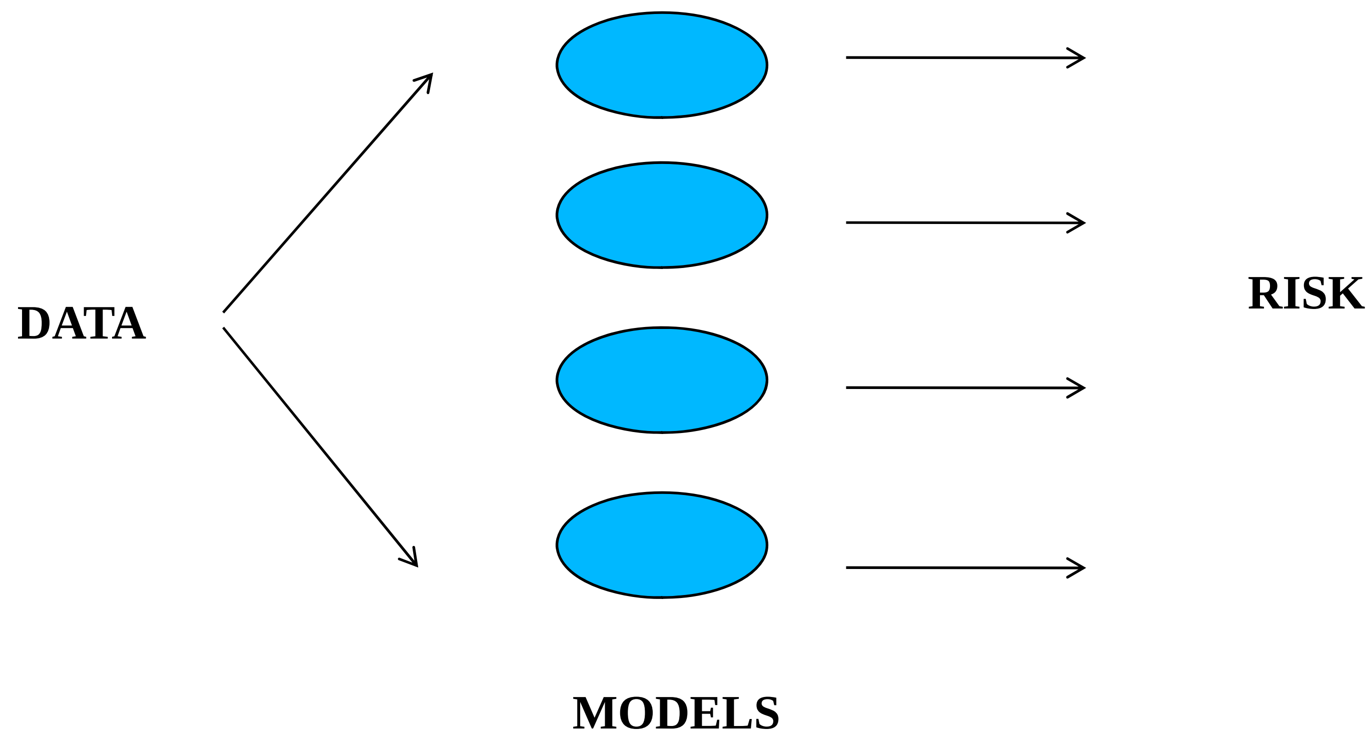
•4. Verified stable plume within model prediction.

•4a Measurements (logs) show no evidence of injected CO_2 beyond secondary containment in Naylor -1 and CRC-1

•4b Air samples collected from existing deep-water wells show no evidence of the injected CO_2. There are four such wells that are monitored by DSE and Southern Water.

•4c Air samples collected over a few days in the proximity of the Naylor-1 and CRC-1 wells shows no evidence of the injected CO_2.

Models and Risk



Longer-term “V” questions

- M&V programme developing range of capabilities in the “M”
- What we are trying to “V” is also a research question
- Risks over a range of timescales and sizes
- Health & safety
- Financial – accounting the stored CO_2
- Climate – so we make a nett abatement
- Geological – do any of the remote risks make sense?
- Probably only the first is well enough posed to design the “M” in a scientific sense, or say how it connects to the risks

Questions of principle

- What should we measure? What do we want to know?
- How sensitive should our measurements be (signal-to-noise)
- What spatial and temporal coverage do we need (where and when should we look)?
- Can we interpret the measurements we make? How do we extrapolate in time and space?
- Can we invert the measurements we make?
- Because models are missing (outside the reservoir) we are in the exploration/correlation/building up experience phase of enquiry
- Pooling of experience with risks and outcomes is vital.


Thank you
N
W
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S

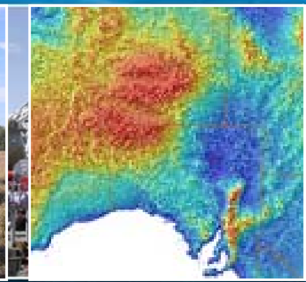
RESTRICTED

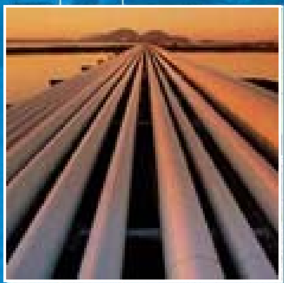
Geostorage Risk Assessment (Shell)

Martin Jagger, Alf Garnett , Simon James

IEA GHG RISK ASSESSMENT WORKSHOP

APRIL 16TH 2009

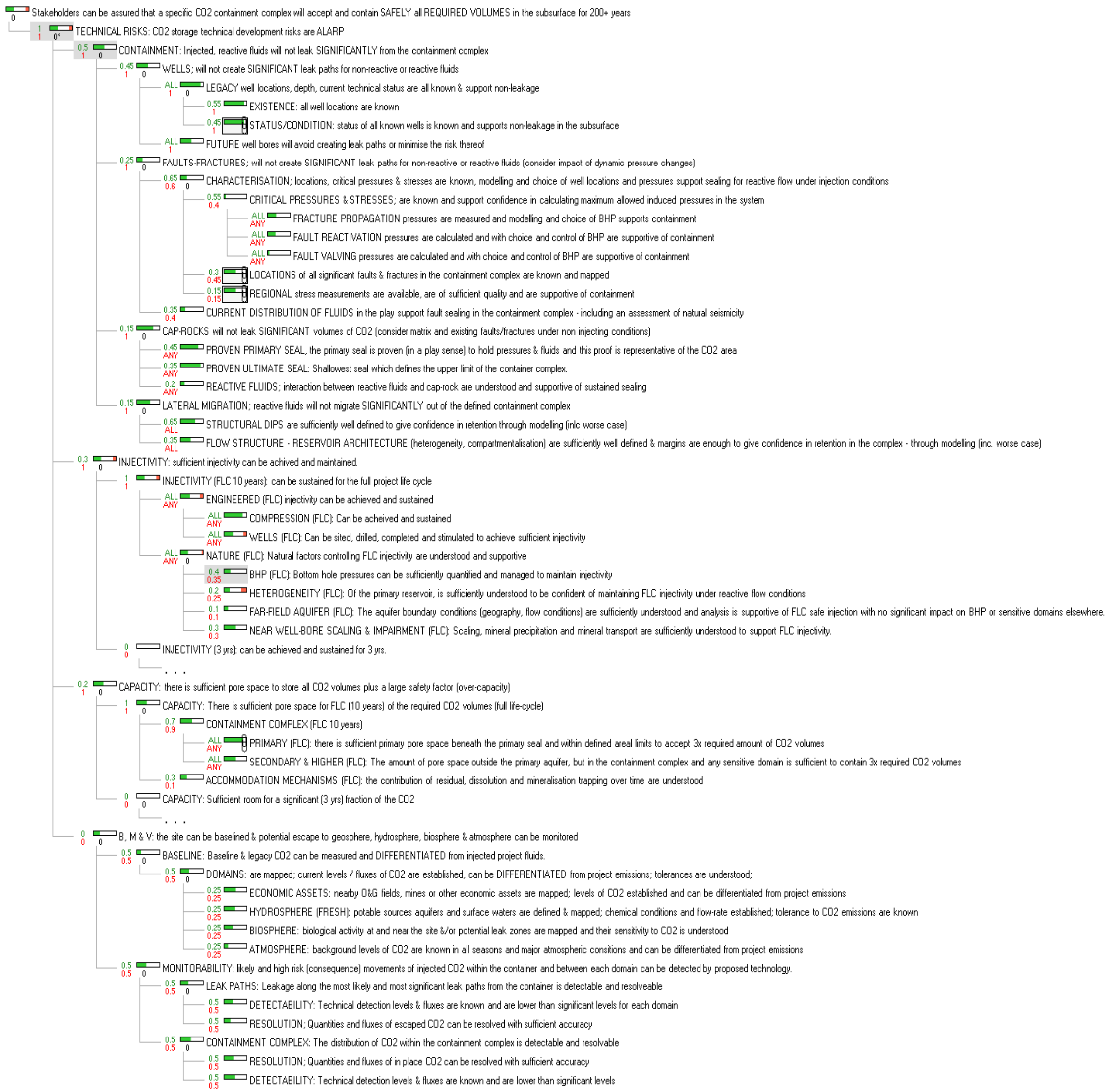




Background

- EXPERT PANEL DISCUSSIONS INVOLVING OVER 70 SHELL TECHNICAL PROFESSIONALS IN STRUCTURED WORK-SHOPS PRODUCED A DETAILED RISK REGISTER AND DETAILED MITIGATION PLANS
- BASED ON THIS WORK A RISK ASSESSMENT TREE BASED ON "ITALIAN FLAG" EVIDENCE BASED RISK ASSESSMENT WAS DEVELOPED, BRANCHES FOR:
  - CONTAINMENT
  - INJECTIVITY
  - CAPACITY
  - MONITORING & VERIFICATION
- STAKEHOLDERS CAN BE ASSURED THAT A "SPECIFIC CONTAINMENT COMPLEX" WILL ACCEPT AND SAFELY CONTAIN "VOLUME X" IN THE SUBSURFACE FOR ">YYYY YEARS"

Generic CO_2 Storage Risk Tree



ZeroGen License 722 - Eastern Flank acquifer injection v3 9/11/2008

Input : Starts with uncertainty

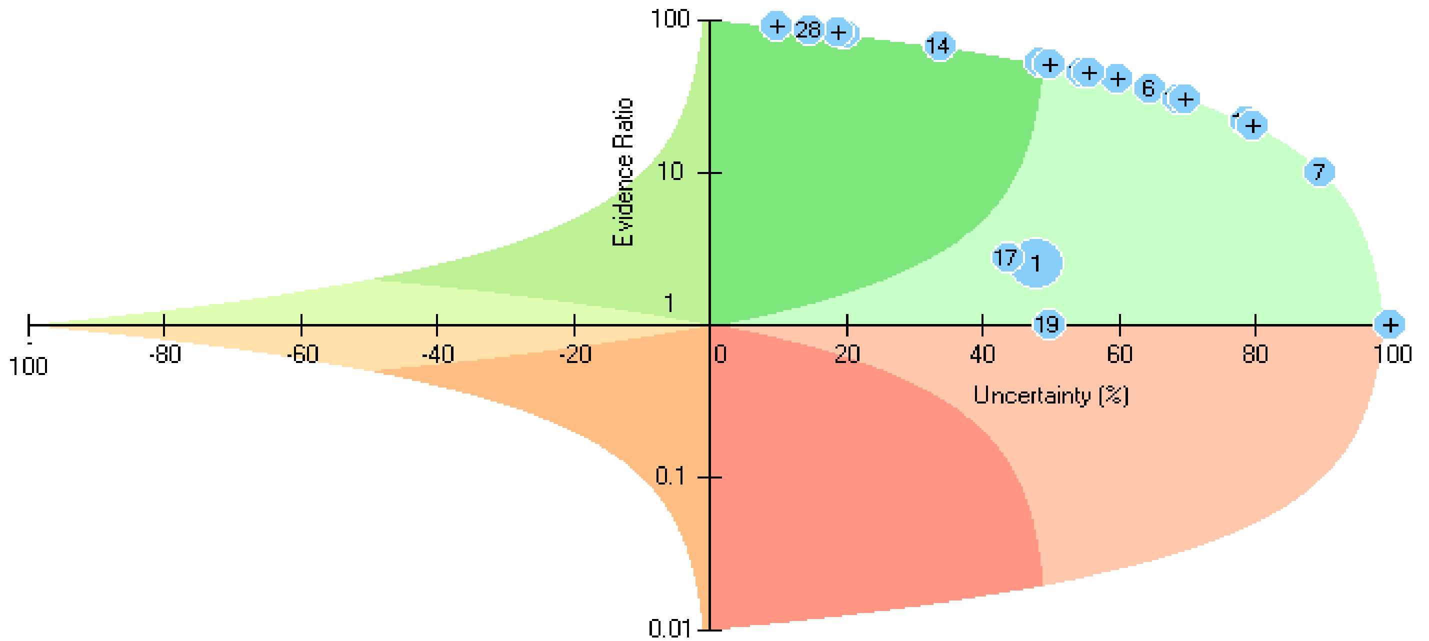
ZeroGen: smarter, cleaner power

Uncertainty Matrix for Saline Aquifer Storage in ATP722

Parameters		Specifc	Picture	Focal Point	Uncertainty description	Level of uncertainty	Potential impact	More study/data?	Low case	Mid case	High case
INJECTIVITY	Engineered Injectivity - Wells	Well Skin		Giridhar Kumar	ZG-1 & ZG-2 drilled with KCL PHPA mud had significant impairment which led to zero injectivity in all zones. The damage caused could also be attributed to cement damage in ZG-1 during casing operations. After stimulation (StimGun) skins of >70 were calculated in Mantuan on the basis of a water injection test. These tests were of insufficient duration to be easily interpretable. A combined test in Mantuan where skin was originally estimated as 40 in one test but has been re-calculated to be around 6 by EPT-S Bangalore). SEM analysis showed that there was no fines impairment in the cores after Jetting experiments	MED	MED	Future plan is to air drill the reservoir section.	10	0	-2
		Trajectory		Landale Cranfield	Whilst drilling ZG-1 & ZG-2 corkscrewing was observed and upto 25m drift. This only implications for the CO2 injection pilot where we need to place a monitoring well as close as possible to the injection well (within 15m)	LOW	LOW		25m drift per 1000m	Vertical	
		Hydraulic Fraccing		Giridhar Kumar	The only uncertainty lying in hydraulic fracturing is the orientation of fracture (horizontal or vertical). This can be attributed to the uncertainty in regional stresses (reverse or normal fault regime)	MED	LOW			Horizontal Fractures	Vertical fractures
		Radial Length and Orientation		Landale Cranfield	Dynamic modelling indicates that successful injection of 50tonnes/day CO_2 for 3 years in the acquifer requires a zero skin well and at least 6 levels of laterals (6 x 4 x 100m - 2400m). Jetting of laterals is unproven in the field in ZeroGen type low permeability rocks. Laboratory tests indicate that a high jetting pressure is required (Tempress & Petrojet were successful with a differential pressure of 7200psi; Radial Technologies were unsuccessful at 3000psi). Uncertainty exists around the ability to jet radials in 8-12% porosity sandstones insitu	HIGH	LOW	A radial drilling trial is planned in ZG-2 during Q2 2009	No success; 0m radials	30m	50m radials in planned orientation
	Natural Injectivity	Reservoir Pressure (initial)		[illegible] Kumar	Santos/Origin report hydrostatic pressures in the updip gas fields and this is confirmed by measurements in ZG wells. Formation repeat tester (FRT) data in the Aldebaran at ZG-1, the reservoir pressure gradient was calculated to be 0.4348 psi/ft or 9.835 kPa/m from a pressure of 1697 psi (11,700.5 kPa) at the reservoir depth of 3903 ft (1194 m) below ground level (BGL). Confirmed by a hydrostatic pressure measurement in ZG-3.	LOW	MED			Hydrostatic Pressure	+5%
		Reservoir Heterogeneity - Architecture		Sudhakar Vijayaraga	The analogue for the Catherine Formation is the high latitude coldwater delta (Copper River delta, Alaska). Highest permeabilities (ZG-5) occur in channel sands thought to be derived from the NW. The channel sands are correlatable to Turkey Creek (upper Catherine) and Springton (Mid Catherine) but their distribution is uncertain. Low N/G (50%) in the Catherine reduces connectivity and makes Kv/Kh ratio important. The lower permeability Freitag & Aldebaran form part of a shoreface environment where individual sand bodies are laterally very correlatable. High N/G in the Freitag & Aldebaran Fms. makes the upscaled model less sensitive to object geometry as there is good connectivity.	MED	LOW		Mantuan/Cath. Low continuity Freitag N/G=25% Aldebaran N/G=75%	Mantuan/Cath. mod. continuity Freitag N/G=50% Aldebaran N/G=90%	Mantuan/Cath. high continuity Freitag N/G=75% Aldebaran N/G=95%
		Reservoir Heterogeneity - Permeability		Sudhakar Vijayaraga	Extensive core (>3000m) and log information is available both in the updip gas fields and synclinal CO2 storage area (ATP722). Permeability is calculated either by phi-k transform on a well-by-well basis based on log data calibrated to core plug measurements. In the high permeability Catherine Fm. channels there is no clear porosity-permeability relationship & the transform underestimates permeability. In these channels an alternative permeability distribution has been achieved using a cloud transform using core data only. No predictive permeability model exists. Santos/Origin report low permeability zones delineating 2km diameter drainage areas, with wider pressure communication over time	MED	HIGH		LOW CONNECTIVITY high permeability restricted to ZG-5	MODERATE CONNECTIVITY high permeabilities spread (co-kriging)	HIGH CONNECTIVITY Permeability from phi-K transform
		Reservoir Heterogeneity - Diagenetic Effects		Sudhakar Vijayaraga	Cementation by quartz overgrowths is the main diagenetic effect in the cleaner sandstones. Degree of silicification is a function of maximum burial depth (temperature). In zones where high permeabilities are preserved and it is believed quartz overgrowths are inhibited by high clay content. Core data show a range of permeability for given porosity and depth. Apart from the high permeability Catherine Channel sands depositional facies is not predictive of reservoir quality as diagenesis has destroyed primary poro-perm characteristics with silicification caused by elevated temperature due to depth of burial or faults providing conduits to aid diagenetic processes. Heat flow models using VR are too coarse to predict diagenetic trends. There is no predictive porosity-permeability model for the reservoir. Updip gasfields have higher permeabilities but no evidence exists for preferential permeability preservation in the gas leg due to late migration of hydrocarbons (past burial history).	MED	HIGH	Diagenetic study to create a predictive porosity-permeability model for the reservoir which explains the interplay between facies distribution, diagenesis and depth of burial (using Touchstone software). Additional samples for SEM from updip gas fields.	Permeability preservation in gas leg only	Moderate depth trend	Weak depth trend
		Reservoir Heterogeneity - Kv/Kh		[illegible] Kumar	Simulations sensitivities have been run on a "worse credible case" and expectation case to take into account variations in Kv/Kh (0.01; 0.1; 1). Number of Kv/Kh analysis conducted are.......	MED	HIGH	Protocol for core plug measurements of Kv being designed.	0.01	0.1	0.3
		Aquifer Strength		Giridhar Kumar	Production data from updip gas fields indicates that they have no or very weak aquifer support. No other evidence is available as to the strength and movement of aquifer in the synclinal areas.	MED	LOW		6 ft/year updip	Zero	6 ft/year downdip
		Aquifer - Salinity		Giridhar Kumar	Fluid samples collected by FRT in ZG-1 and DST in ZG-6 were contaminated by drilling fluid. Six water analyses from offset wells provide a general guide to formation water chemistry. These include samples from Arcturus-2 and Punchbowl Gully-1 (Mantuan); Springton-3 and Indori-1 (Catherine and Aldebaran). The salinities (TDS) increase with depth of occurance. Chlorides range from 180mg/l to 4925mg/l; and TDS from 2835mg/l to 10139mg/l.	HIGH	MED	Obtain virgin water sample during CO2 Injection Pilot (DP2b)	4000 ppm	8000 ppm	16000 ppm
		Near-Wellbore Scaling & Impairment		Giridhar Kumar	Aqueous reactions will take place almost immediately upon the start of CO2 injection. Preliminary geochemical modelling of the ZeroGen reservoir mineralogy (Geochemist Workbench GWB) shows that for a worse case scenario (higher temperature and dirtier reservoir rock) potential short term reactions, with implications for injectivity decline, occur as magnesium in the formation water reacts until depleted. Past evidence of CO2 flood projects indicate minimal impairment in the injection well. Level of solids loading under operational conditions is expected to be low (absorption unit & filters at plant & well-head), if present could cause rapid plugging of injectors under matrix injection	LOW	MED	The detailed design phase will require investigation of the influence upon injectivity of fine particulate matter in the CO_2 stream from the power plant. Possibly involving core flood	Scaling index =	Scaling index =	Scaling index =

Output : Storage Risk Tree

Output : Ratio Plot



1 : Stakeholders can be assured that a specific CO2 containment complex will accept and contain SAFELY all REQUIRED VOLUI

2 : EXISTENCE: all well locations are known

3 : STATUS/CONDITION: status of all known wells is known and supports non-leakage in the subsurface

4 : FUTURE well bores will avoid creating leak paths or minimise the risk thereof

5 : FRACTURE PROPAGATION pressures are measured and modelling and choice of BHP supports containment

6 : FAULT REACTIVATION pressures are calculated and with choice and control of BHP are supportive of containment

7 : FAULT VALVING pressures are calculated and with choice and control of BHP are supportive of containment

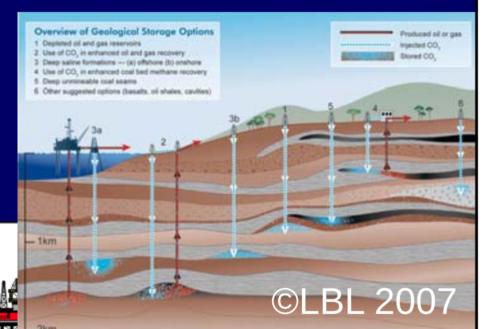
8 : LOCATIONS of all significant faults & fractures in the containment complex are known and mapped

Learnings

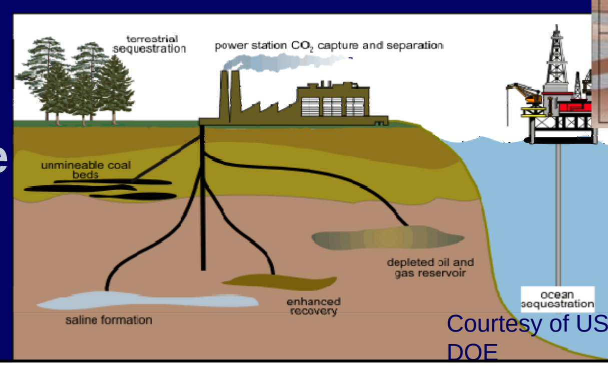
- ENSURES THAT RISK ASSESSMENT CONVERSATIONS ACROSS DIFFERENT PROJECTS, AND WITHIN PROJECTS ACROSS DIFFERENT DISCIPLINES, ALL COVER THE SAME GROUND
- PROVIDES A COMMON LOGICAL FRAMEWORK THAT CAN BE APPLIED TO ALL STORAGE PROJECTS (BENCHMARKING)
- HIGHLIGHTS AREAS OF INSUFFICIENT EVIDENCE (WHITE SPACE) OR WHERE EVIDENCE IS CONFLICTING AND SO DRIVES APPRAISAL, EXPERIMENTAL & STUDY PLANS
- COMPLIMENTS OTHER RISK ASSESSMENT METHODOLOGIES (E.G. FEP), DOES NOT REPLACE

Liability Risk Management & Insurance for CCS

Public Good and
Private Asset Protection –
Balancing Opportunity and Risk in the Face of Global Change



Lindene Patton
Chief Climate Product Office
Zurich Financial Services



Courtesy of US DOE

Risk Management: *Short and Long Term Liability*

THEORY

Risk management is predicated on:

- **Understanding the process or operation**
- **Forecasting the range of possible outcomes,**
- **Determining what influences and drives the outcomes**
- **Recognizing that forecasts can be wrong,**
- **Identifying the consequences of being wrong,**

Identification of existing tools / models, their applications and limitations is critical

And then,

- **Limiting the magnitude of the consequence(s) or finding ways to hedge the bet . . .**

Mitigation of moral hazard can mean the difference between success and failure

Risk Management:

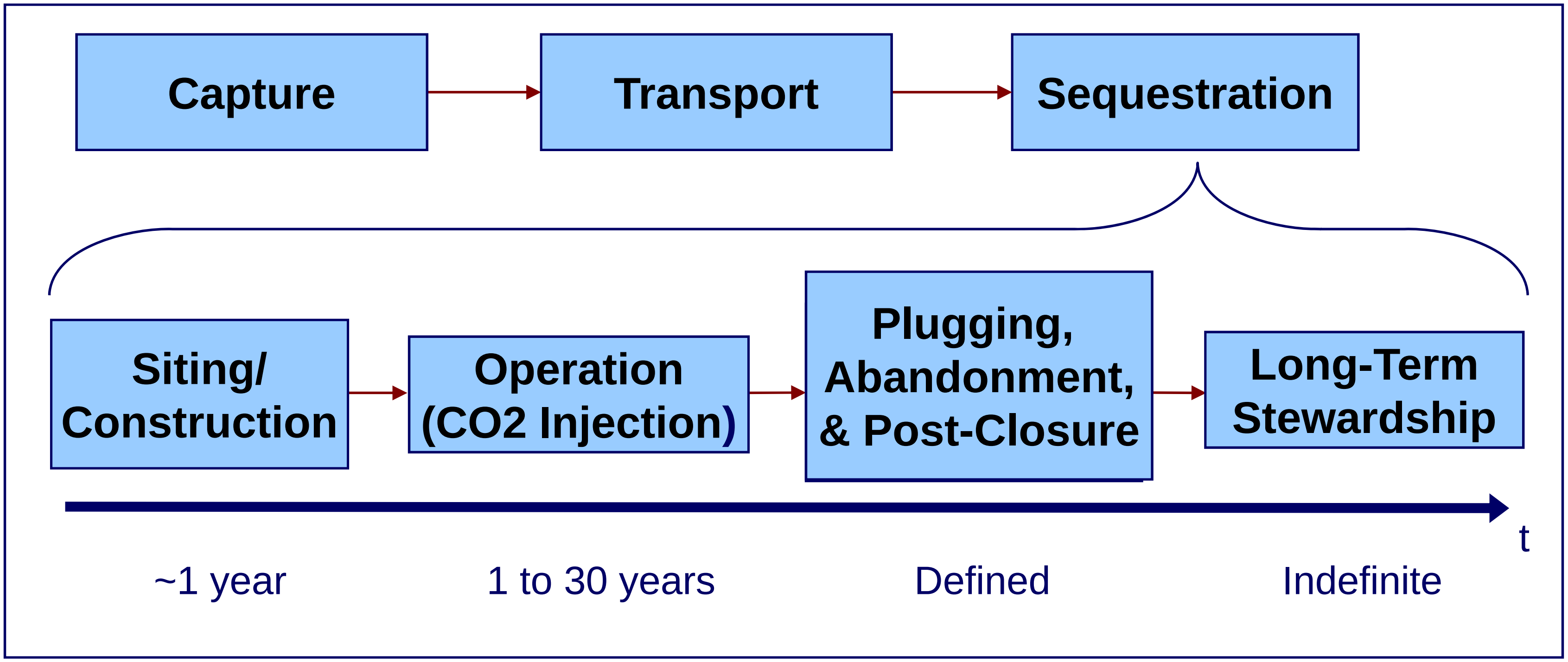
Short and Long Term Liability

STARTING POINT

Common Language is essential ? Are you sure you have it ?

- **RISK – Of what?**
  - **Non-performance / default? Underperformance? Defect? Other contractual liability? Tort Liability for Bodily Injury (BI), (first party) Property Damage (PD), Ecological / Natural Resource Damage? Endangered Species Issues?**
  - **Moral Hazard – Will the party be better off in the event of loss / failure? Is the party indifferent, and therefore won't try to prevent or mitigate certain losses? Is the party motivated to increase the risk because it bears none of the risk ?**
- **FINANCIAL RESPONSIBILITY –** To whom, for what? When?
- **LIABILITY –** Statutory? Common law? Civil law jurisdiction?
- **HARM / INJURY –** BI or PD or other?
- **DAMAGES –** Nature? Type?
- **INDEMNITY –** Contractual? Governmental? First dollar? Excess of retained amount? Insurance? Public / Private?

GS Lifecycle: Critical to Risk Management Framework Design



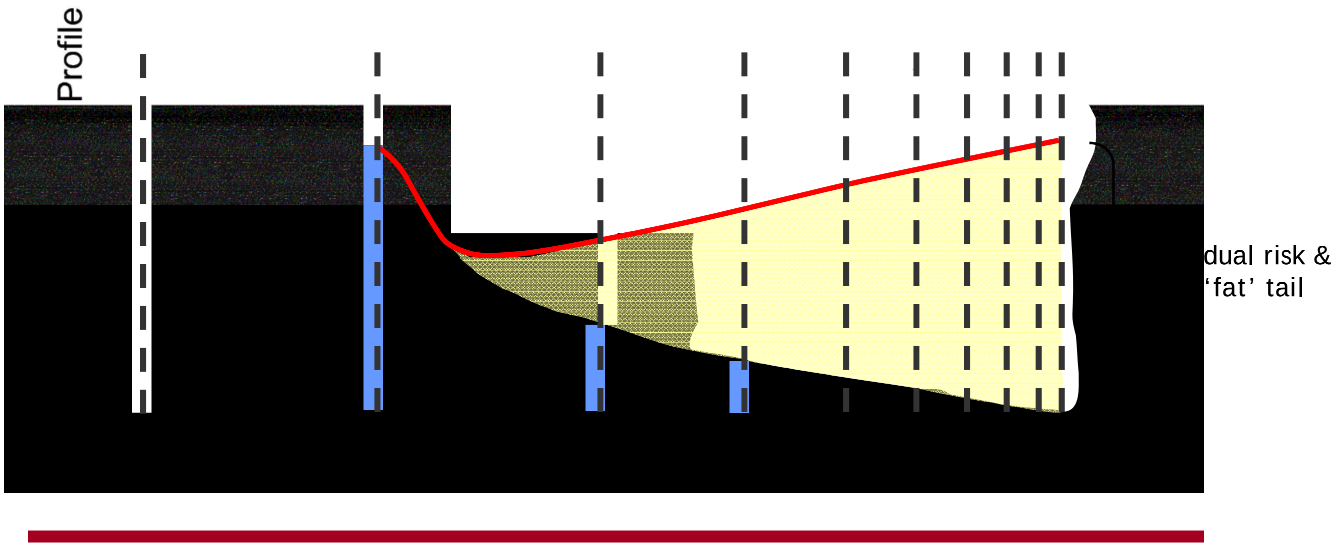
- Industry Sectors – Powergen, Energy (oil & gas EOR), Oil Services, Petrochemical, Industrial Gases, Engineering,
- Early movers (pilots) v. commercial-scale deployment
- Existing statutory implications

Risk Profile for GS Sites

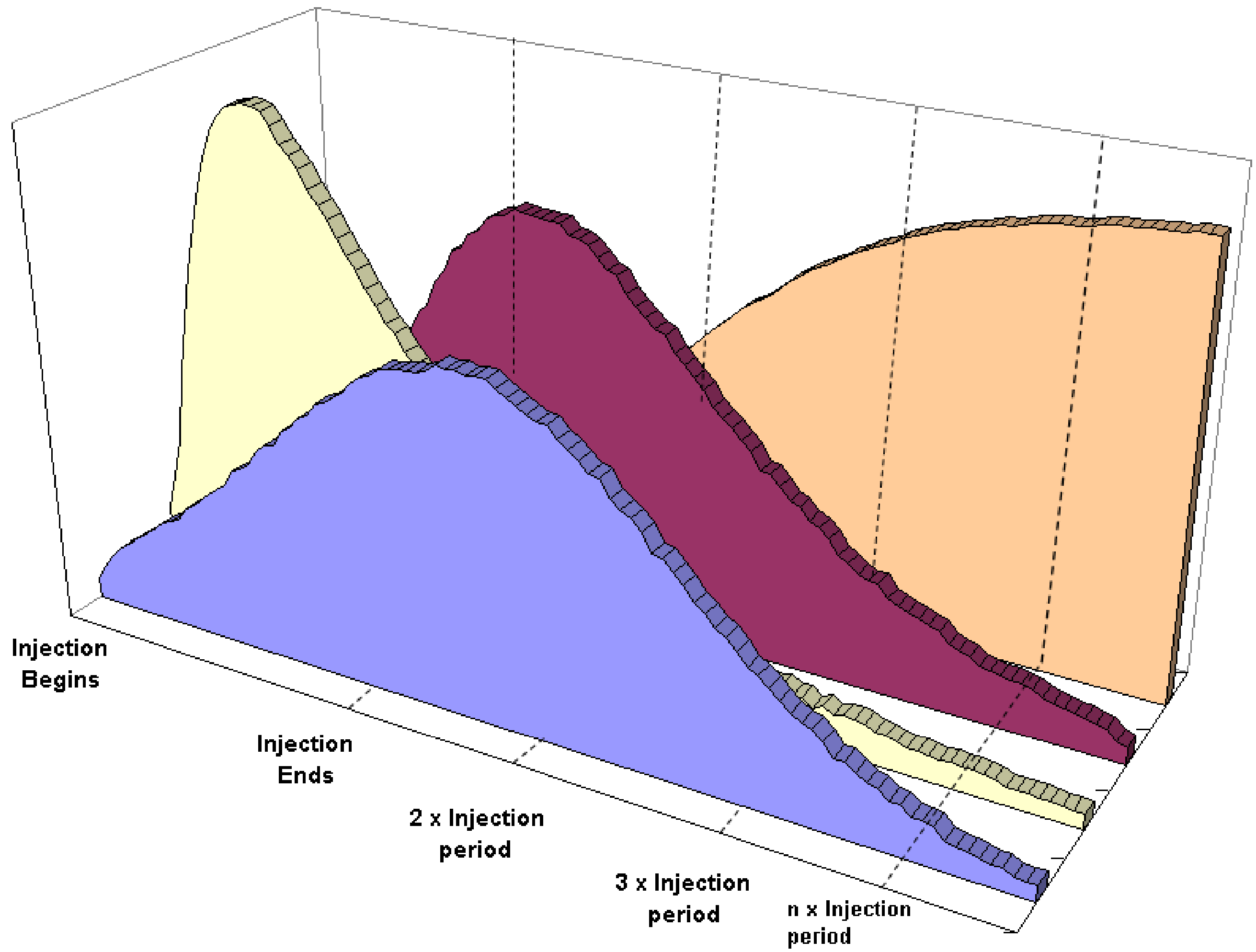
Chart Courtesy of Sally Benson

- **THIS IS 2 DIMENSIONAL SLICE OF A 3 DIMENSIONAL RISK**. It is a statistical, fictional representation. **Key Question:** Is Pressure front a surrogate for ALL causes of loss ????
- The vertical-axis represents frequency for a single site for a single cause (or average of all) of loss.
- The horizontal-axis represents severity for a single site for a single cause of loss (or average of all) .

A Different Risk Profile for CCS Sites



- To estimate the pool of losses, sum the area for every cause of loss and consequence of loss via integral for every site in the pool.
- In other words, make this 3-dimensional, spin it sideways, and consider
- What happens with a FAT TAIL …



For Discussion Purposes - Fictional Financial Impacts of "Pool" of CCS Sites with Differential Risk Profiles

Notable US Liability Frameworks:

Each Has Strengths and Weaknesses; Risk Profile is Key

<Public / Private Frameworks>	<Compensation (Trust) Funds>
	1974 | SDWA UIC Program
1957 | Price-Anderson Nuclear Indemnity	
	1980/1986 | CERCLA/SARA Superfund
1968 | NFIA Indemnity/Risk Pool	
	1990 | TAPAA/OPA OSLTF / TAPLF
2002 | SAFETY ACT Risk/Litigation Management	
	2007 | IRGC / IOGCC State Compensation Funds

Trabucchi and Patton 2008 (BNA WCCR)

Liability (Risk) Management Options

Trabucchi and Patton 2008 (BNA WCCR)

Financial Responsibility Mechanisms	**GS Project Phases**		
	Operation (CO_2 Injection)	Closure & Post-Closure	Long-Term Stewardship (after prescribed post-closure)
Third-Party Instruments (Trust Funds, LOCs, Insurance, Bonds)	✔	✔	✔
Self-Insurance (Financial Test, Corporate Guarantee)	✔	✔	X
Private/Public Frameworks Trust/Compensation Funds Insurance Models	X	X	✔

Suggested CCS RM Framework

- **Operational Phase** – Siting, Operation (Compression & Injection), Delimited Closure
  - Single Goal Financial Instruments – Surety Bonds, Insurance, Letters of Credit, Self-Insurance (Financial Test, Corporate Guarantee)
  - Cost Estimation Requirements
  - Delimiting Requirements for Issuing Institutions

- **Long-Term Stewardship Phase** – Post-Injection, Post-Site Certification
  - Three-Part Solution – Safety Board, CCS Trust, Enabling Legislation

Insurance Policies

- Address Specified Perils in Operational, Closure and Post-Closure Phases of GS / CCS

- CCS Liability Insurance
  - Operational phase
  - Closure / post closure phase (possible)

- Geologic Sequestration Financial Assurance

- Unique in the Industry

CCS Liability Insurance

- CCS Liability policy is a geologic reservoir specific policy comprised of five (5) coverage grants including:
  - pollution event liability,
  - business interruption,
  - control of well;
  - transmission liability and
  - geomechanical liability

Anticipated damages from CCS operations

- Migration of the gas stream to groundwater, creating carbonic acid upon contact with the water, and potential transmission of soluble minerals and metals in a low level – clean up costs or replacement in kind
- Migration of the gas stream to other mineral stocks subsurface, fouling the private goods – replacement in kind or compensation likely required
- Migration of the gas stream outside the reservoir – general trespass and nuisance
- Migration of the gas stream into basements of other low lying areas – damages only long term low level circumstances – like plant death or – in case of huge catastrophic release –- asphyxiation
- Migration of the gas stream to the atmosphere, causing liability for carbon credit loss or tax credit loss – limited by business interruption sub limit for first party; excluded for third party
- Damage to well from gas release – damages – repair to well

Geologic Sequestration Financial Assurance (GSFA) Policy

ZURICH

- Reimbursement for task specified in closure / post closure (as applicable) plans as appended to the permit in force at the time of underwriting and as appended to the policy

- No automatic changes to the policy even if permit changes

- No coverage outside the specified tasks in the closure or post closure plans

- No defence coverage

3 Key areas of risk transfer covered by GSFA

ZURICH

- Zurich is responsible for the cost differential between the GSFA policy's limit of liability and the underwriting expected cost estimate to complete closure / post closure tasks (risk transfer layer risk).

- Zurich is responsible for increased costs due to acceleration of reservoir closure (accelerated closure risk).

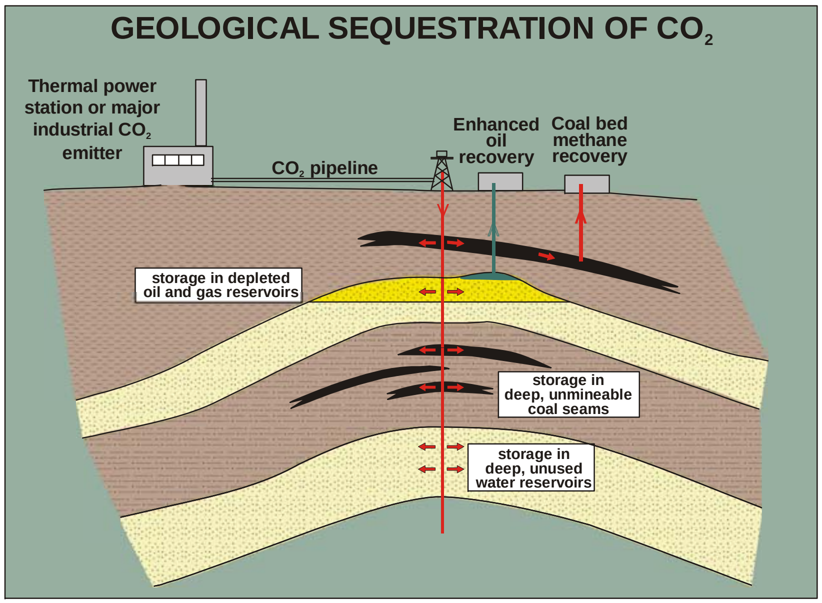
- Inherent financial risk of the percentage rate that the expected reclamation costs are discounted by outpacing the expected rate of return (financial risk).

Interface between insurance industry and technical risk assessment processes

Panel Discussion

Friday 17th April 2009

CO_2 Sequestration Risk Assessment



- Mostly qualitative and dominated by judgement of expert panel members
- Containment primary focus of risk assessment (political and social risk separate analysis).
- Economic modelling separate from risk analysis
- Risk assessment probabilistic for selected parameters
- Appropriate risk parameters and uncertainties not always well understood
- Strong focus on reservoir flow modelling and case study approach with use of oil and gas analogues

Discussion Points

1. What range of CCS risk assessment activities should we adopt (all activities/container focus)?

2. Should economics be integrated into risk assessment and, if so, how?

3. What risk metrics should be employed?

4. How do we value the consequences of a risk event and estimate the uncertainties?

1 & 2) What range of CCS risk assessment activities should we adopt?

A full range of CCS activities:

capture, transport, injection and containment

and influences:

economics, politics, policy, public opinion, safety and technical

to ensure that significant risks are not overlooked and to provide guidance to understanding the full consequences of sequestration.

3) What risk metrics should be employed?

Need to record potential consequences of sequestration in dollar terms, safety to humans and environmental degradation.

$ Cost/tonne CO2 avoided and leakage rates at ground surface or into sub-surface resources (e.g., to assess HS & E and ecological risks)

Discussion Points

1. What range of CCS risk assessment activities should we adopt (all activities/container focus)?

2. Should economics be integrated into risk assessment and, if so, how?

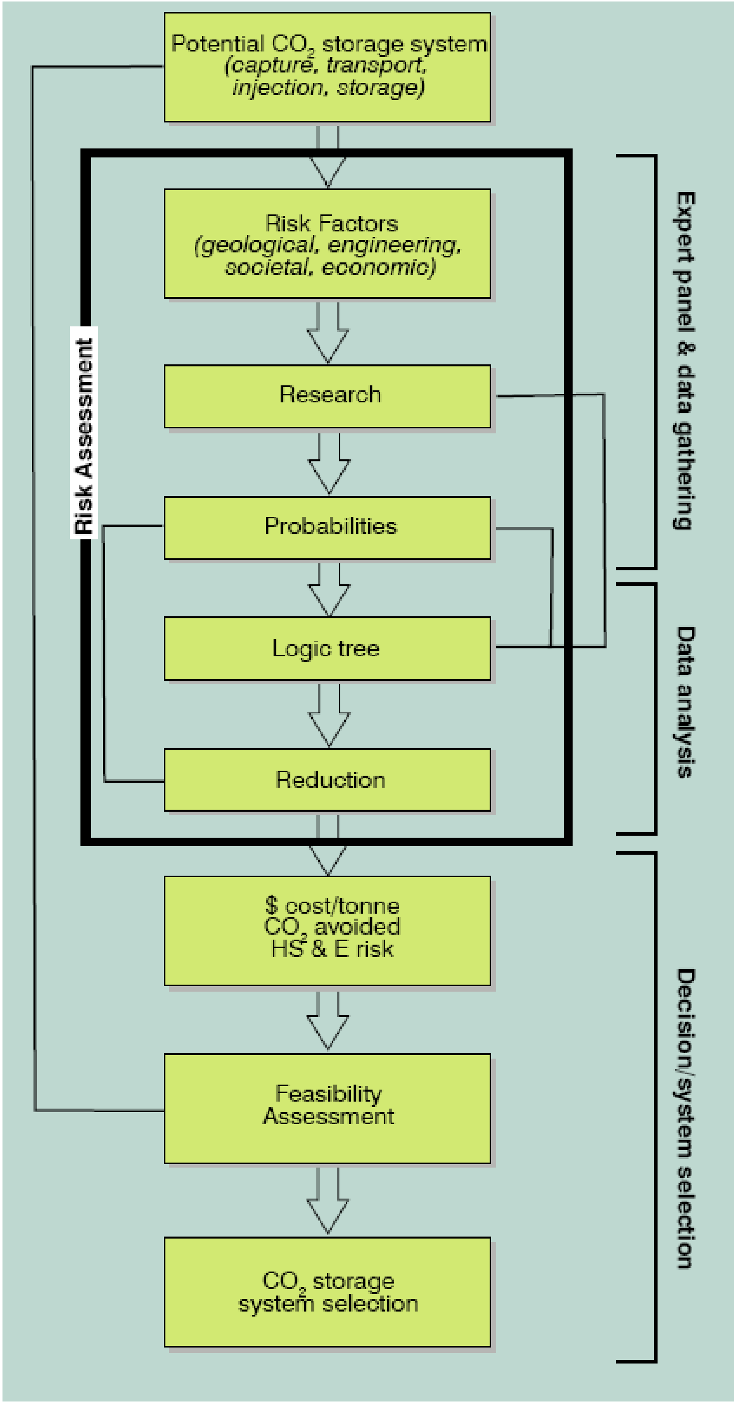
3. What risk metrics should be employed?

4. How do we value the consequences of a risk event and estimate the uncertainties?

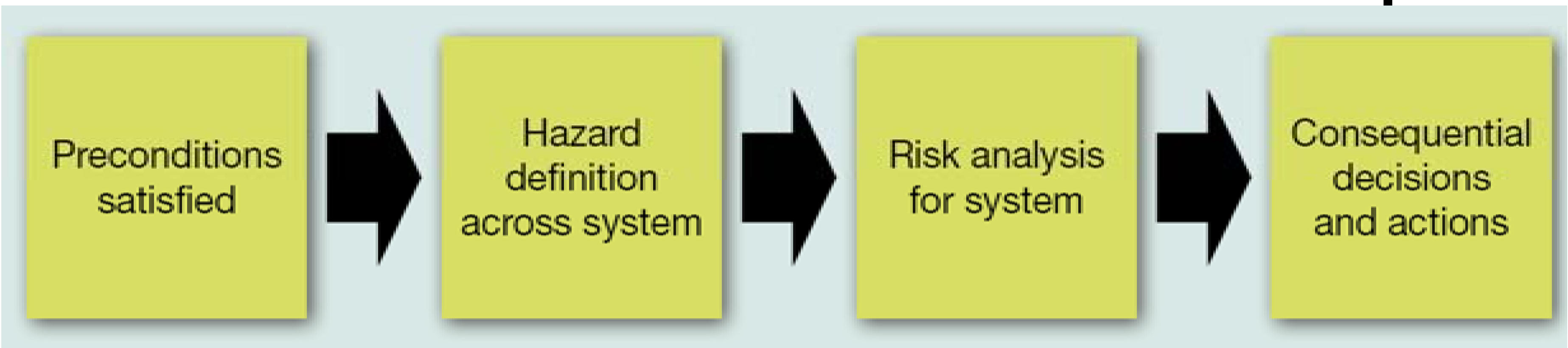
4) How do we value the consequences of a risk event and estimate the uncertainties?

Probability density functions for key parameters, with uncertainties, of important hazardous events that could impact on the successful implementation and completion of a CO_2 storage project

- Iterative process of data gathering, analysis and consultation necessary to minimise uncertainties
- Expert elicitation is unavoidable and should be used as a tool for promoting discussion between experts
- Ability to analyse and compare risks and track all important uncertainties (e.g. logic tree method)
- Use universal risk metrics



1-3) What range of CCS risk assessment activities and risk metrics should we adopt?



No international consensus on a single Risk Assessment (RA) methodology.

- Ideas vary in the level of detail applied, the range of activities to be covered
- range from minimal RA with a focus on monitoring to a systems approach where various risks in the CCS system are assessed separately
- Features Events and Processes (FEPs) database often used as a check for, or to build, RA

CCS Project Risk, Liability & Insurance

SIMON JAMES

MELBOURNE, 17 APRIL 2009

Becoming Decision-driven

Why it is hard, why it matters, how it works

- ALIGNS PROJECT TEAMS IN SUPPORT OF ARTICULATED DECISIONS
- DECISIONS HELP US TO KEEP THE END IN MIND
- DECISIONS ARE DEFINED AS *CHOICES-YET-TO-BE MADE*
- DECISIONS HELP US TO CRAFT IMAGINATIVE OPTIONS
- WE DON'T GET PAID TO MANAGE UNCERTAINTIES, WE GET PAID TO MAKE DECISIONS

UNCERTAINTIES JUST MAKE THE GAME MORE INTERESTING

Project Roadmap

	Identify	Assess	Select
Key Decision	Do we understand the project drivers and the range in timing, volume/rate, composition, locations & spatial footprint of the CCS project?	Do we recognize a full range of feasible CCS options ranked against the project drivers? Do we need a pilot or demonstrator project?	Select a CCS development concept according to defined selection criteria.
Mandate	Frame Opportunity	Establish Feasibility	Appraisal Drilling CO2 Injection Pilot
Deliverables	Opportunity Framing Report Project Initiation Note Risk & Opportunity Register	CCS Project Roadmap Feasibility Report Stakeholder Engagement Plan	Concept Selection Report Storage Development Plan Project Resourcing Plan

Identify

- Key drivers/assumptions behind the regulatory environments that will determine the project's exposure?
- Key technology to acquire or develop?
- Potential showstoppers or risks (TECOP) to prevent CCS activities within area of interest?
- Anticipated rate, volume, duration and composition of the injection stream?
- Require storage capacity to contain CO2 from single or multiple capture processes?
- Sufficient accessible data to mature this opportunity?
- Recognize play concepts that support a range of viable containment options?
- Legacy issues from prior economic developments?
- Appraise to mature opportunity?

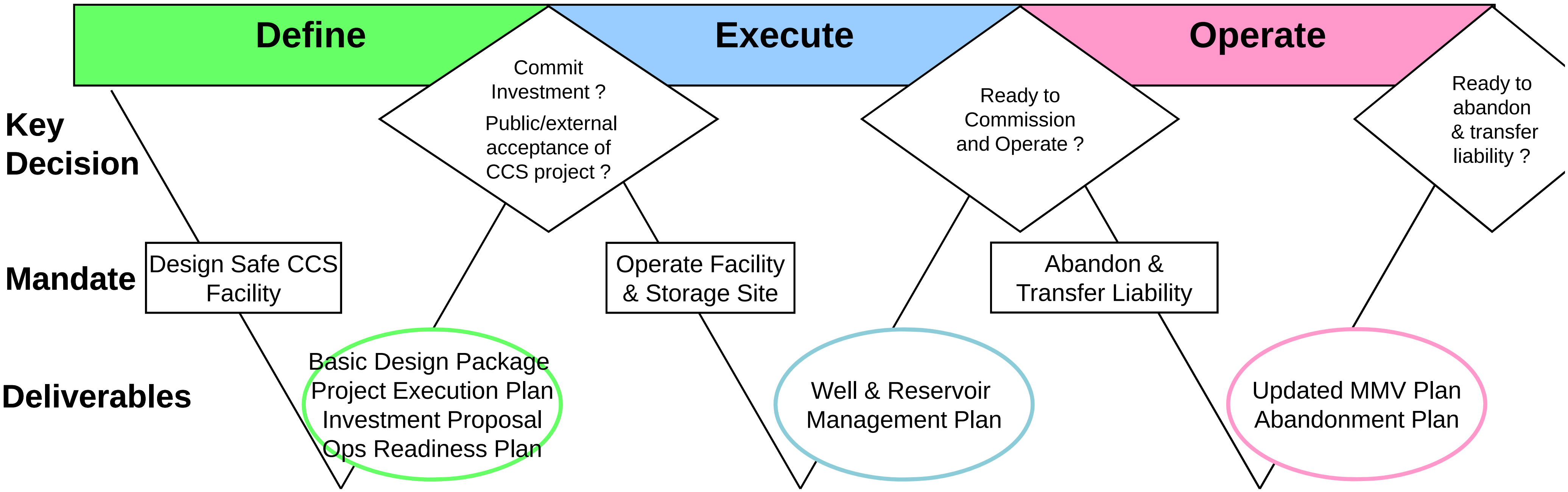
Assess

- Key drivers of the project's CO2 footprint (direct, indirect and product emissions)?
- Key sources of CO2 emissions?
- Potential CO2 reduction/capture opportunities? Require development?
- Broader CO2 opportunities (e.g., supply chain integration, credit trading)
- Effect of contaminants on storage capacity requirements and life-cycle containment?
- Full range of development concepts for the identified?
- Can we measure, monitor and verify (MMV) against an agreed baseline with regulatory acceptance?
- Long-lead items required?
- Appraisal plan?

Select

- Key trade-offs value - cost - risk?
- Acceptable risk level & management plan ?
- Scenarios - CO2 cost doubles (or halves)?
- Demonstrated CO2 plume movement & geochemical and geomechanical effects?
- Leakage pathways, events and processes?
- Risk assessment guides MMV?
- MMV design & baseline meets regulations?
- Project specific technology plan ?
- CCS contracting strategy?
- Preliminary CCS project execution plan
- Regulatory & permitting approval?
- Preferred CCS development concept against the defined selection criteria (TECOP)?
- Under Clean Development Mechanism?
- CO2 pipeline & facilities design specifications consistent with the projected co-constituents?

Project Roadmap



- ❑ Flow assurance & layout issues that constrain the project execution plan ?
- ❑ Layout specific separation distances ?
- ❑ Long-lead items ?
- ❑ Regulatory & permitting conditions sufficiently mature to execute the CCS project? (plot space, transportation corridors, storage permits / licenses)
- ❑ Flow assurance plan to maintain operating specifications?
- ❑ Agreed long-term structures & funding mechanisms in place for post closure activities that address long term liabilities.
- ❑ Risk assessments inform operational decisions, including setting an appropriate injection pressure that will not compromise the integrity of the confining zone.

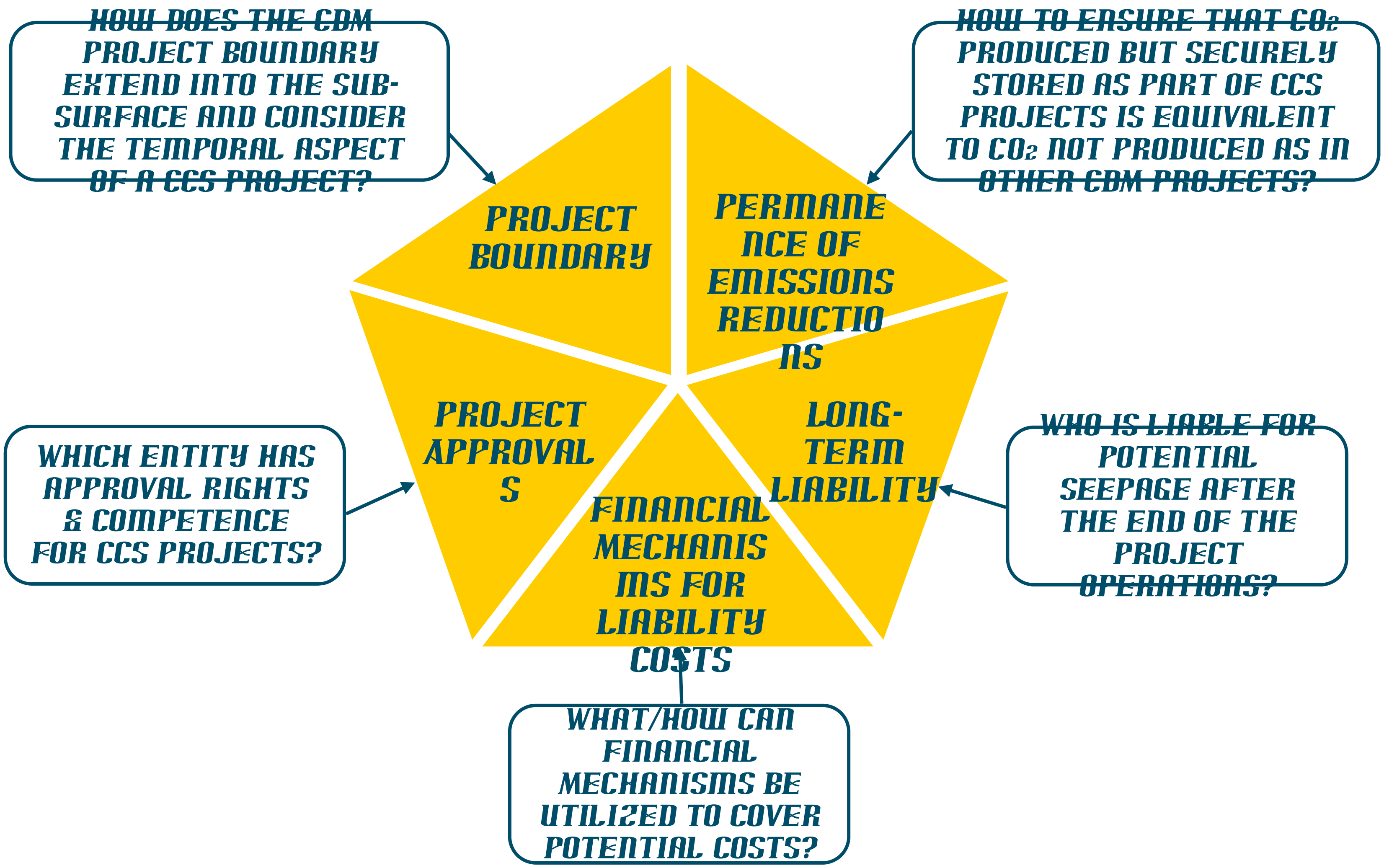
- ❑ CO_2 pricing assumptions & sensitivities ?
- ❑ How robust is the selected CO_2 strategy (and hence project option) to timing/shape of the regulatory environment and sensitivities in pricing and cost pass-through?
- ❑ Agreed long-term liability structures & funding mechanisms in place for post closure activities?
- ❑ Abandonment and remediation plans in place that meet internal and external standards and (emerging) regulatory requirements that support long term containment for existing and future wells?
- ❑ Follow Occupational Safety and Health Administration (OSHA) standards for safe handling of CO_2?
- ❑ Costs of site closure?

- ❑ Due diligence on pipelines located in vulnerable areas or where H_2S content in stream?
- ❑ Phasing/timing of site closure, abandonment and close-out of liabilities?
- ❑ MMV plans reviewed and updated ?
- ❑ Publicly accessible registry for well plugging and abandonment data?
- ❑ Site-specific risk assessment updated based on operational data and observations during closure.

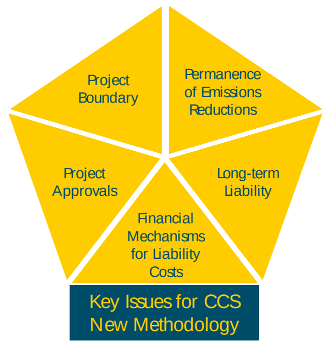
RISK ASSESSMENT (TECOP)

- TECHNICAL
  - ARE TECHNICAL RISK LEVELS ACCEPTABLE?
- ECONOMIC
  - HOW ROBUST IS THE SELECTED CO2 PROJECT OPTION TO TIMING/SHAPE OF THE REGULATORY ENVIRONMENT AND SENSITIVITIES IN PRICING AND COST PASS-THROUGH?
  - HOW SECURE IS PROJECT FINANCING (EG SUBSIDIES)?
- COMMERCIAL
  - WHAT ARE THE KEY PROJECT DRIVERS (REGULATORY REQUIREMENTS, REPUTATION)?
  - HOW MUCH LIABILITY ARE WE TAKING ON?
  - CAN WE STRIKE THE COMMERCIAL DEAL AND PURCHASE THE SERVICES WE NEED TO PERFORM THE WORK?
  - WHAT ARE THE POTENTIAL CONFLICTS OF INTEREST (HC PRODUCTION, UNDERGROUND GAS STORAGE)
  - ARE AGREED LONG-TERM LIABILITY STRUCTURES & FUNDING MECHANISMS IN PLACE FOR POST CLOSURE ACTIVITIES?
- ORGANISATIONAL
  - DO RISK ASSESSMENTS INFORM OPERATIONAL DECISIONS AND ORGANIZATIONAL CAPABILITY?
  - WHAT IS THE POTENTIAL IMPACT OF OPERATOR ERROR
  - WHAT ARE THE CAPABILITIES OF OWN ORGANISATION AND CONTRACTORS?

Proposed New Methodology for CCS in CDM

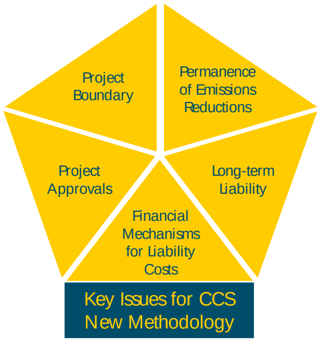


Long-Term Liability



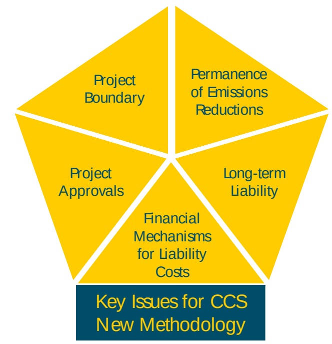
- PROPOSED CONCEPT OF "LIABILITY TRANSFER" AND ASSOCIATED FINANCIAL MECHANISMS BASED ON RISK REDUCING OVER TIME
  - HOST COUNTRY TO TAKE ON LONG-TERM LIABILITY AT SOME POINT AFTER PROJECT ACTIVITY ENDS (MUTUALLY AGREED WITH PROJECT PROPONENTS)
- TERMS & CONDITIONS BY WHICH THE HOST COUNTRY TAKES OVER LIABILITY TO BE SPECIFIED PRIOR TO PROJECT REGISTRATION AND INCLUDED IN THE LETTER OF PROJECT APPROVAL BY DESIGNATED NATIONAL AUTHORITY (AND/OR COMPETENT AUTHORITY APPOINTED BY DNA)
- RESPONSIBILITY FOR MONITORING AND LIABILITY FOR REMEDIATION OF SEEPAGE LIES WITH PROJECT PROPONENT PRIOR TO LIABILITY TRANSFER AND WITH THE HOST COUNTRY THEREAFTER

Financial Mechanisms for Liability Costs



- INSURANCE, BONDS OR ESCROW CAN PROVIDE ASSURANCES FOR LONG-TERM CORRECTIVE MEASURES FOR SEEPAGE POST LIABILITY TRANSFER
- TRANSFERABLE FINANCIAL MECHANISM CAN PROVIDE ASSURANCE THAT FUNDS WILL BE AVAILABLE TO PAY FOR SEEPAGE EMISSIONS REMEDIATION/COMPENSATION POST LIABILITY TRANSFER
- PROJECT PROPONENTS REQUIRED TO OBTAIN ADEQUATE FINANCIAL SECURITY BEFORE THE PROJECT ACTIVITY COMMENCES
- LEVEL OF FINANCIAL SECURITY AGREED BETWEEN HOST COUNTRY & PROJECT PROPONENTS

Project Approvals



- *All existing CDM project approvals apply*
- *The methodology introduces the need for CCS specific plans/reports to be approved:*
  - *Storage complex characterisation report*
  - *Storage complex management plan*
  - *Sub-surface monitoring plan*
  - *Plan for systematic review of monitoring/modelling*
  - *Plan for corrective measures to counteract significant irregularities*
- *Above plans/reports are to be approved by host country DNA (and/or competent authority appointed by DNA), subject to review & comment by the CDM Executive Board and its panels.*
- *Acknowledges the need for CCS competence in project approval framework, potentially in the form of an International Performance Assessment Centre (IPAC) for geological storage of CO_2*

"It could go badly, or it could go well, depending on whether it goes badly or well."

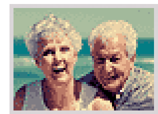
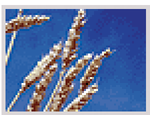
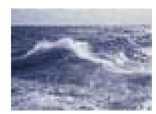
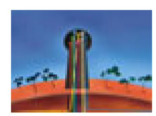
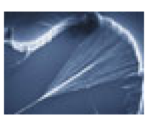
www.csiro.au

Risk communication and CCS!

Peta Ashworth
Senior Social Scientist
17th April, 2009

CSIRO

CSIRO Flagship Program

	**Energy Transformed Flagship** Developing clean, affordable energy and transport technologies for a sustainable future.		**Preventative Health Flagship** Improving the health of Australians through disease prevention and early detection.
	**Food Futures Flagship** Transforming the agrifood sector through frontier technologies and partnering.		**Water for a Healthy Country Flagship** Addressing the sustainable management of Australia's water resources.
	**Light Metals Flagship** Developing new ways to produce light metals, to reduce costs and energy use and improve performance.		**Wealth from Oceans Flagship** Focusing on delivering ocean-based economic, social and environmental wealth to the nation.
	**Climate Adaptation Flagship** Finding ways to adapt to the impacts of climate change and variability.		**Minerals Down Under Flagship** Coordinating minerals research to ensure the competitiveness of Australia's resource base.
	**Future Manufacturing Flagship** Using nanotechnology to create a new wave of industries and add value to existing manufacturing.		

Acknowledgements

- Sarah Wade, AJW Inc., Washington
- Sallie Greenberg, Illinois State Geological Survey
- Judith Bradbury, Battelle, Pacific NW Lab.
- Jeremy Kranowitz, Keystone Centre
- Daniel Byers, Illinois State Geological Survey
- http://www.netl.doe.gov/technologies/carbon_seq/partnerships/partnerships.html

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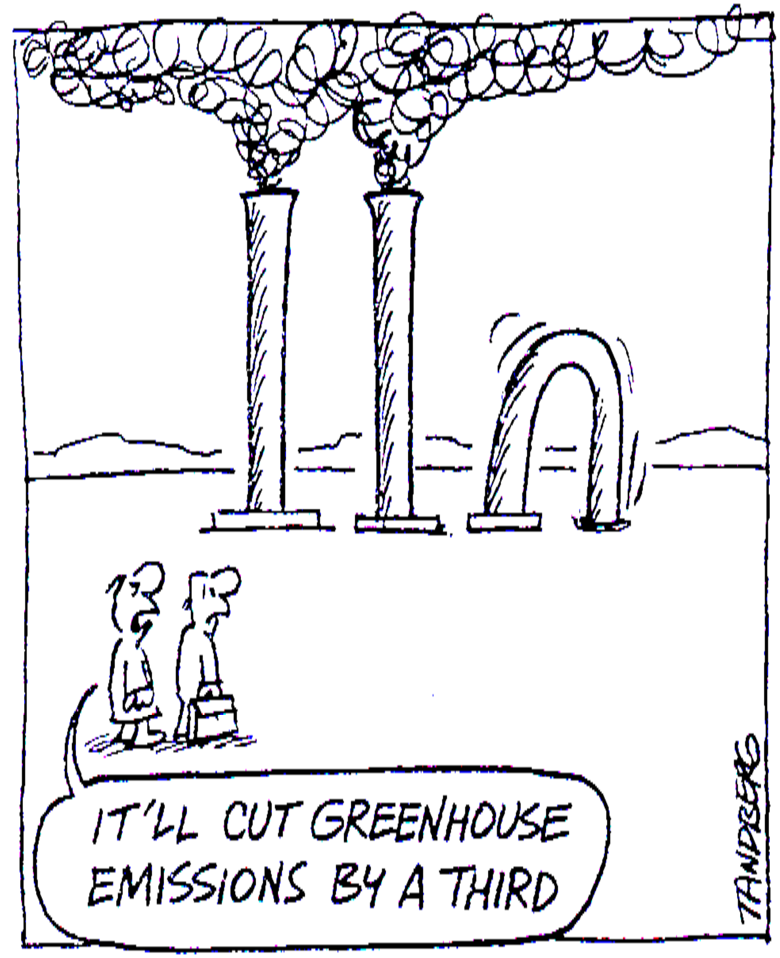
Outline

- Set the context
- Theories of risk
- International context
- Real objections – some examples
- US Carbon Sequestration Regional Partnerships - outreach



Technology and Risk: It's All Perception

Risk Communication and stakeholder engagement. J. Kranowitz (2007) Keystone Centre

Risk versus perception of risk

- A *technical* definition of risk could be written as:

  [Probability of a Hazard **×** Impact of the Hazard Occurring]

- Individuals may have similar reactions or perceptions of risks based on characteristics of the hazards, but any given hazard may engender widely divergent perceptions of risks based on an individual's personal context: their life experience, values and culture. A definition of *perceived* risk has additional factors to the technical definition:

  [Technical Risk **×** **Nature of the Hazard** **×** **Context of the Perceiver]**

Sadler & Kranowitz, 2005 Keystone Centre

CCS Risky Business or Not?

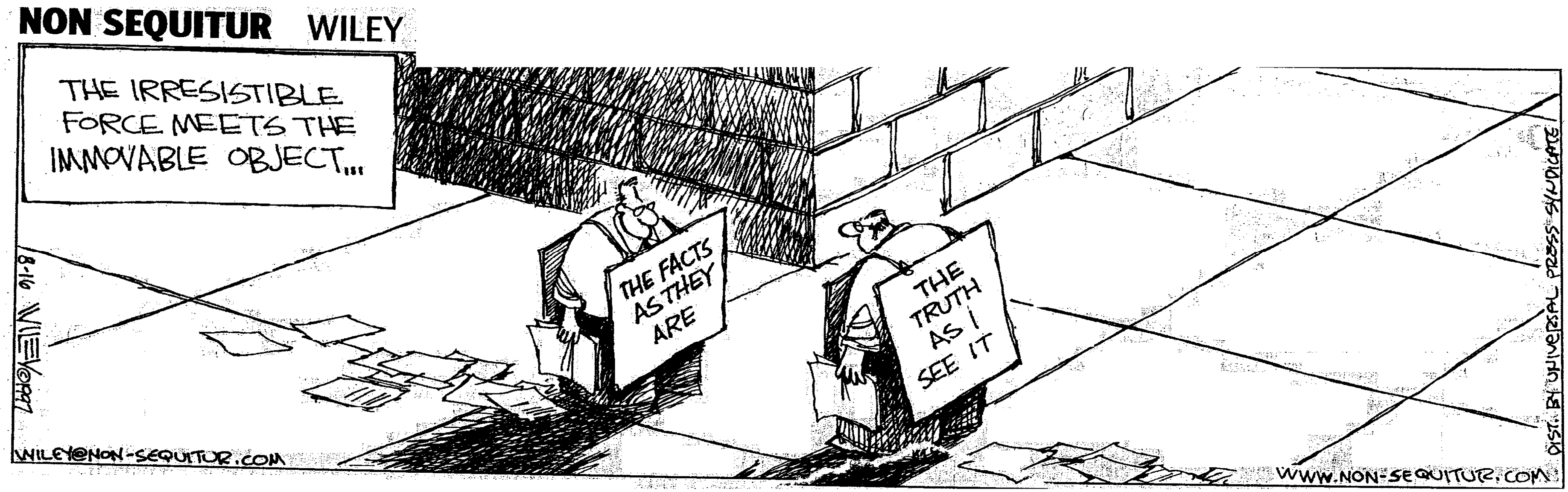
- Stakeholder positions about new ideas and technologies are arrived at through a series of decisions that are made when assessing the risks and benefits of a technology, as well as its moral acceptability.
- Perceptions of risks are heightened when the risk is
  - unknown,
  - catastrophic,
  - felt immediately,
  - uncontrollable, and
  - can harm other people (Slovic, 2000)

Essential elements

- Any worthwhile risk communication strategy for new perceived high risk technologies should include: (Cormick 2004):
  - mechanisms for building trust
  - understanding stakeholder perceptions
  - moral acceptability to society
  - ensuring benefits outweigh risks.

Information and risk perception

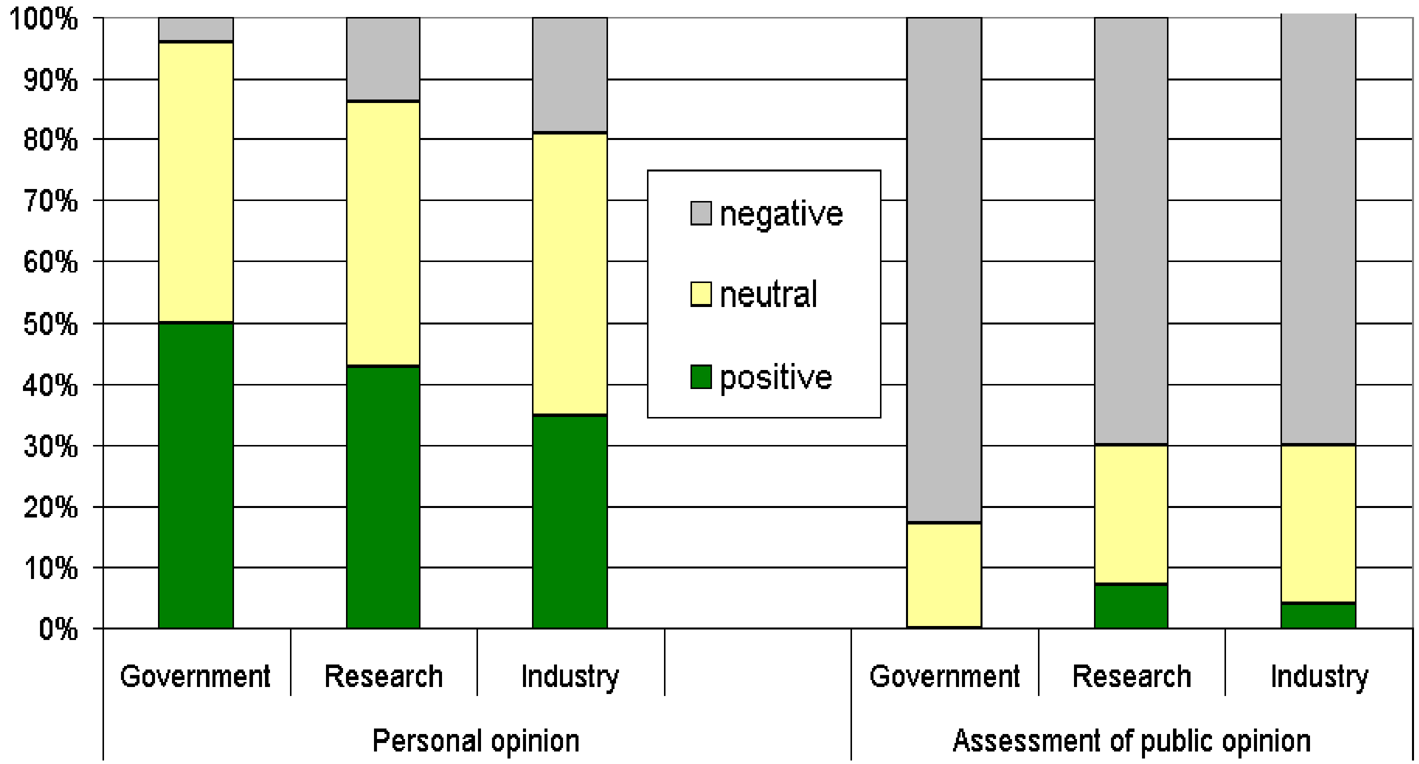
"Where you stand depends on where you sit."



Who is our audience?

- Different groups can view the same set of issues through different lenses.
- Working with different stakeholders provides different frames of reference and units of analysis to approach the same issues.
- Rather than a one-size-fits-all approach, listening to and using the language of different stakeholders allows for different approaches to a similar set of issues, yields higher levels of trust, and creates longer lasting decisions.
  - Influential others
  - Community
  - Education
  - Project specific

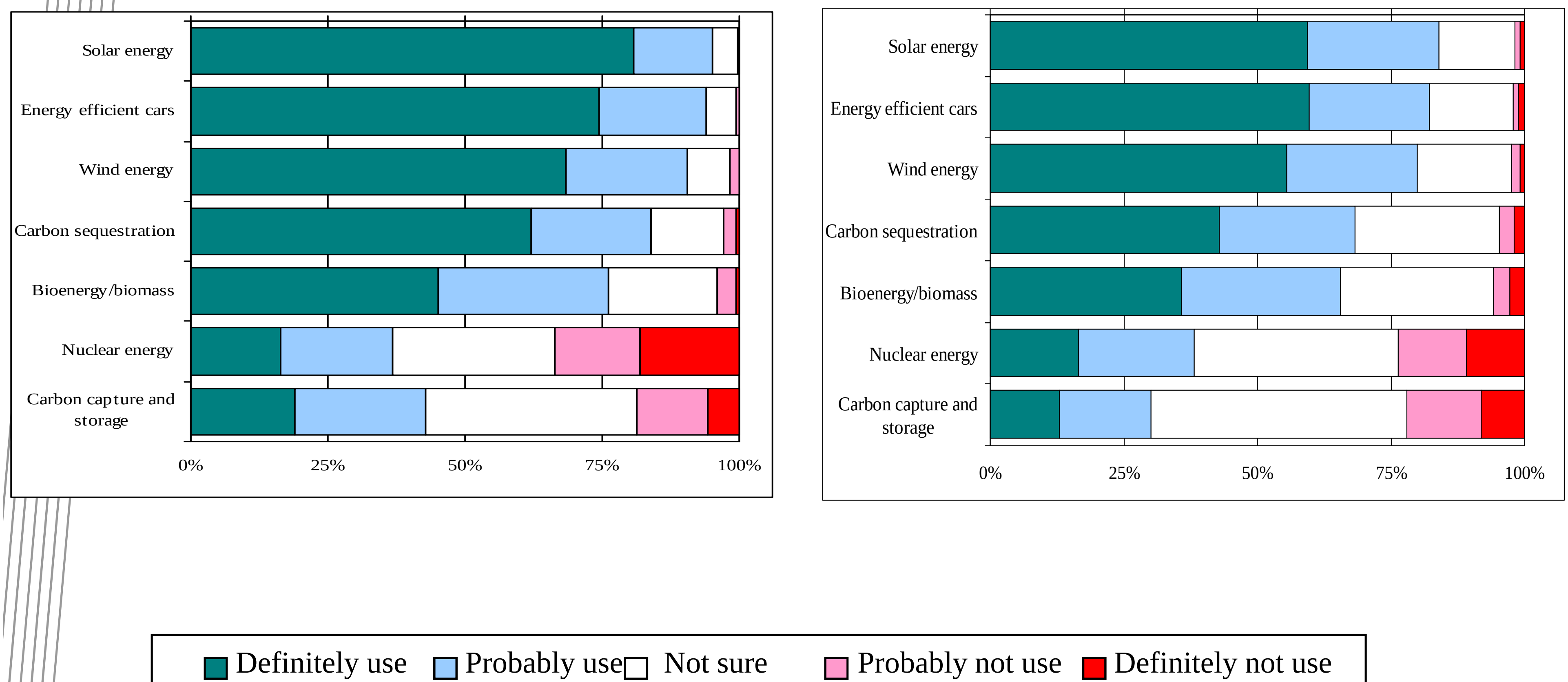
Informed stakeholders personal opinion of CCS (P Radgen et al, 2007)



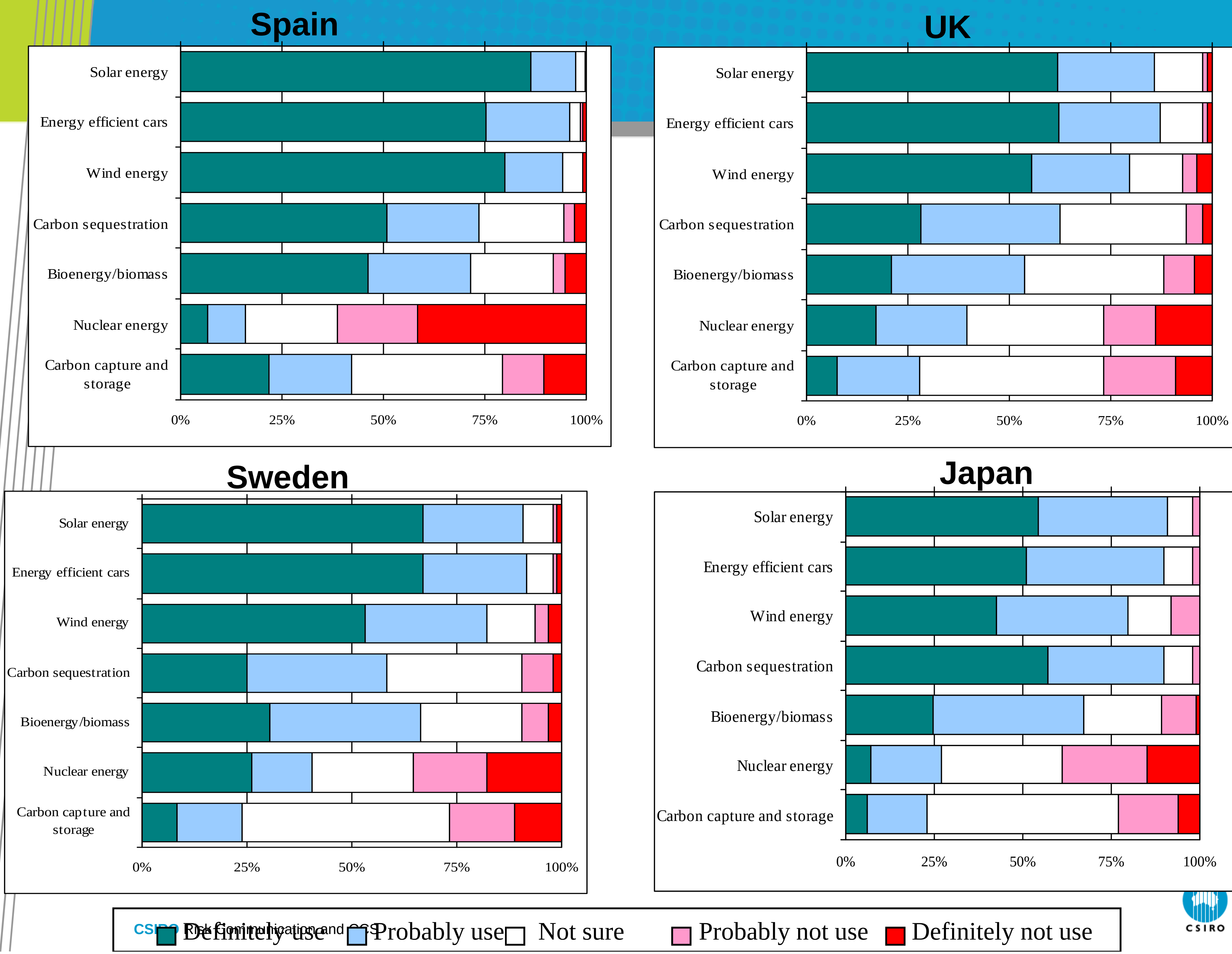
- 171 scientists and engineering students working in CCS
- What is your personal opinion of CCS? What do you think general public's opinion is?
- Shows substantial variations between different nations.
  - Personal opinion most positive in UK, NO and US.
  - Perceived public opinion most positive in FR, NO and UK

Preferred energy technology to address global warming

Australia | US



D. Reiner et al., (2007)*An international comparison of public attitudes towards carbon capture and storage technologies, GHGT-8*


Spain
UK
Sweden
Japan
Solar energy
Energy efficient cars
Wind energy
Carbon sequestration
Bioenergy/biomass
Nuclear energy
Carbon capture and storage
0%
25%
50%
75%
100%
Definitely use
Probably use
Not sure
Probably not use
Definitely not use

Stated Risks From California EJ Group!

- CO_2 liquid's acidic nature is **corrosive** to the underground environment, **contaminating** the ground and would eventually leach to the surface.
- When CO_2 escapes from underground to the surface it also changes from liquid to gas, it is 1.5 times heavier than air, does not readily disperse in the atmosphere, stays close to the ground and **will kill every living human, animal and plant within 20 miles from asphyxiation.**
- When CO_2 leaches up to the surface it will **contaminate underground fresh drinking water aquifers, lakes**, rivers and the ocean.
- Southern California is in **earthquake country** with numerous faults. To sequester the volume of CO_2 the distance underground will require large dangerous high pressure equipment.
- The CO_2 will **not be transported by pipelines to a safe location** away from the population. The plan is to sequester the CO_2 in the Wilmington Oil Field which is located under the City of Los Angeles, City of Long Beach, City of Carson and other neighboring cities.
- Over 500,000 people and **children will be placed in danger**.

And from the 11 year olds' perspective!

Dear Mr Bradshaw,

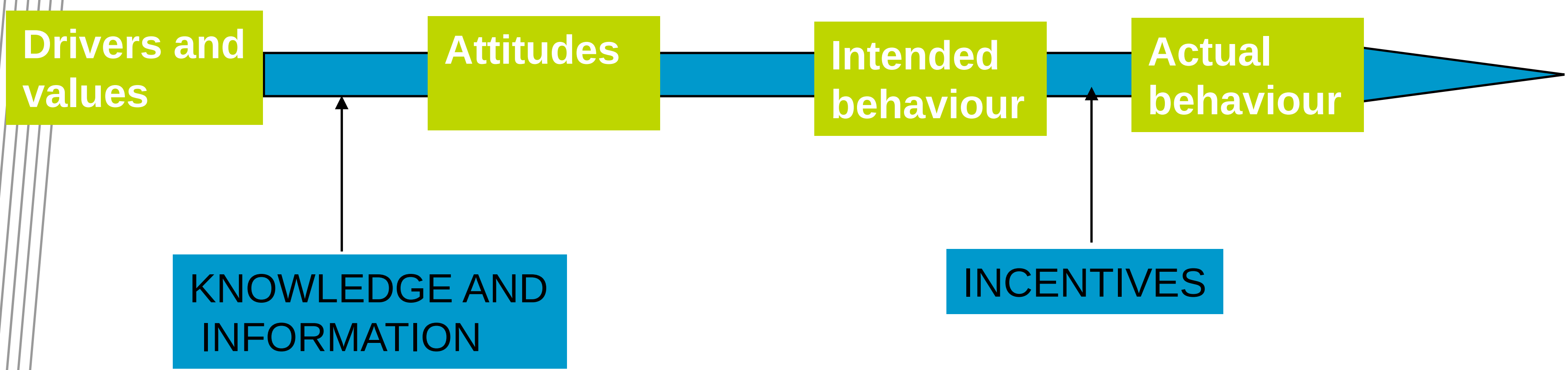
We are two year six students from the International Baccalaureate School, Red Hill Primary. We are currently inquiring into the relationship between population growth and energy use. **We are convinced that Geosequestration would provide a solution to carbon dioxide emissions** produced from coal energy plants and would like to know more about it.

After viewing an episode of Catalyst on geosequestration, we have recorded your name down as an expert on geosequestration and hope that you will share some information on it with us. If you would be able to help us answer these questions or give us some useful websites to look at we would be very thankful.

- Do you think Geosequestration is a practical and achievable solution towards CO2 emissions from coal energy plants? And why?
- What steps would we, as Australians have to take to ensure the success of geosequestration as a permanent solution?
- Is there another country or city that is already using geosequestration successfully?
- What would it cost to install geosequestration?
- Would it be worth us visiting Geoscience Australia on Hindmarsh Drive to see any other information on this? Or to talk with any other experts?

We thank you in advance for your time and professional opinions.

Our Conceptual Framework



How do you deliver information to best effect?

- Face to face essential
- Small group discussion creates dissonance and challenges attitude
- Behaviour change follows
- Support for continued R & D into range of technologies

How can you use information and attitudes to inform policy

- Dialogue

How can you evaluate impact?

- Monitoring and measuring

Qualitative - Large group process

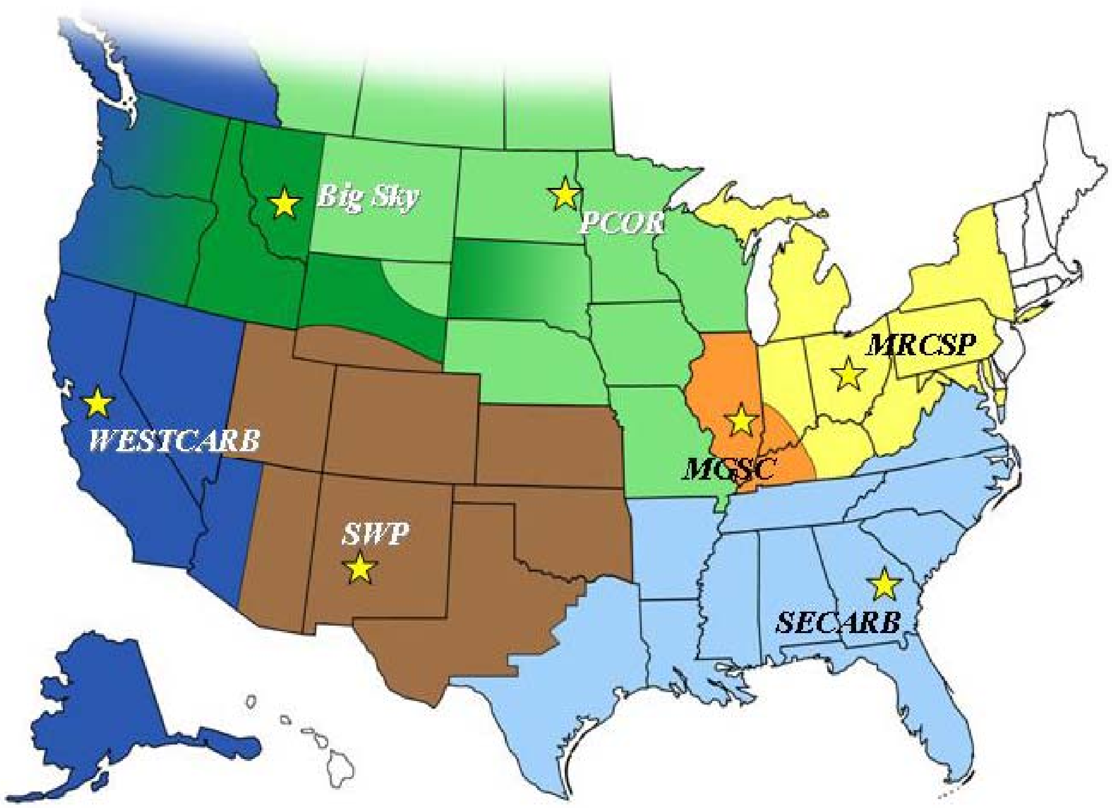
	Feb, 2008 Youth 29		Mar, 2008 Brisbane 60		Jun, 2008 Melbourne 47		Nov, 2008 Perth 62		Feb, 2009 Adelaide 131	
	Before %	After %	Before %	After %	Before %	After %	Before %	After %	Before %	After %
Strongly disagree	6.9	3.6	8.6	10.2	2.1	2.1	1.6	4.8	1.5	0
Moderately disagree	13.8	10.7	5.2	1.7	2.1	4.3	4.8	4.8	3.1	2.3
Disagree	0	14.3	6.9	5.1	14.9	4.3	1.6	6.5	5.3	3.8
Unsure	48.3	25	48.3	32.2	59.6	14.9	54.8	21	47.3	9.9
Agree	13.8	35.7	8.6	27.1	6.4	40.4	22.6	37.1	10.7	22.1
Moderately agree	13.8	7.1	17.2	13.6	8.5	19.1	9.7	17.7	13	38.2
Strongly agree	3.4	3.6	5.2	10.2	6.4	12.8	4.8	6.5	17.6	23.7
Missing responses	0	0	0	0	0	2.1	0	1.6	1.5	0
Total	100	100	100	100.1	100	100	99.9	100	100	100

Ashworth et al. (2008) *Engaging the public on Carbon Dioxide Capture and Storage: Does a large group process work? GHGT9*

Questions about CCS

- *“Have any studies been done on ways to use CO2 emissions for practical uses thereby creating a recycling effect rather than just bury it?”*
- *We need to know more about it before widespread application - Is it safe? What are the long-term effects? Is it a cover-up operation – will it give companies that invest in this technology the appearance of looking green without actually doing anything?*
- *CCS is not an answer but can be a bridge for other technologies. I thought it was bad but now I have changed my opinion.*
- *What is payback period for building CO2 sequestration, brings jobs and progress but how many emissions?*
- *CCS is a pipedream; there is not concrete evidence of it working*
- *How far down the track is carbon sequestration? How soon can we implement? How long can we use the special sequestration spots?*

Regional Carbon Sequestration Partnerships



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US Regional Carbon Sequestration Partnerships

- Characterisation phase 2003 - 2005
  - Collect data on CO_2 sources and sinks and develop the human capital to support and enable future carbon sequestration field tests and deployments
- Validation phase 2005 - 2009
  - Validating the most promising regional opportunities to deploy sequestration technologies
- Development phase 2008 – 2018
  - Demonstrate at large scale that CO_2 capture, transportation, injection, and storage can be achieved safely, permanently, and economically

RCSP Outreach Activities

- Research and Coordination:
  - Focus groups and interviews with stakeholders and partners
  - Mediated modeling
  - Outreach Working Group (OWG) calls
- General Outreach:
  - Websites
  - Information materials – Atlas, fact sheets, posters, videos, models
  - Briefings – civic groups, trade associations, policy makers, ENGOs
  - Media – television and print
  - Education – curricula for grades K-12
- Project Outreach:
  - Detailed project materials – geologic columns, well diagrams, photographs, "Dear Neighbor" packets
  - Targeted communication – neighbors, information open houses at the local level

RCSP's outreach - challenges

- Lack of attention due to small size and remote location of projects
- Lack of familiarity with the natural carbon cycle, the extent of human GHG emissions, and the mitigation potential of carbon sequestration
- General skepticism towards new technology and some participants in RCSPs
- Ambivalence, based on direct or anecdotal experience, about the value of outreach on the part of some RCSP members
- Lack of scientific knowledge on the part of the audience, combined with the complexity of explaining sequestration
- Previous negative experiences with and distrust in government institutions, including regulatory agencies, to safeguard public welfare

Source: Chapter 6, Best Practices for the Implementation of the Regional Carbon Sequestration Partnerships Large-Scale Carbon Sequestration Field Projects

RCSP's outreach - challenges

- Perceived resource competition with renewable energy or energy efficiency
- Lack of full consensus about the role of sequestration by stakeholder groups
- Well publicized CO2 release incidents (e.g. Lake Nyos)
- Resource constraints commensurate with small project size and short duration
- Relationship of the 'messenger' to the project can be important (e.g., public trust is likely to be greater if the messenger is neutral, such as academia)
- Changes in project plans due to permitting or extraneous circumstances

Source: Chapter 6, Best Practices for the Implementation of the Regional Carbon Sequestration Partnerships Large-Scale Carbon Sequestration Field Projects

RCSP's outreach – lessons learned

- "Develop a **solid understanding** of the stakeholders' concerns and **perceptions** about sequestration and the RCSPs' efforts
- Develop and use materials that **address various concerns** and make those **materials accessible** to target audiences
- **Openness and transparency** are essential for gaining broader public "permission" to conduct a research project and are very likely to be important in gaining the same to conduct larger commercial projects.
- Public outreach **does not guarantee** that everyone will **support** a sequestration project but it is very important in identifying"

Source: Chapter 6, Best Practices for the Implementation of the Regional Carbon Sequestration Partnerships Large-Scale Carbon Sequestration Field Projects

Management of the social risk

- But, *management* of risks is the critical factor for public acceptance
  - How can we **have a say** in what happens?
  - Will the process be **fair** and will anyone **listen** to us?
  - Can we **trust** the project developers and government to take care of problems
  - What have our **previous relationships** with these entities shown us?
  - What is the **benefit** to the community
  - How does the project fit or **improve** our way of life?

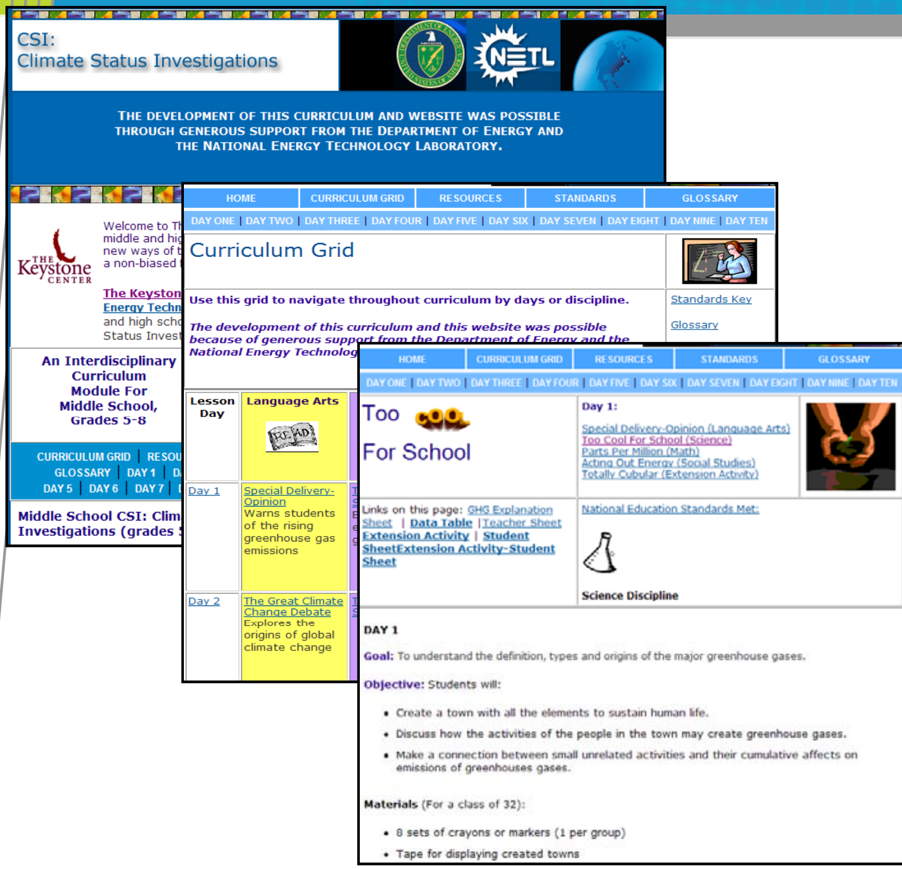
Bradbury, J., et al. *The Role of Social Factors in Shaping Public Perceptions of CCS: Results of Multi-State Focus Group Interviews in the U.S*

Websites

Midwest Geological Sequestration Consortium
Phase III Project Awarded
The Midwest Geological Sequestration Consortium (MGSC), and the Illinois State Geological Survey (ISGS) have been awarded a $66.7 million contract from the U.S. Department of Energy to conduct a Phase III large-scale sequestration demonstration project in the Mt. Simon Sandstone. The MGSC, ISGS, and Archer Daniels Midland Company (ADM) will work together on this carbon sequestration project, which will involve the capture and storage of carbon dioxide from ADM's ethanol plant in Decatur, Illinois. The project is designed to confirm the ability of the Mt. Simon Sandstone, a major regional saline reservoir in Illinois, to accept and store 1 million metric tonnes of carbon dioxide over a period of three years. The carbon dioxide will be provided by ADM from its Decatur, Illinois, ethanol plant, and the project will be located on ADM's Decatur property.
MRCSP
MIDWEST REGIONAL CARBON SEQUESTRATION PARTNERSHIP
Michigan Basin Project Update
Other recent updates
Home
Join Our Mailing List
Learn about Climate Change and Carbon Sequestration
About MRCSP
In the News
Phase I Report
Phase II Geologic Demonstrations
Phase II Terrestrial Demonstrations
What's New
Contact Us
Fact Sheets
Links & Resources
Presentations
Members Area
Managing Climate Change and Securing a Future for the Midwest's Industrial Base
BIG SKY CARBON SEQUESTRATION PARTNERSHIP
A NEW ENERGY FUTURE FOR MONTANA, IDAHO, WYOMING, SOUTH DAKOTA, THE PACIFIC NORTHWEST, AND THE NATION
Partner Log-In
Home
Overview
Carbon Atlas
Terrestrial
Geologic
GIS
Publications / Reports
Presentations
Partners
WEST COAST REGIONAL CARBON SEQUESTRATION PARTNERSHIP
westcarb.org
HOME
CONTACT US
PARTNER LOG-IN
Expand Menu | Collapse Menu
About WESTCARB
What Is Sequestration?
CO2 SEQUESTRATION geologic transport
Sequestration: capture, transport, geologic, terrestrial
WESTCARB is a collaborative research project bringing together dedicated scientists and engineers at 70 public agencies, private companies, and nonprofits to identify and validate the best regional opportunities for keeping CO2 out of the atmosphere and thereby reducing mankind's impact on the climate.
SOUTHWEST PARTNERSHIP CO2 SEQUESTRATION
SWP
MEMBER LOGIN
How Does Carbon Dioxide Affect Global Climate Change?
When the Intergovernmental Panel on Climate Change (IPCC) released its Climate Change 2007 Report, it named carbon dioxide (CO2) the most important human produced greenhouse gas. The report confirmed that the high levels of CO2 in our atmosphere are caused by fossil fuel emissions and are a major contributor to global warming. The increased occurrence of extreme weather such as droughts, heavy precipitation, heat waves, and intensity of hurricanes and typhoons is a symptom of climate change.
Several options will be needed to moderate CO2 levels in our atmosphere. One approach to lowering atmospheric CO2 levels, called Terrestrial Carbon Sequestration, includes planting vegetation or enhancing an already present ecosystem to
Southwest Carbon Partnership
Pioneers in the Carbon Economy
PCOR Partnership
Plains CO2 Reduction Partnership
EERC
Home
EERC
Contact Us
Partners Only
About the Partnership
Carbon Sequestration, Climate Change, and CO2
Region
Publicly Available Products
Documentaries
Kids Only!
Links
What Can I Do?
Frequently Asked Questions
Events
Site Map
Sponsored in Part by the U.S. Department of Energy
What's New? 10/10/2007
Sequestration in the News
Southeast Regional Carbon Sequestration Partnership
SECarbon.org
about the partnership
partners
event schedule
about carbon dioxide and sequestration technologies
regional partnerships
partner area
contact us

Information Materials: Posters, Fact Sheets, Video

Educational Materials

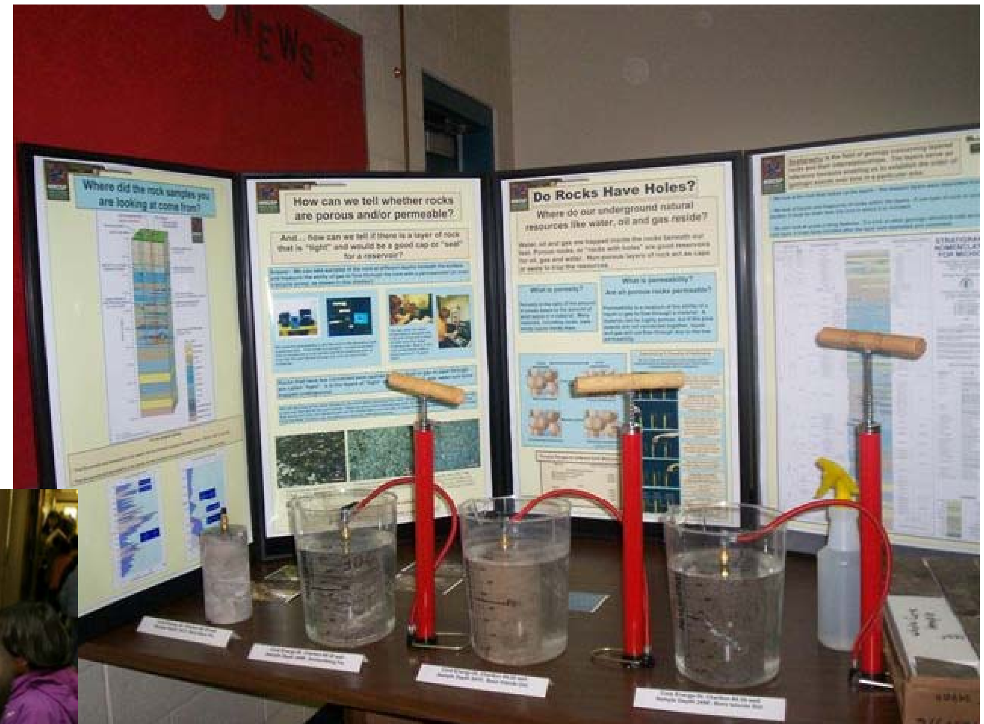


The Keystone Science School Curriculum trains teachers and gives detailed lesson plans and information: http://www.keystonecurriculum.org/

From the PCORP site, several links for educators including The Wisconsin materials http://www.uwsp.edu/cnr/wcee/keep/

CCS Models

Carbon Sequestration in the Illinois Basin



Where did the rock samples you are looking at come from?
How can we tell whether rocks are porous and/or permeable?
Do Rocks Have Holes?
Where do our underground natural resources like water, oil and gas reside?

- How can your work help to mitigate the social risk of CCS projects not being accepted?

- How can you work with communications experts so that they can communicate your findings to the relevant stakeholders groups?

Social Research Team
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Senior Social Scientist

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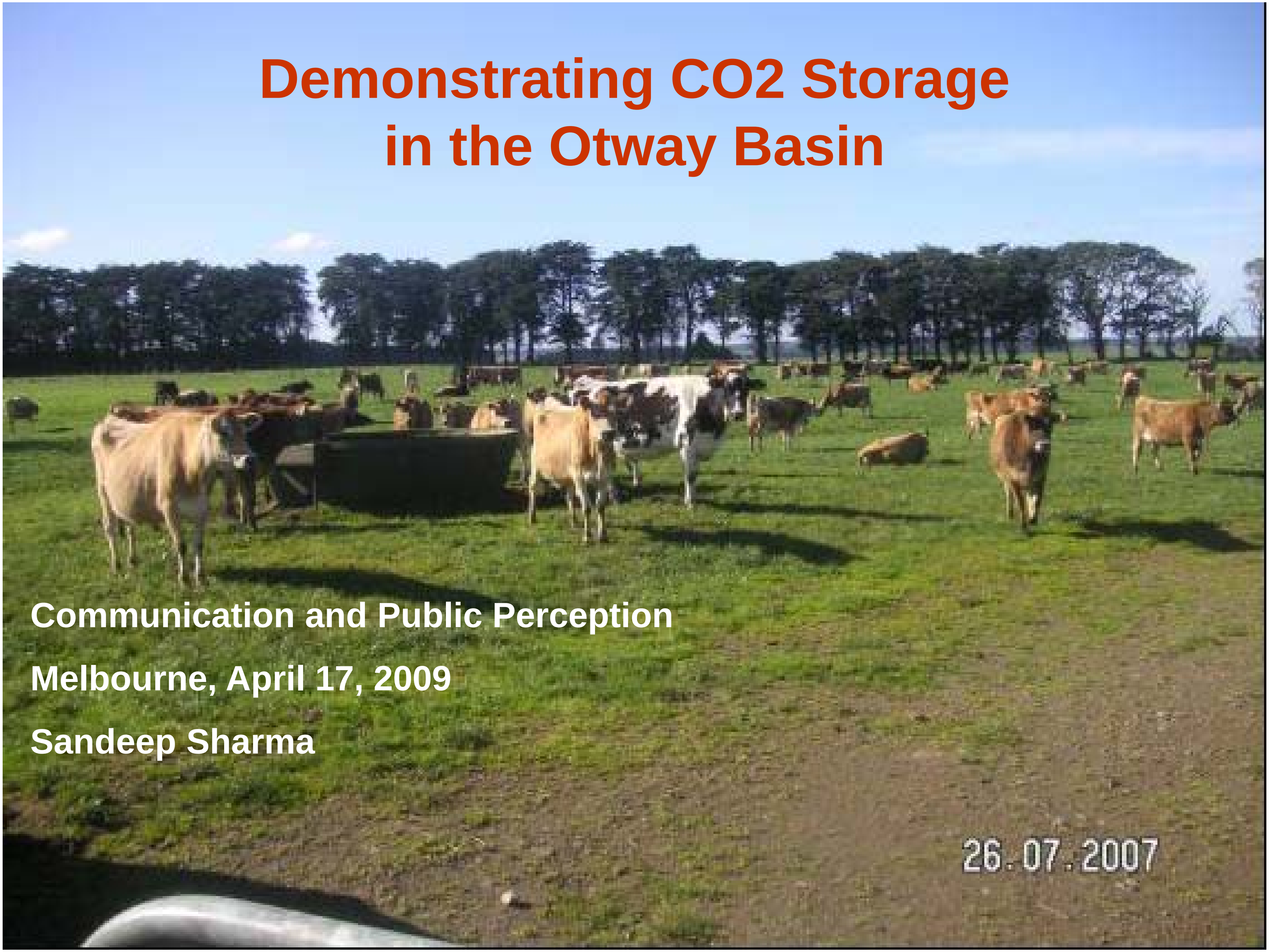
www.csiro.au

Thank you

Contact Us
Phone: 1300 363 400 or +61 3 9545 2176
Email: enquiries@csiro.au Web: www.csiro.au

CSIRO

Demonstrating CO_2 Storage in the Otway Basin



Communication and Public Perception

Melbourne, April 17, 2009

Sandeep Sharma

Otway Project Teamwork

Acknowledgements

- CO2CRC Colleagues
  - P.Cook ... oc ... orv ... .Ka ... Hi ... n, J ... ar ... Pe ... D van Puyvelde, D.Smit ... e-/ ... lyr ... Mo ... .Ste ... per ... th
  - Subsu ... Danc ... aterson, J.Xu, Y.Cinar, J.E King, D ... ock, P vanRuth, R.Cau ... kare ... Dar ... s
  - M&V team: C.Jenkins, A.Hennig, J.Undershultz, M.Urosovic, ... A.Kepic, P.Wisn ... ins ... a ... i ... s
- Government colleagues from DPI, ITR, EPA, AGO, DSE, Moyne Shire, SRW
- International ... atc ... chlumberger Re ... vie ... nd other advisors
- CO2CRC P ... companies
  - Special ... th

Supporting participants: Australian Greenhouse Office | Australian National University | | CANSYD | Meiji University | The Process Group | University of Queensland |LBNL ARC

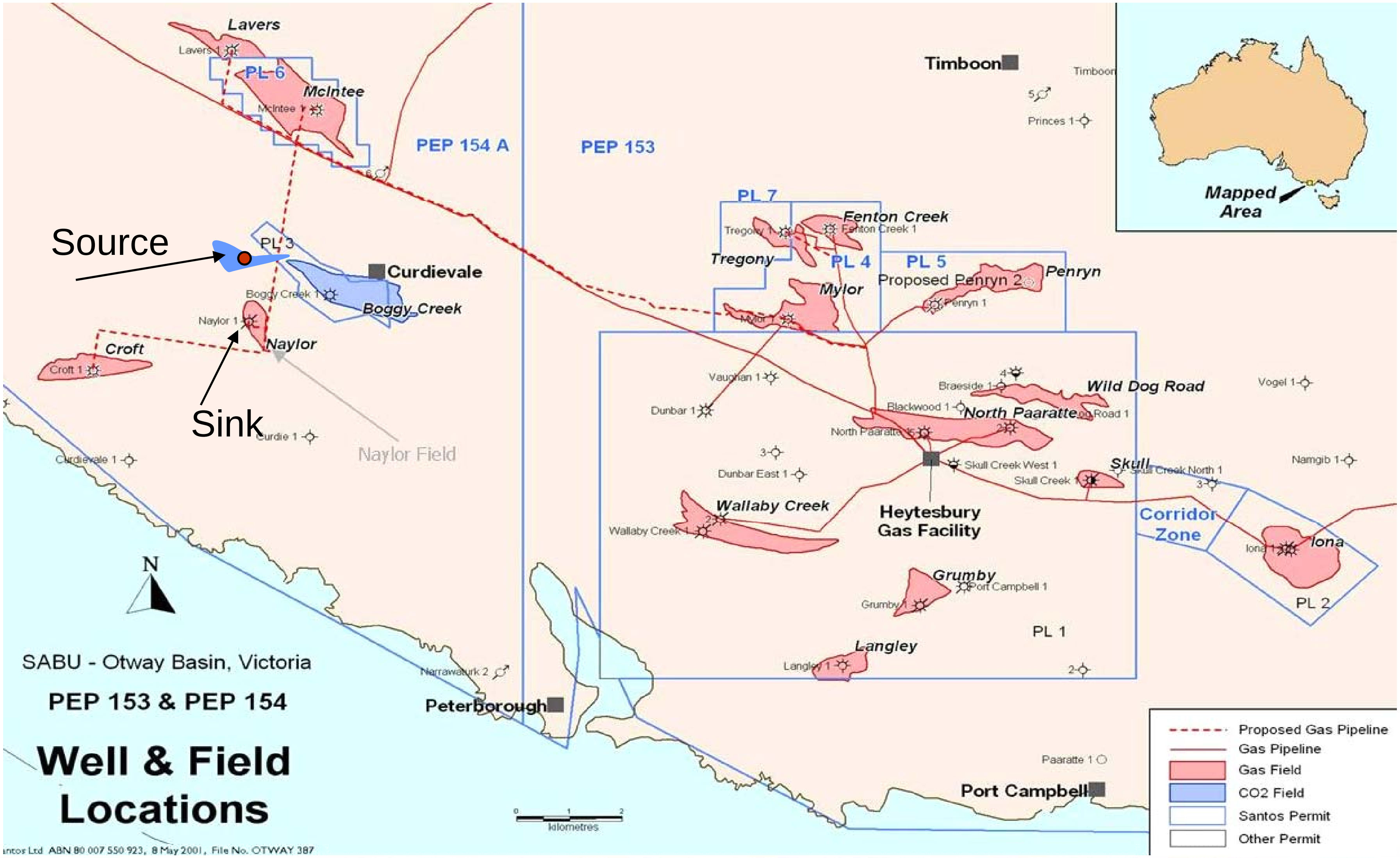
Outline

- The Otway Basin Project
  - Project Goals and Concept
  - Key Challenges
- Community consultation
  - Process and activities
- Performance Scorecard
- Lessons Learnt

CO2CRC Otway Project Goals

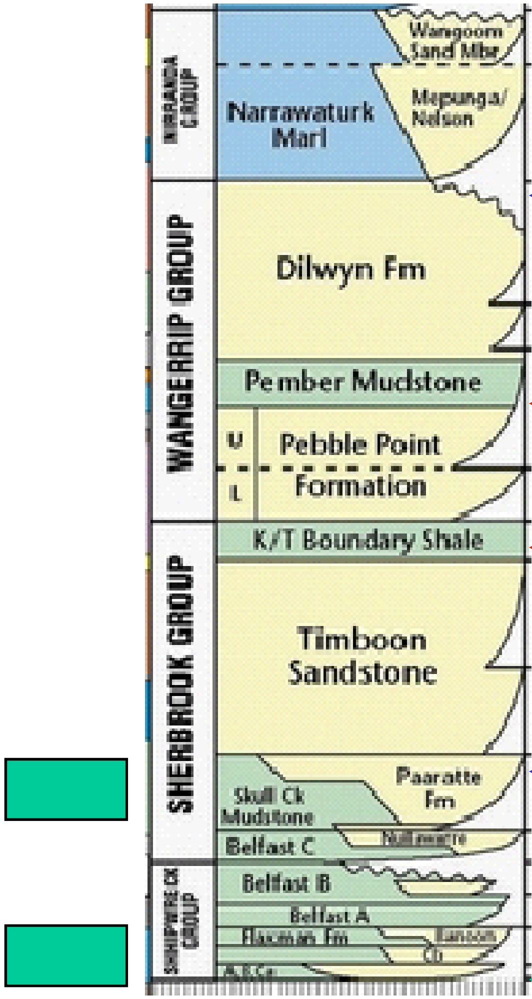
- **Contribute towards CO2CRC Vision and Mission.**
  - Demonstrate that CCS is technically feasible and environmentally safe.
  - Facilitate research into new monitoring technologies
  - Offer opportunities for trial and experimentation thereby supporting education/training in greenhouse gas technologies.
- **Specifically demonstrate to the satisfaction of stakeholders that**
  - CO_2 can be **safely produced, transported and injected** into the sub-surface
  - CO_2 can be **safely stored**
  - **Subsurface behaviour** of the injected CO_2 can be effectively **modeled and monitored**
  - Storage Volume can be verified as far as possible
  - **Build public support for CCS** as a mitigation mechanism

Project Assets and Site



CO2CRC

Otway Basin Stratigraphy



500 M Dilywn

Multiple barriers to Aquifer.
Injection point is > 1 km deeper

896 M Pebble Point

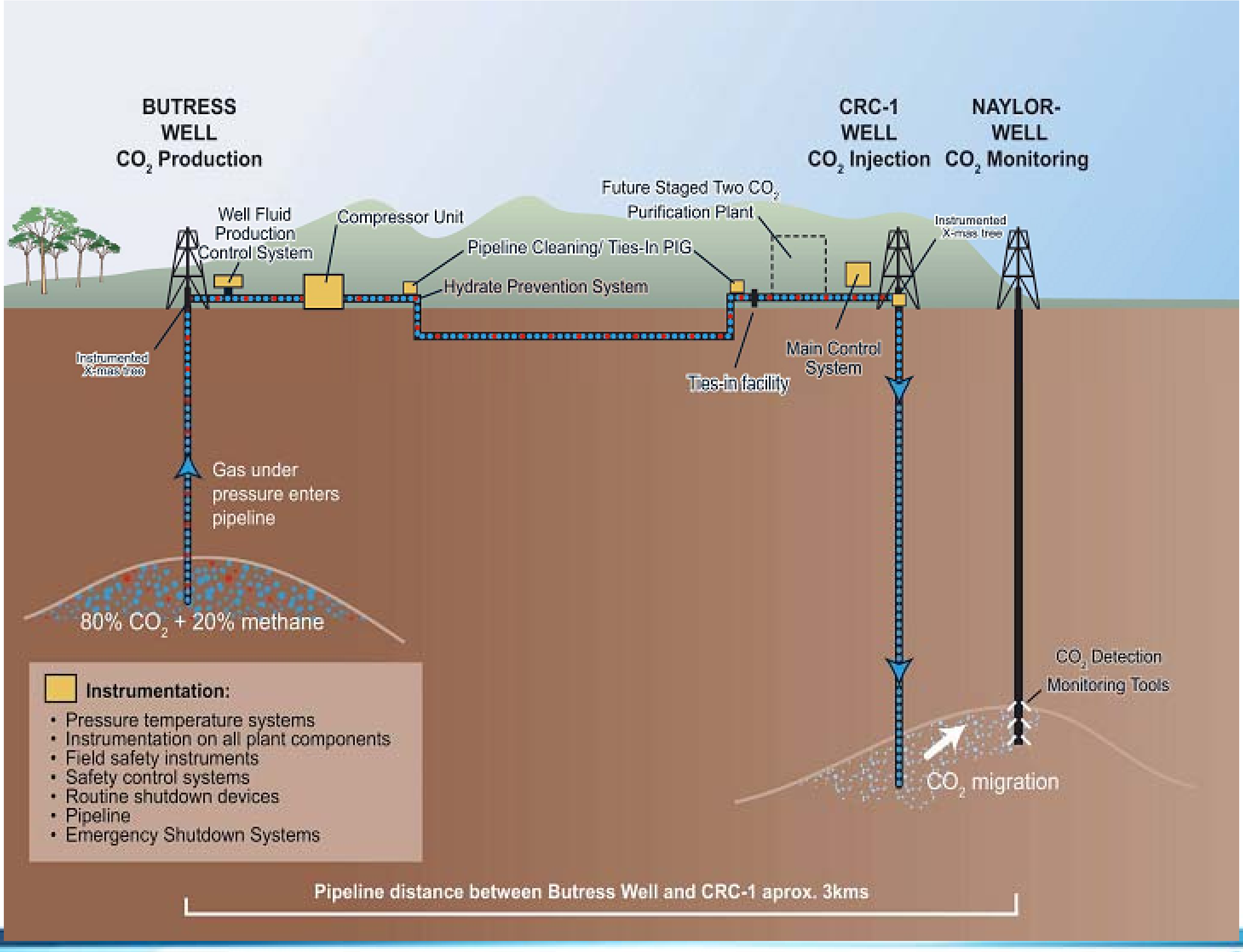
976 M Timboon

1089 M Top Paratte – Injection Horizon Stage 2

Multiple barriers

1977 M Warre C – Injection Horizon Stage 1

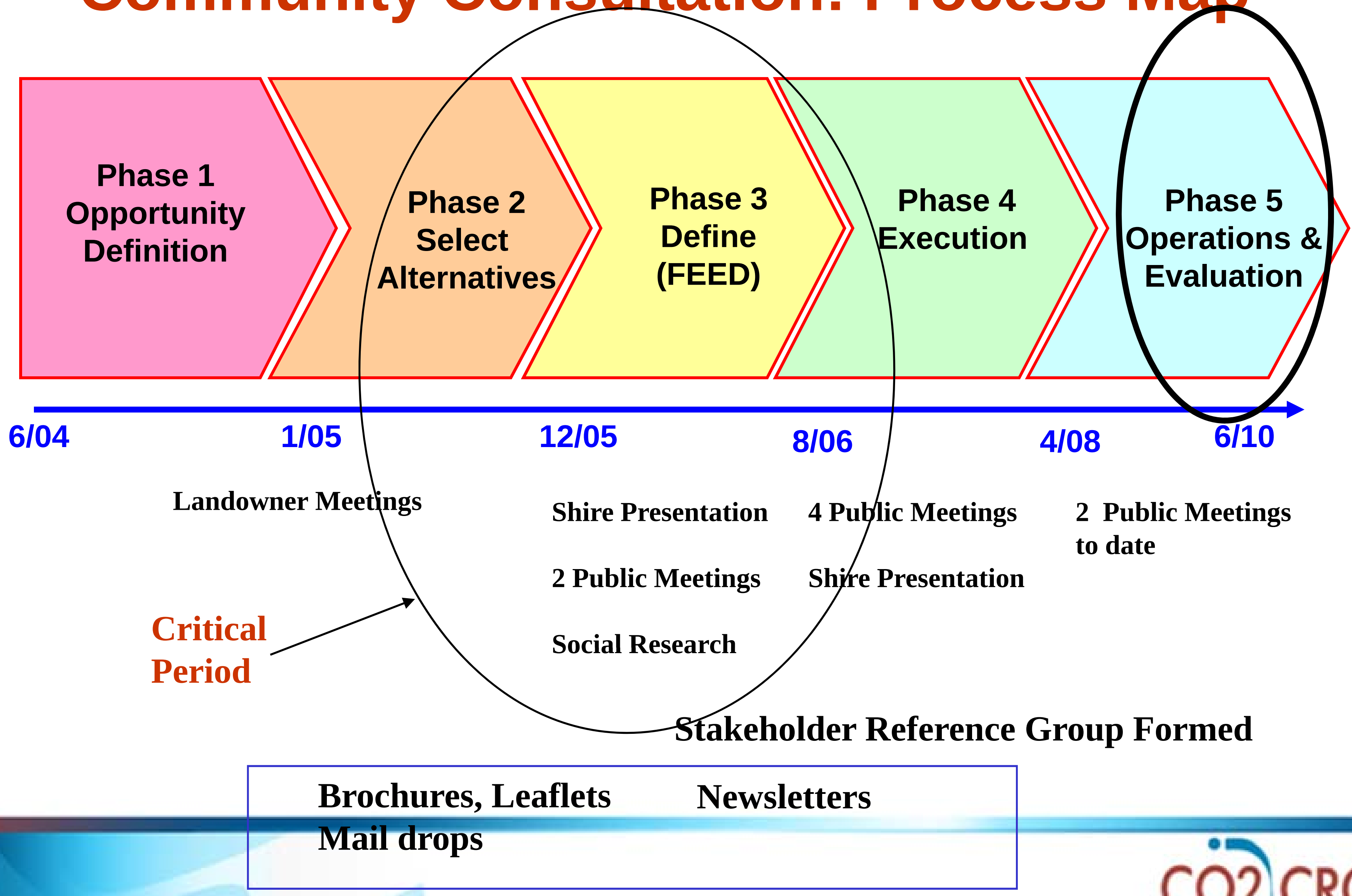
Otway Project Concept



Key Challenges – each a risk !

- **Regulatory**
  - No existing regulation for geo-sequestration.
  - Overlaps between jurisdictions
  - Access
- **Organisational/Operational**
  - CRC not an operating entity
  - Lack of Operations Systems
- **Liability Management**
  - Who would shoulder long term liability.
- **Site Characterisation**
  - Limited data
- **Risk Assessment**
- **Monitoring**
  - Imaging under gas cap
  - Existing wells
- **Community / Public Acceptance**
  - No precedents
  - Mixed reports on CCS in the media
  - Need for compulsory land acquisition

Community Consultation: Process Map



Community Consultation

- Formal program to engage with and brief the community early – starting Jan 05
  - key landholders
  - Shire and neighbouring councils
  - the local media
- Informing via email and offering briefings to:
  - local State Upper and Lower House MPs
  - NGOs (eg WWF, ACF)
  - State and Federal ministers through their Departments
- Invited Mayor and Planning Manager to CRC technical Symposium
- Formal briefing to shire and public
  - Public info packs distributed to 1200 households
  - Advertisements run in local papers
  - Public meeting with state regulators held on Feb 12,06 – others planned
- Social research in community perception

Initial Communication – 2005

- **The CO2CRC**
  - CO2CRC is not-for-profit research organisation, funded by government, industry, and research bodies
  - The Research Project is important for Victoria, Australia and the World
- **The Potential Project**
  - Subject to all the necessary planning and environmental approvals
  - We will be using safe, proven technology and maintain the highest standards of HSE
  - Transparency about the Project at all times
  - Community consultation - we want to hear what you think and work with you
- **Why Moyne Shire**
  - Moyne Shire as a world leader in energy innovation.
  - National and international profile for the region
  - Help Victoria to decrease it's greenhouse gas emissions
  - Economic benefits to Victoria
- **Communication Tools**
  - Brochures, Videos. Mail drops, Web information

Social Research

- **Objectives**
  - Benchmark and track public perceptions of CO_2 geo-sequestration
  - Identify existing and emerging issues and track these over time
  - Provide input to the community consultation plan.
- **Approach :**
  - Focus group discussions with people living in country near the site
  - Focus group discussions with people living in a close by city.
  - In-depth interviews with local landowners.
- **Initial Results:**
  - Contrast between above groups: education, knowledge of CCS
  - General desire to know more: facts not “spin”.
  - However, do not want it to be intrusive

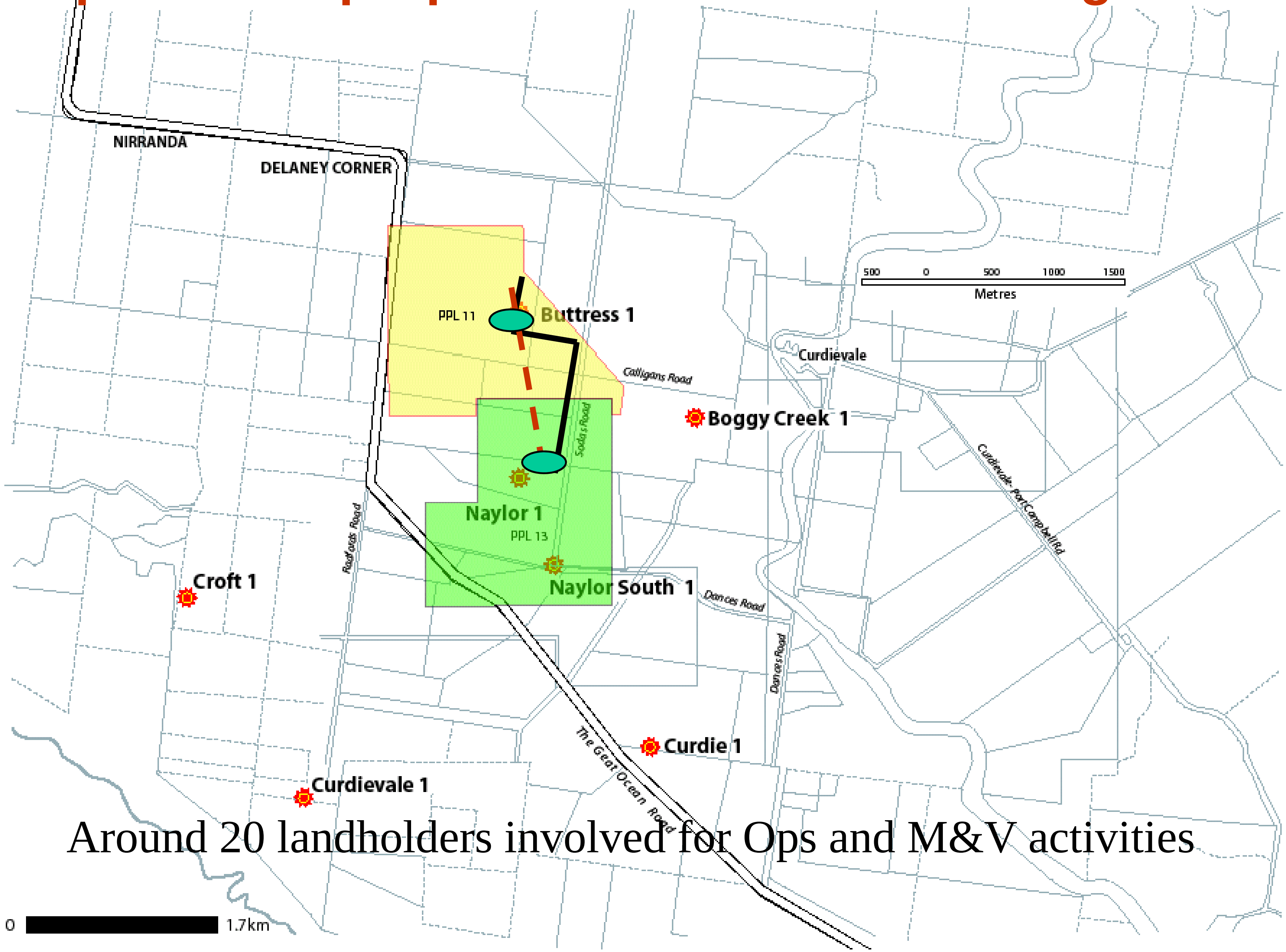
Adapting the Strategy

- Formation of a Stakeholder Reference Group
  - Local Landowners and community representatives
  - Independent chair from DSE
- Fundamental Tenet
  - The community should hear of activities directly from us first
- Address concerns quickly
- Bring scientists to explain their work
- If unable to provide some data explain why
- Quarterly newsletter

Example - Informing Anticipated Activities

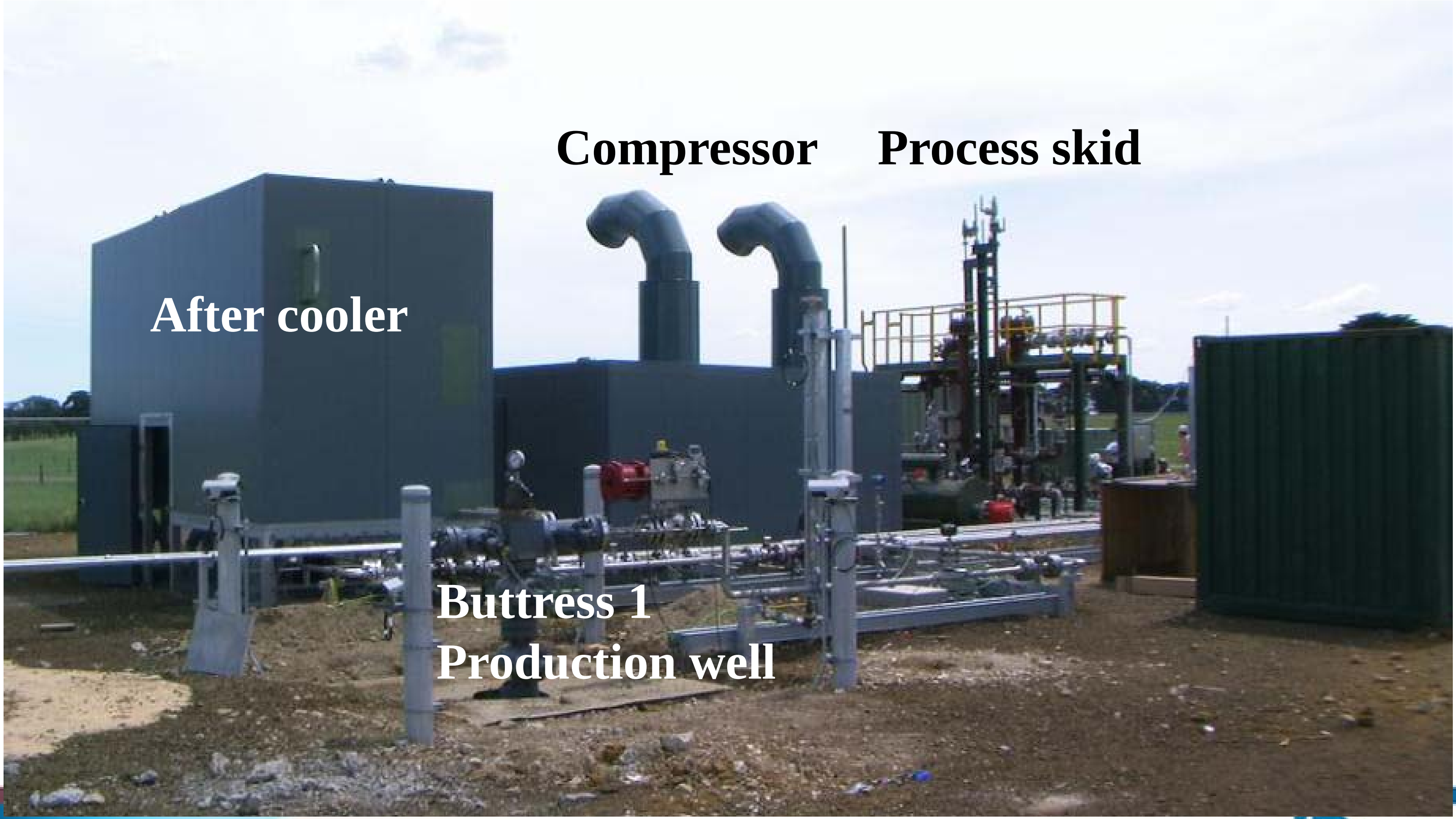
- **Naylor Phase 1**
  - Late March – April : Logs to understand reservoir. 2 –3 trucks, a few people for 2 –3 days.
- **Naylor Phase 2**
  - New well : early 2007
  - Monitoring activity
    - Sampling : 4 –6 months into injection
    - 1 seismic set every 2-3 years (2-3 weeks with a crew of 5-7 people)
    - Well logs 2 –3 times a year (2-3 days each time)
- **Buttress Phase 1**
  - Late March – April : Well Test and Logs : Expected to be a few days
    - Understand well depth : Truck mounted unit with depth gauge
    - Test : Vehicles and storage tanks to flow the well and test gas.
- **Buttress Phase 2**
  - Starting late in the year: Site civil works for plant , Plant assembly and testing. Area needed : 1 ha
  - Plant Operations in 2007-8 for an initial period of up to 2 years

Options for proposed Plant and Gathering line



Around 20 landholders involved for Ops and M&V activities

Production Site: Processing Modules and Compressor Station



Pipeline Installation

Not all Rosy Media Reports

- **Warnambool Standard**
- **Feb 2007**

We will be told by the boffins, in regard to Nirranda, that they have developed better systems.

Gas moves, this fact will never change. It does not come in bricks that can be stacked away for future use.

Gas finds cracks in the rock and rises to the surface.

I urge all residents of Nirranda and surrounding areas to consider the value of your land and water both environmentally and economically and specifically your overseas markets.

Moyne Shire councillors' comments on the proposed development are both ill-informed and a travesty.

One thing you can be sure of is that CO2CRC representative Sandeep Sharma will not be trying to buy land in the area on which to raise his family.

Anna Dillon, Rooneys Road, Panmure

CO2CRC

Not all Rosy

Questions in Parliament

- **Feb 2009**

It therefore disappoints me that I have to raise this issue on behalf of Peter Parsons, the owner of the property where the plant to trial geosequestration is built. Mr Parsons received a letter from the then Department of Infrastructure, dated 13 July 2007, which says:

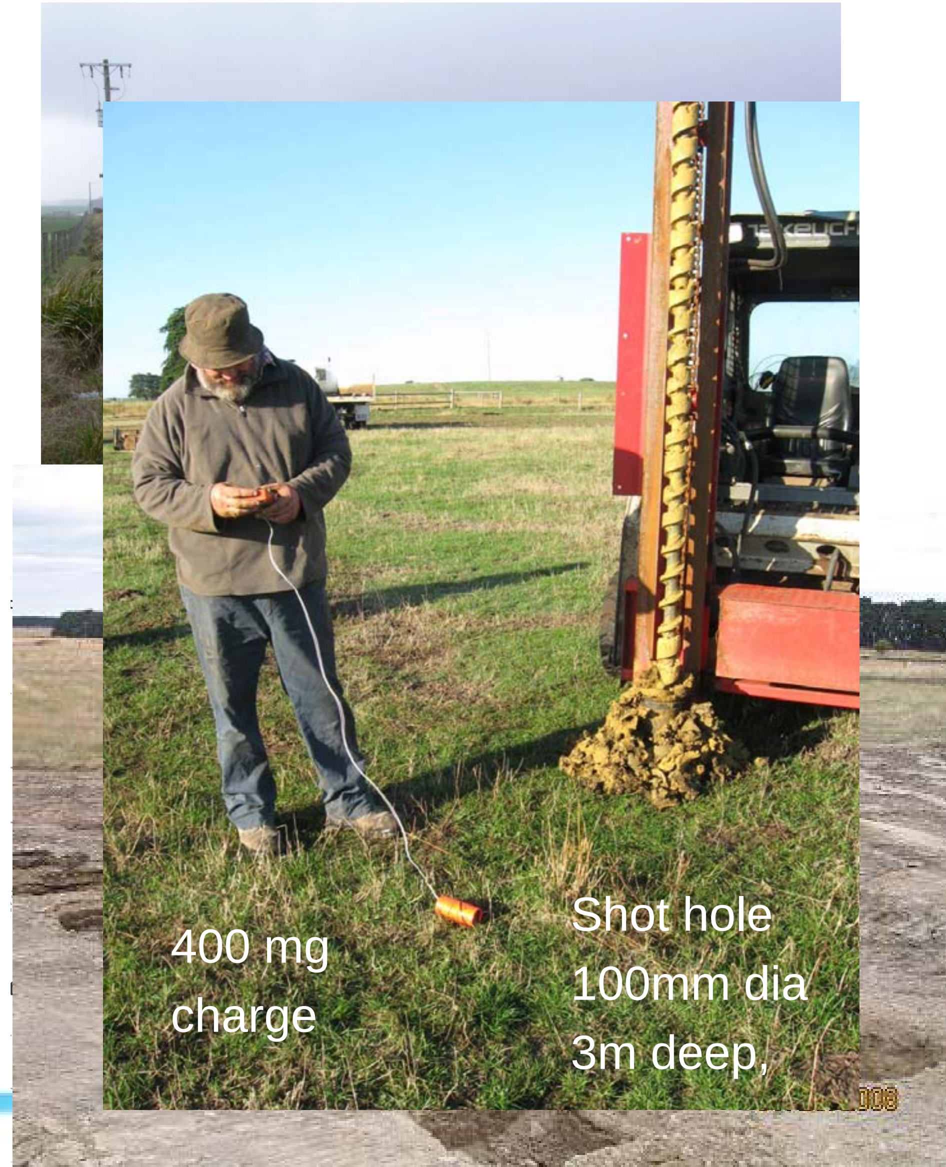
> On 19 June 2007 the Minister for Planning identified your client's property as 'Special Project Land' for the Otway Basin Carbon Capture and Storage Project, by placing a Gazettal Notice in the *Government Gazette*, No. S 131.
>
> Attached is the Notice of Acquisition, Offer of Compensation and Plans identifying those parts of your client's property the Secretary to the Department of Infrastructure ... has acquired together with other statutory notices and forms setting out what is required under the Land Acquisition and Compensation Act ...

Mr Parsons informs me that he is owed more than $5000 for the works carried out in connection with this project. Mr Parsons has provided invoices. There is an invoice dated 5 March 2008 for fence repairs after damage done by CO_2 workers for materials and labour for $1640. Another invoice is for spraying Roundup, for grass seed, power harrowing, and so on, to repair the property after the CO_2 plant was being built and upgraded, for $2048, in April 2008. There is yet another invoice for $1328.80 for gravel for south-side gateways that were dug during the laying of pipelines, for gravel and cartage.

CO2CRC

Operational Challenges

- Boggy ground, windy, rain
- Electric fences – everywhere! More noise
- Access issues: Dairy farms, paddocks, fences



400 mg charge

Shot hole
100mm dia
3m deep,

CO2CRC

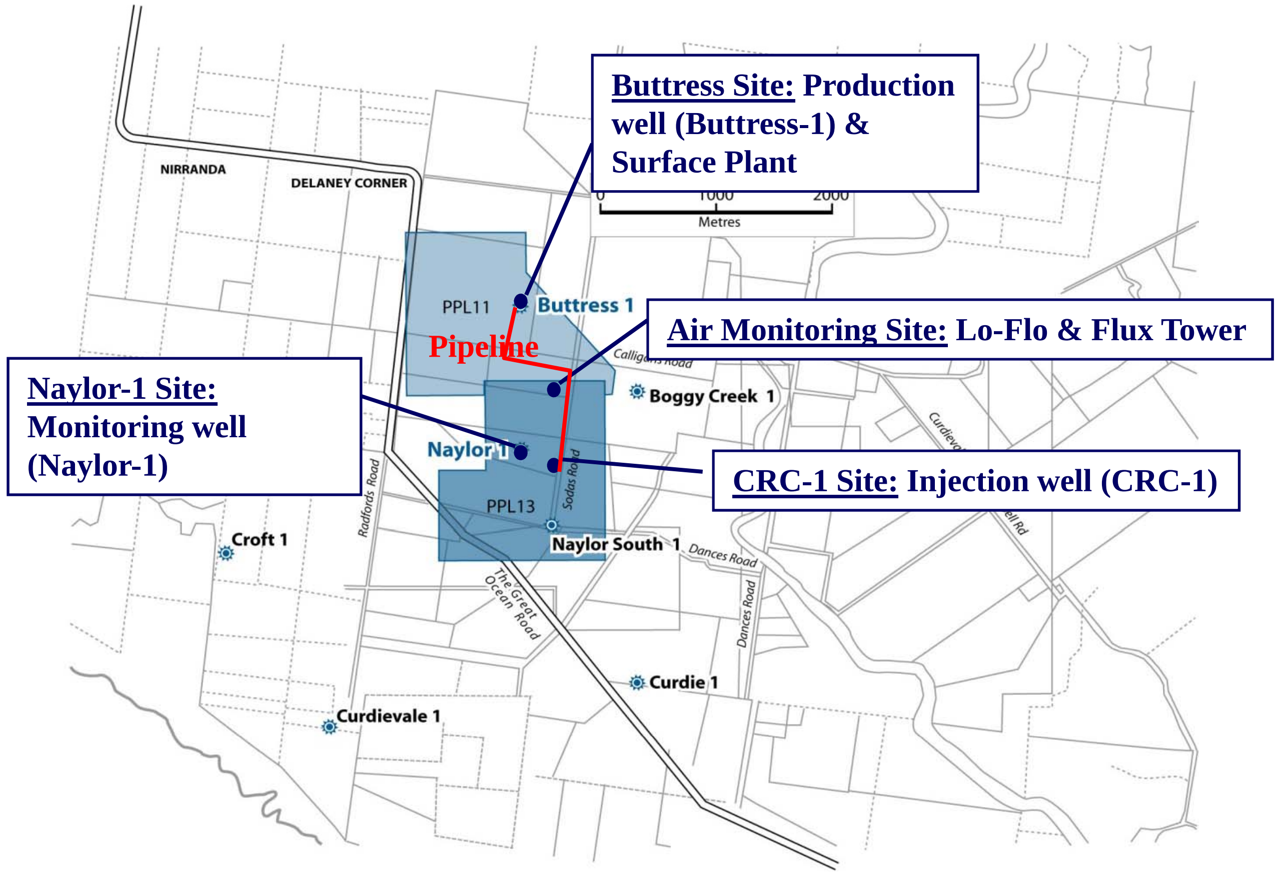
CO2CRC Otway Project Score Card

1. Safely produce CO2 from Buttress, transport and inject in Naylor field
2. Effectively and safely store and monitor CO2 in the sub-surface to satisfaction of stakeholders.
   - Robust Site Characterisation
   - Observations vs Modelling results
3. Test/Develop technology and methodologies for monitoring
4. Build Community Confidence
5. Safely abandon the site and facilities including necessary restoration work.

Scorecard 4: Public Acceptance

Public are interested

- What
- Where
- When
- Impacts
  - Noise
  - Traffic
  - Water
  - Dairy Ops
  - Fire
  - General Safety
  - Compensation



CO2CRC

Community Engagement: Site Emergency Response Plan (ERP

- **10:30 am: Alarm raised – man down Call made to Operator by scientist regrading his colleague being unconscious.**
- **10:39: Peter Dumesny (Operator) arrives. Confirms that he has informed the ERG. Gives CPR**
- **10:55: The CERT and CFA arrive. The CERT team enters the room and attends to the patient.**

  11:00: Ambulance arrives and comes in through the site gate. The stretcher is brought down

  11:20: Patient moved into ambulance.
- **11:45 : Debriefing**

CO2CRC

Achievements

Field Performance

- Strong planning and systems
- Approx. 125,000 manhours without incident
  - CRC-1 and Naylor 1 completion
  - Construction activities
- Approx 47,000 tonnes injected

Regulatory

- Complex pathway
- Compliance with Overlapping jurisdictions

Community

- Landowner Matters : Compulsory Acquisition
- Seismic Issues
- Overall acceptance

Site characterisation

- Further reducing uncertainty

Risk Assessment

- QRA confirmed confidence in site

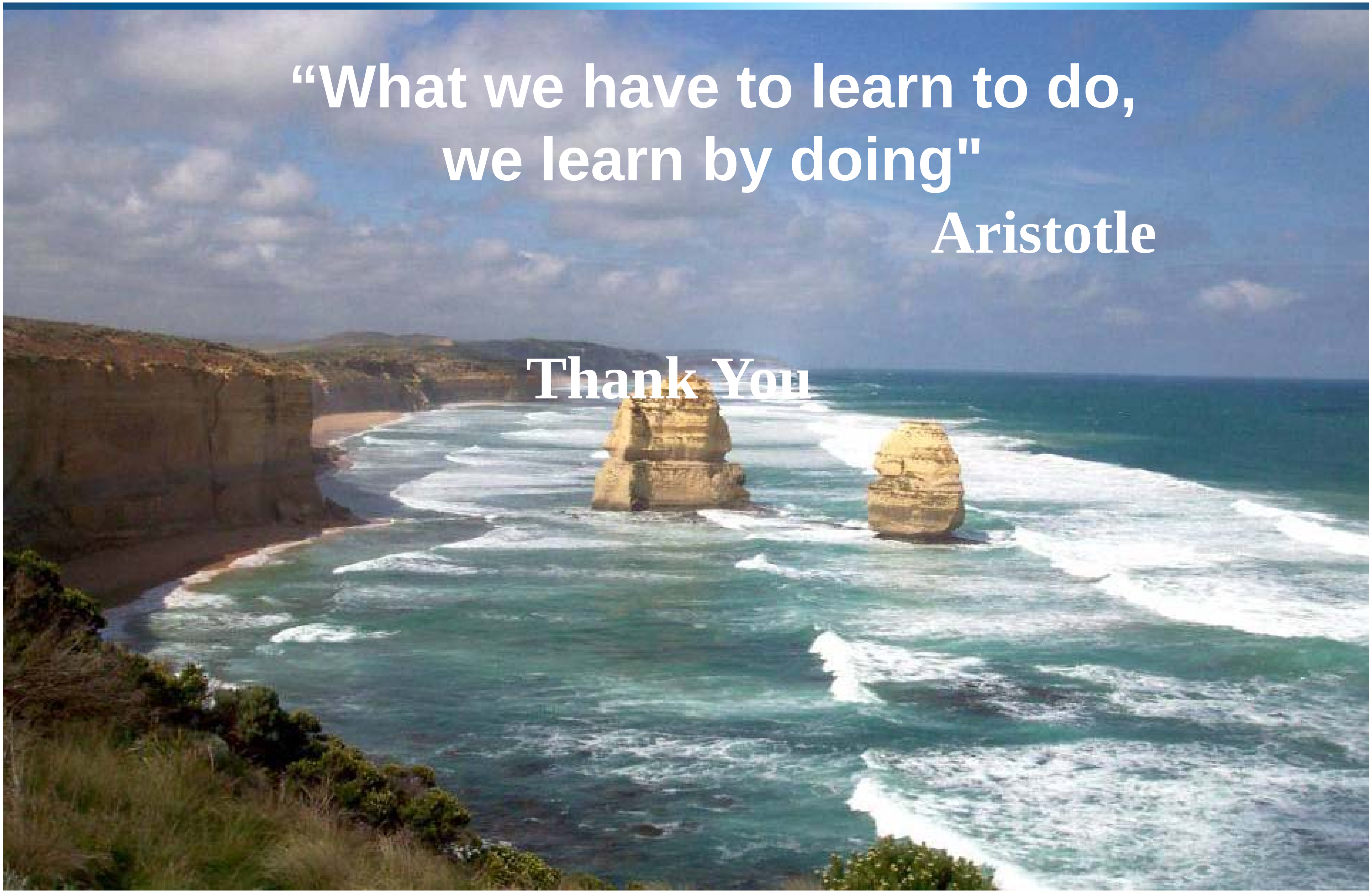
M&V

- Geophysics, Geochemistry and Atmospheric ongoing
- Observations consistent with models

Financial Management

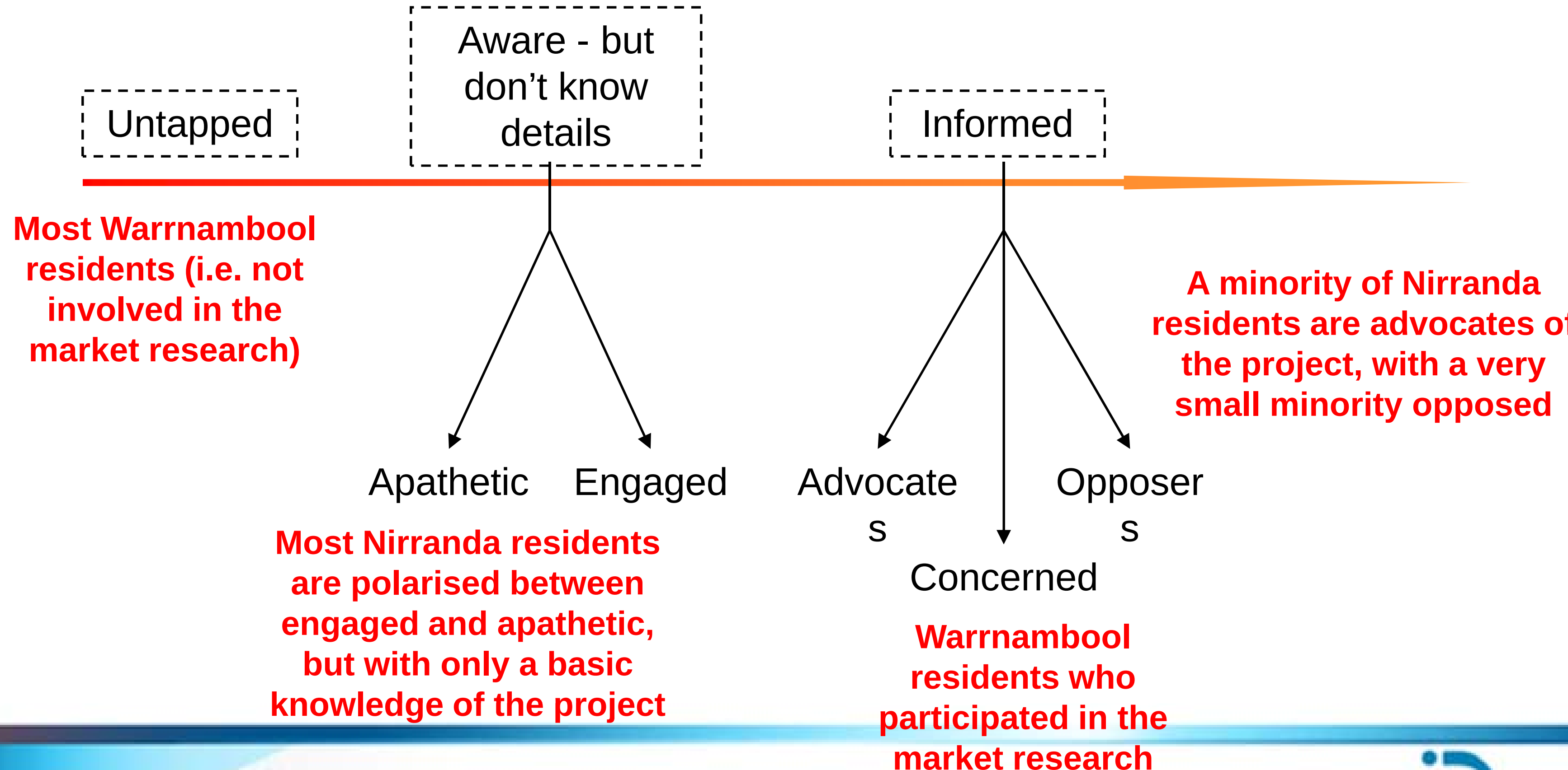
Lessons Learnt

- Do not under-estimate Landowner matters
  - This is their livelihood
  - Their decisions will take time
- Start early on Community consultation – shire, public meetings etc.
- Involve Govt. representatives in public meetings
  - Clear interfaces with Govt, Public, Media
  - A single Govt focal point is of great help.
- The M&V plan should be built early – basis for discussions
  - Explain in simple terms and share information
- There will be difficulties and you cannot please everyone
  - Be consistent, open and transparent
  - Local support is essential


“What we have to learn to do,
we learn by doing"
Aristotle
Thank You

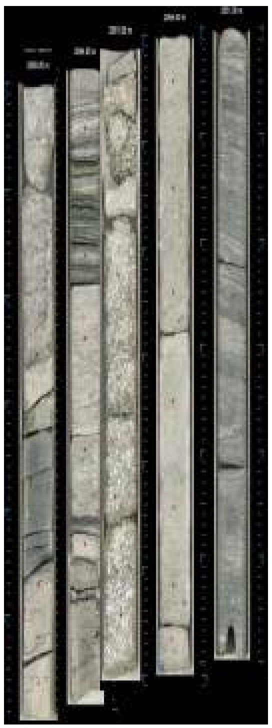
A knowledge continuum

- **Warrnambool respondents not aware of the project, however those who partook in the research, whilst not opposed to the project as such, have several concerns they would like addressed**
- **Nirranda we found much more heterogeneous knowledge bases and opinions**



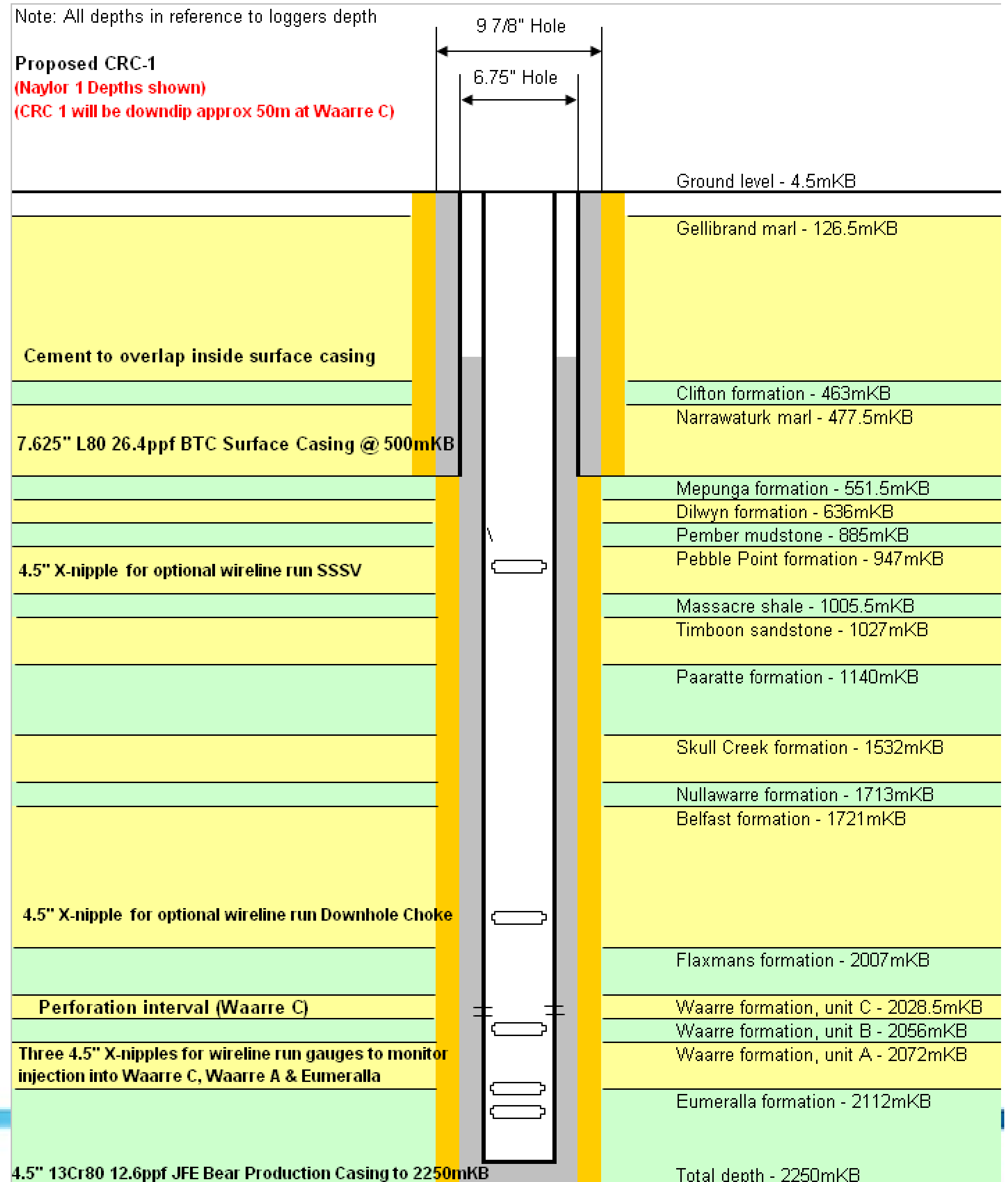
CRC-1 Injection Site

42.9 M Core



Full Suite of Logs

- PEX-HALS, Caliper
- CMR+
- ECS (elemental capture spectroscopy)
- FMI (image log)
- Sonic Scanner
- MDT:
- 3D VSP

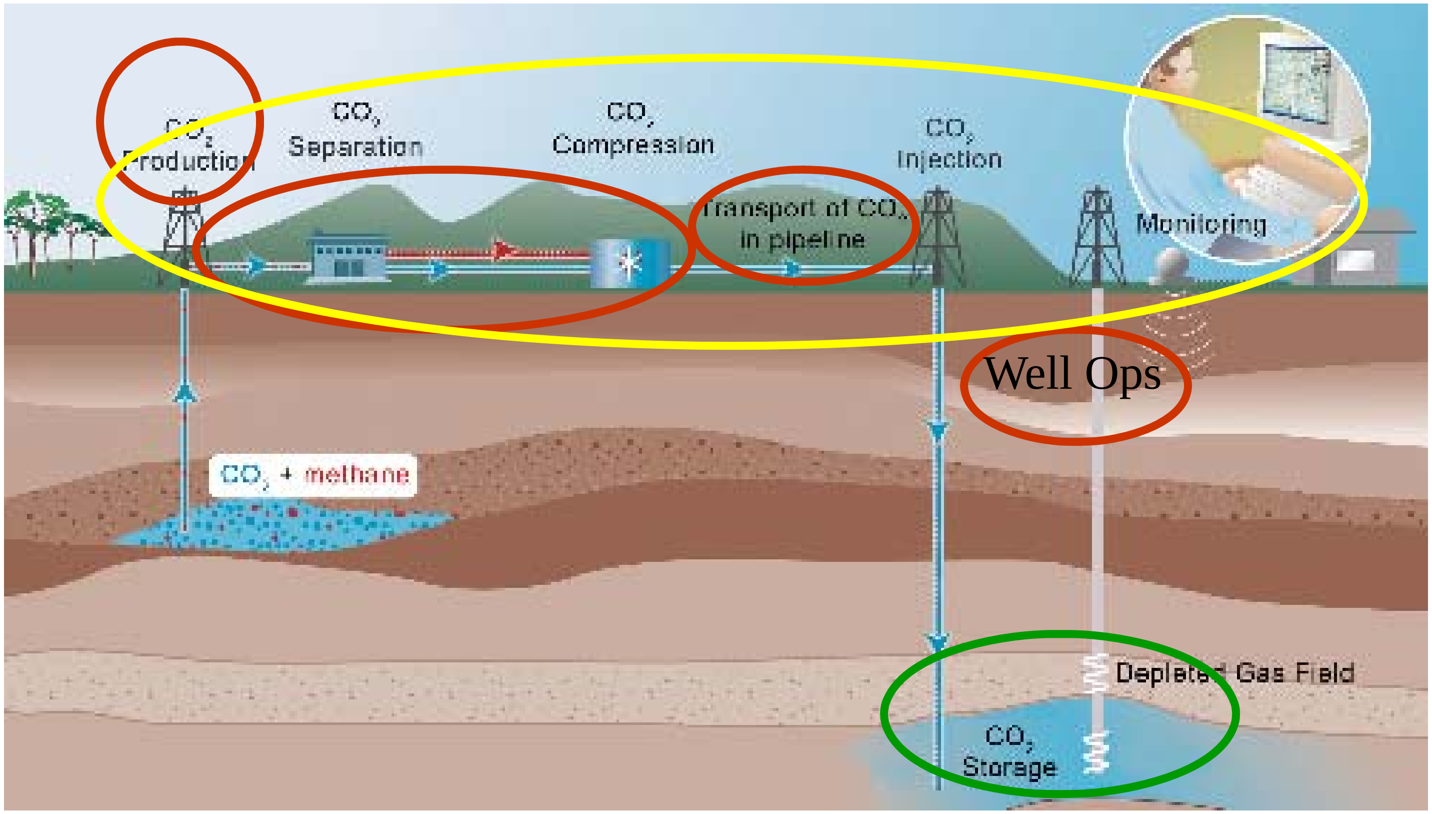


Otway helped identify Legislative Complexities

Petroleum Act
DPI

EPA
SRW

Planning Act
– DSE/Shire



M&V

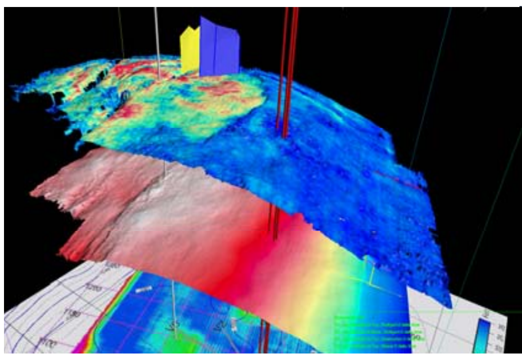
CO2CRC

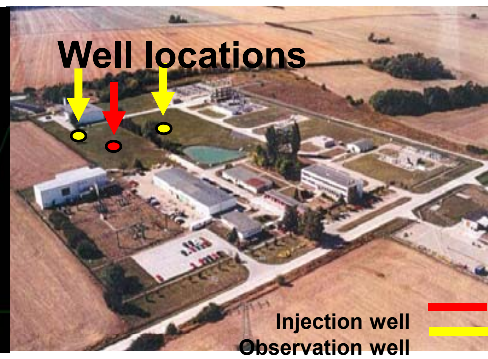
Social Research in 2006

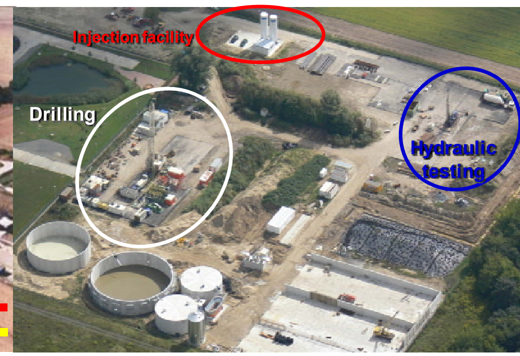
- Overall attitude to the pilot varied
  - Some advocates and others who are opposed
  - Most open to learning more.
- Overall attitude to geosequestration
  - The community in Nirranda, Warrnambool and surrounds are not yet convinced that geosequestration is a viable mitigation option
  - Need more information before they can decide
- Moving forward with community engagement
  - Keen for further community consultation.
  - Community meetings and quarterly newsletters preferred
  - CO2CRC to make information available and transparent to the community
  - Allow the community to initiate engagement rather than being too intrusive.
- Reaction to the communication messages
  - Need to be clear, concise and factual – residents do not want to hear 'spin' but facts.

Risk Assessment for CO_2SINK @ Ketzin
"a double blind approach"
+ Some News from the Project

Frank.Schilling@kit.edu
Hilke.Wuerdemann@GFZ-Potsdam.de
und Team







SIXTH FRAMEWORK PROGRAMME

Federal Ministry of Education and Research

Federal Ministry of Economics and Technology

GFZ Helmholtz-Zentrum Potsdam

Universität Karlsruhe (TH)
Forschungsuniversität • gegründet 1825

GFZ Helmholtz-Zentrum Potsdam

CO_2SINK

Risk of Personal/Company Interests

HSE Risks

Risk for Climate and ETS

News from the Project

Risk of Personal/Company Interests

HSE Risks

Risk for Climate and ETS

News from the Project

In-situ R&D Laboratory for Geological Storage of CO_2
- CO_2SINK Integrated Project -

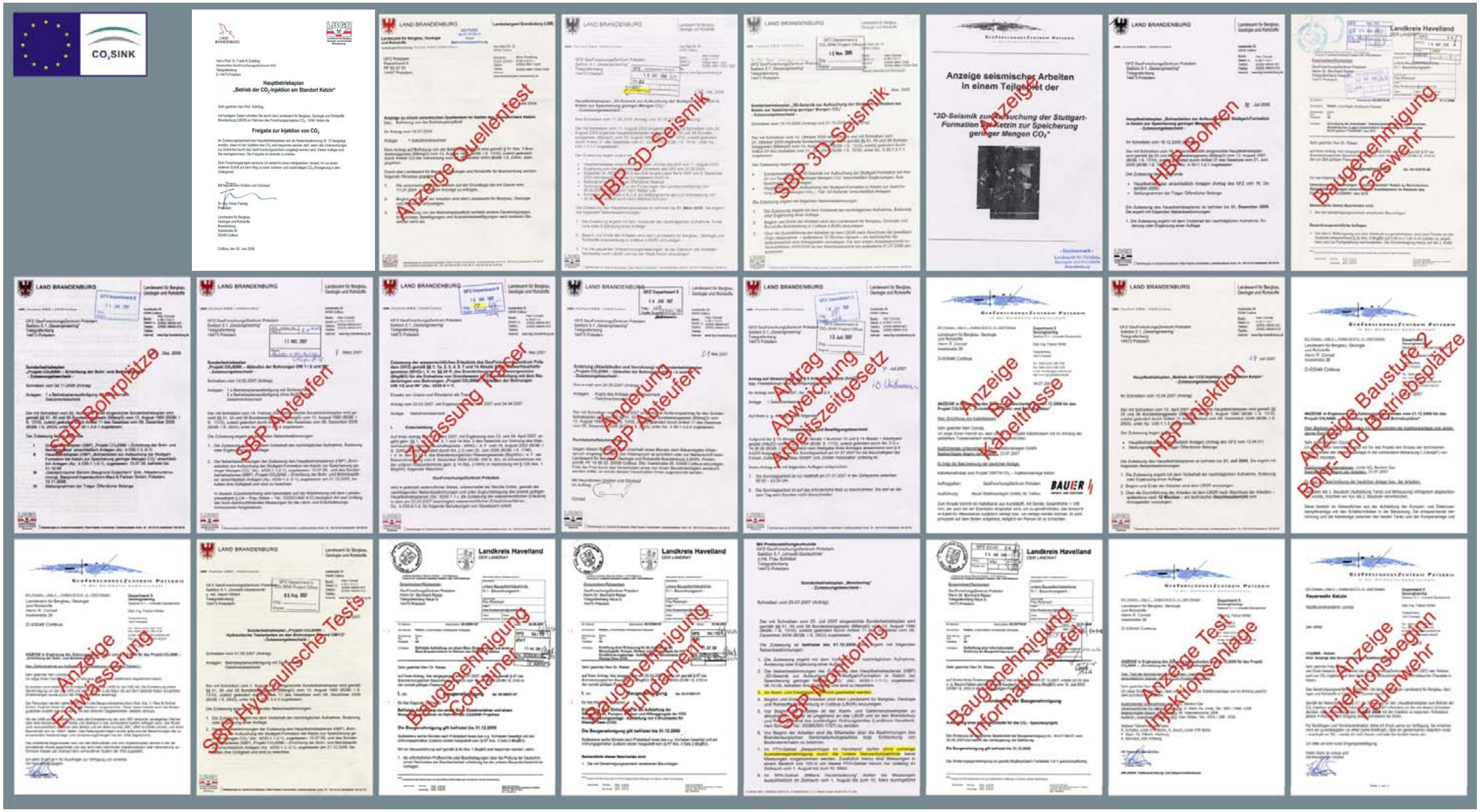
GeoForschungsZentrum Potsdam (D)
G.E.O.S. Freiberg Ingenieurgesellschaft (D)
Geological Survey of Denmark and Greenland (DK)
Mineral and Energy Economy Research Institute (PL)
Det Norske Veritas (N)
StatoilHydro (N)
Shell International Exploration and Production (NL)
University of Stuttgart (D)
Vibrometric Finland (SF)
University of Kent (GB)
Uppsala University (S)
RWE Power AG (D)
International Energy Agency – Greenhouse Gas Programme (GB)
Vattenfall Europe Generation (D)
Verbundnetz Gas AG (D)
Siemens AG Power Generation (D)
E.ON Energie AG (D)
Schlumberger Carbon Services (Fr)

The Risk Assessment Approach

As the risk assessment for CO_2-storage at Ketzin
is mainly based on expert knowledge
a **(at least) double blind approach** was favored.
as we kept in mind...
- never trust one modeler alone
- that one should never neglect the
  "Risk of Personal Interest"
  or "Risk of Company Interest"

A) HSE Risk Assessment for the Ketzin Site
B) Long Term Risk of Leakage not affecting HSE
   (but climate and ETS System)

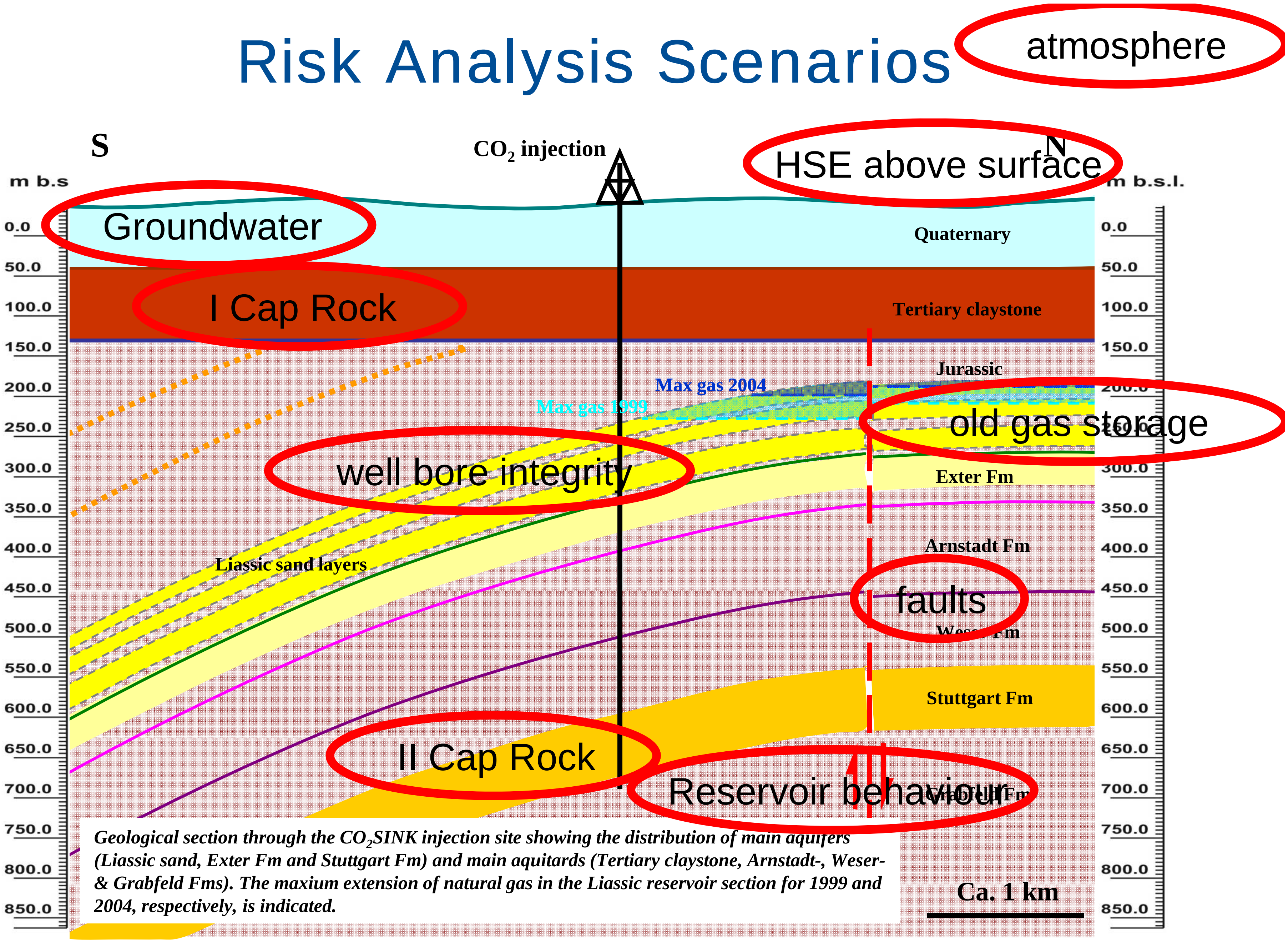
III. Independent Approval by Authorities (Mining Authorities, Landratsamt)



Involved Authoroties

- **lead: Mining Autho according to regul based on Gas Stor (experience from 4**
- **Mining Authoroties**
  - Wasserbehörde (a water)
  - Umweltbehörde (
  - Landratsamt (for Police, Fire Fighte
- Requires “Gefahren Abwehrplan” r
  - Transport of CO_2
  - Operations on Site
  - support for required equipmen (gas-measuring devices)

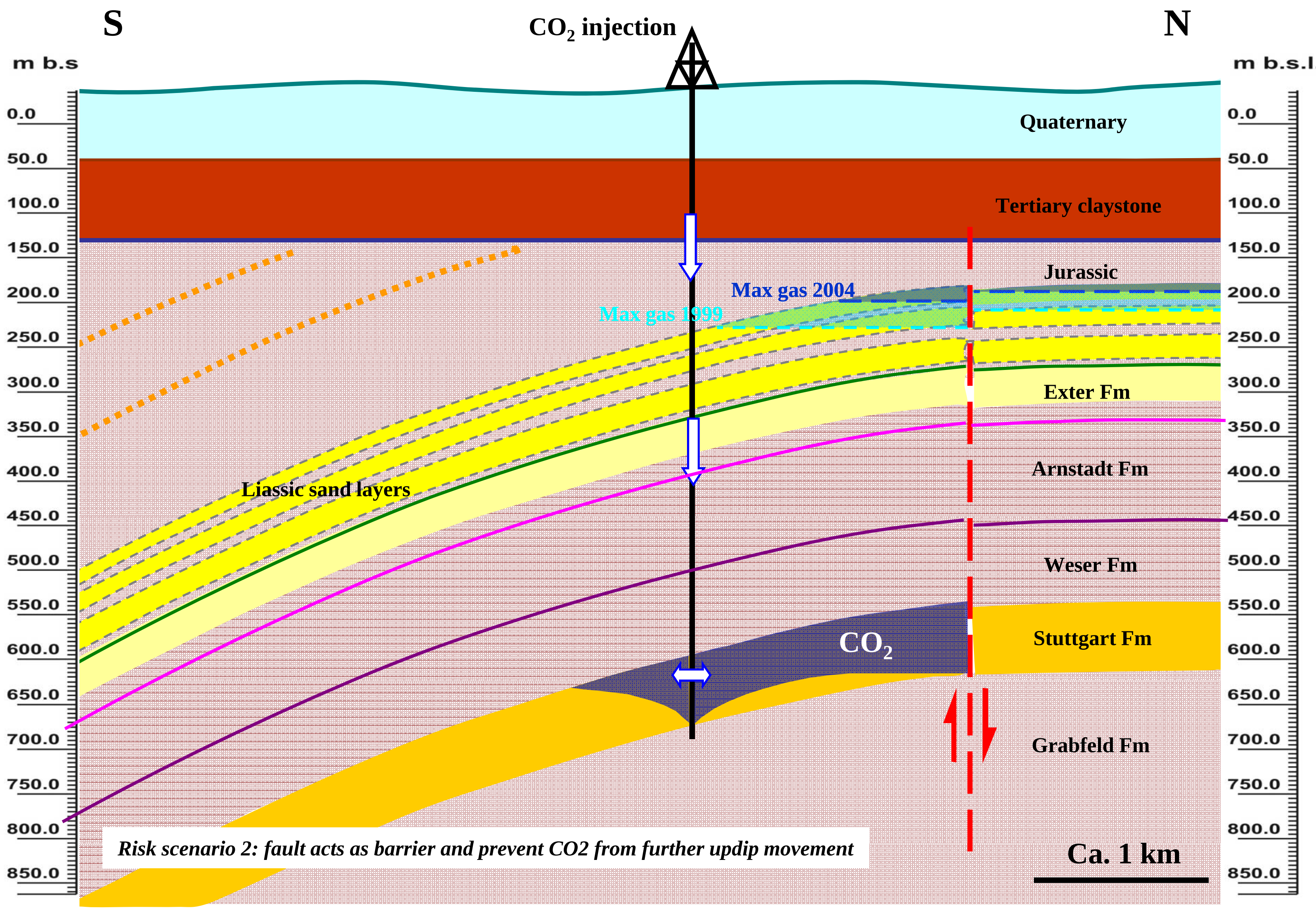
Risk Analysis Scenarios



Geological section through the CO_2SINK injection site showing the distribution of main aquifers (Liassic sand, Exter Fm and Stuttgart Fm) and main aquitards (Tertiary claystone, Arnstadt-, Weser- & Grabfeld Fms). The maxium extension of natural gas in the Liassic reservoir section for 1999 and 2004, respectively, is indicated.

K. Zinck-Jørgensen (GEUS) & M. van der Molen (Shell) 2006

Risk Analysis Scenarios



K. Zinck-Jørgensen (GEUS) & M. van der Molen (Shell) 2006

For more details – please ask Todd Flach/DNV

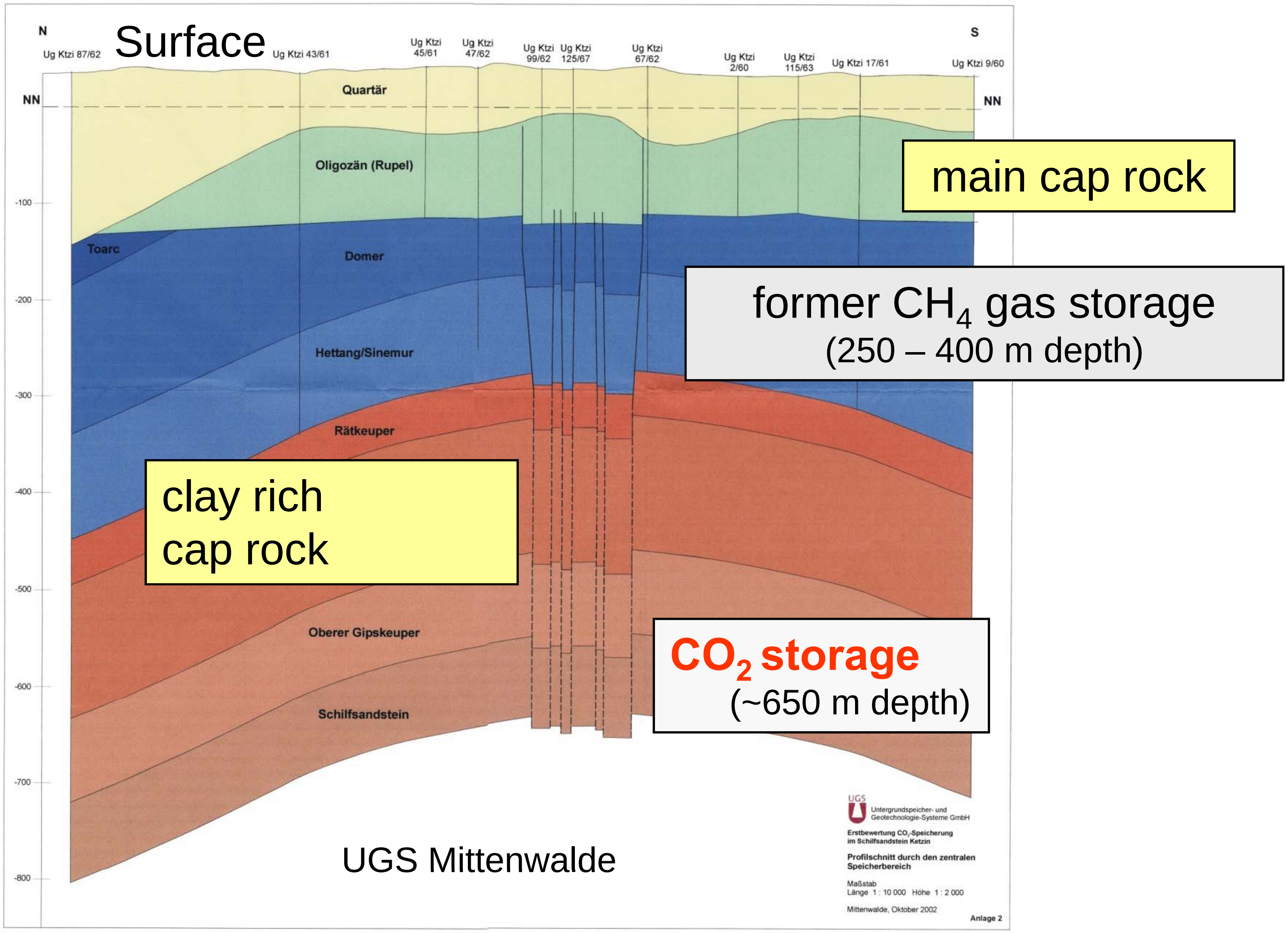
worst case scenarios are the base of this risk assessment

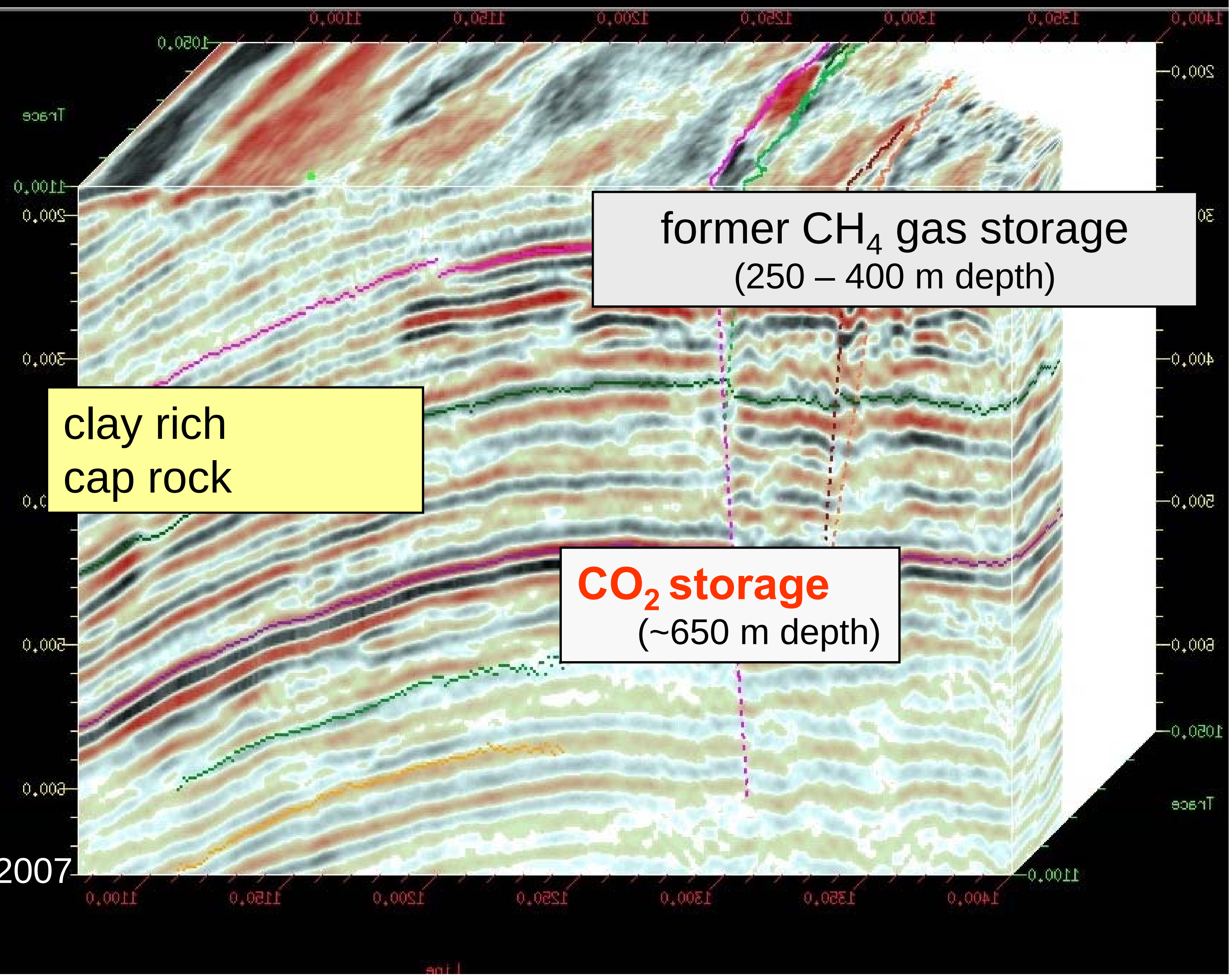
- multi barrier system
- well bore integrity
- natural paths for CO_2
- old gas storage
- and interrelations between the points mentioned above

HSE – some examples

- Worst case scenario for Groundwater pollution
- Influence on biosphere (excluding deep biosphere)
  – for dears and rabbits… – angle of slope for rain water basin adjusted
  - fence
- Deep biosphere (risk for installations)
  - Monitored
  - N2-Lift
- Workers
- fire fighters – on site information, equipment
- children/adults (fence, removal of wheels)
- surveillance (VNG, 24h Security Troop)
- Gefahren- und Abwehrplan (Site, Transport)

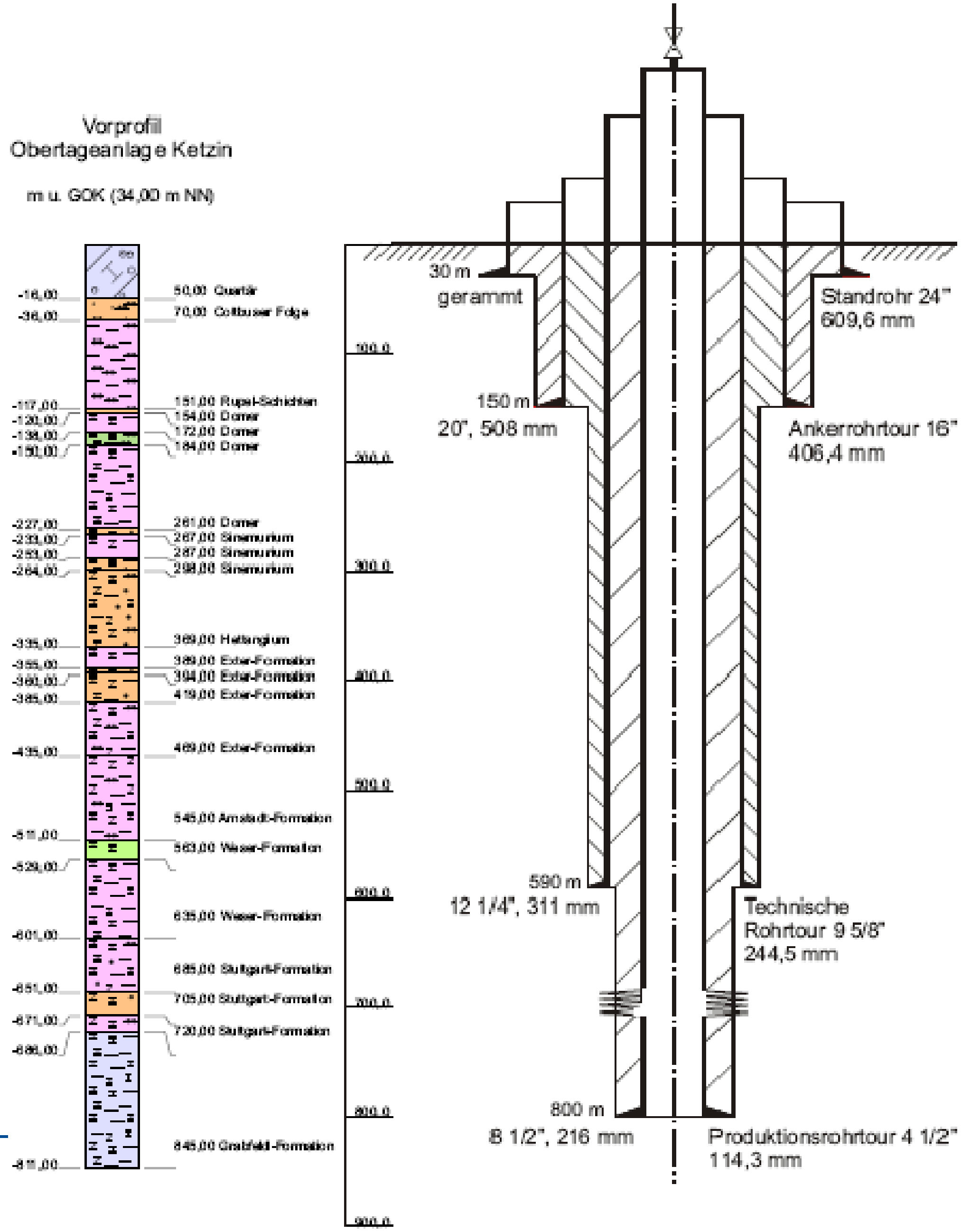
Geological Cross-Section through the subsurface near Ketzin





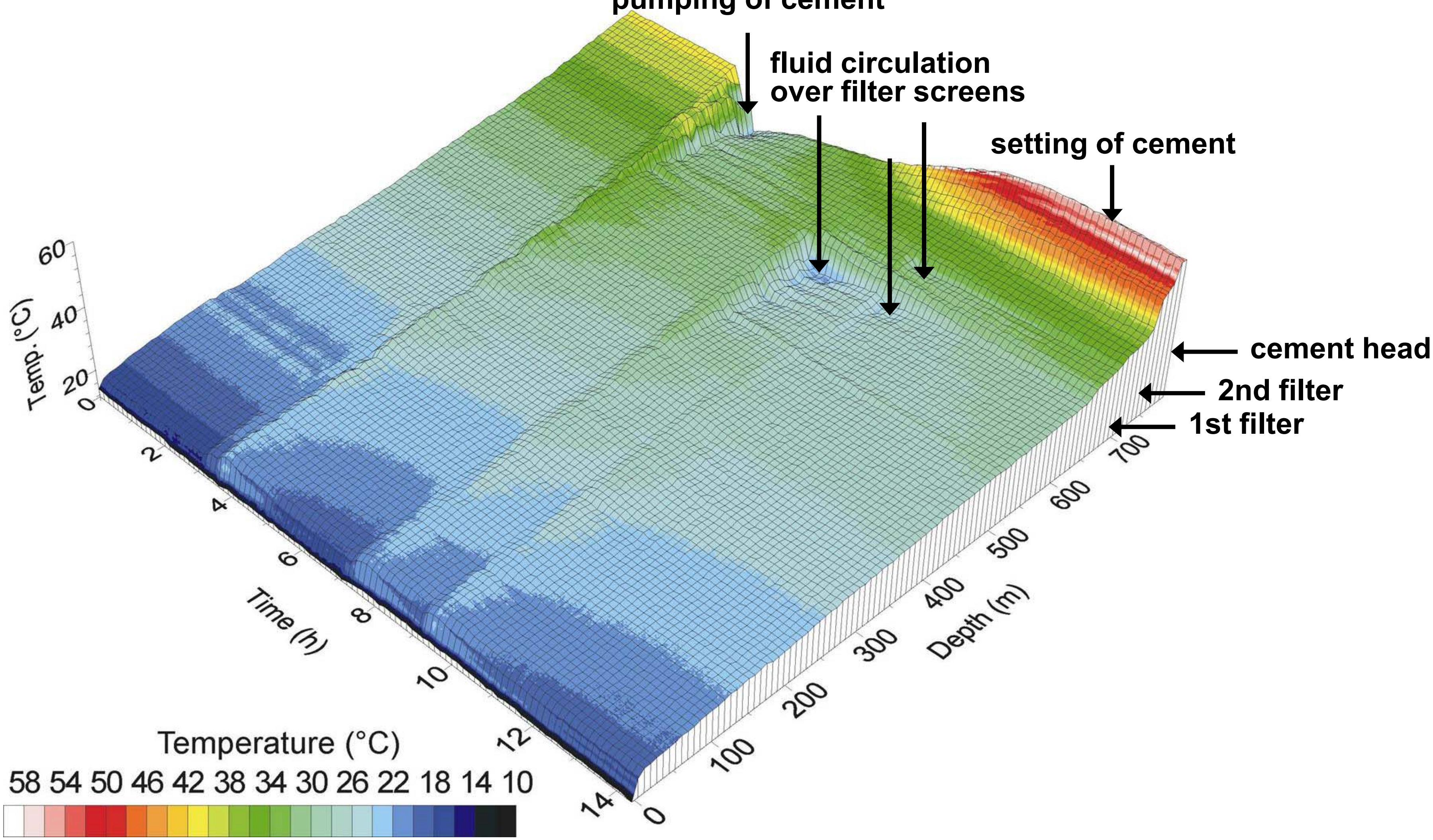
Juhlin *et al.* 2007

Wellbore



Vorprofil
Obertageanlage Ketzin
m u. GOK (34,00 m NN)
50,00 Quartär
70,00 Cottbuser Folge
151,00 Rupel-Schichten
154,00 Domer
172,00 Domer
184,00 Domer
261,00 Domer
267,00 Sinemurium
287,00 Sinemurium
298,00 Sinemurium
369,00 Hettangium
389,00 Exter-Formation
394,00 Exter-Formation
419,00 Exter-Formation
469,00 Exter-Formation
545,00 Arnstadt-Formation
563,00 Weser-Formation
635,00 Weser-Formation
685,00 Stuttgart-Formation
705,00 Stuttgart-Formation
720,00 Stuttgart-Formation
845,00 Grabfeld-Formation
100,0
200,0
300,0
400,0
500,0
600,0
700,0
800,0
900,0
30 m
gerammt
Standrohr 24"
609,6 mm
150 m
20", 508 mm
Ankerrohrtour 16"
406,4 mm
590 m
12 1/4", 311 mm
Technische
Rohrtour 9 5/8"
244,5 mm
800 m
8 1/2", 216 mm
Produktionsrohrtour 4 1/2"
114,3 mm

DTS temperature data during cementing of 5-2/1“ casing



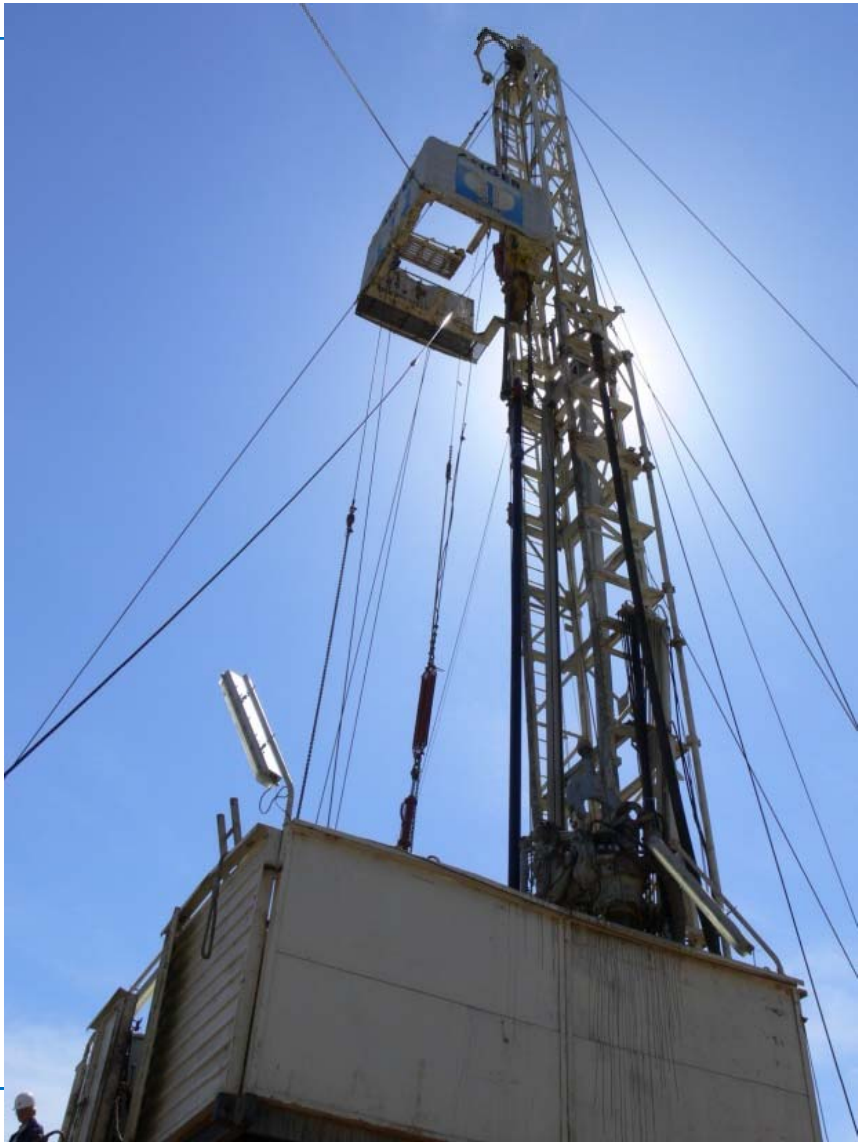
Henninges *et al.* 2007

Conclusion

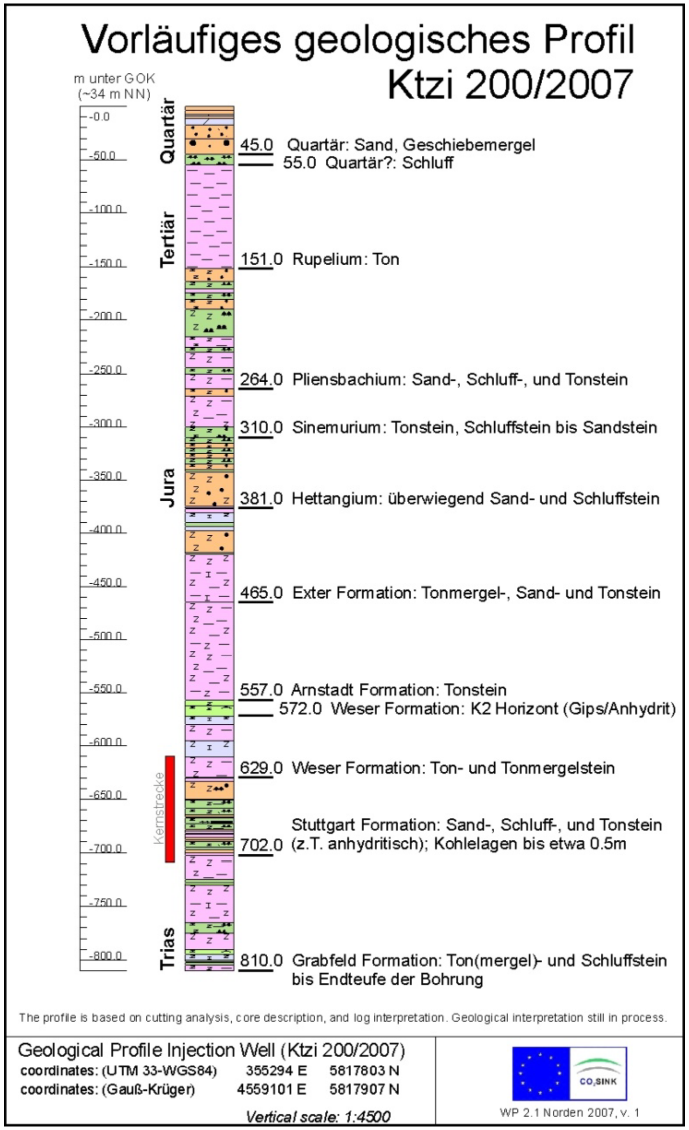
- A at least double blind approach was applied
- Use of "state of the art technology" and a "best practise approach" based on natural gas storage expertise.
- All available data were evaluated and weighted by groups of specialists
  - CO_2 Transport, Storage and Injection
  - Geology
  - Old (Storage) Operation on the Site
  - Drilling/Well Integrity (new and old wells)
  - Integrated Reservoir Models (THMC)
  - Monitoring
    (update of the models and and risk assessment)
- Approval by mining authorities

Public Acceptance:
We told the truth and mentioned risks prior to request

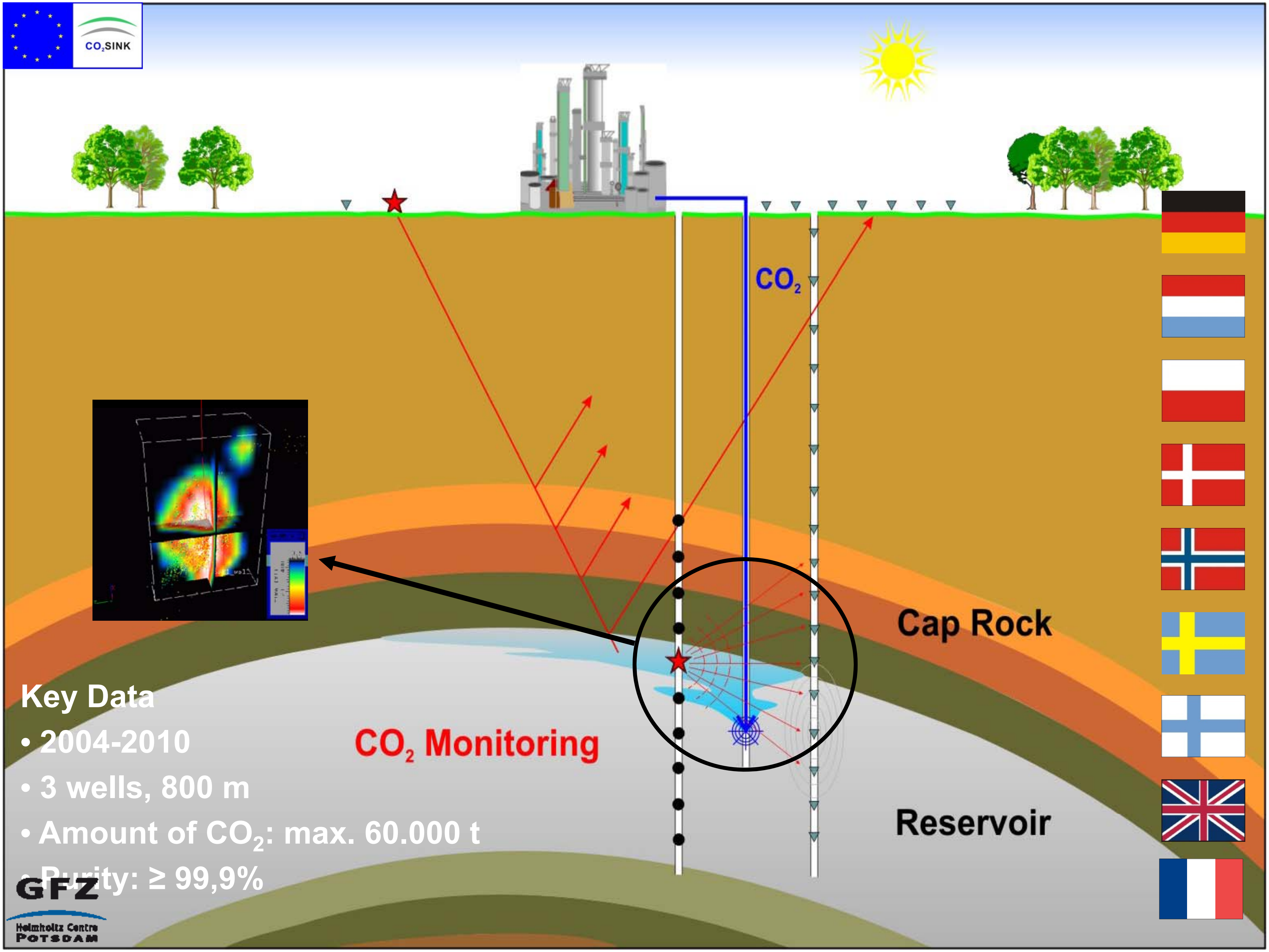
News from the Project



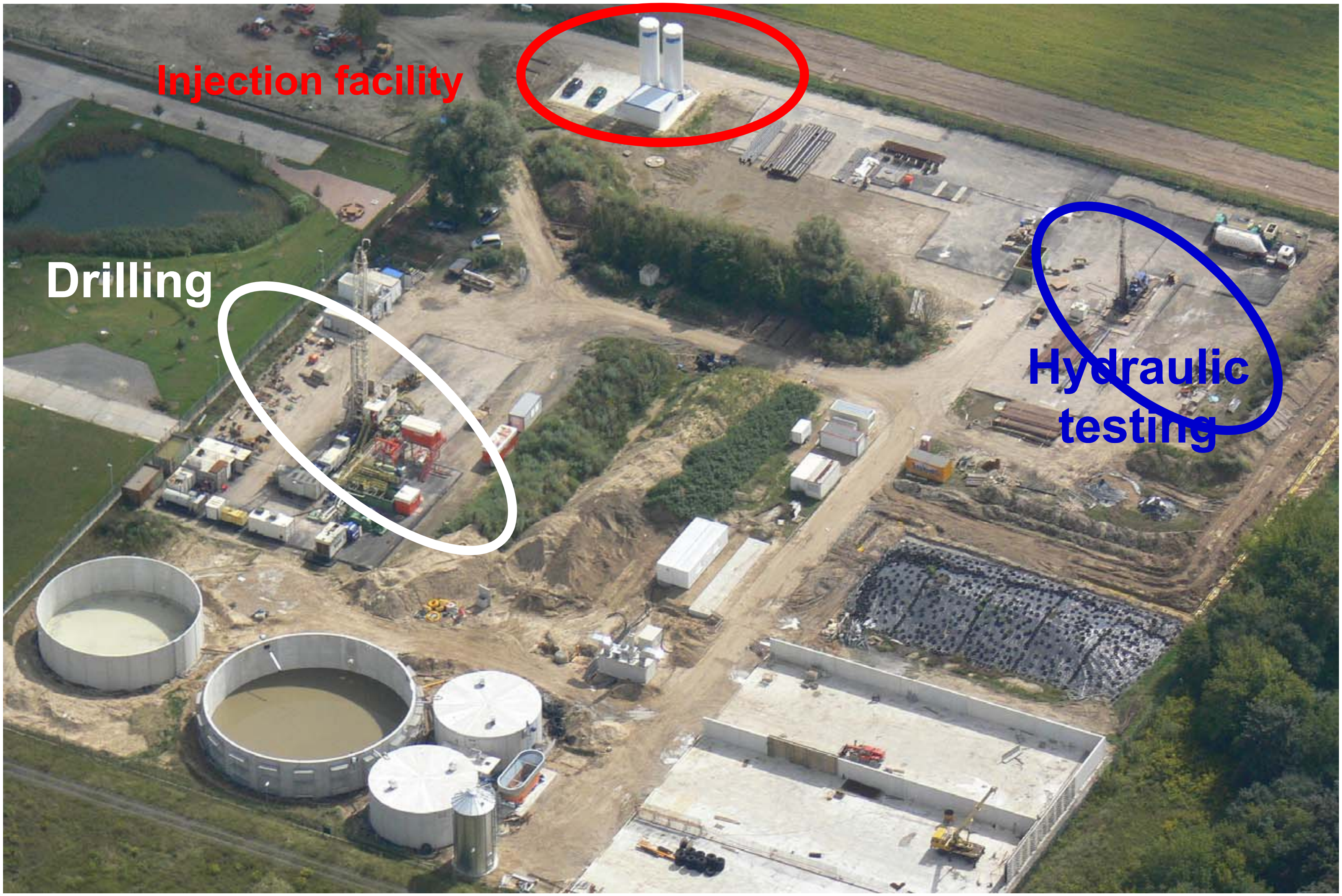
Coring – Geological Profile



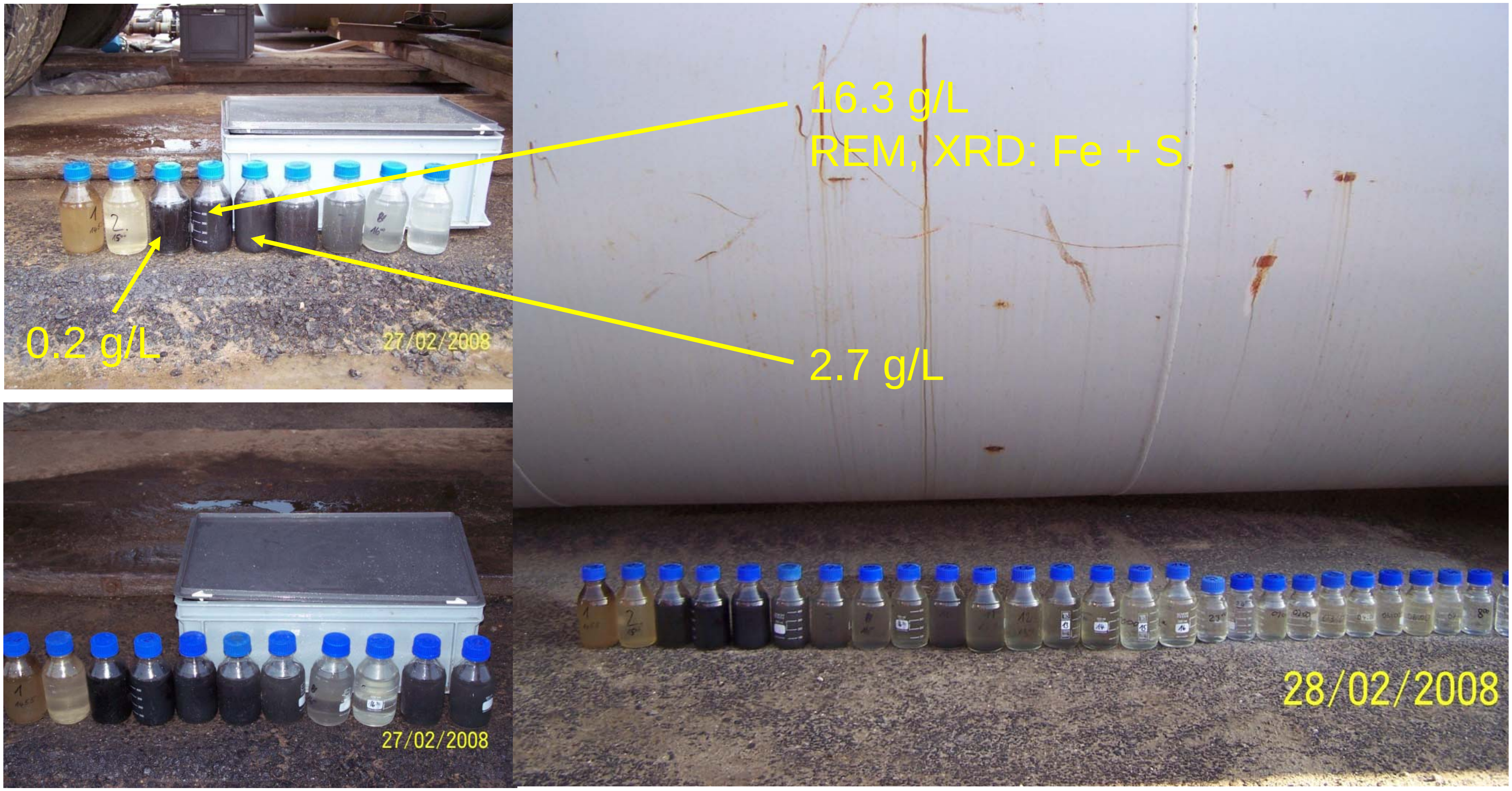
Norden *et al.* – 2007


CO2SINK
CO_2
Cap Rock
Reservoir
CO_2 Monitoring
Key Data
• 2004-2010
• 3 wells, 800 m
• Amount of CO_2: max. 60.000 t
• Purity: ≥ 99,9%
GFZ
Helmholtz Centre
POTSDAM

CO_2SINK in Ketzin

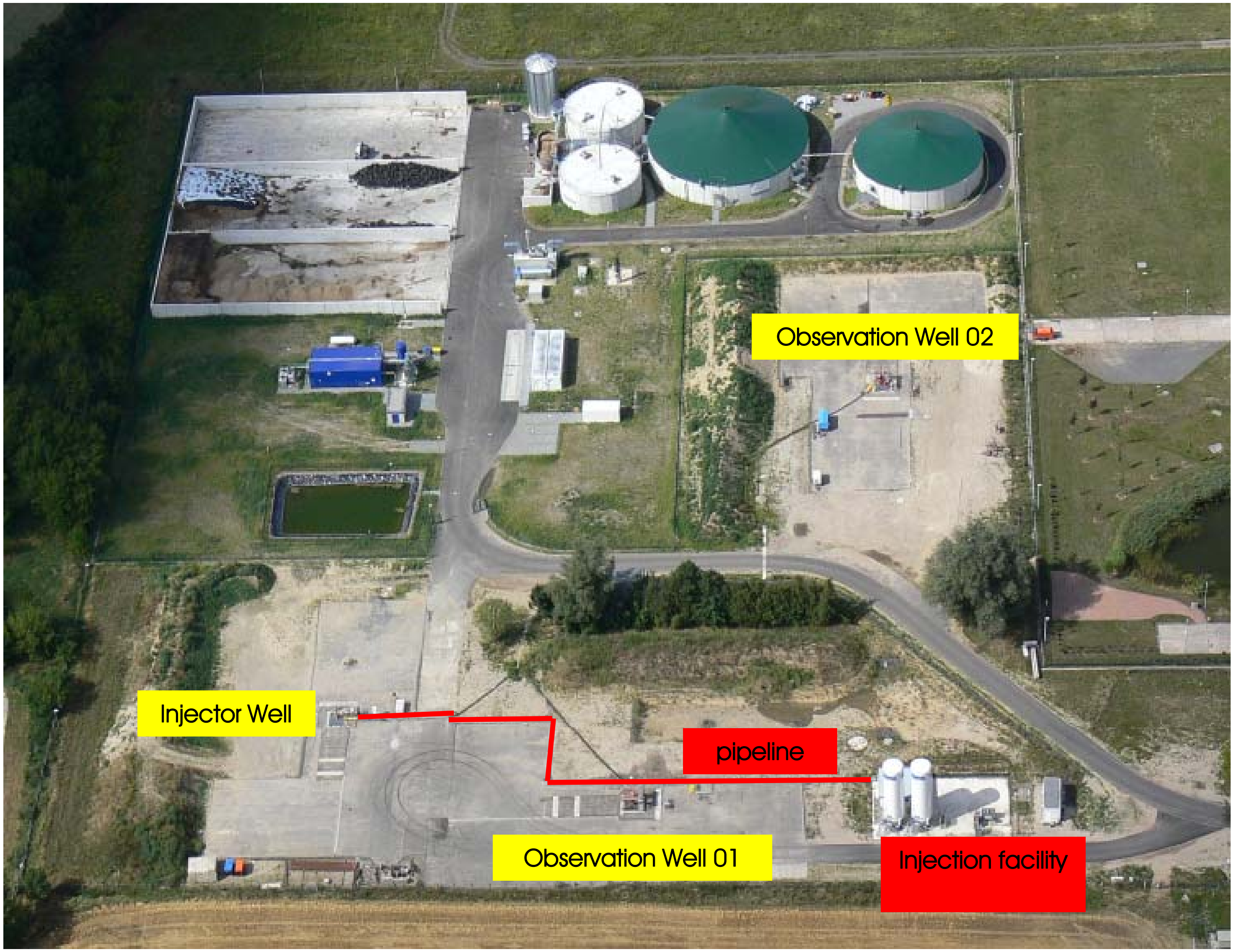


Removal of iron sulphide – Injectivity increase



Würdemann *et al.* - 2008

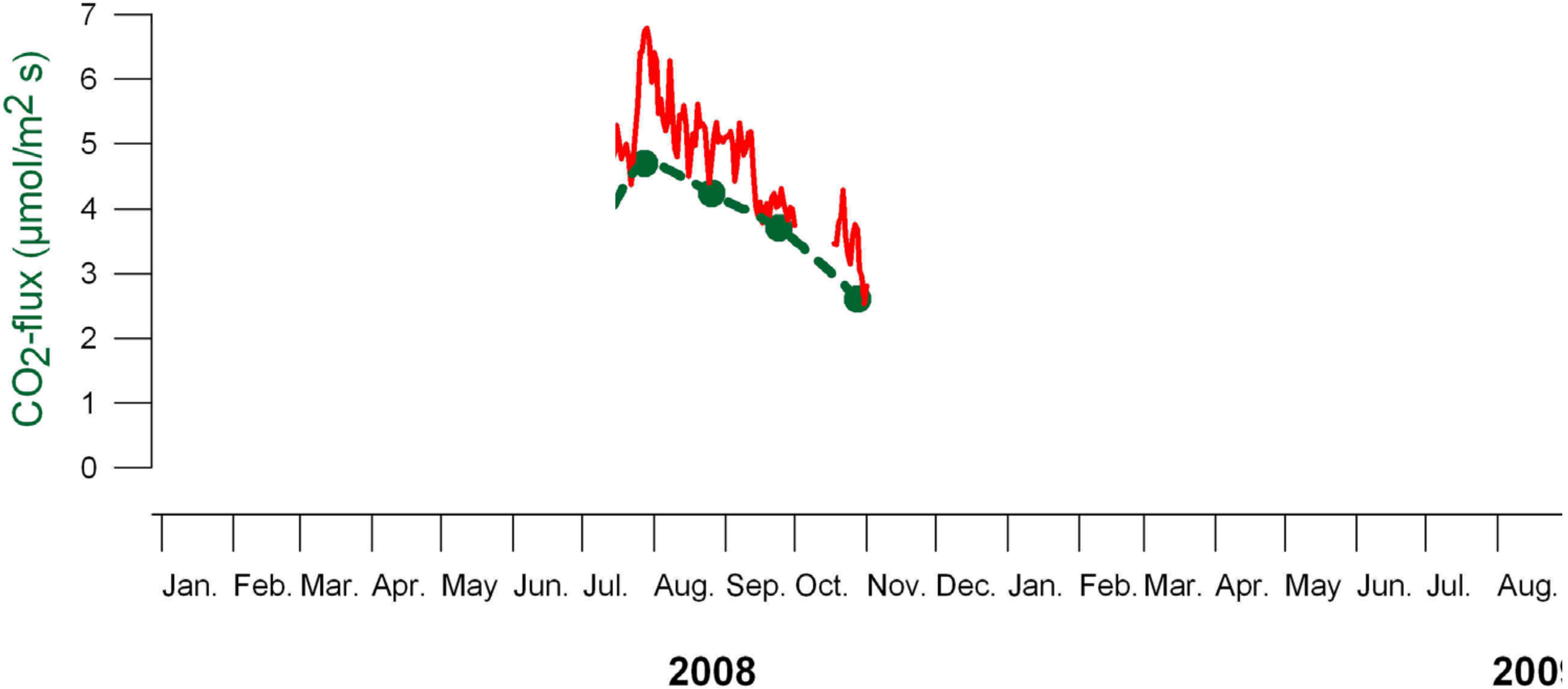
Fines < 1 mg/L – stop of lifting after production of 100 m^3 water


Observation Well 02
Injector Well
pipeline
Observation Well 01
Injection facility

Start of injection 30 June 2008

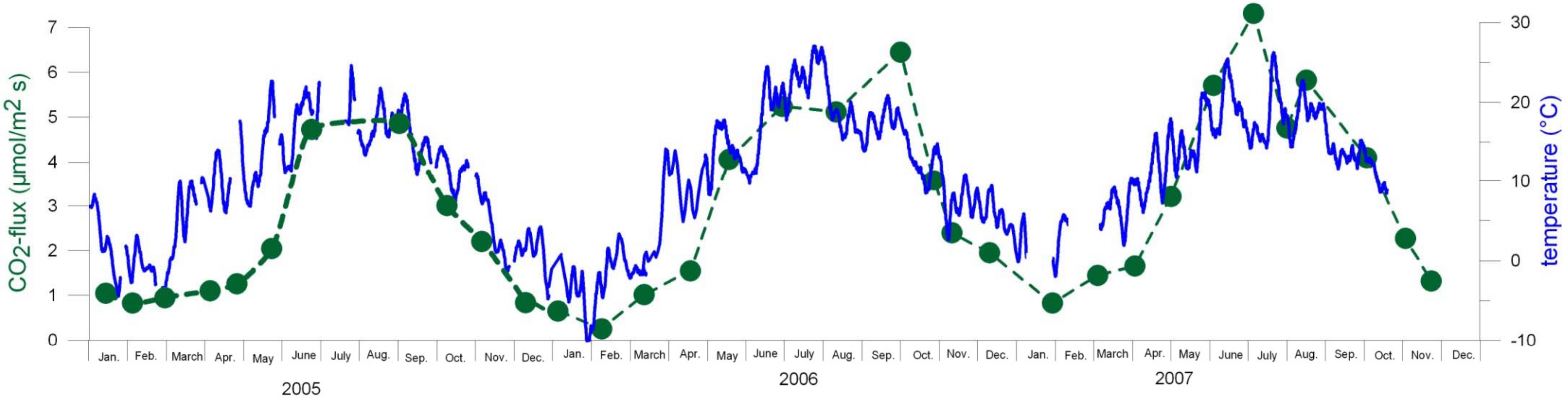
until today: > 12 600 t of CO_2 injected

CO_2 Flux (60 cm Depth)



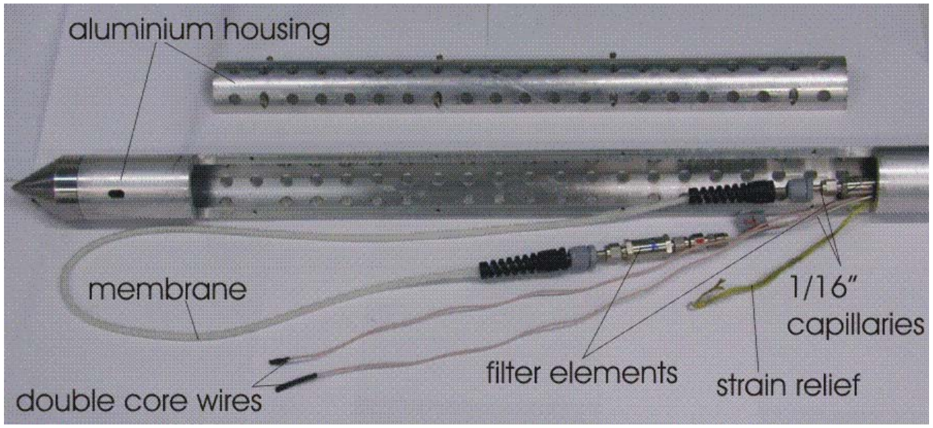
Zimmer et al. 2007

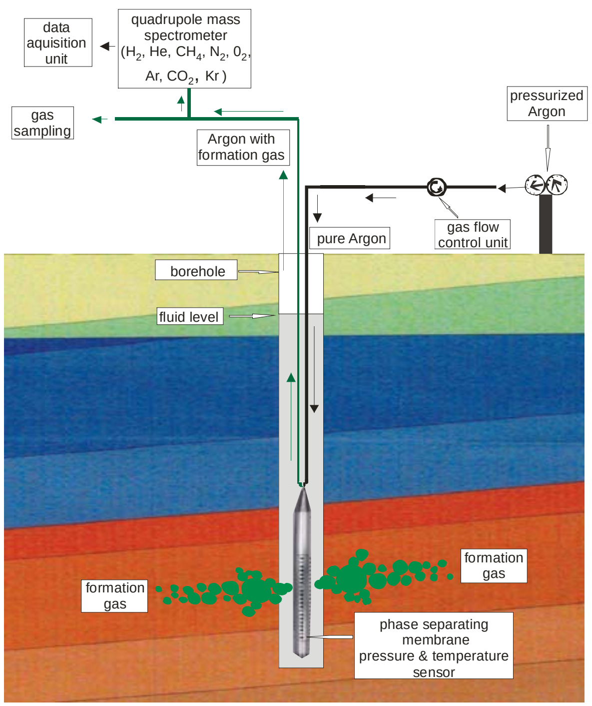
CO_2 Flux (60 cm Depth)



Zimmer et al. 2007

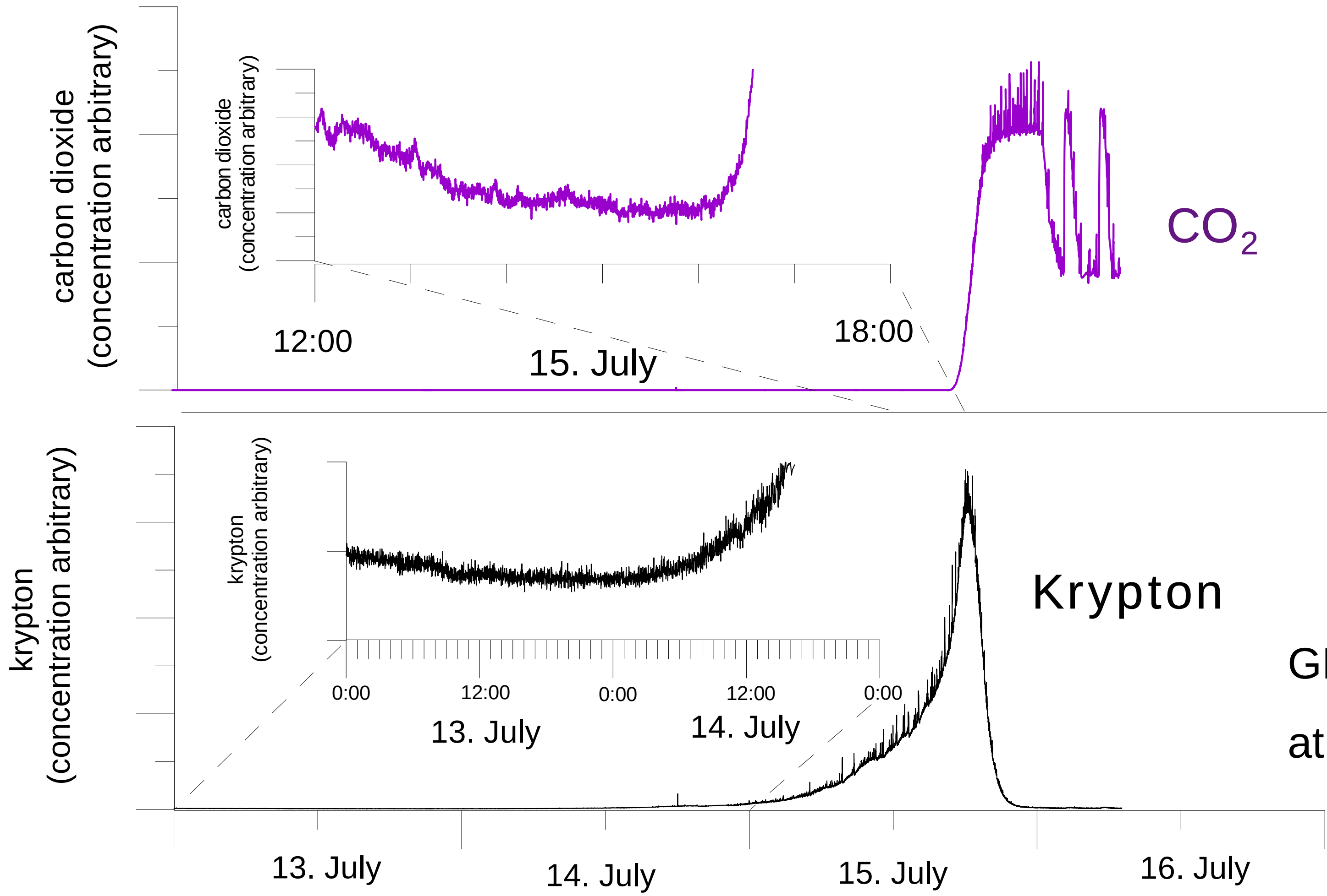
Gas Membrane Sensor





Zimmer et al. - 2008

Arrival of CO_2 in OW1 (Ktzi 200):
Pressure, Temperature, CO_2 and Kr (Tracer)



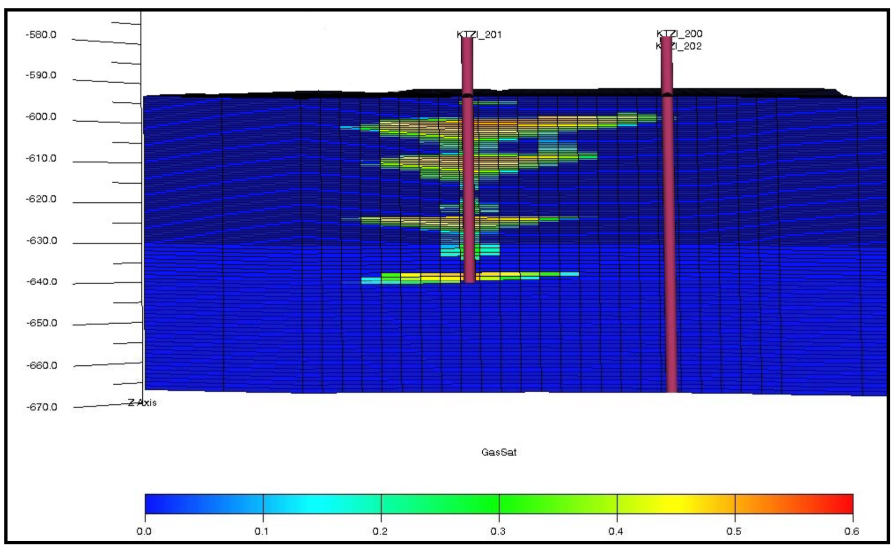
GMS Sensor

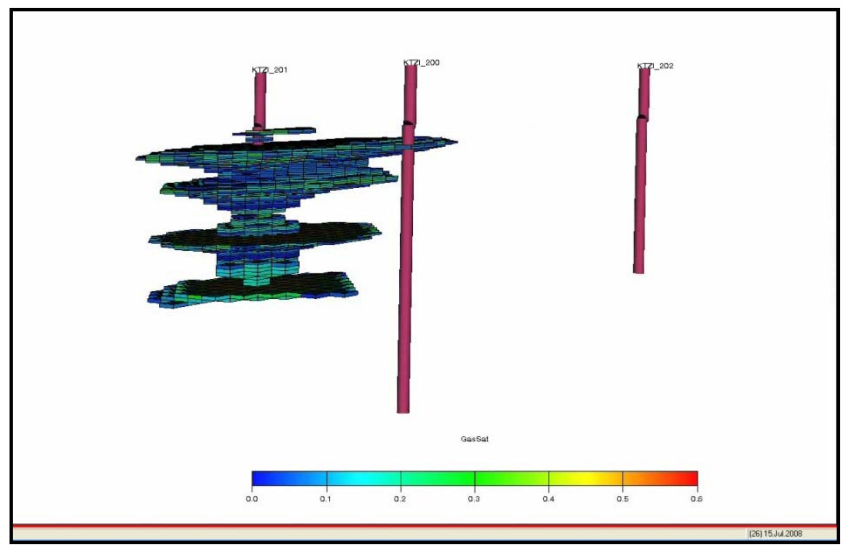
at 150 m depth

Zimmer et al. - 2008

Reservoir simulation –phase 1-

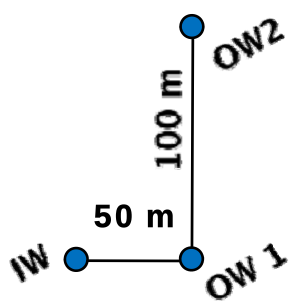
- Phase 1 - breakthrough in 200 -
- good matching with the breakthrough on 15.07.2008
- Next step: Phase 2 breakthrough in 202



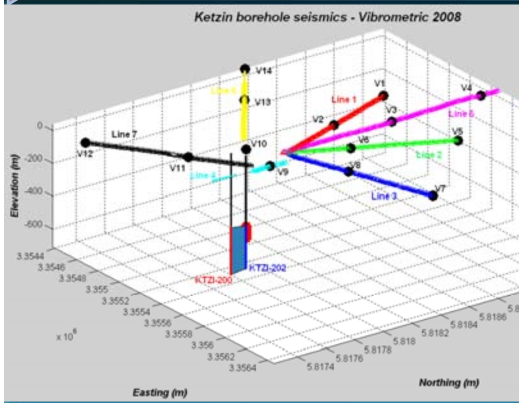


Amout of CO_2 injected

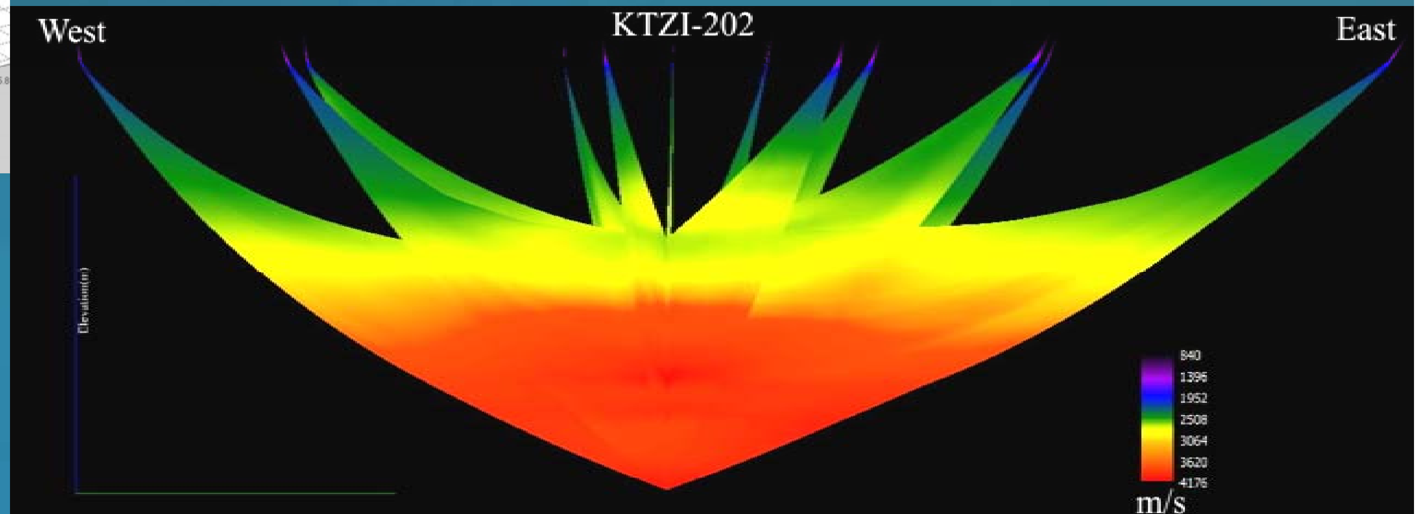
	Date:	injected CO_2:
Facility test & preparation	24.06.2008	test amount of CO_2, Kr-tracer, N_2
Start of CO_2 injection	30.06.2008	~ 0 t CO_2
Arrival of CO_2 at OW1 Arrival of CO2 at OW2	15.07.2008 20.03.2009	531,5 t CO_2 ca. 11 000 t CO_2
Today	16.4.2009	>12 700 t CO_2

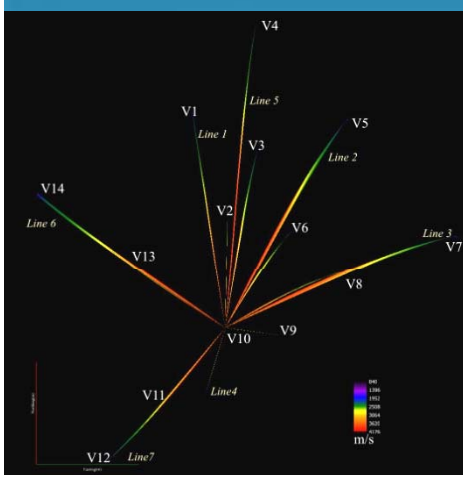


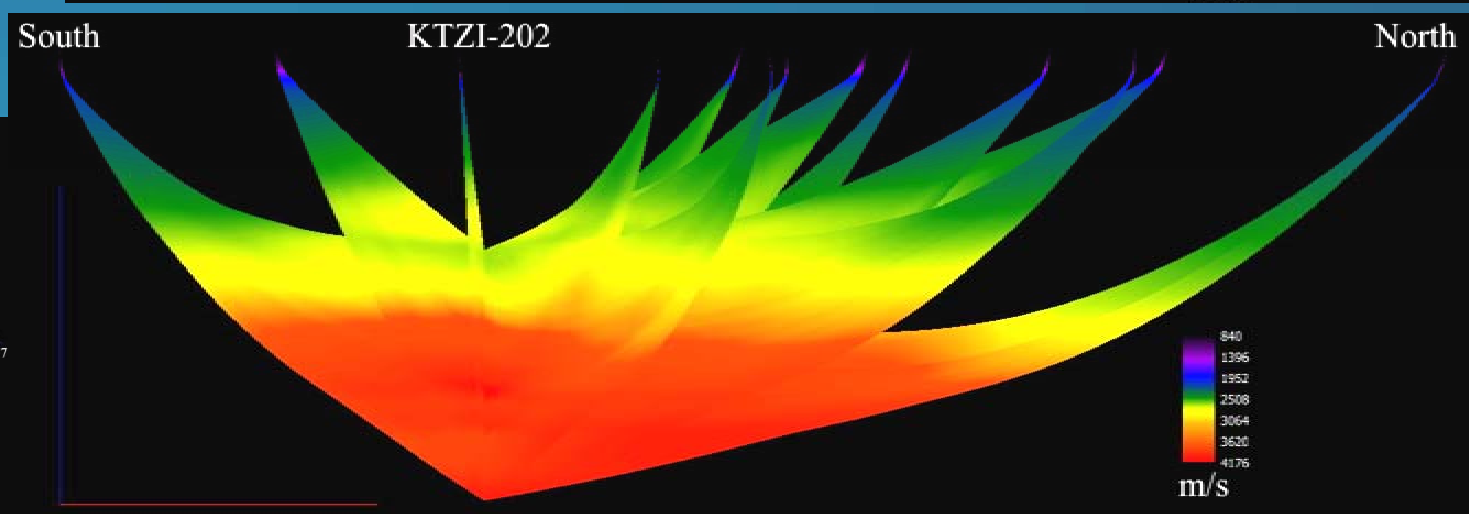
Seismic monitoring – Baseline VSP – P Velocity



3D P-wave velocity reconstruction from VSP data

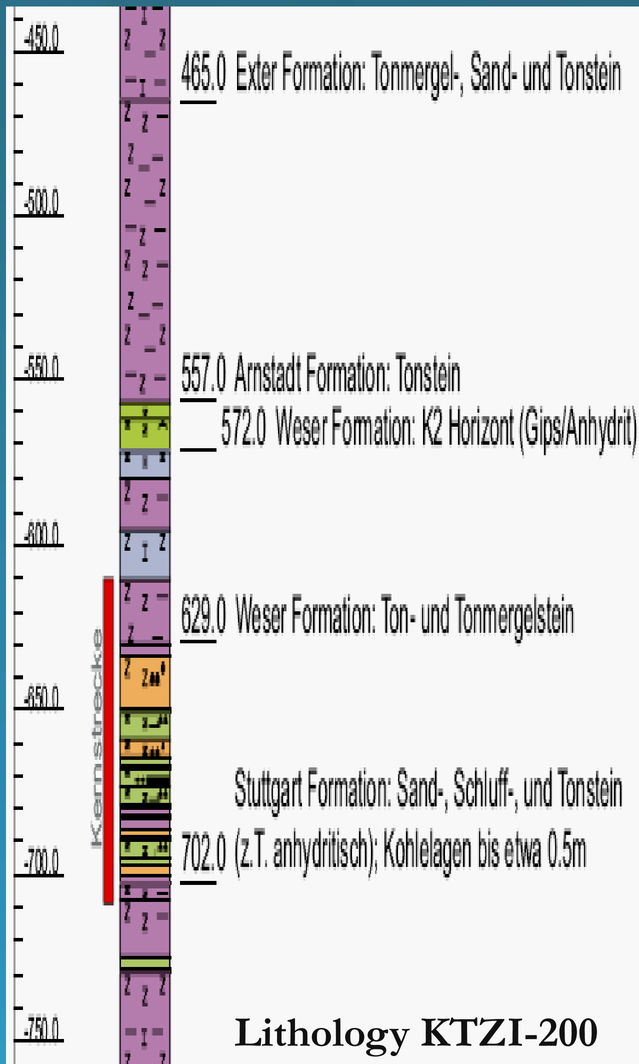




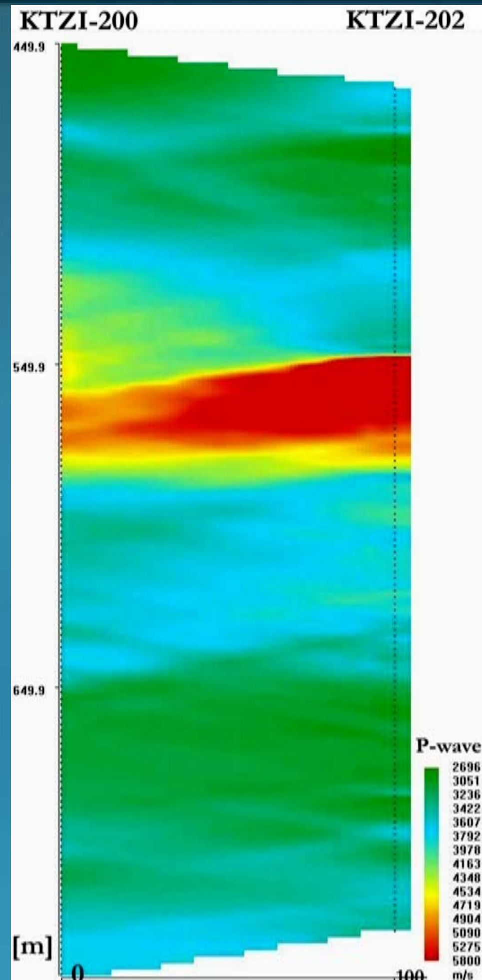


Cosma et al 2009.

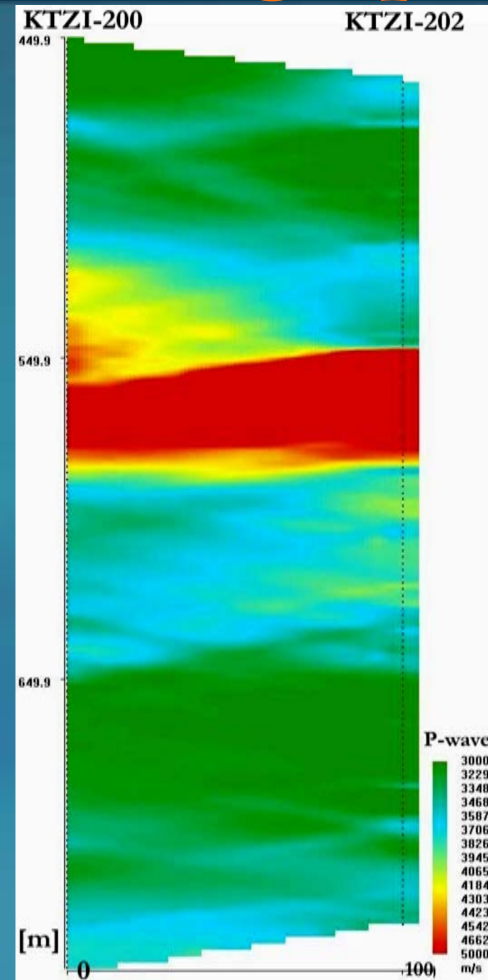
Cross-hole P-wave velocity tomography



Lithology KTZI-200



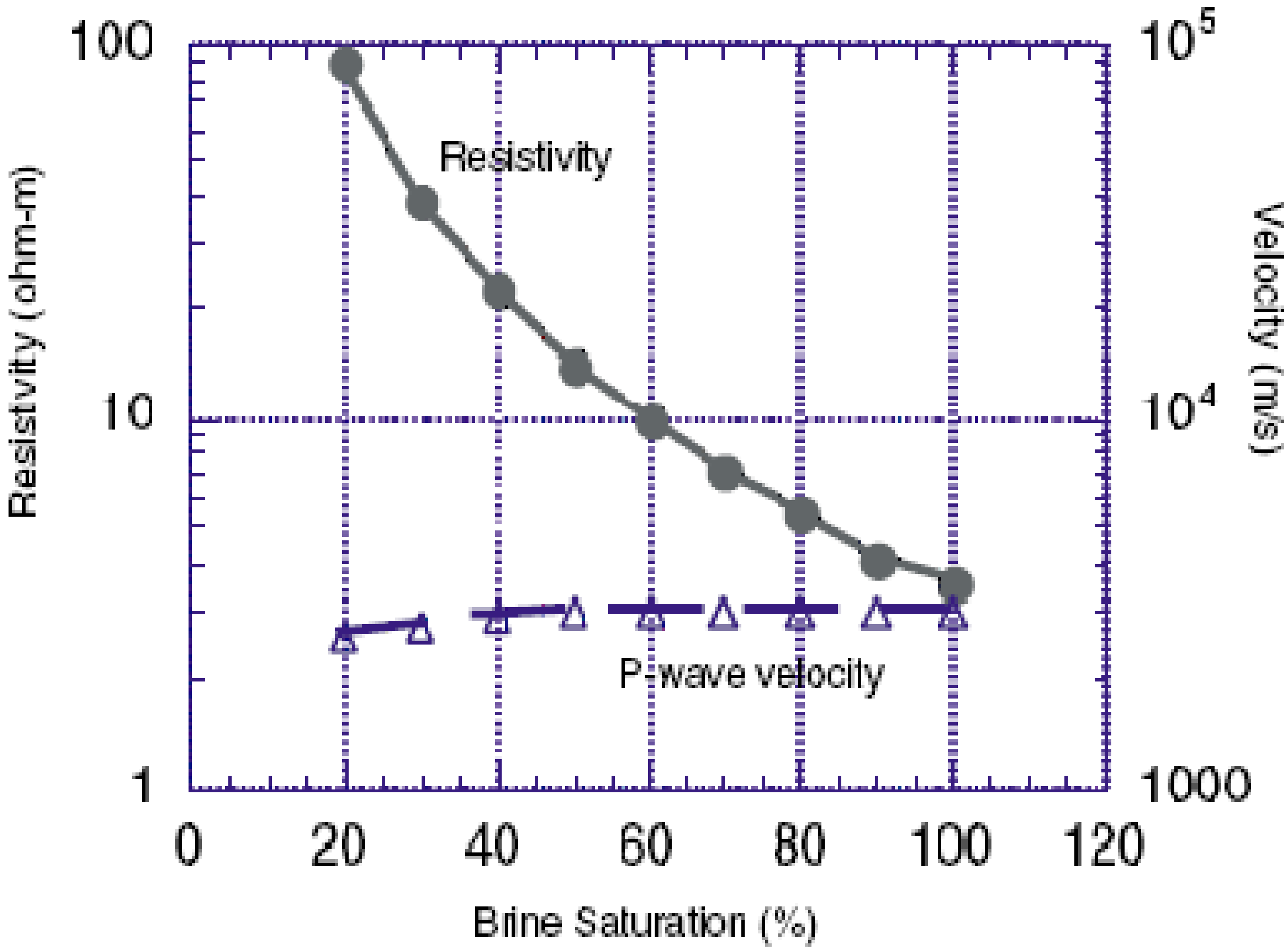
2700 – 5800 m/s



3000 – 5000 m/s

Cosma et al 2009.

Variation of physical properties with CO_2-brine saturation



Wilt & Alumbaugh, 2006

Geoelectrical DC methods for monitoring CO_2

taper pin

electrical cable

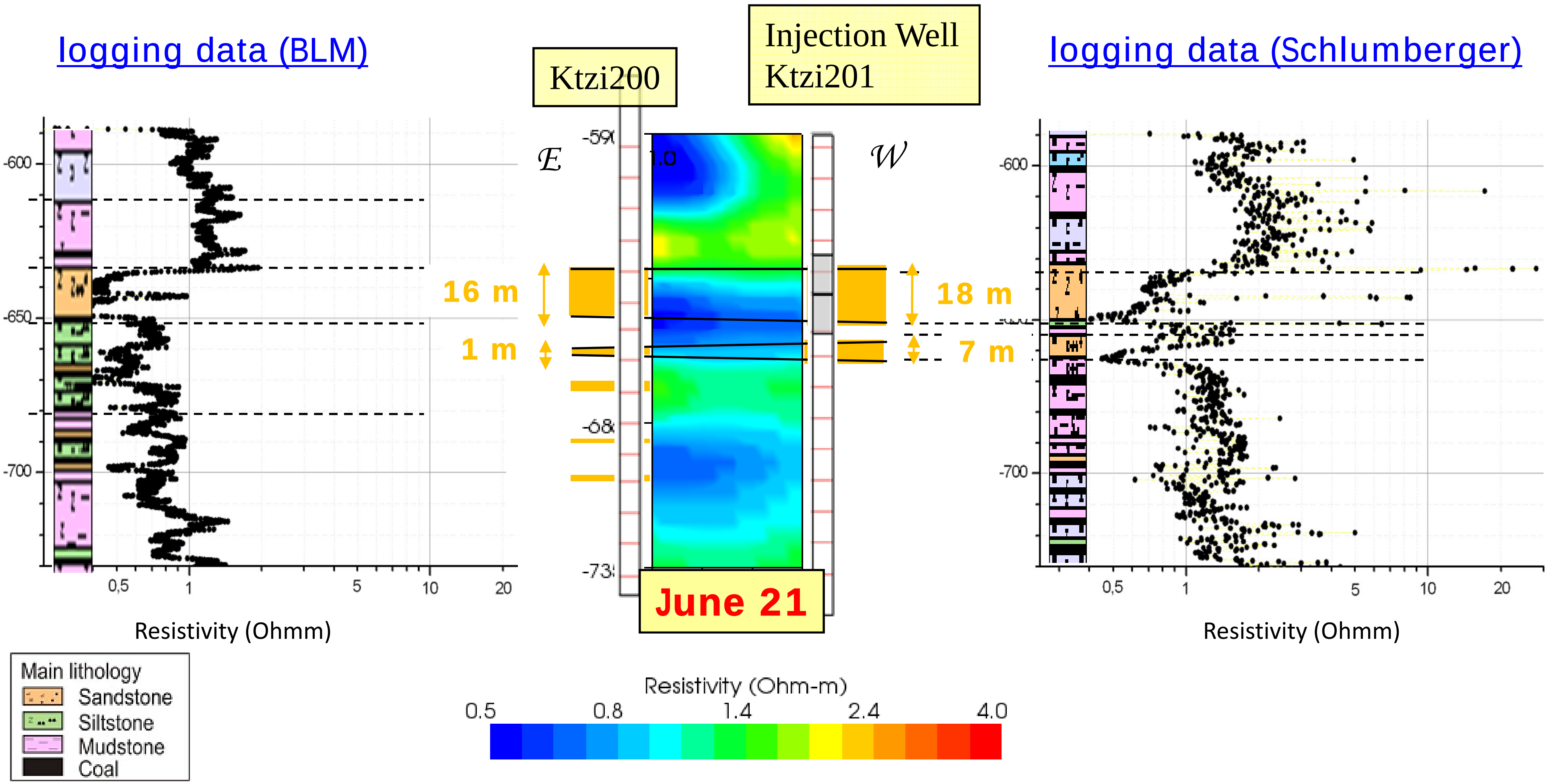
ring-shaped steel electrode

insolated casing



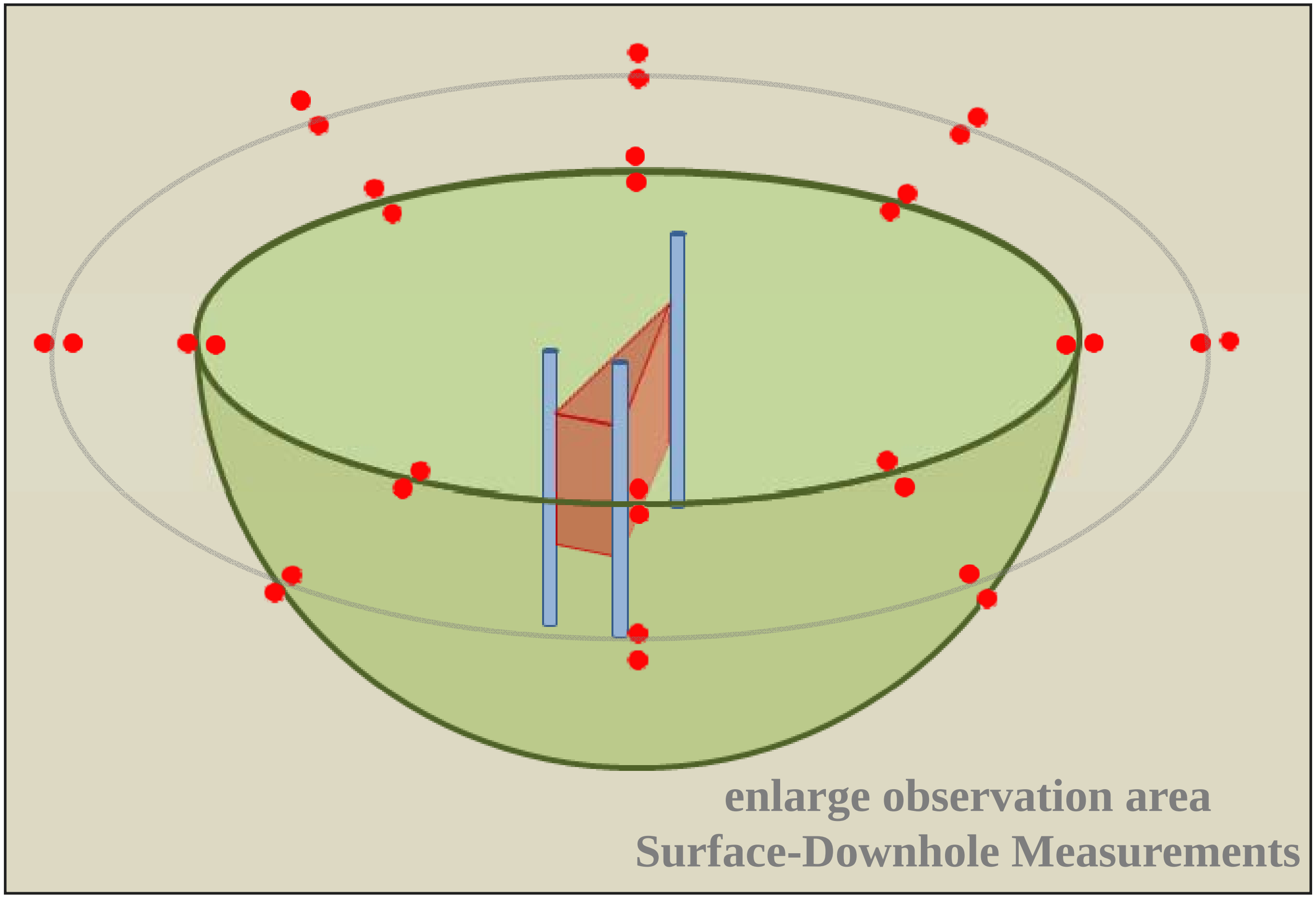


First results and their analysis



Surface-Downhole Measurements

realization:

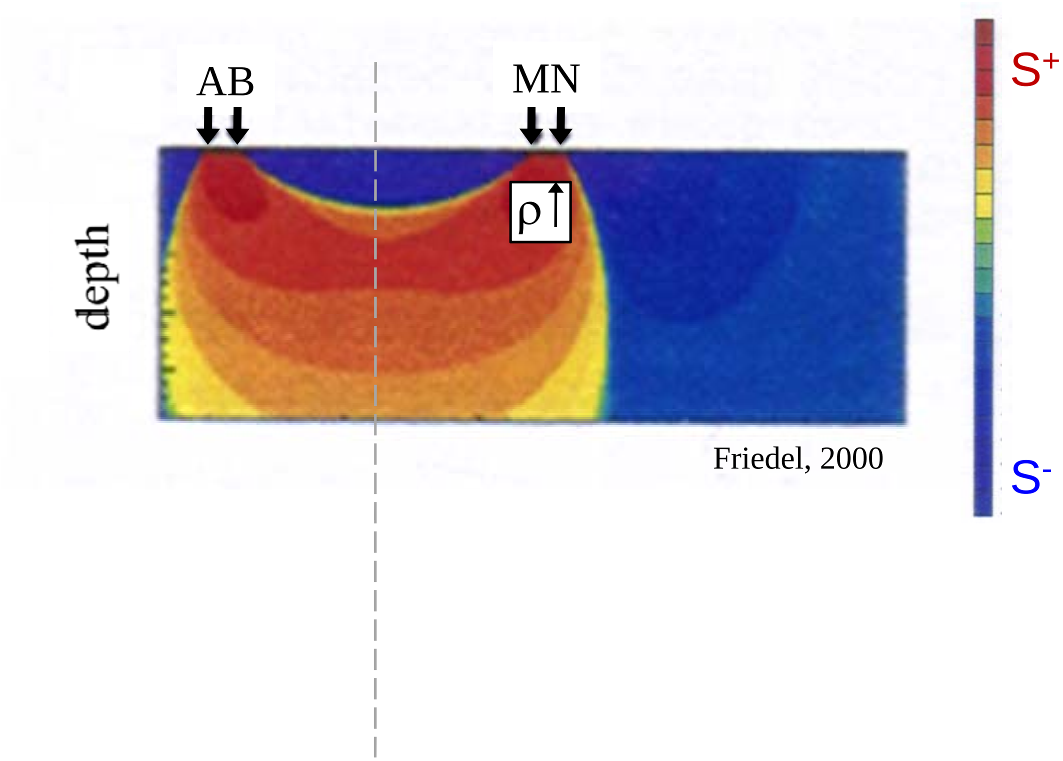


dipoles at surface, r_1 = 800 m and r_2 = 1500 m

Surface-Downhole Measurements

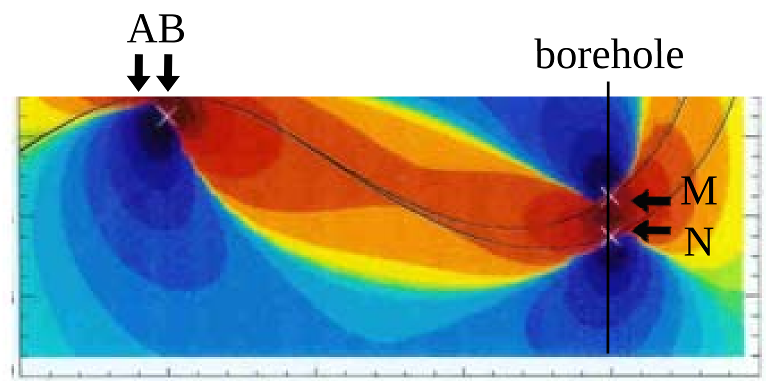
Fundamentals

2D, dipole-dipole-configuration (CCPP)



Friedel, 2000

2D, Surface-Downhole (CCPP)

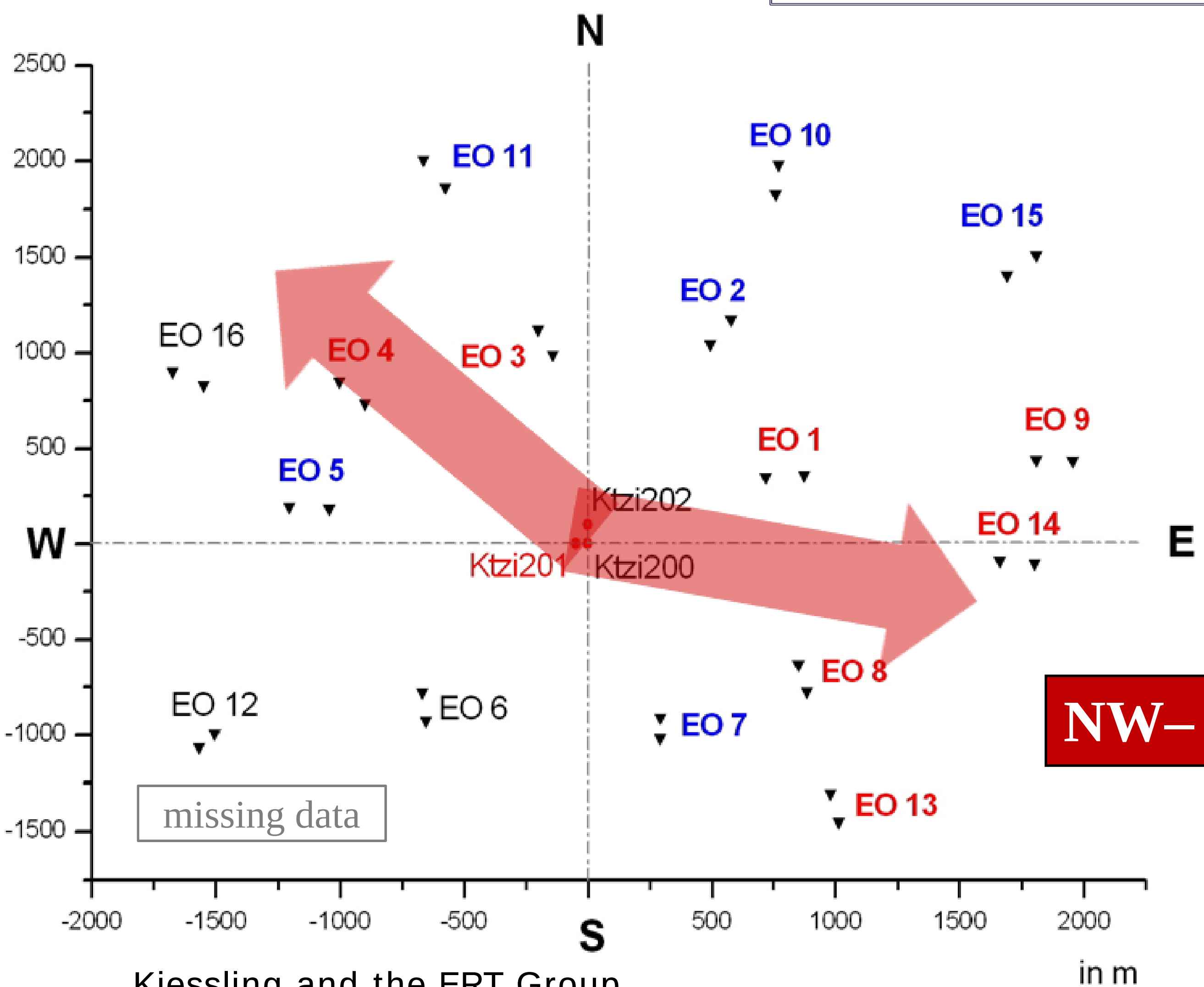


schematic after Friedel, 1995

Surface-Downhole Measurements

Conclusion

➢ **anisotropy in CO2 migration**



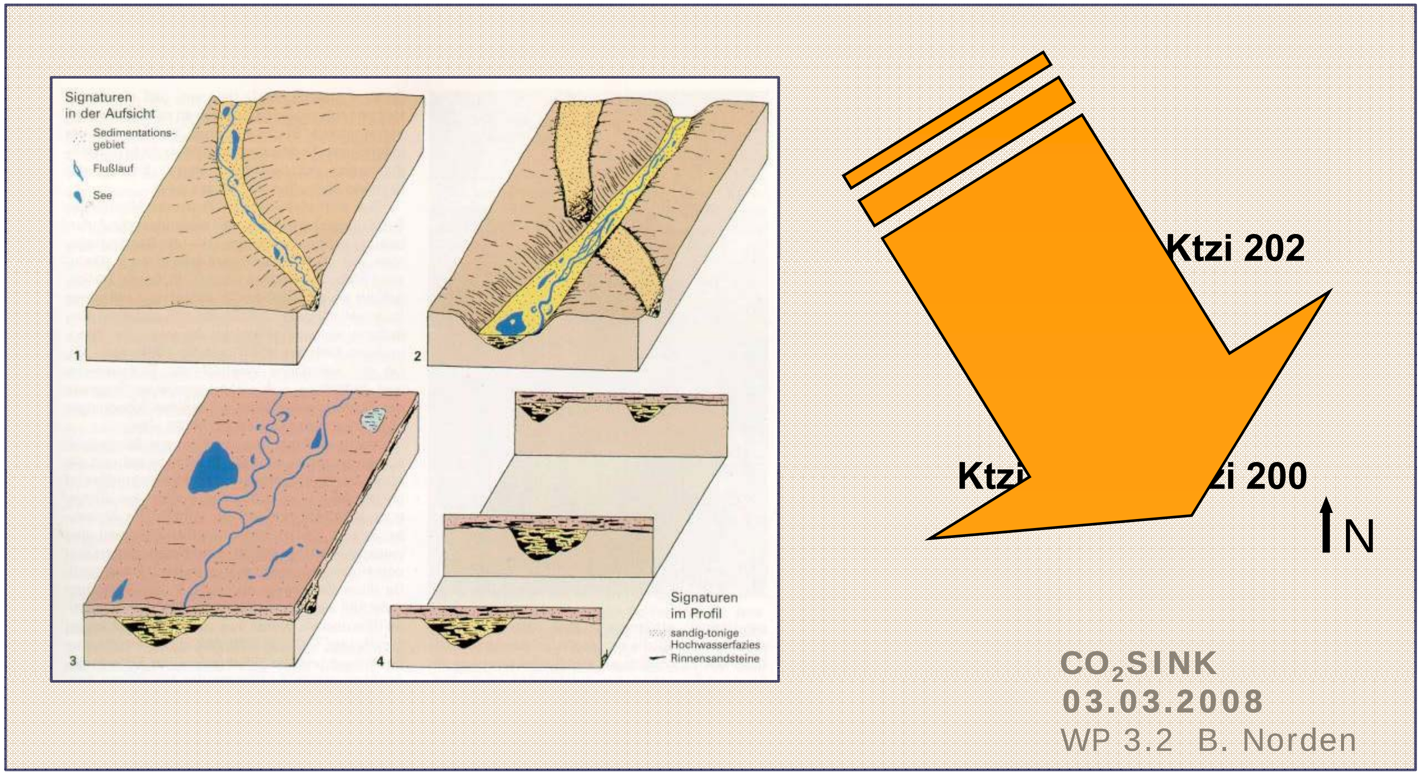
NW– SE - Direction

Kiessling and the ERT Group

Surface-Downhole Measurements

Conclusion

river channel structure and flow direction



Just remember!

General Assembly, 03/2008
B. Norden

Thank you for your attention!

IEA-GHG Risk Assessment Network Meeting
Melbourne - April 16th-17th, 2009

Vattenfall Demo Projects in Germany
Risk Management Approach

Joint Presentation

VATTENFALL

Schlumberger

MANAGING RISK DNV

given by
Claudia Vivalda - Schlumberger

Outline

- Background
- Risk Management Approach
- The Jänschwalde CCS Demo Project
- Risk Management Initial Steps

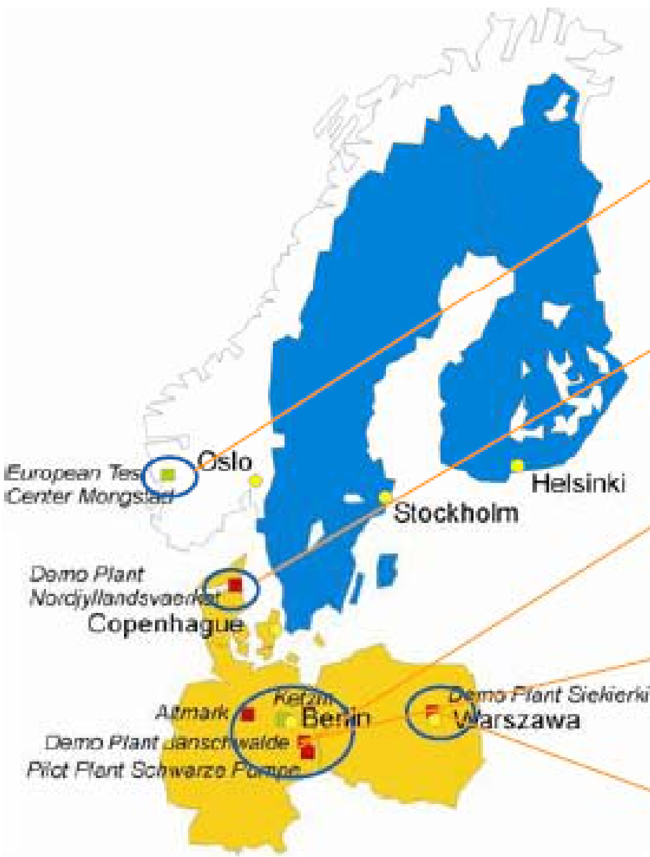
Background

- *Vattenfall* screen **sites in Germany** for injection of carbon dioxide produced in their power plants. Presentation focus: **Jänschwalde CCS Demo project** (well suited to become one of the 12 EU Flagship projects)
- A robust **Risk Management Approach** put in place to ensure that the CCS sites are selected and then managed without harm to the population and the environment while insuring the asset integrity
- *DNV* contracted to **initiate the process** of risk assessment for the geological storage
- A first **Workshop** organized in January 2009 involving main industrial/research/academic stakeholders and relevant authorities
- Outcomes of the workshop recorded and elaborated for **further investigations and actions**

Risk Management Approach

- **All the threaths and opportunities** of the Jänschwalde CCS Demo project are identified, analyzed and managed all along the **project life cycle** by taking into account the methodologies and practices in development in the CCS community
  - E.g. The **initial context** for the **preliminary risk assessment** of the geological storage was set according to the draft Guideline for Carbon Storage site qualification (under development in the JIP CO2QUALSTORE - leaded by DNV, with Vattenfall and SLB sponsors)
- The *Project Team* will **integrate the outcome** of the preliminary risk assessment for the geological storage **with the other elements analyzed/under analysis**, such as the pipeline transportation system and the power plant

Vattenfall CCS Pilot & Demonstration Projects



European Test Center Mongstad
Research new techn. 'chilled ammonia'

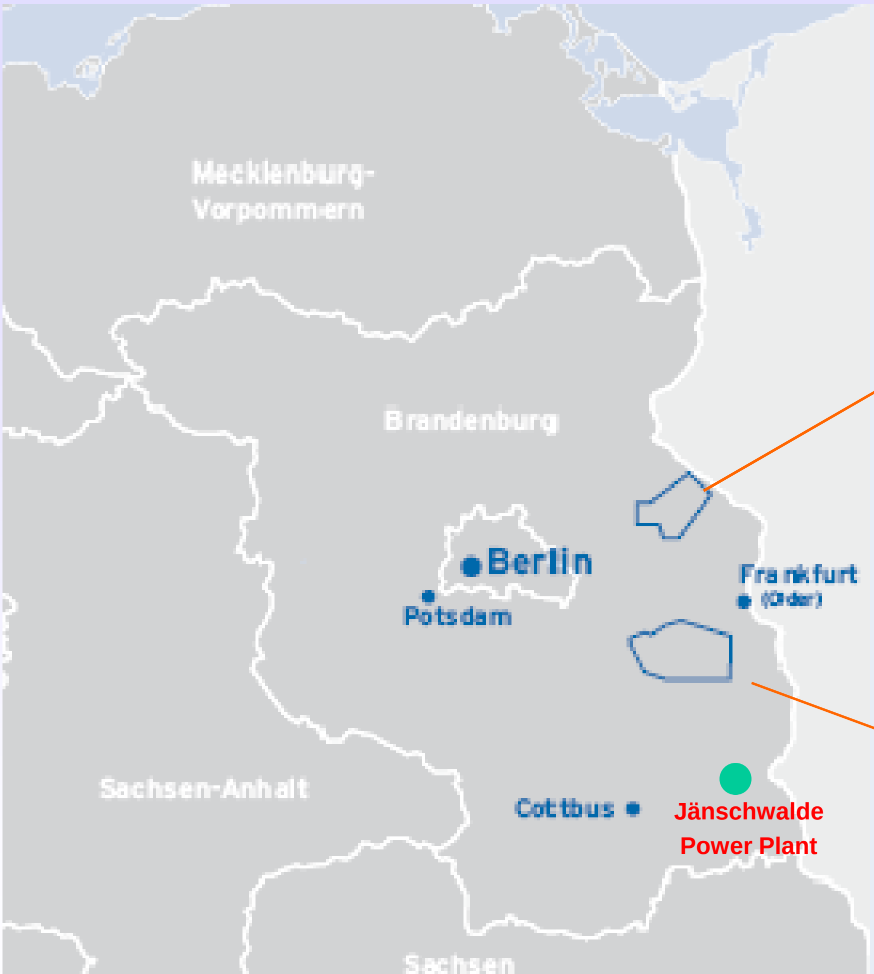
Demo Plant Nordjyllandsvaerket (~300 MW $_{th}$)
Post combustion
Storage 2014/15 in the Vedsted deep saline aquifer

Pilot Plant Schwarze Pumpe (30 MW $_{th}$)
Oxyfuel
EGR 2009 at the Altmark gas field

Demo Plant Jänschwalde (~300 MW $_{th}$)
Oxyfuel & Post combustion
Storage 2014/15,the Birkholz/Neutrebbin storage sites

Demo Plant Siekierki (~150 MW $_{th}$)
Post combustion
Time-schedule not specified

The Jänschwalde CCS Demo project



Roadmap to realisation: Project and forecast for scale-up

Conceptual investigations

Test rig:
0.1 – 0.5 MW_{th}
< €3 million

Pilot plant:
30 MW_{th}
€70 million

Demonstration plant:
300 – 700 MW_{th}
~ € 600 million

Commercial concept:
~ 1000 MW_{th}

2001

- Theoretical studies

2004

- Research
- Basic principles
- Combustion characteristics

2008

- **Demonstration of the process chain**
- **Interaction of components**
- **Validation of basic principles and scale-up criteria**
- **Long term characteristics**
- **Non-commercial**

2013 – 2015

- Verification and optimization of the component choice, the process and reduction of risks
- Must be commercially viable incl. subsidies

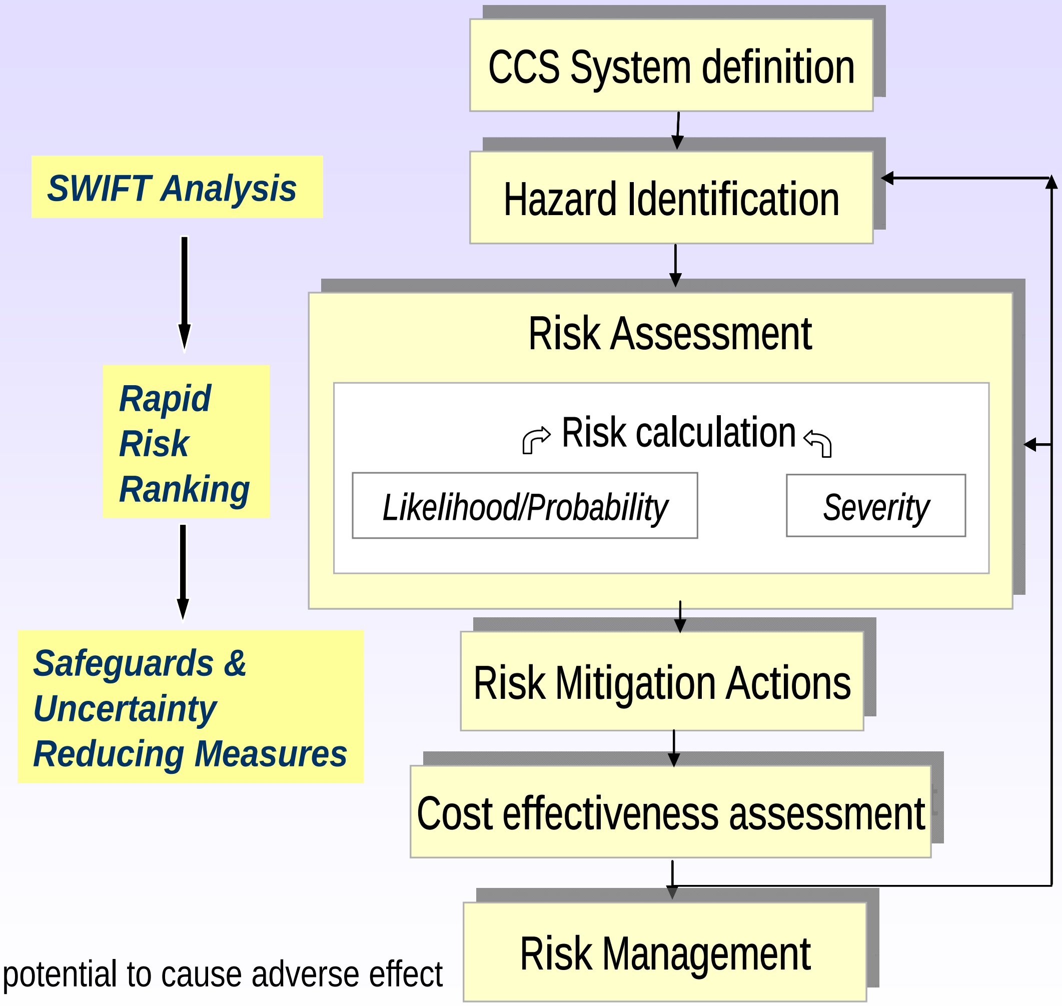
2020

- Competitive in the market at that time
- No subsidies

VATTENFALL

Risk Management - Initial Steps

- The first steps of risk management are usually qualitative / semi-quantitative
- For the geological storage DNV suggested the use of:
  - Structured *What-IF checklisT* (SWIFT) to identify the hazards
  - *Screening and Ranking Framework* (SFR) to assess the containment integrity



*Hazard:a source of potential harm or a situation with a potential to cause adverse effect

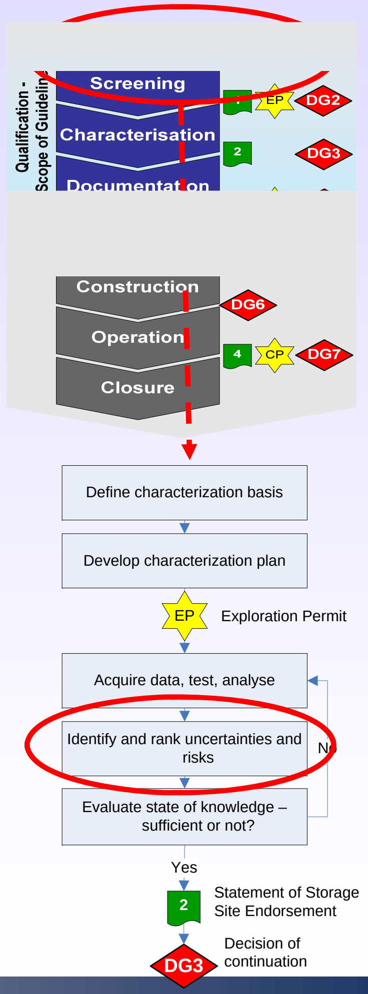
**Risk: chance of something happening that will have an impact

Qualitative Risk Assessment approach

Structured What IF checklisT

a group-based approach to identifying hazards.

- Identifies hazards* and evaluates risks** in a qualitative sense, and recommend appropriate additional safeguards.
- Top-down perspective starting with systems or operations, rather than individual equipment, tasks or failure modes.
- The foundation of a successful SWIFT is a good team that consist of several specialists in different aspects of the subject.
- "What-ifs..?" – questions to identify situations or issues or threats with a potential for causing harm.
- To complement issues raised by the group, the SWIFT process may consult FEP (Features, Events and Processes) databases for completeness.

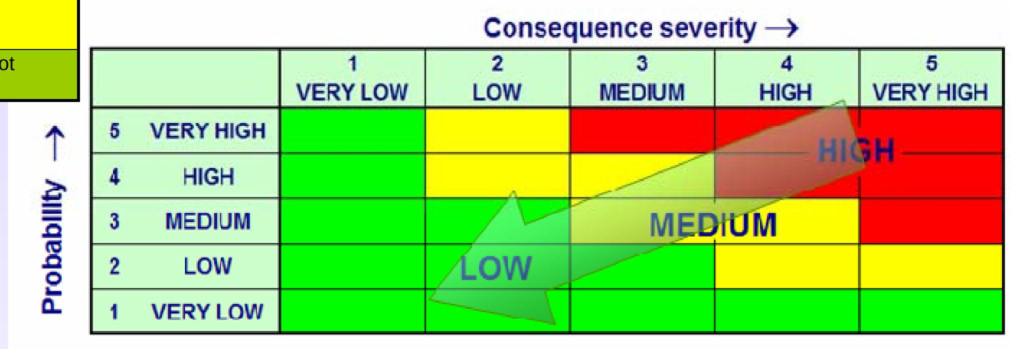


Rapid Risk Ranking

Level	Level name	Description
H	High	High risk, not acceptable. Further analysis should be performed to give a better estimate of the risk. Risk reducing measures must be implemented to decrease risk.
M	Medium	The risk may be acceptable but further analysis should be performed to decrease the uncertainty in the analysis. Risk reducing measures should be implemented if reasonably practical. When assessing the need of remedial actions, the number of FEPs of this risk level should be taken into consideration.
L	Low	The risk is low and further assessment or risk reducing measures are not necessary

Risk categories

Identification and assessment of safeguards



Risk reduction

PROBABILITY EXAMPLES FOR RAPID RISK RANKING

No.	Name	Description	Event (E)	Frequency	Feature (F) / Process (P)	Probability
1	Very Low	Improbable, negligible	Very unlikely to occur during the next 5000 years	About 1 per 10000 years or less	Disregarded	Less or equal 1%
2	Low	Remotely probable, hardly likely	Very unlikely to occur during injection operations	About 1 per 1000 years	Not expected	Less or equal 10%
3	Medium	Occasional, likely	Likely to occur during injection operations	About 1 per 100 years	50/50 chance	Less or equal 50%
4	High	Probable, very likely	May occur several times during injection operations	About 1 per 10 year	Expected	Less or equal 90%
5	Very high	Frequent, to be expected	Will occur several times during injection operations	About 1 per year or more.	Sure	Less or equal 99%

CONSEQUENCE EXAMPLES FOR RAPID RISK RANKING

No.	Name	Impact on Injectivity	Impact on Capacity	Impact on Storage Integrity	Impact on Local environment	% CO2 leaked after 5000 yrs	Impact on Reputation	Consequence for Permit to operate
1	Very Low	Small temporary reduction. No interruption of injection	Small chance of reduced capacity in the future	None	Minor environmental damage	0,0001	Slight or no impact	None
2	Low	Small reduction, minor interruption to injection (hours)	Minor reduction in capacity, does impact project viability	Unexpected migration of CO2 inside the defined storage complex	Local environmental damage of short duration	0,001	Limited impact	Small fine
3	Medium	Significant temporary reduction, interruption to injection for days	Significant reduction in capacity, fixable without new wells	Unexpected migration of CO2 outside the defined storage complex	Time for restitution of ecological resource < 2 years	0,01	Considerable impact	Large fine
4	High	Significant permanent reduction, new injectors needed	Significant reduction in capacity, fixable with new wells	Leakage to vadose zone over small area (<100m2)	Time for restitution of ecological resource 2 - 5 years	0,1	National impact	Temporary withdrawal of permit
5	Very high	Significant permanent reduction, no fix available	Significant reduction in capacity, no fix available	Leakage to vadose zone over large area (>100m2)	Time for restitution of ecological resource such as marine bio-systems, ground water >5	1	International impact	Permanent loss of permit

Probability and consequence classes

Risk Workshop on Geological Storage Sites

Risk Workshop – SWIFT Analysis

- **2 potential sites** assessed: Birkholz site used as reference and Neutrebbin site compared for differences
- Duration: **2 days**
- Participants: **selected experts** from main companies and institutions (25 + 5 facilitators)
  - *Competencies*: Regional geology, Drilling and completion, Basin modelling, Wellbore integrity, Stratigraphy, Engineering geology, Geochemistry, Hydrogeology, Geostatistics, Geophysics, Reservoir engineering, Ecology and terrestrial environment, Reservoir modelling, Risk assessment

Category Specific Keyword Checklists used in SWIFT Analysis

Hazard category FEP keywords

Reservoir

- Spatial domain of interest
- CO2 quantities, injection rate
- Overpressuring
- CO2 composition
- Reversibility
- Remedial actions
- CO2 properties
- CO2 phase behaviour
- CO2 solubility and aqueous speciation
- CO2 interactions
- Displacement of saline formation fluids
- Induced seismicity
- Thermal effects on the injection point
- Heavy metal release
- Mineral dissolution and precipitation
- Reservoir geometry
- Pore architecture
- Heterogeneities
- Stress and mechanical properties

Seal

- Effects of pressurisation of reservoir on cap rock
- Drilling activities
- Desiccation of clay
- Additional seals
- Lithology
- Lithification/diagenesis

Overburden

- Buoyancy-driven flow
- Co-migration of other gases
- Unconformities
- Heterogeneities
- Undetected features
- Vertical geothermal gradient
- Modified hydrology and hydrogeology
- Microbial processes

Vadose zone

- Near-surface aquifers and surface water bodies
- Water management
- Soils and sediments
- Hydrological regime and water balance

Surface

- Impacts on humans
- Land and water use
- Buildings
- Terrestrial environment
- Terrestrial ecological systems
- Sinkhole formation
- Diet and food processing
- Community characteristics
- Asphyxiation effects
- Ecotoxicology of contaminants
- Modification of microbiological systems
- Future human actions
- Sea level change
- Periglacial effects
- Subsidence or uplift

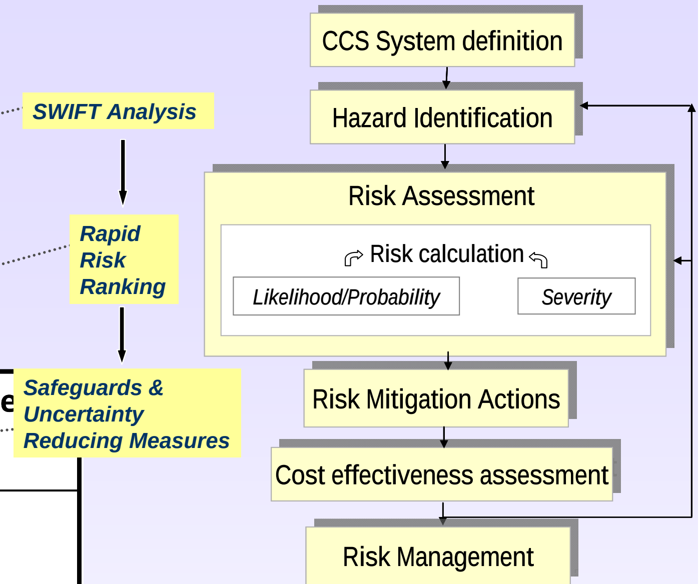
Wells

- Borehole seals and abandonment
- Drilling and completion
- Formation damage
- Well lining and completion
- Workover
- Monitoring wells
- Well records
- Closure and sealing of boreholes
- Seal failure
- Blowouts
- Soil creep around boreholes

Fault zones

- Fractures and faults
- Transmissive faults
- Fault Valving

Example of log-sheet



Keyword Checklists	What-If	Causes	Consequences	P	C	Safeguards	Note
Reservoir	Pressure pulses in system give undesired effects	Emergency shut-down	(1) Cement sheath cyclically loaded and damaged (cracked) (2) Mobilize fines that plug the formation				
Fault zones	Unidentified fractures related to faults	Insufficient data (resolution or coverage) and understanding and characterization	(1) Leakage through fault zone out of permit area of either CO_2 or brine (2) Reduced storage capacity relative to initial expectation				

Risk Workshop Follow-up

Follow-up 1:Results elaboration to create risk database

- Creation of *Risk database* from the list of Hazards, the Rapid Risk Ranking and the identified Safeguards

Follow-up 2: Screening and Ranking Framework

- Questionnaire sent out to individual experts
  - Recording individuals' understanding of containment features: weight property relevance and assign "goodness" and certainty values
- Answers collected and elaborated to derive *Integrity Attributes*
  - Measuring the degree of consensus amongst individual experts
  - Generating graphical display to present range and spread of assessments and certainties

Characteristics	Attributes	Properties
Potential for primary containment	Primary seal	Thickness Lithology Demonstrated sealing Lateral continuity
	Depth	Distance below surface
	Reservoir	Lithology Permeability and porosity Thickness Fracture or primary porosity Pore fluid Pressure Tectonics Hydrology Deep wells Fault permeability
Potential for secondary containment	Secondary seal	Thickness Lithology Demonstrated sealing Lateral continuity Depth
	Shallower seals	Thickness Lithology Lateral continuity Evidence of seepage
Attenuation Potential	Groundwater hydrology	Regional flow Pressure Geochemistry Salinity

Ref. C. Oldenburg at LBNL

Way forward

Integration of the outcome of the preliminary risk assessment for the geological storage with the other elements analyzed/under analysis, such as pipeline transportation and power plant to:

- ✓dig further the potential risks identified;
- ✓implement preventive and corrective measures to mitigate them; and
- ✓take the risks under control all along the project development.

URS *Business Risk Strategies*

PTRC Weyburn EOR/CCS Project

Risk Assessment Update

Adrian Bowden – URS Melbourne

Donna Pershke – URS Perth

Melbourne, Australia

17th April 2009

URS Business Risk Strategies

Outline

- Background and approach
- Application to PTRC Weyburn project
  - Reservoir (Geosphere) risk assessment
  - Environmental (Biosphere) risk assessment
  - Future stakeholder engagement program

Background

- Risk assessment methodology developed as part of Geodisc program of the Petroleum CRC
- APPEA paper (Bowden and Rigg) on assessing risk in storage projects
- Application of methodology with CO2CRC to several storage projects (e.g. Gorgon, Otway Basin PP, Denison Trough, Gippsland Basin, In Salah)
- Apply method to Weyburn EOR Project and expand methodology to include environmental and social risk

Approach

- The approach utilises the RISQUE method (Bowden et al, 2001)
- Risk = Likelihood x Consequence
- Systematic process that uses a formal group of experts to provide judgements on likelihoods and consequences
- Produce outputs that can be used to assist decisions

URS Business Risk Strategies

Application to PTRC Weyburn Project

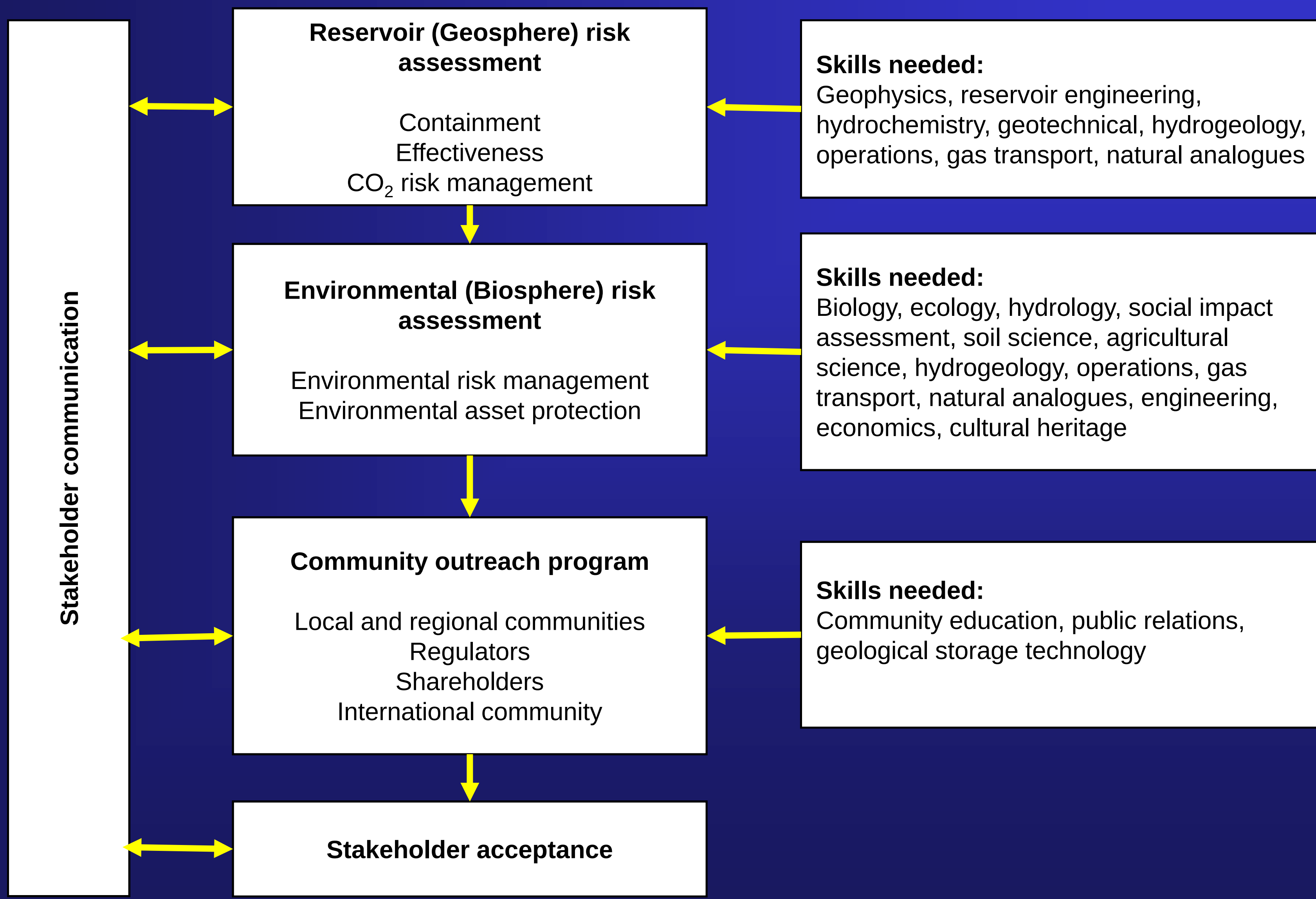
PTRC Weyburn risk assessment objectives

- Apply CO2CRC risk assessment to PTRC Weyburn
- Benchmarking
- Further develop methodology
- Expand the risk assessment from purely technical into the environmental and stakeholder domains
- Provide guidance to future research
- Assist the process of gaining stakeholder support

URS

Business Risk Strategies

Process towards stakeholder acceptance

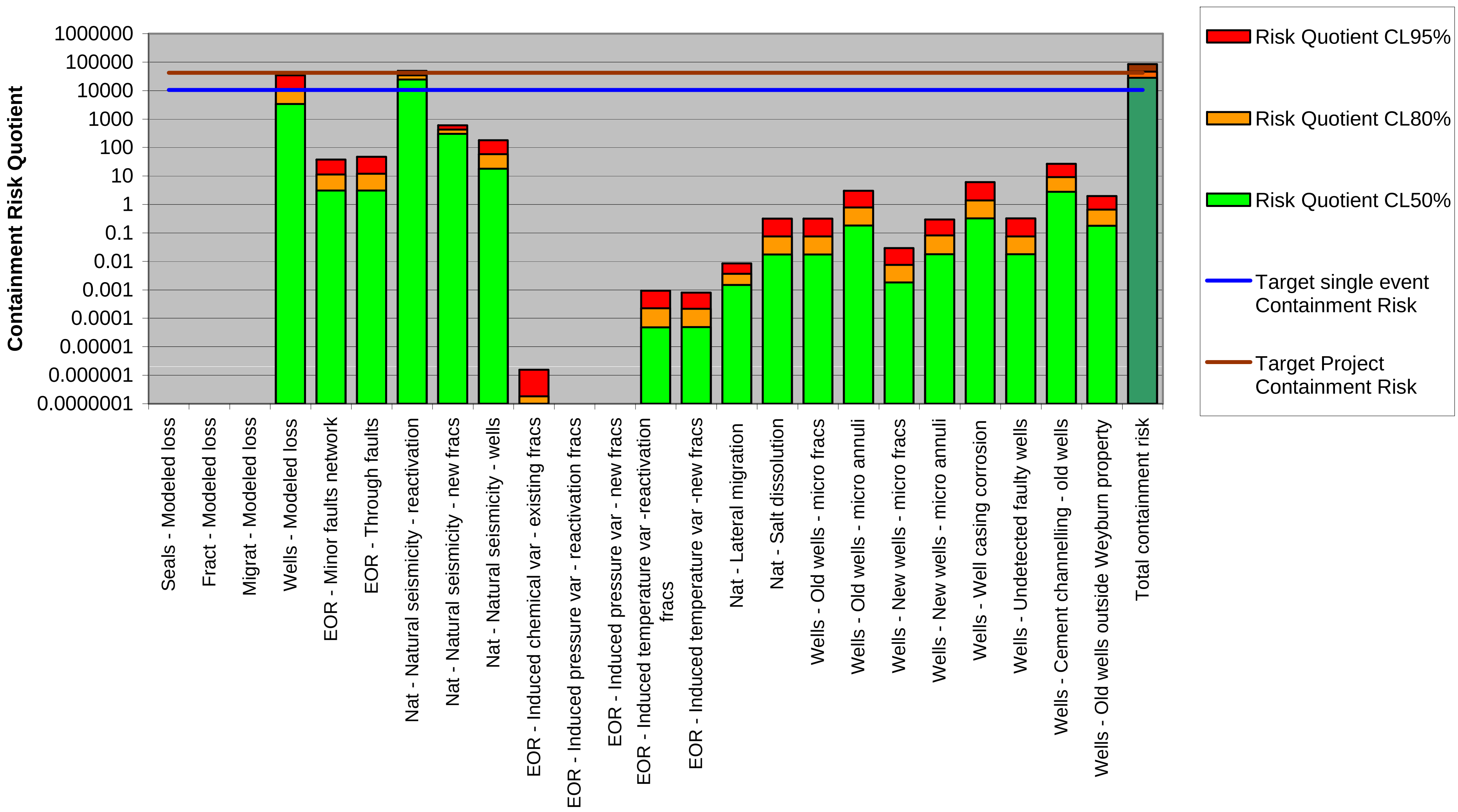


1. Reservoir (Geosphere) risk assessment

- Is the project going to meet CO_2 storage objectives?
  - Accept the planned storage volumes? - Effectiveness
  - Retain 99% of injected CO_2 in geosphere for 1,000 years? - Containment
- What are the risk events that could initiate CO_2 movement from the geosphere?
- What are the key pathways for movement from the geosphere?
- What are the potential rates of CO_2 escape from the geosphere?

URS Business Risk Strategies

Comparison of event containment risk



URS Business Risk Strategies

Containment risk assessment conclusions

- The process has identified gaps and uncertainties in information relating to the risks associated with CO_2 release to the biosphere
- The current outputs of the risk model are only a guide to the risk profile of the project
- Outputs useful to direct the focus for future studies
- Need to incorporate the estimates of CO_2 release to the biosphere into an appropriate assessment of the potential environmental impacts on the biosphere

URS

Business Risk Strategies

Process towards stakeholder acceptance

Stakeholder communication

Reservoir (Geosphere) risk assessment

Containment
Effectiveness
CO_2 risk management

Skills needed:
Geophysics, reservoir engineering, hydrochemistry, geotechnical, hydrogeology, operations, gas transport, natural analogues

Environmental (Biosphere) risk assessment

Environmental risk management
Environmental asset protection

Skills needed:
Biology, ecology, hydrology, social impact assessment, soil science, agricultural science, hydrogeology, operations, gas transport, natural analogues, engineering, economics, cultural heritage

Community outreach program

Local and regional communities
Regulators
Shareholders
International community

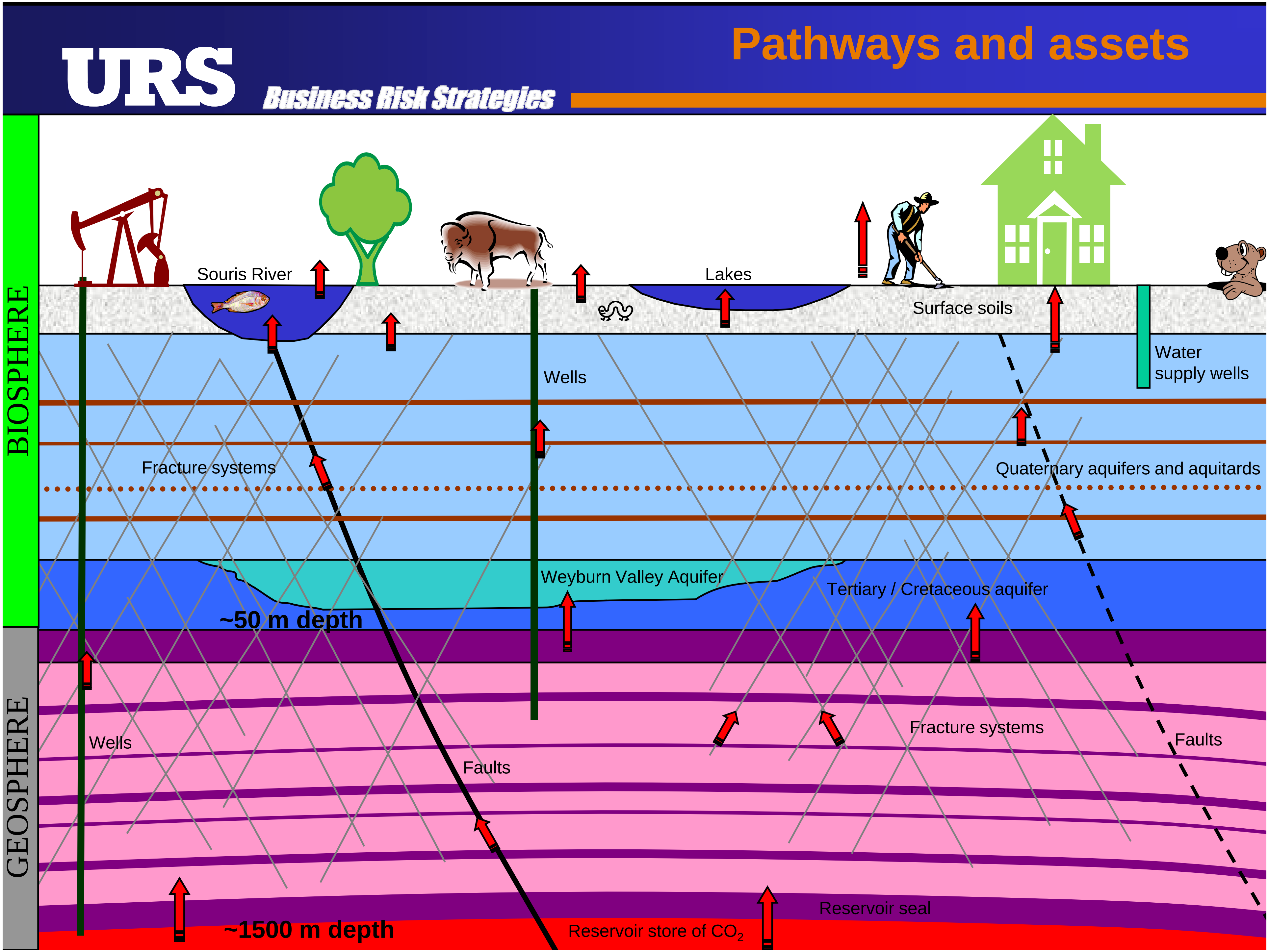
Skills needed:
Community education, public relations, geological storage technology

Stakeholder acceptance

URS Business Risk Strategies

2. Environmental (Biosphere) risk assessment

- Typical EES approach – what are the predicted and potential effects on the wider environment
- Which environmental and community assets are valued by the community?
- What are the community concerns?
- Where and how much CO_2 could enter the biosphere?
- What are the highest risk pathways?
- Which assets are at most risk?
- Which Biosphere components are the main contributors to the risk?


URS
Business Risk Strategies
Pathways and assets
BIOSPHERE
GEOSPHERE
Souris River
Lakes
Surface soils
Water supply wells
Wells
Fracture systems
Quaternary aquifers and aquitards
Weyburn Valley Aquifer
Tertiary / Cretaceous aquifer
~50 m depth
Wells
Faults
Fracture systems
Faults
Reservoir seal
~1500 m depth
Reservoir store of CO_2

Risk identification

URS Business Risk Strategies

- Cause and effect process
- Likelihoods – for each step
- Consequences – Consequences table

CONSEQUENCE LEVEL		Negligible	Minor	Moderate	Major	Extreme
		Minimal, if any impact for some communities. Potentially some impact for a small number (<10) of individuals.	Low level impact for some communities, or high impact for a small number (<10) of individuals.	High level of impact for some communities, or moderate impact for communities area-wide.	High level of impact for communities area-wide.	High level of impact Province-wide.
		0.1	1	10	100	1000
PROPERTY / INFRASTRUCTURE	Cost to repair, replace, remediate (and lost revenues)	Approximate range from $0 to $0.1 million.	Approximate range from $0.1 to $1 million.	Approximate range from $1 to $10 million.	Approximate range from $10 to $100 million.	Approximate range $100 million to more than $1 billion.
ENVIRONMENTAL	Ecosystem Function (need to consider resilience and resistance)	Alteration or disturbance to ecosystem within natural variability. Ecosystem interactions may have changed but it is unlikely that there would be any detectable change outside natural variation / occurrence.	Measurable changes to the ecosystem components without a major change in function (no loss of components or introduction of new species that affects ecosystem function). Recovery in less than 1 year.	Measurable changes to the ecosystem components without a major change in function (no loss of components or introduction of new species that affects ecosystem function). Recovery in 1 to 2 years.	Measurable changes to the ecosystem components with a major change in function. Recovery (ie within historic natural variability) in 3 to 10 years.	Long term and possibly irreversible damage to one or more ecosystem function. Recovery, if at all, greater than 10 years.
	Habitat, communities and / or assemblages	Alteration or disturbance to habitat within natural variability. Less than 1% of the area of habitat affected or removed.	1 to 5% of the area of habitat affected in a major way or removed. Re-establishment in less than 1 year (relative to component seasonality).	5 to 30% of the area of habitat affected in a major way or removed. Re-establishment in 1 to 2 years.	30 to 90% of the area of habitat affected in a major way or removed. Re-establishment in 3 to 10 years.	Greater than 90% of the area of habitat affected in a major way or removed. Re-establishment, if at all, greater than 10 years.
	Species and / or groups of species (including protected species)	Population size or behaviour may have changed but it is unlikely that there would be any detectable change outside natural variation / occurrence.	Detectable change to population size and / or behaviour, with no detectable impact on population viability (recruitment, breeding, recovery) or dynamics. Recovery in less than 1 year	Detectable change to population size and / or behaviour, with no impact on population viability (recruitment, breeding, recovery) or dynamics. Recovery in 1 to 2 years.	Detectable change to population size and / or behaviour, with an impact on population viability and or dynamics. Recovery (ie within historic natural variability) in 3 to 10 years.	Local extinctions are imminent / immediate or population no longer viable. Recovery, if at all, greater than 10 years.

Example model inputs

URS Business Risk Strategies

Initiating event	Pathway to biosphere	Likelihood over 1,000 years	Affected biosphere component	Specific asset	Impact on asset	Likelihood of having an impact on the asset	Consequence category	Consequence	Consequence level
EOR - induced pressure vari	Minor faults	0.0012	Rivers	Souris River	pH change	0.5	Environment	Ecosystem function	1
EOR - induced pressure vari	Minor faults	0.0012	Lakes	Permanent lakes	pH change	1	Social	Amenity - recreation	1
EOR - induced pressure vari	Minor faults	0.0012	Soils	Soil layer	Soil water pH change	1	Environment	Species	100
EOR - induced pressure vari	Minor faults	0.0012	Groundwater	Channel aquifers	Contaminants	0.001	Public health and safe	Illness, injury, fatality	10
EOR - induced pressure vari	Minor faults	0.0012	Groundwater	Glacial aquifers	pH change	0.1	Property, infrastructure	Repair, replace	10
EOR - induced pressure vari	Minor faults	0.0012	Air	Air quality	Air exclusion	0.01	Public health and safe	Illness, injury, fatality	100
EOR - induced pressure vari	Minor faults	0.0012	Air	Air quality	Contaminants	1	Social	Amenity - sensory, perc	100
EOR - induced pressure vari	Through faults	0.0002	Rivers	Souris River	pH change	1	Environment	Ecosystem function	10
CO2 out-migration	Reservoir flow lines	1E-06	Soils	Soil layer	Soil air exclusion	1	Environment	Habitat, communities, a	10
CO2 out-migration	Reservoir flow lines	1E-06	Soils	Soil layer	Soil air exclusion	1	Environment	Species	100
CO2 out-migration	Reservoir flow lines	1E-06	Soils	Soil layer	Soil water pH change	0.1	Environment	Species	100
CO2 out-migration	Reservoir flow lines	1E-06	Groundwater	K/T aquifer	pH change	0.0001	Public health and safe	Illness, injury, fatality	10
CO2 out-migration	Reservoir flow lines	1E-06	Groundwater	K/T aquifer	Contaminants	0.01	Social	Amenity - sensory, perc	10
Salt dissolution	Collapse chimneys	2E-05	Rivers	Souris River	pH change	1	Environment	Ecosystem function	100
Salt dissolution	Collapse chimneys	2E-05	Rivers	Souris River	pH change	1	Environment	Habitat, communities, a	100
Salt dissolution	Collapse chimneys	2E-05	Rivers	Souris River	pH change	1	Social	Amenity - sensory, perc	10
Salt dissolution	Collapse chimneys	2E-05	Lakes	Intermittent lakes	pH change	1	Environment	Habitat, communities, a	10
Salt dissolution	Collapse chimneys	2E-05	Lakes	Intermittent lakes	pH change	1	Environment	Species	100
Seismic - fault reactivation	Reactivated fractures	0.009	Lakes	Permanent lakes	Free CO2	1	Environment	Habitat, communities, a	100
Seismic - fault reactivation	Reactivated fractures	0.009	Soils	Soil layer	Soil air exclusion	1	Environment	Habitat, communities, a	100
Seismic - fault reactivation	Reactivated fractures	0.009	Soils	Soil layer	Soil air exclusion	1	Environment	Species	1000
Seismic - fault reactivation	Reactivated fractures	0.009	Soils	Soil layer	Soil air exclusion	1	Social	Amenity - recreation	10
Old wells failure	Micro fractures	0.5477	Soils	Soil layer	Soil water pH change	1	Property, infrastructure	Repair, replace	1
Old wells failure	Micro annuli	5.4772	Groundwater	K/T aquifer	pH change	1	Economic	Agriculture	0.1
New wells failure	Micro annuli	0.5477	Air	Air quality	Air exclusion	0.001	Public health and safe	Illness, injury, fatality	100
Well casing corrosion	Well casing	0.1225	Soils	Soil layer	Soil air exclusion	1	Environment	Habitat, communities, a	0.1
Well casing corrosion	Well casing	0.1225	Soils	Soil layer	Soil air exclusion	0.01	Environment	Species	100
Well casing corrosion	Well casing	0.1225	Soils	Soil layer	Soil air exclusion	0.01	Social	Amenity - recreation	10
Well casing corrosion	Well casing	0.1225	Soils	Soil layer	Soil air exclusion	0.01	Social	Amenity - sensory, perc	100
Undetected faulty wells	Micro fractures	0.0055	Soils	Soil layer	Soil water pH change	1	Property, infrastructure	Repair, replace	1
Old wells cement	Cement channels	8.6603	Soils	Soil layer	Soil water pH change	1	Property, infrastructure	Repair, replace	1
Old wells cement	Cement channels	8.6603	Soils	Soil layer	Soil water pH change	1	Economic	Agriculture	0.1
Old wells cement	Cement channels	8.6603	Groundwater	K/T aquifer	pH change	1	Property, infrastructure	Repair, replace	10
Old wells cement	Cement channels	8.6603	Groundwater	K/T aquifer	pH change	1	Environment	Habitat, communities, a	0.1
Old wells cement	Cement channels	8.6603	Groundwater	K/T aquifer	pH change	1	Economic	Agriculture	0.1
Old wells outside Weyburn p	Micro annuli	5.4772	Soils	Soil layer	Soil water pH change	1	Property, infrastructure	Repair, replace	1

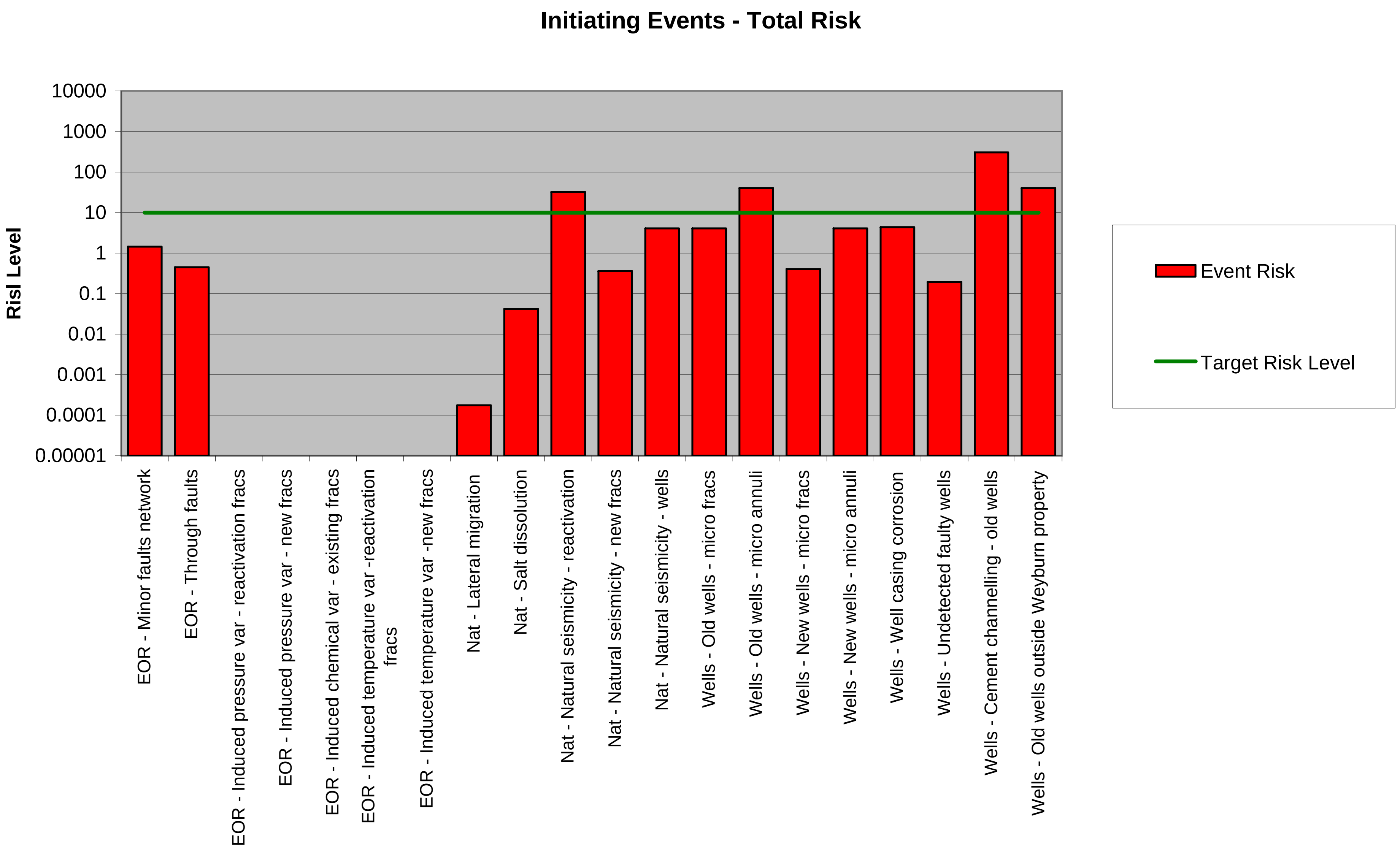
URS Business Risk Strategies

Biosphere risk assessment outputs

- Use to:
  - Progressively modify project design and research planning
  - Reduce overall risk of project
  - Communicate risk to wider community
  - Demonstrate level of risk to specific assets
  - Demonstrate due diligence

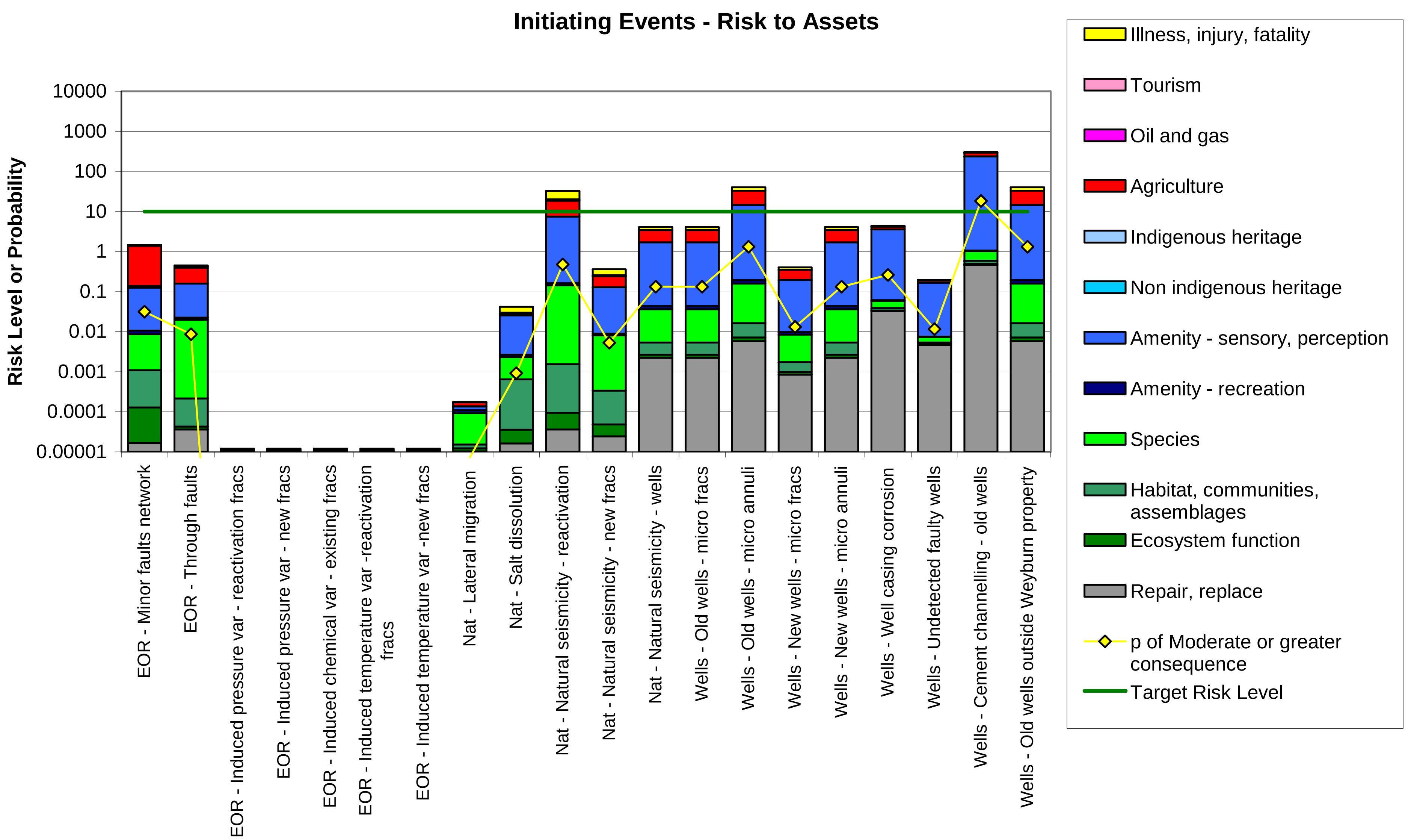
URS Business Risk Strategies

What are the highest risk pathways?



URS Business Risk Strategies

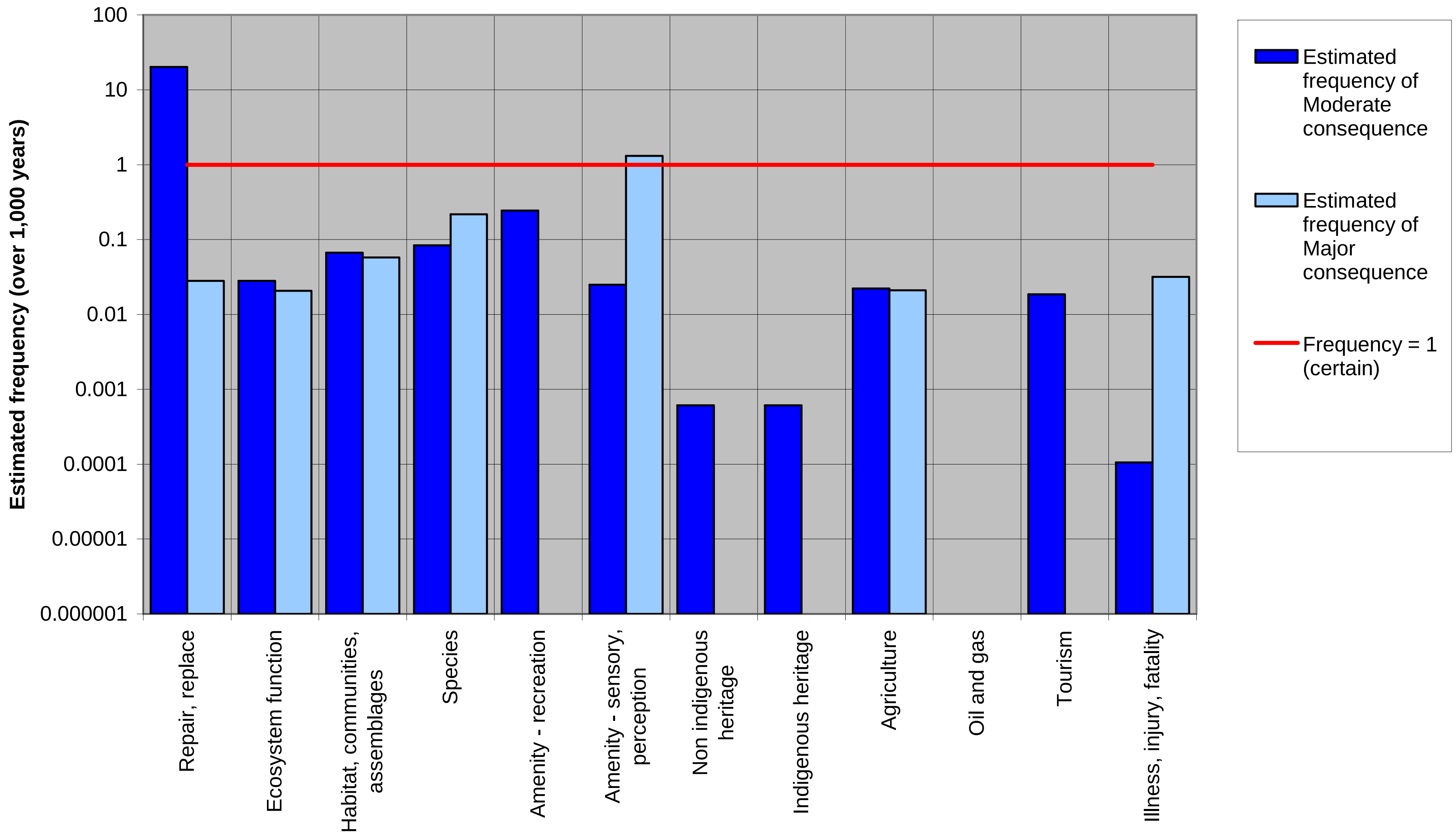
Which assets could be affected?



What is the impact on any asset?

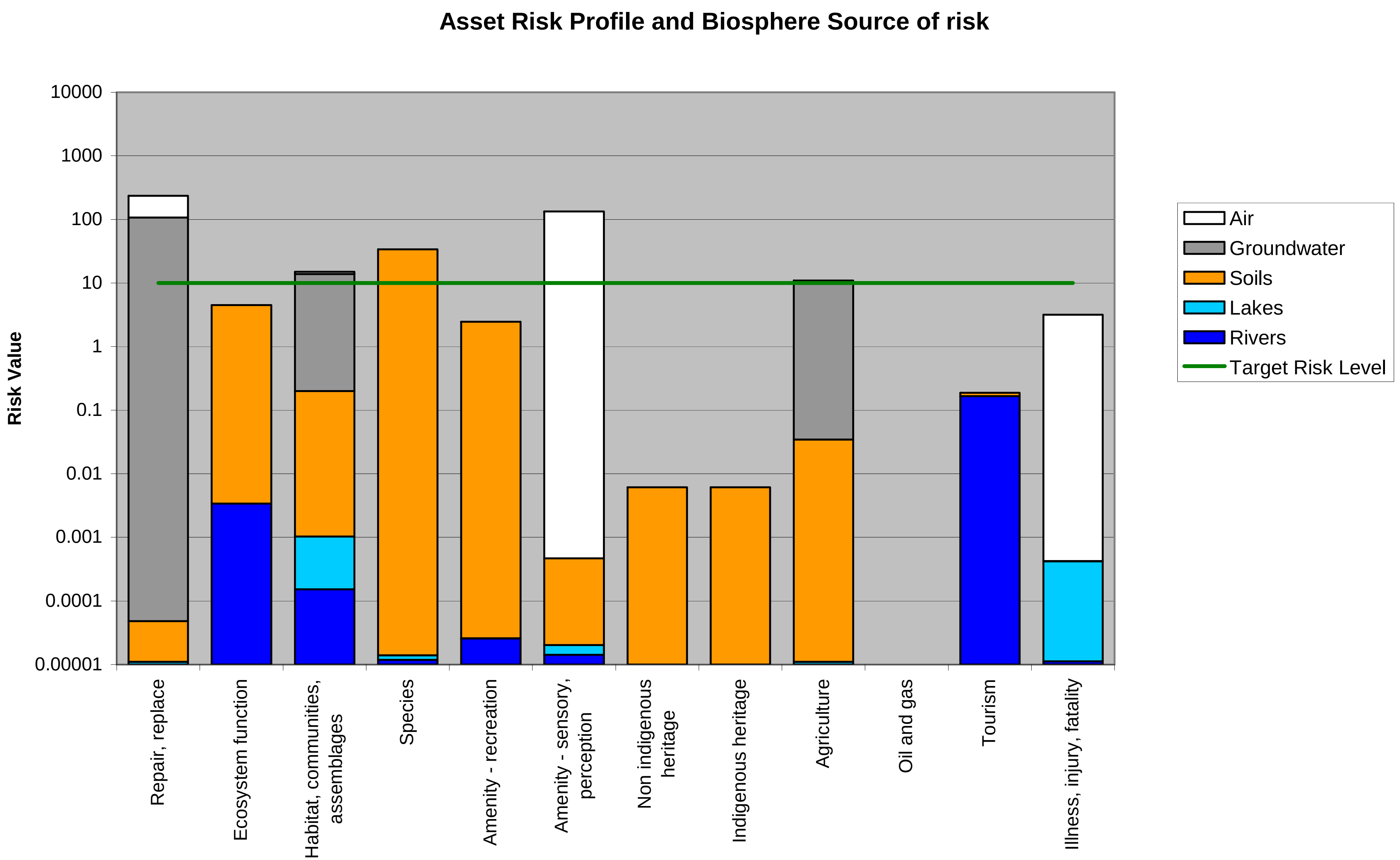
URS Business Risk Strategies

Estimated frequencies of Moderate and Major consequence levels for environmental assets



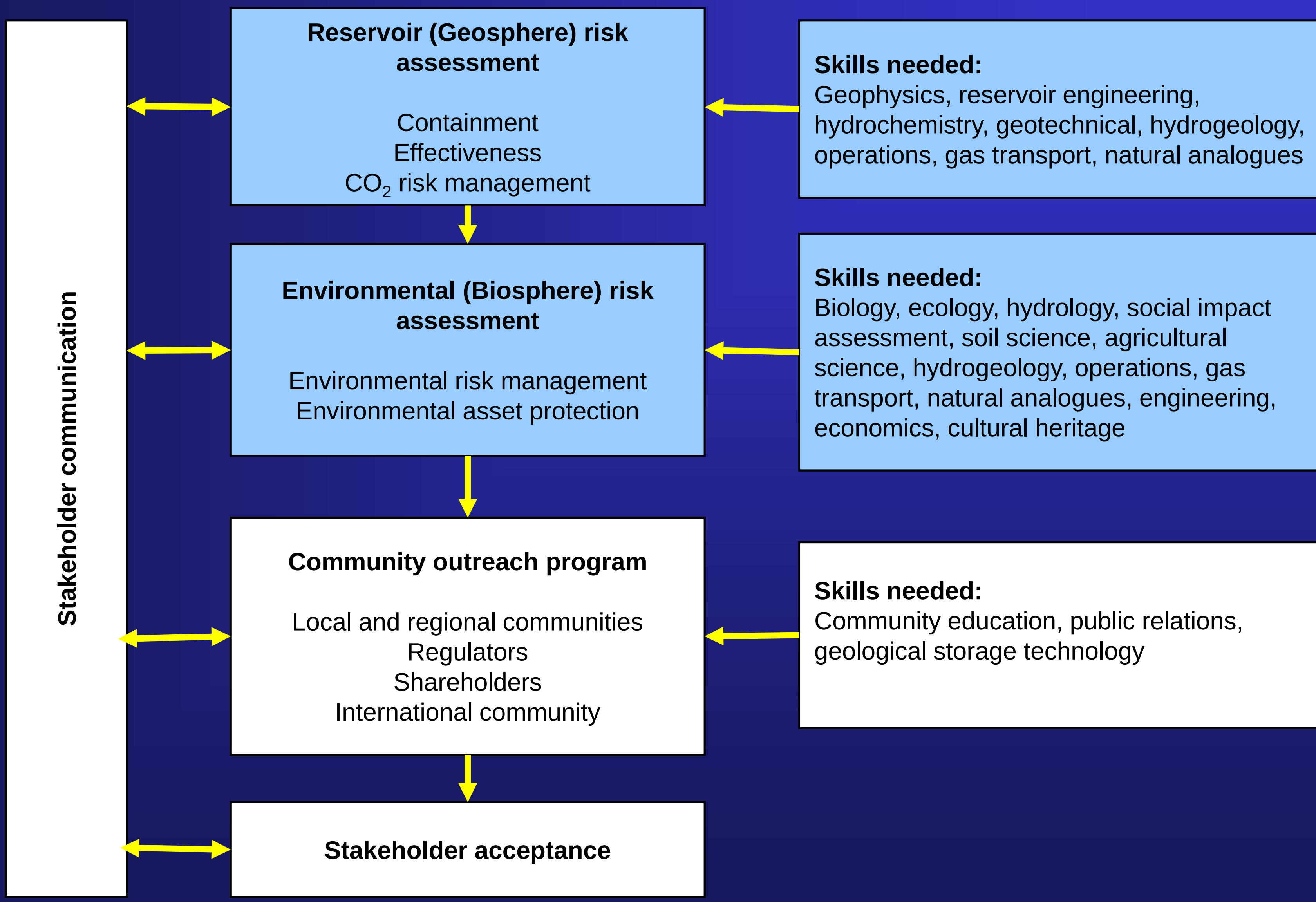
Which assets are most at risk?

URS Business Risk Strategies



URS
Business Risk Strategies

Process towards stakeholder acceptance



URS Business Risk Strategies

3. Community outreach program (Future)

- Complete the link between technical issues and community perceptions
- Program to ensure that community perceptions of risk have been properly addressed
- Community education program to provide communities with an understanding of the risks associated with CO_2 storage?
- Identify and engage appropriate professional resources

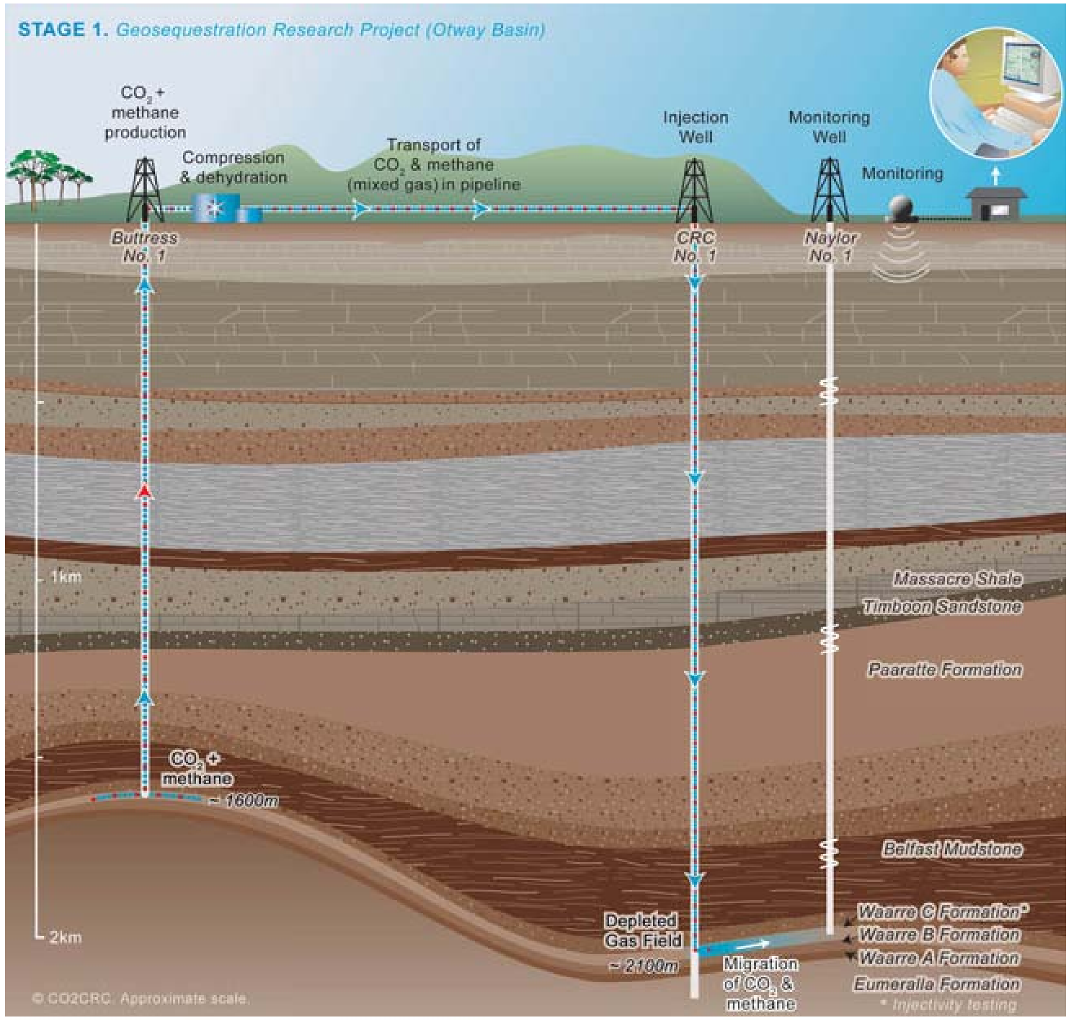
Stage 2 of the CO2CRC Otway Project: Design of a Single-Well Residual Saturation Test

Lincoln Paterson (CO2CRC/CSIRO)
with contributions from Jonathan Ennis-King, Martin Leahy (CO2CRC/CSIRO)
Mike Krause (CO2CRC/Stanford University)
Yingqi Zhang, Barry Freifeld, Stefan Finsterle (Lawrence Berkeley National Laboratory)

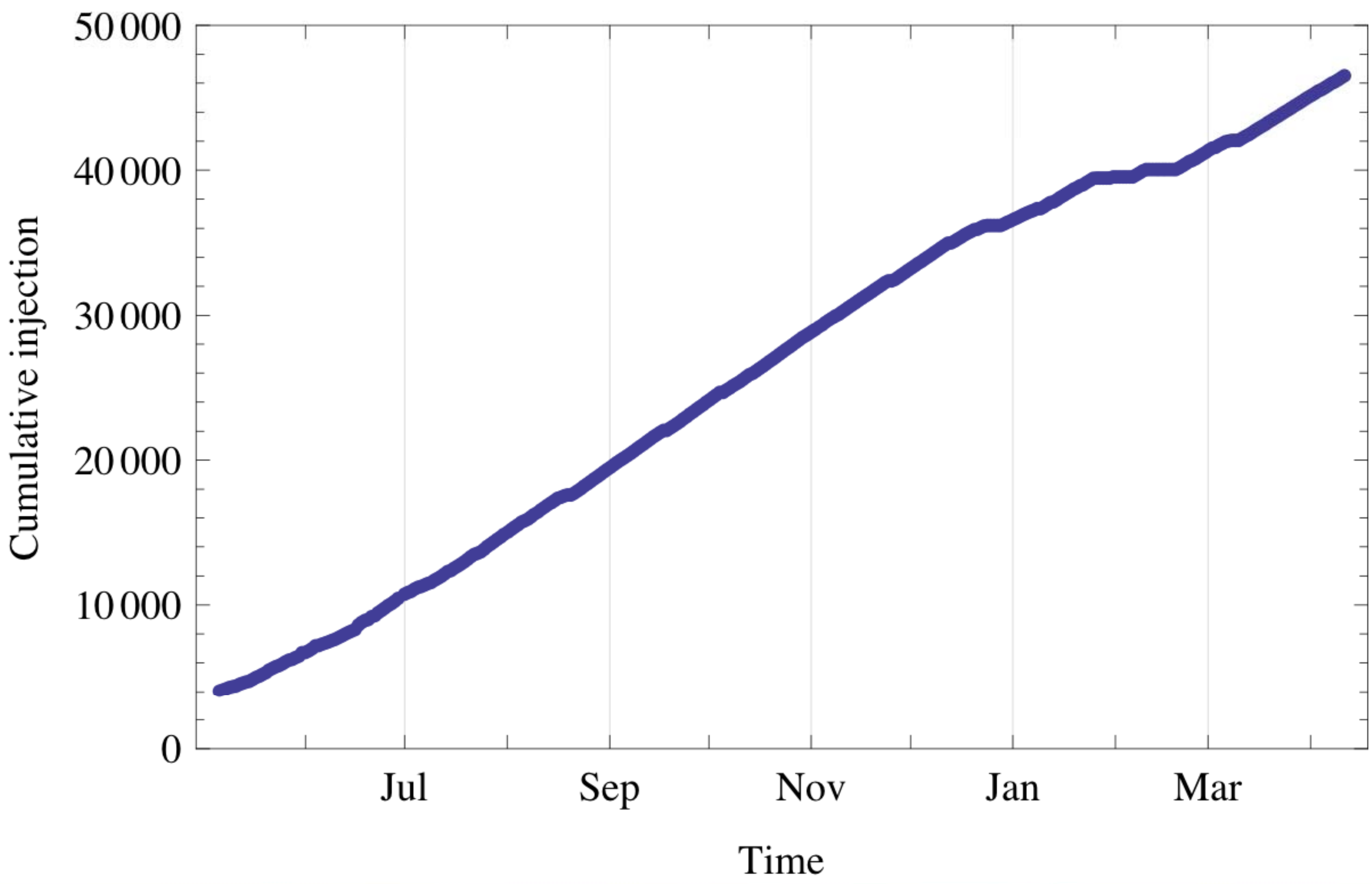
Outline

- Short review of the CO2CRC Otway Project Stage 1
- Trapping mechanisms: residual trapping
- Objective of the CO2CRC Otway Project Stage 2
- Design options and sensitivity studies

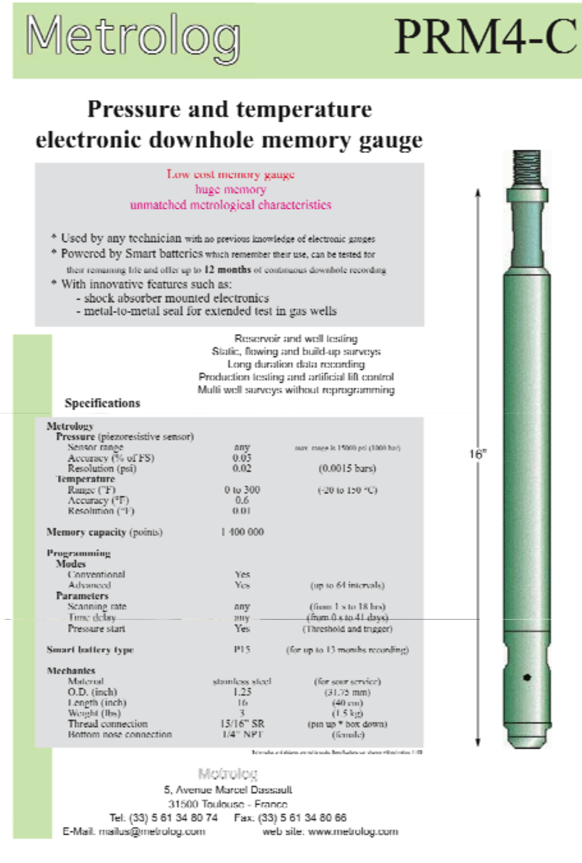
Stage 1: Storage in a depleted gas field



Stage 1 cumulative injection (tonnes)



Downhole pressure gauges



Metrolog PRM4-C

Pressure and temperature electronic downhole memory gauge

Low cost memory gauge
huge memory
unmatched metrological characteristics

* Used by any technician with no previous knowledge of electronic gauges
* Powered by Smart batteries which remember their use, can be tested for their remaining life and offer up to **12 months** of continuous downhole recording
* With innovative features such as:
  - shock absorber mounted electronics
  - metal-to-metal seal for extended test in gas wells

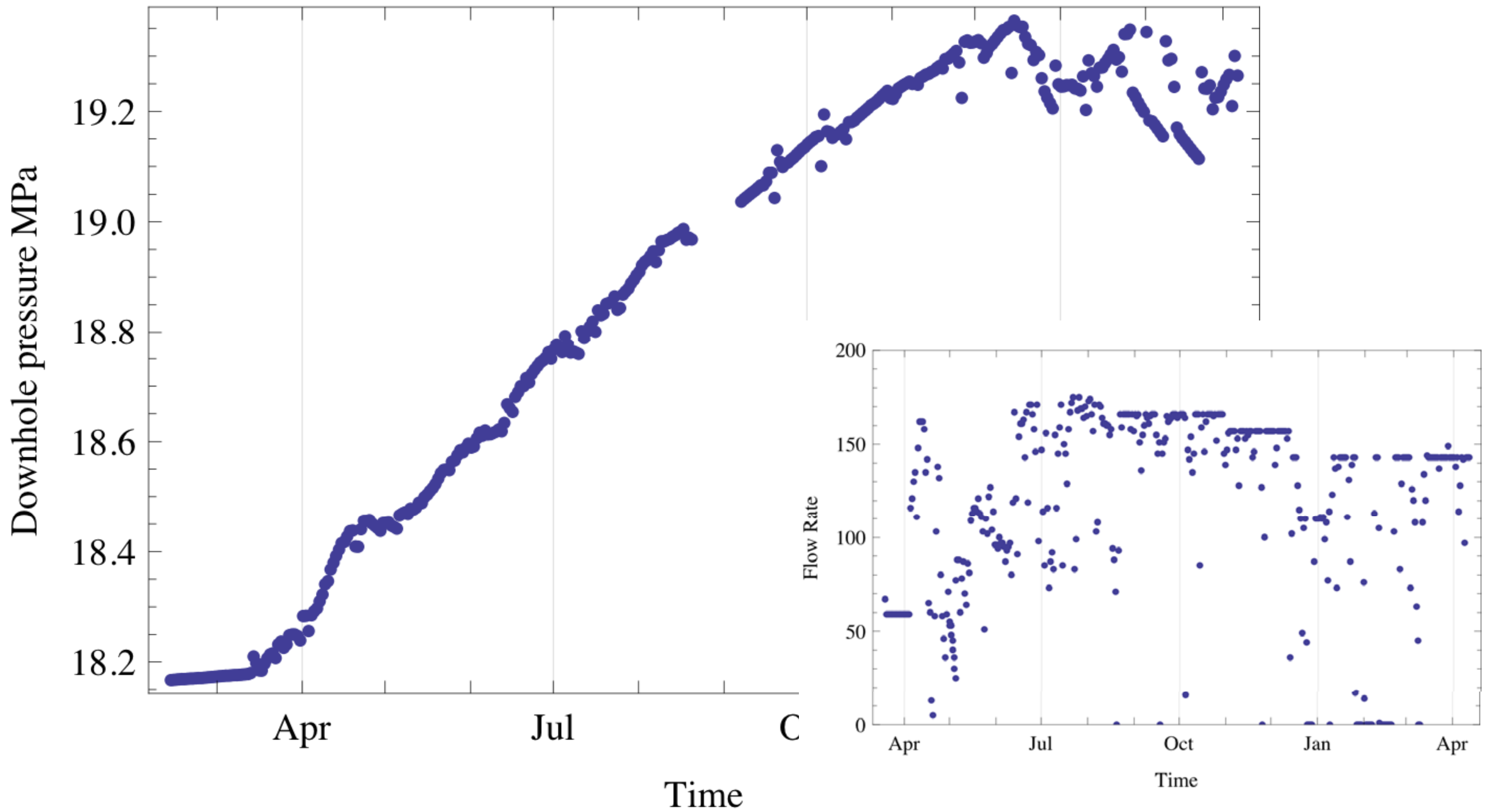
Reservoir and well testing
Static, flowing and build-up surveys
Long duration data recording
Production testing and artificial lift control
Multi well surveys without reprogramming

Specifications

Metrology		
Pressure (piezoresistive sensor)		
Sensor range	any	max. range is 15000 psi (1000 bar)
Accuracy (% of FS)	0.03	
Resolution (psi)	0.02	(0.0015 bars)
Temperature		
Range (°F)	0 to 300	(-20 to 150 °C)
Accuracy (°F)	0.6	
Resolution (°F)	0.01	
Memory capacity (points)	1 400 000	
Programming		
Modes		
Conventional	Yes	
Advanced	Yes	(up to 64 intervals)
Parameters		
Scanning rate	any	(from 1 s to 18 hrs)
Time delay	any	(from 0 s to 41 days)
Pressure start	Yes	(Threshold and trigger)
Smart battery type	P15	(for up to 13 months recording)
Mechanics		
Material	stainless steel	(for sour service)
O.D. (inch)	1.25	(31.75 mm)
Length (inch)	16	(40 cm)
Weight (lbs)	3	(1.5 kg)
Thread connection	15/16" SR	(pin up * box down)
Bottom nose connection	1/4" NPT	(female)

Metrolog
5, Avenue Marcel Dassault
31500 Toulouse - France
Tel: (33) 5 61 34 80 74 Fax: (33) 5 61 34 80 66
E-Mail: mailus@metrolog.com web site: www.metrolog.com

CRC-1 downhole pressure

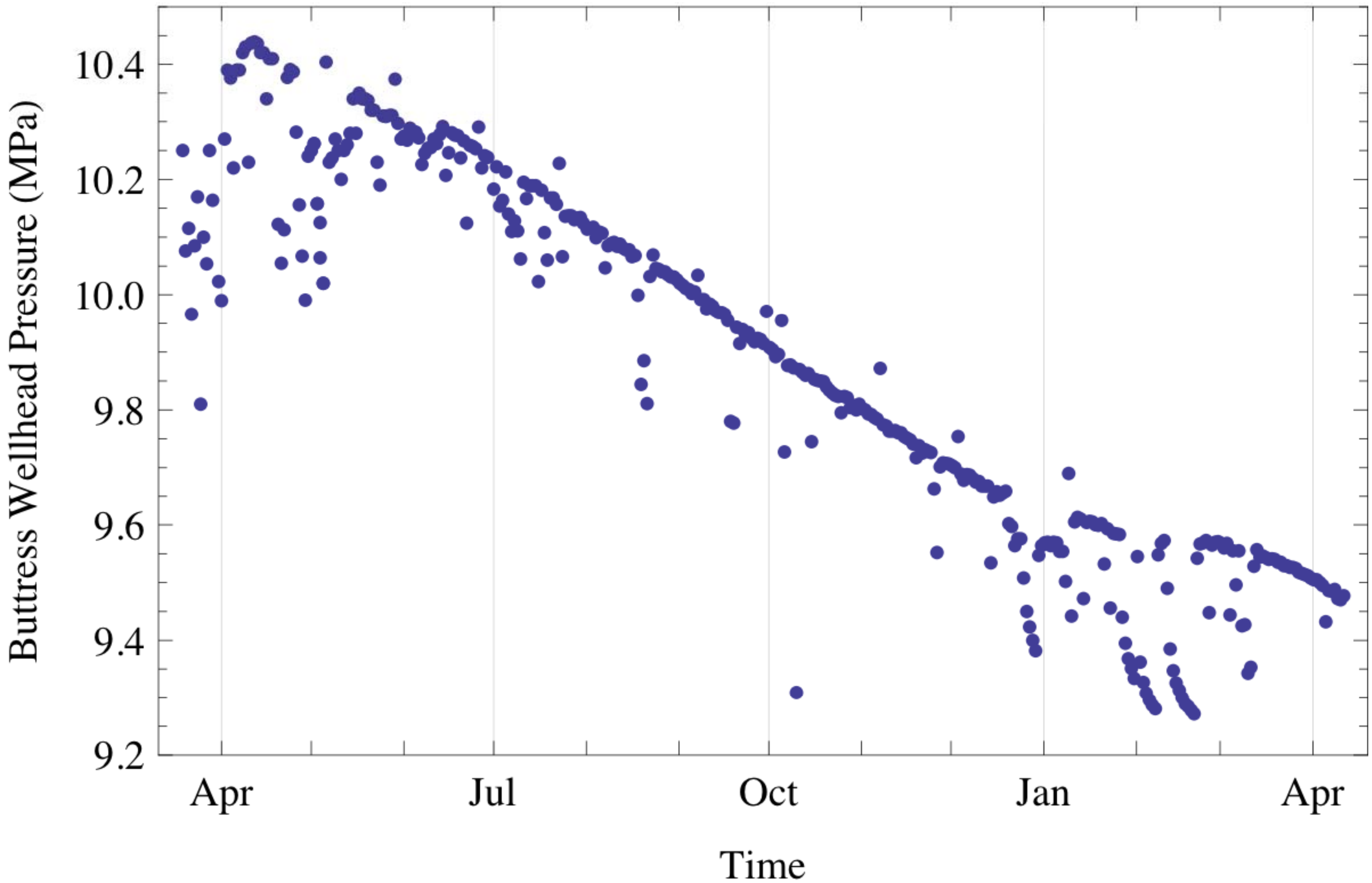


Injection rate

CSIRO

CO2CRC

Buttress wellhead pressure



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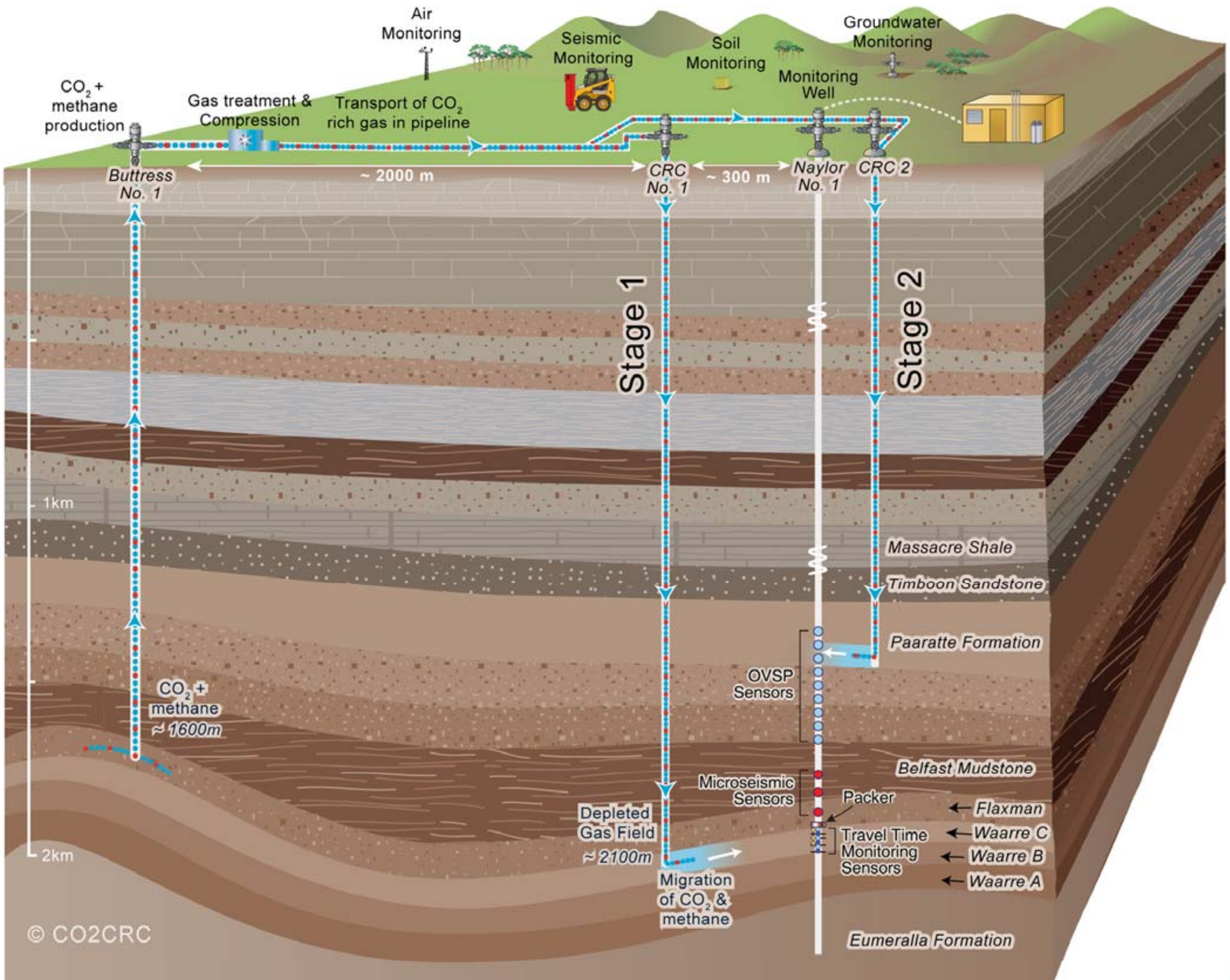
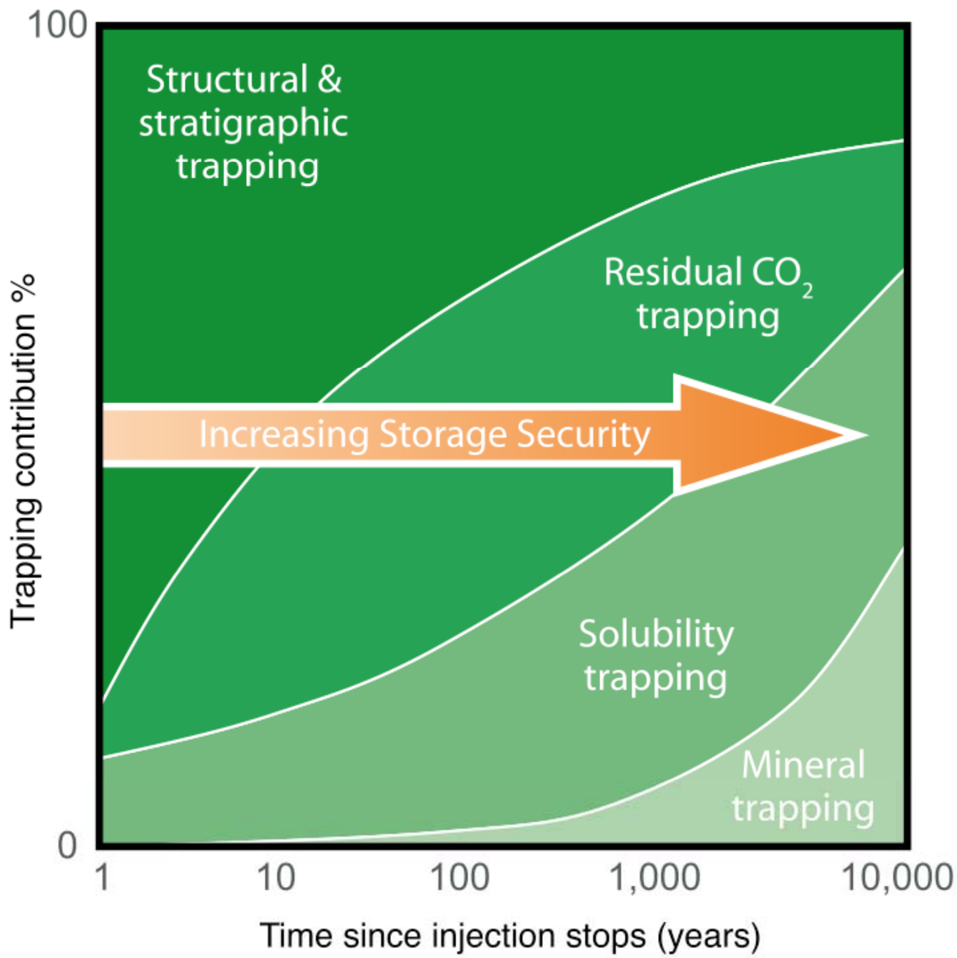
Stage 2: Focus on non-structural trapping



Trapping mechanisms (IPCC Special Report)

1. **Structural trapping**
2. **Residual trapping**
3. **Solubility trapping**
4. **Mineral trapping**



Residual capillary trapping

- CO_2 can be effectively immobilised during CO_2 injection into saline aquifers by residual trapping - also known as capillary trapping - a process resulting from capillary snap-off of isolated CO_2 bubbles.
- The method does not rely on impermeable cap rock to contain the CO_2, hence reduces risk.
- Usually faster than dissolution or mineral trapping
- Efficient residual trapping in dipping aquifers may allow CO_2 storage where there is not structural closure, providing the migration path is sufficiently long.

Residual capillary trapping

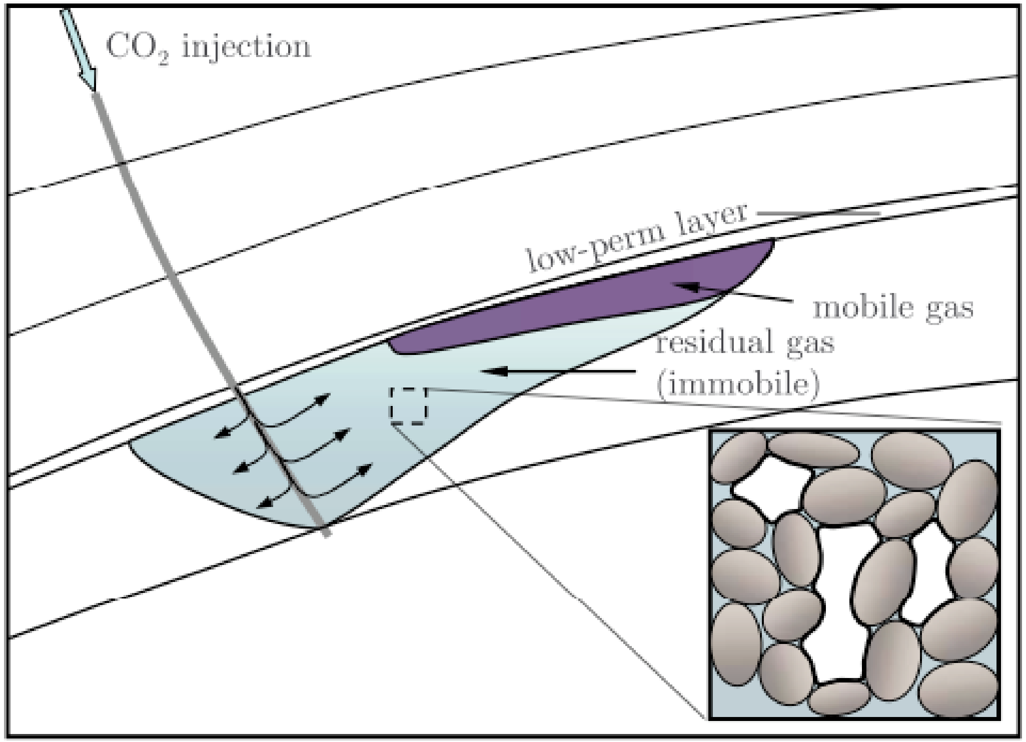


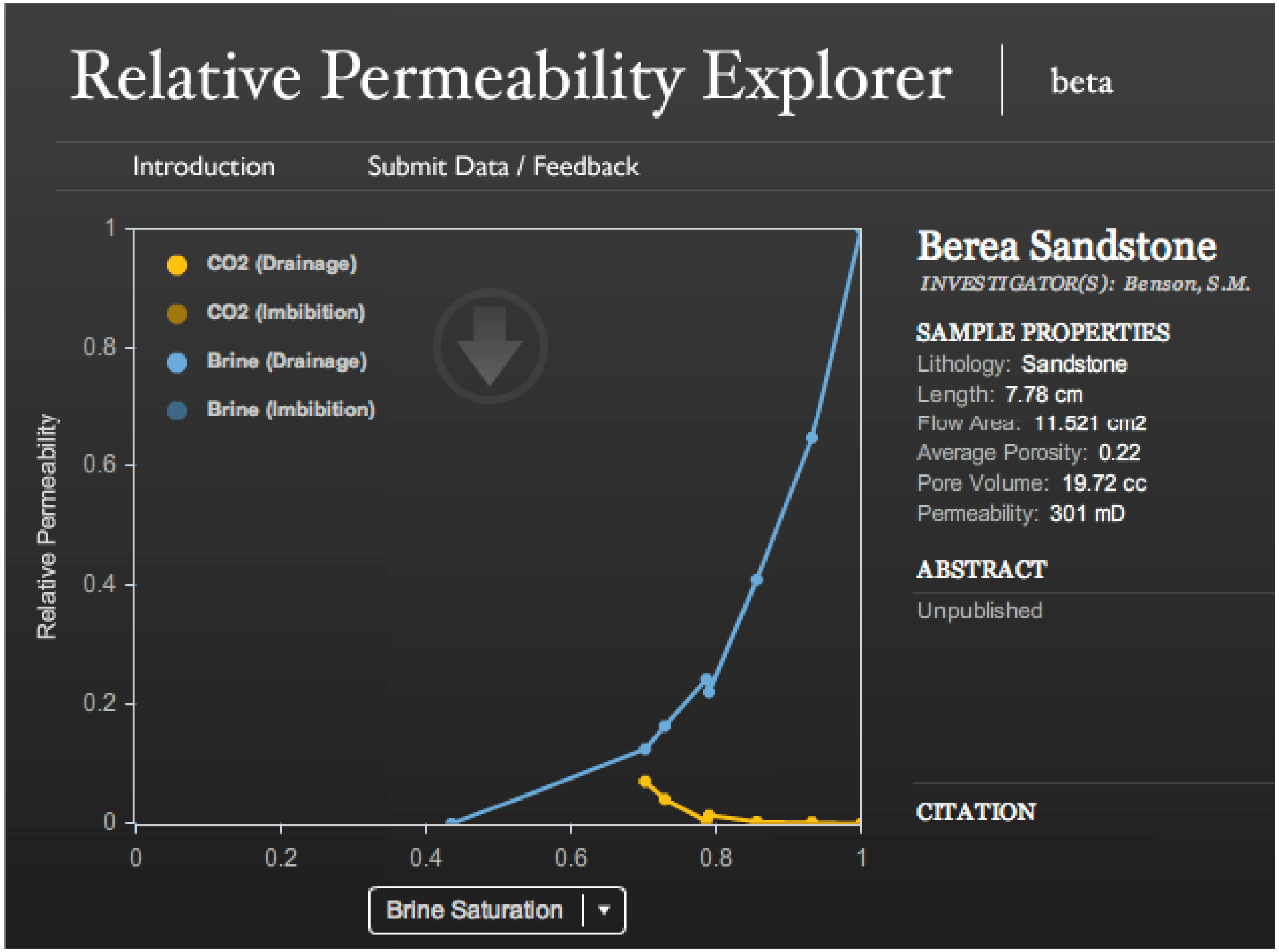
Figure 1. Schematic of the trail of residual CO_2 that is left behind because of snap-off as the plume migrates upward during the postinjection period.

From: Juanes, Spiteri, Orr, Blunt; Water Resources Research (2006)

Residual oil image from digital core

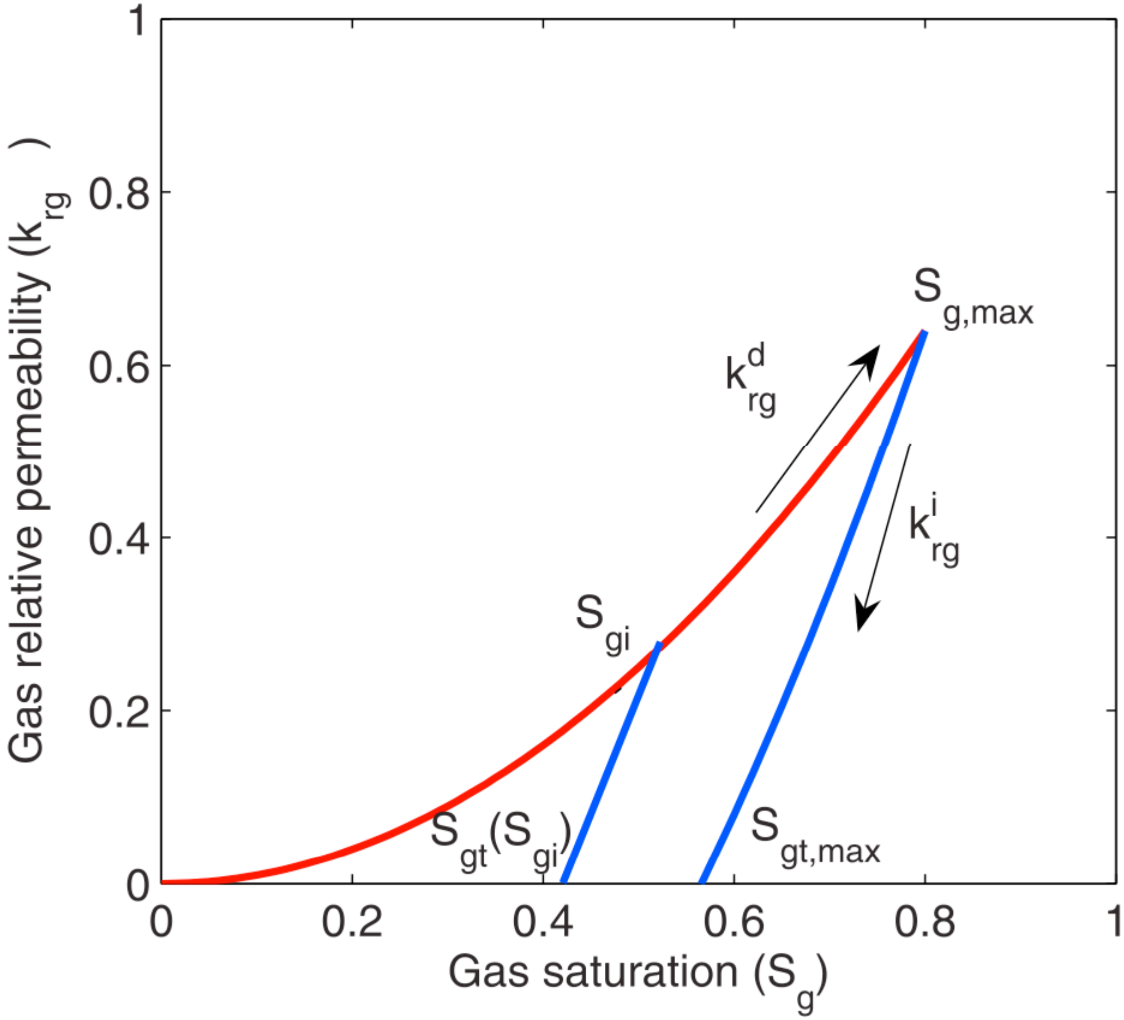
Image from Mark Knackstedt, ANU

Relative permeability



http://pangea.stanford.edu/research/bensonlab/relperm/index.html

Relative permeability hysteresis



From: Juanes, Spiteri, Orr, Blunt; Water Resources Research (2006)

“Huff and puff”

- The huff and puff process is a type of oil well stimulation which involves
  - (i) injecting CO_2 into a well,
  - (ii) shutting in the well to allow the CO_2 to dissipate and dissolve, and
  - (iii) producing the well back.
- This is normally repeated over several cycles and it can lead to increased oil recovery via removal of some productivity damage, reduced oil viscosity, increased dissolved gas content, oil swelling and vaporisation of lighter components of oil. Huff and puff operations can also suppress water production. They can significantly boost short-term oil production.

CO2CRC Otway stage 2 objective

- **Objective**
  - **To determine residual CO_2 saturation at the "field" scale**
- **Limitations**
  - **CO_2 capillary trapping needs to be separated from dissolution and migration effects.**
  - **Heterogeneity may make data analysis uncertain and non-unique, thus the test needs to be robust to heterogeneity.**
  - **Multiple complementary approaches will improve estimation.**

CO2CRC Otway stage 2 design

- **Three complimentary approaches:**

1. **Fluid cycling → history match pressure and flow rate data**
2. **Partitioning tracer test → concentration data**
3. **Repeat borehole logging → thermal and/or other log**

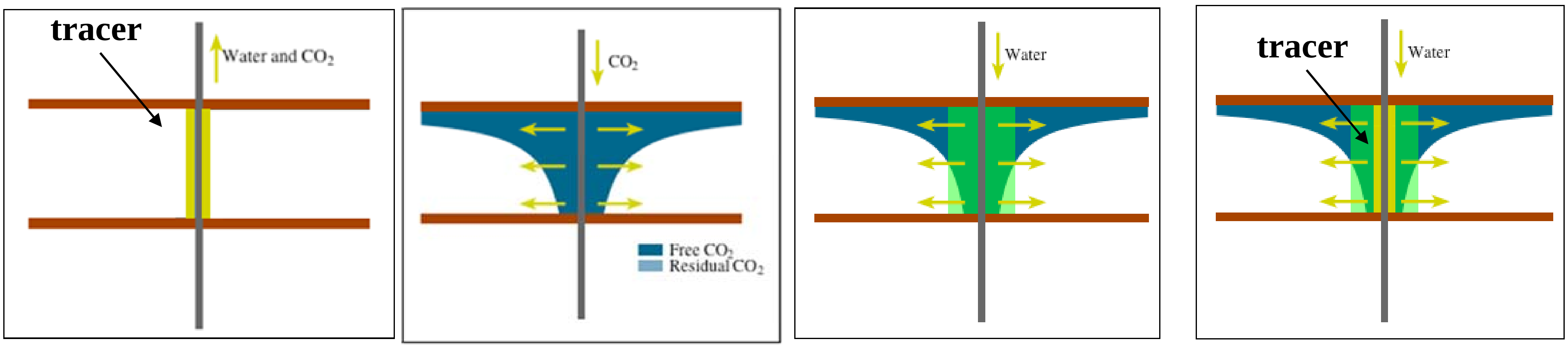
Injection design 1 strategy

Water test 1 (pre CO_2) for 1d (50 t)

CO_2/CH_4 injection for 2 days (300 t)

Water injection (120 t)

Water test 2 (post CO_2) for 1d (50 t)



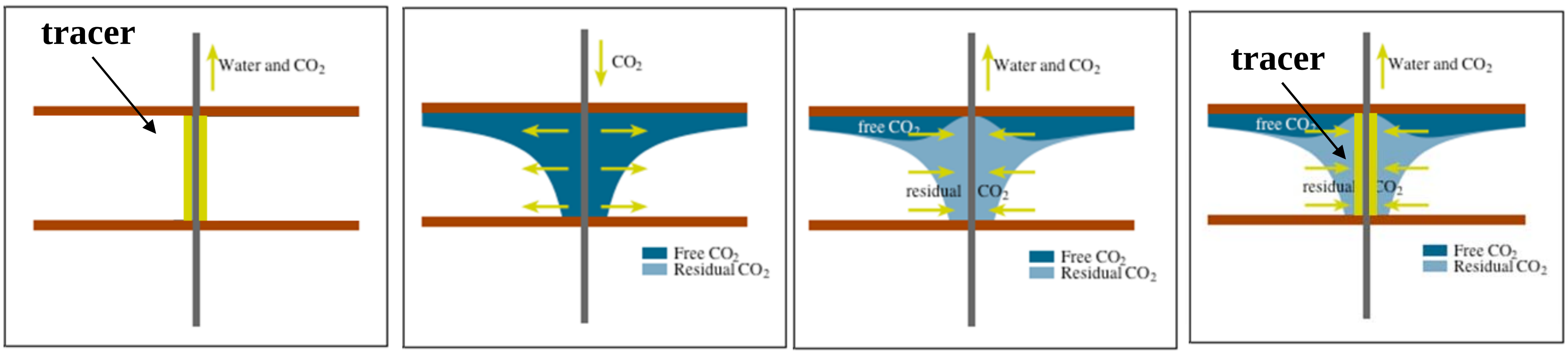
Injection design 2 strategy

Water test 1 (pre CO_2) for 1d

CO_2/CH_4 injection for 2 days

Production for 9 days

Water test 2 (post CO_2) for 1d



Reservoir and fluid definition

- **Parameters used in simulations:**
  - **Injected gas composition 90% wt CO_2 and 10% wt CH_4**
  - **Original and injected brine (where used) salinity of 2000 ppm**
  - **Pressure: initially at hydrostatic equilibrium at 14.2 MPa**
  - **Temperature: 63 C**
  - **Hysteretic relative permeabilities**

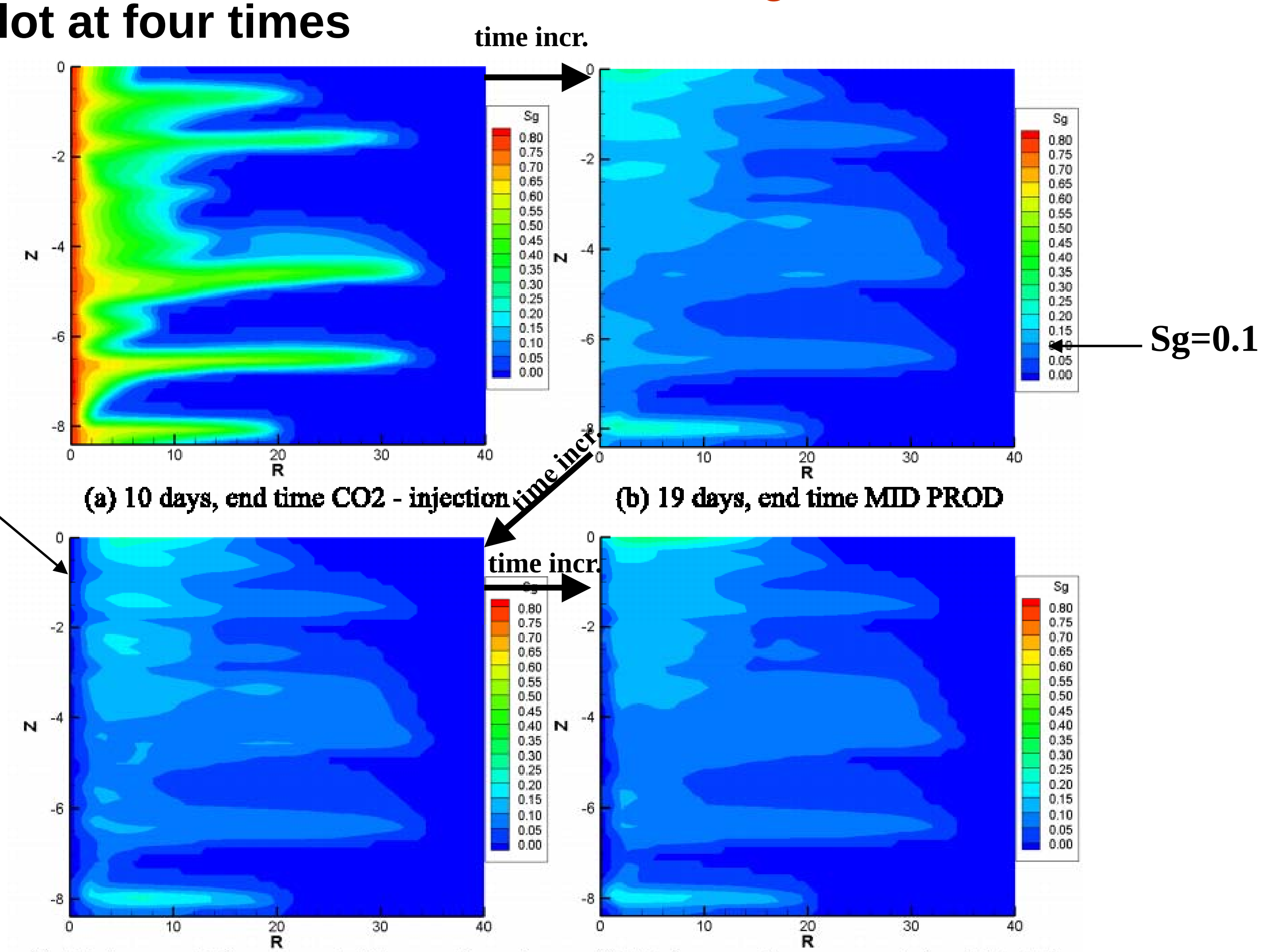
Reservoir definition

- Zone 1 consists of a series 10 alternating distinct shale and sand sub-zones.
- Sub-zone 6 from 1487 m to 1495 m is a thick sandstone layer being considered for the test, with shale seals above and below.
  - The shale layers have very low permeability and high entry capillary pressure.
- All of the 8 m thick reservoir layer is perforated in the completion.
- Permeability up to 5 darcy in the layer.

Results Design 2 – S_{gr}= 0.1

- **Contour plot at four times**

Injected water dissolves gas partially



(a) 10 days, end time CO2 - injection

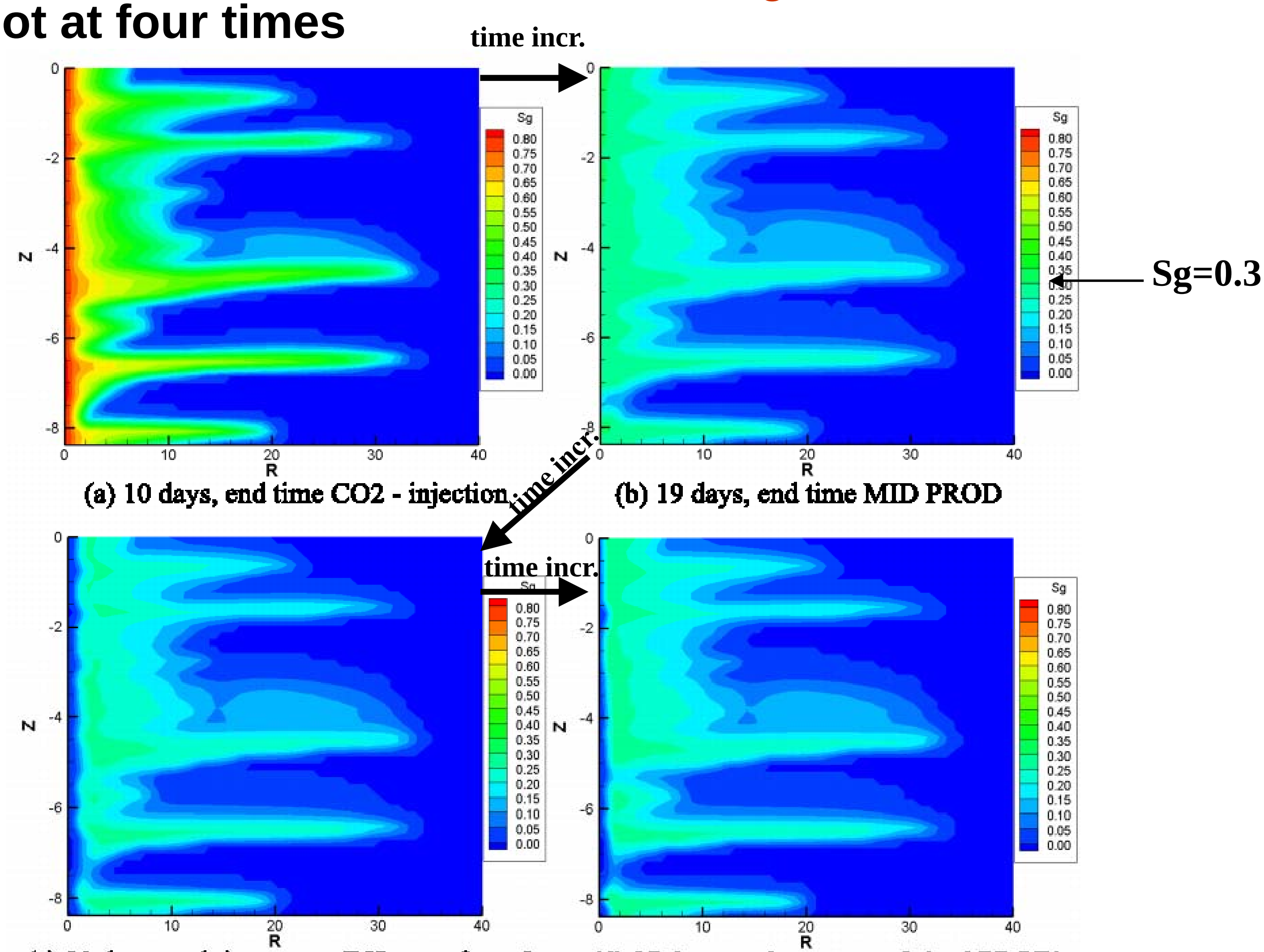
(b) 19 days, end time MID PROD

(c) 20 days, end time water INJ part of test 2

(d) 27 days, end water test 2 (end PROD)

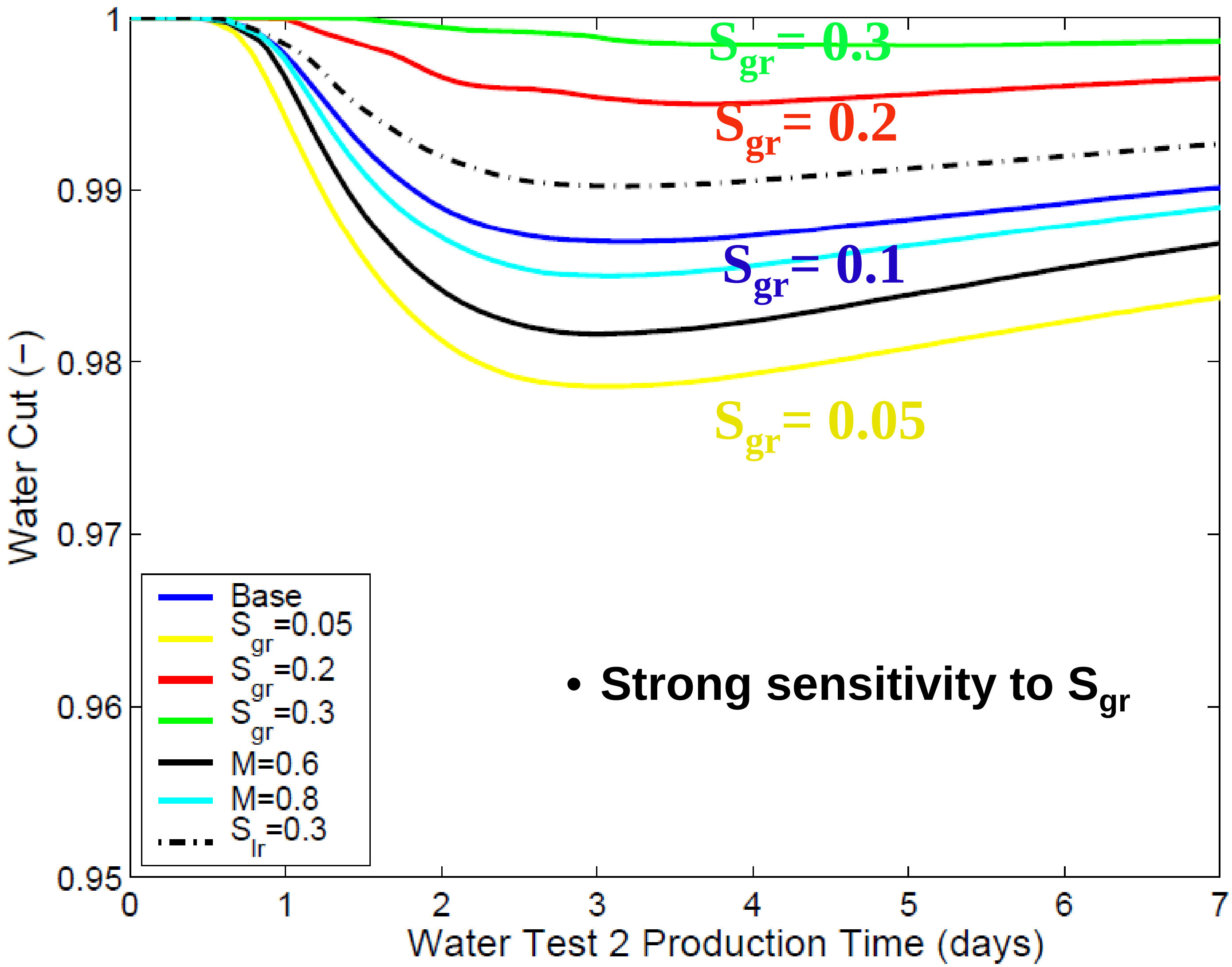
Results Design 2 – S_{gr}= 0.3

- **Contour plot at four times**

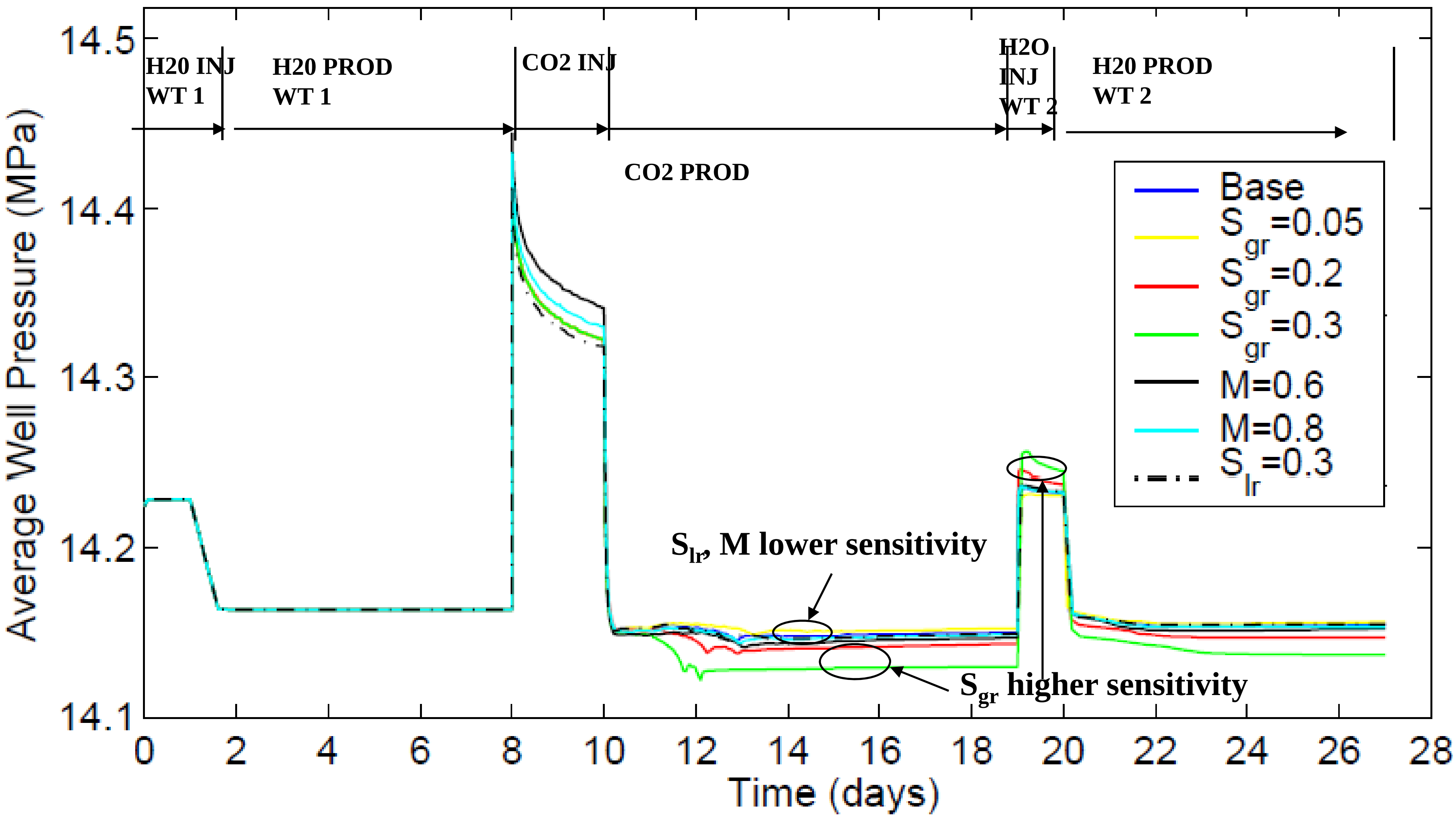


(a) 10 days, end time CO2 - injection
(b) 19 days, end time MID PROD
(c) 20 days, end time water INJ part of test 2
(d) 27 days, end water test 2 (end PROD)

Water production fraction - Design 2



Average well pressure - Design 2



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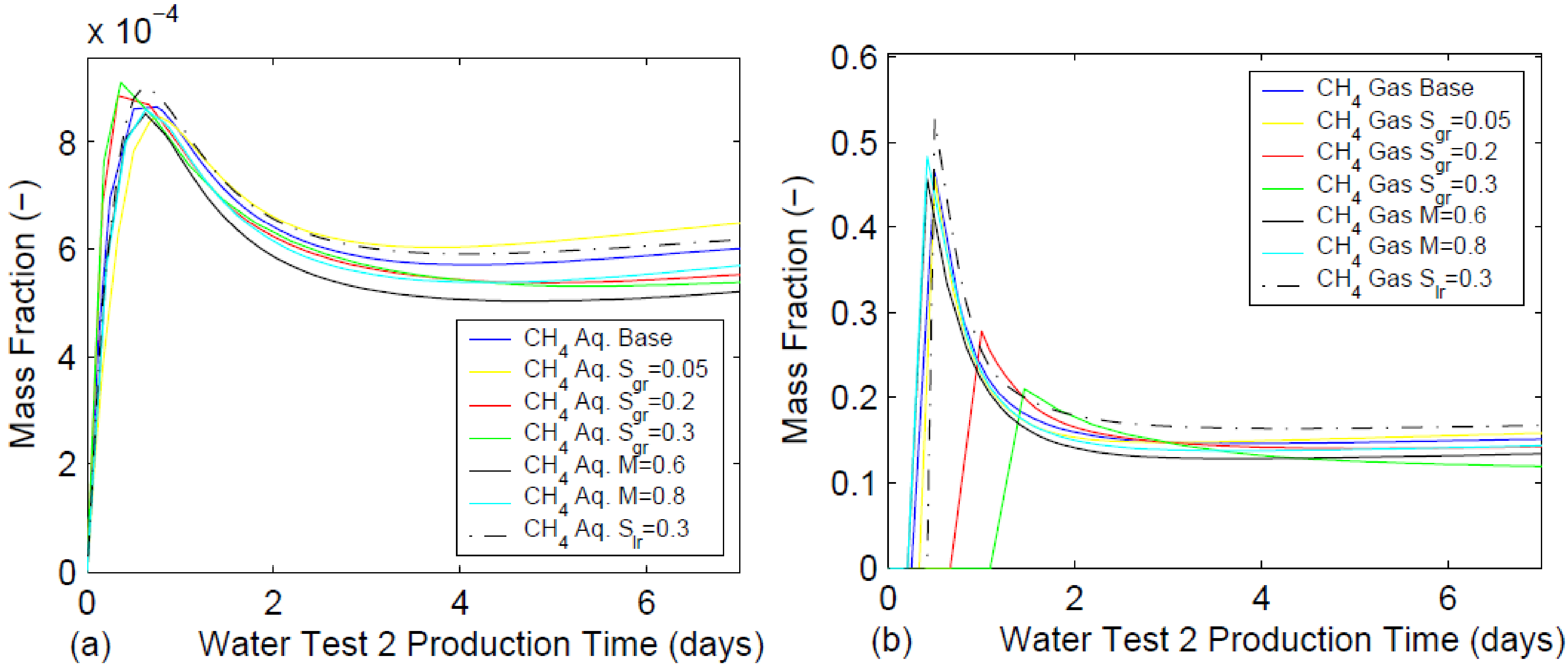
CH_4 during production - Design 2



- **Methane concentrated due to lower solubility**
  - **Reasonable sensitivity to S_{gr}.**

CSIRO

CO2CRC

Conclusions

- Huff-push-pull tests can be used to study residual capillary trapping as a dominant trapping mechanism.
- Two injection/production designs have been studied
  - Design 1: Water injection pushes CO_2 only.
  - Design 2: Produce CO_2 and water after injection.
- Design 2 gives history matching that is more robust to heterogeneity.
- Further testing against additional heterogeneity scenarios is currently being undertaken.

Conclusions

- **Three independent measurement approaches to determining residual trapping give increased confidence that the test will work:**
  - **History match injection and production**
  - **Tracer partitioning**
  - **Repeat borehole logging**
- **If successful, similar small-scale tests could be used at commercial injection sites to reduce uncertainty and risk.**