Statistical Analysis of CO_2 Exposed Wells to Predict Long Term Leakage through the Development of an Integrated Neural-Genetic Algorithm

Project DE FE0009284

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U.S. Department of Energy

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Carbon Storage R&D Project Review Meeting
Developing the Technologies and
Infrastructure for CCS

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Presentation Outline

- Benefits to DOE Program
- Project Overview
- Technical Status
- Accomplishments to Date
- Summary

Benefit to DOE Program

The project conducts research under DOE's *Fossil Energy Research and Development* Area of Interest 1, Studies of Existing Wellbores Exposed to CO_2.

The project performs analysis of available industry data to assess risks of well failure by various factors such as age of construction, region, construction materials, incident reports, logging and Mechanical Integrity Testing.

The computer models developed in this project will contribute to the DOE programs' effort of ensuring 99% CO_2 storage permanence in the injection zone(s) for 1000 years and support the development of Best Practices Manual.

Project Overview
Goals and Objectives

The overall objective of this project is the development of a novel computer model for predicting long-term leakage risks of **wells** exposed to CO_2.

The final goal is to deliver DOE and public a useful tool for evaluating the risk of long-term leakage of **wells** in future CO_2 sequestration projects.

Technical Status

- ✓ Understanding the problem
- ✓ Assessment of well conditions
- ✓ Mechanics modeling of wellbore conditions
- ✓ Identification of leak scenarios
- ➢ Prediction of leakage by Integrated Neural-Genetic Algorithm

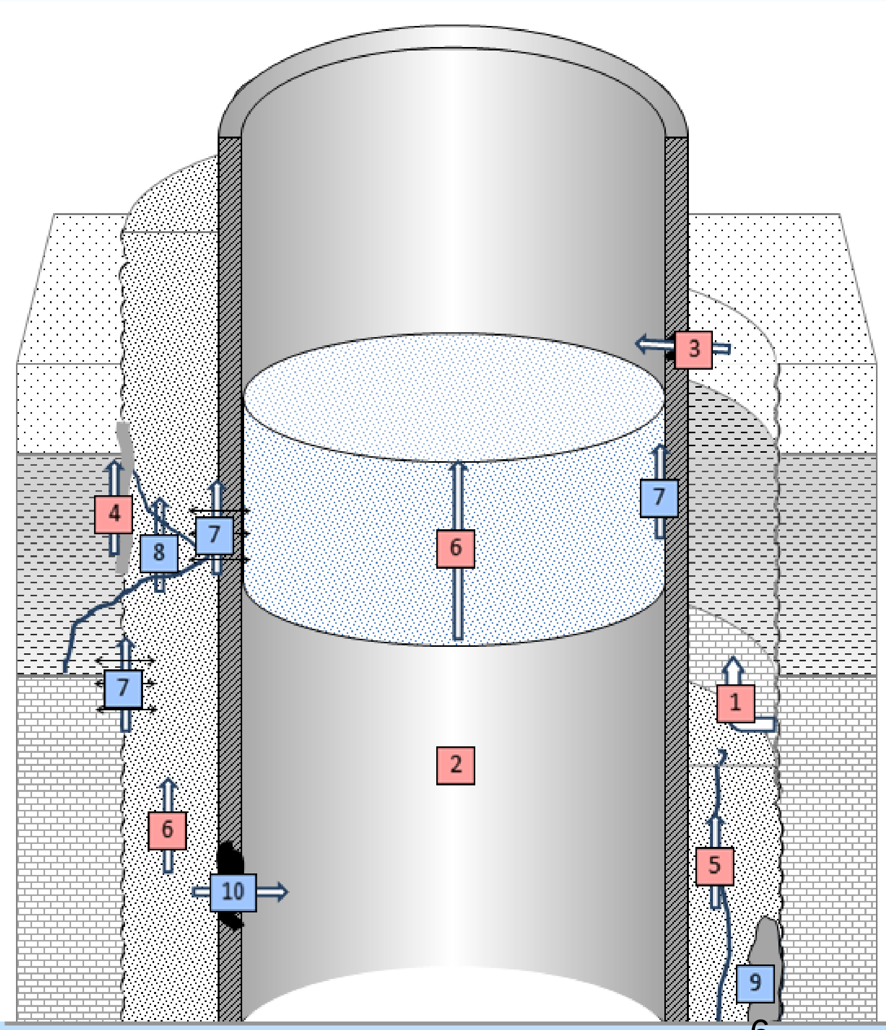
Understanding the Problem

PRIMARY

1. Incomplete annular cementing job, doesn't reach seal layer
2. Lack of cement plug or permanent packer
3. Failure of the casing by burst or collapse
4. Poor bonding caused by mudcake
5. Channeling in the cement
6. Primary permeability in cement sheath or cement plug

SECONDARY

7. De-bonding due to tensile stress on casing-cement-formation boundaries
8. Fractures in cement and formation
9. Chemical dissolution and carbonation of cement
10. Wear or corrosion of the casing

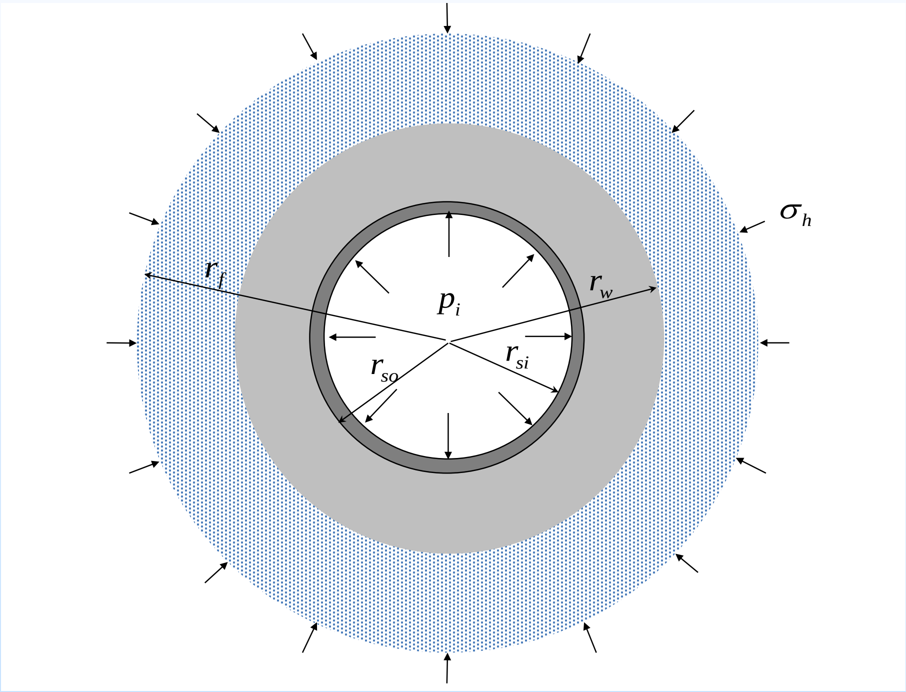


Assessment of Well Conditions

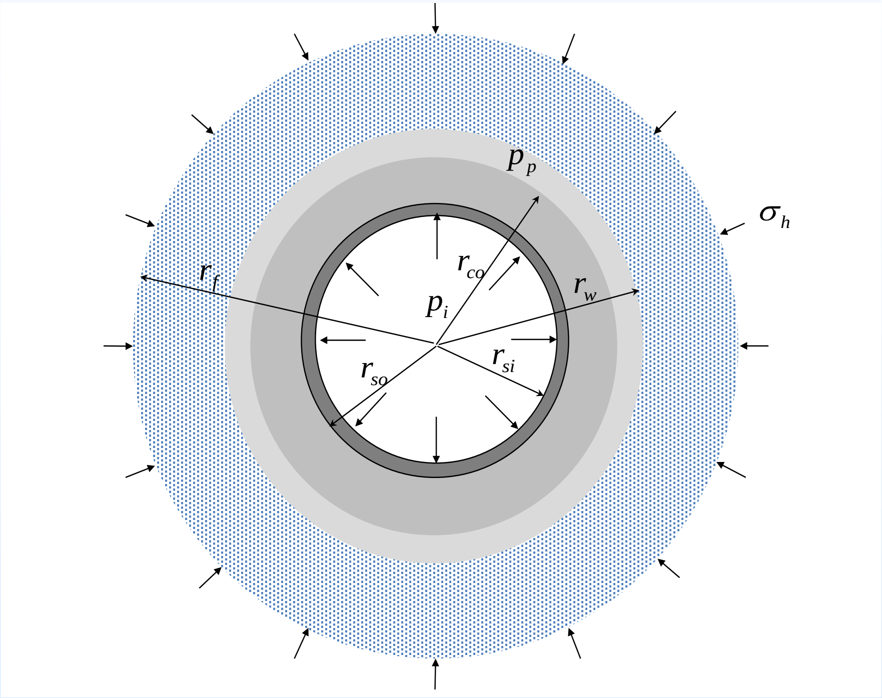
- Well history data
- Well design data
- Well operation data
- Leak potential analysis

  - Maximum Permissible Pressure (MaxPP)
  - Minimum Permissible Pressure (MinPP)

- Maximum Permissible Pressure (MaxPP)
- Minimum Permissible Pressure (MinPP)



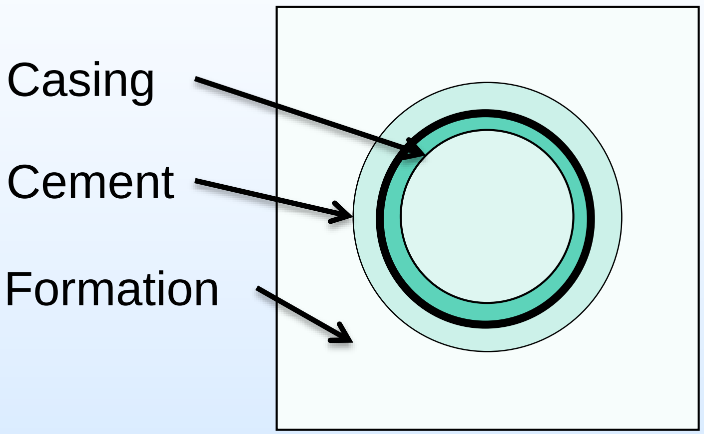
Perfect Cement Collar



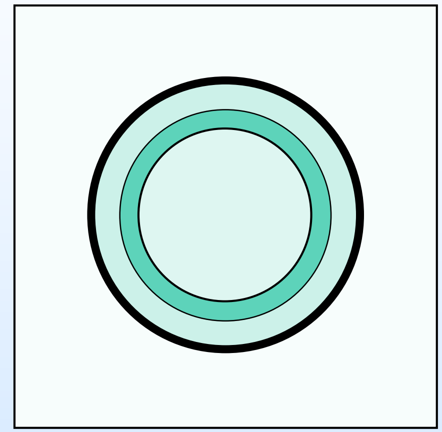
Imperfect Cement Collar

Mechanics Modeling of Wellbore Conditions

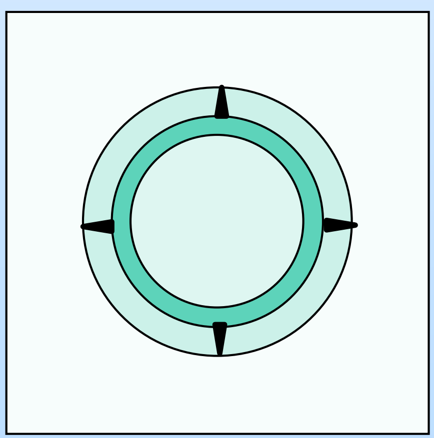
De-Bonding at Casing-Cement Interface



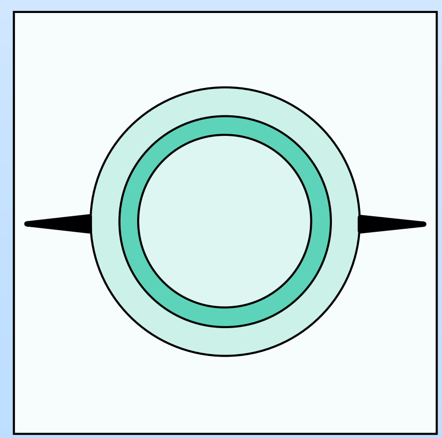
De-Bonding at Cement-Formation Interface

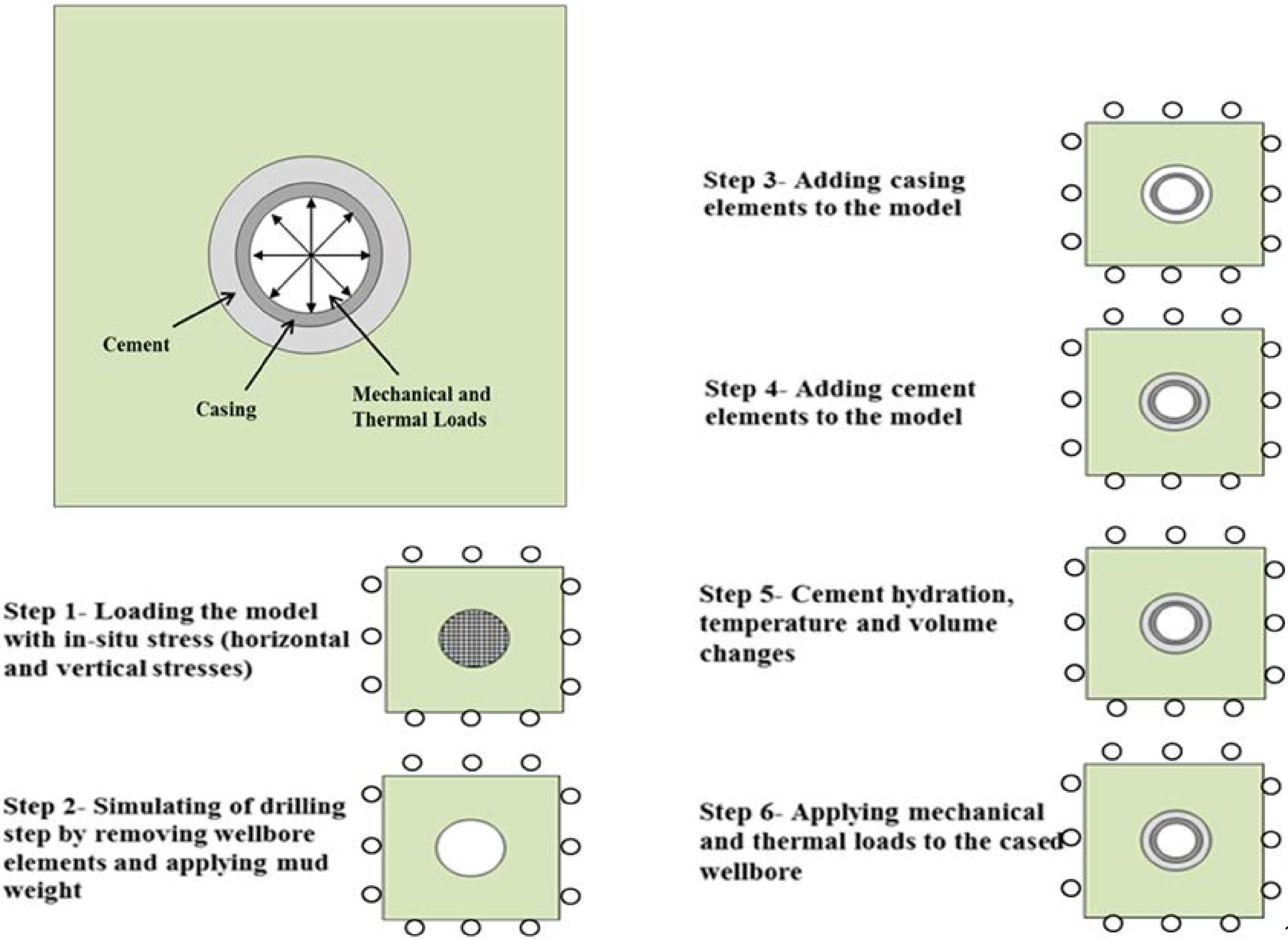


Radial Fractures in Cement Sheath



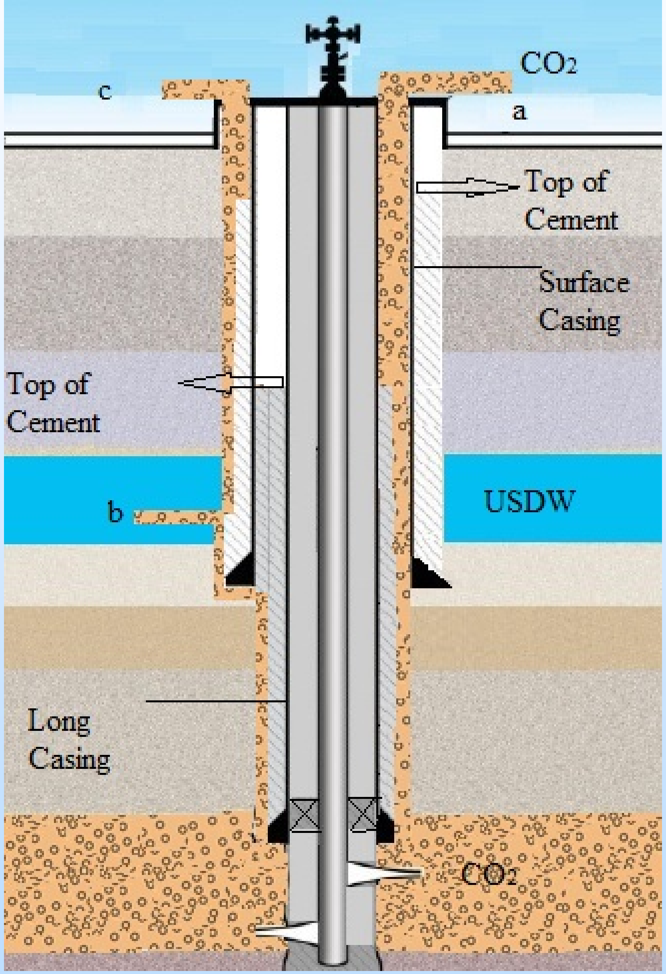
Radial Fractures in Formation




Cement
Casing
Mechanical and
Thermal Loads
Step 1- Loading the model with in-situ stress (horizontal and vertical stresses)
Step 2- Simulating of drilling step by removing wellbore elements and applying mud weight
Step 3- Adding casing elements to the model
Step 4- Adding cement elements to the model
Step 5- Cement hydration, temperature and volume changes
Step 6- Applying mechanical and thermal loads to the cased wellbore

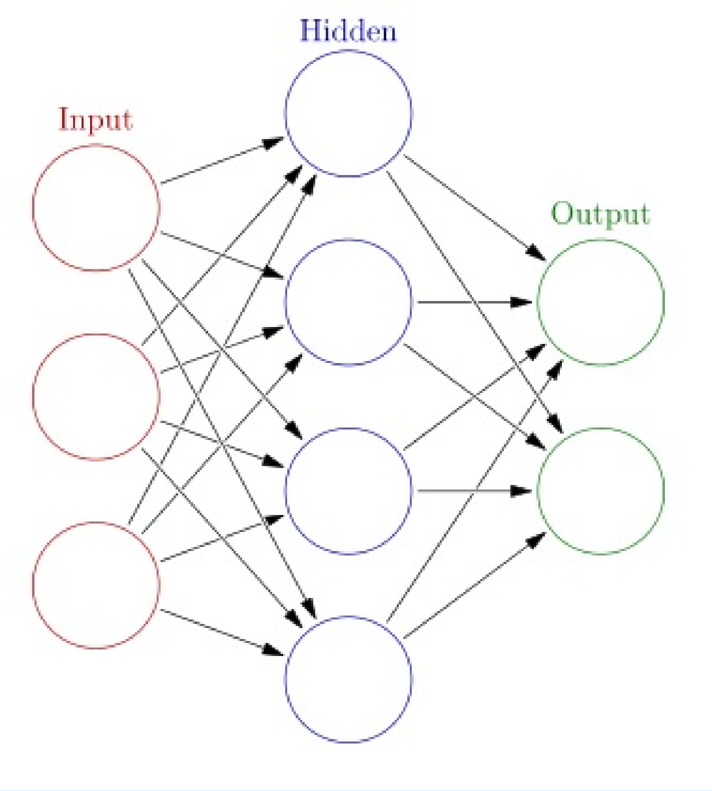
Identification of Leak Scenarios

- Cement properties
- Cement shrinkage
- Injection and shut in of wells
- Initial cement placement operations
- Cement degradation



Prediction of Leakage by Integrated Neural-Genetic Algorithm

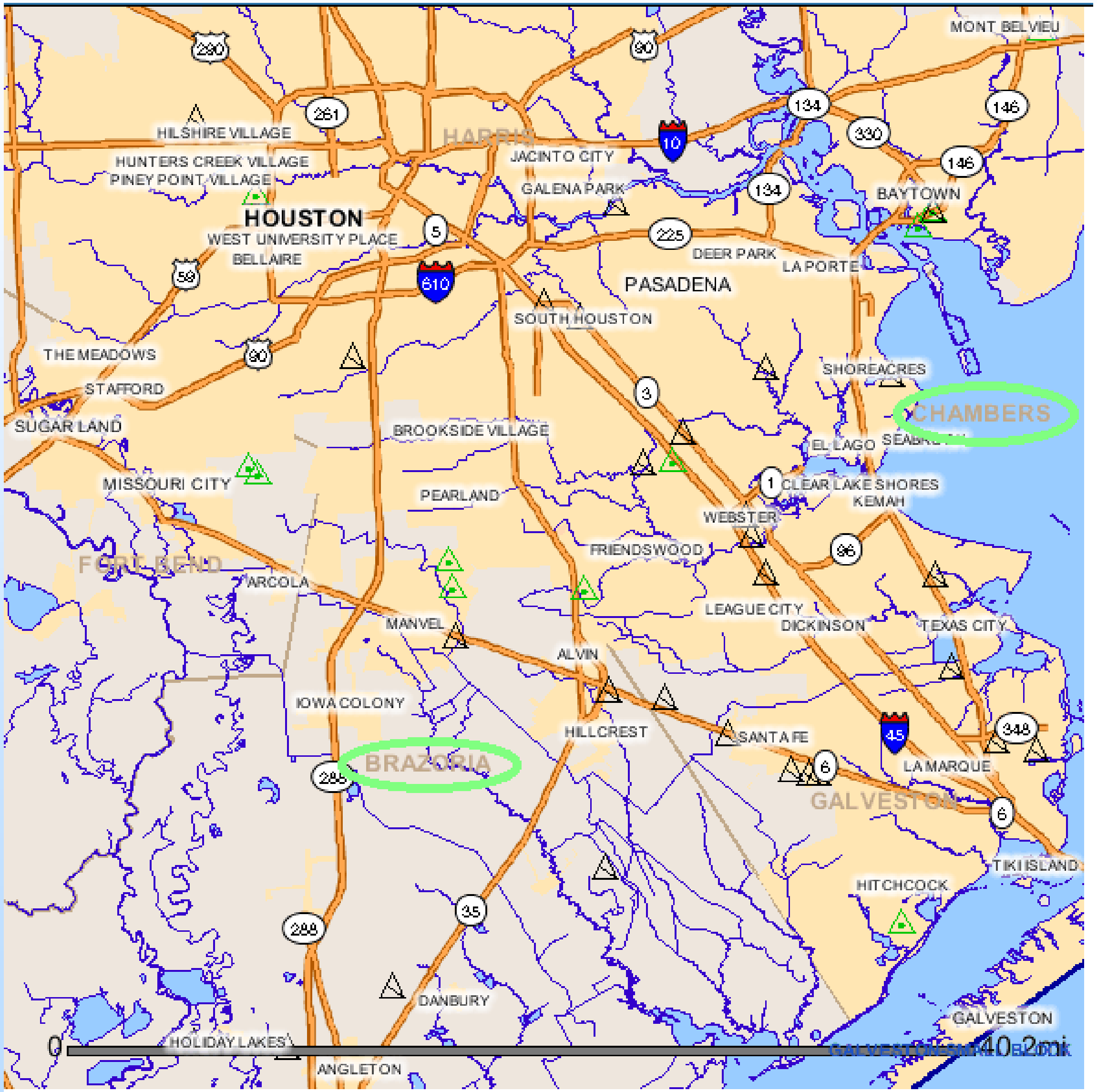
- Model construction has been completed
- Model training and validation is in progress
- Prediction with the model is planned



Accomplishments to Date

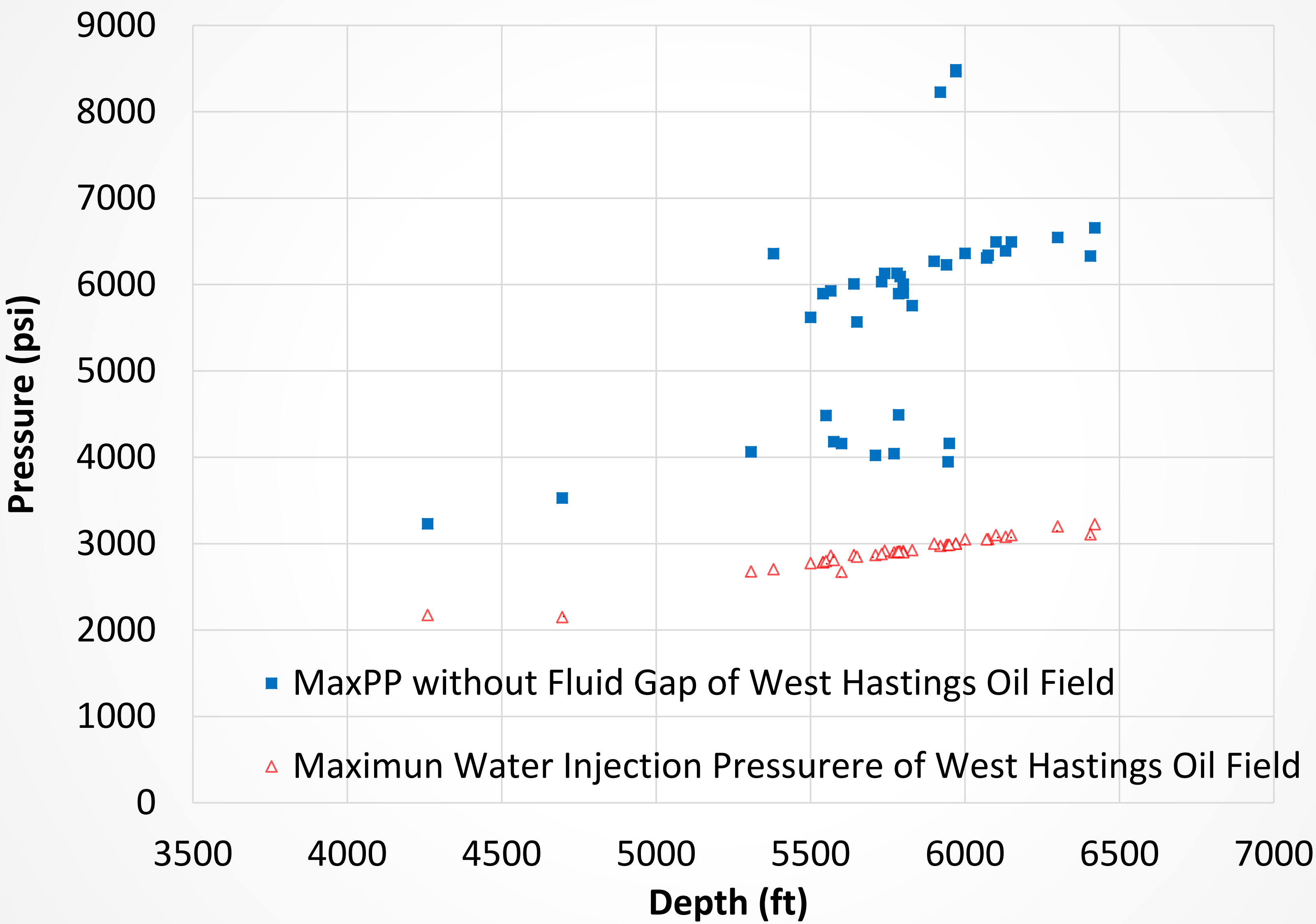
- ✓ Data mining
- ✓ Assessment of well conditions
- ✓ Identification of leak scenarios with mechanics model
- ✓ Test site selection
- ✓ Development of Integrated Neural-Genetic Algorithm

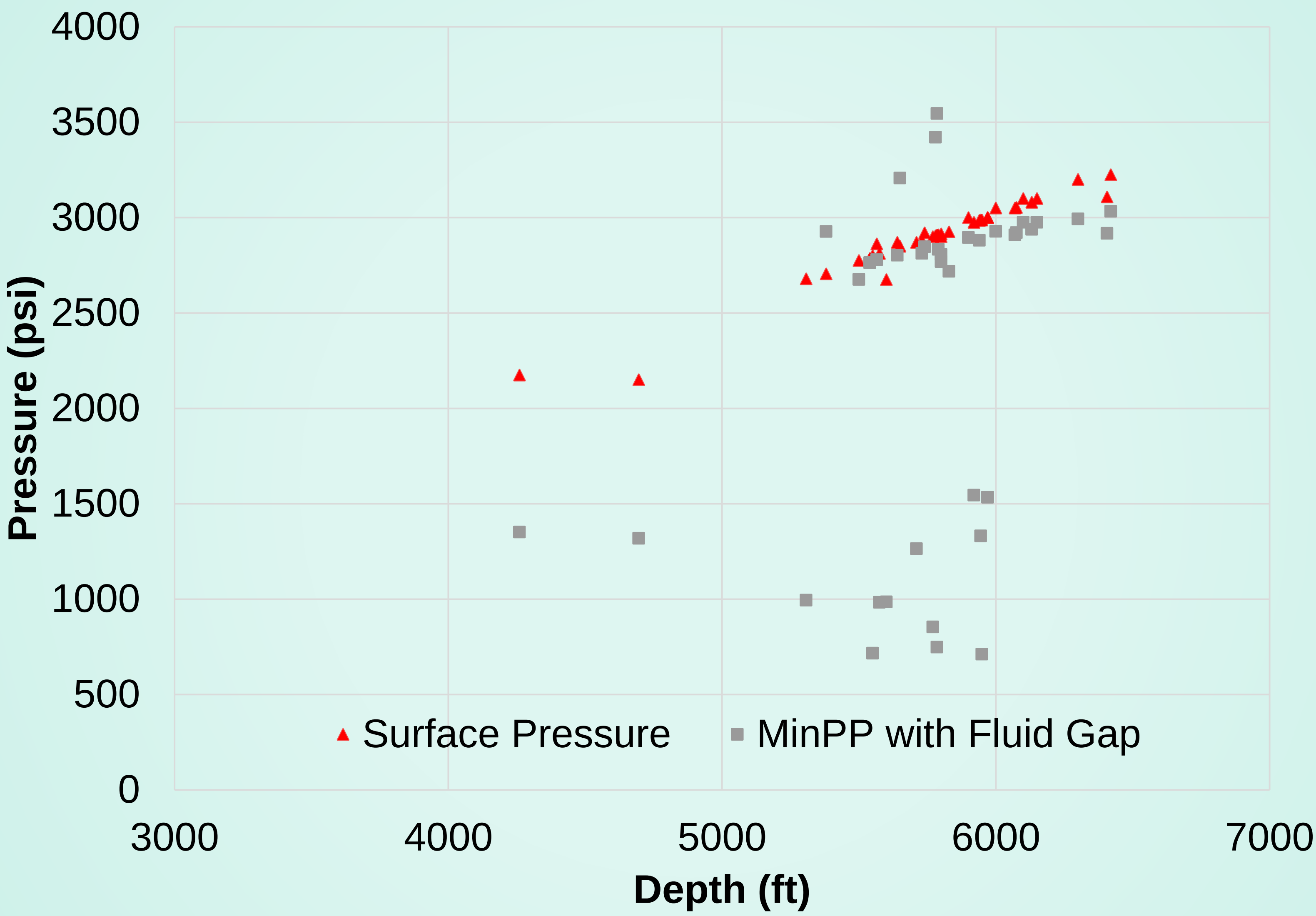
Data Mining in the Texas Gulf Coast Region



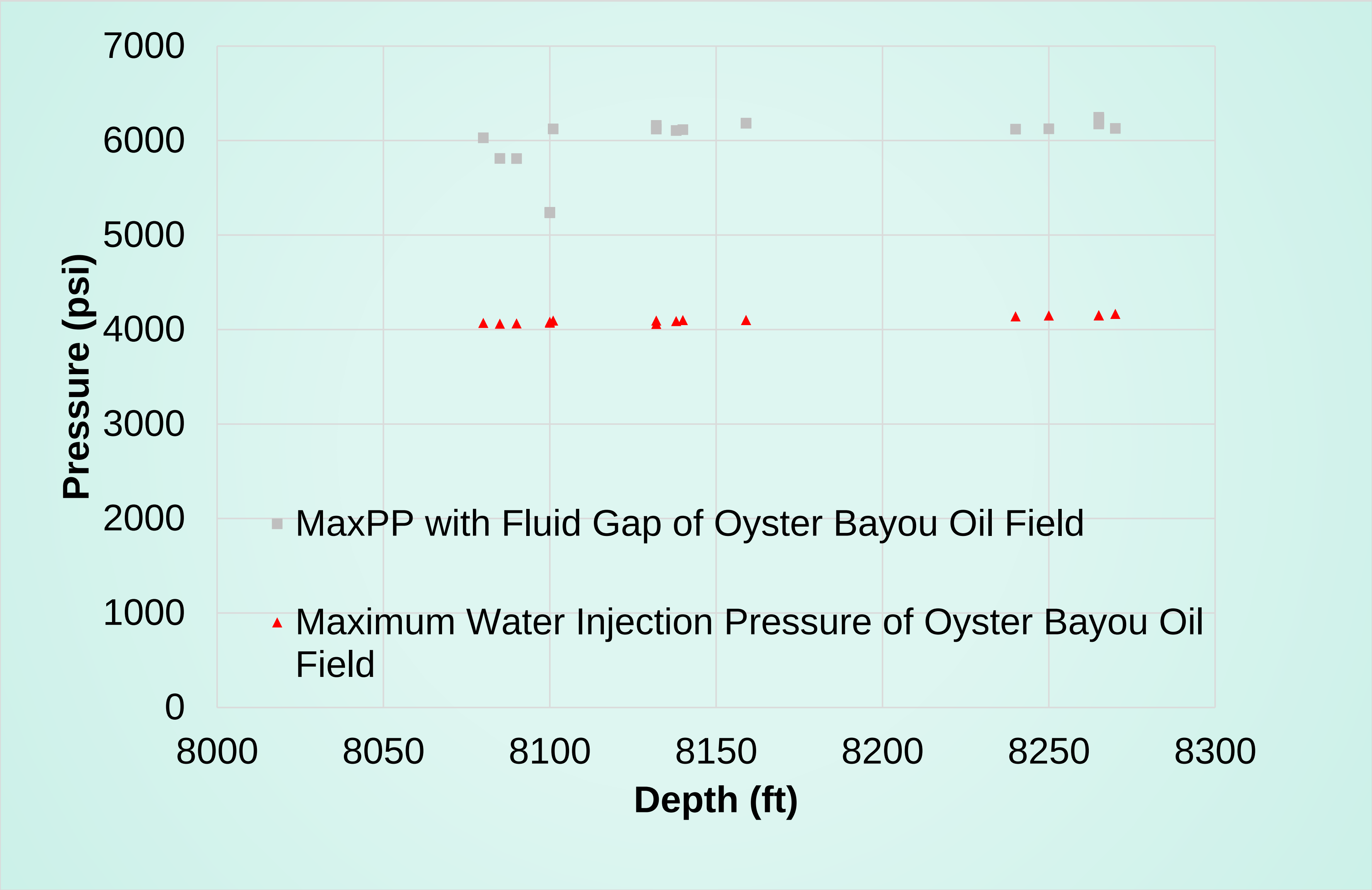
- West Hastings and Oyster Bayou oil fields, Texas.
- 510 CO_2-exposed wells.
- Data base established

Assessment of Well Conditions





Pressure (psi)
4000
3500
3000
2500
2000
1500
1000
500
0
3000
4000
5000
6000
7000
Depth (ft)
Surface Pressure
MinPP with Fluid Gap

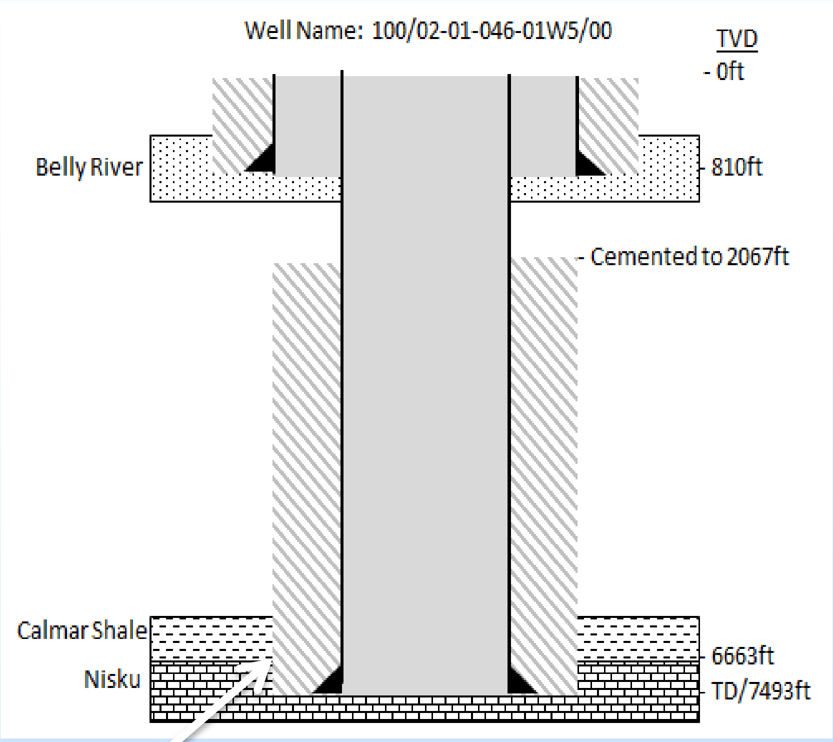

7000
6000
5000
4000
3000
2000
1000
0
Pressure (psi)
8000
8050
8100
8150
8200
8250
8300
Depth (ft)
MaxPP with Fluid Gap of Oyster Bayou Oil Field
Maximum Water Injection Pressure of Oyster Bayou Oil Field

Group No.	Criteria One	Criteria Two	Safety Indicator
1	S-Csg< H_2O-zone	Cement Top>H_2O-zone	0
2	S-Csg< H_2O-zone	Cement Top<H_2O-zone	1
3	S-Csg> H_2O-zone	Cement Top>H_2O-zone	2
4	S-Csg> H_2O-zone	Cement Top<H_2O-zone	3

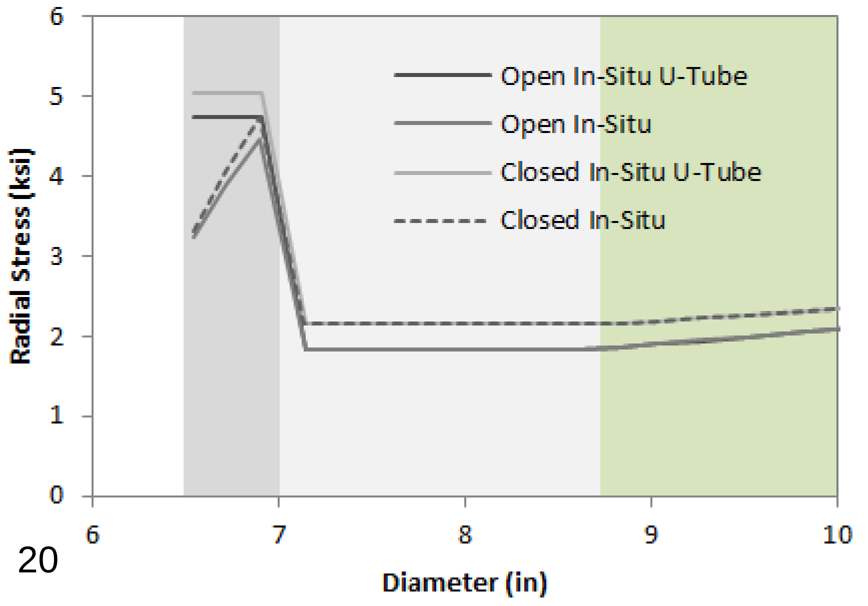
Field	Group 1	Group 2	Group 3	Group 4	Total
Oyster Bayou	0	0	16	4	20
West Hasting	23	0	4	12	39

Identification of Leak Scenarios with Mechanics Model

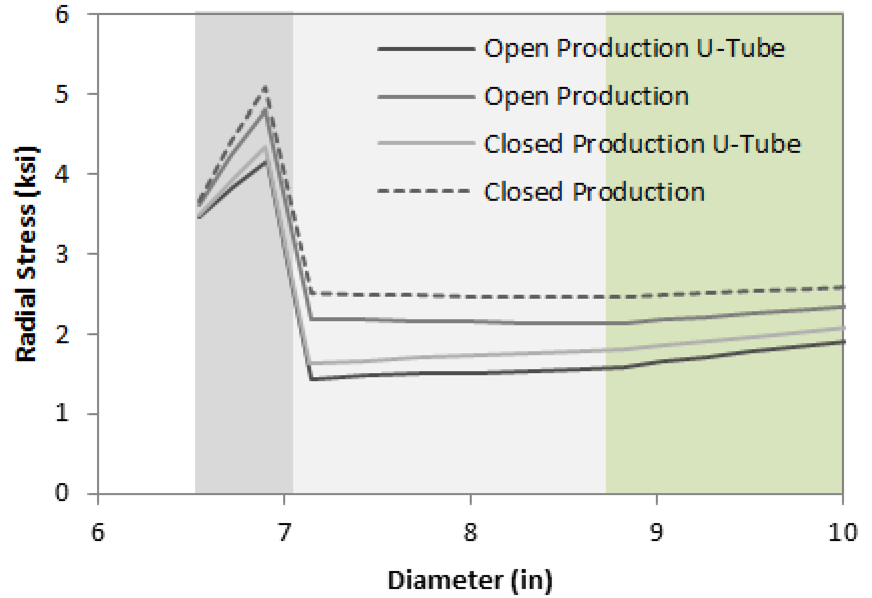
- Long Term Analysis
  - 4 Scenarios
    - In-Situ Stress Conditions
    - Production Conditions
    - Depletion Conditions
    - Injection Conditions
  - 2 Initial Wellbore Pressures
    - Hydrostatic and U-tube
  - Point of interest is production casing at bottom of sealing formation



- In-Situ Stress Conditions
  - Based on cement annular pressure (open vs closed)
  - Based on formation in-situ stresses
  - Based on internal casing pressure (hydrostatic vs U-tube)
  - Overall no failure

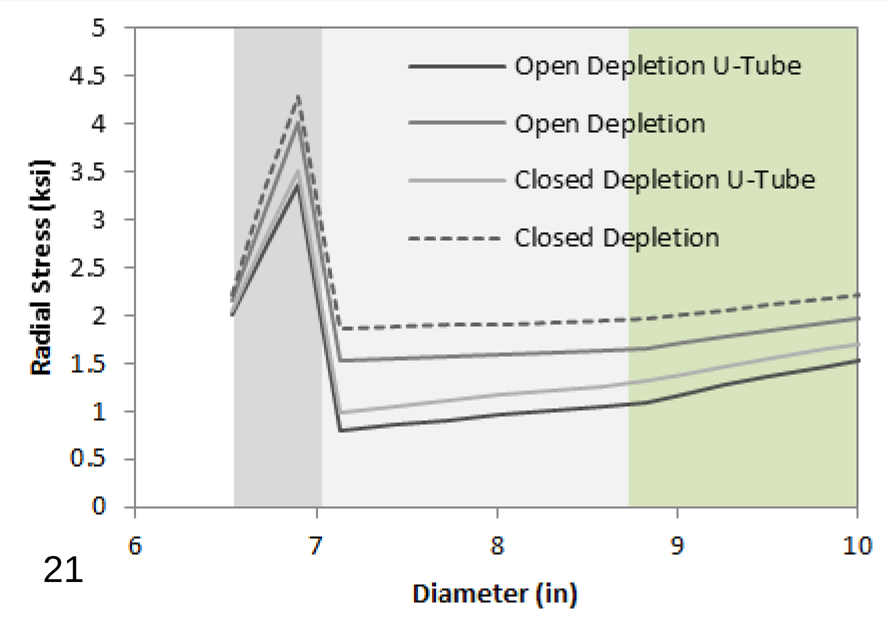


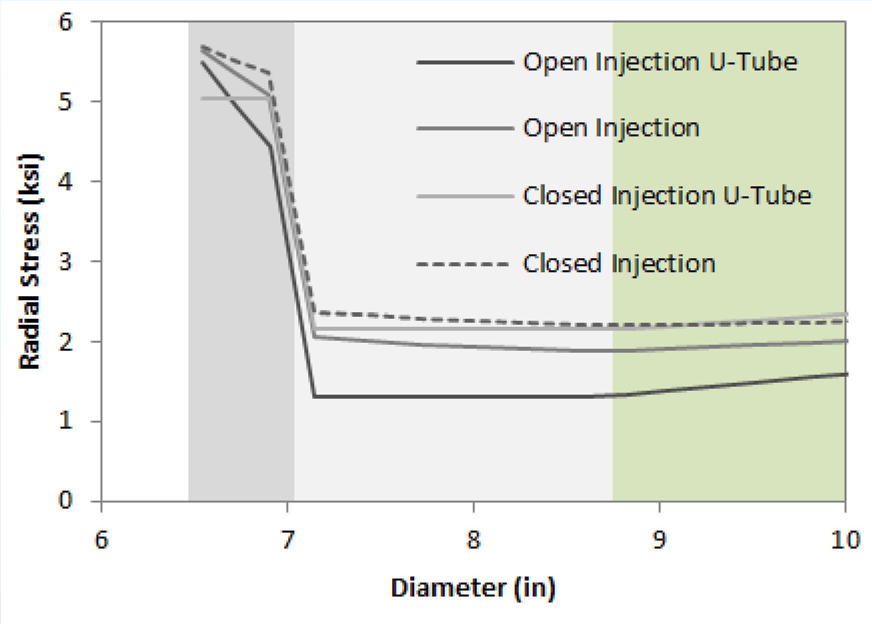
- Production Conditions
  - For gas well pressure equals reservoir pressure
  - Temperature equals reservoir temperature
  - Open U-tube shows greater potential for radial de-bonding
  - Open hydrostatic shows greater potential for tensile fracturing
  - Overall no failure



- Depletion Conditions
  - For gas well pressure equals half reservoir pressure
  - Temperature equals reservoir temperature
  - U-tube scenarios are at greater potential of radial de-bonding
  - Overall no failure

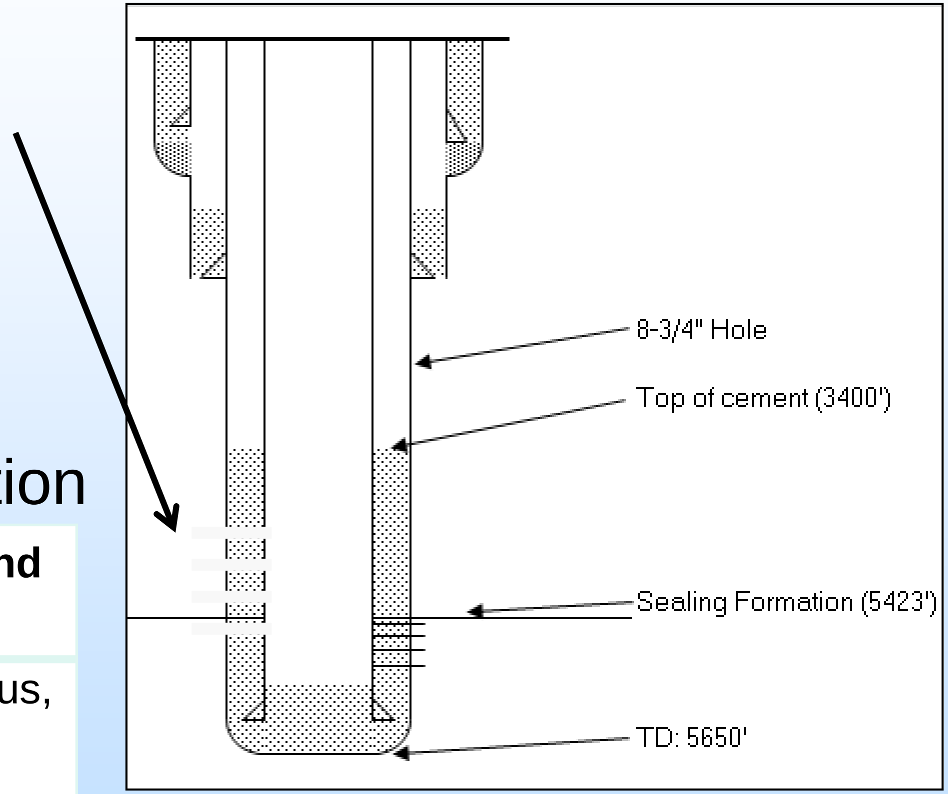
- Injection Conditions
  - Injection temperature change 51°C or 92°F decrease
  - 20MPa or 2.9ksi injection pressure increase above hydrostatic
  - Open annulus U-tube is at the greatest potential of de-bonding
  - Open hydrostatic is at the greatest potential of tensile failure
  - Overall no failure





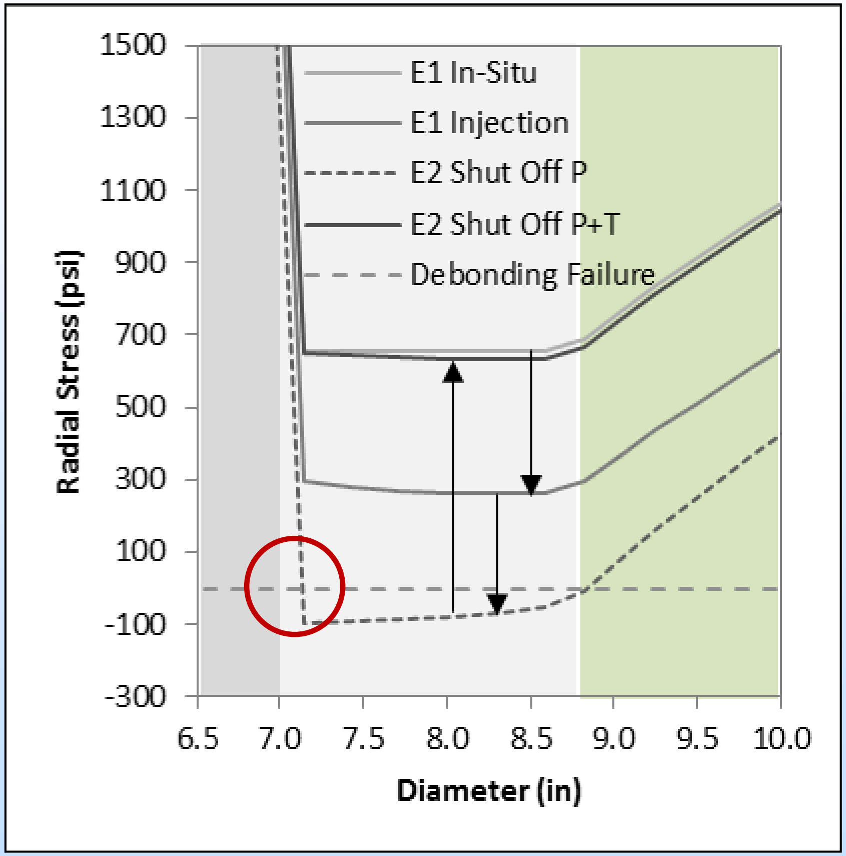
Potential CO_2 Field Case Study

- Actual Injection Well (Schlumberger Carbon Services)
- Cores gathered along the production section
- Lab samples made to replicate cement composition

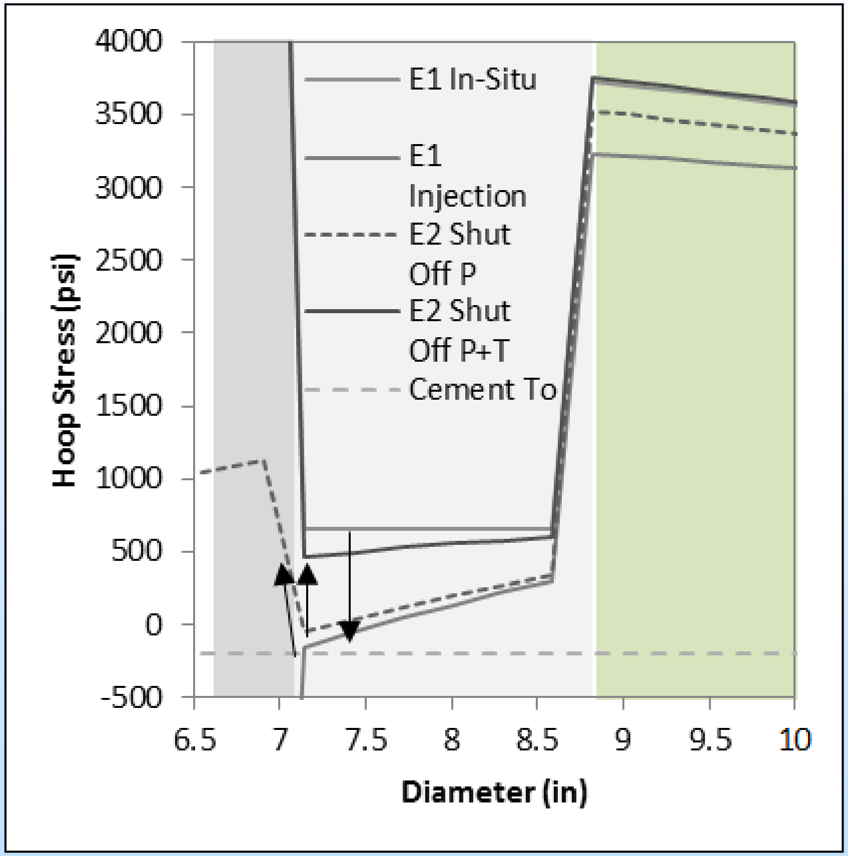


Cement Mechanical Properties Before and After CO_2 Degradation		
	Poisson's Ratio, *v*	Young's Modulus, E (10^6 psi)
Lab Samples	0.27	1.78
Aged Cores	0.28	1.245

Radial Stress



Hoop Stress



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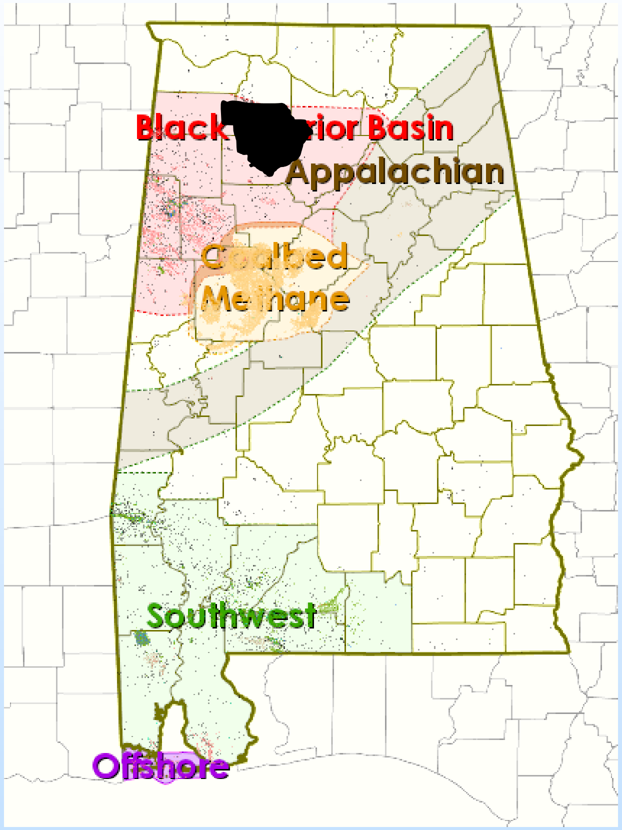
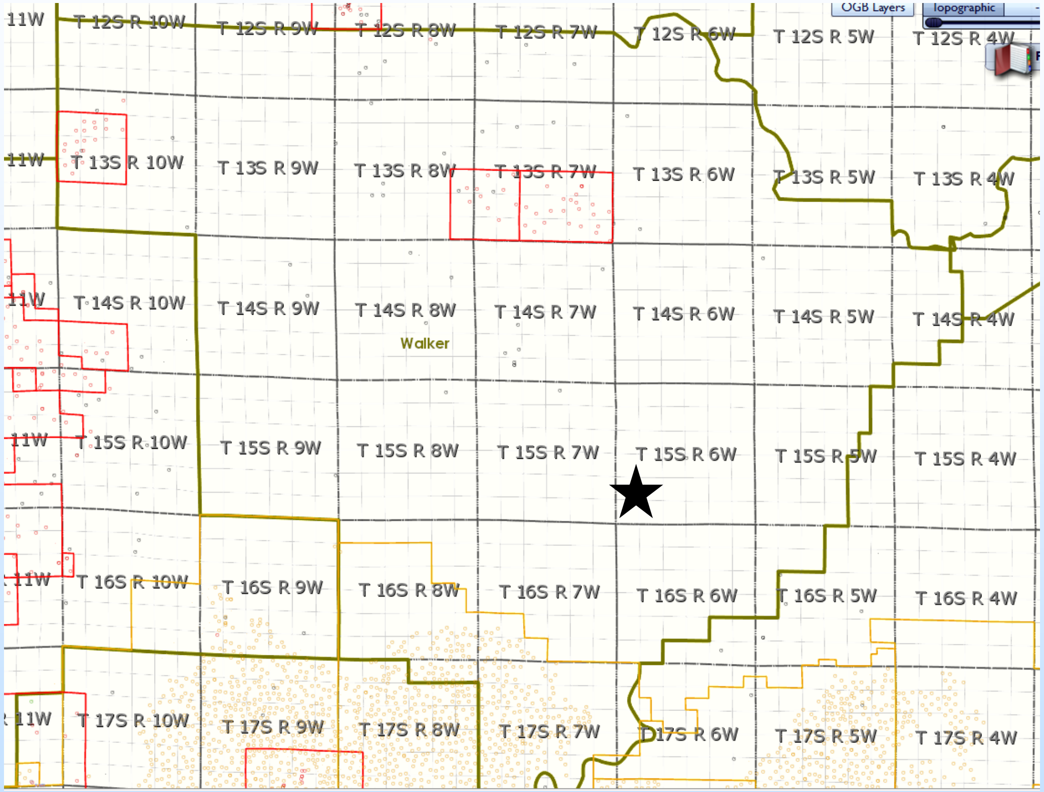
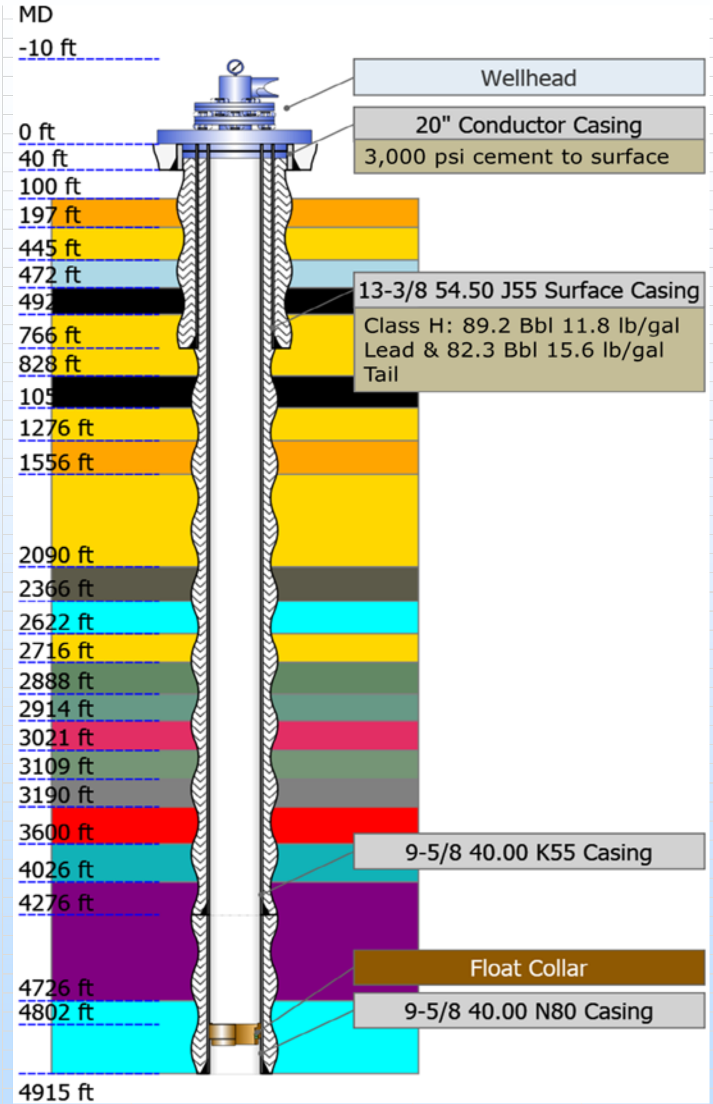
Test Site Selection





- Gorgas #1 Well, Walker County, Alabama
- Proximity to oil and gas wells will allow the testing of algorithms developed

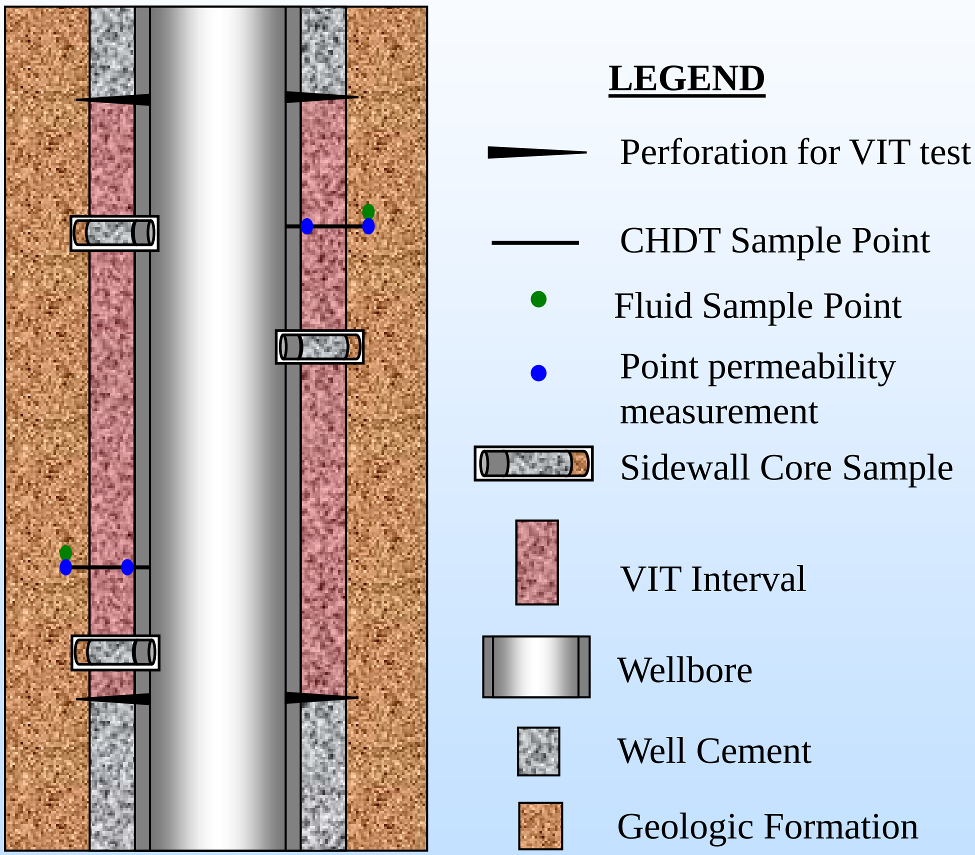


- DOE-NETL funded characterization well used for " Site Characterization for CO_2 Storage from Coal-fired Power Facilities in the Black Warrior Basin of Alabama" (DE FE0001910)
  - Collaboration with other DOE NETL projects
  - Well characterized allowing us to focus our resources on collecting well integrity data

Potential Tools for Data Collection

- Logging Tools
- Isolation Scanner* cement evaluation service
- Sonic Scanner* acoustic scanning platform
- SCMT* slim cement mapping tool

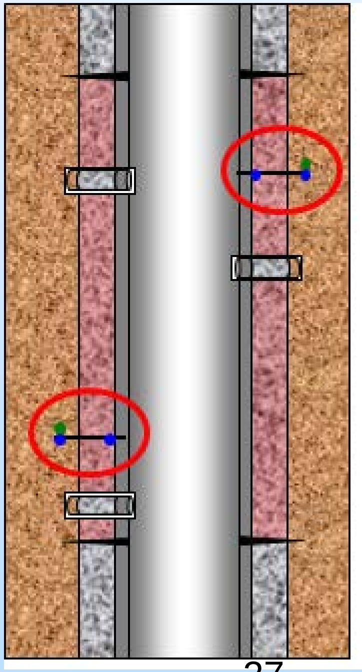
- Testing and Sampling Tools
- CHDT* cased hole dynamics tester
- MDT* modular formation dynamics tester
- MSCT* mechanical sidewall coring tool



Well Sampling and Point Permeability Measurement – CHDT

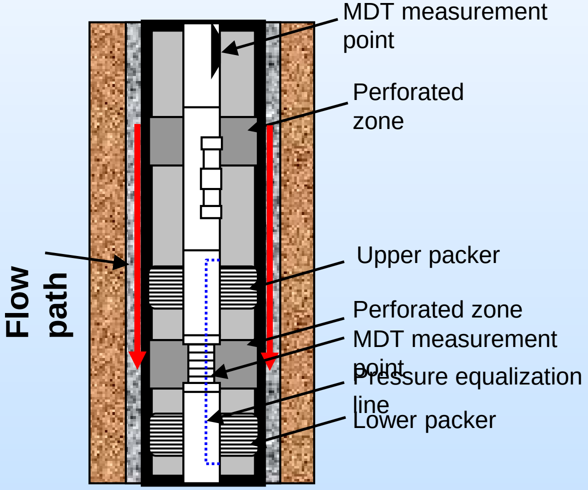
O-ring Seal

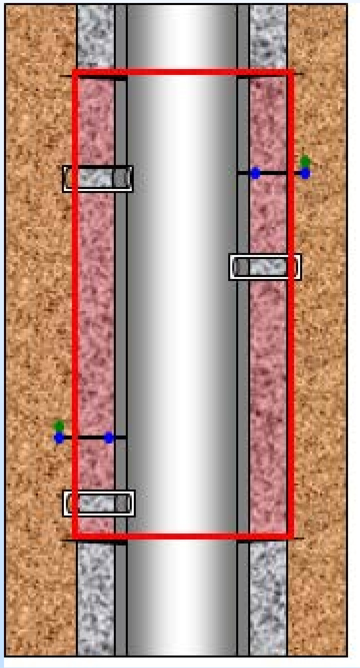
7mm Drill Bit



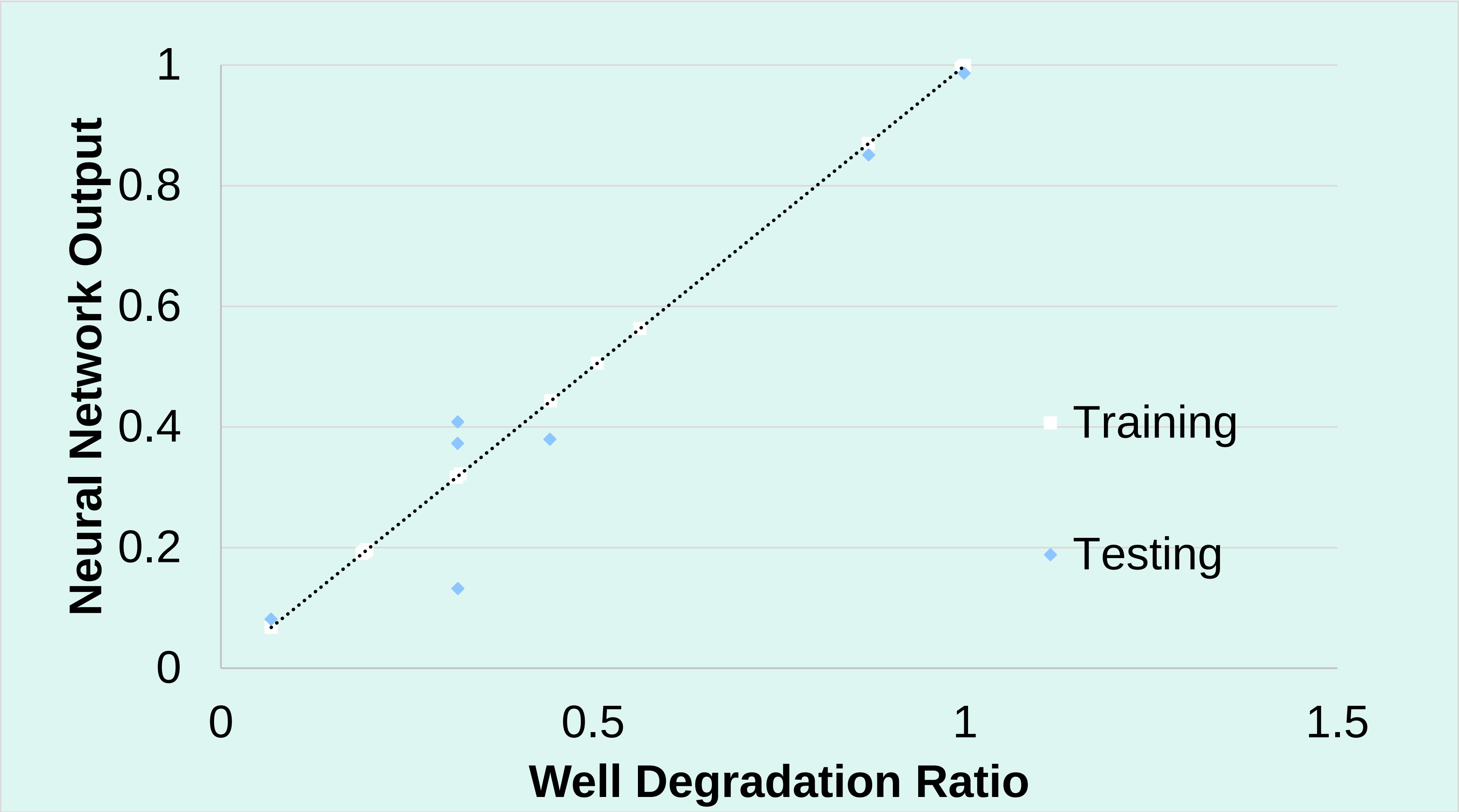
Feet to push O-ring against casing wall

Average Annular Permeability Measurement – MDT





Development of Integrated Neural-Genetic Algorithm



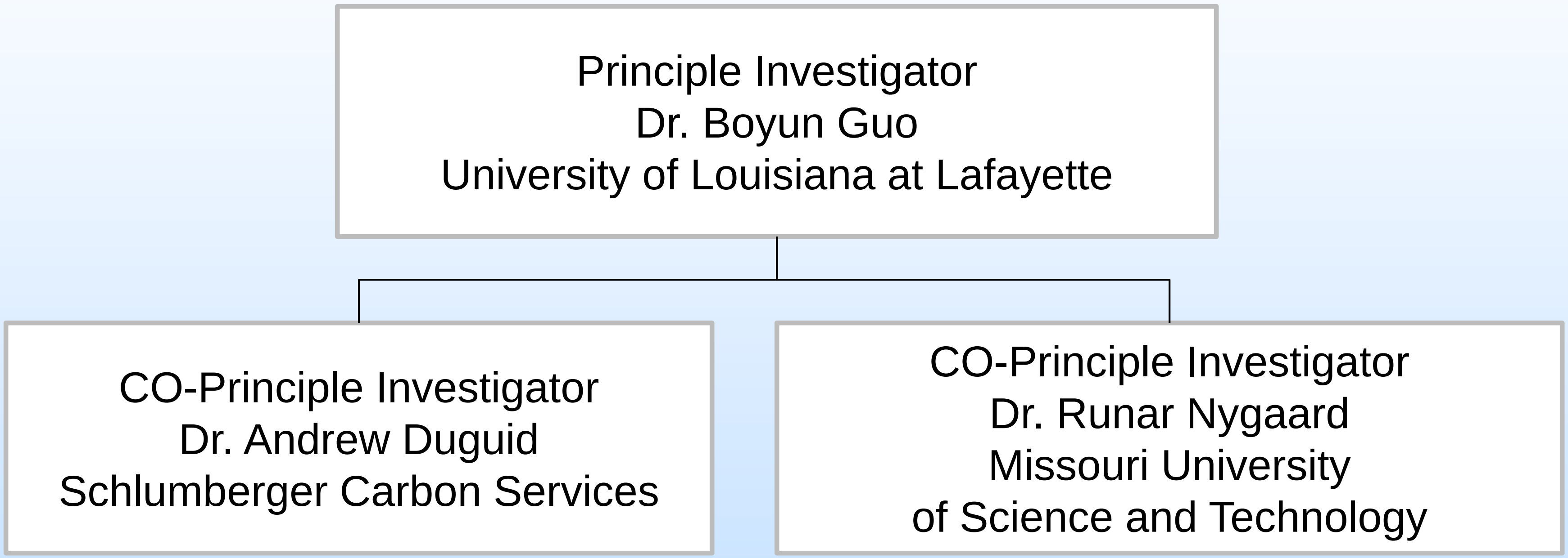
Summary

– Inadequate number of wells were found to have CO_2 leakage problems in the Oyster Bayou and West Hasting fields to perform rigorous statistical analysis.
– Risk assessment shows that wells in the Oyster Bayou field are under higher risk of leak than the wells in the West Hasting field.
– A computer model with Integrated Neural-Genetic Algorithm was developed to predict well leak probability.
– A mechanics model was built to predict well leak scenarios. It needs to be validated by test site data.
– A test site has been selected and will be used to verify the computer models.

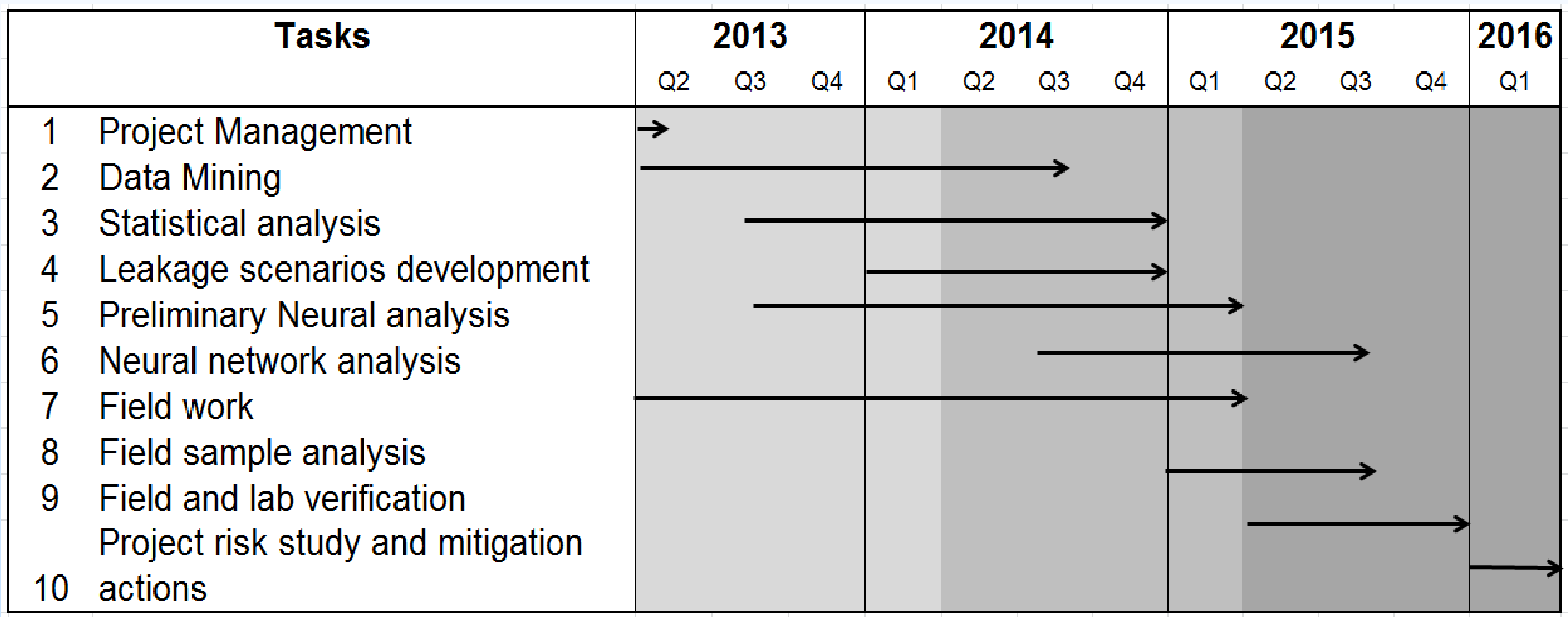
Appendices

Appendix A – Organization Chart
Appendix B – Gantt Chart
Appendix C – Bibliography

Appendix A – Organization Chart



Appendix B – Gantt Chart



Appendix C – Bibliography

1. Weideman, B., and Nygaard, R., 2014, How Cement Operations affect your Cement Sheath Short and Long Term Integrity, paper AADE-14-FTCE-20 presented at the 2014 AADE Fluids Technical Conference and Exhibition, April 15-16, 2014, Houston, Texas.
2. Li, B., Guo, B., Li, H., and Song, J., 2014, Carbon Sequestration: Predicting Potential Well Leakage over Long Timescales – A Case Study of The Texas Gulf Coast. Paper ES-FuelCell2014-6367 presented at the ASME 2014 8th International Conference on Energy Sustainability & 12th Fuel Cell Science, Engineering and Technology, June 30 - July 2, 2014, Boston, Massachusetts.