In-Situ MVA of CO_2 Sequestration Using Smart Field Technology

FE - 0001163

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U.S. Department of Energy

National Energy Technology Laboratory
Carbon Storage R&D Project Review Meeting
Developing the Technologies and Building the
Infrastructure for CO_2 Storage

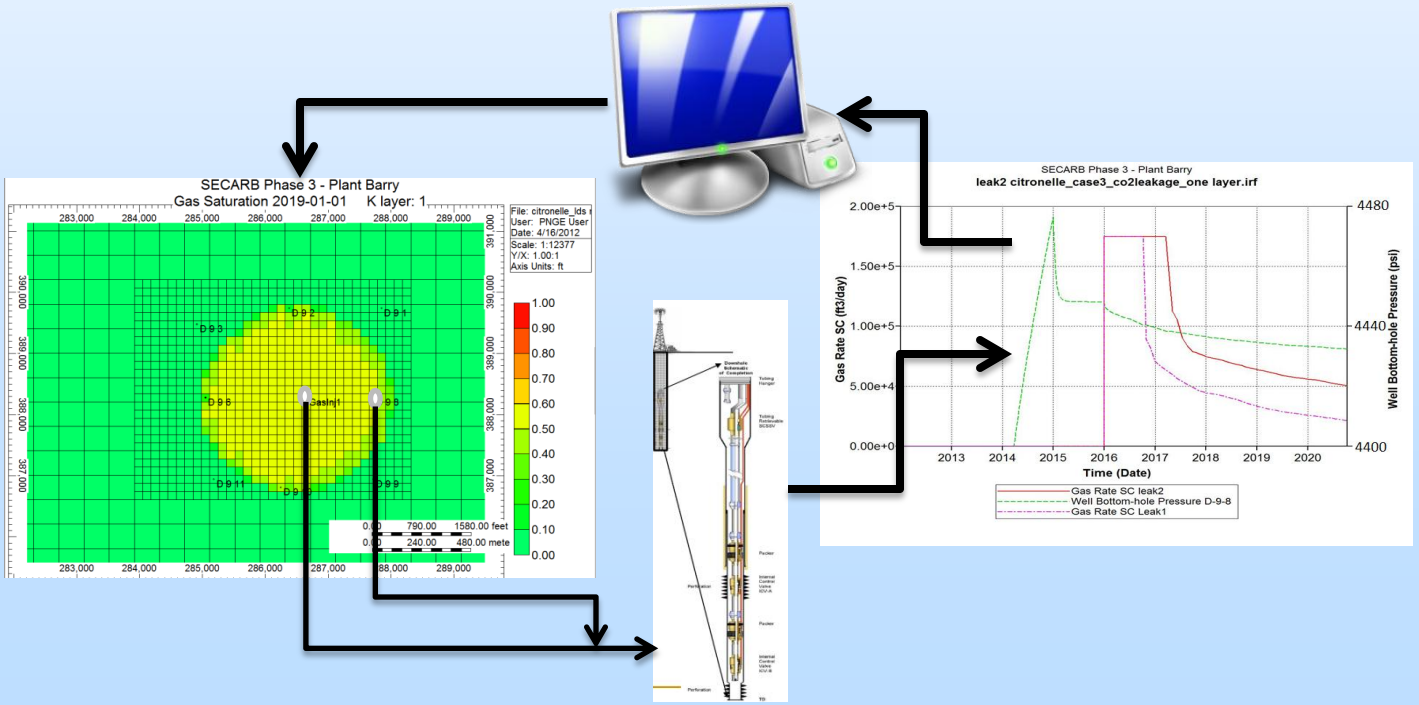
August 21-23, 2012

Presentation Outline

- Introduction
  - Objective
  - Industrial Review Committee
  - Background
- Steps Involved
  - Geological and Reservoir Simulation Modeling
  - Leakage Modeling & Real-Time Data Processing
  - Pattern Recognition & Intelligent Leakage Detection System (ILDS)
- Accomplishments to Date
- Summary

Objective

- Develop an in-situ CO_2 leak detection technology based on the concept of Smart Fields.
  - Using real-time pressure data from permanent downhole gauges to estimate the location and the rate of CO_2 leakage.



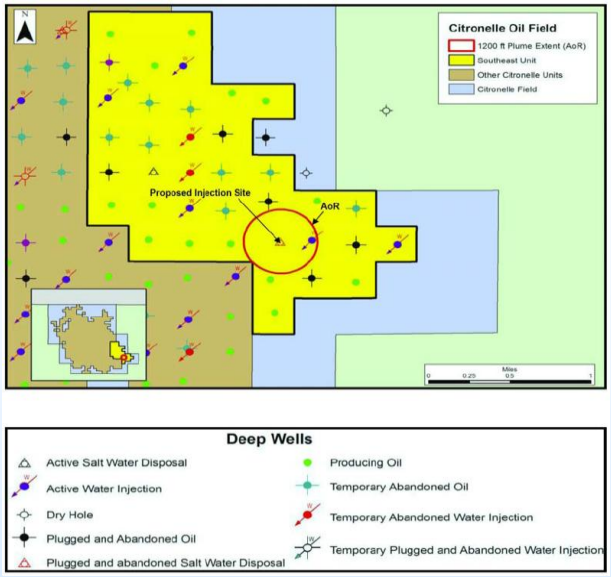
Industrial Advisory Committee (IAC)

- Project goes through continuous peer-review by an Industrial Review Committee.

Name	Affiliation
Neeraj Gupta	Battelle
Dwight Peters	Schlumberger
George Koperna	ARI
Grant Bromhal	DOE-NETL
Richard Winschel	CONSOL

- Meetings:
  - November 6th 2009 :
    - Conference call
    - Site selection criteria
  - November 17th 2009:
    - A meeting during the Regional Carbon Sequestration Partnership Meeting in Pittsburgh
    - Selection of a suitable CO_2 sequestration site
  - November 18th 2011:
    - Reporting the modeling process to IAC
  - February 16th 2012
    - Reporting the modeling process to NETL/DOE

Background



- Type of Waste:

  Carbon Dioxide

- Depth of Well: **11,800 feet**
- Depth and Geological Name of Injection Zone:

  Paluxy Formation

- Depths and Geologic Name of Injection Interval:

  9,400 – 10,500 feet below GL

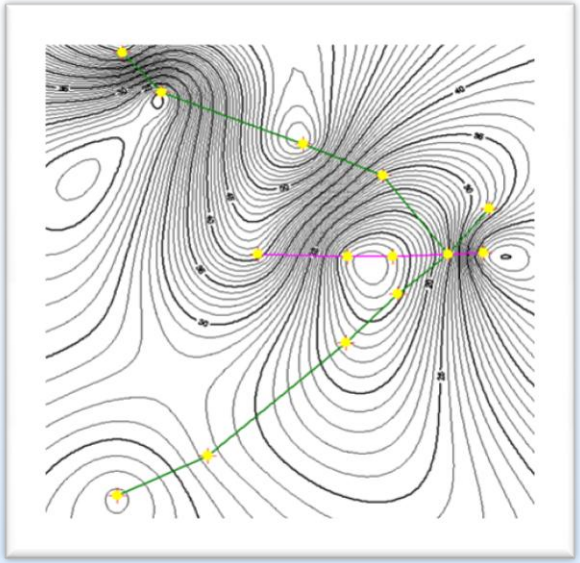
  Paluxy Formation
- Injection Volumes:

  Average Daily Volume: **148,000 gal/day** (500 ton/day)-- 182500 ton/year

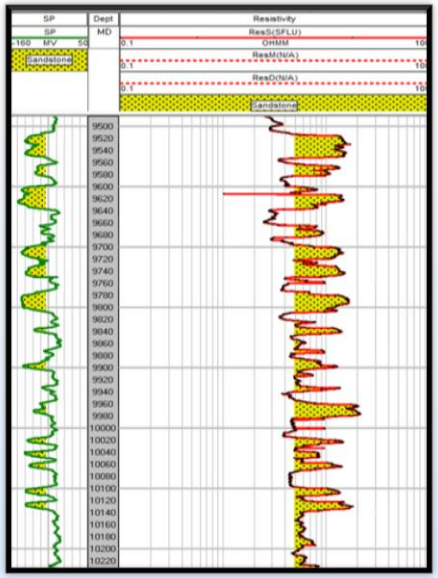
Steps Involved in the Methodology

- Building a Geological Model.
    - Using Well Logs (40 wells)
    - Using Core Data
    - Multiple Rock Types
- Building a Reservoir Simulation Model.
    - 1.2 Million-cell, base model.
- Building a Leakage Model.
    - Modeling leakage through abandoned wells.
    - Seismic studies have concluded no faults in the area.
- Real-Time Data Preparation.
    - Data cleansing and abstraction.
- Pattern Recognition for Leakage Detection.
    - Data set preparation
    - Data-Driven Model Training, Calibration and Validation

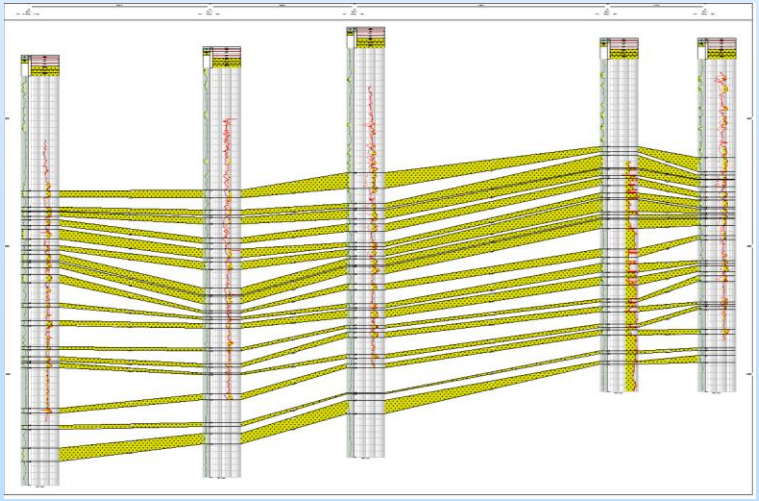
Geological Model



3 Cross Sections



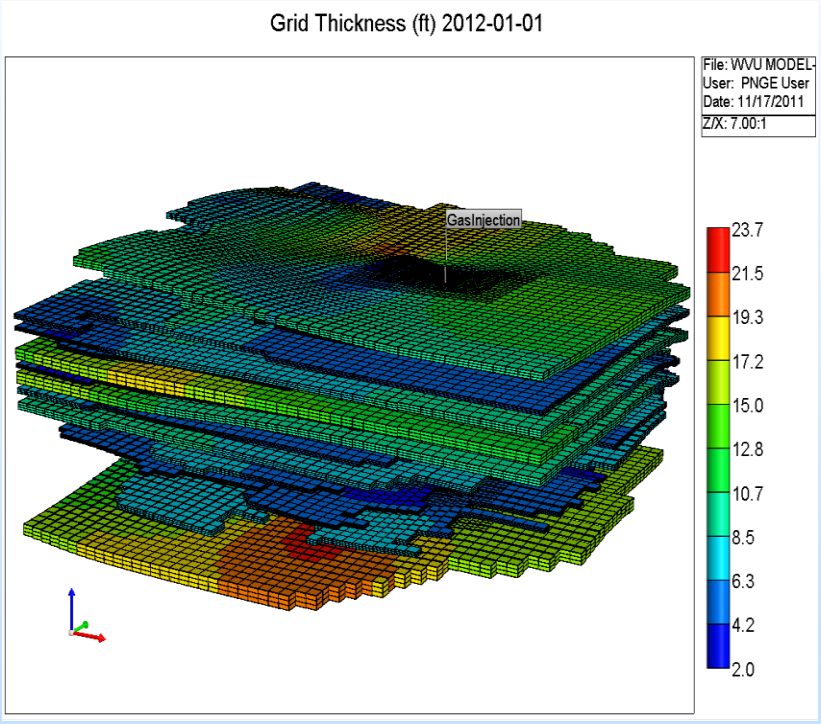
Sand Layers-D-9-7

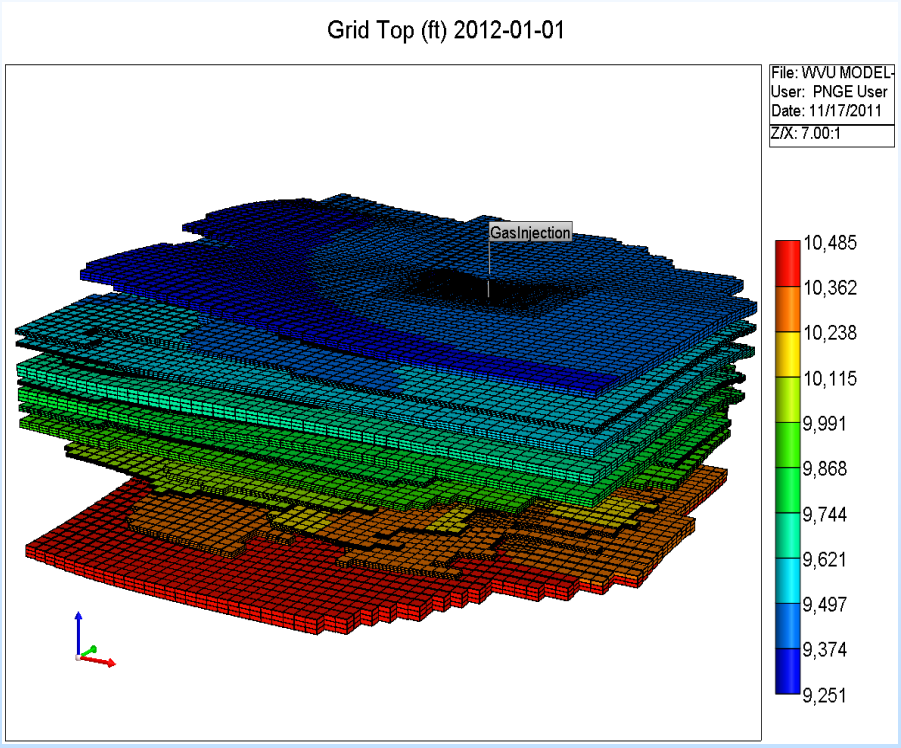


Cross Section B-B`

Geological Model

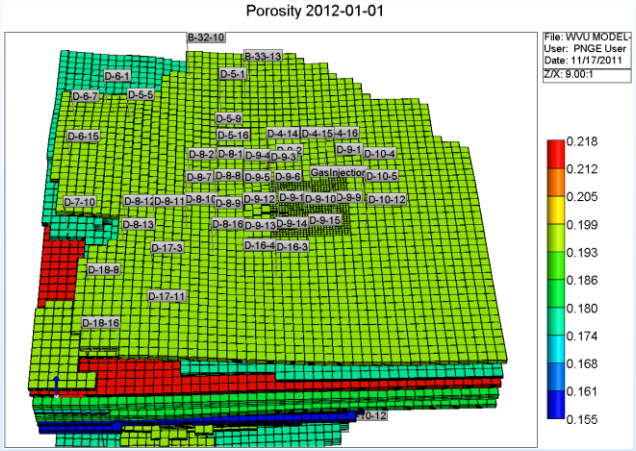
- 17 Geological Layers
- 51 Simulation Layers



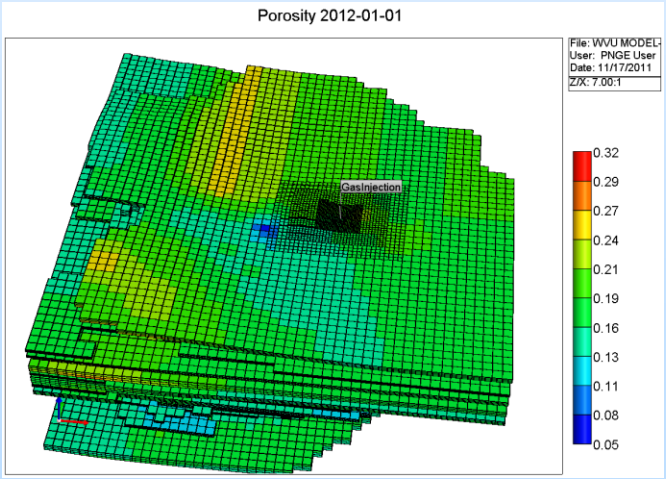


Porosity Determination

Well Log data from 40 wells were used to generate porosity distribution for the reservoir

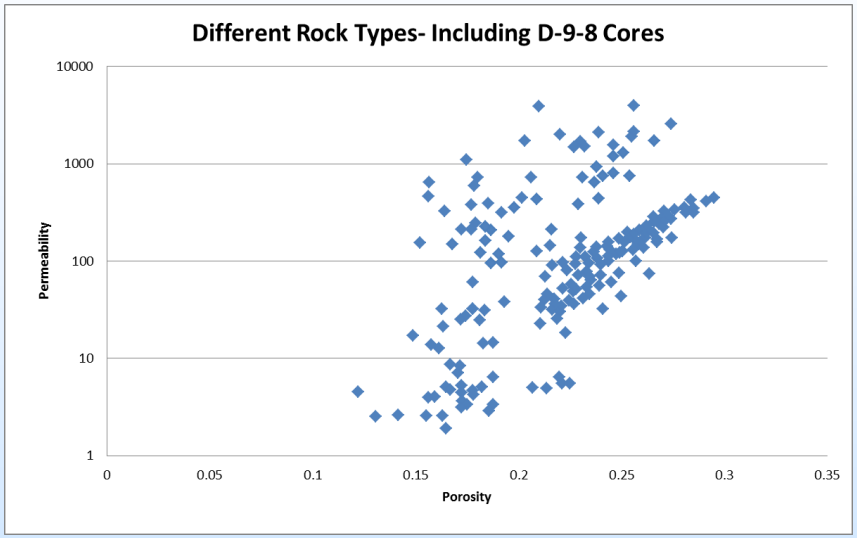


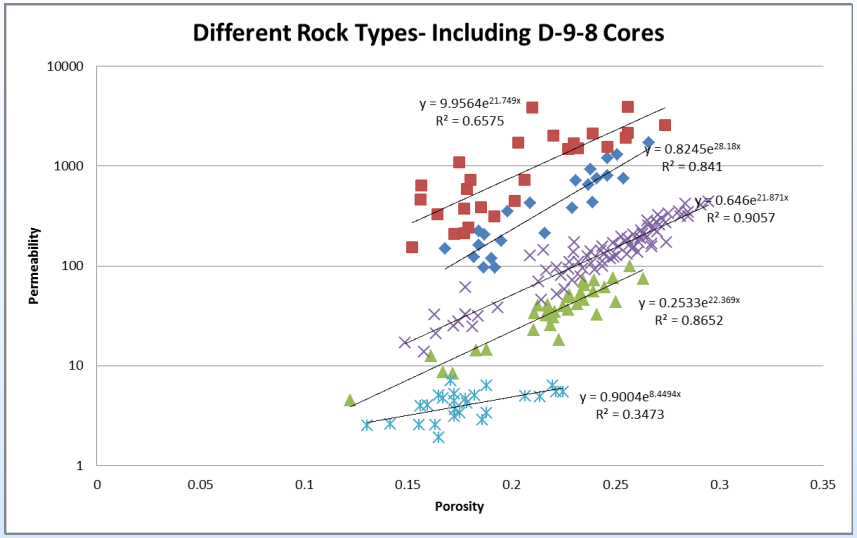
Imposing Local Grid Refinement around the injection well.



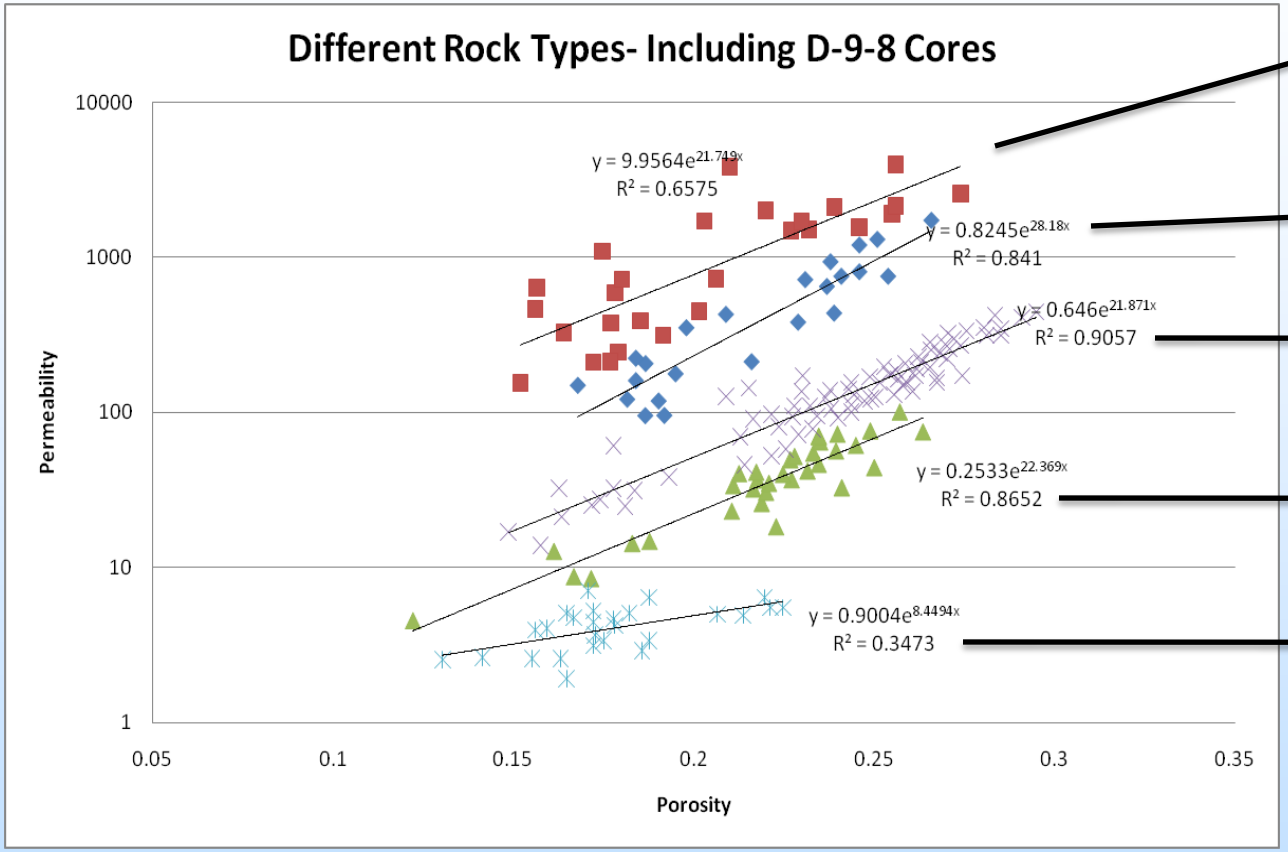
D-9-8			
top	bottom	ϕ(resistivity)	ϕ(Induction)
9648.2	9658.1	0.1160	0.1596
9658.1	9667.9	0.1769	0.2139
9752.7	9759.1	0.0892	0.1711
9759.1	9765.6	0.0809	0.1774
9765.6	9772.0	0.0755	0.1669
9822.8	9829.9	0.1214	0.1313
9829.9	9836.9	0.1280	0.1272
9836.9	9844.0	0.1263	0.1237
9925.8	9929.3	0.1300	0.1259
9929.3	9932.9	0.1282	0.1313
9932.9	9936.4	0.1332	0.1578
9967.7	9969.7	0.1136	0.1745
9969.7	9971.6	0.1015	0.1785
9971.6	9973.6	0.0982	0.1765
9971.4	9972.9	0.0977	0.1781
9972.9	9974.4	0.0987	0.1746
9974.4	9975.9	0.0985	0.1734
10159.2	10162.3	0.0966	0.1464
10162.3	10165.3	0.0869	0.1242
10165.3	10168.4	0.0805	0.1178
10231.6	10241.3	0.1319	0.1425
10241.3	10251.1	0.1057	0.1590
10251.1	10260.8	0.1177	0.1291
10324.3	10341.2	0.1279	0.1374
10341.2	10358.2	0.1153	0.1755
10358.2	10375.1	0.1044	0.1438

Reservoir Rock Types using Core Permeability Values





Permeability Realizations



ROCK TYPE

Very Conductive

Conductive

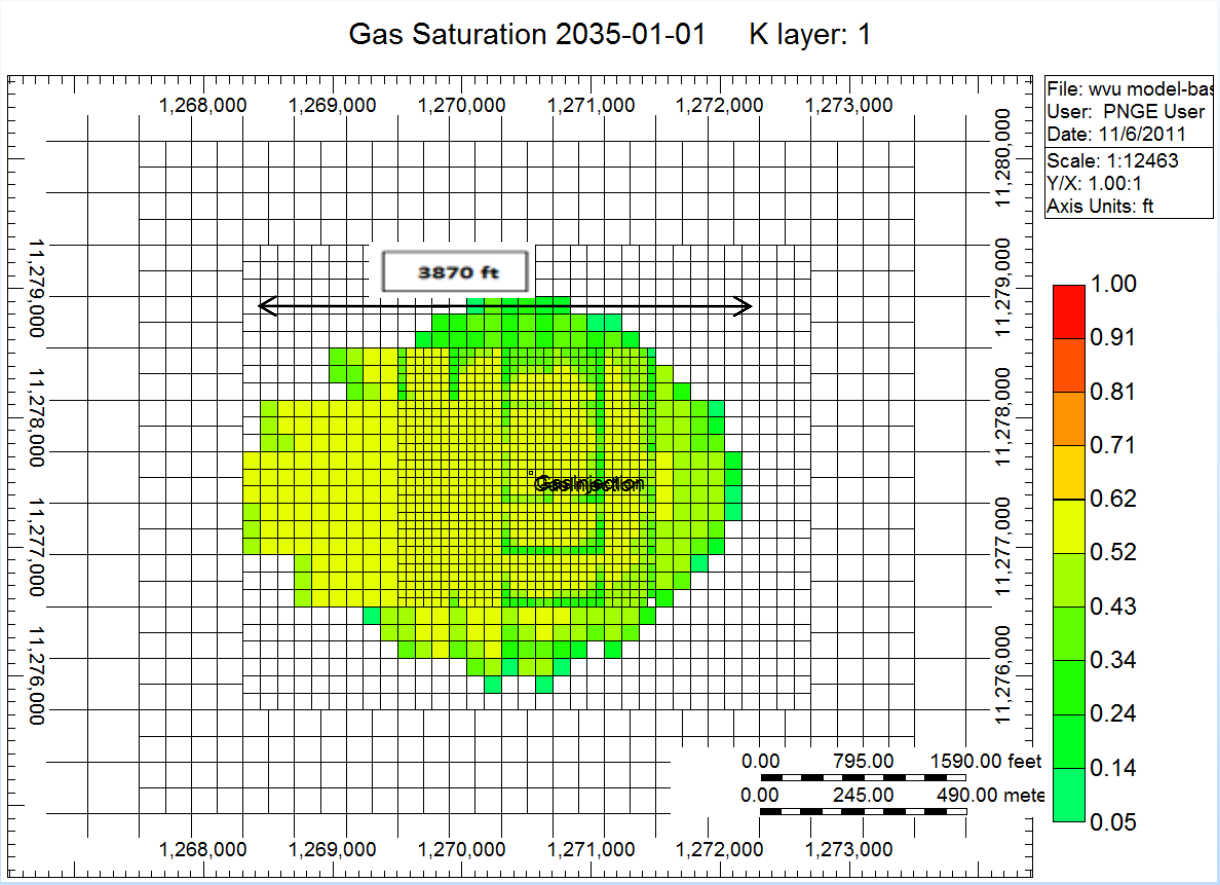
Average

Tight

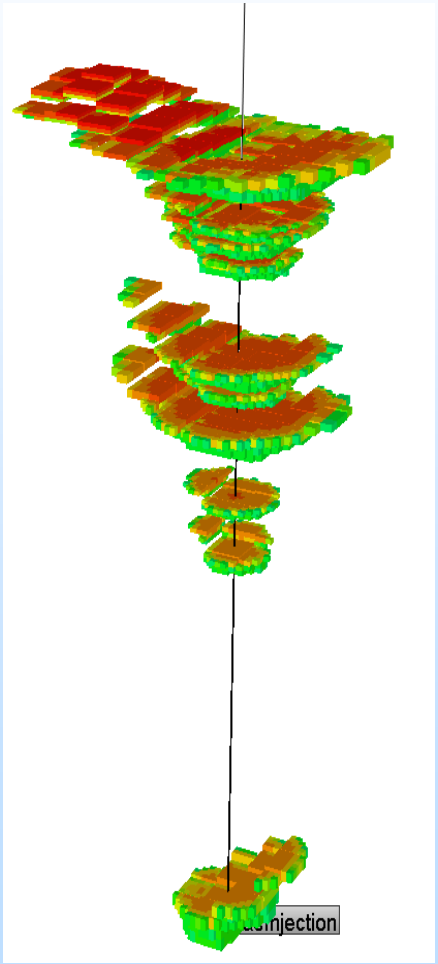
Very Tight

Plume Extension

- CO_2 Injected for three years.
- Plume extension: 20 years after injection ends.
- Rock Type = Conductive

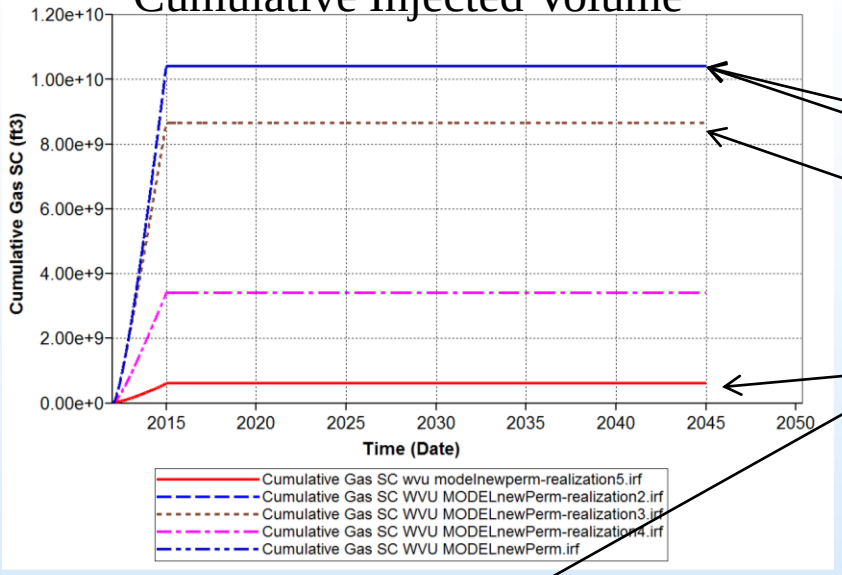


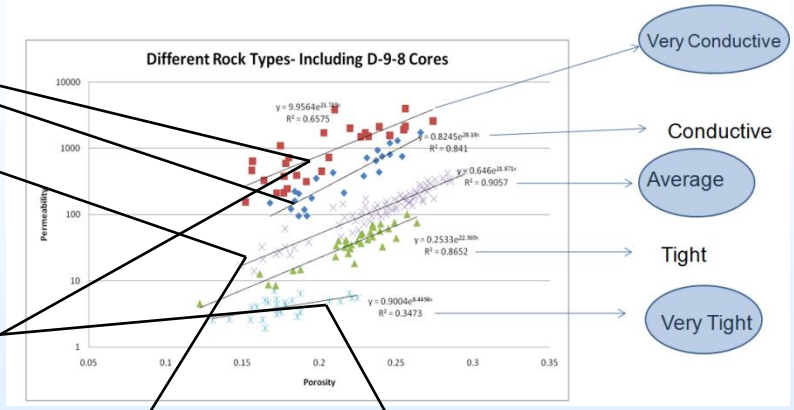
Plume extension is shown only for the blocks with CO2



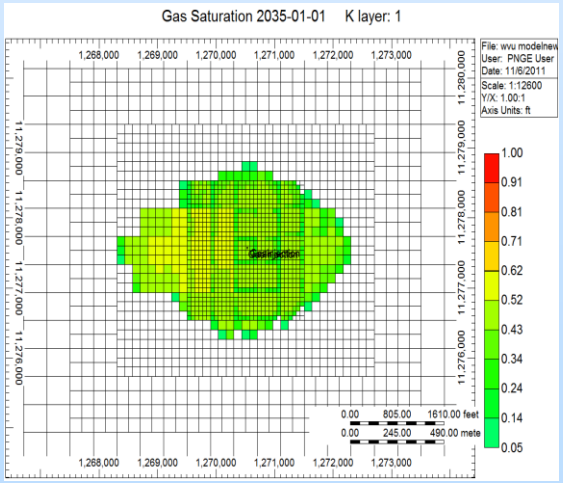
Permeability Realizations

Cumulative Injected Volume

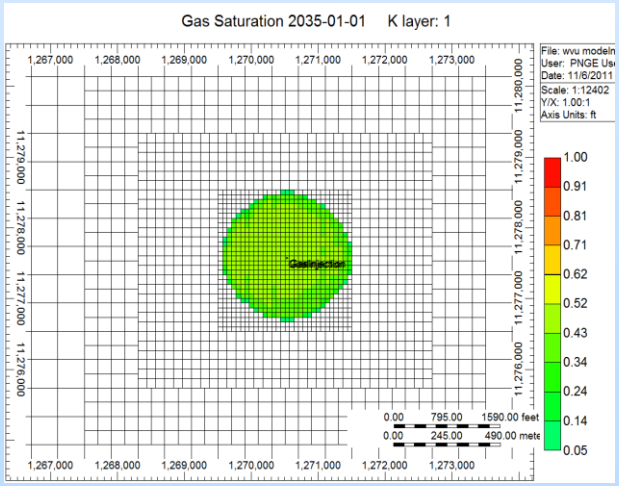




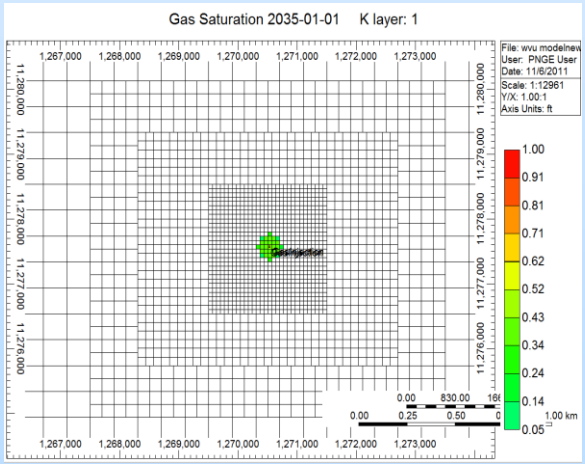
Very Conductive



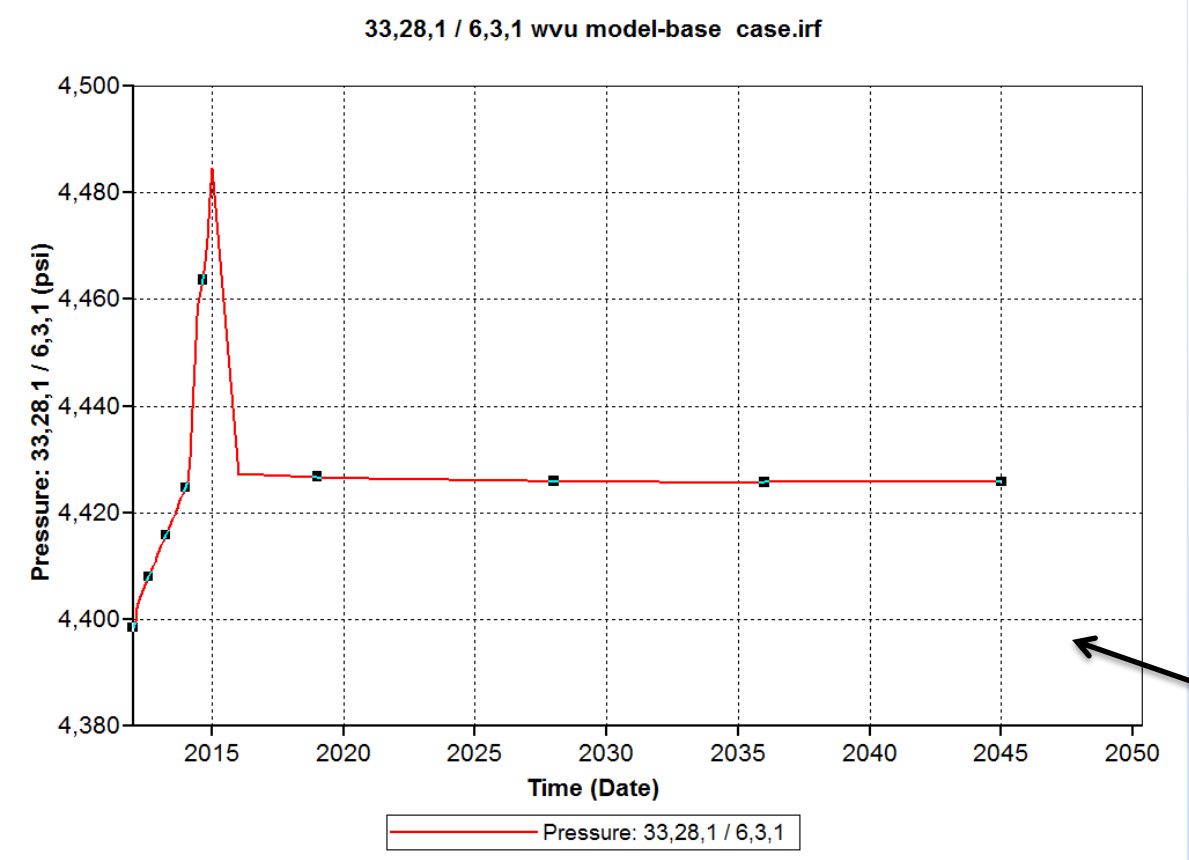
Average

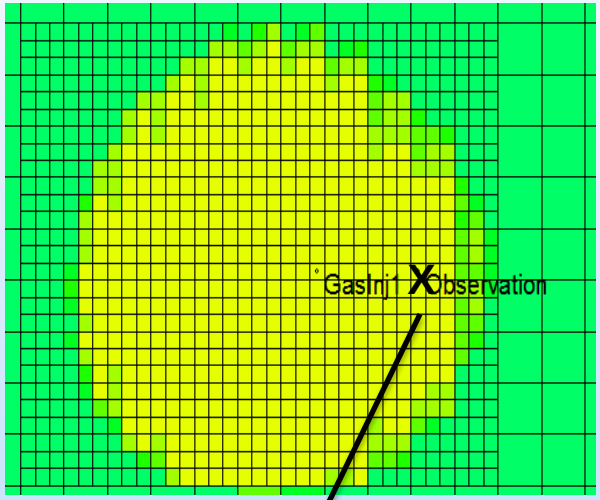


Very Tight

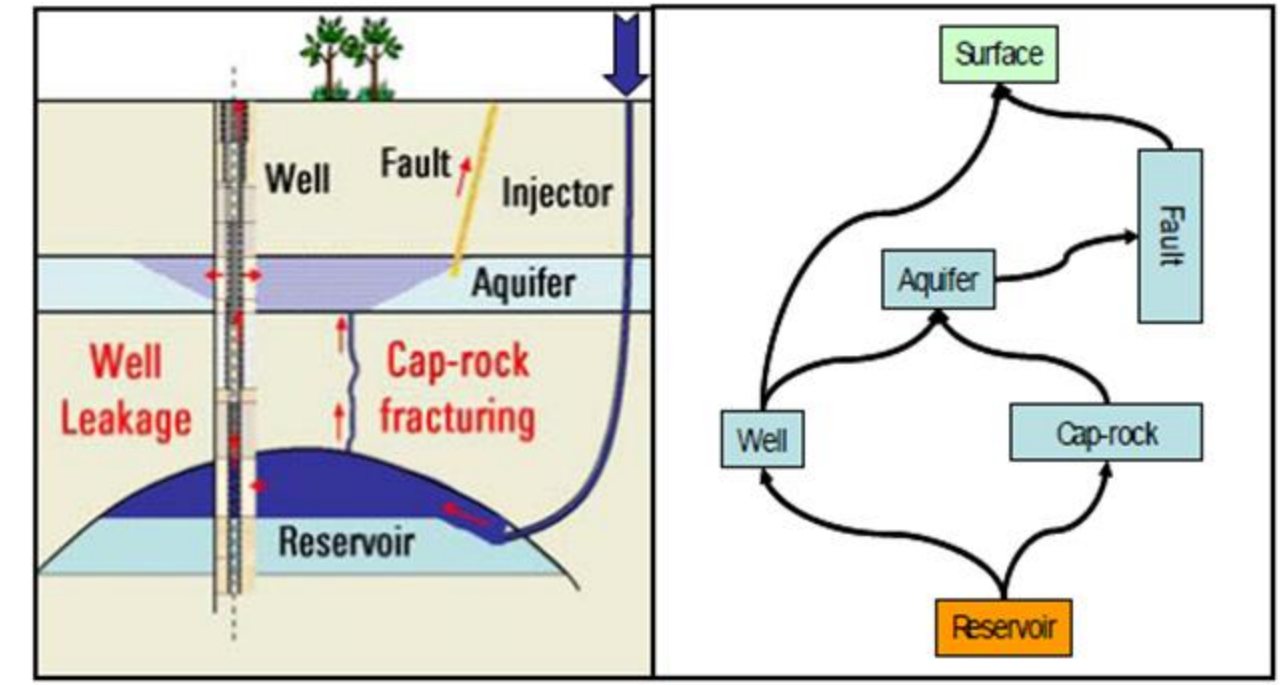


Pressure Behavior (Observation Well)



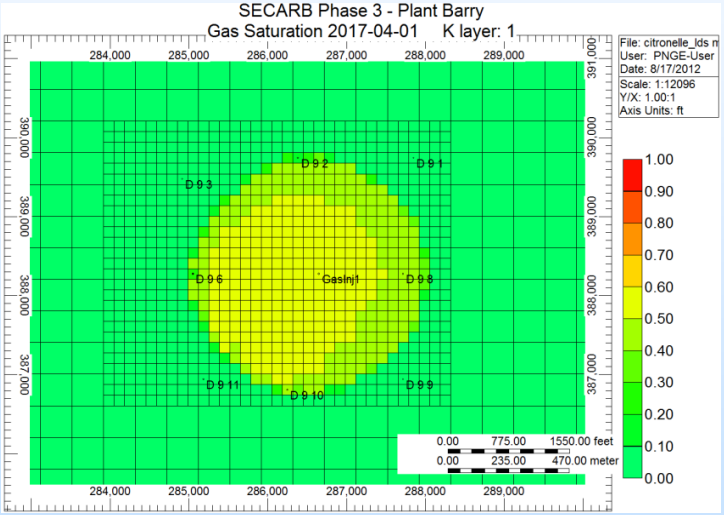


Leakage Modeling

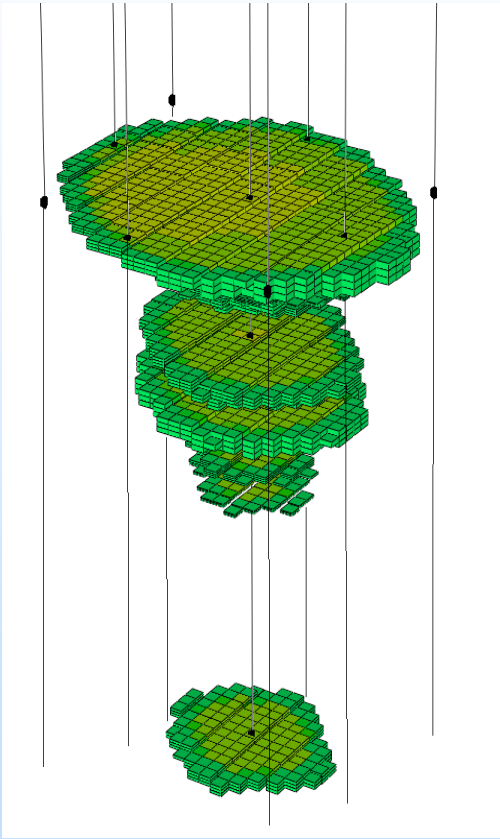


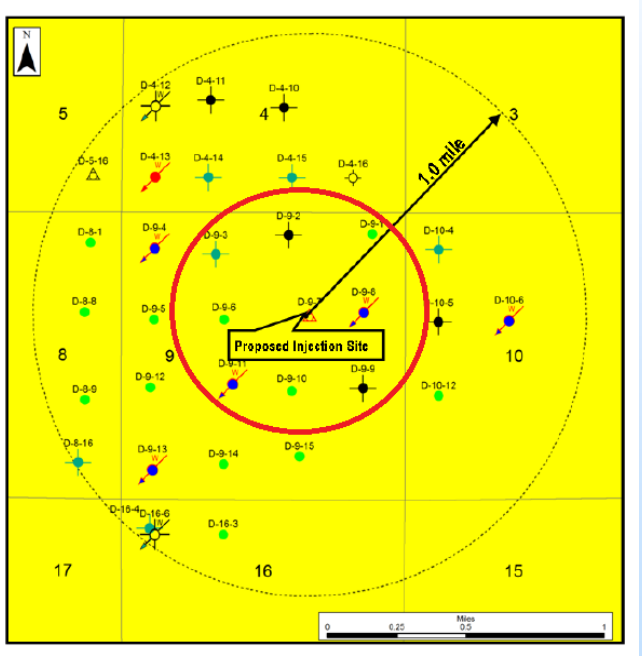
Ref:SPE108525

Leakage Modeling



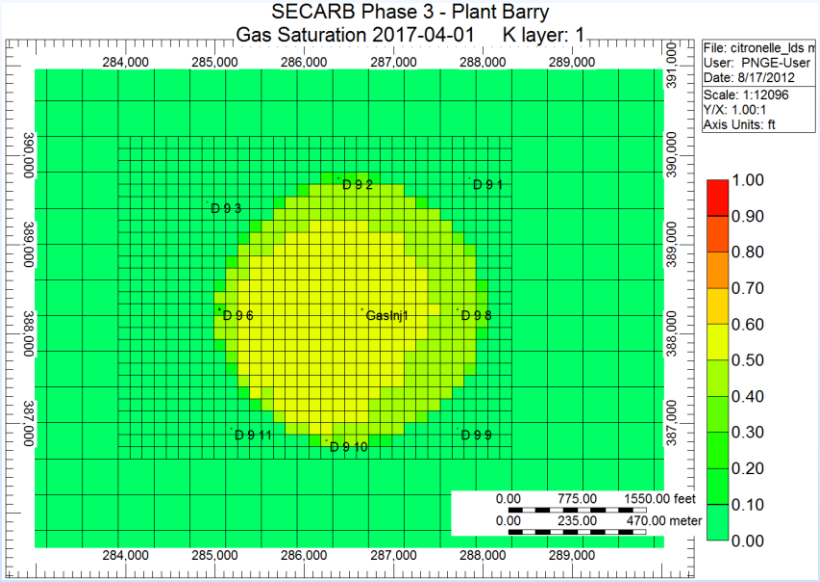
RT = Conductive



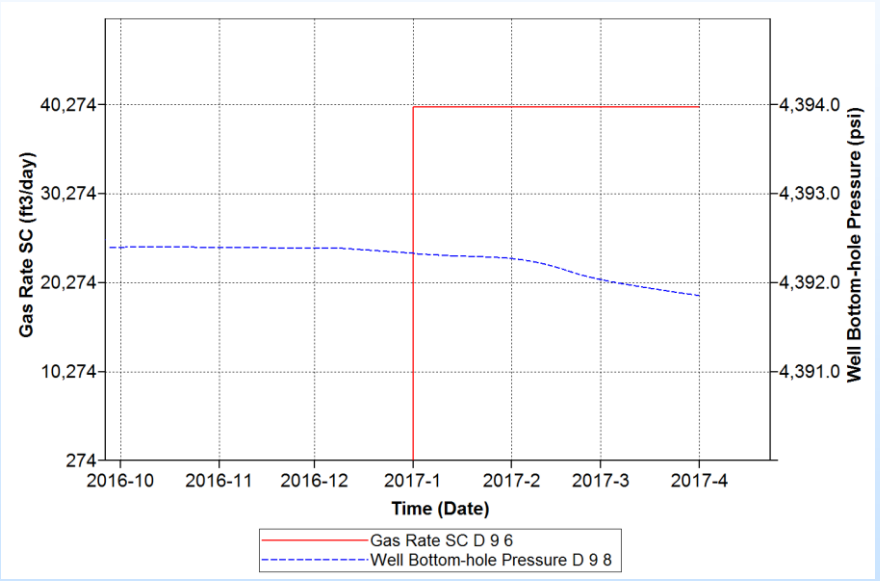


Leakage Modeling

Leakage Rate=40Mcf/day @ Well D-9-6



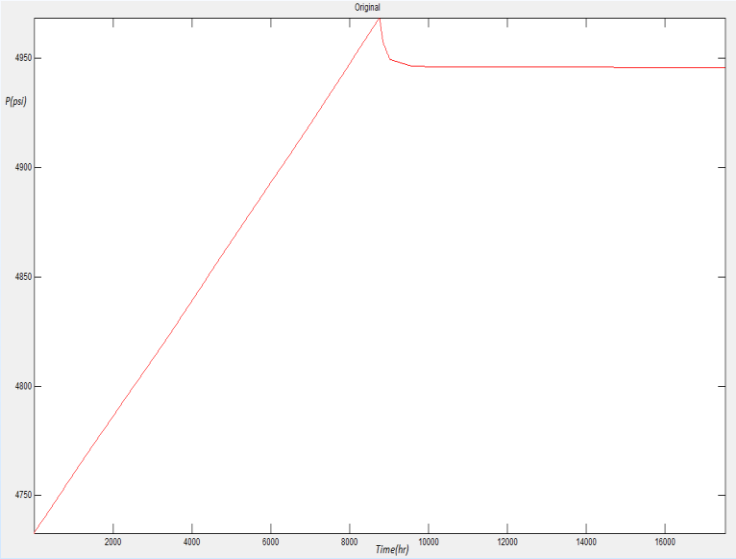
Examples of leakage in the reservoir (through existing wells)



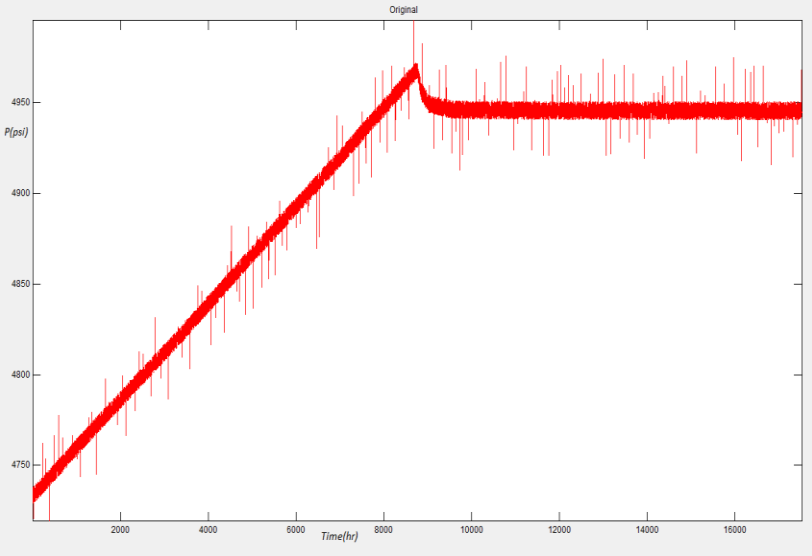
Pressure Behavior @ Observation Well

High-frequency data

Pressure Behavior at the Observation well

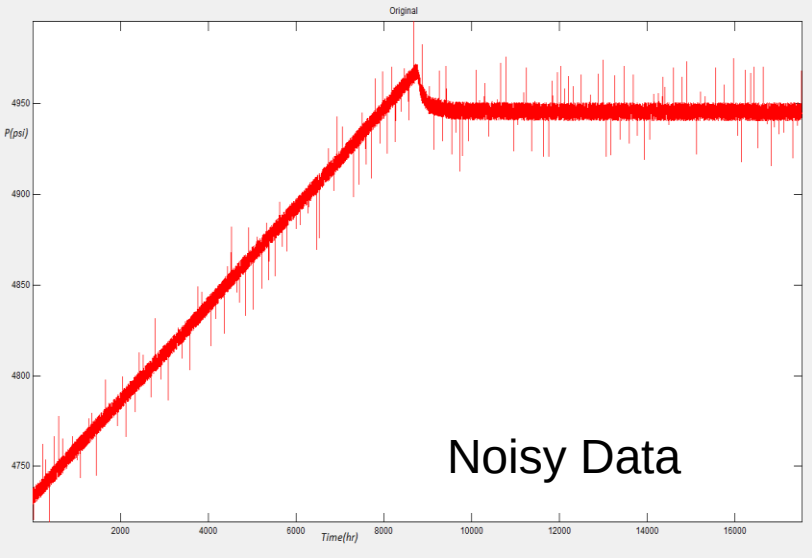


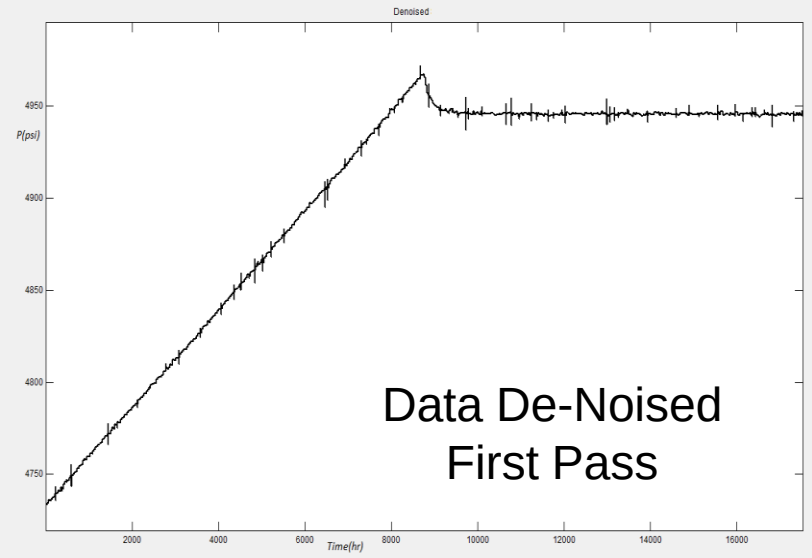
Clean Data from Simulator

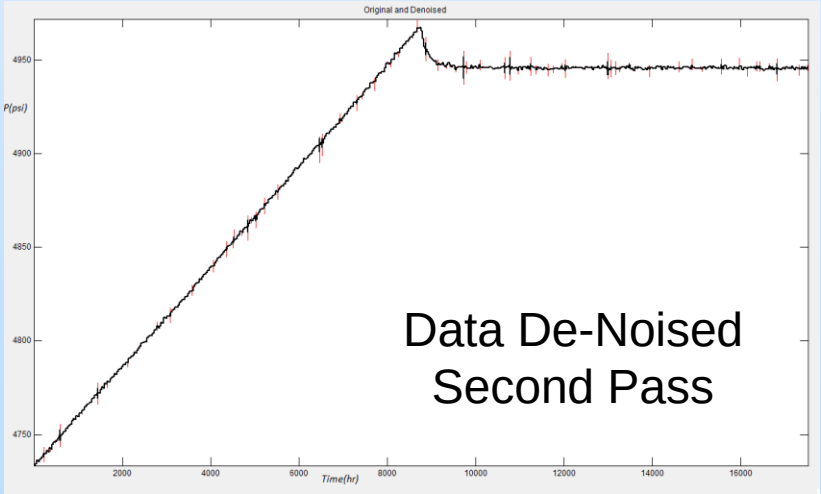


Simulated Noisy Data

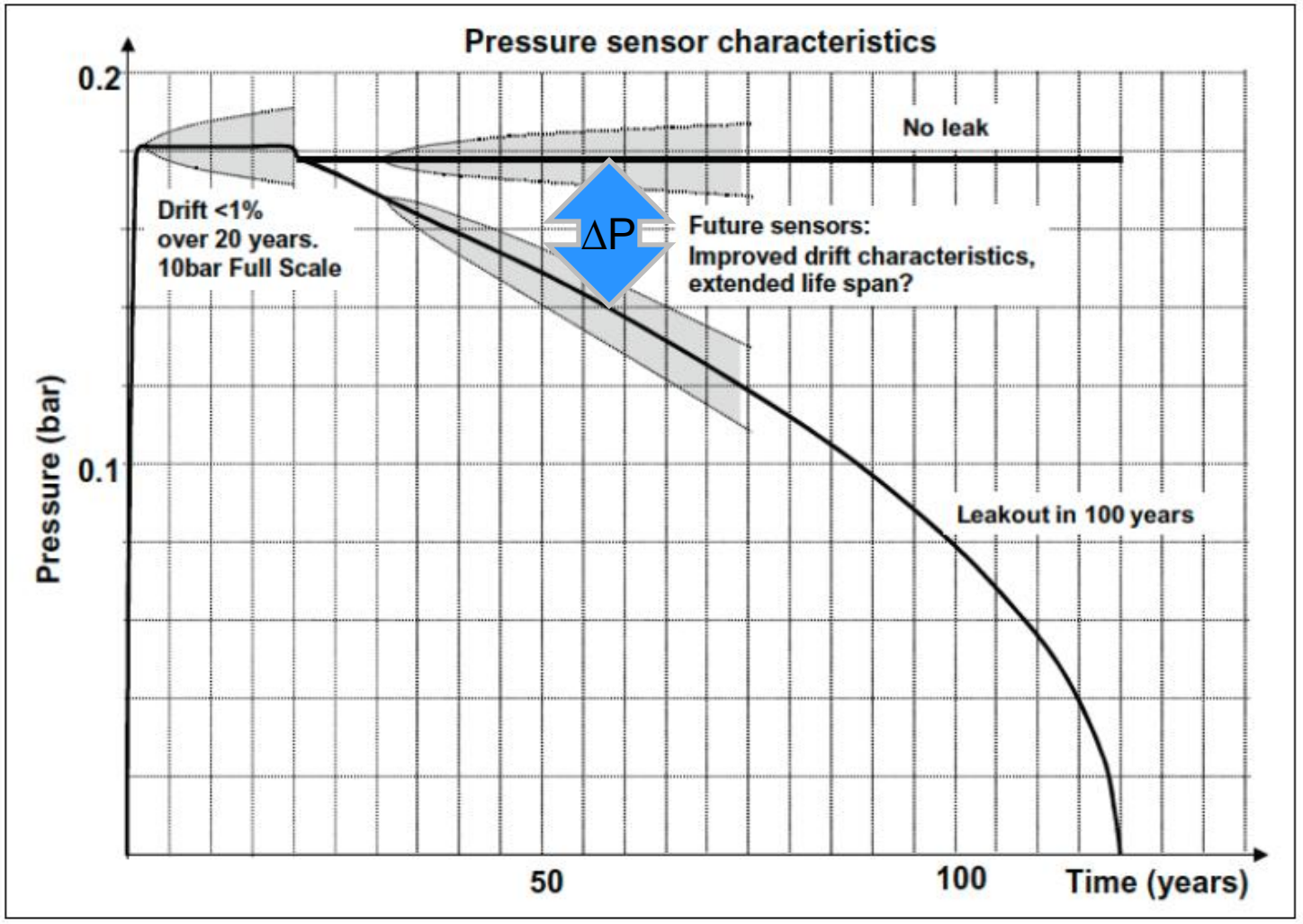
Data Cleansing
De-noising Using Wavelet Threshold Method





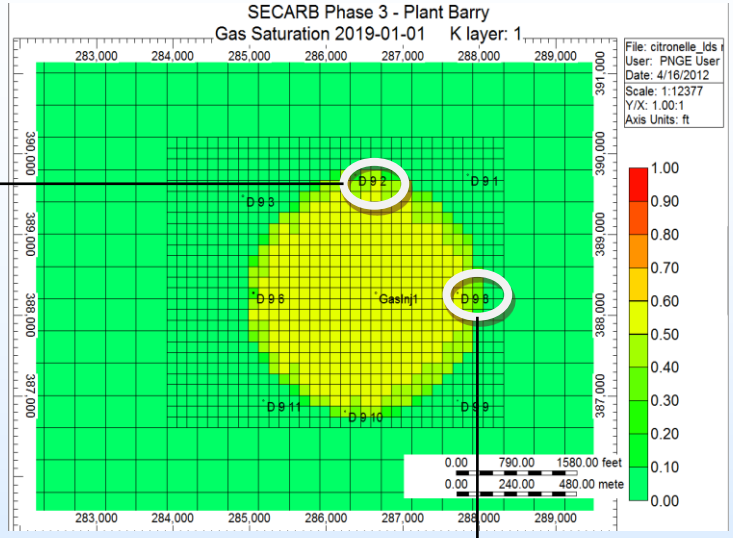


Leakage Detection

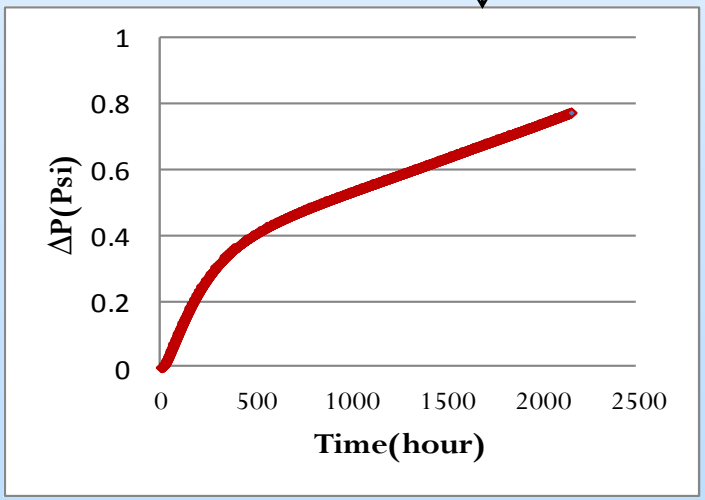


ΔP in the observation well
Leakage in well D-9-2 (Leakage rate = 30MSC/day)

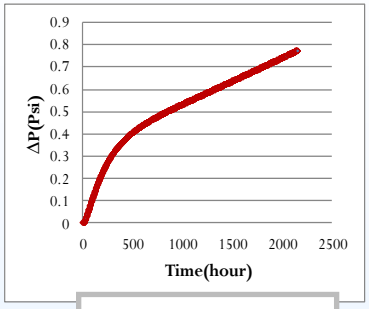
Leaking Well(D-9-2)



Observation Well

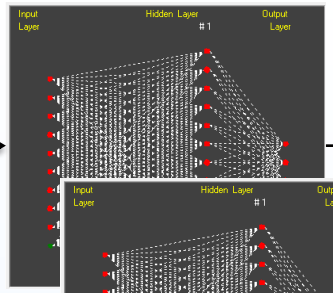


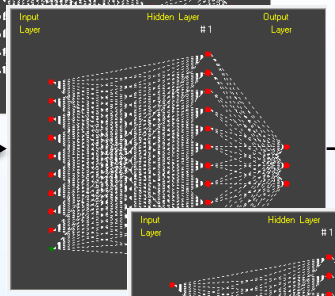
Pattern Recognition

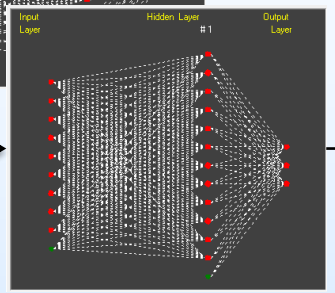


Descriptive Statistics

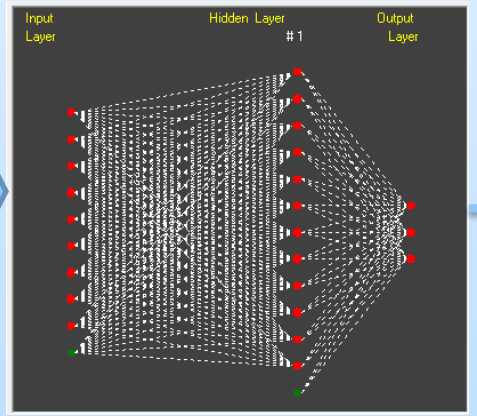
D-9-2	
Mean	0.091532
Standard Error	0.004755
Median	0.091797
Mode	0
Standard Deviation	0.061636
Sample Variance	0.003799
Kurtosis	-1.31344
Skewness	0.029047
Range	0.194824
Minimum	0
Maximum	0.194824
Sum	15.37744
Count	168







Leakage Rate



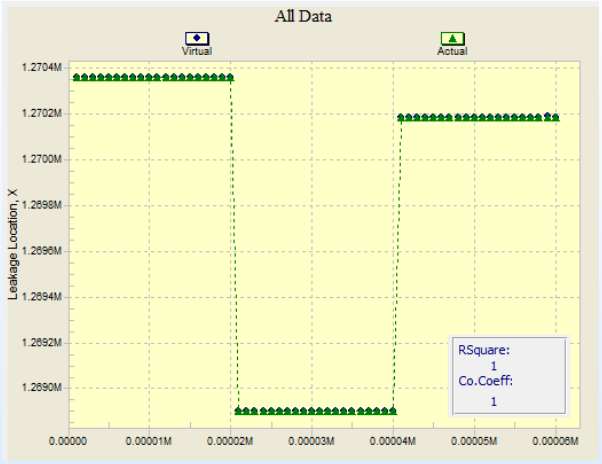
Leakage Location

Results of Detection System (ILDS)
Leakage Rate and Location

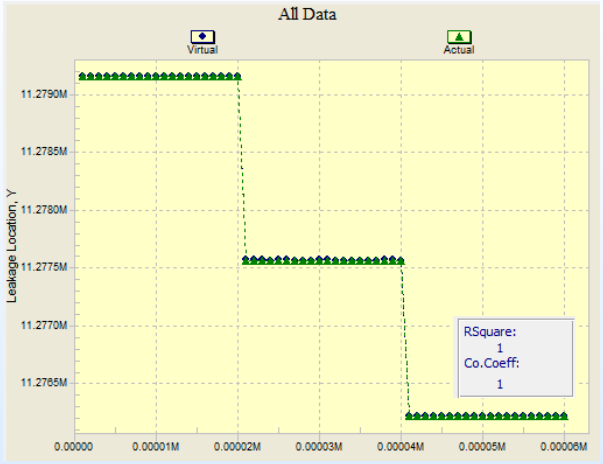
Leakage Rate used for training

Mcf/day
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110

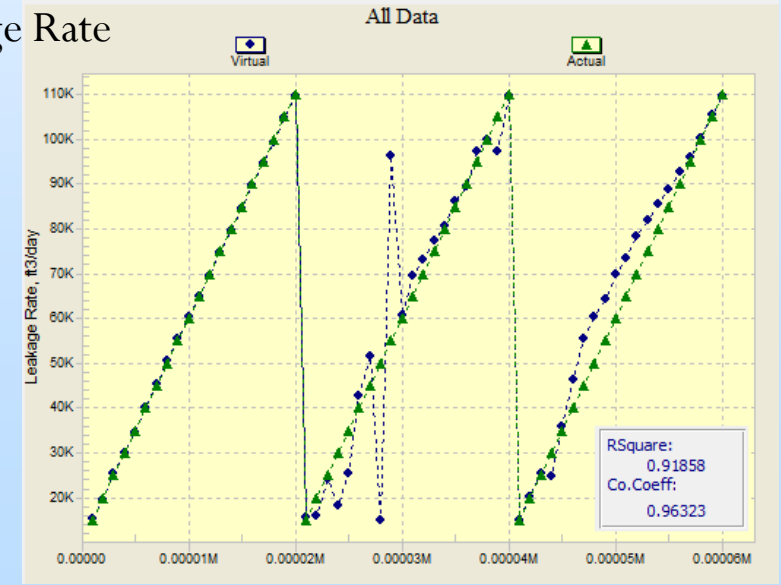
Leakage Location (Longitude)



Leakage Location (Latitude)



Leakage Rate

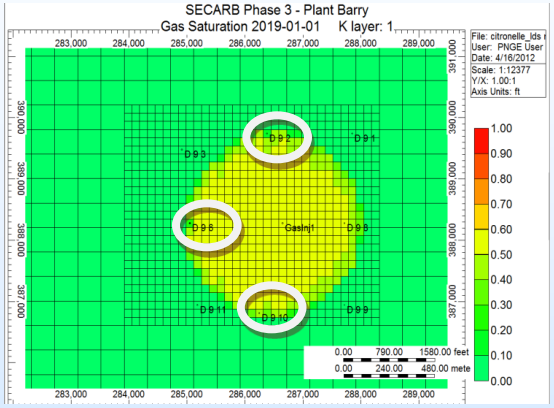


Hourly Pressure **one week** after the start of the leakage

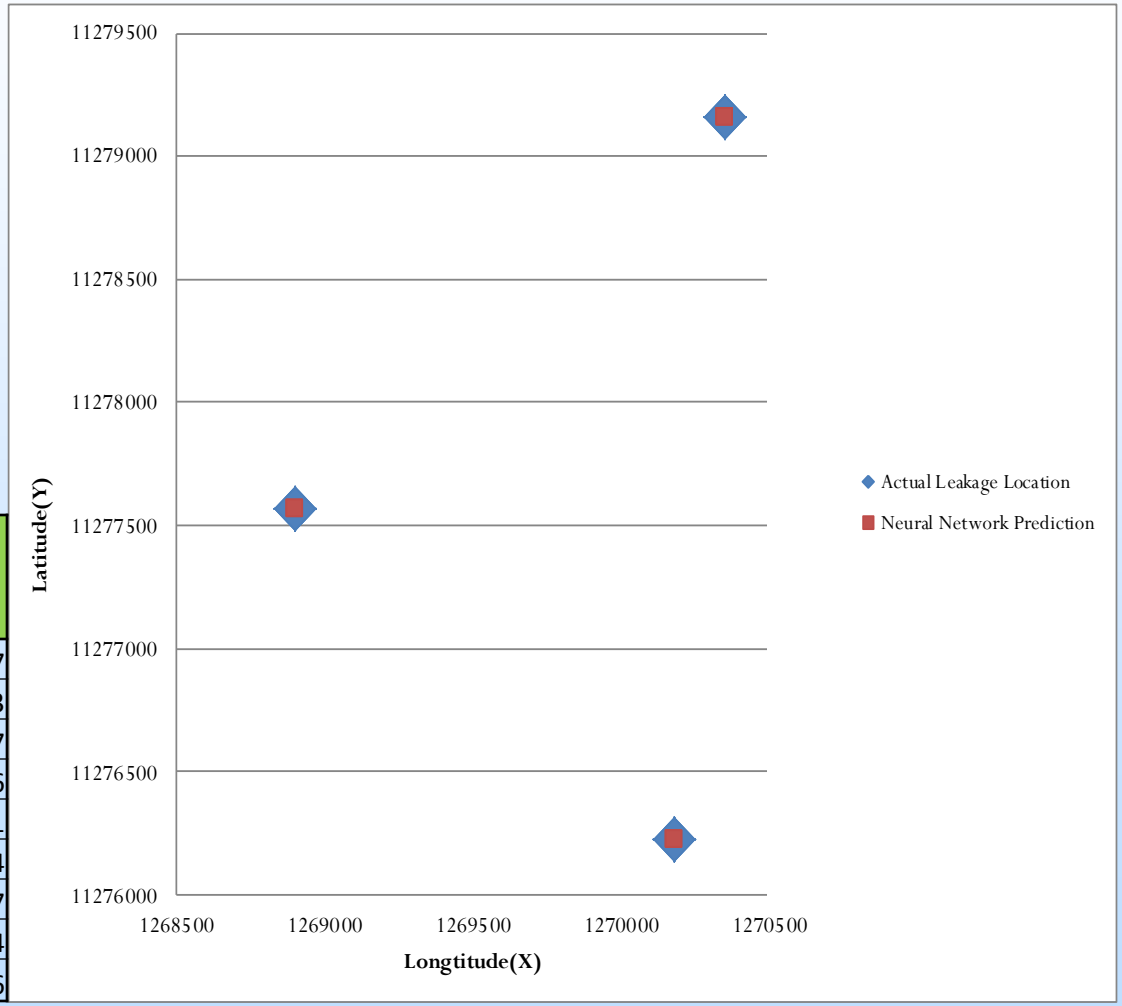
Validation of the Intelligent Leakage Detection System (ILDS) Blind Run Results - Leakage Location

Nine new leakage Scenarios

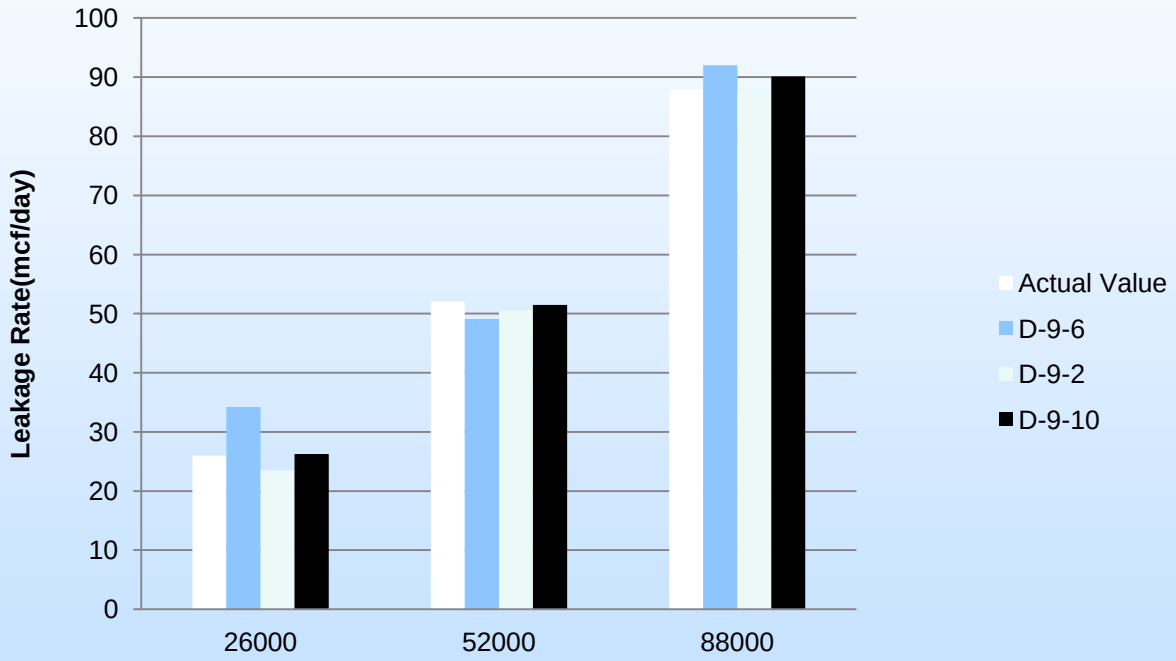
Leakage Rate Mcf/day
26
52
88



Run	Leakage Location(X) Actual	Leakage Location(X) N.N	Leakage Location(Y) Actual	Leakage Location(X) N.N
1	1268902.53	1268903.05	11277566.74	11277569.97
2	1268902.53	1268902.78	11277566.74	11277565.13
3	1268902.53	1268902.55	11277566.74	11277567.57
4	1270359.37	1270359.03	11279158.24	11279157.46
5	1270359.37	1270359.11	11279158.24	11279157.51
6	1270359.37	1270359.17	11279158.24	11279157.44
7	1270184.29	1270184.53	11276221.98	11276223.47
8	1270184.29	1270185.16	11276221.98	11276224.14
9	1270184.29	1270183.81	11276221.98	11276222.66



Blind Run Results - Leakage Rate



Accomplishments to Date

- Geological model was developed.
- Reservoir Simulation Model was developed.
- CO_2 Leakage was modeled.
- High Frequency data was cleansed and summarized.
- Intelligent Leakage Detection System (ILDS) was designed and developed.
  - Initial Design
  - Validated for Simple Reservoir System
  - Validated for Simple Leakage System

Summary

Key Findings:

- Location and amount of CO_2 leakage can be detected and quantified, rather quickly, using continuous monitoring of the reservoir pressure.
- Pattern recognition capabilities of Artificial Intelligence and Data Mining may be used as a powerful deconvolution tool.

Lessons Learned(proof of concept):

- Development of an Intelligent Leakage Detection System (ILDS) is initiated for detection and quantification of CO_2 leakage.

Future Plans:

- Increase the robustness of ILDS by:
  - + Including permeability heterogeneity (multiple rock types),
  - + Examining impact of different boundary conditions,
  - + Including more sources of leakage,
  - + Examining detection of simultaneous multiple leakages.

Appendix
Benefit to the Program

- Program goals :
  - Develop technologies to demonstrate that 99 percent of injected CO_2 remains in the injection zones.

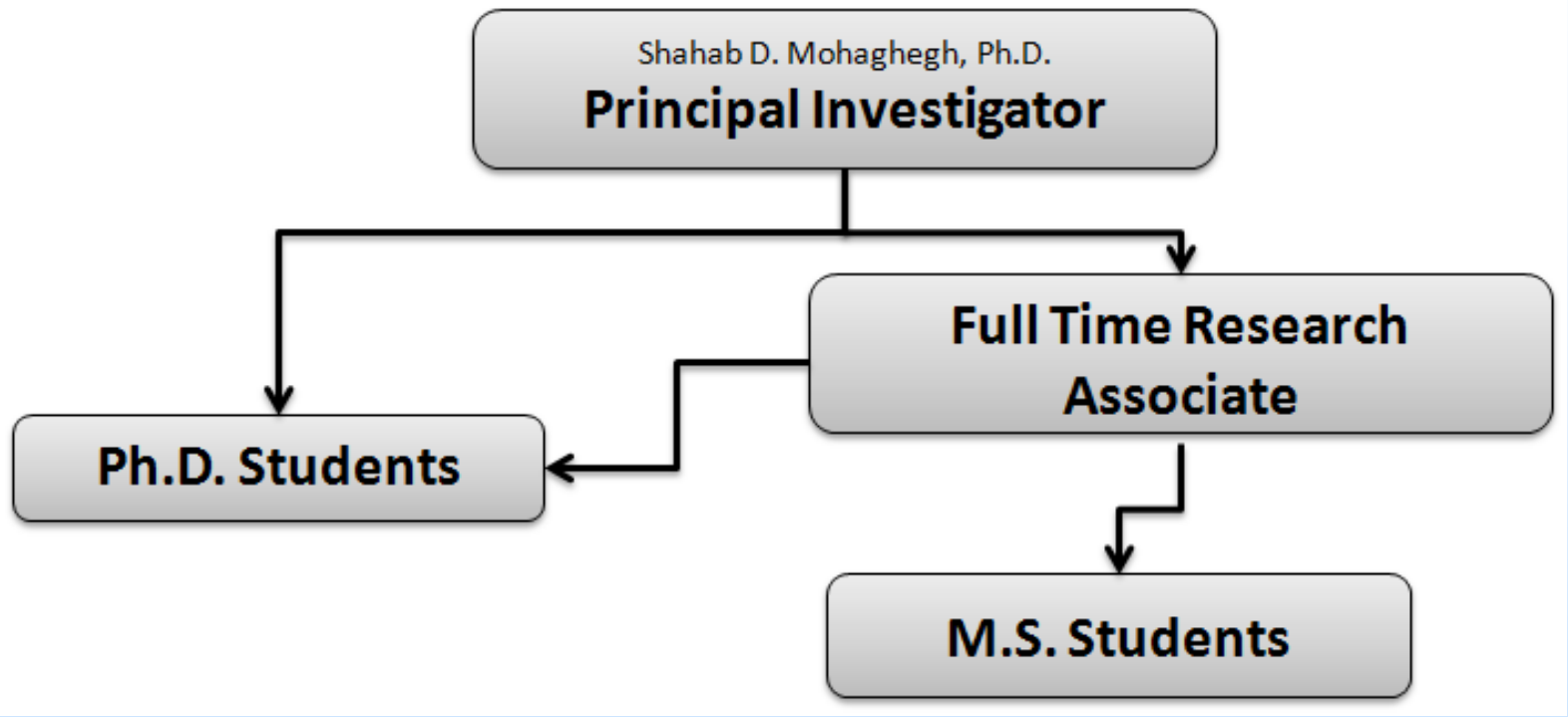
- Benefits statement:
  - This project is developing the next generation of intelligent software that takes maximum advantage of the data collected using “Smart Fields” technology to continuously and autonomously monitor and verify CO_2 sequestration in geologic formations. This technology will accommodate in-situ detection and quantification of CO_2 leakage in the reservoir.

Appendix
Project Overview:
Goals and Objectives

- Goals and objectives in the Statement of Project:
  - This project proposes developing an in-situ CO_2 Monitoring and Verification technology based on the concept of “Smart Fields”. This technology will identify the approximate location and amount of the CO_2 leakage in the reservoir in a timely manner so action can be taken and ensure that 99 percent of the injected CO_2 remains in the injection zone.

- Success Criteria and Decision Points:
  - There are a total of 10 milestones (and 4 sub-Milestone) in this project.
  - Decision points come at the end of quarters 4 (Milestone 2.2) and 15 (Milestone 6). At the decision points a “go” or “no go” decision on the continuation of the project is made based on the accomplishments of the project up to that point.

Appendix
Organization Chart

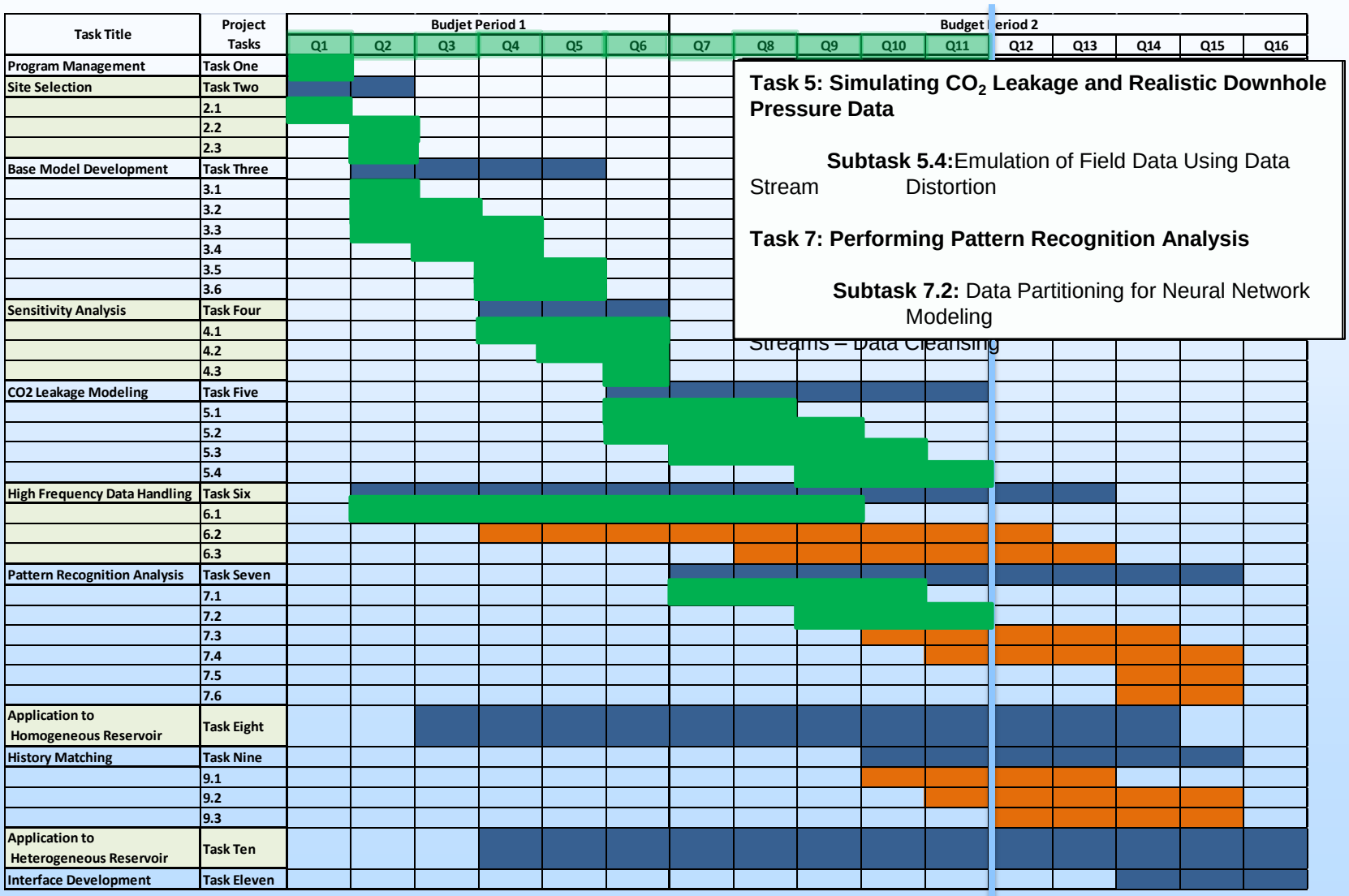


Main Contributors (Research & Development): Alireza Haghighat, Alireza Shahkarami, Daniel Moreno, Najmeh Borzoui, and Yasaman Khazaeni.

Full Time Research Associate: Vida Gholami,

Appendix
Gantt Chart

August 15, 2012



Task 5: Simulating CO_2 Leakage and Realistic Downhole Pressure Data

Subtask 5.4: Emulation of Field Data Using Data Stream Distortion

Task 7: Performing Pattern Recognition Analysis

Subtask 7.2: Data Partitioning for Neural Network Modeling

Streams – Data Cleansing

Milestone Timelines

Milestone log				
	Title	Description	Related task or subtask	Completion Date
Budget Period 1				
Milestone 1.1	Advisory Board Meeting	Advisory board should get together for a meeting (or conference call) to select a site for the project.	Subtask 2.1	End of First Quarter
Milestone 1.2	Site Selection	A site must be selected for the project.	Subtask 2.2, 2.3	End of Second Quarter
Milestone 2.1	Data collection	Completion of geologic and production data collection	Subtask 3.2	End of Third Quarter
Milestone 2.2	Completion of geological model	Completion of geologic/geo-cellular model	Subtask 3.3	End of Fourth Quarter
Milestone 2.3	Completion of the base model	Completion and testing the base flow model	Subtask 3.6	End of Fifth Quarter
Milestone 3	Sensitivity Analysis	Completion of the sensitivity analysis on the reservoir model	Subtask 4.3	End of Sixth Quarter
Budget Period 2				
Milestone 4.1	CO2 Leakage Modeling	Model realistic CO2 leakage from the formation	Subtask 5.1	End of Eighth Quarter
Milestone 4.2	Downhole pressure modeling	Model realistic real-time downhole pressure measurements.	Subtask 5.2, 5.3, 5.4	End of Eleventh Quarter
Milestone 5	Handling High Frequency Data	Developing techniques for handling high frequency data	Subtask 6.1, 6.2, 6.3	End of Thirteenth Quarter
Milestone 6	Pattern recognition	Completing pattern recognition analysis	Subtask 7.1, 7.2, 7.3, 7.4, 7.5, 7.6	End of Fifteenth Quarter
Milestone 7	Application to Homogeneous system	Completing of analysis and application to Homogeneous system	Task 8	End of Fifteenth Quarter
Milestone 8	CO2 Injection Modeling	Completion of modeling the CO2 injection.	Subtask 9.3	End of Fifteenth Quarter
Milestone 9	Application to Heterogeneous system	Completing of analysis and application to Heterogeneous system	Task 10	End of Sixteenth Quarter
Milestone 10	Build Program Interface	Completion of Software Package	Task 11	End of Sixteenth Quarter