In-Situ MVA of CO_2 Sequestration Using Smart Field Technology

FE - 0001163

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West Virginia University

U.S. Department of Energy

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

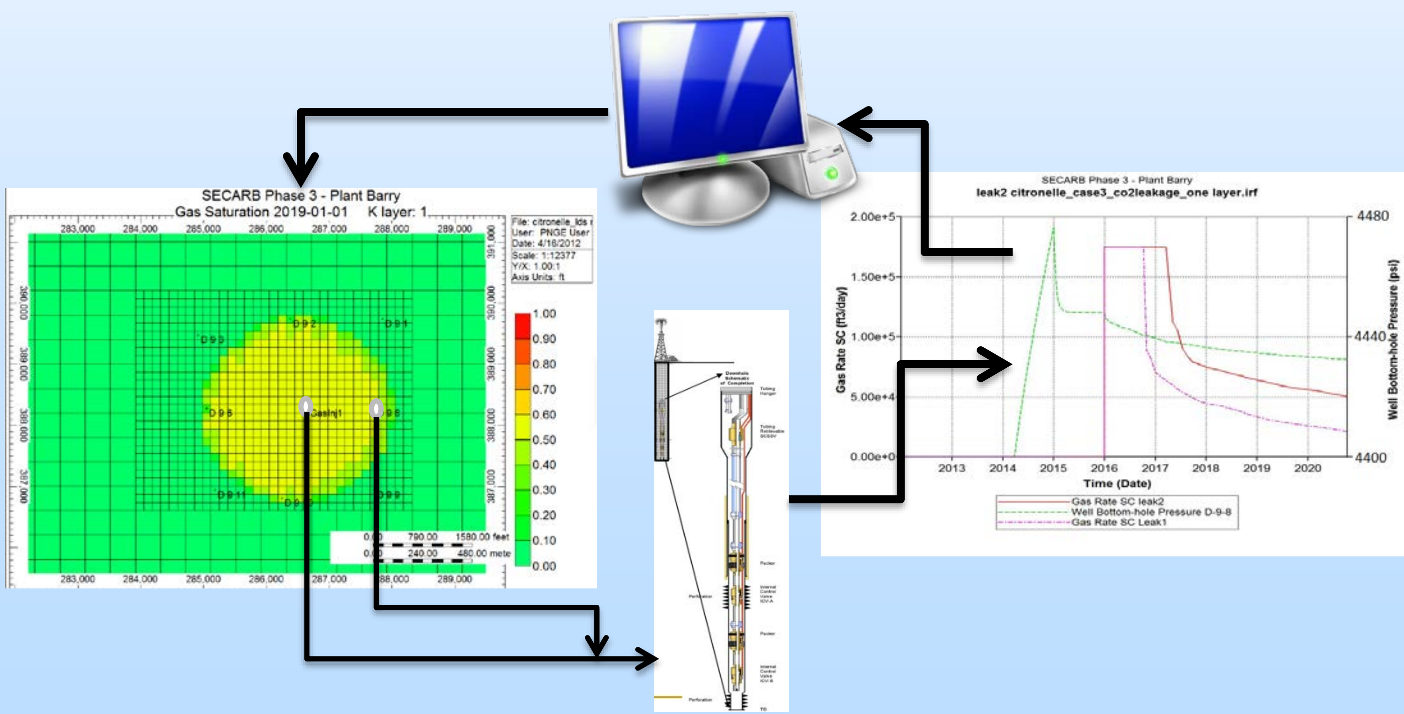
August 12-14, 2014

Presentation Outline

- Introduction
  - Objective
  - Background
  - Industrial Review Committee
- Model Development and History Match
- Real-time Intelligent Leakage Detection System (R-ILDS) Development
- R-ILDS Comprehensive Assessment
- 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)

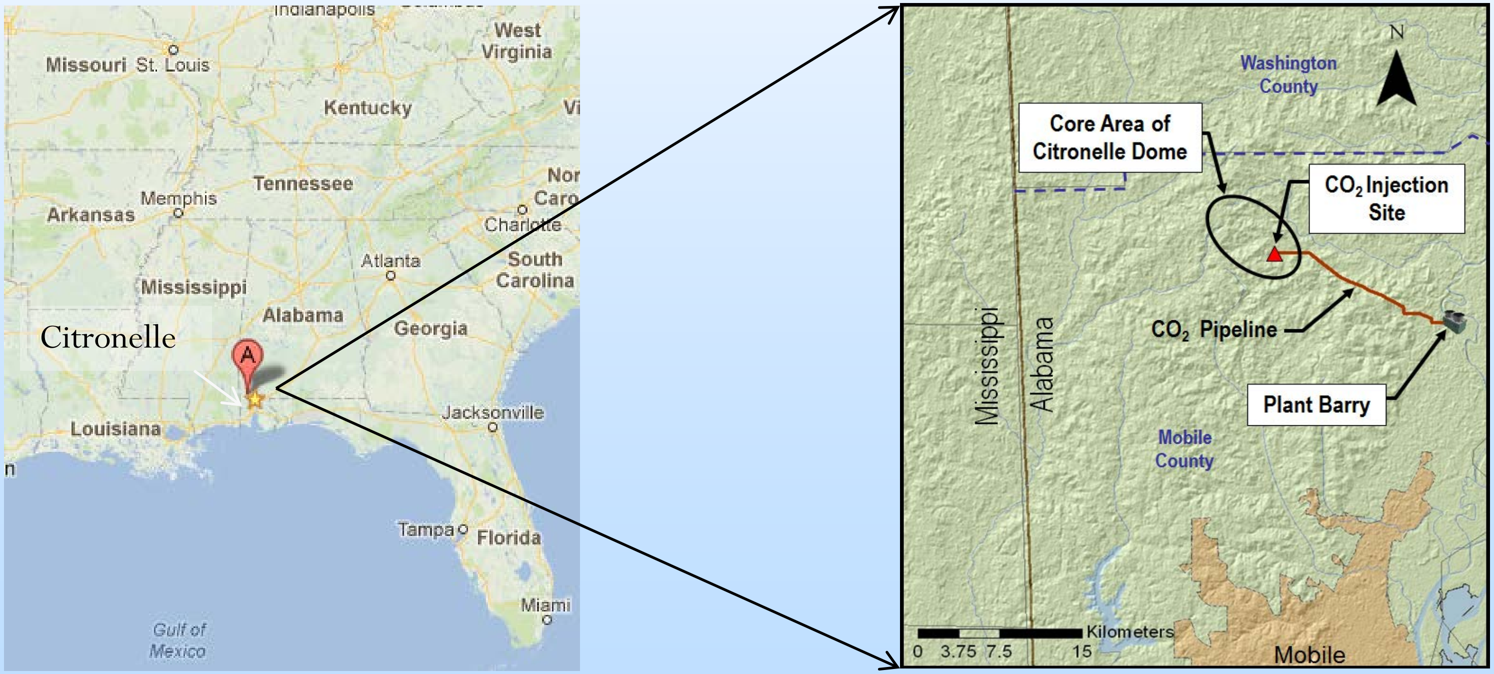
- Project goes through continuous peer-review by an Industrial Review Committee.

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 in parallel to 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
  - April 8th 2013
    - Reporting the modeling process, history match and leakage detection system results to NETL/DOE

Project Overview(Citronelle)

Fluid Being Injected	**Carbone Dioxide**
Geological Formation	***Paluxy***
Depth	***9,400-10500 ft below GL***
Depth of Injection Well	***11,800 ft***
Injection Volumes	***500 ton/day(9.48 Bcf/day)***
Injection Duration	***3 Years(2012-2015)***

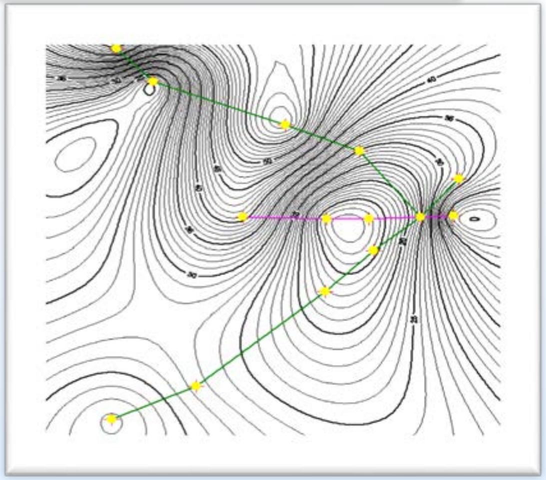


Steps Involved in the Methodology

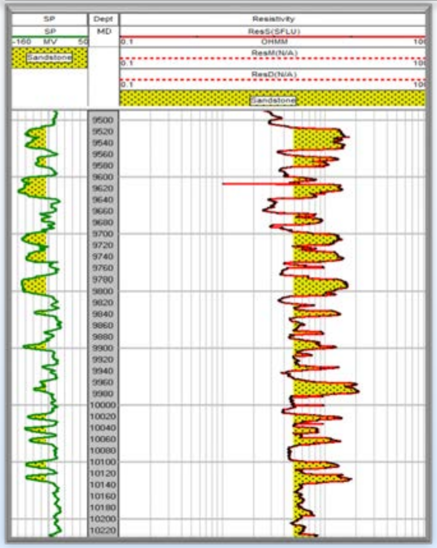
- Building a Geological Model.
  - Using Well Logs (40 wells)
  - Using Core Data
  - Multiple Rock Types
- Building a Reservoir Simulation Model.
  - 800,000 cells base model
- History Match Reservoir Simulation Model.
  - 400 simulation runs
- Building a Leakage Model.
  - Modeling leakage through abandoned wells.
- Real-Time Data Preparation.
  - Data cleansing and abstraction.
- Pattern Recognition for Leakage Detection.
  - Data set preparation
  - Data-Driven Model Training, Calibration and Validation
- Final Evaluation.
  - Test the developed system over various realizations

Geological Model

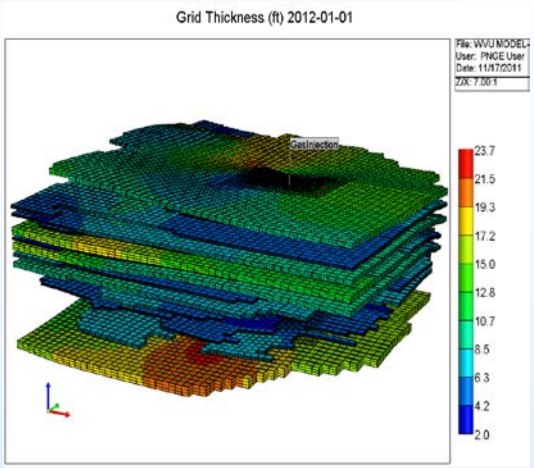
3 Cross Sections



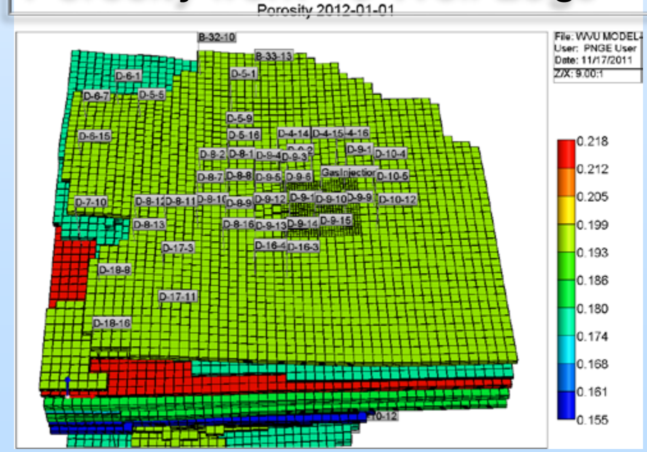
Sand Layers-D-9-7



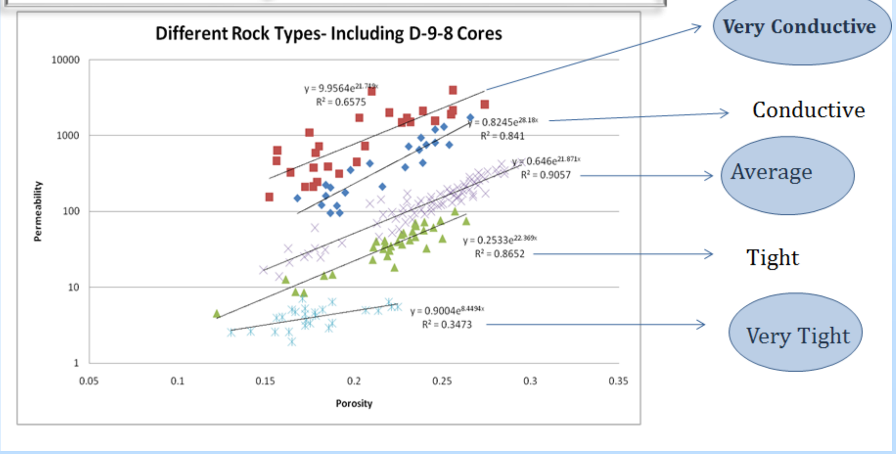
Grid Thickness



Porosity from 40 Well Logs

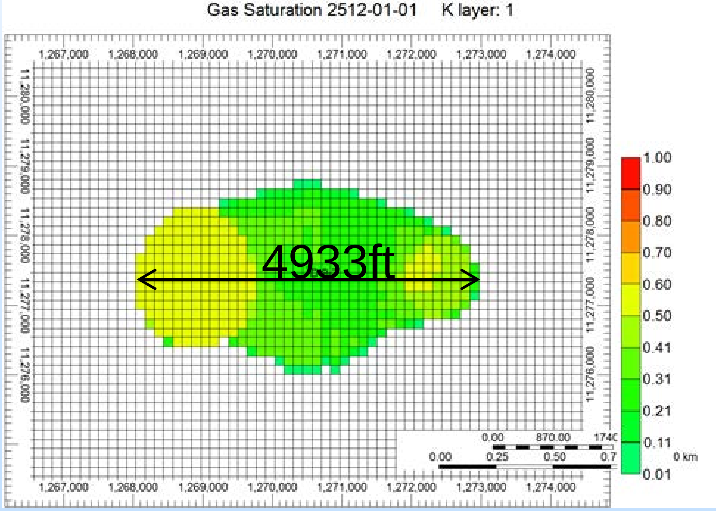


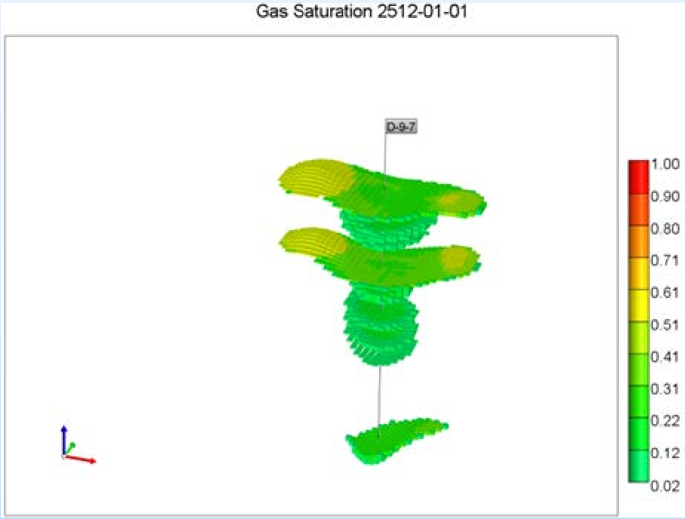
Permeability Realizations



Reservoir Simulation Model

- 17 Layers(10 Injection Layers)
- 51 Simulation Layers
- 800,000 Grid Blocks
- Porosity(maps) & Permeability(conductive rock)





Plume extension: 500 years after injection ends.

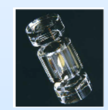
Plume extension is shown only for the blocks with CO_2

Citronelle Field

Observation Well

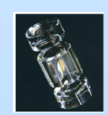
Injection Site

PDG 5109

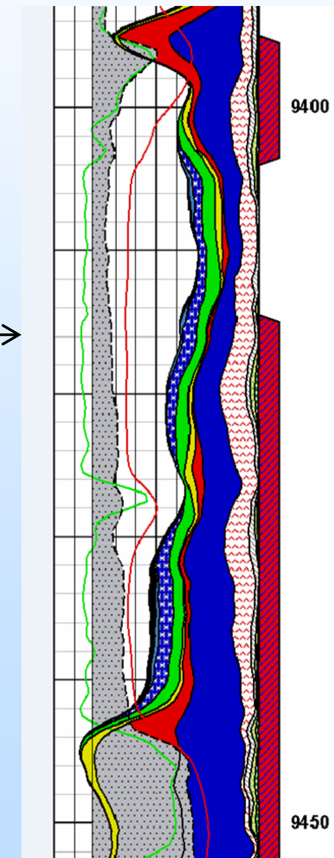


9416ft

PDG 5108



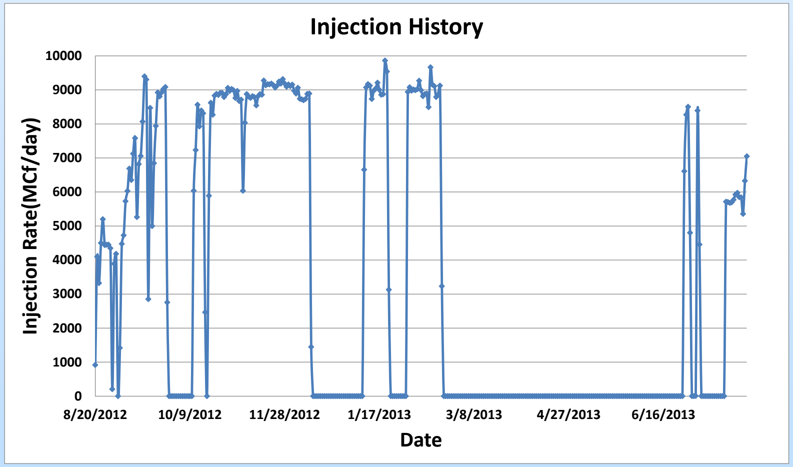
9441ft

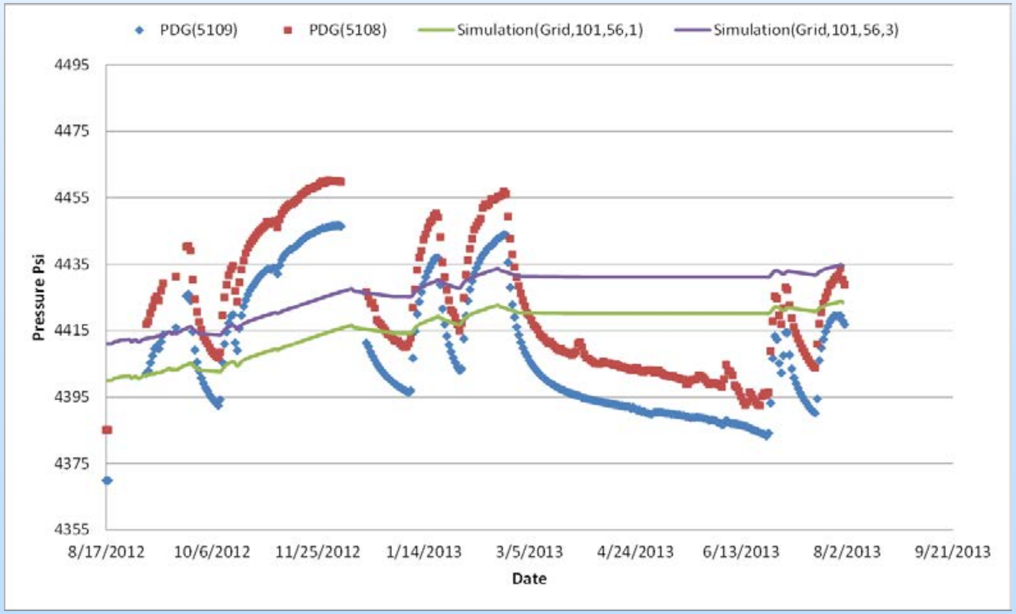


Base Reservoir Simulation Model

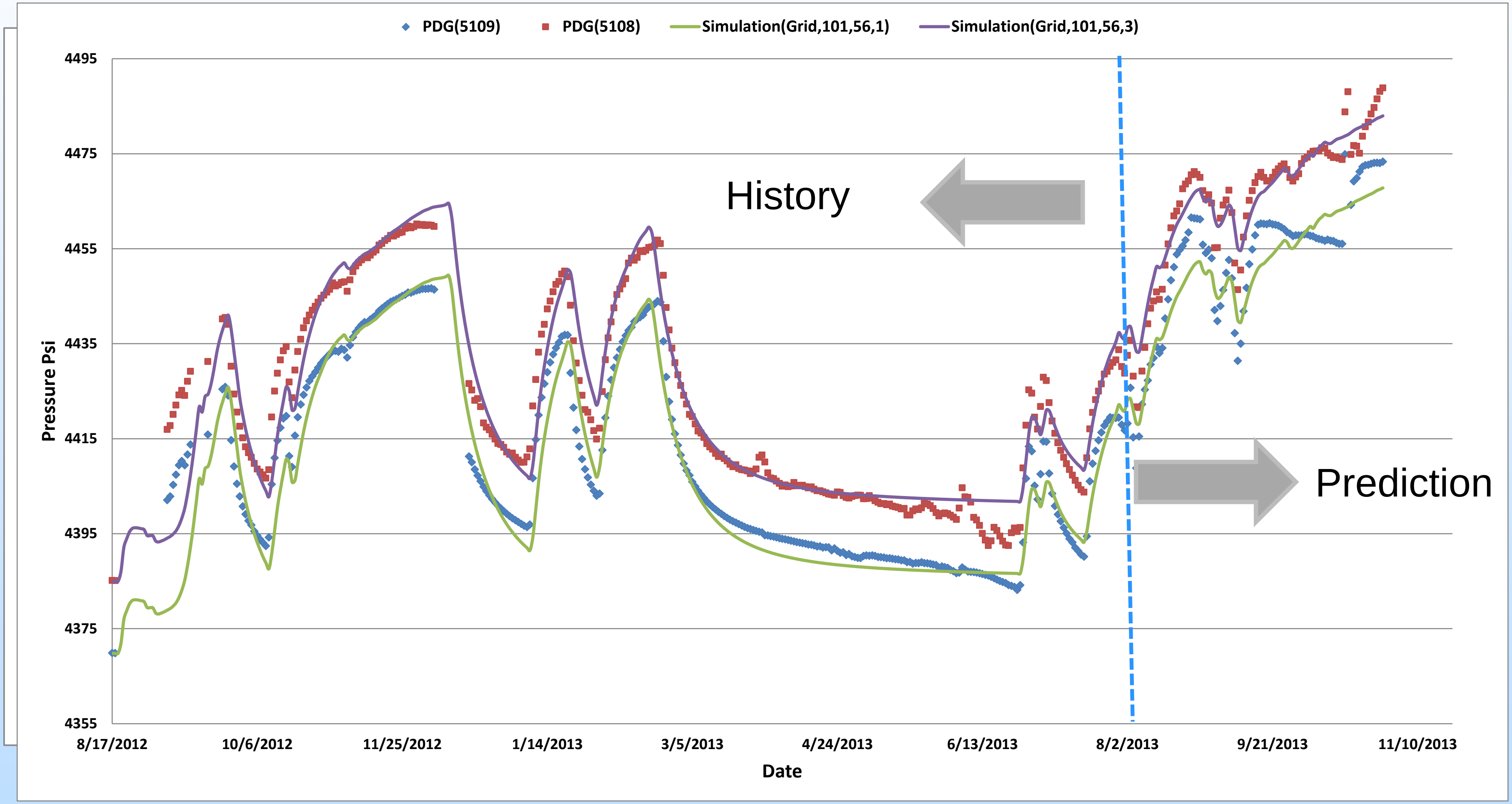
-17 Layers(10 Injection Layers)
-51 Simulation Layers
-Porosity Distribution from 40 Well Logs
-125*125*51(800000) Grid Blocks
-Relative Perm: Mississippi Test site
-Operational Constraints: Actual Rate +Max BHP

Parameter	Value	Parameter	Value
Permeability (md)	460	Water density (lb/ft3)	62
Temperature (◦F)	230	Water viscosity (cp)	0.26
Salinity (ppm)	100,000	Water compressibility (1/psi)	3.2E-6
Residual gas saturation	0.35	Kv/Kh (permeability ratio)	0.1
Residual water saturation	0.6	Pressure reference@9415 ft (psi)	4393



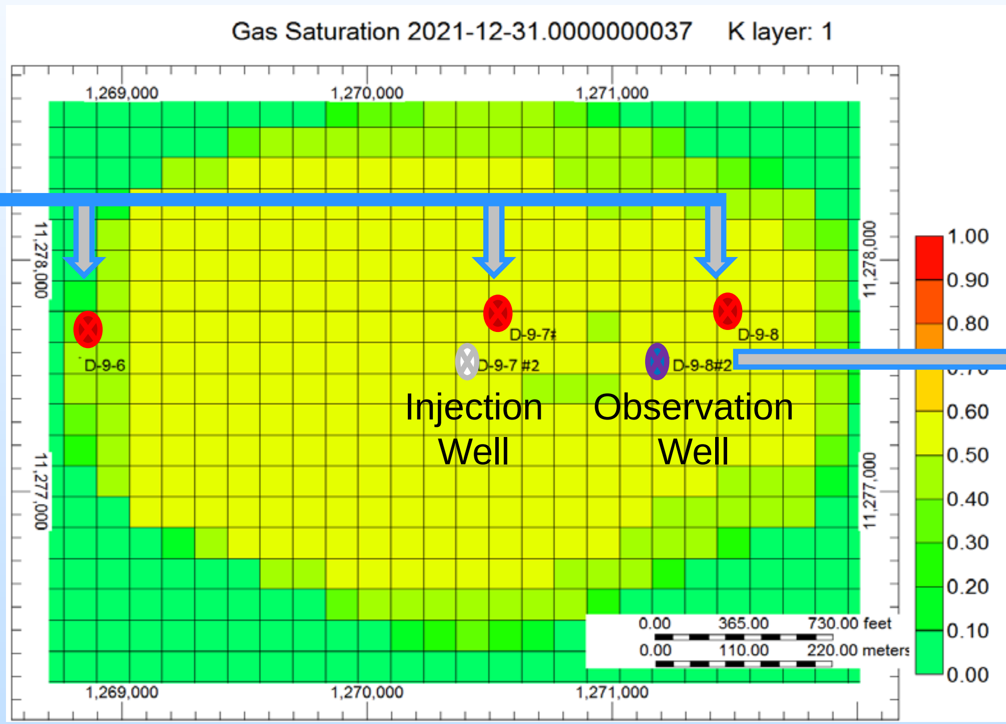


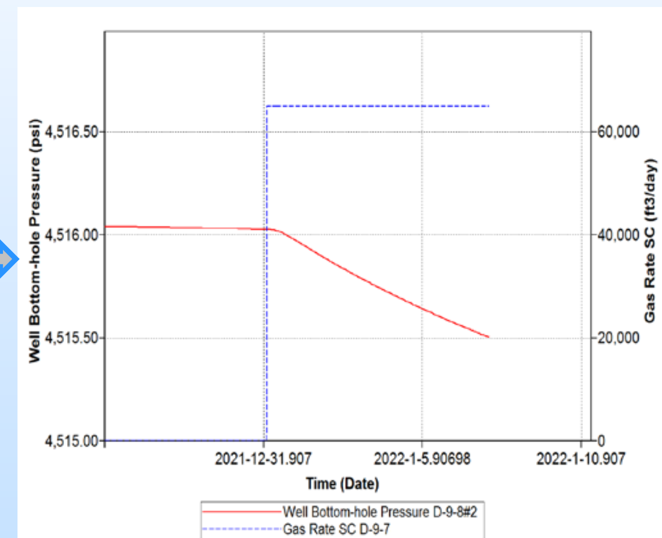
Final History Match



Real-time Intelligent leakage Detection System(R-ILDS)

Pressure Signal





Leakage Rate
Mcf/day
15
25
35
45
55
65
75
85
95
105

R-ILDS

Input

ΔP

t

$\frac{\Delta P}{\Delta t}$

Sum

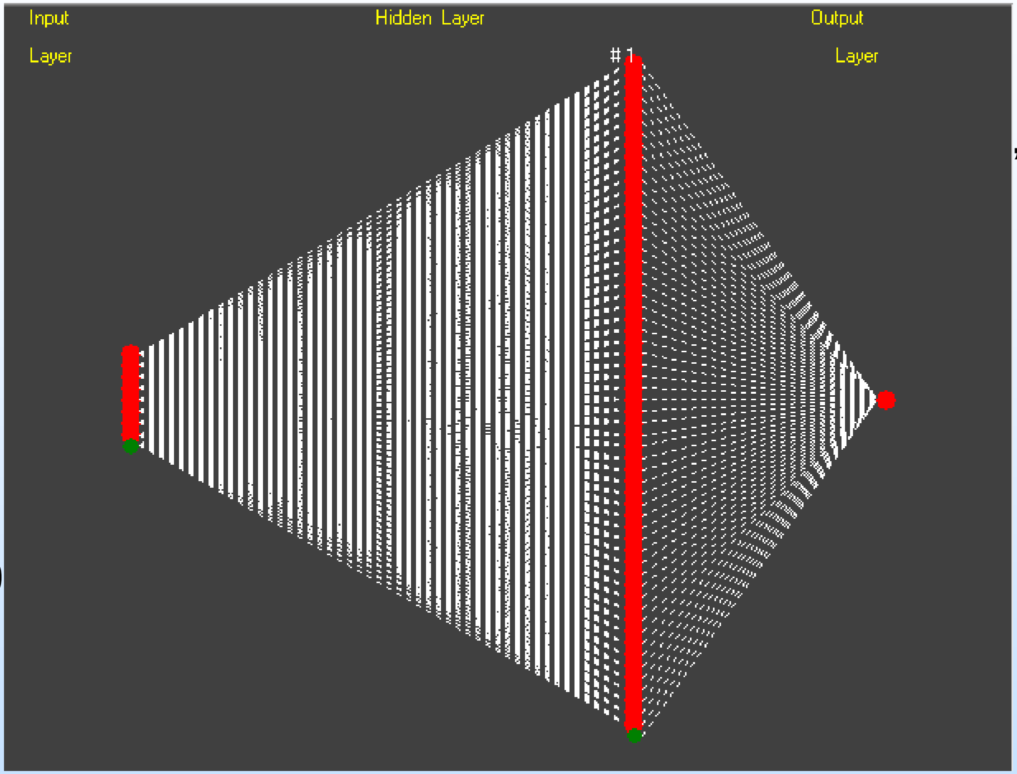
Average

STD

Skewness

Kurtosis

ΔP=0.0



Output

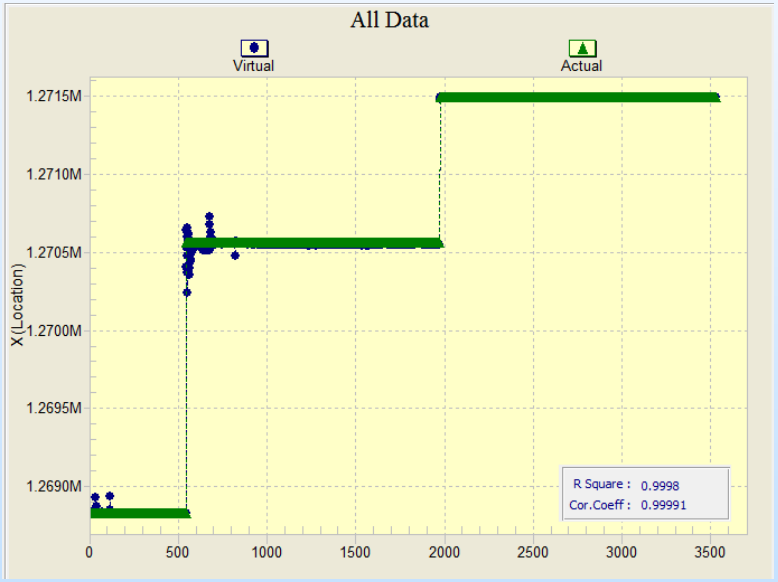
, Kurtosis

Q(Leakage)

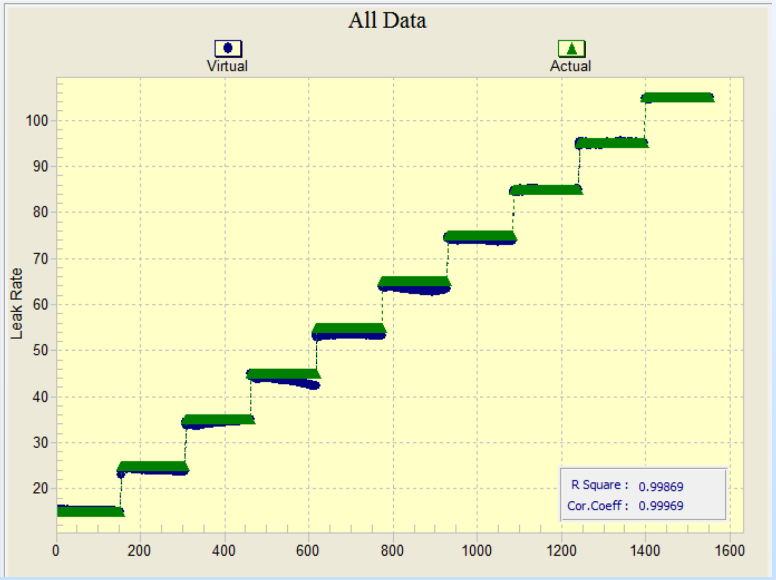
X(Leakage)

R-ILDS Results – Training

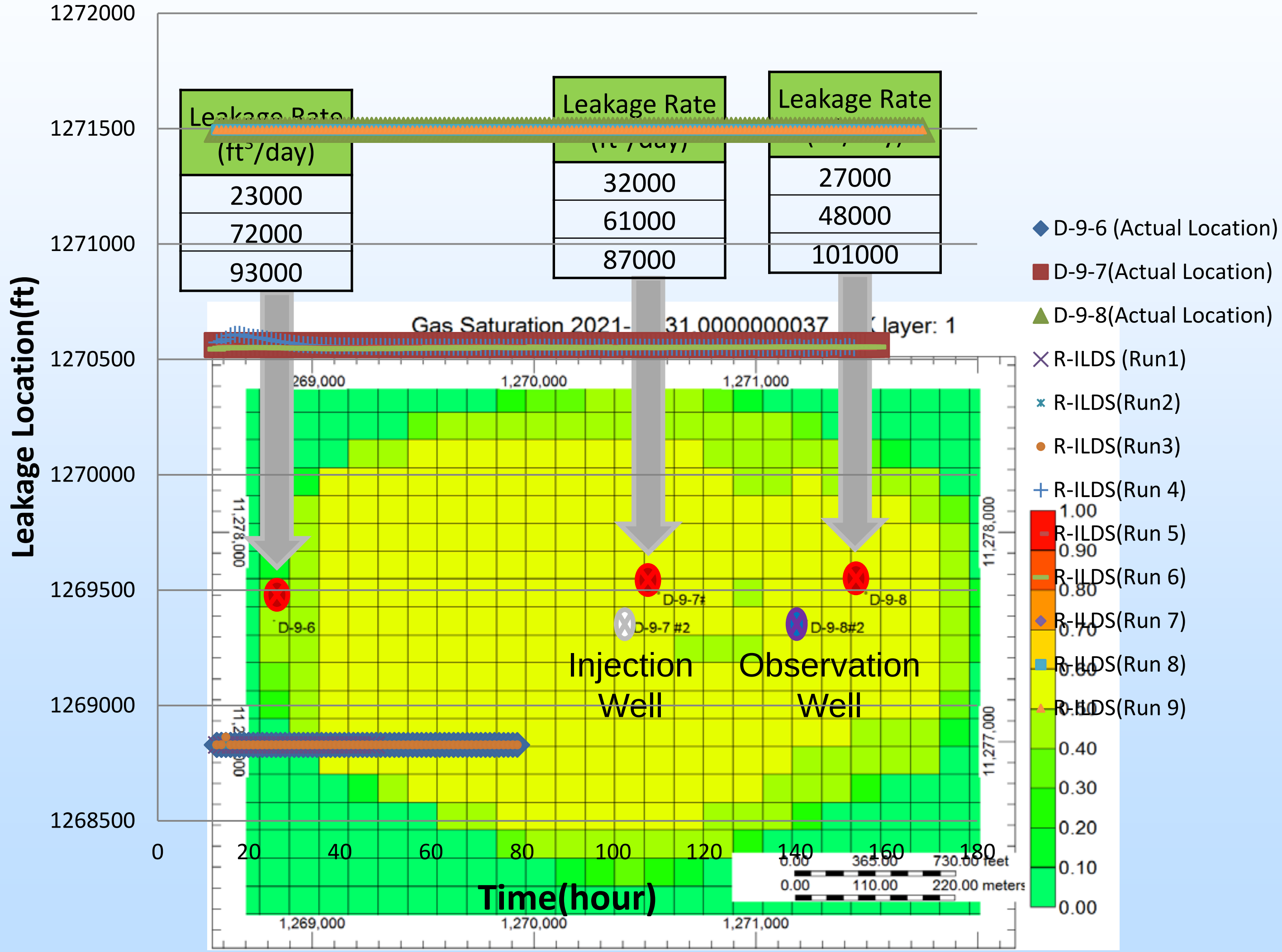
Leakage Location



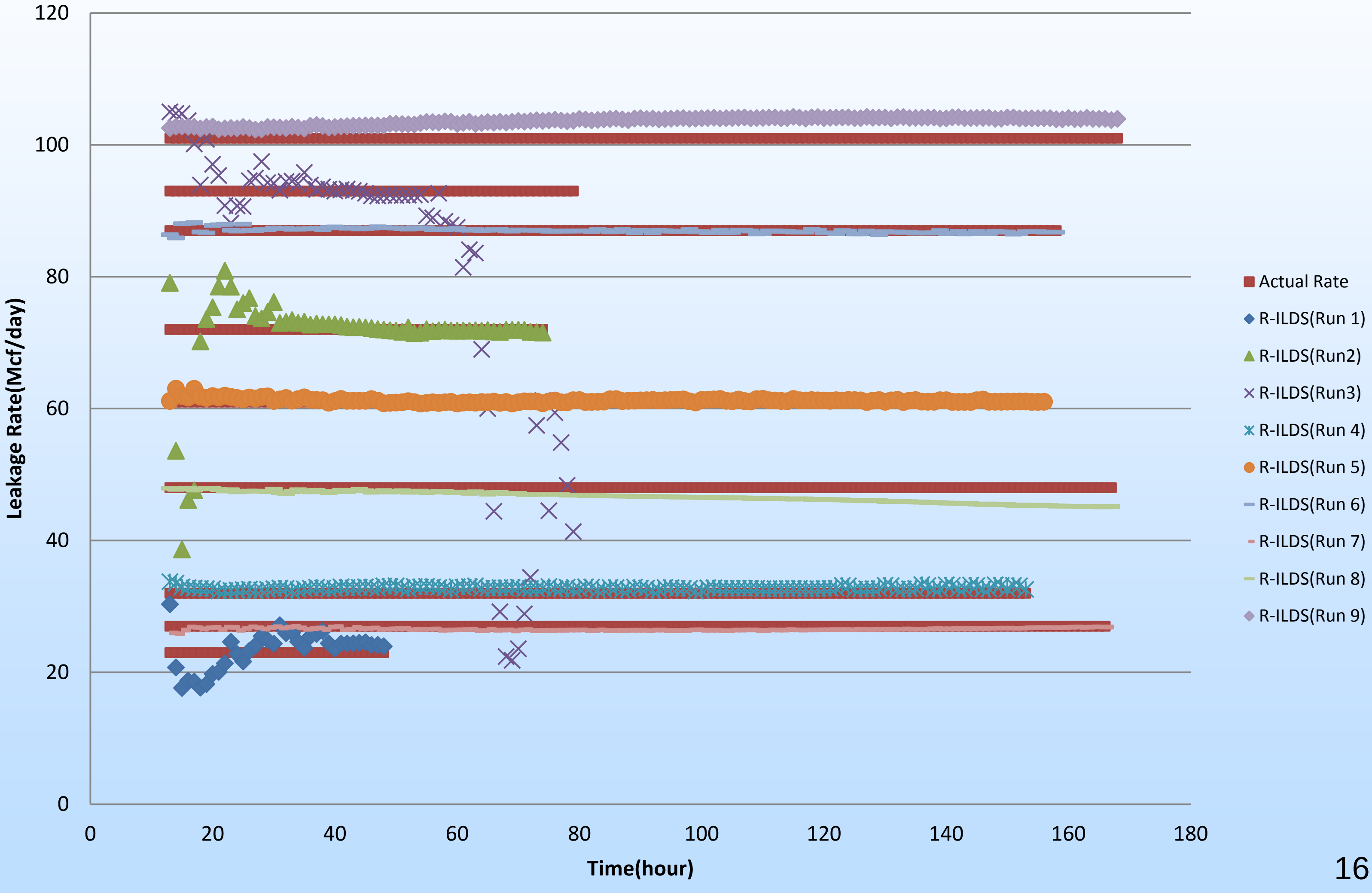
Leakage Rate



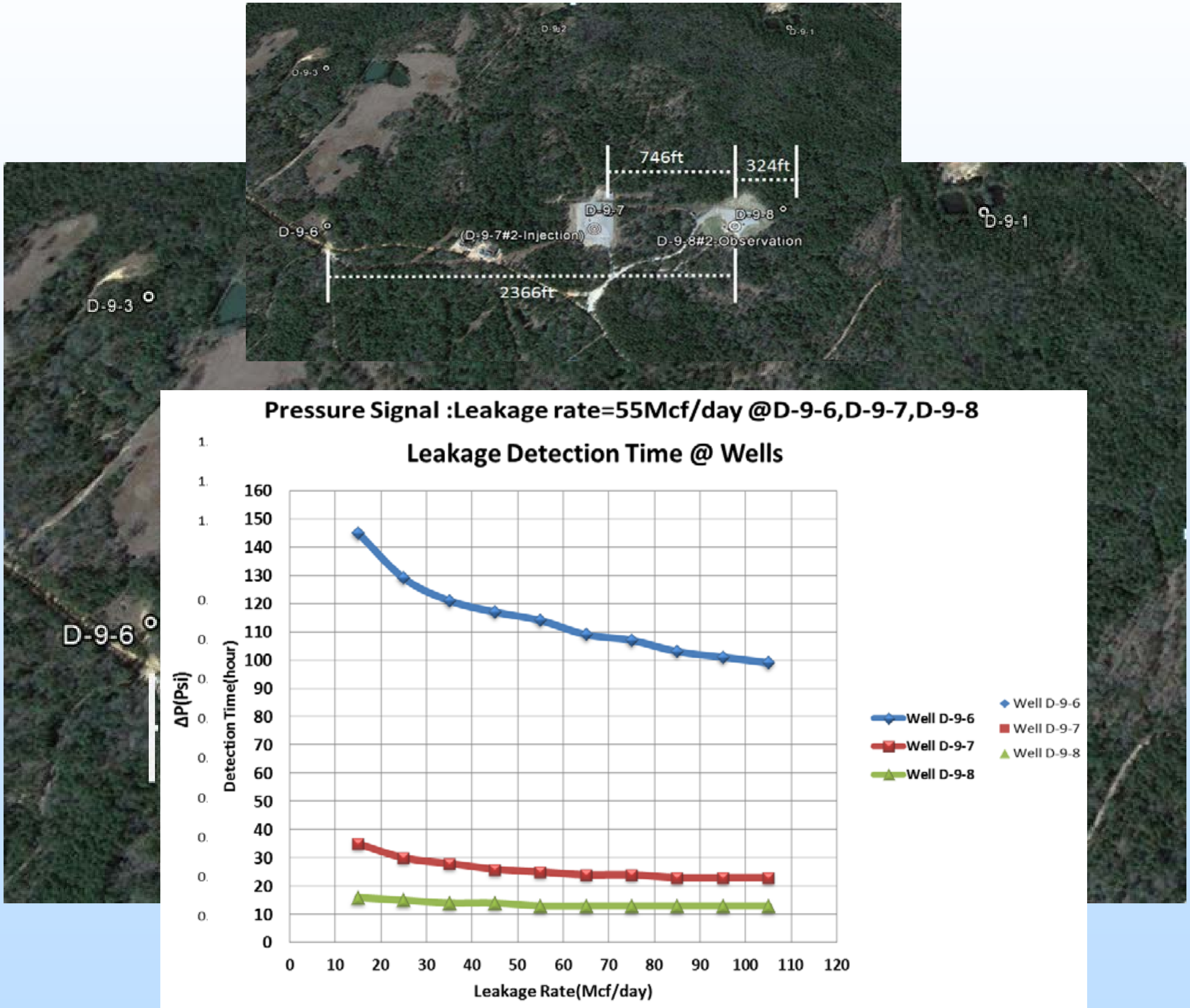
R-ILDS Results – 9 Blind Validation Runs



R-ILDS Results – 9 Blind Validation Runs



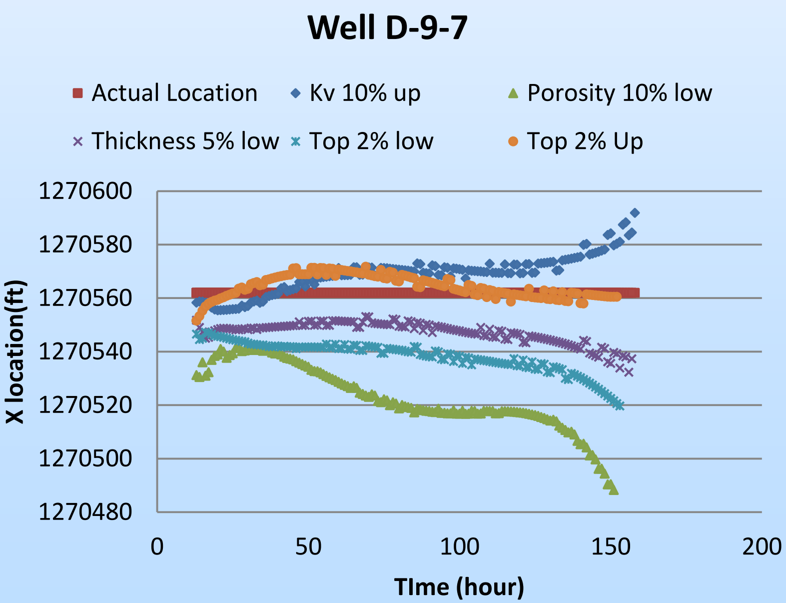
Detection Time

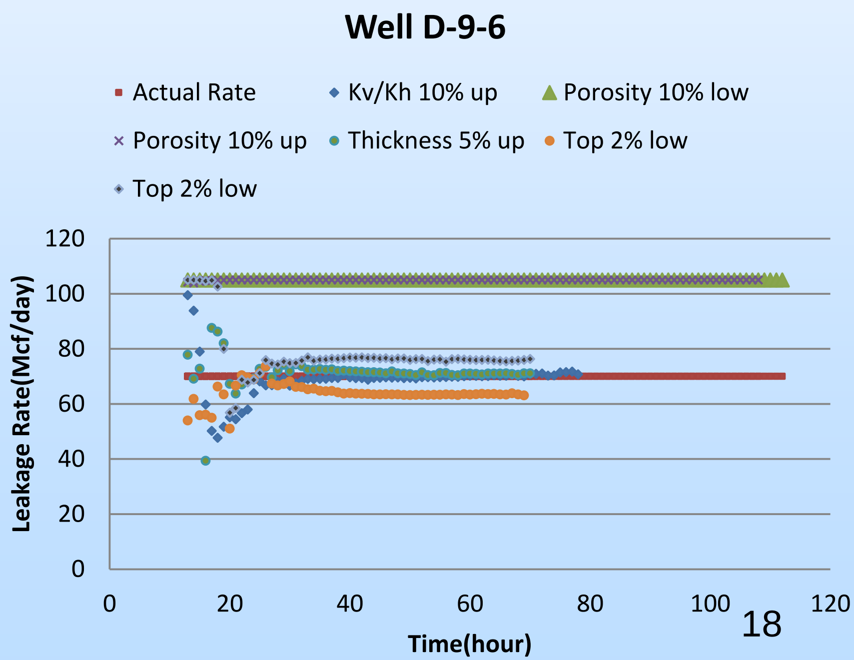


Impact of Geologic Realization

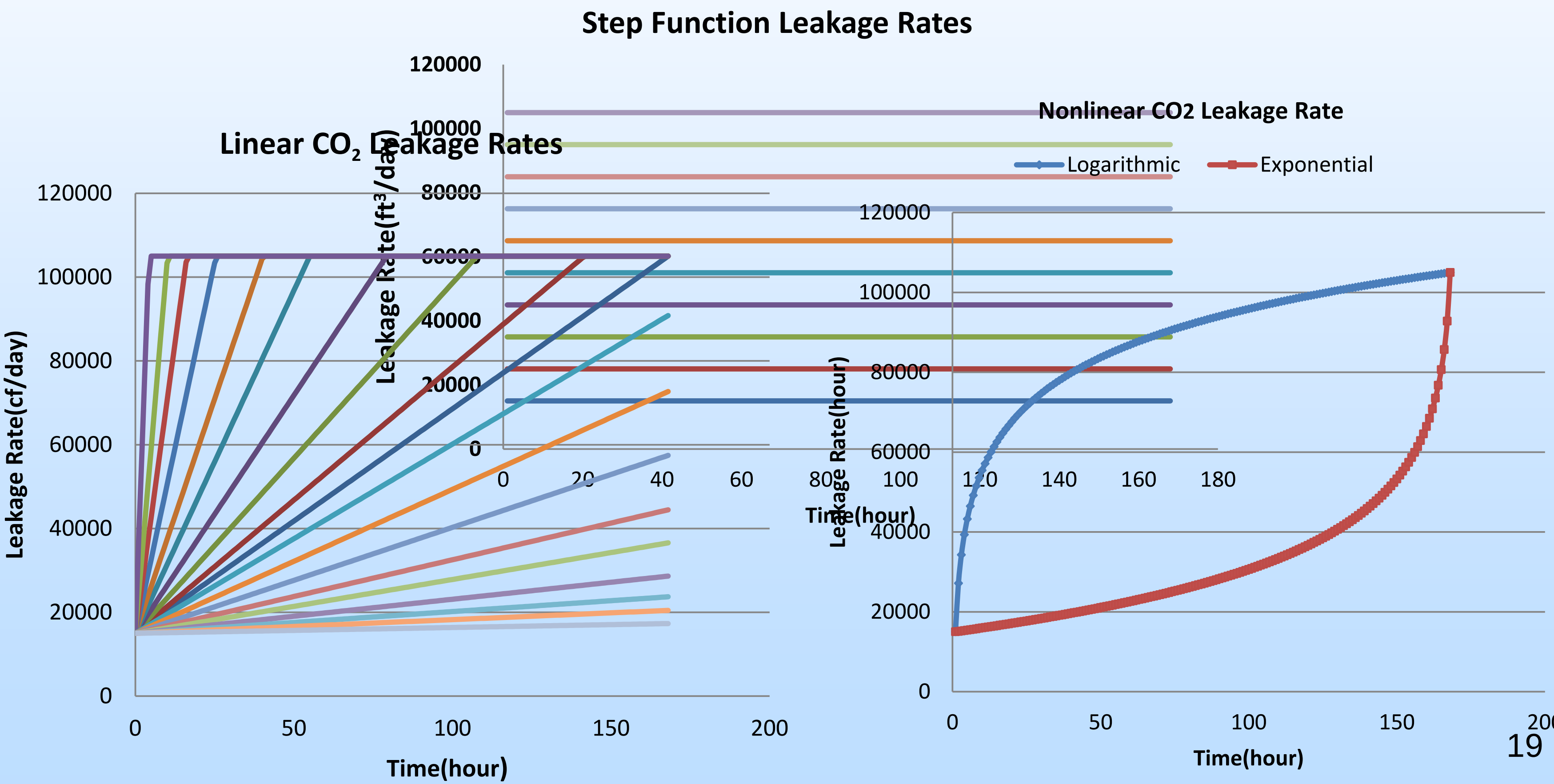
Reservoir Parameter \ Variation	2% UP	2% Down	5% Down	10% up	10% Down
Porosity				X	X
Sand Layer Top	X	X			
Sand Layer Thickness			X		
Vertical to Horizontal Permeability Ratio				X	

$$K = 0.64e^{21.87\varphi}$$



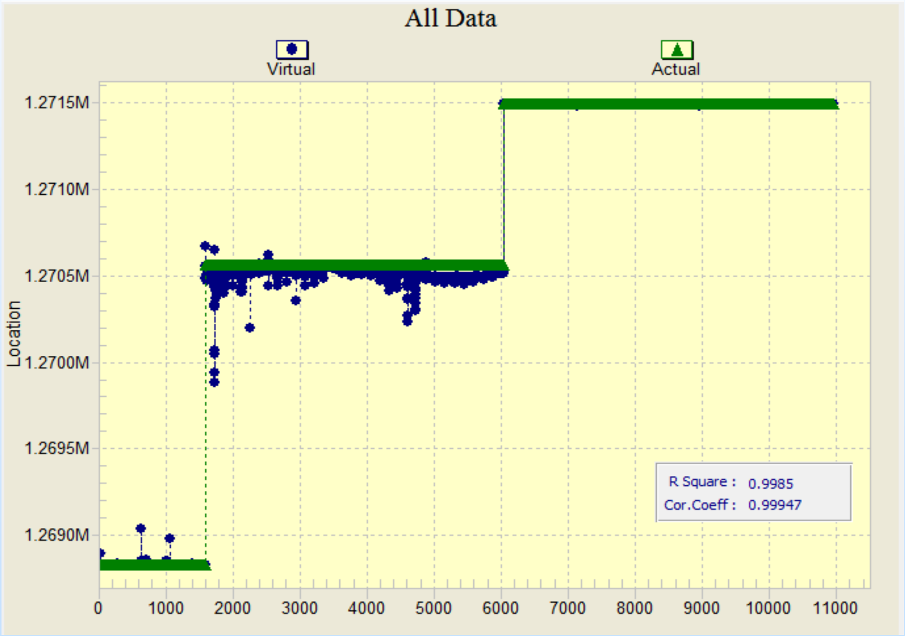


Variable Leakage Rate

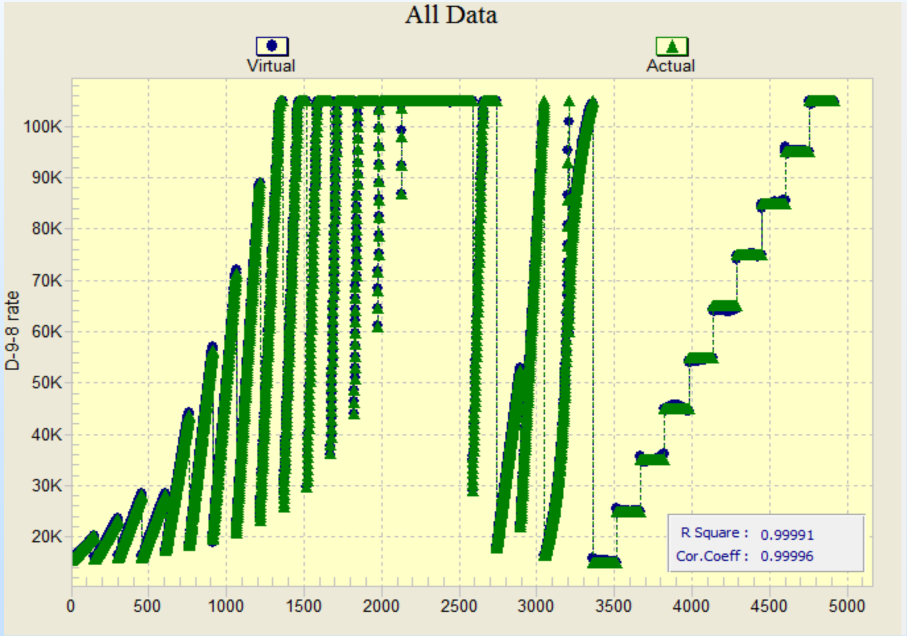


Variable Leakage Rate - Training

Leakage Location

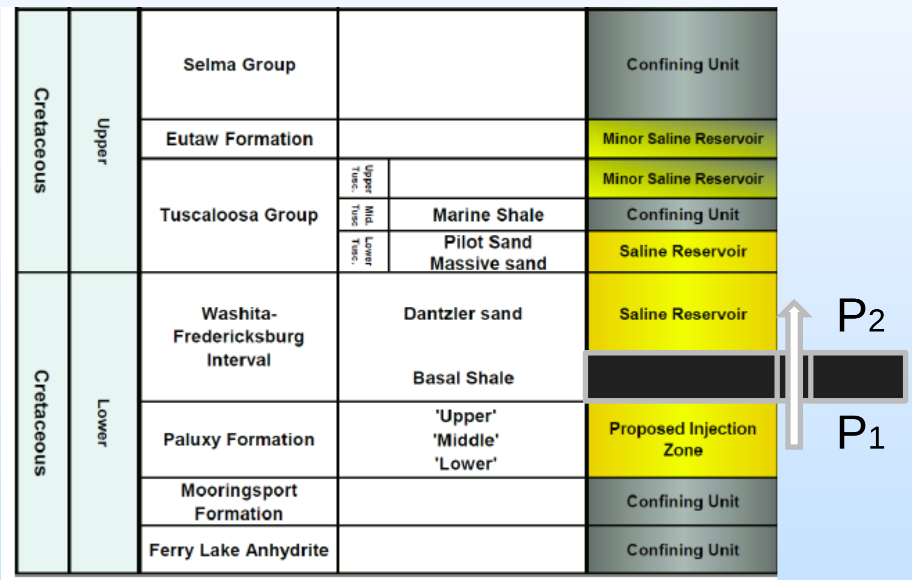


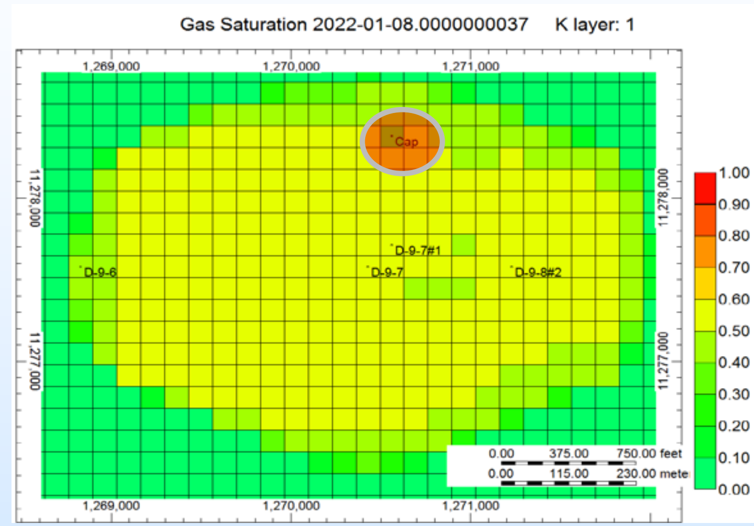
Leakage Rate

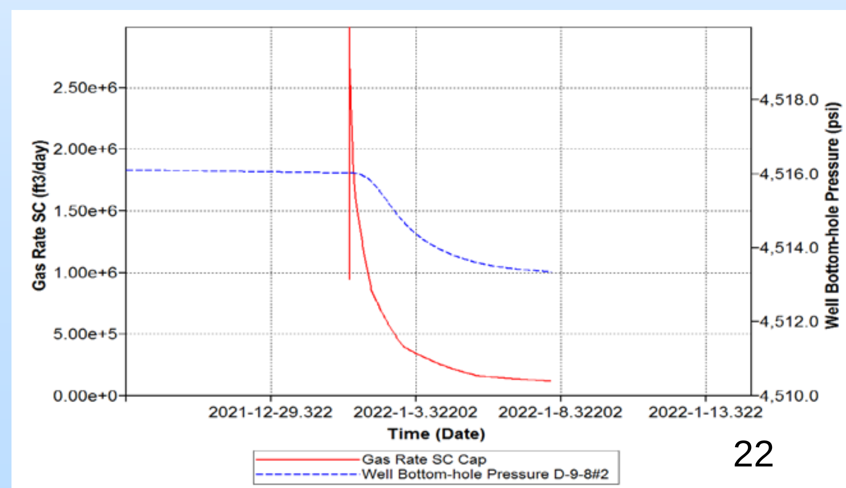


Variable Leakage Rate- Blind Validation

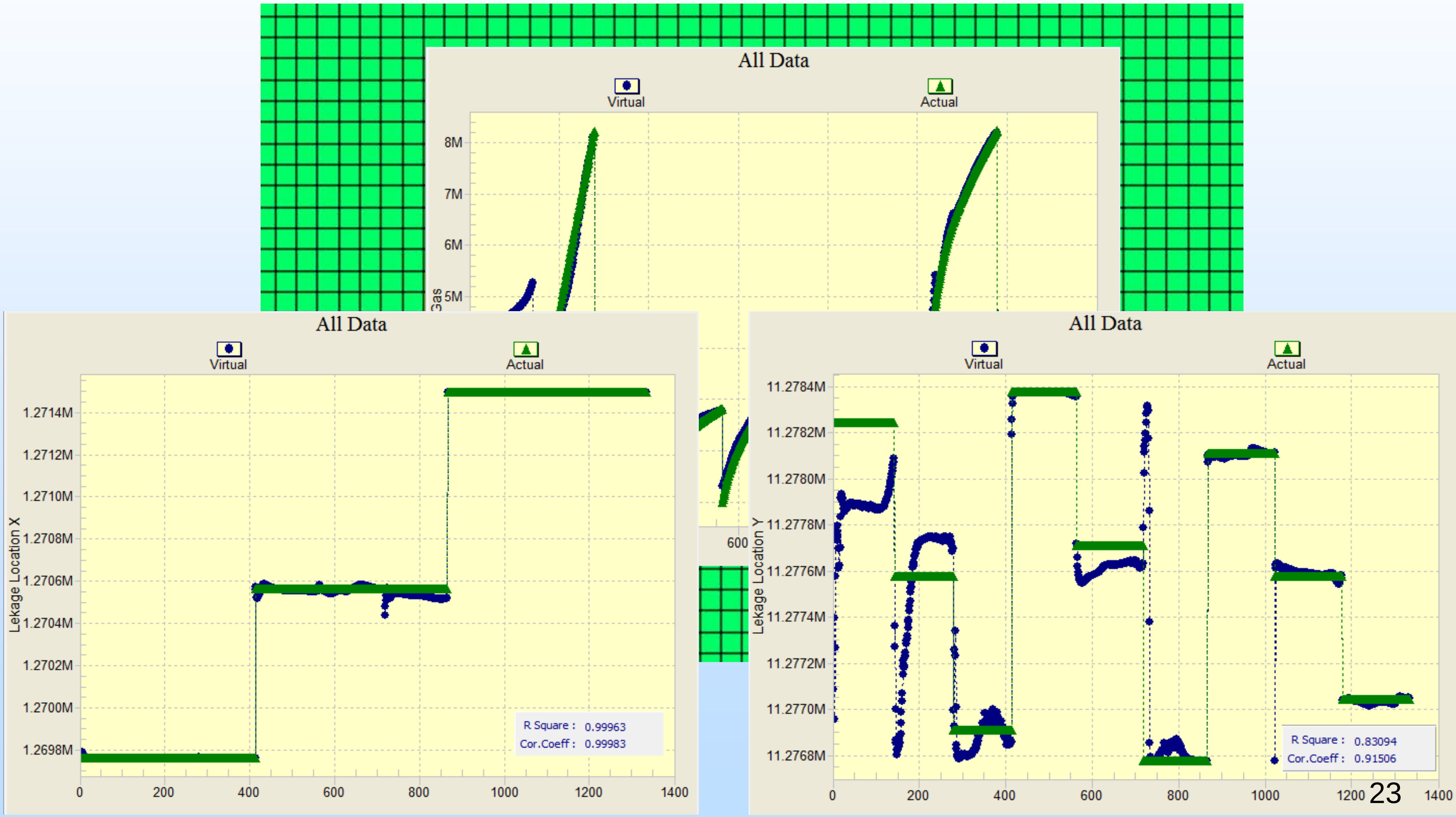
Cap-rock leakage



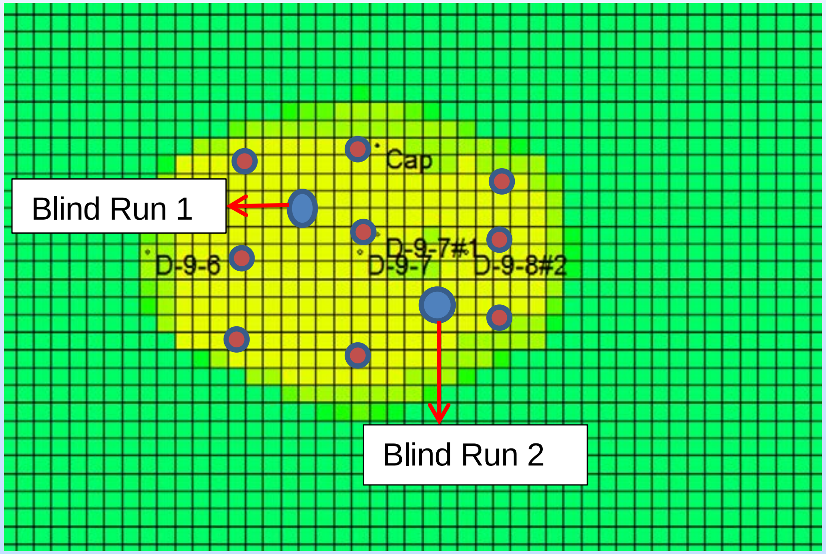




Cap-rock leakage - Training



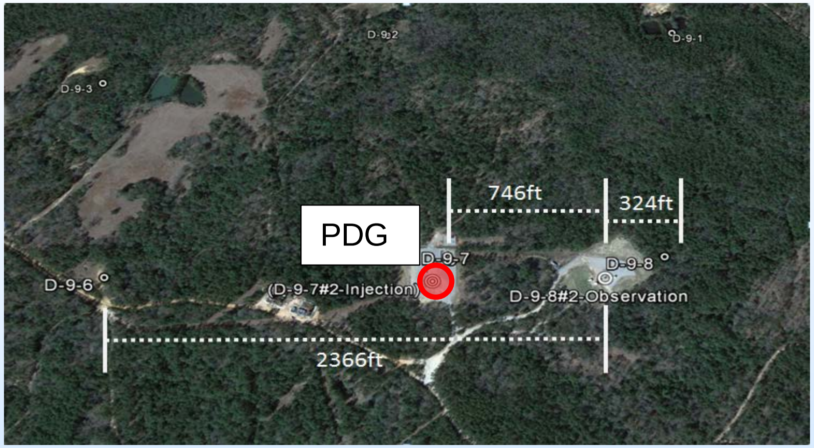
Cap-rock leakage: Blind Validation



Multi-Well Leakage - Training

Two Well			Three Well		
Leakage Rate(Mcf/day)			Leakage rate(Mcf/day)		
D-9-6	D-9-7	D-9-8	D-9-6	D-9-7	D-9-8
15	15	0	15	15	15
15	60	0	15	15	60
15	105	0	15	15	105
60	15	0	15	60	15
60	60	0	15	60	60
60	105	0	15	60	105
105	15	0	15	105	15
105	60	0	15	105	60
105	105	0	15	105	105
15	0	15	60	15	15
15	0	60	60	15	60
15	0	105	60	15	105
60	0	15	60	60	15
60	0	60	60	60	60
60	0	105	60	60	105
105	0	15	60	105	15
105	0	60	60	105	60
105	0	105	60	105	105
0	15	15	105	15	15
0	15	60	105	15	60
0	15	105	105	15	105
0	60	15	105	60	15
0	60	60	105	60	60
0	60	105	105	60	105
0	105	15	105	105	15
0	105	60	105	105	60
0	105	105	105	105	105

54 combinations of leakage locations and rates

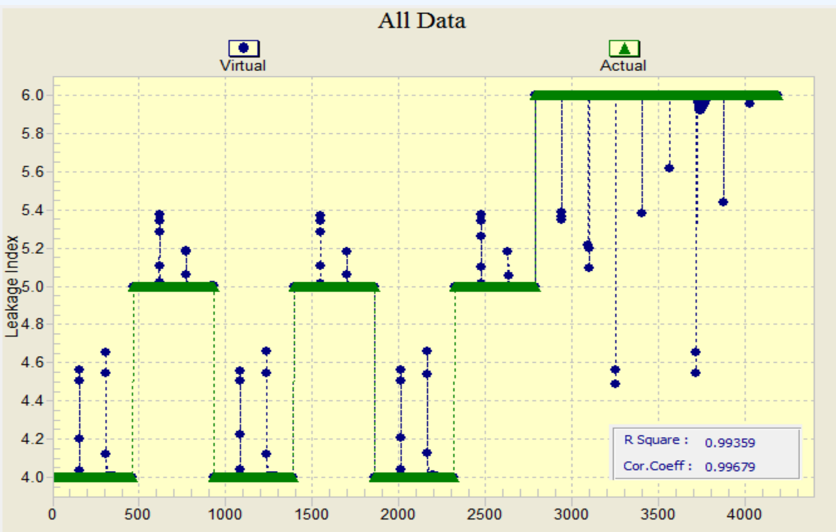


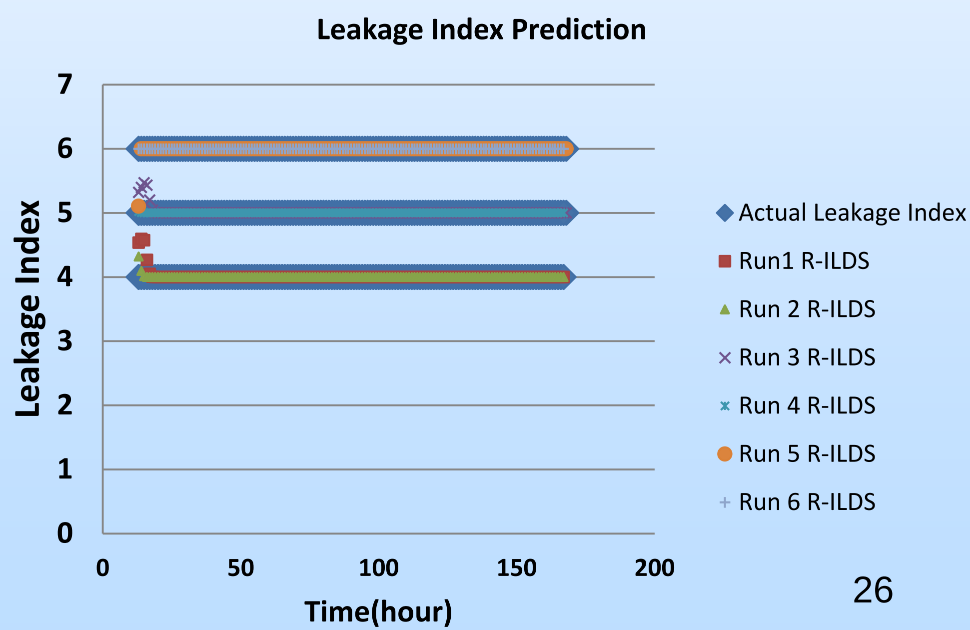
Leaking Well	Leakage Index
D-9-6	1
D-9-7	2
D-9-8	3
D-9-6 & D-9-7	4
D-9-6 & D-9-8	5
D-9-7 & D-9-8	6
D-9-6 & D-9-7 & D-9-8	7

Two-Well Leakage

Multi-Well Leakage – Blind Validation

Blind Run	Two Well Leakage Rate(Mcf/day)			Leakage Index
	D-9-6	D-9-7	D-9-8	
1	40	80	0	4
2	80	40	0	4
3	40	0	80	5
4	80	0	40	5
5	0	40	80	6
6	0	80	40	6





Accomplishments to Date

- Geological model was developed.
- Reservoir simulation model was developed.
- Reservoir simulation model was history matched and verified
- High frequency data was cleansed and summarized.
- Real-time Intelligent Leakage Detection System (R-ILDS) was designed and developed.
  - Validated for history matched reservoir system
  - Validated for various leakage systems

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 a Real-time Intelligent Leakage Detection System (ILDS) is initiated for detection and quantification of CO_2 leakage.

Future Plans:

- Finalize R-ILDS software-interface

Appendix
Benefit to the Program

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

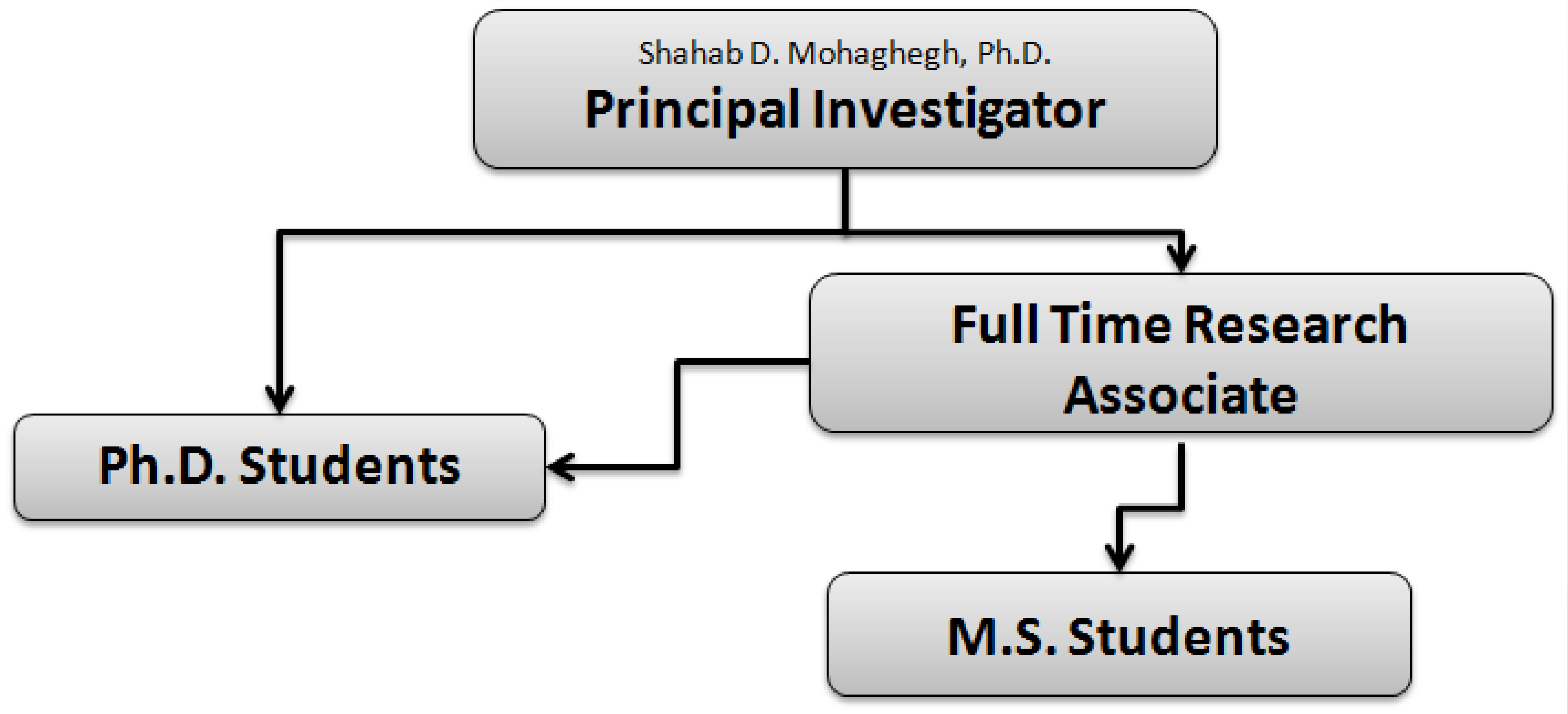
- Benefits statement:
  - This project is developing the next generation of intelligent software that takes maximum advantage of the data collected using “Smart Fields” technology to continuously and autonomously monitor and verify CO_2 sequestration in geologic formations. This technology will accommodate 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:
  - Decision points come at the end of each milestone. There are 16 milestones in this project. After quarters 4 and 15 a "go" or "no go" decision on the continuation of the project was made based on the accomplishments of the project up to that point.

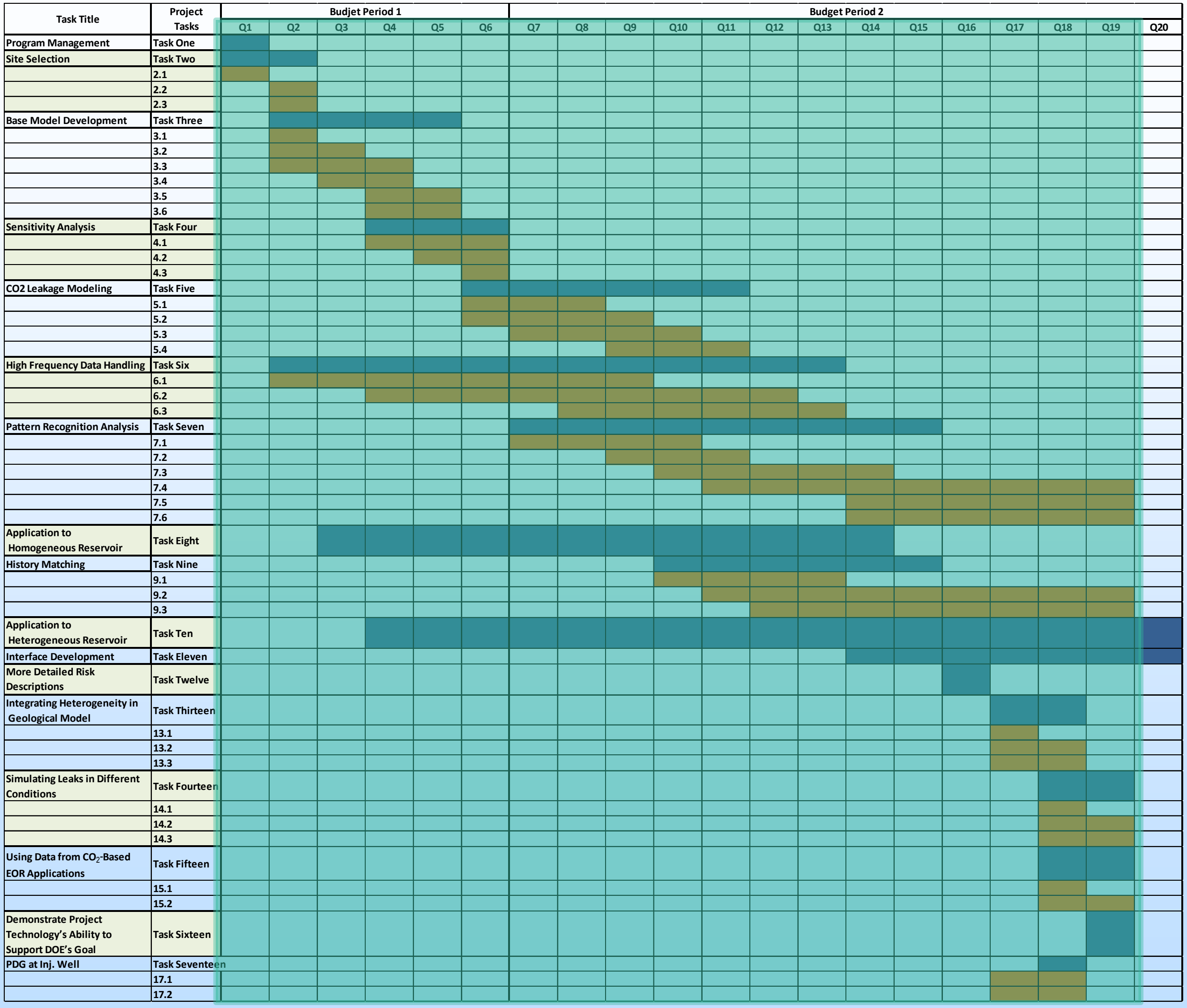
Appendix
Organization Chart



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

Full Time Research Associate: Vida Gholami,

Appendix
Gantt Chart



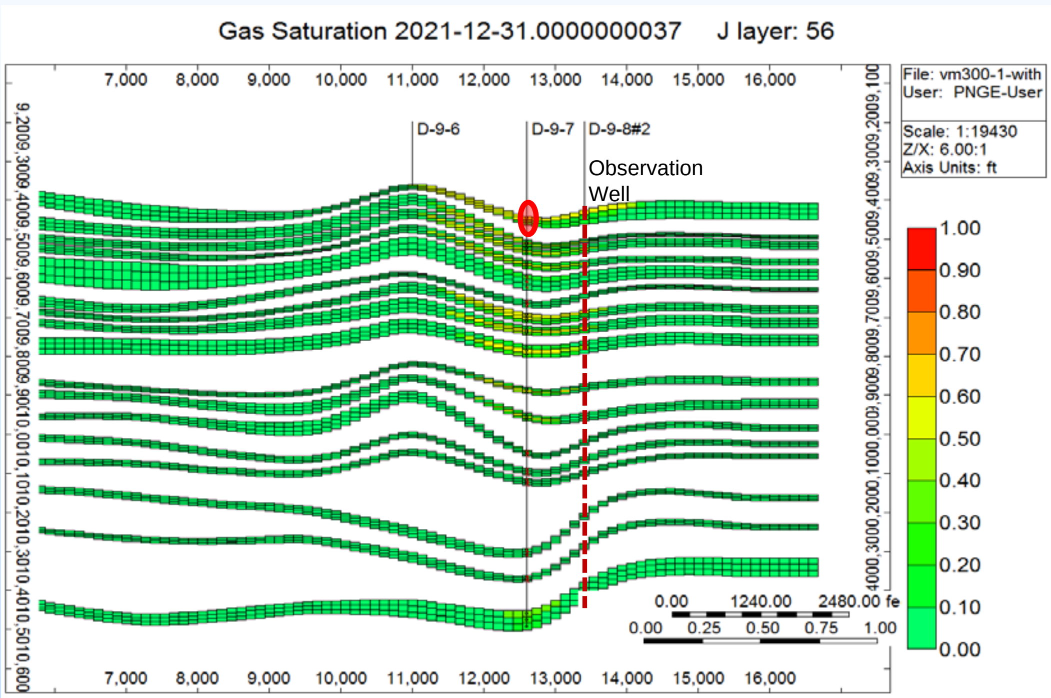
-All tasks have been completed by end of Quarter 19(Aug 2014)

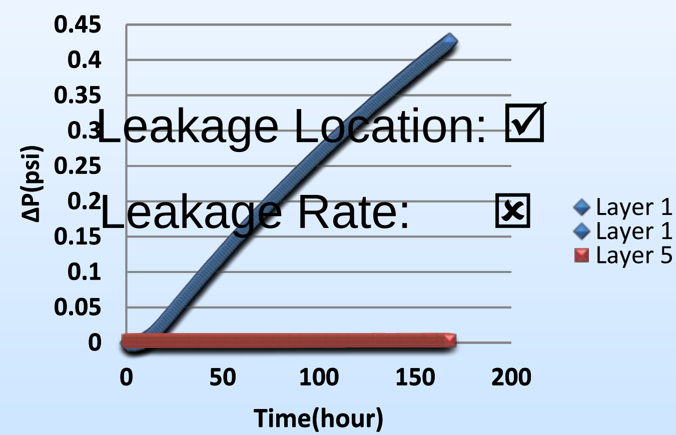
-Interface development will be done by end of quarter 20

Milestone Timelines

	Title	Description	Related task or subtask	Completion Date	Validation Technique and Milestone Progress
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	Meeting minutes received by Project Manager
Milestone 1.2	Site Selection	A site must be selected for the project.	Subtask 2.2, 2.3	End of Second Quarter	E-mail confirmation of site sent to PM.
Milestone 2.1	Data collection	Completion of geologic and production data collection	Subtask 3.2	End of Third Quarter	Memo regarding data type and extent received by Project Manager
Milestone 2.2	Completion of geological model	Completion of geologic/geo-cellular model	Subtask 3.3	End of Fourth Quarter	Memo received by Project Manager
Milestone 2.3	Completion of the base model	Completion and testing the base flow model	Subtask 3.6	End of Fifth Quarter	Quarterly Technical Report
Milestone 3	Sensitivity Analysis	Completion of the sensitivity analysis on the reservoir model	Subtask 4.3	End of Sixth Quarter	Quarterly Technical Report
Budget Period 2:					
Milestone 4.1	CO_2 Leakage Modeling	Model realistic CO_2 leakage from the formation	Subtask 5.1	End of Eighth Quarter	E-mail received by PM
Milestone 4.2	Downhole pressure modeling	Model realistic real-time downhole pressure measurements.	Subtask 5.2, 5.3, 5.4	End of Eleventh Quarter	E-mail following successful demonstration of model to PM held at WVU
Milestone 5	Handling High Frequency Data	Developing techniques for handling high frequency data	Subtask 6.1, 6.2, 6.3	End of Thirteenth Quarter	Topical report received by PM
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	Memo regarding recognition analysis received by PM
Milestone 7	Application to Homogeneous system	Completing of analysis and application to Homogeneous system	Task 8	End of Fifteenth Quarter	Progress report received by PM
Milestone 8	CO_2 Injection Modeling	Completion of modeling the CO_2 injection.	Subtask 9.3	End of Fifteenth Quarter	Technology progress report received by Project Manager
Milestone 9	Risk Description	More detailed risk description	Task 12	End of Sixteenth Quarter	Progress report received by PM
Milestone 10	Heterogeneity Integration	Integrating Heterogeneity in Geological Model	Task 13	End of Eighteenth Quarter	Progress report received by PM
Milestone 11	Leak Simulation	Simulating Leaks in Different Conditions	Task 14	End of Nineteenth Quarter	Progress report received by PM
Milestone 12	Using CO2 EOR Data	Integrating more similar real cases data in pressure analysis	Task 15	End of Nineteenth Quarter	Progress report received by PM
Milestone 13	DOE's Goal Support	Demonstrate Project Technology's Ability to Support DOE's Goal	Task 16	End of Nineteenth Quarter	Progress report received by PM
Milestone 14	PDG at Inj. Well	Evaluating Usage of Pressure Data Coming From Injection Well	Task 17	End of Nineteenth Quarter	Progress report received by PM
Milestone 15	Application to Heterogeneous system	Completing of analysis and application to Heterogeneous system	Task 10	End of Twentieth Quarter	Topical Report received by PM
Milestone 16	Build Program Interface	Completion of Software Package	Task 11	End of Twentieth Quarter	Software Package delivered to PM

Leakage Along Vertical Locations

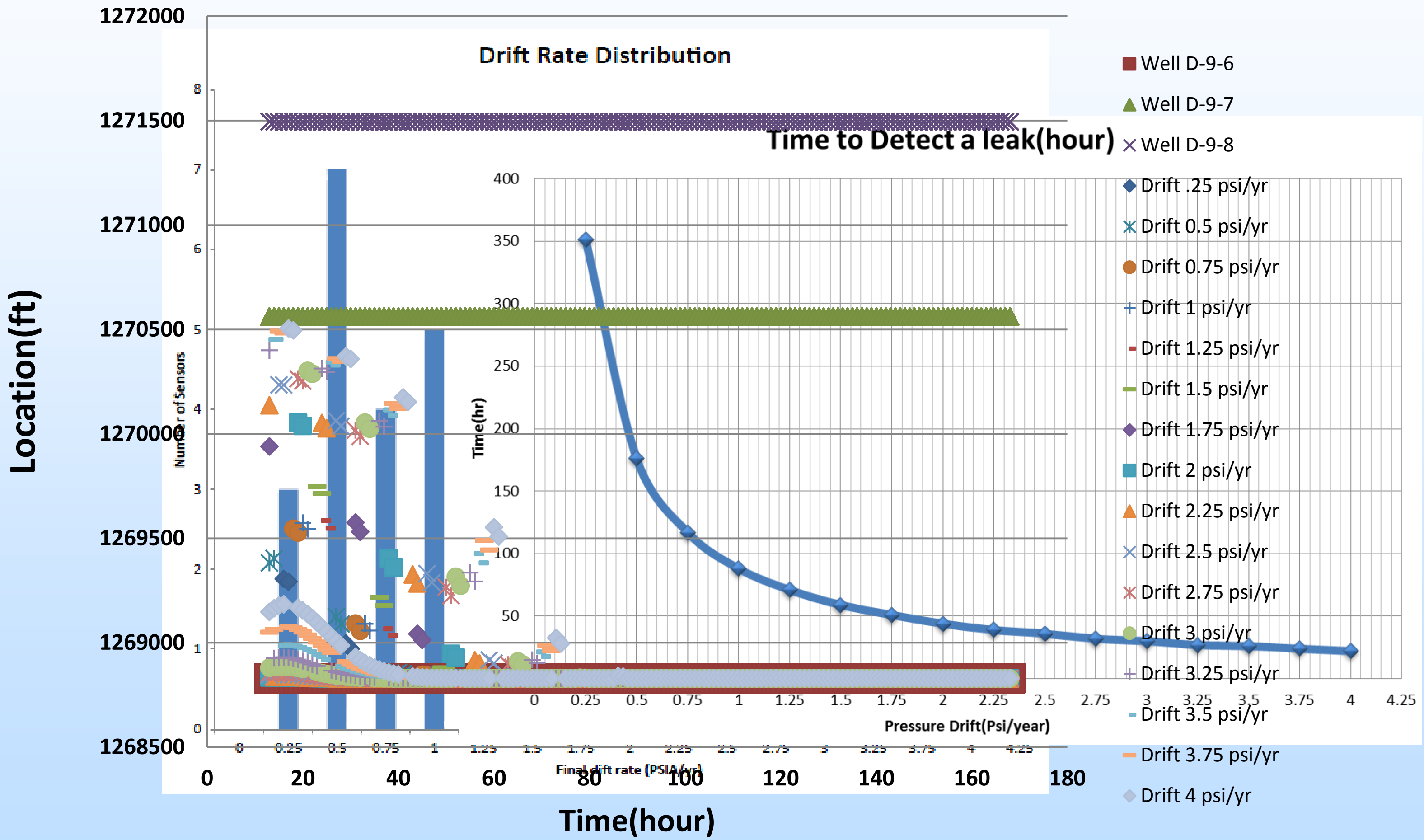




Leakage Location: ☑

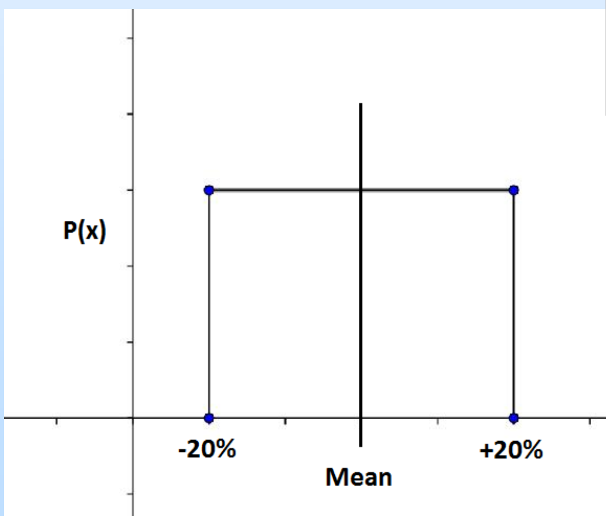
Leakage Rate: ☒

Effect of Pressure Drift



Variable Leakage Rate-Results

Rank	Feature	% Degree of Influence
1	Cum Sum(DeltP)	100
2	Cum Avereage(DeltP)	80
3	Cum ST Dev(DeltP)	64
4	Cum Skewness(DeltP)	56
5	Derivative	51
6	Delta P	48
7	Time(New)	3
8	Cum Kurtosis(DeltP)	1



Monte-Carlo Simulation