



PUMP CANYON CHARACTERIZATION AND MODELING

Prepared For:
Southwest Partnership 2008 Phase II Annual Review Meeting

Prepared By:
ADVANCED RESOURCES INTERNATIONAL, INC.
Houston, TX

October 22-23, 2008
Albuquerque, New Mexico



ConocoPhillips



KINDER MORGAN
INC.

Schlumberger



New Mexico Tech
Petroleum Recovery Research Center

PINNACLE
PINNACLE TECHNOLOGIES INC
ONE SOURCE FOR ALL YOUR NEEDS.

Los Alamos
NATIONAL LABORATORY
EST. 1943



Sandia
National
Laboratories

SWP
SOUTHWEST PARTNERSHIP
CO₂ SEQUESTRATION

U THE
UNIVERSITY
OF UTAH



Advanced Resources
International, Inc.



Advanced Resources
International, Inc.

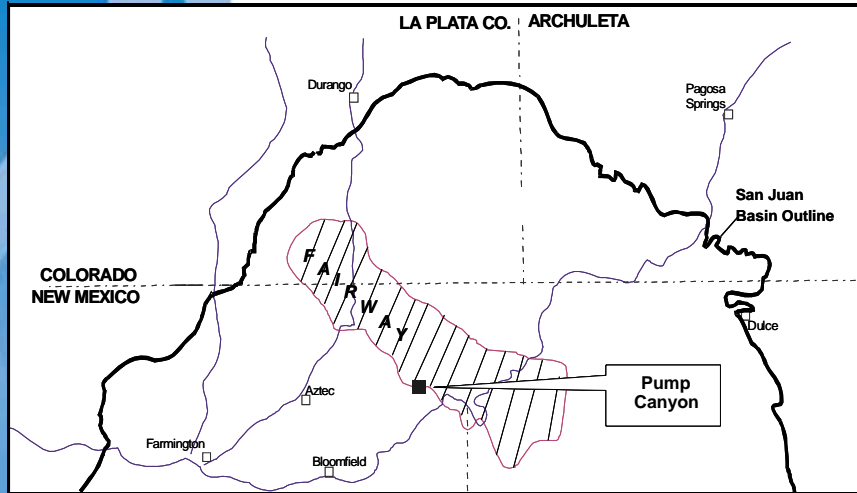
Presentation Outline

- Site Description
- Reservoir Description
- Model Construction
- History-Matching
- Next Steps
- Conclusions

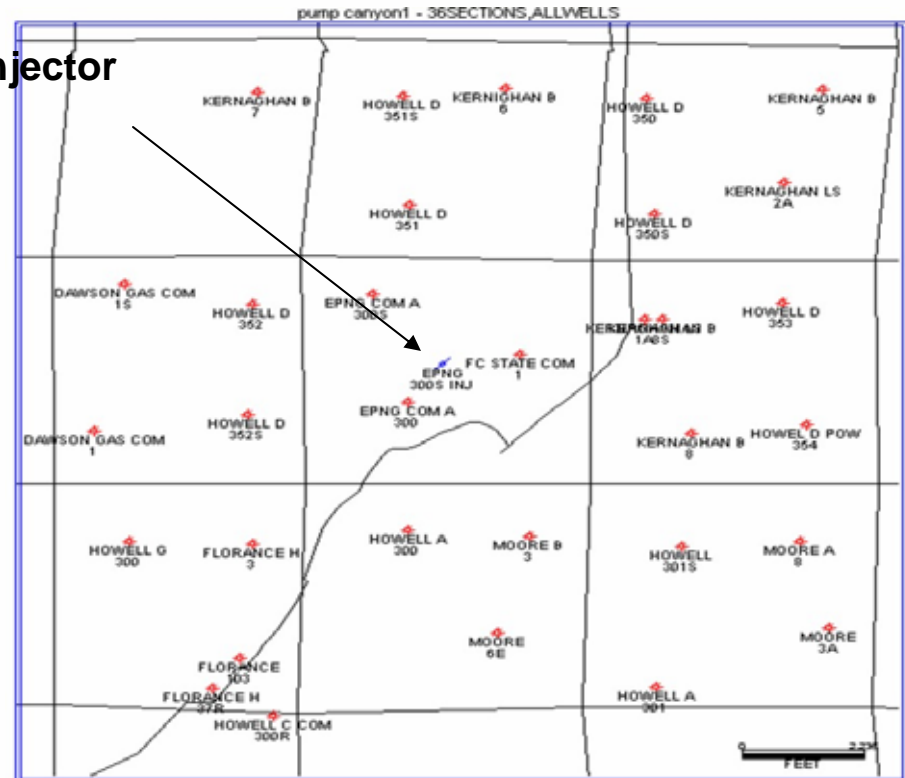


Advanced Resources
International, Inc.

Site Description



Injector



31 production wells

Unconventional Resources • Enhanced Recovery • Carbon Sequestration



Basic Coal Information

- Pump Canyon wells produce from three primary Fruitland Formation coals
 - the Upper coal (combination of Blue and P1)
 - the Middle coal (P2 and G1)
 - the Basal coal (G2, G3, B1 and B2)

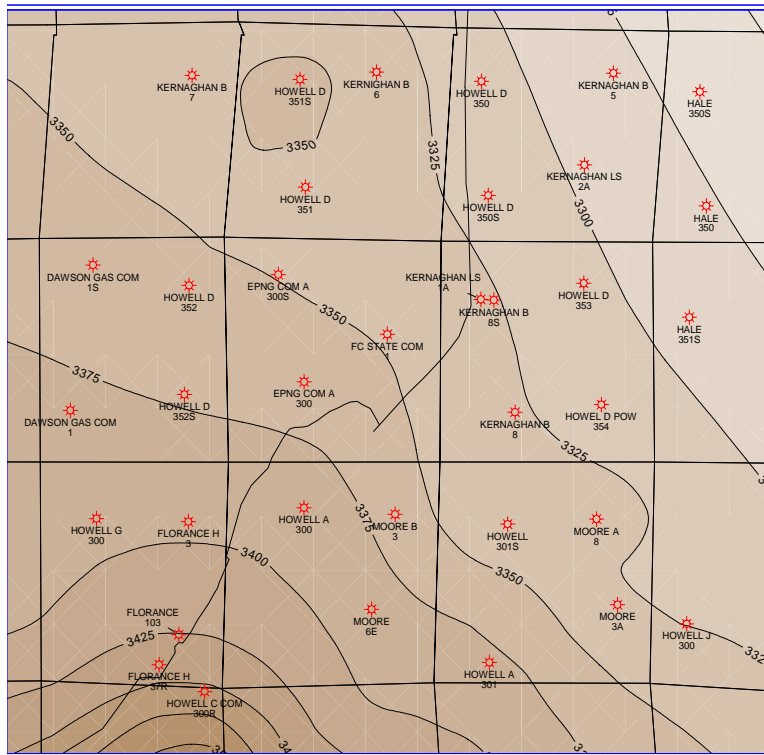
Property	Value
Average Depth to Top Coal	3,012 feet
Average Total Net Thickness	60 feet Upper Coal: 16 feet Middle Coal: 15 feet Basal Coal: 29 feet
Initial Pressure	1500 psi @ 3600 ft above sea level
Temperature	126°F



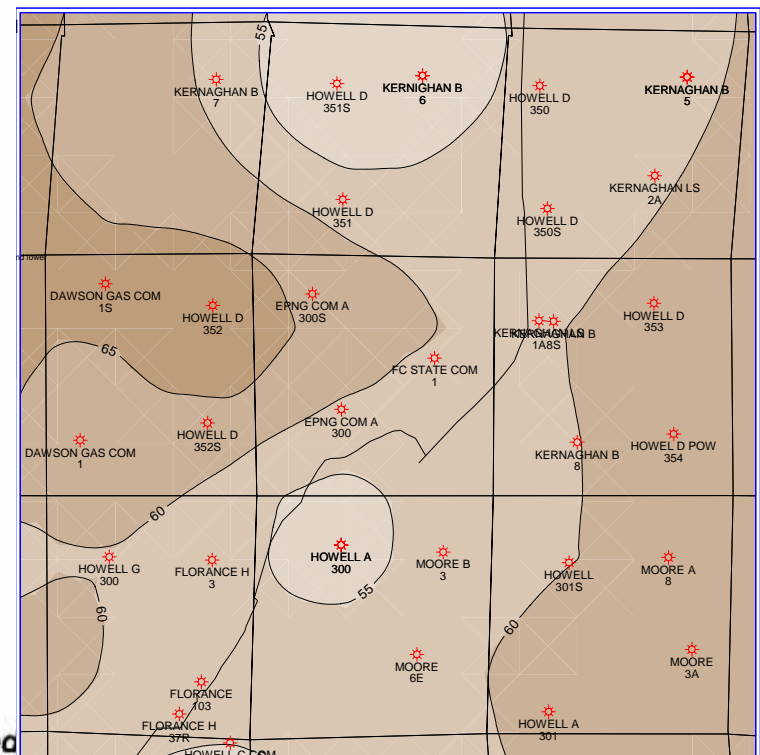
Reservoir Description

- Structure and isopach maps of each coal were constructed based on ConocoPhillips picks of tops and bottoms from logs (available data from 21 wells)

Top Structure



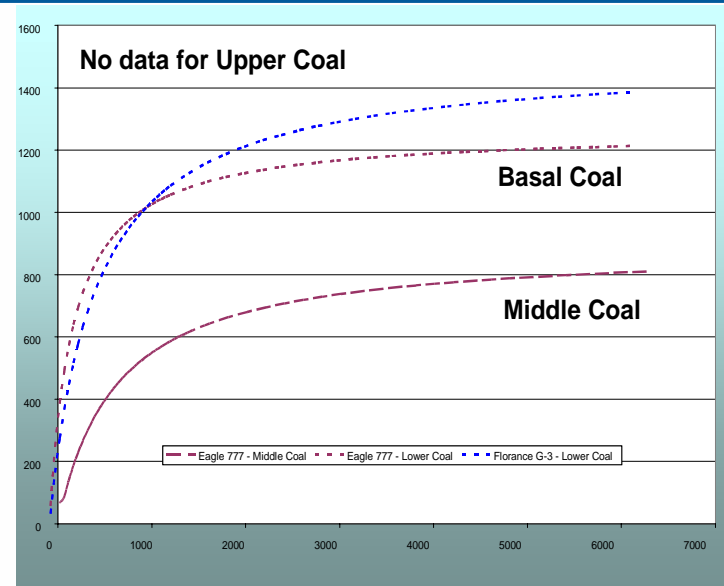
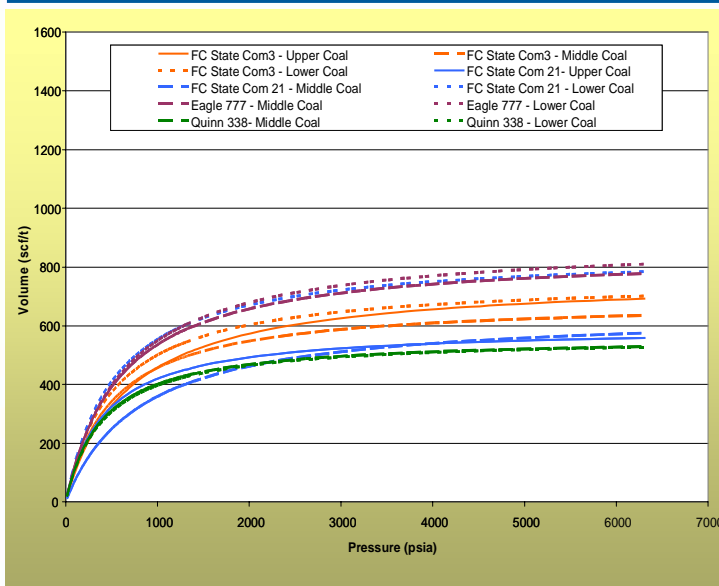
Total Coal Net Thickness





Advanced Resources
International, Inc.

Isotherm Data



Coal	Methane*		Carbon Dioxide*	
	V _L (scf/ton)	P _L (psia)	V _L (scf/ton)	P _L (psia)
Upper	596 – 766	420 – 672	1234 ⁺	317 ⁺
Middle	563 - 851	404 – 807	1244	260
Lower	562 – 890	418 – 621	1274 – 1506	253 - 490

*dry, ash-free basis

+ computed based upon CO₂/CH₄ Langmuir constant ratios for middle and lower coals

Unconventional Resources • Enhanced Recovery • Carbon Sequestration



Advanced Resources
International, Inc.

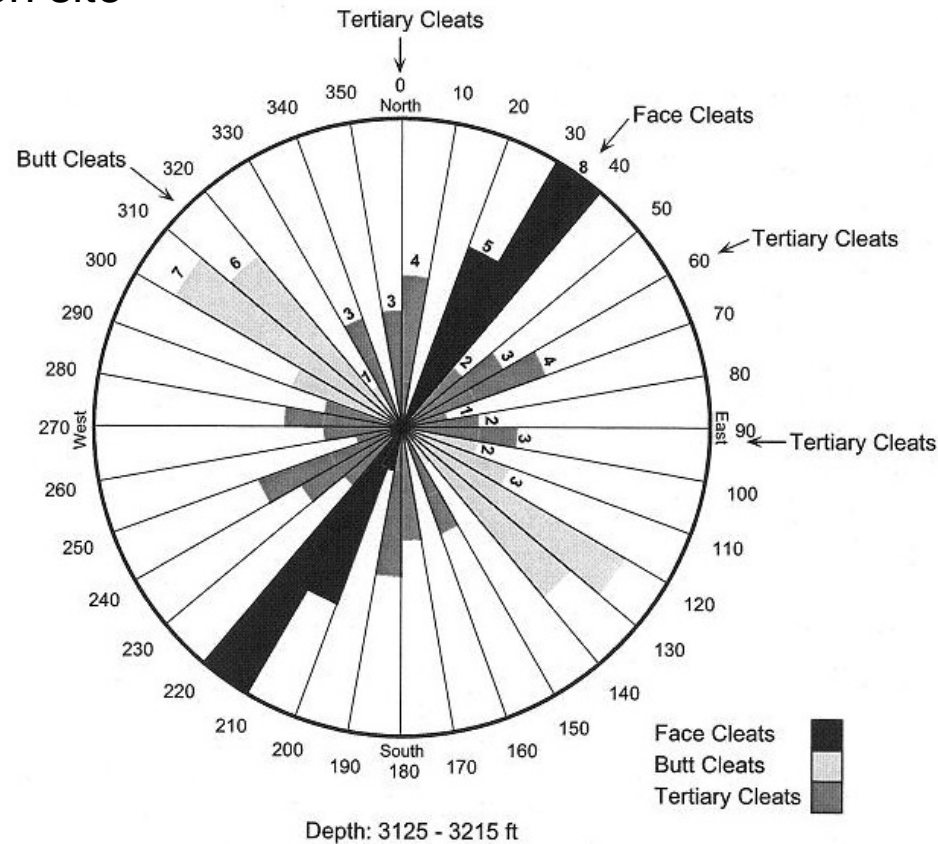
Pressure Data

Well Number	Date	Depth (ft)	Pressure (psi)	Pressure Gradient (psi/ft)
Howell D 352	Jun-88	3150	1584	0.50
EPNG Com A 300	May-89	3075	1604	0.57
Howell G Com 300	Apr-89	2800	1604	0.57
Howell A 300	Jun-88	3070	1613	0.53



Cleat Orientation

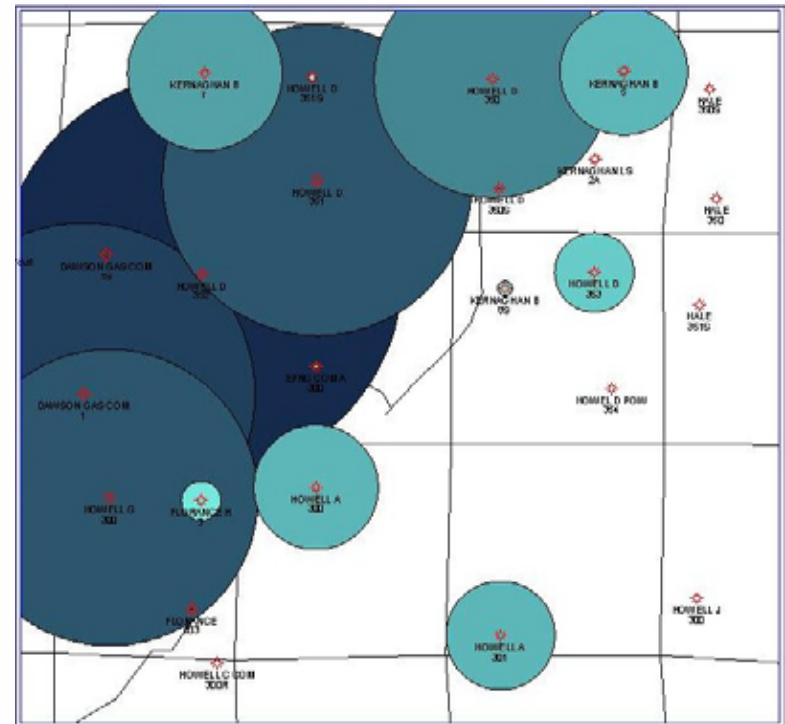
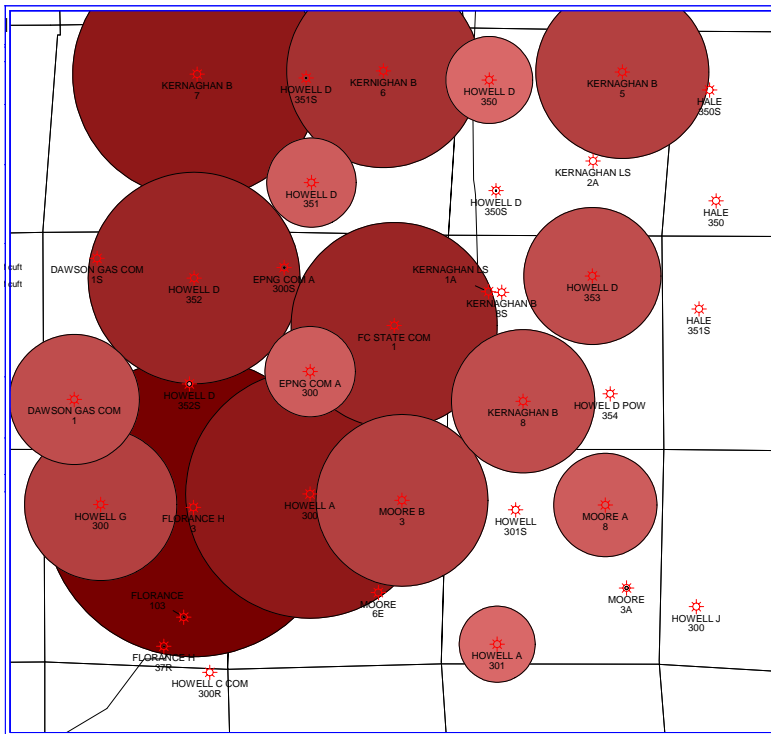
- Cleat orientation was measured in the Northeast Blanco Unit #403 well, approximately seven miles to the east of the demonstration site





Geostatistical Characterization - Permeability

- Bubble maps of cumulative gas and water production (until end of 2006) suggest that significant reservoir heterogeneity exists



Note: water data not used in subsequent analysis because considered inaccurate (under reported or missing)

Unconventional Resources • Enhanced Recovery • Carbon Sequestration



Advanced Resources
International, Inc.

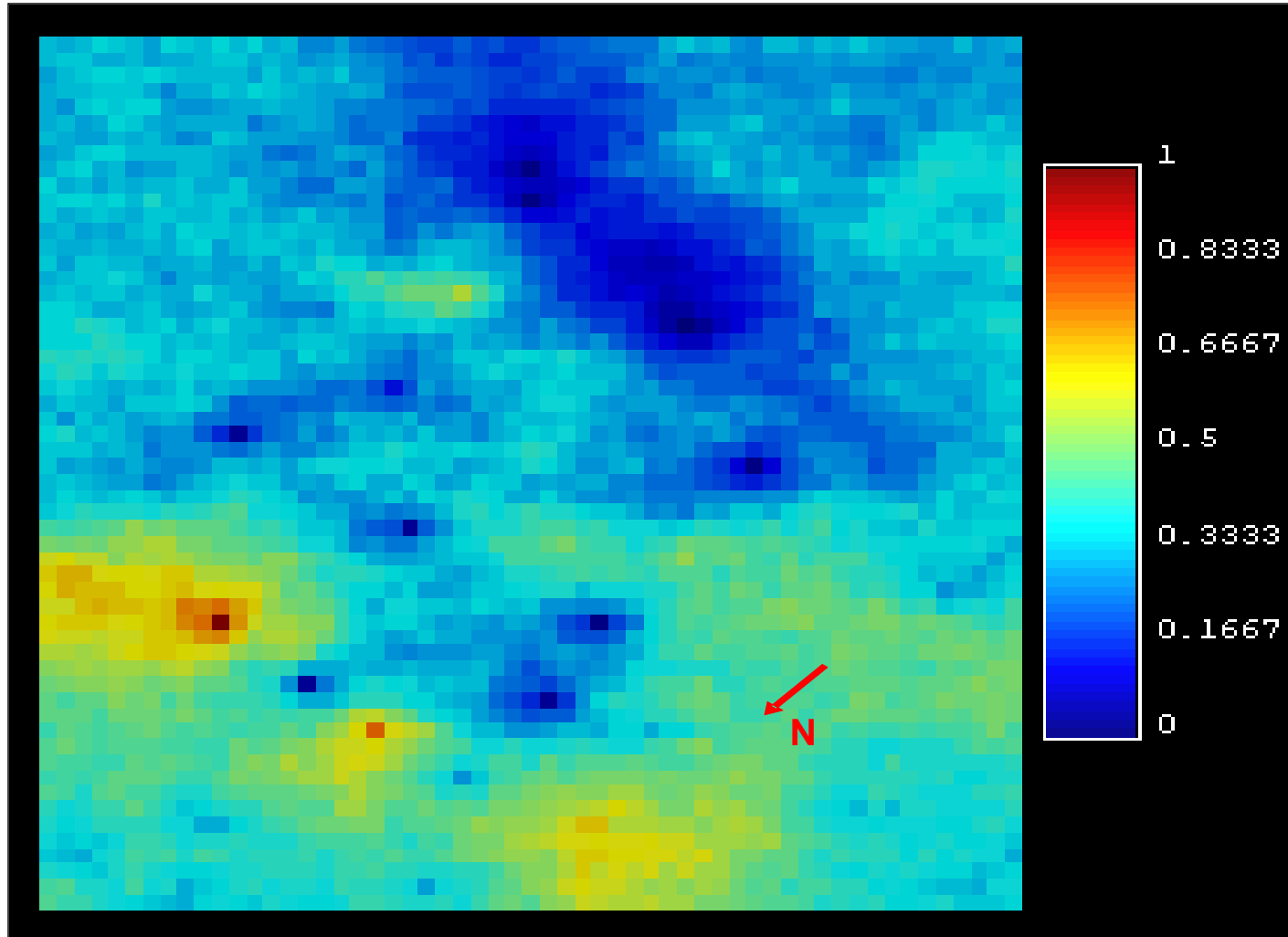
Geostatistical Characterization - Permeability

- Gas production was used as a loose proxy for coal permeability
- The gas production parameter used was average gas production over the active well life (“production index”)
- A sequential Gaussian simulation algorithm was adopted for generating 50 2D realizations of the production index
- The arithmetic average of the 50 different simulated values was selected as a central value for a final characterization
- This index map was then multiplied by an average permeability to create a permeability map for use in reservoir simulation



Advanced Resources
International, Inc.

Geostatistical Characterization - Permeability



Unconventional Resources • Enhanced Recovery • Carbon Sequestration



Geostatistical Characterization - Porosity

- Porosity was assumed to be correlated with permeability
- According to Schwerer and Pavone

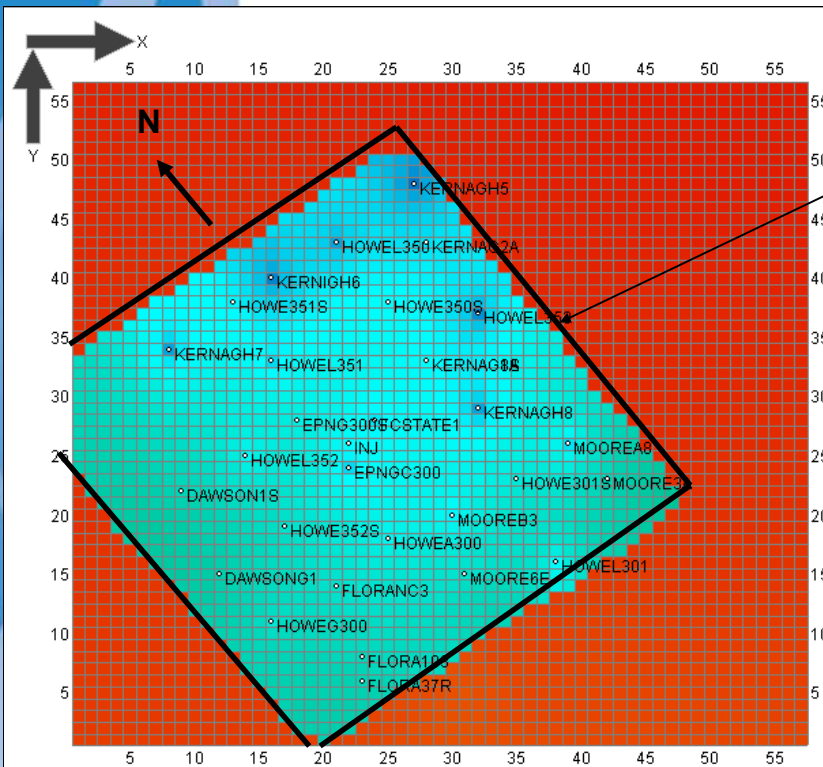
$$\frac{k}{k_i} = \left(\frac{\phi}{\phi_i} \right)^n \quad \xrightarrow{\text{Typically } 3} \quad \phi = a * k^{0.3333}$$

- a varied during the optimization process

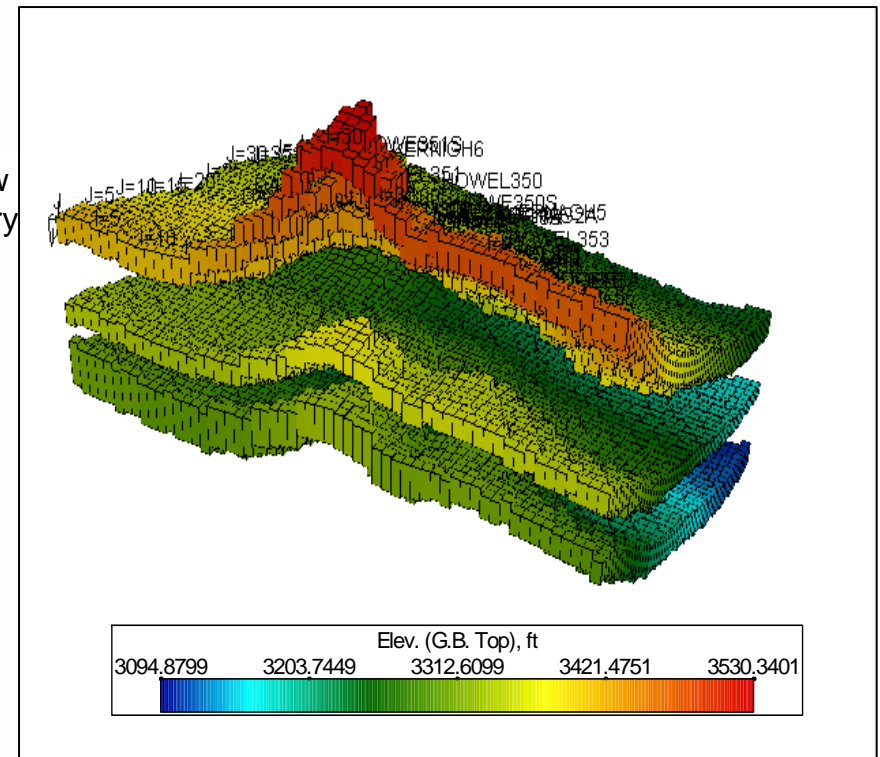


Model Construction

- **COMET3** reservoir simulator model
- **3 layers, 9-section** model
- **Elevation and thickness** maps included
- **Grid oriented to respect face-cleat orientation**

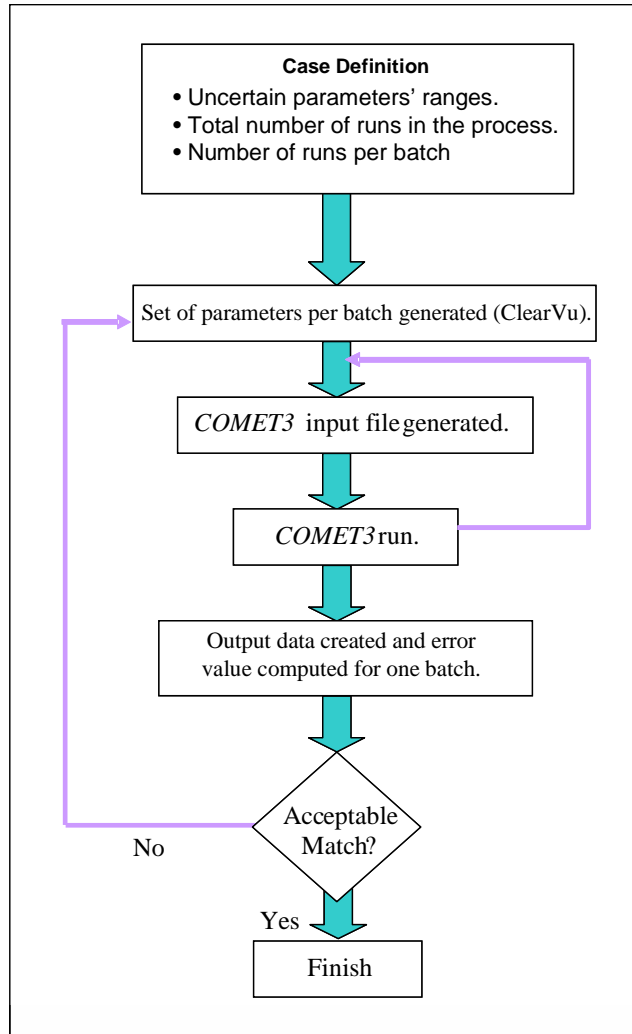


No Flow
Boundary





History Matching Process



$$ErrorValue = \frac{\sum \left(\frac{(SimData - ActualData)^2}{2 * Variance} \right)}{NumberOfData}$$

$$Variance = \frac{\sum (ActualData - Mean)^2}{NumberOfData}$$

$$Mean = \frac{\sum ActualData}{NumberOfData}$$



Advanced Resources
International, Inc.

History Match

- Simulations run with the wells producing on gas rate
- Matching gas rate, gas composition and bottomhole pressure (when available), as well as the field average reservoir pressure
- Inaccurate water data were not matched



History-Match Fixed Input Parameters

Parameters	Units	Value
Formation Properties		
Vertical Permeability	mD	0.0001
In-situ CH4 Langmuir Volume, Layer 1	scf/ton	447
In-situ CH4 Langmuir Volume, Layer 2	scf/ton	436
In-situ CH4 Langmuir Volume, Layer 3	scf/ton	542
CH4 Langmuir Pressure, Layer 1	psi	546
CH4 Langmuir Pressure, Layer 2	psi	606
CH4 Langmuir Pressure, Layer 3	psi	520
Sorption Time, CH4	days	1
In-situ CO2 Langmuir Volume, Layer 1	scf/ton	809
In-situ CO2 Langmuir Volume, Layer 2	scf/ton	766
In-situ CO2 Langmuir Volume, Layer 3	scf/ton	1038
CO2 Langmuir Pressure, Layer 1	psi	317
CO2 Langmuir Pressure, Layer 2	psi	260
CO2 Langmuir Pressure, Layer 3	psi	372
Sorption Time, CO2	days	1
Differential Swelling Factor	-	1.5
Permeability Exponent	-	3
Relative Permeability Relationships		
Maximum Krw	-	1
Irreducible Gas Saturation	-	0



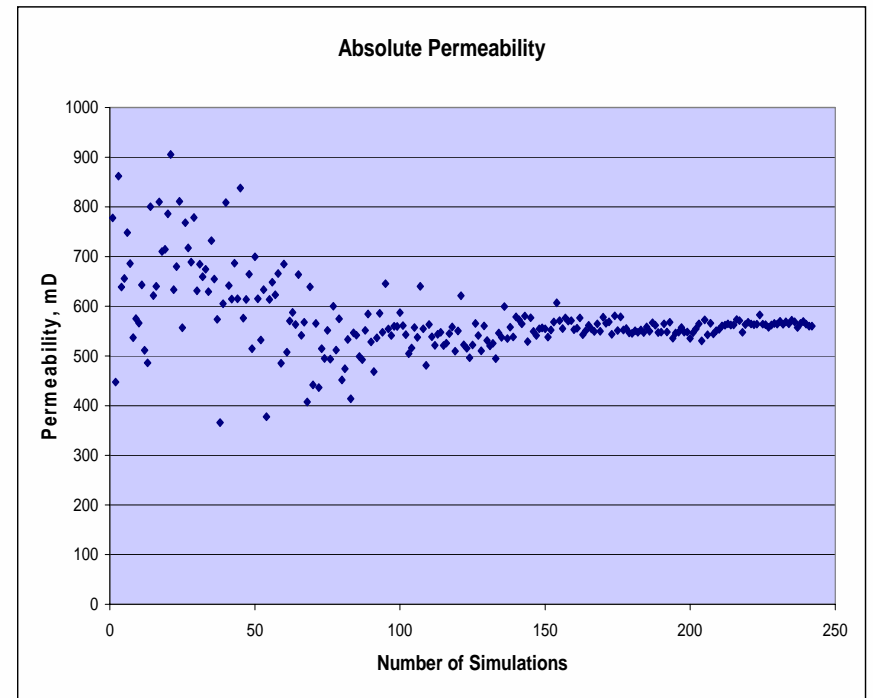
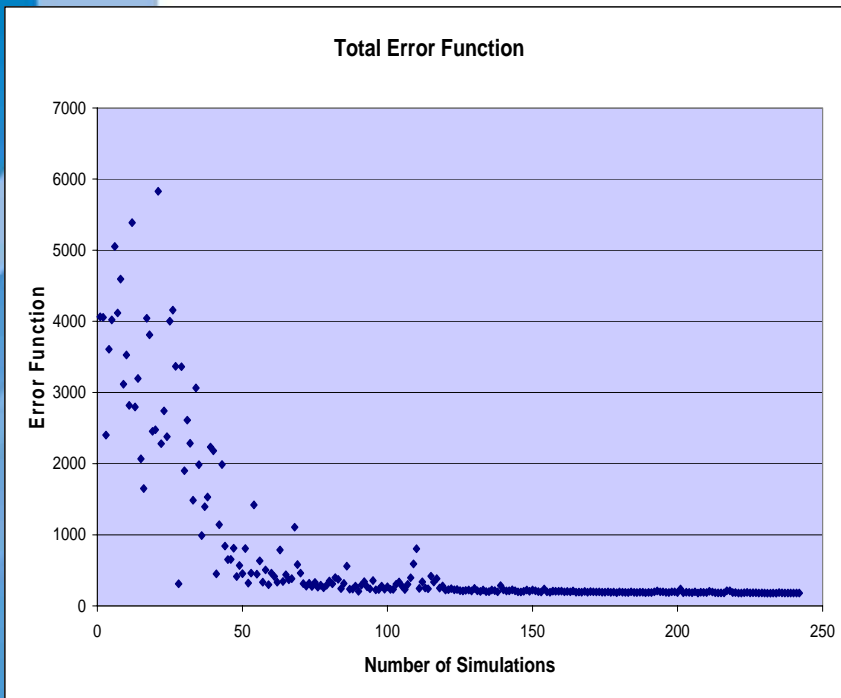
History-Match Variables and Ranges

Parameters	Units	Min	Max
Formation Properties			
Porosity Factor a	-	0.001	0.0045
Initial Water Saturation	fraction	0.75	1
Average Absolute Permeability	mD	10	1000
Permeability Anisotropy	fraction	1	5
Pore Compressibility	1/psi	1.00E-05	6.00E-04
Matrix Compressibility	1/psi	1.00E-07	5.00E-06
CO2 Content	fraction	0.01	0.25
Relative Permeability Relationships			
Irreducible Water Saturation	-	0.05	0.4
Maximum Krg	-	0.65	0.95
Krw Exponent	-	1	3
Krg Exponent	-	1	3
Well Parameters			
Initial Skin	-	-1	2
Stimulated Skin	-	-5	0

Note: No capillary pressure effects were considered



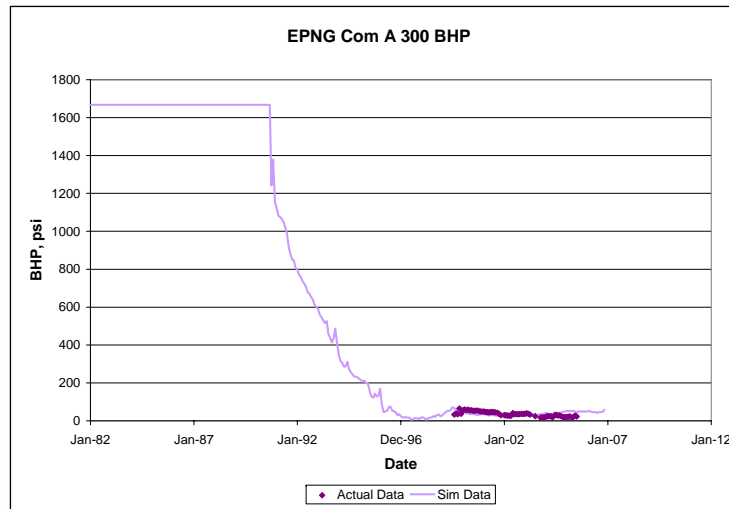
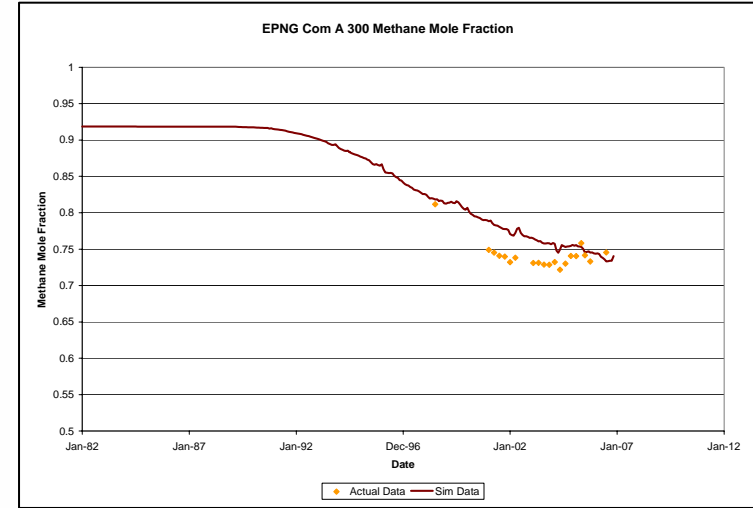
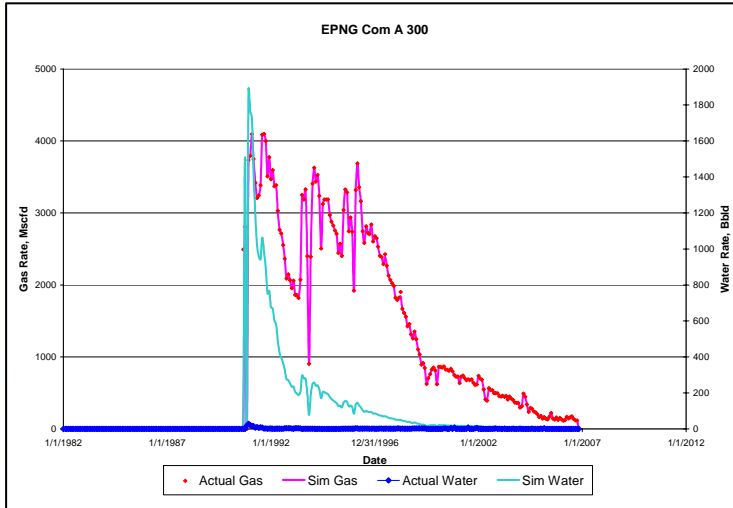
Convergence Plots





Advanced Resources
International, Inc.

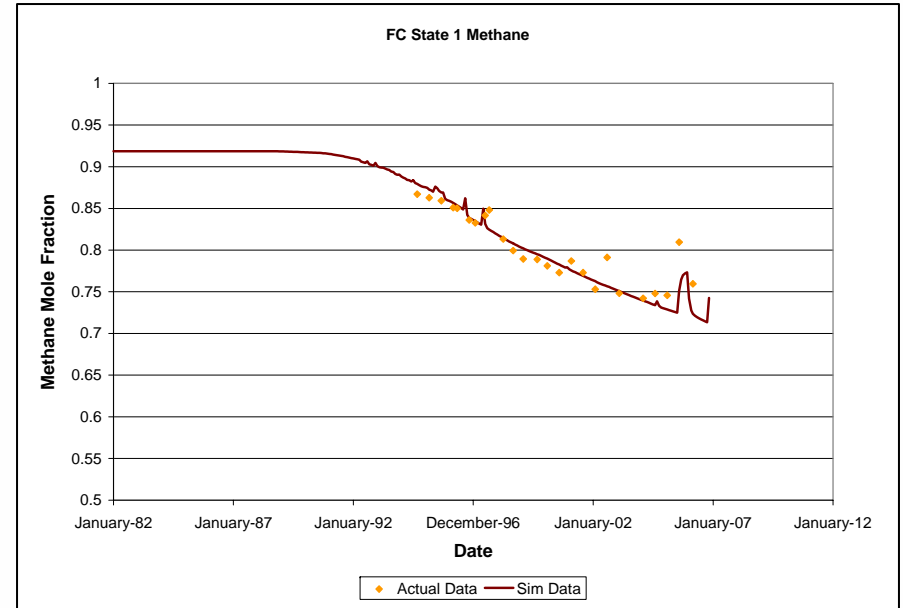
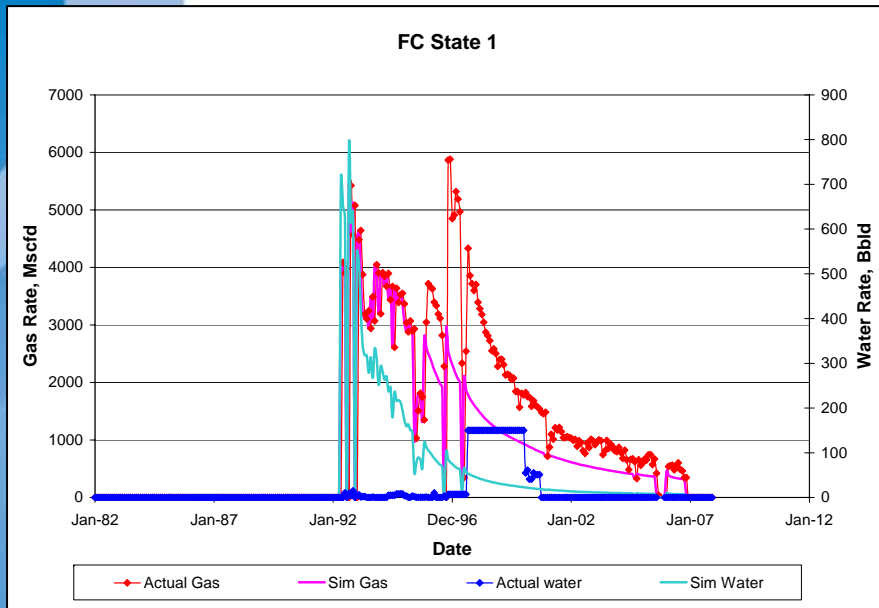
EPNG Com A 300 Plots



Unconventional Resources • Enhanced Recovery • Carbon Sequestration



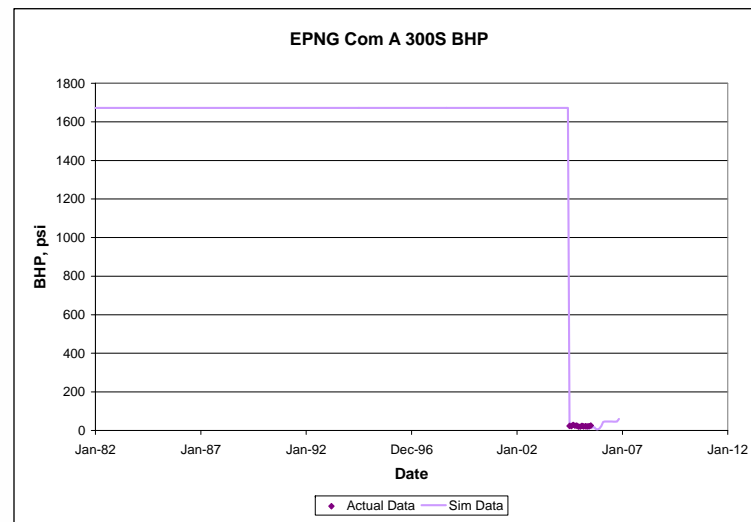
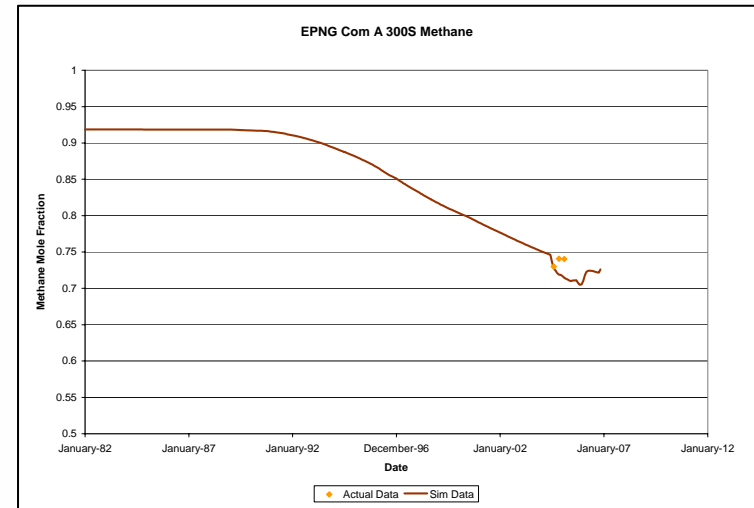
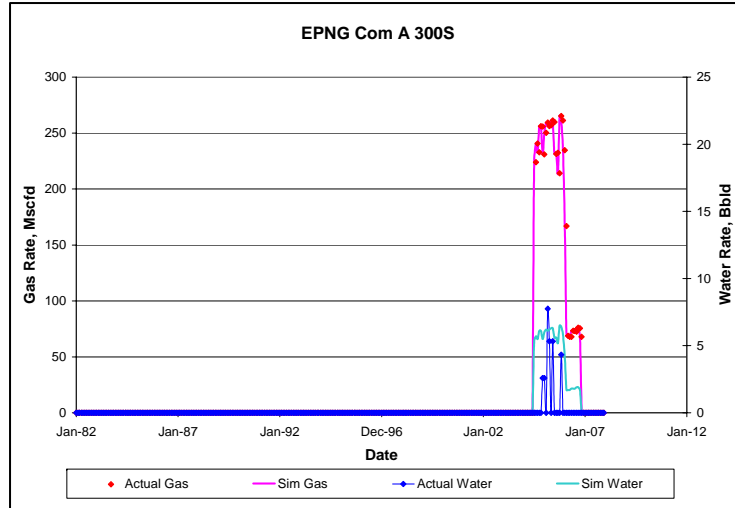
FC State Com 1 Plots





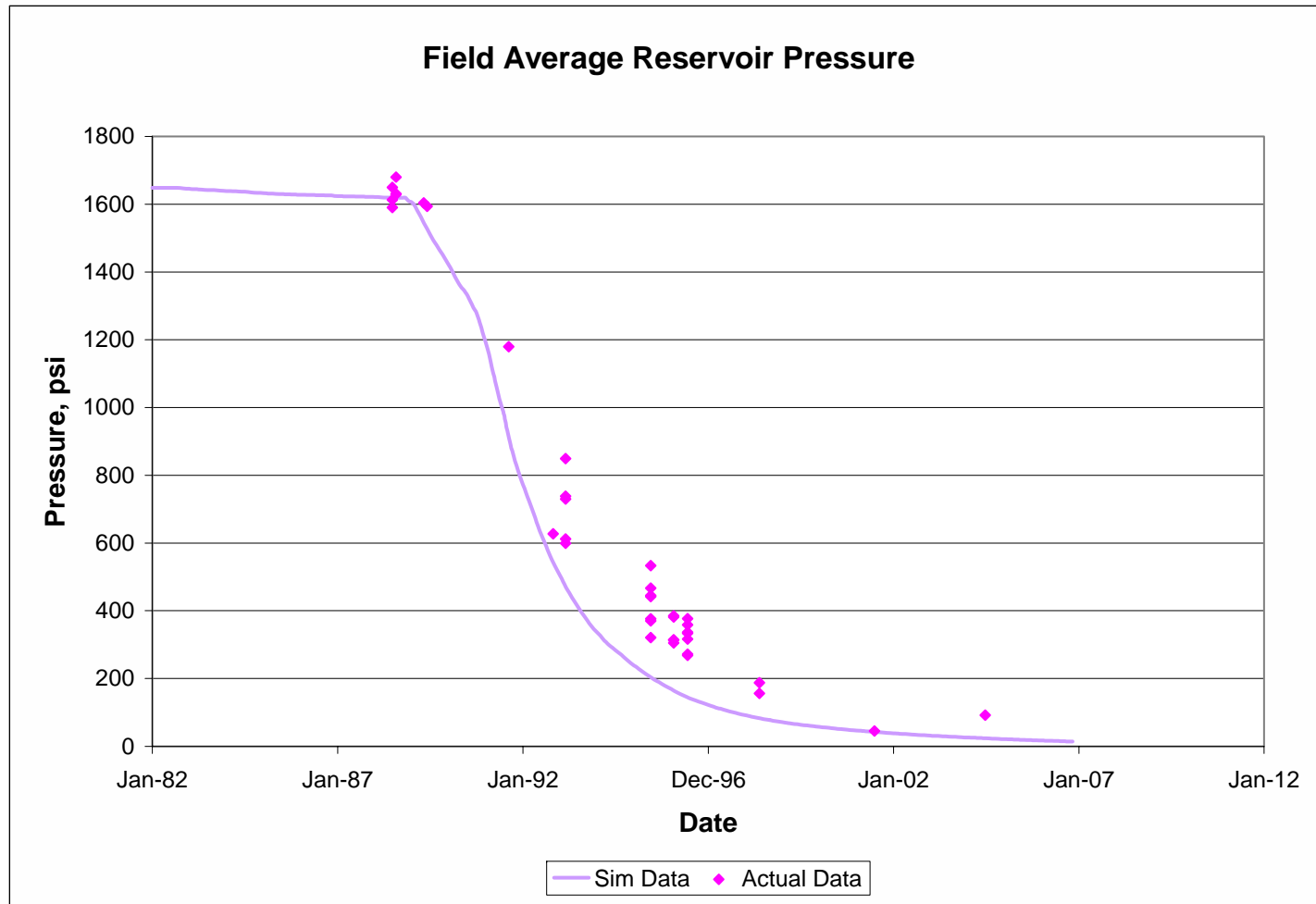
Advanced Resources
International, Inc.

EPNG Com A 300S Plots





Field Average Reservoir Pressure



Unconventional Resources • Enhanced Recovery • Carbon Sequestration



Optimized Parameters

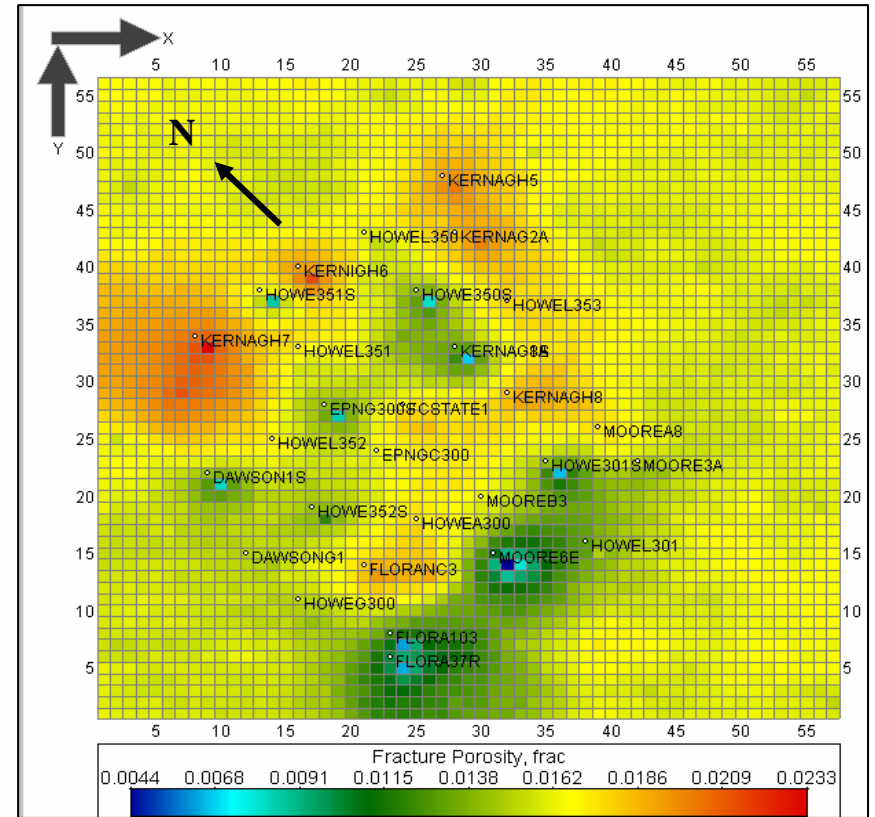
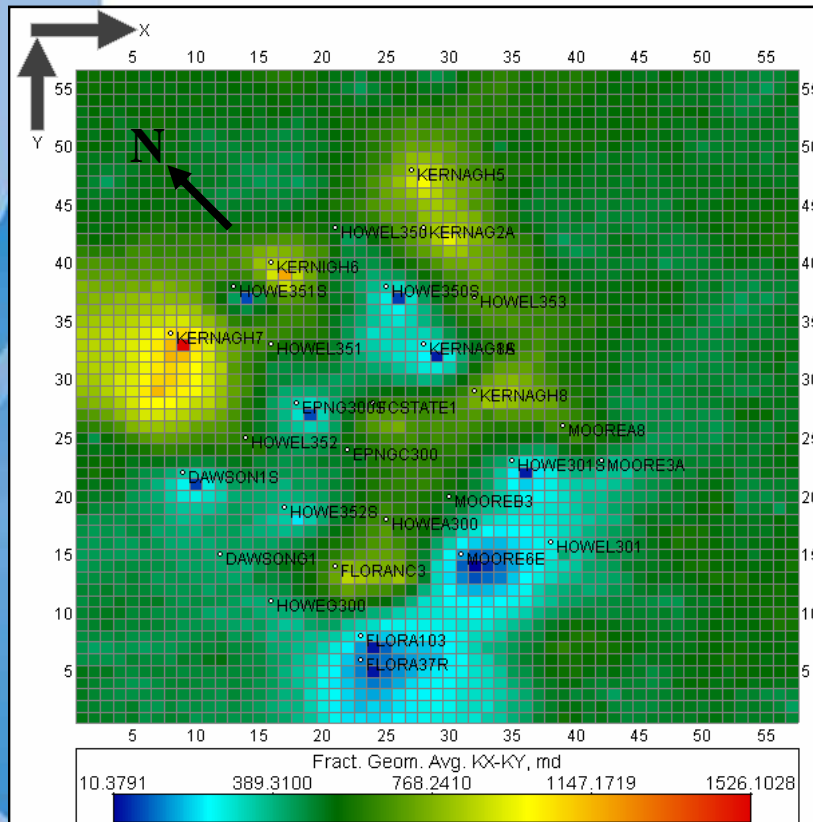
Parameters	Units	Min	Max	Optimized
Formation Properties				
Porosity Factor a	-	0.001	0.0045	0.002
Initial Water Saturation	fraction	0.75	1	0.94
Average Absolute Permeability	mD	10	1000	549
Permeability Anisotropy	fraction	1	5	1.8
Pore Compressibility	1/psi	1.00E-05	6.00E-04	3.86E-04
Matrix Compressibility	1/psi	1.00E-07	5.00E-06	3.54E-06
CO2 Content	fraction	0.01	0.25	0.08
Relative Permeability Relationships				
Irreducible Water Saturation	-	0.05	0.4	0.26
Maximum Krg	-	0.65	0.95	0.75
Krw Exponent	-	1	3	2.7
Krg Exponent	-	1	3	2.7
Well Parameters				
Initial Skin	-	-1	2	1.1
Stimulated Skin	-	-5	0	-1.9

Note: A porosity factor of 0.002 corresponds to an average porosity of 1.6%



Advanced Resources
International, Inc.

Final Permeability and Porosity Maps





Advanced Resources
International, Inc.

History-Match Conclusions

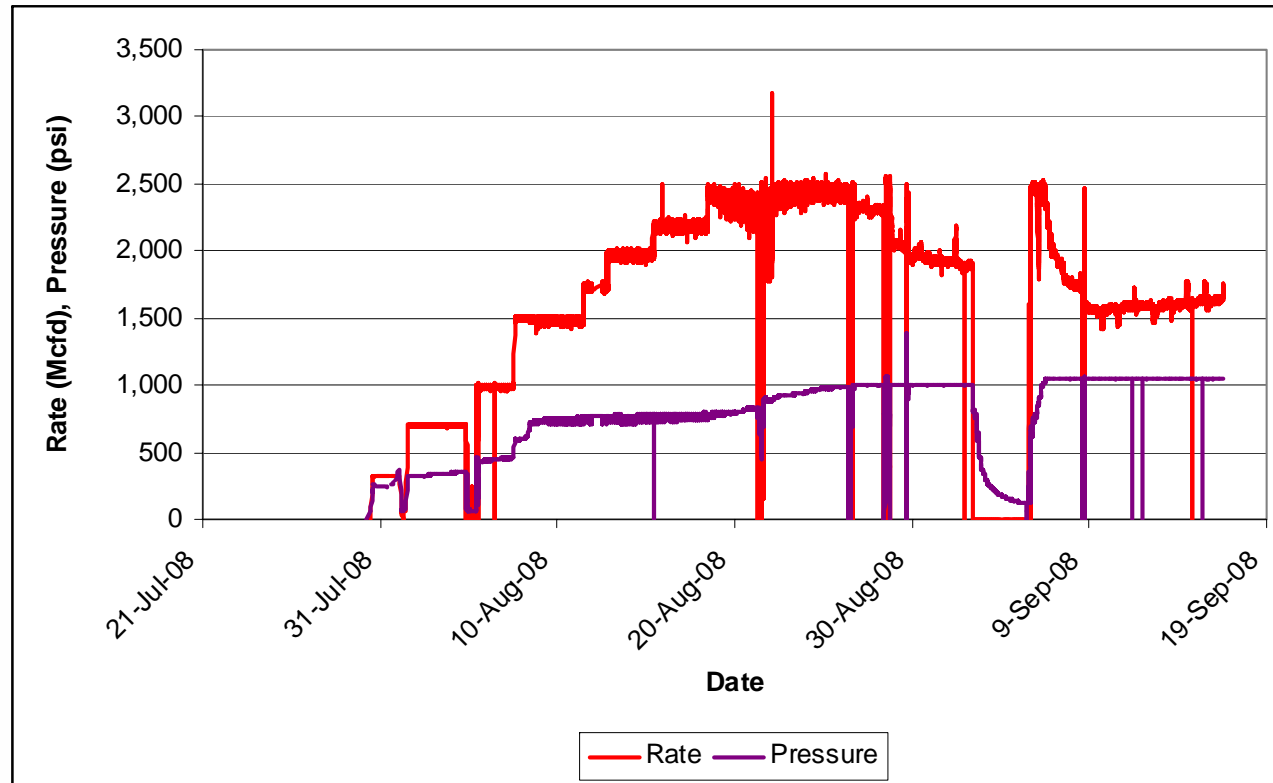
- Overall, satisfactory results
- Late water production data matched reasonably well
- Bad gas match along the northern border, which seems to confirm the hypothesis that gas could be migrating into the pattern area from the north-northeast (no-flow boundary was assumed)



Advanced Resources
International, Inc.

Next Step CO₂ Injection History-Match

- Previous injection simulations need to be updated with real data



Unconventional Resources • Enhanced Recovery • Carbon Sequestration



Conclusions

- Successful history-match of individual well production achieved
- Results indicated an average initial permeability of 549 md, an average porosity of 1.6% that was correlated to permeability, and a permeability anisotropy of 1.8
- PTA tests performed seem to confirm values found via simulations (same order of magnitude)
- Need to update and match current injection data.



Advanced Resources
International, Inc.

Contact Information



Office Locations

Washington, DC
4501 Fairfax Drive, Suite 910
Arlington, VA 22203 USA
Phone: (703) 528-8420
Fax: (703) 528-0439

Houston, Texas
11490 Westheimer Rd, Suite 520
Houston, TX 77077 USA
Phone: (281) 558-9200
Fax: (281) 558-9202