SPE-API Technical Luncheon: "Developing an Early-Warning System for Well/Reservoir Problems"

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NEW ORLEANS, LA
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Outline

- Background: Data Acquisition & Processing
  - Data Measurement, Transfer and Visualization
  - Virtual Rate Measurement
- The Wellbore-Completion-Reservoir System
  - PVT
  - Heat Loading & Thermal Modeling
  - Inflow Modeling
- Analysis/Evaluation Tools
  - PTA, RTA, Decline Analysis, p/z
  - Nodal Analysis
  - Reservoir Simulation

Outline II

- Creating an On-line Well Monitoring package
  - Take a batch process and make it continuous
  - The Hard Parts in More Detail
    - Wellbore Thermal and PVT Modeling
    - Completion Model
    - Reservoir Model
    - Don’t Forget the Coupled Effects
  - Need to have a Closed Solution for Well Bore and Reservoir
  - Effective Transient & Regime Recognition
  - Combine steady-state and transient effects into same system of eqns
  - Include Internal Checks for Validity

Outline III

- Examples of RT Process
- Interactive Tools: Transient Nodal
- Conclusions

Data Acquisition: Instrumentation

- What do I really need to measure accurately?
  - Wellhead Pressure
  - Wellhead Temperature (Thermowell)
  - Flow Rates of Oil, Gas & Water
    - Multiphase Meters, Venturi Meters, Turbine Meters
    - Sep T & P
    - Choke Setting
    - Virtual Rate Measurement (VRM)
  - Bottomhole Pressure
  - Bottomhole Temperature
  - Distributed Temperature
  - NOTE: Last 3 not required for gas wells (still nice to have)

Data Acquisition: Pressure Gauges

- What to ask your gauge/instrument supplier:
  - What is the resolution (digital) or “effective resolution” for Scada gauges?
  - How many bits in the A/D converter?
    - (Needs to be >14 for 1 psi resolution)
  - How quickly can it sample or be polled?
  - Is it thermally compensated? How much temperature change is required to cause the pressure to change 1 psi?
  - Does the gauge measure and export its internal temperature?
  - How susceptible is the gauge to plugging?

A/D Conversion: Scada/DCS

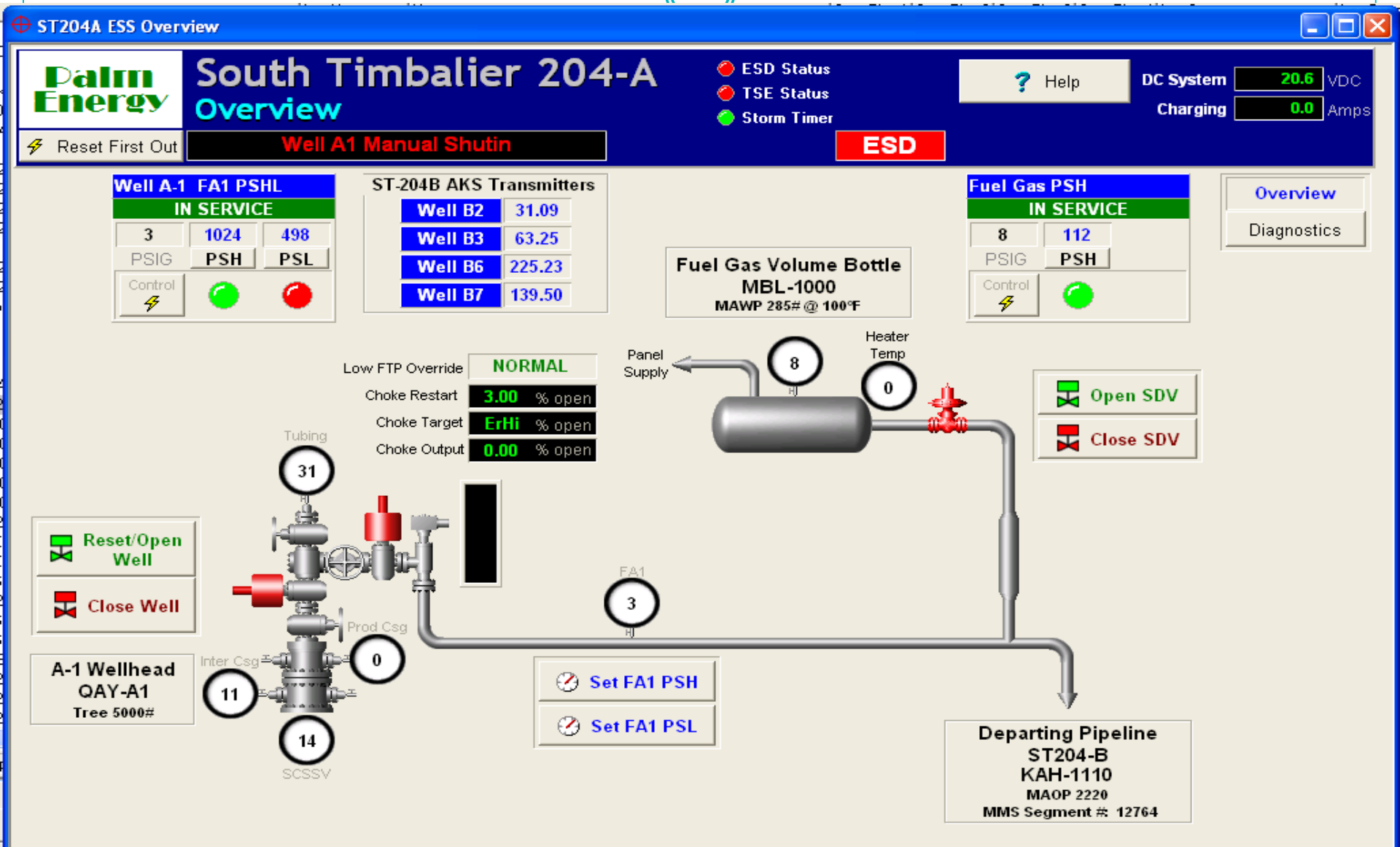
Resolution based on Scale and A/D Conversion

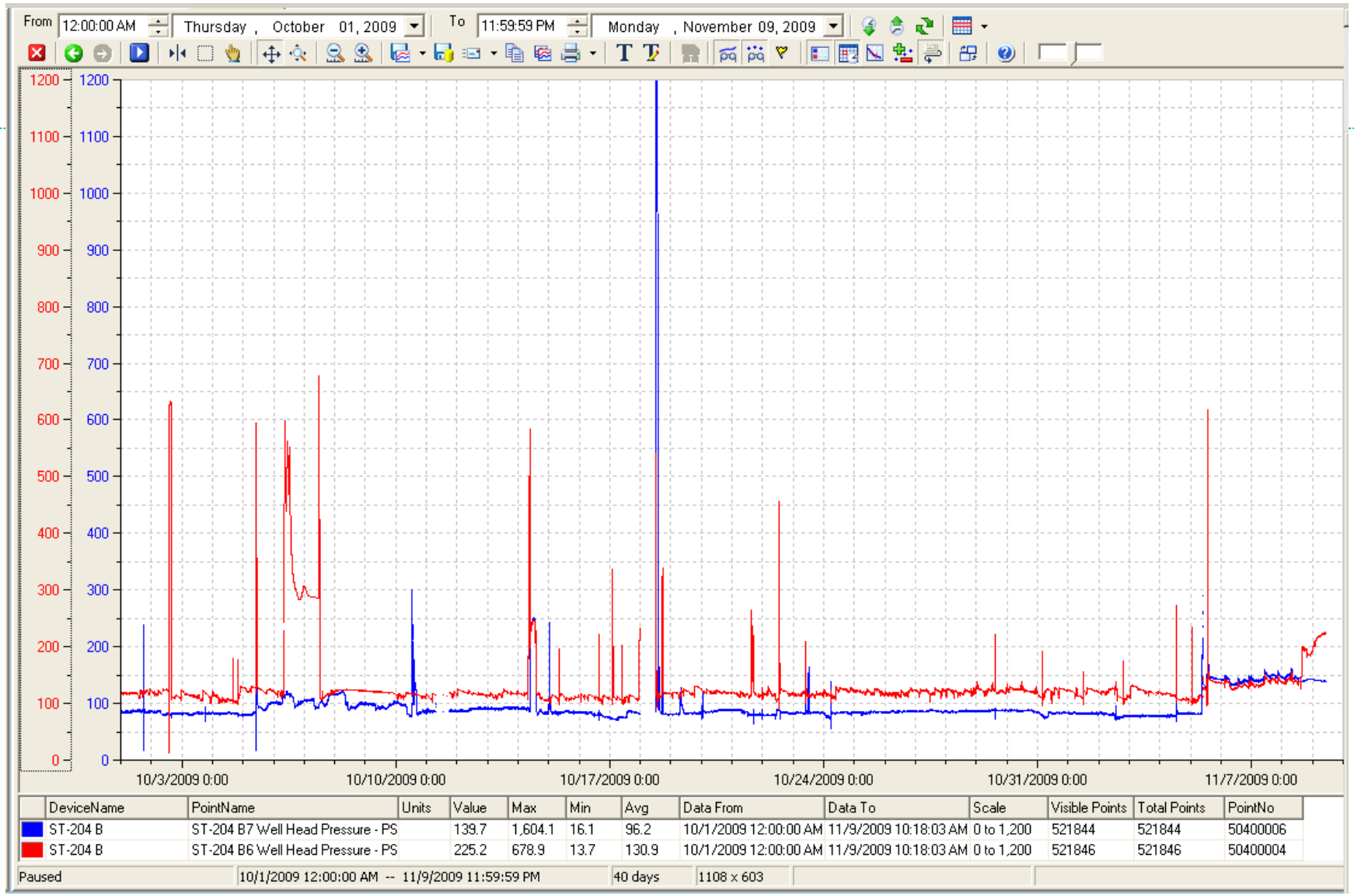
	Resolution per bit (Bar)				
Range (bar)	**8**	**12**	**14**	**18**	**24**
0-200	0.78125	0.048828	0.012207	0.000763	1.19E-05
0-400	1.5625	0.097656	0.024414	0.001526	2.38E-05
0-700	2.734375	0.170898	0.042725	0.00267	4.17E-05
0-1000	3.90625	0.244141	0.061035	0.003815	5.96E-05

Data Transfer: Don’t Lose Resolution!

- Before it gets to you, Your Data is likely to pass through:
  - One or two A/D converters
  - An I/O card on the Control Panel
  - Dead-band filters
  - Signal filters
  - Archive filters
- You can lose sampling resolution (frequency) and instrument resolution at any point along the way

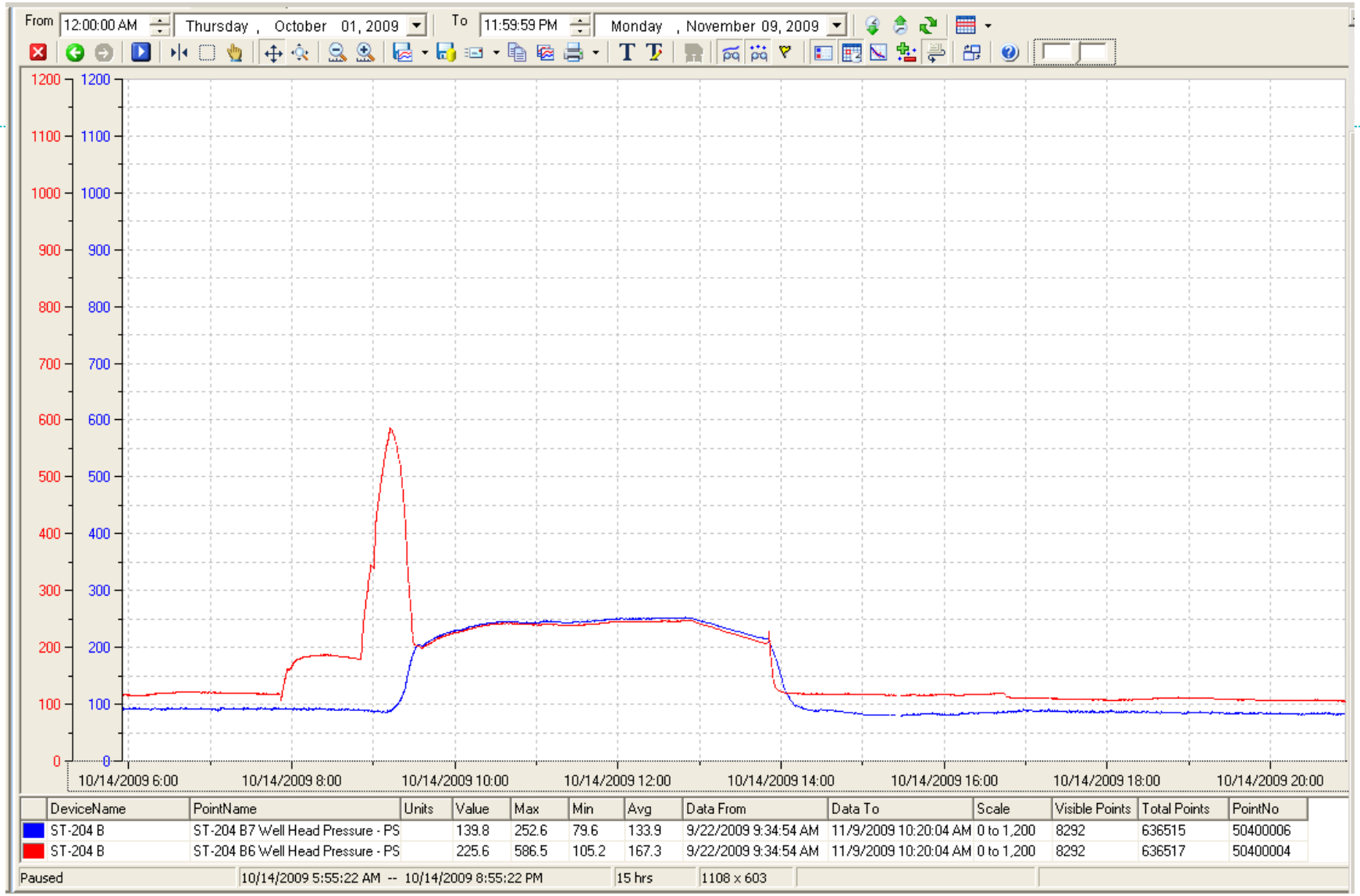
Data Visualization





DeviceName	PointName	Units	Value	Max	Min	Avg	Data From	Data To	Scale	Visible Points	Total Points	PointNo
ST-204 B	ST-204 B7 Well Head Pressure - PS		139.7	1,604.1	16.1	96.2	10/1/2009 12:00:00 AM	11/9/2009 10:18:03 AM	0 to 1,200	521844	521844	50400006
ST-204 B	ST-204 B6 Well Head Pressure - PS		225.2	678.9	13.7	130.9	10/1/2009 12:00:00 AM	11/9/2009 10:18:03 AM	0 to 1,200	521846	521846	50400004

Paused | 10/1/2009 12:00:00 AM -- 11/9/2009 11:59:59 PM | 40 days | 1108 x 603



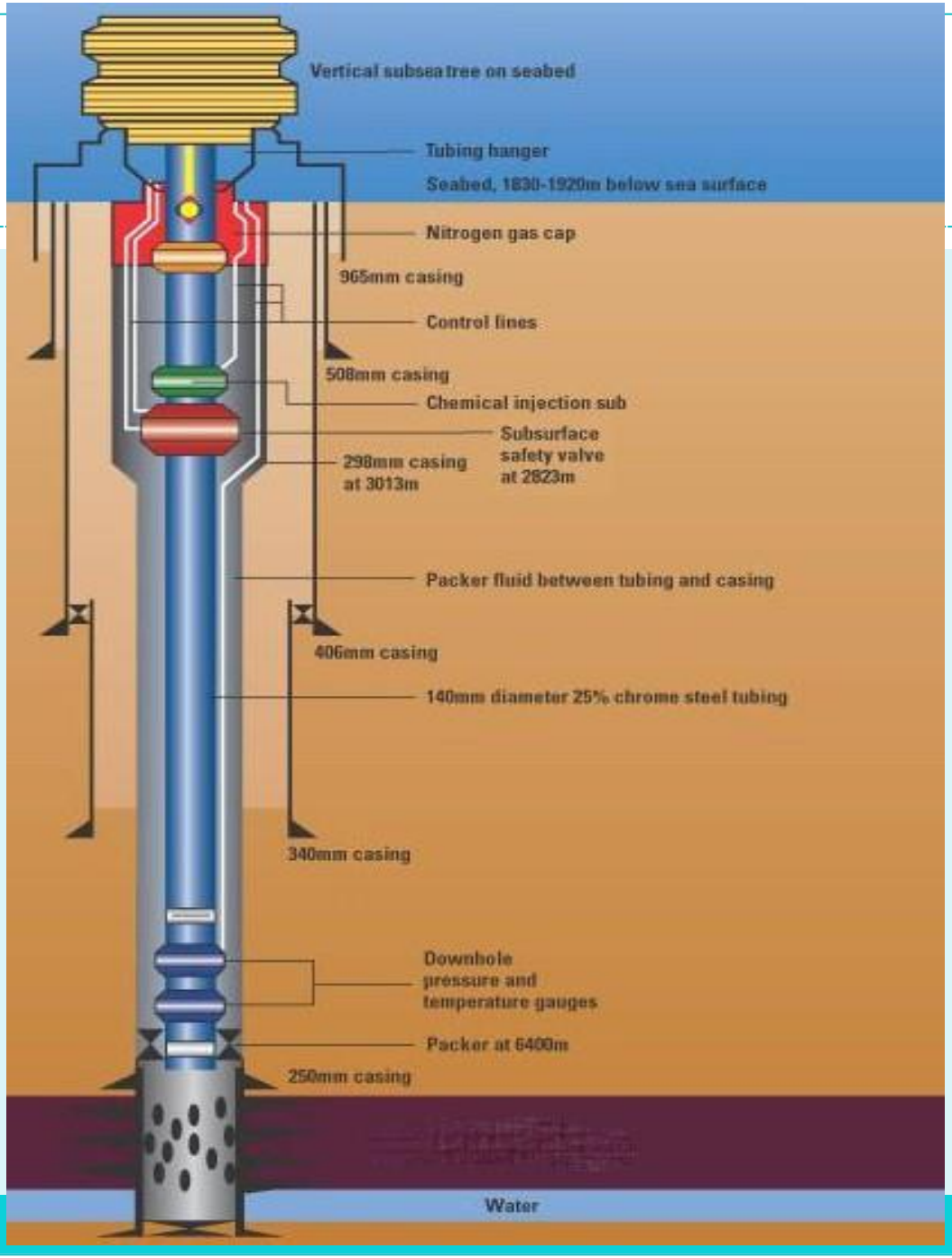
DeviceName	PointName	Units	Value	Max	Min	Avg	Data From	Data To	Scale	Visible Points	Total Points	PointNo
ST-204 B	ST-204 B7 Well Head Pressure - PS		139.8	252.6	79.6	133.9	9/22/2009 9:34:54 AM	11/9/2009 10:20:04 AM	0 to 1,200	8292	636515	50400006
ST-204 B	ST-204 B6 Well Head Pressure - PS		225.6	586.5	105.2	167.3	9/22/2009 9:34:54 AM	11/9/2009 10:20:04 AM	0 to 1,200	8292	636517	50400004

Paused | 10/14/2009 5:55:22 AM -- 10/14/2009 8:55:22 PM | 15 hrs | 1108 x 603

Virtual Rate Measurement

- Used for Scenarios where there is not continuous rate measurement
- Common Instances:
  - Use productivity and periodic test sep rates
  - Use choke settings and DPs
  - Use WHT and Heat Loading model
  - Allocation by Difference (Platform)
  - Sonic/Ultra-sonic

The Wellbore-Completion-Reservoir System


Vertical subsea tree on seabed
Tubing hanger
Seabed, 1830-1920m below sea surface
Nitrogen gas cap
965mm casing
Control lines
508mm casing
Chemical injection sub
Subsurface safety valve at 2823m
298mm casing at 3013m
Packer fluid between tubing and casing
406mm casing
140mm diameter 25% chrome steel tubing
340mm casing
Downhole pressure and temperature gauges
Packer at 6400m
250mm casing
Water

Governing Physics Laws & Rules

- Flow in Pipe (Well Bore)
  - 1st Law of Thermo (Mechanical Energy Balance)
  - Fluid Mixing Rules
  - Continuity
- Flow in Reservoir
  - 1st Law of Thermo
  - 2nd Law of Thermo (Power Dissipation Seeks Equilibrium)
  - Darcy's Law (porous media)
  - Radial Coordinates: Flow is Radially Constrained
- Flow in Completion & Near-Well Region
  - Conflicts resolved between Radial Flow and Well Geometry
  - Common Solution is to employ a "skin" factor

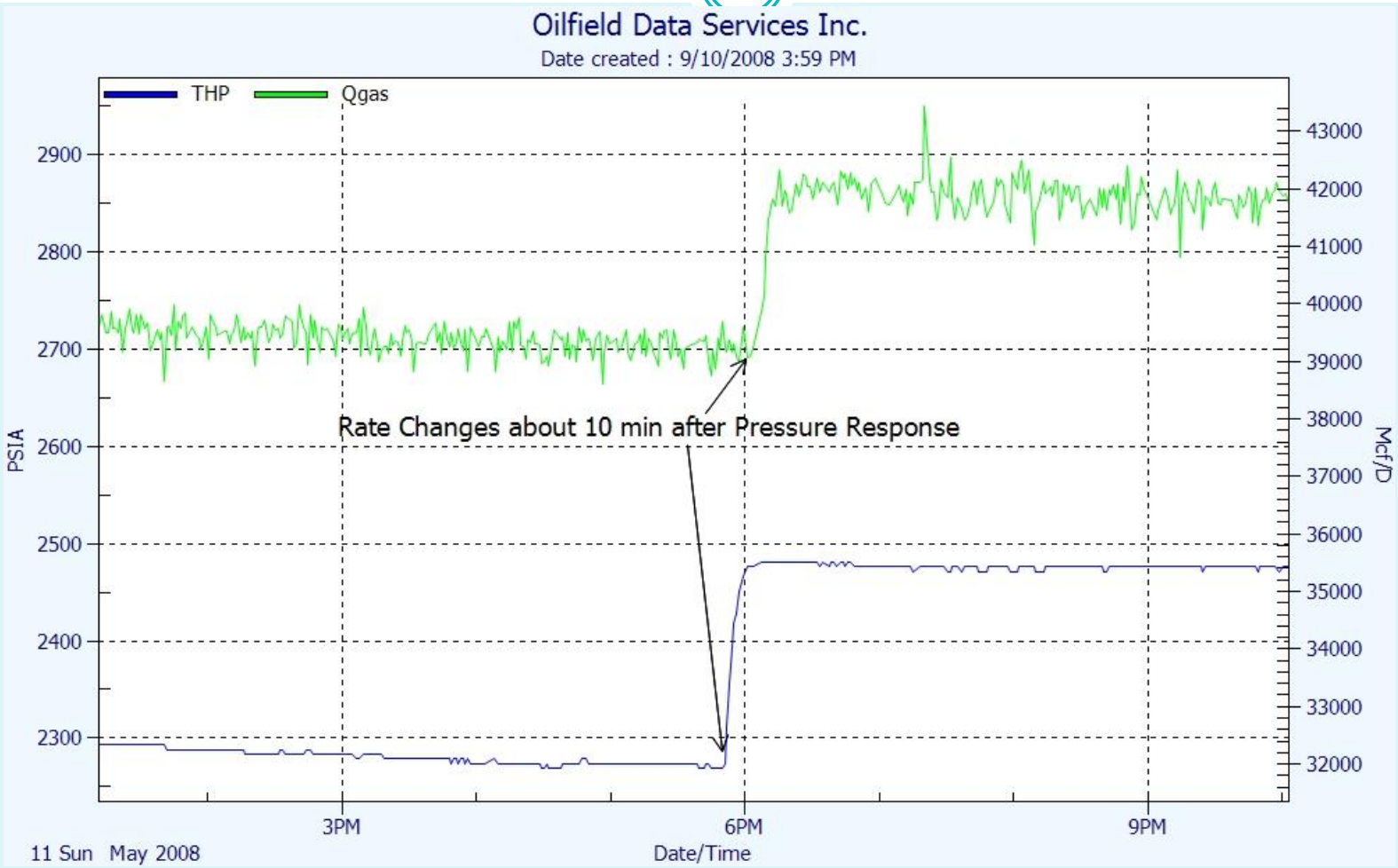
Important Relationships For Multi-Phase Wells

- Well Bore
  - PVT Relationships
    - Density
    - Viscosity & Internal Energy
    - Effective Friction Contribution
    - Phase Interaction (Phase to Phase & Phase to Pipe BL)
- Rock & Fluid Interactions
  - Formation Compressibility and Elasticity (System Comp)
  - Capillary Forces & Capillary Memory
  - Threshold Pressure (Capillary Entry Pressure)
  - Relative Permeability
  - Inertial Forces

Other Complications

- Residence Time
- Joule-Thompson Cooling/Heating
- Partial Penetration/Perforation
- Pay Loss/Growth away from Completion
- Coupled Effects
  - Rate Surge/Decay
  - Rate-Thermal
  - Phase Blocking (Water Block, Condy Block)
  - Rate-Thermal-Phase Effects

Residence Time

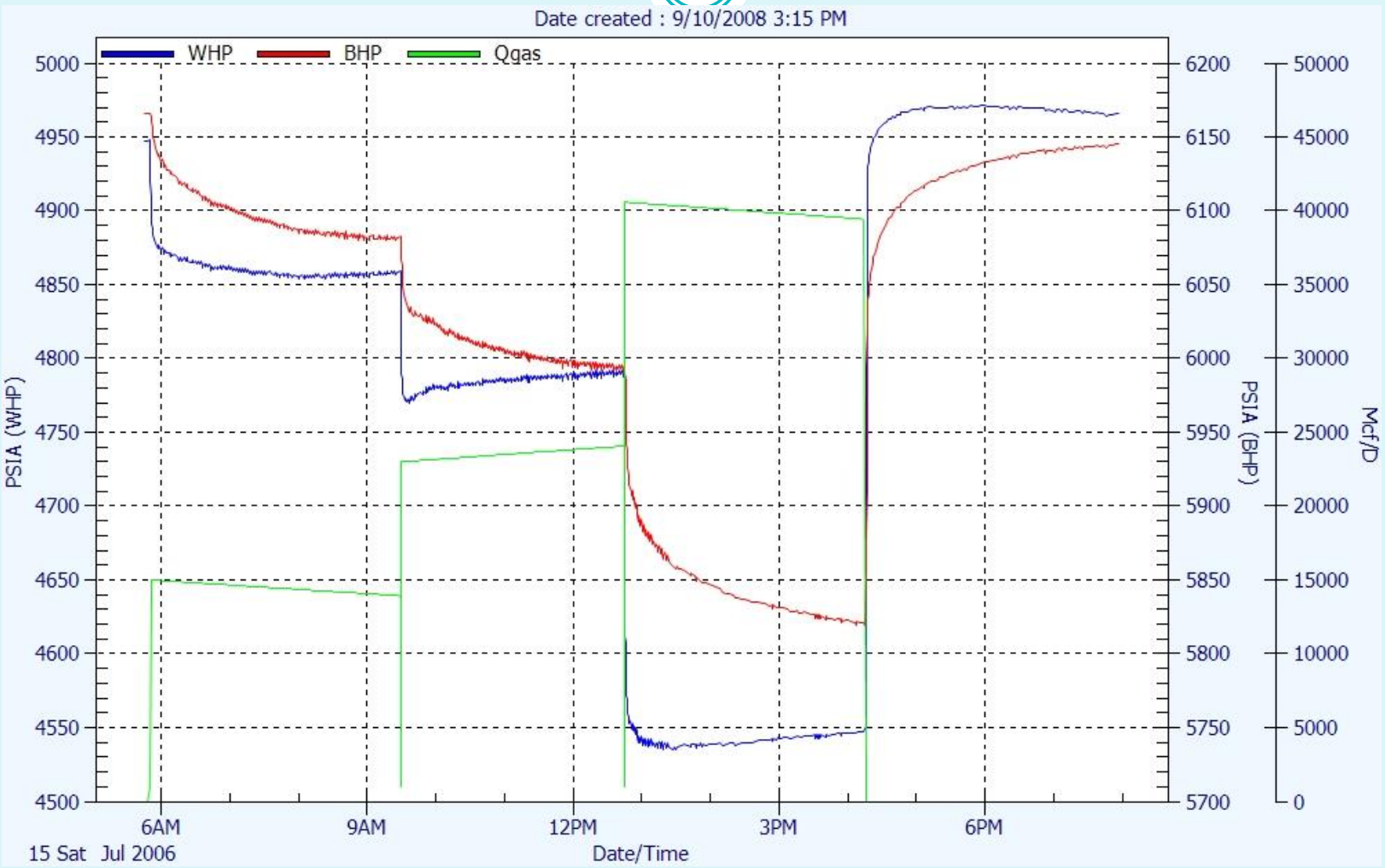


Rate Surges-Decays

Coupled Rate-Thermal Problem

- DHG responds “normally”
- WHP gauge responds differently
- WHP increases as DHGP decreases during flow
- Wellbore starts off “cool” & with higher inflow potential (flush production)
- Wellbore heats up, density decreases (head decreases)…mass flow rate decreases…which affects the heat loading…which affects the density…
  - And so on…and so on…
  - Continues until the well reaches thermal equilibrium

Rate Surge #2


Date created : 9/10/2008 3:15 PM
WHP
BHP
Qgas
PSIA (WHP)
PSIA (BHP)
Mcf/D
5000
4950
4900
4850
4800
4750
4700
4650
4600
4550
4500
6200
6150
6100
6050
6000
5950
5900
5850
5800
5750
5700
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
6AM
9AM
12PM
3PM
6PM
15 Sat Jul 2006
Date/Time

Analysis/Evaluation Tools

WHAT THEY ARE AND WHAT THEY TELL YOU

Analysis Types and Their Objectives

- PTA (Pressure Transient Analysis)
  - Skin, Perm, Deliverability, Communication, Productivity, Reservoir Boundaries, Reserves
- RTA (Rate Transient Analysis)
  - Same as PTA, but with less reliability on boundaries
- Pres/z Plots (gas) & DPres Plots (oil)
  - Oil and/or Gas in Place
- Decline Analysis: Flowing BHP vs Time
  - Apparent Reserves – Running MBAL
- Inverse Productivity Analysis (DP/DQ vs Time)
  - Apparent Reserves – Running EBAL

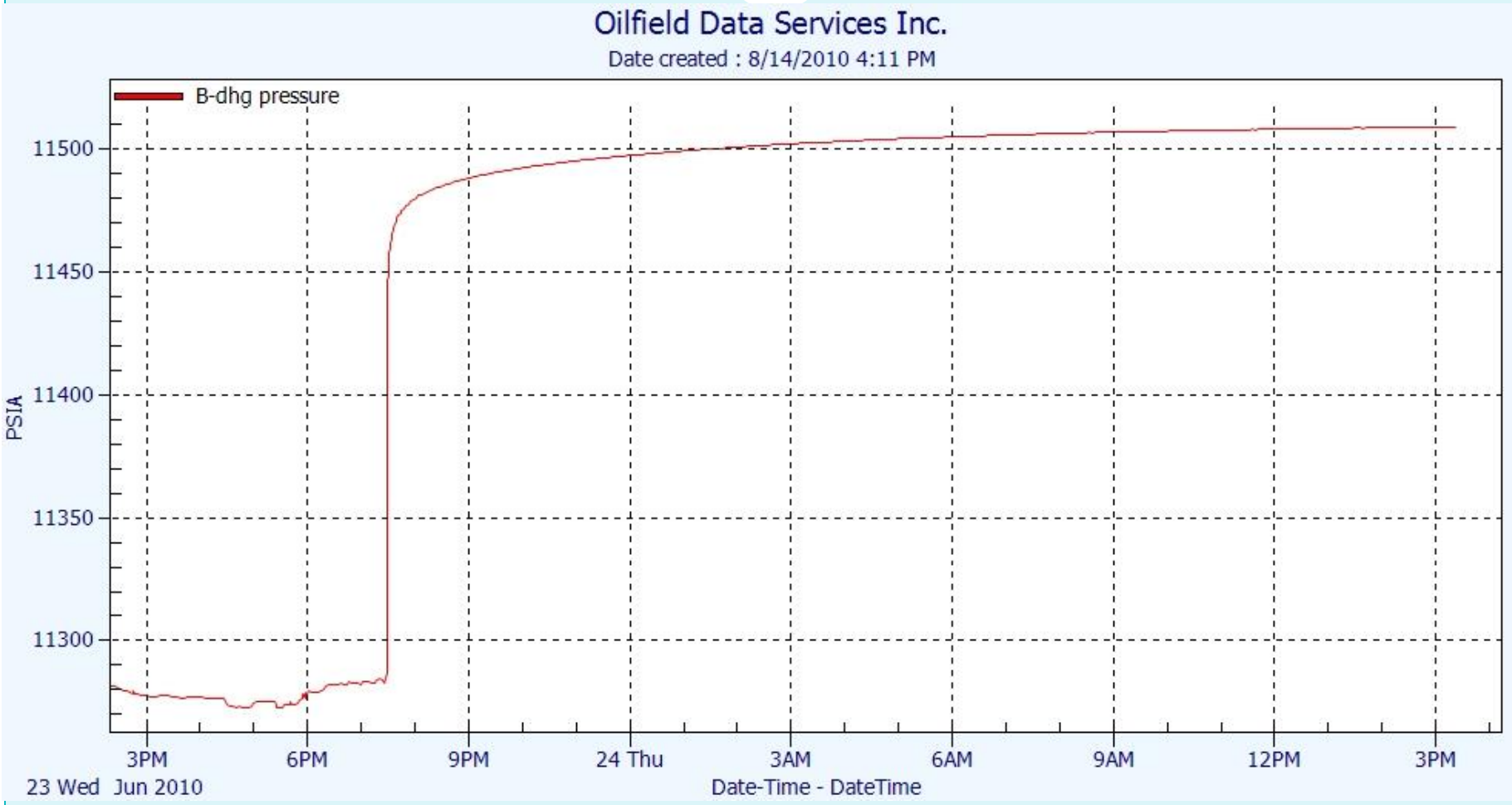
Analysis/Evaluation Tools: PTA

- Build-up: After flowing the well for a while, shut it in and observe the pressure response
- Drawdown: After shutting in the well for a while, flow it on a constant choke and observe the pressure and rate response
- 2-rate: Change the rate enough to create a new transient; observe P & Q
- Multi-rate: Change the rates and compare DP vs Q
- Communication: Shut-in a well and see if a neighboring well causes the Pressure to drop

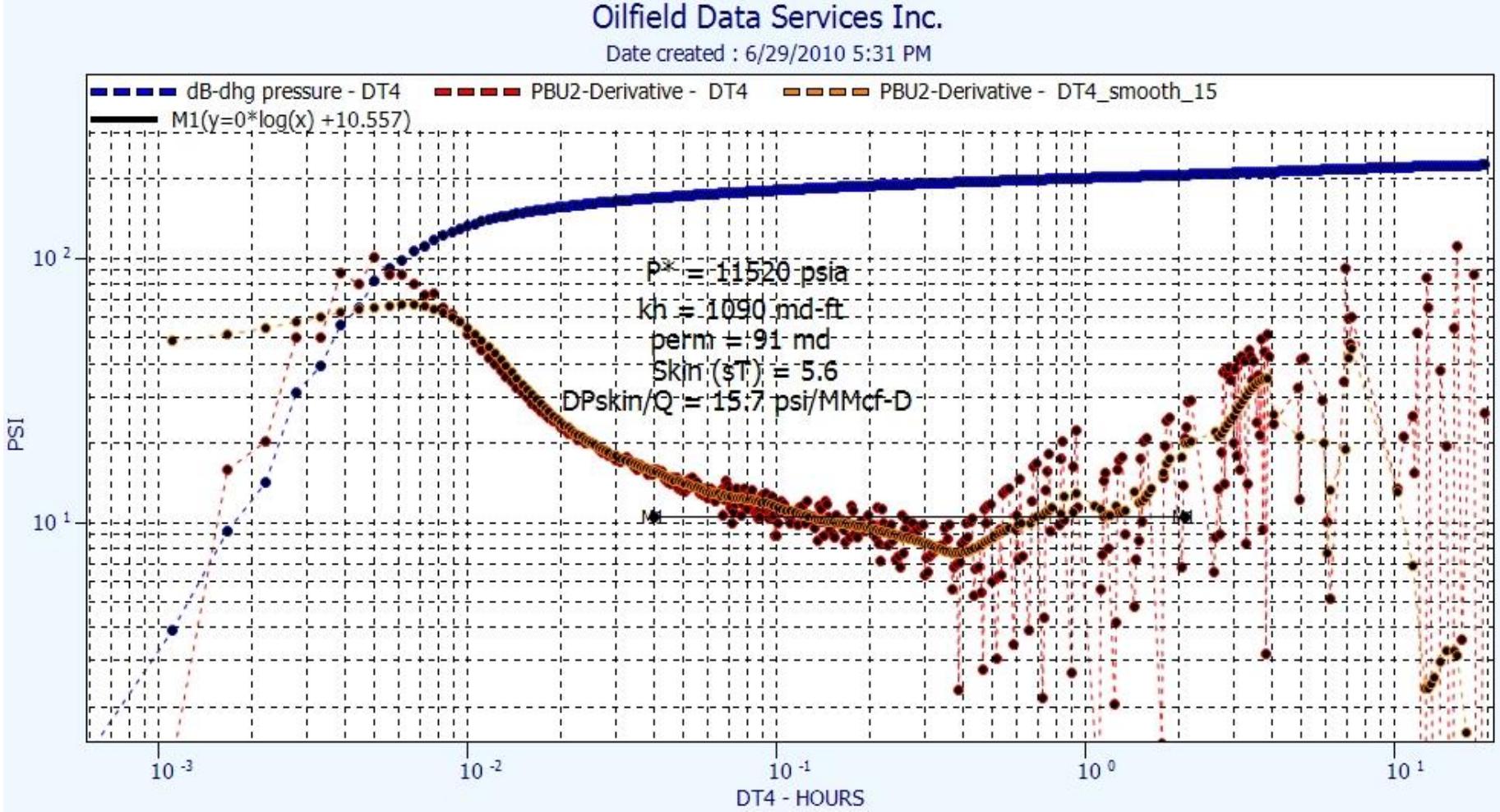
Analysis Type Examples

- Build-up PTA Derivative
- Drawdown PTA Semilog
- RTA
- P/z
- Decline Analysis (Running MBAL)
- IPA (Running EBAL)

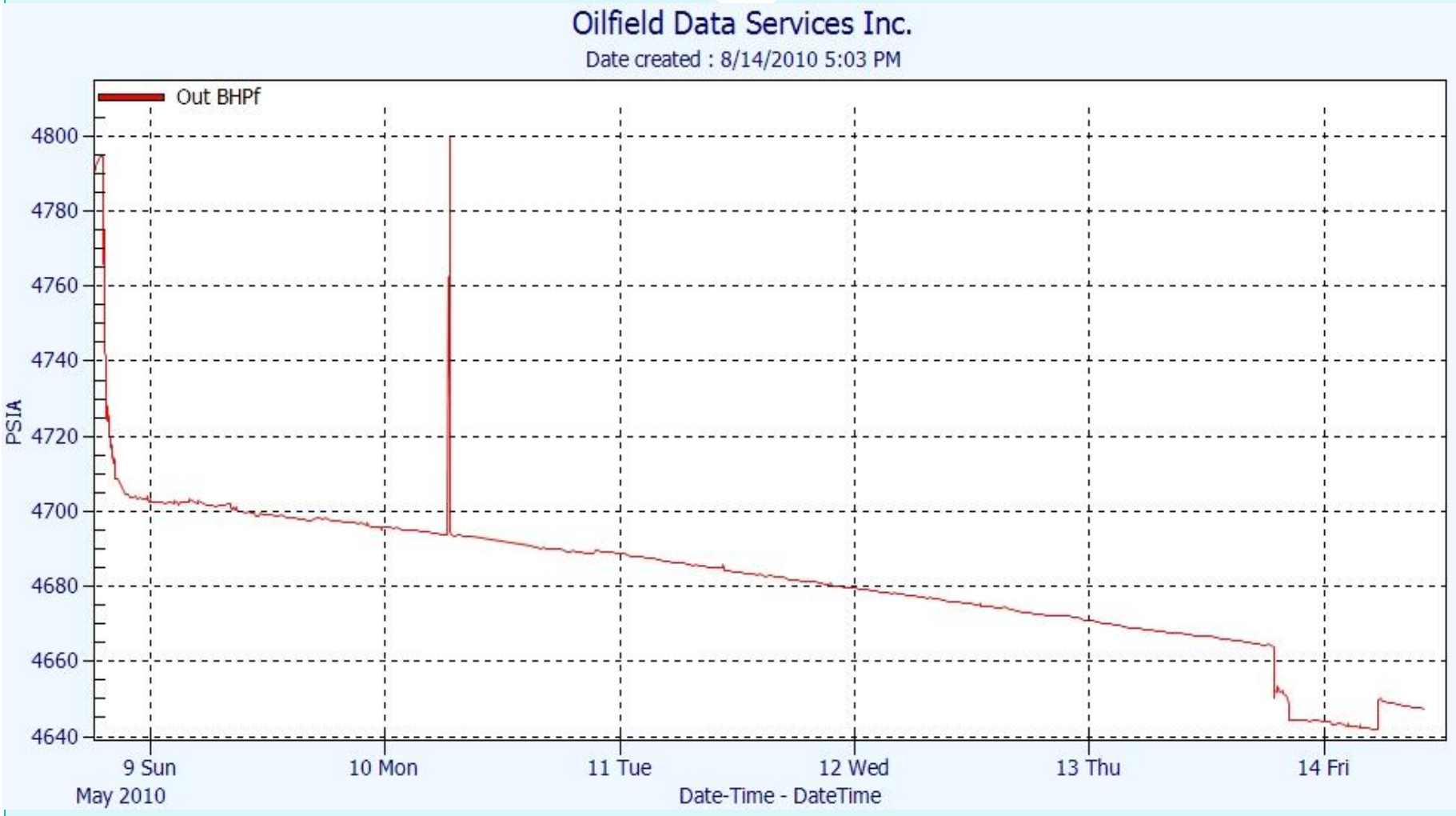
Build-up PTA


Oilfield Data Services Inc.
Date created : 8/14/2010 4:11 PM
B-dhg pressure
11500
11450
11400
11350
11300
PSIA
3PM
6PM
9PM
24 Thu
3AM
6AM
9AM
12PM
3PM
23 Wed Jun 2010
Date-Time - DateTime

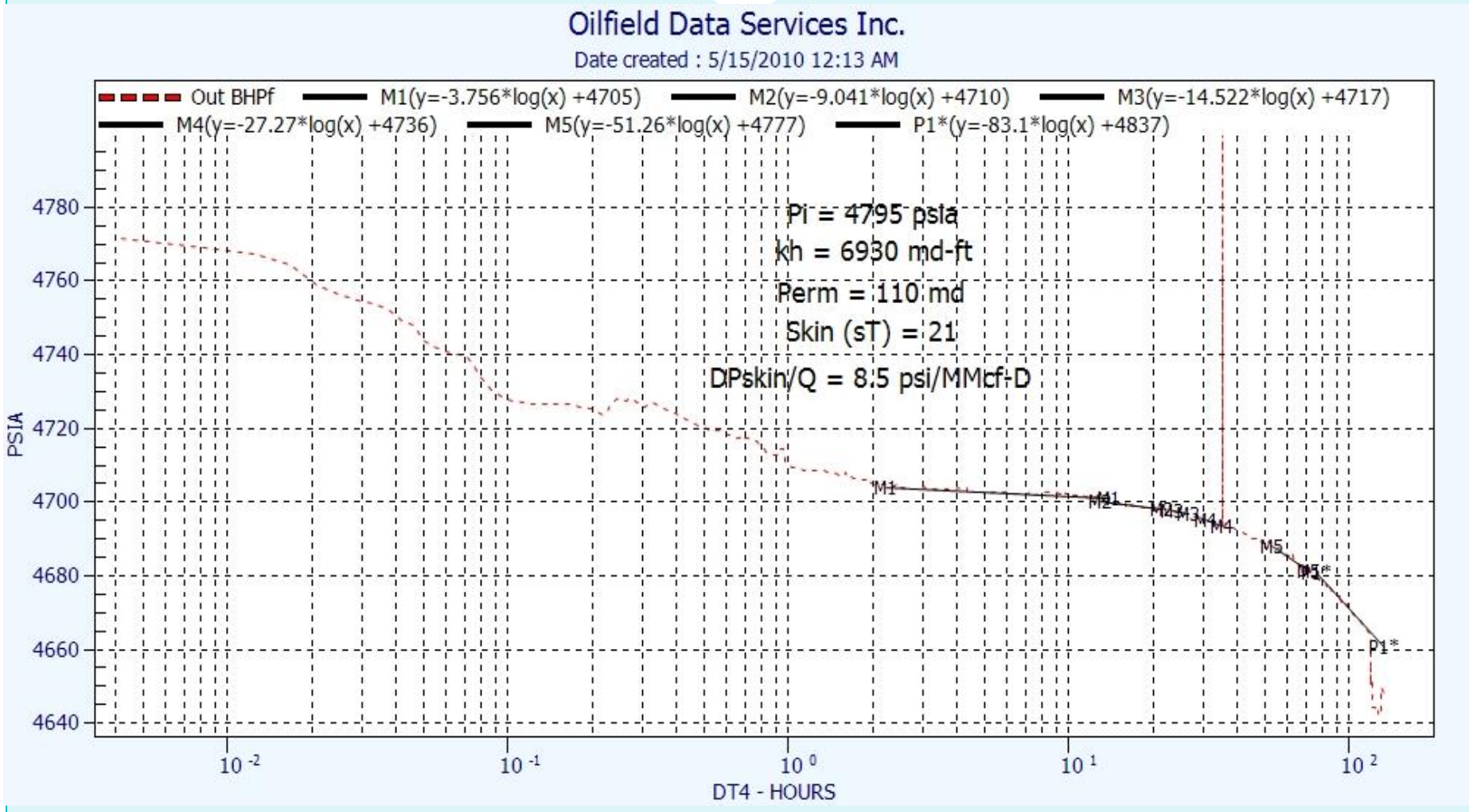
Build-up Derivative Analysis



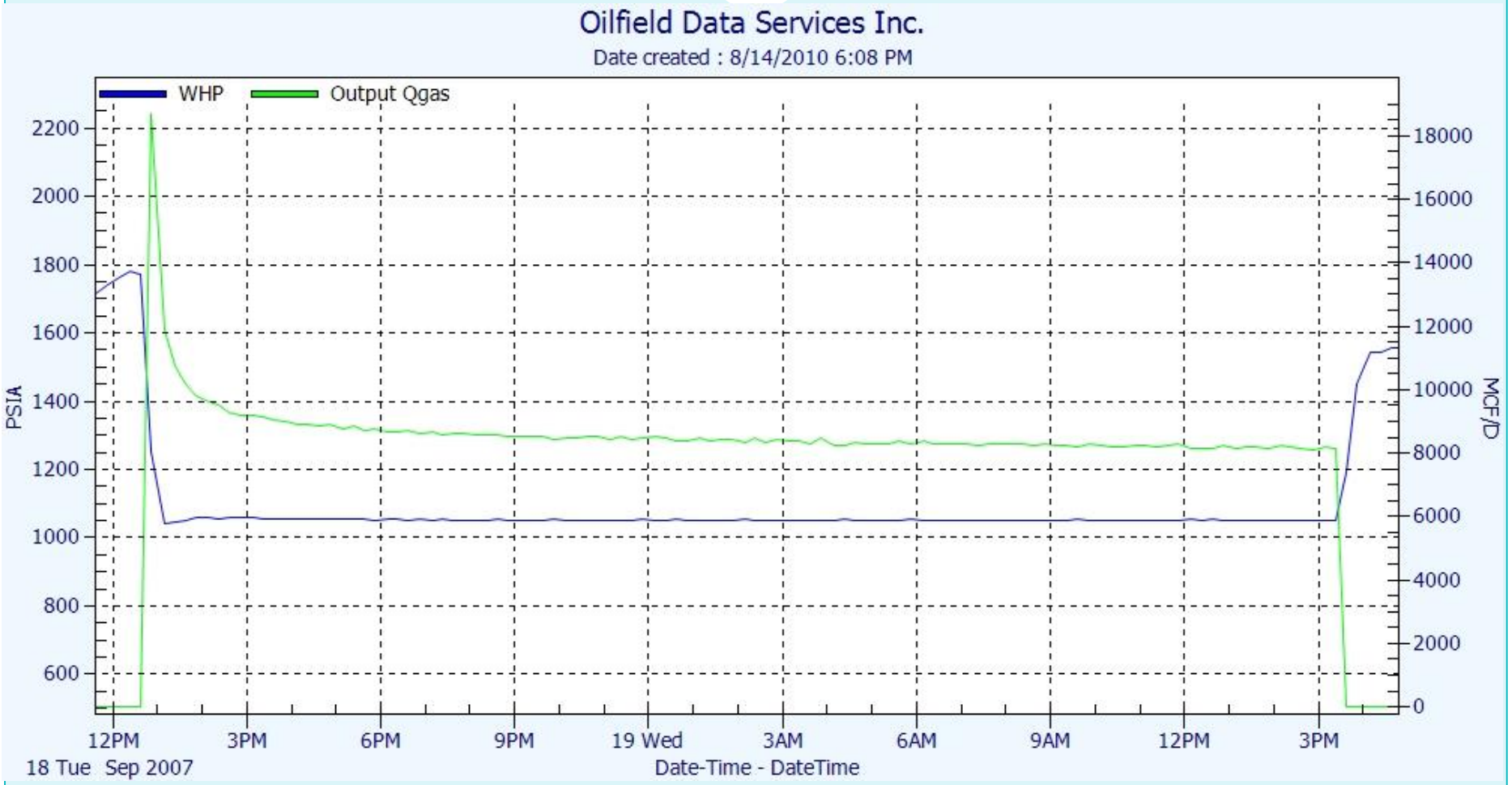
Drawdown - PTA



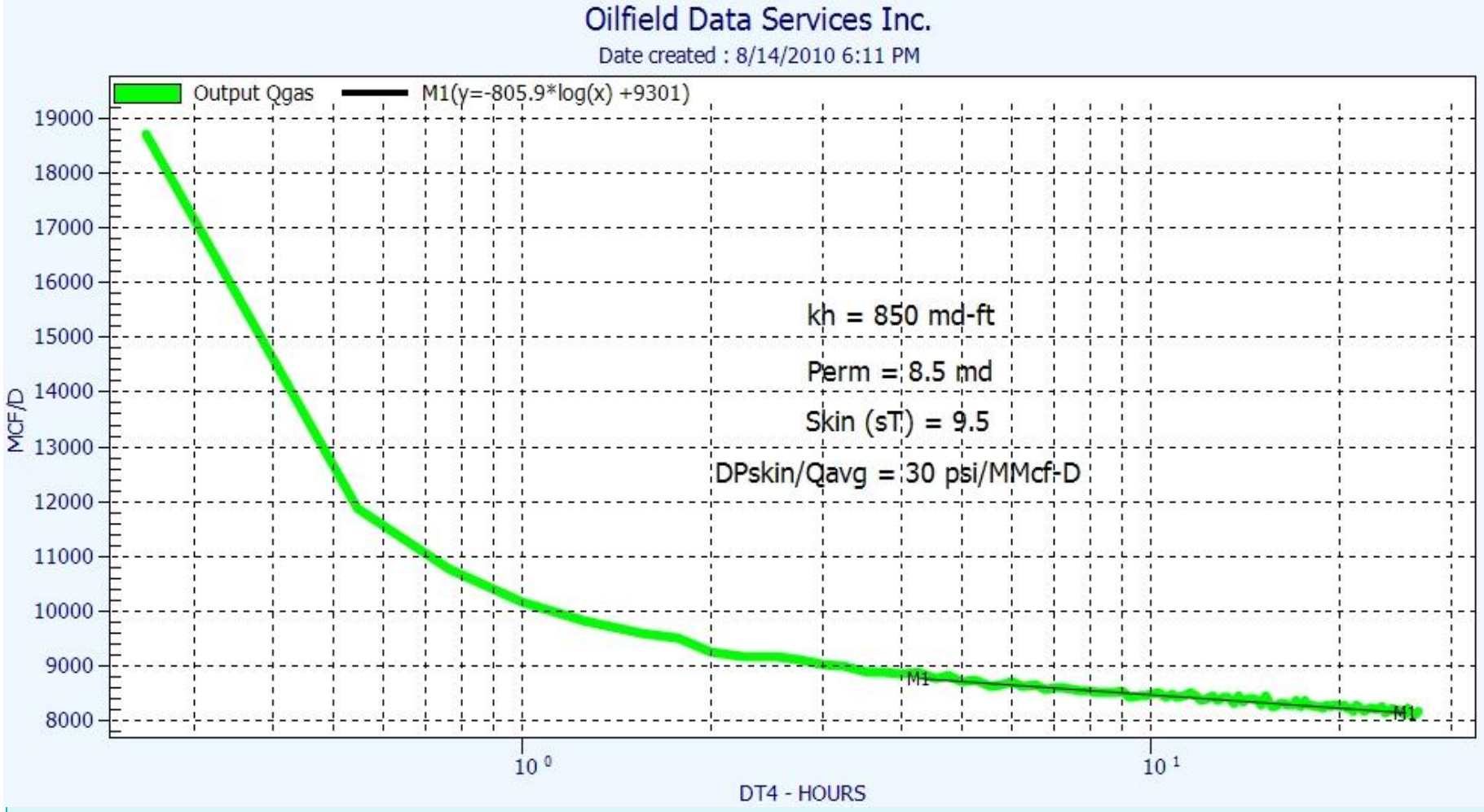
Drawdown PTA - Semilog Analysis



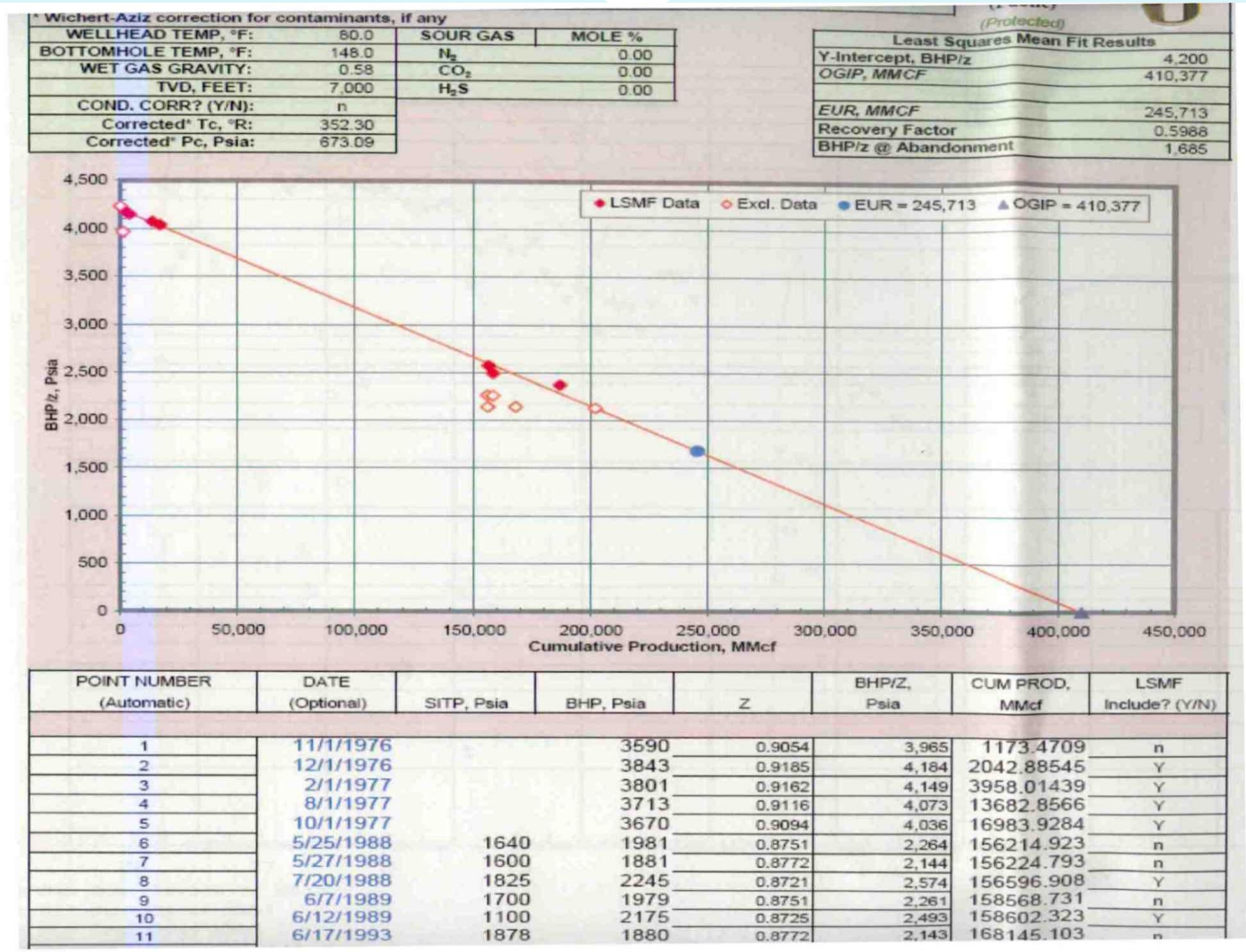
RTA Example - Cartesian



RTA – Semi-log Analysis



P/z Example



* Wichert-Aziz correction for contaminants, if any

WELLHEAD TEMP, °F:	80.0
BOTTOMHOLE TEMP, °F:	148.0
WET GAS GRAVITY:	0.58
TVD, FEET:	7,000
COND. CORR? (Y/N):	n
Corrected* Tc, °R:	352.30
Corrected* Pc, Psia:	673.09

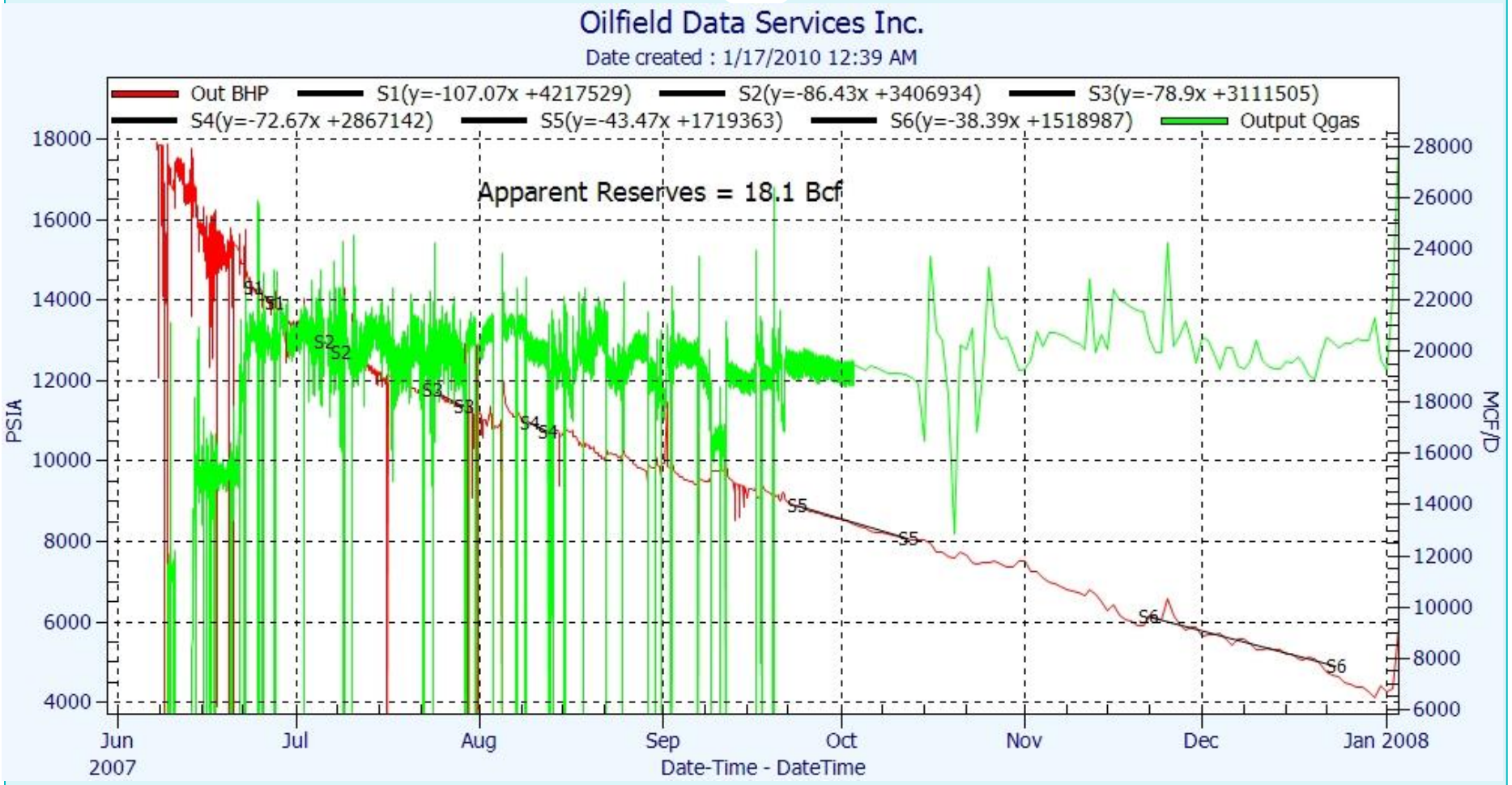
SOUR GAS	MOLE %
N_2	0.00
CO_2	0.00
H_2S	0.00

(Protected)

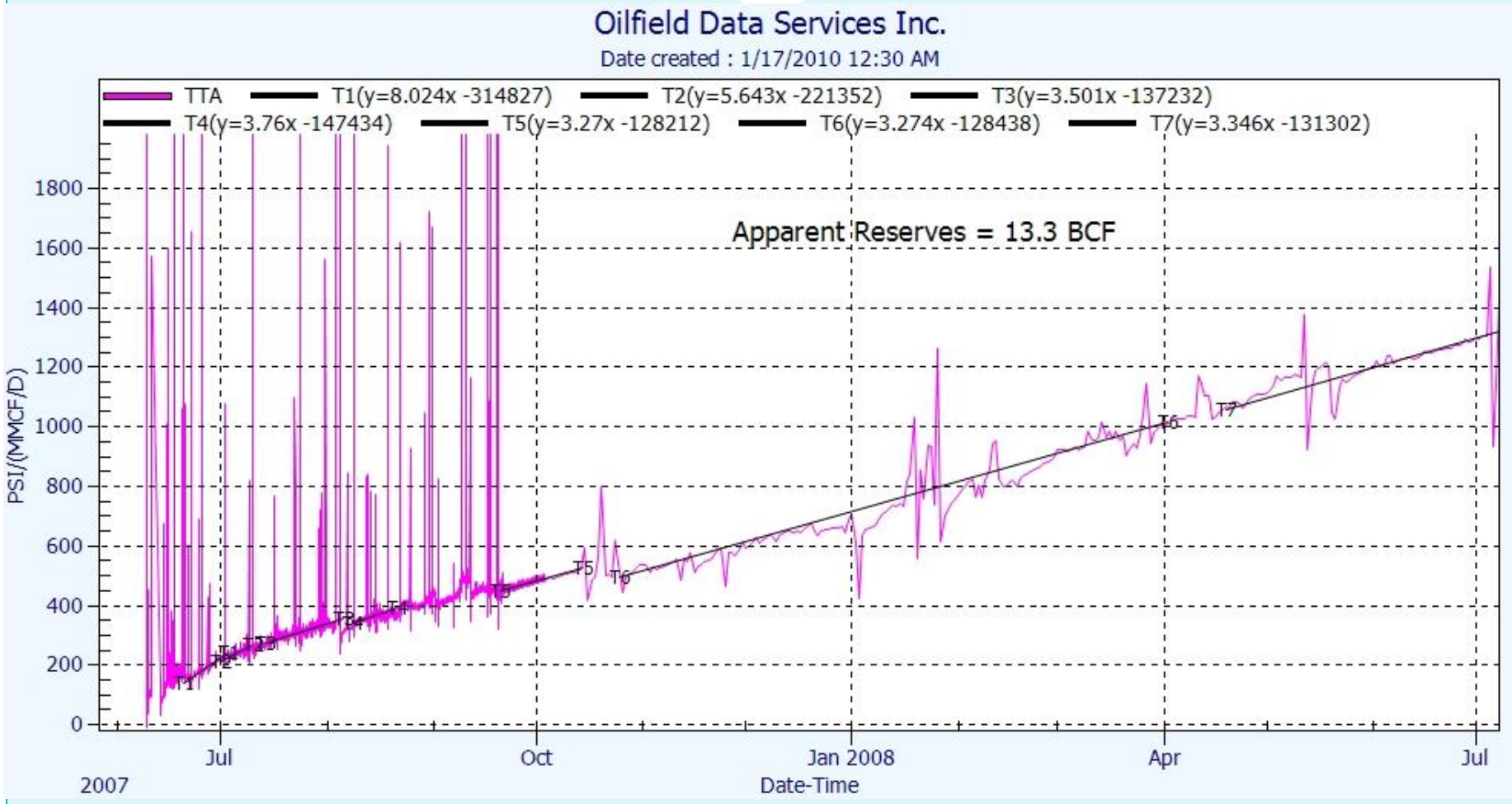
Least Squares Mean Fit Results	
Y-Intercept, BHP/z	4,200
OGIP, MMCF	410,377
EUR, MMCF	245,713
Recovery Factor	0.5988
BHP/z @ Abandonment	1,685

POINT NUMBER (Automatic)	DATE (Optional)	SITP, Psia	BHP, Psia	Z	BHP/Z, Psia	CUM PROD, MMcf	LSMF Include? (Y/N)
1	11/1/1976		3590	0.9054	3,965	1173.4709	n
2	12/1/1976		3843	0.9185	4,184	2042.88545	Y
3	2/1/1977		3801	0.9162	4,149	3958.01439	Y
4	8/1/1977		3713	0.9116	4,073	13682.8566	Y
5	10/1/1977		3670	0.9094	4,036	16983.9284	Y
6	5/25/1988	1640	1981	0.8751	2,264	156214.923	n
7	5/27/1988	1600	1881	0.8772	2,144	156224.793	n
8	7/20/1988	1825	2245	0.8721	2,574	156596.908	Y
9	6/7/1989	1700	1979	0.8751	2,261	158568.731	n
10	6/12/1989	1100	2175	0.8725	2,493	158602.323	Y
11	6/17/1993	1878	1880	0.8772	2,143	168145.103	n

Decline Evaluation



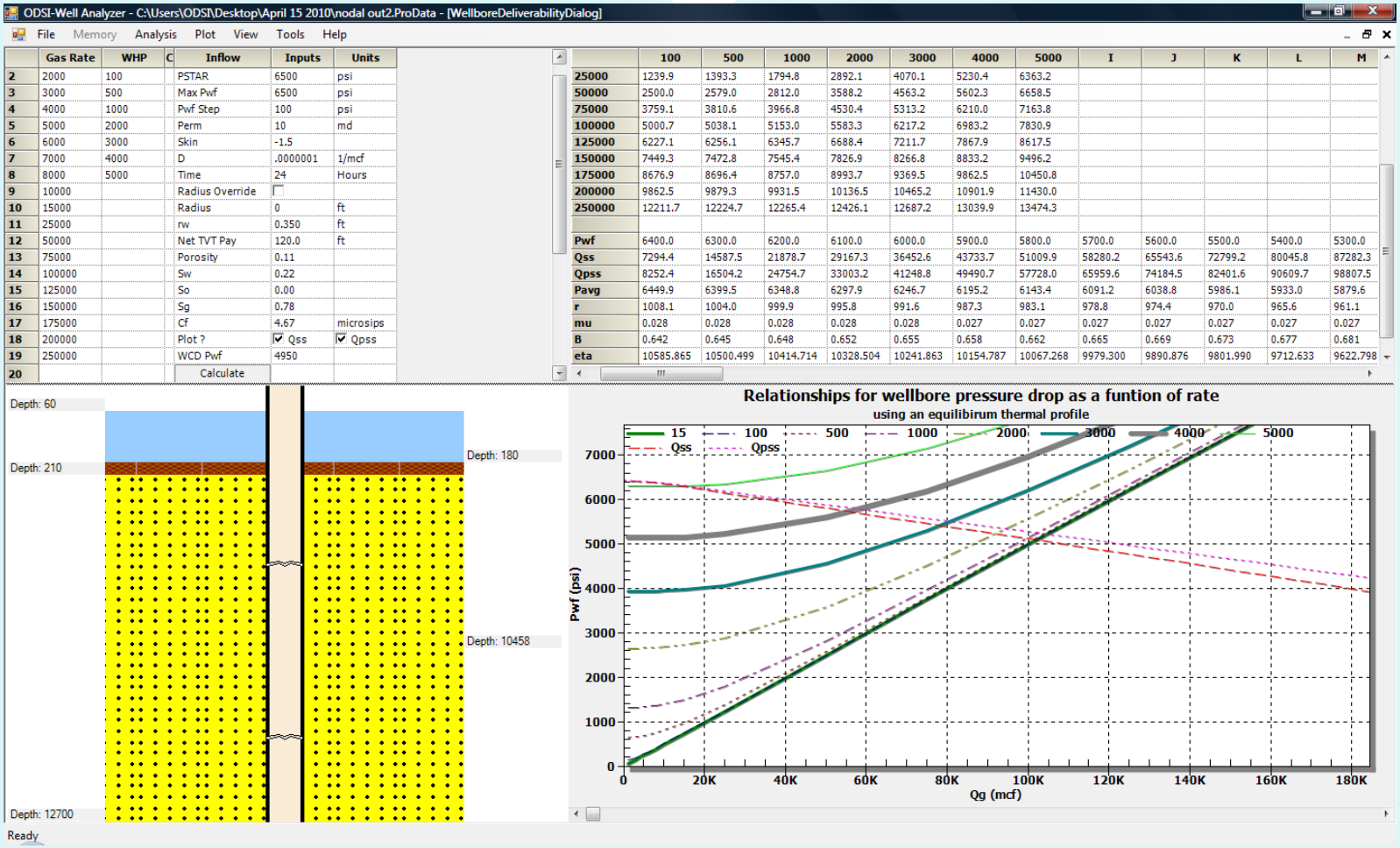
IPA Example


Oilfield Data Services Inc.
Date created : 1/17/2010 12:30 AM
TTA
T1(y=8.024x -314827)
T2(y=5.643x -221352)
T3(y=3.501x -137232)
T4(y=3.76x -147434)
T5(y=3.27x -128212)
T6(y=3.274x -128438)
T7(y=3.346x -131302)
Apparent Reserves = 13.3 BCF
PSI/(MMCF/D)
0
200
400
600
800
1000
1200
1400
1600
1800
Jul
2007
Oct
Jan 2008
Apr
Jul
Date-Time

“Static” Nodal Analysis

- Compares Reservoir Inflow (IPC) with Wellbore Performance (VLP)
  - Allows Prediction of DP to achieve a Rate (vice versa)
  - Allows Prediction of Liquid Loading Scenarios
  - Allows Optimization of Tubular Design
- Problems with Nodal
  - Infinite # of combos of skin & perm calculate the same rate (Can’t use nodal to determine skin or perm)
  - User has to pick the right inflow model and right VLP correlation
  - Doesn’t handle transient situations well – may match your well today, but not next month

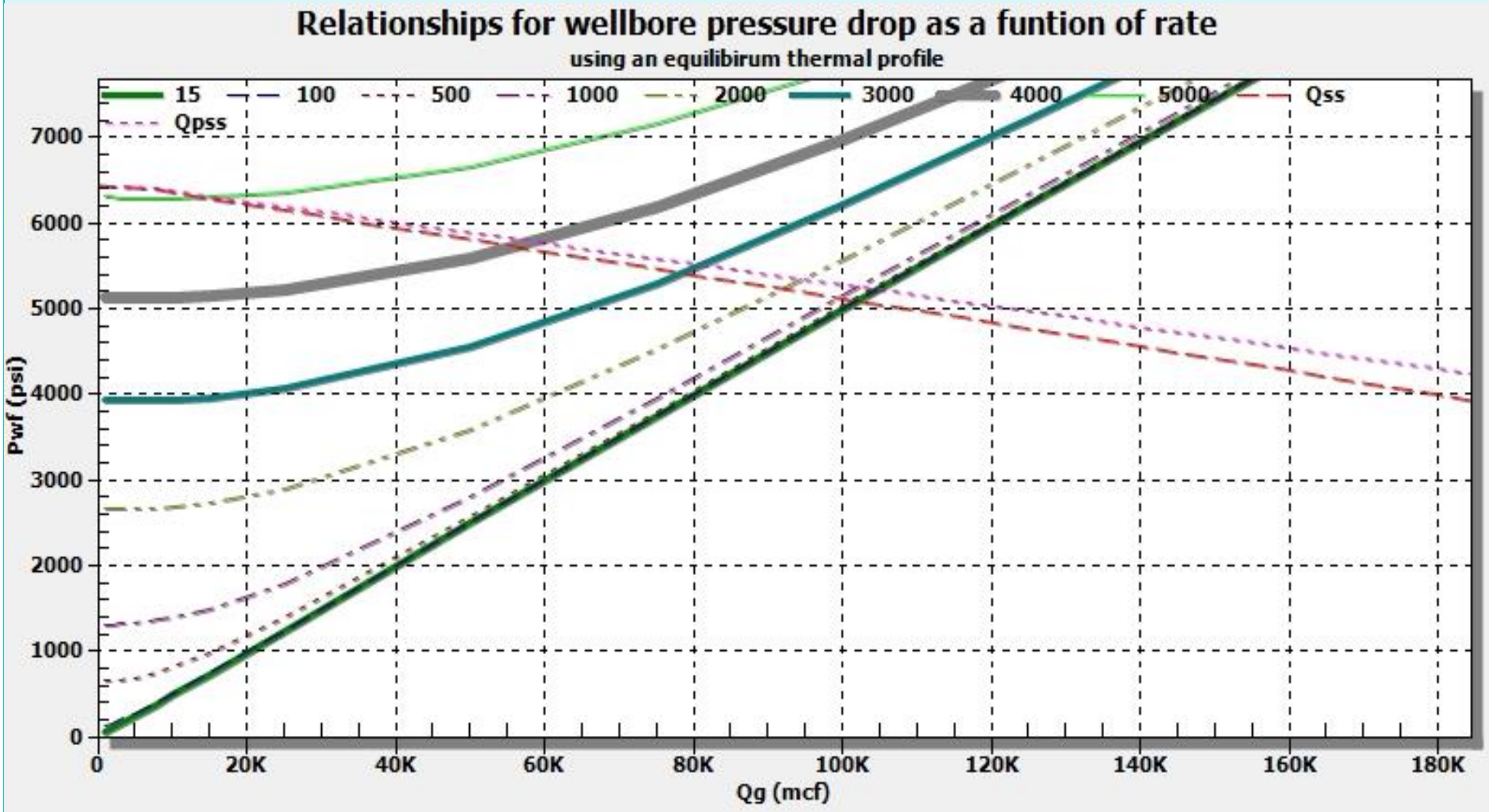
Nodal – IPC + VLP



	Gas Rate	WHP	C	Inflow	Inputs	Units
2	2000	100		PSTAR	6500	psi
3	3000	500		Max Pwf	6500	psi
4	4000	1000		Pwf Step	100	psi
5	5000	2000		Perm	10	md
6	6000	3000		Skin	-1.5	
7	7000	4000		D	.0000001	1/mcf
8	8000	5000		Time	24	Hours
9	10000			Radius Override	☐	
10	15000			Radius	0	ft
11	25000			rw	0.350	ft
12	50000			Net TVT Pay	120.0	ft
13	75000			Porosity	0.11	
14	100000			Sw	0.22	
15	125000			So	0.00	
16	150000			Sg	0.78	
17	175000			Cf	4.67	microsips
18	200000			Plot ?	☑ Qss	☑ Qpss
19	250000			WCD Pwf	4950	
20				Calculate		

	100	500	1000	2000	3000	4000	5000	I	J	K	L	M
25000	1239.9	1393.3	1794.8	2892.1	4070.1	5230.4	6363.2					
50000	2500.0	2579.0	2812.0	3588.2	4563.2	5602.3	6658.5					
75000	3759.1	3810.6	3966.8	4530.4	5313.2	6210.0	7163.8					
100000	5000.7	5038.1	5153.0	5583.3	6217.2	6983.2	7830.9					
125000	6227.1	6256.1	6345.7	6688.4	7211.7	7867.9	8617.5					
150000	7449.3	7472.8	7545.4	7826.9	8266.8	8833.2	9496.2					
175000	8676.9	8696.4	8757.0	8993.7	9369.5	9862.5	10450.8					
200000	9862.5	9879.3	9931.5	10136.5	10465.2	10901.9	11430.0					
250000	12211.7	12224.7	12265.4	12426.1	12687.2	13039.9	13474.3					
Pwf	6400.0	6300.0	6200.0	6100.0	6000.0	5900.0	5800.0	5700.0	5600.0	5500.0	5400.0	5300.0
Qss	7294.4	14587.5	21878.7	29167.3	36452.6	43733.7	51009.9	58280.2	65543.6	72799.2	80045.8	87282.3
Qpss	8252.4	16504.2	24754.7	33003.2	41248.8	49490.7	57728.0	65959.6	74184.5	82401.6	90609.7	98807.5
Pavg	6449.9	6399.5	6348.8	6297.9	6246.7	6195.2	6143.4	6091.2	6038.8	5986.1	5933.0	5879.6
r	1008.1	1004.0	999.9	995.8	991.6	987.3	983.1	978.8	974.4	970.0	965.6	961.1
mu	0.028	0.028	0.028	0.028	0.028	0.027	0.027	0.027	0.027	0.027	0.027	0.027
B	0.642	0.645	0.648	0.652	0.655	0.658	0.662	0.665	0.669	0.673	0.677	0.681
eta	10585.865	10500.499	10414.714	10328.504	10241.863	10154.787	10067.268	9979.300	9890.876	9801.990	9712.633	9622.798

Nodal VLP-IPC Plot

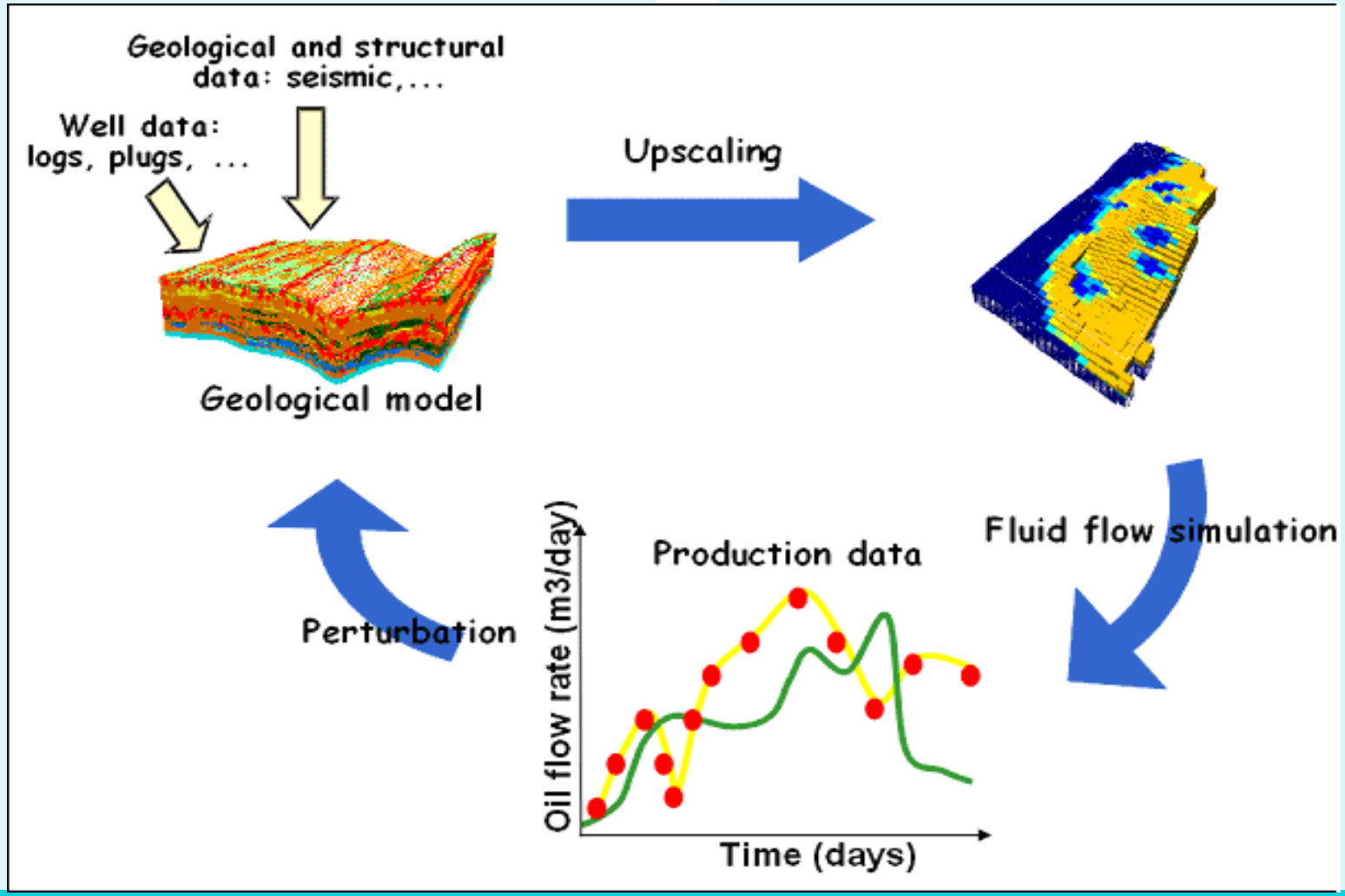


Reservoir Simulation

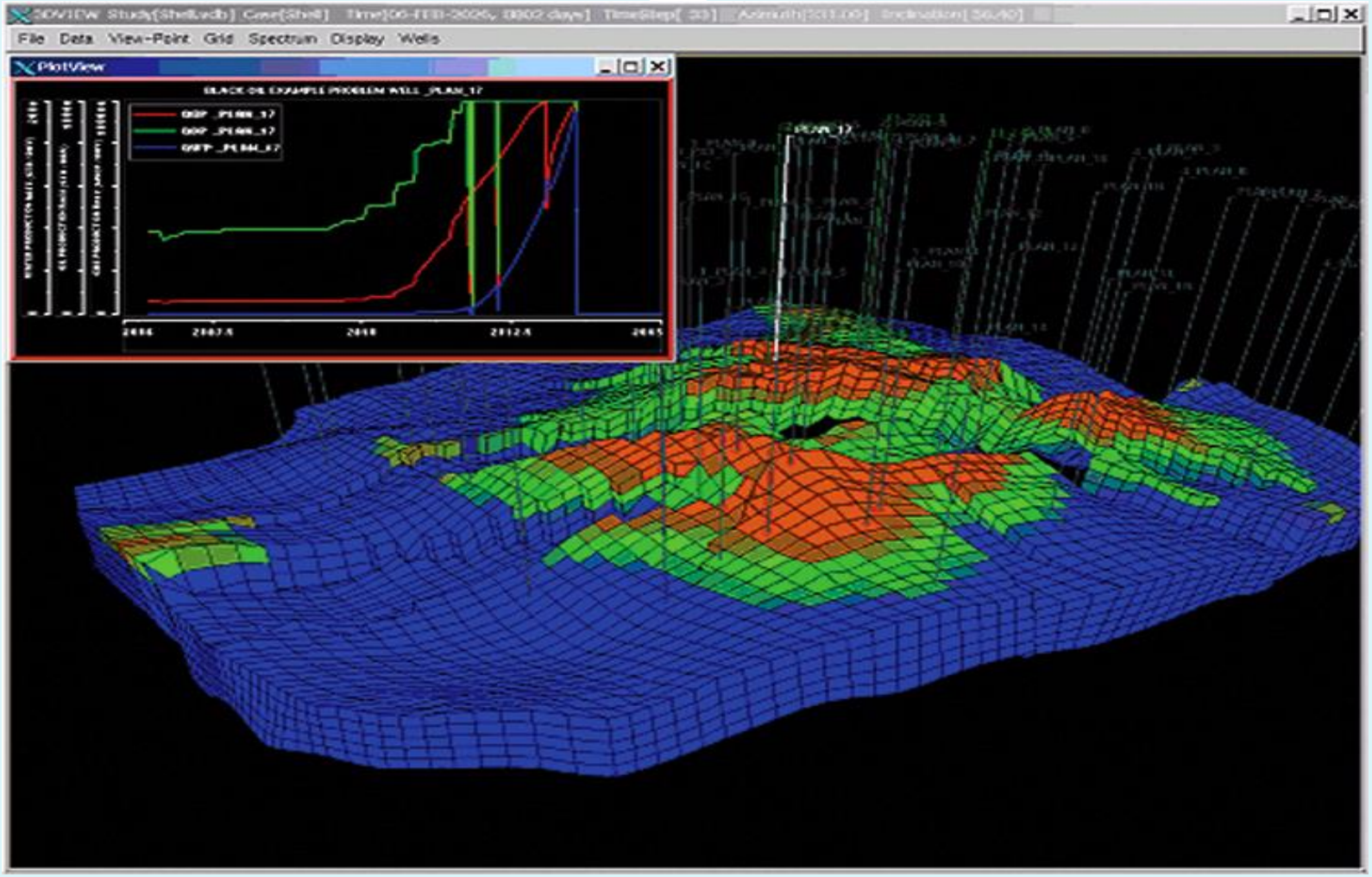
- Tracks behavior (esp Pressure and Saturation) in the reservoir
- Incorporates Multiple Wells/Multiple Zones
- Matches History and Attempts to Predict Future Performance
- Coupled with a Wellbore Simulator, can do amazing things

- Drawback: It takes a while to run…but they're getting faster

Simulation Gist…



Simulation: Well Grid



Components of a Real-Time Well Evaluation Package

TAKE ALL THE BITS AND BOLT THEM TOGETHER

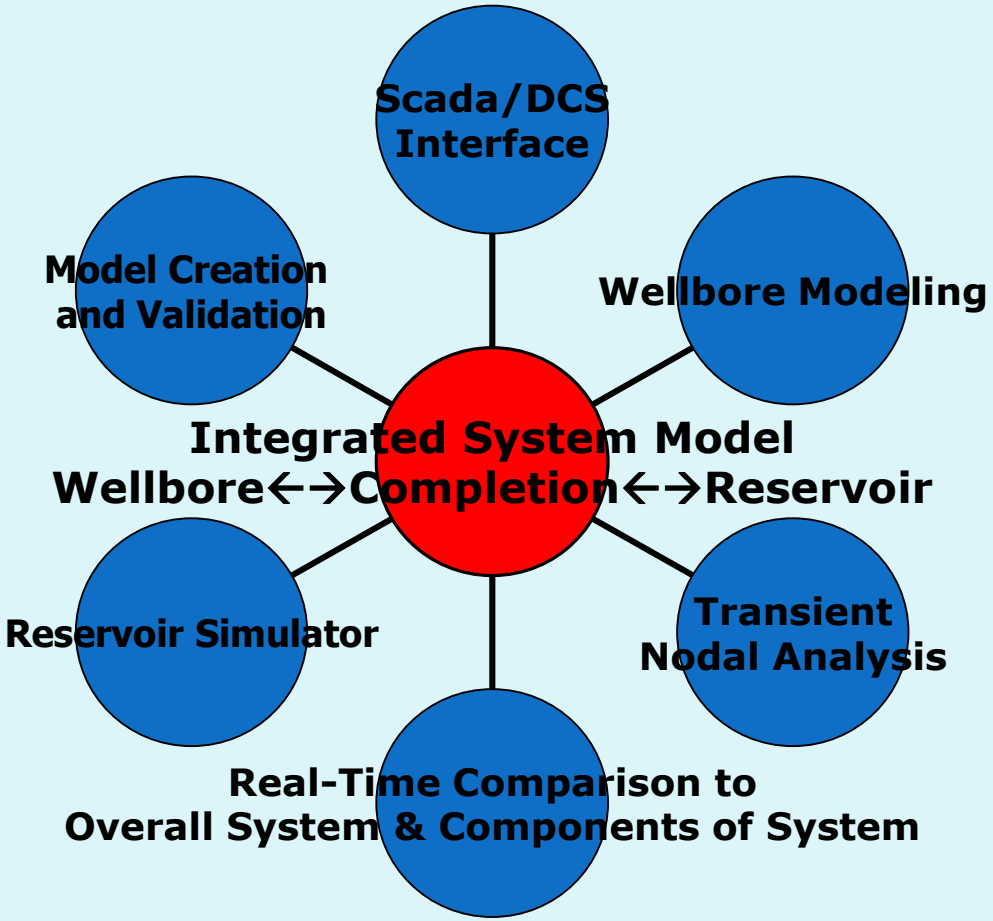
What Do We Already Have? (Batch Process)

- Hopefully…adequate data frequency and quality
- “Snapshot” VLP
- “Snapshot” Inflow
- Reservoir Simulator
- Wellbore Model
- Geologic/Geo-Physical Model
- Enough Well History?

What Do We Need to Make it Real-Time?

- Link to RT Data (w/Validation of Data)
- Closed-Loop Wellbore Solution (w/Thermal Modeling)
- Closed-Loop Completion Solution - Can incorporate w/Reservoir Model
- Closed-Loop Reservoir Model
- Transient Recognition
- Regime Recognition
- Prediction vs. Actual Comparison
- Engineering by Difference (Did anything Change?)

The Bits…


Scada/DCS Interface
Model Creation and Validation
Wellbore Modeling
Integrated System Model
Wellbore←→Completion←→Reservoir
Reservoir Simulator
Transient Nodal Analysis
Real-Time Comparison to Overall System & Components of System

Closed-Loop WB Components

- Wellbore Thermal Modeling (Warming/Cooling)
- Liquid Drop Out (Build-ups)
- Liquid Surge (Start-up)
- Phase Behaviour EOS Calcs
  - Use SRK or PR w/Peneloux
- Rate Modeling
  - Residence Time
  - Rate Surging & Decay
- Coupled Effects (Rate-Thermal-Phase)

Developing Thermal/PVT Models

- Run Static Temp/Pressure Survey
- Run Flowing Temp/Pressure Survey
  - Multiple Rates
- Develop Heat Transfer Model – Account for:
  - Heat Capacity of Fluids/Tubulars/Annuli/Sinks
  - Heat X-fer via Conduction
  - Heat X-fer via Convection
  - Heat X-fer via Forced Convection
- Can Tune PVT using same data…just get a good sample first

Continuity Equation

$$\frac{\partial \rho}{\partial t} \equiv -(\nabla \bullet \rho v)$$

- Rate of Change in Density Caused by Changes in Mass Flux

Differential Form of Bernoulli Eqn Compressible Conditions

$$\Delta \tfrac{1}{2}(v)^2 + g\Delta h + \int_{p1}^{p2} dp/\rho + Ws +$$

$$\sum_i \left(\tfrac{1}{2} v^2 \frac{L}{R_h} f\right)_i + \sum_i \left(\tfrac{1}{2} v^2 e_v\right)_i = 0$$

Mechanical Energy Balance (Bernoulli Equation)

- For Single-Phase Gas Flow in Pipes, the MEB reduces to:

$$dp/\rho = -(g \sin\theta/g_c + 2f_f u^2/g_c D)\, dL$$

- Basis for CS, Gray & A-C

Bernoulli for Single Phase Oil Incompressible Conditions

$$\frac{dp}{d\rho}+\frac{vdv}{g_c}+\frac{g}{g_c}dz+\frac{2f_f v^2 dL}{g_c D}+dW_s=0$$

- Basis for Hagedorn-Brown & Beggs/Brill

Bernoulli Solution Process

Build Parametric Models & Well Configuration

↓

Assume Continuity

↓

Solve Bernoulli (MEB)

↓

Check Continuity

Note: If Continuity Doesn't Hold, the Well is Loading–up (which is important to know)

Using a Direct Bernoulli Solution for WB

- Works for Oil, Gas or Water (Continuity)
- Gas
  - Have DP, solve for rate
  - Have Rate, solve for DP
- Oil
  - Have Rate, solve for Water cut
  - Have DP, solve for Water cut
- Much Easier to Apply Parametric Models Continuously:
  - Thermal Transients
  - Rate Transients
  - Phase Transients
  - Combined Rate, Phase & Thermal Transients

Completion Modeling

- Reconcile Well Geometry (frac, horizontal, etc.) with base inflow
  - Build Dual Perm Model
  - Build “skin” model (easiest way if it works)
- Reconcile Completion/Reservoir Interaction
  - Partial Perforation/Penetration
  - Pay Loss/Growth
  - Near Well Stresses – Elasto-Plastic Rock
- True “Afterflow” vs. Terminal Velocity Flow

Closed-Loop Reservoir Solution

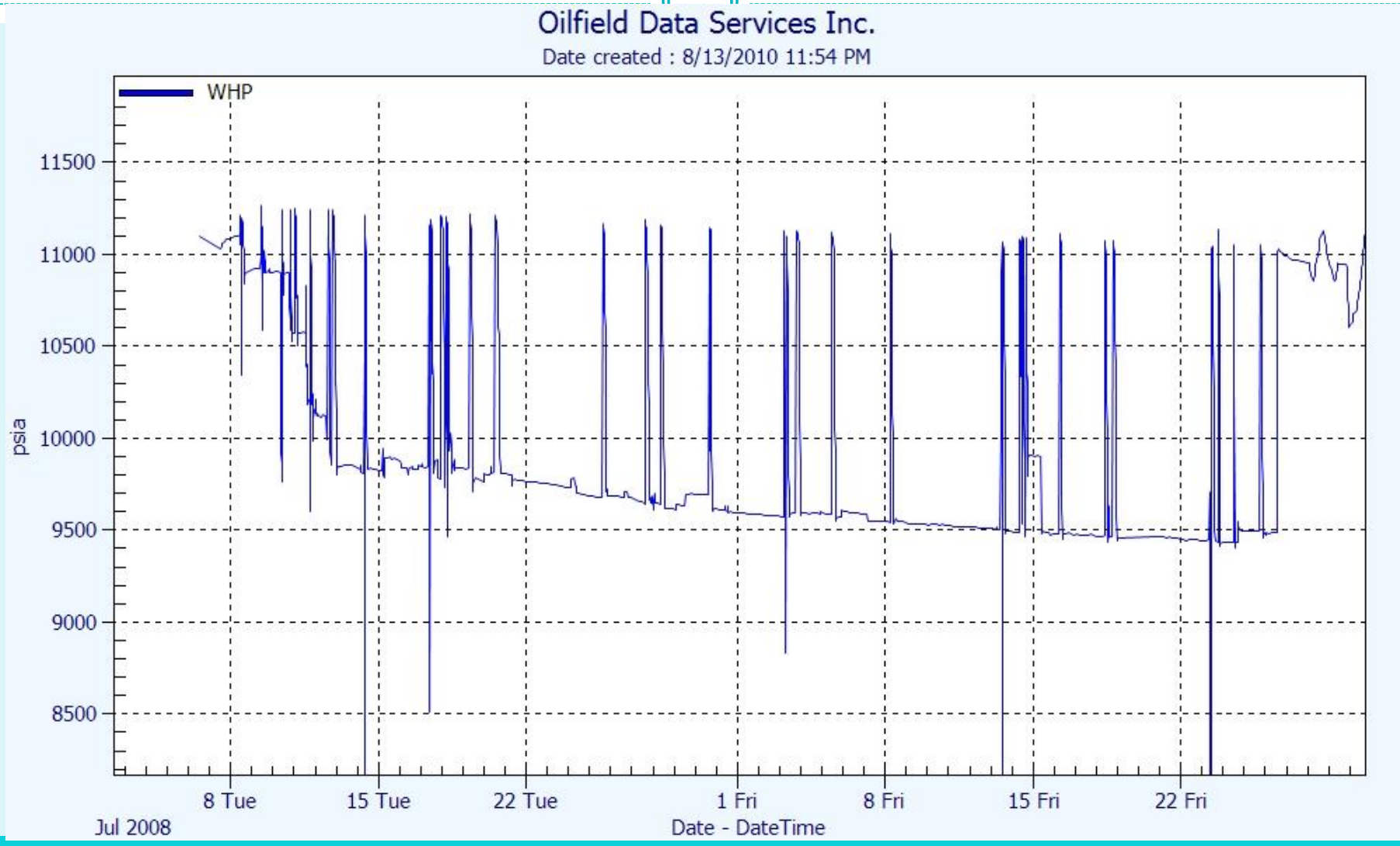
- Use “Static Reservoir Model” as input
- Use Transient Reservoir model when in transient flow
- Use Steady-State Reservoir model in SS flow
- Use Transient Recognition to “bob & weave”

- Objective: Run very quickly & get close
- Recognize if there’s a problem with the “static” model
- Still a work in progress…

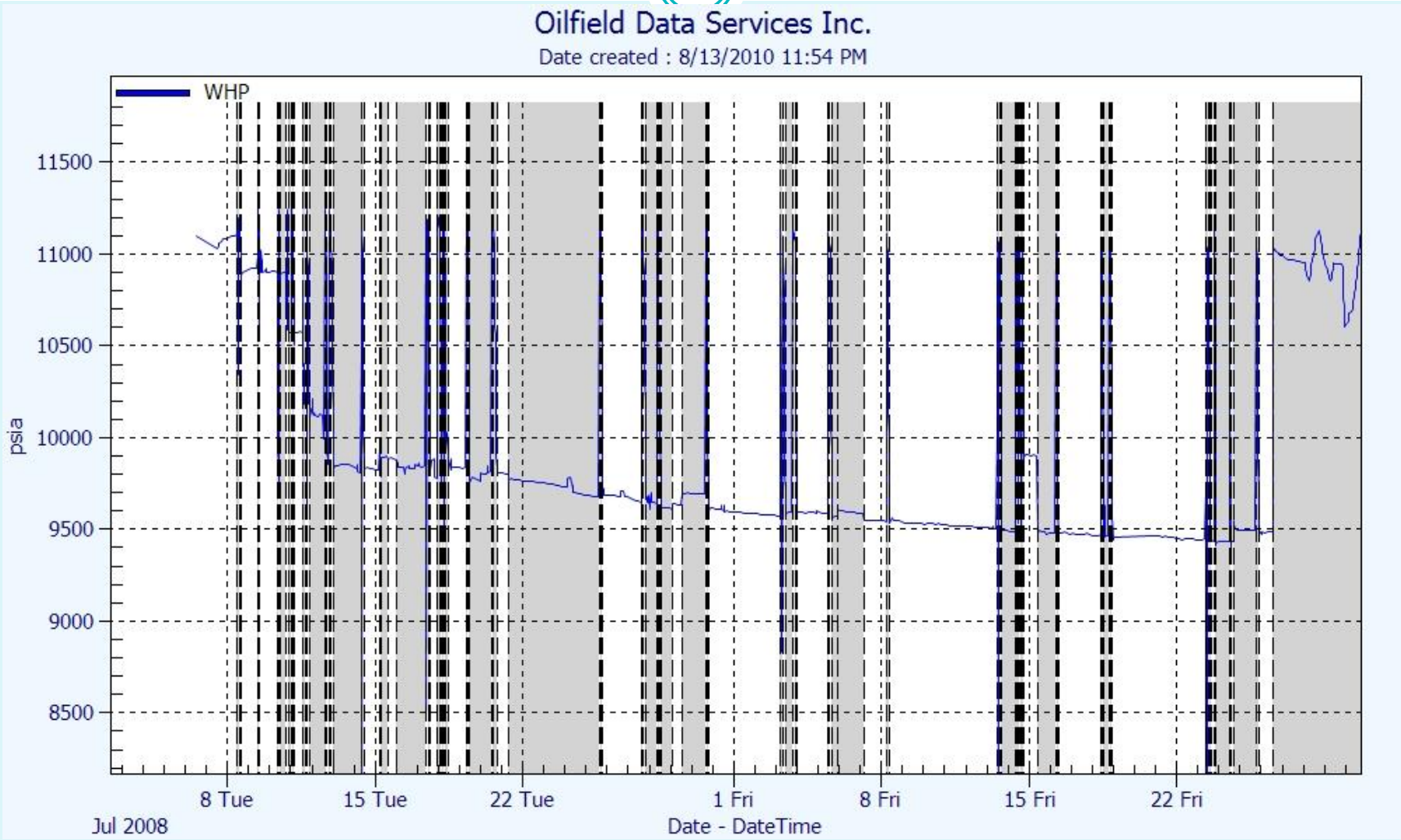
Transient and Regime Recognition

- Locate New Transients
  - Rate goes to zero, Rate stops being zero
  - Rate changes enough to start new transient
  - Pressure Methods
    - Wavelets
    - De-convolution Variance
    - DP Logic
- Banded Response Recognition
  - Transient vs. Steady-State
  - Boundary Recognition
  - Transition Recognition

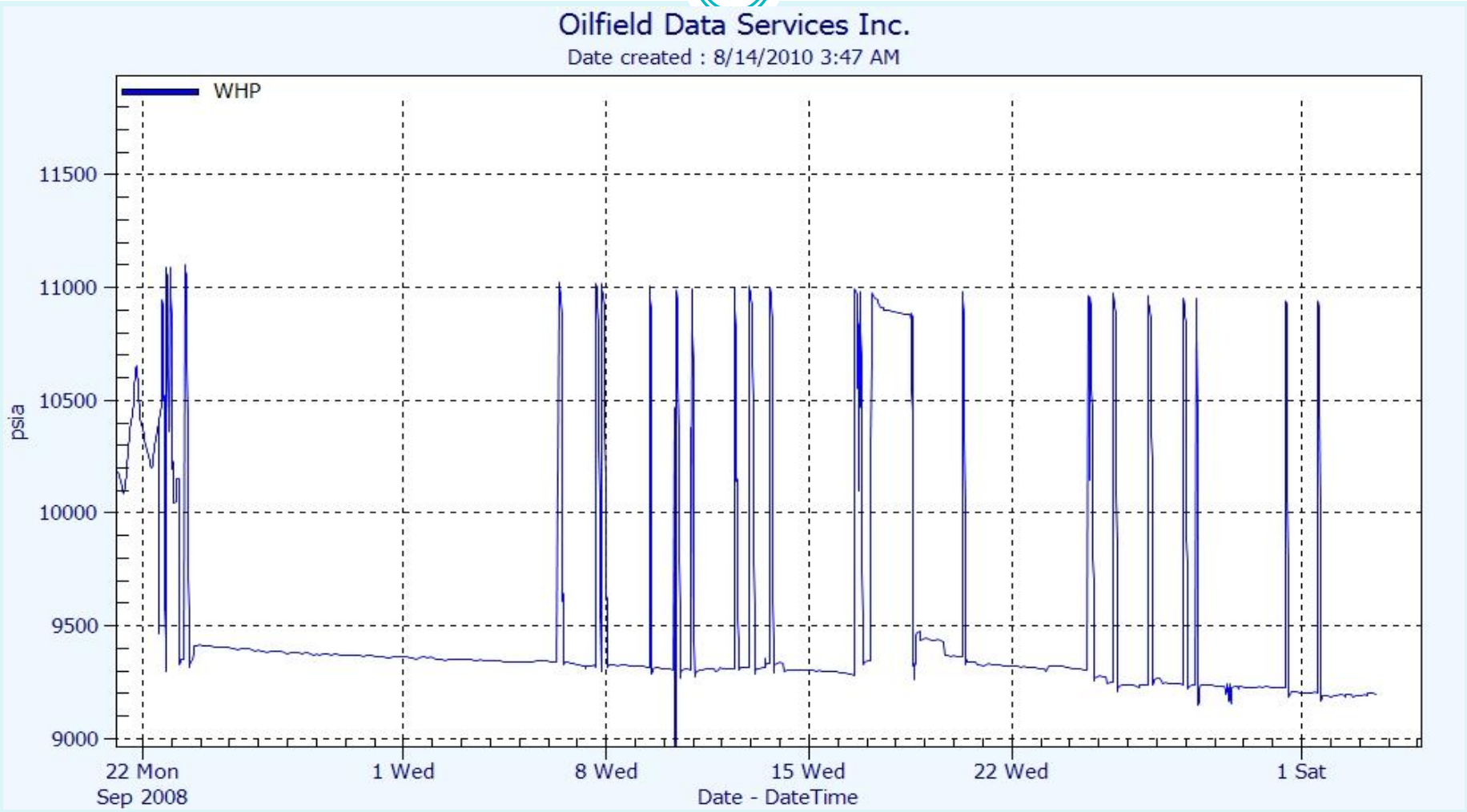
Transient Recognition



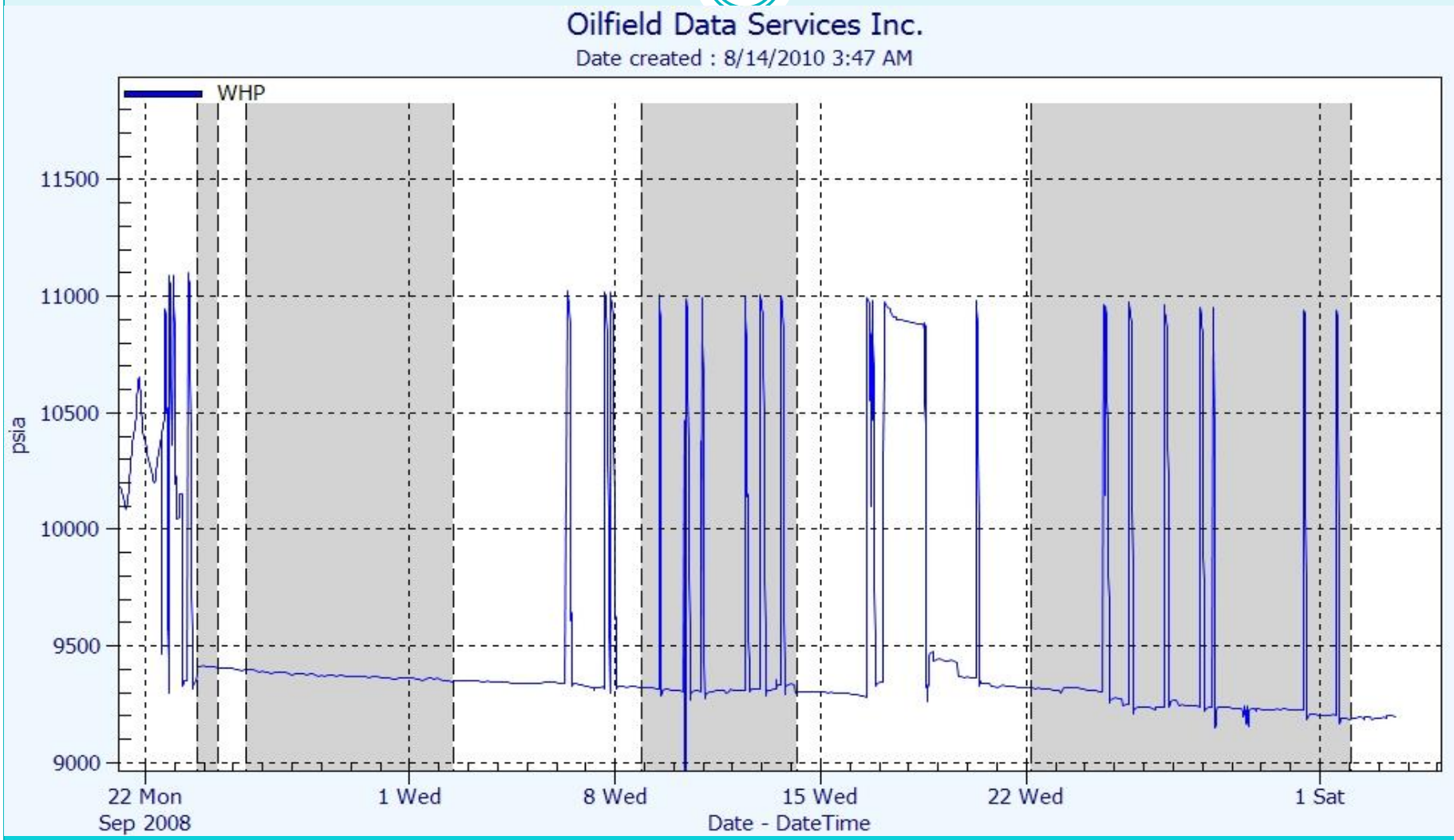
Transient Recognition



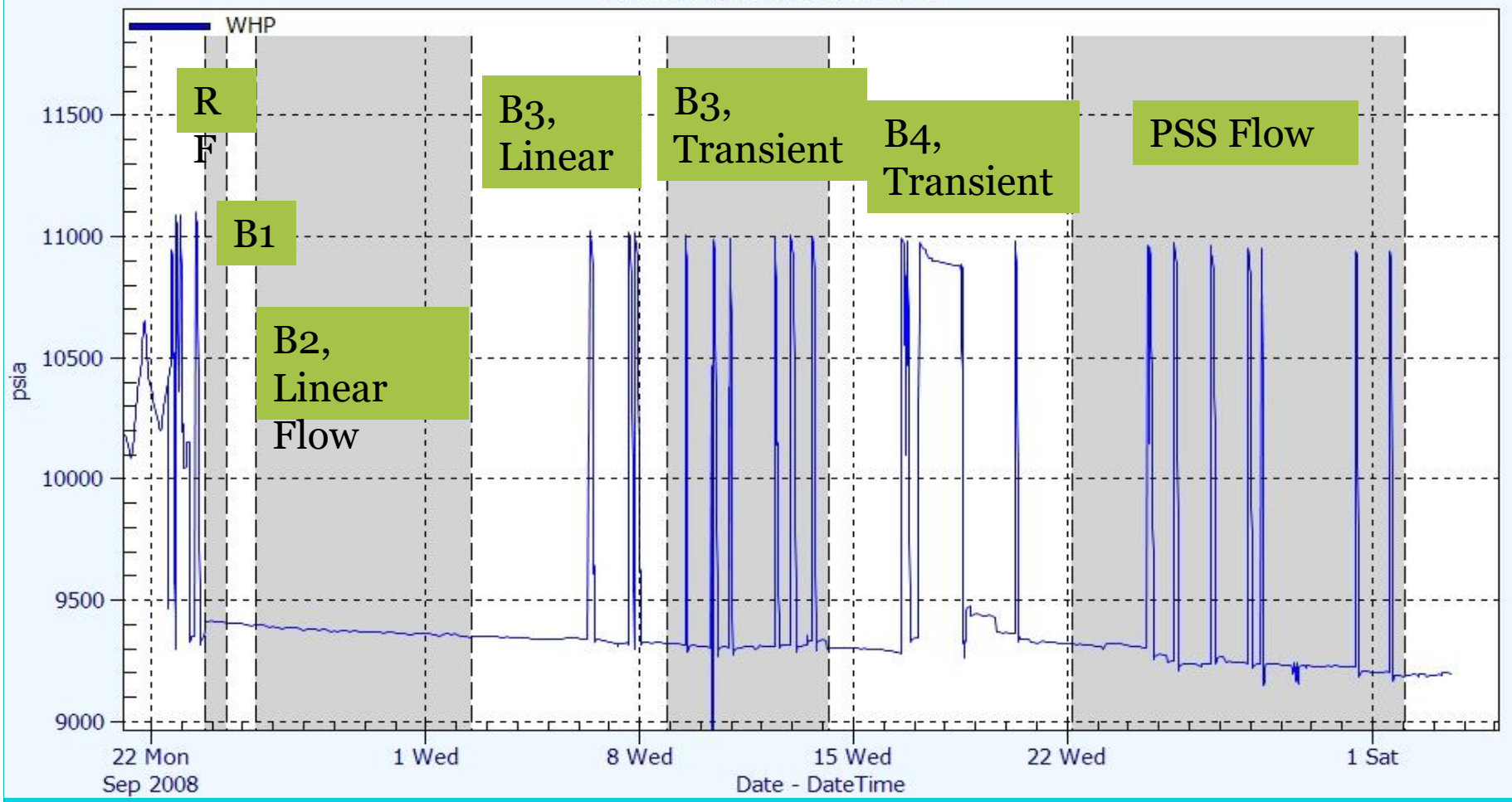
Regime Recognition



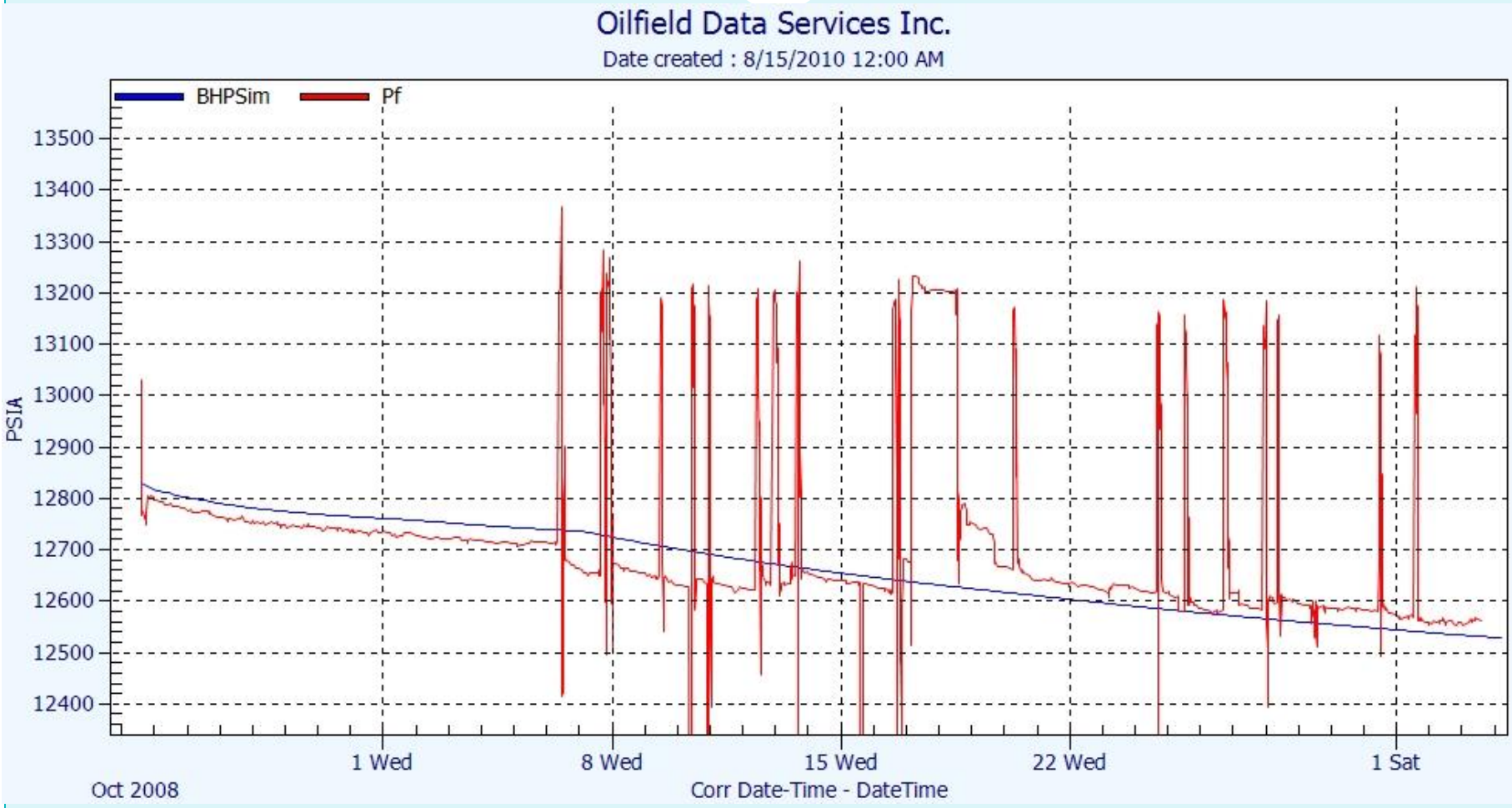
Regime Recognition



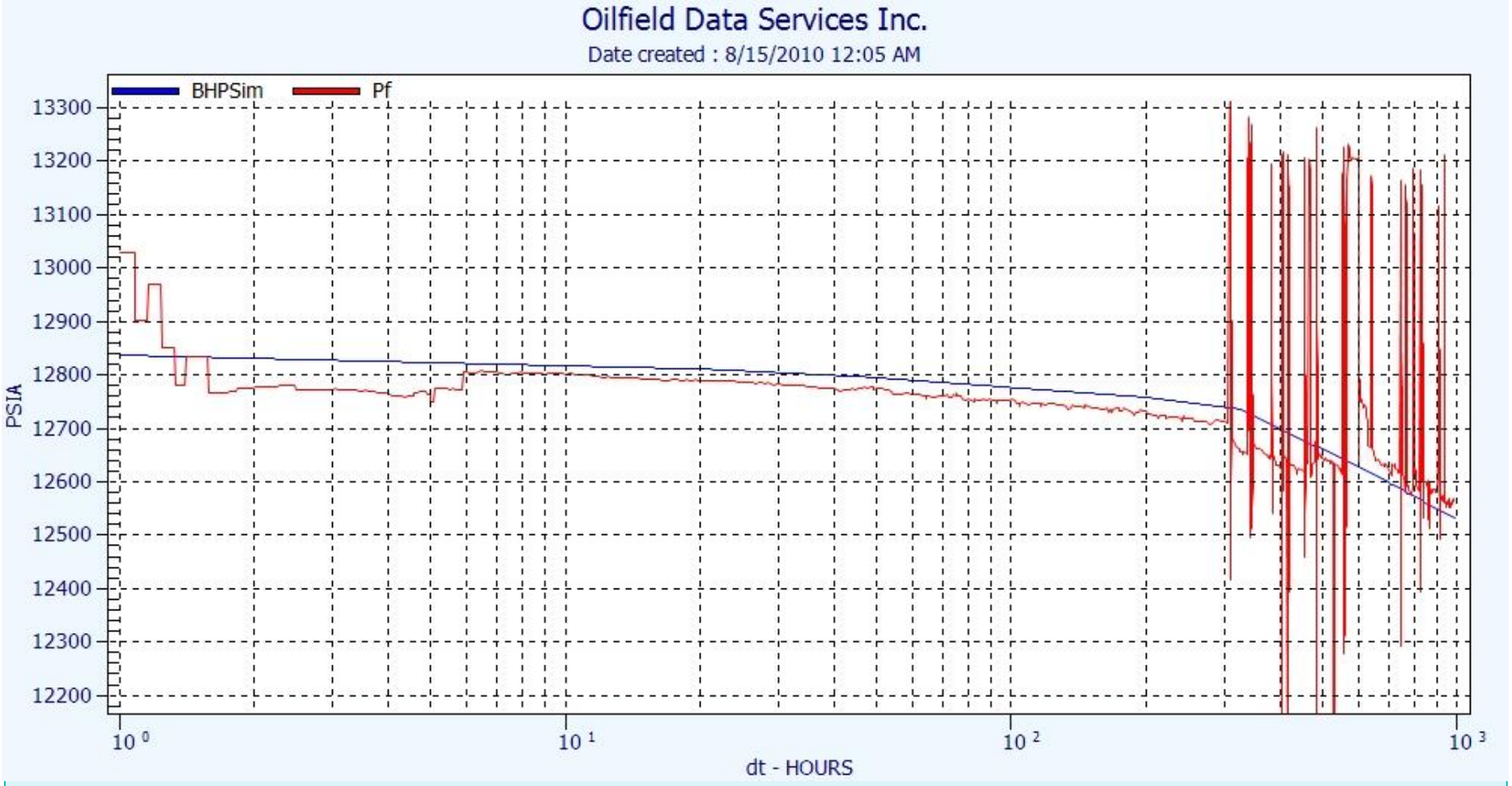
Boundary/Regime Recognition



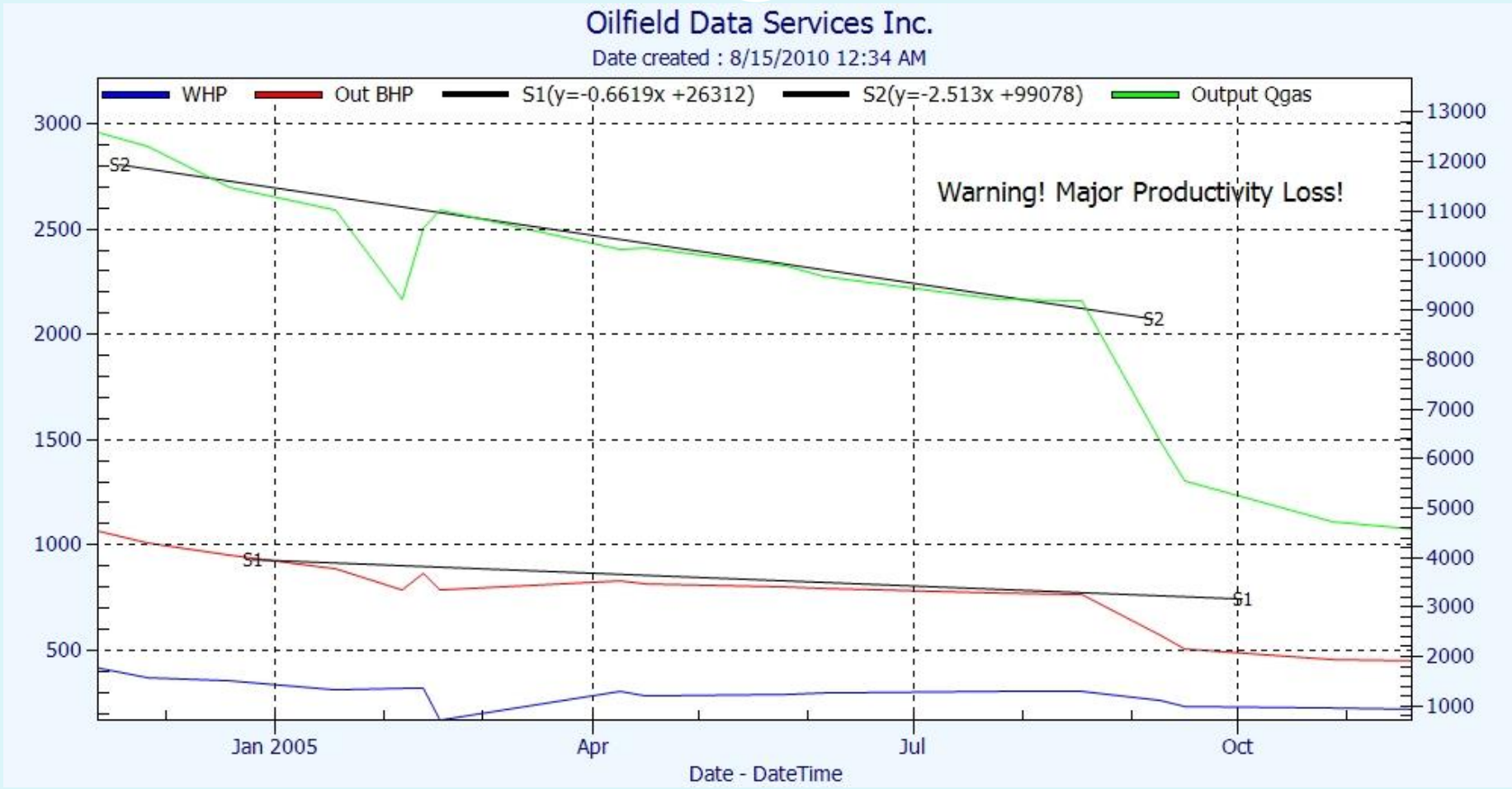
Simulator Prediction vs Actual



Simulator Prediction vs Actual - Semilog



Recognition of Productivity Changes



Productivity Change (Factor of 2!)

The Trick…

- Start with most valid pressure measurement point
- Use Measured, Calculated or Inferred Rate
- Work the Mech NRG solution to WHP and mid-completion BHP
- Employ Complex Completion Model if Required
- Use Banded Energy Solution, along with Transient/Regime Recognition to determine Reservoir Inflow in both Transient and Steady-State Flow
- Bob & Weave – incorporate changes in Reservoir Model as it changes (i.e. Moving Water Contact)
- Keep track of the important stuff & Warn PE's when something goes wrong!

Translation Back to Customary Views

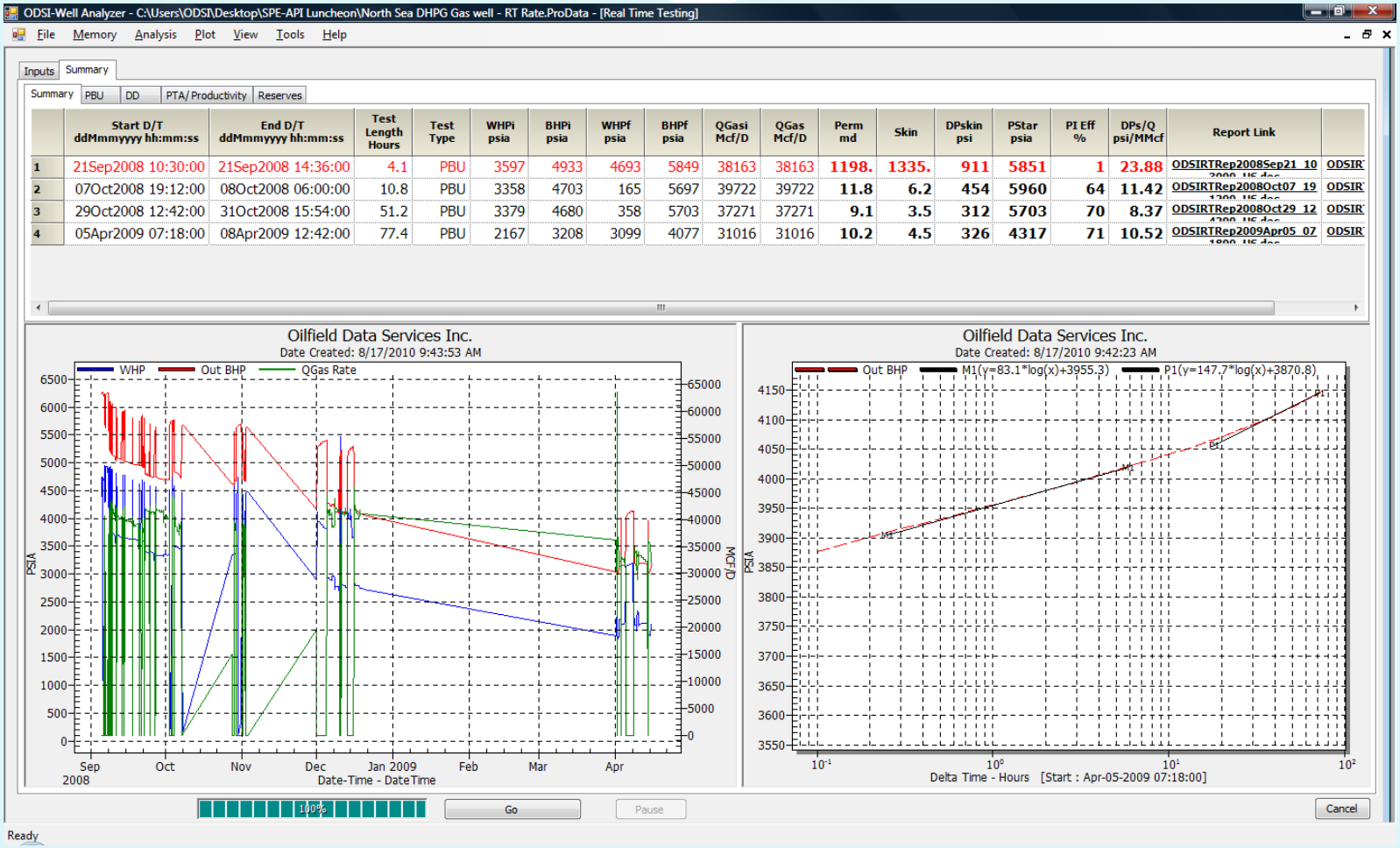
- Present the Results in a way that folks are used to…

  …or at least in terms they are accustomed to
- Well Test Analysis Results
- Productivity Tracking
- In-Place, Hydraulically Connected, and Mobile Hydrocarbon Volumes
- Reservoir Map (Energy Equivalent Map)
- Nodal Plots (Snapshots as fcn of time)
  - Includes Dynamic WBM & Res Inflow Model

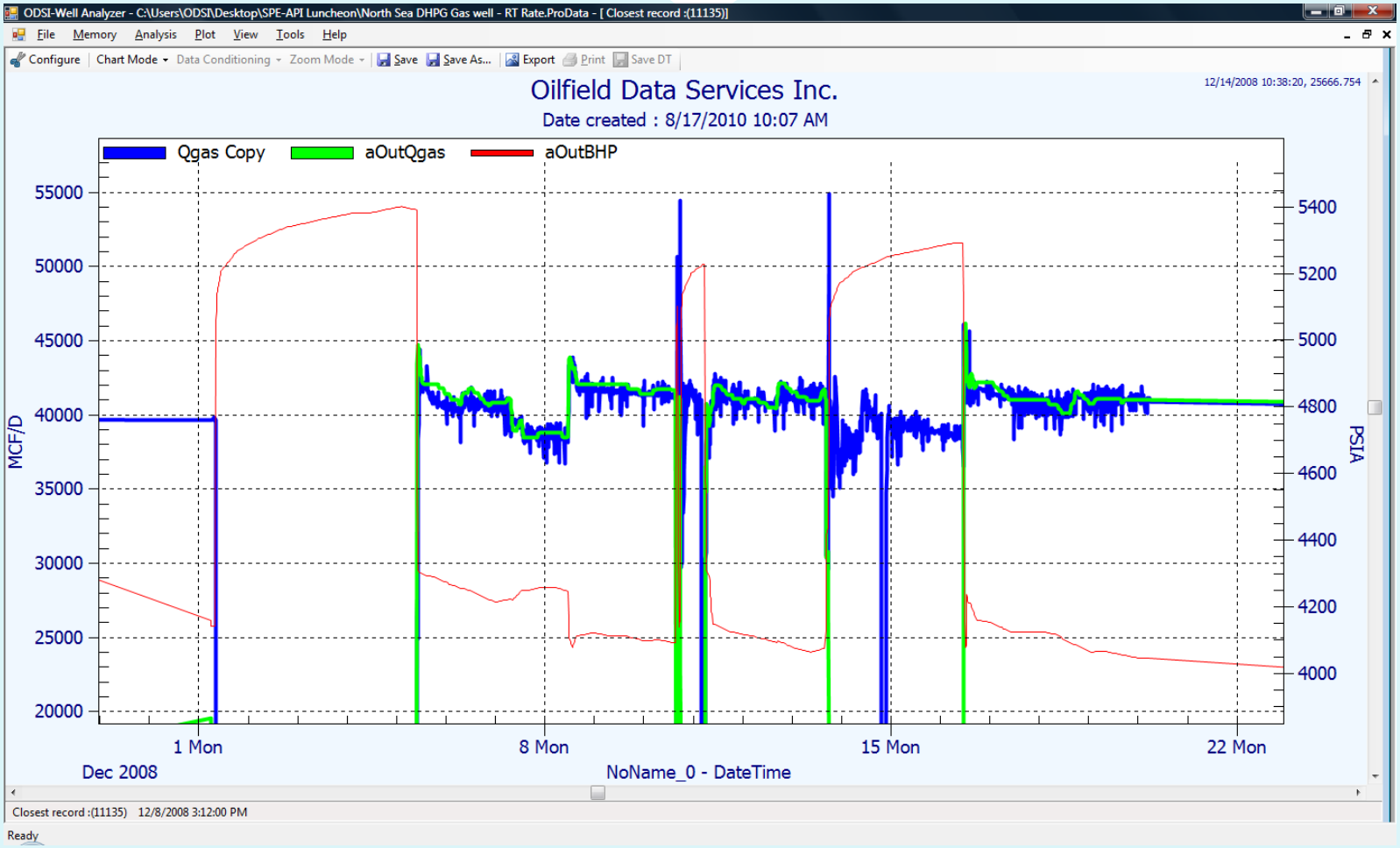
The Magic Show:

- Run Program (change names of operators to protect the guilty)
- Add Slides for those not in attendance

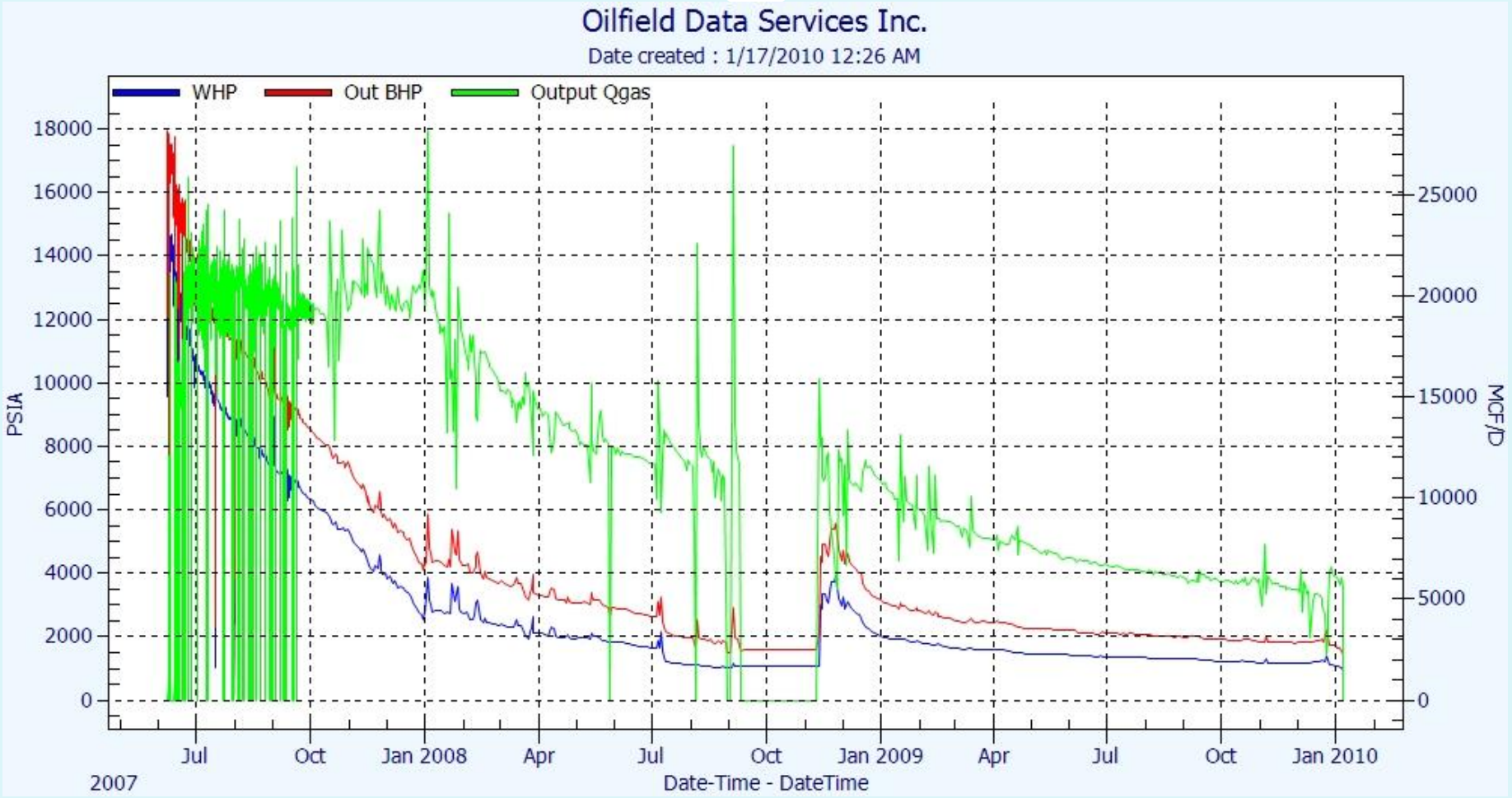
RT Rate Calc & PTA



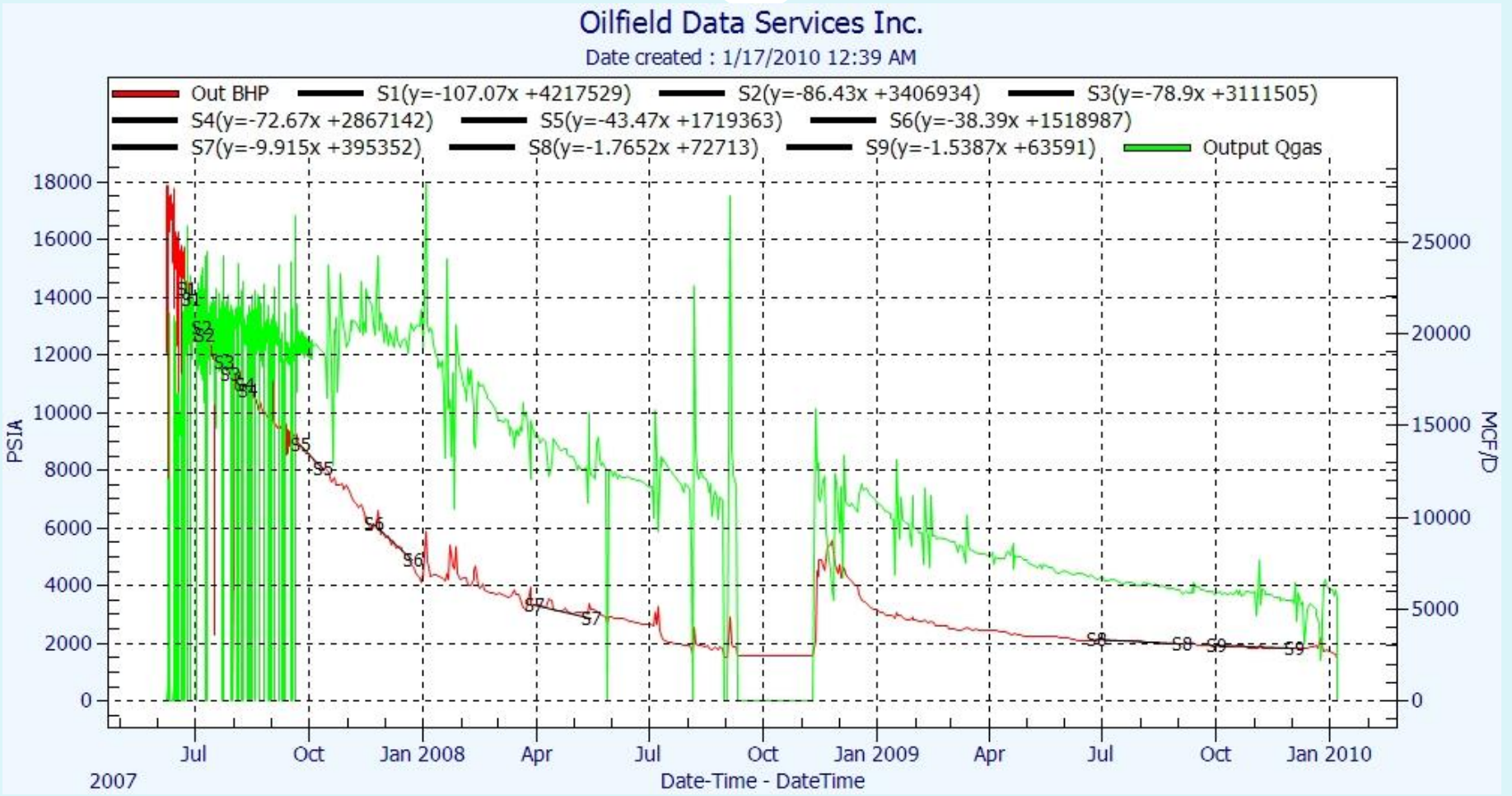
Calculated Qgas (green) vs. Measured Qgas (blue)



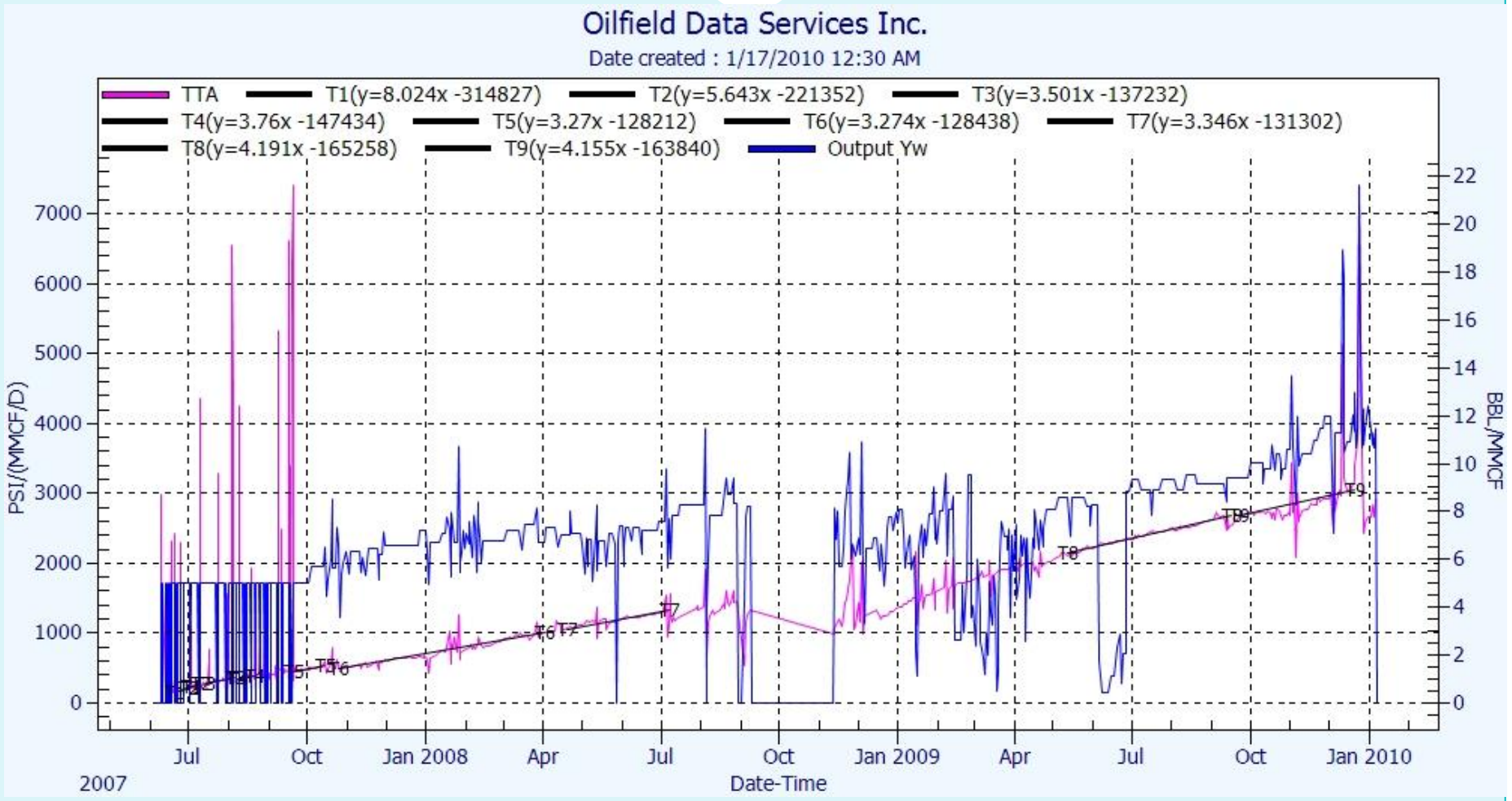
HC Volume Example



Pressure Decline Evaluation



PV-Work Decay Evaluation



Manual HC Volume Output

1	Company:	Big Oil Co																		
2	Field/Well:	Deep Gas			Mbal Inputs - G = Gmax						Pab =	0	psi							
3	Interval:	Hot n Nasty			G	1.93E+10	scf				Pi =	17860	psia							
4	Date:	15-Jan-10			Swi	0.45	frac				Bgi =	4.37E-04	RB/scf							
5					cf	3.90E-06	1/psi				Tres=	829.6	Deg F							
6					cw	3.00E-06	1/psi				zi =	1.8668	dimless							
7					if water sat and cf are const, solve for D(Pavg)						SGg-i	0.6254	dimless							
8					if water sat or cf are const, solve for D(Pavg) and Sw or cf iteratively						Start PSS	9/1/2007								
9					Sat & cf term is:	9.55E-06	1/psi				TTAi @ PSSi	400	Psi/MMcf							
10		**Conventional Volumetrics**																MBal	Volumetric	Note: if D(Pavg) diverges, reservoir is vol
11	Slope	Date	Pres/Pavg	Bg	DP/DT	Qgas(avg)	Ct	V-SLD	Vc	Incr Gp	cum Gp	VSLD + Gp	Vc + Gp		D(DP-DT)			G	D(Pavg)	This one diverges
12	#		PSI	RB/scf	PSI/Day	MMcf/D	µsips	Bcf	Bcf	Bcf	Bcf	Bcf	Bcf		PSI			Bcf	psi	w/Sw and Cf
13	S1	6/25/2007	17860	4.37E-04	107.1	20.5	17.02	3.4	11.2	0.240	0.240	3.659	11.486					#DIV/0!	1.30E+03	
14	S2	7/6/2007	17860	4.37E-04	86.43	20.5	17.02	4.2	13.9	0.250	0.490	4.726	14.426					#DIV/0!	2.66E+03	
15	S3	7/25/2007	17860	4.37E-04	78.9	20	17.02	4.5	14.9	0.370	0.860	5.387	15.753					#DIV/0!	4.67E+03	
16	S4	8/10/2007	17860	4.37E-04	72.67	20	17.02	4.9	16.2	0.280	1.140	6.055	17.310					#DIV/0!	6.19E+03	
17	S4	9/1/2007	17860	4.37E-04	72.67	20.5	17.02	5.0	16.6	0.424	1.564	6.602	18.138	Start of PSS				#DIV/0!	8.49E+03	
18	S5	10/1/2007	12000	5.21E-04	43.47	19	27.4	5.2	16.0	0.993	2.133	7.378	18.085		Solve for Pres @ which Vc's match			13.296126	-6.23E+03	
19	S6	1/1/2008	9400	5.93E-04	38.39	20	37.76	4.9	13.8	1.769	3.902	8.799	17.699					14.846634	-8.62E+03	
20	S7	5/1/2008	7900	6.56E-04	9.92	13.5	48.1	10.8	28.3	1.858	5.760	16.511	34.053					17.258949	-5.55E+03	
21	S8	8/1/2009	5200	8.69E-04	1.765	6.4	84.95	18.9	42.7	3.666	9.426	28.282	52.111					18.963305	-1.81E+03	
22	S9	10/31/2009	4950	0.000902	1.539	6	90.8	19.3	43	0.544	9.97	29.26824561	52.897059					19.349742	286.99254	
23		**TTA/Decline Evaluation:**																		
24													Delta-Inertail	Delta Mbal					MBal	
25	Slope	Date	P*/Pavg	Bg	DTTA/DT	Ct		V-SLD	Vc	Incr Gp	cum Gp	VSLD + Gp	Vc + Gp	Delta Gi	Delta Gi		D(DTTA-DT)			G
26	#		PSI	RB/scf	D[DP/Q-D	µsips		Bcf	Bcf	Bcf	Bcf	Bcf	Bcf	Bcf	Bcf		Psi/MMcf/D			Bcf
27	T1	6/25/2007	17860	4.37E-04	8.024	17.02		2.2	7.3	0.240	0.240	2.466	7.562	3.924	#DIV/0!					#DIV/0!
28	T2	7/6/2007	17860	4.37E-04	5.643	17.02		3.2	10.4	0.250	0.490	3.655	10.902	3.524	#DIV/0!					#DIV/0!
29	T3	7/25/2007	17860	4.37E-04	3.501	17.02		5.1	16.8	0.370	0.860	5.961	17.642	-1.889	#DIV/0!					#DIV/0!
30	T4	8/10/2007	17860	4.37E-04	3.76	17.02		4.8	15.6	0.280	1.140	5.890	16.766	0.544	#DIV/0!					#DIV/0!
31	T4	9/1/2007	17860	4.37E-04	3.76	17.02		4.8	15.6	0.424	1.564	6.314	17.190	0.948	#DIV/0!	Start of PSS Flow				#DIV/0!
32	T5	10/1/2007	12000	5.21E-04	3.27	27.4		3.7	11.2	0.993	2.133	5.803	13.294	4.791	0.002	i.e. start of validity for calcs for total/final Res Volume				13.296126
33	T6	1/1/2008	9400	5.93E-04	3.274	37.76		2.9	8.1	1.769	3.902	6.773	11.991	5.708	2.856					14.846634
34	T7	5/1/2008	7900	6.56E-04	3.346	48.1		2.4	6.2	1.858	5.760	8.121	11.973	22.079	5.286					17.258949
35	T8	8/1/2009	5200	8.69E-04	4.191	84.95		1.2	2.8	3.666	9.426	10.667	12.235	39.876	6.729					18.963305
36	T9	10/31/2009	4950	0.000902	4.155	90.82		1.2	2.7	0.544	9.97	11.161	12.620	40.277	6.730					19.349742
37																Note: Can extraplolate out Pres from Volumetric and work out delta Gi down to Pab				
38																				

Sheet1 Sheet2 Sheet3

Ready 100%

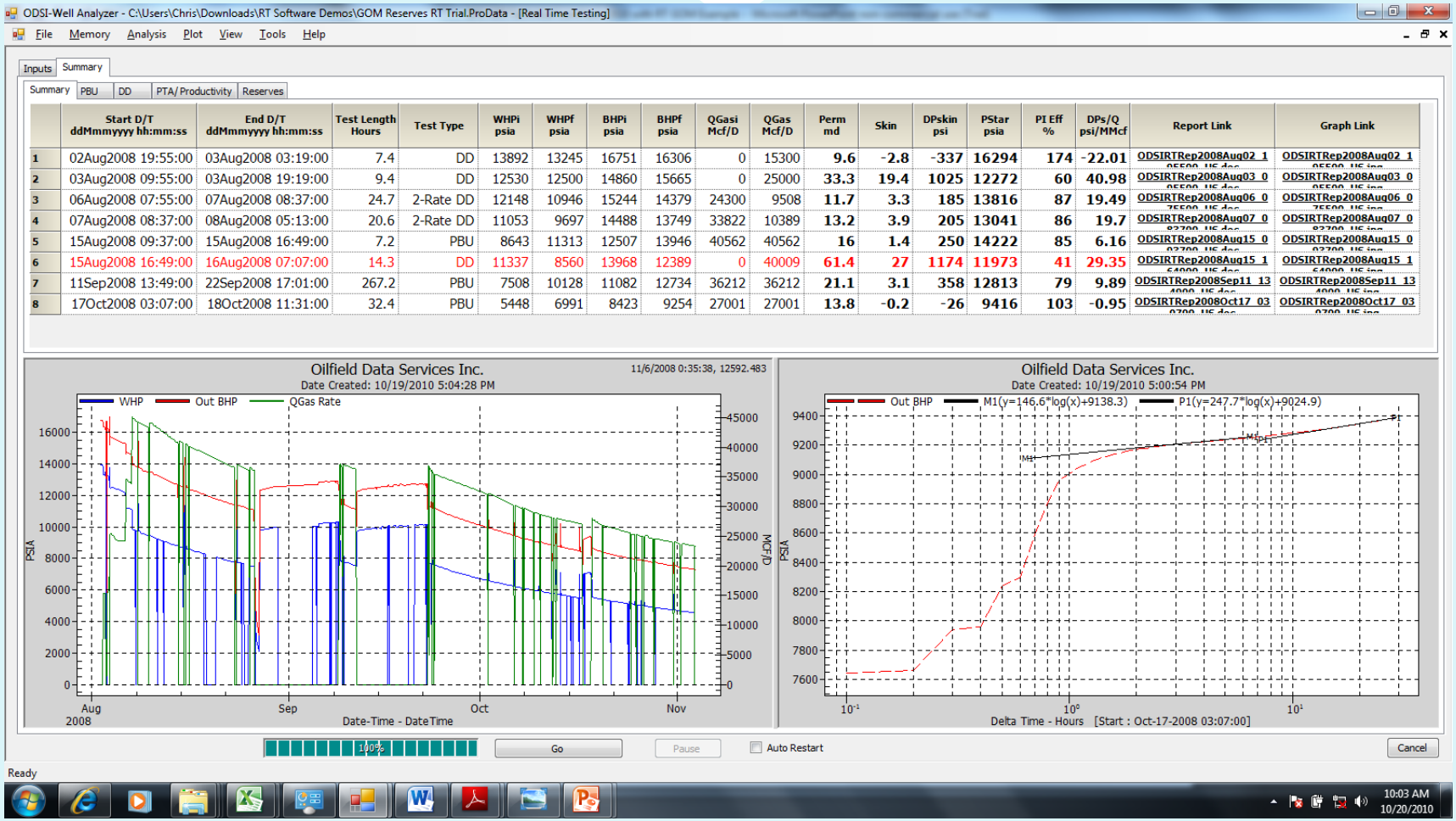
Reserves Conclusions

- 1) GIP = 18-20 Bcf
- 2) Initial Connected Volume ~ 18 Bcf
- 3) Initial Mobile Volume ~ 13 Bcf (Very Little Change)
- 4) Water Influx becomes suspicious in May, 2008 and obvious by Aug 2009
- 5) No apparent pay loss during life of well
- 6) Productivity changes in Dec 09 and Jan 10 do not appear to be reservoir related
- 7) Productivity changes in early 2010 appear to be plugging or loading
- 8) ~ 2 Bcf remaining likely recoverable gas

Big Picture: RT Monitoring

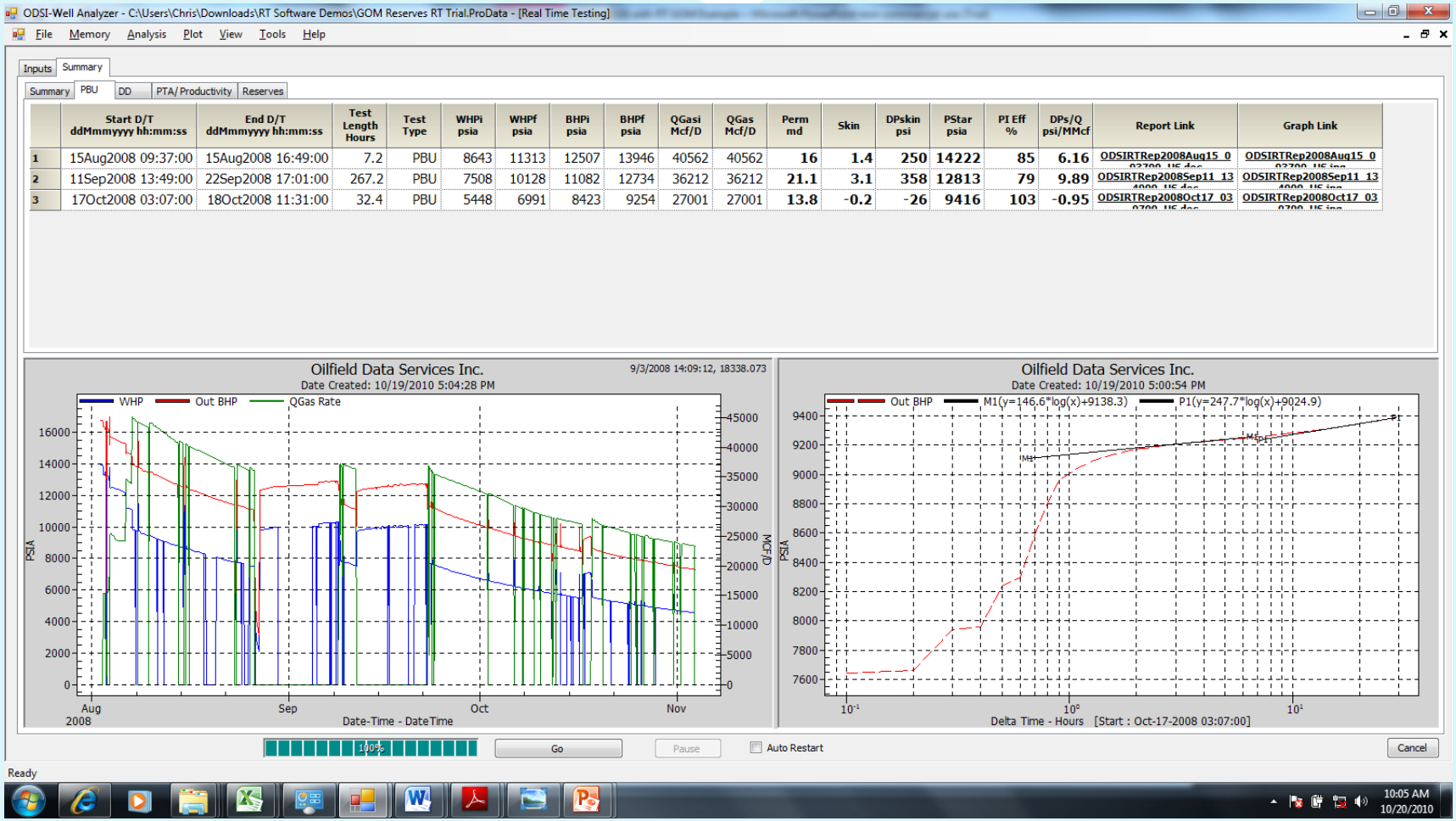
- Create Map from Flowback or Initial Production Data…or just trust the G&G folks (Static Model)
- Plug things into RTS Config
- Evaluate Data as it comes in
  - Skin
  - Perm
  - Preservoir
  - Productivity (changing?)
  - Problem with Mbal, Ebal, P/z?
- Warn the Engineer if anything dodgy happens

Conversion to BHP and Automatic PTA



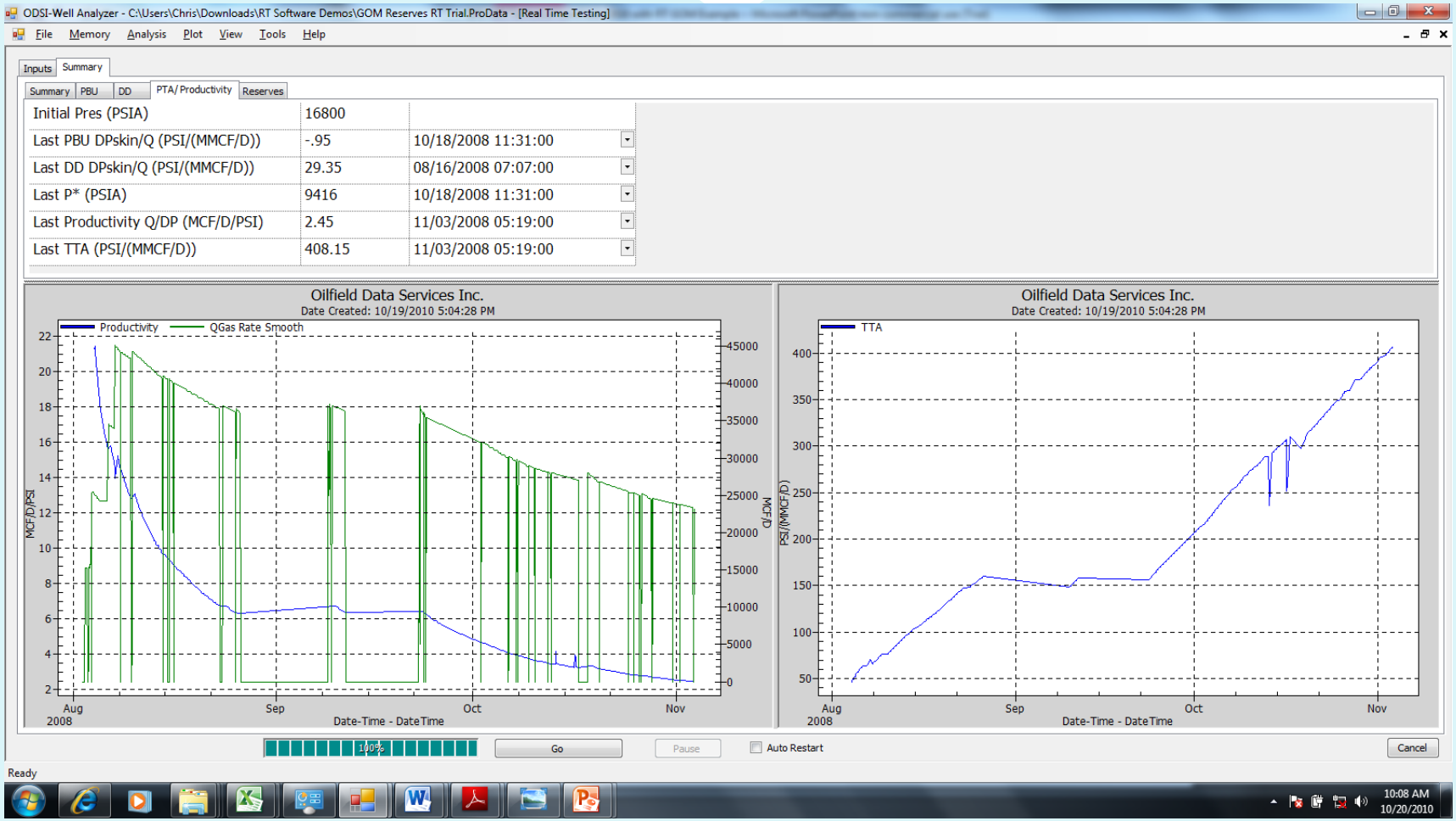
	Start D/T ddMmmyyyy hh:mm:ss	End D/T ddMmmyyyy hh:mm:ss	Test Length Hours	Test Type	WHPi psia	WHPf psia	BHPi psia	BHPf psia	QGasi Mcf/D	QGas Mcf/D	Perm md	Skin	DPskin psi	PStar psia	PI Eff %	DPs/Q psi/MMcf	Report Link	Graph Link
1	02Aug2008 19:55:00	03Aug2008 03:19:00	7.4	DD	13892	13245	16751	16306	0	15300	9.6	-2.8	-337	16294	174	-22.01	ODSIRTRep2008Aug02_1	ODSIRTRep2008Aug02_1
2	03Aug2008 09:55:00	03Aug2008 19:19:00	9.4	DD	12530	12500	14860	15665	0	25000	33.3	19.4	1025	12272	60	40.98	ODSIRTRep2008Aug03_0	ODSIRTRep2008Aug03_0
3	06Aug2008 07:55:00	07Aug2008 08:37:00	24.7	2-Rate DD	12148	10946	15244	14379	24300	9508	11.7	3.3	185	13816	87	19.49	ODSIRTRep2008Aug06_0	ODSIRTRep2008Aug06_0
4	07Aug2008 08:37:00	08Aug2008 05:13:00	20.6	2-Rate DD	11053	9697	14488	13749	33822	10389	13.2	3.9	205	13041	86	19.7	ODSIRTRep2008Aug07_0	ODSIRTRep2008Aug07_0
5	15Aug2008 09:37:00	15Aug2008 16:49:00	7.2	PBU	8643	11313	12507	13946	40562	40562	16	1.4	250	14222	85	6.16	ODSIRTRep2008Aug15_0	ODSIRTRep2008Aug15_0
6	15Aug2008 16:49:00	16Aug2008 07:07:00	14.3	DD	11337	8560	13968	12389	0	40009	61.4	27	1174	11973	41	29.35	ODSIRTRep2008Aug15_1	ODSIRTRep2008Aug15_1
7	11Sep2008 13:49:00	22Sep2008 17:01:00	267.2	PBU	7508	10128	11082	12734	36212	36212	21.1	3.1	358	12813	79	9.89	ODSIRTRep2008Sep11_13	ODSIRTRep2008Sep11_13
8	17Oct2008 03:07:00	18Oct2008 11:31:00	32.4	PBU	5448	6991	8423	9254	27001	27001	13.8	-0.2	-26	9416	103	-0.95	ODSIRTRep2008Oct17_03	ODSIRTRep2008Oct17_03

Auto PTA – Build-ups Only

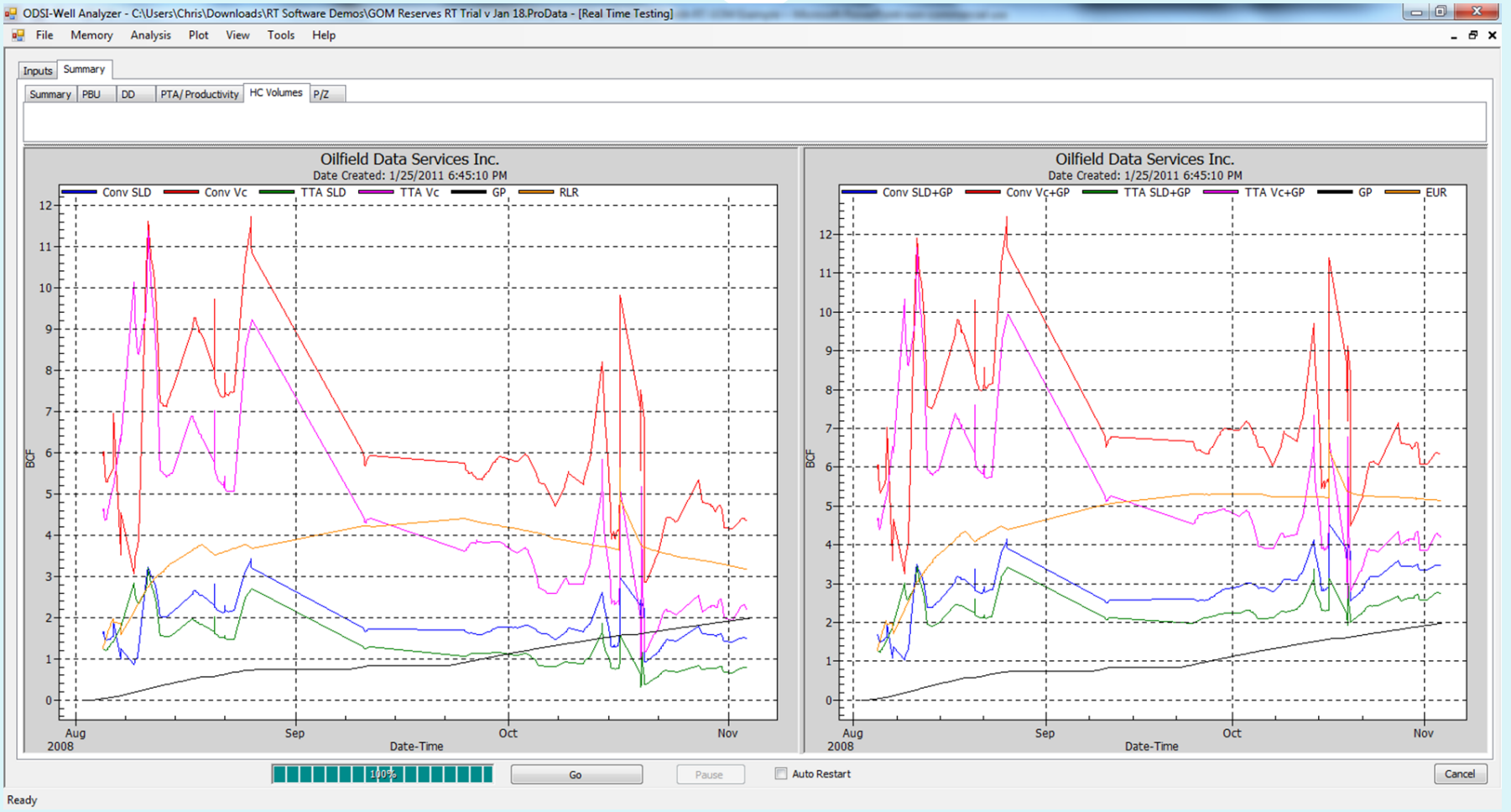


	Start D/T ddMmmyyyy hh:mm:ss	End D/T ddMmmyyyy hh:mm:ss	Test Length Hours	Test Type	WHPi psia	WHPf psia	BHPi psia	BHPf psia	QGasi Mcf/D	QGas Mcf/D	Perm md	Skin	DPskin psi	PStar psia	PI Eff %	DPs/Q psi/MMcf	Report Link	Graph Link
1	15Aug2008 09:37:00	15Aug2008 16:49:00	7.2	PBU	8643	11313	12507	13946	40562	40562	**16**	**1.4**	**250**	**14222**	**85**	**6.16**	ODSIRTRep2008Aug15_0	ODSIRTRep2008Aug15_0
2	11Sep2008 13:49:00	22Sep2008 17:01:00	267.2	PBU	7508	10128	11082	12734	36212	36212	**21.1**	**3.1**	**358**	**12813**	**79**	**9.89**	ODSIRTRep2008Sep11_13	ODSIRTRep2008Sep11_13
3	17Oct2008 03:07:00	18Oct2008 11:31:00	32.4	PBU	5448	6991	8423	9254	27001	27001	**13.8**	**-0.2**	**-26**	**9416**	**103**	**-0.95**	ODSIRTRep2008Oct17_03	ODSIRTRep2008Oct17_03

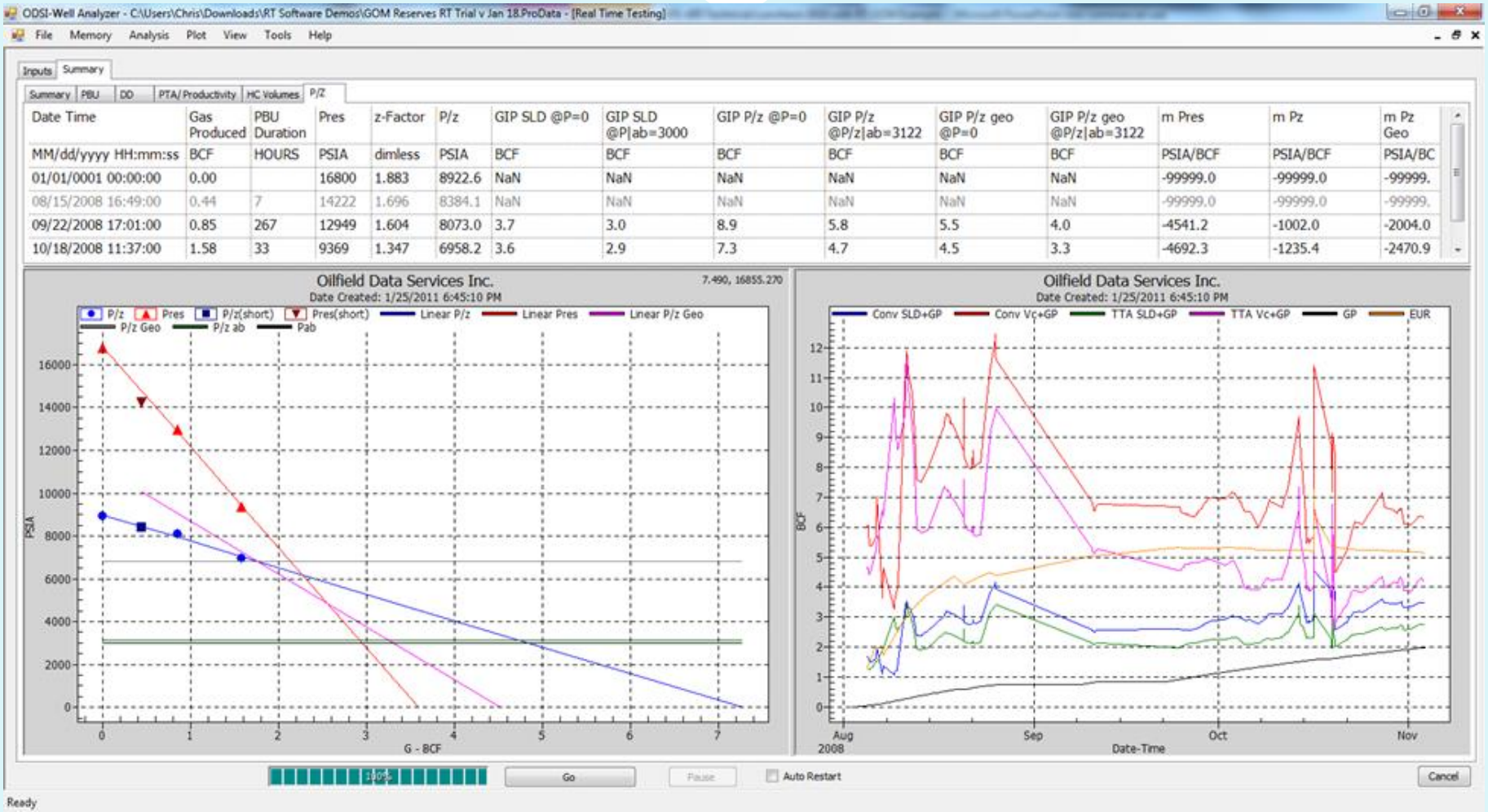
Relative Productivity Tracking



Gas Volume Tracking: Remaining & EUR



Pres & P/z – GIP Determination



Review: "Static" Nodal Analysis

- Compares Reservoir Inflow (IPC) with Wellbore Performance (VLP)
  - Allows Prediction of DP to achieve a Rate (vice versa)
  - Allows Prediction of Liquid Loading Scenarios
  - Allows Optimization of Tubular Design
- Problems with Nodal
  - Infinite # of combos of skin & perm calculate the same rate (Can't use nodal to determine skin or perm)
  - User has to pick the right inflow model and right VLP correlation
  - Doesn't handle transient situations well – may match your well today, but not next month

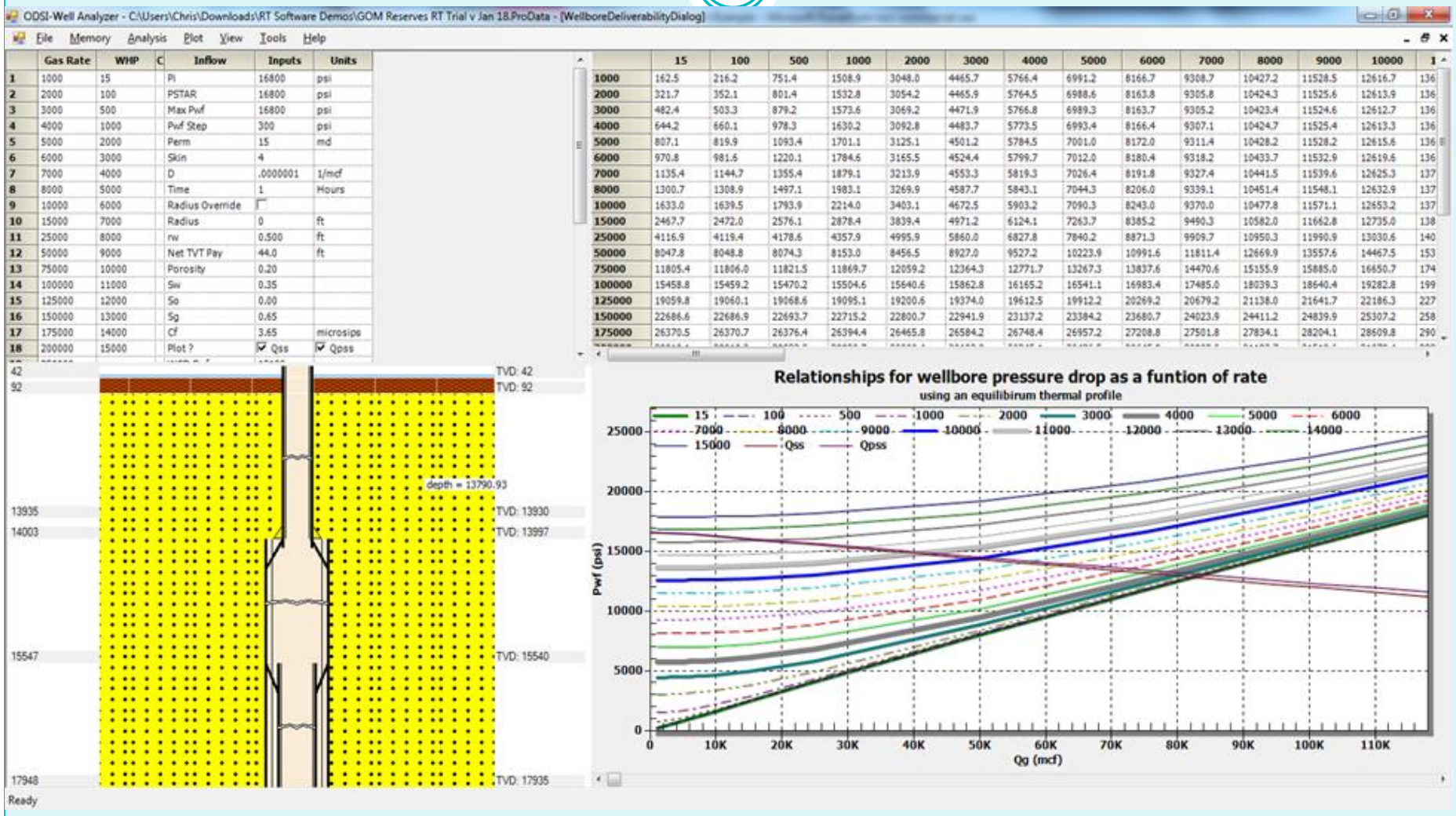
Transient Nodal Analysis Tool

- Keep track of changing produced fluid composition
- Update skin & perm from last valid PTA
- Update P* from last valid PBU
- Keep track of pressure decay during drawdown
  - Adjust Preservoir while producing
  - Use Transient Inflow model when in transient flow
  - Use Appropriate Steady State Inflow model when in SS Flow
- Link Reservoir Simulator to Wellbore Model

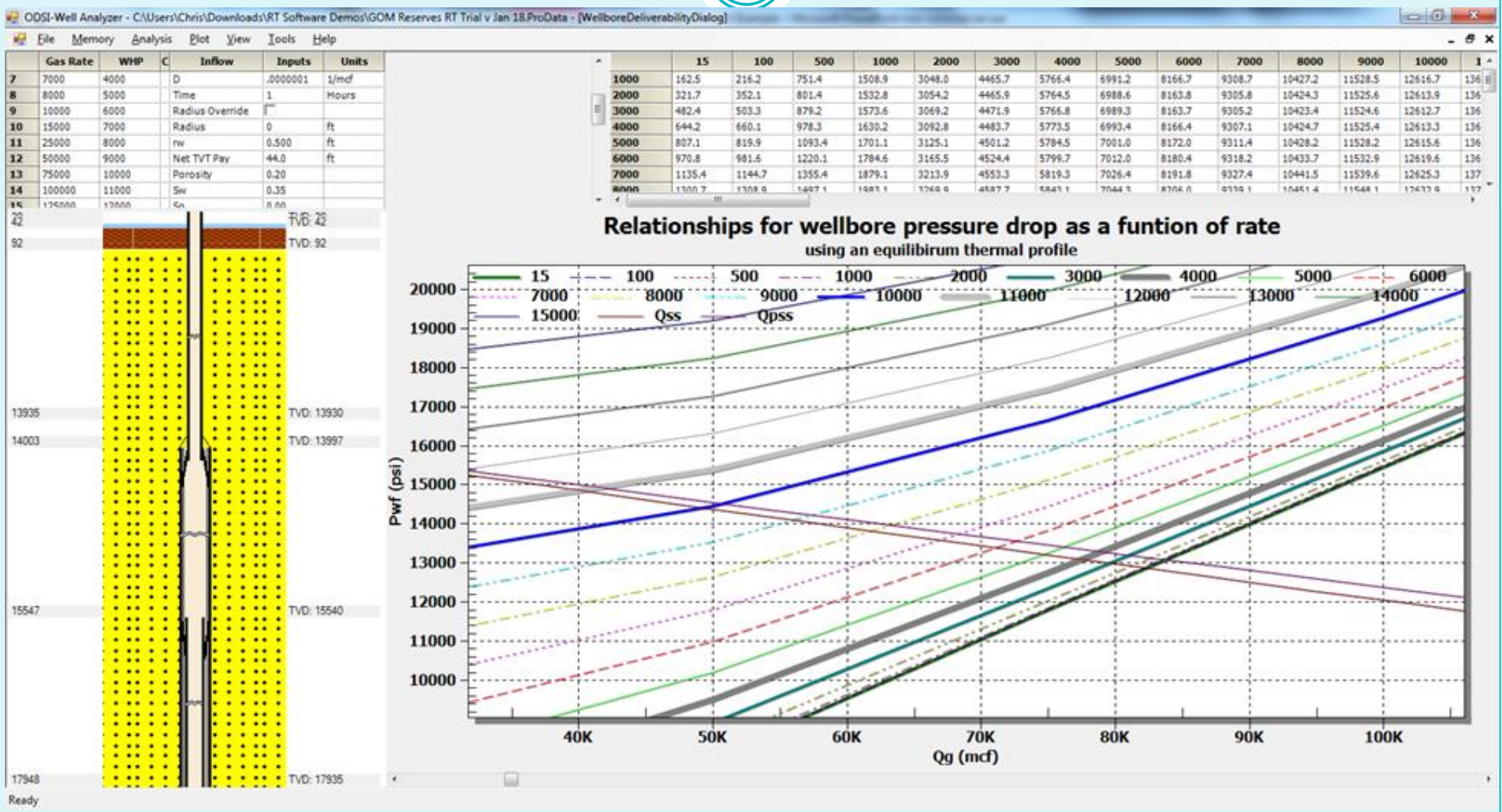
Transient Nodal Initiation

- Preservoir, Treservoir
- Skin (s & D) & Perm from Flowback PTA
- Wellbore Radius and Net TVT pay
- Fluid PVT
- Well Configuration/Geometry
- Petro-physical inputs
  - Sw, porosity, formation compressibility
- Forced Fixed Reservoir Volume or Floating Reservoir Volume
- Production Time Since last Valid P*/Pres

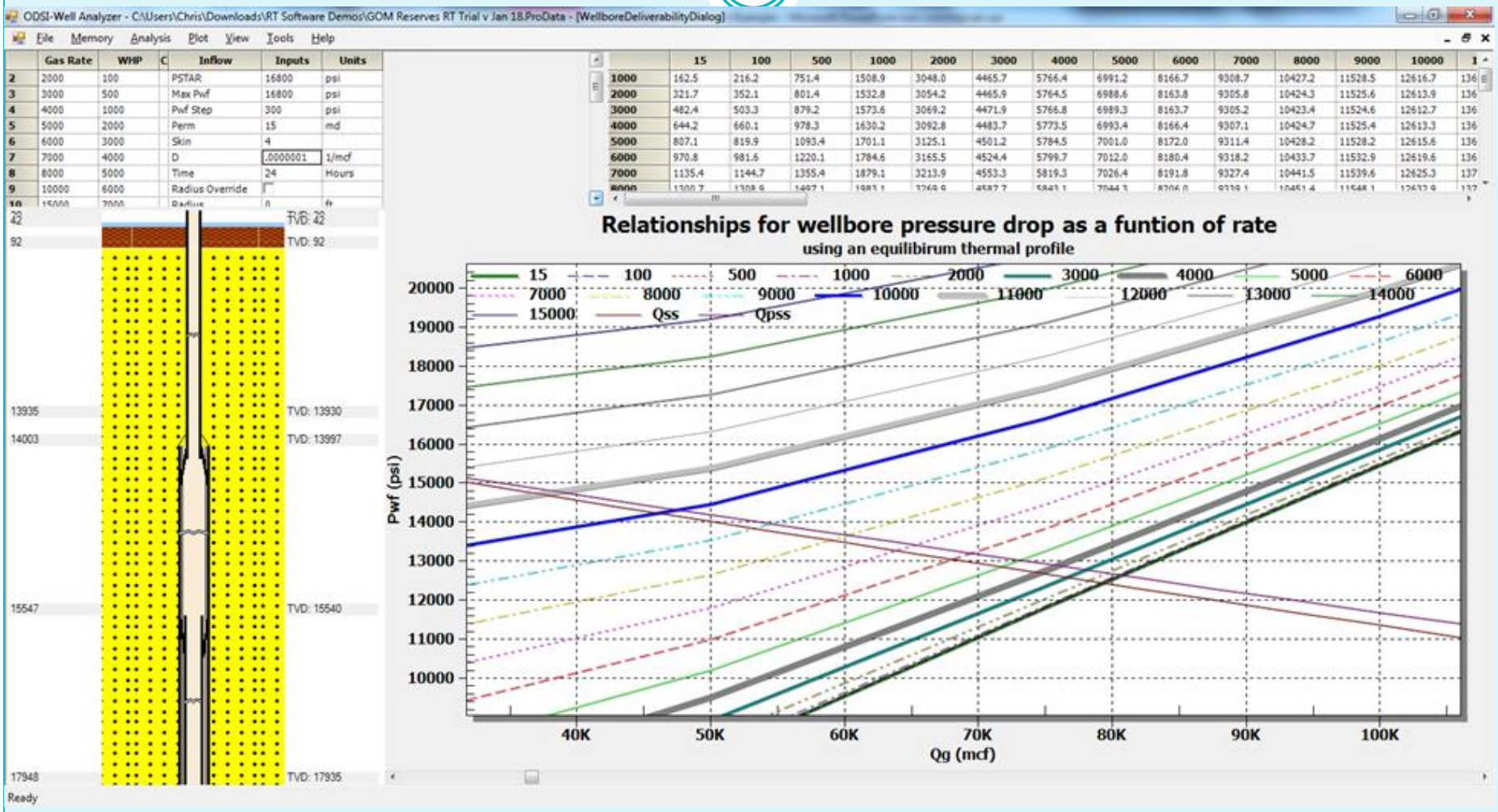
Nodal Initiation Run



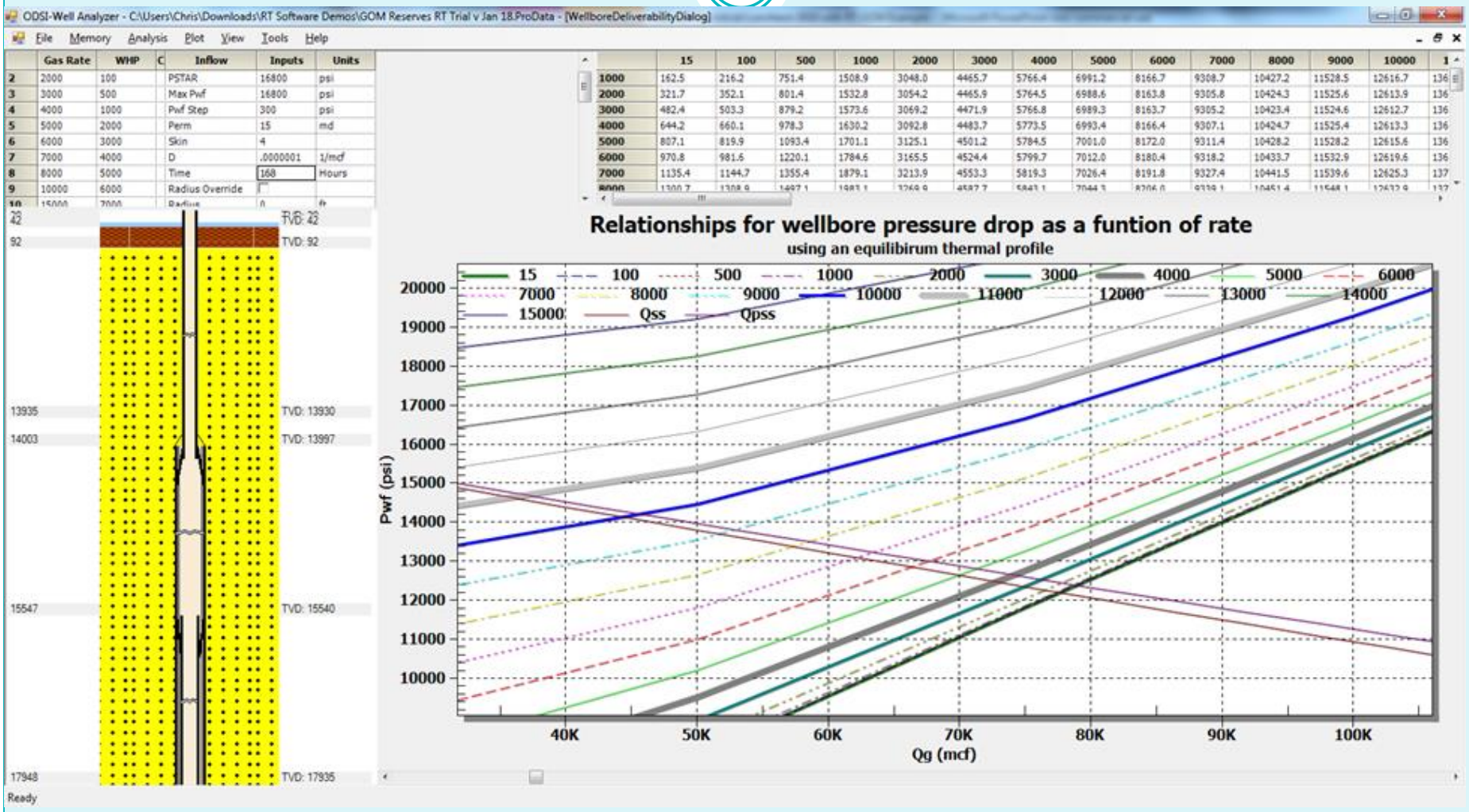
Inflow and VLP for Tp = 1 hour



Inflow and VLP for Tp = 24 hours



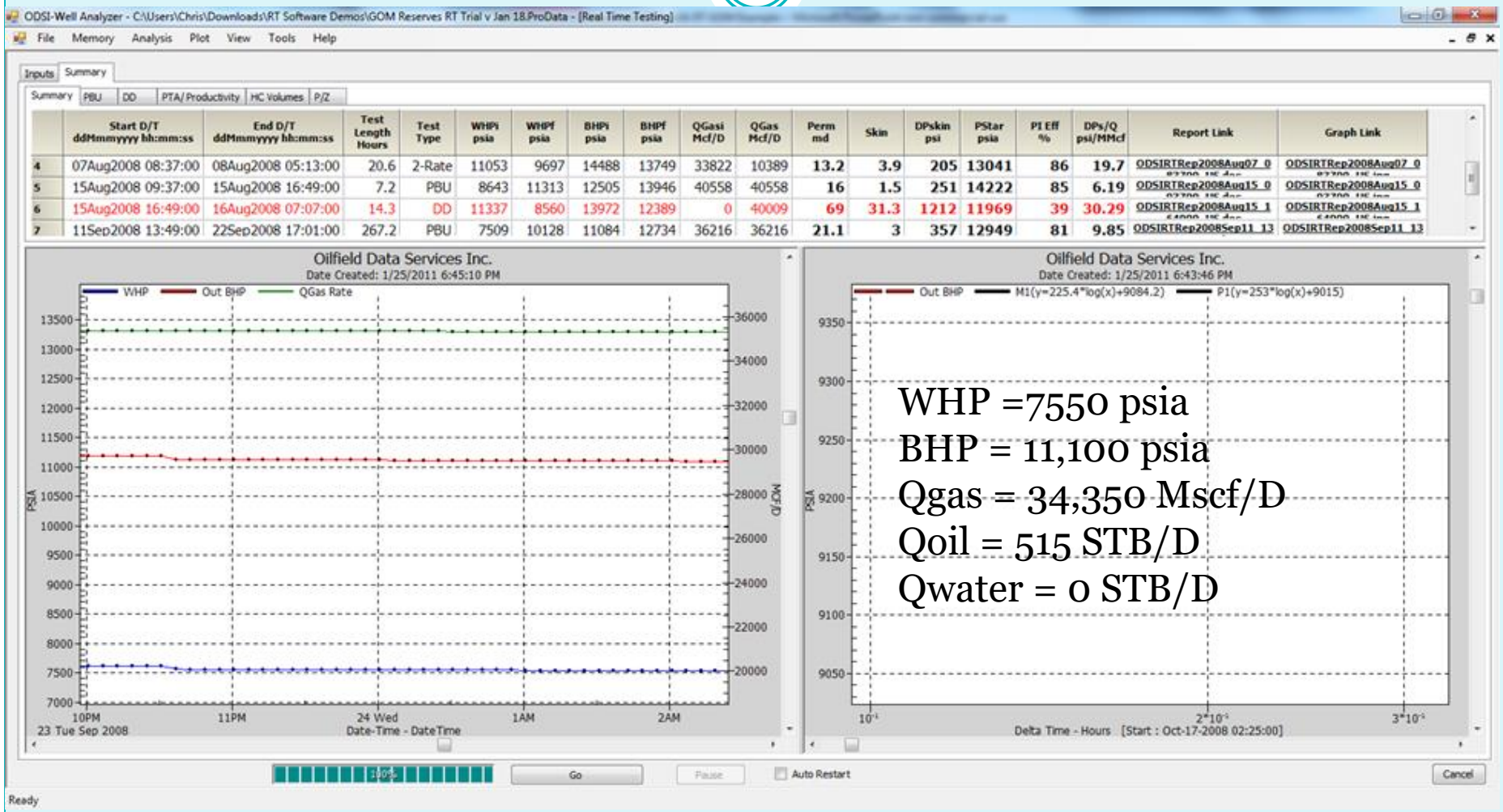
Inflow and VLP for Tp = 168 hours



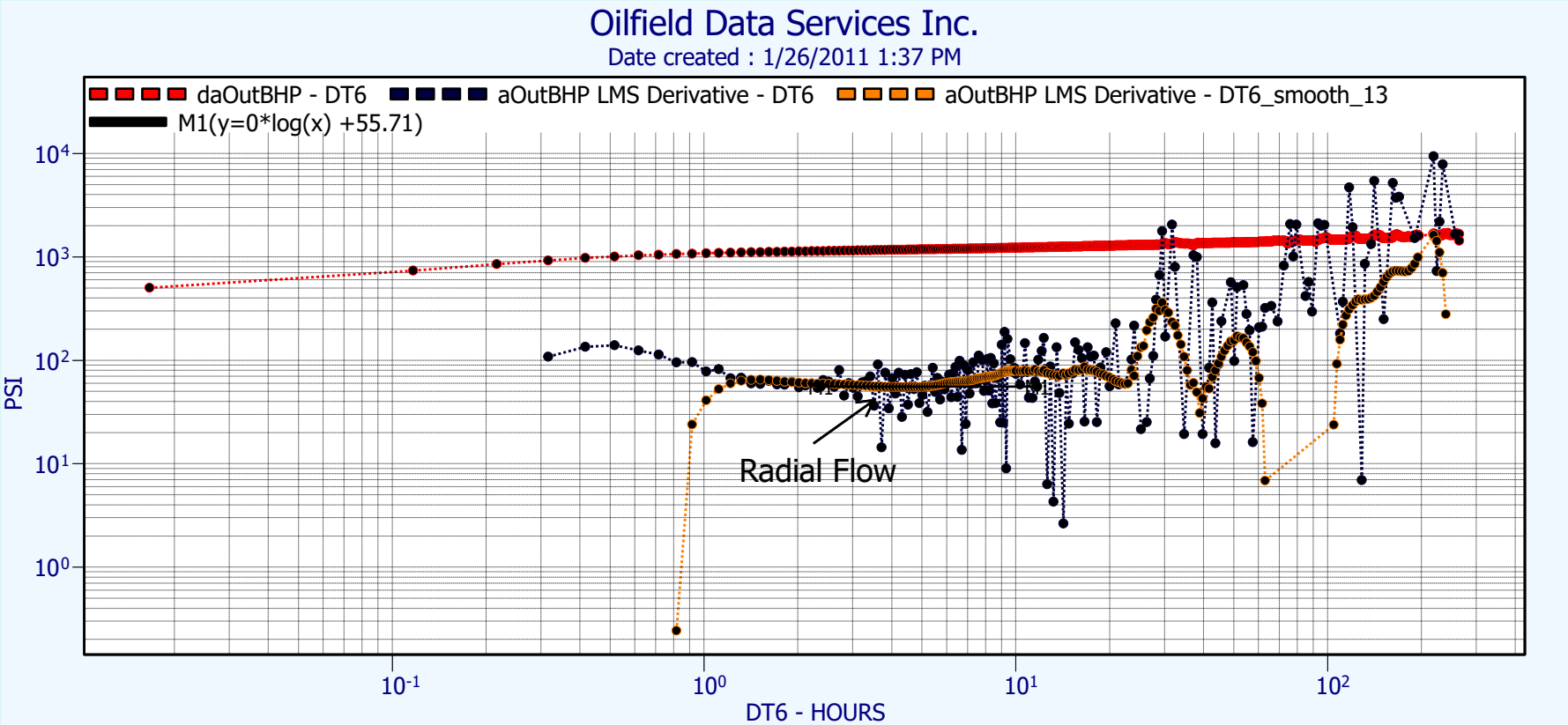
Interactive Transient Nodal Example

- Objective: Using data starting on Sept 24, 2008, Predict Well Performance on Oct 1, 2008, assuming continuation of 400 Mcf/D rate decay (24/64 ck)
- Using Real Well Data, adjust Nodal parameters to match continued production on same ck setting
  - Get P* from Sep 2008 PBU, along with kh & skin
  - Validate/Correct Analysis of PBU
  - Use Mbal & Ebal & P/z to determine Reservoir Volume
  - Use TTA methods to adjust Pres while on production
  - Use observed rate decay from prior production
  - Use observed WHP decay of 150 psi/day on 24/64 ck

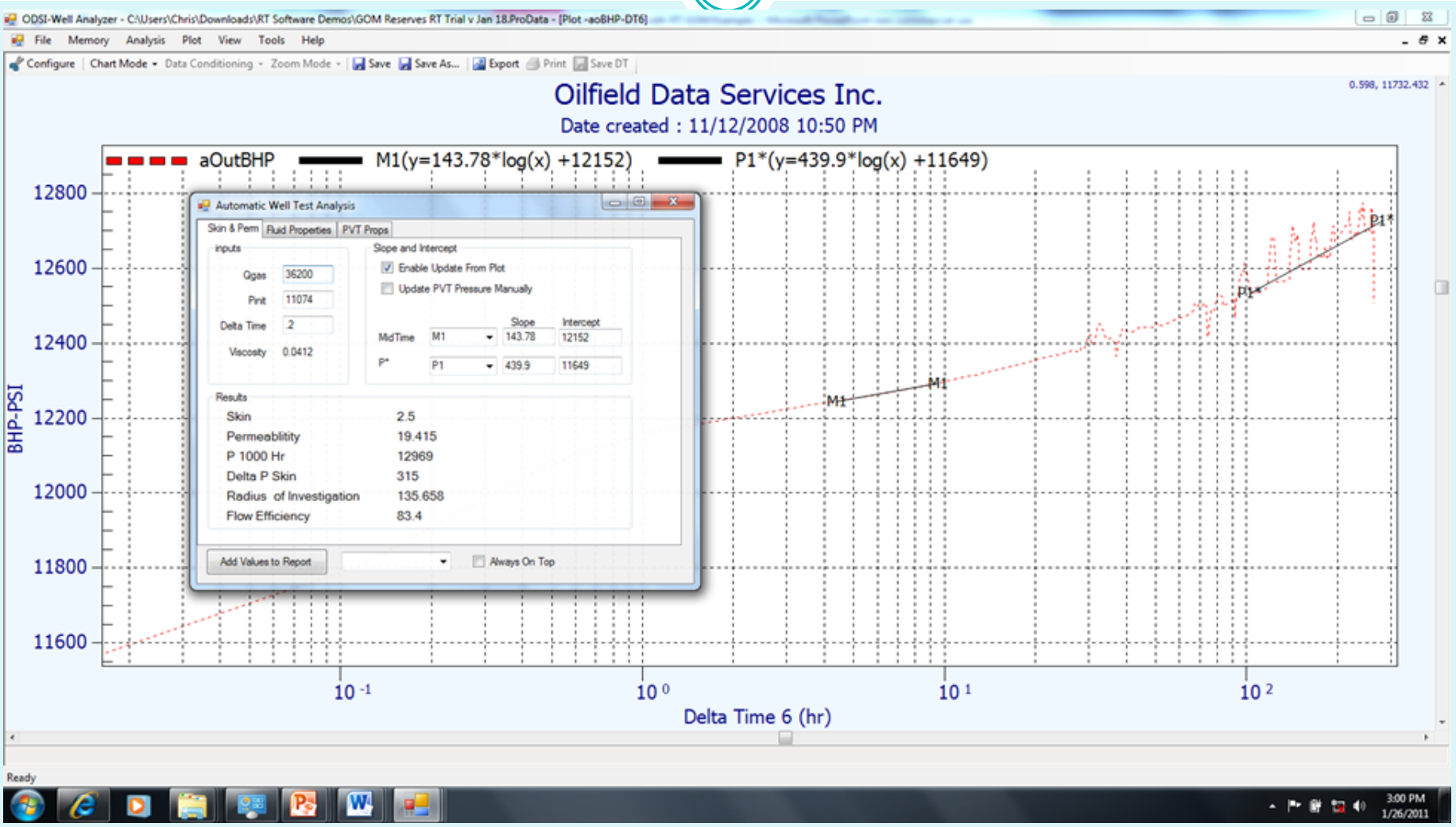
Performance at 00:00 on 9/24/2008



Validate PBU Analysis



Corrected Analysis – Sep 2008 PBU



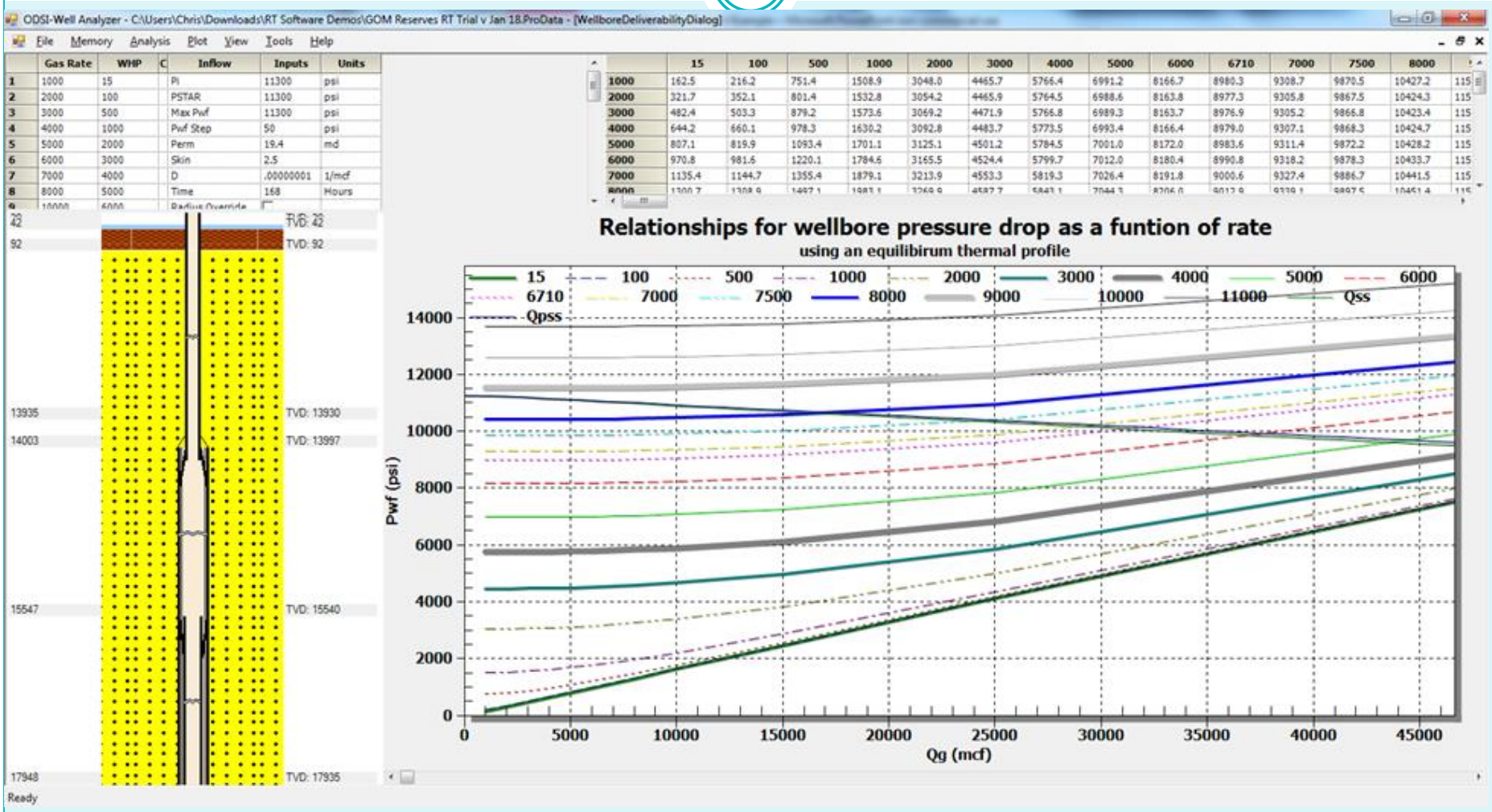
Reservoir Volumes & Pres Determination

- P/z GIP: 7.3 Bcf
- Hydraulically Connected Energy Volume: 6.5 Bcf
- Free/Mobile Gas Volume: 4.5 Bcf
- Gp on Sept 24, 2008 = 0.887 Bcf
- Pinit = 16,800 psia
- Last P* = 12,960 psia
- Gp for last P* = 0.848 Bcf

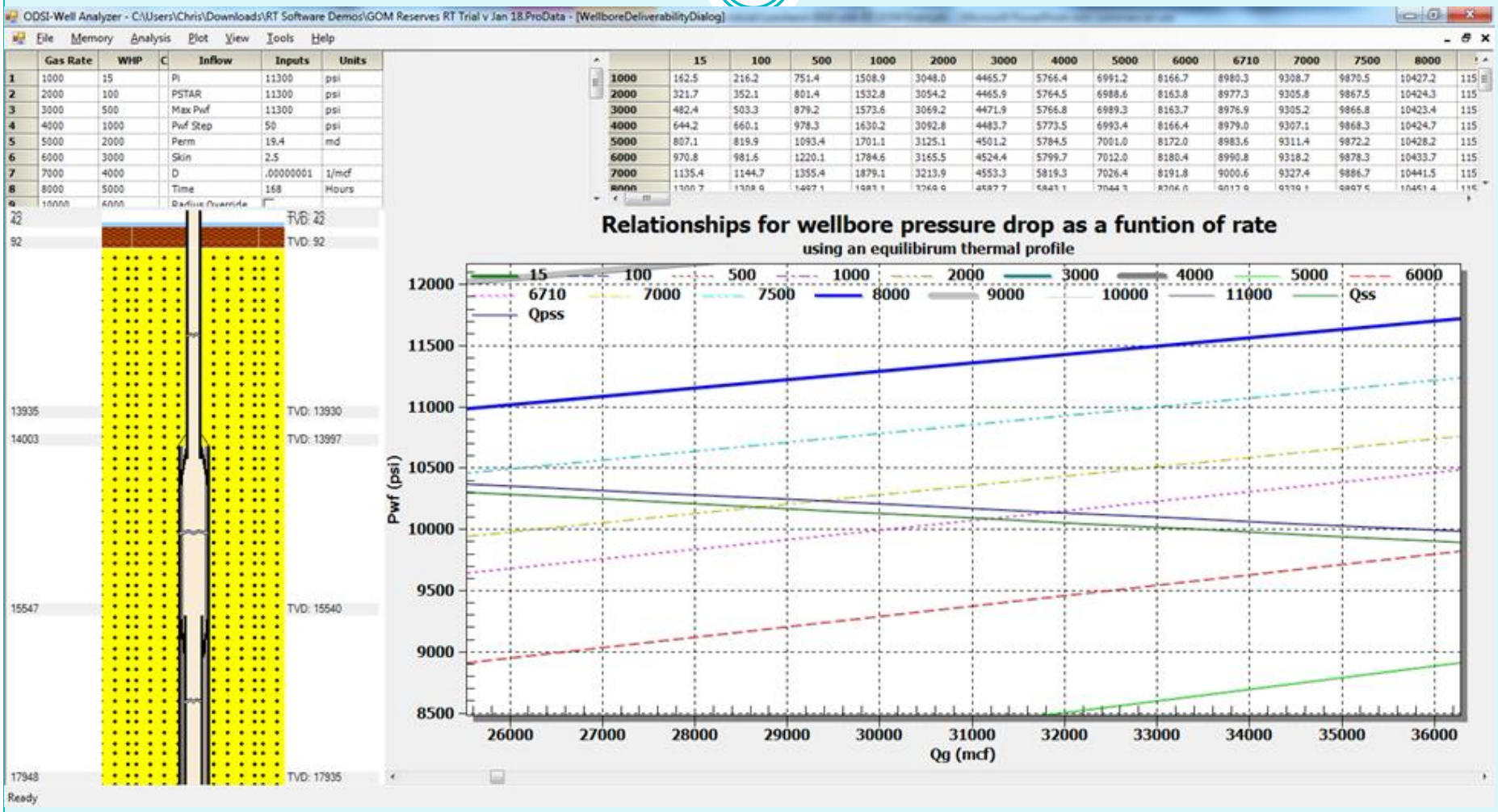
Projected Pres on Oct 1, 2008 = 11,300 psia

Qgas ~ 32,600 Mcf/D; WHP ~ 6,500

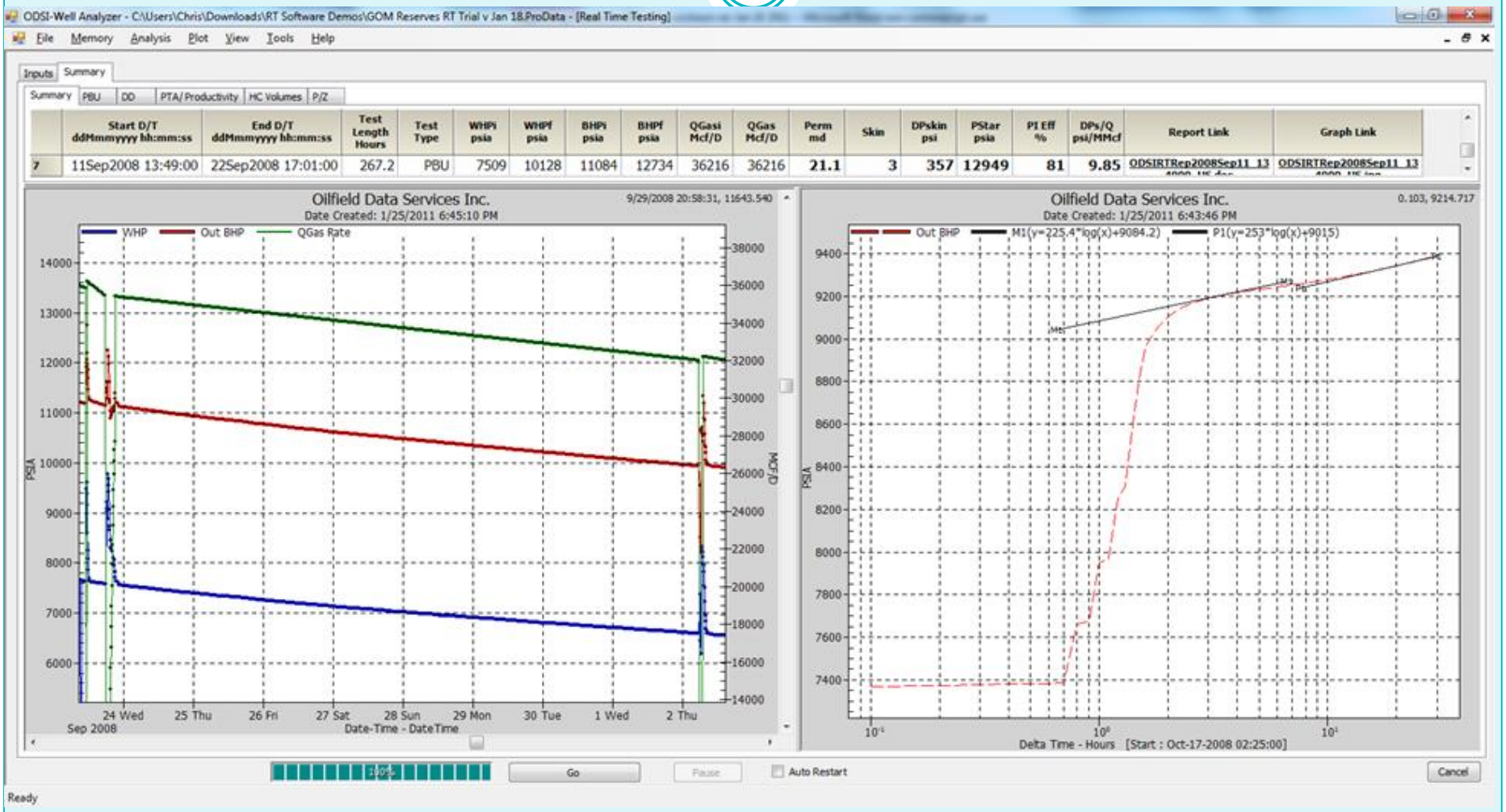
Plug Inputs into Transient Nodal Pak



Zoom – WHP = 6710 psi (measured)



Actual WHP & Qgas, Calc'd BHP



Comparison with Actual Data

- Qgas from Nodal = 32,000 Mcf/D
- Qgas Actual = 32,500 Mcf/D
- Note: Withdrawal rate slightly low

- BHPwf from Nodal = 10,150 psia
- BHPwf Actual = 10,090 psia
- Note: Withdrawal amount slightly low

Maybe getting some water influx or compaction?

Going Forward…

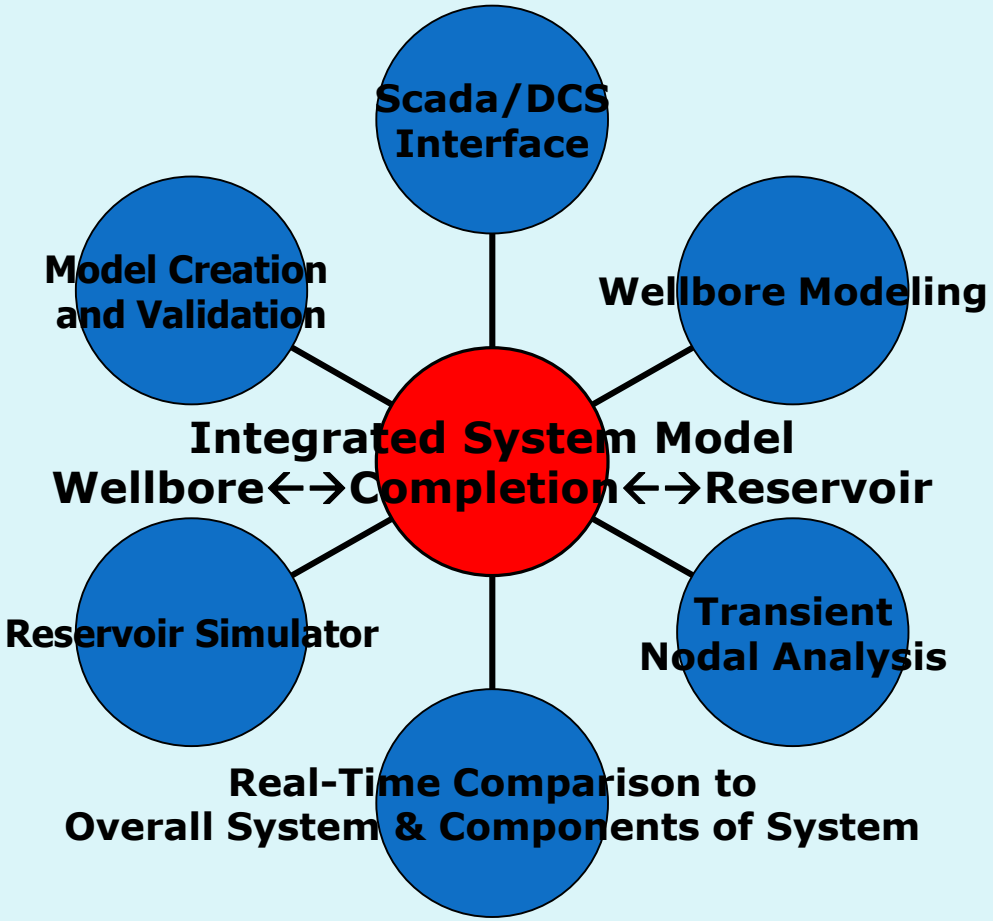
- If an engineer can interact with a nodal package…

Why not automate some of the calculations & give the engineer a heads-up when something dodgy is happening?

Better yet, why not integrate a reservoir simulator with the nodal package?

And while you're at it, make the simulator work using the same static model when you're in transient flow or steady-state flow…

What ODSI is Trying to Accomplish



Conclusions

- Proper Instrumentation and Visualization Software are the 1st Step (Don't Drop Bits!)
- Closed-Loop Solutions for the Wellbore and Reservoir make this System Possible
- This is NOT a fully automated system!
  - Requires initial and interim calibration (esp for WB)
  - Requires manual changes to models (for now)
  - Requires vigilance on part of REs & PTs
- It is possible to create such a system with existing technology (someone may have already done it)
- Warning an Engineer when (or before) something bad happens is more important than being accurate to the 9th decimal place

ODSI RTS Review: Done & Field Tested

- Wellbore Transient Phase & Thermal Modeling
  - Coupled Rate-Temp-PVT effects
  - Some problems with PVT package on Black Oil wells, but working to integrate commercial PVT package to sort
- Wellbore Pressure & Rate Modeling
  - Have 1 pressure & 1 Rates – BHP (and pressure profile)
  - Have 2 pressures (WHP & DHGP)
    - Gas & Gas/Condy – Calc Rates, then mid-completion BHP
    - Volatile Oil – Calc Rates; Calculate water cut, then BHP
    - Black Oil – Calculate water cut, estimate rates, then BHP, unless the PVT pak bombs
- If WBM crashes, well is loading…

ODSI RTS Review: Done & Field Tested

- Automatic Well Test Analysis
  - Build-ups, Drawdowns & 2-rate tests
    - Skin, perm & P* (PBUs)
    - Analysis Validation
- Relative Productivity Tracking
- P/z & SLD-P GIP evaluation
  - With Geo-pressure adjustment
- HC Volume Evaluation (gas & gas/condy for now)
  - Conventional & TTA (PV-Work) methods
  - In-Place, Hydraulically Connected & Mobile Gas Volumes
  - Recognition of Water Influx

ODSI Batch Modules: Not Incorporated in RTS yet

- 1-D Reservoir Simulator
  - Single-phase gas or oil in reservoir
- Transient Nodal
  - Variable PVT and Thermals
  - Transient, PSS & Hybrid Inflow
- J-T Cooling/Heating
- WCD (worst case discharge) reporting

What's The "Chris & Ric" Show Doing Next?

- Algorithms for Recognizing when a well begins to slug, has the onset of loading, or is loading-up
  - Conventional Tubing Well bores
  - Annular Flow (CSM)
- 2-D (r-theta) Reservoir Simulator (1-phase)
- "Universal Translator" to make our RTS more "plug n' play" with HMI's/Historians (PI, PhD, OFC, OVS, etc.)
- Fix PVT Package (crashing problems near Psat for oil wells)
  - Allows for multiphase oil and 3-phase PVT calcs

In the works…

- Mate Auto-Simulator and WBM to create automated Transient Nodal Package
  - Link to Static Model
- Link to more rigorous Simulation Programs when Static Model needs to be re-worked
- Link to Subsea/Surface/Facilities Programs
  - Production Allocation assistance
  - Flow Assurance assistance

ODSI Base Business Model: