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Engineer Your Gas-Condensate Systems, Reservoir to Sales Meter

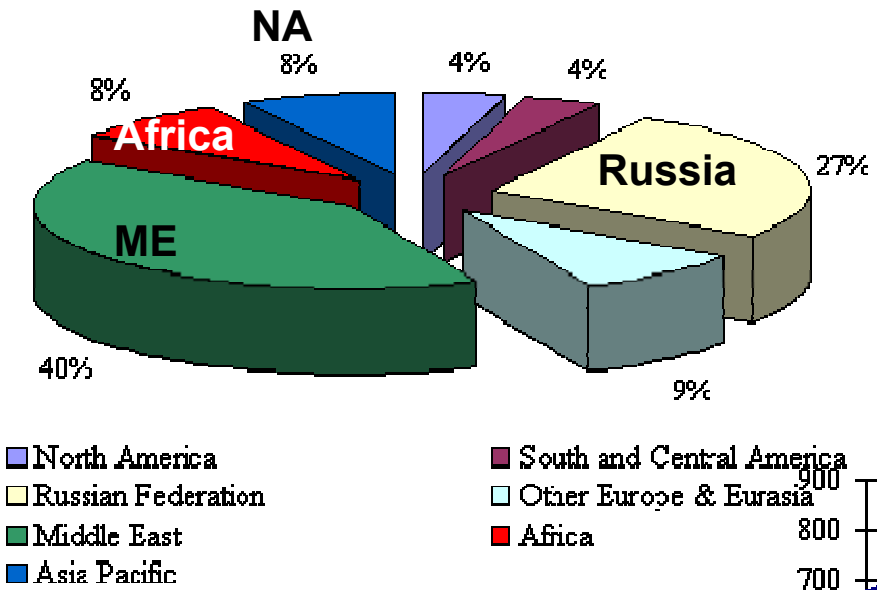
Shah Kabir
Chevron Energy Technology Company

SPE 95531, 95528, 89753, 89754, 100384

Presentation Outline

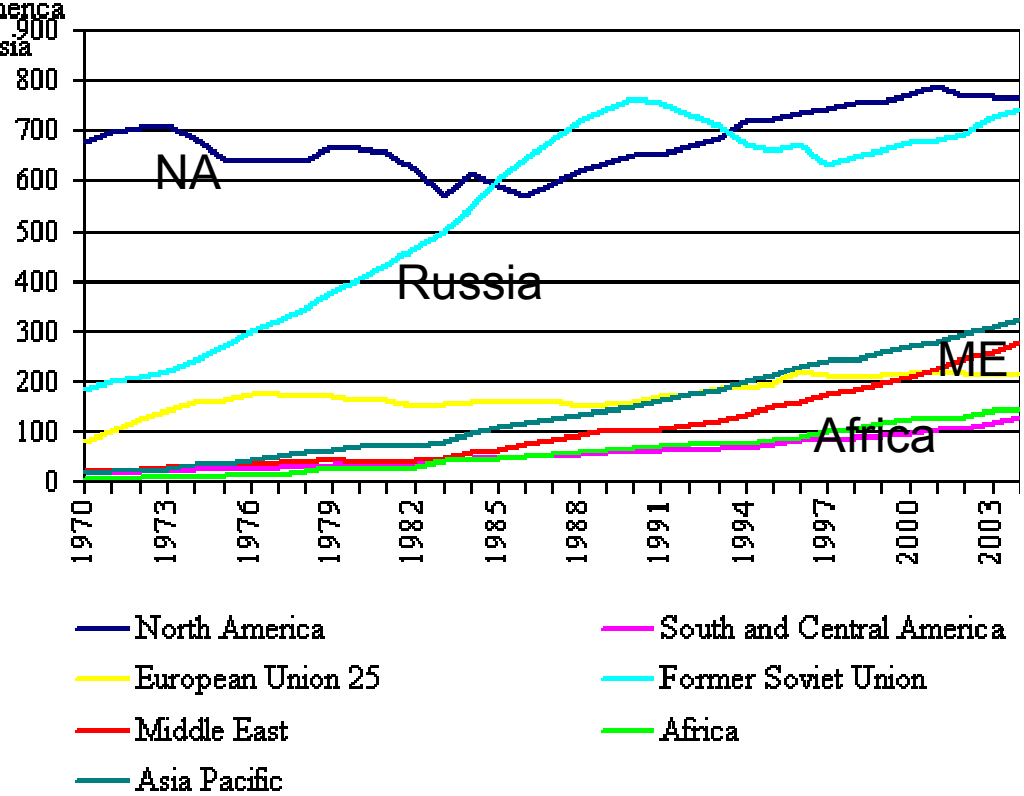
- Reserves & Consumption of Natural Gas
- Useful Correlations for RF and Gas Cycling
- Simple Simulator: Well Count
- Coupled Modeling w/Economics: Pipe Size
- Real-Time Reservoir Management
- Concluding Remarks

Distribution of Proved Natural Gas Reserves (%) in 2004

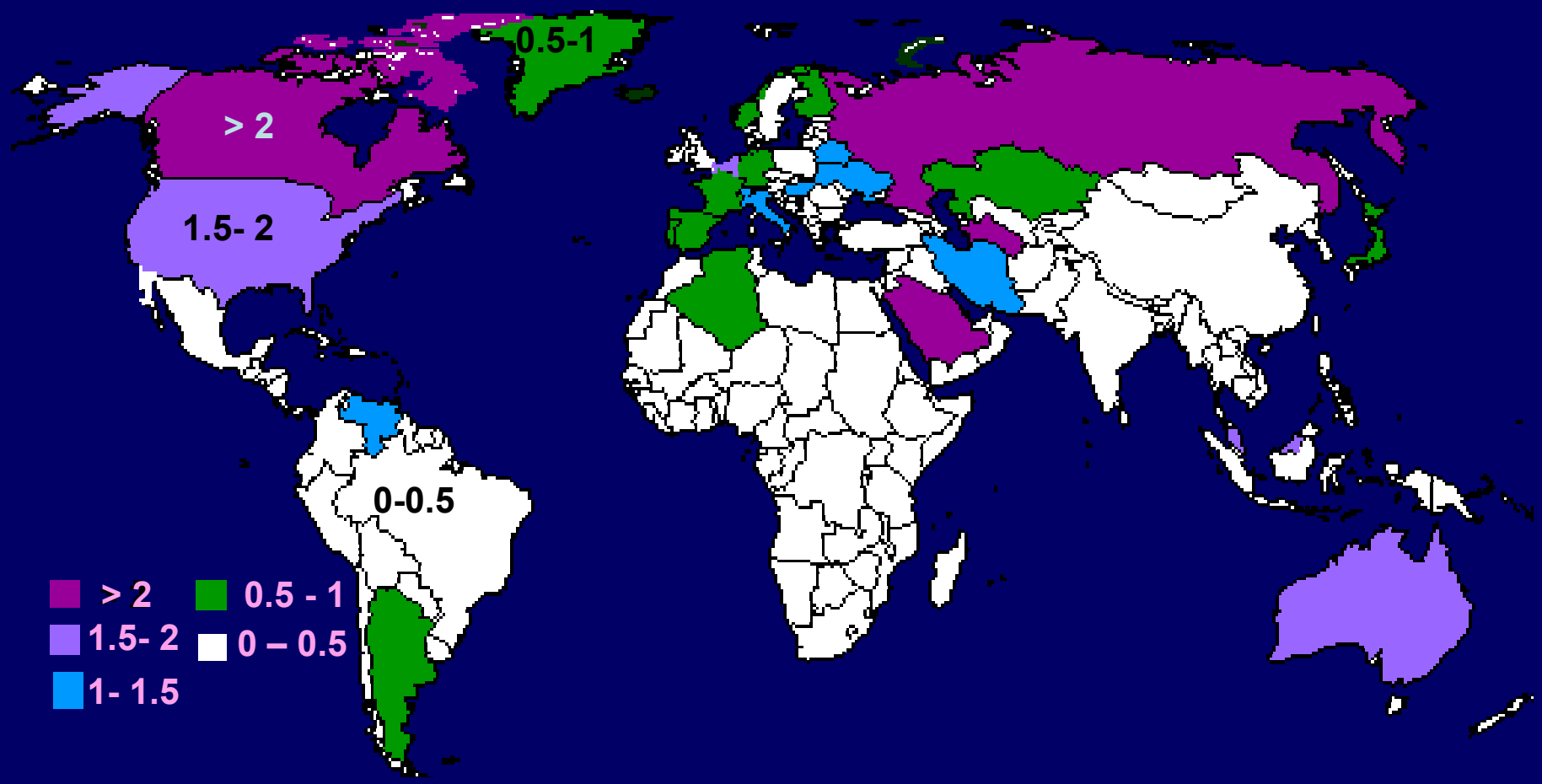


Natural Gas Production (billion cubic metres), 1970-2004

Source: UNCTAD based, June 2005



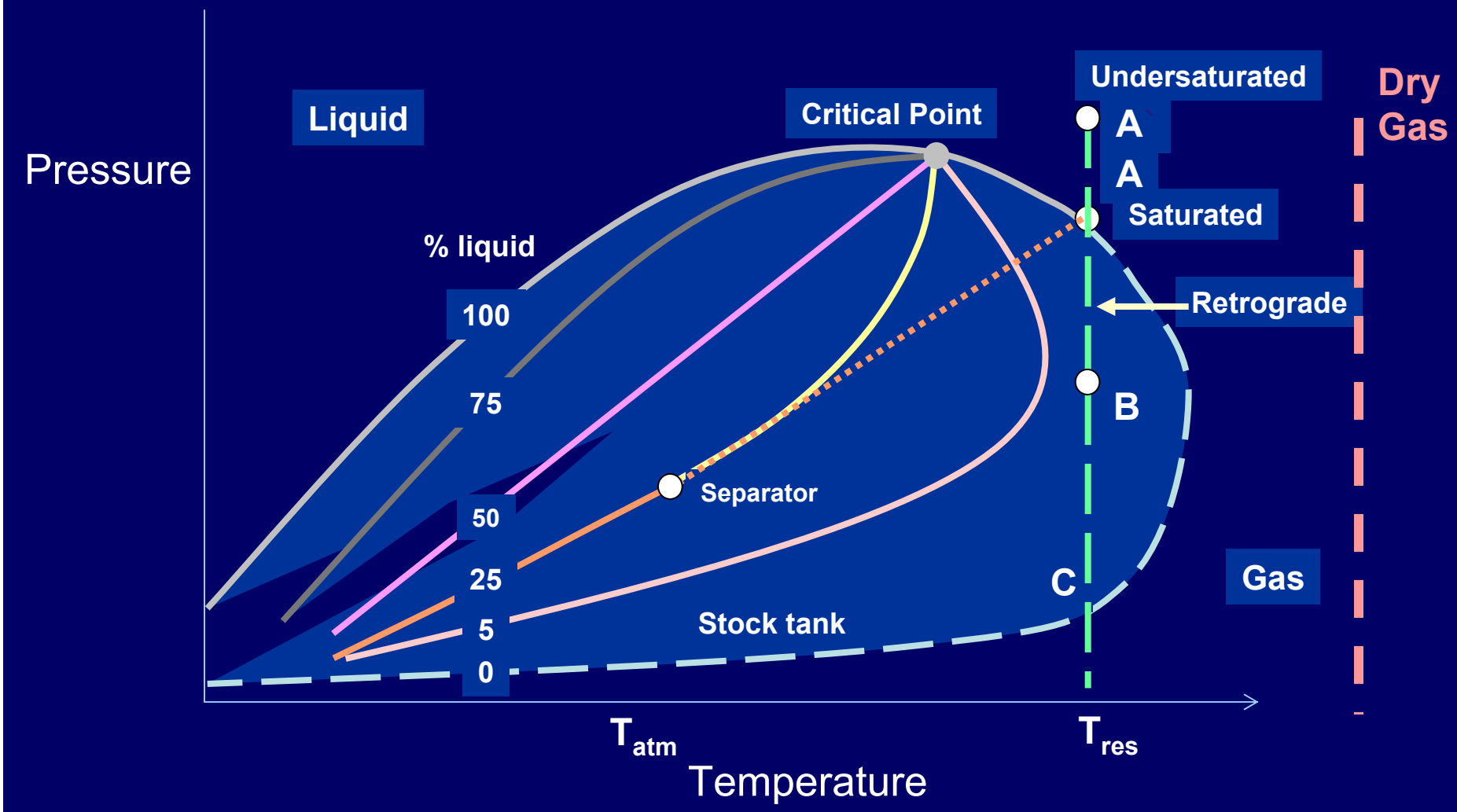
Consumption Per Capita By Country, Tonnes Oil Equivalent



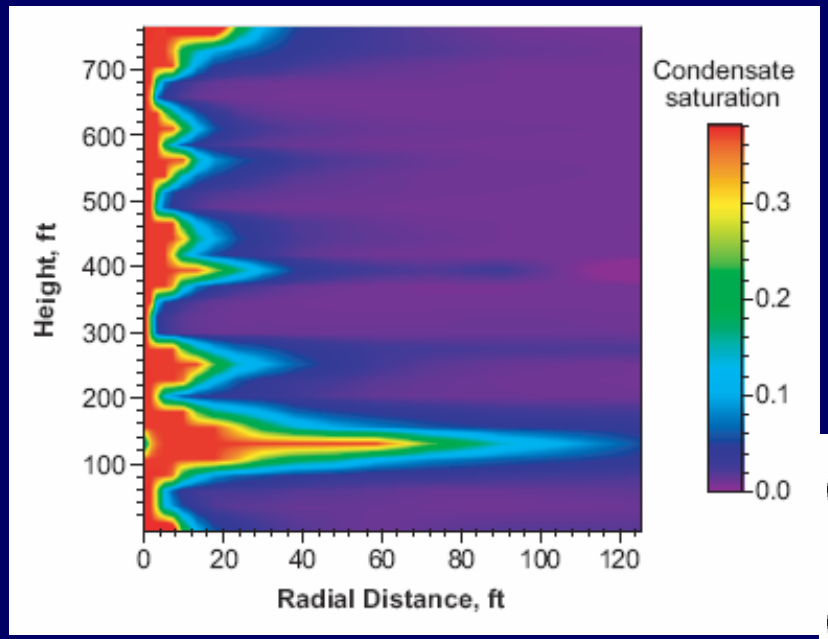
Source: UNCTAD based, June 2005

Estimating Gas & Liquid Recovery Factors

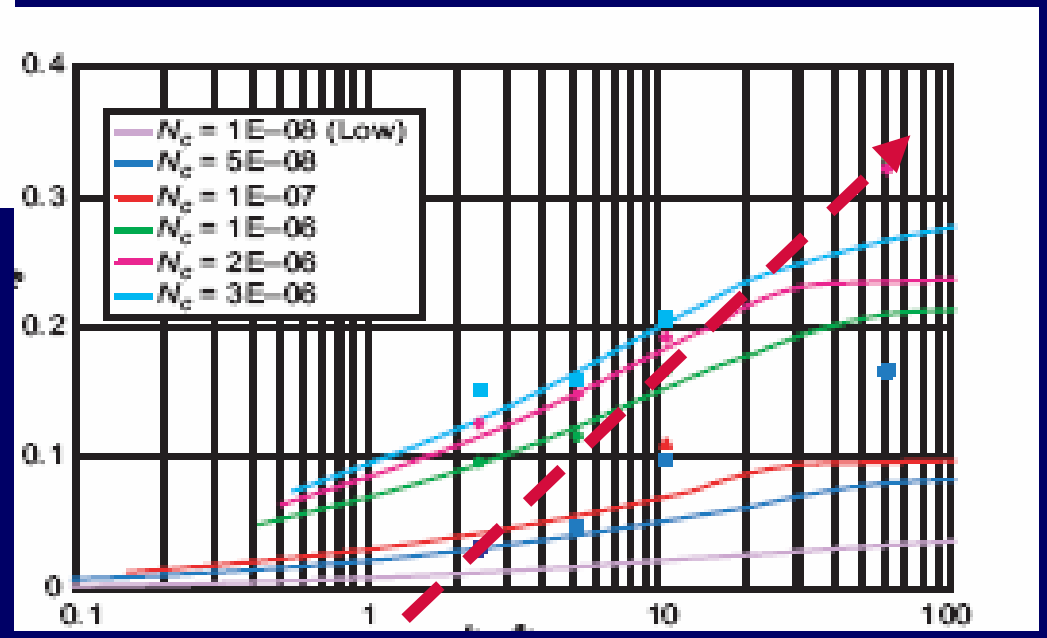
Phase Diagram of Retrograde Condensate Fluid



Condensate Banking & Role of N_c



$N_c = \mu v/\sigma$



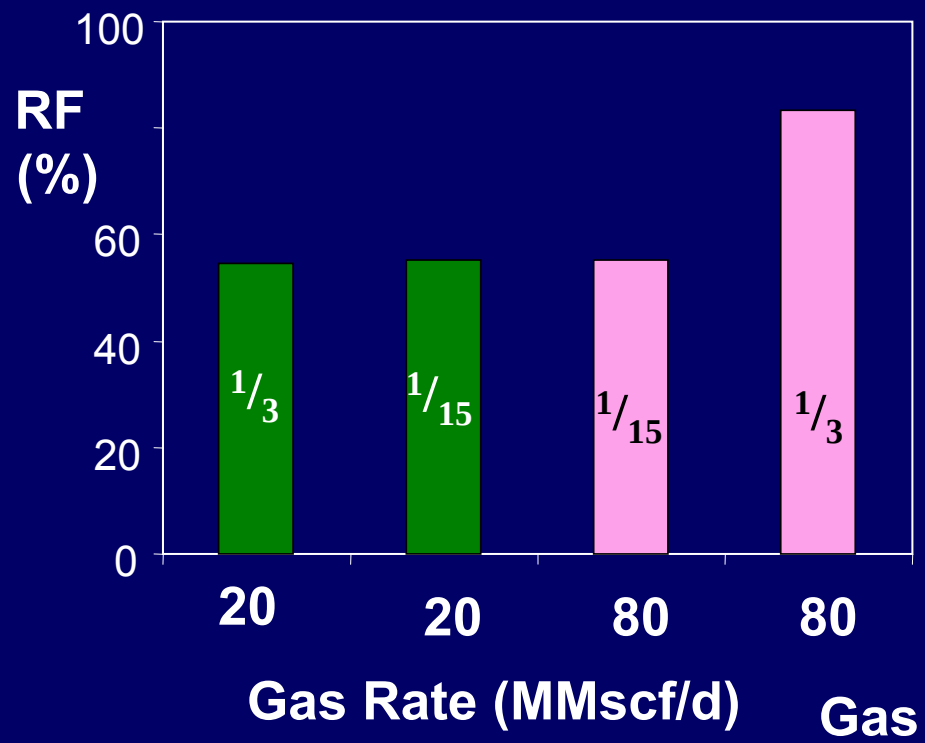
k_{rg}

k_{rg}/k_{ro}

(after Kamath, *JPT*, April 2007)

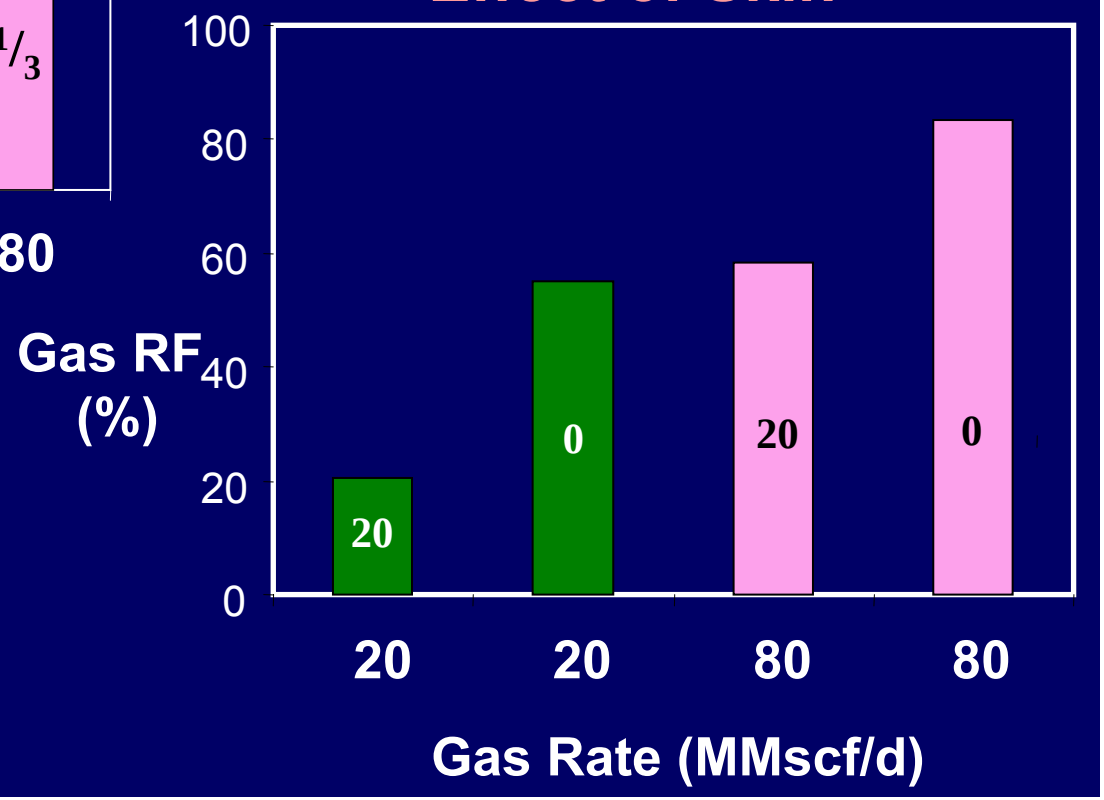
Gas RF: Low-Perm, Low-Yield Scenario

Effect of Perforated Length



10 md, 45 STB/MMscf

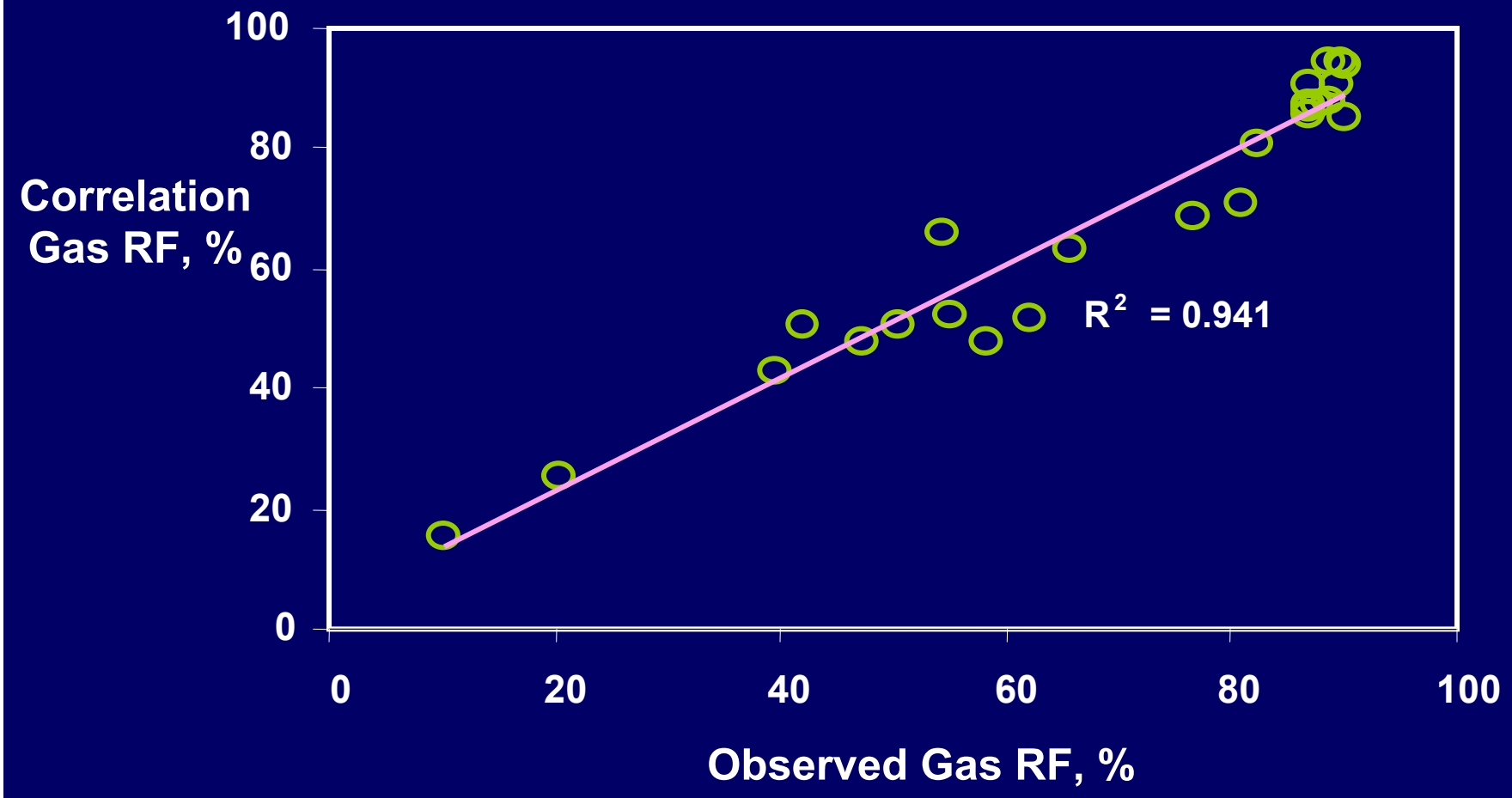
Effect of Skin



(after SPE 95531, 2005)

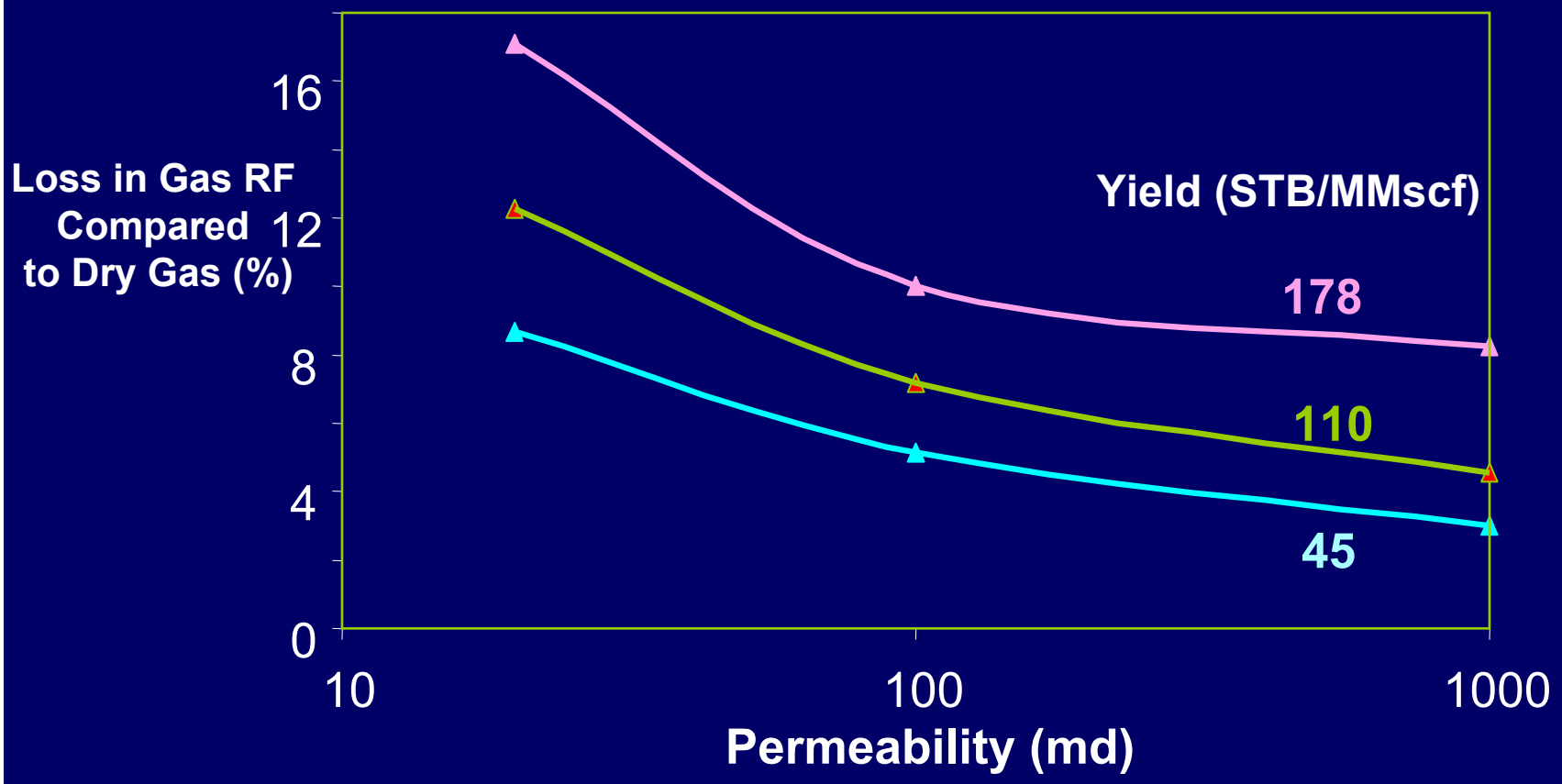
Gas Recovery Correlated to Five Variables

$$RF = 46.682 + 0.585*Perm - 0.091*Yield - 1.448*Skin + 42.51*Perf\ Int - 0.00135*Perm^2 + 0.003772*Perm*Skin...$$



(after SPE 95531, 2005)

Effect of Yield and Permeability on Gas RF



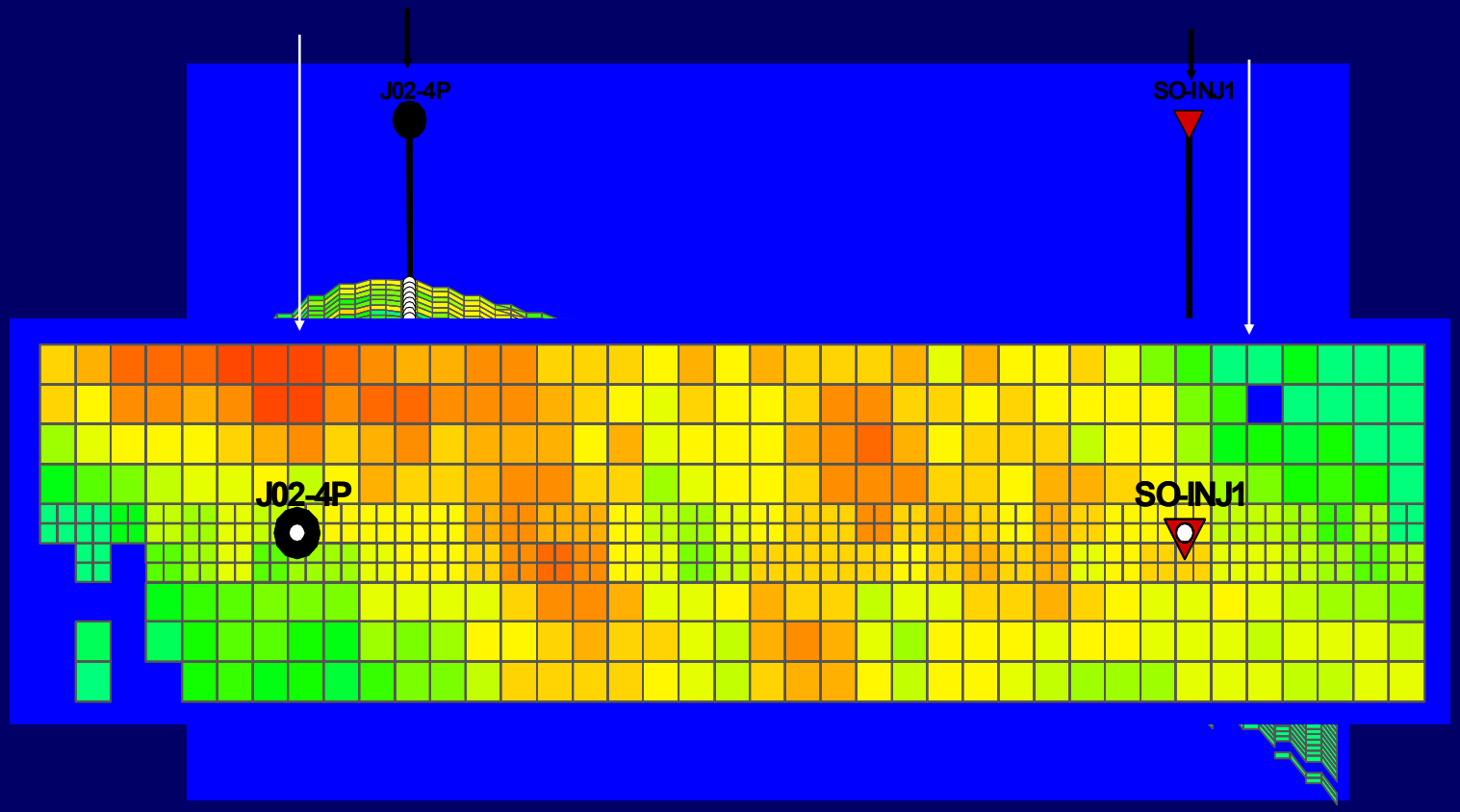
$$RF = 57.605 + 0.16*Perm - 0.014*Yield - 0.00014*Perm^2 - 0.000146*Yield^2$$

(after SPE 95531, 2005)

To Cycle or Not to Cycle

Up-dip Producer

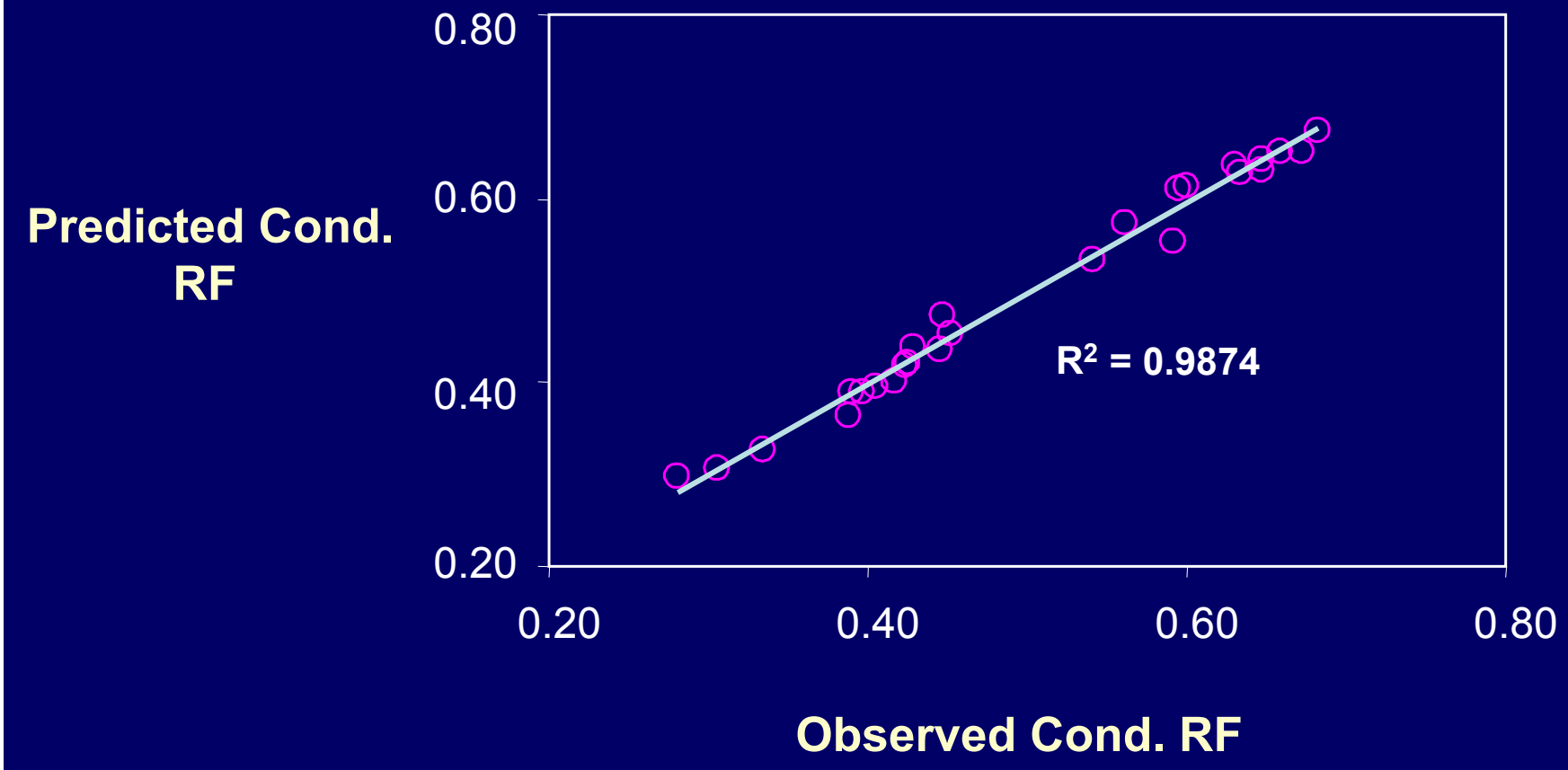
Down-dip Injector



(after SPE 95531, 2005)

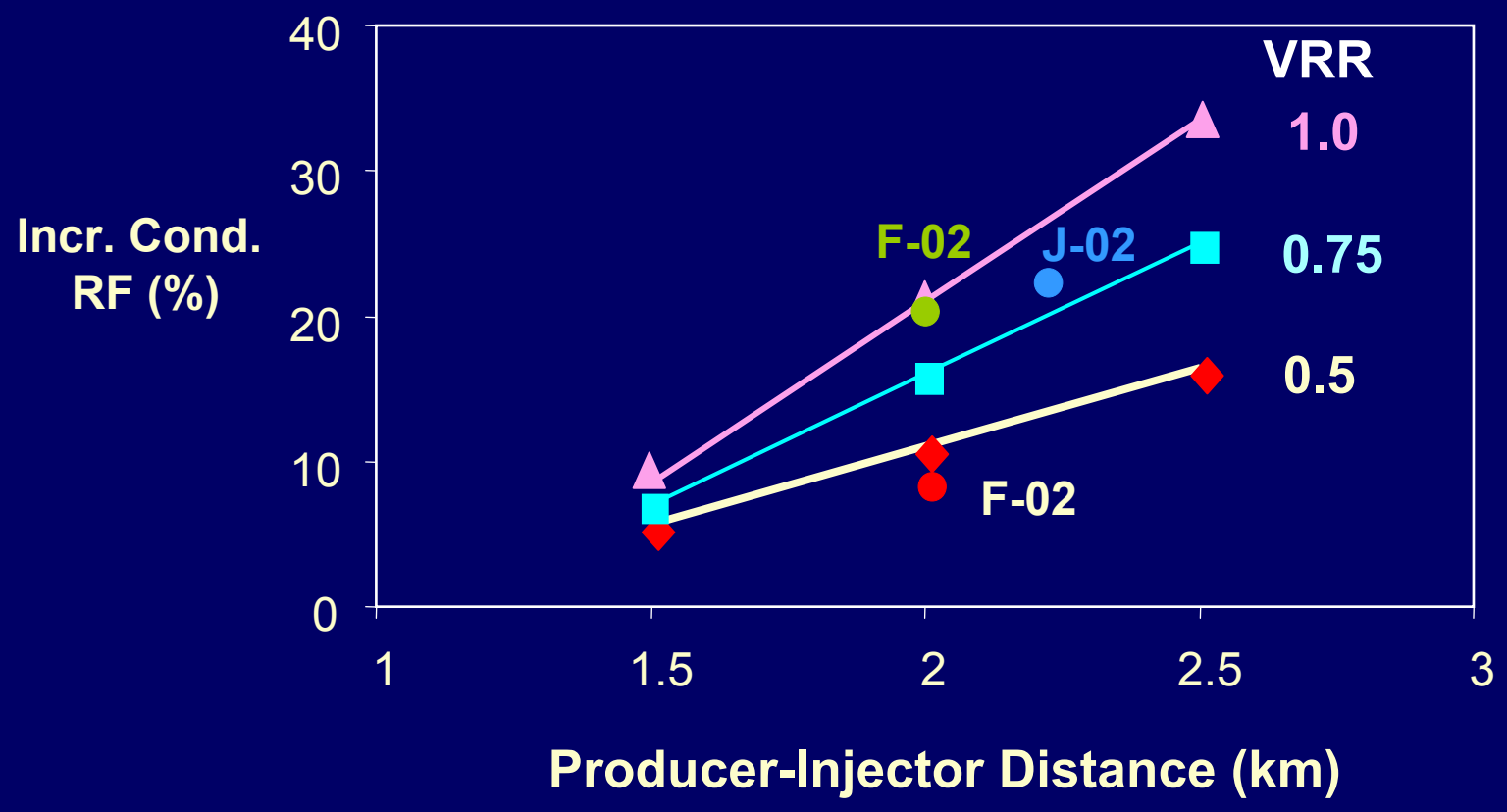
Recovery Factor Correlation to Evaluate Potential Cycling Candidates

RF = 0.459 – 0.00067*Yield – 0.00004*Perm - 0.355*VRR – 0.028*PID + 0.277*VRR*PID



(after SPE 95531, 2005)

Incremental Condensate RF in Cycling



Inc. RF (%) = 8.532 - 0.0057*Perm - 37.14*VRR - 3.44*PID + 28.52*VRR*PID

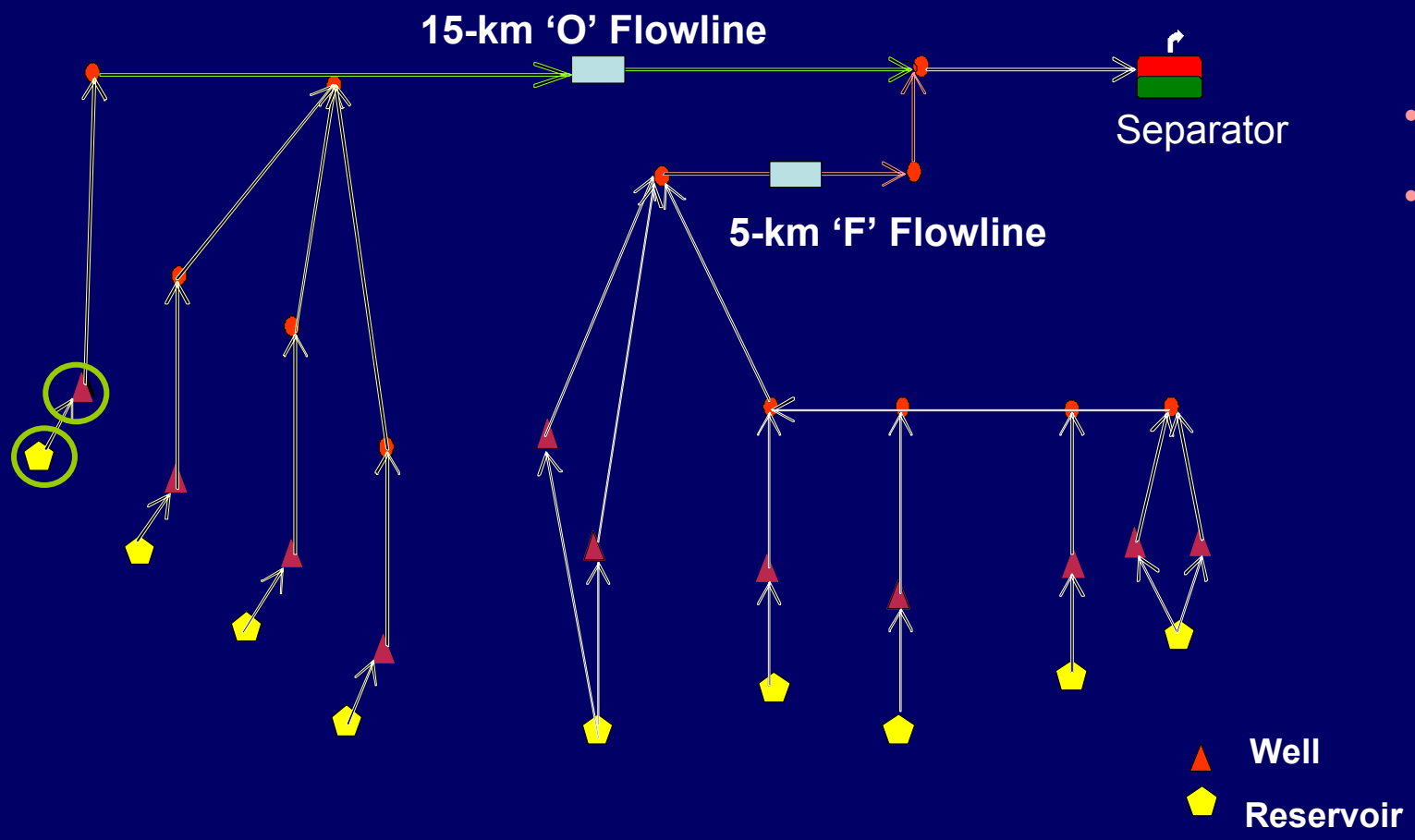
(after SPE 95531, 2005)

Summary

- Condensate Banking Impairs Gas Recovery
  - Impairment Severe for Low-Perm, High-Yield Systems
  - Completion Issues Important in Low-Perm Systems
- In Gas Cycling, Liquid Recovery Improves When
  - VRR > 75%
  - PID > 2.5 km
- Appropriate Correlations Presented for Initial Assessment of G-C Systems

Estimating Well Count & Pipe Diameter

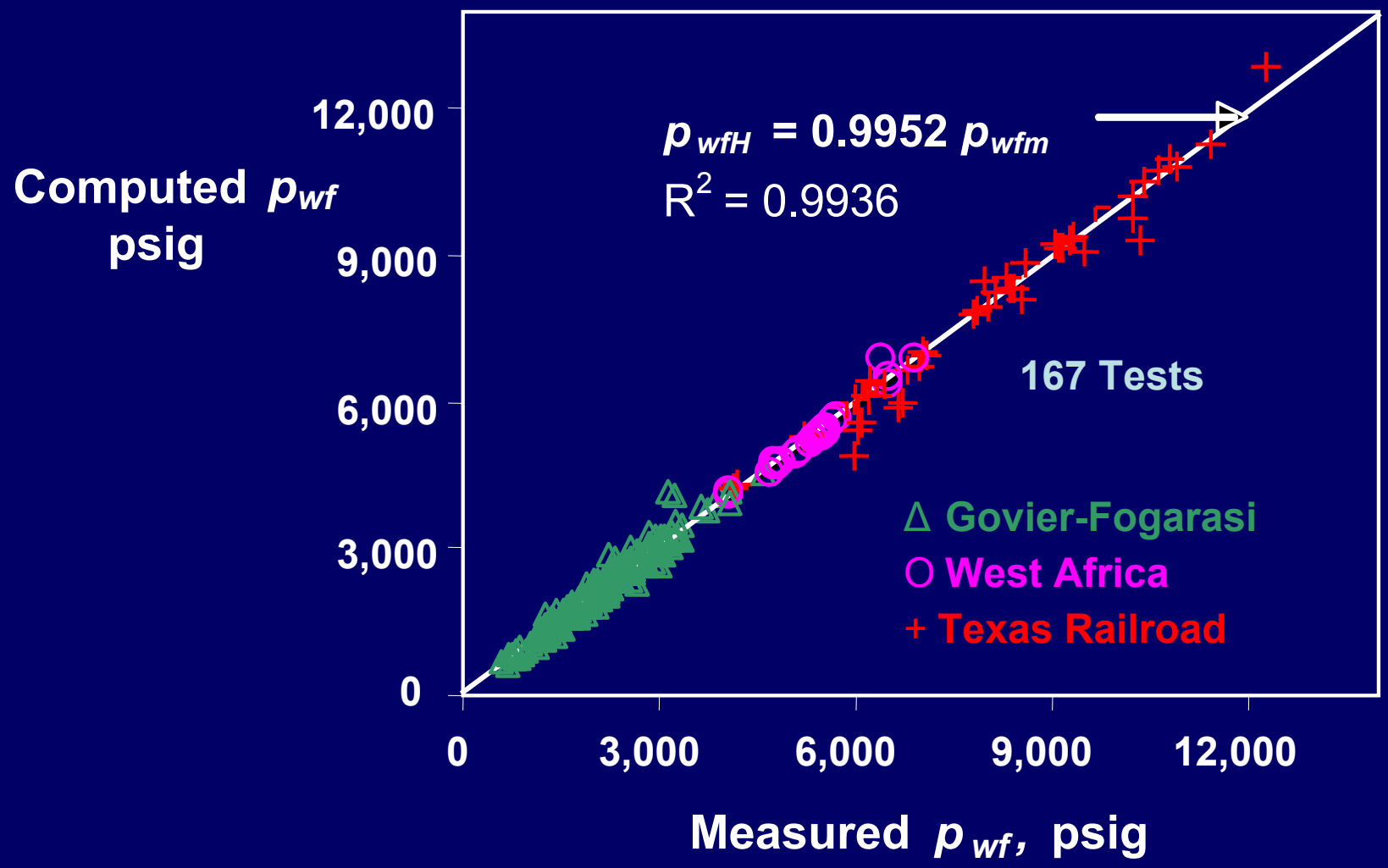
Gas Supply Network for an LNG Plant



- Well Count
- Pipe Dia

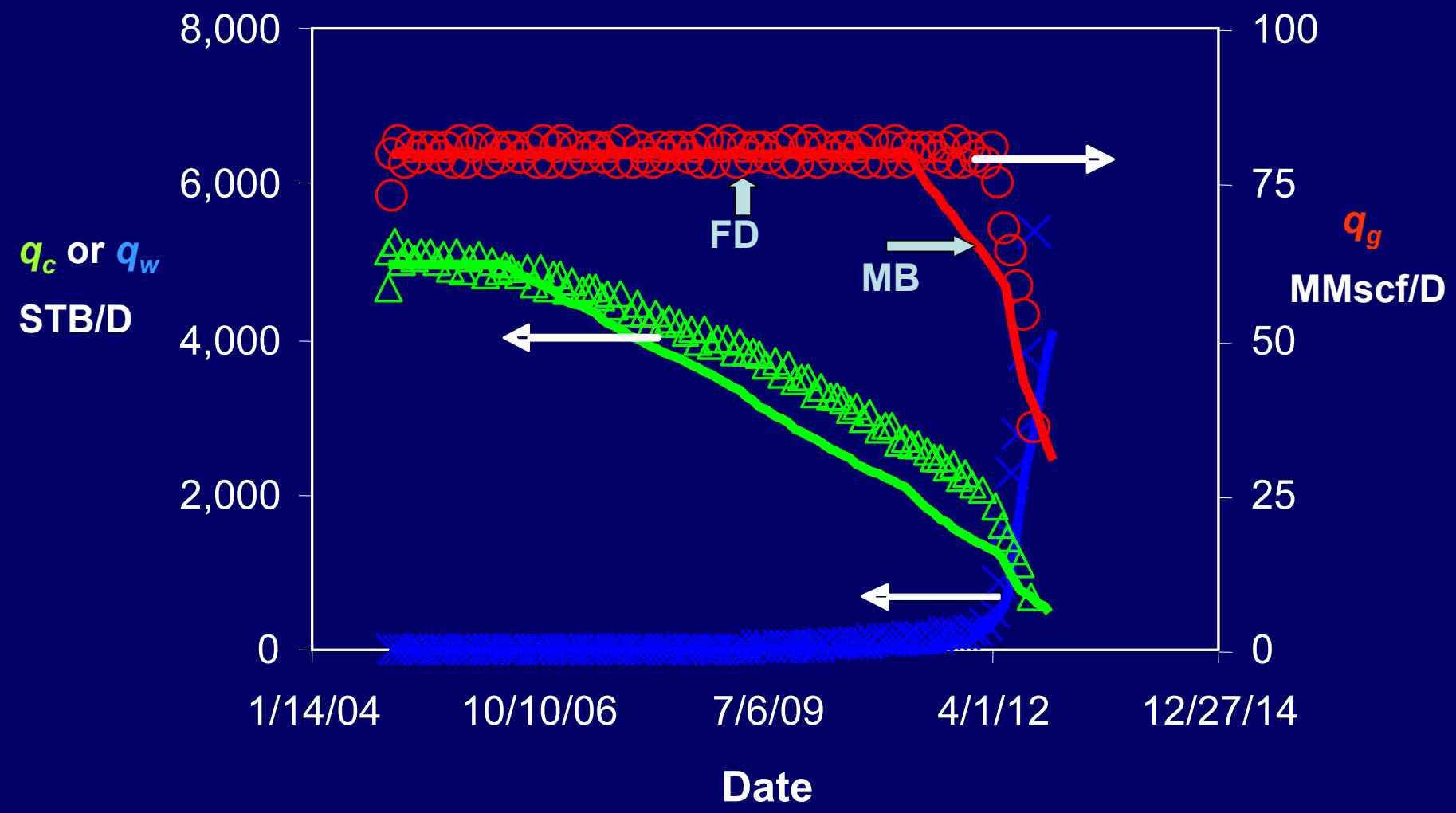
(after SPE 95528, 2005; *SPEREE*, June 2007)

Homogeneous Model's Performance in Gas/Condensate Wells



(after SPE 89754, *SPEPO*, Feb. 2006)

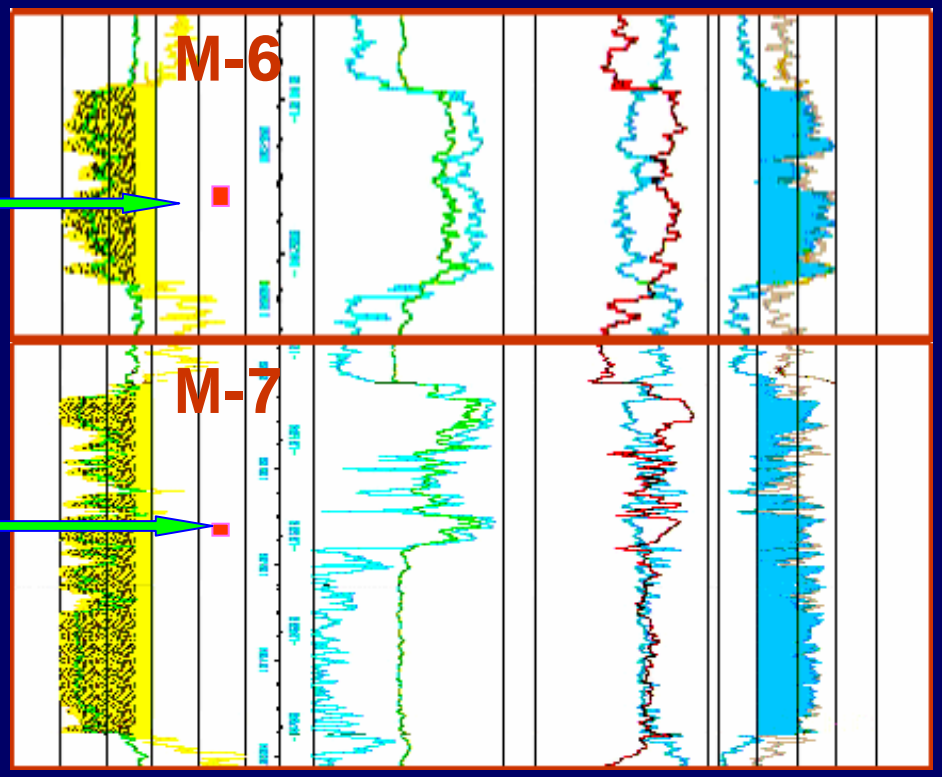
Comparison of MB & FD Solutions



(after SPE 95528, 2005; *SPEREE*, June 2007)

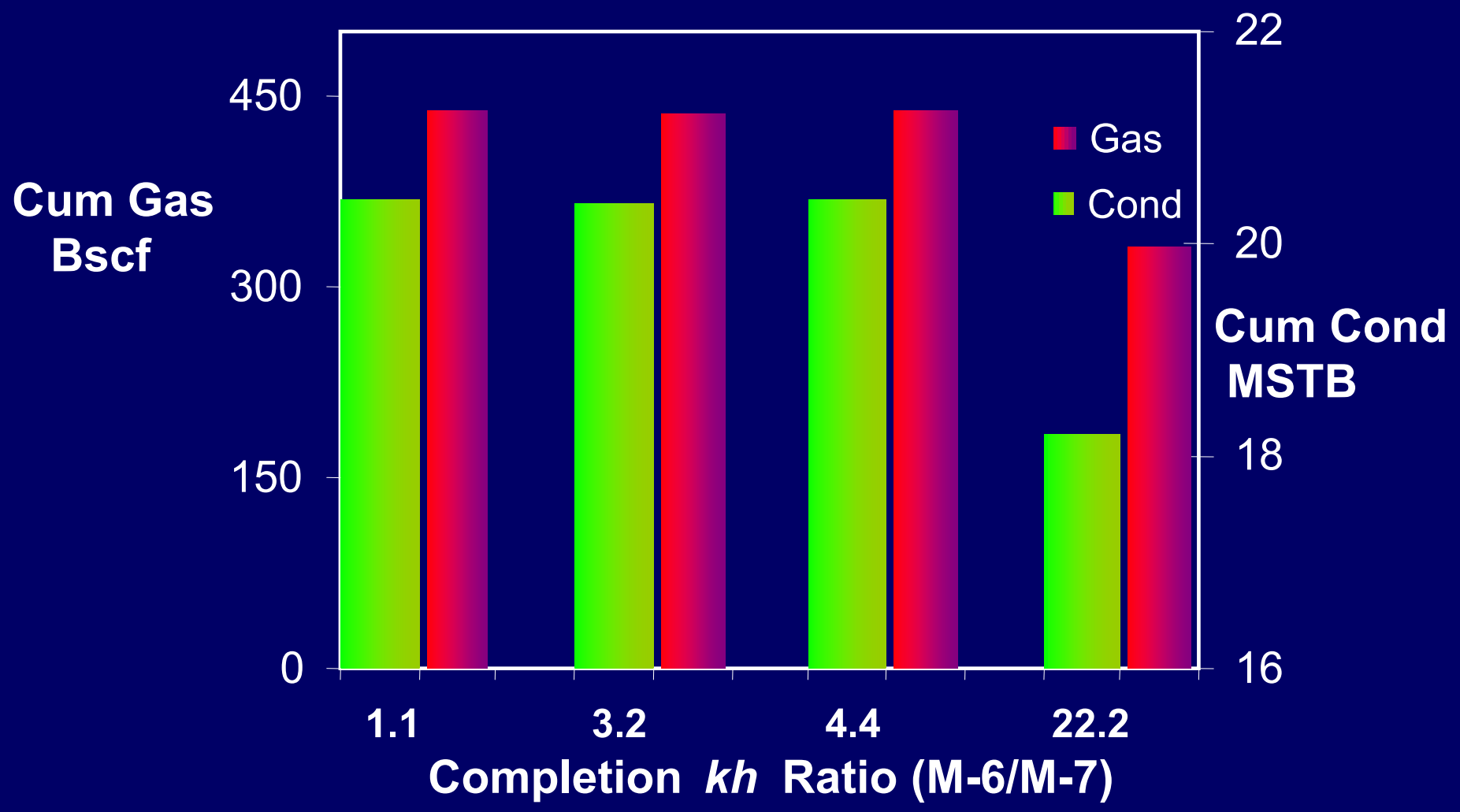
Results From DST & Volumetric Analyses

OGIP Ratio	*k* md	*h* ft	*s*	*D* D/Mscf
1	5,115	67	187	0.097
1.16	2,770	30	30	0.0112



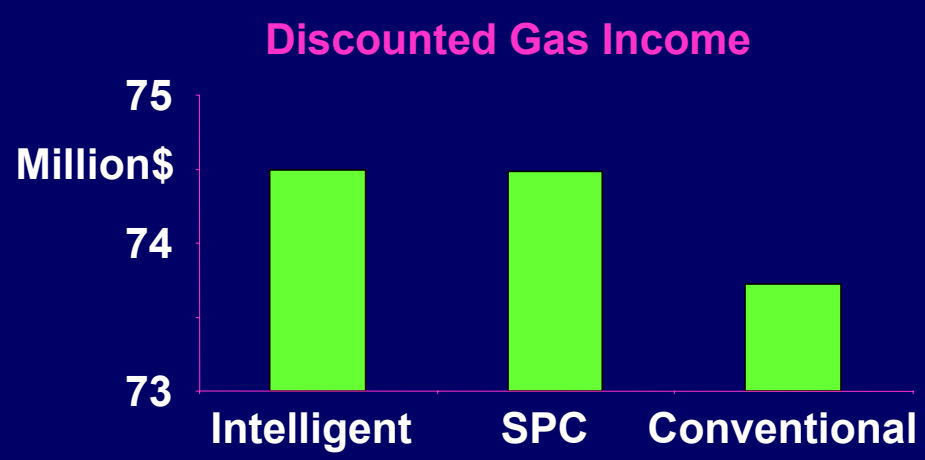
(after SPE 89753, *SPEREE*, Feb. 2006)

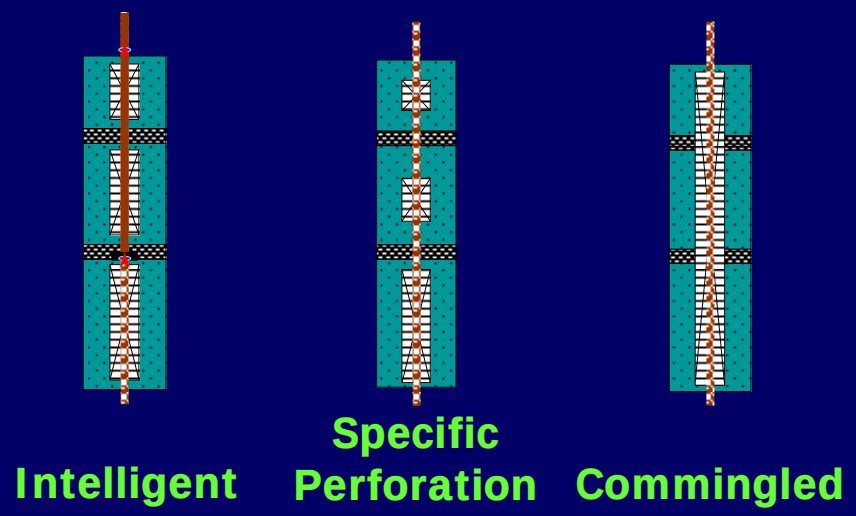
Performance Comparison of Completion Scenarios

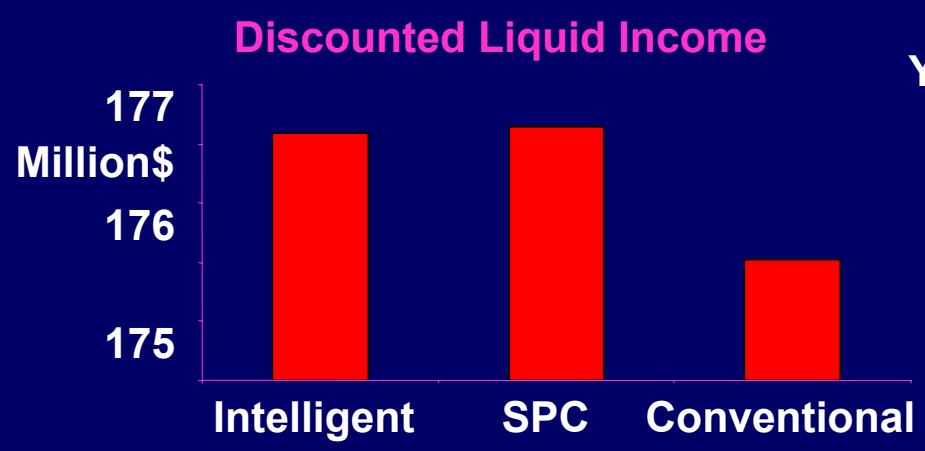


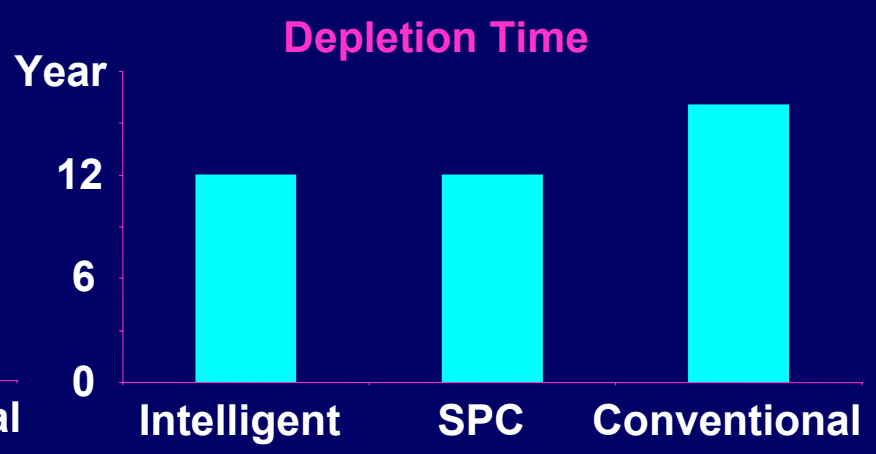
(after SPE 89753, *SPEREE*, Feb. 2006)

Discounted Income Comparison









(after SPE 89753, *SPEREE*, Feb. 2006)

Essence of a Simple Simulator

Single-Reservoir, Single-Well, Spreadsheet-Based Simulator

- **Gas Properties Correlations: Gas Viscosity, B_g, Z-factor, etc**
- **Material-Balance Model**
- **Wellbore Model for Homogeneous Flow**

Input

Fluid Properties
Reservoir Properties
Completion Details
Production Constraints
Economic Scenario

→

Computations

Material Balance
Wellbore Model
Economic Evaluation

→

Output

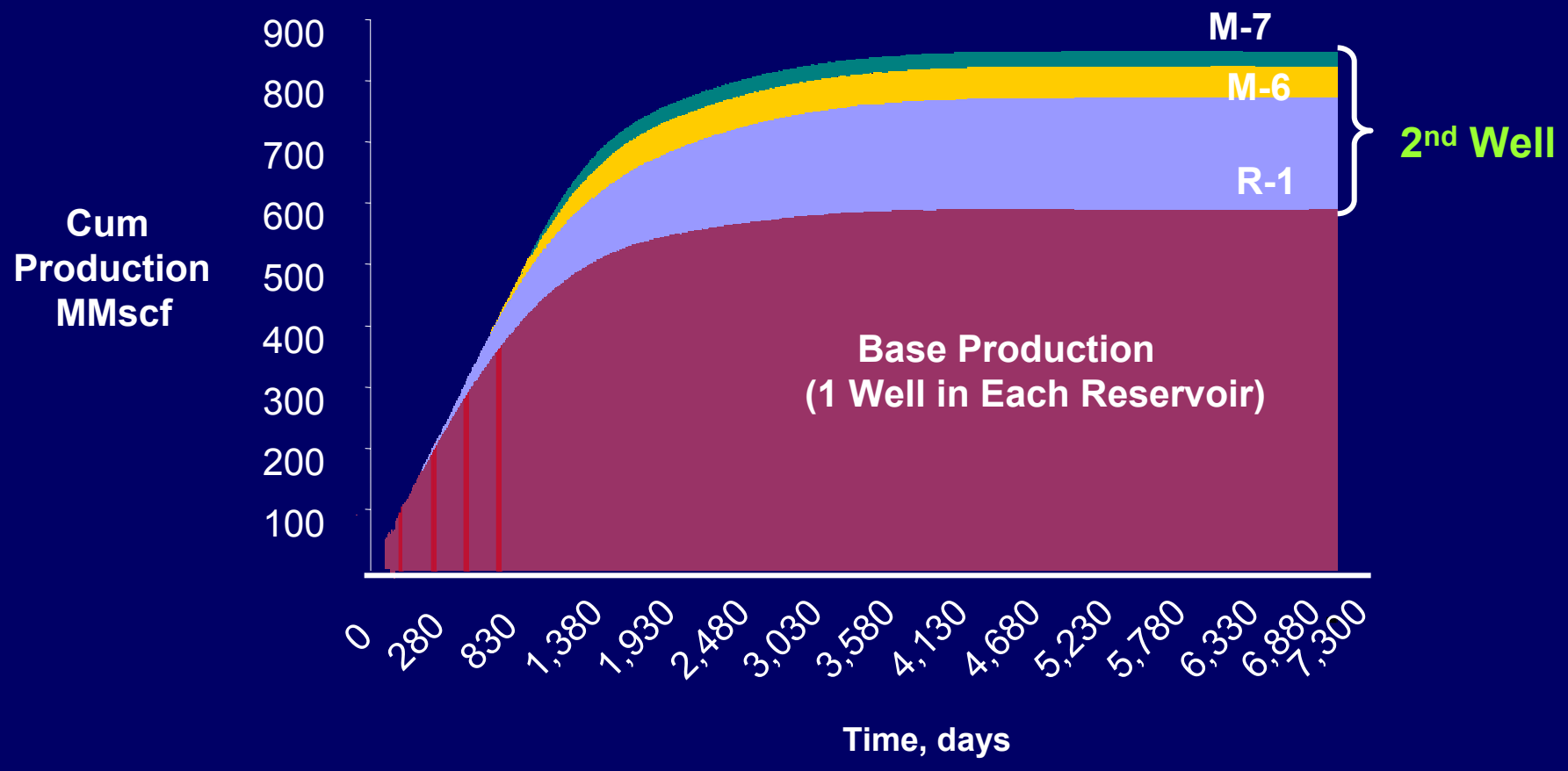
Rate Forecast
Cum Production
Res Pressure Forecast
NPV

(after SPE 95528, 2005; *SPEREE*, June 2007)

Template for a Deterministic Run

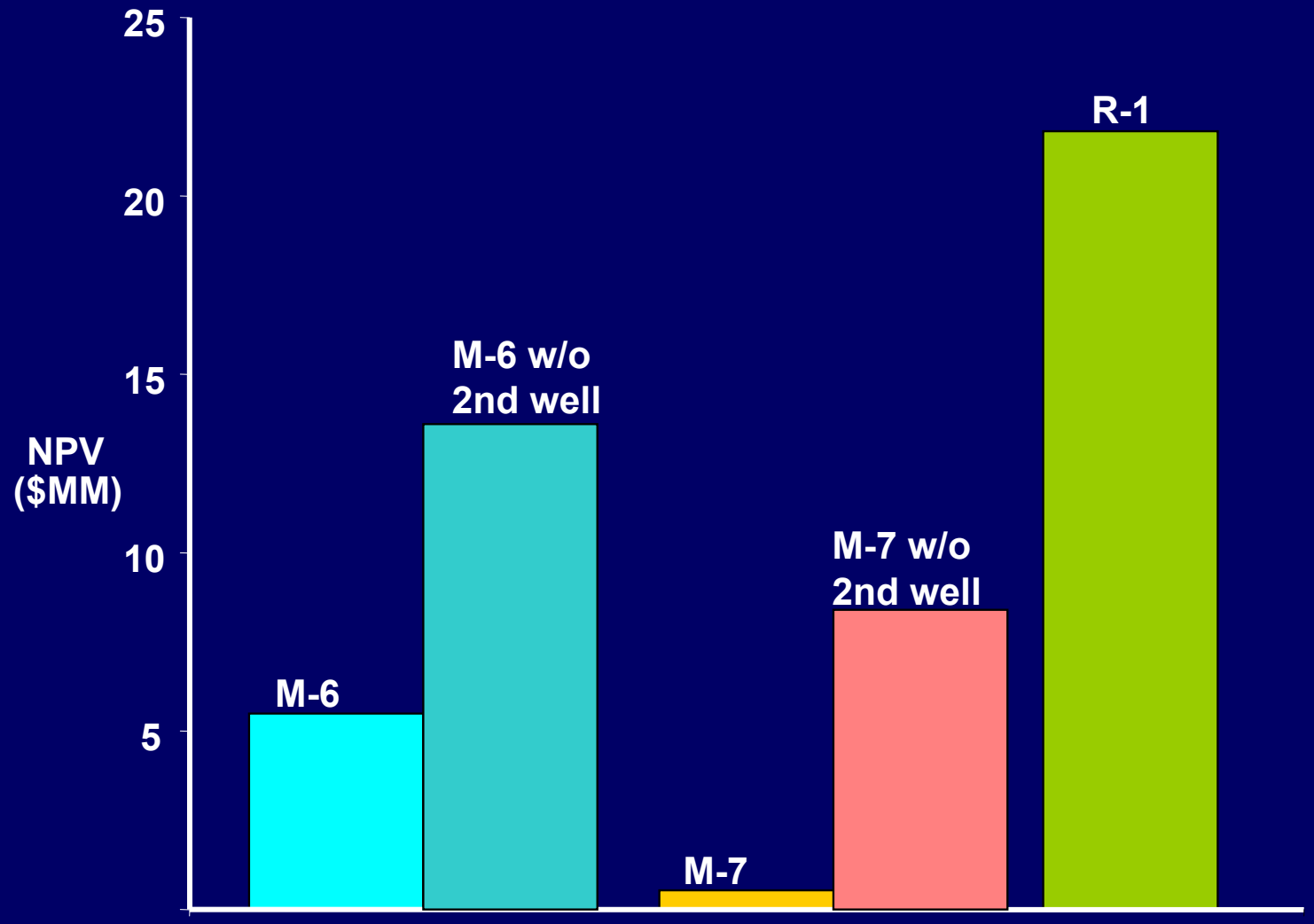
	M-6	M-7	R-1
Reservoir/Fluid Variables			
OGIP (Bscf)	306	238	586
Initial Pressure (psia)	5,800	5,800	5,800
Reservoir Temperature (F)	241	241	241
Gas Gravity (-)	0.68	0.68	0.68
Reservoir Permeability (md)	6,646	2,894	151
Net Pay (ft)	150	150	200
Reservoir Geometry/ Wellbore			
Area (acres)	930	930	1,620
Shape factor	30.88	30.88	30.88
Skin	20	20	20
Non-Darcy Coefficient (D/Mscf)	0.00097	0.00097	0.00047
Wellbore Radius (ft)	0.25	0.25	0.25
Production Constraints			
Imposed Constant Rate (MMscf/D)	140	140	145
No. of wells	**1**	**1**	**1**
Wellbore Model Variables			
Tubing Inside Diameter (in)	4.95	4.95	4.95
Wellhead Pressure (psig)	1,000	1,000	1,000
Wellhead Temperature (F)	80	80	80
Well depth (ft)	10,000	12,000	10,000
Pipe roughness ratio	0.0018	0.0018	0.0018

Deterministic Cumulative Production



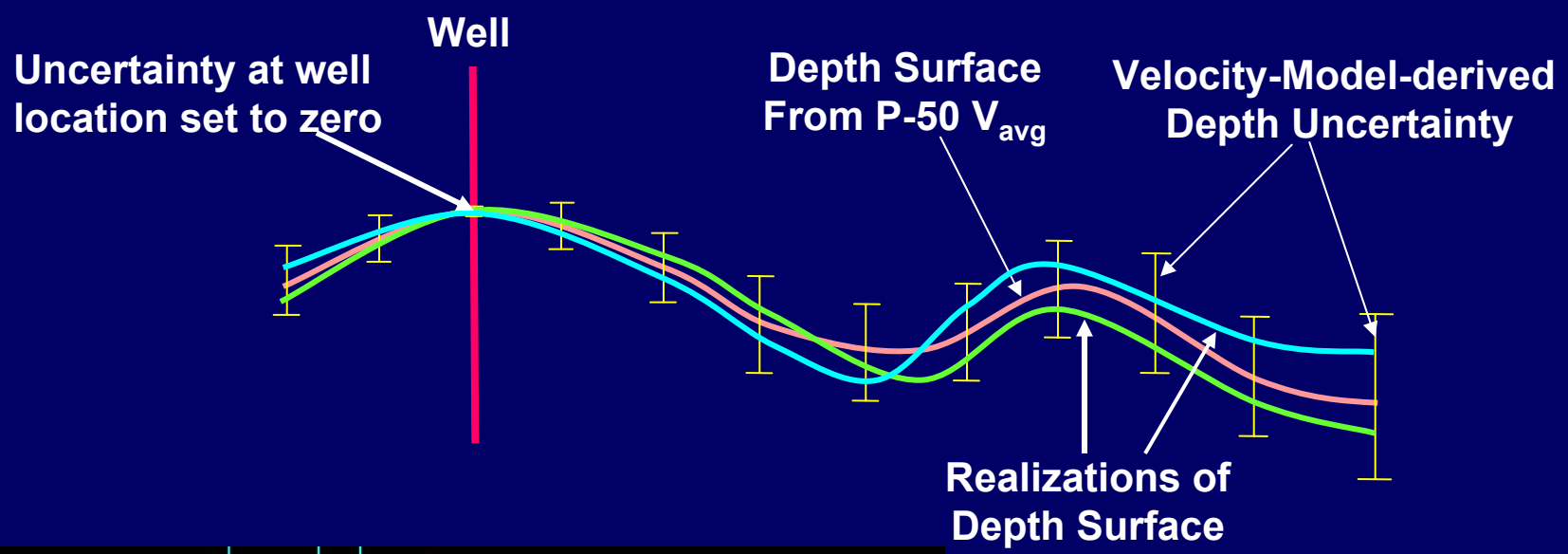
(after SPE 95528, 2005; *SPEREE*, June 2007)

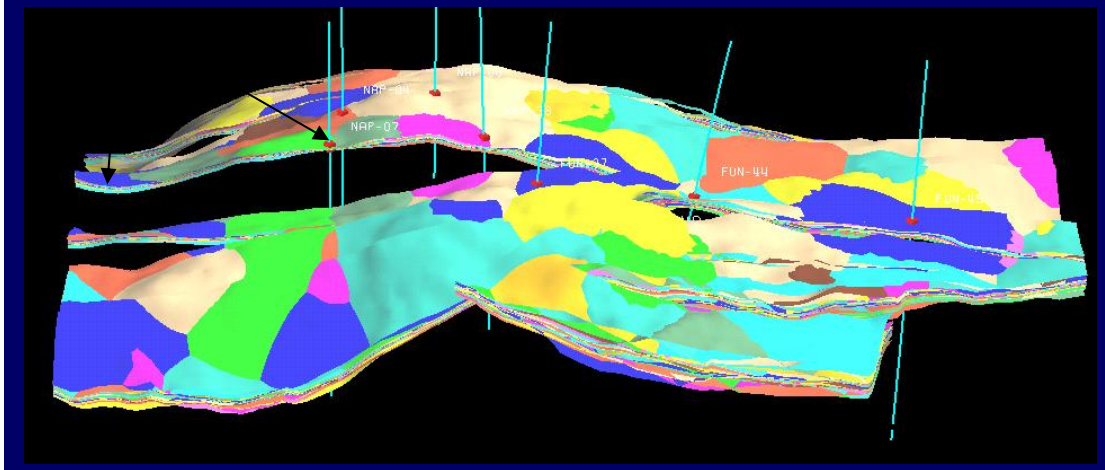
Deterministic NPV for Assessing Well Count



(after SPE 95528, 2005; *SPEREE*, June 2007)

Creating Multiple Depth Surfaces With Velocity Uncertainty

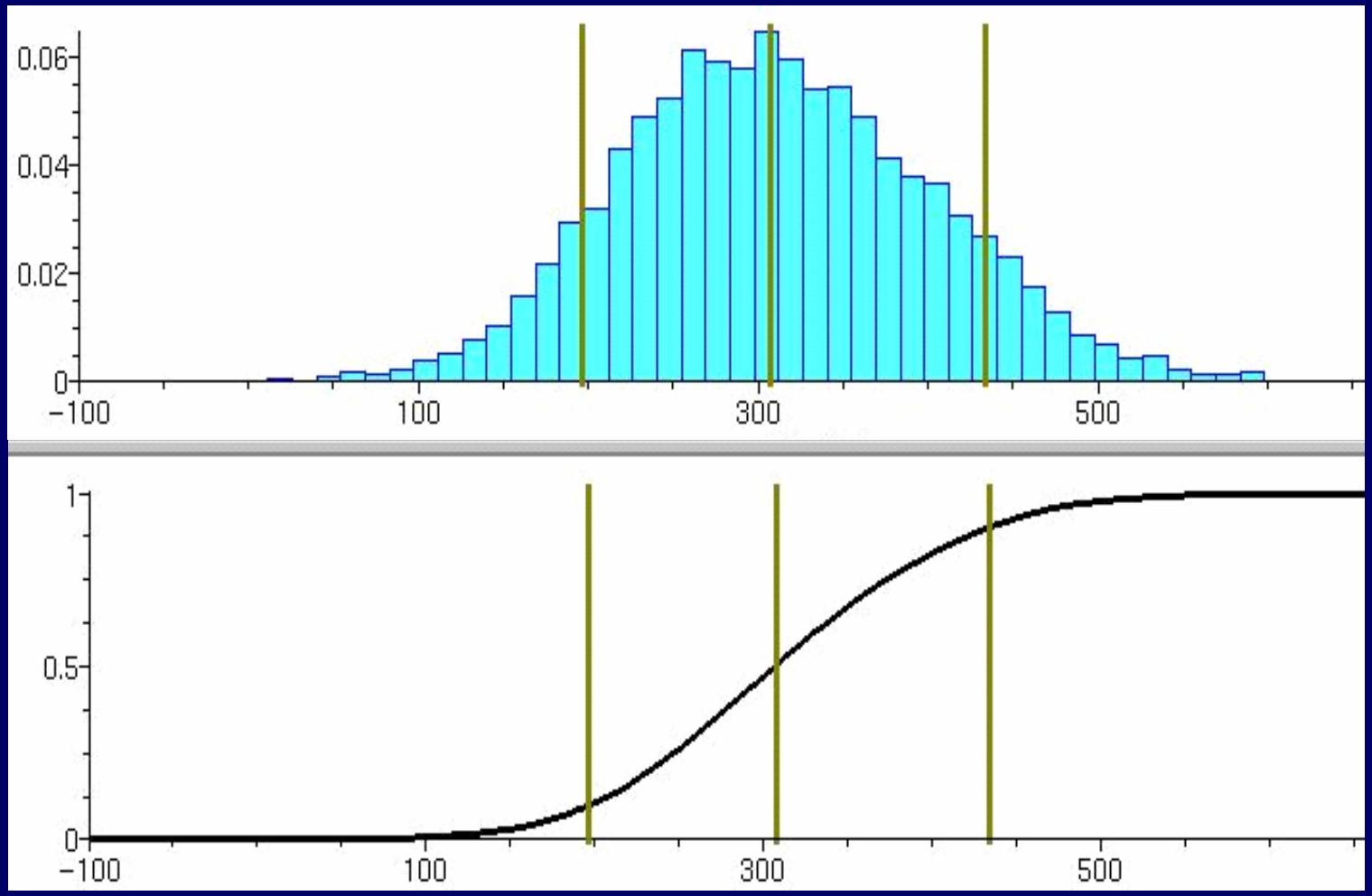




100 top depth surfaces of M-6 Sand

(after SPE 95528, 2005; *SPEREE*, June 2007)

Probability Distribution of OGIP in M-6 Sand

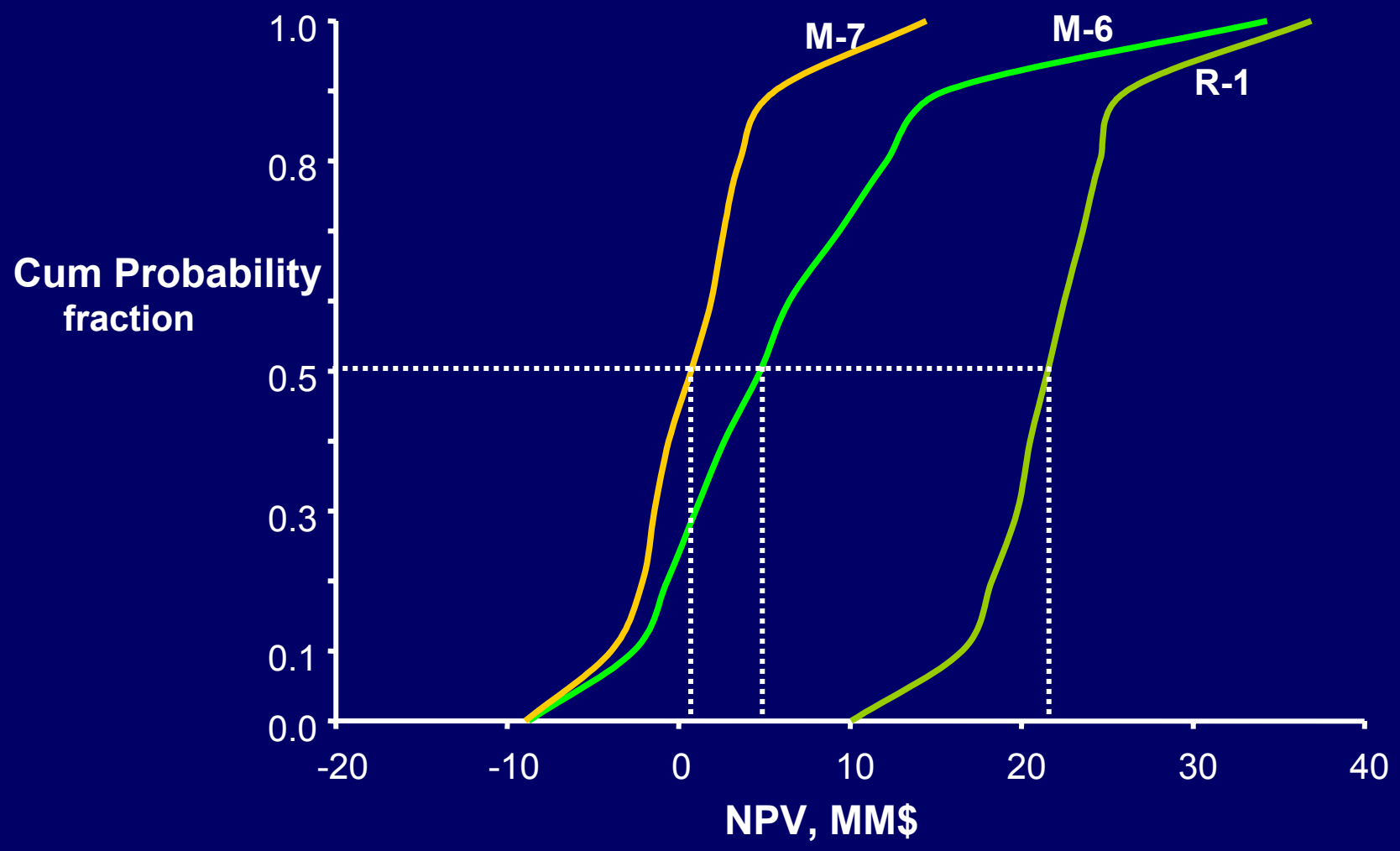


CDF

OGIP, Bscf

(after SPE 95528, 2005; *SPEREE*, June 2007)

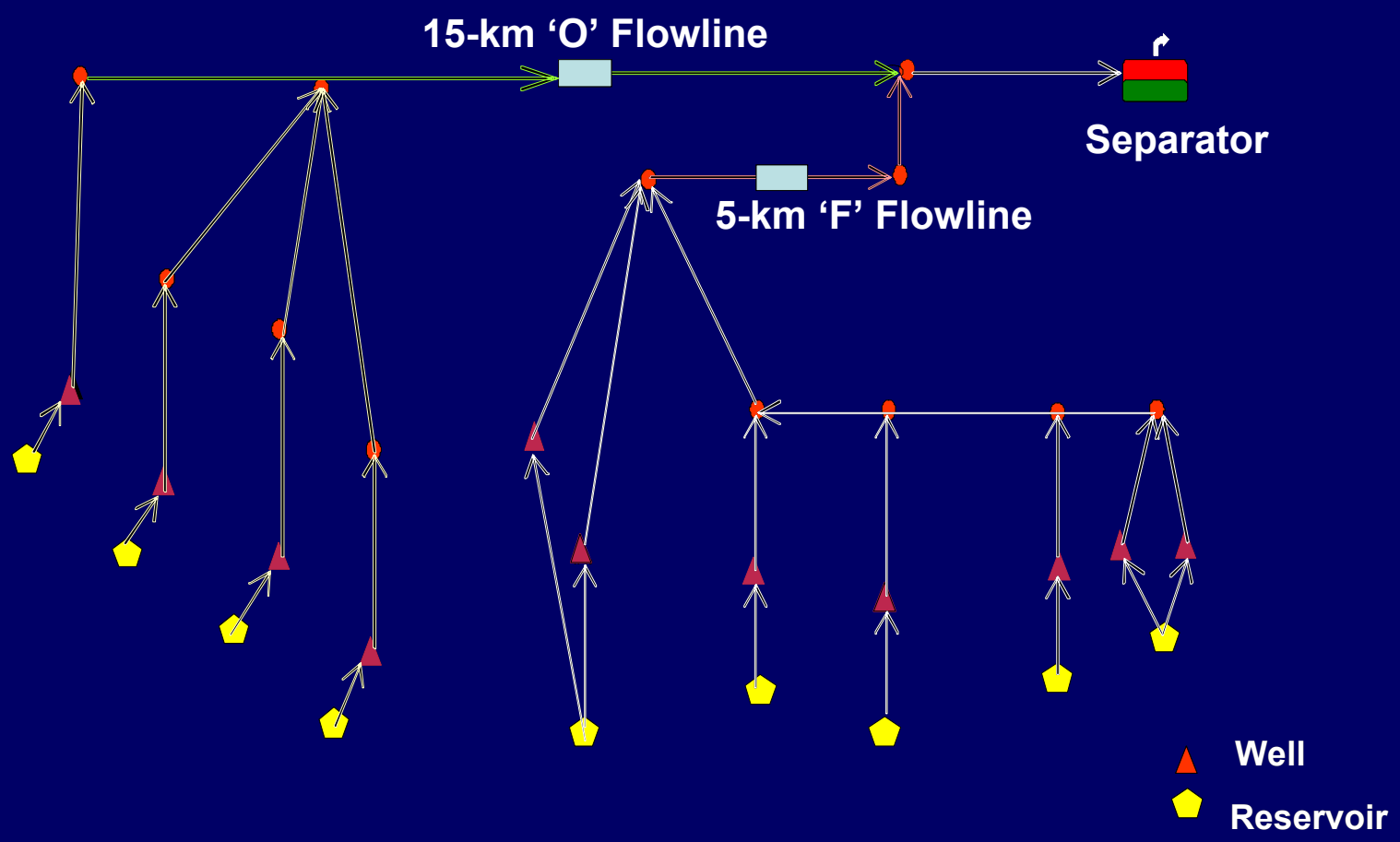
Probabilistic NPV for Each Reservoir



(after SPE 95528, 2005; *SPEREE*, June 2007)

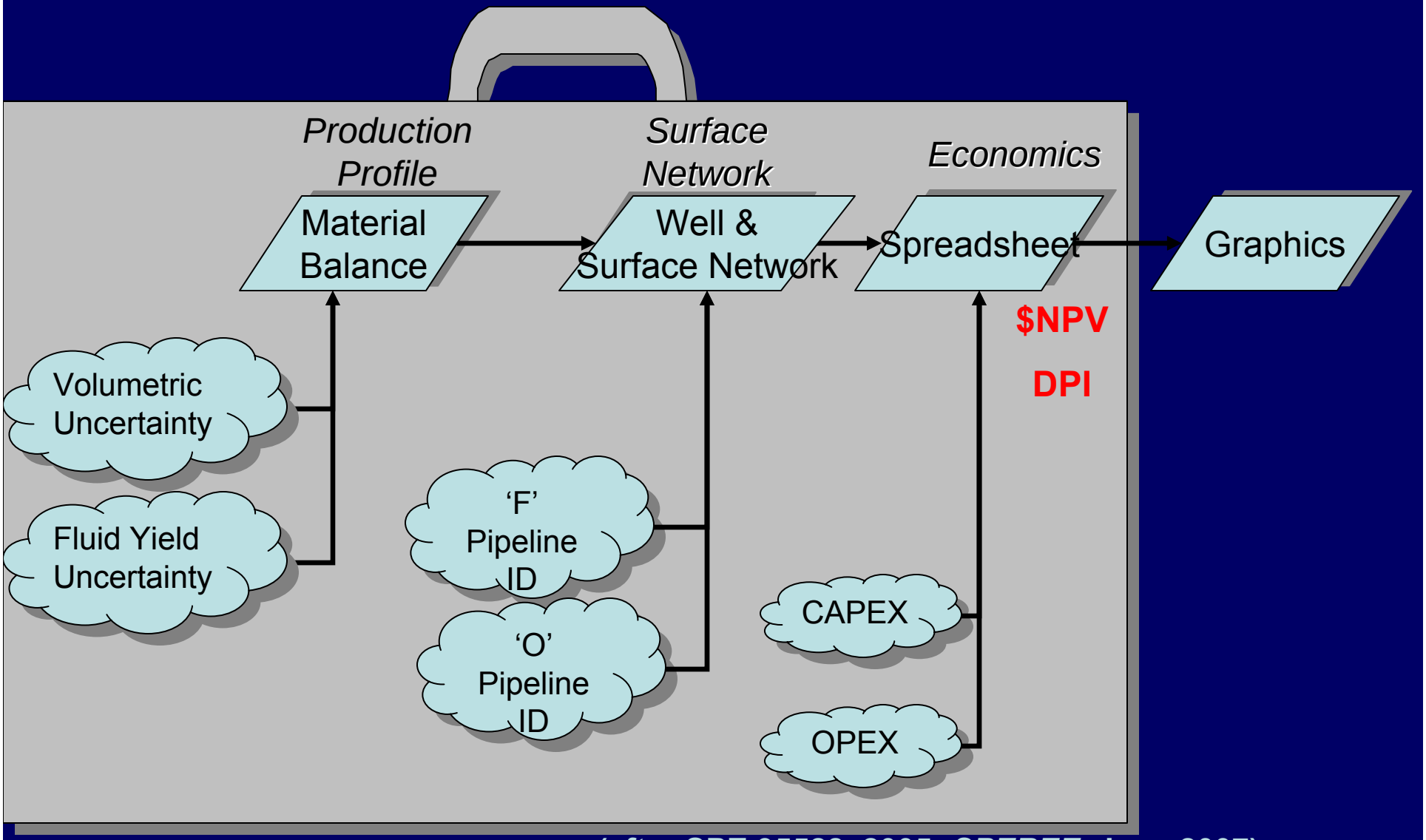
Modeling Multiple Reservoirs w/Uncertainties

Discerning Pipe ID



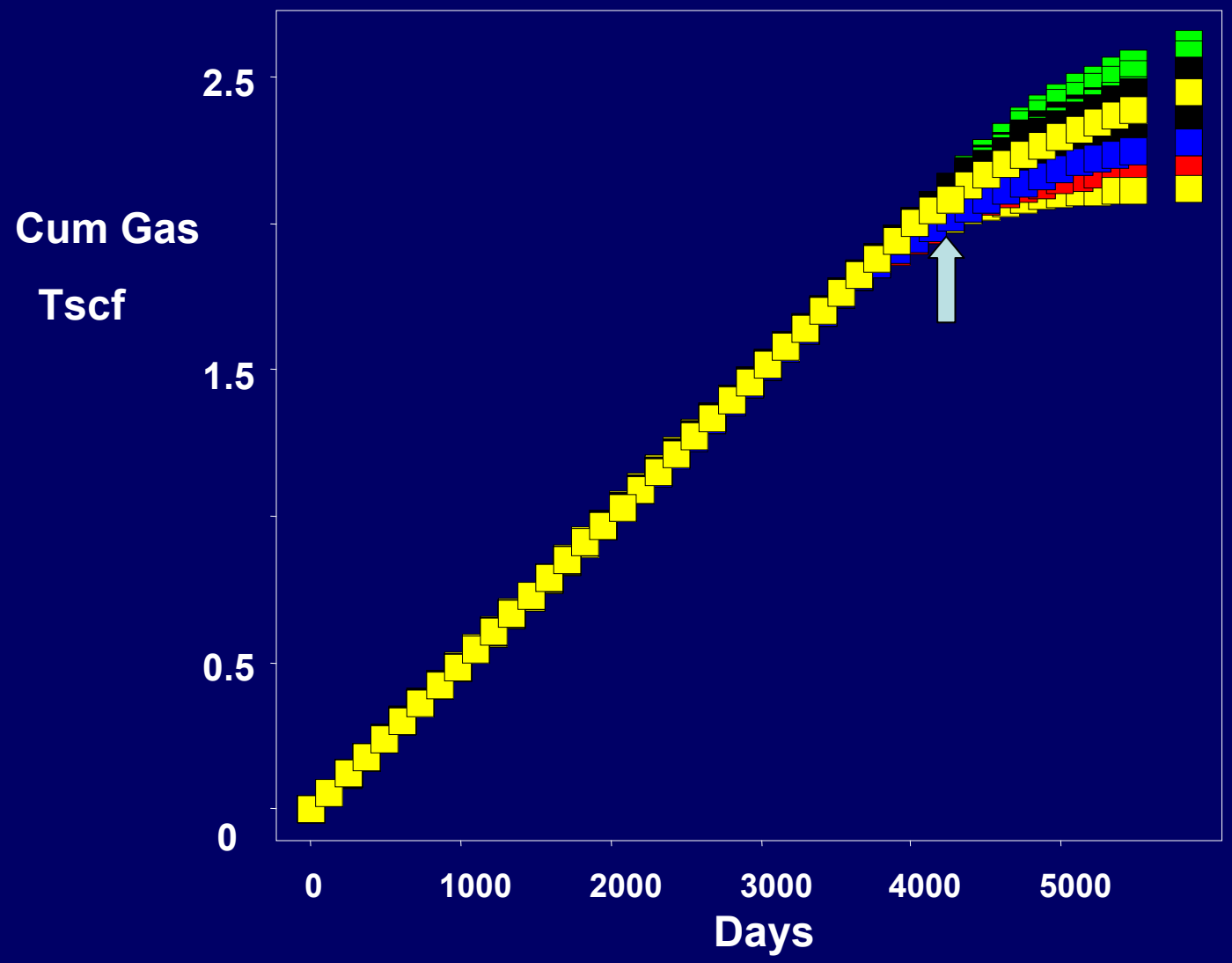
(after SPE 95528, 2005; *SPEREE*, June 2007)

Decision Management System



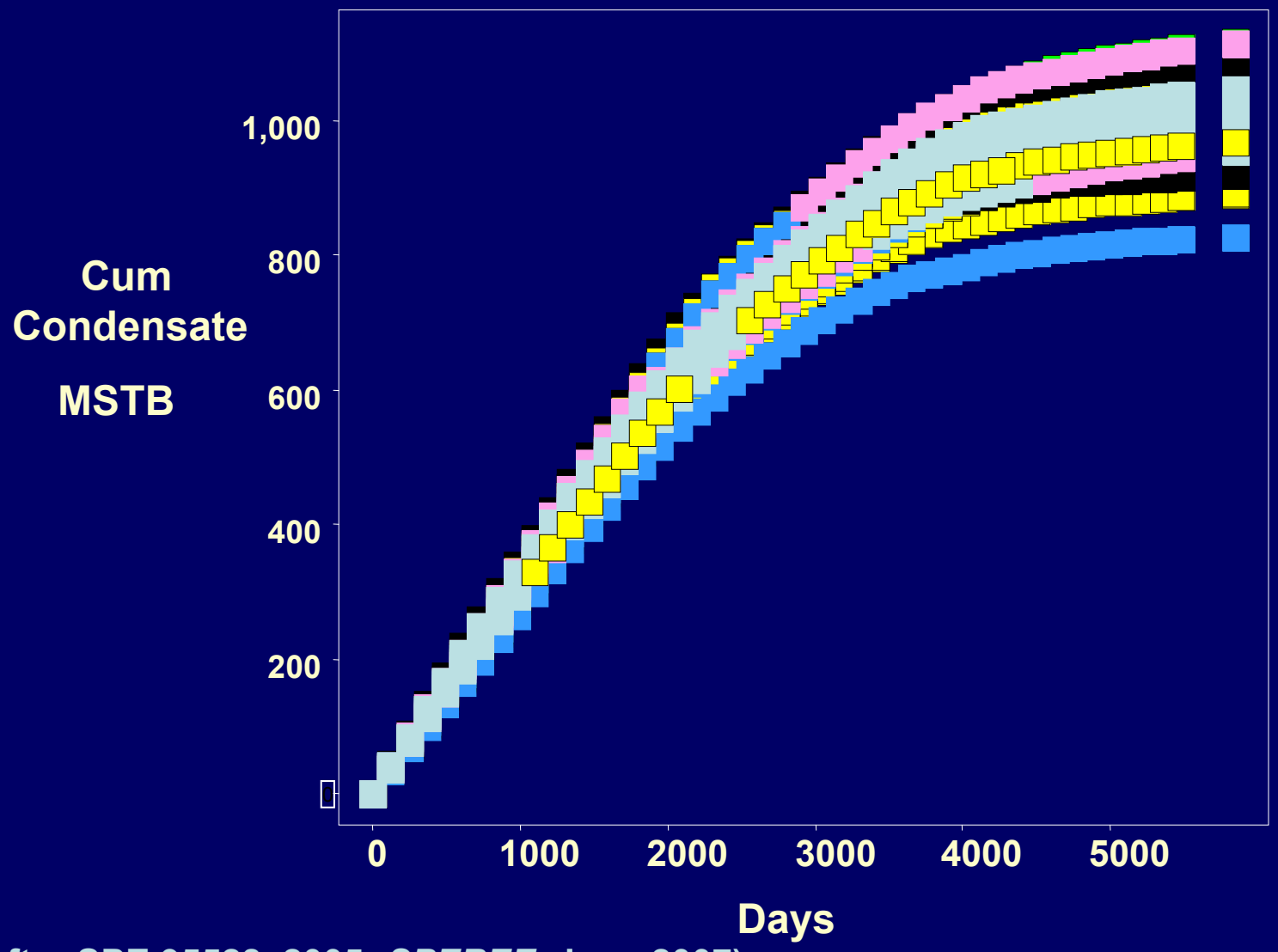
(after SPE 95528, 2005; *SPEREE*, June 2007)

Cum Gas Shows Delivery Certainty



(after SPE 95528, 2005; *SPEREE*, June 2007)

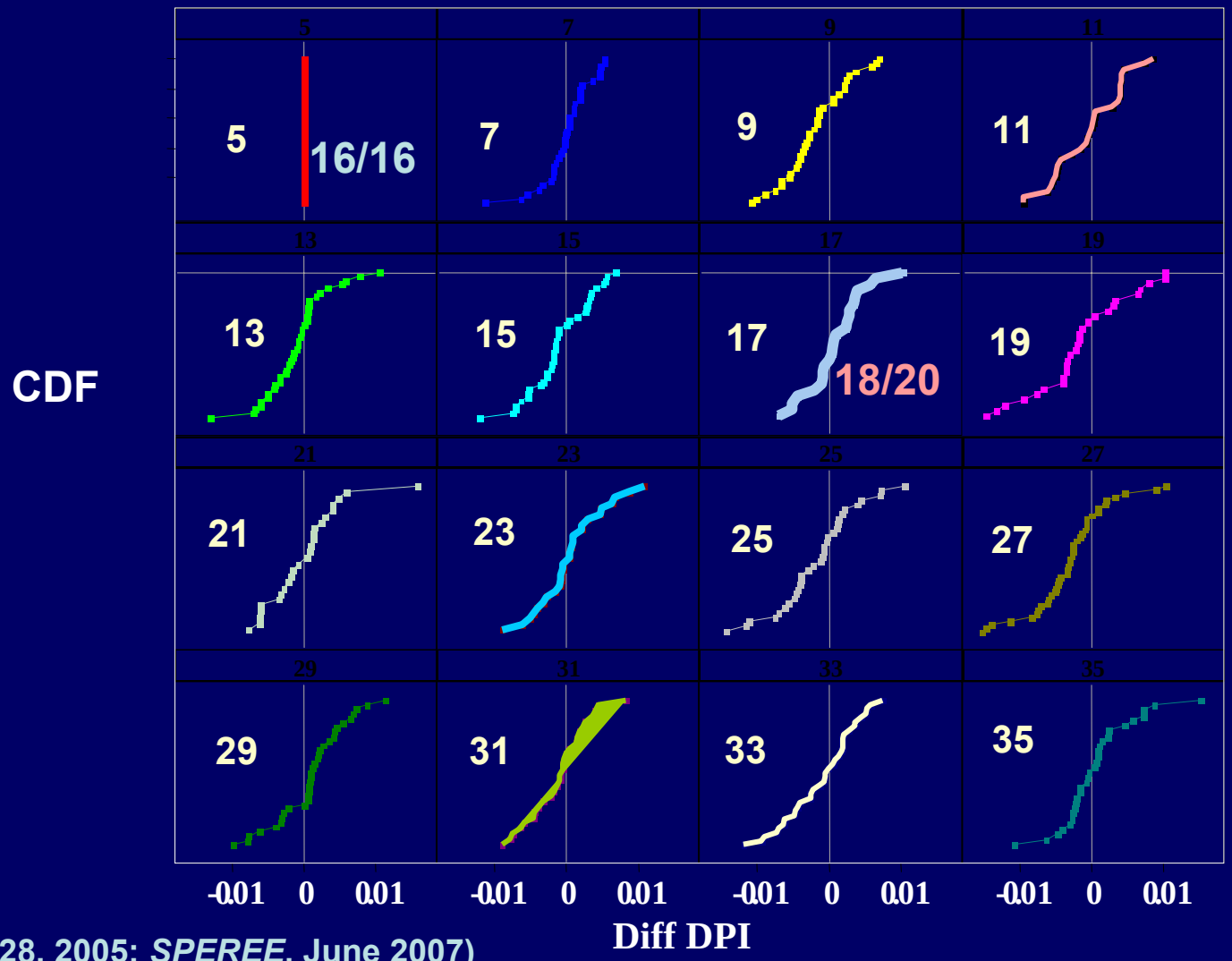
Cum Liquid Shows Uncertainty Spread



(after SPE 95528, 2005; *SPEREE*, June 2007)

CDF's of Various Pipe Combinations

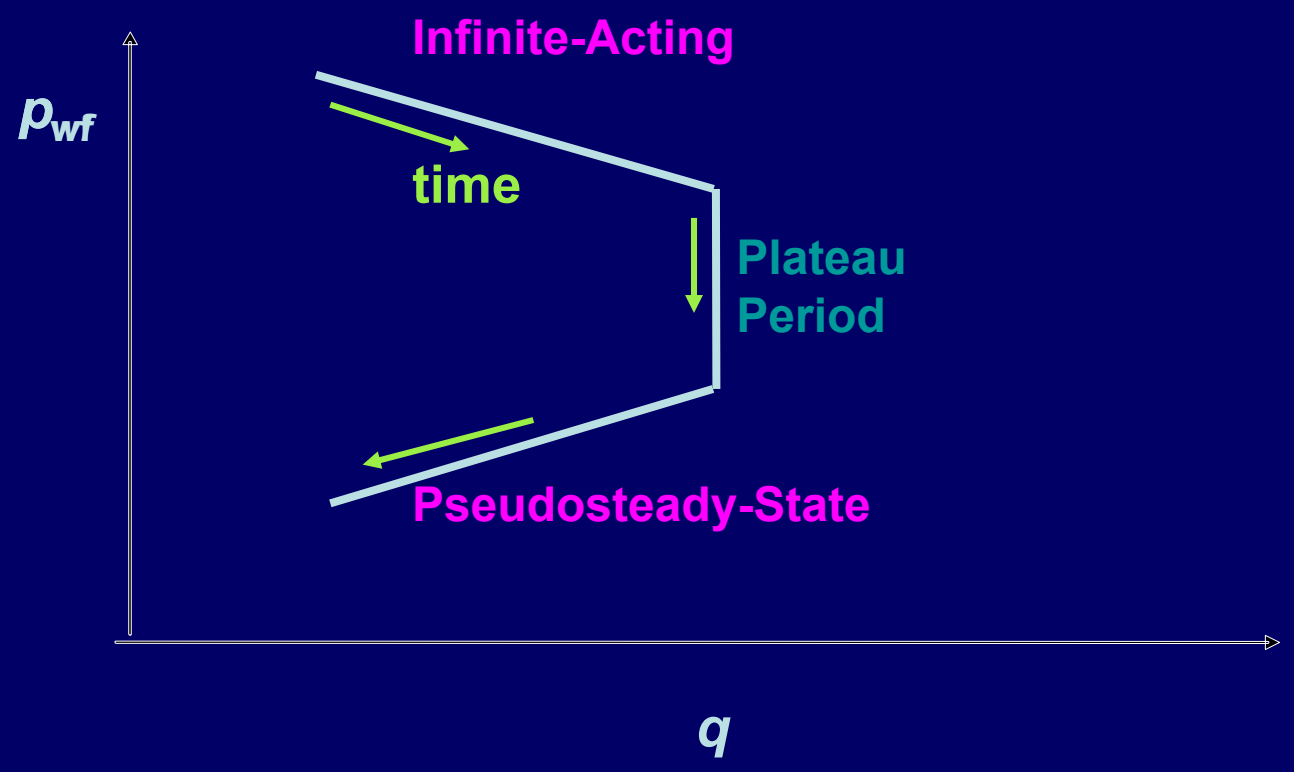
500 LH Sampling



(after SPE 95528, 2005; *SPEREE*, June 2007)

Assessing Reservoir Compartmentalization Issue

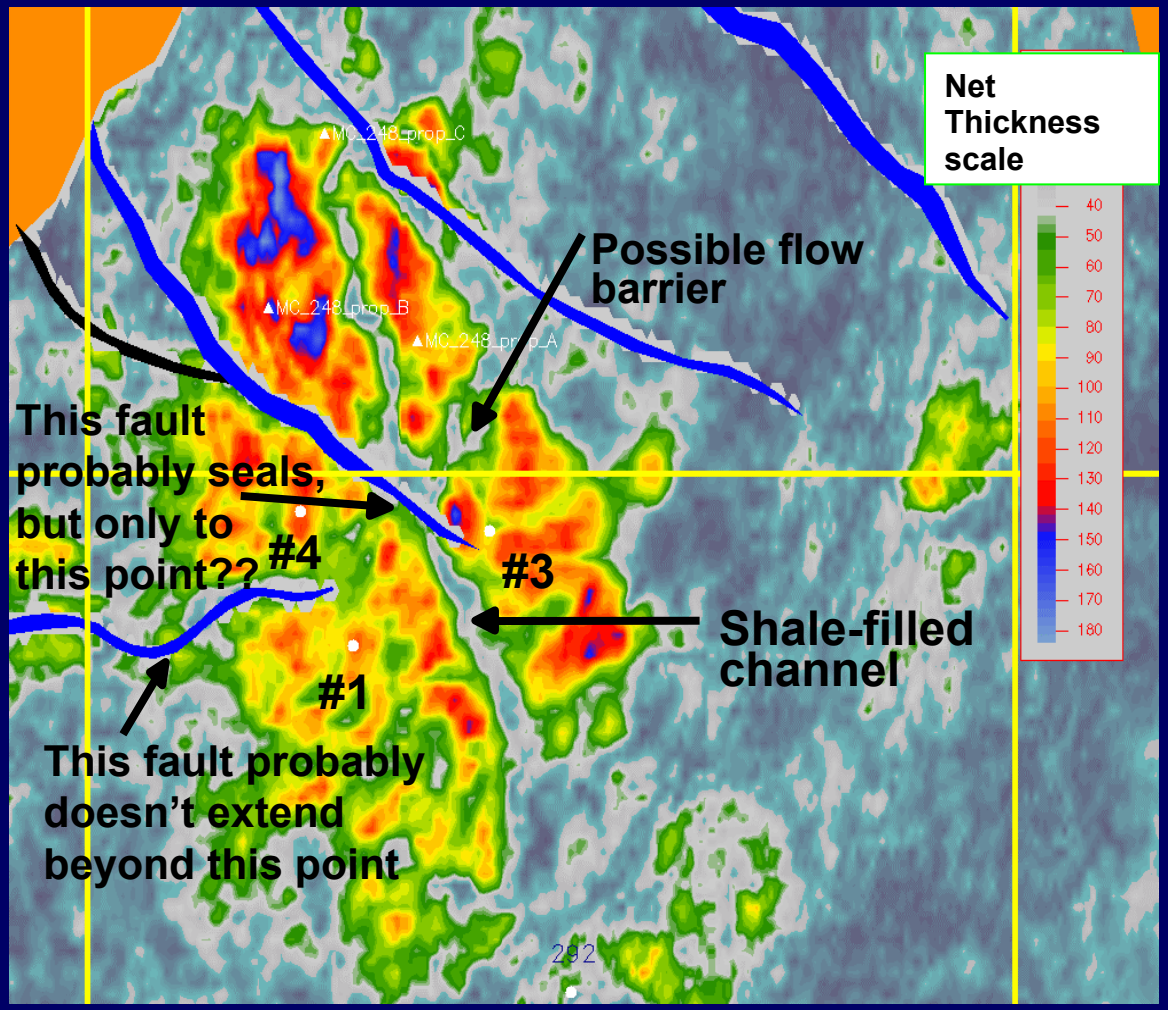
Diagnosing Reservoir Performance



(after SPE 100384, 2006)

Seismic Map Shows Barriers

Deepwater Gas/Condensate Field: FE–2

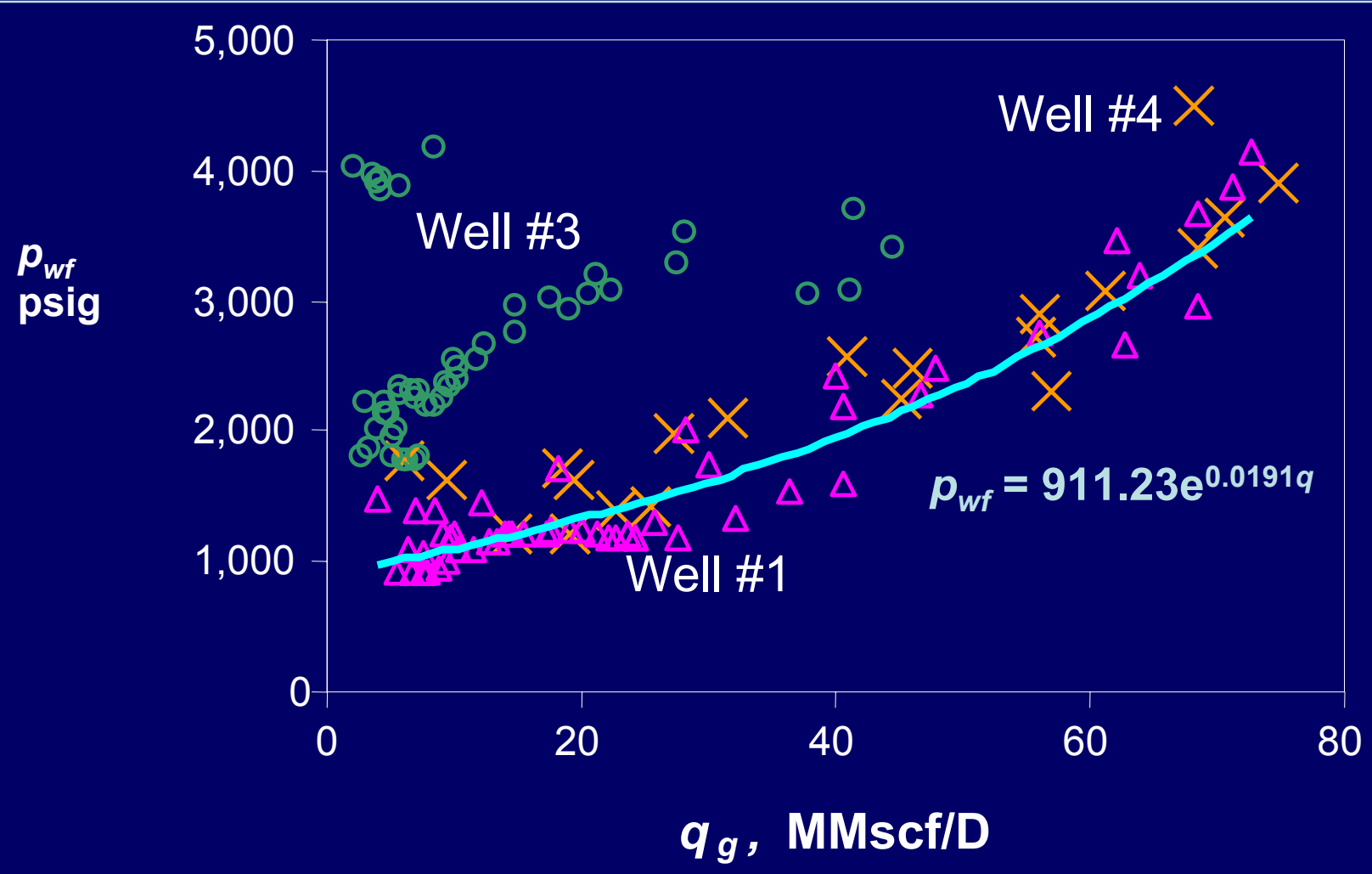


Are Wells #1 and #4 Separated From Well #3?

(after SPE 100384, 2006)

Compartments Evident From Well Behavior

Field Example–2



(after SPE 100384, 2006)

Concluding Remarks

- Need for Additional Wells Screened w/Unbiased Tool
- CRWS Modeling When Combined w/Economics Allows
  - > Handling Uncertainty in Many Variables
  - > Understanding Importance of Decision Variable
- Commingled Completion Feasible When Res Volumes Similar
- Reservoir Compartmentalization Question Answered by Monitoring Pressure and Rate