

Reserves Definitions & Estimation Techniques

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Reserves - Presentation Outline

- 1) **Definitions**
- 2) **Company's Process**
- 3) **Categories**
- 4) **Uncertainties**
- 5) **Estimation Process**
- 6) **Estimation Techniques**
- 7) **Calculation Example**

Reserves Definition – General

Hydrocarbon Reserves -

are the estimates of technically recoverable quantities of crude oil, natural gas and natural gas liquids from naturally occurring accumulations which have been delineated and characterized by a combined analysis of available geo-scientific data (geological, geophysical, petro-physical and reservoir engineering etc.). To be developed, reserves must be economically viable under the current and prevailing business environment. All reserves estimates involve some degree of uncertainty for which a reasonable assessment should be attempted.

Reserves Definition – By Reserves Category

•Proved Reserves -

Represents that portion of ultimate reserves which can be recovered with a high degree of certainty and/or a level of confidence based on actual or similar field performance (e.g. 80%) and using primary recovery, pressure maintenance and enhanced oil recovery (EOR) methods where their successes have already been demonstrated for that type of reservoir in that geological basin.

•Probable Reserves -

Represent that portion of additional reserves which can be recovered through a better than expected reservoir performance and/or reservoir engineering methods. Probable Reserves have a reasonable degree of certainty and/or confidence (e.g. 50%). Recovery and production methods are based on the same technology available for Proved Reserves.

•Possible Reserves -

Represent the ultimately recoverable resources which can be recovered with a relatively low degree of certainty and/or a minimal level of confidence (e.g. 15%). Possible Reserves represent the maximum ultimate recovery estimated for a known hydrocarbon accumulation once all testing, delineation and evaluation of this accumulation has been completed. Possible reserves are also incremental EOR Reserves not booked previously. Recovery and production methods are based on the same technology available for Proved Reserves.

Reserves Definition - SPE & SEC

•Reserves (SPE) -

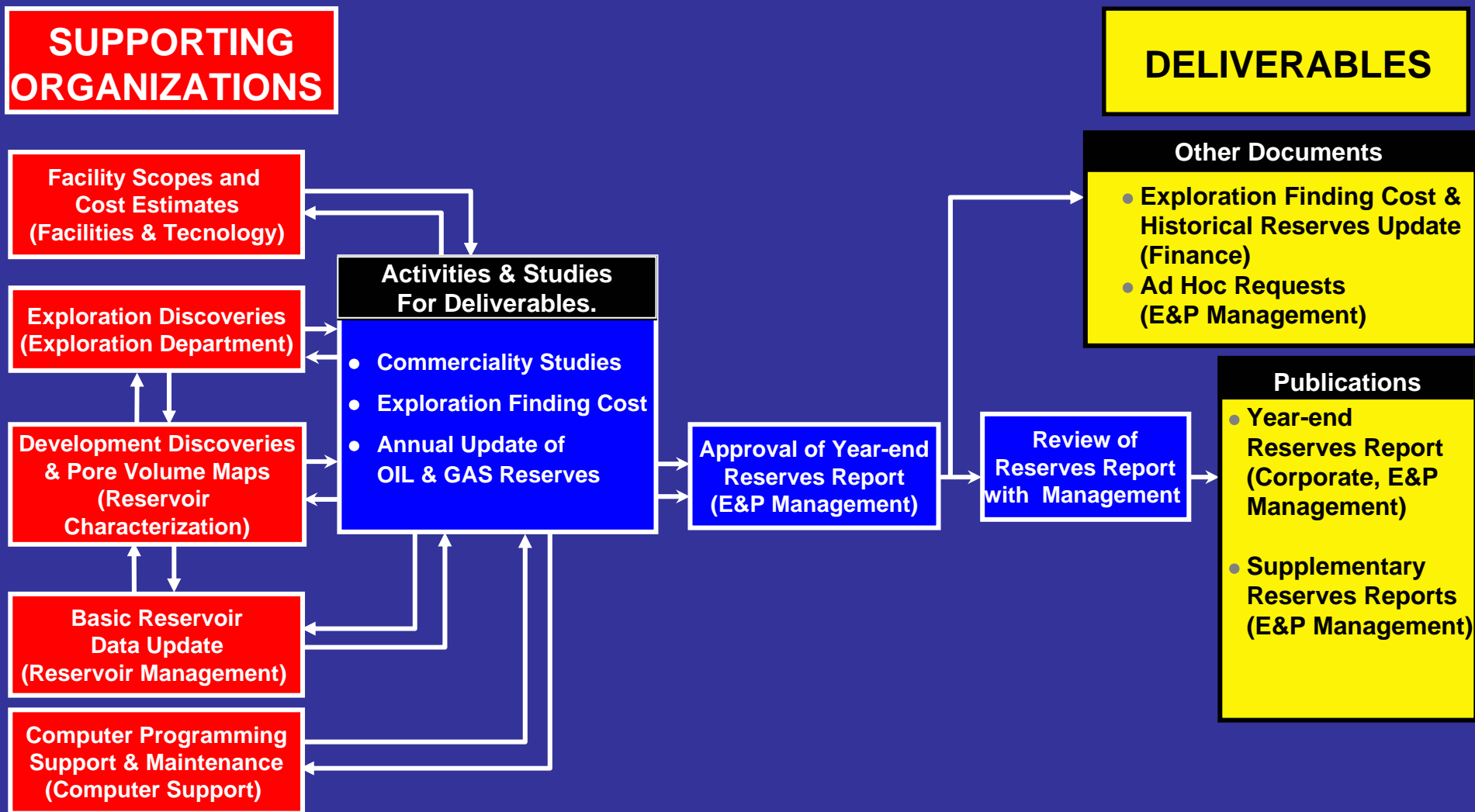
“Reserves are estimated volumes of crude oil, condensate, natural gas, natural gas liquids and associated substances/products anticipated to be commercially recoverable from known accumulations from a given date forward, under existing economic conditions, by established operating practices and under current government regulations. Reserve estimates are based on interpretation of geologic and/or engineering data available at the time of the estimate.”

•Reserves (SEC) -

“Proved Oil and Gas Reserves: Proved oil and gas reserves are the estimated quantities of crude oil, natural gas and natural gas liquids which geological and engineering data demonstrate with reasonable certainty to be recoverable in future years from known reservoirs under existing economic and operating conditions, i.e., prices and costs as of the date the estimate is made. Prices include consideration of changes in existing prices provided only by contractual arrangements, but not on escalations based upon future conditions.”

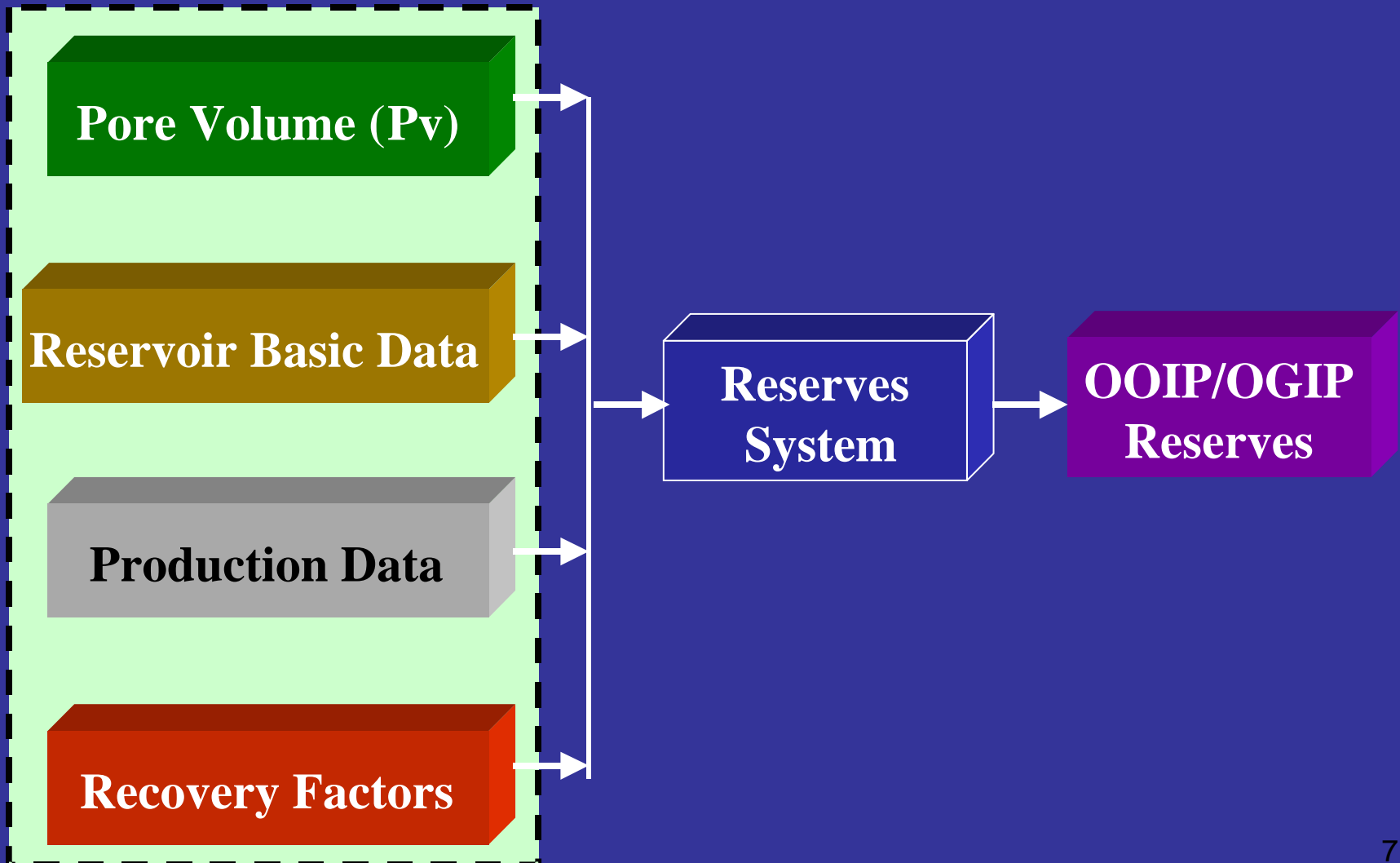
Reserves Determination / Estimation Process

A COMPANY'S OIL & GAS RESERVES



Summary of Reserves Inputs / Outputs

Input Parameters



Categorization of Reserves & Resources

	Resource Category	Degree of Geological Assurance and Engineering Certainty	Economic Feasibility
RESERVES	Proved Reserves	A high probability	Definite
	Probable Reserves	A moderated probability	Definite
	Possible Reserves	A low probability	Most Likely
RESOURCES	Potential Resources	Poor estimates of hydrocarbons in-place	Marginal or Undetermined (limited by data)
	Conceptual Resources	Well-defined or conceptual exploration leads in a <u>productive basin</u>	Undetermined (limited data)
	Speculative Resources	Exploration leads in an <u>untested basin</u>	Undetermined (lack of data)

Reserves Uncertainties & General Categories

- **Technical Uncertainty** -
Geological / Geophysical / Reservoir Engineering
- **Economic Uncertainty** -
Facilities Cost Estimates / Future Market Prices
- **Geopolitical Uncertainty** -
Fiscal Regime Change / Markets
- **General Categorizations** -
Based upon combination of technical / economic uncertainties and considerations:
 - Proved
 - Probable
 - Possible
 - Potential
 - Conceptual
 - Speculative

Reserves Estimation Process - Time Line

Development Stage

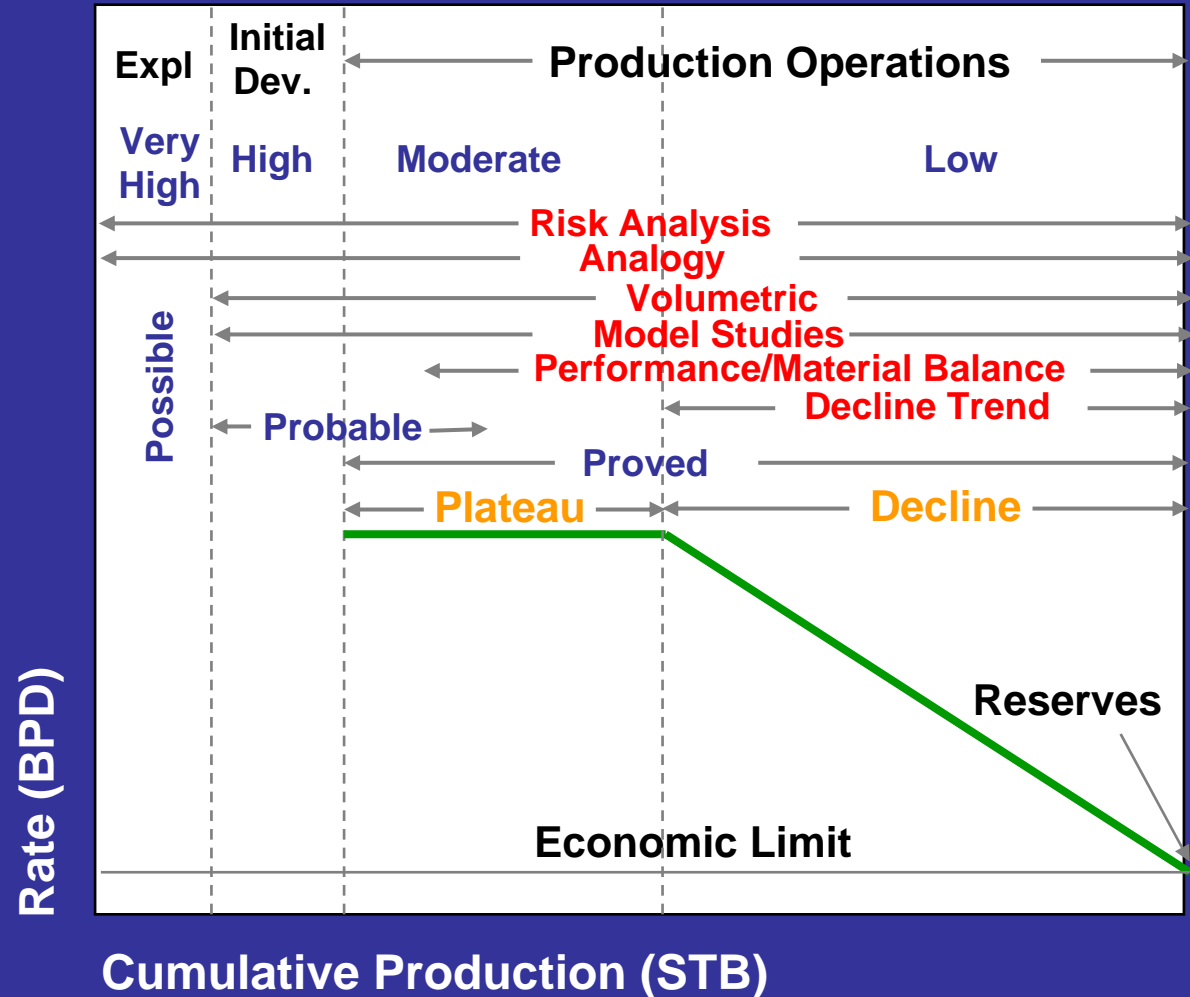
Risk

Reserves Estimation
Methods / Techniques

Reserves Type

Depletion Stage

Production Profile



Reserves Estimation Techniques

- **Risk Considerations**
- **Volumetric**
 - Deterministic
 - Stochastic
- **Reservoir Analogy**
- **Material Balance Computations**
- **Decline Curve Analysis**

Reserves Estimation – Risk Considerations

Geologic Risk and Uncertainty -

Geologic uncertainty depends upon four mutually exclusive variables:

- Presence of Mature Source Rock (Ps)
- Present of Reservoir Rock (Pr)
- Presence of Hydrocarbon Trap (Pt)
- Structural / Migration Dynamics (Pd)

The risk associated with Geologic Uncertainty (Pg) can be assessed by these four mutually exclusive factors:

$$P_g = P_s * P_r * P_t * P_d$$

Qualitatively:

- 0.0 < Pg < 0.3 => Unfavorable
- 0.3 < Pg < 0.5 => Questionable
- 0.5 < Pg < 0.7 => Encouraging
- 0.7 < Pg < 1.0 => Favorable

Reserves Estimation – Risk Considerations

Engineering Risk and Uncertainty -

depends mainly on the amount and quality of geo-scientific / reservoir engineering data and is also affected by geological complexity, stage of development and degree of reservoir depletion.

Economic Risk and Uncertainty -

- Oil Prices
- Development & Production Cost (CAPEX & OPEX)
- Taxes and Royalties

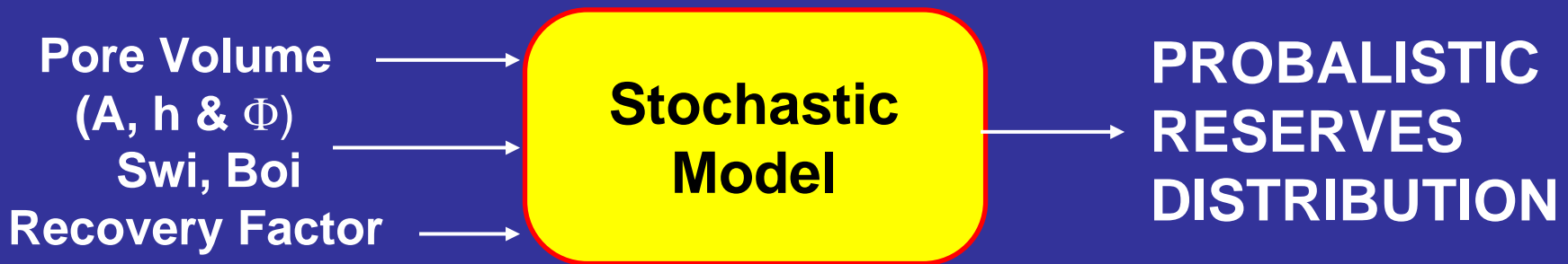
Geo-Political Risk and Uncertainty -

is highly dependent upon the locale

Deterministic Reserves – Stochastic Reserves



Deterministic: Each INPUT and OUTPUT is determined as a single numerical value (usually average reservoir parameter values) and a single reserves number (i.e. an average) is derived.



Stochastic: Each INPUT and OUTPUT parameter is assumed to be a random variable and can be represented by a probability distribution curve by use of Monte Carlo or Latin Hypercube simulation.

Deterministic Reserves – Volumetric Equation

•Volumetric Reserves Equation (Oil) -

$$\text{OOIP} = A h \Phi (1 - S_{wi}) / B_{oi} = \text{Pore Volume } (1 - S_{wi}) / B_{oi}$$

Reserves = OOIP (STB) x Recovery Factor (fraction)

•Recovery Factor or Efficiency -

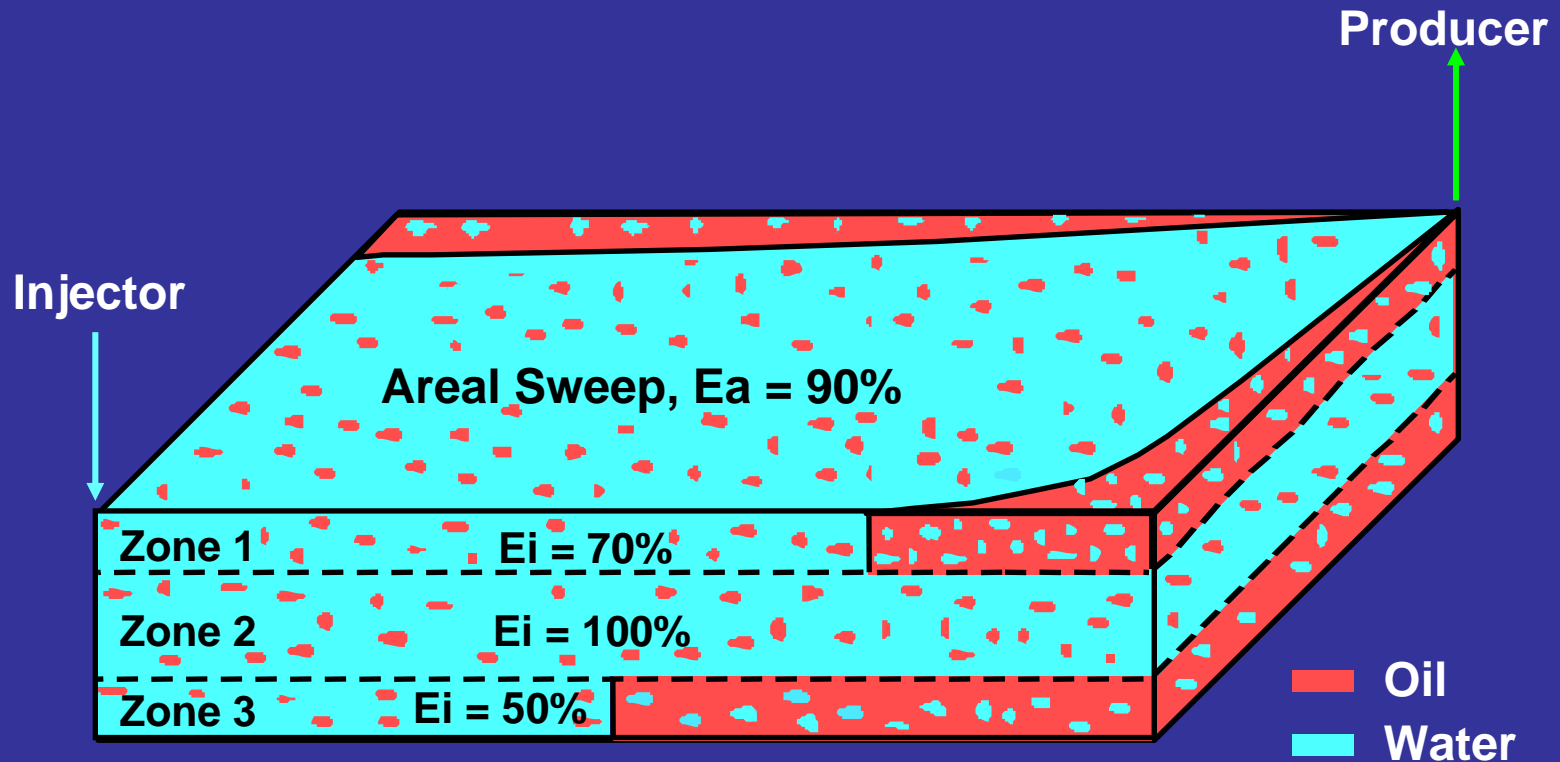
$$\text{Recovery Factor} = \text{Displacement Efficiency (} E_d \text{)} \times$$
$$\text{Vertical Sweep Efficiency (} E_i \text{)} \times$$
$$\text{Areal Sweep Efficiency (} E_a \text{)}$$

where:

Displacement Efficiency,	$E_d = (S_{oi} - S_{or}) / S_{oi}$
Volumetric Sweep Efficiency,	$E_v = E_i \times E_a$

Deterministic Reserves – Sweep Efficiency

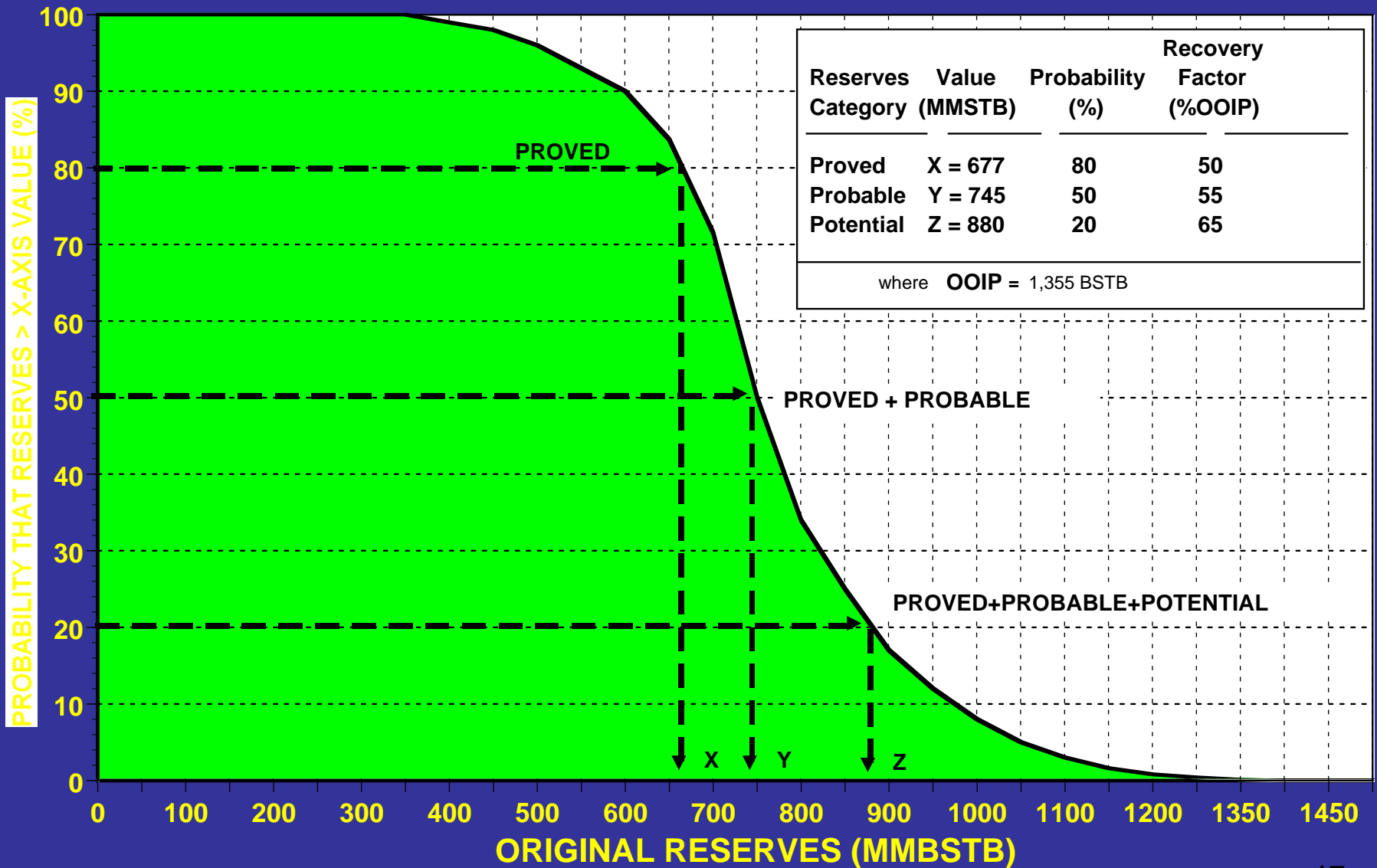
Illustration of Water Flood Displacement Efficiency



Vertical Sweep Efficiency: $E_i = 0.25 \times 0.70 + 0.5 \times 1.0 + 0.25 \times 0.5 = 0.80$ or 80%

Volumetric Sweep Efficiency: $E_v = E_i \times E_a = 0.80 \times 0.90 = 0.72$ or 72%

Stochastic Reserves – Probability Distribution



Reserves Estimation – Field/Reservoir Analogy

Field / Reservoir Analogy -

For undeveloped reservoirs without detailed reservoir engineering studies but with minimal geological / geophysical and petro-physical data then correlations established from model results and/or production histories of adjacent and/or similar fields within the geological basin may be used to estimate recovery factors and reserves.

Example Field / Reservoir Correlations -

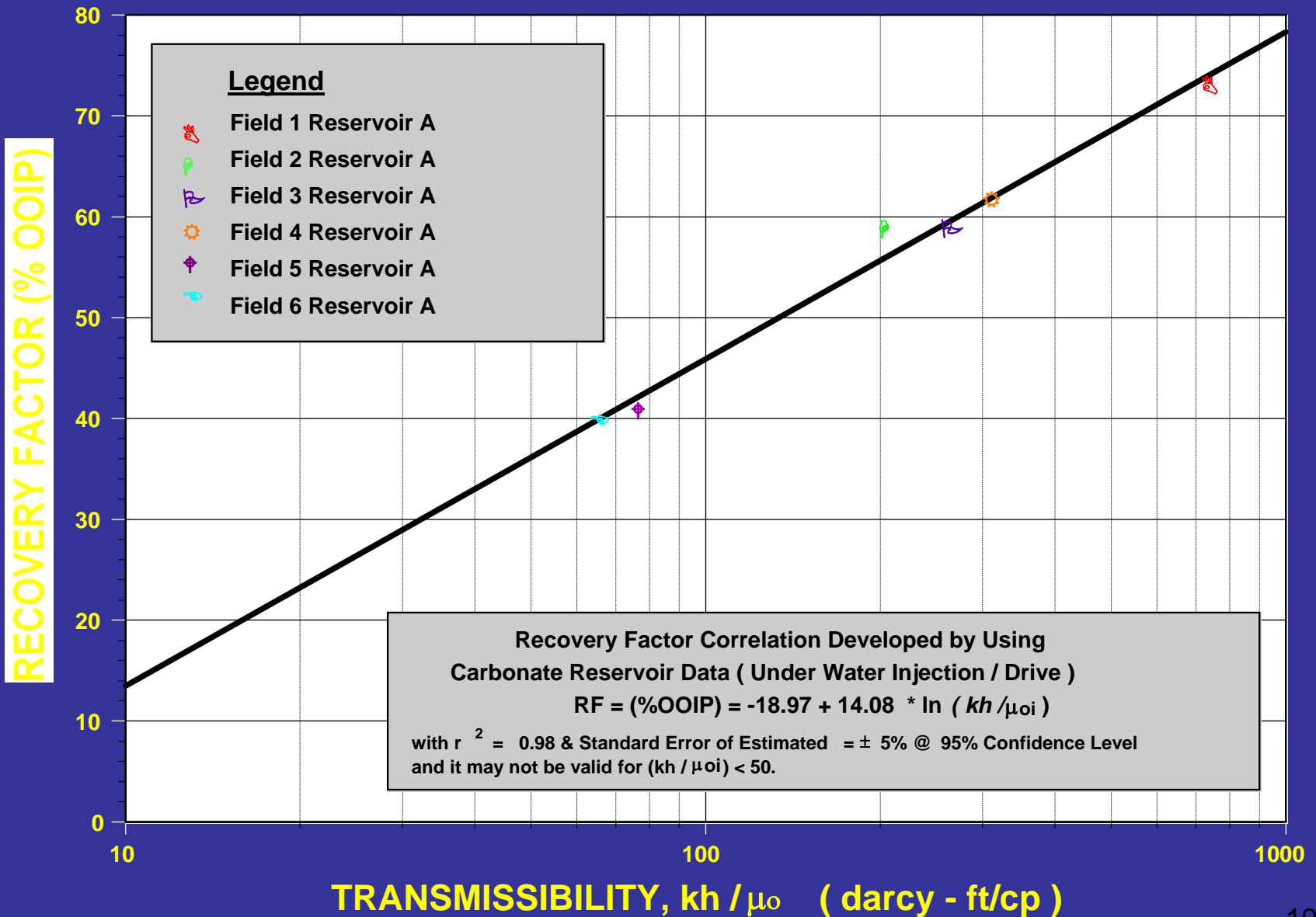
Reservoir Analogy: (data shown in graphical form follows)

$$RF = (\% OOIP) = -18.97 + 14.08 * LN (kh / \mu_{oi})$$

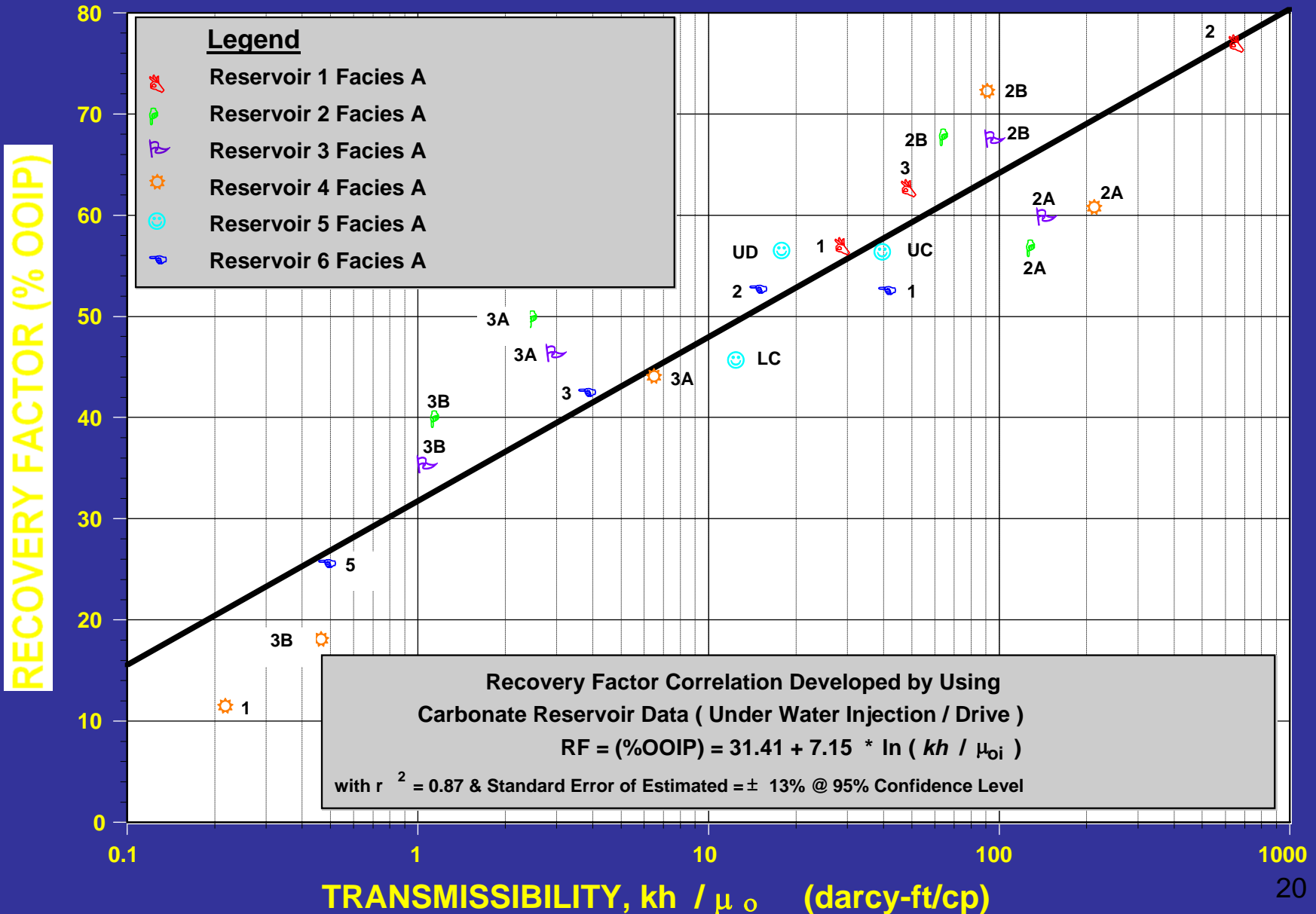
Facies Analogy: (data shown in graphical form follows)

$$RF = (\% OOIP) = +31.41 + 7.15 * LN (kh / \mu_{oi})$$

Recovery Factor vs. Reservoir Transmissibility



Recovery Factor vs. Reservoir Transmissibility



API Correlations – Field / Reservoir Analogy

1. Water Drive Reservoirs (70 Sandstone Fields – c. 1867 API)

$$RE(\% OOIP) = 54.898 * \left[\frac{\phi(1 - S_{wi})}{B_{oi}} \right]^{0.0422} * \left[\frac{K\mu_{wi}}{\mu_{oi}} \right]^{0.0770} * (S_{wi})^{-0.1903} * \left(\frac{P_i}{P_a} \right)^{-0.2159}$$

with $r^2 = 0.92$ & Standard Error of Estimate = $\pm 32\%$ @ 95% Confidence Level.

2. Solution Gas Drive Reservoirs (Sandstones and Carbonates - 80 Reservoirs with 13 on Carbonates c. 1967 API)

$$RE(\% OOIP) = 41.815 * \left[\frac{\phi(1 - S_{wi})}{B_{ob}} \right]^{0.1611} * \left[\frac{K}{\mu_{ob}} \right]^{0.0979} * (S_{wi})^{0.3722} * \left(\frac{P_b}{P_a} \right)^{0.1741}$$

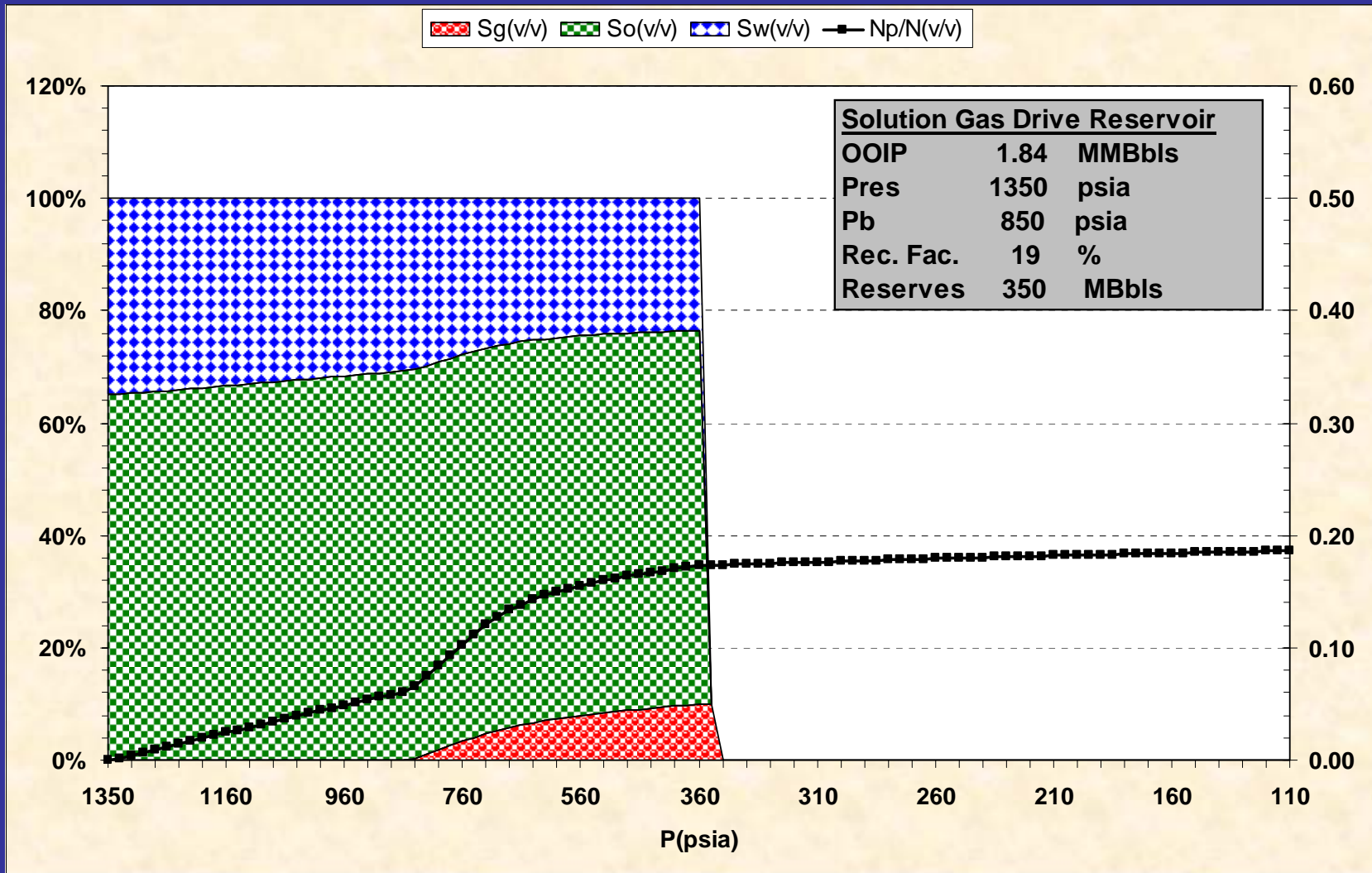
with $r^2 = 0.87$ & Standard Error of Estimate = $\pm 40\%$ @ 95% Confidence Level.

3. Water Drive Reservoirs (Carbonates - 19 Reservoirs - c. 1983)

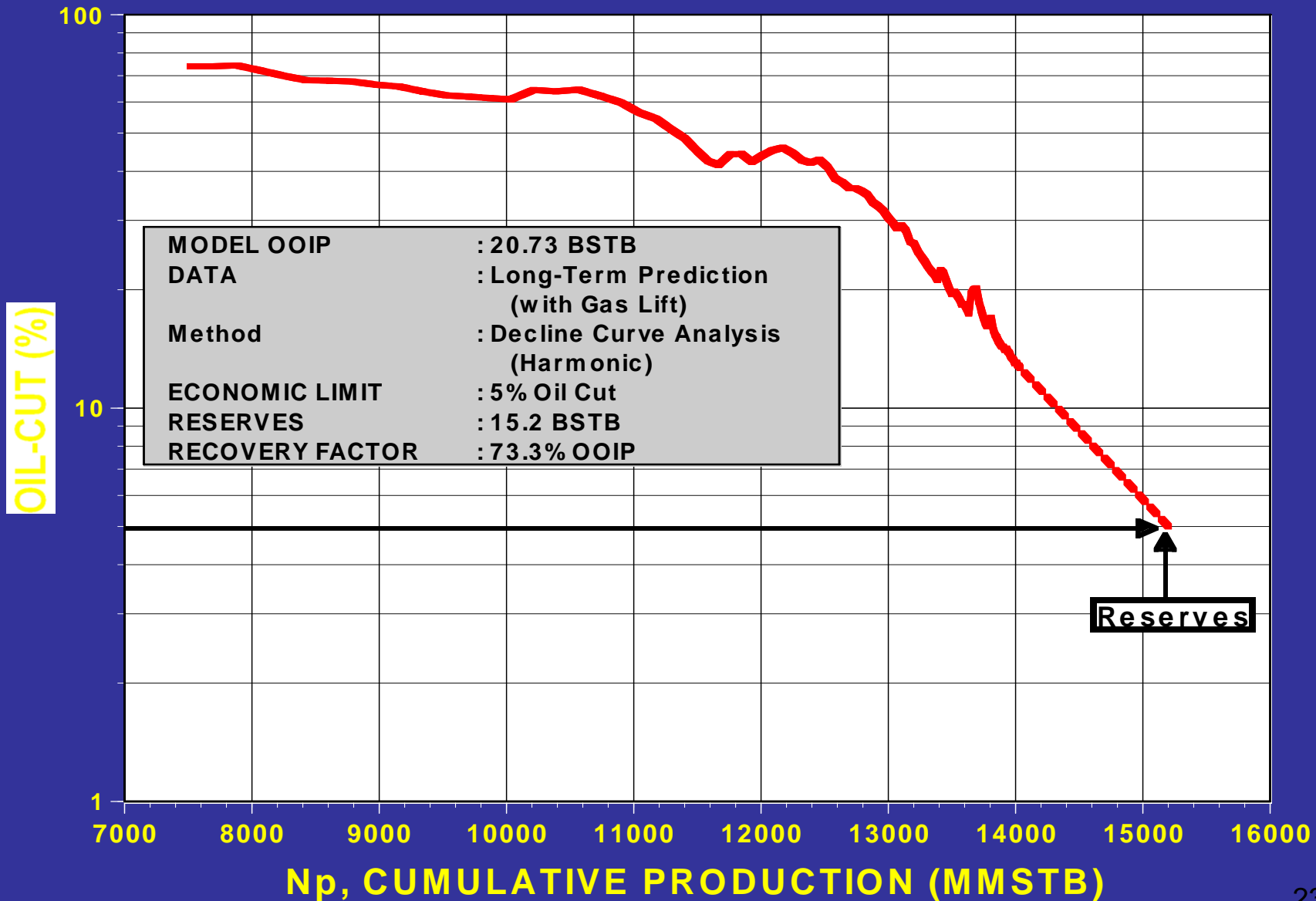
$$RE(\% OOIP) = 52.70 * \left[\frac{\phi(1 - S_{wi})}{B_{oi}} \right]^{0.4068} * \left[\frac{K\mu_{oi}}{\mu_{wi}} \right]^{0.0337} * (S_{wi})^{-0.04096}$$

with $r^2 = 0.58$ & Standard Error of Estimate = $\pm 20\%$ @ 95% Confidence Level.

Recovery Factor (Primary) – Material Balance



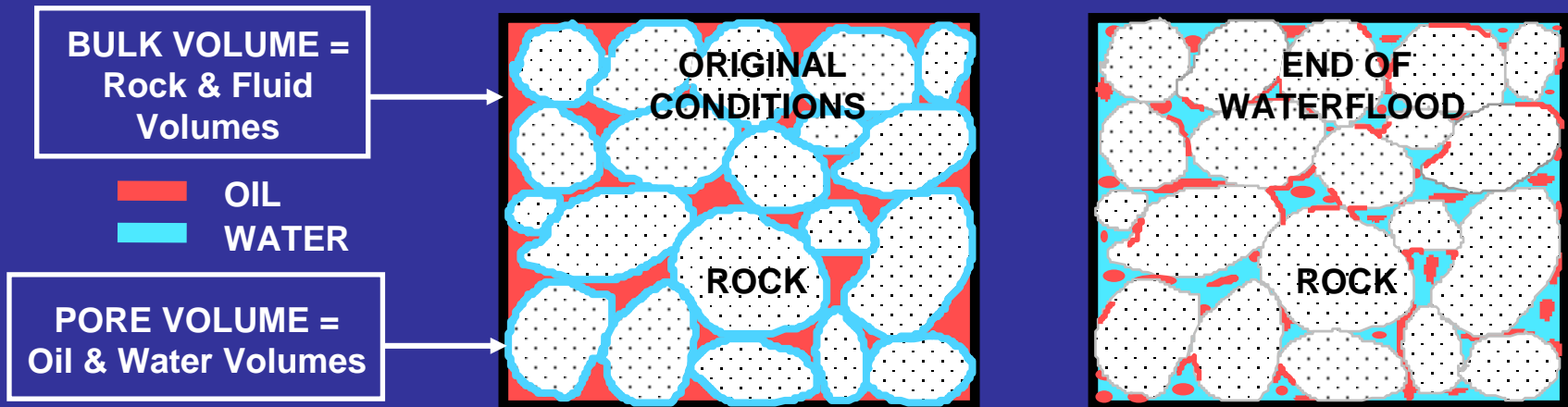
Deterministic Reserves – Decline Curve Analysis



Calculation of Oil In Place - Example

Step 1: Calculate Original Oil In Place –

$$\text{OOIP} = \text{Pore Volume} \times \text{Oil Saturation} \times \text{Oil Shrinkage} = \text{Oil Volume} \times \text{Oil Shrinkage}$$



EXAMPLE

Bulk Volume BV (MM Barrels)	100 (assumed)	100
Rock Volume RV (MM Barrels)	80	80
Pore Volume PV (% BV=Porosity)	20 %	20 %
Pore Volume (MM Barrels)	20	20
Water Volume (% PV=Water Saturation)	15 %	70 %
Water Volume (MM Barrels)	3	14
Oil Volume (% PV=Oil Saturation)	85 % (initial)	30 % (residual)
Oil Volume (MM Barrels)	17	6
Oil Gravity (API)	36 °API	36 °API
Oil Shrinkage (Fraction)	0.67	0.67
OOIP (MM Stock Tank Barrels)	11	4 (EOR) ³⁴

Calculation of Recovery Factor and Reserves

Step 2: Calculate Recovery Factor and Reserves –

OIL RESERVES = OOIP (barrels) x Recovery Factor (fraction)

Recovery Factor = Displacement Efficiency (E_d) x
Volumetric Sweep Efficiency (E_v)

E_d = $(S_{oi} - S_{or}) / S_{oi}$ or
= (Original Oil Vol. – Remaining Oil Vol.) / Original Oil Volume
= $(0.85 - 0.30) / 0.85$ or $(17 - 6) / 17 = 0.65$ or 65% OOIP

E_v = Vertical Sweep Efficiency x Areal Sweep Efficiency
= $0.80 \times 0.90 = 0.72$ or 72% (see illustration of water flood figure)

Recovery Factor = $0.65 \times 0.72 = 0.47$ or 47% OOIP

OIL RESERVES = $(11 \times 0.47) = 5$ MM Stock Tank Barrels

Summary of Example Calculation:

VOLUME	:	Bulk	Pore	OOIP	Reserves
MM BBL	:	100	20	11	5

- Thank You