SOCIETY OF PETROLEUM EVALUATION ENGINEERS

Applied Probabilistic Reserves and Economics Calculations

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Introduction

- SEC disclosure regulations allow for deterministic or probabilistic reserve estimates.
- The regulations in effect for filings after January 1, 2010 allow for the disclosure of probable and possible reserves in addition to proved reserves.
- Presumably, we could now disclose
  - Developed Producing Proved Reserves
  - Developed Producing Probable Reserves
  - Developed Producing Possible Reserves
  - Along with undeveloped Reserves in the same categories
- Presumably, we could do this using deterministic or probabilistic methods.

SEC and SPE/// PRMS

- "Many of the definitions [in Rule 4–10 of Regulation S–X] are designed to be consistent with the Petroleum Resource Management System (PRMS)."
  - » **SEC, Federal Register** / Vol. 74, No. 9 / Wednesday, January 14, 2009 / Rules and Regulations
- "PRMS is designed to help a company manage its reserve base; it is not designed to be used for regulatory reporting."
  - » Paraphrase of statement by John Etherington, SPEE Short Course, 2008

What we are going to talk about today

- How to do a probabilistic calculation of reserves using
  - Volumetric Equation
  - Decline Curves
- Dependencies and some ways to model them.
- Fitting distributions to data.
- Probabilistic Economic Calculations
  - *Ignoring the first or second most important thing.*
- Some gotchas.

What we are NOT going to talk about today

- The new SEC definitions

Exercise 1

- Estimation of Uncertainty
- Two Groups – Group A and Group B
  - Group A – Please give me a 50% confidence interval for the answers.
  - Group B – (I just can't live with 50% of the answers being wrong!) Please give me an 90% confidence interval for your answers.

Defining the Problem

- Three kinds of variables
  - Single-Valued variables (known values)
  - Stochastic variables (uncertain values)
  - Correlated variables
    - Absolute correlations (functions)
    - Stochastic correlations (fuzzy)

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Volumetric Estimate of Reserves

- 3-parameter estimate
  - A, h, BAF
- 6-parameter estimate
  - A, h, φ, S_w, Bo (Bg), RF

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3-Parameter Estimate

- A – Area in acres, say 600 to 2000
- h – net productive thickness in feet, say 10 to 30
- BAF – recovery factor in barrels per acre-ft, say 100 to 300
- Input into @Risk & lets play.
  - 3-Parameter Volumetric.xls

6-Parameter Estimate

- A – Area in acres, say 600 to 2000
- h – net productive thickness in feet, say 10 to 30
- Porosity – say 10% to 20%
- S_w – say 10% to 35%
- B_o – say 1.25
- RF – say 15% to 30%
- Lets play.
  - 3-Parameter Volumetric.xls Tab 6

Newendorp Example

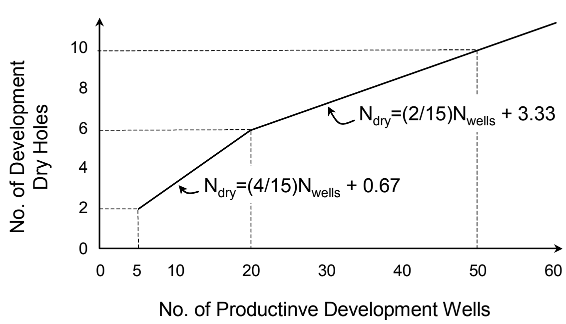
Success Case

- The following parameters are random variables described as probability distributions:
  - a. Productive Area, in acres
  - b. "A" sand net pay thickness, in feet
  - c. Primary Recovery, in barrels/acre-foot
  - d. Initial Potential, IP per well, in BOPD/well
  - e. Development Well Cost (productive, $/well)
  - f. Development Dry Hole Cost, in $/well
  - g. Margin, in $/barrel

Excerpt from *Decision Analysis for Petroleum Exploration, 2nd Edition* by Paul Newendorp and John Schuyler, 2000, Planning Press. Reproduced and adapted for SPEE with permission.

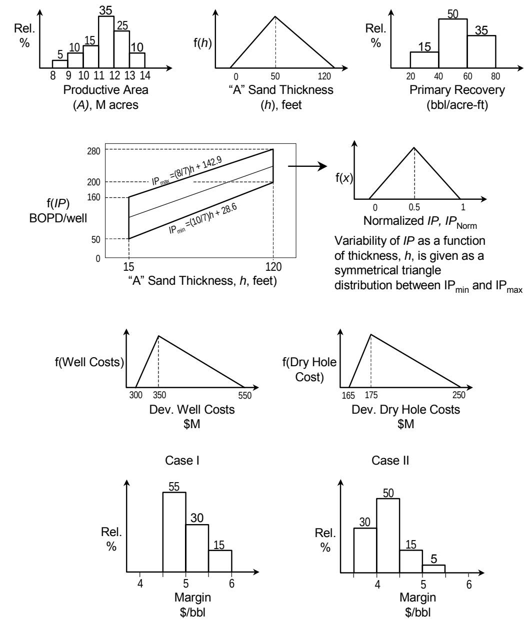
Dry holes

- "Having determined the Number of Development Wells, they next determined the Number of Development Dry Holes likely to be drilled around the productive limits of the field assuming this relationship:"



Excerpt from *Decision Analysis for Petroleum Exploration, 2nd Edition* by Paul Newendorp and John Schuyler, 2000, Planning Press. Reproduced and adapted for SPEE with permission.

Other parameters



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Spreadsheet

- Newendorp Bryarwood.xls
- Discussion

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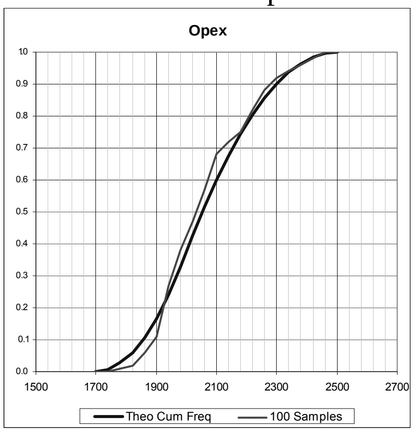
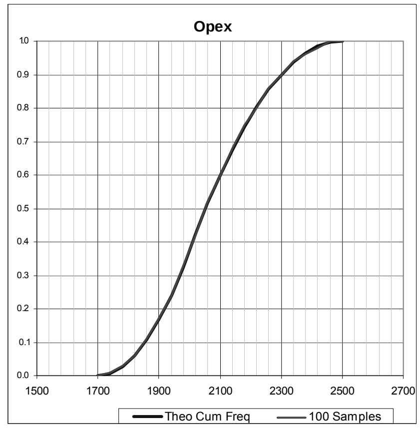
Monte Carlo v. Latin Hypercube

100 MC Samples



100 LH Samples



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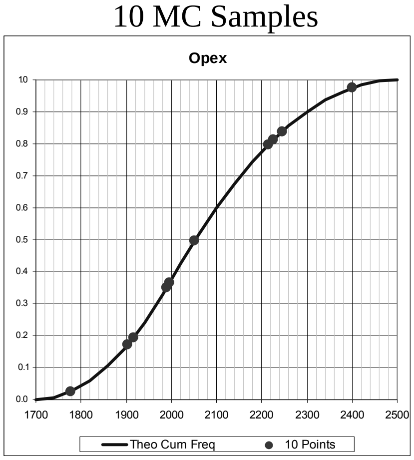
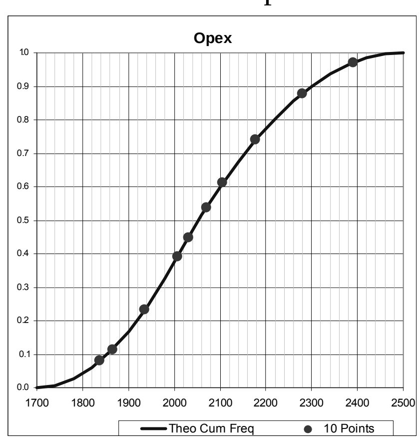
Monte Carlo v. Latin Hypercube

10 MC Samples



10 LH Samples



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Goodness of Fit

- Chi-Squared
  – Used in @Risk
- Kolmogorov-Smirnov
  – Uses cumulative distribution functions
- Anderson-Darling
  – Also uses cum dist function
- Eyeball

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Chi-Squared Test

- Test to see if the observed frequency distribution is NOT consistent with an assumed theoretical distribution.
- Bin the observed data
  – Equal probability usually best
- Calculate the number of expected data in each bin from the theoretical distribution
- Calculate the chi-squared statistic

$$X^2 = \sum_{i=1}^{N} \frac{\left(O_i - E_i\right)^2}{E_i}$$

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Chi-Squared (cont)

- Figure out the “degrees of freedom” = number of bins less one less number of theoretical parameters calculated from observed data.
  - (Log)Normal dist = mean, std dev
  - Some others require 3+ parameters
  - Often =number of bins – 3
- Find out the probability you are wrong if you say the theoretical distribution does NOT fit the data

  =CHIDIST(X^2,Deg Freedom)

Handling Dependencies

- Dependencies exist in most calculations
- Volumetric
  - Φ and S_w
  - B_o and RF?
  - A and h?
  - A and S_w?
  - Spacing and RF
- Decline curves
  - D_i and b
- Economics
  - Prices and Capital costs

What happens when you ignore dependencies?

- Variability is reduced
- Nothing
- Variability is increased

It Depends

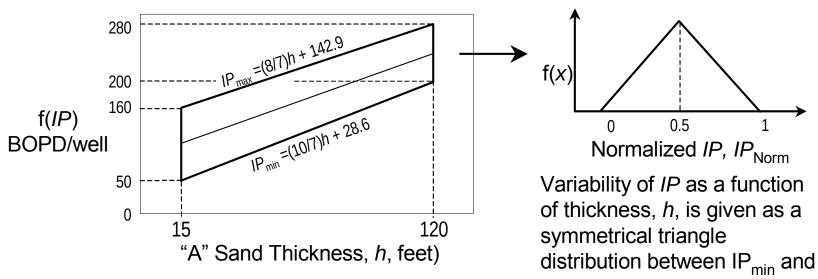
How do you handle dependencies?

- Basically two ways

1. Explicit code
2. Rank order correlation

Coding Dependencies

- Example on page 462 of Newendorp & Schuyler.
- IP is a function of Sand Thickness



Variability of *IP* as a function of thickness, *h*, is given as a symmetrical triangle distribution between IP_{min} and IP_{max}

Excerpt from *Decision Analysis for Petroleum Exploration, 2nd Edition* by Paul Newendorp and John Schuyler, 2000, Planning Press. Reproduced and adapted for SPEE with permission.

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Rank Order Correlations

- In a perfect Rank Order Correlation (1.0) the largest value of the dependent variable will be used with the largest value of the independent variable in one pass.
- Then the 2nd largest with the 2nd largest, etc.
- Rank Order Correlation coefficient ranges from -1 to +1.
- At zero there is no correlation.
- At about .8 to .9 there is a pretty strong correlation with some fuzziness.
- The closer the number is to zero the more the fuzziness.
  - RiskNormal(0.15,0.03,RiskIndepC("Porosity"))
  - 0.03*L2*RiskUniform(0.8,1.2,RiskDepC("Porosity",K1))

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Example

- SwvPhi02.xls
- Have to check “Random Values”

Can we use Rank Order Correlations?

- How?

Fitting Decline Curves

- Eyeball
- Acceptable values of “b”
- Least squares
- Outliers
- Automating the process
- How do we get ranges of Qi, Di, b?
  - Guess
  - Using the “bootstrap” method
- Dependencies and Correlations????

Decline Curve Equations

- 2 Equations (rate-time; rate-cum)
- 6 Unknowns

Nominal Decline

$$q = q_i(1+bD_i t)^{-1/b} \text{ or } q = q_i e^{-Dt}$$

$$N_p = \frac{q_i^{-b}}{D_i(1-b)}\left(q_i^{(1-b)} - q_{el}^{(1-b)}\right)f$$

q_{el} is almost always known!

Effective Decline per year

$$D_e = \frac{q_i - q_{1year}}{q_i}$$

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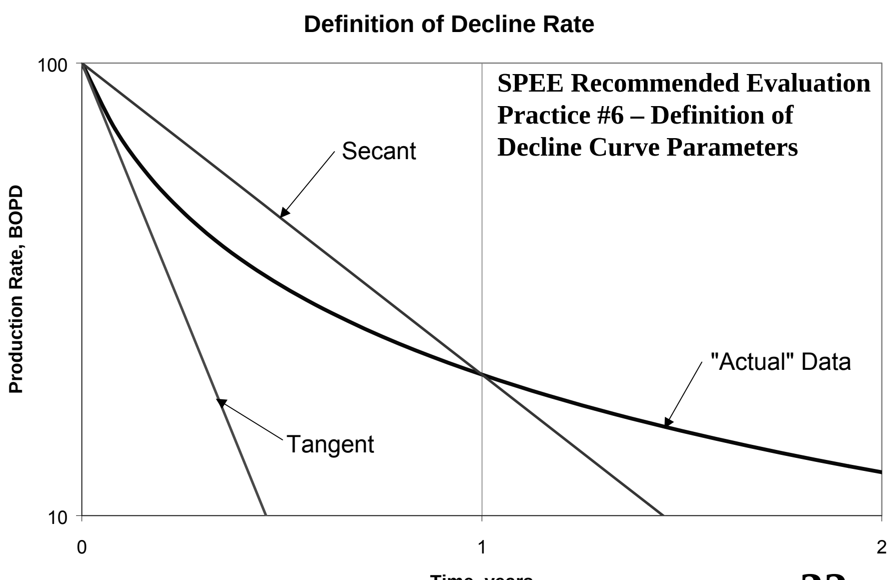
Hyperbolic Decline



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Decline Curves

Converting Effective Decline to Nominal Decline

- Exponential

$$D = -\ln(1 - D_e)$$

- Hyperbolic (Tangent)

$$D_i = -\ln(1 - D_{ei})$$

- Hyperbolic (Secant)

$$D_i = \frac{(1 - D_{ei})^{-b} - 1}{b}$$

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Values of "b"

based on Fetkovich & others

- b = 0
  - Oil reservoirs above the bubble point.
  - Oil reservoirs producing under gravity drainage with no free surface.
  - Gas reservoirs with constant compressibility (high pressure).
  - Gas reservoirs in turbulent flow.
- b = 0.333
  - Oil reservoirs under solution-gas-drive and laminar (?) flow.
- b = 0.5
  - Oil reservoirs under gravity drainage with a free surface (secondary gas cap).
  - Oil reservoirs in turbulent (?) flow
  - Gas reservoirs in laminar flow.
- b = 0.667
  - Oil reservoirs where P vs Np Is linear and In laminar (?) flow.
- b = 1
  - Waterfloods late in life
- b ≈ 2
  - Tight wells with massive hydraulic fractures
  - Horizontal wells

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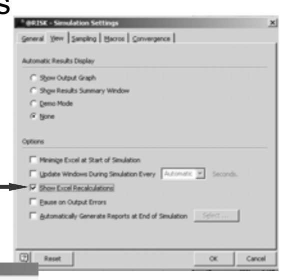
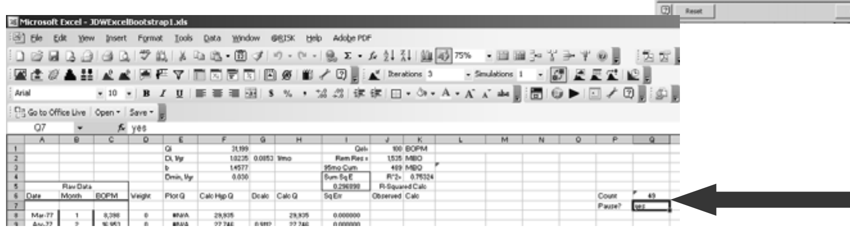
Running Bootstrap

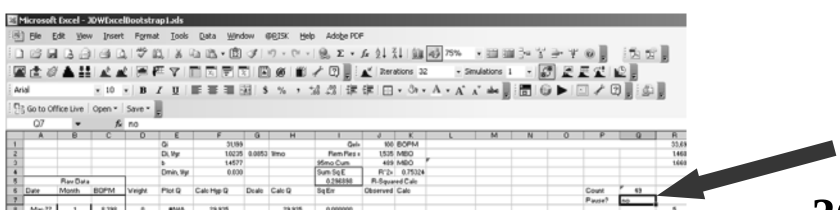
- To view each realization
  - Check Show Excel Recalculations
  - Set Cell Q7 to yes





Running Bootstrap

- To run fast (>10 realizations)
  - UNcheck Show Excel Recalculations
  - Set Cell Q7 to no



Addition

- The "Portfolio Effect"
- When what you are adding is not correlated you get tighter distributions of the sum
  - Big values of variable 1 are likely to be added to small values of variable 2.
- When what you are adding is perfectly correlated you get the same value as arithmetic addition

- Open "Addition.xls" and let's play

Probabilistic Economic Eval

- Deterministic Variables
  - W.I.
  - N.R.I.
  - Tax rates?
  - Discount rate
  - Dmin?
- Probabilistic Variables
  - Drilling Schedule (days to drill)
  - Qi, Di, b
  - BTU or API
  - LGR's or GOR's
  - Opex
  - Capex (& timing)
  - Prices
- Dependencies
  - Per lease or well
    - Qi, Di, b
  - Across leases
    - Prices
    - Opex and Capex escalation
    - Pipeline constraints
    - Capex (Rig Rates) = f(Price)????
  - Others?

Example Spreadsheet

- Dmin.xls
- Enough talk! Let's do!

Additional Reading

- Newendorp, Paul and Schuyler, John, 2000, "Decision Analysis for Petroleum Exploration, 2nd Edition", Planning Press, Aurora, Colorado
- Capen, E. C., 1976, "The Difficulty of Assessing Uncertainty", Journal of Petroleum Technology, August, 1976, P. 843
- Carter, Peter J., and Enrique Morales, "Probabilistic Addition of Gas Reserves within a Major Gas Project," Asia Pacific Oil & Gas Conference and exhibition, Perth, Australia October 1998. SPE paper 50113.
- Schuyler, John, 2007, "Probabilistic Reserves: Current Practices, Challenges And Issues" excerpt from Decision Analysis Collection, Planning Press

The End

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