SPE Reserves, Resources and Definition Workshop

15 – 18 August 2016 ● DoubleTree by Hilton Hotel
Kuala Lumpur, Malaysia

SOCIETY OF PETROLEUM ENGINEERS
SPE Asia Pacific (M) Sdn. Bhd.
Level 35, The Gardens South Tower, Mid Valley City, Lingkaran Syed Putra, 59200 Kuala Lumpur, Malaysia

Reservoir Simulation - Beyond the Best Case

Antony Corrie-Keilig IntPE (Aus) SPEC

RISC ADVISORY

With acknowledgments to Peter Stephenson, Stephen Newman, Geoff Barker and Thomas Thrasher

Synopsis

- Dynamic reservoir simulation is increasingly being used to estimate 2P reserves, however simulation is rarely if ever performed with the objective to estimate proved (1P) reserves or proved + probable + possible (3P) reserves

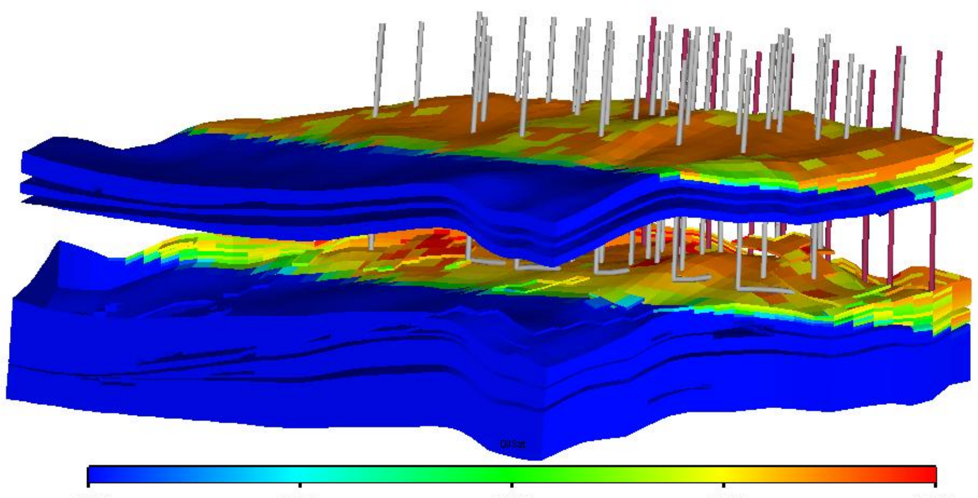
- Focus is characterizing the Best Case on which investment decisions are typically made. Quantifying uncertainty may be inadequate due to anchoring to the Base Case reservoir and geological model characteristics and as such sensitivities of Base Case static and dynamic parameters may not capture the full range of uncertainty

- This presentation outlines how the full range of uncertainties may be captured by challenging the fundamental geological connectivity and drive mechanism of the reservoir rather than parameter sensitivities within a Base Case model and how this was achieved through the integration of geological and analytical reservoir engineering techniques

The Challenge

"The challenge is really in determining whether the model is representative (enough) of the actual reservoir for the particular type of forecast"

SPE 96410 Reservoir Simulation and Reserves Classification



PRMS – Use of Simulation

- Doesn't explicitly address fitness of simulation models for specific reserves categories, however identifies range of application and key issues when employing simulation:
  - Reservoir simulation may be used in either volumetric or performance-based analyses
  - Computer reservoir modeling or reservoir simulation can be considered a sophisticated form of material balance analysis:
    - While such modeling can be a reliable predictor of reservoir behavior under a defined development program, the reliability of input rock properties, reservoir geometry, relative permeability functions, and fluid properties are critical
    - Predictive models are most reliable in estimating recoverable quantities when there is sufficient production history to validate the model through history matching
    - Key assumptions must be made regarding reservoir drive mechanisms

PRMS Application Guidelines – Use of Simulation

- Simulation very briefly discussed. It states there are no published generally accepted rules, but several generic observations can be made:
  - With limited data (geoscience and engineering) the model is best suited to make sensitivity scenario projections to bracket what is possible around the Best Case
  - In the ideal case one may have three different geological realizations (representing the low, best, and high scenarios) and associated reservoir simulation models that can be used to directly estimate the respective in-place volumes, EURs, Reserves:
    - This is preferred, practice given the time and expense to develop several rigorous models
    - But…… may not be feasible for all operators
  - A single integrated reservoir simulation model may exist, which can be used to estimate a single most likely (or Best Case) value of project HCIIP, EUR, Reserves or Contingent Resources exists.
    - In deterministic analysis, sensitivity predictions to understand the range of uncertainty and assign the 1P and 3P categories accordingly may be undertaken
  - But…..
    - Current trend to build uncertainty distributions from many deterministic scenario runs may be inadequate if key uncertainties are not fully understood
    - Anchoring to the Base Case reservoir and geological model characteristics may result in the full range of uncertainty not being captured
    - A Best Case reservoir simulation model may have fundamental 1P compliance issues

Modifying the Best Case Model

- Attempting to make a model constructed with "Best Case" or P50 parameters generate proved forecasts may have pitfalls beyond a pore volume multiplier:
  - LKH / HCIIP not honored
  - Unproved areas / areal extent
  - "Proved" recovery process not modelled e.g. aquifer support,
  - Unproved reservoirs & reservoir properties included
  - History match is never unique (study impact through sensitivity runs)
  - Non-compliant well spacing or undeveloped offset locations

- But this does not preclude using the Best Case Model to derived Proved forecasts as SPE 71430 "The Adaption of Reservoir Simulation for use in Reserves Simulation" suggests:
  - *Alternatively, a less desirable, but more practical approach is to perform calculations by appropriate modifications of the simulator results (i.e. external to the model) to estimate the the recovery that reasonably approximates what would have been calculated had the model actually been constructed in accordance with the proved reserves definitions "*
- But....
  - Requires an abundance of simulation output
  - Engineering judgement

Uncertainty under the PRMS

- Reservoir Engineers are unlike other Engineers for three reasons:
  - Firstly, Reservoir Engineers unlike other Engineers never actually see what they are working on, it just happens to be several kilometers underground
  - Secondly, there are always more unknowns than knowns hence conclusions may not be unique
  - Thirdly, Reservoir Engineers can never give an exact answer, they live in a world characterized by *uncertainty*

- Uncertainty as defined by the PRMS:
  - Uncertainty is the range of possible outcomes in a series of estimates. For recoverable resource assessments, the range of uncertainty reflects a *reasonable* range of estimated potentially recoverable quantities for an individual accumulation or a *project*
  - Uncertainty in resource estimates is best communicated by reporting a *range of potential results*
  - Technical uncertainty is defined by the indication of the varying degrees of uncertainty in estimates of recoverable quantities influenced by range *of in-place hydrocarbon volumes* within the reservoir and the *range of the recovery efficiency* of the recovery project being applied

- Key Phrases: reasonable, range of potential results, in-place hydrocarbon volumes, range of recovery efficiency

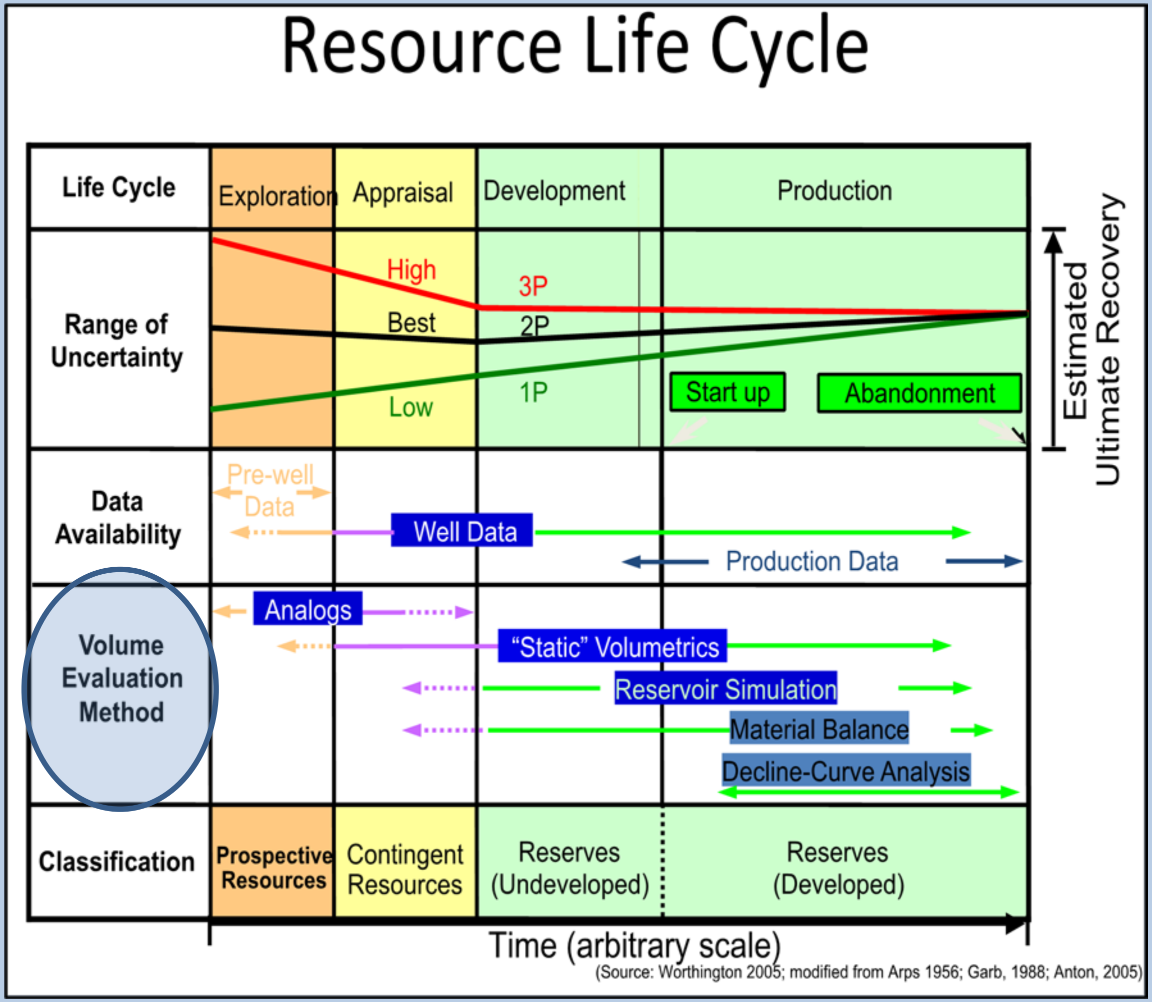
Quantifying Uncertainty

- A cautionary statement by Thiele (2010):
  - *"The industry has long recognized the importance of quantifying uncertainty. As a result, computational resources are being directed more toward simulating large ensembles of models.*
  - *For multimillion-dollar capital investments, it is far more important to acknowledge the possibility of catastrophic outliers and invest in reducing uncertainty by guided data acquisition than to tweak a single reality to excess."*

- PRMS Approach to Uncertainty:
  - Evaluators may assess recoverable quantities and categorize results by uncertainty using the deterministic incremental (risk-based) approach, the deterministic scenario (cumulative) approach, or probabilistic methods. *In many cases, a combination of approaches is used*
  - Assuming that projects have been classified according to their project maturity, the estimation of associated recoverable quantities under a defined project and their assignment to uncertainty categories may be based on one *or a combination of analytical procedures*
    - The confidence in assessment results generally increases when the estimates are *supported by more than one analytical procedure*

- Key Phrases: combination of approaches, combination of analytical procedures, supported by more than one analytical procedure

Integrating Numerical and Analytical Techniques



Modified from IPTC 10809 – Reserves Getting it Right

Framing the High & Low Cases with Material Balances

- The first step in any simulation history matching process is establishing the global quality of the model as an overall material balance and this is dominated by volumetric and drive mechanism considerations

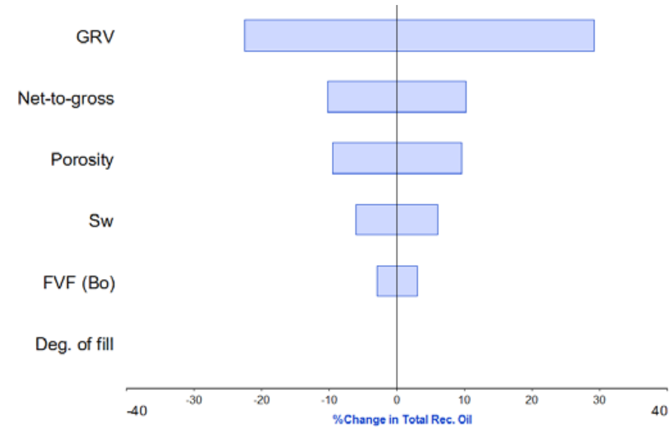
- To paraphrase Dake, the Material Balance whether static or flowing it is the safest technique in the business since it is the minimum assumption route through the subject of reservoir engineering concerning the basic understanding of the physics of reservoir performance:
  - Sees connected HCIIP
  - Immune to petrophysical cutoffs
  - No geometrical considerations (geological models) are involved
  - Material balance can be used to calculate the hydrocarbons in place and define the drive mechanism which are likely to be greatest uncertainty

– Non uniqueness of material balance history match less of an issue than with simulation, but dependent on individual circumstances such as hydraulic diffusivity, multiphase flow, rate sensitivity and amount/quality of production data etc...

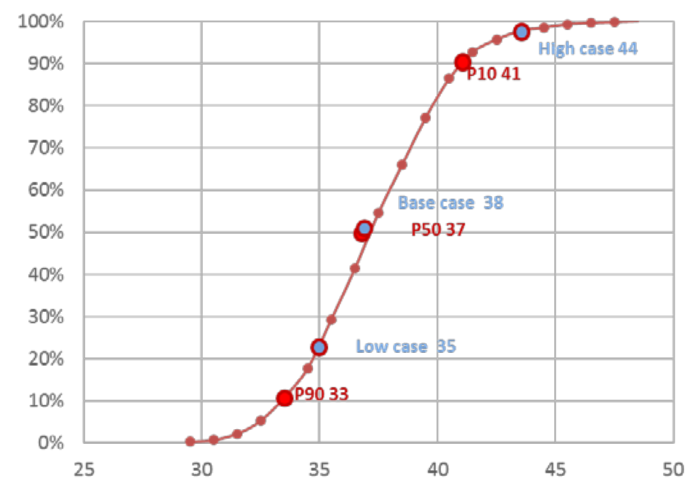
Framing the Low Case with Geological Model

- In-place resource estimates are nearly always estimated by 1D Monte Carlo simulation of the volumetric input parameters
- This can be used to calibrate and "bookend" an appropriate range in static models, noting a static model provides a more accurate assessment of the in-place volume than a 1D model
- Further refinement can be achieved with integration of the history matched simulation model when applying a "break the case" philosophy

Monte Carlo Inputs



Monte Carlo resource distribution



Recent Audit Example on Gas Fields – Case 1

- Gas field with several years of history matched production from Down Hole (DH) Gauges, with a weak edge aquifer modelled (analytical) in the simulation model
- P/Z modelling indicated volumetric depletion drive
- The presence of an aquifer was assumed in the simulation model based on slight pressure build up when the field was shut in, however the Base Case Simulation model struggled to match the build up whilst honoring the early time history match
- Geology was revisited and the Base Case simulation model revised to include an area of poorly connected GIIP (“slow GIIP”), based on logged data
- Adjustments to Base Case simulation model:
  - High Case defined by adjusting main and slow GIIP, based on static and flowing material balance assuming volumetric depletion, noting no aquifer support on P/Z plot
  - Best Case defined by Best History match on revised Best Case Static realization
  - Low Case defined by setting the Best Case GIIP to the P90 probabilistic GIIP and “breaking the case” with and edge aquifer. That is adjusting GIIP in the dynamic model (pressure – cumulative) to a minimum whilst still having a reasonable history match

Recent Audit Example on Gas Fields – Case 2

- Gas field with only 2 years of production with Down Hole (DH) gauges appeared volumetric
- P/Z modelling indicated volumetric depletion drive, but more importantly the P/Z derived GIIP was much closer to P10 GIIP than P50 GIIP
- Geology was revisited and the Base Case static model was found not to include a significant interval of reservoir quality sand due to the positioning of a subcrop edge based on limited appraisal well control
- Adjustments to Base Case simulation model:
  - High Case GIIP defined by static material balance derived GIIP
  - Best Case defined by history match on revised Best Case Static realization
  - Low Case defined by deterministic static model low case realization GIIP with tuned edge aquifer

Summary and Conclusions

- The Base Case geological model and drive mechanism must be challenged to fully capture Low and High cases:
  - “Perturbations” around the Base Model are unlikely to capture the full range of uncertainty
  - Don’t be anchored by the Base Case Model, accept it is one of many potential realizations
- Simple analytical material balance models can readily bracket the range of outcomes as applied in gas fields:
  - No aquifer as a high side
  - Maximum pressure/aquifer support as a low side
- “Breaking the Case”, that is determining minimum GIIP that still gives an acceptable history match with an aquifer to demonstrate that this GIIP and aquifer combination could be a P90 geological realization is an important quality control check.
- Thinking outside the box to create alternate geological realizations that honor pressure and production data is more effective than attempting to finesse simulation models:
  - Sophisticated models do not replace thinking to accurately capture uncertainty ranges
- A true 1P (Proved) model requires estimation of proved in place volumes (LKH, lateral continuity etc…) whilst fully honoring dynamic (production and pressure) data:
  - It is the reservoir engineers responsibility to push the boundaries trying to match a 1P (Proved) in place volume

Questions and Discussion

PRMS - Proved Reserves

- The area of the reservoir considered as Proved includes:
  - The area delineated by drilling and defined by fluid contacts, if any, and
  - Adjacent undrilled portions of the reservoir that can reasonably be judged as continuous with it and commercially productive on the basis of available geoscience and engineering data.

- In the absence of data on fluid contacts, Proved quantities in a reservoir are limited by the lowest known hydrocarbon (LKH) as seen in a well penetration unless otherwise indicated by definitive geoscience, engineering, or performance data. Such definitive information may include pressure gradient analysis and seismic indicators

- Reserves in undeveloped locations may be classified as Proved provided that:
  - The locations are in undrilled areas of the reservoir that can be judged with reasonable certainty to be commercially productive.
  - Interpretations of available geoscience and engineering data indicate with reasonable certainty that the objective formation is laterally continuous with drilled Proved locations.