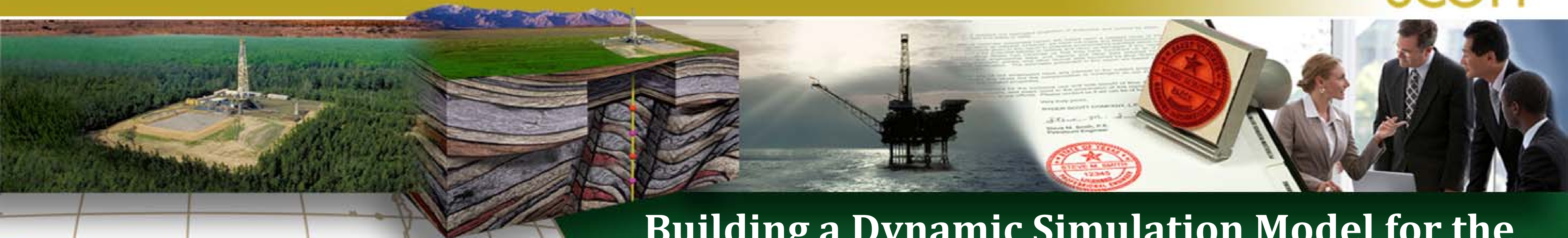
Houston • Denver • Calgary

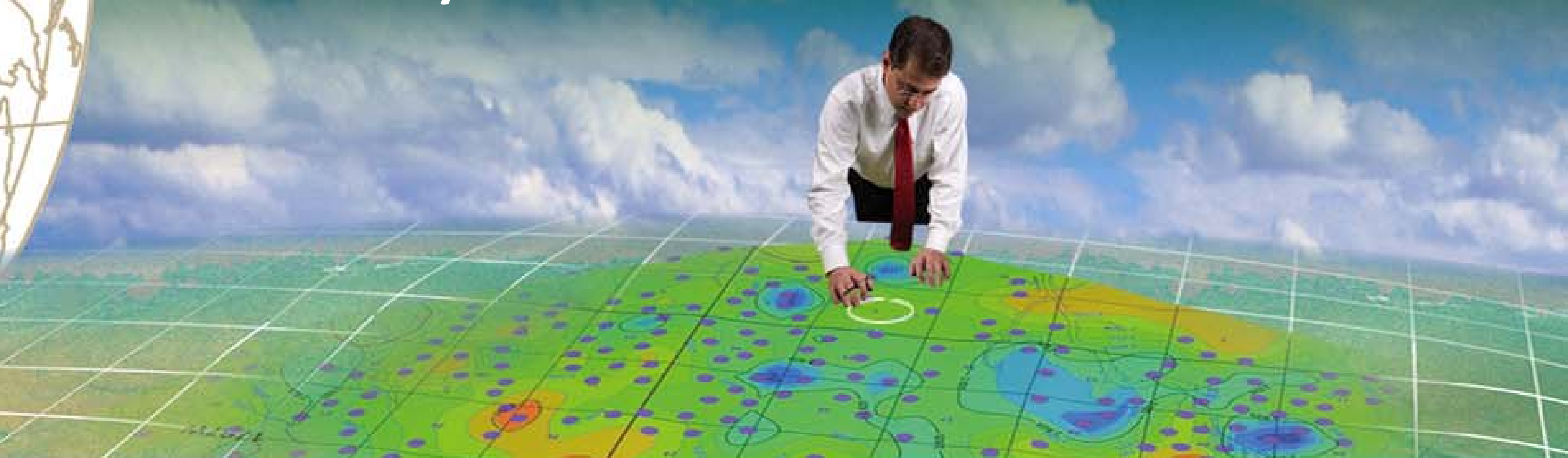
RYDER SCOTT



Building a Dynamic Simulation Model for the Purpose of 1P, 2P & 3P Reserves Estimation

Presented by: Miles Palke, P.E.

Ryder Scott Petroleum Consultants



RESERVOIR SIMULATION AT RYDER SCOTT

- Conduct approximately 20 reservoir simulation studies a year
- Staff members are recognized technical experts in simulation
  - Developed and taught reservoir simulation schools through the SPE
  - Current SPE instructors for the two-day course “Reservoir Simulation for Practical Decision Making” – Miles Palke and Dean Rietz
  - Dean Rietz, Chairman & CEO
    - Adjunct Professor at the University of Houston of master’s level simulation course
    - SPE Distinguished Lecturer in 2016-2017, presenting on reservoir simulation throughout the world

SPE PAPERS WRITTEN BY RYDER SCOTT STAFF

- "The Adaptation of Reservoir Simulation Models for Use in Reserves Certification under Regulatory Guidelines or Reserves Definitions," (SPE 71430), 2001
- "Reservoir Simulation and Reserves Classifications-Guidelines for Reviewing Model History Matches To Help Bridge the Gap between Evaluators and Simulation Specialists" (SPE 96410), 2005
- "Case Studies Illustrating the Use of Reservoir Simulation Results in the Reserves Estimation Process" (SPE 110066), 2007
- "A Novel Simulation Model Review Process" (SPE 159274), 2012

AGENDA

- What are Reserves?
- What do Reserves/Resource Guidelines say about Reservoir Simulation?
  - SEC
  - SPE-PRMS
- What do you need to consider about Uncertainty?
- How do you address this Uncertainty with Simulation?
  - Deterministic
  - EOD / Probabilistic
- Examples
  - Green Field
  - Mature
- Pitfalls
- Conclusions

WHAT ARE RESERVES?

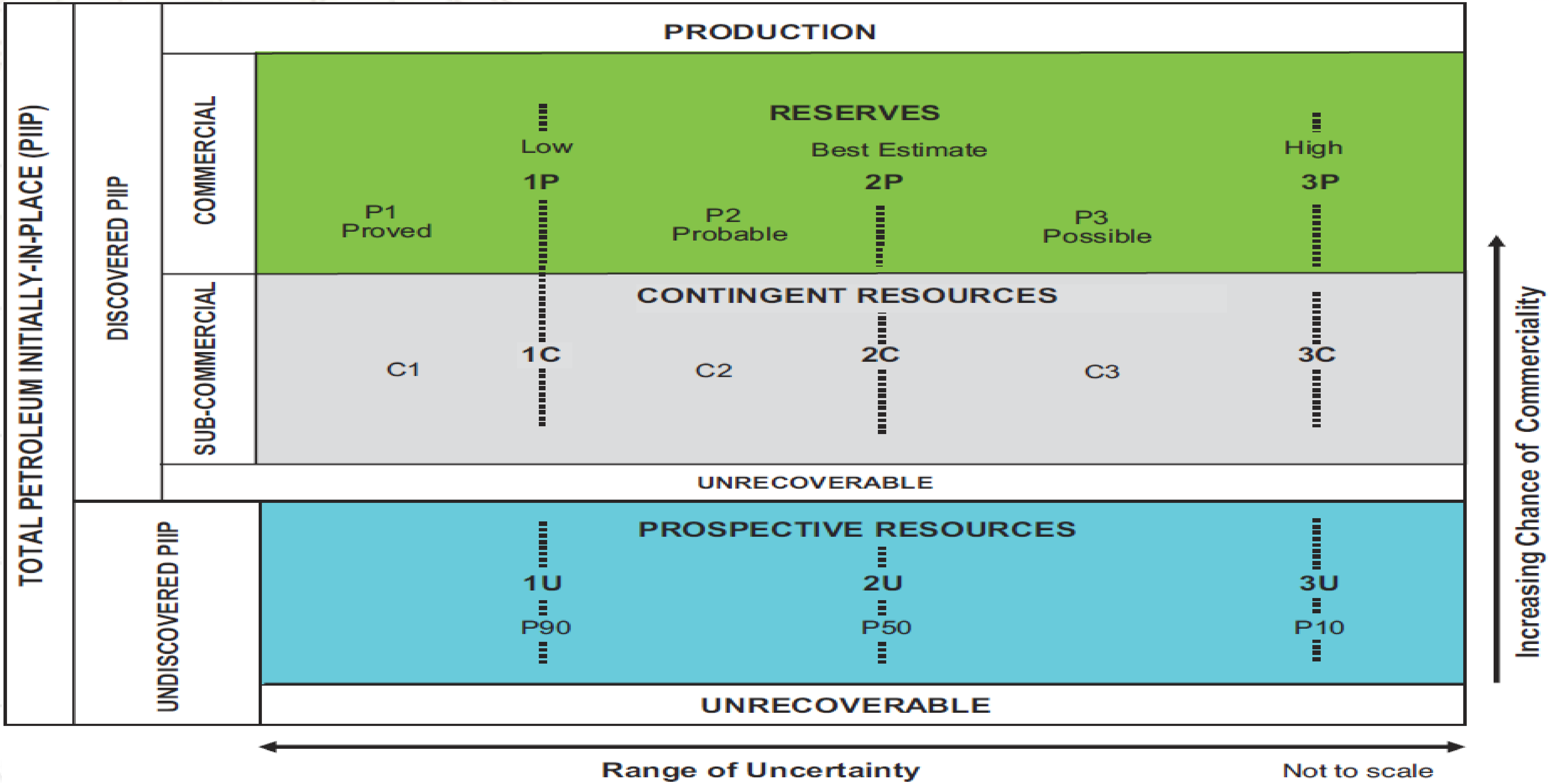
- Those quantities of petroleum anticipated to be commercially recoverable by application of development projects to known accumulations from a given date forward under defined conditions. Reserves must satisfy four criteria: They must be
  - ***discovered,***
  - ***recoverable,***
  - ***commercial, and***
  - ***remaining***
- ***based on the development project(s) applied***.

WHAT ARE RESERVES?

- Regardless of the evaluation methods used, any estimate of future recovery does not necessarily qualify as an estimate of reserves.
- Aside from economic viability, specific criteria must be met to qualify estimated recoverable volumes as reserves.
- These criteria are generally defined in the form of "reserves definitions."

- SEC
- SPE-PRMS

RESERVES CLASSIFICATIONS



AGENDA

- What are Reserves?
- What do Reserves/Resource Guidelines say about Reservoir Simulation?
  - SEC
  - SPE-PRMS
- What do you need to consider about Uncertainty?
- How do you address this Uncertainty with Simulation?
  - Deterministic
  - EOD / Probabalistic
- Examples
  - Green Field
  - Mature
- Pitfalls
- Conclusions

SEC REFERENCE TO SIMULATION WITH RESERVES

Historical
Pre 2009

SEC and Reservoir Simulation

http://www.sec.gov/divisions/corpfin/guidance/cfactfaq.htm

Home | Previous Page

U.S. Securities and Exchange Commission

Division of Corporation Finance:
Frequently Requested
Accounting and Financial Reporting
Interpretations and Guidance

Prepared by Accounting Staff Members
in the Division of Corporation Finance
U.S. Securities and Exchange Commission,
Washington, D.C.

March 31, 2001

II. Guidance About Disclosures

F. Issues in the Extractive Industries

3. Definition of Proved Reserves

In a new reservoir with only a few wells, reservoir simulation or application of generalized hydrocarbon recovery correlations would not be considered a reliable method to show increased proved undeveloped reserves. **With only a few wells as data points from which to build a geologic model and little performance history to validate the results with an acceptable history match, the results of a simulation or material balance model would be speculative in nature.** The results of such a simulation or material balance model would not be considered to be reasonably certain to occur in the field to the extent that additional proved undeveloped reserves could be recognized. The application of recovery correlations which are not specific to the field under consideration is not reliable enough to be the sole source for proved reserve calculations.

Historical Pre 2009

"With only a few wells as data points from which to build a geologic model and little performance history to validate the results with an acceptable history match, the results of a simulation or material balance model would be speculative in nature."

REFERENCE TO SIMULATION WITH RESERVES SEC (2009)

RYDER SCOTT

2008 Regulation 210.4-10
Page 6 of 7

Reliable technology is a grouping of one or more technologies (including computational methods) that has been field tested and has been demonstrated to provide reasonably certain results with consistency and repeatability in the formation being evaluated or in an analogous formation.

convenience of the user and are not part of the official SEC document.

{2008 Conforming Version No. 33-8935 Pgs 132-143} *(a) Definitions.*

{1978} *(1) Acquisition of properties. Costs incurred to purchase, lease or otherwise acquire a property, including costs of lease bonuses and options to purchase or lease properties, the portion of costs applicable to minerals when land including mineral rights is purchased in fee, brokers' fees, recording fees, legal costs, and other costs incurred in acquiring properties.*

{2008} *(2) Analogous reservoir. Analogous reservoirs, as used in resources assessments, have similar rock and fluid properties, reservoir conditions (depth, temperature, and pressure) and drive mechanisms, but are typically at a more advanced stage of development than the reservoir of interest and thus may provide concepts to assist in the interpretation of more limited data and estimation of recovery. When used to support proved reserves, an "analogous reservoir" refers to a reservoir that shares the following characteristics with the reservoir of interest:*
(i) Same geological formation (but not necessarily in pressure communication with the reservoir of interest);
(ii) Same environment of deposition;
(iii) Similar geological structure; and
(iv) Same drive mechanism.

{2008} *Instruction to paragraph (a)(2): Reservoir properties must, in the aggregate, be no more favorable in the analog than in the reservoir of interest.*

{2008} *(3) Bitumen. Bitumen, sometimes referred to as natural bitumen, is petroleum in a solid or semi-solid state in natural deposits with a viscosity greater than 10,000 centipoise measured at original*

{1978} *(23) Proved properties. Properties with proved reserves.*

{2008} *(24) Reasonable certainty. If deterministic methods are used, reasonable certainty means a high degree of confidence that the quantities will be recovered. If probabilistic methods are used, there should be at least a 90% probability that the quantities actually recovered will equal or exceed the estimate. A high degree of confidence exists if the quantity is much more likely to be achieved than not, and, as changes due to increased availability of geoscience (geological, geophysical, and geochemical), engineering, and economic data are made to estimated ultimate recovery (EUR) with time, reasonably certain EUR is much more likely to increase or remain constant than to decrease.*

{2008} *(25) Reliable technology. Reliable technology is a grouping of one or more technologies (including computational methods) that has been field tested and has been demonstrated to provide reasonably certain results with consistency and repeatability in the formation being evaluated or in an analogous formation.*

{2008} *(26) Reserves. Reserves are estimated remaining quantities of oil and gas and related substances anticipated to be economically producible, as of a given date, by application of development projects to known accumulations. In addition, there must exist, or there must be a reasonable expectation that there will exist, the legal right to produce or a revenue interest in the production, installed means of delivering oil and gas or related substances to market, and all permits and financing required to implement the project.*

{2008} *Note to paragraph (a)(26): Reserves should not be assigned to adjacent reservoirs isolated by major, potentially sealing, faults until those reservoirs are penetrated and evaluated as economically producible. Reserves should not be assigned to areas that are clearly separated from a known accumulation by a non-productive reservoir (i.e., absence of reservoir, structurally low reservoir, or*

- 4.1.0.1 The analytical procedures for estimating recoverable quantities fall into three broad categories: (a) analogy, (b) volumetric estimates, and (c) performance-based estimates (e.g., material balance, history-matched simulation, decline-curve analysis, and rate-transient analysis. Reservoir simulation may be used in either volumetric or performance-based analyses.

- 4.1.2.4 Given estimates of the in-place petroleum, the portion that can be recovered by a defined set of wells and operating conditions must then be estimated based on analog field performance and/or modeling/simulation studies using available reservoir information. Key assumptions must be made regarding reservoir drive mechanisms.

- 4.1.3.2 Reservoir modeling or reservoir simulation can be considered a more rigorous 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, fluid properties, and constraints (e.g., wells, facilities, and export) are critical***. *Predictive models are most reliable in estimating recoverable quantities when there is sufficient production history to validate the model through history matching.*

AGENDA

- What are Reserves?
- What do Reserves/Resource Guidelines say about Reservoir Simulation?
  - SEC
  - SPE-PRMS
- What do you need to consider about Uncertainty?
- How do you address this Uncertainty with Simulation?
  - Deterministic
  - EOD / Probabilistic
- Examples
  - Green Field
  - Mature
- Pitfalls
- Conclusions

UNCERTAINTY IN SIMULATION MODELS

- Few properties of real petroleum reservoirs are known to great precision.
- Volumetric uncertainties are generally straightforward to address.
  - Where is the Water Oil Contact? What is a 1P or proved WOC compared to a 3P or Possible WOC?
  - Can sand thickness get better beyond well control?

UNCERTAINTY IN SIMULATION MODELS

- The uncertainty in other parameters can be harder to address.
- The impact of some parameters may be difficult to assess or lead to unintuitive results.
- When constructing 1P, 2P, and 3P models care needs to be given to whether non-volumetric parameters are also appropriate for the reserves category, and not just the volumetric parameters:
  - Size of aquifer
  - Formation compressibility
  - Well or facility constraints
  - Fluid properties (or distribution)

AGENDA

- What are Reserves?
- What do Reserves/Resource Guidelines say about Reservoir Simulation?
  - SEC
  - SPE-PRMS
- What do you need to consider about Uncertainty?
- How do you address this Uncertainty with Simulation?
  - Deterministic
  - EOD / Probabilistic
- Examples
  - Green Field
  - Mature
- Pitfalls
- Conclusions

RYDER SCOTT

- Two prevailing approaches in the industry
  - Deterministic
  - Stochastic Based on Design of Experiments
- For cases with historical performance, it must be considered
  - i.e. each case must, within tolerance, be able to reproduce historical performance

- History match is usually difficult to obtain.
- While a history match does not guarantee a reliable prediction, it does at least guarantee that past performance can be explained by the model.

- History match is important.
- Should result from logical adjustments.
- Consistent with geological and engineering evidence.
- Uncertain parameters / Sensitivity studies

- History matching is subjective.
- No two engineers arrive at the exact same solution.
- Certain parameters that may have a limited impact upon the history match could have a dramatic impact upon the predictions from the same model.
  - Any parameters suspected of falling into this category be tested through the use of sensitivity studies.

- Recognize situations where the physical processes governing reservoir behavior are expected to be different in the future than they have been in the past.
  - Many different re-development scenarios
  - Integrate observations from analog or nearby fields or laboratory test data to improve confidence

AGENDA

- What are Reserves?
- What do Reserves/Resource Guidelines say about Reservoir Simulation?
  - SEC
  - SPE-PRMS
- What do you need to consider about Uncertainty?
- How do you address this Uncertainty with Simulation?
  - Deterministic
  - EOD / Probabilistic
- Examples
  - Green Field
  - Mature
- Pitfalls
- Conclusions

IMMATURE RESERVOIR EXAMPLE

- Discovered and delineated field
- Tested, but not produced
- Heavily faulted area
- Unpenetrated blocks with amplitude

IMMATURE RESERVOIR EXAMPLE

- Review of the model as built revealed that static model and volumetric assumptions were overall reasonable.
- However, several non volumetric assumptions were made that were not supportable
  - Relative permeability optimistic
  - Producer flowing pressures low
  - Wells flow at unrealistically high rates
  - Wells inject at pressures exceeding fracture gradient

[redacted]

- Non volumetric parameter problems were resolved, and model results accepted for 3P scenario

RYDER SCOTT

- SPE-PRMS rules restrict calling volumes in undrilled blocks reserves.
- 2P scenario, most distant undrilled block deactivated. Residual oil saturation increased. Vertical communication decreased within range of uncertainty.
- 1P scenario, adjacent undrilled block deactivated. Residual oil saturation further increased. Communication across fault blocks restricted beyond base level.

3P

[redacted]

2P

[redacted]

1P

[redacted]

MATURE RESERVOIR EXAMPLE

- Fully developed low-permeability gas condensate field. Approximately 100 wells with over 10 years history.

- Static model characterized by multiple facies
- Proximal facies higher Φ, S_g, K, RF
- Distal facies lower Φ, S_g, K, RF
- P50 dynamic model attained good history match by adjusting facies petrophysical properties and distribution consistent with geology.

RYDER SCOTT

- Review of the history matched model as built revealed assumptions were overall reasonable.

- However,
  - The history match is non-unique. History match obtained through adjustment of the properties of each facies.
  - Degree of permeability contrast between distal vs. proximal facies is very uncertain.
  - Relative contribution of the distal facies to long term recovery is a significant uncertainty.

- 3P scenario, use the HM model except upside distal facies properties which has minimal impact on history match.
- 2P scenario, use the HM model with most likely facies distribution.
- 1P scenario, deactivated the grid cells associated with the most distal volumes which has minimal impact on history match.

3P *2P*

[redacted]

1P

[redacted]

AGENDA

- What are Reserves?
- What do Reserves/Resource Guidelines say about Reservoir Simulation?
  - SEC
  - SPE-PRMS
- What do you need to consider about Uncertainty?
- How do you address this Uncertainty with Simulation?
  - Deterministic
  - EOD / Probabilistic
- Examples
  - Green Field
  - Mature
- Pitfalls
- Conclusions

PITFALLS

- If history is available, it should be matched within reason (and within the bounds of the quality of the data).
- The constraints placed on future rates need to be carefully understood and reviewed.
- There are phenomena affecting real oil and gas fields that cannot be practically captured in models!
- Look out for the addition of physically unrealistic parameters or features to models.

BEST PRACTICES

- Underlying static model construction is critical.
- Changes made to models to capture historical performance must be reasonable.
- The controls placed on wells in forecast mode need careful review for reasonableness.
- Models should be able to transition reasonably from history to prediction.
- The relevant guidelines for reserves definitions need to be applied to create relevant 1P, 2P, 3P cases.

AGENDA

- What are Reserves?
- What do Reserves/Resource Guidelines say about Reservoir Simulation?
  - SEC
  - SPE-PRMS
- What do you need to consider about Uncertainty?
- How do you address this Uncertainty with Simulation?
  - Deterministic
  - EOD / Probabilistic
- Examples
  - Green Field
  - Mature
- Pitfalls
- Conclusions

CONCLUSIONS

- Reservoir simulation is an acceptable tool for use in arriving at 1P, 2P, and 3P reserve estimates.
- Care needs to be taken, especially for 1P cases.
- Models need to be run in a fashion consistent with the system of guidelines being followed.
- Historical performance data must be honored.