Anadarko Lunch & Learn
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"Reservoir Simulation Models and Their Use in The Estimation of Reserves"

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This Discussion is based on:

“The Adaptation of Reservoir Simulation Models for Use in Reserves Certification under Regulatory Guidelines or Reserves Definitions”

SPE 71430

(Palke & Rietz)

Outline

- Introduction
- Reserves Definitions & Classes
- Reservoir Simulation
- Simulation and Proved Reserves
- Immature & Mature Reservoirs (History Matching)
- Mixed Reserves Classes
- Conclusions

Caveats

- SPE 71430 originally written to start a dialogue.
- Present some suggested methods but they are not the only methods.
- Defense of simulation results before regulatory bodies is somewhat “untested”.
- Overlying theme is consistent with SEC guidelines- *Reasonable Certainty* – Revisions should be much more likely to be upward rather than downward.
- This is intended to be a discussion related to reservoir simulation models.

Introduction

- 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”.

Reserves Definitions

- SEC (Part 210.4-10 (a) of Regulation S-X). (1978) & Subsequent Staff Accounting Bulletins
  - Proved reserves
- Society of Petroleum Engineers and the World Petroleum Congress (SPE/WPC). (1987)
  - Proved, probable, and possible reserves

Reserves Classifications

- Different grades reflecting certainty (risk) of recovery.
- Proved reserves for financial reporting and lending.
- Probable and possible reserves (upside potential).

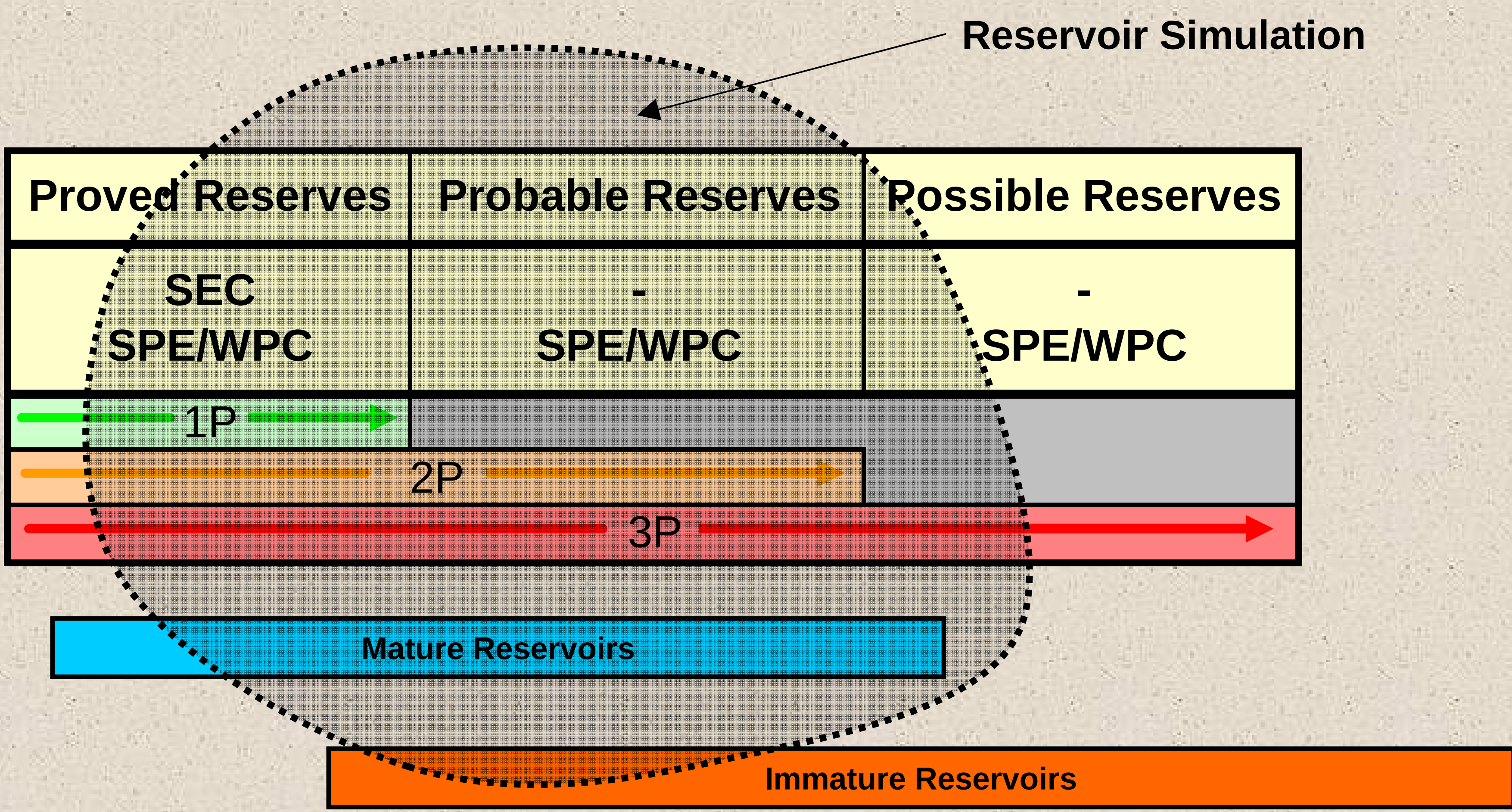
Prevalence of Reservoir Simulation

- A numerical model that is expected to behave like a particular oil or gas reservoir.
- After the history match is achieved, the model can be “run” to predict future performance.
- Simulation continues to become a more widely used tool.
- Simulation has also been increasingly promoted as a means to estimate reserves.

Limitations of Simulation

- Parameters uniform within grid blocks (possibly very large).
- Average block properties not accurately known.
- Undetected structural features may not be in a model.
- Generally very data intensive.

Where Do Simulation and Reserves Estimation Overlap?



Reference to Simulation with Reserves

SEC and Reservoir Simulation

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

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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.

SPE/WPC and Reservoir Simulation
??

Applying Simulation Results to Estimate Proved Reserves

- Simulation studies are rarely performed with the objective to estimate proved reserves. Usually the primary objective of a model is to improve the understanding of the reservoir to improve recovery (2P).
- Sensible to consider the best estimate of total potential when planning.
- Modeling & formulating a development plan based on proved reserves only is likely to reduce overall recovery efficiency.

Applying Simulation Results to Estimate Proved Reserves

- Models built for proved reserves typically too limited and unrealistic.
- Special circumstances
  - Contentious reserves situations
  - Reserves largely proved

Applying Simulation Results to Estimate Proved Reserves

- The presumed “most likely” scenario is most commonly modeled with the reservoir simulator.
- Due to the specific regulatory definitions of proved reserves, “most likely” is a level of recoverable volumes that is more consistent with proved + probable reserves, rather than proved alone.
- Therefore, it is very common that results from a simulation model cannot be directly applied to the proved reserves category, even if they are passed through a cashflow analysis to prove economic viability.

Applying Simulation Results to Estimate Proved Reserves

- It is not just original hydrocarbon in-place that may not fit the definition of proved reserves.
- Models may include pressure support from aquifers or rock compressibility that are not “proved”.
- Numerous other parameters would also fall into this category.
- The key is to search for sources of reservoir drive energy that may increase recoveries beyond what would be considered proved.

Applying Simulation Results to Estimate Proved Reserves

- Two approaches
  - 1. Modify so model complies with reserves definitions.
  - 2. Modify the simulation results.

Assuming the model and the forecasts are valid

Applying Simulation Results to Estimate Proved Reserves Method 1 – Modify Model

- Consider the case of a reservoir for which the level of the hydrocarbon-water contact has not been established from the geological and engineering data. In this situation, the hydrocarbon-water contact in the model should be set at the lowest observed occurrence of hydrocarbons (lowest known oil/gas, or oil-down-to), as specified in the definition of proved reserves.
- As long as the other components of the definition are also honored, the results generated from this model could be utilized in the estimation of proved reserves.
- “Good history match” is implied (will discuss later).

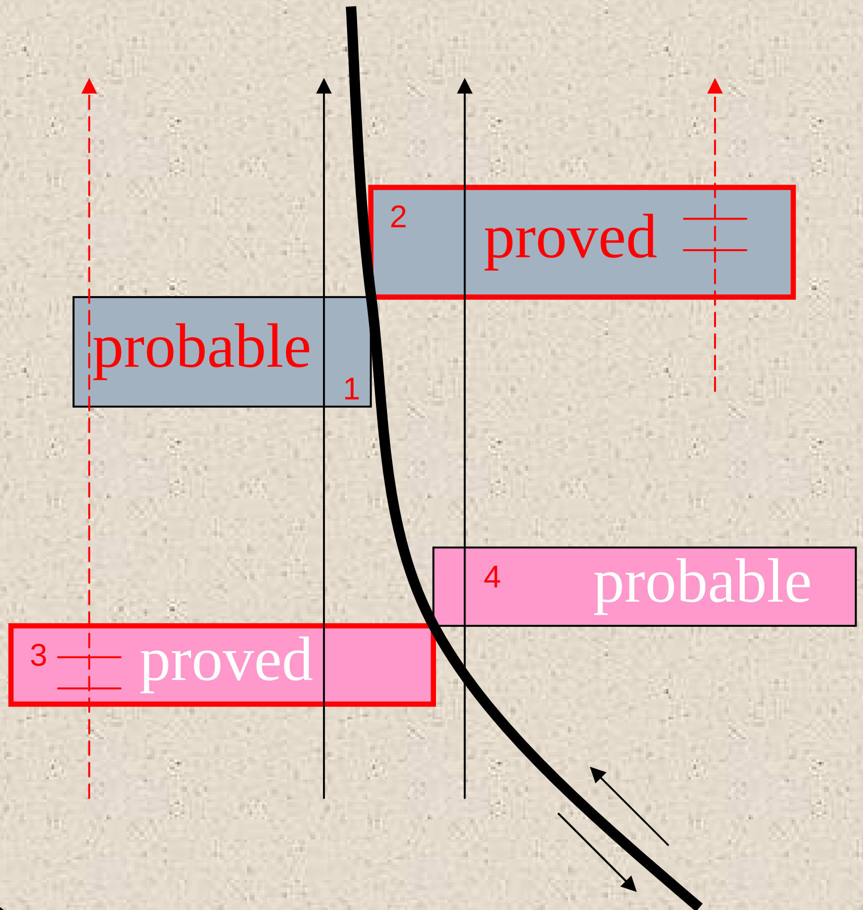
Applying Simulation Results to Estimate Proved Reserves Method 1 - Modify Model

- Potentially difficult.
- Modify description/grid.
- Modify the planned wells and facilities.
- In addition to the question of constraints, substantial modifications to the original grid/description could also be required.
  - Models derived from seismic data often feature thickening between wells based on reasonable interpretation of the data. This thickening may or may not be permitted under the reserves definitions.

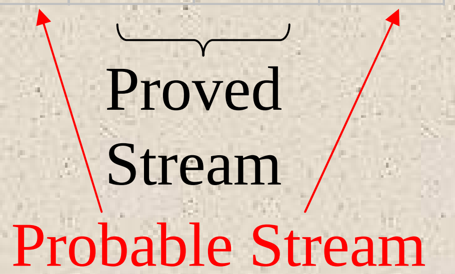
Applying Simulation Results to Estimate Proved Reserves Method 2 - Modify the Results

- Appropriate modifications of the simulator results.
- Some of the rigorous nature of the simulation is lost.

Applying Simulation Results to Estimate Proved Reserves Method 2 - Modify the Results



	ROPR 1	ROPR 2	ROPR 3	ROPR 4
DATE	STB/D	STB/D	STB/D	STB/D
1-Jan-02	1,000	0	1,500	0
1-Feb-02	970	0	1,455	0
1-Mar-02	941	0	1,411	0
1-Apr-02	913	750	1,369	2,000
1-May-02	885	728	1,328	1,940
1-Jun-02	859	706	1,288	1,882
1-Jul-02	833	685	1,249	1,825
1-Aug-02	808	664	1,212	1,771
1-Sep-02	784	644	1,176	1,717
1-Oct-02	760	625	1,140	1,666
1-Nov-02	737	606	1,106	1,616
1-Dec-02	715	588	1,073	1,567
1-Jan-03	694	570	1,041	1,520



Immature Reservoirs

- Description relies primarily on geophysical and geological data to set reservoir parameters.
- A “history match” of the model to the reservoir is easy to obtain since there are few if any performance points to be matched.
- Because it is so easy to obtain, however, the match is not very meaningful in terms of calibrating and improving the reliability of the model.

Immature Reservoirs

- “Most likely” hydrocarbons in-place generally not proved.
- Unlikely to be acceptable for proved reserves estimation.
- Models helpful in estimating hydrocarbon recovery efficiency.

Immature Reservoirs

- Sensitivity studies.
- Unless contradicted by analogy data (or experience).
- Remember upward revisions should be (much) more likely.

Mature Reservoirs & History Matching

- History match is usually difficult to obtain.
- The match is more meaningful in terms of enhancing model reliability.

Mature Reservoirs & History Matching

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

Mature Reservoirs & History Matching

- History matching is generally a somewhat subjective process.
- It is unlikely that any two engineers would arrive at the exact same solution.
- It is normal that certain parameters that may have a limited impact upon the history match would have a dramatic impact upon the predictions from the same model.
  - Aquifer dimensions
  - Original hydrocarbon in-place!
- Recommend that any parameters suspected of falling into this category be tested through the use of sensitivity studies.

Mature Reservoirs & History Matching

- Consistent with traditional techniques, well established performance may override volumetric guidelines.
- Imperative that reasonable assumptions be made.

Mature Reservoirs & History Matching (Appropriateness)

- It is also important to recognize situations where the physical processes governing reservoir behavior are expected to be different in the future than they have been in the past, and to adjust expectations for the model accordingly.
  - Solution gas drive during history but model used to predict waterflood performance.
  - History match includes only vertical wells but predictions contain horizontal wells.
  - Observations from analog or nearby fields or laboratory test data could be incorporated into the model to improve the confidence when forecasting under different depletion mechanisms.

Mature Reservoirs & History Matching (Appropriateness)

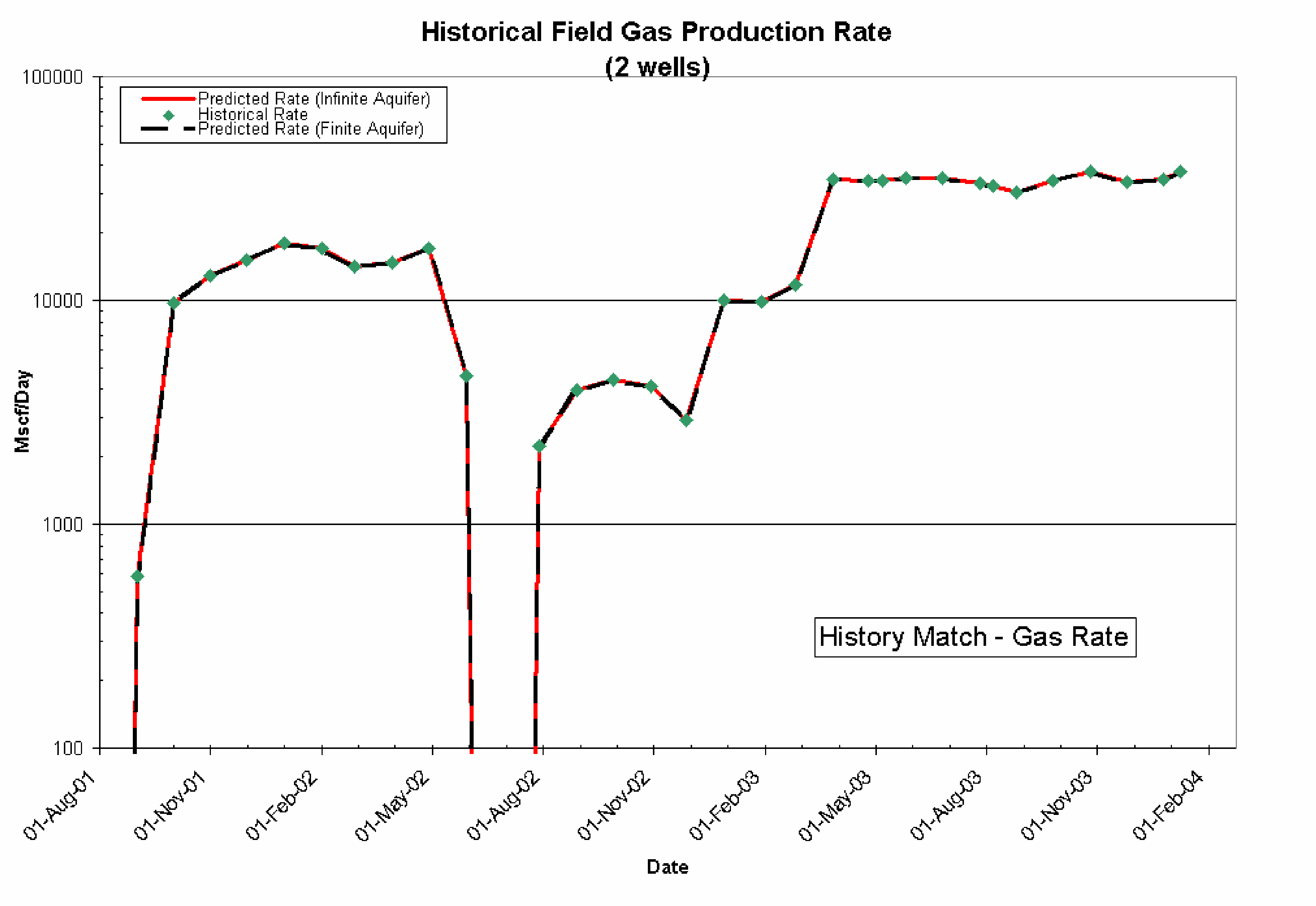
- As a final check, the evaluator should verify that the transition from historical to predicted production is smooth if the model is run as a status quo, or “do nothing” case.
- An abrupt change at the end of history is indicative of an inappropriate model, even if the history match appears to be reasonable in all other respects.

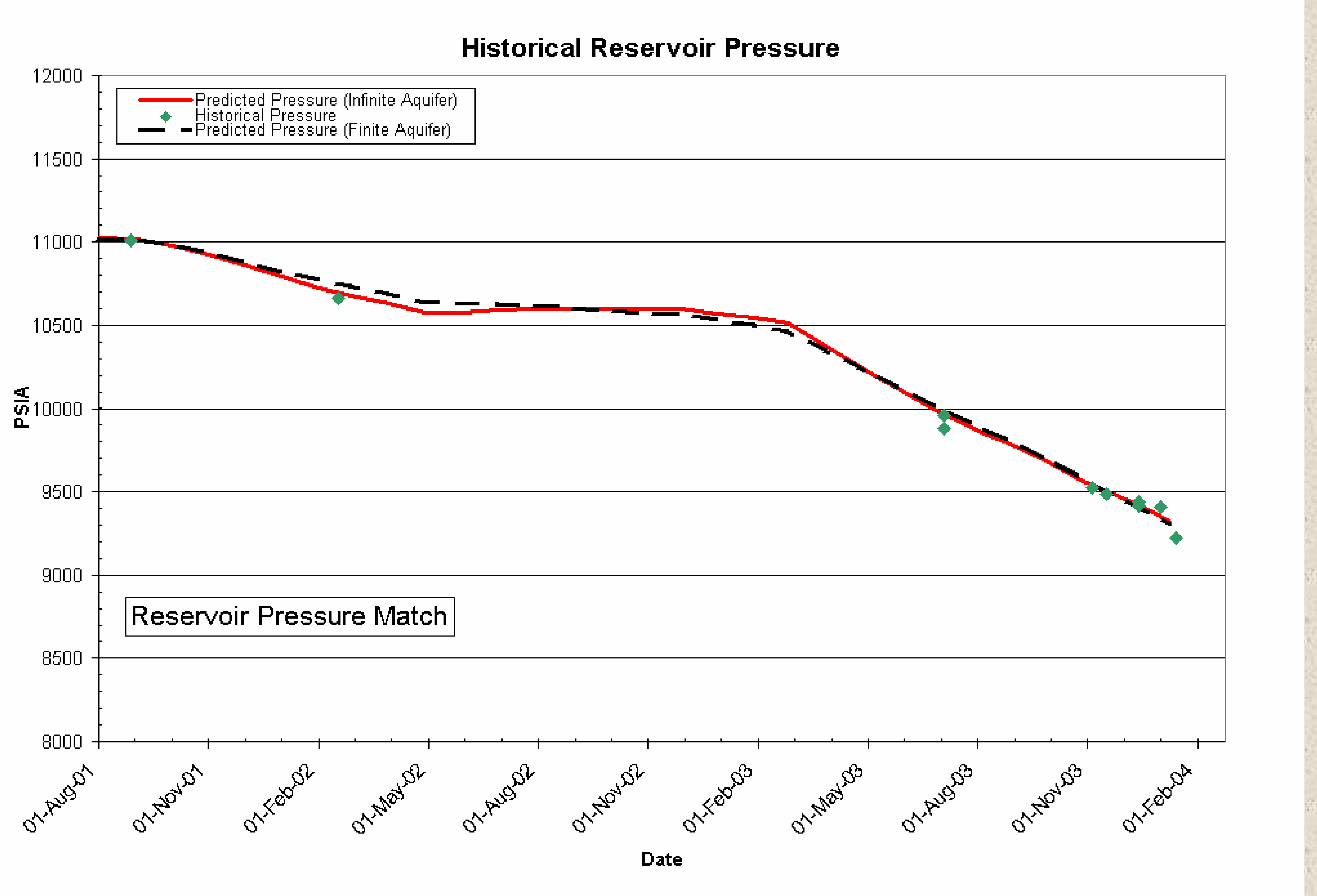
Mature Reservoirs & History Matching (Appropriateness)

- How much data is enough for a good history match or what defines maturity?

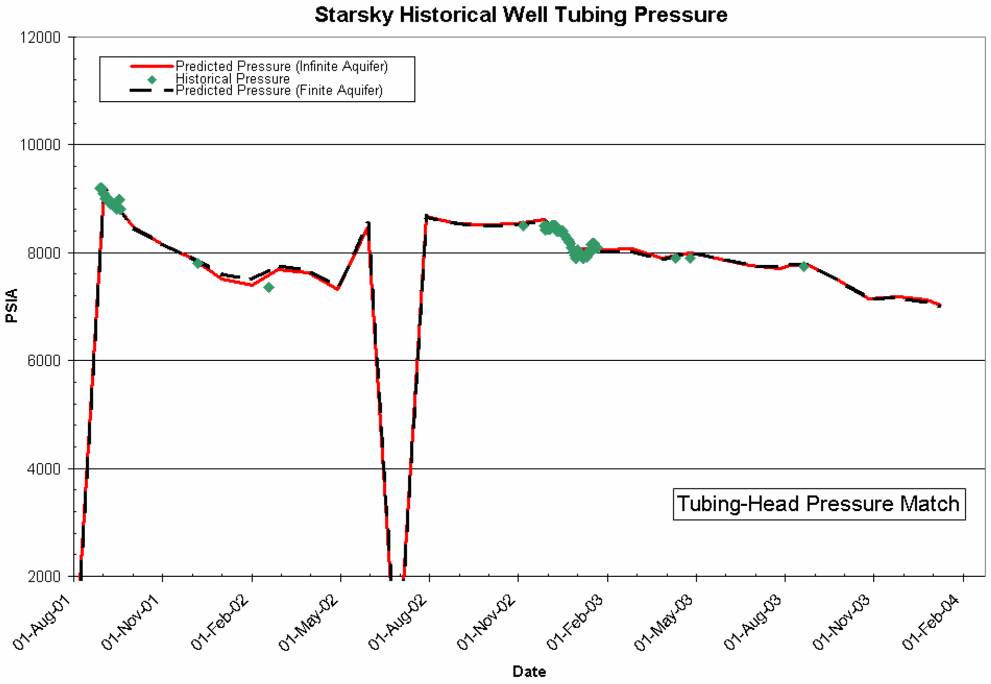
Mature Reservoirs & History Matching (Appropriateness)

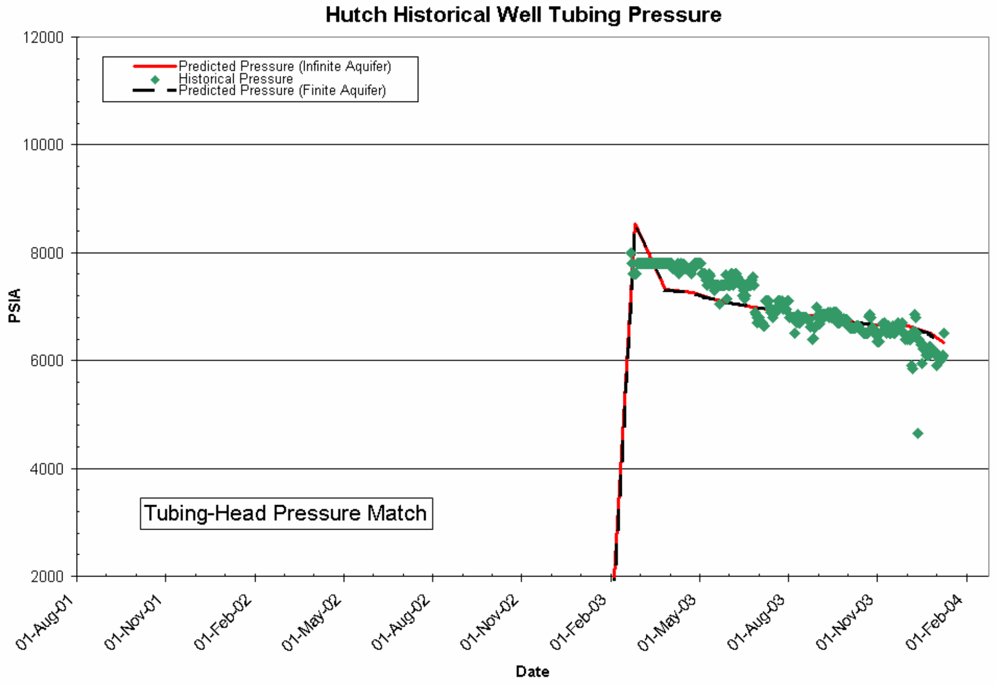
- Here is an example of a good history match but there still exists geological uncertainty.


Historical Field Gas Production Rate
(2 wells)
100000
10000
1000
100
Mscf/Day
Predicted Rate (Infinite Aquifer)
Historical Rate
Predicted Rate (Finite Aquifer)
History Match - Gas Rate
01-Aug-01
01-Nov-01
01-Feb-02
01-May-02
01-Aug-02
01-Nov-02
01-Feb-03
01-May-03
01-Aug-03
01-Nov-03
01-Feb-04
Date



Historical Reservoir Pressure
12000
11500
11000
10500
10000
9500
9000
8500
8000
PSIA
Predicted Pressure (Infinite Aquifer)
Historical Pressure
Predicted Pressure (Finite Aquifer)
Reservoir Pressure Match
01-Aug-01
01-Nov-01
01-Feb-02
01-May-02
01-Aug-02
01-Nov-02
01-Feb-03
01-May-03
01-Aug-03
01-Nov-03
01-Feb-04
Date


Starsky Historical Well Tubing Pressure
Predicted Pressure (Infinite Aquifer)
Historical Pressure
Predicted Pressure (Finite Aquifer)
Tubing-Head Pressure Match
PSIA
Date
12000
10000
8000
6000
4000
2000
01-Aug-01
01-Nov-01
01-Feb-02
01-May-02
01-Aug-02
01-Nov-02
01-Feb-03
01-May-03
01-Aug-03
01-Nov-03
01-Feb-04

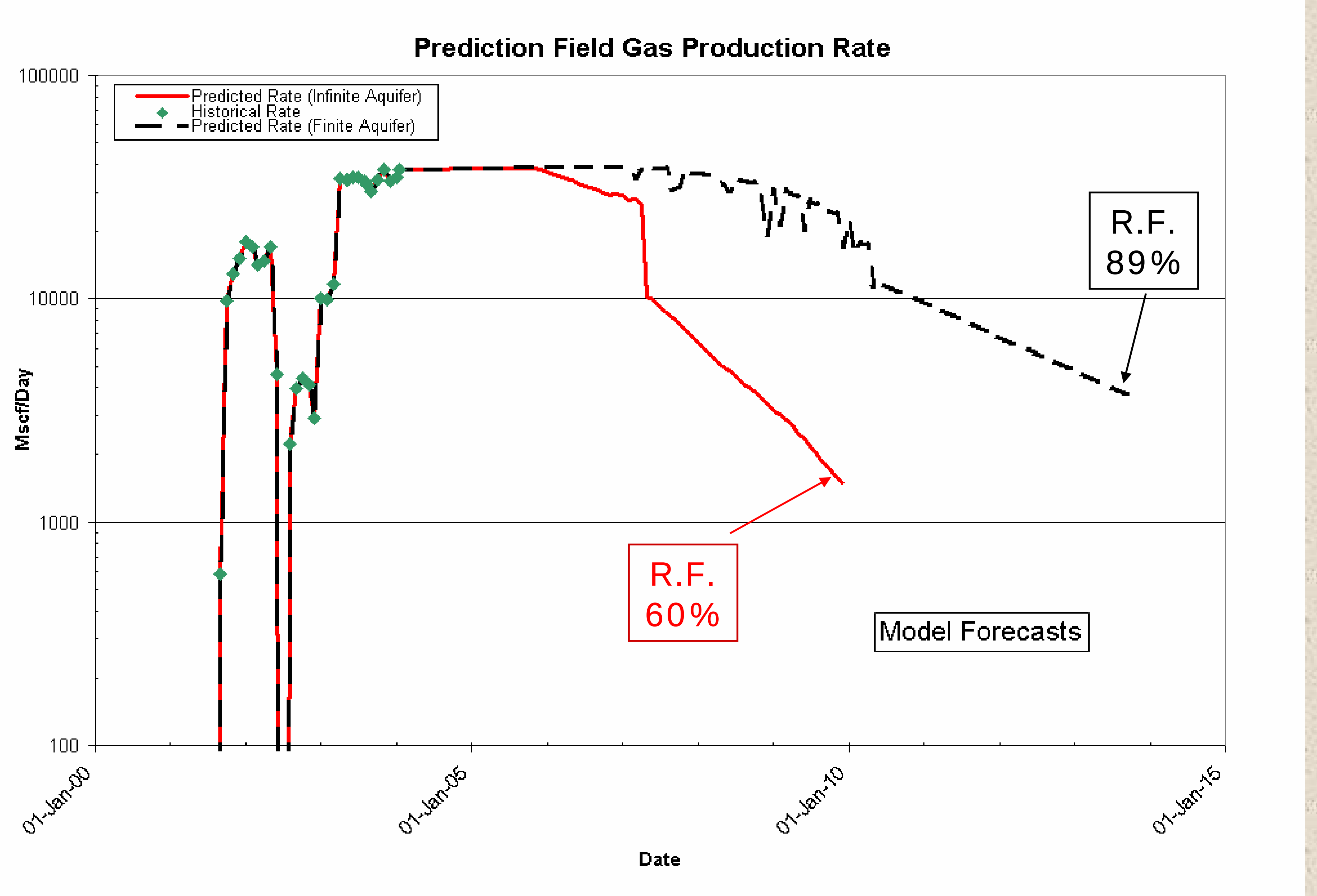

Hutch Historical Well Tubing Pressure
Predicted Pressure (Infinite Aquifer)
Historical Pressure
Predicted Pressure (Finite Aquifer)
Tubing-Head Pressure Match
PSIA
Date
12000
10000
8000
6000
4000
2000
01-Aug-01
01-Nov-01
01-Feb-02
01-May-02
01-Aug-02
01-Nov-02
01-Feb-03
01-May-03
01-Aug-03
01-Nov-03
01-Feb-04

Mature Reservoirs & History Matching (Appropriateness)

- How much confidence should be placed in this model?

Mature Reservoirs & History Matching (Appropriateness)

- Hint: How well do we know the geology?

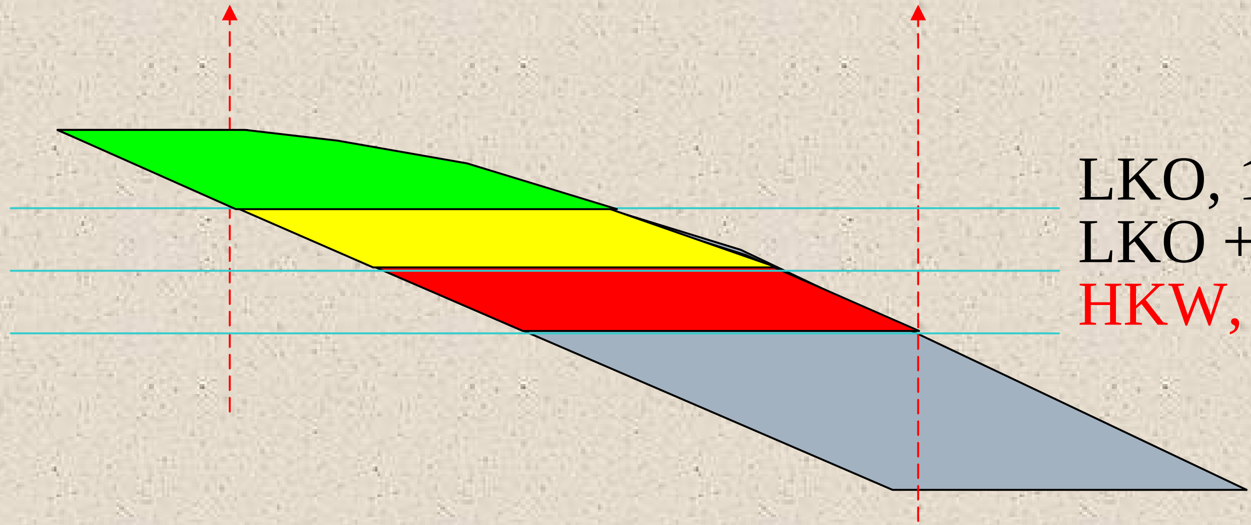


Prediction Field Gas Production Rate
Predicted Rate (Infinite Aquifer)
Historical Rate
Predicted Rate (Finite Aquifer)
100000
10000
1000
100
Mscf/Day
01-Jan-00
01-Jan-05
01-Jan-10
01-Jan-15
Date
R.F. 89%
R.F. 60%
Model Forecasts

Mixed Reserves Classes

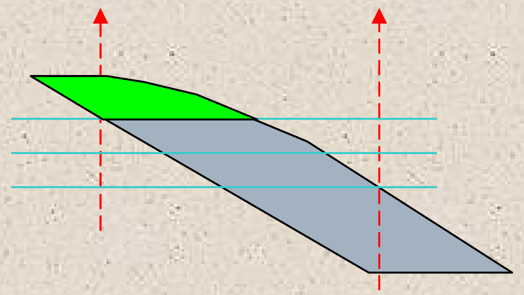
- Best that an acceptable proved + probable or proved + probable + possible model be developed, history matched, and forecast.
- This model would then be modified for the higher classification runs.
- Probable reserves incremental between proved and proved + probable simulations.

Mixed Reserves Classes

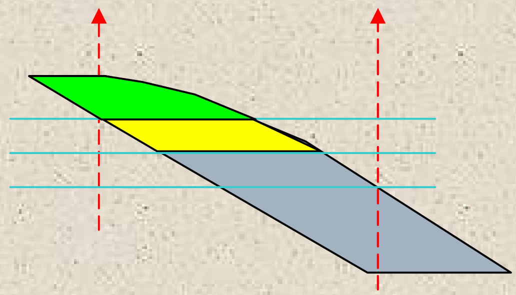


LKO, 1P
LKO + 1 Sand Thickness, 2P
HKW, 3P

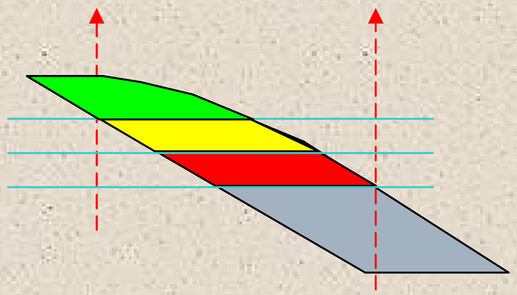
Proved Model



Proved + Probable Model

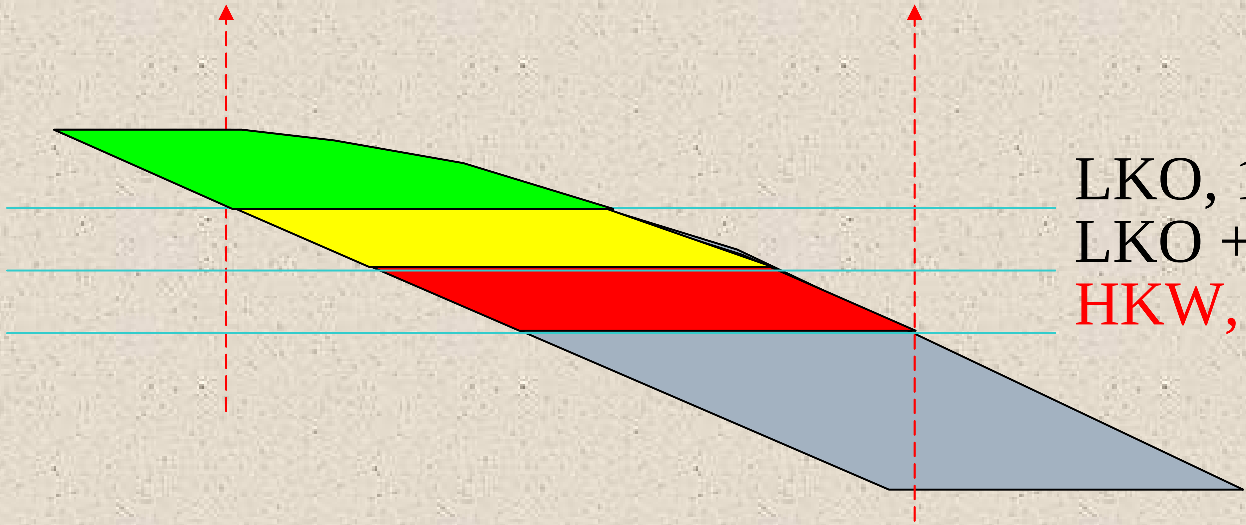


Proved + Probable + Possible Model



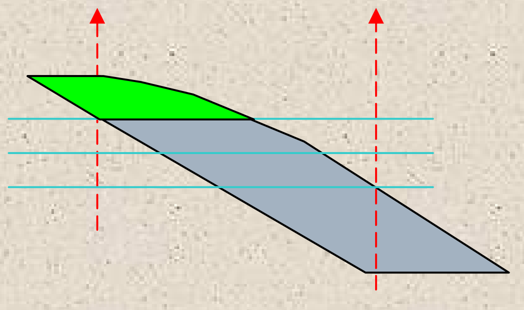
Best Approach

Mixed Reserves Classes

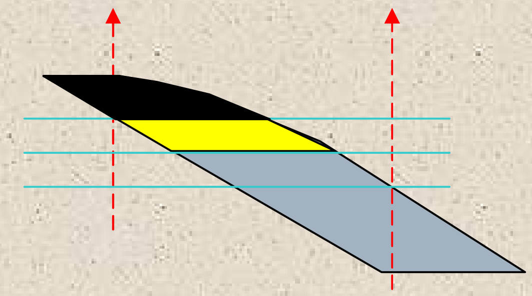


LKO, 1P
LKO + 1 Sand Thickness, 2P
HKW, 3P

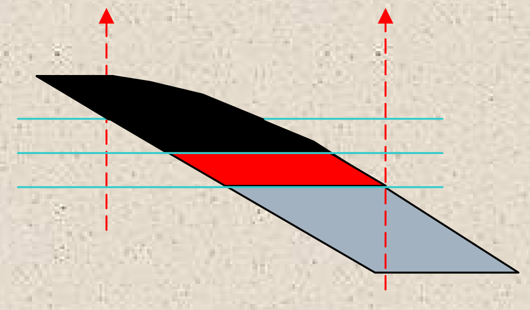
Proved Model



Probable Model



Possible Model



Less Desirable Approach
(separate models)

Mixed Reserves Classes

- Note, removing hydrocarbon volumes from a history matched model can have unforeseen consequences that must be investigated.
  - There are cases where rate forecasts from proved reserves reach higher rates than the reserves forecasts from the history matched proved + probable model, despite featuring less OOIP and fewer wells.
  - This could be caused by mobility contrasts between the cases and enhanced contact with the aquifer when bands of hydrocarbon are removed from a history matched model.

Conclusions

- **Analogy**
- Must follow Reserves Definitions
- Models typically capture “most likely” description
- Models can be modified to comply with the definitions
- May alter the simulation output
- Immature reservoirs - hydrocarbon recovery efficiency
- Sensitivity studies for uncertain parameters
- Reasonable history matches
- Status Quo Cases

Conclusions Analogy

- *In general, simulation results should be treated as if they are actual results from an analog field.*
- *If the simulation model is very detailed, properly constructed, and well history matched, then the model can be treated as a nearly perfect analog.*
- *It is our conclusion that when incorporating simulation modeling results into reserves estimation, the model should be treated as additional data, rather than the sole source of data.*

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Conclusions
Must follow Reserves Definitions

- *Reservoir simulation should be used to improve the understanding of a reservoir, but should not be used to circumvent the terms of the Reserves Definitions.*

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Conclusions
Sensitivity Studies

- *Some parameters will be uncertain, even in a history matched model. These parameters may strongly influence the prediction mode results. The impact of uncertain parameters should be studied through the use of sensitivity runs.*
  - *How would you incorporate this in reserves?*
  - *Use low side.*

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Conclusions
Reasonable History Matches

- *Models of mature reservoirs should feature reasonable history matches before they are accepted for reserves purposes. The uniqueness and the quality of the history match affect the confidence to be placed in a model's ability to predict future performance, and thus dictate the model's appropriate usage in the process of estimating reserves.*

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Closing Thoughts

- The reliability of the results from a model is strongly dependent on the understanding of the geology and the confidence in all of the parameters used to construct the model.
  - What is needed?
    - Reasonable Assumptions
    - Good History Match
    - Good/Reasonable Forecast
    - Sensitivity Cases
  - Documentation/Supporting Information

Final Remarks

- Defense of simulation results before regulatory bodies is somewhat “untested”.
- Don’t expect to use models directly for proved reserves.
- If you want to use models, provide significant supporting information.
- Think of model as an analogy.
- Reasonable Certainty – Revisions should be much more likely to be upward rather than downward.

Questions & Comments?

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