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Optimism in Reservoir Production Forecasting – Impact of Geology, Heterogeneity, Geostatistics, Reservoir Modeling, and Uncertainty

(Why Are Reservoir Production Forecasts Optimistic?)

Dr. W. Scott Meddaugh
Midwestern State University
Wichita Falls, Texas

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Poll Question

What is your job title?

4

Poll Question

What is your primary reservoir interest?

5

Poll Question

Who is your employer?

6

Poll Question

How many years of experience do you have?

7

Poll Question

What geographic region ***are you from***?

8

Poll Question

What geographic region ***do you currently work***?

9

Dr. W. Scott Meddaugh
RL Bolin Distinguished Professor of Petroleum Geology,
Midwestern State University

Outline

- Some key terms
- Are reservoir forecasts optimistic?
- What is the evidence?
  - Indirect
  - Direct
- Impact on forecasts
  - Model grid size and up-scaling
  - Model parameter selection
  - Well location optimization
  - Human bias
- Conclusions

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Some Key Terms

- Forecast – Quantitative description of the oil, gas, and water production from a reservoir as a function of a defined development plan.
- Model – Numerical, often grid-based representation of the subsurface properties such as porosity, permeability, and saturation.

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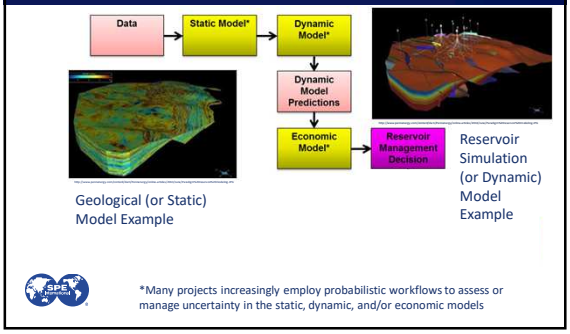
Typical Subsurface Project Workflow

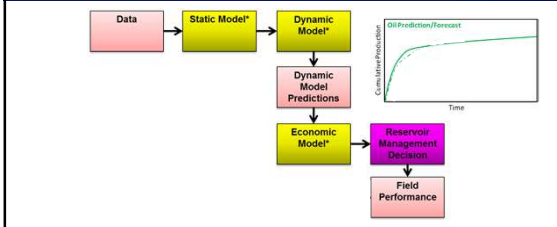


Geological (or Static) Model Example

Reservoir Simulation (or Dynamic) Model Example

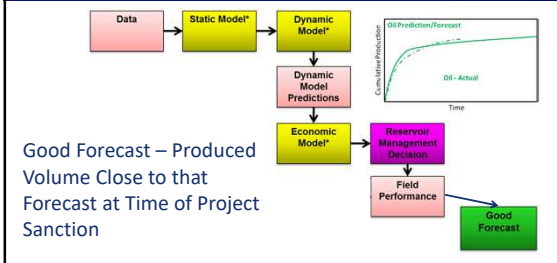
*Many projects increasingly employ probabilistic workflows to assess or manage uncertainty in the static, dynamic, and/or economic models

Typical Subsurface Project Workflow



*Many projects increasingly employ probabilistic workflows to assess or manage uncertainty in the static, dynamic, and/or economic models

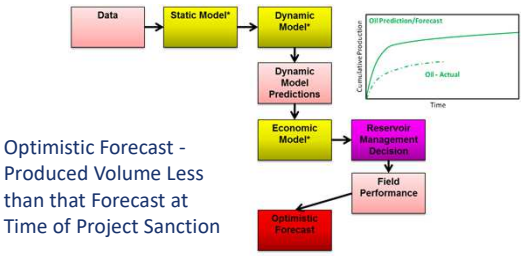
Typical Subsurface Project Workflow



Good Forecast – Produced Volume Close to that Forecast at Time of Project Sanction

*Many projects increasingly employ probabilistic workflows to assess or manage uncertainty in the static, dynamic, and/or economic models

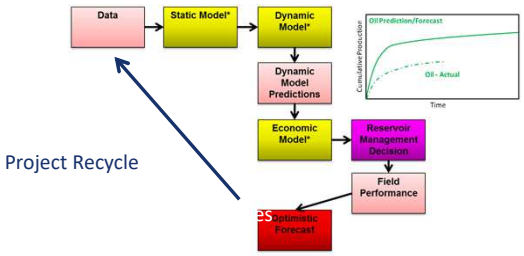
Typical Subsurface Project Workflow



Optimistic Forecast - Produced Volume Less than that Forecast at Time of Project Sanction

*Many projects increasingly employ probabilistic workflows to assess or manage uncertainty in the static, dynamic, and/or economic models

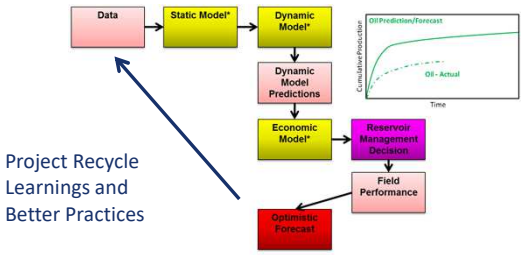
Typical Subsurface Project Workflow



Project Recycle

*Many projects increasingly employ probabilistic workflows to assess or manage uncertainty in the static, dynamic, and/or economic models

Typical Subsurface Project Workflow



Project Recycle Learnings and Better Practices

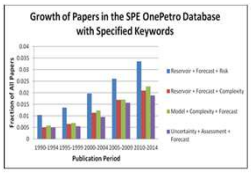
*Many projects increasingly employ probabilistic workflows to assess or manage uncertainty in the static, dynamic, and/or economic models

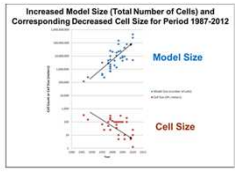
Some Key Terms

- **Forecast** – Quantitative description of the oil, gas, and water production from a reservoir as a function of a defined and financially sanctioned development plan.
- **Model** – Numerical, often grid-based representation of the subsurface properties such as porosity, permeability, and saturation.
- **Optimistic Forecast** – Forecast oil and/or gas production volumes are significantly above the actual produced volumes.

Are Reservoir Forecasts Optimistic?

- **Indirect Evidence** – Increased focus of papers; Larger models with much smaller cells





(from Meddaugh et al, 2011, 2014)

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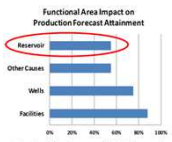
Are Reservoir Forecasts Optimistic?

- **Direct Evidence** – Nandurdikar and Wallace reported in 2011* based on an Independent Project Analysis Inc. (IPA) study that major capital projects today are delivering on average only 75% of production forecast at financial sanction due to:
- Optimistic subsurface assumptions
- Failure of internal assurance processes
- Lack of accountability for production volumes including project/decision look-backs



Note that projects impacted by reservoir "issues" achieve only about 55% of the forecast production volumes

*Failure to Produce: An Investigation of Deficiencies in Production Attainment (Nandurdikar and Wallace, 2011, SPE 145437)

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Why Are Production Forecasts Optimistic? (1 of 2)

1. Underlying geological models may not adequately model reservoir heterogeneity due to model parameter choices.
2. Original or remaining hydrocarbon in place too high
   - Sparse, non-representative data that is often biased towards better reservoir quality
   - Inadequate or improperly used analog data and/or uncertainty assessment workflows

Why Are Production Forecasts Optimistic? (2 of 2)

3. Reservoir simulation models that are inadequate due to grid size, up-scaling, and/or the use of well location optimization workflows.
4. Human Biases
   - Technical team "sourced" bias
   - Management "sourced" bias

Why Are Production Forecasts Optimistic? Impact of Model Grid Size

- Geological models typically now have tens to hundreds of million of model cells.
- Reservoir simulation models typically have only a few million model cells at most often due to run-time limits.
- Consequently, geological models are generally up-scaled.
- An impact of up-scaling may be the loss of "geology", particularly permeability contrasts (e.g. barriers/baffles, thief zones).

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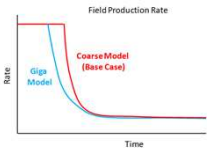
Why Are Production Forecasts Optimistic? Impact of Model Grid Size

- Coarse Grids Likely Give Very Optimistic Recovery; Perhaps as Large as 10-15 or More Recovery Factor Units (RFU)
- Note that 1 RFU = 1% of Forecast Recovery



10-15% Production Forecast Increase Predicted from Coarse Model Compared to Giga-Cell Model Forecast (After Obi et al.,2014)

Model Grid Size = Total number of cells and cell dimensions

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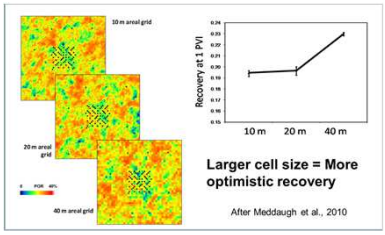
Why Are Production Forecasts Optimistic? Impact of Model Grid Size

- Larger model cell size = More optimistic recovery

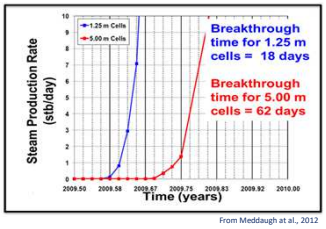


Model Grid Size = Total number of cells and cell dimensions

26

Why Are Production Forecasts Optimistic? Impact of Model Grid Size

- Smaller model cells give more rapid and more realistic breakthrough times



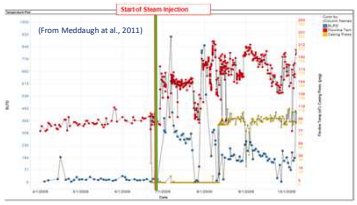
From Meddaugh at al., 2012

Model Grid Size = Total number of cells and cell dimensions

27

Why Are Production Forecasts Optimistic? Impact of Model Grid Size

- Smaller model cells give more rapid and more realistic breakthrough times
- Field data at right

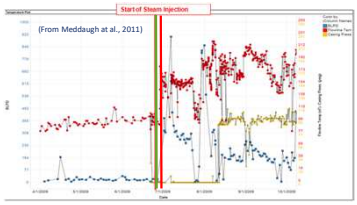


Green line shows start of steam injection

28

Why Are Production Forecasts Optimistic? Impact of Model Grid Size

- Smaller model cells give more rapid and more realistic breakthrough times
- Field data at right

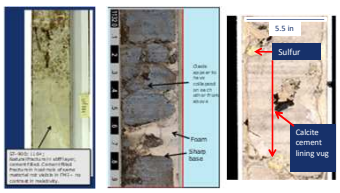


Hot water observed at a producer within a few days!

29

Possible Reasons for Rapid Well Response to Steam Injection

- High permeability pathways
  - Fractures
  - Karst zones
  - Stratigraphy or diagenesis-related (connected vugs)



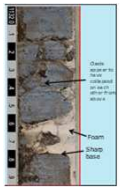
Small Fractures in Core | Small Karst Zone in Core | Open and Filled Vugs in Core

30

Possible Reasons for Rapid Well Response to Steam Injection

- High permeability pathways
  - Fractures
  - Karst zones
  - Stratigraphy or diagenesis-related (connected vugs)
  - Connected very high permeability not due to any of the above

Small Fractures in Core

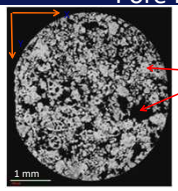


Small Karst Zone in Core

Open and Filled Vugs in Core

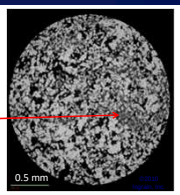
31

Micro-CT Images and Calculated Porosity and Permeability from Pore Network



Grains (white)
Pores (black)

Organic Matter (gray)



Preliminary Permeability Values

X-Perm = 6700mD
Y-Perm = 6100mD
Z-Perm = 6900mD

Preliminary Permeability Values

X-Perm = 720mD
Y-Perm = 710mD
Z-Perm = 790mD

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Why Are Production Forecasts Optimistic? Impact of Model Grid Size

- Coarse grid models do not capture enough heterogeneity and thus minimize "channels" or "thief zones" (green cells)" in reservoir models.
- During primary production, higher quality reservoir is produced earlier.
- During waterflooding, the water preferentially will move through the higher quality path leading to "early breakthrough" and less recovery than forecast

	1	2	3	4	5
1	47.0	43.0	18.2	5.8	30.6
2	21.2	30.1	47.7	45.6	3.7
3	8.0	40.4	14.5	43.8	14.3
4	47.8	24.3	26.0	37.5	21.3
5	39.8	30.7	37.9	25.6	39.9

Simple "coarse grid" model showing direct and "best" flow path. Though longer, fluid moving through the "best" path will arrive at the producer earlier. Coarser cells lead to higher recovery. Pore volume of best path is 6% higher than coarse path for this grid.

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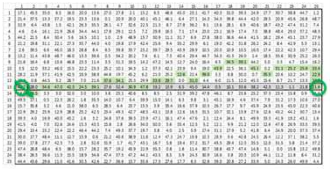
Why Are Production Forecasts Optimistic? Impact of Model Grid Size

- Coarse grid models do not capture enough heterogeneity and thus minimize "channels" or "thief zones" (green cells)" in reservoir models.
- During primary production, higher quality reservoir is produced earlier.
- During waterflooding, the water preferentially will move through the higher quality path leading to "early breakthrough" and less recovery than forecast



Simple "fine grid" model showing direct and "best" flow path. Though longer, fluid moving through the "best" path will arrive at the producer much earlier. Smaller cells lead to lower recovery. Pore volume of best path is 30% higher than coarse path for this grid.

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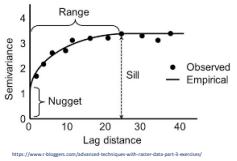
Why Are Production Forecasts Optimistic? Impact of Semivariogram

- Semivariogram (γ) – measure of spatial continuity
- Range parameter increases as the spatial continuity of the property of interest (e.g. porosity) increases

$$\gamma^*(h) = \frac{1}{2N_h}\sum_{i=1}^{N_h}\left[Z(x_i+h) - Z(x_i)\right]^2$$

Z = Data Value at locations *x(i)* and *x(i+h)*
N = Number of sample pairs at separation distance ***h***



https://www.r-bloggers.com/advanced-techniques-with-raster-data-part-3-exercises/

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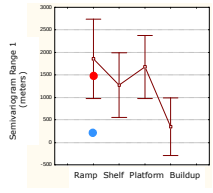
Why Are Production Forecasts Optimistic? Impact of Semivariogram

Map at right shows the carbonate reservoirs included in survey (after Meddaugh, 2006a, 2010)



- Wafra First Eocene Full Field (>25,000 acres with 1000 m average well spacing)
- Wafra First Eocene Large Scale Steamflood Pilot (LSP) Project (40 acres with 40 m average well spacing)

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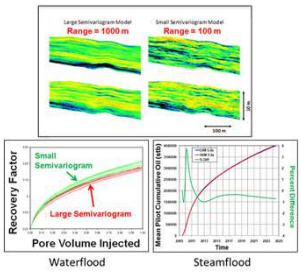
Why Are Production Forecasts Optimistic? Impact of Semivariogram

- For **Waterfloods** – Models generated using small semivariogram range models and large semivariogram range models give different recovery, on the order of only 2-3 recovery factor units (RFUs) difference.
- For **Steamfloods** – virtually no difference between models generated with large or small semivariogram range values (from Meddaugh et al., 2012)



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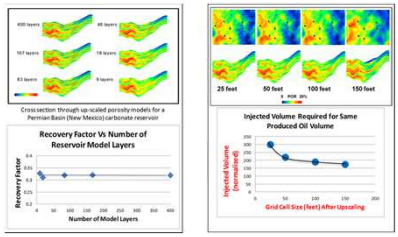
Why Are Production Forecasts Optimistic? Impact of Model Upscaling

- Vertical upscaling (left) has small, if any impact on forecast.
- Areal upscaling (right) shows optimistic impact, perhaps 3-5 RFUs (after Meddaugh, 2006).



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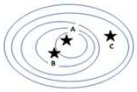
Why Are Production Forecasts Optimistic? Impact of Sparse Data

- Forecast, as a function of well drilling order is shown in table at bottom. Forecast is based on a data set consisting of 18 analog reservoirs.
  1. One well forecast recovery range is 27-51%
  2. Two well forecast recovery range is 34-46%
  3. Three well forecast is 40%
- Impact of sparse data on forecast may be large; about 10-15 RFUs in this "very simple" example. (From Meddaugh, 2015)

Table 1 - Well Properties for the "Test" Reservoir

Well	Net Avg. Porosity %	Net Avg. Perm md	Net Pay feet
A	27	320	61
B	22	300	55
C	15	260	35



"Test" Reservoir Forecast

Drilling Order	1 Well	2 Wells	3 Wells
ABC	41.7	46.2	39.8
BAC	50.6	46.2	39.8
CBA	27.0	38.8	39.8
ACB	41.7	34.3	39.8
BCA	50.6	38.8	39.8

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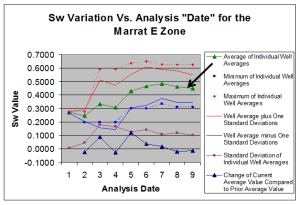
Why Are Production Forecasts Optimistic? Impact of Sparse Data

- Variation of "Average" Reservoir Property as a Function of "Time" for the Humma Marrat Reservoir



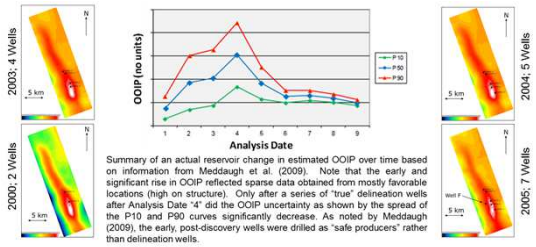
Initial well average Sw = 0.28

After three wells, the average Sw = 0.40

After five wells, the average Sw = 0.45

40

Why Are Production Forecasts Optimistic? Impact of Sparse Data



Summary of an actual reservoir change in estimated OOIP over time based on information from Meddaugh et al. (2009). Note that the early and significant rise in OOIP reflected sparse data obtained from mostly favorable locations (high on structure). Only after a series of "true" delineation wells after Analysis Date "4" did the OOIP uncertainty as shown by the spread of the P10 and P90 curves significantly decrease. As noted by Meddaugh (2009), the early, post-discovery wells were drilled as "safe producers" rather than delineation wells.

Map Shown are Structure Maps on top of Marrat Formation

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Why Are Production Forecasts Optimistic? Impact of Well Location Optimization

- Well Optimization Workflow
  - Automated process used to refine well locations to maximize recovery for a given recovery process (e.g. waterflooding)
  - Based on a particular dynamic model, usually the P50 model but; occasionally also the P10 and P90 models.
- Although the evaluation is in progress, the method generally may yield optimistic forecasts particularly for reservoirs with significant permeability contrasts and for displacement-based recovery processes

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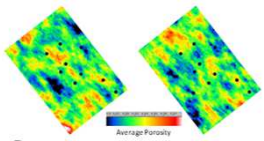
Why Are Production Forecasts Optimistic? Impact of Well Location Optimization

- Well Optimization Evaluation Workflow
  - Build multiple realizations (e.g. 25) of static model
  - Randomly choose one of the realizations to optimize well locations
  - Evaluate forecasts for all realizations using the same optimized well locations



Average porosity maps for two of the 25 realizations generated for the reservoir used for the well optimization study. Note the significant difference in the porosity distribution in the two realizations. Well locations with data used to build models shown by black circles.

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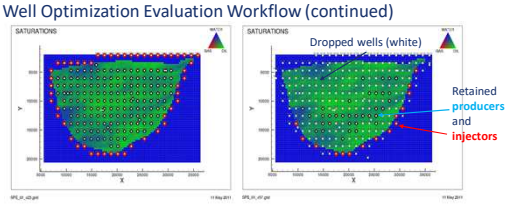
Why Are Production Forecasts Optimistic? Impact of Well Location Optimization

- Well Optimization Evaluation Workflow (continued)



Black circles = active producers, red diamonds = active injectors, white squares = shut in producers, injectors based on cumulative oil/EUR (after Meddaugh et al., 2011).

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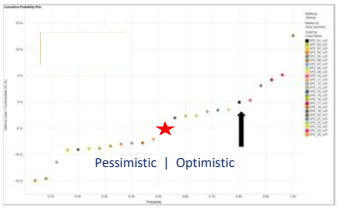
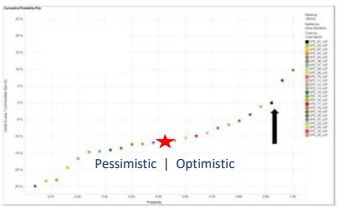
Well Optimization Impact - Oil



Delta cumulative produced oil compared to Case 1 (reference case; highlighted by arrow). Note that the forecasts for 19 of the 25 realizations give less oil using the same "optimized" well locations as Case 1. Star highlights P50 oil.

45

Well Optimization Impact - Gas



Delta cumulative produced gas compared to Case 1 (reference case; highlighted by arrow). Note that the forecasts for 23 of the 25 realizations give less gas using the same "optimized" well locations as Case 1. Star highlights P50 gas.

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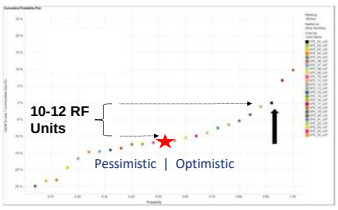
Well Optimization Impact - Gas



Delta cumulative produced gas compared to Case 1 (reference case; highlighted by arrow). Note that most of the forecasts for 23 of the 25 realizations give less gas using the same "optimized" well locations as Case 1. Star highlights P50 gas.

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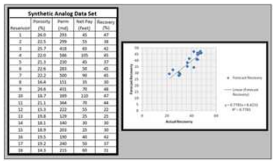
Why Are Production Forecasts Optimistic? Impact of Human Bias

- Technical Team or Management "Induced" Bias to Move a Project Towards (or Away) from Sanction
  - An "experiment" was done (Gilbert et al, 2015; Meddaugh 2015) in which a group of student volunteers were given specific instructions (next slide) and an "exhaustive" analog data set with 18 reservoirs with known reservoir properties and ultimate recoveries



Analog Data set showing simulated recovery for 18 synthetic reservoir models (Meddaugh 2015).

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Why Are Production Forecasts Optimistic? Impact of Human Bias

- **The "Experiment" Set-Up**

Pro-Project Bias	Anti-Project Bias
"Your management has decided that it needs to move forward on the project for the sake of their job as well as yours (cutbacks are coming and bonuses are planned for those staff retained!). You need this project to go forward. Therefore, management has "requested" the **highest possible recovery forecast** that can be defended using a minimum of eight of the 18 analog reservoirs. There will be no peer review of the analog data base used to support your analysis."	"Your local management has decided that it needs to cancel this dubious project even though the company owner believes it to be a very good project. Thus, you need help your local manager to cancel this dubious project. Therefore, local management has "requested" the **lowest possible recovery forecast** that can be defended using a minimum of eight of the 18 analog reservoirs. There will be no peer review of the analog data base used to support your analysis."

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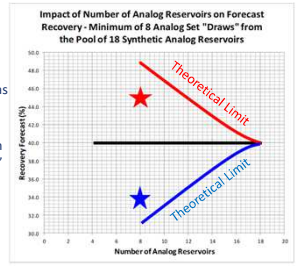
Why Are Production Forecasts Optimistic? Impact of Human Bias

- The Recovery Forecast "Experiment" Results:
  - Most Optimistic Student Forecast (45% of OOIP) with Applied "Project Forward" Bias Shown by **Red Star**
  - Most Pessimistic Student Forecast (33.5% of OOIP) with Applied "Project Termination" Bias Shown by **Blue Star**
- Conclusion – Human Bias Impact Can Be Quite Large; Easily 5-10 or more RFUs



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Summary of Potential Recovery Forecast Bias Sources, Impact, and Direction

Bias Source	Magnitude in Recovery Factor Units (RFUs)	Direction of Bias – Optimistic, Pessimistic, or Either
Reservoir Modeling Parameters	Small, less than 5 RFU.	Either
Vertical Upscaling	Small, less than 5 RFU.	Optimistic
Horizontal Upscaling, Areal Cell Size	Small to Large, likely between 5-15 RFUs	Optimistic
Well Location Optimization	Large, likely between 5 -15 RFU. May tend to be larger for strongly anisotropic reservoirs (e.g. channelized)	Optimistic though additional study is much needed.
Sparse Data	Large, likely between 10-15 RFUs	Either; will be optimistic if early wells sample higher quality reservoir volume as is the "usual" case
Human Decision Bias	Moderate, at least 5-10 RFUs; maybe higher (up to 15 RFUs)	Either; will almost certainly be optimistic given the typical "need" to move projects towards sanction

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Key Messages

- Human, workflow, and software choices likely drive forecasts towards significant optimism
- Although additional studies are needed, many of the optimism "sources" may be mitigated by:
  - Better use of statistics and analogs
  - Wider knowledge of the impact of modeling parameters and well optimization on forecasts
  - Enhanced use of management-independent peer teams and assurance processes to reduce human-induced optimism in forecasts
- Bottom line
  - Better forecasts = Better use of capital and improved company financial performance

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Better Practices

- Incorporate larger range of uncertainty – respect the potential impact of sparse data as well as the potential "non-randomness" of sparse data
- Use models with small areal grid block (cell) sizes – smaller is much better!
- Increased use of actual reservoir lookbacks to assess impact of sparse data on in-place volumes and forecasts
- Increased use of external peer reviews to reduce project team and management bias

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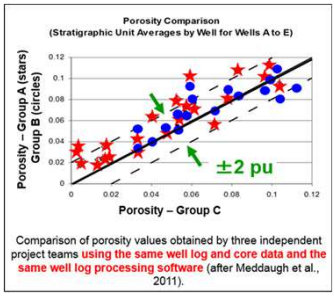
A Closing Thought or Question
How Well Do We Really "Know" Even Our Most Basic Data?



Comparison of porosity values obtained by three independent project teams **using the same well log and core data and the same well log processing software** (after Meddaugh et al., 2011).

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Thank You!

Webinars

- Questions or Comments?

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