鲁棒优化和概率预测量化地质模型不确定性

Quantifying Geologic Uncertainty through Brownfield Optimization and Probabilistic Forecasting

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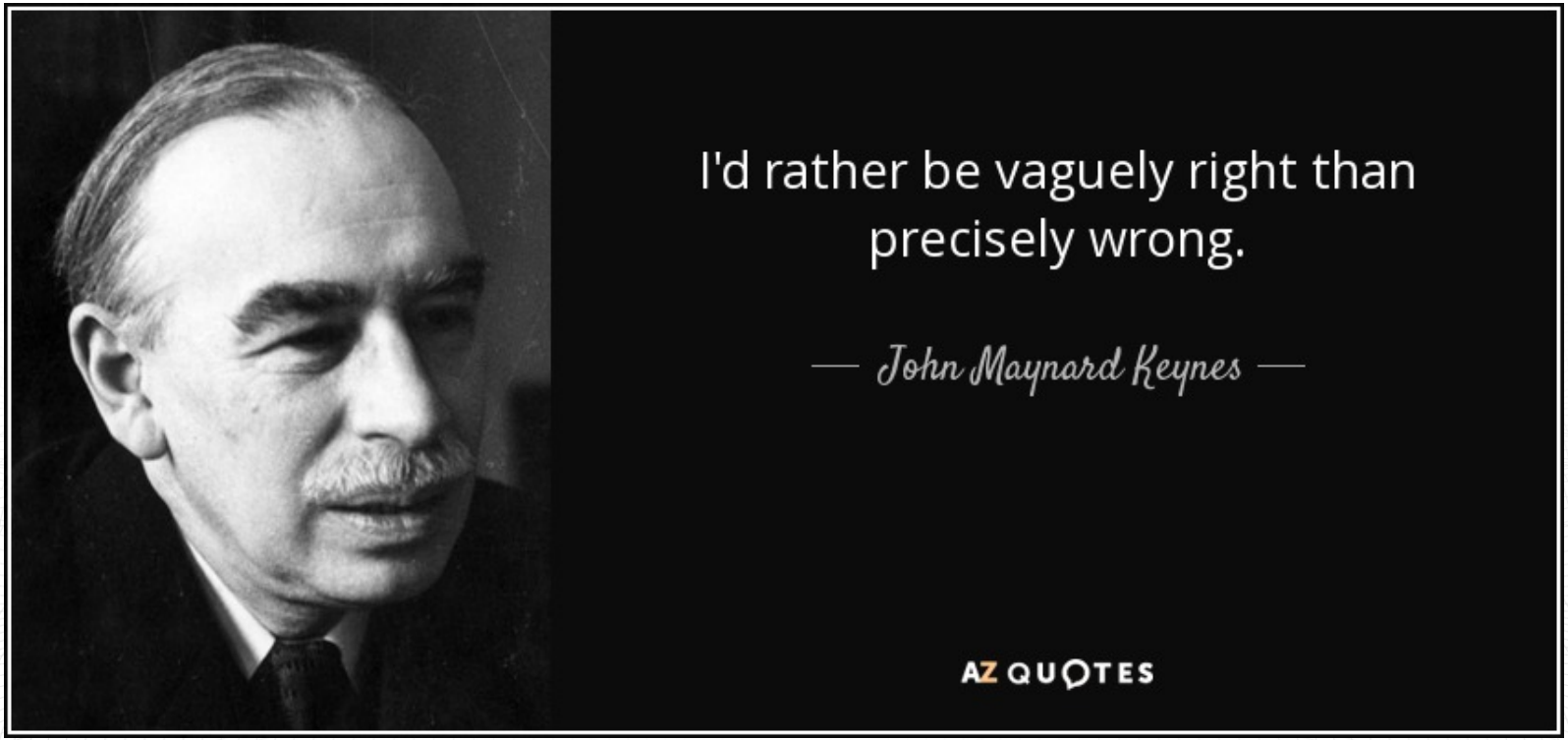

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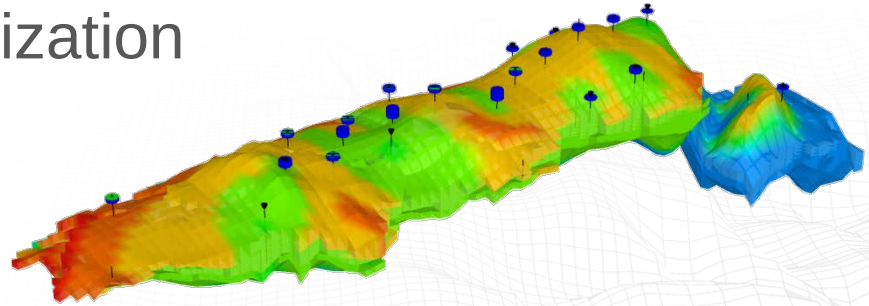
Agenda

- New Approach to History Matching
- Probabilistic Forecasting
- Introduction to Robust Optimization



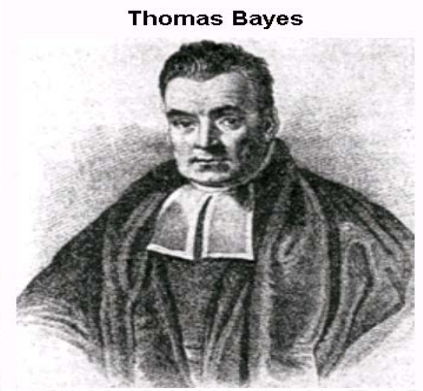
Keynes' Challenge

Would I Rather Have One Precise History Match Or A Range Of Plausible Solutions?

Bayesian Formulation

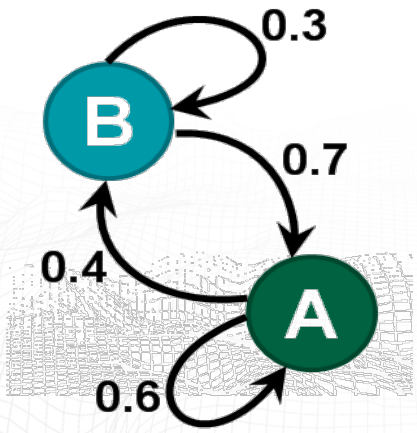
$$\mathrm{P}(model|data) = P(model)\frac{\mathrm{P}(data|model)}{\mathrm{P}(data)}$$

Posterior Probability **Prior Probability** **Conditional Probability**

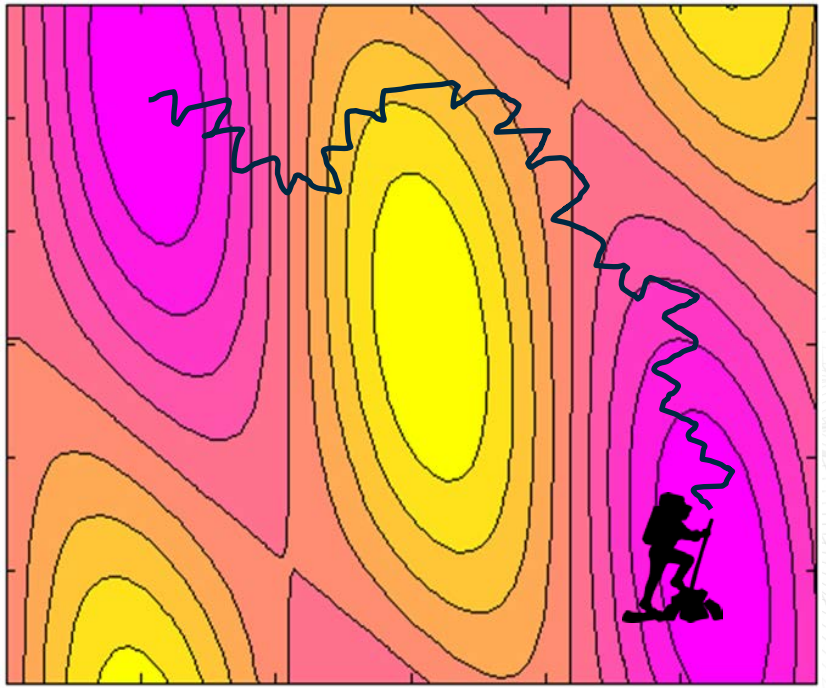


1701-1761

Metropolis-Hastings Markov Chain Monte Carlo (MCMC)



Markov Chain



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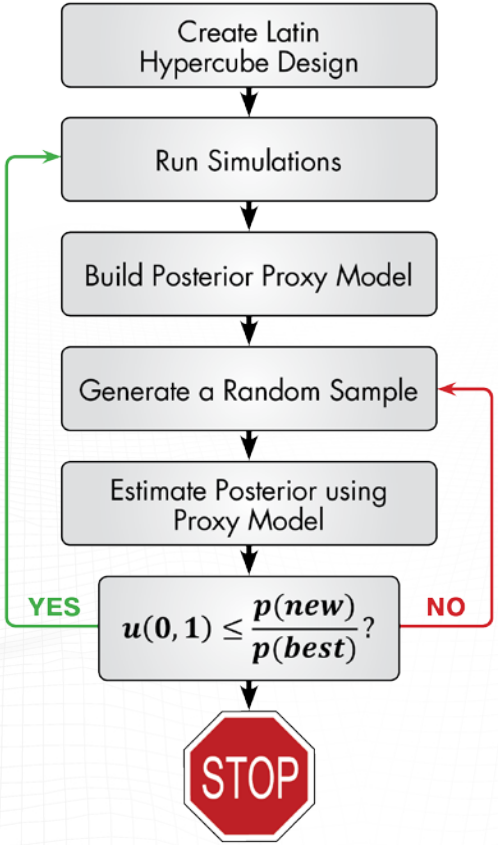
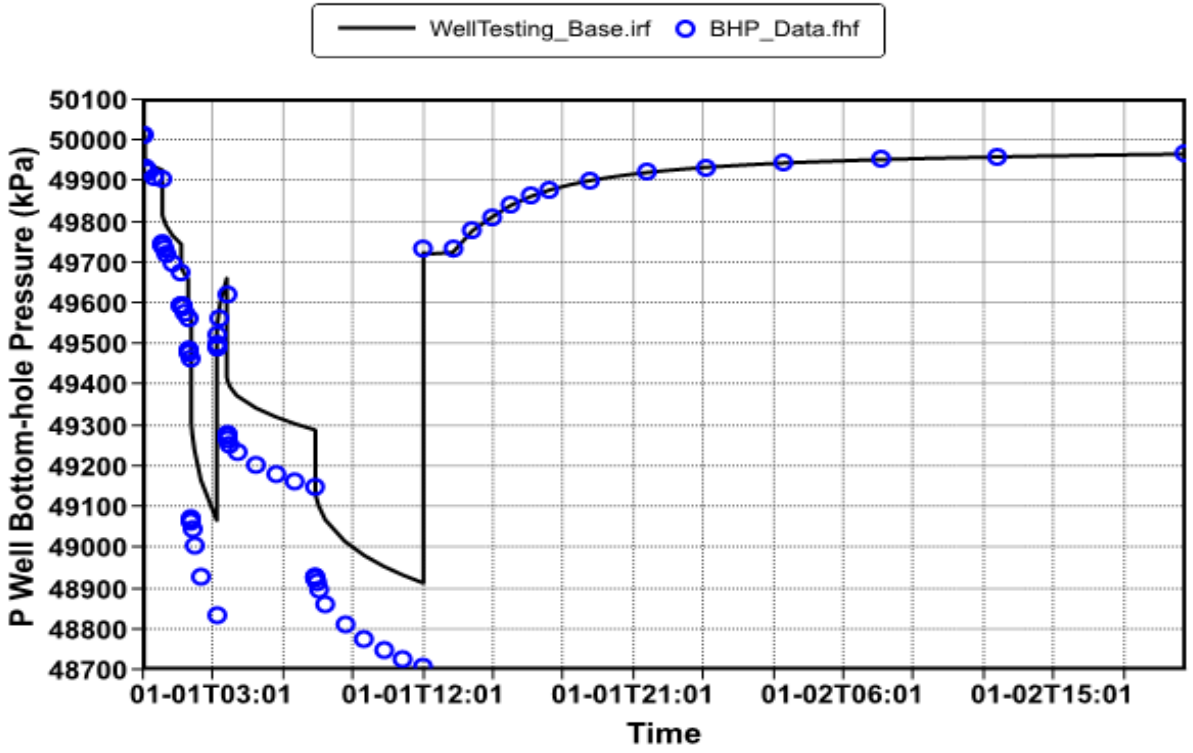
Proxy-based Acceptance-Rejection (CMG PAR)



SPE 175122

Two Parameter Proof of Concept



HM Parameters:

- **Permeability**
- **Skin**

$$PI = \frac{2\pi k h f f_h}{\ln\frac{re}{rw} + S}$$

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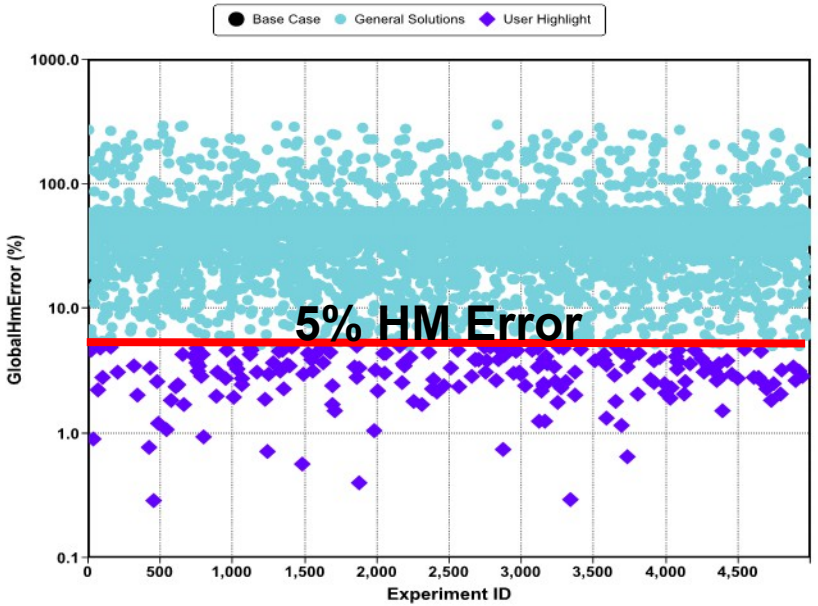
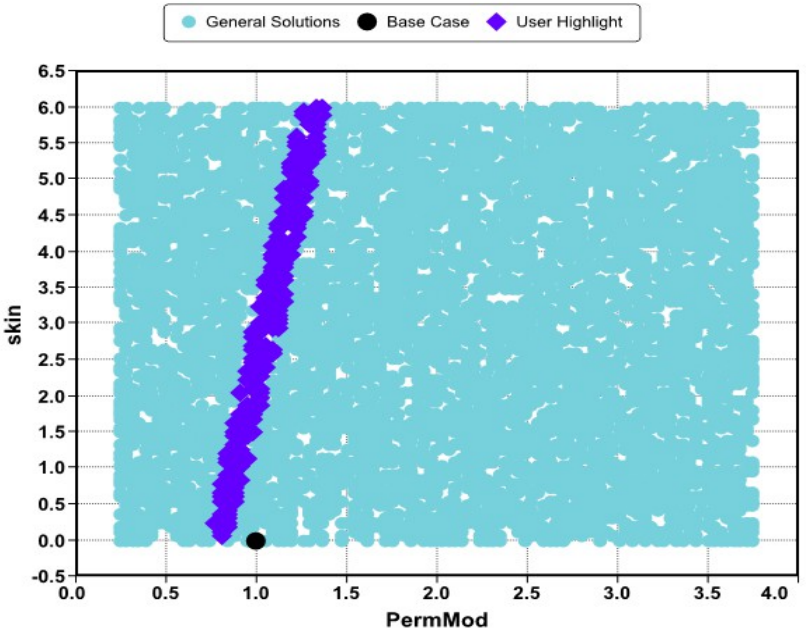
Reference Result – 5000 Brute Force Search





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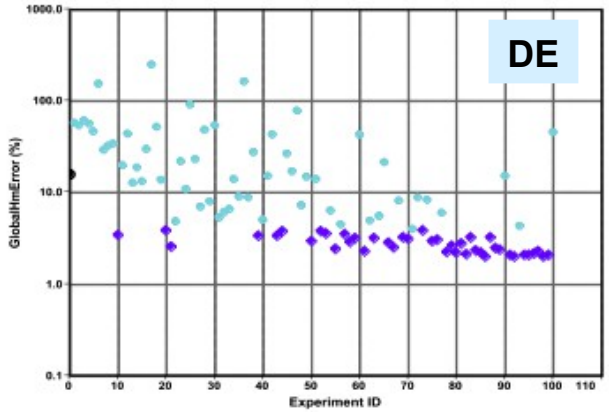
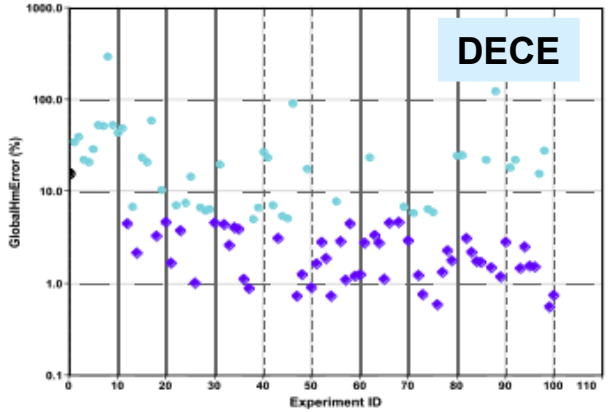
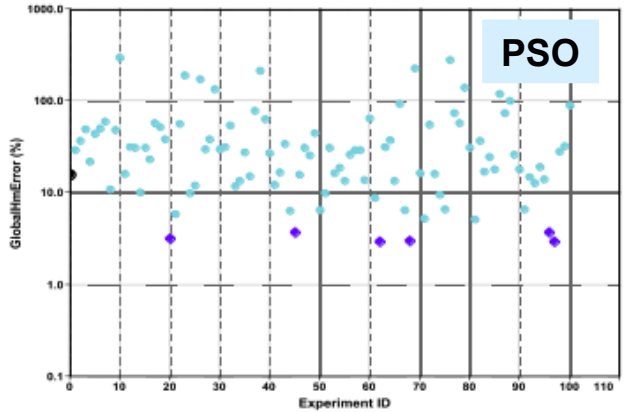
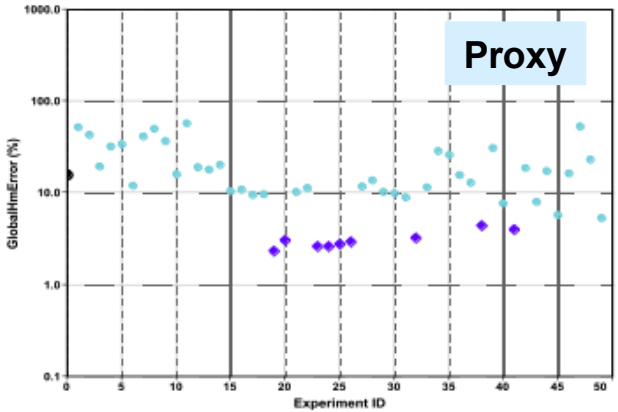
Results from Current Engines









Each engine runs 100 jobs

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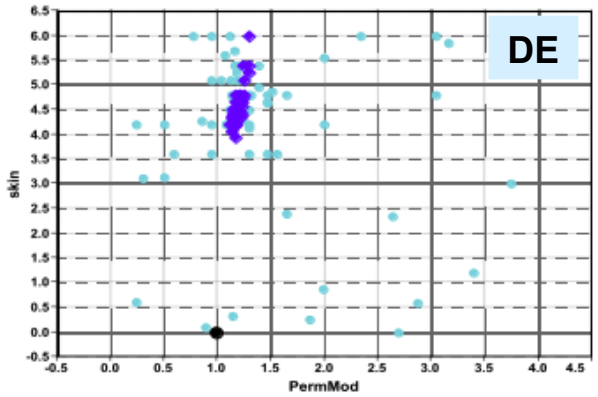
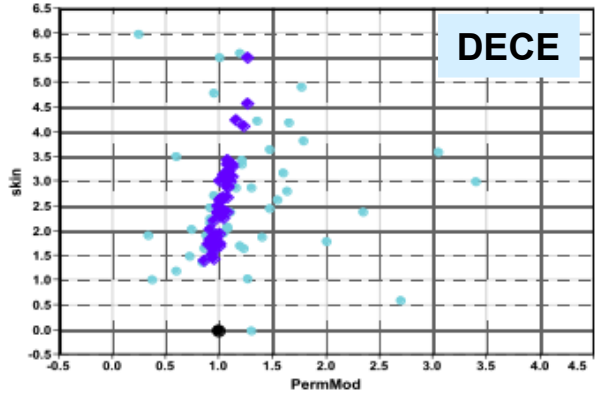
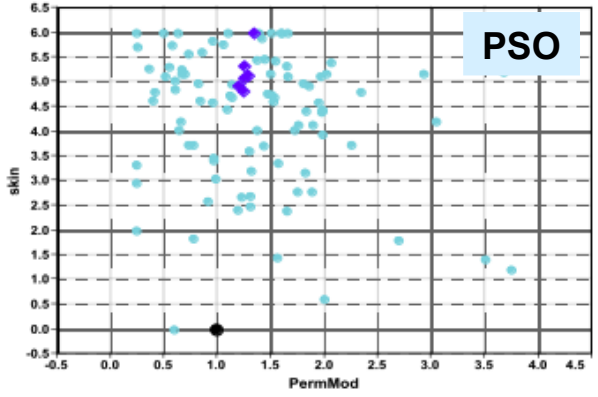
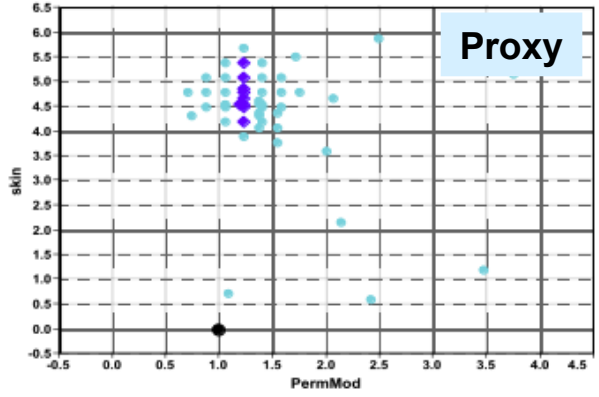
Results from Current Engines









Each engine runs 100 jobs

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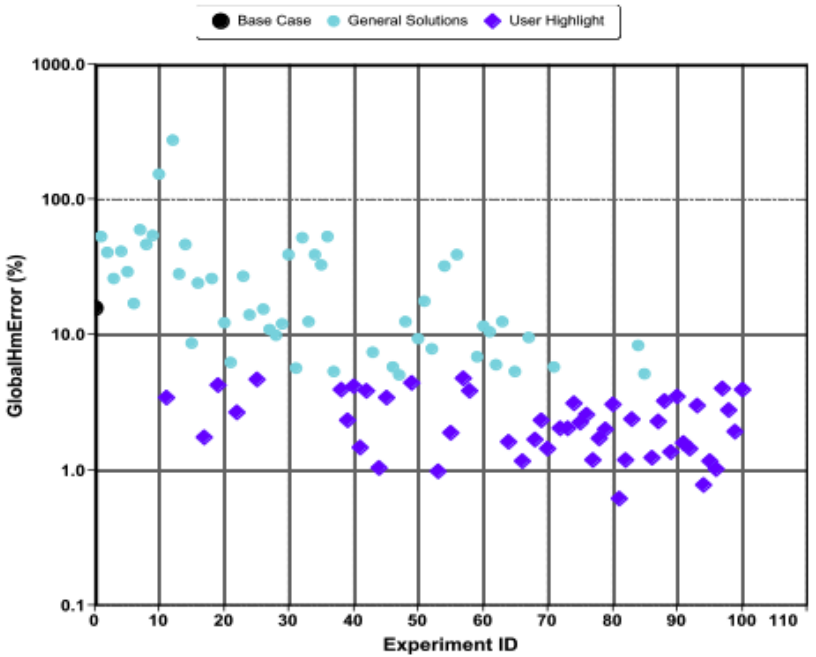
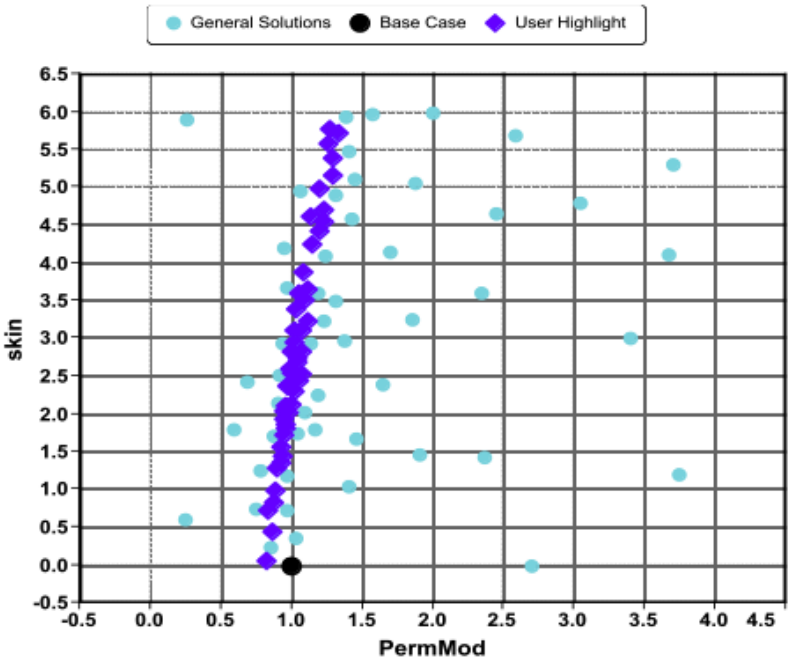
Results from CMG PAR





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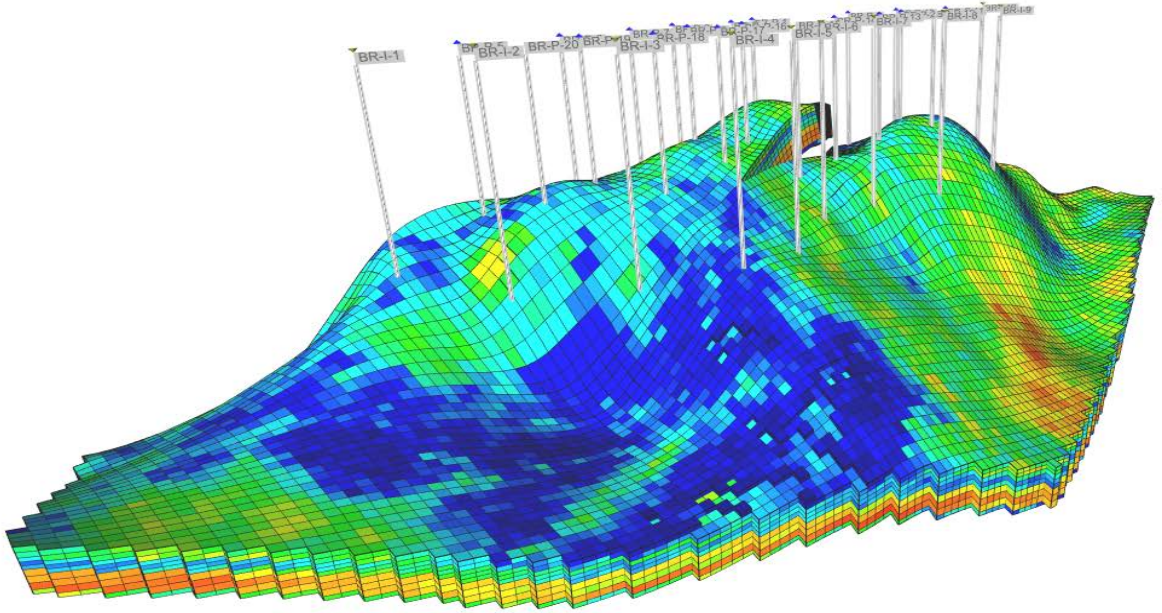
Brugge HM Case Study

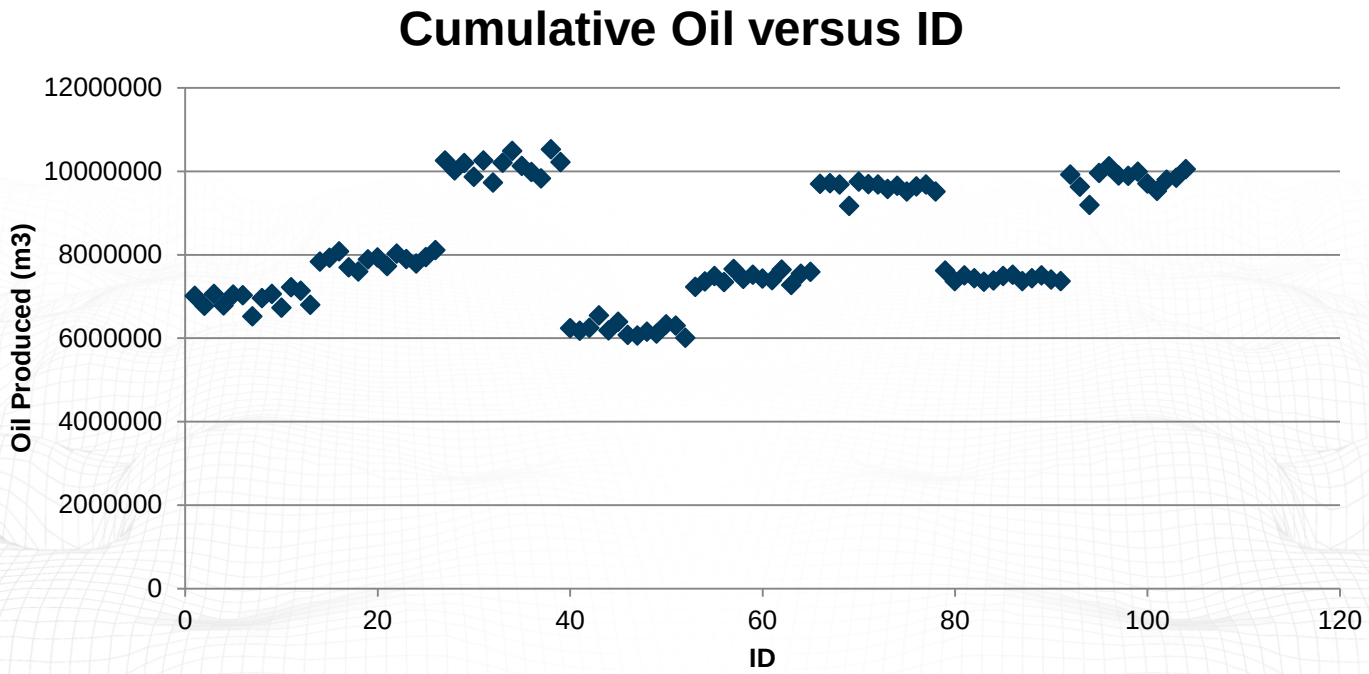


Courtesy of TNO

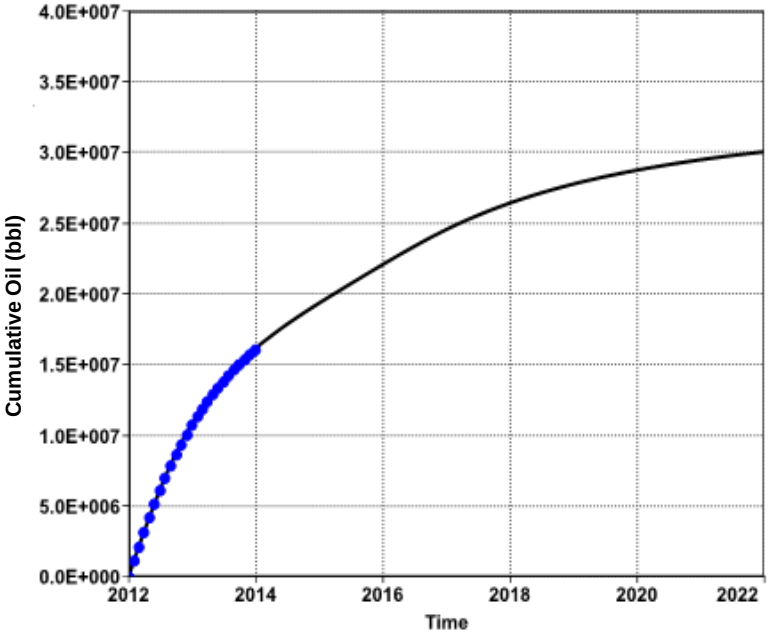
HM Workflow

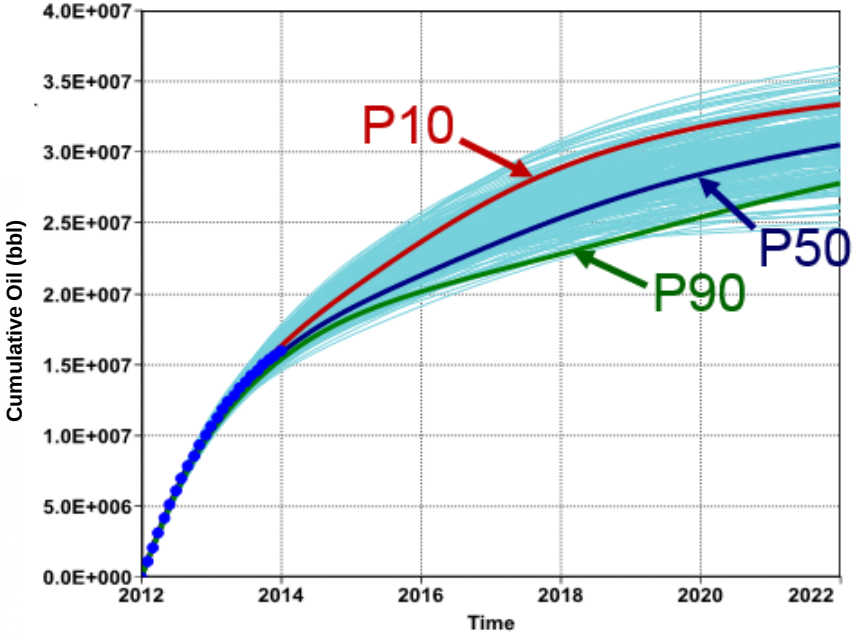

Rank and Select Representative Geologic Realizations
Apply Additional Uncertain Parameters
Select History Match Parameters
Run CMG PAR Engine

Rank Geologic Realizations



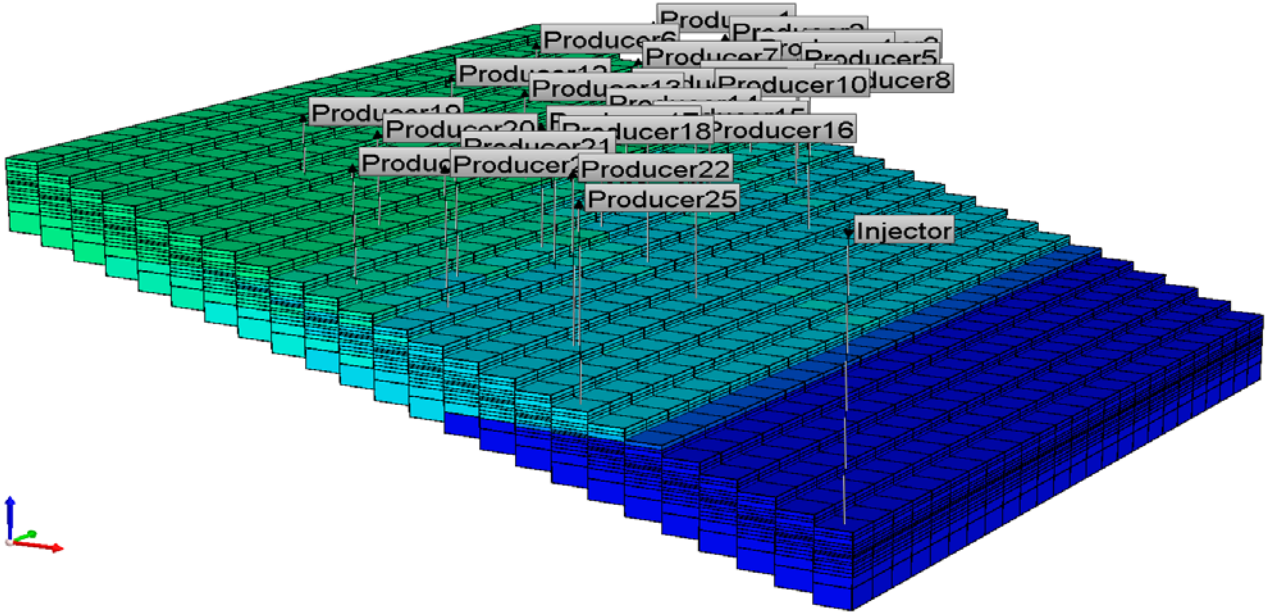
Probabilistic Forecasts





Probabilistic Forecast Proof of Concept

- 9th SPE comparative solution project
- 24×25×15 grid
- 1 water injection well, 12 producers



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History Matching Parameters

- Permeability multipliers
  - 15 multipliers, one for each layer
- KV to KH ratio
  - One for entire model

Summary of HM parameters

SWT and capillary pressure (end points and exponents)	10
SLT (end points and exponents)	6
Permeability multipliers	15
KV to KH ratio	1
Total	**32**

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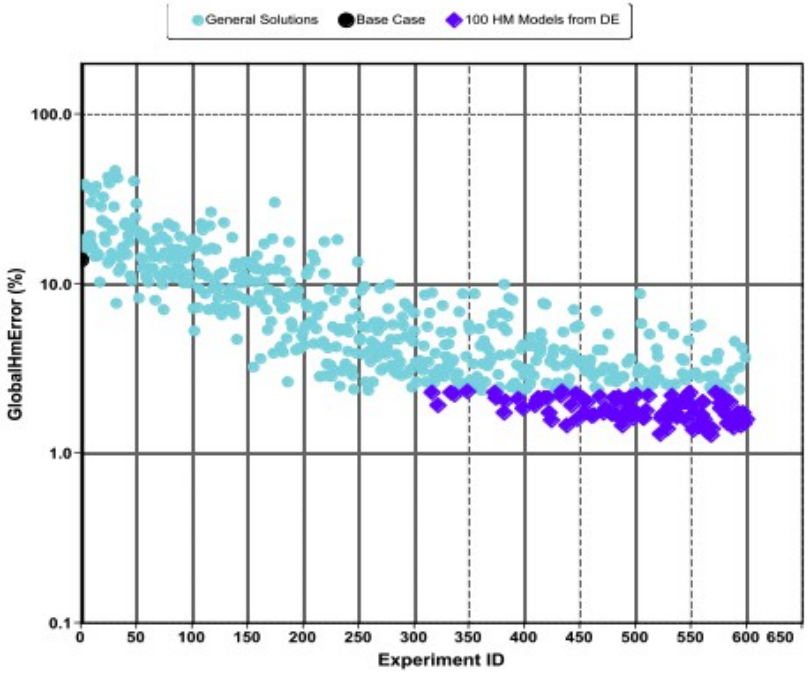
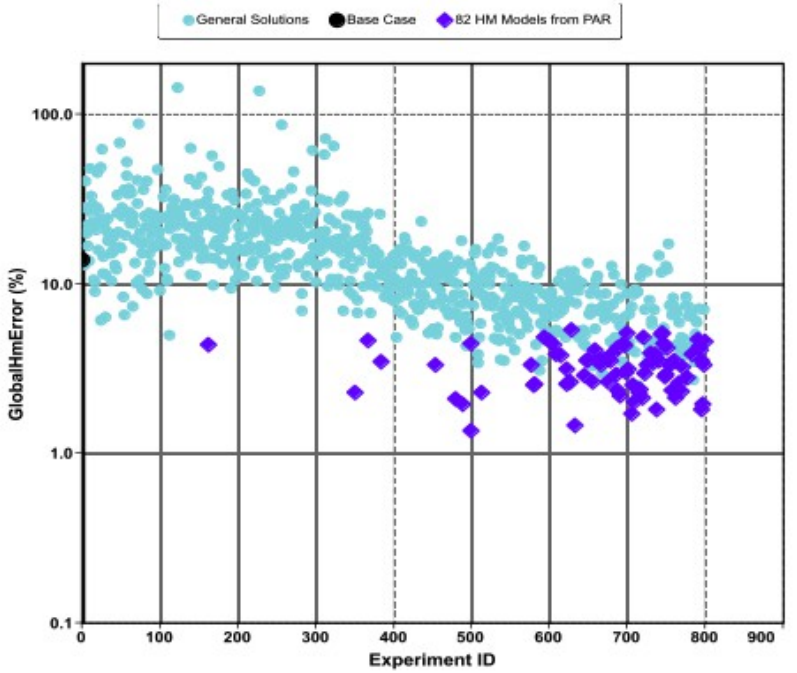
History Matching





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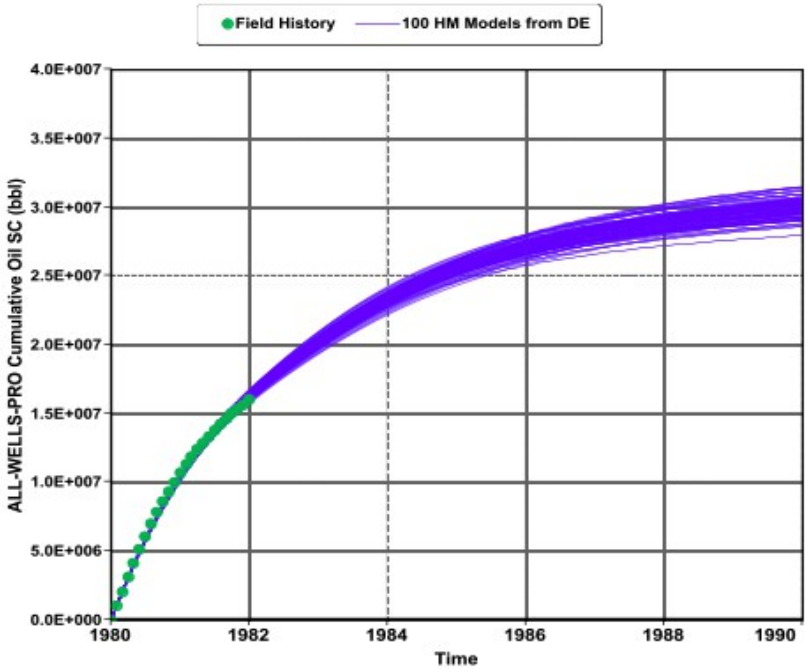
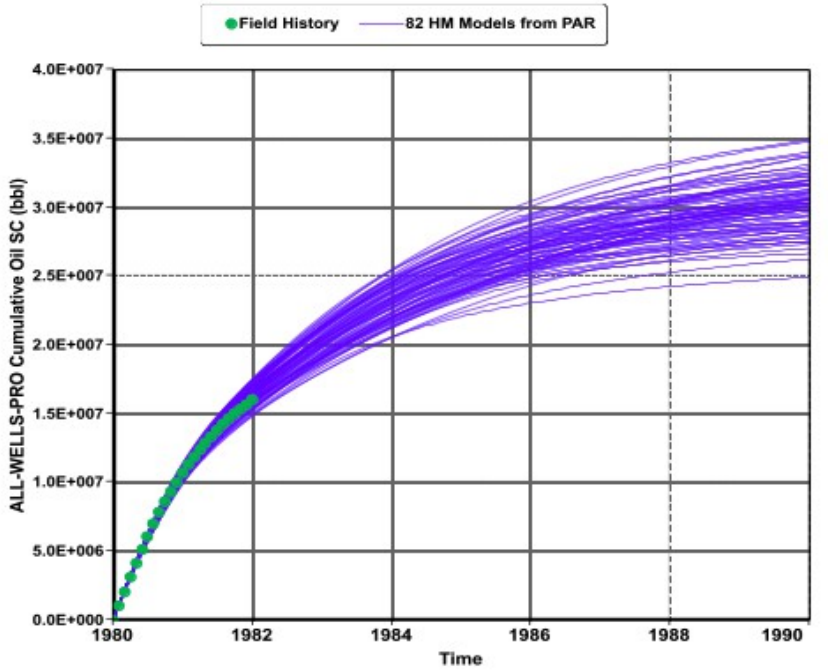
Probabilistic Forecast





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Probabilistic Forecast Workflow using CMG PAR Sampling Method

Bayesian HM using CMG PAR

- Experimental design
- RBF proxy modelling
- Proxy-based Acceptance-Rejection (PAR) sampling

Filtering HM Result

- Review HM result
- Determine HM quality thresholds
- Identify models with acceptable HM quality

Probabilistic Forecast

- Set forecast well constraints
- Forecast simulations based on acceptable HM models
- Statistical analysis

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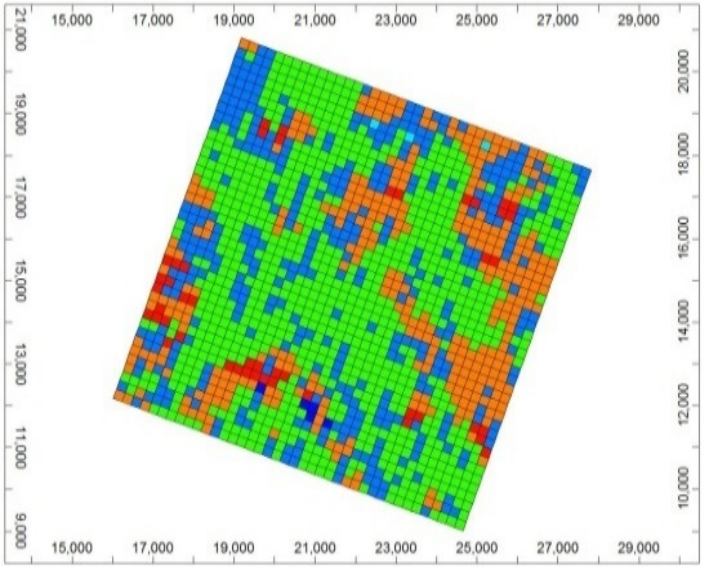
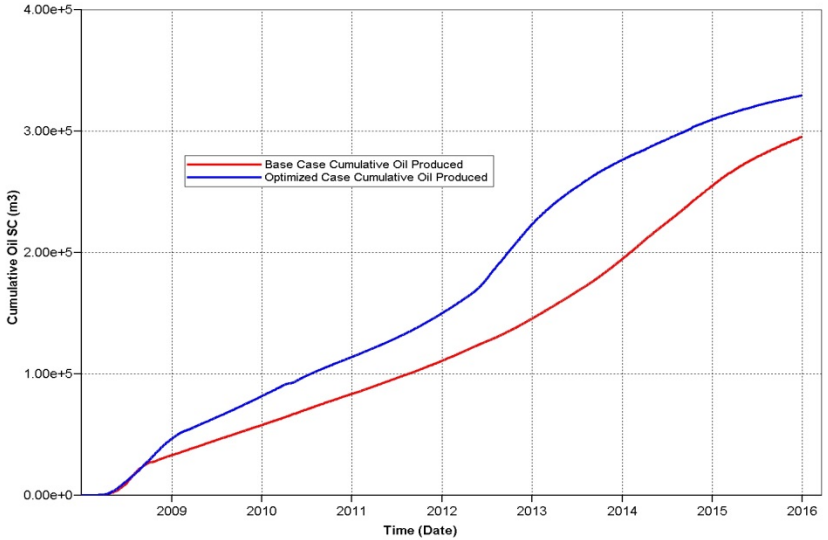
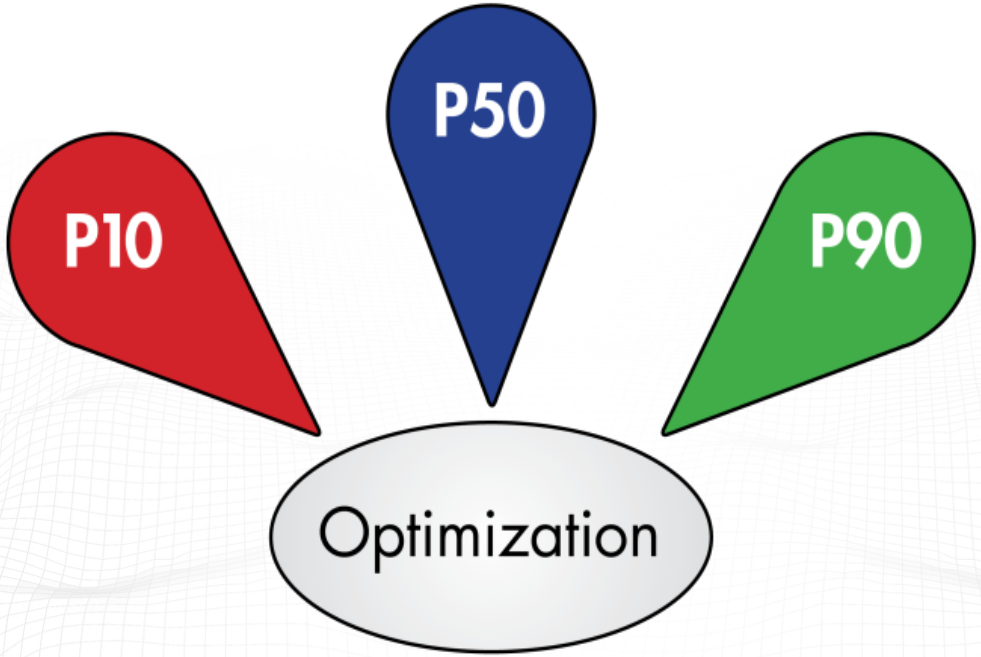
Traditional Nominal Optimization





Are we “precisely wrong?”

What is Robust Optimization?



Nominal vs. Robust Optimization

Nominal Optimization

Pros

- Fast: one simulation per scenario
- Likely to improve results

Cons

- No guarantee of success
- May be suboptimal in reality

Robust Optimization

Pros

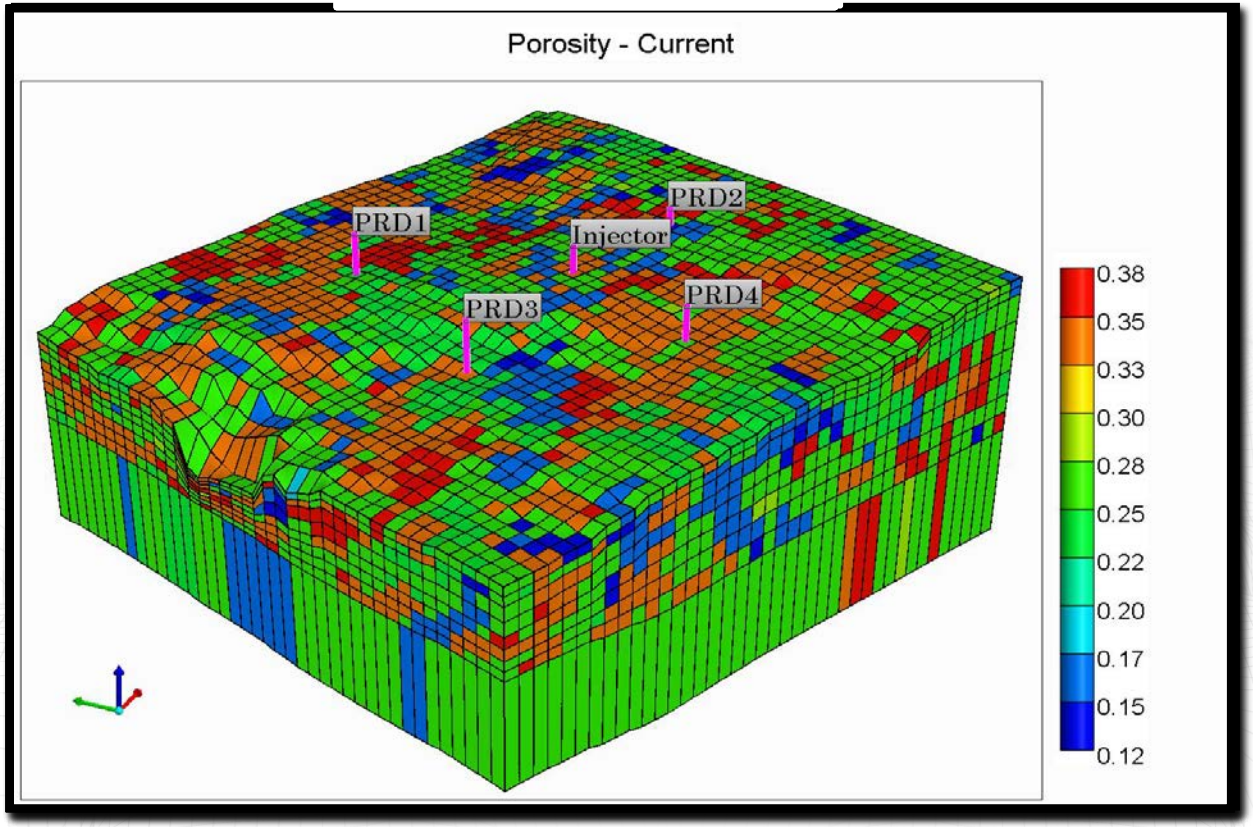
- Higher probability of success
- Lower risk

Cons

- Additional computation

Results: Optimal Wells Locations

Realization 5



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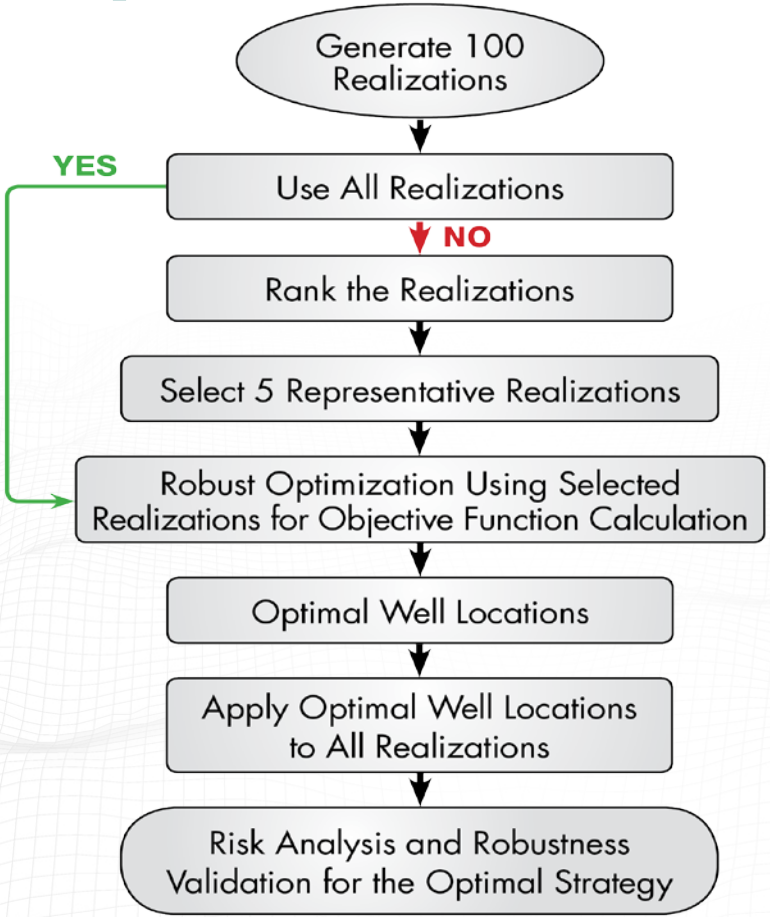
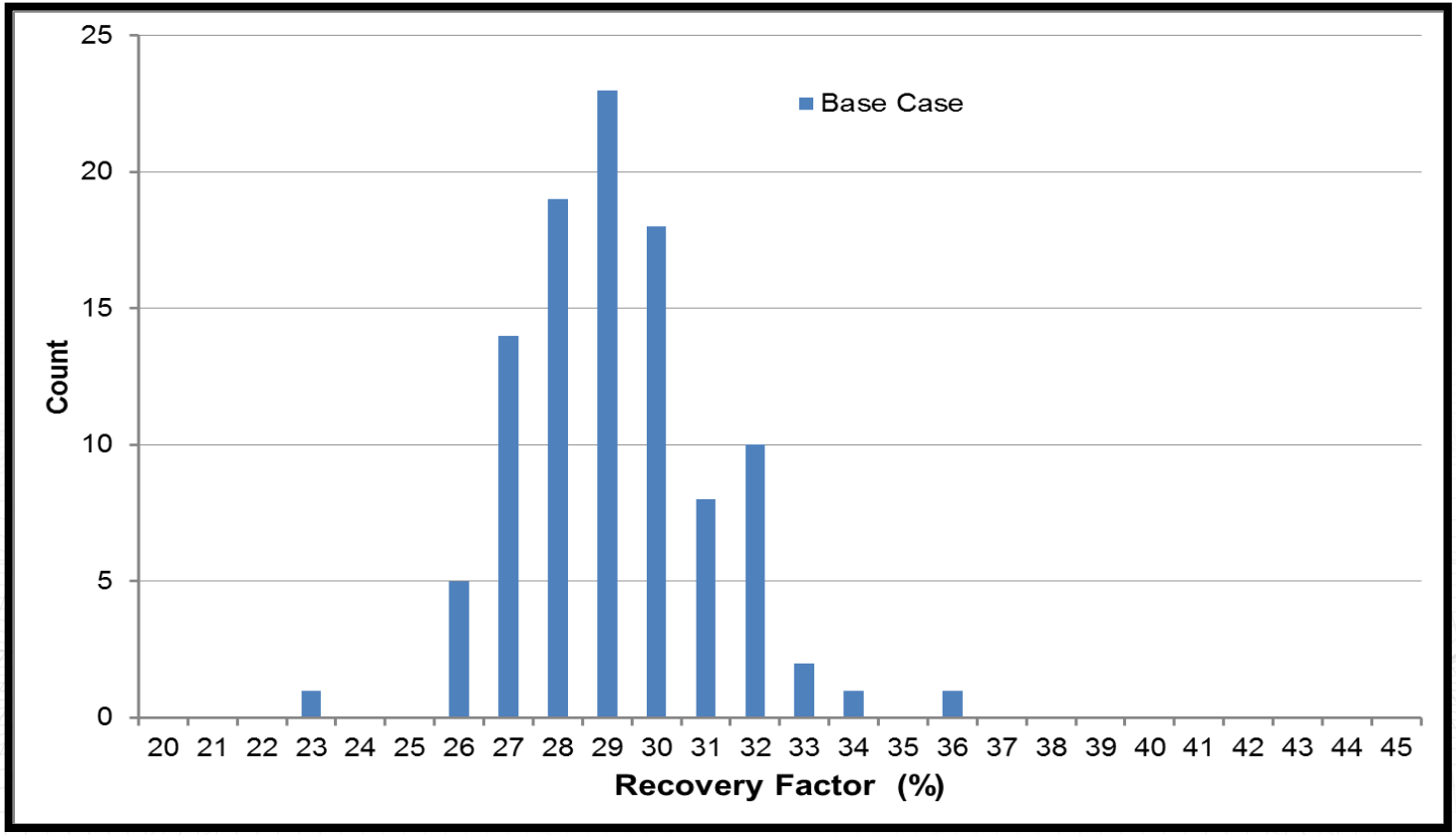
Robust Optimization



Base Case Histogram



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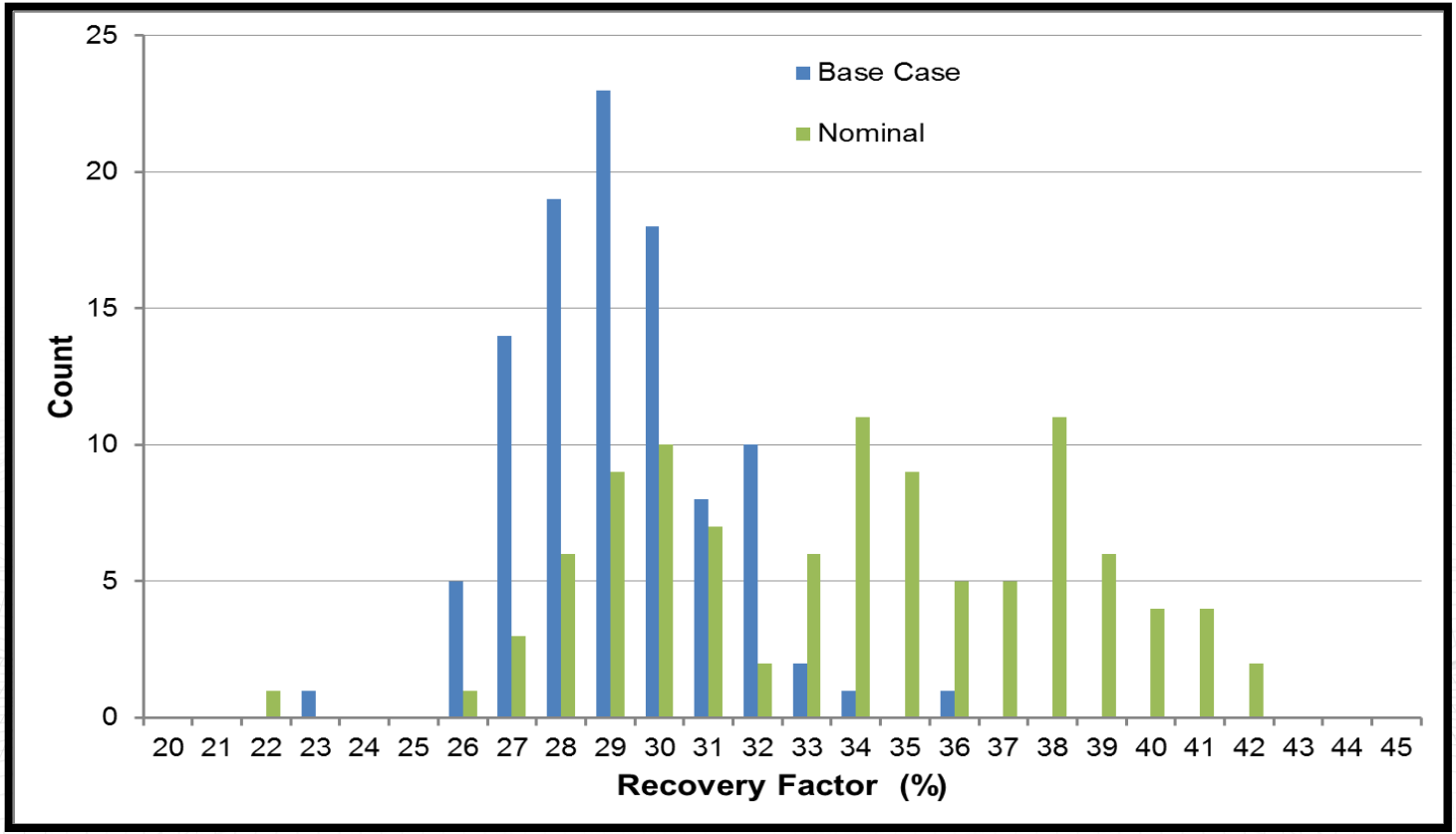
Base Case vs. Nominal



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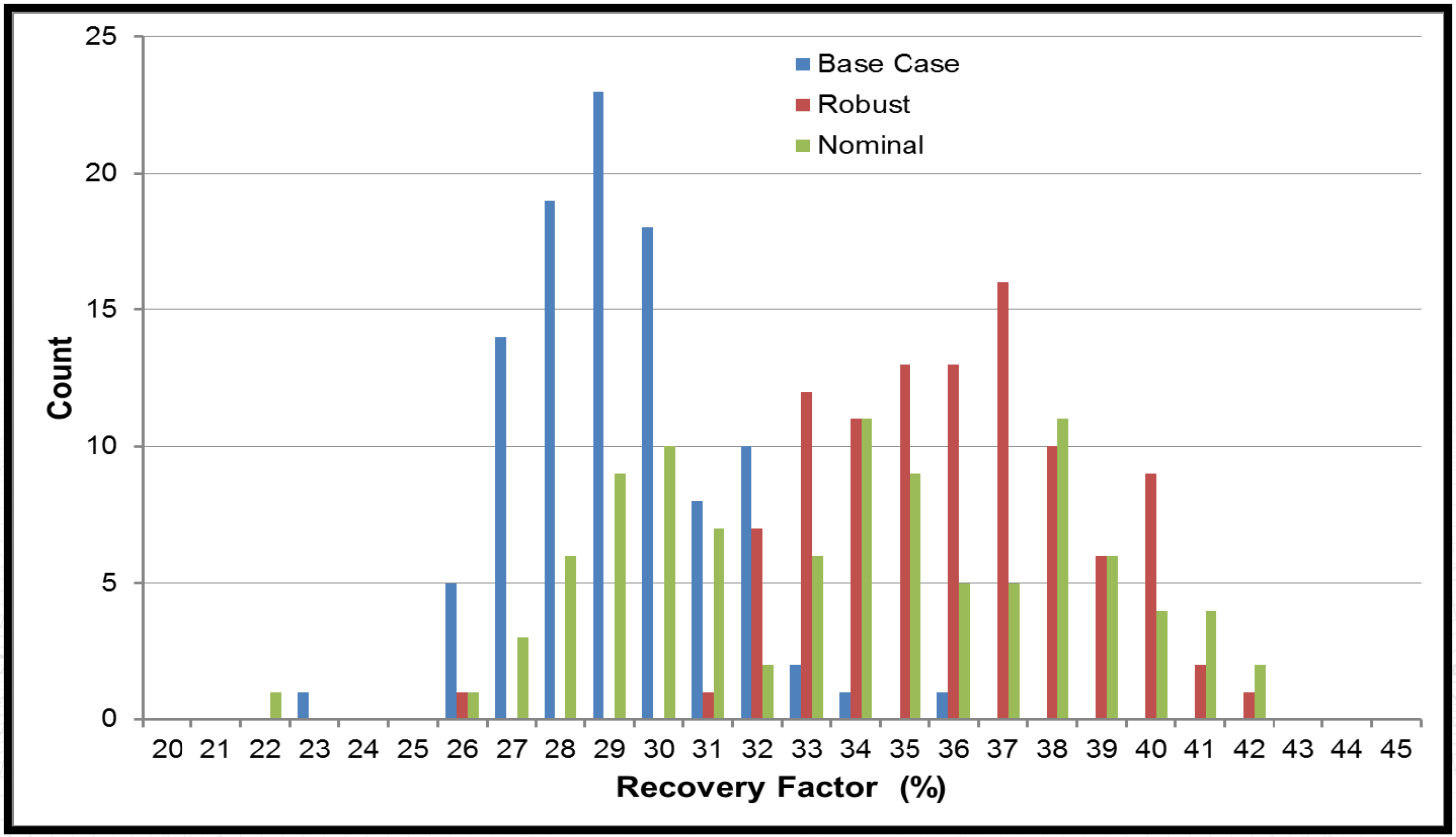
Base Case vs. Nominal & Robust Optimizations



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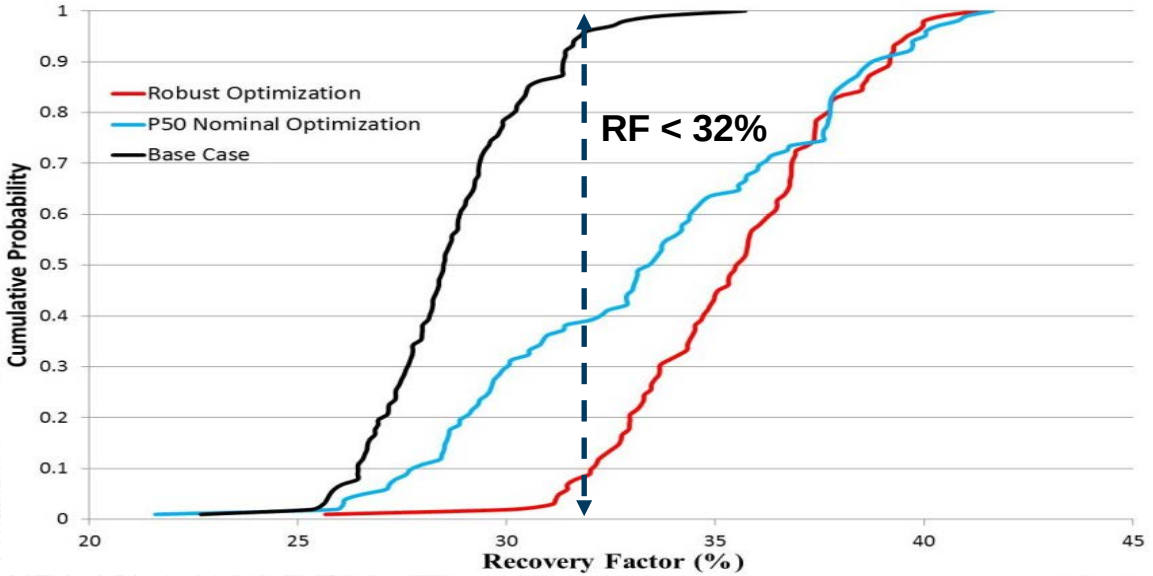
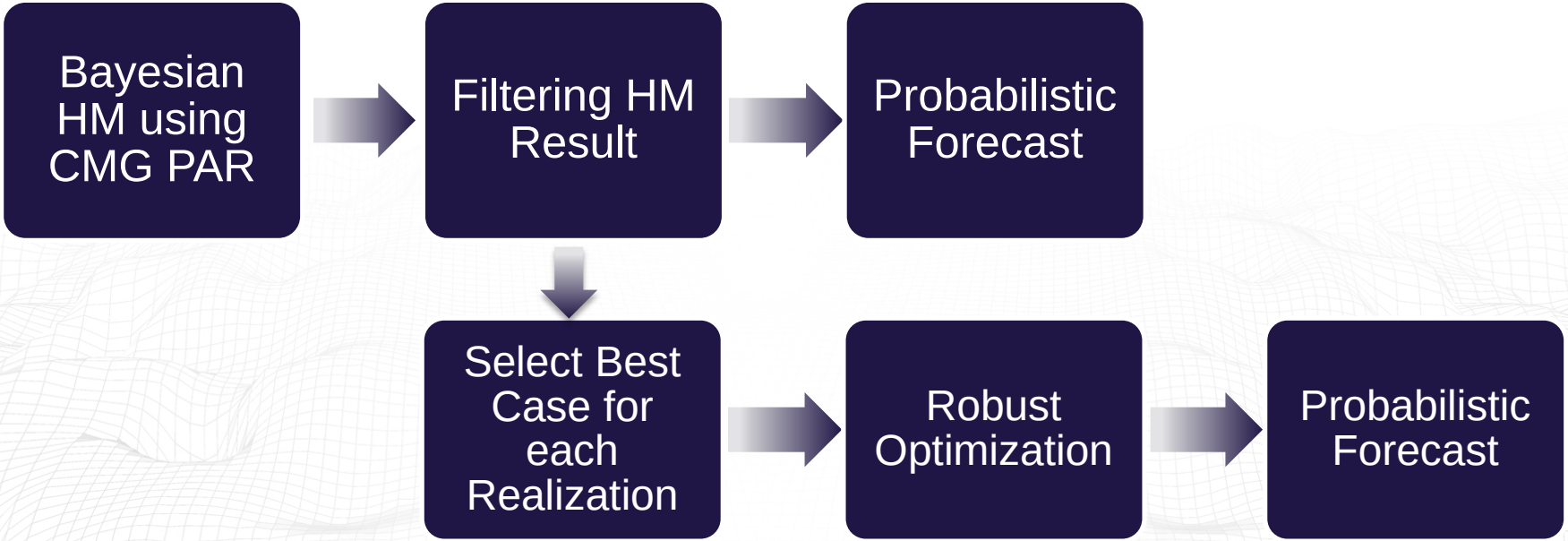
Cumulative Probability: Base Case – Nominal – Robust Optimization

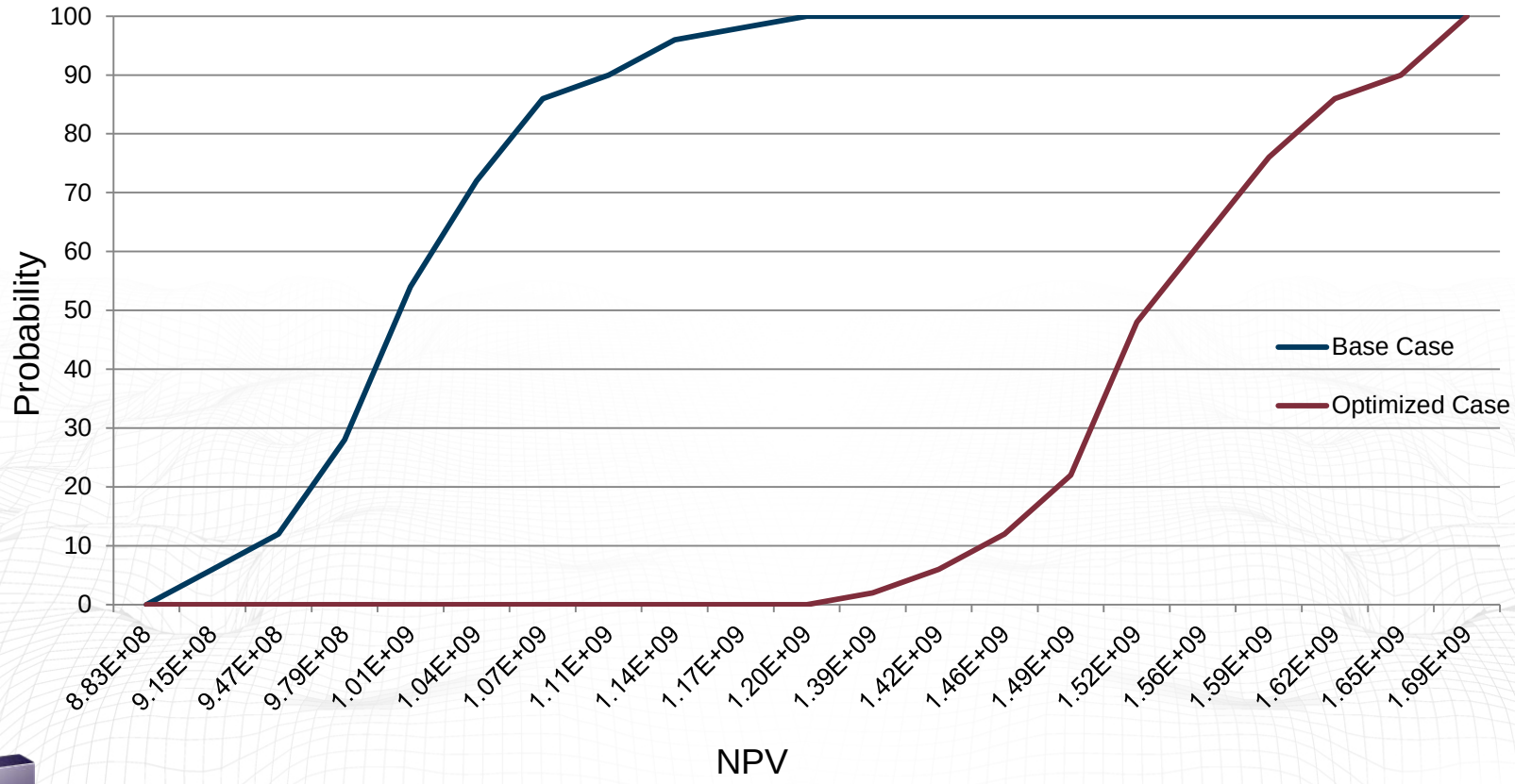


RF < 32%	Probability
Base case	96%
Nominal optimization	39%
Robust optimization	9%

Robust Optimization for Brownfields



Cumulative Probability: Base Case – Nominal – Robust Optimization



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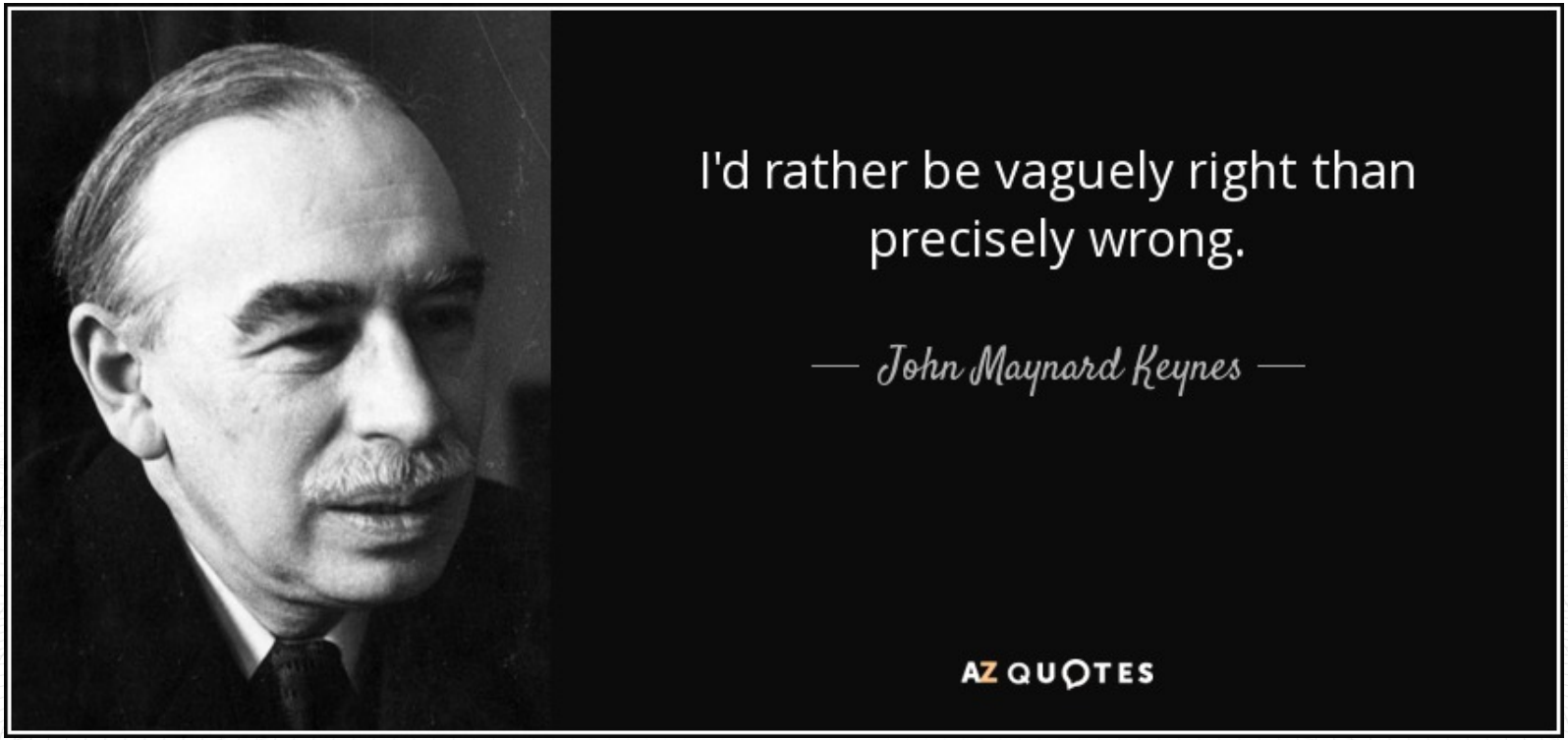
Conclusions

- In today’s market more than ever quantifying uncertainty is crucial
- CMG has tools to help carry geologic uncertainty easily through your workflows
- Carrying this uncertainty through the workflow provides immense value in making better decisions



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CMG's Vision

To be the leading developer and supplier of dynamic reservoir technologies in the **WORLD**