Gas Field Development - Challenges and Current Best Practices to Maximise Value

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Stochastic Dynamics in Reservoir Modelling – A Probabilistic Framework for Uncertainty Management

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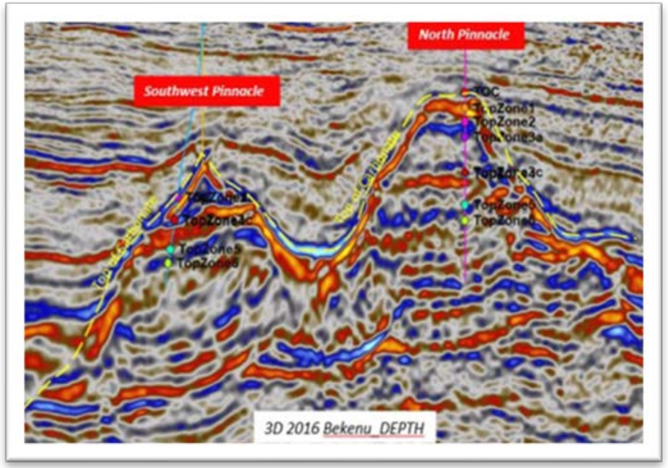
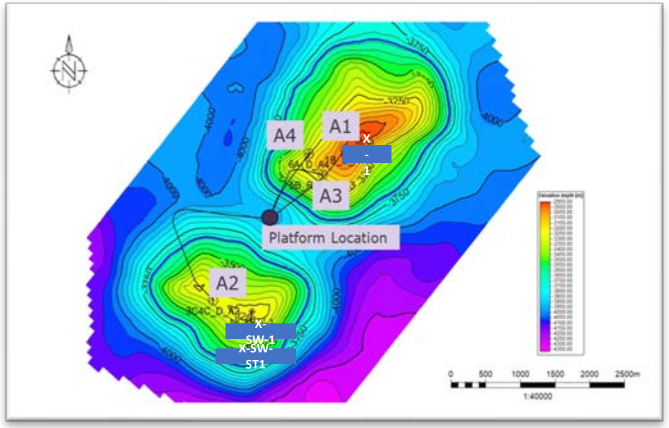
1. Introduction/Background

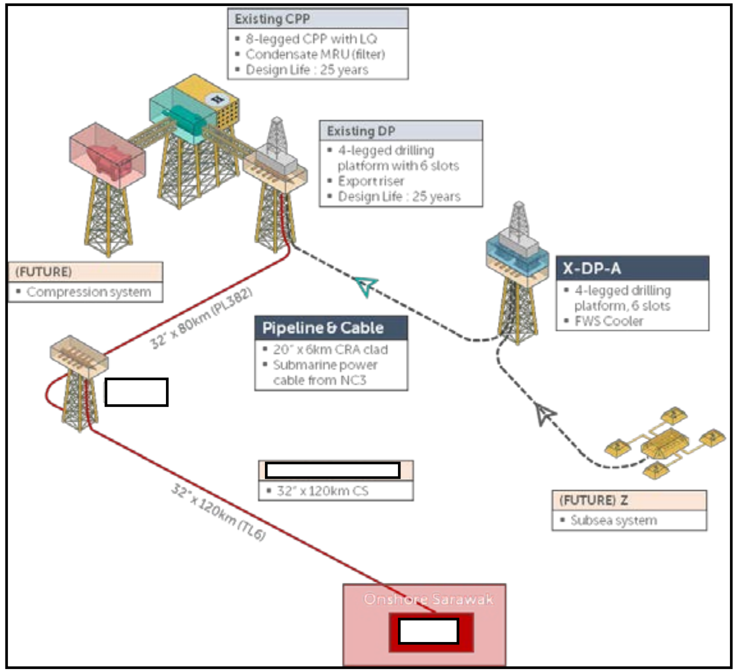
- Conventionally, simulation models have been generated from a single static model.
- This results in deterministic production forecast. Past project performance has showed deviation in the actual realized against plan, partly contributed by the challenges related to subsurface uncertainties
- More data acquisitions can improve reservoir understanding, however there are limitations. Hence, identifying the most critical data which impacts decision will help to improve project cost.
- Probabilistic modelling approach:
  - Improve reliability of production forecasts and resource estimation
  - Enable quantification of risks and its impact for better decision making
  - Having true probabilistic P90, P50, P10 profiles
- Motivation: uncertainty management in reservoir modelling due to complex and unpredictable nature.
  - Not all uncertainties are equal. An uncertainty can create risk, but not always.

Objectives: field development plan of a gas carbonate reservoir, with full assessment of its risk and uncertainties

Field Background







Existing CPP
- 8-legged CPP with LQ
- Condensate MRU (filter)
- Design Life : 25 years

Existing DP
- 4-legged drilling platform with 6 slots
- Export riser
- Design Life : 25 years

(FUTURE)
- Compression system

X-DP-A
- 4-legged drilling platform, 6 slots
- FWS Cooler

Pipeline & Cable
- 20" x 6km CRA clad
- Submarine power cable from NC3

[redacted]

[redacted]
- 32" x 120km CS

(FUTURE) Z
- Subsea system

Field Overview	
Discovery	EX-1 (2009) & EX-SW-1 (2011)
Reservoir type	Cycle IV/V Carbonate
Age	Middle to Late Miocene
Structure	Pinnacle Type of Build-Up
Areal extend	6 x 3 km
Pressure & Temperature	6,900 psia / 209 degC at GWC

Field Overview	
Water depth	107 m
Development Scope	4 gas producers 1 well head platform 20" gas pipeline
Design life	25 years

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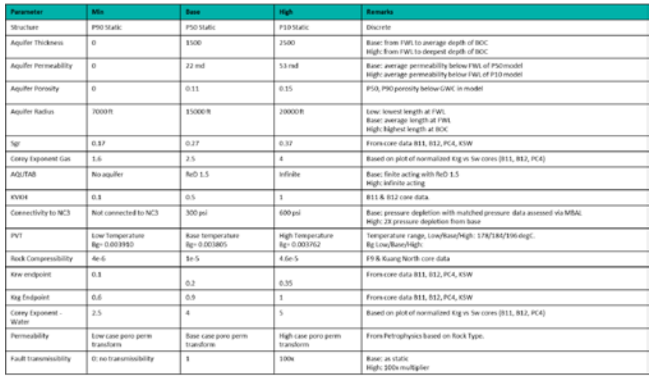
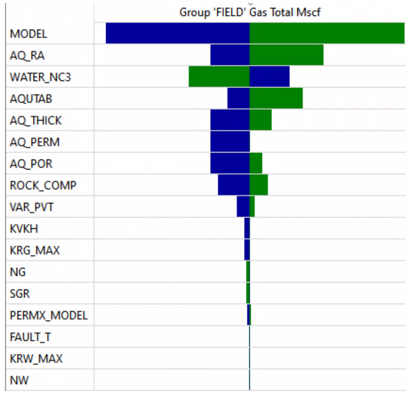
2. Probabilistic Framework

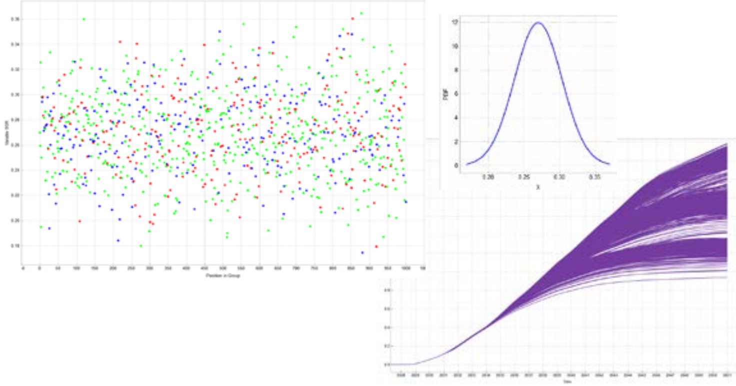


Parameter	Min	Base	High	Remarks
Structure	P90 Static	P50 Static	P10 Static	Discrete
Aquifer Thickness	0	1500	2500	Base: from FWL to average depth of BOC High: from FWL to deepest depth of BOC
Aquifer Permeability	0	22 md	53 md	Base: average permeability below FWL of P50model High: average permeability below FWL of P10 model
Aquifer Porosity	0	0.11	0.15	P50, P90 porosity below GWC in model
Aquifer Radius	7000 ft	15000 ft	20000 ft	Low: lowest length at FWL Base: average length at FWL High: highest length at BOC
Sgr	0.17	0.27	0.37	From core data B11, B12, PC4, KSW
Corey Exponent Gas	1.6	2.5	4	Based on plot of normalized Krg vs Sw cores (B11, B12, PC4)
AQUTAB	No aquifer	ReD 1.5	Infinite	Base: finite acting with ReD 1.5 High: infinite acting
KVKH	0.1	0.5	1	B11 & B12 core data
Connectivity to NC3	Not connected to NC3	300 psi	600 psi	Base: pressure depletion with matched pressure data assessed via MBAL High: 2X pressure depletion from base
PVT	Low Temperature Bg= 0.003910	Base temperature Bg= 0.003805	High Temperature Bg= 0.003762	Temperature range, Low/Base/High: 178/184/196 degC. Bg Low/Base/High:
Rock Compressibility	4e-6	1e-5	4.6e-5	F9 & Kuang North core data
Krw endpoint	0.1	0.2	0.35	From core data B11, B12, PC4, KSW
Krg Endpoint	0.6	0.9	1	From core data B11, B12, PC4, KSW
Corey Exponent - Water	2.5	4	5	Based on plot of normalized Krg vs Sw cores (B11, B12, PC4)
Permeability	Low case poro perm transform	Base case poro perm transform	High case poro perm transform	From Petrophysics based on Rock Type.
Fault transmissibility	0: no transmissibility	1	100x	Base: as static High: 100x multiplier

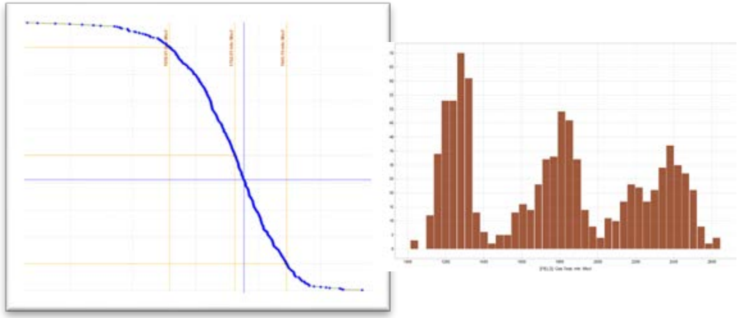
Identify reservoir uncertainties (static and dynamic) & ranges.



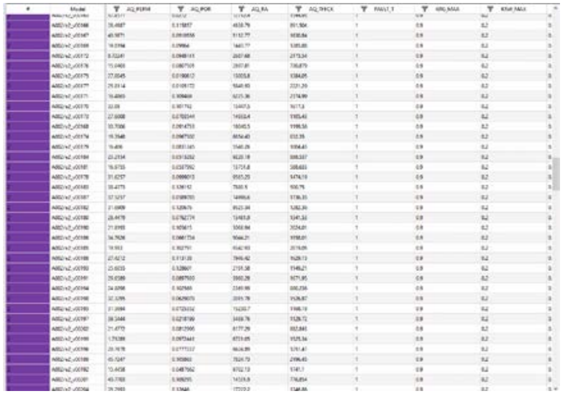
Sensitivity Analysis. Identify heavy hitters to EUR from tornado plot



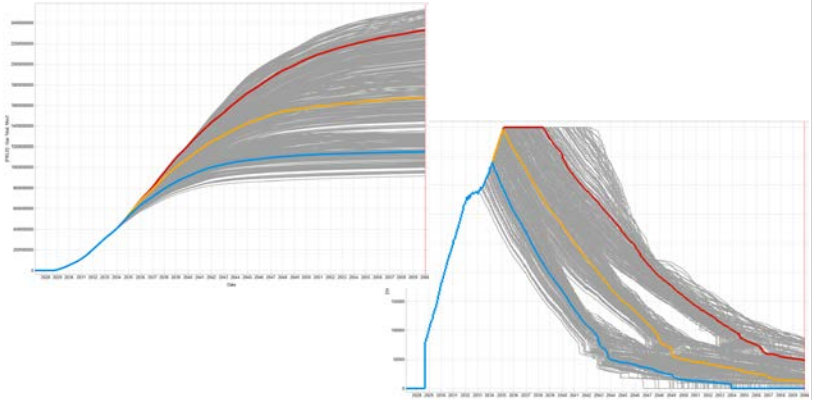
Identify the parameter ranges distribution. Perform experimental design, using latin hypercube algorithm



Generate CDF plot of EUR and observe P90, P50, P10 recoverable



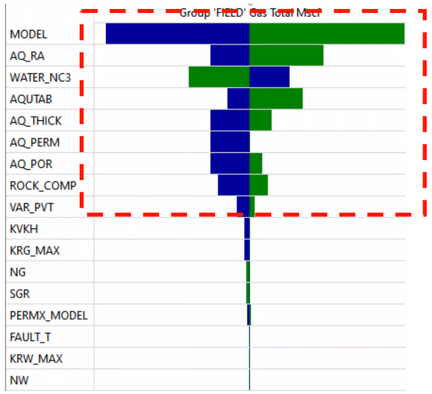
P90, P50, P10 model selection for final production forecast estimation



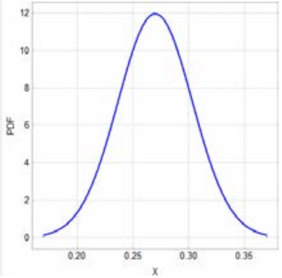
Final production forecast estimation compilation for all products gas, condy, water

3. Methodology:

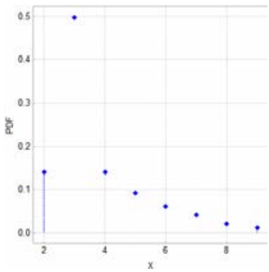
- Tornado or Pareto analysis to identify heavy hitters.
- The distribution of the “heavy hitters” need to be fully understood. **This heavily impacts the outcome of the probabilistic modelling.**
- Stochastic modelling techniques: Monte Carlo, Latin Hypercube, etc.
  - o Aim: To extract as much information as possible about the outcome by conducting number of experiments using combinations of variables.
- Multiple parameters which are deemed to have effects on the outcome are varied at the same time to gain sensitivity information about the maximum interference between input parameters and response parameters.



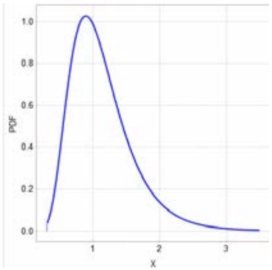
Tornado:
Take only the min & max of a variable and test it against the base value of other variables.
Number of run: 2N+1



Normal distribution:
For variable that have normal distribution, such as porosity, etc



Discrete distribution:
For variable that have normal distribution, such as structure model, aquifer influx table, etc



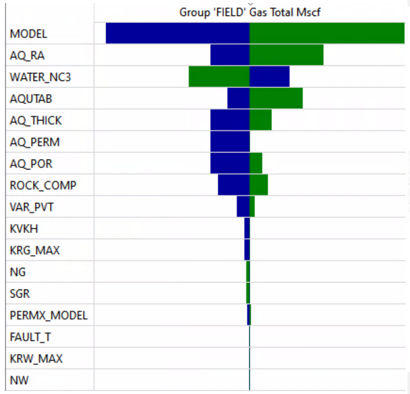
Log-normal distribution:
For variable that have normal distribution, such as permeability

4. Case Studies & Applications:

- Field X development

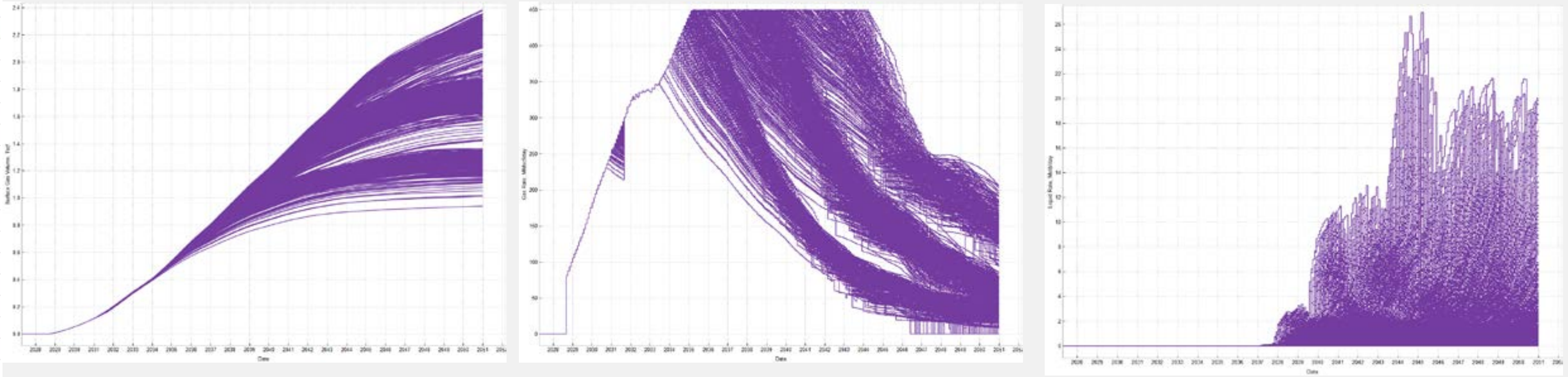
Data	Remarks
RCA	Analogue
SCAL	Analogue
PVT	Poor recombination
DST	Yes
Logs	Yes
MDT	Yes

Data Availability



Tornado plot

Outcome
1,000 realizations:

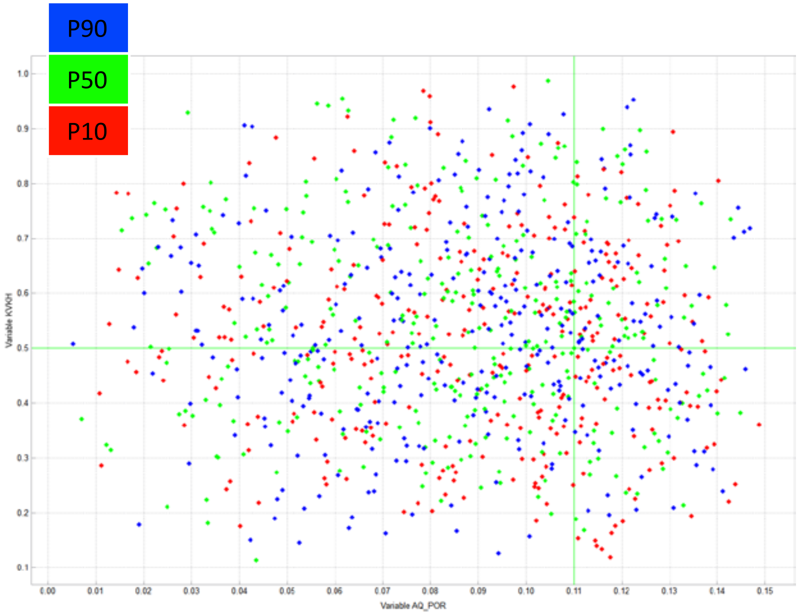


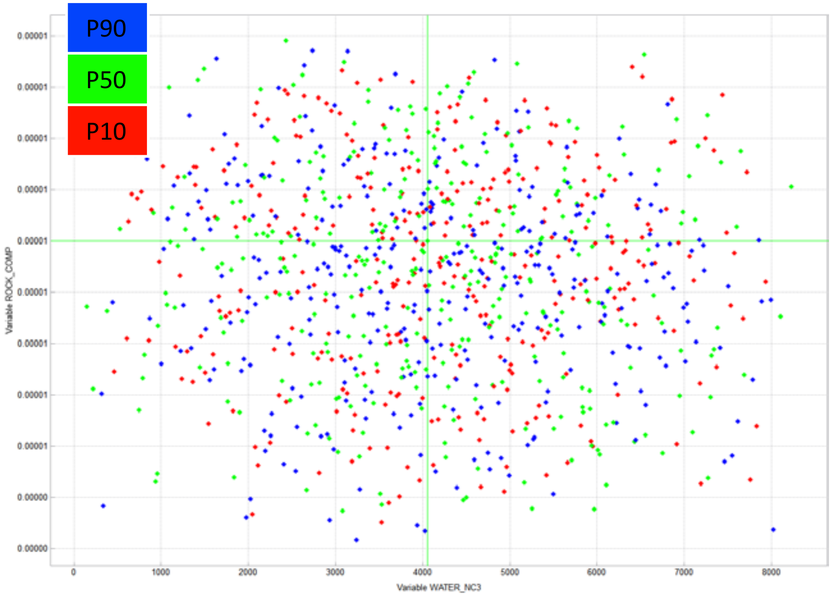
EUR Gas rate Water rate

Observations:

- Not all uncertainties are equal, apparent through the tornado plot.
- Range of outcome can be probabilistically understood and quantified
- Water production is a risk but may come at later stage of the production life, even at its worst case scenario

Experimental Design





Randomness: Uncertainty parameter #1 interaction with #2

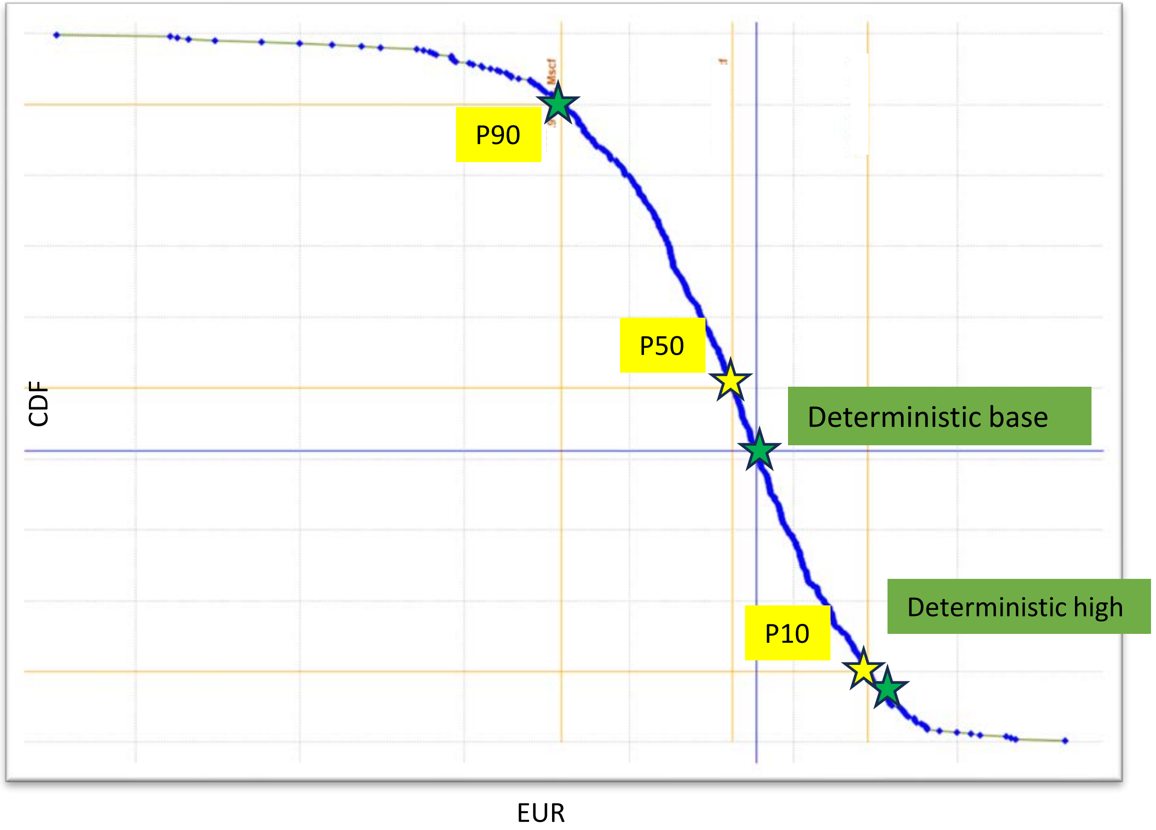
Randomness: Uncertainty parameter #3 with #4

Discretely distributed (AQUTAB table or PVT table)

Observation: Interactions of multiple uncertainty parameters with one another. Advantage of Probabilistic workflow

5. Results and Discussion

- Observation:
    - P50 is lower than deterministic base case
    - P90 is within range of deterministic low case
    - P10 is lower than deterministic high case
- Interactions of various parameters across respective range is assessed and quantified into probabilistic outcome
- Insights gained
    - Deterministic case could be over or underestimated.
    - Not all uncertainties are equal. Few parameters dominate the outcome more than the others
    - Though there is risk of water breakthrough, happens at later stage of the production.



5. Result and Discussion

	Deterministic	Probabilistic
	• Only a single realization is initialized in dynamic model • No involvement of randomness	• Stochastic realizations generated from each scenario • Incorporates randomness and uncertainty into risk analysis process
Advantage	• Simpler & faster • Suitable for low-risks, low hanging fruits opportunity.	• Provides real probabilistic range of forecast and recoverable resources (P90-P50-P10), therefore better project definition and decision making • **Interactions and dependencies between uncertainties are captured** • Auditable process
Disadvantage	• Not true P50 • Scenario based, not **associated to probability** • **Interactions of various uncertainties are not captured** • No proper identification of key uncertainties and risks, hence affect risks mitigation and data acquisition plan	• Uncertainties in defining the ranges can dominate the results. • Time consuming as multiple variants need to be generated & run

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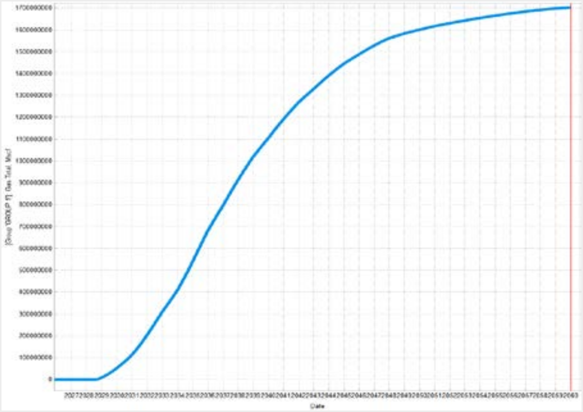
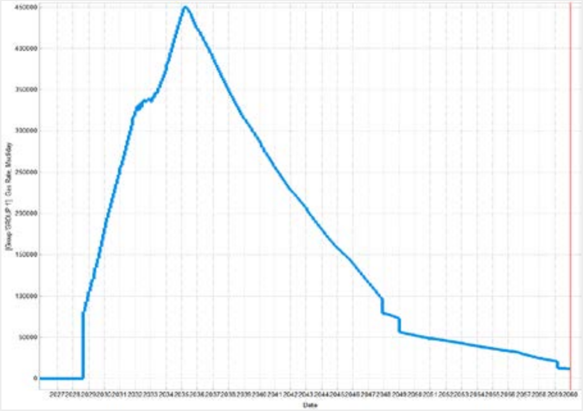
5. Result and Discussion

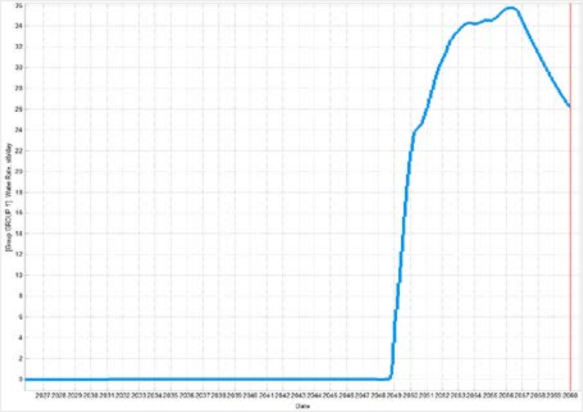
Deterministic



EUR



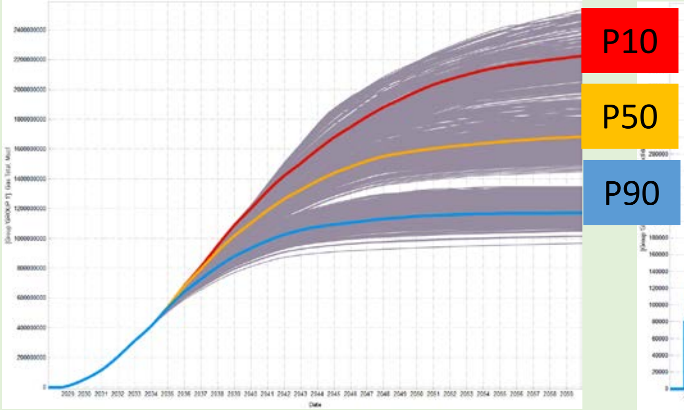
Production rate



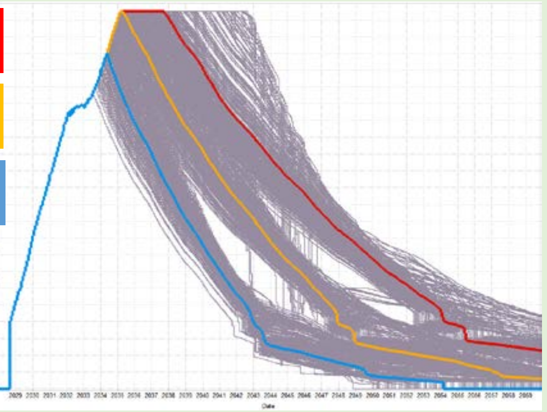
Water rate

- Single realization & outcome
- Other risk are not quantified
- Single scenario may cloud other assessment, i.e water

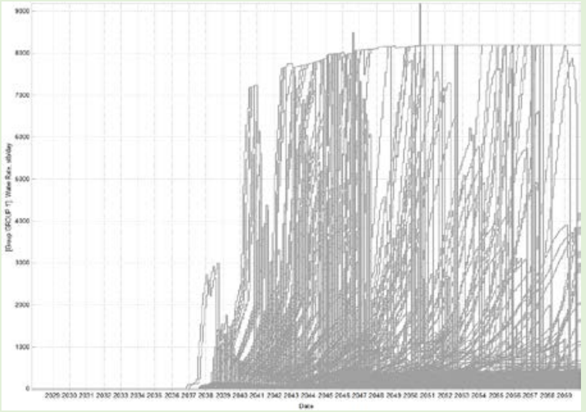
Probabilistic



EUR



Production rate



Water rate

- Multiple realizations & outcome
- Quantified probabilistically
- Other realizations enable assessment of other objective, i,e water

6. Conclusion

- Probabilistic Modelling enable multiple realizations with interactions of multiple uncertain parameters and produce range of probabilistic outcome
- Its outcome not only helpful to reservoir recovery but also enable assessment of other objectives such as water production. Useful information for surface facilities design.
- Not all uncertainties are equal. Probabilistic modelling can help to identify which parameter needs more attention as part of derisking process.
- Deterministic is best if we have all the data necessary to predict the outcome with certainty. However, for reservoir modelling, certainty is almost impossible. Hence, probabilistic modelling helps decision makers understand the likelihood of different scenarios and make informed decision based on the level of uncertainty.

Thank You