Applying Probabilistic Approach for Uncertainty Quantification to De-Risk Development Prospects: Case Study from KG Basin

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Abstract

The scarcity of conventional, easy to find oil & gas reserves along with the dramatically increased hydrocarbon demand has created a paradigm shift in the industry, as exploration and exploitation of more challenging unconventional reservoirs have increased tremendously over the past decade. However, **accurate reservoir characterization** and **building a sub-surface model** incorporating heterogeneity are two most predominant challenges from which a myriad of field development issues for these reservoirs have arisen. Inadequate Dataset, inconsistent G&G interpretations, spatial variability, geological complexities and human bias may introduce great uncertainties in the output of reservoir model. Therefore, understanding & quantification of uncertainties are very essential tool to support effective decision making.

In this study, a probabilistic approach is being presented by combining **Latin-Hypercube Monte Carlo (LHMC) sampling** and **Sensitivity analysis** of reservoir parameters to improve the efficiency and reliability of the uncertainty quantification. A novel workflow has been established to handle multiple scenarios, and multiple realizations with given input. Multiple realizations were run on a base case 3D model by focusing on-

- Structural & Contact uncertainty
- Rock & Fluid uncertainty

This paper emphasizes the integrated workflow applied in a tight oil reservoir to identify **highest ranked contributors to the uncertainty** and value addition in **de-risking future development locations**. This paper identifies the key measures that must be adopted and critical data that needs to be acquired in upcoming development phase for mitigating subsurface uncertainty associated with geological complexities.

1. Introduction

Since the advent of the industry, to meet the ever-growing energy demand; exploration & development process has covered different reservoir types with varying environments and a growing variety of approaches. Thus, over the years; geoscientists & subsurface engineers have devoted significant efforts to develop reservoir models and digital twins of the fields. Developing reservoir model includes building a static model and calibrating the same with historical pressure & production data.

These models are mostly deterministic in nature and thus does not account for randomness of the natural forces & mother earth. However, there are quite a number of ways through which uncertainties arise in the reservoir models. These include limited data availability, natural subsurface variability, varying geological settings, misinterpretations, human induced errors, technology exploitation, amongst others. These uncertainties may induce error in **Initial Hydrocarbon In-Place** (IHIP) estimation in the range of **±10%** to **±50%**, also pervasion of other errors (deviation from envisaged geological model, misleading modelling & simulation results) may taint output of the base case reservoir model (*Ringrose and Bentley, 2015*) substantially. Overlooking such model uncertainties can lead to erroneous wells placement, incorrect sizing of surface facilities, inaccurate reservoir in-place & recovery estimation, flawed development strategies and wrong investment decisions. Hence, the importance of a well-informed reservoir uncertainty analysis cannot be over emphasized.

The uncertainty in the randomness of such geological systems as well as systematic and measurement uncertainties can be quantified by **deterministic**, **probabilistic (stochastic)** and with very recent development of **embedding some artificial intelligence algorithms**. This paper focuses on the probabilistic approach of uncertainty investigation, which is based on Monte-Carlo simulation with Latin-Hypercube Monte Carlo (LHMC) sampling method. Multiple realizations were run to sample a specific uncertainty space (multiple hypothesis with multiple scenarios considered). In addition, to examine relative influence of each uncertain variable, sensitivity analysis was performed on the target reservoir model.

The remainder of the paper is organized with Section 2 discussing general geological characteristics along with reservoir description of the study area. Section 3 presents brief review of non-deterministic uncertainty analysis method and sensitivity tasks. Section 4 presents the integrated workflows adopted for performing uncertainty analysis of two target reservoirs. Section 5 concludes the paper by highlighting lessons learned and recommending means to mitigate subsurface uncertainty.

2. General Description of the Study Area

The Krishna Godavari Basin is a Continental Passive Margin basin comprising of a number of North East – South West trending horsts and graben. The basin has a polycyclic (dual-rift) evolution history in the eastern continental margin of Indian Plate. Tectonically, the basin can be divided into three sub basins, namely the Krishna, West Godavari and East Godavari Sub Basins, which are separated by the Bapatla and Tanuku Horsts respectively (Figure-1).

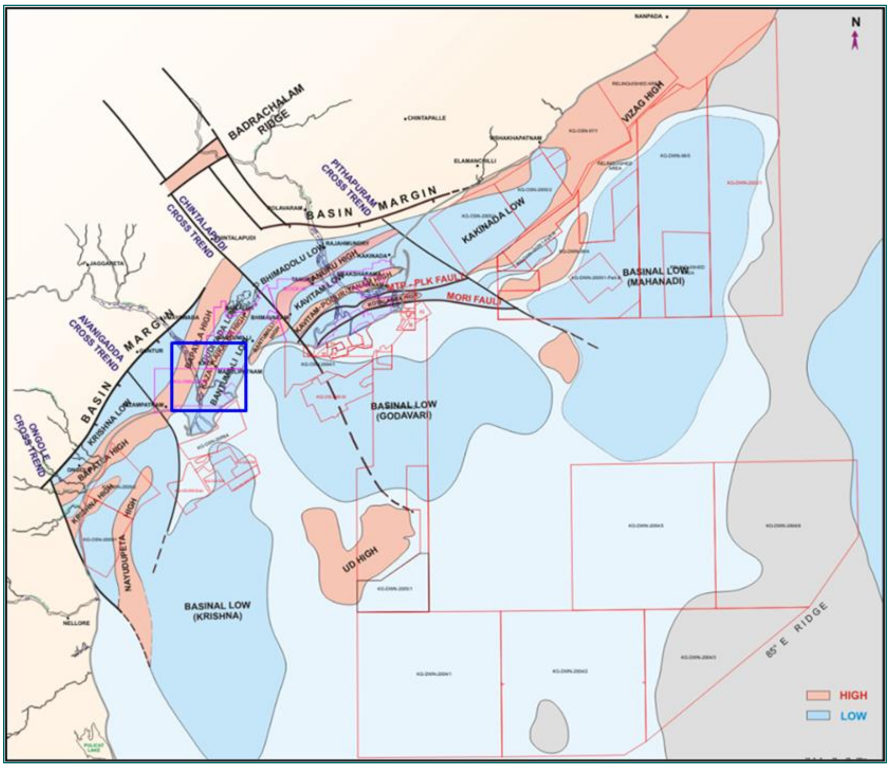


Figure-1: Tectonic set-up of KG Basin.

The study area, is located in the southern part of KG onshore Basin, located near the mouth of River Krishna (blue polygon in Figure-1) and holds the one of the largest hydrocarbon deposits of India discovered in the last decade. The area has undergone several phases of exploration, culminating into **Two discoveries from late Jurassic Cretaceous system**.

The target reservoir consists of two distinct pay zones, the lower part is Gollapalli Formation which consists mainly fine-grained sandstones, and the upper part is cleaner Raghavapuram Formation sandstones. Gollapalli Formation represents Synrift sediments in the area; it is nearly 800m thick deposits (~180m Net pay), chiefly composed of arenaceous sediments with average permeability of less than 0.1 mD and effective porosity of 7-8%. The ~35 m thick Raghavapuram Formation with relatively better reservoir quality having average permeability and porosity of ~0.1 mD & 10-12% respectively. Thick carbonaceous shale deposited during thermal sagging phase, separates these reservoirs.

Three appraisal wells were drilled between 2010 to 2013 to assess the economical flowing potential of the target reservoirs. Massive hydraulic fracturing treatments were done to exploit these layers and maximize commercial viability of the reservoirs. Integrating all data, phase wise field development plan was chalked out with Gollapalli Formation as primary development target (*ONGC, 2017*). In development Phase-I, drilling of three wells indicated a significant deviation from the predicted pay configuration for Raghavapuram as well as Gollapalli Pays (Table-I). Enormous difference in the model predicted versus actual field behavior has compelled to incorporate heterogeneities and uncertainties into the reservoir model before proceeding for next phase of development.

Parameter	**Well-D1**		**Well-D2**		**Well-D3**	
	ANTICIPATED	ACTUAL	ANTICIPATED	ACTUAL	ANTICIPATED	ACTUAL
RGP Pay Top, TVDSS	4016	3988	4041	3994	4085	4059
RGP Pay Thickness, m	~25	0	~8	23	~15	3
GLP Top, TVDSS	4070	4046	4090	4082	4170	4154
GLP OWC, TVDSS	4284	4316	4284	4286	4410	4260
GLP Pay Thickness, m	210	250	190	220	220	78

Table-I: Prognosed vs. Actual results of development phase-I wells

3. Uncertainty & Sensitivity Analysis

Some of the major inherent challenges of the region are HPHT conditions, tight deep sands with extremely low permeability, pay sands mapping & discrimination, reservoir heterogeneity and uncertainty quantification. To make efficient development decision given the uncertainties associated, the reliable uncertainty analysis of the reservoir model along with sensitivity analysis of uncertain parameters is inevitable.

Uncertainty can be described as the measurement of the degree to which a data deviates from its modeled (predicted) values (*Schlumberger, 2016*). Uncertainty with respect to reservoir model can be explained as the range to which a modeled property might deviate from its true value. Approaches for reservoir uncertainty analysis range from the deterministic and probabilistic methods (*Yu et. al., 2016*), geostatistical methods (*Caers, 2011*), to the new paradigm of artificial intelligence (AI) methods (which incorporates genetic algorithms, ANN, Bayesian networks and other intelligent computing algorithms) (*Shahkarami, 2016*) which are increasingly pushing the frontiers to improved uncertainty analysis.

In this study, probabilistic approach is demonstrated in a step-by-step manner by applying it on the reservoir modeling case of tight reservoirs of KG Onshore field. Best case 3D grid (representing a hypothesis) was selected as base case scenario and multiple realizations were run to sample the same uncertainty space. Parameters involving both the structural & contact uncertainty (Gross Rock Volume) and Rock & fluid uncertainty were varied to arrive at volumetric range (Figure-2).

Stochastic sampling algorithm viz. Latin-Hypercube Monte Carlo (LHMC) was adopted for the present study to randomly assign the uncertainty variable from their respectively assigned distributions. LHMC was considered over other sampling method as it requires fewer model runs to approximate the desired variable distribution than a completely random sampling. The algorithm divides the range of the chosen variable into N equiprobable bins where N is the specified number of samples, which in turn ensures that the closely located samples also doesn’t become part of the same cluster. Furthermore, in order to identify the parameters having greatest influence on the uncertainty & hydrocarbon in-place, Sensitivity analysis of different uncertainty parameters (sub-process) of target reservoir was carried out. Probabilistic uncertainty task was carried out to investigate the combined uncertainties for all of the uncertain parameters; whereas **principal aim of sensitivity task was to investigate the relative influence of each uncertain variable**.

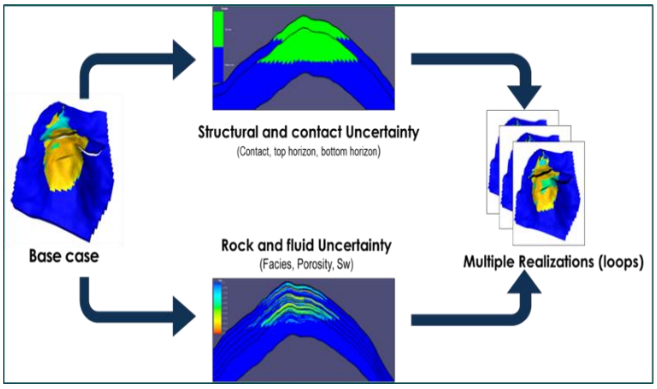


Figure-2: Uncertainty parameter types

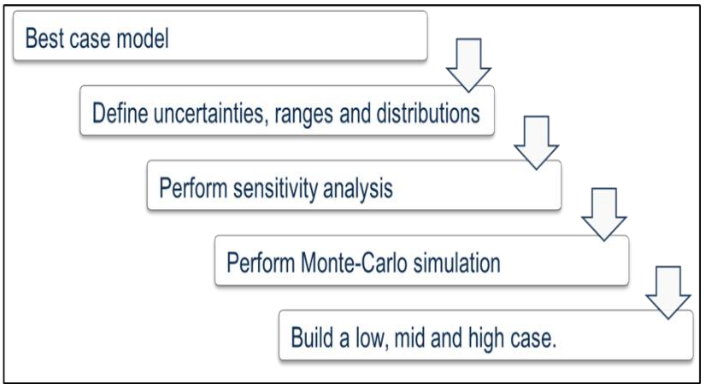


Figure-3: 3D modeling Uncertainty workflow

4. Integrated Workflow

In order to investigate reservoir level uncertainty as a part of the field development strategy, a geological uncertainty study was initiated separately for each of the target reservoir. Thereafter, best case 3D static models were selected as base case scenario, a method to quantify the uncertainty associated with geological parameters was proposed, and all combinations of these parameters were tested. To quantify the uncertainty in the field, the main uncertain parameters and their respective ranges were first identified using the data available. Once defined their respective impact on stock tank oil initially in place (STOIIP) was calculated by sensitivity analysis. Monte Carlo simulation was then used to combine the different parameters, in order to obtain a pessimistic, base and optimistic case. Generalized workflow devised for the study was fine-tuned for each reservoir taking input uncertainty variables into consideration (Figure-3). The proposed workflow comprises the following steps:

- » Building Structural Framework (using depositional sequences and major faults)
- » Geological model building (Facies propagation into 3D grid)
- » Petrophysical properties propagation (generating porosity and water-saturation models)
- » Uncertainty & Sensitivity analysis

Structural, Hydrocarbon contact, and Petro-physical uncertainties for both Raghavapuram and Gollapalli reservoirs are depicted in Figure-4.

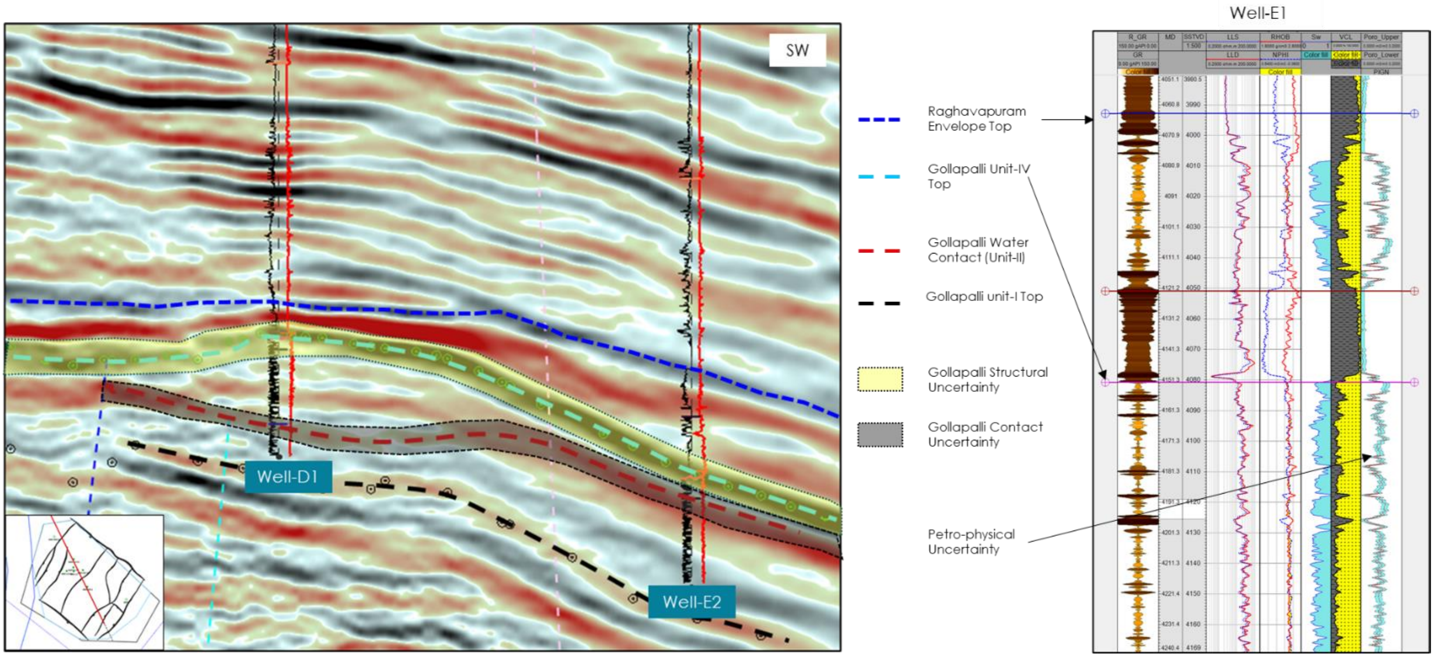


Figure-4: Seismic Section and Well log depicting structural, contact and Petro-physical Uncertainties

4.1 Uncertainty Analysis: Raghavapuram Formation

The discrete sand bodies of Raghavapuram Formation, are seismically not mappable and Oil Water contact is not identified in any well log. Raghavapuram pay sands, which are having Strati-structural contact, 3 different areal limits were considered as low, base & high cases (3 different hypothesis/scenarios). Hence to quantify uncertainty, a fit for purpose uncertainty workflow was adopted for Raghavapuram pay sand (Figure-5). Appropriate minimum & maximum ranges of uncertainty parameter were fixed on each hypothesis based on data analysis and geological understanding of the field (Table-II).

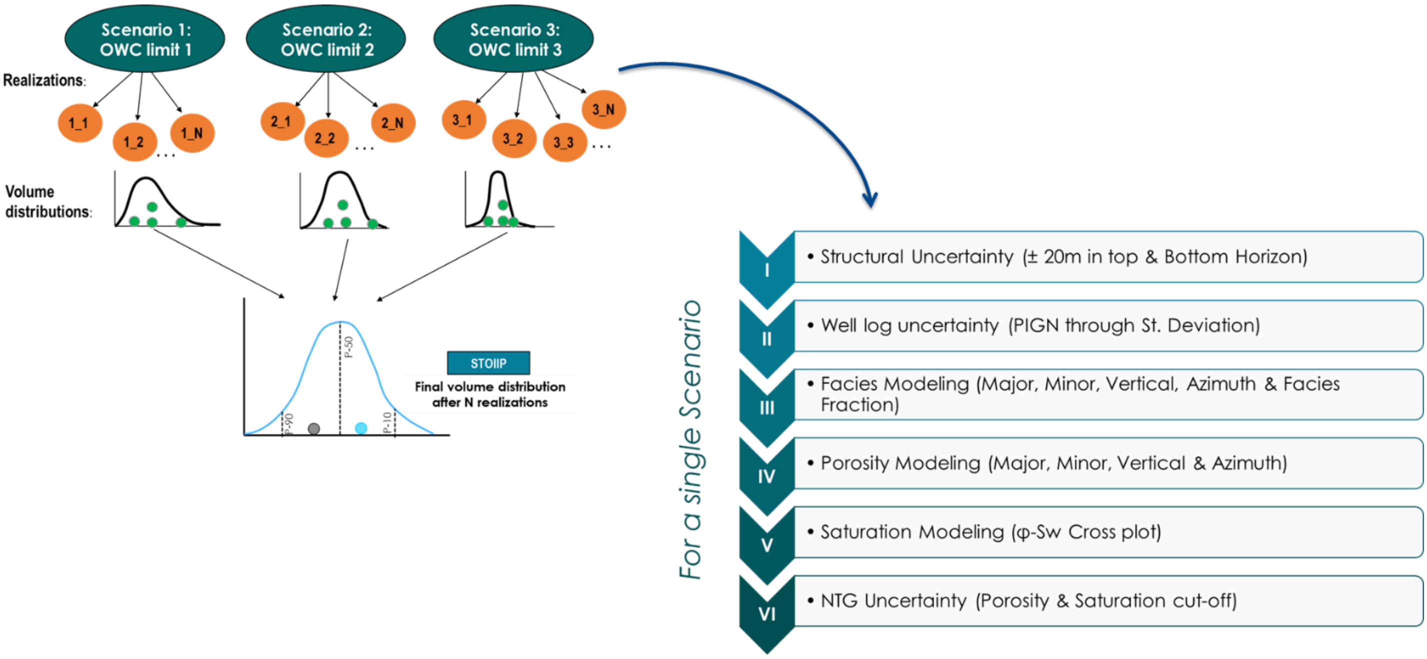


Figure-5: Uncertainty workflow adopted for Raghavapuram pay zone

Sensitivity analysis of different uncertainty parameters (sub-process) of Raghavapuram reservoir was carried out to identify critical parameters (combined by sub-processes) affecting hydrocarbon in-place. As evident by STOIIP sensitivity plot (Figure-6), **most significant parameters affecting IOIP** of Raghavapuram pay sand are **Contact uncertainty** & **Structural uncertainty**, followed by water saturation uncertainty. As a result of this uncertainty analysis; probabilistic volume distribution plot was generated for Raghavapuram reservoir (Figure-7) and P-10, P-50 & P-90 volume cases were identified.

Parameter	Base Value	Distribution	Minimum	Maximum
Azimuth	25	Uniform	20	30
Shale fraction	67	Uniform	60	75
Silt fraction	4	Uniform	0	8
Major range	525	Uniform	400	700
Minor range	500	Uniform	400	600
Vertical range	5.4	Uniform	4	7.2
Sw-Ø constant	1.0633	Uniform	1.0033	1.1233
PHIE cutoff	0.07	Uniform	0.06	0.08
Sw cutoff	0.70	Uniform	0.65	0.75

Table-II: Uncertainty parameter ranges considered for Raghavapuram pay zone

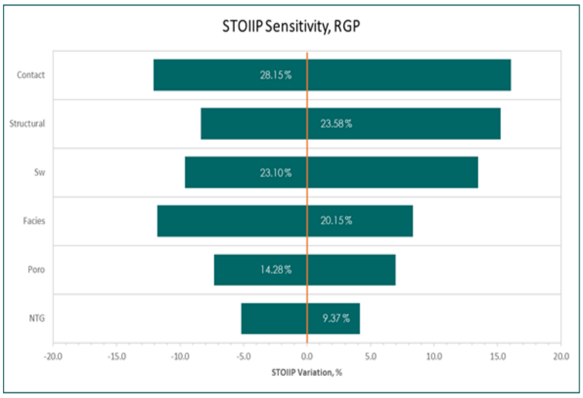
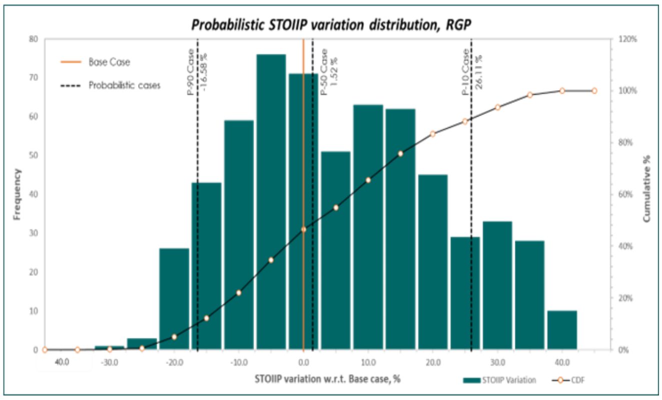


Figure-6: Sensitivity analysis plot (STOIIP)

Figure-7: Probabilistic STOIIP distribution plot



4.2 Uncertainty Analysis: Gollapalli Formation

The Gollapalli Formation is classified into four units representing different phases of Synrift which controls the hydrocarbon distribution pattern. Upper two hydrocarbon bearing units (Unit-III & IV) are separated from lower two water bearing units through an unconformity surface. In an effort to inspect Structural & Contact uncertainty of Gollapalli pay unit, appropriate uncertainty range of top & bottom surfaces and hydrocarbon contacts were identified. To improve the reliability of the Rock & Fluid uncertainty quantification of Gollapalli reservoir, a thorough analysis was conducted, by identifying & defining uncertainty parameters for Facies, Porosity, Water Saturation & NTG cut-offs (Table-III).

The identified **highest ranked contributors** to Gollapalli reservoir uncertainty are: **Water saturation modeling**; **Net-to-Gross uncertainty**; and range of parameters used for **facies modeling** (Figure-8). As a result of this uncertainty analysis; probabilistic volume distribution plot was generated for Gollapalli reservoir (Figure-9) and low, base and high volume cases were identified.

Parameter	Base Value	Distribution	Minimum	Maximum
Main Block contact	4284	Uniform	4309	4259
South Block contact	4414	Uniform	4439	4389
Azimuth	25	Uniform	20	30
Shale fraction	8.1	Uniform	5	12
Major range	1004	Uniform	750	1250
Minor range	516	Uniform	400	650
Vertical range	2.15	Uniform	1.5	3
Sw-Ø constant	1.1208	Uniform	1.0808	1.1608
PHIE cutoff	0.06	Uniform	0.05	0.07
Sw cutoff	0.70	Uniform	0.65	0.75

Table-III: Uncertainty parameter ranges considered for Gollapalli pay zone

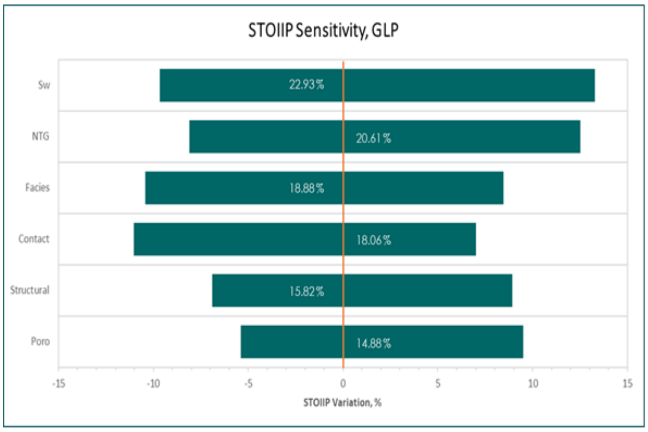
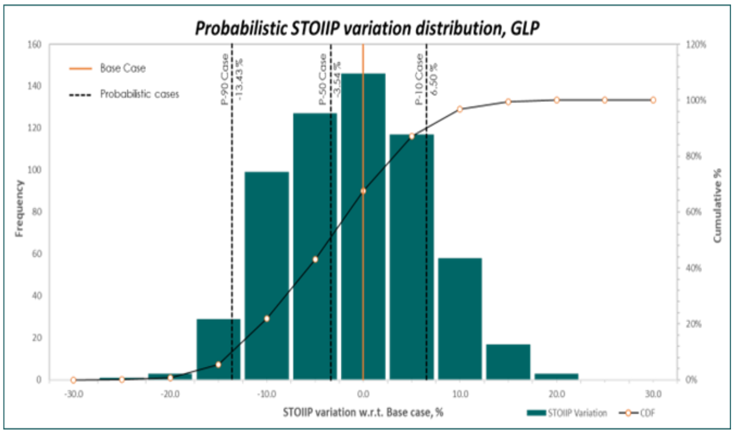


Figure-8: Sensitivity analysis plot (STOIIP)

Figure-9: Probabilistic STOIIP distribution plot



5. Conclusion

In order to meet the industry's demands as the scope of reservoir modelling expands to cover more complex systems and unconventional resources; building a static model (Structural & Property modeling) and subsequently calibrating it with pressure-production history of the wells is of paramount importance. Structural modeling & Petro-physical evaluations are carried out for a number of different purposes, including operational decision-making, volume in place estimation and reservoir modeling. In all cases, the uncertainty in the deliverables of gross thickness, net reservoir, porosity, water saturation and contact locations are critical. However, these data are usually provided without quantitative determination of their uncertainties.

To overcome above mentioned issues, surprises met in 1st phase of development drilling; in order to quantify the uncertainty within the field, its impact on the recovery and the development strategy; **An integrated and holistic workflow** was developed that included following:

- Representation of various hypothesis through building of multiple 3D base case model.
- Performing Probabilistic Uncertainty Analysis through multiple realizations on all base cases of both Raghavapuram & Gollapalli pays.
- Carrying out sensitivity analysis in order to identify the most critical parameters.

The workflow used in this study successfully integrated petro-physical, geophysical and geological data, and all geological uncertainty scenarios. This established workflow is able to handle both multiple scenarios, and multiple realizations of a given scenario. Major lessons learned during development & application of the workflow can be summarized as:

- Geological complexity and heterogeneity can lead to significant deviations between predicted and actual field behavior.
- Capturing the right level of heterogeneity along with measuring, mapping and incorporation of sub-surface level uncertainty especially in the green fields will led to better defining of '***Expectation curve'***.
- **Development strategy needs to be fine-tuned** considering uncertainty associated with both Raghavapuram & Gollapalli pays.
- **Investment decisions should be finalized based on the volumetric range** deriving out of the pessimistic case, base case and optimistic case.
- **Mapping and quantifying uncertainty associated with unconformity surface** separating hydrocarbon bearing units from water bearing units of Gollapalli Formation will address the issue of surprises met in terms of different contacts established in development wells of 1st phase as well as locations planned in next phase.
- Sensitivity and reservoir uncertainty analysis for Raghavapuram Formation indicates that oil water contact, structure, and water saturation are the most critical factors. Hence, future locations and data acquisition should be planned accordingly. Advance log suite including resistivity independent water saturation estimation is recommended to mitigate uncertainty and ascertain water contact.

- Probabilistic uncertainty analysis in combination with sensitivity analysis reveals that water saturation modeling, NTG uncertainty and Facies have highest impact on the STOIIP of Gollapalli Formation. Relevant data acquisition in form of core (Unit-III) & well logs and refinement of reservoir model with incorporation of new wells is recommended to reduce the uncertainty and hence its impact. Additionally, Pre-fracture and Post-fracture Production logging is recommended to establish cut-off values of Effective porosity and water saturation.

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References

Ringrose, P. and Bentley, M., 2015, *Reservoir Model Design*, Springer, Dordrecht.

ONGC, Addendum to FDP – KG-ONN-2003/1, 2017 and other internal reports

Schlumberger, *Schlumberger Oilfield Glossary*. Available: http://www.glossary.oilfield.slb.com [2016, January 15].

Wei Yu, Xiaosi Tan, Lihua Zuo, Jenn-Tai Liang, Hwa C. Liang, and Suojin Wang, 2016, *A New Probabilistic Approach for Uncertainty Quantification in Well Performance of Shale Gas Reservoirs, SPE-183651.*

Caers, J., 2011, *Modeling Uncertainty in the Earth Sciences*, Wiley-Blackwell, West Sussex.

Shahkarami, A., Mohaghegh, S.D., Gholami, V. and Bromhal, G., 2015, *Application of Artificial Intelligence and Data Mining Techniques for Fast Track Modeling of Geologic Sequestration of Carbon Dioxide – Case Study of SACROC Unit*, SPE Digital Energy Conference and Exhibition, Woodlands, Texas.