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Uncertainty analysis of reservoir parameters based on "Umid" gas-condensate field.

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“Ümid” qaz-kondensat yatağının timsalında rezervuar parametrlərinin qeyri-müəyyənlik analizi.

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Abstract

A reservoir is the result of geologic processes and is not randomly generated. However, the predominant challenge from which a myriad of other field development issues arise has been on how to accurately characterise reservoir parameters because the obtained results are largely associated with uncertainties due to subsurface geological complexities. Uncertainties can be mitigated by gaining more information and/or using better science and technology. To know what needs to be known and what can be known should be the main focal points of uncertainty analysis in reservoir parameters.

My thesis will focuse on the evolving advances and current practices in reservoir uncertainty modelling and gives insight into the future trends. This work examines the foremost statistical reservoir uncertainty analysis approaches with the current probabilistic and stochastic uncertainty modelling workflows which are typically based on various numerical models. The very recent development of software programs such as Crystall Ball in reservoir uncertainty analysis, which now points to a future of using more sophisticated methods for achieving reservoir models and parameters with higher confidence.

The Monte Carlo (MC) approach was applied to assess and quantify uncertainty in “Umid” gas-condensate field’s reservoir parameters and as well as in probabilistic reserve estimates and improve risk decision making, regrdless of that it can be quite computationally intensive. MC method has the advantages of generating possible outcomes that contain more information relative to deterministic and scenario approach by taking into consideration the uncertainty associated with various input variable.

The results proved that the approach was both effective and flexible enough to be applied to a complex geological and petrophysical interpretations. The quantitative evaluation of the uncertainty associated to the reservoir parameters provided a significant improvement in the knowledge of the true risk analysis and reserve estimation.

Referat

Lay geoloji proseslərin nəticəsidir və təsadüfi olaraq yaranmır. Buna baxmayaraq, çox sayda fərqli yataqların işlənilmə problemlərindəki əsas çətinlik, lay parametrlərinin necə dəqiq xarakterizə etmək ilə bağlıdır, çünki əldə edilən nəticələr əsasən yeraltı geoloji mürəkkəbliklər səbəbindən yaranan qeyri-müəyyənliklərlə əlaqələndirilir. Qeyri-müəyyənliklər daha çox məlumat əldə etmək və ya daha yaxşı elm və texnologiyadan istifadə etməklə aradan qaldırıla bilər. Nəyin bilinməli olduğunu və nəyin bilinə biləcəyini lay parametrlərində qeyri-müəyyənlik analizinin əsas mərkəz nöqtələri olmalıdır.

Tezisim, lay parametrlərinin qeyri-müəyyənliyinin təyinininində mövcud olan yeniliklər və hal-hazırki təcrübələrə yönələcəkdir və ehtiyatların qiymətləndirilməsi üçün fikir verəcəkdir. Bu iş, müxtəlif ədədi modellərə əsaslanan mövcud ehtimal və stoxastik qeyri-müəyyənlik modelləşdirmə iş axını ilə ən qabaqcıl statistiki lay qeyri-müəyyənlik təhlili yanaşmalarını araşdırır. Lay qeyri-müəyyənliklər analizində istifadə olunan “Crystall Ball” kimi proqram təminantlarının inkişafı, gələcəkdə lay modellərinin və parametrlərinin yüksək dəqiqlikdə təyin olunması üçün daha gəlişmiş metodlardan istifadəni işarə edir.

Monte Karlo (MK) yanaşması, "Ümid" qaz-kondensat yatağının lay parametrlərindəki qeyri-müəyyənliyi qiymətləndirmək və miqdarını təyin etmək və habelə hesablama baxımından olduqca intensiv olmasından asılı olmayaraq ehtimal olunan ehtiyatların qiymətləndirmələrində və risk qərar verilməsini yaxşılaşdırmaq üçün tətbiq edilmişdir. MC metodu, müxtəlif giriş dəyişənləri ilə əlaqəli qeyri-müəyyənliyi nəzərə alaraq deterministik və ssenari yanaşmaya nisbətən daha çox məlumat ehtiva edən mümkün nəticələrin əldə edilməsinin üstünlüklərinə malikdir.

Nəticələr yanaşmanın mürəkkəb geoloji və petrofiziki interpretasiya tətbiq olunması zamanı kifayət qədər effektiv və uyğun olduğunu sübut etdi. Lay parametrləri ilə əlaqəli qeyri-müəyyənliyin miqdari olaraq qiymətləndirilməsi düzgün risk analizi və ehtiyatların hesablanması mövzusunda irəliləyiş təmin edir.

Declaration of Authorship

I, Faraj Nabiyev, confirm that this work submitted for assessment is my own and is expressed in my words. Any uses made within it of the works of other authors in any form (e.g. ideas, equations, figures, drawings, text, tables, other forms of data, programs) are properly acknowledged and referenced at the point of their use. A list of the references employed is included.

Signed on

Signature ____________________

Acknowledgements

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Contents

Chapter 1. Introductıon

1.1 Background: Problem and solution method related with uncertainty

Uncertainty is the consequence of lacking knowledge or information about a certain scenarios. The complexity of the reservoir and the variations in the parameters of the reservoir make it challenging for people to have a apparent understanding of them and their characteristics. The description of the sediment is the outcome of the complexity of the subsurface and the limited data required to describe it.

In order to determine the uncertainty associated with the reservoir description, the uncertainty needs to be quantified and managed. It is difficult to know all the static and dynamic characteristics of the reservoir, so it is almost inaccessible to get an ideal reservoir model. It provides insights into the development of dynamic behavior in production scenarios throughout the life of the site. Good forecasts about future dynamic behavior will help enhance oilfield development and oilfield management from an economic and recovery perspective. Historical comparison is important in order to make definite forecasts about future production. Historical matching is called the process of adjusting the reservoir model to match historical statistics.

The purpose of this article is to provide an up-to-date assessment of the uncertainty of the gas field. The dynamic behavior of the reservoir can be difficult to predict and needs to be estimated using simulation software. The records matching trouble is a non-specific trouble, because of this that it has more than one solutions. To be capable of record and diminish the reservoir uncertainties the ensemble based technique Markov chain Monte Carlo is utilized in a Bayesian updating. Some authors have shown that probabilistic applications can be advantageous for quantifying the uncertainty among others; McVay and Dossary (2014) and Bickel and Bratvold (2007). The study will use Crystal Ball software to assist in historical comparisons, reduce uncertainties correspond to reservoir parameters and dynamic behavior, and provide (anticipated) production prognosis.

1.2 Plan of thesis

The thesis is an about uncertainty analysis of gas-condensate field. Since it is vital to know about basic knowledge of framework and techniques, the thesis begins with analyzing reliant concept and literature, previously the field of study is introduced. In conclusion, outcomes and findings are examined and linked together. This thesis is divided into four chapters. The following is an summary of the structure within the thesis:

- Chapter 2 proposes phrases and ideas utilized in probability theory. In addition, the probabilistic method to deal with and apprehend the uncertainty withinside the subsurface are analyzed. The ultimate section of the chapter discuss the way to generate grade from uncertainty.

- Chapter 3 proposes the theory and case of historical matching, together with the use of Monte Carlo algorithm to update the Bayesian formula of uncertainty analysis. A general discussion and concept about sensitivity analysis and Monte Carlo method will be introduced.

- Chapter 4 proposes the reservoir that will be investigated in thesis. There is a discussion of common field data, geological analyis and uncertainties correspond to studied reservoir. In addition, the model of reservoir will be introduced briefly. This chapter also will charactherize the application of theory and the outcomes of history matching as well as the forecast scenarios. The results of analysis and important findings will be discussed before ending with remarks from study and recommendations.

Chapter 2. Conceptual framework of uncertainty analysis

2.1 Definitions in probabilistic approach

Some of phrases which are utilized in uncertainty analysis and decision evaluation have distinctive definitions inside specific disciplines that can cause misconception. This segment will talk and outline phrases which are often used at some stages of the thesis.

Probability, event and outcome

Probability shows possibility of certain outcome can take place as a result of event. The probability describing the chance of the outcome will occur which is assigned by the individual and it should solely be supported by all offered facts and datas[1]. Tamas Rudas defines the probability with the following expressions: "*A probabilistic model formulates relationships among the observables – relationships that are not supposed to hold exactly for each observation but still give a description of the fundamental tendencies governing their behavior. Probabilistic models allow the researchers to incorporate uncertainty into the fundamental laws they use to describe their findings*." [2]. To be able to determine probabilities it's vital to possess a certain characterization of the result. There are some guidelines referred to probabilities which are vital always. First rule is that value of probabilities have to be vary in a scalar range of 0 to 1 (or 0 to 100 %). When outcome will not occur then value of probability shows 0 and for vice versa case value of 1 shows validity that outcome will occur. Another rule is total amount of probabilities of all feasible results should be equal to 1. It is clear from the last rule that at least one result must always occur [1].

It can be beneficial to differentiate an *event* from an *outcome*. In probability theory, an *outcome* is a likely end result of an test or trial.[1] Each feasible final results of a selected test is unique, and distinct effects are collectively exclusive (only one outcome will happen on every trial of the test). In probability, the set of outcomes from an experiment is known as an *event* [3]. For example, shoot of seismic or drilling a well are one of the event, although subsurface geological structure after seismic operation can be fault, fold or etc., that is called outcome of operation.

Uncertainty and Risk

In the petroleum business, individuals are very interested about quantities like original hydrocarbon in place, reserves, and also the time for the recovery mechanism, that are all essential to the economic returns. Those portions play a key function in making essential choices for each the oil producers and the investors at distinct stages of reservoir development. But being certain of those values is normally impossible. It is due to the insufficient knowledge, or details, which generates uncertainty in reservoir simulation.

Uncertainty means we can not identify the amount (or outcome) of some output, eg the average porosity of a particular formation (or the porosity of a core-sized segment of rock in some place through the reservoir). Uncertianty is measured with a probability distribution which related with our case of data about the possibility of which the unique, actual grade of the uncertain volume is. Though we can be uncertain about which example arguments, outcome parameters and grade variables to select, they do not have “true” values. Instead we want to find which are “good” or “best” values (for instance, the purpose of decision-making is to achieve the optimal grade of the decision parameters). Decision principle, can be intention of as having “true” values because of their reliance on empirical volumes. If a principle was to rely just on (be estimated from) empirical volumes so it could be assumed to contain true values, e.g. OOIP [4].

Risk is viewed as output of luck and (negative) event, possibility of failing (insufficiency) when relative to whole possibly events. To find out the risk analytically a systematic study of the condition is important, the resolve of the range of chances and the potential of specific results. In essence, probability theory manage the principles of risk distribution [5].

2.2 Probabilistic Method

Jointly with statistics, probability theory is a branch of mathematics that has been developed to deal with uncertainty. An experiment can in general be thought of as any process or procedure for which more than one outcome is possible. The goal of probability theory is to provide a mathematical structure for understanding or explaining the chances or likelihoods of the various outcomes actually occurring. A *random variable* is formed by assigning a numerical value to each outcome in the sample space of a particular experiment [6]. There are two important types of random variables, discrete and continuous. A random variable is *discrete* if its possible values form a discrete set. This means that if the possible values are arranged in order, there is a gap between each value and the next one. For any discrete random variable, if we specify the list of its possible values along with the probability that the random variable takes on each of these values, then we have completely described the population from which the random variable is sampled [7]. Strictly, this is called a *Probability Mass Function* (PMF), sometimes just called a probability distribution. For example the number of dry (suitably defined!) wells in a 5-well drilling campaign could be exactly 0, 1, 2, 3, 4, or 5 wells, with probabilities of say 0.08, 0.26, 0.34, 0.23, 0.07 and 0.01. Since the events are mutually exclusive, and we have listed all possible events (they are collectively exhaustive), the sum of their probabilities must equal one. The failure to identify all possible events in an uncertain situation is a significant cause of poor decision outcomes – the unpredicted events often being called, euphemistically, “surprises”). Figure 1 shows an example of a discrete probability distribution with eight different outcomes that are assigned with individual probabilities [4].

A *continuous random variable* is defined to be a random variable whose probabilities are represented by areas under a curve. This curve is called the *probability density function* (PDF). Because the probability density function is a curve, the computations of probabilities involve integrals, rather than the sums that are used in the discrete case [7]. Figure 2 pictures a continuous probability distribution. The probability that the random variable lies between two values a and b is obtained by integrating the probability density function between these two values, so that

$$P(a \leq X \leq b) = \int_{a}^{b} f(x)dx \tag{1}$$

$$f(x) \geq 0 \quad \forall X$$

The total area under the continuous probability distribution will always be equal to one. This is because any outcome must be captured by the range of the distribution by definition in Equation 2. By the definition of a continuous distribution, the probability of getting a single outcome is equal to zero. It is useful to notice that the probability that a continuous random variable X takes any specific value a is always 0! [6]. Technically, this can be seen by noting with below equation 2:

$$P(X = a) = \int_{a}^{a} f(x)dx = 0 \tag{2}$$

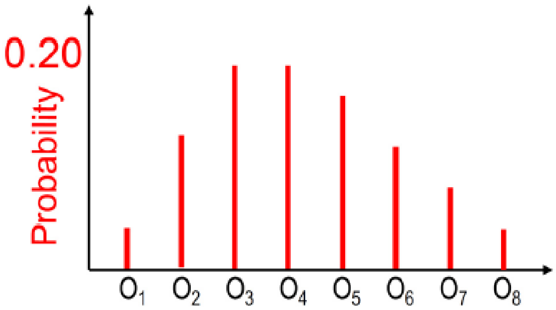


Figure 1. Discrete probability mass function-each outcome is assigned to probability. Sum of probabilities= 1 [4]

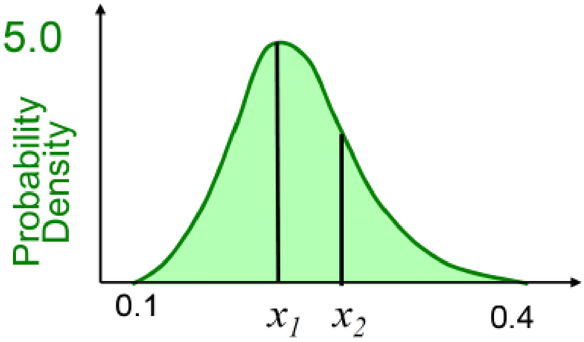


Figure 2. Continuous probability density function-Probability is meaningful only between two points, say X_1 and X_2 and is the area under the curve between those two points. Total area under curve = 1 [4]

The most common of generic distribution types is the *cumulative distribution function* (CDF). Given a random variable X, the cumulative distribution function F(x) is defined as:

$$F(x) = Prob(X \leq x) \tag{3}$$

In words, F(x) is the probability of finding a value of a random variable X that is less. than or equal to x. The argument of F is x, the bounding value, not X the random variable. Thus, F says something only about the probability of X being less than a certain value, but says nothing precisely about what X is [8]. For any discrete random variable X, the cumulative distribution function F(x) can be computed by summing the probabilities of all the possible values of X that are less than or equal to x. Note that F(x) is defined for any number x, not just for the possible values of X.

The probability mass function of X is the function:

$$p(x) = P(X = x) \tag{4}$$

The cumulative distribution function of X is the function:

$$F(x) = \sum_{t \leq x} p(t) = \sum_{t \leq x} P(X = t) \tag{5}$$

$$\sum_{x} p(x) = \sum_{x} P(X = x) = 1 \tag{6}$$

where the sum is over all the possible values of X [7].

For a continuous random variable, the value of F(x) is obtained by integrating the probability density function. The cumulative distribution function of X is the function:

$$F(x) = P(X \leq x) = \int_{-\infty}^{x} f(t)dt \tag{7}$$

Figure 3 and Figure 4 show how discrete and continuous probability density functions can be shown as cumulative density functions.

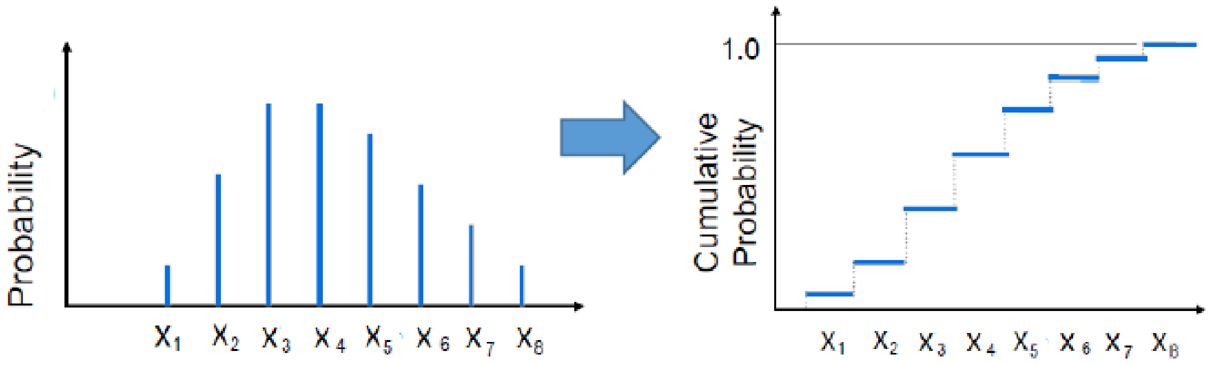


Figure 3. A discrete probability density function transformed to a cumulative density function.

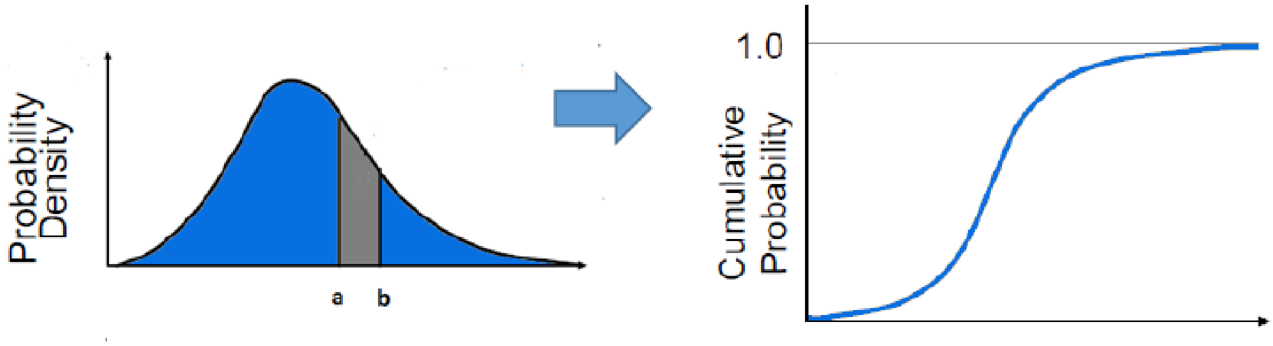


Figure 4. A continuous probability density function transformed to a cumulative density function.

Probability Definitions

One of the most basic summary measures is the *expectation* or *mean* of a random variable, which is denoted by E(X) and represents an “average” value of the random variable. The expected value or expectation of a discrete random variable with a probability mass function $P(X = x_i) = p_i$ is

$$E(X) = \sum_i p_i x_i \tag{8}$$

E(X) provides a summary measure of the average value taken by the random variable and is also known as the mean of the random variable.

The expected value or expectation of a continuous random variable with a probability density function f (x) is

$$E(X) = \int_{-\infty}^{+\infty} x f(x) dx \tag{9}$$

E(X) can be interpreted as a weighted average of the values within the state space, with weights corresponding to the probability density function f (x).

The median is another summary measure of the distribution of a random variable that provides information about the “middle” value of the random variable. It is defined to have the property that the random variable is equally likely to be either smaller or larger than the median. The median is most often used with continuous random variables and is the value of x will be equal the value of 50 percent also written as P50. The mode is the value that appears most often in a set of data.

Another important summary measure of the distribution of a random variable is the variance, which measures the spread or variability in the values taken by the random variable. Specifically, the variance of a random variable is defined as

$$Var(X) = E((X - E(X))^2) \tag{10}$$

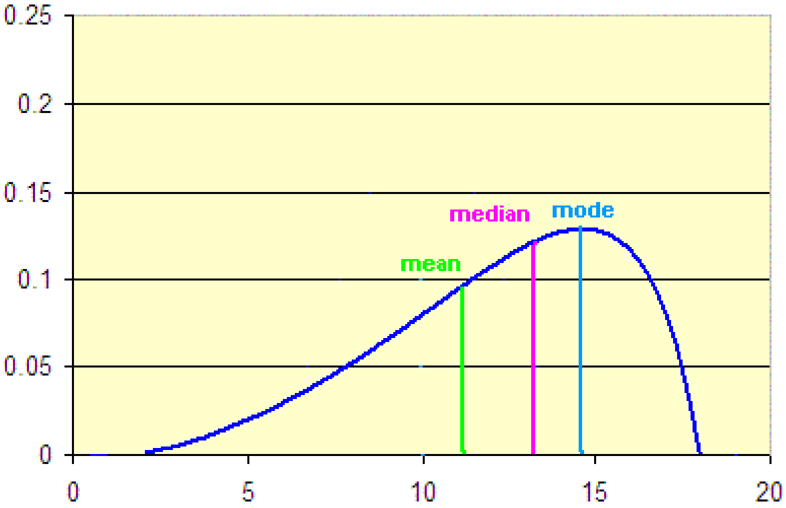


Figure 5. Log normal distribution with the points Mode, Median and Mean

It is common to use the symbol μ to denote the mean or expectation of a random variable and the symbol σ^2 to denote the variance. The square root of the variance, σ, is known as the standard deviation of the distribution of the random variable and is often used in place of the variance to describe the spread of the distribution.

$$\sigma(X) = \sqrt{Var(X)} \tag{11}$$

Figure 6 shows PDFs with different standard deviations; zero, small and large that all have the same mean.

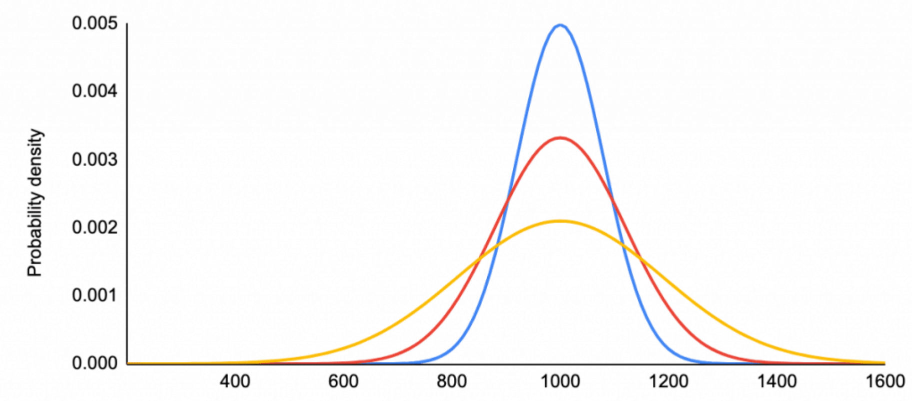


Figure 6. Normal distribution with different standard deviation

Covariance describe how two random variables are related. If the variables move in the same direction they are positively related. When the variables move in opposite directions they are inversely related. The inverse- and positive relations are often referred to as correlations, ranging from -1 to 1, respectively, where 1 represents perfect correlation. The covariance of the variables X and Y is defined by:

$$Con(X,Y) = E[(X - E[X])(Y - E[Y])] \tag{12}$$

In the cases where both the variables, X and Y takes a value that both are greater, or smaller than their respective means, the covariance take a positive value.

The *normal distribution* (also called the Gaussian distribution) is by far the most commonly used distribution in statistics. The mean of a normal random variable may have any value, and the variance may have any positive value. The probability density function of a normal random variable with mean μ and variance σ^2 is given by

$$f(x) = \frac{1}{\sqrt{2\pi\sigma^2}} \exp\,(-\frac{(x-\mu_x)^2}{2\sigma^2}) \tag{13}$$

If x is a random variable whose probability density function is normal with mean μ and variance σ^2, we write $x \sim N(\mu, \sigma^2)$.

The Gaussian function is characteristic by its bell shape and symmetry around its mean value. Other commonly used probability distributions in the oil and gas industry and their corresponding properties can be seen in Figure 7.

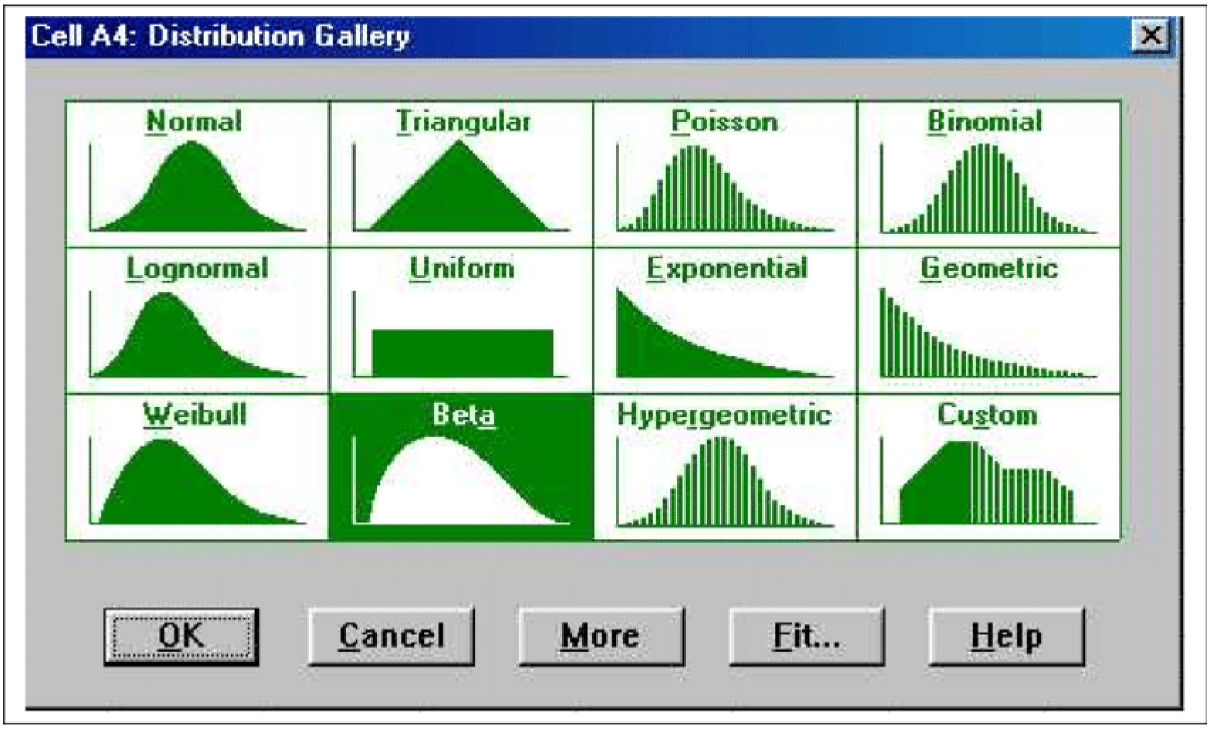


Figure 7. Commonly used probability distributions and their corresponding properties, in the oil and gas industry

2.3 Main causes forming uncertainties

Reserves represent main funds of oil and gas companies. The companies – on the upstream side - carry out improvement and production designs relied on resources, and shareholders and the community value oil and gas companies mainly relied on reserves held. Reliability and compatibility of reserves, for this reason, is an important point in the oil industry. Although it may sound like ordinary, it is better to specify at the beginning that the generally utilized phrase "reserves accuracy" – also utilized in this thesis on the basis of comfort – is a mistake. Accuracy mentions to the grade to which an appraised quantity shows the actual value. Accuracy is evaluated by contrast with the actual value. With respect to reserves, nevertheless, the actual value will be recognized while the last barrel of oil or the last cubic foot of gas is produced, and that intends for years. Since there is no grade with which to compare an evaluation previously and during production, accuracy changes into an incalculable and unrealistic aim v field abandonment. A less challenging phrase, 'reliability," sounds more suitable for reserves. A commonly held vision in the industry is that reserves uncertainty, simply similar good wine, enhances in the course of time, fitting smaller or narrower when a field changes from exploration step to appraisal, to production and abandonment [9].

Based on the grade of risk, there are various ways to handle it. The selection of the optimal risk control strategy rely on the direction of statistical analyzing. That is, the approval of essential strategies covering the progression period of oil and gas fields and the whole period of operation allows good management. U.S. scientists Zwee Bodi and RK Merton have commented extensively on the very important, uncertain risk. The risk management procedure need to go through the following five steps:

- risk detection;
- risk assessment;
- selection methods of risk management;
- implementation of selection methods;
- review of results.

The risk element is one of the highly studied topic in the oil and gas industry lately. From the apprasial and exploration of oil and gas reservoirs to the final step of the advancement procedure, there is a chance of risk in the processes within analysis. Trustworthy risk management while field appraisal and exploration relys mostly on the quality and size of geological-geophysical and coring info acquired from exploration wells. The uncertainties associated in petroleum area are commonly connected to [10]:

a. *Reservoir*: performance and thermodynamic of fluid, drainage area, reserve estimation, recovery factor, restriction on production rates, declining rate, soil characteristics, relative permeability, saturation, marketing quantity of oil and gas, productivity and output rate.

b. *Geology*: Geological texture, reservoir seals and traps, source rocks, reservoir storage capacity, or hydrocarbon displacement.

c. *Drilling*: Well positioning, selection between vertical or horizontal well, demand for injector, selection between wet or dry tree, choice of vertical X-mas tree or horizontal X-mas tree, accomplishment of the wild cat well drilling.

d. *Facility*: Selection of equipment for liquid treatment, interval from closer facility, tie-in development, project programme, transportation and allocation facility, storage, measuring, handling technology, and performance.

e. *Technological*: Usage of recent technology, advancement of in operation technology, applying of technology

f. *Economical*: Oil cost, gas cost, rate of discount, rate of inflation, petroleum demand, price of underground and surface facility

g. *Others*: There are various uncertainty not connected to technical and business such as

- *Social uncertainties*. It is connected with legislation, politic/ authority (rule, regulation, war), systematical risk (market movement, inflating, financing atmosphere), community atmosphere (well-being, schooling, culturing, social security system)

- *Natural environment uncertainties*. Influence of natural environment to the installation building (tsunami, earthquake, hurricane)

- *Management uncertainties*. Uncertainties connected to project steering and implementation. It has impact on administrative and personal performance, joint process, controlling of action, organization. Shammas & Gudmestad (2005) study individual and organizational aspect in offshore disasters, and they determined that administrative problems at an premature step of a project is especially essential because this can avoid escalation[11].

- *HSE uncertainties*. Uncertainty with personal protection and HSE culture, conditions of employment, and collective protection mentality.Although, there are uncertainties about the effectiveness and the content of the principle “safety culture”, we must build a extensive safety culture jointed with a healthy conditions of employment and natural environment to address the comprehensive approach of companies to fulfil sustainable development. HSE culture is a fresh phrase for safety culture.

2.4 Geological uncertainties and classification model

The uncertainties as a result of human drawback, incompetency or insufficient conditions may take place in all steps of geological researchs and they are extremely assorted. This is the cause why they were not examined consistently as yet. It is completely necessary to discriminate and to categorize them, since they present the larger piece of the total uncertainty of the geological researchs. Their primary resources are insufficient knowledge of the particular geological object or procedure, drawbacks in modeling, the inaccurate implementation of mathematical techniques and eventually economically, financial, seasonal or other natural restrictions of the research. Subsequently the risks can be arised from geological analysis are corresponded [12]:

1. *Lack of representative sampling*. Most input data of a geological research are gained with sampling. It is highly hard to gain a representative sampling consequence, since usually solely a very few part of a geological formation or rock mass is available by the sampling processes, as temporal and economic constraints provide only a small number of boreholes etc. to build up. The primary causes of sampling faults can be summarized this way:

- *Adequate volume of the samples*. The sample sizing need to match to the grain size of the obtained rock. In addition, its material must be adequate in quantity for the expected one or various laboratory assessments.
- *The sampling pattern* need to geometrically match to the initial pattern of the investigated geological object.
- *Sampling density* is the space of the sampling points. interpolation between sampling areas, or calculation from one sampling area is acceptable solely inside the given range of impact. This is a highly ordinary source of fault, because variograms are seldom calculated in the course of geological researchs.
- *Inadequate sample size* is as well a ordinary source of fault. Tukey [13] mentioned that relying on the mathematical process to be implemented, at least 30 to 50 samples are important to generate mathematically accurate outcome. Nonetheless, it is not simple

in geological researches to generate this multiple samples, because numerous sampling methods - e.g. drilling of boreholes - are quite costly.

2. *Insufficient laboratory measurements*. The sorts of laboratory measurements that are essential for the explanation of a scholarly or applied geological issue must be comprehensively selected before launching any research. It is kmown that whole assessment errors include casual and systemic components. The primary sources of these errors are:

- Weakness of sample preparation, e.g. sample orientation, optimal grain size, homogenization, removal of favored orientation etc.
- Adjustment faults.
- Weakness of the apparatus and of the type of assessment.
- Imperfect ability and/or awareness of the assessment personnel.

3. *Uncertainties in the description of non-measurable properties* (uncertainty or lack of clarity in the mathematical categorization discussed aforesaid). A extensive percentage of geological characteristics or objects can't be measured, they can be seen and specified solely. They are termed qualitative parameters. In geological researchs the frequency of a provided factor can be frequently characterized solely by qualitative phrases, for example very rare, rare, common, frequent, very frequent.

4. *Conceptual and model uncertainties*. Necessarily, a conception is a generalize objective, gained from certain cases. Geological designs mention to geological objects (e.g. rocks, mineral sediment, specimens etc.), features (e.g. composition, framework, texture etc.) or processing (sedimentation, mountain forming etc.) indicating general familial concepts about them. Some geological ideas are identified not enough, result in extra confusion. Although concepts are generalizations of some examples, the models are simplistic representatives of the natural phenomenon of one specific geological object, feature or processing, such it is not possible to illustrate and characterize them in all details, from point-to-point. The two major individual sources of model uncertainties are, in accordance with Nilsen and Aven [14] the constraints of the scientist's knowledge (background) and conscious simplifications launched by the scientist. Both are usual sources of uncertainty in the geologic researchs.

5. *Uncertainties of mathematical modeling*. It is notorious that mathematical statistics provides in many instances a number of alternate mathematical models to clarify a particular problem. For instance, mean values are utilized in determinist modeling and probability density functions in stochastic modeling. It is not simple to get the most appropriate, most sufficient

mathematical model for the specific task. As the results are usually not same, the selection of modeling methods can include more or less uncertainty to the outcomes of the geological researches. A furthermore uncertainty of mathematical modeling occurs from the event that connections amongst the studied variables are not all acquainted or they are known wrongly. Uncertainties of the end conclusions of a geological researches or tasks. Generally various conclusions can be extracted from a geological investigation. It is generally feasible to distribute individual probabilities to the probable versions and to grade them.

When summing up the sources of uncertainties and faults in geological researches, it has to be emphasized that variableness is a characteristic of nature, existent autonomously of us. In contrast, all the rests are because of human drawbacks. Natural variableness can be studied, measured and specified, yet it cannot be reduced.

The ultimate levels of plan uncertainty and risk arise during the mine possibility study step. McCarthy [15] performed a poll of 105 mining projects to determine frequent issues occuring from feasibility studies. The results are demonstrated in Fig.8. Almost two thirds of the risks can be categorized as geological risk. It stressing that geological uncertainty and risk ought to be considered in ore/coal resources/reserves estimation procedure.

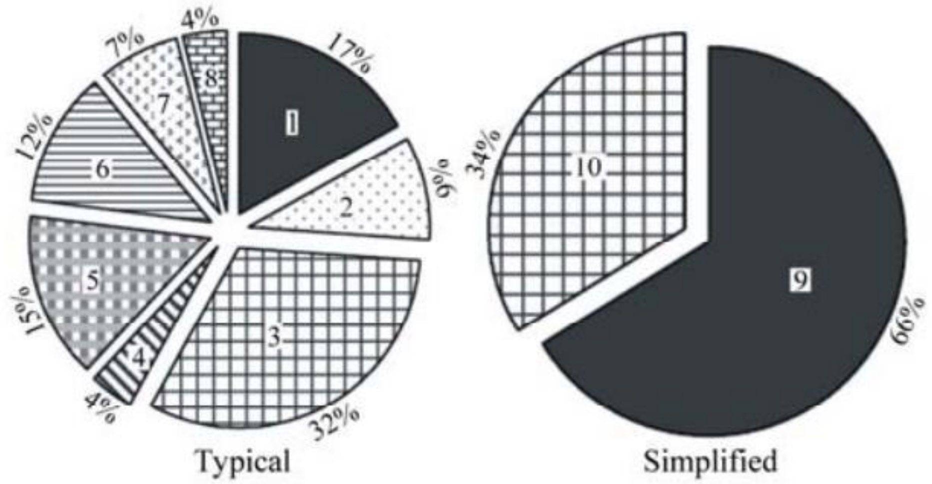


Figure 8. Typical and simplified mining risk profile-Sources of technical risk in feasibility study outcomes (105 case studies reported by McCarthy, 2003)

1—Geology, resource and reserve estimation; 2—Geotechnical analysis; 3—Mine design and scheduling; 4—Mining equipment selection; 5—Metallurgical testwork, sampling and scale-up; 6—Process plant equipment design and selection; 7—Cost estimation; 8—Hydrology; 9—Geological inputs and interpretations; 10—Non-geology related inputs

2.5 The main geological risks in the oil and gas fields of Azerbaijan

The main new oil and gas fields in Azerbaijan have been identified in the sea area, and geological and geophysical research, as well as the development of proven reserves, require several times more investment than onshore fields.

In this regard, the uncertainties and risks that may arise during the exploration and development stages of offshore fields should be more accurately assessed.

Initially estimated oil and condensate reserves and prospective resources ($C_2 + C_3$) are 24% in offshore fields and 9% in onshore fields (Figure 9). Gas reserves of the same category are 31% in offshore fields and 2% in onshore fields. Hydrocarbon reserves and resources registered in the state balance are an important part of the country's energy resources. In this regard, the assessment of geological risks is a topical issue. According to the assessment of geological risks in the oil and gas fields of Azerbaijan, the following uncertainties affect [16]:

- complexity of structural-tectonic structure of deposits (mud volcanoes, tectonic faults, lithological or stratigraphic fault zones) and deep deposition;

- hydrocarbon saturation coefficient of structures and oil and gas fields;
- oil and gas saturation coefficient of collectors;
- layer parameters (collector and thermobaric properties);
- fluid parameters (density, viscosity, etc.).

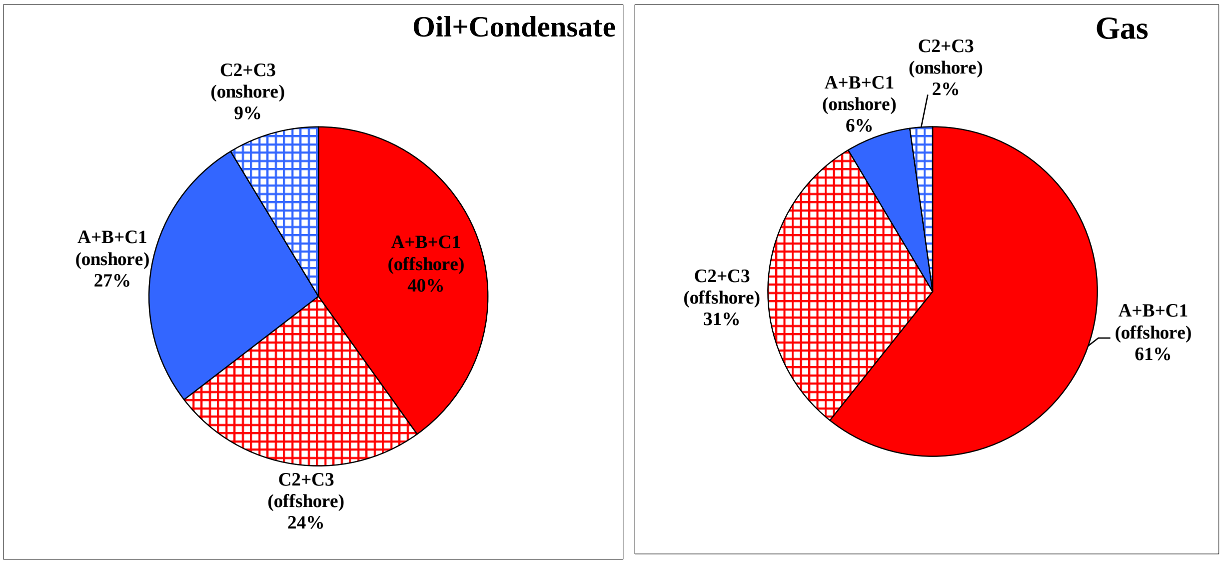


Figure 9. Distribution of geological reserves and resources of Azerbaijan fields

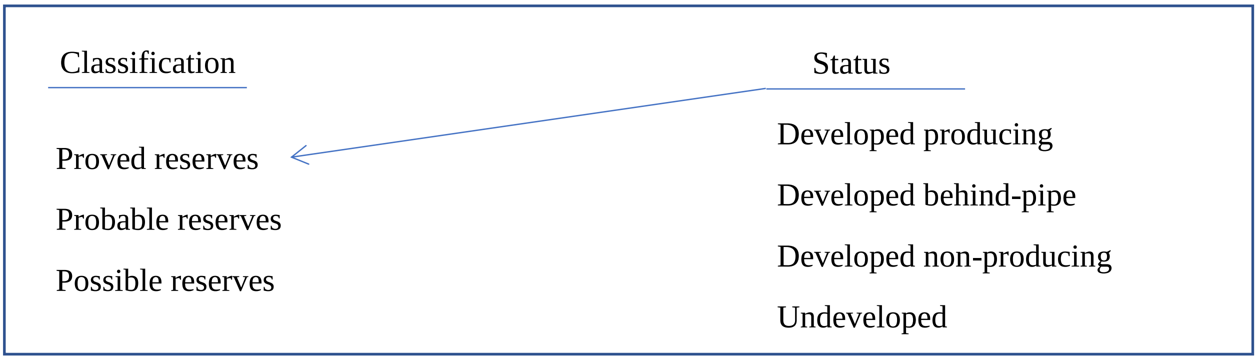
These parameters were studied at different levels in different fields. In this regard, a risk matrix should be developed to assess geological risks so that it is possible to identify risks according to the degree of impact of geological and mining parameters on the volume of reserves, as well as the level of study of this data. Depending on the geological issue under consideration, a risk matrix of different formats can be compiled.

Chapter 3. Uncertainty analysis and research methods

3.1 Directions for solving uncertainty problems

The petroleum industry acknowledged the uncertainty in predicting reserves a long time ago, and although a general description of reserve classifications stay to be recognized, technical associations and regulatory authority agencies proceed to collaborate toward evolving a general lexicon practical in determining the confidence one should set to reserves of various groups (Table 1). Although there are meaning variations, most groups of reserve categorizations involve the classifications of proved reserves, probable reserves, and possible reserves. The proved-reserve classification is generally divided into developed producing, developed behind-pipe, developed nonproducing, and undeveloped. "Developed" is generally implemented once a well exists which ccan produce the reserves, whereas "undeveloped" involves that the finance for drilling of wells and/or the instalment of secondary or recovery plans is still needed. Independently of the descriptions utilized, the different categorizations have been created to determine the certainty in the assessments. Since the categorizations indicate the certainty in the reserve assessments, they could be valuable when estimating uncertainty factors for computing the predicted ampunt of a producing feature [17].

Table 1. Reserve definitions.



To evaluate the geological risks of each project in the oil industry, the accuracy and amount of geological and mining information of the reservoir or advancement being investigated have to be reviewed. According to the results, a method is chosen to evaluate the geological risks.

For instance, a geological risk evaluation is needed to find out the accuracy of the measured amount of hydrocarbon reserves in a field. In this regard, firstly, the amount and quality of geological-mining parameters that instantly impact the hydrocarbon reserves of the investigated field are examined. The level of examining of these parameters in the field of productive zone is studied and multi-layered mathematical statistical studies are performed. Determination of distribution designs of geological-geophysical-mining variables, variagrams, histograms, etc. It is scheduled to collect graphic photos. If uncertainties in the field of the layer overcome, analog or logical methods are utilized, and conversely, geological-mathematical methods. Identical and logical methods are generally utilized in the primary exploration step of new exploration fields or oil and gas zones. The most frequently utilized methods for evaluating geological uncertainties in the oil and gas field are [16]:

Analog method. In this way, geological risks can be predicted in the uncertain structures of the oil and gas region, where the risks have already been assessed in one or more fields. In this way, geological risks can only be identified. When other methods are not possible, experts use this method only to assess the geological risks of hydrocarbon deposits with limited geological-geophysical-mining data. It is not possible to quantify geological risks in this way.

The *logical method* has similarities and differences with a analog method. With the application of this method, it is possible to assess the geological risks only qualitatively. Unlike the analog method, this method is used to assess the geological risks of hydrocarbon deposits with a certain amount of geological-geophysical-mining data.

Geological-mathematical methods. Unlike both methods, this method assesses geological risks both qualitatively and quantitatively. For this, it is necessary to fully study the main geological-geophysical-mining parameters of the studied field. Depending on the field of study, geological, geological-mathematical or hydrodynamic models are developed to evaluate the process. With the help of models, the geological factors influencing the process are assessed and an existing or completely new risk matrix is compiled, depending on the degree of study of the parameters. All calculations are performed with extensive application of geological and mathematical methods.

The proposed algorithm can assess the risks of any geological problem. However, there are logical aspects of the method, which are applied in different ways to solve such problems.

3.2 A new approach for analysis of uncertainties

The probability and stochastic theory are frequently applying in the risk and uncertainty analysis. Below are the methods usually utilized as risk and uncertainty analysis in petroleum project:

a. *Probability assignment and distribution*

Probabilistic method has been frequently conducted to describe uncertainty in the entrance parameter of a model. In probabilistic method, uncertainty is specified by the probability allocation or division or certainty interval. The probability number or distributions are grouped and implemented to the uncertain variable. The pessimistic, most probable, and optimistic instances are determined relied on the probability distribution of the variable. The later state is anticipated utilizing propagation probability distribution in input parameter into model to get uncertainty for magnitudes examined. Monte Carlo simulation or experimental design theory technique may be implemented as propagation instrument.

b. *Decision tree and expected value*

The numerous realization tree method has been utilized in the petroleum field to evaluate eventual recovery and field reserves. This method is a robust method that serves decision-making.

The overall process of this method involves:

- Create tornado diagrams to determine the critical uncertainties from the reservoir variables to lighten the multiple realization trees following history matching.

- Build multiple realization trees to determine the reserves.

- Allocate probabilities to the sections of the multiple realization trees relied on discretisation of the continuous probability functions.

- Examine simulation drive to make the probability distribution function of the reserves.

The first stage is the identical with the experimental design and response surface method. The recovery or reserves is the root of the multiple realization tree; the most influential parameter is positioned at the first stage, and whole the other main parameters are positioned at separate stages relied on their significance from the tornado diagram. Fig. 10 demonstrates the multiple realization trees. The parameter porosity here is the most essential one for reserves; hence, it is the first stage. Permeability and skin factor are positioned at the second and third stages. In this illustration, we have three crucial parameters [18].

The probabilities for each section – the pessimistic, the most likely, and the optimistic value – are allocated on the base of the optimum science of the incorporate reservoir investigation. If we have n reservoir parameters in the multiple realization tree, the tree will have n levels (not involving the root “reserves”), and 3n leaves (three probabilities for each reservoir parameter). Fig. 10 shows three levels: porosity, permeability, and skin factor, and $3^3 = 27$ leaves, which are positioned at the very root of the tree. The probability for each leaf is the product of the probabilities of whole its predecessor. For instance, the probability of the left-most leaf is the product of the probabilities of pessimistic porosity, pessimistic permeability, and pessimistic skin factor. For each leaf, we must carry out one simulation run to get the reserves or recovery. After the reservoir simulation runs are completed and the probability for each leaf is estimated, we may obtin the hydrocarbon allocation [19].

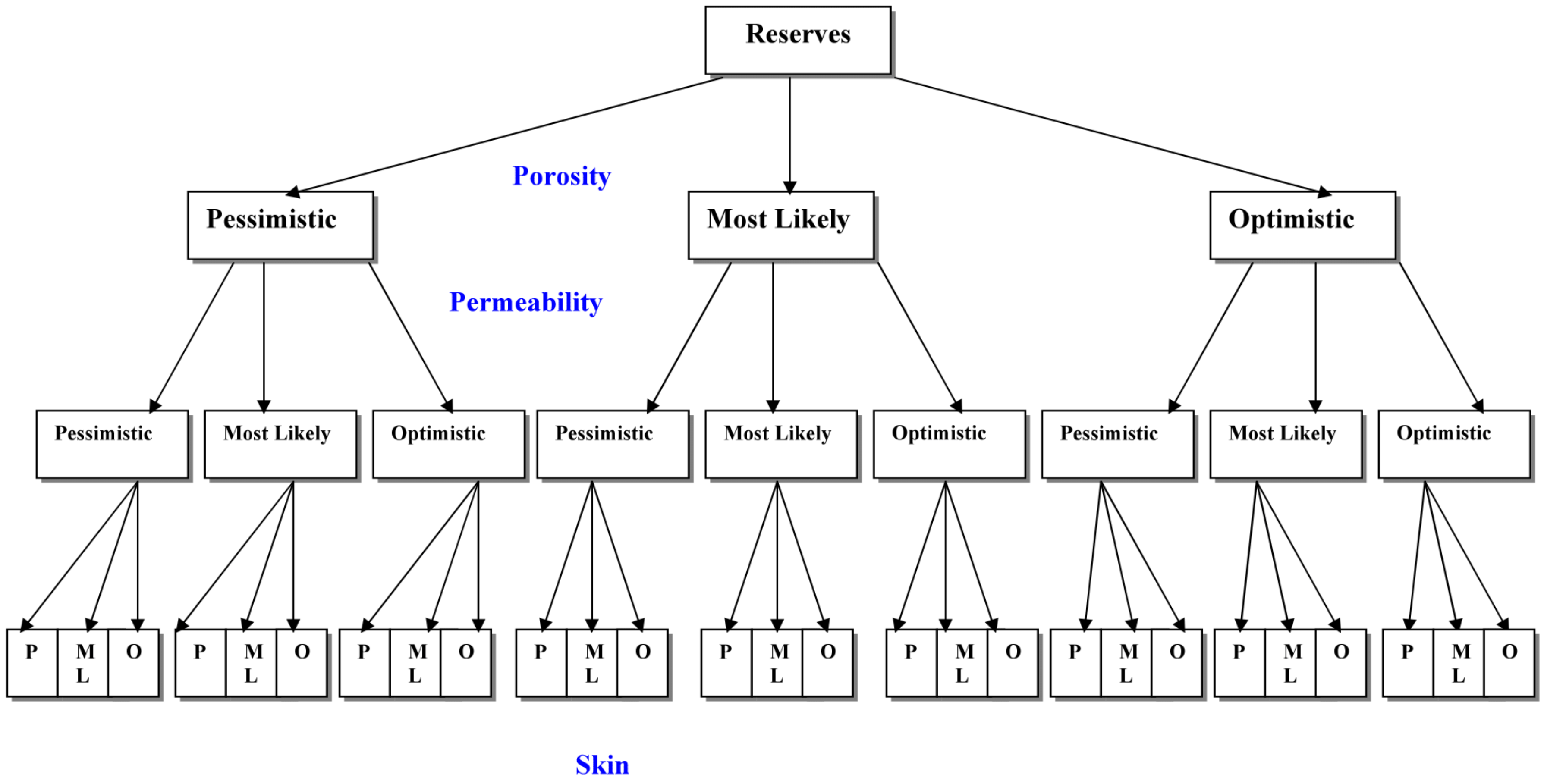


Figure 10. Multiple realization tree structure based on reserves estimation.

c. *Bayesian*

In the Bayesian method, an effort is performed to handling whole accessible information to diminish the quantity of uncertainty exhibit in desicion-making problem. When new data is gained, it is jointed with prior data to decrease uncertainty and allow better desicion-making. The formal mechanism utilized to joint the new data with the prior available data is recognized as Bayes' theorem. The possibility or variation in the input is evaluated handling relative frequency probability method. Priori distribution is tasked application of subjective probability and it is upgraded to create consequent distribution. The resultant distribution is utilized to create prognostic distribution to express the variation and uncertainties because of shortcoming of knowledge.

To create a priori distribution, we initially find out the probability distributions of parameters to measure gas in place (G), aquifer productivity index (J), and aquifer size (W_i) utilizing the volumetric approach. Parameters utilized in that procedure are area of the gas reservoir (A_r), effective thickness (h_r), porosity (Ø), water saturation (S_w), gas formation volume factor (Bg), aquifer permeability (k), aquifer thickness (h_a), and aquifer area (A_a).

Description of the Bayesian probability function based on the specification of a model for the uncertainty related to the recorded dynamic information from the field, pressure and production data in that instance. The probability function is gained by integrating the pressure data (d) and a forward model g(m) expresses pressure implicitly like a function of G, J, and W_i.

The a posteriori distribution is the product of the a priori distribution with the probability distribution, in that instance the prior distribution from volumetric analysis and the probability distribution from the material balance analysis. The posterior distribution is usually non-Gaussian. A point which is generally of marked interest is the mode of the posteriori distribution, named the maximum a posteriori (MAP) estimation. The MAP is the mixture of values of G, J, and Wi with the maximize posterior probability [20].

d. *Real option*

An estimation relied on fixed presumption may deceive the decision maker because it does not consider for alternative after the decision is achieved. Real option is suggested to reflect modifications which collaborative can perform after the project is se chosen. Real option is performed with decision tree where the chance to increase, postponing, or abandon the project are calculated and considered. In the scenario choice, alternative are performed to reflect future potential scenarios. The outcomes are recomputed taking into account the option to carry out.

Achievement or failing probability of a scenario is multiplying with result to obtain anticipated price of the scenario in real option. Price of information and flexibility are the crucial understanding for real option theory. Flexibility price is computed from variations of predicted value with applied option and without performing it. During first steps of project (post exploration), limited data is applicable and operator must decide under uncertainty and uncompleted knowledge. Advancement strategy over early stages of project impacts the value of next stage. Value of flexibility is used to reflect all alternatives and to decide the proper time to build the field through detailed design stage. Real option analysis has the capability to help administration to try enhanced options [21].

3.3 Sensitivity Analysis

Generally several reservoir parameters impact the eventual reserves distribution. Some of the reservoir parameters are more essential than rests, hence they should not be skipped in the reserves uncertainty analysis. Nonetheless, we cannot allow to involve too many reservoir parameters in the experimental design method. The number of reservoir simulation runs increases rapidly with the increase of the number of reservoir parameters included in the experimental design. A vast number of simulation runs can be highly costly because of the time-consuming process of reservoir simulation. Involving many reservoir parameters in an experimental design may not produce a positive consequence. Involving nonsensitive reservoir parameters may escalate the response surfaces to the stage that there is no response surface. For this reason, the initial stage of experimental design is to detect the critical reservoir parameters. Sensitivity analysis is the method of how the uncertainties in the consequence (OIIP) of a mathematical model (volumetric equation) can be distributed to various sources of uncertainties in its inputs (Boi, Soi, $\emptyset$). The parameter and theory of any model are liable to change and fault. Sensitivity analysis, as extensively specified, is the analysis of these possible variations and faults, and their influence on the model result. Outcomes from sensitivity analysis may be utilized for [27];

i. Decision making i.e. determining crucial values, sensitive or essential variables.

ii. Communication i.e. making suggestions more reasonable, understandable, convincing or cogent.

iii. Improved interpretation of a system i.e. assessing and understanding the connection between input and output variables.

iv. Model improvement i.e. emphasizing procurement of information.

Tornado diagram, as well named tornado chart is a specific type of bar chart in which the data sections are outlined horizontally rather than the normal vertical tabling. The sections are arranged in such a way that the major bar comes out at the top of the chart; the second major comes out second from the top; and etc. Tornado diagrams are advantageous for stochastic sensitivity analysis- comparative than the relative significance of variables. In a tornado diagram of variables (Boi, Soi, ∅), the top bars will show the parameter that provide the nearly to the variability of the result (OIIP); and hence what the decision maker have to concentrate on [28].

To build the reserves tornado chart for n reservoir parameters, we needing 2n+1 reservoir simulation runs: one run for whole the reservoir parameters with their most likely price–the history-matched concept– furthermore two runs for each parameter–one at the pessimist price and the other at the optimistic price for each parameter. For per reservoir parameter which impacts the eventual reserves, geoscientists and engineers operate jointly to find out the most-likely, pessimistic, and optimistic prices. The most-likely, pessimistic, and optimistic reserves values are later computed with the related reservoir parameter value. For instance, for reservoir porosity, the optimistic reserves is computed with the optimistic porosity value; the most likely reserves is computed with the most likely porosity value; the pessimistic reserves value is computed with the pessimistic value. Eventually, a reserves collection is achieved from the pessimistic and optimistic reserves values.

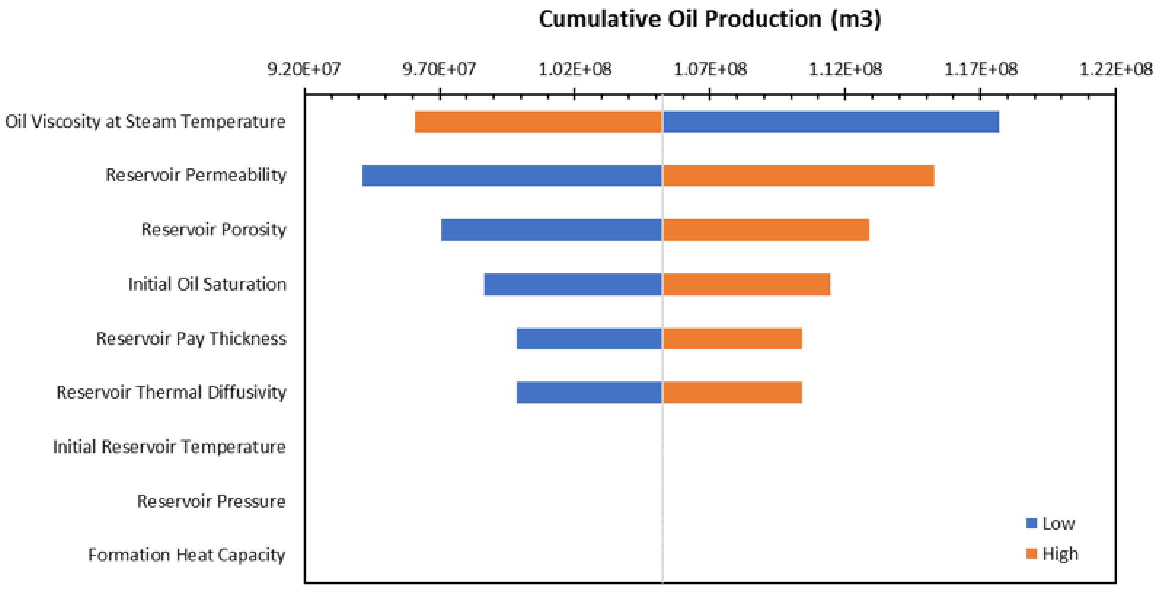


Figure 11. Tornado Diagram for Reservoir Parameters [29].

3.4 Monte Carlo Method

Monte Carlo is a effective statistical method which has been utilized for more than half a century. It has been implemented widely in the petroleum sector for decades. As early as 1969, it was utilized for pressure transient analysis. The Monte Carlo method has been utilized for different other targets in the industry for example reserves evaluation, material balance analysis, workover risk evaluation, and producing property evaluation [22]. It is an alternate to both stochastic assessment and the scenario method that shows pessimistic, most likely, and optimistic instance scenarios [23].

The Monte Carlo approach commences with a mathematical model in which a dependent variable is a function of the independent variables. The reliant variable generally is the magnitude of interest for example original hydrocarbons in place or cumulative oil production at a future time. The reliant variables are the reservoir parameters, for example porosity, permeability, and saturation. Various independent variables may have several statistical distributions, or they may have several parameters although they are the identical type of distribution. For instance, two normal distributions could include separate parameters: mean and standard deviation. Later the mathematical model is constructed, many random numbers are created for each separate variable relied on their certain statistical distributions. To produce random numbers for the reliant variables, we require probability density functions for them. Therefore, these probability density functions must be calculate before Monte Carlo method can be implemented.

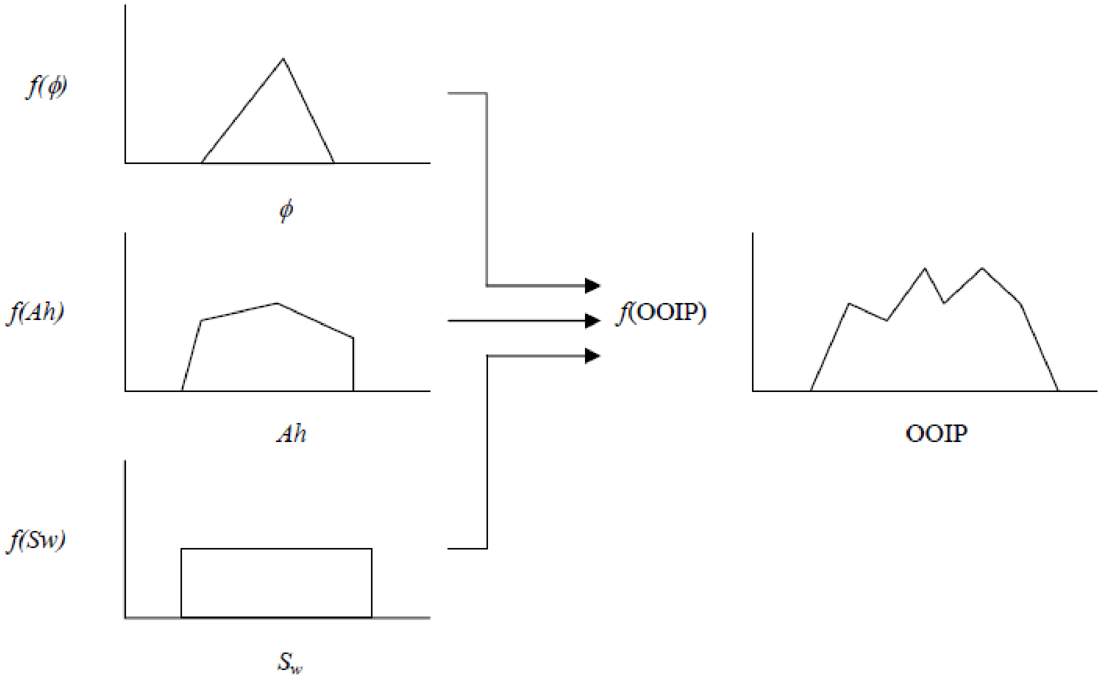


Figure 12. Monte Carlo simulation graphical representation.

The procedure of simulation is showed in Figure 13. It includes of evaluating the likely existence of each variable contributed to the reserves in an accumulating process. By consistently choice of these variables based on with input distributions, computing the resultant reserves and storage of the results, an prediction curve can be created. From this could be computed the specific values. These could be smoothly adjusted to account for the commercial principle essential to transform it into technically and commercially recoverable reserves [24].

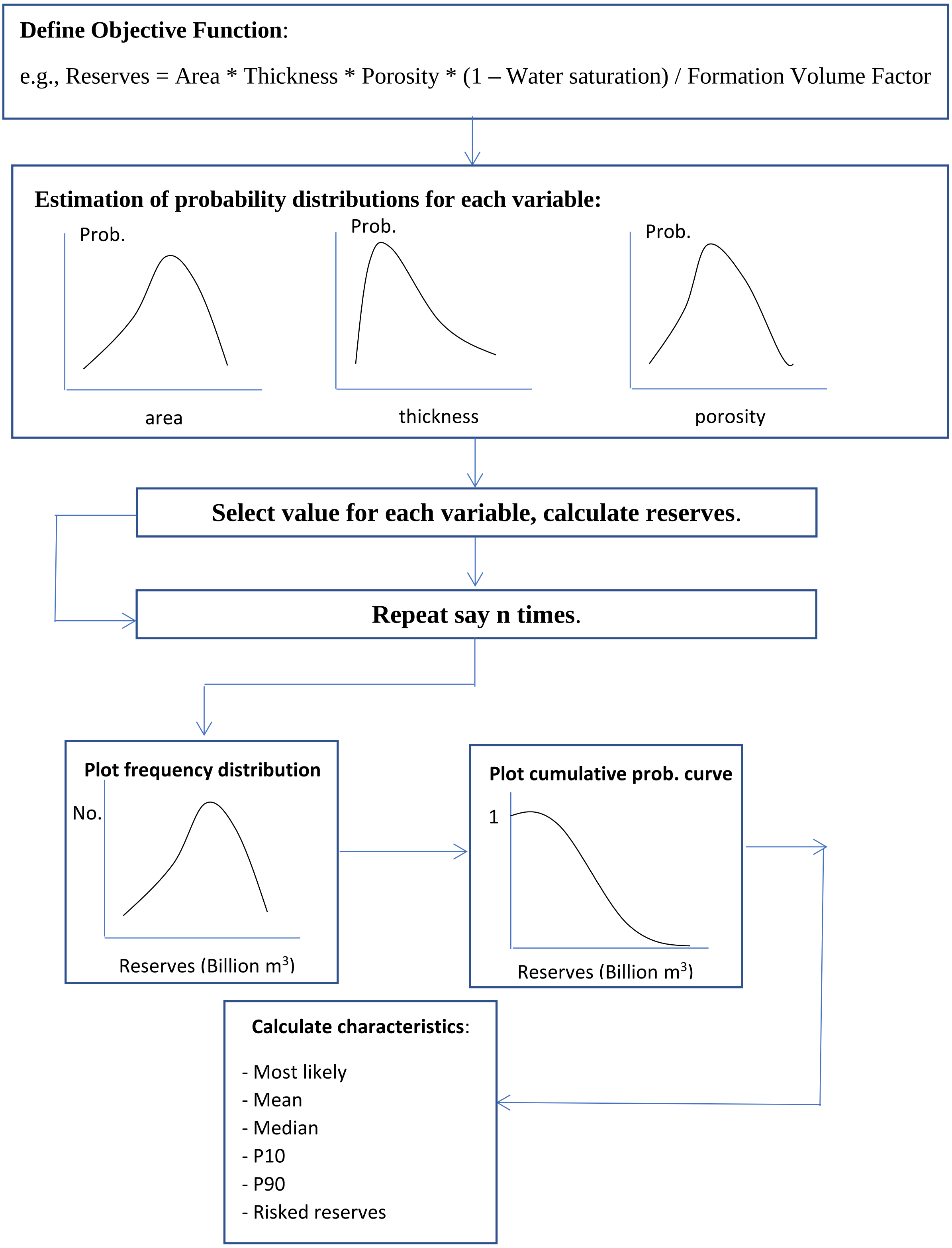


Figure 13. Monte Carlo simulation flowchart.

Statistical distributions are classified by various numbers of parameters. A normal distribution has two type parameters: mean and variance. A triangular distribution has three parameters: low limit, most likely value, and high limit. A random number of each independent variable is interconnected into the mathematical model, and a dependent variable is computed. Therefore, many values of the dependent variable are acquired by utilizing those values of the independent variables. A distribution can be developed with the values of the dependent variable (Fig. 12).

For the targets of demonstration, we utilize reserves evaluation–by far the most common utilize of Monte Carlo like an instance [25]. The original oil in place (OOIP) and original gas in place (OGIP) are calculated by Eq.14 and 15 .

$$OOIP = \frac{7758 * A * h * \varphi * (1 - S_w)}{B_{oi}} \tag{14}$$

$$OGIP = \frac{43560 * A * h * \varphi * (1 - S_w)}{B_g} \tag{15}$$

A*h is the reservoir volume, Boi is the oil formation volume factor, Sw is the water saturation, and φ is formation porosity. In that sample, Eq. 14 is the mathematical model for the original oil in place is calculated. OOIP is the reliant on variables; porosity, water saturation, and reservoir volume are the independent variables. A random number creator in a computer software (as Microsoft Excel) creates random numbers for whole the reliant variables, porosity, water saturation, and reservoir volume, from their customer-described probability density functions. After that the original oil in place is computed by the mathematical model (Eq. 14). That procedure is repeating an randomly significant number of times (hundreds or thousands). We obtain many values of original oil in place from the procedure mentioned using the mathematical model. From these values, we can arise with the probability density function (PDF) and cumulative distribution function (CDF) for the original oil in place, from which summarized statistics for example the mean and median could be computed too.

The cumulative distribution function and probability density function of the reliant variable rely instantly on the input parameter distributions. Lacking input parameter distributions will consequence in a poor-quality assessment of the value of interest (as original oil in place). Provided which the results are responsive to the input parameter distributions, we require high quality input parameter distributions. The generally utilized distributions involve normal, triangular, lognormal, and uniform.

Choice of distributions and their sort of parameters is vital to the efficient implementation of Monte Carlo approach. Direction for chosen input parameter distributions can be attained from three sources: fundamental principles, expert assessment, and historical data. Based on statistical principles, multipying of variables tend to have lognormal distributions; summations of variables tend to have normal distributions. Monte Carlo aprroach is look like a black box. Unless any prior information about the distributions or type of parameters of reliant variables, expert assessment may be very valuable at the initial step of Monte Carlo method for some projects. With time-lag, more and more information become accessible. The applicable data can be utilized to study the distributions of the relaint variables of concern.

The Monte Carlo approach could be very mathematically vigorous. If plenty reliant variables are random and they all have significant variabilities, an extensive number of runs of the mathematical simulation might be required to identify the series of the dependent variable responding. An essential aspect about the Monte Carlo approach is that the transferred dependent-variable distribution is sensible to the input parameter distributions.

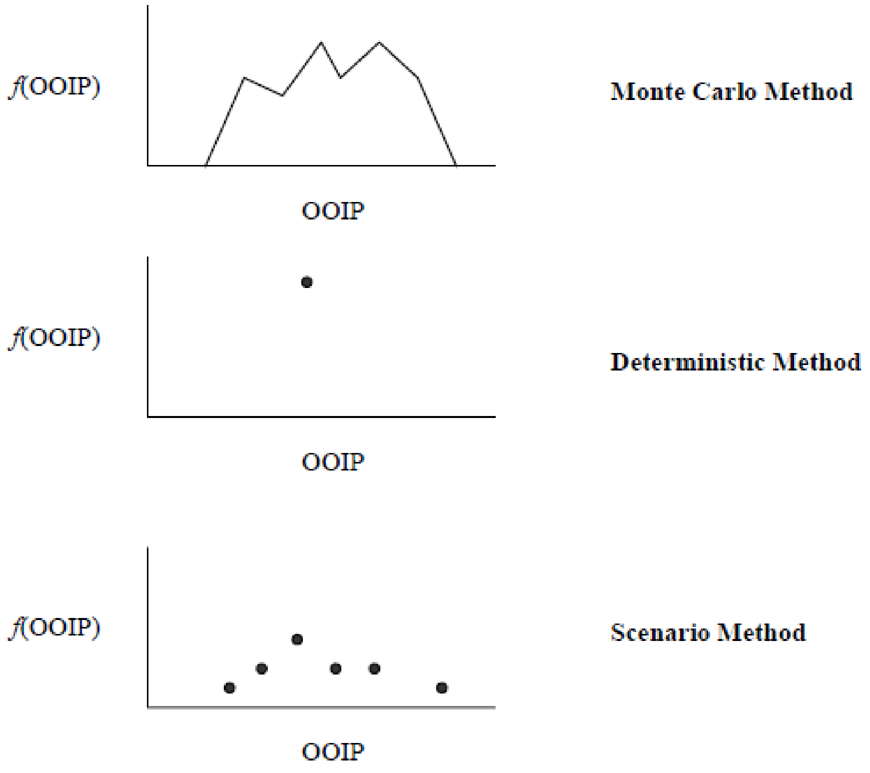


Figure 14. Monte Carlo method vs. discrete approaches.

The Monte Carlo approach has some benefits and drawbacks. The consequences involve more data about potential results than the stochastic and scenario method (Fig. 14). Monte Carlo outcomes are continuous distributions for example probability density and cumulative-distribution functions in place of discontinuous points like from the stochastic or scenario approach. The Monte Carlo ourcomes offer the clients ideas about the probability of the most likely outcome, the pessimistic outcome, and the optimistic result. Therefore, users can measure the type of risks they are dealing with. The users may even get a reliable range for the expected variable–how likely the expected value will be positioned inside an interval. Nevertheless, the Monte Carlo approach is a statistical method; thus, some knowing of statistics is necessity both for its right implementation and for the understanding of the outcomes. This may be a limitation for its implementation in the industry. Furthermore, deciding the input variable distributions and their character parameters includes some intentionality. Although its restrictions, Monte Carlo approach has been extensively utilized in the petroleum industry for risk analysis [26], project assessment, and even fracture-characteristic research.

Chapter 4. Uncertainty analysis of “Umid” field reservoir parameters

4.1 Case Study: Exploration processes in “Umid” field

Umid (former name Andreyev) is located in the central part of the oil-gas region of Baku archipelago, 75 km south of Baku and 44 km from the island of Khara-Zira. The depth of the sea in the area of the uplift covers the range of 40-120 m and does not show itself over the water. a The shallowest part of the sea (5.4 m) is marked in this area [30].

The study area varies from 20 to 550 m as it extends from west to east (Figure 15). The seabed is soft in the work area. Sludge mixed with shells and sand predominates here.

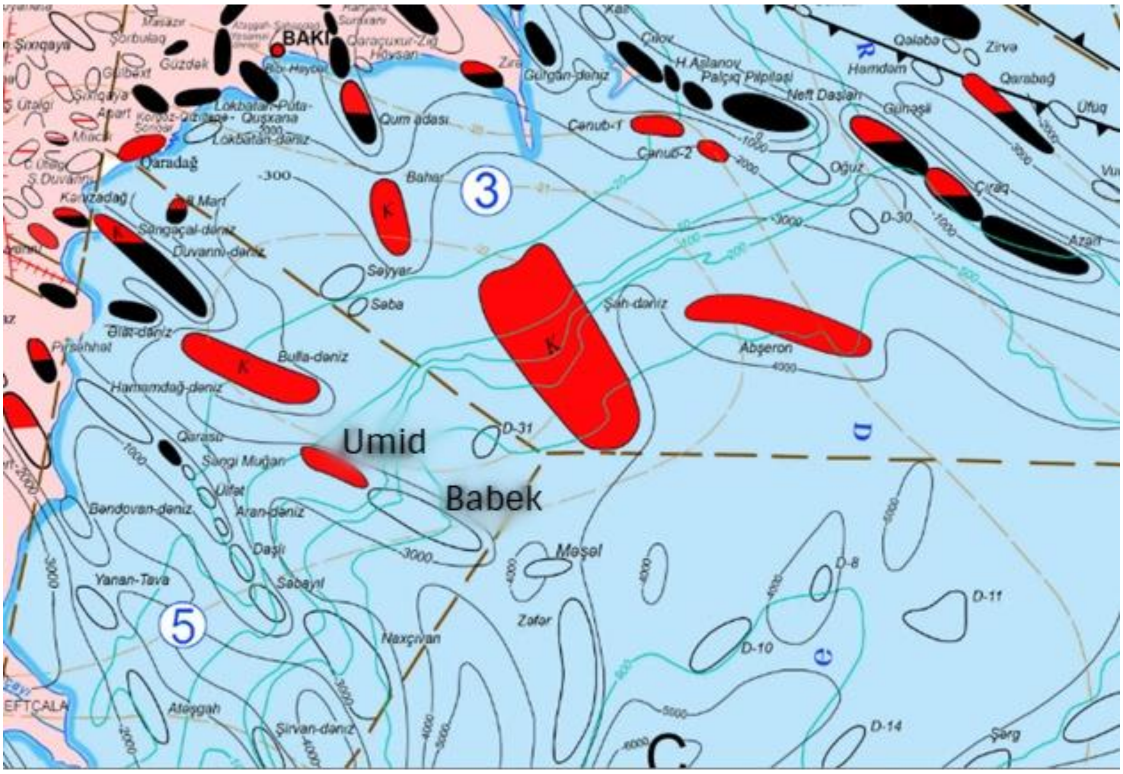


Figure 15. Structural Scheme of Umid Field.

It has been well studied as a result of geological-geophysical exploration and deep offshore drilling. Starting from the 50s of the last century, geological-geophysical researches, structural mapping and structural search excavations were carried out in the research area and its surroundings by various methods. General gravimetric work was carried out in 1951, and detailed work in 1972.

Drilling in Umid field was started in 1954 with the drilling of 4 structural-mapping wells. Exploration wells were drilled in 1977 with well No.1. The well opened the crest of the productive layer at a depth of 2273 m. The well drilled to a depth of 6158 m opened the horizon V of the productive stratum in the range of 5922-6060 m. Horizon V is composed of medium and fine-grained sand, sandstone sediments and alternating layers of intermediate clay, according to the lithological composition. The assumed specific resistance of sand and sandstone strata is 10 Ohm.m and is characterized by well-differentiated Well Potential (WP) curves.

In 2009, well No. 8 with a project depth of 6,500 m was drilled in the north-eastern wing of the Umid field. The well opened zone V of the productive stratum in the range of 5475-5582 m and zone VII in the range of 5923-6006 m. Assumed specific resistances (ASRs) of zones V and VII vary between 10-12 and 30-32 Ohm.m, respectively. WP curves are well differentiated.

At a depth of 4,550 m, gas and rock debris occurring is observed when a production casing is released into the well for testing in zones V and VII at a depth of 6006 m. The operation of lowering the production casing is not complete and the trapping is recorded. Due to the ineffectiveness of the fishing operation of the accident, the well was put into conservation for 3 years from 11.01.2011. According to the results of exploration well No.8, the Umid gas condensate field can be considered discovered.

Drilling of exploration well No. 10 was started on 01.07.2011. Drilling was carried out to a depth of 6400 m. Zone V was opened at 5777-5868 m and Zone VII at 6248-6364 m. The production casing was launched to a depth of 6400 m. On 08.06.2013, a filter was opened in the well in the range of 6356-6336 m and according to the initial calculations, the well worked with the production of 1200 thousand m^3 of gas and 200 tons of condensate. Due to the lack of a transmission line from the platform, the well was temporarily conserved. After the completion of the construction of the transmission line to the platform, test operation of the well was carried out on 19.09.2012. At present, the well is being operated, with an average daily production of 480,000-500,000 cubic meters of gas and 80-85 tons of condensate.

On November 6, 2012, drilling was started in production well No. 12. Drilling was carried out to a depth of 6346 m. The productive formation V zone was opened at a depth of 5855-5975 m. After the 193.7 mm “liner” casing was lowered to a depth of 6346 m (upper part of the productive layer Vll zone), a “window” was opened from 4872 m due to an accident during cementing, and the second pipe was drilled. Well 6309 m (upper part of MG VII zone) was drilled and the production casing was lowered and cemented. In 2014, formation testing was carried out on zone VII and the well was commissioned with high gas condensate production.

4.2 Stratigraphy of “Umid” gas-condensate reservoir

The part of the Fourth Period, Absheron, Agjagil floors and “Productive Series” sediments up to the VII zone (“Prerive” stratum) was opened in Umid area.

The sediments of the “Fourth Period” are lithologically composed of grayish-brown, fine and fine-grained sandy loams, brittle fine and medium-grained sandstones, marls, limestones, shells and conglomerates. In the south-east direction, the amount of clay increases and dominates. The thickness of the “Fourth Period” sediments is 400-500 m in the Shamakhi-Gobustan basin in the north-west, while this thickness increases to 1000-1300 m in the Umid-Babek uplift area in the north-west.

The Absheron strata is mainly composed of gray, sandy, calcareous clays and sandy limestones. Galechnik, conglomerate and in some cases volcanic ash can be found in this section. The structure is represented by 1150-1300 m isohips. The angles of inclination on both wings of the structure are 7-9 degrees. The arch of the structure is complicated by the upper continuation of the tectonic faults which is observed mainly from the Surakhani sediments.

Agjagil strata - Mainly composed of gray, calcareous clays and volcanic ash. According to the 1950-2300 isohips, the dimensions of the Agjagil strata are 7.6x3.6 km and the amplitude is 350 m. According to the map of Agjagil strata, the Umid structure inherits the following sediments, but the location of tectonic faults at these levels is slightly different. Thus, the fractures are mainly collected around the arch of the Umid structure, following the extension of the structure.

Zone VII of “Productive series” was opened in 5 wells (4, 6, 8, 10,12) in Umid. The lithological composition consists of gray, brown-gray, fine and medium-grained limestone sandstones, sands, gray, brown-gray, calcareous, sandy hard clays. Sandstone and sandstones predominate.

Zone VII, which is at the intersection of the Baku archipelago, corresponds to the "Fasila stratum" of the Absheron archipelago. In wells 4 and 10 № drilled in the Umid structure, the full thickness of the V and VII horizons is 120 and 150 m, respectively.

Table 2. Depths of stratigraphic boundaries on wells

Name of Field	Well No	Altitude	IV period	Upper Pliose	Lower Pliosen Productive Layer - N_2^1												Bottomhole (m)
			Absheron	Agjagil	PL top	Surakhani	Sabunchu	Balakhani	V zone		VII zone		QUG	QUQ	QD	QAD	
									top	*bot*	*top*	*bot*					
Umid	1	22	1500	2180	-	2273	-	-	5922	6060	-	-	-	-	-	-	6158
	2	22	1263	1868	-	1924	-	-	-	-	-	-	-	-	-	-	2936
	3	22	830	1780	-	1830	-	-	-	-	-	-	-	-	-	-	2649
	4	22	1330	2140	-	2230	3873	-	6150	6300	6618	-	-	-	-	-	6715
	5	22	1295	2230	-	2325	-	-	-	-	-	-	-	-	-	-	5150
	6	22	1288	2091	-	2167	-	-	6046	6156	6565		-	-	-	-	6619
	7	22	1254	2162	-	2214	-	-	-	-	-	-	-	-	-	-	4409
	8	32.6	880	1855	-	-	-	-	5475	5582	5923	-	-	-	-	-	6006
	9	22	1360	2200	-	2280	-	-	-	-	-	-	-	-	-	-	4449
	10	32.6	880	1886	-	-	-	-	5777	5863	6248	6364	-	-	-	-	6400
	11	32.6	1253	1957	-	2005	-	-	-	-	-	-	-	-	-	-	4445
	12	32.6	884	1890	-	-	-	-	5765	5885	6236	-	-	-	-	-	6309
Bulla-deniz	7	22	-	1324	-	1386	1940	-	4640	4780	5140	-	-	-	-	-	-
	29	22	750	1485	-	1552	-	-	-	-	5080	-	-	-	-	-	5180
	31	22	170	1563	-	1640	-	-	4935	5084	5400	-	-	-	-	-	5504
	67	22	718	2140	-	2210	2979	-	5668	5810	6050	-	-	-	-	-	6236
	86	22	980	2140	-	2140	-	-	5240	5390	5730	5865	-	-	-	-	6080
	55	22	664	1905	-	1965	-	-	5410	5598	5980	-	6123	6070	-	-	6505
	58	22	689	2032	-	2071	2750	-	5480	5628	6020	-	-	-	-	-	6150
	89	22	1160	1987	-	2024	-	-	5420	5598	5914	-	6129	6364	6439	-	6505
Nakhcıvan	1	23	593	961	-	1759	4273	-	6184	-	6372	-	6711	-	-	-	6800
Zafar-M	1	25	977	1840	-	2155	4782	-	6406	-	6611	-	6907	6991	7045	-	7087
Shahdeniz	4Y	22	1085	2040	-	2119	4646	-	6184	-	6300	-	6616	-	-	-	7300
Alat-deniz	23	22	280	465	-	525	-	-	3265	3417	3830	3929	3930	4190	4247	4632	4660

4.3 Tectonics of “Umid” gas-condensate reservoir

Tectonically, the Umid and Babek structures belong to the Baku archipelago’s oil-gas region and occupy a special position between the anticline lines, located in the Kichikdag-Umid syncline and partly in the Jeyrankechmez depression. One of the characteristic features of Umid and Babek structures is that they change the direction of the fold axis and lie deeper than other structures. The uplift consists of a brachianticlinal fold extending in a north-west and south-east directions.

The south-eastern periclinal part of the Umid uplift is complicated by a mud volcano of the same name. Several structural mapping wells with a depth of up to 70 m were drilled from the barge in this area and opened mud volcanic breccias, indicating the presence of a large underwater mud volcano cone.

The Umid structure has an asymmetrical structure, and the slope angles of the layers are different on the wings. According to Zone VII sediments, the bedding angles of the strata in the north-eastern and south-western wings are 20-25 ° C and 35-45 ° C, respectively, and gradually increase in depth.

The uplift is connected to the Babek structure by a deep and wide saddle through the north-western pericline, the Khara-Zira-sea anticline, and a short south-eastern pericline. This combination is noted in the overlying sediments, and in the deeper layers, both uplift is recorded as a single structure.

In order to calculate the hydrocarbon reserves for the zones V and VII of the Umid gas condensate field and to involve them in development, the selection of the GWC for horizons was carried out. To do this, 3D seismic exploration work carried out in the field and three options were considered in the geological model based on data from drilled wells and analog deposits.

V Zone GWC:

Lower case: According to the logging diagram of the drilled well 10 №, the maximum gas-saturated apparent depth (MGSD) of the V zone is 5850 m. For the lower case, GWC 5850 m isohypsy was taken.

Medium (Main) case: Considering that the maximum gas-saturated maximum depth (MGSD) of the horizon according to the logging diagram of well 10 № is 5850 m and the opening depth of zone V according to the logging diagram of well 6 № is 6179 m The average depth between the two was taken as the main GWC at 6000 m isohips.

Higher case: Zone V in well 4 № was tested in the range of 6234-6179 m and produced 16-18 m^3 / day of produced water. It can be proved that the well falls behind the contour according to the V zone. According to the logging diagram of well 6 №, zone V was opened in the range of 6156-6046m. The open average depth of the zone was taken as the highest GWC.

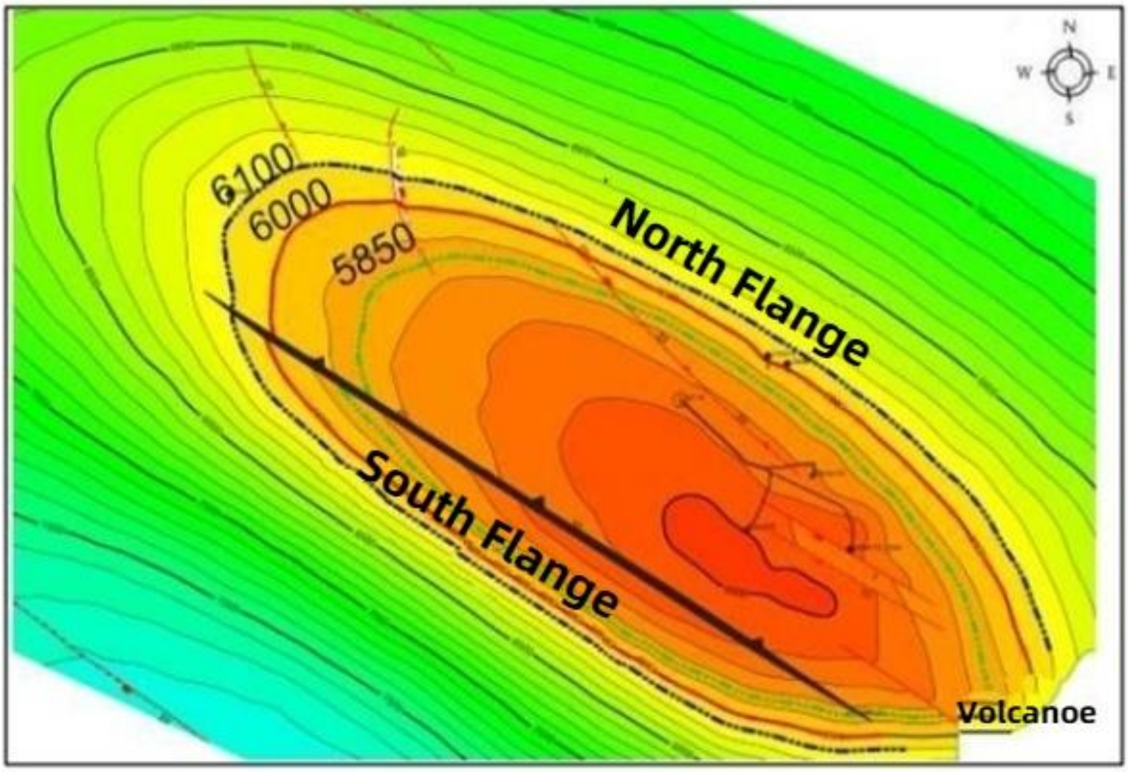


Figure 16. Structural map of the Zone V based on top of layer with showing the GWCs

VII Zone GWC:

Low case: According to the logging diagram of the drilled well 10 №, the maximum gas-saturated apparent depth (MGSD) of zone VII is 6400 m. Tested in the range of 6356-6336m and gas condensate was obtained. It has been in operation since 19.09.2012. To date, 550 million cubic meters of gas and 90,000 tons of condensate have been produced. No water is observed in the production. The calculated drainage radius is 500-600 m. For the lower case, the GWC 6400 m isohypsy was taken. Based on the long-term operation of well 10 № and the calculated drainage radius, we can confirm that the GWC is deeper than the 6400 m isohips.

Medium (Main) case: According to the logging diagram of well 4 №, gas saturation is shown at 6700 m of zone VII, but no flow was obtained despite testing in the intervals of 6673-6664 and 6662-6659 m. The reason may be contamination of the formation during drilling.

Higher case: It was based on the saturation coefficients of adjacent analog fields because the GWC on the VII zone was not accurately determined by the well and AVO and amplitude analyzes were not performed in seismic. According to the interpretation of 3D seismic exploration in the Umid field, the closing isohips of Zone VII is 6950m, and if we take the 90% saturation coefficient, it is possible to take 6850m isohips as GWC. In the neighboring Bulla-Deniz field, the saturation coefficient of the VII zone is in the range of 93-96% for tectonic blocks.

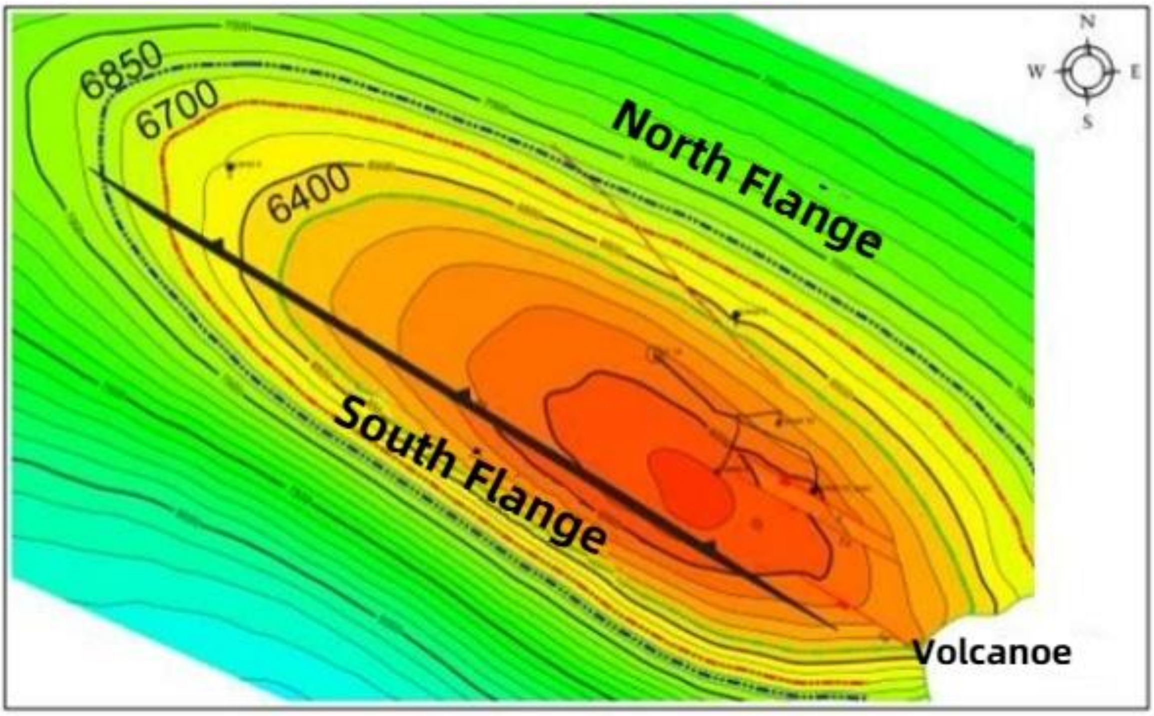


Figure 17. Structural map of the Zone VII based on top of layer with showing the GWCs

4.4 Evaluation of reservoir parameters in “Umid” field

The data obtained from drilled wells in the Umid gas condensate field and alternative fields are mainly based on the following formation parameters.

No direct measurements have been made to determine the formation pressure in the Umid field [31]. Therefore, technological parameters of operating wells (wellhead pressure and hydrostatic pressure) were used to determine these parameters. It should be noted that due to the fact the wells are in operation, it is difficult to determine the wellbore pressure based on the wellhead pressure and thus the formation pressure (due to pressure loss in the well related with friction). The formation temperature was measured in wells No 10 and 12. Thus, the values of formation pressure and temperature for zones V and VII in the Umid field are given in the following table:

Table 3. Formation Presssure of Zone V and VII

Parameters	V zone	VII zone
Formation Pressure (atm)	900-920	950-980
Formation Temperature (°C)	100-105	115-120

- **Porosity**:

Except for a small number of core samples taken from the V zone, no direct porosity was measured in the Umid field. The average porosity value was determined based on data from neighboring fields and logging estimates of Umid wells.

Table 4. Porosity values by fields

Field	Porosity (%)		
	V zone	VII zone	VIII zone
Shah Deniz (logging data)	13	12	
Shah Deniz (BP)		13	
Bulla Deniz (core sample)	14	12	
Bahar (core sample)		16—19	
NAKX-1x (core sample)		9.8	
ZAFX-1H1		13—19	
Umid (core sample)	3.9—13.8		
Umid (logging data)	13—16	15—18	

- **Permeability**:

The relationship between porosity and permeability and data from analog fields were used to determine the permeability of the V and VII zones. Based on debits of production wells No. 10 and 12, the average value of permeability on VII zone is estimated to be 18-20 md. For V horizon calculated value is 12-15 md.

- **Water Saturation**:

There is also uncertainty about the saturation of water, as the porosity coefficient does not have an exact value determined by accurate studies. Water saturation was calculated based on data from analog fields and interpretation of logging diagrams for wells 4, 6, 8, 10, and 12 [32].

Table 5. Water Saturation values by fields

Field	Water Saturation (%)		
	V zone	VII zone	VIII zone
Shah Deniz (logging data)	30	30	
Shah Deniz (BP)		22	
Bulla Deniz		30–40–50	
NAKX-1x		40	49
Umid (logging data)	36	35	
Umid (dataroom logging)	15–25	20–35	

- **Gas saturation**:

Permeability was determined using the relationship between porosity and permeability (results from the study of core samples of the Bulla offshore field), and then water and gas saturation coefficients were determined using well test data and interpretation of logging diagrams. According to the calculations made by the Oil and Gas Research and Design Institute, the gas saturation coefficient in the Umid field was set at 0.67 / 0.73 on zone V and 0.74 / 0.79 on zones VII and VIII.

- **Reservoir fluids**:

Measurements of fluid data obtained at the Umid Field were based on the composition, parameters and condensate output of gas / liquid samples taken from the wellhead and separator. General information obtained:

Table 6. Fluid properties by fields

Gas Density (kg/m3)	Condensate Density (kg/m3)	Condensate Output (q/m3)	Gas Factor (m3/m3)
0.71-0.73	810-815	160-170	4850-5100

- **Free water level**:

Gas/Water Contact & Free Water Level: An oil or gas reservoir is usually defined by a structural closure above a petroleum/water contact. This can be determined most often from well logs, formation tests and/or fluid gradient surveys. Virtually all petroleum accumulations have a transition zone interval above or below the petroleum/water contact where petroleum-free water is encountered and referred to as free water level (FWL). This transition zone may be as little as a few inches in a highly permeable reservoir to as much as fifty feet or more for lower permeability reservoirs. FWL may often be determined by combining well pressure tests and capillary test data taken from cores from the formation. These two important parameters, hydrocarbon/water contacts and FWL are often required to obtain the estimated total volume of reservoir rock [33].

The development of the Umid gas condensate field is planned mainly due to the depletion of gas as a result of expansion. Thus, no other measures are planned to maintain the secondary formation pressure in the development of the field. However, the impact of the water basin in the lower part of the gaseous zone of the field on the productive zones (zones V and VII) on the field development may also be high. In addition, the presence of an oil boundary between the gas zone and the water basin significantly affects the development of gas condensate fields. For this reason, as part of the sensitivity analysis, the water basin and oil margin were modeled and impact rates were studied in the hydrodynamic model of the field.

Carter-Tracy and Fetkovich water basin models were used to model the water basin. Absolute permeability, porosity, internal radius, height and water viscosity of the water basin using the Carter-Tracy model; Through the Fetkovich model, the degree of impact of the water basin on the initial pore volume and productivity coefficient was studied. The most influential of the parameters in the water basin is the pore volume of the water basin in the Fetkovich model.

4.5 Uncertainty and risks of reservoir parameters

In this analysis, uncertainty in multi-layered volumetric reserve evaluation was measured utilizing Monte Carlo simulation for whole the uncertain parameters, and the total recoverable gas and condensate achieved from stochastic approach induced to the Crystal Ball software for sensitivity analysis. Pessimistic, most likely and optimistic reserve values were gained with their relevant certainty for whole the simulation scenarios. Mathematical formula utilized in which a reliant variable is a function of independent variable is indicated in equation below:

$$OGIP = \frac{43560 * A * h * \varphi * (1 - S_w)}{B_g}$$

This shows that the gas in place is stated with regard to area, net pay, porosity, water saturation and gas formation volume factor. When the values for each input are determined, the output value is later computed. The stages included in this analysis as consisted in software algorithms are as proceeds: Entry geologic information for example area thickness, porosity, water saturation and formation volume factor; after that, create the distribution of the inputs using rectangular, triangular and (or) normal probability distribution function. Run a Monte Carlo simulation to forecast reserve distribution. Afterwards, create the multiple realization of reservoir (multi layer) with regard to pessimistic (P90), most likely (P50) and optimistic (P10). Runing sensitivity analysis of the input parameters, to find out the failure involved by each parameter. In addition, this fault was combined to set up the total impact on the recoverable reserve (forecast variable). With the help of error parameters and sensitivity analysis, the simulation have measured potential errors which can effect in reserve quantification and the consequent volume of hydrocarbon which could be achieved in a multi-layer reservoir.

The reservoir includes two zones: V and VII, each zone has its own group of geologic and formation properties data (uncertain variables). Table 7 and 8 below provided the reservoir description for both layers (zones studied).

Table 7. Zone V reserves volumetric estimation parameters

Value	**Area, thousand m^2**	**Effective thickness, m**	**Gas Saturation, %**	**Porosity, %**	**Reservoir Pressure, MPa**	**Reservoir temperature, C**	**Gas Density, kg/m^3**	**Condensate Density, kg/m^3**	**CGR, g/m^3**
Minimum	15400	2,0	56	12	70	90	0,670	810	170
Base	21000	23,0	76	18	80	100	0,680	815	176
Maximum	25000	35,0	80	23	90	110	0,740	820	200

Table 8. Zone VII reserves volumetric estimation parameters

Value	**Area, thousand m^2**	**Effective thickness, m**	**Gas Saturation, %**	**Porosity, %**	**Reservoir Pressure, MPa**	**Reservoior temperature, °C**	**Gas density, kg/m^3**	**Condensate density, kg/m^3**	**CGR, g/m^3**
Minimum	18000	33,0	70	15	90	100	0,670	810	170
Base	29500	37,4	77	18	100	110	0,680	815	176
Maximum	44439	50,0	85	20	110	120	0,740	820	190

Table 9 and 10 below show the result of the Monte Carlo simulation indicating how the gas and condensate reserve forecasts vary respectively (percentiles).

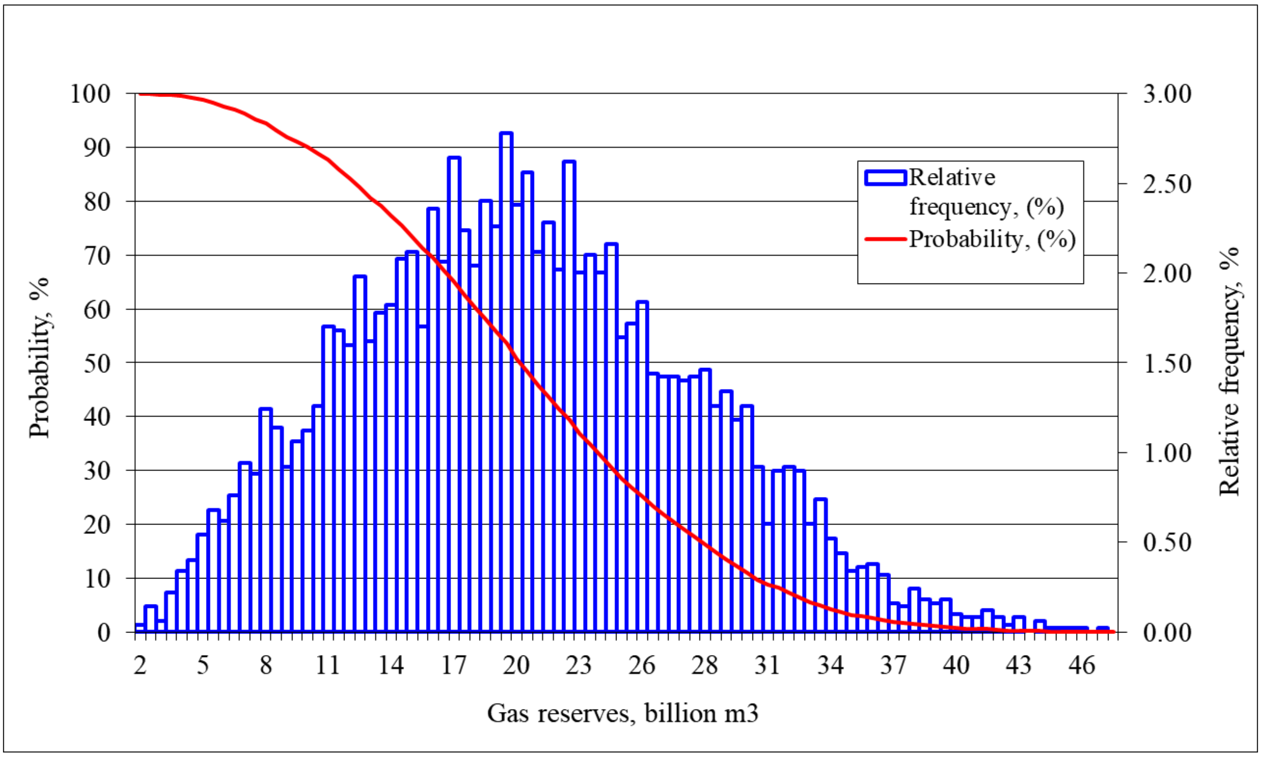
Table 9. Zone V forecast scenario

Percentiles	Forecast values (billion m3)
P100	2
P90	10
P80	13
P70	16
P60	18
P50	20
P40	22
P30	24
P20	27
P10	31
P0	46

Table 10. Zone V forecast scenario

Percentiles	Forecast values (thousand tonne)
P100	358
P90	1792
P80	2330
P70	2778
P60	3136
P50	3494
P40	3853
P30	4301
P20	4749
P10	5466
P0	8422

The figures below present the amount of total recoverable reserve based on the level of certainty. It could be seen that in figure 1 below, the certainty level is 100% which correspond to the maximum gas reserve of 46 billion m^3 and the minimum of 2 billion m^3 could be obtained under base case simulation. About condensate reserves for the certainty level is 100 % correspond to the maximum condensate reserve of 8422 thousand tonne and the minimum of 358 thousand tonne.



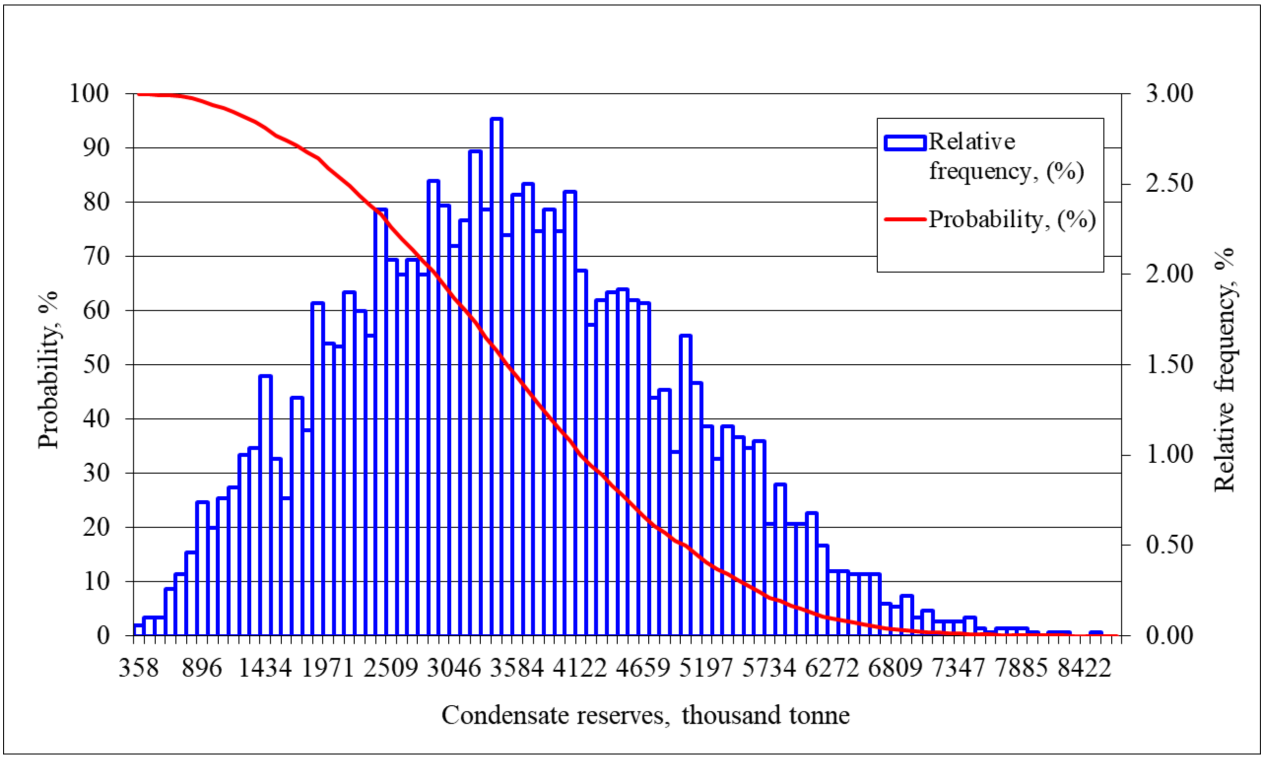


Figure 18. Gas and Condensate reserve estimation versus probability and relative frequency

Realisations of gas and condensate reserves for Zone V in terms of pessimistic, most likely and optimistic figure 19 and 20, respectively.

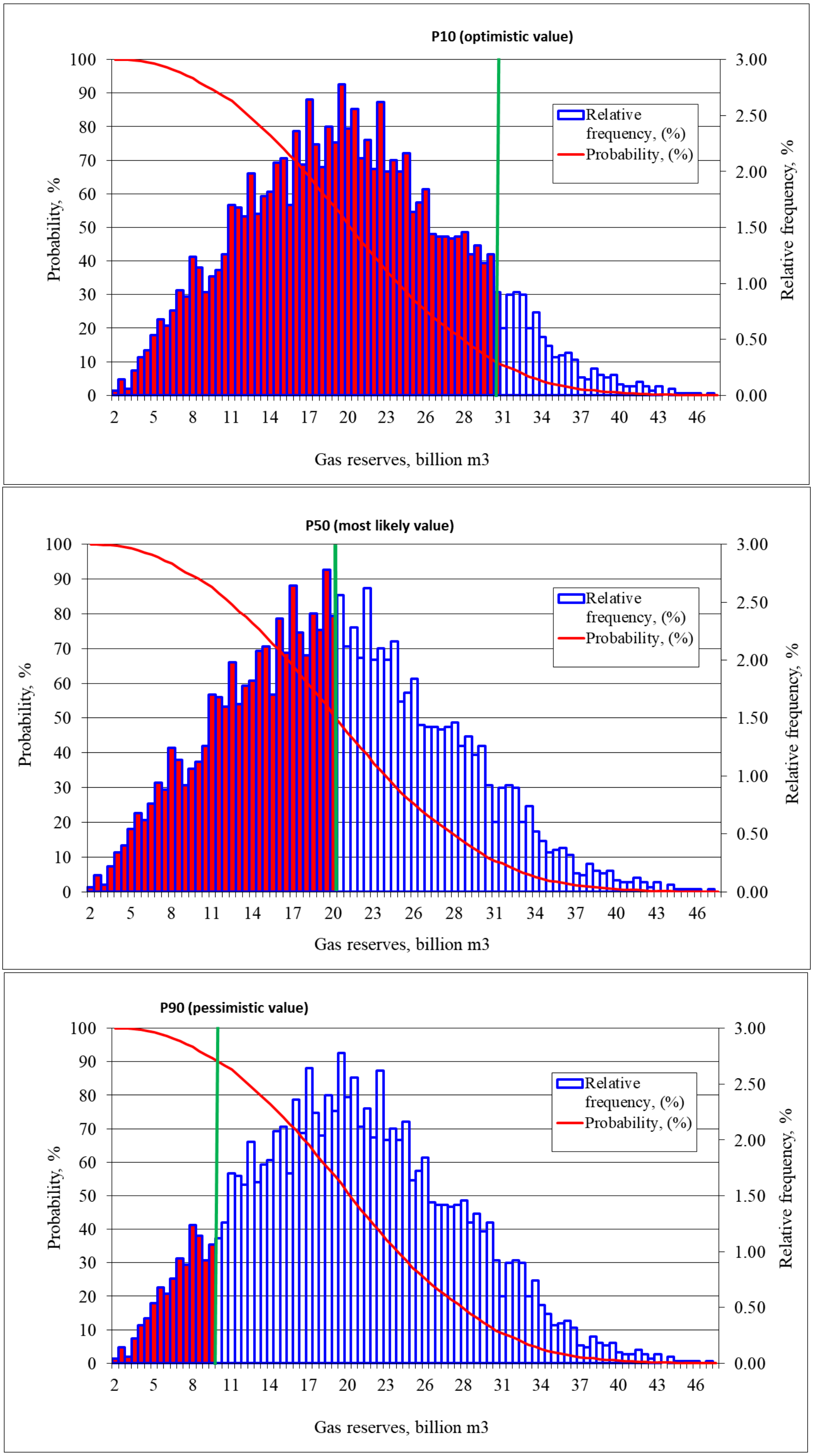


Figure 19. P90, P50 and P10 gas reserve values along with its certainty

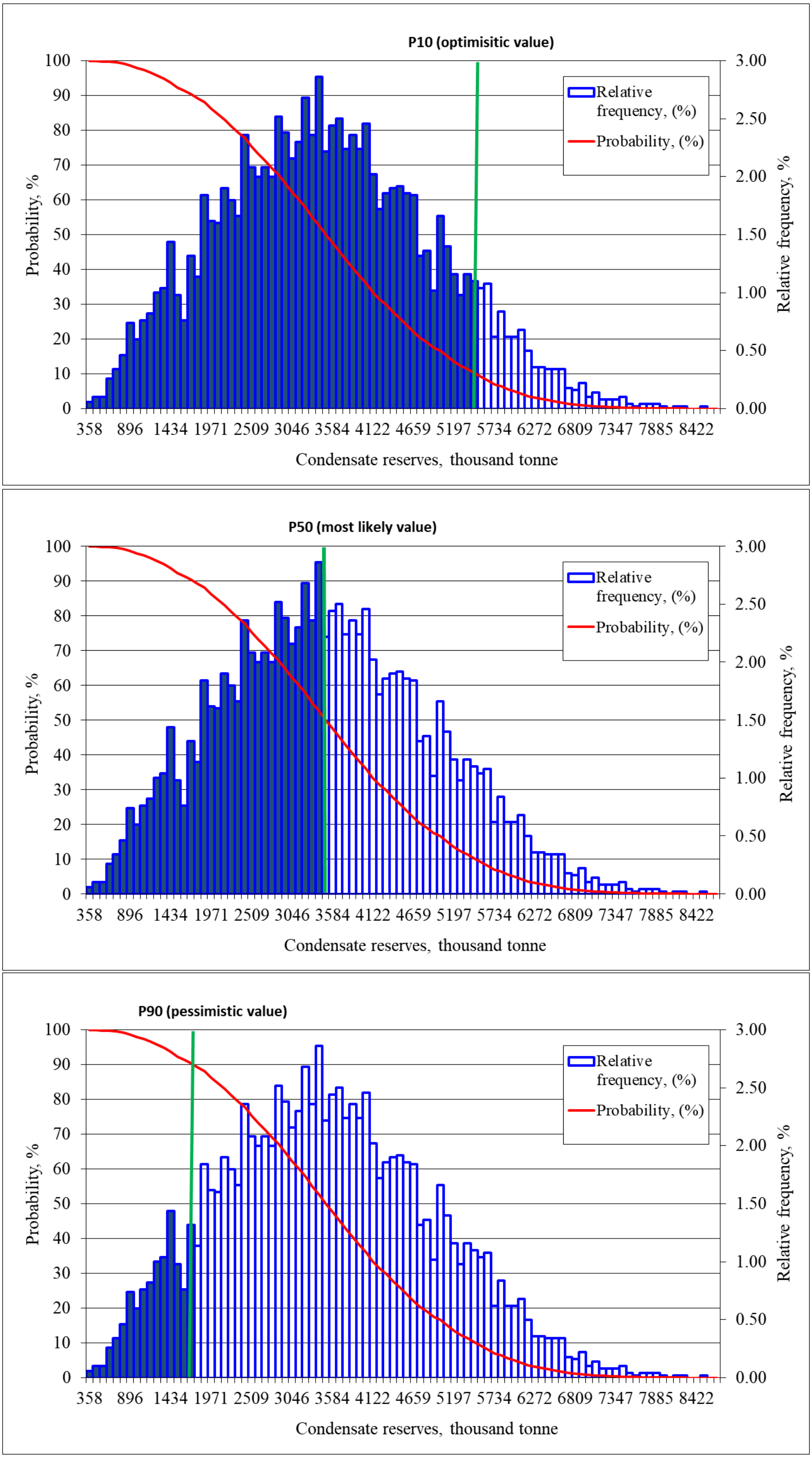


Figure 20. P90, P50 and P10 condensate reserve values along with its certainty

Table 11 and 12 below show the result of the Monte Carlo simulation indicating how the Zone VII gas and condensate reserve forecasts vary respectively (percentiles).

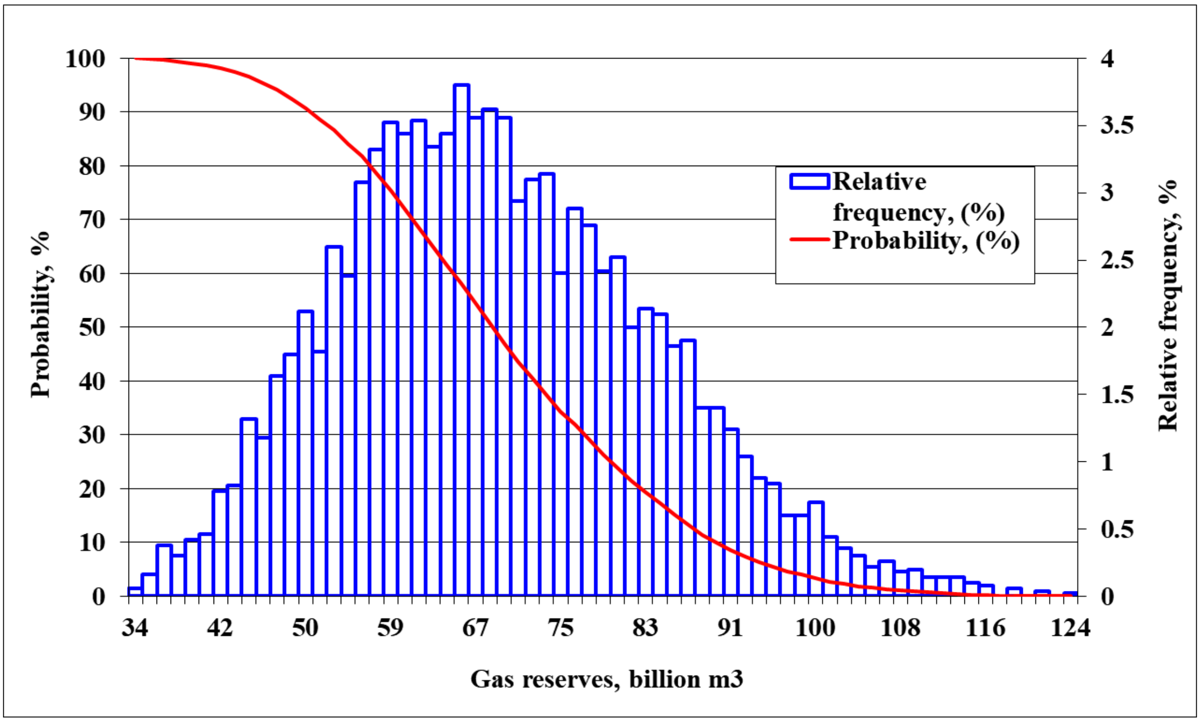
Table 11. Zone VII forecast scenario

Percentiles	Forecast values (billion m^3)
P100	34
P90	50
P80	57
P70	61
P60	64
P50	68
P40	72
P30	78
P20	83
P10	90
P0	124

Table 12. Zone VII forecast scenario

Percentiles	Forecast values (thousand tonne)
P100	5776
P90	8780
P80	9704
P70	10629
P60	11091
P50	11784
P40	12477
P30	13401
P20	14326
P10	15712
P0	21026

It could be seen that in figure 1 below, the certainty level is 100% which correspond to the maximum gas reserve of 124 billion m^3 and the minimum of 34 billion m^3 could be obtained under base case simulation. About condensate reserves for the certainty level is 100 % correspond to the maximum condensate reserve of 21026 thousand tonne and the minimum of 5776 thousand tonne.



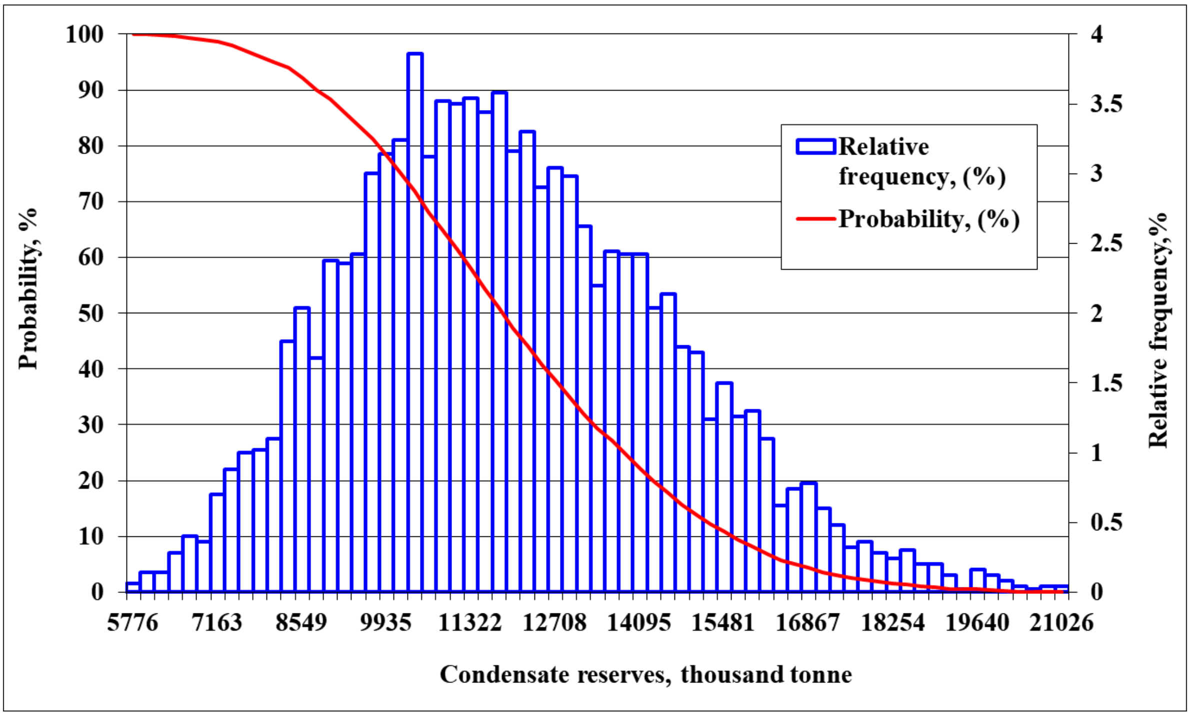


Figure 21. Gas and Condensate reserve estimation versus probability and relative frequency

Realisations of gas and condensate reserves for Zone VII in terms of pessimistic, most likely and optimistic figure 22 and 23, respectively.

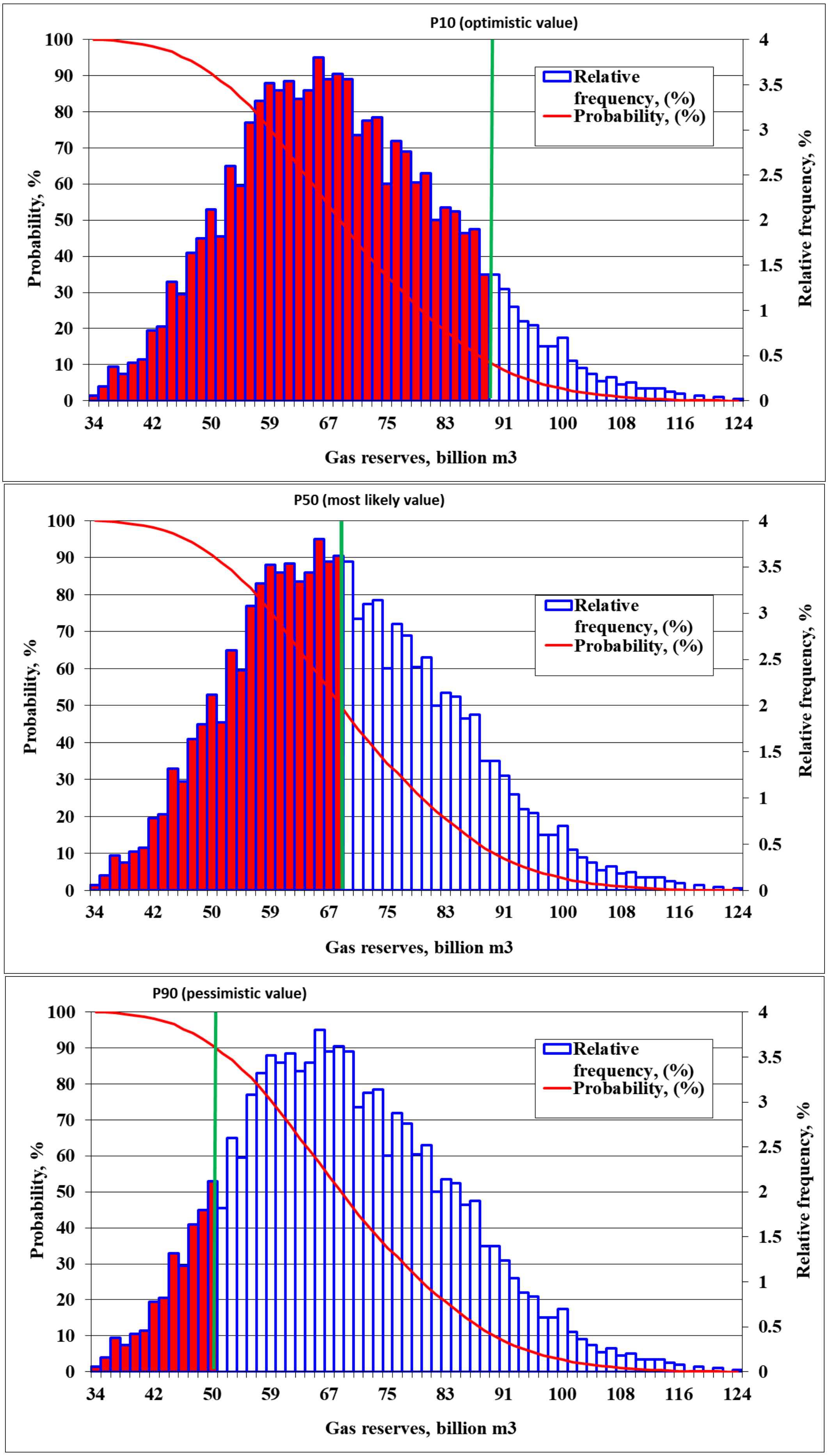


Figure 22. P90, P50 and P10 gas reserve values along with its certainty

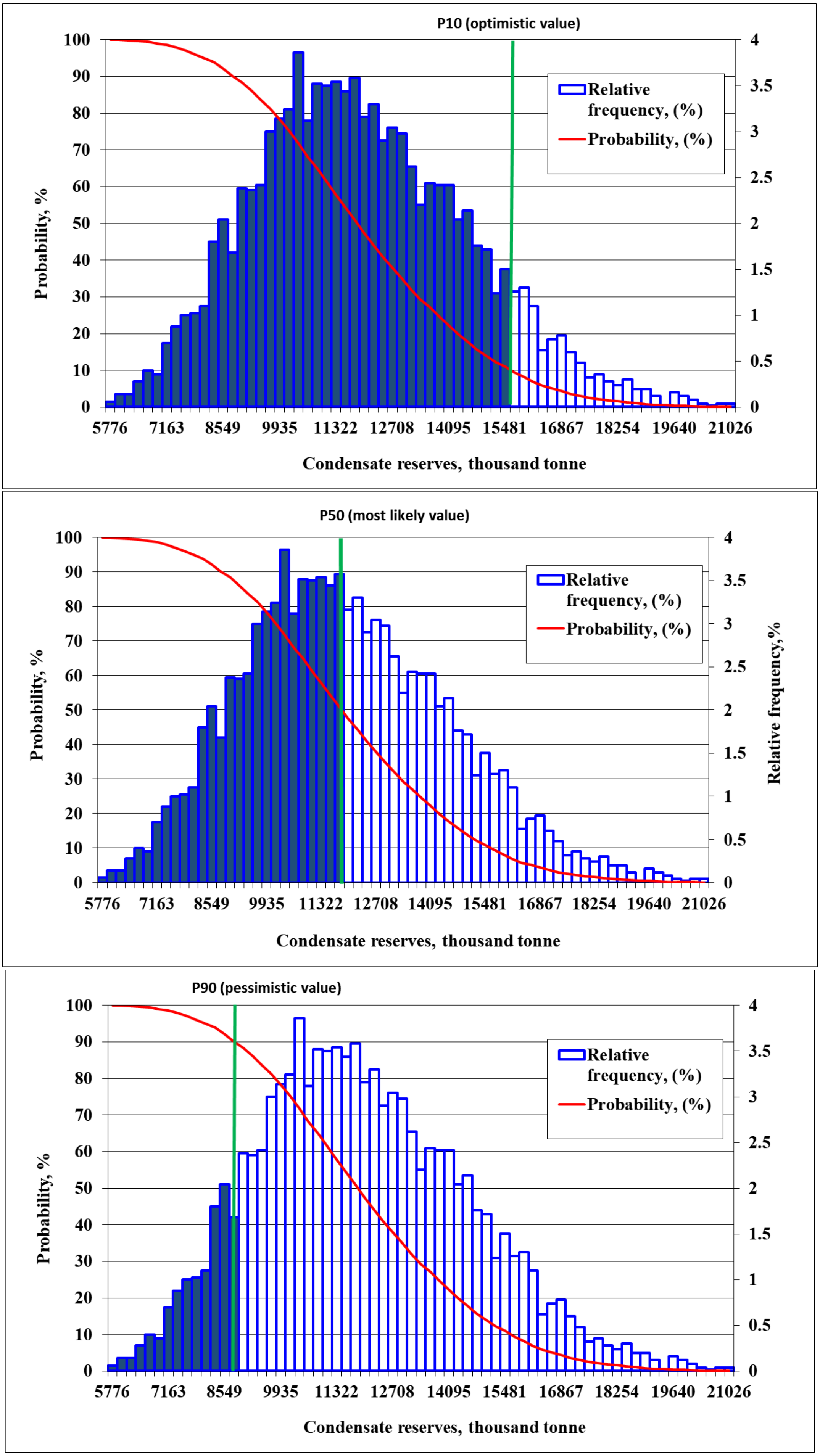


Figure 23. P90, P50 and P10 condensate reserve values along with its certainty

Sensitivity analysis of the uncertain variables clearly showing below each parameter and its contribution /effect on total recoverable gas and condensate reserves of Zone V.

Table 13. Zone V Gas Reserves for minimum, base and maximum cases

Gas reserves, billion. m^3	**Area, (1000 m^2)**	**Effective thickness, (m)**	**Gas saturation, (%)**	**Porosity, (%)**	**Reservoir pressure, (MPa)**	**Reservoir temperature, (°C)**	**Gas density, (kg/m^3)**	**Condensate density, (kg/m^3)**	**CGR, (g/m^3)**
Minimum	15	12	16	13.7	18.8	20.2	19.8	19.8	19.9
Base	19.8	19.8	19.8	19.8	19.8	19.8	19.8	19.8	19.8
Maximum	20.5	34.8	22.7	26.3	20.6	19.4	19.8	19.8	19.7

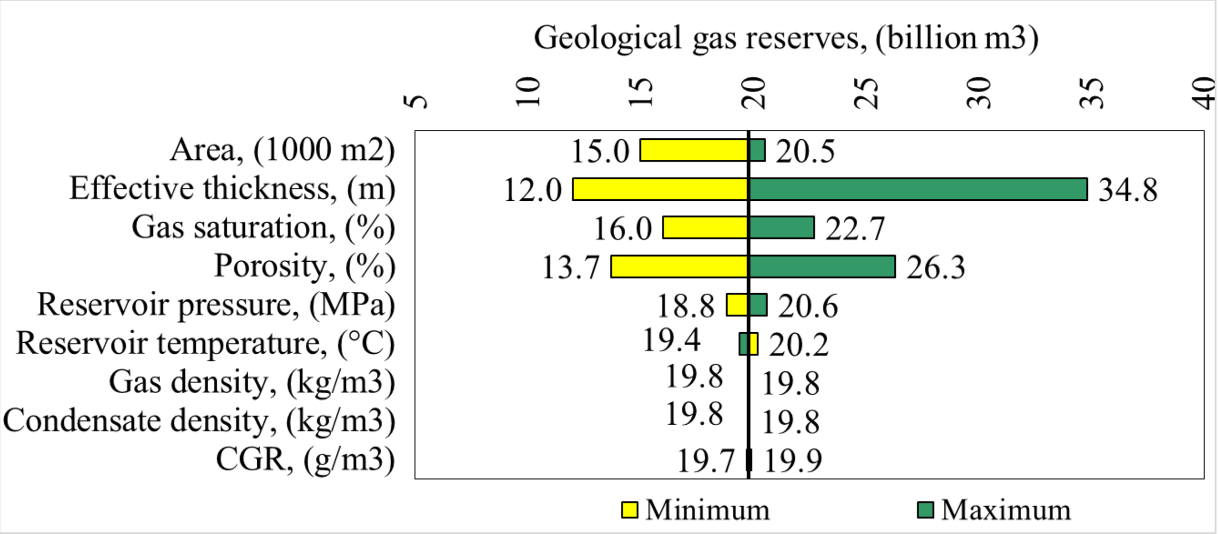


Figure 24. Tornado diagram for Zone V gas reserve

Table 14. Zone V Condensate Reserves for minimum, base and maximum cases

Condensate reserves, ths tonne	**Area, (1000 m^2)**	**Effective thickness, (m)**	**Gas saturation, (%)**	**Porosity, (%)**	**Reservoir pressure, (MPa)**	**Reservoir temperature, (°C)**	**Gas density, (kg/m^3)**	**Condensate density, (kg/m^3)**	**CGR, (g/m^3)**
Minimum	2668	2104	2789	2410	3324	3556	3513	3491	3267
Base	3491	3491	3491	3491	3491	3491	3491	3491	3491
Maximum	3638	6137	3984	4620	3635	3426	3465	3491	3827

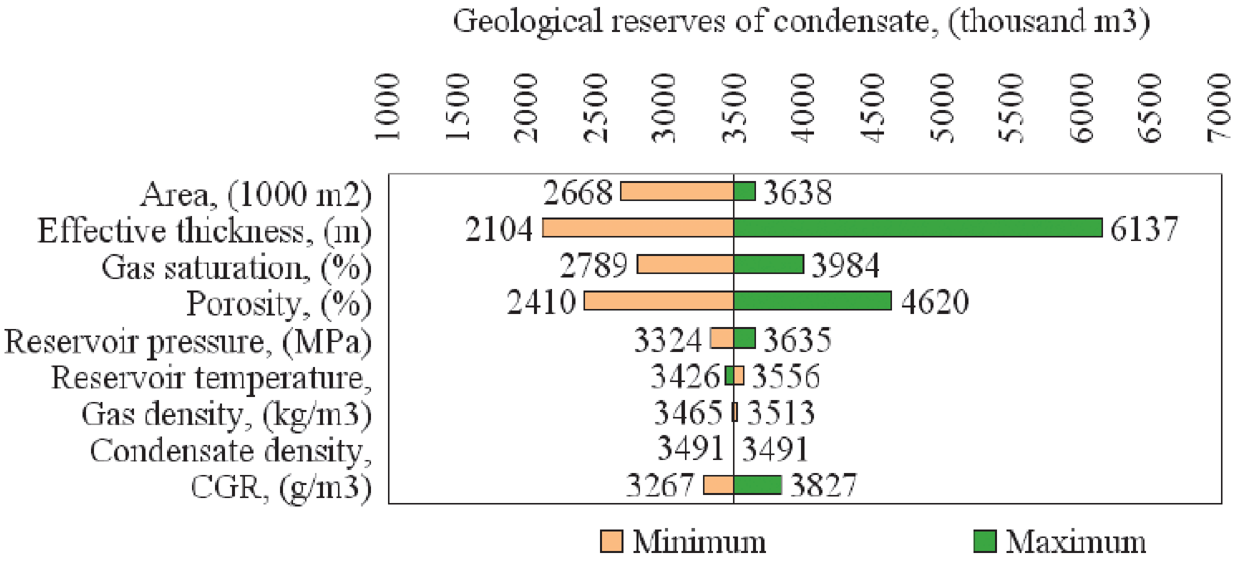


Figure 25. Tornado diagram for Zone V condensate reserve

Sensitivity analysis case simulation for Zone VII:

Table 15. Zone VII Gas Reserves for minimum, base and maximum cases

Gas reserves, billion m^3	Area, (1000 m^2)	Effective thickness, (m)	Gas saturation, (%)	Porosity, (%)	Reservoir pressure, (MPa)	Reservoir temperature, (°C)	Gas density, (kg/m^3)	Condensate density, (kg/m^3)	CGR, (g/m^3)
Minimum	40.6	56.5	61.9	58	66.1	69.6	68.5	68.5	68.6
Base	68.5	68.5	68.5	68.5	68.5	68.5	68.5	68.5	68.5
Maximum	100.3	85.6	75.1	77.3	70.6	67.4	68.6	68.5	68.2

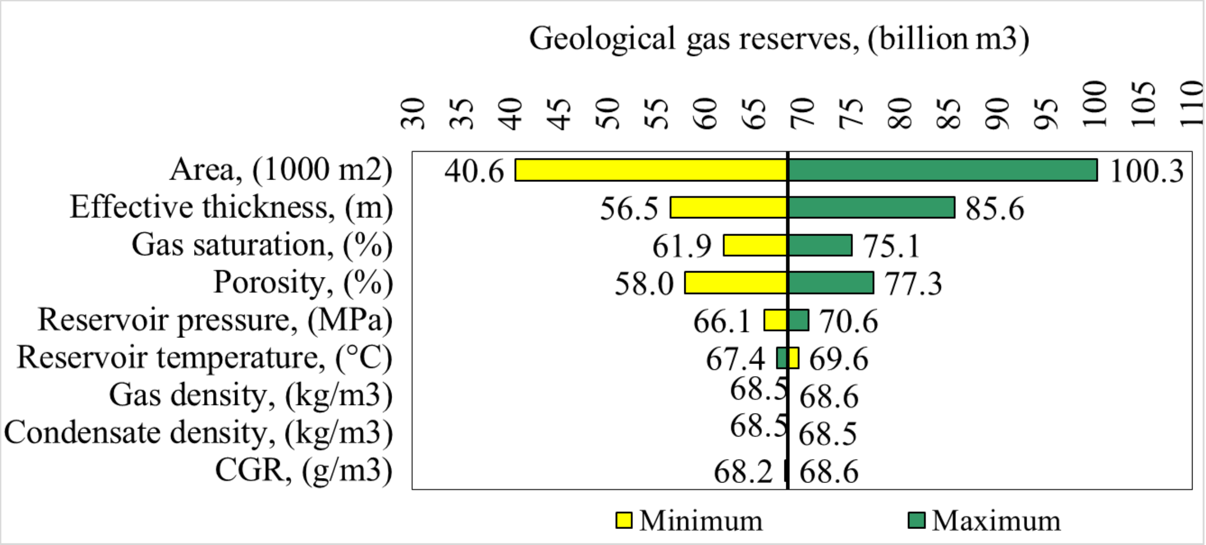


Figure 26. Tornado diagram for Zone VII gas reserve

Table 16. Zone VII Condensate Reserves for minimum, base and maximum cases

Condensate, ths m^3	Area, (1000 m^2)	Effective thickness, (m)	Gas saturation, (%)	Porosity, (%)	Reservoir pressure, (MPa)	Reservoir temperature, (°C)	Gas density, (kg/m^3)	Condensate density, (kg/m^3)	CGR, (g/m^3)
Minimum	7036	9773	10711	10046	11433	12026	11927	11841	11277
Base	11841	11841	11841	11841	11841	11841	11841	11841	11841
Maximum	17371	14807	13007	13395	12201	11656	11719	11841	12559

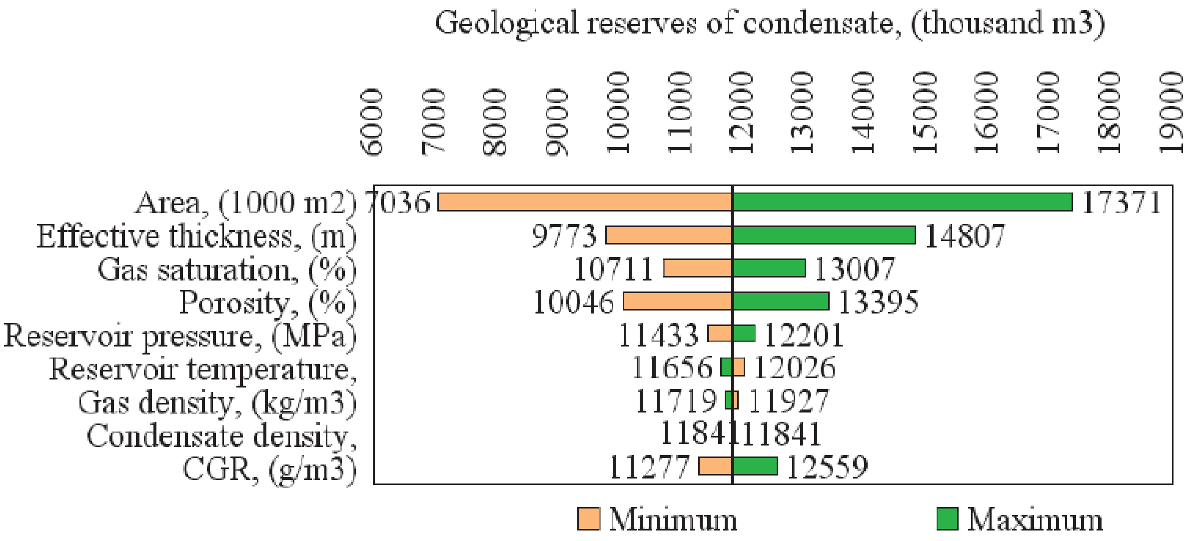
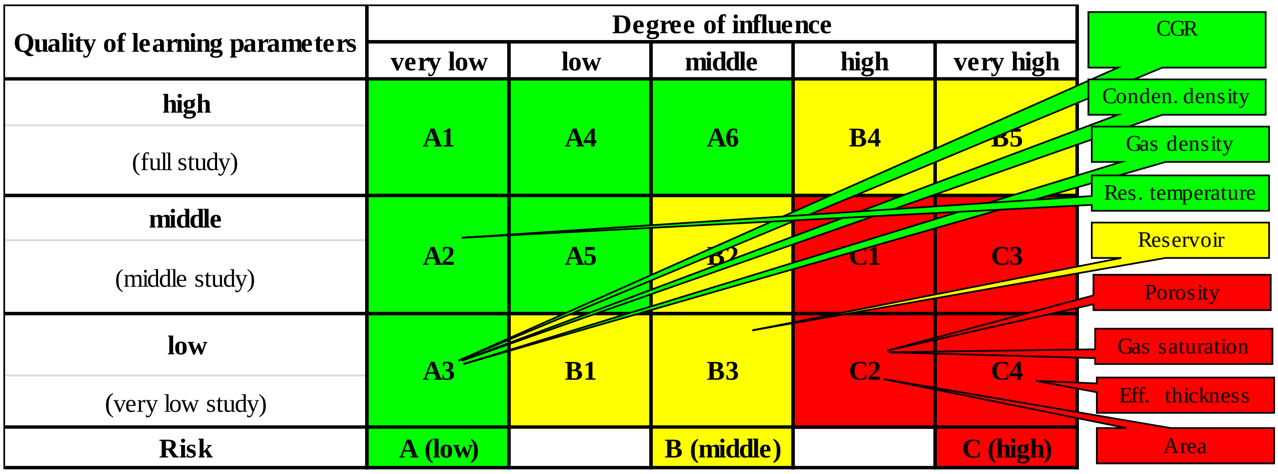


Figure 27. Tornado diagram for Zone VII condensate reserve

Risk analysis: The purpose of risk analysis is to establish a risk matrix by determining the degree of risk of the parameters. The risk matrix includes indicators of the effect of parameters on the system, the degree of study of parameters and the degree of risk. The effect of parameters on the system is based on the degree of uncertainty. Accordingly: Low (0-5%), medium (5-10%) and high (> 10%). The main indicator of the degree of risk is the effect of the parameters on the system. The level of study of all parameters is low (except for the layer thickness) due to the lack of testing and operation in the V Zone. On Zone VII, the layer thickness and the degree of study of the gas factor were assessed as average (partially high) [34].

Table 17. Zone V reservoir parameters - degree of influence and learning of quality

Reservoir parameters	Degree of learning	Degree of influence	Situated square	Risk
Area	low	high	C2	high
Effective thickness	low	very high	C4	high
Gas saturation	low	high	C2	high
Porosity	low	high	C2	high
Reservoir pressure	low	middle	B3	middle
Reservoir temperature	middle	very low	A2	low
Gas density	low	very low	A3	low
Condensate density	low	very low	A3	low
CGR	low	very low	A3	middle

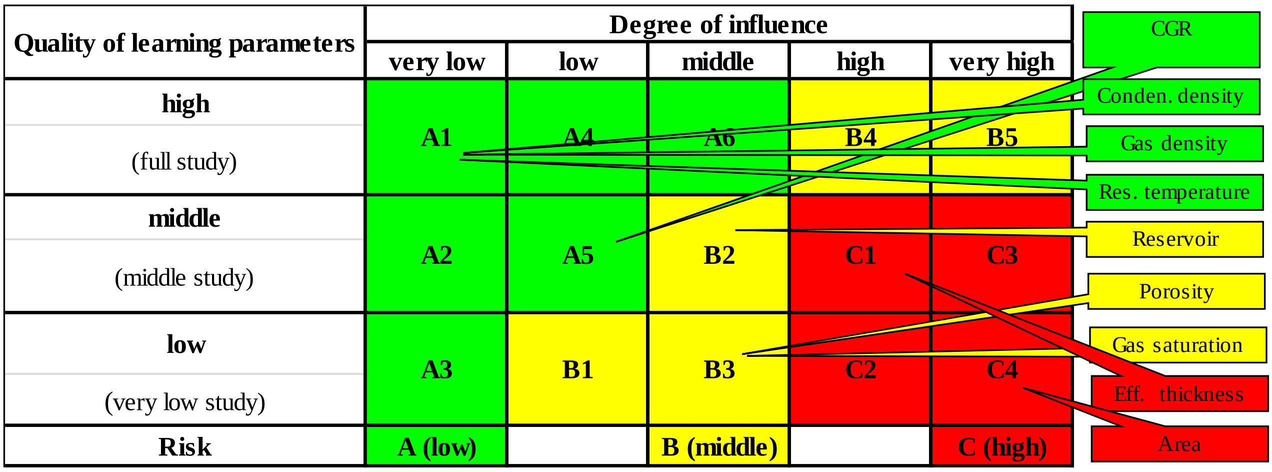


Quality of learning parameters	Degree of influence				
	very low	low	middle	high	very high
high (full study)	A1	A4	A6	B4	B5
middle (middle study)	A2	A5	B2	C1	C3
low (very low study)	A3	B1	B3	C2	C4
Risk	A (low)		B (middle)		C (high)

Figure 28. Risk matrix for zone V

Table 18. Zone VII reservoir parameters - degree of influence and learning of quality

Reservoir parameters	Degree of learning	Degree of influence	Situated square	Risk
Area	low	very high	C4	high
Effective thickness	middle	high	C1	high
Gas saturation	low	middle	B3	middle
Porosity	low	middle	B3	middle
Reservoir pressure	middle	middle	B2	middle
Reservoir temperature	high	very low	A1	low
Gas density	high	very low	A1	low
Condensate density	high	very low	A1	low
CGR	middle	low	A5	low



Quality of learning parameters	Degree of influence				
	very low	low	middle	high	very high
high (full study)	A1	A4	A6	B4	B5
middle (middle study)	A2	A5	B2	C1	C3
low (very low study)	A3	B1	B3	C2	C4
Risk	A (low)		B (middle)		C (high)

Figure 28. Risk matrix for zone VII

Conclusion

The summary results also showed 90%, 50% and 10% probabilities of the gas in place calculation for Zone V as 10 Bm^3, 20 Bm^3 and 31 Bm^3 respectively. The same probabilities for gas reserves in Zone VII are 50 Bm^3, 68 Bm^3 and 90 Bm^3.

From base case 19.8 and 68.5 billion cubic meter gas reserves was obtained for zone V and zone VII respectively, which seem to be good. However, the uncertainty associated with input parameters and variability contributed to the risk associated with this estimate. In order to quantify uncertainty associated with this value, reserve evaluation was subjected in to stochastic method using “Oracle Crystal Ball” software.

Quantification of uncertainty in reserve estimation is influenced by the number of iterations which in turn determines the configuration of the distribution and the convergence rate of the output result. Thus, several trials were considered in each simulation analysis to guarantee maximum reliability of the process. The sensitivity analysis was carried out on 21 variants; the first variant was estimated according to the basic values and the others according to the minimum and maximum values of each geological parameter. The results of sensitivity analyses are presented in Tornado diagrams.

It seems from the diagrams, gas condensate reserves in Zone V are mainly influenced by net thickness and porosity, and in Zone VII by the area and net thickness. In other words, the variation of these geological parameters in a broad range may be stated as a reason for the minimization of geological reserves. This means by better handling (modelling) of these inputs with higher percentages of uncertainties; one can reduce the risk and uncertainty associated with the estimate in general terms.

The results obtained in this work ensure the development of an action plan to clarify the layer parameters with a larger uncertainty range. Exploration work on the field has not been completed and it is proposed to clarify these uncertain parameters during the drilling of new exploration wells and to reinterpret seismic data on the field.

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