

Impact of the Sensitivity Study and Risk Analysis on Development of a Large Carbonate Oil Reservoir in Persian Gulf

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Abstract: This paper describes a development strategy with peripheral water flood for a large oil bearing carbonate reservoir in part of the Persian Gulf oil reservoirs. It is explained how the sensitivity assessment and risk analysis can be used to identify the most dominating risk component(s) with respect to the field productivity and capability of meeting the oil production target. Once these dominating risk components become known, we could: a) further optimize the field development by properly formulating the drilling and completion strategy, b) re-prioritize the data acquisition and reservoir characterization program to lessen the uncertainties and further minimize the risks. Then we have used the Experimental Design Methodology to shorten the number of simulation runs required for sensitivity assessment and risk analysis. The probability analyses identify and rank the most sensitive parameters that help in field development: maximize the exposure to the reservoir components that bring positive impact and minimize those that have the negative impact on field recovery and economics. The most sensitive parameters with respect to oil recovery are identified for reassessment and further improvement and optimization of the development plan. Data acquisition program, reservoir performance evaluation and production injection strategies are conducted with these sensitivities in mind. They are executed with the highest priorities given to the most sensitive parameters.

Key words: Oil Reservoir • Simulation • Kv/Kh ratio • Vertical Transmissibility • Horizontal Transmissibility

INTRODUCTION

Reshadat field is located in the Persian Gulf and consists of 4 reservoirs. The main reservoir is Sarvak-reservoir (S-reservoir). To accurately simulate this complex reservoir, the simulation model has been built (Figure 1). The following development plan is suggested for this reservoir:

Injecting water peripherally into the reservoir by 12 horizontal injectors. All the injectors will be completed in the 4th layer and Producing oil by 8 horizontal producers, which are all completed in the 1st layer.

The development plan of the field can be improved when one understands the reservoir behaviors with respect to the uncertainties of the reservoir parameters [1, 2]. Therefore, it is necessary to perform as many simulations runs as possible to analyze the effect of each source of uncertainty.

In this study we have used the Experimental Design Methodology to reduce the run time of the simulations. The essential ideas are to identify the key reservoir parameters that are likely to affect the recovery and the

production plateau. Use of experimental design has shortened the number of simulation runs required for sensitive assessment and risk analysis, particularly in large reservoir dual porosity-dual permeability models. Sensitive parameters are on the top priority on the list of data acquisition. This helps put the investment where it matters the most in terms of improved recovery and rate of return.

MATERIALS AND METHODS

Geological and Simulation Setting: The first discovery well was drilled in 1969. S-reservoir is the main reservoir of the field. Oil production from S-reservoir started in February 1971. There are 11 oil producers in the reservoir from them 3 wells are equipped with electrical submersible pumps.

The S-reservoir is the top most formation of the Thamama group and is overlain by the Nahr umr formation of the Wasia group. The S-formation comprises generally clean limestone. The structure of this field, at the top S-formation, has an irregular roughly circular outline

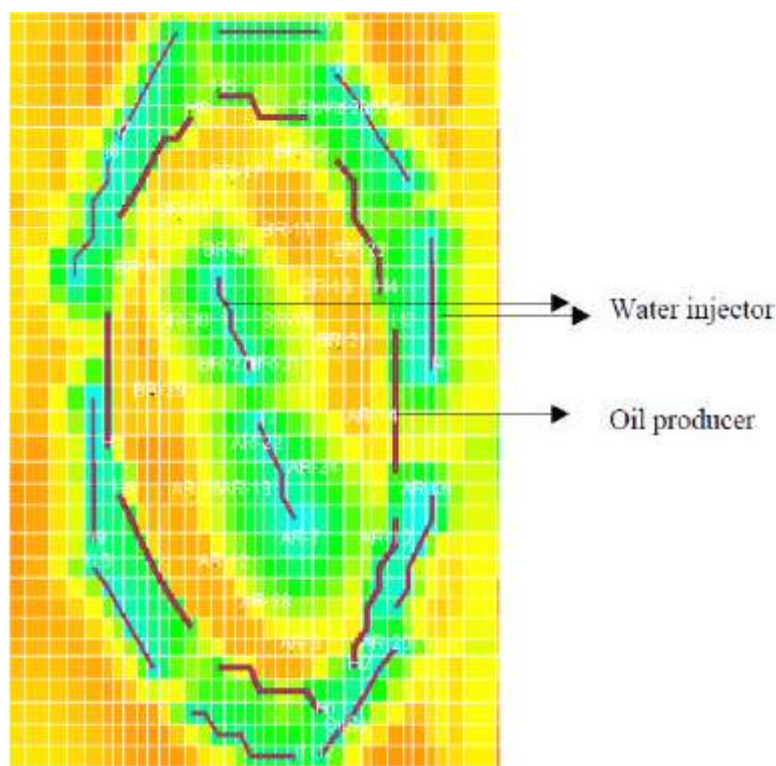


Fig. 1: Simulation model of S-reservoir, development plan: water injection peripherally through 12 horizontal injectors

with 4 way dip closure. Dips are shallower to the west and southwest, but steeper to the north, east and south. The structure is not a uniform dome anticline, but shows irregularities with highs around wells no. 17, 12 and 10 and a low embayment between wells no. 8 and 17.

The Nahr umr shales cap the S-reservoir. Structural growth is generally considered to have been initiated in the early cretaceous. It is likely that the structure was a bathymetric high at the time of deposition of the S-formation. This would form a likely site for rudist reef development. Construction of isopachs for the total S-formation does not reveal regular downflank thickening, such as might be expected in a growing structure. The position is complicated, however, by reef growth and possible later erosion.

The major lithologies with differing reservoir quality, are rudist lime stones and chalky lime stones. The high porosity high permeability rudist limestone can be identified on wire line logs by higher porosity, lower gamma ray and higher resistivity (within the oil zone) when compared with the chalky limestone [3,4].

The reservoir zonation is essentially based upon depositional facies. Four layers (1 to 4) are recognized (Figure 2), with layer 2 being subdivided into 2a, 2b and

2c. layers 2a and 2c are equivalent to the reef-shale rudist lime stones whereas 2b, 3 and 4 are chalky lime stones of the shallower and deep carbonate facies. There are no indications of total permeability barriers within the reservoir although the high water saturations and low permeability of the chalky limestone are clearly of importance in dictating reservoir flow patterns. The NTG of layer 1 is almost zero and for this reason it is excluded from the simulation model. The correspondence between geological and final model layers is summarized in the table below:

Geological Layer	Model Layer
2a	1 and 2
2b	3
2c	4
3	5, 6 and 7
4	8, 9 and 10

By extending the current situation and without any development plan, the S-reservoir will be closed very soon due to the low and non-economic oil production rate. Peripheral water flood is suggested for the development of this reservoir. In this study we are trying to minimize the risk associated with this development plan.

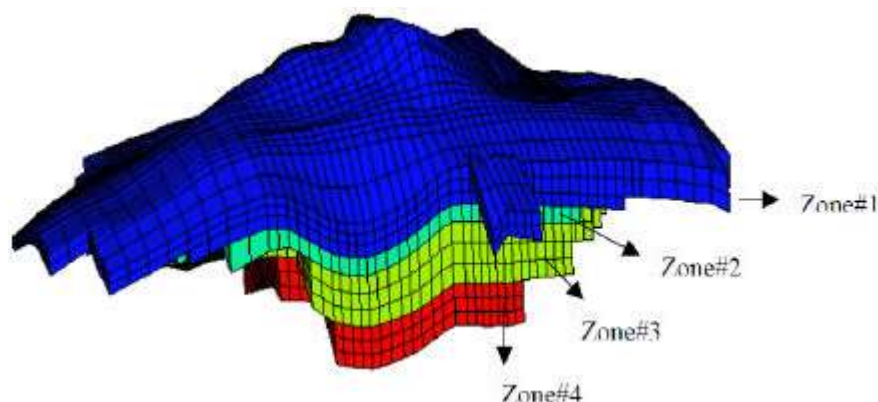


Fig. 2: Different regions (zones) of the model

Optimization Through Sensitivity Study and Risk Analysis: The S-reservoir development scheme can be improved when one understands the reservoir behaviors with respect to the uncertainties of the reservoir parameters. Therefore, it is necessary to perform as many simulations runs as possible to analyze the effect of each source of uncertainty. For this reason the S-reservoir that is approximately 30 Km in the East-West direction and 20 KM in the north-south direction are divided into 4 regions, each presented by different K values. These 4 different regions (zones) have been designed in order to facilitate the application of a sensitivity approach. The model enables a study of the most influential parameters, like vertical/horizontal permeability ratio, horizontal transmissibility for all 4 regions of the reservoir, vertical transmissibility for all 4 regions of the reservoir, residual oil saturation, aquifer external radius, aquifer permeability, skin factor and I and J locations of one producer.

As shown in Figure 1, model has a dimension of 50x66x10 cells. With the total number of cells in the order of 33000, the model can be run and evaluated quickly, given the currently existing computing power.

The essential ideas are to identify the key reservoir parameters that are likely to affect the recovery and the production plateau. Once the most sensitive parameters are identified, they become the business decision drivers that affect the field development plan:

- The drilling and completion of the wells have to reflect the impact of these key drivers. This will result in cost reduction in the business plan as will be illustrated later.
- The data gathering efforts should emphasize on the uncertainty reduction of these key parameters.

The Workflow Approach of the Sensitivity Study: In order to effectively run the models with numerous possibilities of the reservoir parameters uncertainties, Experimental Design Methodology is used [5]. The experimental design methodology is an efficient statistical technique, which provides the maximum information at the lowest simulation cost by varying all the uncertain parameters simultaneously. In this study, the experimental design approach has been applied using the tools recently developed by IFP [6, 7].

Given a number of uncertain parameters and their associated range of variation, the experimental design approach defines a small set of the reservoir simulations that optimally covers the uncertain domain. In the first step, a sensitivity analysis is performed from the simulation results, which ranks the influence of the uncertain parameters regarding any simulation data, like the cumulative oil production or the plateau duration. The method also provides the possible interactions between those parameters [5,7].

In the second step, the experimental design approach can be used, generally with a fewer number of parameters, to perform a risk analysis [8]. In that case, another set of reservoir simulations are computed, that covers more accurately the uncertain domain. The result is an accurate and predictive quantification of the studied response (cumulative oil production, plateau duration) as a function of the parameters. This function is therefore used to compute a probability distribution of the studied response from some probability distributions of the uncertain parameters, using the Monte-Carlo sampling technique.

For the simplification purpose, the probability distribution is presented with 3 probabilistic values noted P10, P50 and P90. There is one chance out of 10 that the

result is below P10, one chance of 2 that the result is below P50 and one chance out of 10 that the result is above P90.

The Sensitivity Parameters Studied: From previous studies as well as preliminary simulation results it was suspected that the permeability and transmissibility of different regions of the model are the most influential parameters regarding the dynamic behavior of the reservoir. Hence, they have been considered as first order parameters in the sensitivity studies we performed. In addition to those, 6 other parameters have been studied:

Residual oil saturation, aquifer external radius, aquifer permeability, skin factor, I and J location of the horizontal producer H5.

The Following Uncertain Parameters Were Studied:

- *The horizontal transmissibility of 4 regions* (the first 4 parameters)
- *The vertical transmissibility of 4 regions* (the next 4 parameters)

It has been studied that the permeability of the S-reservoir varies within a range going from 1 mD to 101 mD. From the preliminary simulation results it was observed that the reservoir permeability in different regions affect the dynamic behavior of the field. In order to quantify the influence of permeability and cell sizes, the horizontal and vertical transmissibility multipliers (noted TMX and TMZ) have been assigned as the first 8 uncertain parameters and sensitivity runs are performed for different transmissibility multiplier in the range of 0.1 to 2 times the calculated original transmissibility.

3- the Well Locations (9th and 10th Parameters):

The I and J locations of one horizontal producer (H5) are considered as uncertain parameters and sensitivity runs are performed for different location of this well:

I location of well H5: 23-27 (noted H5X)

J location of well H5: 16-21 (noted H5Y)

4- Skin Factor (The 11th Parameter): When the study started, there was a large uncertainty on the damaged skin factor of horizontal wells because there were no horizontal wells present in the S-reservoir. This parameter (noted SKIN) was used within the range going from 0 to +20. It must be underlined that a skin factor of +20 is a

pessimistic value regarding the actual measurements, but the objective here was to investigate a large scope of operational risks.

5- Vertical/Horizontal-Permeability Ratio (12th

Parameter): The horizontal producers that composed the development plan are, or will be, drilled at the top of the reservoir in layer 1 (region 1). The horizontal injectors will be drilled in layer 4 (region 2). Because of this geometrical configuration, water breakthrough may occur due to high vertical permeability or due to coning effect in the reservoir. Therefore vertical permeability is expected to have a large influence on water production. The vertical/horizontal permeability ratio (noted KZM) has been tested in the range of 0.01 to 2 in all the 4 regions. It is important to note that from the simulation point of view, this parameter has not only an impact on the vertical transmissibility between cells but also on the productivity index of the perforated cells.

6- Aquifer Radius and Aquifer Permeability (13th and 14th Parameters):

According to the past simulation studies, the history match of pressure data in S-reservoir is not an easy task. In particular the size of the aquifer used to achieve the match significantly varies from one study to another. Hence it is considered the aquifer external radius (noted AQR) and aquifer permeability (noted AQK) as an uncertain parameters and sensitivity runs are performed in the range of 100 to 100000 ft for aquifer radius and in the range of 1 to 100 mD for aquifer permeability.

7- Residual Oil Saturation (15th Parameter): It is worth quantifying the influence of the residual oil saturation on the field performance as this parameter certainly governs the long-term recovery. On the other hand, this parameter has been extensively studied in the past with consistent results. Therefore the range of uncertainty we applied is relatively small from 0 to 20% (noted SOR). This was done by changing the endpoints of the relative permeability curves used in the simulation model.

Running the Simulation Models: As mentioned previously, the sensitivity study has been performed in 2 steps. First, the influence of the 15 uncertain parameters together is quantified. In the second step, so called the risk analysis, 8 parameters are more precisely studied and the oil production (or the plateau duration) is modeled as a function of these parameters in order to provide a probability distribution of the response.

Table 1: The 32 runs of the sensitivity study

Runs	Kv/Kh ratio	ver. Trans. multiplier in zone 1	ver. Trans. multiplier in zone 2	ver. Trans. multiplier in zone 3	ver. Trans. multiplier in zone 4	hor. Trans multiplier in zone 1	hor. Trans multiplier in zone 2	hor. Trans multiplier in zone 3	hor. Trans multiplier in zone 4	Residual oil saturation	Aquifer radius [ft]	Aquifer permeability [mD]	Skin	l-location of well H5	l-location of well H5
1	0.01	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0	100	1	0	23	16
2	2	0.1	0.1	0.1	0.1	2	2	2	0.1	0.2	100000	1	20	23	16
3	0.01	2	0.1	0.1	0.1	2	2	0.1	2	0.2	100	100	0	27	16
4	2	2	0.1	0.1	0.1	0.1	0.1	2	2	0	100000	100	20	27	16
5	0.01	0.1	2	0.1	0.1	2	0.1	2	2	0	100000	100	0	23	21
6	2	0.1	2	0.1	0.1	0.1	2	0.1	2	0.2	100	100	20	23	21
7	0.01	2	2	0.1	0.1	0.1	2	2	0.1	0.2	100000	1	0	27	21
8	2	2	2	0.1	0.1	2	0.1	0.1	0.1	0	100	1	20	27	21
9	0.01	0.1	0.1	2	0.1	0.1	2	2	2	0	100	1	20	27	21
10	2	0.1	0.1	2	0.1	2	0.1	0.1	2	0.2	100000	1	0	27	21
11	0.01	2	0.1	2	0.1	2	0.1	2	0.1	0.2	100	100	20	23	21
12	2	2	0.1	2	0.1	0.1	2	0.1	0.1	0	100000	100	0	23	21
13	0.01	0.1	2	2	0.1	2	2	0.1	0.1	0	100000	100	20	27	16
14	2	0.1	2	2	0.1	0.1	0.1	2	0.1	0.2	100	100	0	27	16
15	0.01	2	2	2	0.1	0.1	0.1	0.1	2	0.2	100000	1	20	23	16
16	2	2	2	2	0.1	2	2	2	2	0	100	1	0	23	16
17	0.01	0.1	0.1	0.1	2	0.1	0.1	0.1	0.1	0.2	100000	100	20	27	21
18	2	0.1	0.1	0.1	2	2	2	2	0.1	0	100	100	0	27	21
19	0.01	2	0.1	0.1	2	2	2	0.1	2	0	100000	1	20	23	21
20	2	2	0.1	0.1	2	0.1	0.1	2	2	0.2	100	1	0	23	21
21	0.01	0.1	2	0.1	2	2	0.1	2	2	0.2	100	1	20	27	16
22	2	0.1	2	0.1	2	0.1	2	0.1	2	0	100000	1	0	27	16
23	0.01	2	2	0.1	2	0.1	2	2	0.1	0	100	100	20	23	16
24	2	2	2	0.1	2	2	0.1	0.1	0.1	0.2	100000	100	0	23	16
25	0.01	0.1	0.1	2	2	0.1	2	2	2	0.2	100000	100	0	23	16
26	2	0.1	0.1	2	2	2	0.1	0.1	2	0	100	100	20	23	16
27	0.01	2	0.1	2	2	2	0.1	2	0.1	0	100000	1	0	27	16
28	2	2	0.1	2	2	0.1	2	0.1	0.1	0.2	100	1	20	27	16
29	0.01	0.1	2	2	2	2	2	0.1	0.1	0.2	100	1	0	23	21
30	2	0.1	2	2	2	0.1	0.1	2	0.1	0	100000	1	20	23	21
31	0.01	2	2	2	2	0.1	0.1	0.1	2	0	100	100	0	27	21
32	2	2	2	2	2	2	2	2	2	0.2	100000	100	20	27	21

Table 2: The 81 runs of the risk analysis

Runs	Aquifer permeability [mD]	Kv/Kh ratio	hor. Trans multiplier in zone 1	hor. Trans multiplier in zone 2	hor. Trans multiplier in zone 3	hor. Trans multiplier in zone 4	ver. Trans multiplier in zone 1	Ver. Trans multiplier in zone 3
1	1	0.1	0.1	0.1	0.1	0.1	2	2
2	1	0.1	0.1	0.1	0.1	2	2	0.1
3	1	0.1	0.1	0.1	2	0.1	2	0.1
4	1	0.1	0.1	0.1	2	2	2	2
5	1	0.1	0.1	2	0.1	0.1	0.1	2
6	1	0.1	0.1	2	0.1	2	0.1	0.1
7	1	0.1	0.1	2	2	0.1	0.1	0.1
8	1	0.1	0.1	2	2	2	0.1	2
9	1	0.1	2	0.1	0.1	0.1	0.1	0.1
10	1	0.1	2	0.1	0.1	2	0.1	2
11	1	0.1	2	0.1	2	0.1	0.1	2
12	1	0.1	2	0.1	2	2	0.1	0.1
13	1	0.1	2	2	0.1	0.1	2	0.1
14	1	0.1	2	2	0.1	2	2	2
15	1	0.1	2	2	2	0.1	2	2
16	1	0.1	2	2	2	2	2	0.1
17	1	2	0.1	0.1	0.1	0.1	0.1	2
18	1	2	0.1	0.1	0.1	2	0.1	0.1
19	1	2	0.1	0.1	2	0.1	0.1	0.1
20	1	2	0.1	0.1	2	2	0.1	2
21	1	2	0.1	2	0.1	0.1	2	2
22	1	2	0.1	2	0.1	2	2	0.1
23	1	2	0.1	2	2	0.1	2	0.1
24	1	2	0.1	2	2	2	2	2
25	1	2	2	0.1	0.1	0.1	2	0.1
26	1	2	2	0.1	0.1	2	2	2
27	1	2	2	0.1	2	0.1	2	2
28	1	2	2	0.1	2	2	2	0.1

Table 2: Continued

29	1	2	2	2	0.1	0.1	0.1	0.1
30	1	2	2	2	0.1	2	0.1	2
31	1	2	2	2	2	0.1	0.1	2
32	1	2	2	2	2	2	0.1	0.1
33	100	0.01	0.1	0.1	0.1	0.1	0.1	0.1
34	100	0.01	0.1	0.1	0.1	2	0.1	2
35	100	0.01	0.1	0.1	2	0.1	0.1	2
36	100	0.01	0.1	0.1	2	2	0.1	0.1
37	100	0.01	0.1	2	0.1	0.1	2	0.1
38	100	0.01	0.1	2	0.1	2	2	2
39	100	0.01	0.1	2	2	0.1	2	2
40	100	0.01	0.1	2	2	2	2	0.1
41	100	0.01	2	0.1	0.1	0.1	2	2
42	100	0.01	2	0.1	0.1	2	2	0.1
43	100	0.01	2	0.1	2	0.1	2	0.1
44	100	0.01	2	0.1	2	2	2	2
45	100	0.01	2	2	0.1	0.1	0.1	2
46	100	0.01	2	2	0.1	2	0.1	0.1
47	100	0.01	2	2	2	0.1	0.1	0.1
48	100	0.01	2	2	2	2	0.1	2
49	100	2	0.01	0.1	0.1	0.1	2	0.1
50	100	2	0.01	0.1	0.1	2	2	2
51	100	2	0.01	0.1	2	0.1	2	2
52	100	2	0.01	0.1	2	2	2	0.1
53	100	2	0.01	2	0.1	0.1	0.1	0.1
54	100	2	0.01	2	0.1	2	0.1	2
55	100	2	0.01	2	2	0.1	0.1	2
56	100	2	0.01	2	2	2	0.1	0.1
57	100	2	2	0.1	0.1	0.1	0.1	2
58	100	2	2	0.1	0.1	2	0.1	0.1
59	100	2	2	0.1	2	0.1	0.1	0.1
60	100	2	2	0.1	2	2	0.1	2
61	100	2	2	2	0.1	0.1	2	2
62	100	2	2	2	0.1	2	2	0.1
63	100	2	2	2	2	0.1	2	0.1
64	100	2	2	2	2	2	2	2
65	1	1.005	1.05	1.05	1.05	1.05	1.05	1.05
66	100	1.005	1.05	1.05	1.05	1.05	1.05	1.05
67	50.5	0.01	1.05	1.05	1.05	1.05	1.05	1.05
68	50.5	2	1.05	1.05	1.05	1.05	1.05	1.05
69	50.5	1.005	0.1	1.05	1.05	1.05	1.05	1.05
70	50.5	1.005	2	1.05	1.05	1.05	1.05	1.05
71	50.5	1.005	1.05	0.1	1.05	1.05	1.05	1.05
72	50.5	1.005	1.05	2	1.05	1.05	1.05	1.05
73	50.5	1.005	1.05	1.05	0.1	1.05	1.05	1.05
74	50.5	1.005	1.05	1.05	2	1.05	1.05	1.05
75	50.5	1.005	1.05	1.05	1.05	0.1	1.05	1.05
76	50.5	1.005	1.05	1.05	1.05	2	1.05	1.05
77	50.5	1.005	1.05	1.05	1.05	1.05	0.1	1.05
78	50.5	1.005	1.05	1.05	1.05	1.05	2	1.05
79	50.5	1.005	1.05	1.05	1.05	1.05	1.05	0.1
80	50.5	1.005	1.05	1.05	1.05	1.05	1.05	2
81	50.5	1.005	1.05	1.05	1.05	1.05	1.05	1.05

Following the Experimental Design Methodology, the first step involves 32 simulation runs for a sensitivity study on 15 parameters. The simulation runs and their parameters are presented in Table 1. The sensitivity study has been performed on 4 different regions of the reservoir. The 8 parameters that has been kept for the risk analysis studies are the following: vertical/horizontal permeability ratio, horizontal transmissibility multiplier in region 1, horizontal transmissibility multiplier in region 2, horizontal transmissibility multiplier in region 3, horizontal transmissibility multiplier in region 4, vertical transmissibility multiplier in region 1, vertical

transmissibility multiplier in region 4 and aquifer permeability. As detailed later on, they have been chosen because their effect on the field behavior can't be influenced by operational management. The risk analysis study with the above 8 parameters involves 81 simulation runs (Table 2).

Compared with the sensitivity study for which the 2 extreme values of each parameter are needed, the risk analysis study requires the use of these values: the 2 extreme, minimum and maximum and a medium value. Finally, up to 81 simulation runs were performed for the sensitivity and risk analysis studies.

RESULTS AND DISCUSSION

Results of the Sensitivity Study: We focused the analysis of the sensitivity study simulations on the cumulative oil production of the whole reservoir and the associated plateau duration.

Figure 3 shows the cumulative oil produced after 15 years from the 32 simulations performed for the sensitivity study. Figures 4 and 5 show the oil rate Vs time and water cut Vs time respectively. One can see the large spread of the results, which presents about 20% to 30% of the recoverable. Figure 8 shows the cumulative oil production for 15 years.

The best case obtained is the case with highest vertical permeability, with highest horizontal transmissibility of layers 1 and 4 and an aquifer of low permeability (simulation#10), see Figure 6. Surprisingly the aquifer size is not influential uncertain parameter and the aquifer permeability has negative effect on oil production. The Pareto Diagram (Fig. 7) confirms this observation. It indicates that the 11 most influential parameters are in decreasing order:

1- Vertical/Horizontal Permeability Ratio (Noted KZM): the higher the vertical permeability is, the more oil is produced after 15 years. The vertical to horizontal permeability ratio has an impact both on the well productivity (like the skin factor) and the gravity segregation process. Here, simulation runs have shown that the gravity segregation effect is strong, even for a vertical/horizontal permeability ratio lower as 0.01.

2- Horizontal Transmissibility Multiplier in Region 1 (Noted TMX1): it has a positive impact on the oil production from region 1, because it enhances both the pressure support and the well productivity.

3- Horizontal Transmissibility Multiplier in Region 2 (Noted TMX2): it has a positive impact on the oil production from region 2. That means the higher the horizontal transmissibility of the region 2 is, the more oil will be produced.

4- Vertical Transmissibility Multiplier in Region 1 (Noted TMZ1): it has a positive impact on oil production from region 1.

5- Skin Factor (Noted SKIN): it has a negative impact on the oil production. That means the higher the skin factor is, the less oil is produced. The negative impact of the

skin factor on the production is easily explained by the fact that by decreasing the well productivity, the pressure constraint (at the bottom or the top of the producer) is reached quicker. The plateau duration will therefore be shorter as the skin factor increases.

6- Horizontal Transmissibility Multiplier in Region 3 (Noted TMX3): It has a negative effect on oil production. The higher the transmissibility of the region 3 is, the less oil will be produced.

7- J Locations of Horizontal Producer H5 (Noted H5Y): will be discussed later.

8- Vertical Transmissibility Multiplier in Region 3 (Noted TMZ3): it has a positive impact on oil production. The higher it is, the more oil will be produced.

9- Aquifer Permeability (Noted AQK): it has a negative effect on oil production. It can be explained due to this fact that aquifer absorbs a part of the energy provided by injection and decreases the water injection efficiency.

10- I Locations of Horizontal Producer H5 (Noted H5X): will be discussed later.

11- Horizontal Transmissibility Multiplier in Region 4 (Noted TMX4): it also has a negative impact on the oil production. It can be explained due to this fact that we inject water in the layer 4 (region 4). Low horizontal transmissibility of this layer results in higher displacement efficiency and as a consequence more oil will be produced and the water production will be delayed.

Having in mind that the pressure maintenance is the main issue, the impact of the other parameters can be explained as follows:

To explain the impact of the aquifer size and the aquifer permeability, it is important to remember that, due to the lateral size of the reservoir, a strong injection is needed to support the pressure at the producers. In such a case, both of the size and the permeability of the aquifer have a major impact since the aquifer absorbs a part of the energy provided by the injection and decreases its efficiency. Therefore, the larger (and higher permeability) of the aquifer, the worse the pressure support is. As the consequence, oil production is lower and the plateau life is shorter.

Residual oil saturation (SOWCR): the residual oil saturation has mainly an impact on the long-term recovery. Considering the relatively short time frame for

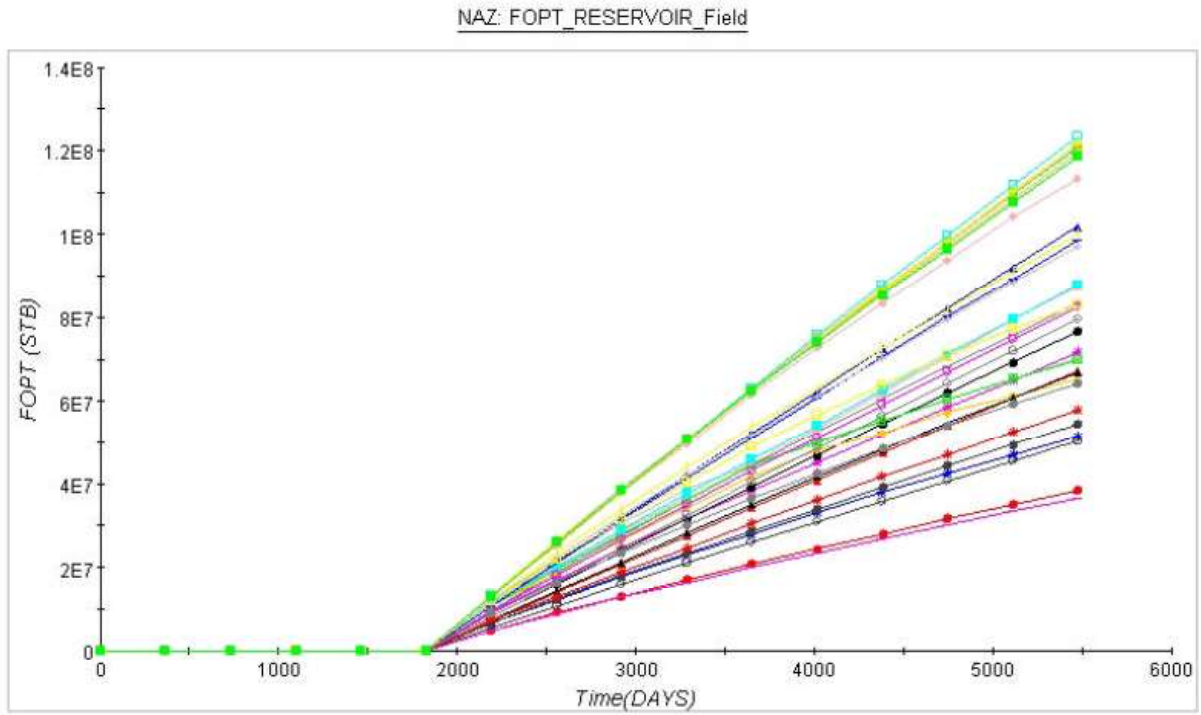


Fig. 3: Sensitivity results: cumulative oil Vs time

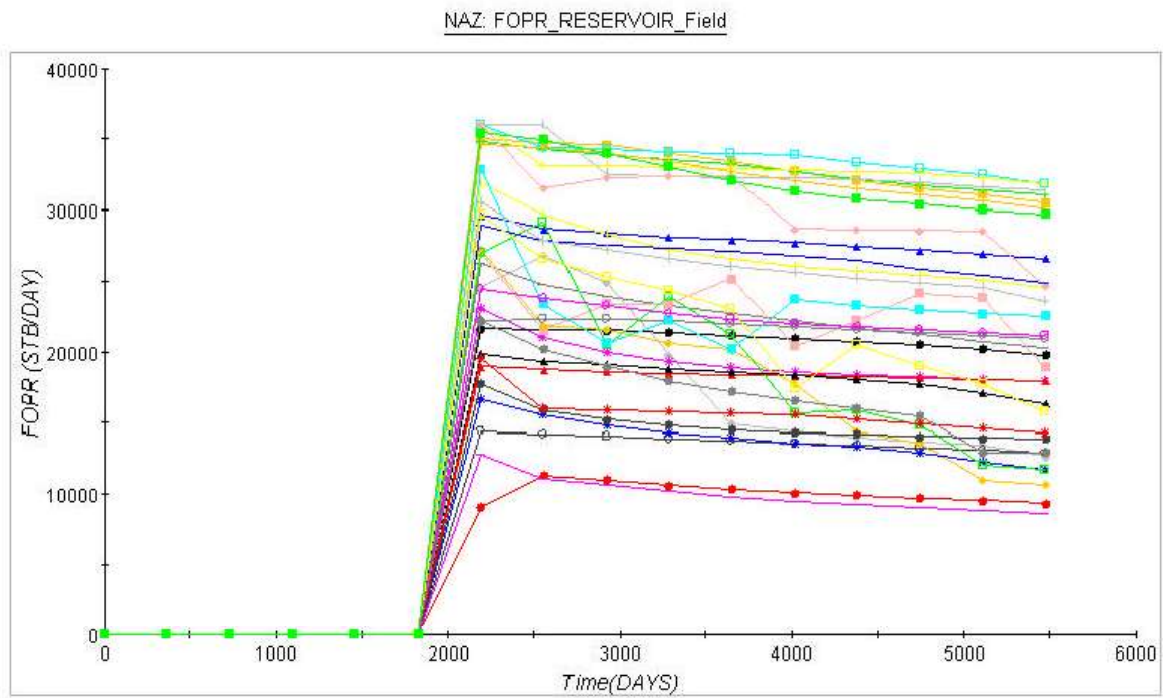


Fig. 4: Sensitivity study results: oil rate Vs time

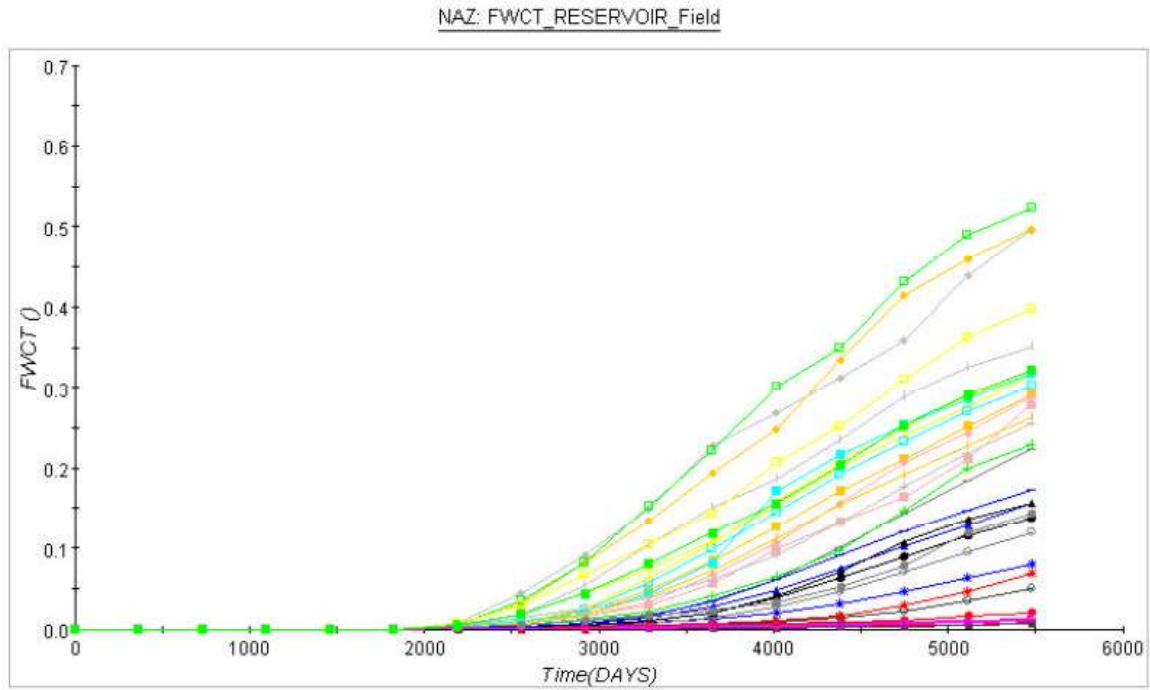


Fig. 5: Sensitivity study results: water-cut Vs time

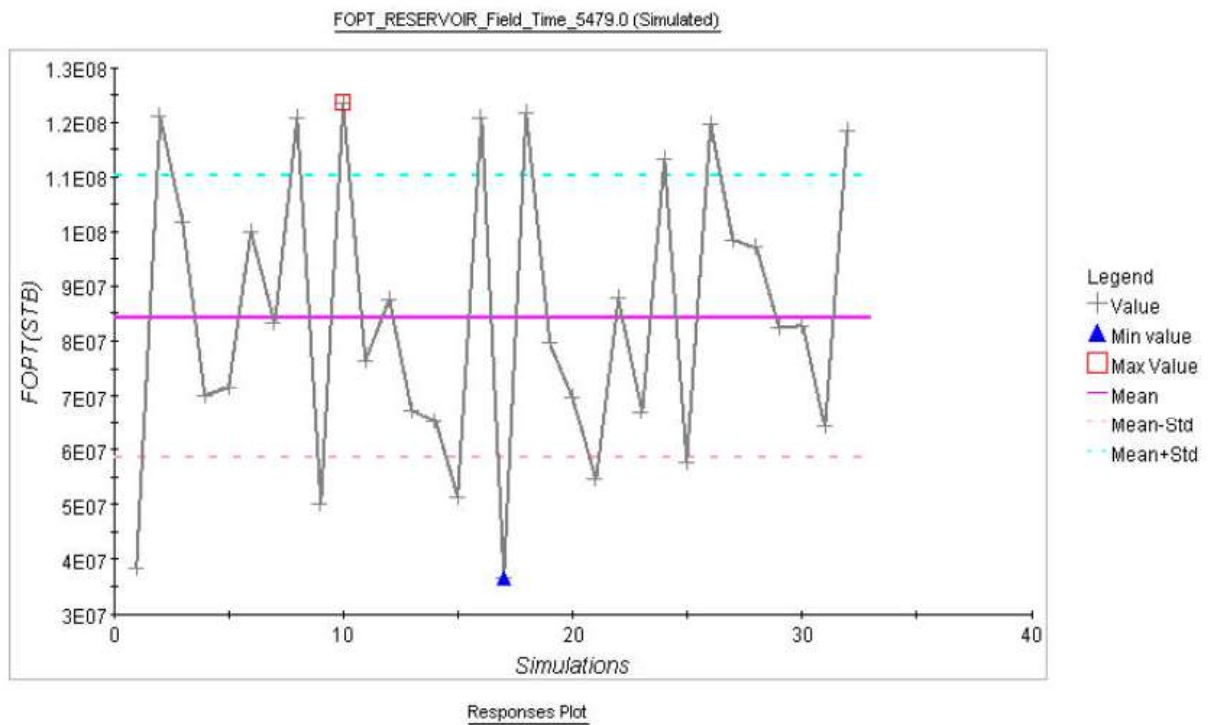


Fig. 6: Results of the sensitivity study runs: the best case and the worst case

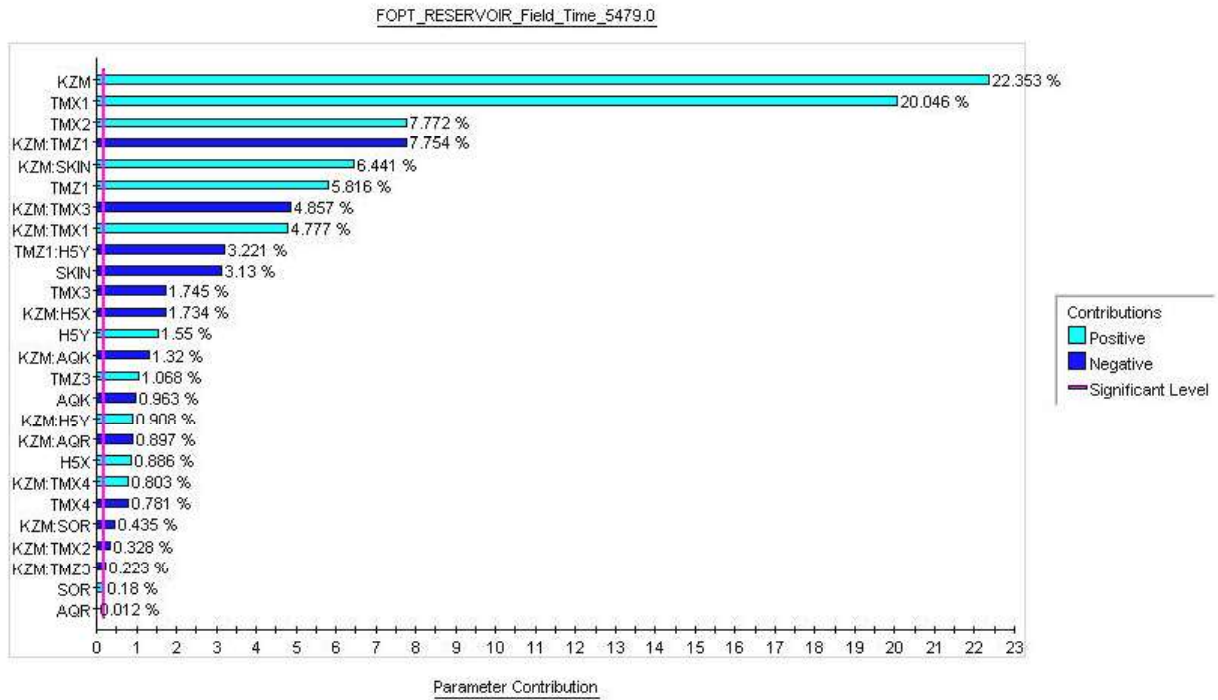


Fig. 7: Sensitivity study: Pareto Plot for the cumulative oil produced

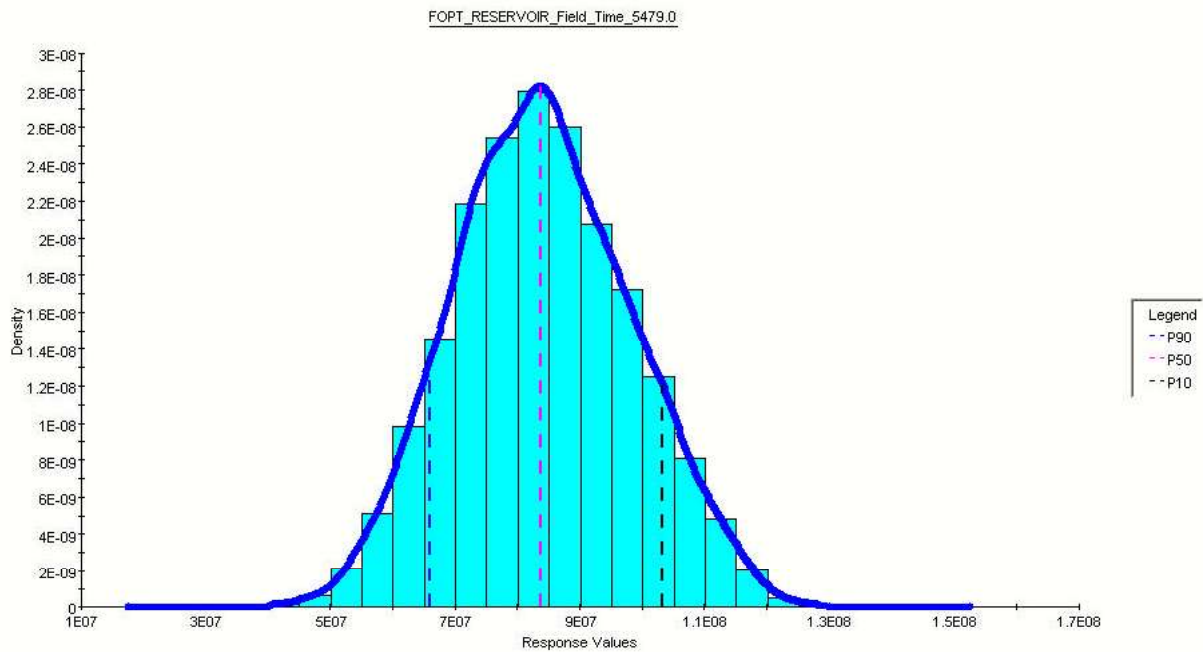


Fig. 8: Sensitivity study: cum. oil production after 15 years, (Probability density function)

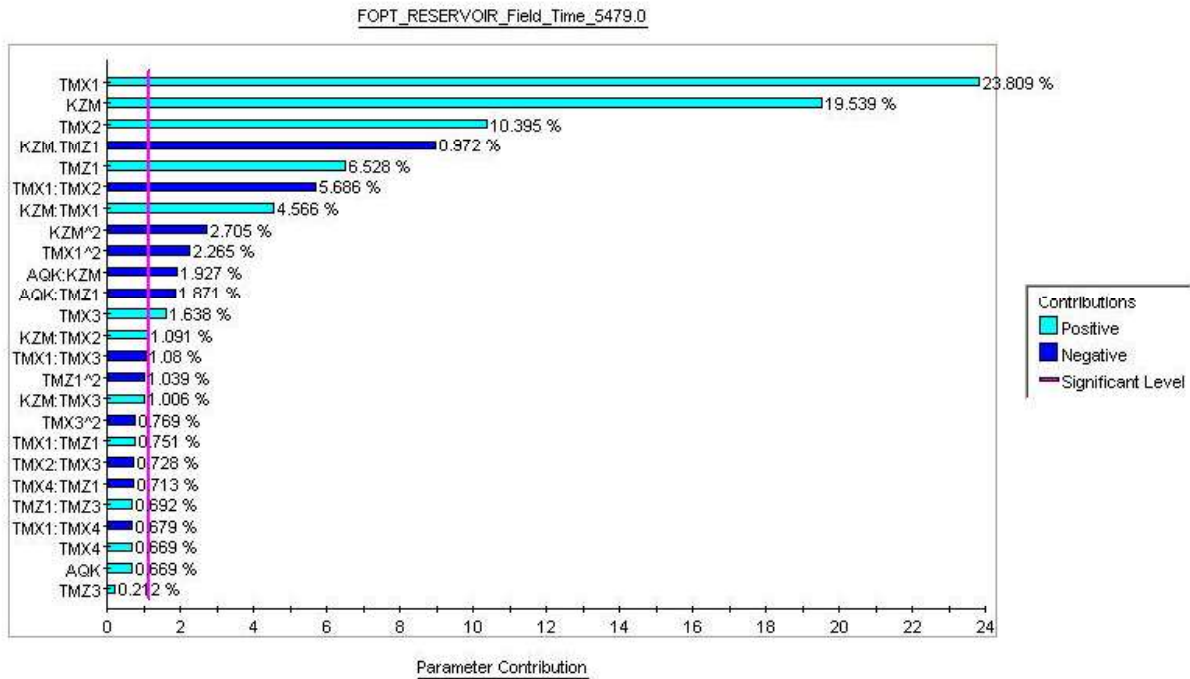


Fig. 9: Risk analysis: Pareto plot for the cumulative oil produced.

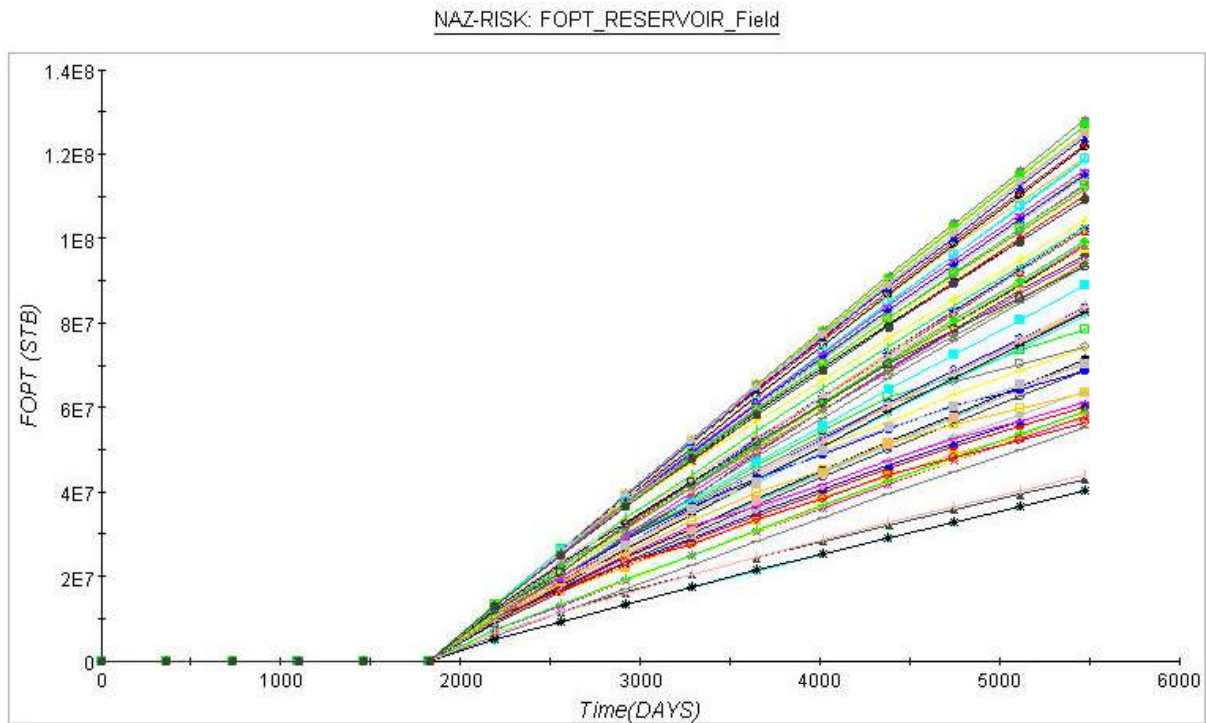


Fig. 10: Risk analysis results. Influence of the most influential uncertain parameters on cumulative oil production

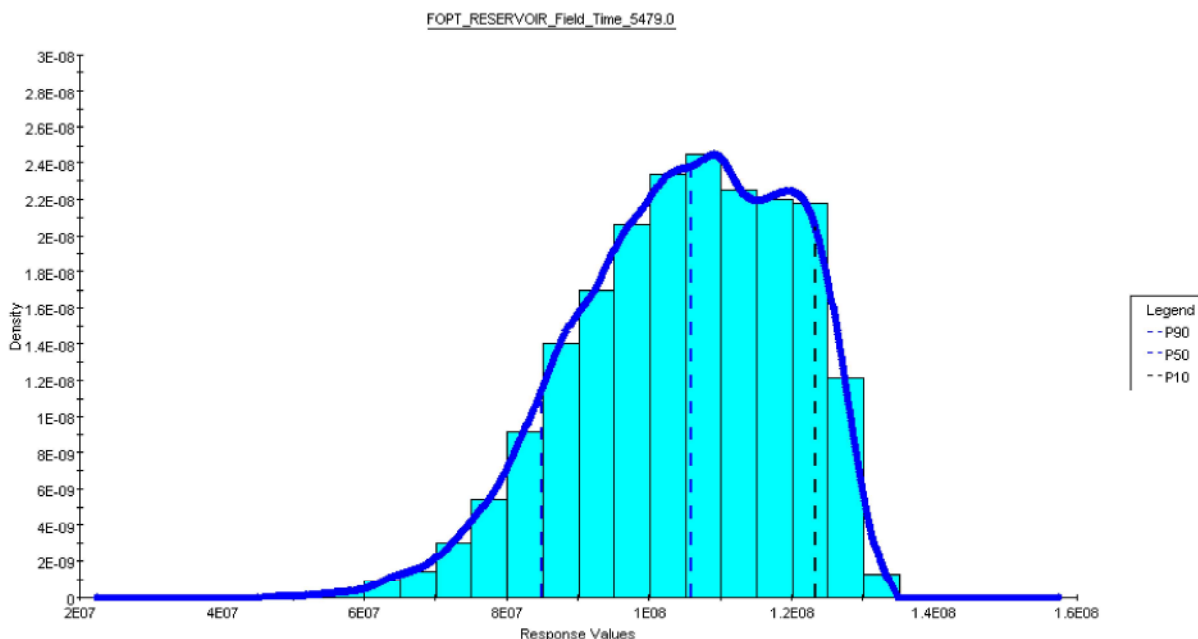


Fig. 11: Risk analysis: Probability density function of the plateau duration

which the simulations were run (15 years is not long regarding the dimensions and the volume in place of the reservoir), this parameter has only a very limited influence on the model results. Figure 8 shows the probability density function of the plateau duration.

Risk Analysis: As mentioned previously, the risk analysis has been performed on the 8 following parameters: Vertical/horizontal permeability ratio, horizontal transmissibility of region 1, horizontal transmissibility of region 2, horizontal transmissibility of region 3, horizontal transmissibility of region 4, vertical transmissibility of region 1, vertical transmissibility of region 3 and aquifer permeability. The other 3 influential uncertain parameters (skin, I and J locations of the well) have been removed because their effect can be balanced by operational interventions at wells and optimizing the well locations. The skin damage can be removed.

The risk analysis process has enabled to model the cumulative oil production after 15 years and the plateau duration as a function of 8 influential parameters studied. The Pareto Plot issued from this study for the cumulative oil production after 15 years is shown in Figure 9. The 2 most influential uncertain parameters are horizontal transmissibility of region 1 and the vertical/horizontal permeability ratio. They both have positive impact on oil production.

Figure 10 shows the cumulative oil produced for 79 simulation runs. Figure 11 shows the probability density function of the plateau duration. Here again, the plateau duration is mainly controlled by the Kv/Kh ratio and horizontal transmissibility of layer 1. The P50 value for the plateau duration is the plateau used for planning purpose.

Impact of the Sensitivity Study and Risk Analysis on Development: The results from sensitivity study and risk analysis clearly impact the way we develop the S-reservoir.

- As has been identified, the parameters with the most impact on production plateau and oil recovery is the Kv/Kh ratio. Kv/Kh ratio ranges from 0.01 to 2. All simulation runs have shown that gravity segregation effect is strong, even for a Kv/Kh ratio as low as 0.01. Based on this observation, horizontal producers should be drilled and it will have a positive impact on S-reservoir development.
- Horizontal transmissibility of layer 1 has a positive impact on the oil production because it enhances both the pressure support and the well productivity. This supports our development strategy that producers should be completed in layer 1 to promote the probability of the wells intersecting the high permeable region 1.

- Skin has a negative impact on production [9], i.e., the higher the skin is, the lower production rate. This is a common understanding that one could say that there is no need to have skin factor as one of the parameters for sensitivity analysis. However, what the sensitivity analysis and the Pareto plot have revealed is that the skin factor ranks as one of the most sensitive parameters that impact the production and the plateau life of the S-reservoir. This understanding elevates the urgency of removing skin factor from the well bores and reprioritizes the way we develop and operate the field. Acid jetting (while the drilling rig is still on location) as well as drilling under balance is currently employed to remove skin damage.
- Aquifer size and permeability have negative effect on oil production [10, 11]. Larger and more permeable aquifer reduces the effectiveness of the pressure support because aquifer absorbs part of the energy provided by the injectors. In order to account for this uncertainty, we suggest injecting at a higher voidage displacement volume. Since the pressure support is a critical element as it is a common issue in most of the sensitivity runs, we should have permanent bottom hole pressure monitoring to make sure that the reservoir is producing at the most optimum conditions with respect to rates and recovery.
- The residual oil saturation, it has mainly an impact on the long-term recovery [12, 13]. Considering the relatively short time frame for which the simulations were run (15 years), this parameter has only a very limited influence on the results and therefore has no immediate impact on the field development and operation.

Particularly efficient in this method can be noted that Probability analyses identify and rank the most sensitive reservoir parameters that help in field development: maximize the exposure to the reservoir components that bring positive impact and minimize those that have the negative impact on field recovery and economics.

CONCLUSIONS

The sensitivity assessment and risk analysis identify the most dominating risk component(s) with respect to the field productivity and capability of meeting the oil production target. Once these dominating risk components become known, we could: a) further optimize

the field development by properly formulating the drilling and completion strategy and b) re-prioritizing the data acquisition and reservoir characterization program to lessen the uncertainties and further minimize the risks.

- The numbers of simulation runs required for the uncertainty analysis can be shortened by means of Experimental Design Methodology.
- Sensitivity assessment and risk analysis can be used to identify the risk components with respect to the field productivity.
- Once the risk components are known, the field development plan can be optimized by properly designing the drilling and completion strategy.
- Identifying the risk components can help us to re-prioritize the data acquisition and reservoir characterization program to lessen uncertainties and to minimize the risk.
- The uncertainty analyses identify and rank the most sensitive parameters that help in field development.
- Maximize those uncertain parameters that have positive impact and minimize those that have negative impact on field recovery and economics.
- The most sensitive parameters with respect to the oil recovery are identified for reassessment and further improvement and optimization of the development plan.
- The development plans must be executed with the highest priority given to the most sensitive uncertain parameters.

REFERENCES

1. Pham, T.R., 2002. logistic approach in using an array of reservoir simulation and probabilistic models in developing a giant oil reservoir with super permeability and natural fractures, 2 October 2002, San Antonio, Texas. SPE 77566.
2. Gorell, S., 0000. Trends in reservoir simulation: big models, scalable models? Will you please make up your mind', SPE 71596
3. Valle, A., 1993. Development and use of a finely gridded window model for a reservoir containing super permeable channels, paper 25631 presented at the 1993 middle east oil show in Bahrain, 3-6 April, 1993.
4. Cosentino, L., 0000. Integrated study of a fractured middle east reservoir with stratiform super-K intervals- part 2: upscaling and dual media simulation, SPE 68184.

5. Johnson, N.L., 1964. statistic and exp8erimental design in engineering and the physical sciences, volume II, New york 1964.
6. Dejean, J.P. and G. Blanc, 2000. Managing Uncertainties on Production Predictions Using Integrated Statistical Methods. SPE 56696, SPE Annual Technical Conference and Exhibition, Huston, Texas.
7. Manceau, E., 2001. combination of experimental design and joint modeling methods for quantifying the risk associated with deterministic and stochastic uncertainties- an integrated test study, SPE 71620
8. Floris *et al.*, 2002. Integrated Scenario and Probabilistic Analysis for Asset Decision Support”, Petroleum Statistical Geoscience, 8: 1-6.
9. Dejean *et al.*, Oct. 3-6, 1999.’ SPE Annual Technical Conference and Exhibition, Managing Uncertainties on Production Predictions Using Intetrated Statistical Methods’. pp: 1-15.
10. Cochran, W. and G. Cox, 1960. Experimental Designs. John Wiley & Sons Inc., New York, second Edition.
11. Manceau, E., M. Mezghani, I. Zabalza-Mezghani and F. Roggero, 2001. Combination of Experimental Design and Joint Modeling Methods for Quantifying the Risk Associated with eterministic and Stochastic Uncertainties – An Integrated Test Study. SPE 71620, SPE Annual Technical Conference and xhibition, New Orleans, Louisiana.
12. Saxena, U. and V. Pavelic, 1999. Factorial designs as an effective tool in mining and petroleum engineering. SPE 3333.
13. Leuangthong, O. and C. Deutsch, 2003. Experimental Design Matrix of Realizations for Optimal Sensitivity Analysis. Technical report, Centre of Computational Geostatistics, University of Alberta, Edmonton, AB, September2003.