American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-7, Issue-2, pp-01-12
www.ajer.org
Research Paper Open Access

Well Placement and Uncertainty Ranking Based On Kriged Production at Early Field-Life Cycle

Antonio Sampayo-Trujillo[1], Her-Yuan Chen[2] and Xuan Zhang[3]
[1]*(Petroleum Engineering Department/ New Mexico Institute of Mining and Technology, USA, and PetróleosMexicanos, México)*
[2,3]*(Petroleum Engineering Department/ New Mexico Institute of Mining and Technology, USA)*
Corresponding Author: Antonio Sampayo-Trujillo

ABSTRACT: *This paper deals with the determination of well placement at early stages using information of oil wells based on simulation runs, and it is the first part of a research work that only considers synthetic cases. Most of the information is sparse at early stages and the objective of an Exploration and Production company is to develop the field in order to have production as soon as possible. The challenge at early stage of production is to propose the position of wells to be drilled. However, due to the lack of information at the early field life, the problem becomes more challenging. The proposed methodology is based on the conclusions obtained by applying the procedure mentioned above in seven synthetic cases of a squared reservoir of 2700 x 2700 ft, under single phase flow of hydrocarbons through the porous media and corroborated with numerical reservoir simulations, called exhaustive methodology. A period of three months is used to update hydrocarbon production, which is a reasonable time period to have stabilized production. Production maps were generated by means of the Kriging approach, as well as the corresponding uncertainty maps. A good match was found for the analyzed cases.*

Keywords *–Field-life, Kriged, Production, Uncertainty, Well Placement*

Date of Submission: 22-01-2018 Date of acceptance: 12-02-2018

I. INTRODUCTION

A cornerstone for well placement site selection is to achieve the maximum revenue while minimizing operating costs by satisfying several constraints. From these points of view, many challenges need to be overcome. The problem requires many large-scale reservoir simulations and description of uncertainties.

Even when a reservoir engineer with many years of experience analyze the large number of possible scenarios, the procedure may result inefficient in most of the cases. This can lead to expensive solutions due to the time spent in the process of analyzing several possible scenarios, and the outcomes could be far from the optimal case, as a consequence, material economic losses may originate due to the inefficient process of analysis. Roboust algorithms have been used to analyze and the problem of well placement optimization [1,2,3]. History matching, well location, production scheduling, and surface facilities design and construction are the basic categories that are included in the above references.

Particular attention has been received by the case described by the well placement optimization process, and the use of optimization algorithms began to be reported about 20 years ago [4,5]. Several cases have been reported in literature to propose the types of wells, number, and orientation of wells, different geological characteristics and numerical approaches for the simulation process [6-11]. Due to the complexity and diversity of the parameters that govern the fluid flow through porous media there has been some works [12,13] trying to simplify these complex phenomena into a simple two-dimensional representation of the reservoir, called a quality map [12].

Zhang [14] presented a preliminary assessment that uses production data in a Kriging model. One major advantage of applying Kriging methods is that uncertainty values can be estimated, giving to the reservoir engineers reliable elements to decide where to drill infill wells. These criteria will depend on the problem to be solved. If the objective is to drill wells in zones where the highest production is present, a production map can be used. If the objective of a study is oriented to reducing the uncertainty and has more information of the reservoir, then an uncertainty map given by the standard errors is most profitable to be used. This methodology is an alternative approach to be used in solving the problem of well placement. It is important to mention that this approach is not a replacement of the robust numerical schemes; it is an alternative method to help companies to decide where to drill infill wells at the early stage of the field development. Early production, and well coordinates of previously wells drilled are the input data.

II. STATEMENT OF THE PROBLEM AND OBJECTIVES

The development of an oil and/or gas field is of great importance in order to generate economic value of the asset. One major target is to determine the number of wells to be drilled in order to optimize the recovery of hydrocarbons at minimum cost. At early stages, reservoir information is scarce, making the decision of proposing new infill locations riskier than if reservoir properties were known.

The determination of the number of wells to be drilled in order to optimize the recovery of hydrocarbons depends on several factors. In order to solve the well placement problem, industry has used several approaches, and the use of these approaches depends primarily on data availability (lifecycle stage), data quality/certainty, drilling purpose, expertise, money, time, and human resources among others. The use of static models and maps based on porosity, saturation, and thickness has been used to solve the problem of well placement. Exhaustive flow simulation models have been used for trying all possible locations in the reservoir; however, the methodology requires high demanding efforts in terms of time and money for a company. Another approach widely used is the optimization scheme, which requires a guided search (algorithm) with a prescribed objective function (e.g., maximizing Net Present Value). The Objective-function evaluation is expansive (using "simplified" proxy models is common to reduce computational burden), and of course algorithm choice needs special expertise.

In order to show how big the computational burden will be if an exhaustive approach is used to decide where to drill a well, consider for example the case for one geological model (realization) with 27x27 (= 729) gridblocks, the possible well locations and simulation runs are given by the possible combinations of well positions given by the permutation formula: Number of gridblocks! / [(Number of gridblocks – Number of wells to be drilled)!], 729! / [(729 – 3)!]$\cong 4\times10^8$. It means that 4×10^8 simulation runs need to be done just to determine where to drill three wells in a reservoir. This kind of problem is difficult due to the large combination of well locations, and from the practical point of view is not feasible.

The solution of this kind of problem requires a cost-effective approach to meet a timely decision consistent with flow physics and field understanding. Additionally, it is important to mention that uncertainty quantification is required.

The scope of this work considers the study of well placement/location decision by using production data only. Strong emphasis is considered at early field-lifecycle (sparse wells), permeability field, and production (primary). The variation in drilling schedule, explicit modeling of well type/completion, and a detailed field study are not considered in detail.

Based on the above, the present study has the following specific objectives: 1) To develop a production-based methodology for well placement with uncertainty ranking, 2) Validate the developed method for various synthetic permeability fields, and 3) Identify ways to integrate geostatistics (kriging) and flow-physics.

III. PROPOSED APPROACH

The proposed methodology considers the use of Kriged Production with uncertainty quantification. The rationale for using only production data at early stage is due to fact that production data is a direct measurement, easily accessible, always updated, catch-all geology-engineering "quality" indicator, it is a business driver, and no uncertainty is present (except measurements). Additionally, production data can capture future uncertainties. It is a project-maturity driver (along a value chain, e.g., go/no-go; risk of spending more money). In a nutshell, production data provide cost-effective and uncertainty-enhanced decision-making.

The input data for the methodology are production data ("exact information from flow simulation runs") and locations of the wells already drilled in the reservoir. The process starts with the exhaustive process by running the cases one by one in ECLIPSE^{TM}. Next step is to select the location of the infill well based on the cumulative production and an exact answer is found. Lack of uncertainty is present in this step. On the other hand, when the Kriging methodology is used, production data generated from the simulation runs is used as input data into the Kriging algorithm. One fundamental step in applying Kriging is the semivariogram calculation [15], spatial correlation needs to be known. Spatial autocovariance is a function of a semivariogram [16]. The semivariogram is a function only of lag distance [15]. Semivariogram shows the dissimilarities of production performance throughout the reservoir. This information and well locations of the initially wells drilled in the reservoir are the input data for the estimation of the best locations to drill infill wells. Additionally, an uncertainty is estimated during the process. This uncertainty is given by the standard error at every location. When the processes described above are completed, a comparison of the results is performed. Figure 1 shows the methodology.

ASSUMPTIONS AND DEVELOPMENT

A preliminary assessment that follows the above approach was presented by Zhang14. This preliminary approach employs cumulative production data at every three months of production for wells previously drilled in the area under study to update the information and then interpolate and / or extrapolate the cumulative production data by means of Kriging. Figure 2 shows the case analyzed by Zhang [14]. The reservoir is a horizontal 1-layer, with an area of 2700x2700 ft2(≈ 167-acre square), a uniform net thickness of 20 ft, and the uniform initial reservoir pressure considered in this study is 3600 psia. A constant bottom-hole pressure of 2500 psi was assumed. Water saturation and porosity are 22, and 20 percent, respectively. This study considers that all the wells are vertical producing wells. Figure 2 shows the reservoir simulation model considered in this study. The specific objective is to ensure that two independent works are in agreement in computation and basic physical understanding. The synthetic reservoir cases analyzed by Zhang [14] correspond to a rectangular homogeneous reservoir (k = 10 mD), and a heterogeneous reservoir with different zones of permeability (1, 5, and 14.8 mD, respectively). The initial well placement of the 6 wells depends on the configuration of the reservoir based on the best potential zones to be drilled, for example distribution of permeabilities. As it is well known, and based on the Darcy's Law and keeping all the variables constant except permeability, the best zones to propose the development of the field will be the zones with the highest permeabilities. In this work it is assumed that there are no faults or any other barrier that can cause the reservoir to be break into segments or zones. This is just a simple case of study to show and understand the performance of the kriging method by assuming well locations and cumulative production data for the three first months. Many parameters need to be considered in designing the production time frame, such as the reservoir characteristics, the operating controls, types, well pattern and many more. For example, well production cannot be too long. There are operating and economic factors that control the duration of well production.

PRODUCING MODE & INFILL-WELL SCHEDULE

In this study a time period of 15 years of production is considered. This period is a reasonable time to study the well performance based on the reservoir characteristics of this field. After 15 years, the oil production tends to be zero [14]. In this work the economics of the project is not considered. Zhang [14] found and corroborated the results obtained by Rodriguez and Cinco-Ley [17], and Camacho et. al [18]. It was concluded that the total production rate shows an exponential decline exponent. It is important to mention that in this work, it is assumed that a good indicator to be used as input data for the kriging model and for deciding where to drill infill wells is the cumulative production of the first three months. From the practical point the past three months of production is considered as the production indicator during field operations. Zhang [14], proved that in order to have a stabilized production, a period of three months can be considered. Figure 3 shows the performance of the wells when simulation runs were developed. Based on the previous results, there is a linear relationship between oil cumulative production and time, and three months of production is a reasonable time to be taken at early stages as stabilized period of production, and it was considered the production of the wells above the bubble point, with constant flowing BHP at 2500 psia for all wells.

In this work, six initial wells already drilled in the reservoir are considered. The objective is to develop a plan to propose the position where three more wells need to be drilled in the reservoir. Based on the above, a production and sequential infill schedule needs to be considered, as well as decision time at which the first production starts and the time at which a decision has to be taken in order to propose the well placement of infill wells. Firstly, the first initial wells start production at the same time, and after a period of three months of production, a decision has to be taken and cumulative production of each well is recorded. In other words his time corresponds a decision time for next infill-well location (sequential well-placement). Based on the previous data, numerical flow simulation and Kriging approaches are developed. Based on the above, a map of the reservoir can be built in order to determine the best position to drill a well, considering the highest production with the exhaustive approach (simulation runs) and Kriging. When the Kriging approach is used, it is possible to estimate an uncertainty map that depends on the semivariogram, distances, and configuration of the wells. Then, it is possible to propose the location of the next infill well to be drilled and proceed with the methodology.

In order to continue with the sequence of well placement, the proposed methodology considers that once the decision has been taken about where to drill the next infill well, reservoir flow model has to be run considering the six initial wells and the new well. It is assumed that the first production of the new well will be after three months, considering drilling and completion time, and the decision time used to take the decision where to drill the next additional well will be three more months. In other words, this decision time is nine months. The sequence is depicted in figure 4.

It is important to mention that order to develop the above approach, constraints need to be considered. Unlike reservoir simulation, Kriging is based on statistics about the physics of the phenomena. In this particular case, production data is considered as an input data for the model. Due to legal aspects and flow-physics considerations, constraints are common in practice. This study assumes that no wells are allowed to be drilled along outer/lease boundary grids, as well as no wells can be drilled next to each other (separated by at least one grid in any direction). No water production is considered in this study. Table 1 summarizes the reservoir fluid system.

WELL PLACEMENT SELECTION

One of the main objectives of the present work is to test the proposed methodology with different cases of permeability distributions. A total of seven synthetic cases where analyzed. The cases are combinations of permeability distributions. For example, the first case corresponds to the case shown in figure 2, low-medium-high permeability distribution. A combination of these possible scenarios was considered: low-high-medium, high-medium-low, high-low-medium, medium-high-low, medium-low-high, and low-high-low. This latter scenario was chosen in order to observe how the contrast and repeatability of permeabilities affect the well placement selection process.

Figure 5 shows the results (normalized) when the above methodology described in figure 1 is applied for the case corresponding to the low-medium-high permeability distribution scenario. One important result is that when simulation (exhaustive approach) is used, selected targets also are the “best” production-potentials. Exhaustive approach consists of developing several runs (75 runs by moving the position of the well under study) and observes the cumulative production for every run and determines where will be the best position of the wells, in terms of production. Strictly speaking, if a company had infinite resources (human and economic resources) the best solution is to do reservoir simulation. However, as it was stated at the beginning of the paper, one major objective is to evaluate the performance of the methodology proposed in this work by using production data only. The upper part of figure 6 shows the best position of the wells selected when applying the Kriging method, by knowing the first three months of production, and well coordinates. Kriged-production more or less reflects the permeability trend; and larger variation after adding wells. Actually, the selected targets are not the “best” production-potential. The plots to the right of figure 5 show the variation between the numbers of grids open to production vs production potential. Actually, implicit in these plots are the well interference, and the different zones of permeabilities. Flow simulation model shows a steeper behavior, reflecting the different zones of permeability distribution.

In order to analyze the performance of this methodology based on the physics of the reservoir, it is important to take a look of the plots depicting the flow simulation results. These plots show the consistency of the study cases. The first plot, field oil rate vs time shows a comparison of the base case (when the six initial wells are operating) and how the drilling of the infill wells are affecting the performance of the reservoir. This comparison is developed for the cases of exhaustive and Kriging approaches.

As it can be seen, the field performance is almost the same even though well placements are different. From the previous plot the interference of wells 7, 8, and 9 is observed. The spikes separated every six months show this fact. These results are confirmed when field cumulative oil and pressure are plotted vs time, cumulative productions are almost the same. In terms of practical applications, this small variation does not represent a material difference. This variation is observed when field oil rate is plotted. Unlike the upper part of figure 6, where the variations are shown in semi-log scale, the lower part of figure 6 shows the behaviors when log-log representation is used. The last part of figure 6, field pressure against field cumulative oil, shows a linear behavior. Strictly speaking it is a material balance relationship between field-pressure and cumulative oil.

IV. DISCUSSION OF RESULTS – PRODUCTION MAPS

Among the advantages of using Kriging over other estimation or interpolation methods are that it treats clusters more like single points, and gives estimate of estimation error (kriging variance), along with estimate of the variable. Special attention must be pointed out when an uncertainty map (standard error map) is obtained. The error map is essentially a scaled version of a map of distance to nearest data point, so not that unique [15, 19, 20]. Figure 13 shows the evolution of uncertainty map for high-medium-low permeability distribution case.

The black circles are showing the location of wells selected based on the production potential by using the Kriging-based methodology. If the criterion of well placement has been to reduce the uncertainty of the location of the infill wells (based on standard errors) the position would not have been the same, because the objectives of the infill drilling are different.

Low-uncertainty (red) is around the well cluster (as expected), high-uncertainty (green) indicates "lack of information". In fact, this kind of map is useful not only for production engineering area, but also for the exploration team. Certainly, the uncertainty values estimated by this procedure are not correlated to the estimated values. In other words, the potential value of the well is unrelated to the standard error (see figures 14, 15, and 16). However, this kind of map can help exploration areas to develop a study for reducing the uncertainty in areas where no information has been taken. The kriging standard errors (uncertainty) depend only on the distance from observations and not on the observed values of production potentials or estimated values [15, 19-21]. The Kriging standard errors can be used as a criterion to improve sampling design [21], which will be useful to use for the exploration team. In fact, when the objective is to drill infill wells in areas where high production potentials are the priority, then a production map has to be used. On the other hand, if the objective of the study is to reduce uncertainty and investigate more about the reservoir, then a standard error map is more useful.

One practical application of this methodology is when a new reservoir has been discovered and few wells have been drilled based on geological and geophysical information. Then, the reservoir needs to be developed and produce as soon as possible to generate economic value. Additionally, at the early stage of the development of a field, small amounts of the hydrocarbon reserves are classified as proved, and the rest as probable and possible reserves.

The use of this methodology can help to reclassify a higher uncertainty category of reserves (for example probable or possible areas) into a less uncertain classification, giving to the project a positive variation in its economic value. This could be possible based on the proposed methodology and early production data.

I. FIGURES AND TABLES

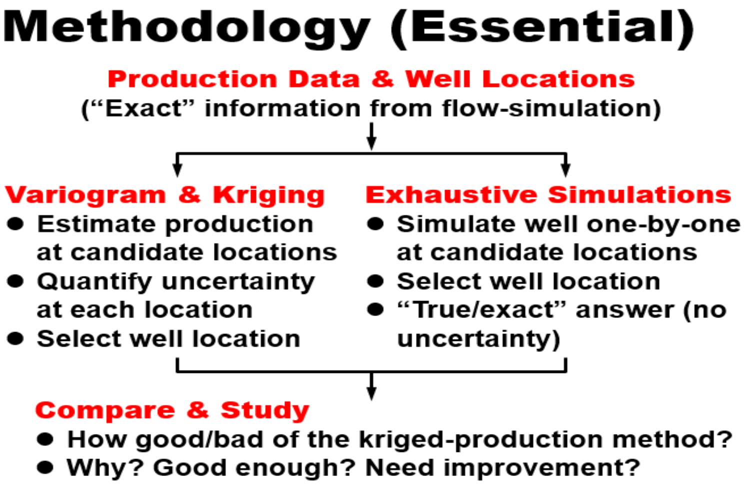
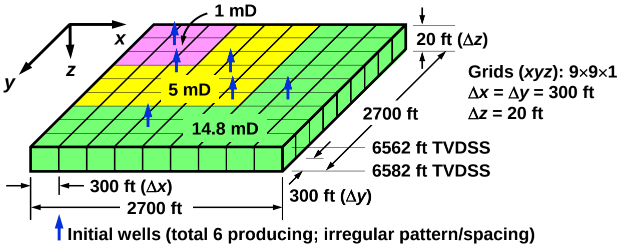


Fig. 1 Proposed methodology to develop the well placement process



- Horizontal 1-layer
- Area = 2700×2700 ft^2 (≅ 167-acre square)
- Thickness (net) = 20 ft *
- Initial reservoir pressure = 3600 psia *
- Water saturation = 22% *
- Porosity = 20% *
- Permeability (isotropic): 14.8-5-1 mD (3 low-medium-high regions)

* Uniform

Fig. 2 Reservoir Simulation Model

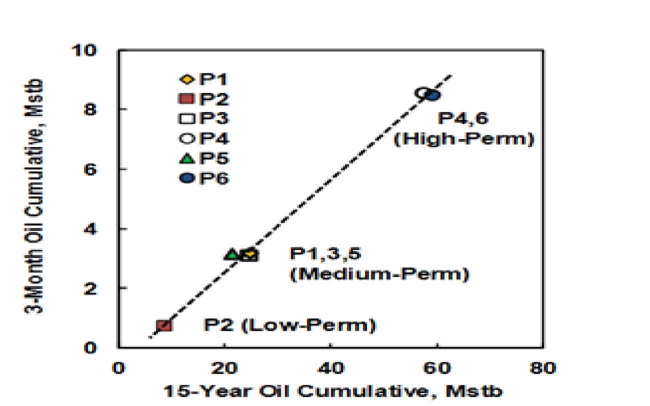
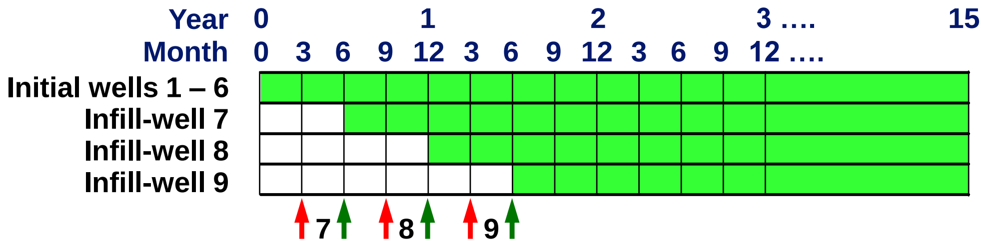


Fig. 3 Cross-plot of the first 3 months and 15 years cumulative oil production, considering a constant BHP of 2500 psi



Decision-time for next infill-well location (sequential well-placement)

First-production: 3 months (drilling/completion …) after decision-time

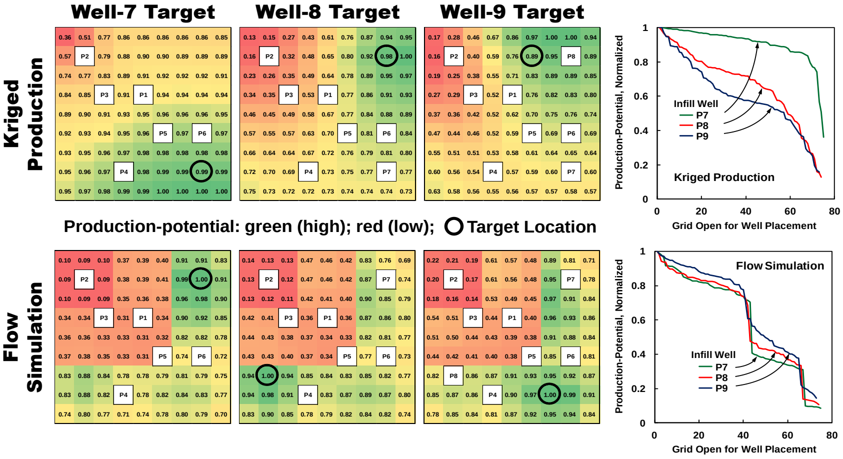
* All wells are vertical production wells.
Average acres/well: 27.9 (initial 6-well development); 18.6 (infill 9-well).

Fig. 4 Producing Mode & Infill-Well Schedule

Table 1 Reservoir fluid system

Oil, initial saturation status	Undersaturated
Oil bubblepoint pressure, psia	1200
Solution GOR, Mscf/stb	0.1
Oil density (surface), lbm/ft^3	45
Oil FVF, rb/stb *	1.11
Oil compressibility, psi^{-1}	5×10^{-5}
Oil viscosity (constant), cP	2.65
Water density (surface), lbm/ft^3	62.14
Water FVF, rb/stb *	1.01
Water compressibility, psi^{-1}	0
Water viscosity (constant), cP	0.28

* At reference pressure p_{ref} = 3600 psia



Kriged Production – Well-7 Target

0.36	0.51	0.77	0.86	0.86	0.86	0.86	0.86	0.85
0.57	P2	0.79	0.88	0.90	0.90	0.89	0.89	0.89
0.74	0.77	0.83	0.89	0.91	0.92	0.92	0.92	0.91
0.84	0.85	P3	0.91	P1	0.94	0.94	0.94	0.94
0.89	0.90	0.91	0.93	0.95	0.96	0.96	0.96	0.95
0.92	0.93	0.94	0.95	0.96	P5	0.97	P6	0.97
0.93	0.95	0.96	0.97	0.98	0.98	0.98	0.98	0.98
0.95	0.96	0.97	P4	0.98	0.99	0.99	○ 0.99	0.99
0.95	0.97	0.98	0.99	0.99	1.00	1.00	1.00	1.00

Kriged Production – Well-8 Target

0.13	0.15	0.27	0.43	0.61	0.76	0.87	0.94	0.95
0.16	P2	0.32	0.48	0.65	0.80	0.92	○ 0.98	1.00
0.23	0.26	0.35	0.49	0.64	0.78	0.89	0.95	0.97
0.34	0.35	P3	0.53	P1	0.77	0.86	0.91	0.93
0.46	0.45	0.49	0.58	0.67	0.77	0.84	0.88	0.89
0.57	0.55	0.57	0.63	0.70	P5	0.81	P6	0.84
0.66	0.64	0.64	0.67	0.72	0.76	0.79	0.81	0.80
0.72	0.70	0.69	P4	0.73	0.75	0.77	P7	0.77
0.75	0.73	0.72	0.72	0.73	0.74	0.74	0.74	0.73

Kriged Production – Well-9 Target

0.17	0.28	0.46	0.67	0.86	0.97	1.00	1.00	0.94
0.16	P2	0.40	0.59	0.76	○ 0.89	0.95	P8	0.89
0.19	0.25	0.38	0.55	0.71	0.83	0.89	0.89	0.85
0.27	0.29	P3	0.52	P1	0.76	0.82	0.83	0.80
0.37	0.36	0.42	0.52	0.62	0.70	0.75	0.76	0.74
0.47	0.44	0.46	0.52	0.59	P5	0.69	P6	0.69
0.55	0.51	0.51	0.53	0.58	0.61	0.64	0.65	0.64
0.60	0.56	0.54	P4	0.57	0.59	0.60	P7	0.60
0.63	0.58	0.56	0.55	0.56	0.57	0.57	0.58	0.57

Flow Simulation – Well-7 Target

0.10	0.09	0.10	0.37	0.39	0.40	0.91	0.91	0.83
0.09	P2	0.09	0.38	0.39	0.41	0.99	○ 1.00	0.91
0.10	0.09	0.09	0.35	0.36	0.38	0.96	0.98	0.90
0.34	0.34	P3	0.31	P1	0.34	0.90	0.92	0.85
0.36	0.36	0.33	0.33	0.31	0.32	0.82	0.82	0.78
0.37	0.38	0.35	0.33	0.31	P5	0.74	P6	0.72
0.83	0.88	0.84	0.78	0.78	0.79	0.81	0.79	0.75
0.83	0.88	0.82	P4	0.78	0.82	0.84	0.83	0.77
0.74	0.80	0.77	0.71	0.74	0.78	0.80	0.79	0.70

Flow Simulation – Well-8 Target

0.14	0.13	0.13	0.47	0.46	0.42	0.83	0.76	0.69
0.13	P2	0.12	0.47	0.46	0.42	0.87	P7	0.74
0.13	0.12	0.11	0.42	0.41	0.40	0.90	0.85	0.79
0.42	0.41	P3	0.36	P1	0.36	0.87	0.86	0.80
0.44	0.43	0.38	0.37	0.34	0.33	0.82	0.81	0.77
0.43	0.43	0.40	0.37	0.34	P5	0.77	P6	0.73
0.94	○ 1.00	0.94	0.85	0.84	0.83	0.85	0.82	0.77
0.94	0.98	0.91	P4	0.83	0.87	0.89	0.87	0.80
0.83	0.90	0.85	0.78	0.79	0.82	0.84	0.82	0.74

Flow Simulation – Well-9 Target

0.22	0.21	0.19	0.61	0.57	0.48	0.89	0.81	0.71
0.20	P2	0.17	0.61	0.56	0.48	0.95	P7	0.78
0.18	0.16	0.14	0.53	0.49	0.45	0.97	0.91	0.84
0.54	0.51	P3	0.44	P1	0.40	0.96	0.93	0.86
0.51	0.50	0.44	0.43	0.39	0.38	0.91	0.88	0.84
0.44	0.42	0.41	0.40	0.38	P5	0.85	P6	0.81
0.82	P8	0.86	0.87	0.91	0.93	0.95	0.92	0.87
0.85	0.87	0.86	P4	0.90	0.97	○ 1.00	0.99	0.91
0.78	0.85	0.84	0.81	0.87	0.92	0.95	0.94	0.84

Fig. 5 Well-Placement Comparison. Permeability distribution: Low-Medium-High. Kriged-Production vs. Flow-Simulation

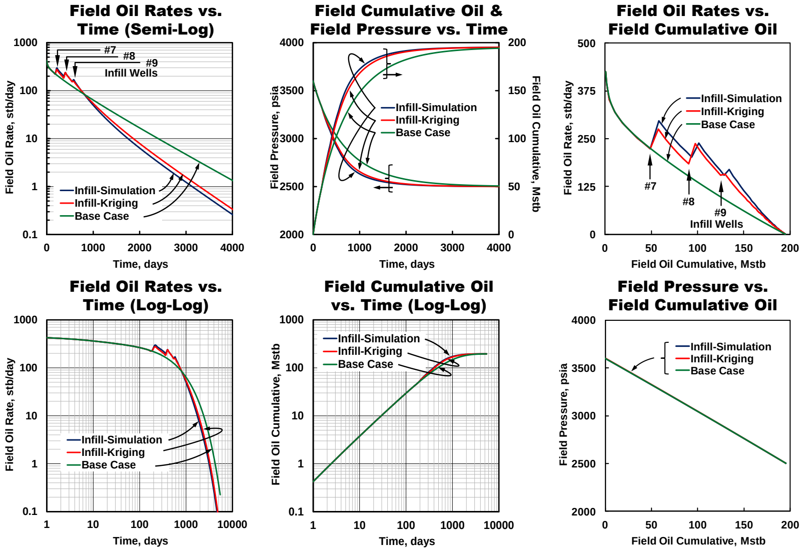


Fig. 6Field performance of flow-simulation-based. Well-placement slightly Outperform the kriged-production-based well-placement

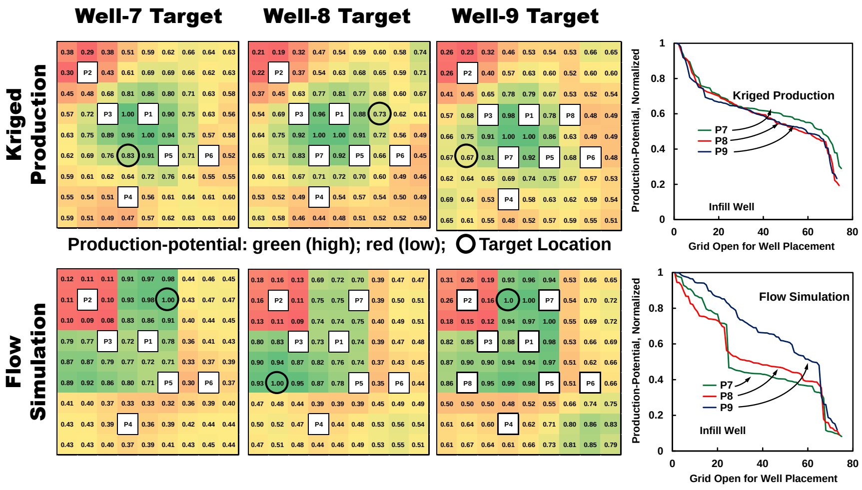


Fig. 7 Well-Placement Comparison. Permeability distribution: Low-High-Medium. Kriged-Production vs. Flow-Simulation

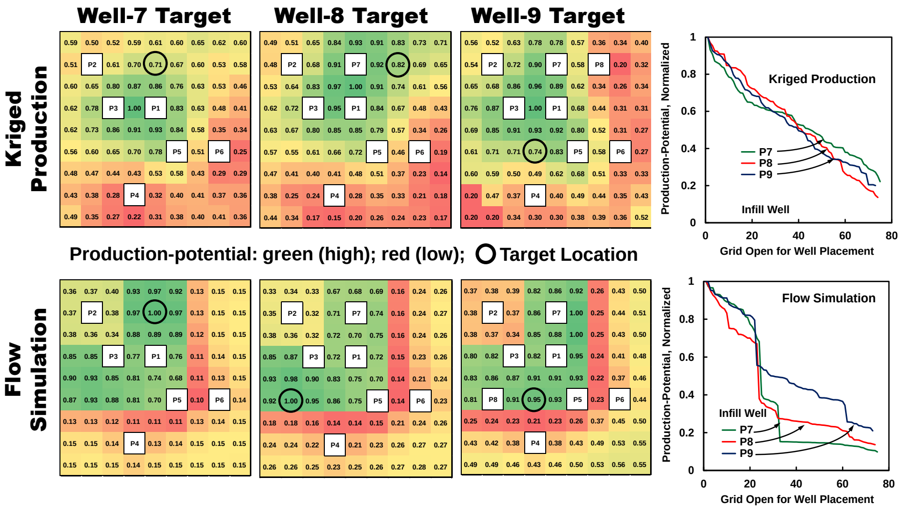


Fig. 8 Well-Placement Comparison. Permeability distribution: Medium-High-Low. Kriged-Production vs. Flow-Simulation

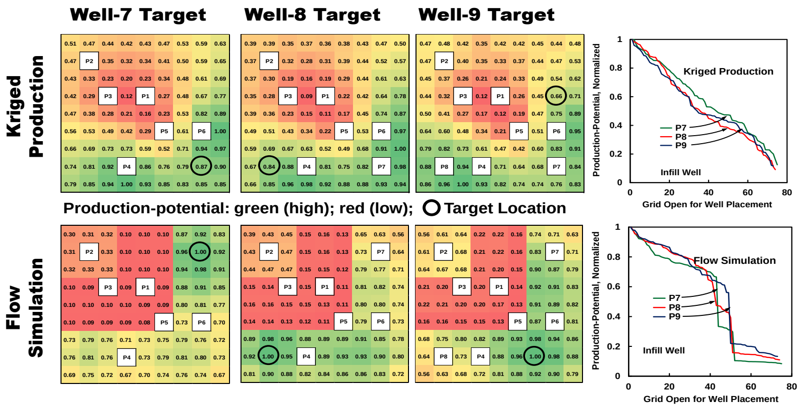


Fig. 9 Well-Placement Comparison. Permeability distribution: Medium-Low-High. Kriged-Production vs. Flow-Simulation

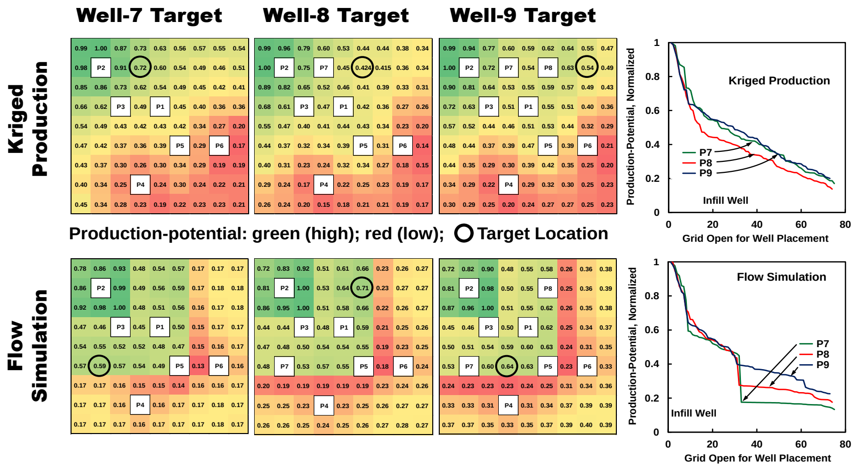


Fig. 10 Well-Placement Comparison. Permeability distribution: High-Medium-Low. Kriged-Production vs. Flow-Simulation

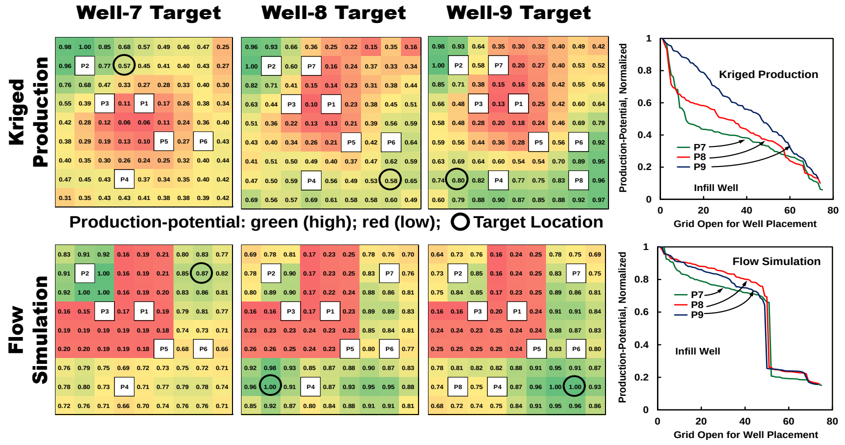


Fig. 11 Well-Placement Comparison. Permeability distribution: High-Low-Medium. Kriged-Production vs. Flow-Simulation

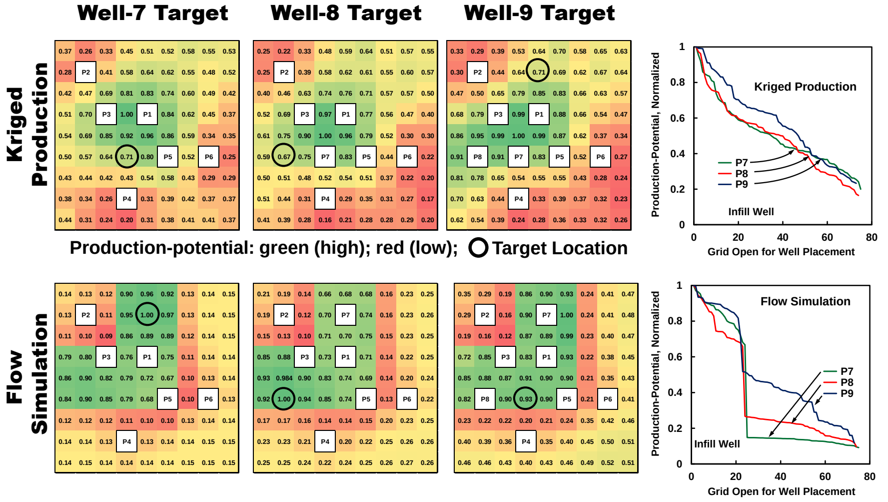
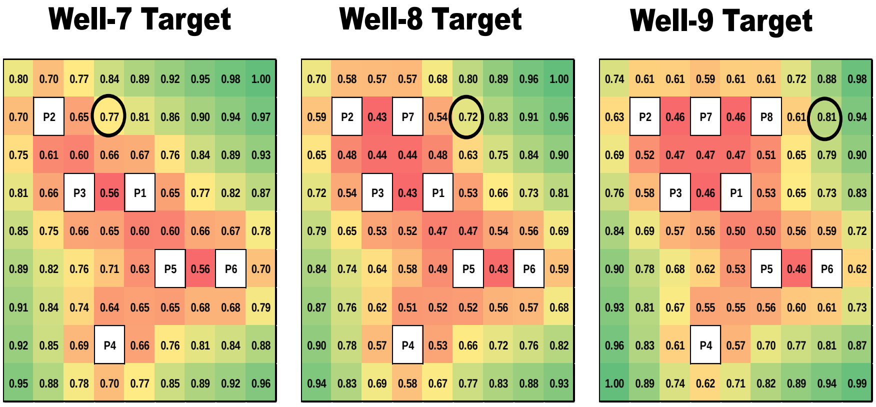


Fig. 12 Well-Placement Comparison. Permeability distribution: Low-High-Low. Kriged-Production vs. Flow-Simulation



Well-7 Target

0.80	0.70	0.77	0.84	0.89	0.92	0.95	0.98	1.00
0.70	P2	0.65	0.77	0.81	0.86	0.90	0.94	0.97
0.75	0.61	0.60	0.66	0.67	0.76	0.84	0.89	0.93
0.81	0.66	P3	0.56	P1	0.65	0.77	0.82	0.87
0.85	0.75	0.66	0.65	0.60	0.60	0.66	0.67	0.78
0.89	0.82	0.76	0.71	0.63	P5	0.56	P6	0.70
0.91	0.84	0.74	0.64	0.65	0.65	0.68	0.68	0.79
0.92	0.85	0.69	P4	0.66	0.76	0.81	0.84	0.88
0.95	0.88	0.78	0.70	0.77	0.85	0.89	0.92	0.96

Well-8 Target

0.70	0.58	0.57	0.57	0.68	0.80	0.89	0.96	1.00
0.59	P2	0.43	P7	0.54	0.72	0.83	0.91	0.96
0.65	0.48	0.44	0.44	0.48	0.63	0.75	0.84	0.90
0.72	0.54	P3	0.43	P1	0.53	0.66	0.73	0.81
0.79	0.65	0.53	0.52	0.47	0.47	0.54	0.56	0.69
0.84	0.74	0.64	0.58	0.49	P5	0.43	P6	0.59
0.87	0.76	0.62	0.51	0.52	0.52	0.56	0.57	0.68
0.90	0.78	0.57	P4	0.53	0.66	0.72	0.76	0.82
0.94	0.83	0.69	0.58	0.67	0.77	0.83	0.88	0.93

Well-9 Target

0.74	0.61	0.61	0.59	0.61	0.61	0.72	0.88	0.98
0.63	P2	0.46	P7	0.46	P8	0.61	0.81	0.94
0.69	0.52	0.47	0.47	0.47	0.51	0.65	0.79	0.90
0.76	0.58	P3	0.46	P1	0.53	0.65	0.73	0.83
0.84	0.69	0.57	0.56	0.50	0.50	0.56	0.59	0.72
0.90	0.78	0.68	0.62	0.53	P5	0.46	P6	0.62
0.93	0.81	0.67	0.55	0.55	0.56	0.60	0.61	0.73
0.96	0.83	0.61	P4	0.57	0.70	0.77	0.81	0.87
1.00	0.89	0.74	0.62	0.71	0.82	0.89	0.94	0.99

Fig. 13 Uncertainty Map – Evolution, High-Medium-Low. Circles show the well placement position (Kriging based). Low-uncertainty (red) is around the well cluster (as expected), High-uncertainty (green) indicates "lack of information"

Table 2 Infill wells positions based on two different criteria, exhaustive (reservoir flow model) and Kriged-based production

Permeability case	well P7 Kriging-based method (grid)	well P8 Kriging-based method (grid)	well P9 Kriging-based method (grid)	P7 Exhaustive - based method (grid)	P8 Exhaustive - based method (grid)	P9 Exhaustive -based method (grid)
LMH	(8,8) H	(8,2) H	(6,2) M	(8,2) H	(2,8) H	(7,8) H
LHM	(4,6) H	(7,4) M	(2,6) H	(6,2) H	(2,6) H	(4,2) H
MHL	(5,2) H	(7,2) L	(4,6) H	(5,2) H	(2,6) H	(4,6) H
MLH	(8,8) H	(2,8) H	(8,4) H	(8,2) H	(2,8) H	(7,8) H
HML	(4,2) M	(6,2) M	(8,2) L	(2,6) M	(6,2) M	(4,6) M
HLM	(4,2) L	(8,8) M	(2,8) M	(8,2) M	(2,8) M	(8,8) M
LHL	(4,6) H	(2,6) H	(5,2) H	(5,2) H	(2,6) H	(4,6) H

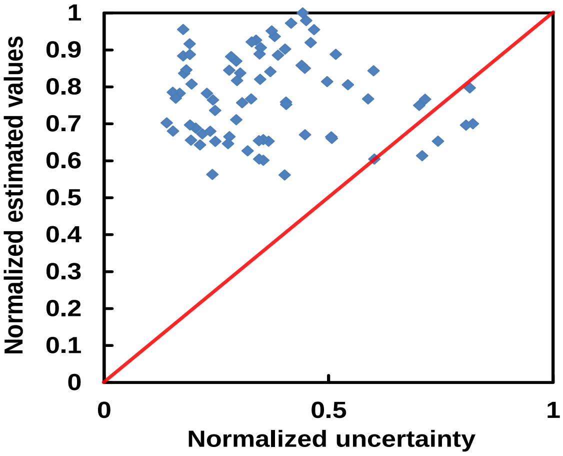


Fig. 14 Cross plot showing the relationship between estimated values and uncertainties – High-Medium-Low.(Well-7 target). Potential values of the wells show poor correlation to the standard error

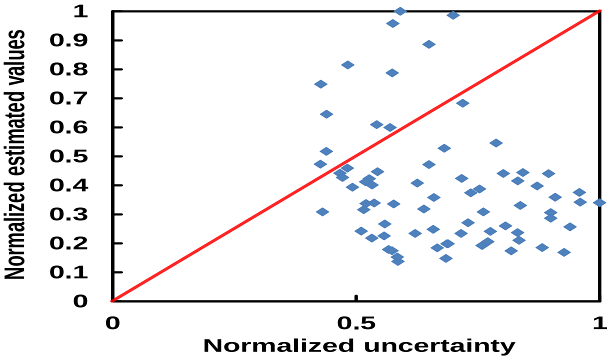


Fig. 15 Cross plot showing the relationship between estimated values and uncertainties – High-Medium-Low.(Well-8 target). Potential values of the wells show poor correlation to the standard error

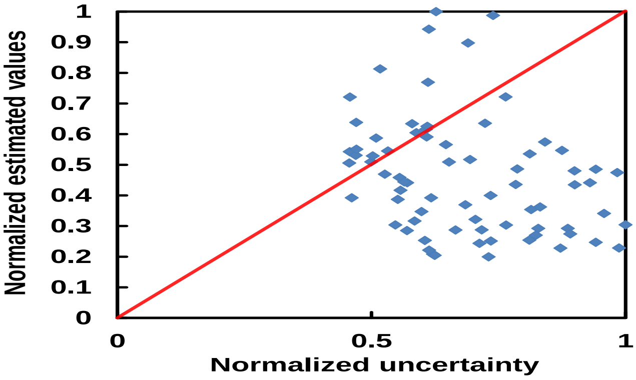


Fig. 16 Cross plot showing the relationship between estimated values and uncertainties – High-Medium-Low.(Well-9 target). Potential values of the wells show poor correlation to the standard error

V CONCLUSION

A key concept which is tipically applied when a field will be developed is the premise that production potential has to be maximized by selecting the best position where the wells have to be drilled.

This paper explored a methodology that can be applied to develop a field and assumes the use of only easily-accessible updated production data. Some unique features are: by-pass explicit reservoir description, no flow-simulations/history-matching, no formal optimization algorithms, and relatively easy and inexpensive.

The following conclusions may be reached based on the results presented in this paper.

1. The use kriged-production map to select infill-well location is promising
2. The proposed approach is comparable to the exhaustive flow-simulations in field performance even though the well-placements are different
3. The proposed approach uses only the easily-accessible production data (the single most attractive feature)
4. The well placement location depends on the objective of the study, if the target is to maximize production, then a production map needs to be built, if the target is to reduce uncertainty and study more the reservoir properties, then a standard error map is more suitable to be used
5. The contribution of the proposed methodology to the industry is that this approach represents a cost-effective and uncertainty-enhanced well-placement method.

Acknowledgements

We thank the support of PEMEX Exploration and Production and New Mexico Institute of Mining and Technology to publish this paper.

REFERENCES

[1]. A. Sampayo-Trujillo, *Well Placement and Uncertainty Ranking Based on Kriged Production at Early Field Lifecycle*. Doctoral diss, New Mexico Institute of Mining and Technology, Department of Petroleum Engineering, Socorro, NM,2016.

[2]. X. Zhang, *Identifying Infill-Well Location Using Kriged-Production Map - A Preliminary Assessment.*Msc. Thesis, New Mexico Institute of Mining and Technology, Department of Petroleum Engineering, Socorro, NM,2014.

[3]. P.M Padalos, and M.G.C. Resende, eds.: Handbook of Applied Optimization, pp. 801-813. Oxford University Press (2002)

[4]. C.C Mattax,and R.L.Dalon, *Reservoir Simulation*. (SPE Monograph Series, volume 13, Richardson, Texas, 1990)

[5]. P.M. Padalos, and M.G.C. Resendeeds, *Handbook of Applied Optimization*, (New York: Oxford University Press2002) 801-813

[6]. F. Ahang, and A. Reynolds: Optimization algorithms for automatic history matching of production data *8th European Conference on the Mathematics of Oil Recovery*, ECMOP, Freiberg, Germany, EAGE, 2002

[7]. B.L. Becker, and X. Song, X: Field development planning using simulated annealing-optimal economic well scheduling and placement.*SPEAnnual Technical Conference and Exhibition*, Dallas, Texas, USA,1995

[8]. D.T. Rian, and A. Hage: Automatic optimization of well locations in a north sea fractured chalk reservoir using a front tracking reservoir simulator, *SPE International Petroleum & Exhibition of Mexico*, Veracruz, Mexico, 1994.

[9]. A.C. Bitterncourt,, and R.N. Horne: Reservoir development and design optimization, *Annual Technical Conference and Exhibition*, San Antonio, Texas, USA, 1997

[10]. B. Guyaguler: *Optimization of well placement and assessment of Uncertainty.*Doctoraldiss, Stanford University, Department of Petroleum Engineering, Palo Alto, Cal., 2002.

[11]. B. Guyaguler, and R.N. Horne: Uncertainty assessment of well placement optimization,*SPE Annual Technical Conference and Exhibition*, New Orleans, Louisiana, 2001

[12]. Y. Pan, and R.N. Horne: Improved methods for multivariate optimization of field development scheduling and well placement design, *SPE Annual Technical Conference and Exhibition*, New Orleans, Louisiana, 1998

[13]. B. Yeten: *Optimum deployment of nonconventional wells*. Doctoral diss, Stanford University, Department of Petroleum Engineering, Palo Alto, Cal., 2003

[14]. B. Yeten, L.J. Durlofsky, and K. Aziz: Optimization of nonconventional well type, location, and trajectory *SPEJ*, 2003, 200-210

[15]. P. S. Da Cruz, P. S, R.N. Horne, and C.V. Deutsch: The Quality Map: A Tool for Reservoir Uncertainty Quantification and Decision Making, *SPE Annual Technical Conference and Exhibition*, Houston, TX, 1999

[16]. O. Badru: Well – *Placement Optimization using the Quality Map Approach*. Msc. thesis, Stanford University, Department of Petroleum Engineering, Palo Alto, Cal., 2003

[17]. R. Webster, M.A. Oliver: *Geostatistics for Environmental Scientistsin Practice* Series, 315 pp. John Wiley & Son Ltd.(2007)

[18]. J.R. Carr: *Numerical Analysis for the Geological Sciences*, 592 pp. Prentice Hall (1995)

[19]. F. Rodríguez, and Cinco-Ley, H.: A New Model for Production Decline, *Production Operations Symposium*, Oklahoma, OK, 1993.

[20]. R.G. Camacho-V, F. Rodríguez, A. Galindo-N., A, and M. Prats: Optimum Position for Wells Producing at Constant Wellbore Pressure, *SPE International Petroleum Conference & Exhibition of Mexico*, Veracruz, 1994

[21]. M. Hohn,: Geostatistics and Petroleum Geology (Computer Methods in the Geosciences), 231 pp. Van Nostrand Reinhold (1988)

Antonio Sampayo-Trujillo " Well Placement and Uncertainty Ranking Based On Kriged Production at Early Field-Life Cycle” American Journal of Engineering Research (AJER), vol. 7, no. 2, 2018, pp. 01-12.