American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-7, Issue-2, pp-24-34
www.ajer.org
Research Paper Open Access

Early Field-Life Cycle Well Placement and Uncertainty Ranking Using Kriged Production: Application To Real Field Cases

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ABSTRACT: *This paper is oriented to studying oil/gas wells placement at early field-life cycle. This paper is a continuation of a research work developed to study the use of early production data applied to the development of an oil and/or gas field. 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 (exhaustive methodology).Based on the good match obtained for the seven synthetic cases we extended and applied the procedure to three field cases. An academic case and two real cases in Mexico are analyzed. Production maps were generated by means of the Kriging approach, as well as the corresponding uncertainty maps. Considering that production data is a direct measurement, and easily accessible, this methodology can provide a good option for a company to propose the well placement process, by considering only production data at early stages of production, saving time and financial resources.*

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

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

I. INTRODUCTION

A particular problem for the oil and gas industry arises when companies need to know where to drill wells in order to develop the fields. When new wells need to be drilled, they need to be located in places of the reservoir with the objective of draining as much oil and/or gas as possible. Another important aspect to be taken into account is the well interference problem [3]. The degree of heterogeneity in the reservoir is an important parameter that needs to be considered. For example, there may be places where wells need to be drilled closer together or further away, depending on reservoir properties and optimization objectives. Drilling too many wells has an important impact in terms of hydrocarbon recovery, causing an economic effect in terms of costs. What it is important to point out is that at early stages in areas to be developed is that engineers have to rely on the information that they have at the moment at which the field will be exploited. The only reliable information that considers all the important parameters of the reservoir is the production data. Every company measures production data. Production data is measured at surface conditions, and included in the production data are reservoir permeability, thickness, area, and the necessary energy to produce hydrocarbons, which is given by the difference between the reservoir pressure and the bottomhole pressure. Additionally, it is required a solution framed with uncertainty-quantification[1]. It means that every oil/gas company needs to assess commercial/value risk to realistically reflect the uncertain real-world (instead of an unrealistic, impossibly "accurate" answer). Oil and gas production is a direct measurement, easily accessible, always updated, considers all geological features, it is a business driver, and there is no uncertainty (except measurements). From the practical point of view the well placement problem needs a cost-effective approach to meet a timely decision consistent with flow physics and current field understanding [1]. Since production data honors the geological characteristics of the reservoirs, captures future uncertainties, and provides a cost-effective and uncertainty-enhanced decision-making, it represents the main parameter to be used in the well placement process. Many approaches have been used to propose the best position of wells to be drilled. Most of the procedures deal with robust and complex mathematical algorithms [4-12]. Recently, Zhang [2] presented a preliminary assessment to evaluate the use of production data to propose the best position of wells. This preliminary assessment shows good agreement between the simulation procedure and the geostatistical approach by using Kriging to solve this problem in a squared reservoir under single-phase flow. In Ref. 1, several synthetic cases are analyzed to prove that the use of production data can be applied for well placement selection. Good agreement between numerical simulation models and the use of Kriging were obtained. Additionally, the methodology is applied and extended for real cases in Mexico [1].

II. THEORETICAL BASIS AND METHODOLOGY

Theoretical basis of geostatistics have been fully explained by several authors13-17. The main step in geostatistics is to build the smi-variogram. The semi-variogram, (h), expresses the spatial dependence between neighboring observations. The definition of the semi-variogram is given by equation [1].

$$\gamma(h) = \frac{1}{2N}\sum_{i=1}^{N(h)}\left[X(u_i) - X(u_i + h)\right]^2 \qquad (1)$$

In geostatistical estimations, one important step is the determination of the spatial correlation given by the semi-variogram analysis. This step is associated what it is known as structural analysis, which includes the determination of the appropriate geostatistical model, and the trend if it is present. A second step considers the estimation of maps of both estimated values and estimation errors obtained by means of kriging. This step requires the solution of the appropriate kriging equations (there are numerous software packages for this purpose). The methodology for the structural analysis is not well established because its determination is closely related to the physical meaning of the particular variable being analyzed [19].

In equation 1, X (u) indicates the magnitude of the variable, and N (h) is the total number of pairs of attributes that are separated by a distance h. Prior to the geostatistical calculations, it is require a model that enables us to compute a variogram value for any possible sample interval. In practice, the most commonly used models are Spherical, Exponential, Gaussian and Pure nugget13. Variograms measure something that is real. The importance of variograms is because implicitly in the process of calculating the variogram the physics of the phenomena is considered. The spatial variation in reservoir properties or dimension of the heterogeneity is given by the variogram. Variograms are extremely important when Kriging methods are used. They can be used to measure the dregree of dissimilarities when a specific variable is studied, such as permeability, porosity or production data. Kriging technique is an exact interpolation used to find the best linear unbiased estimate. It is required that the best linear unbiased estimator have minimum variance of estimation error13-17. A detailed discussion of Kriging methods can be found in Ref. 16. The general equation of Kriging estimator is given by equation 2, as follows:

$$X^*(u_o) = \sum_{i=1}^{n}\lambda_i X(u_i) + \lambda_o \qquad (2)$$

In order to achieve unbiased estimations in kriging the following set of equations need to be solved simultaneously:

$$\sum_{i=1}^{n}\lambda_i C(u_i, u_j) + \mu = C(u_i, u_o) \qquad (3)$$

$$\sum_{i=1}^{n}\lambda_i = 1 \qquad (4)$$

Where $X^*(u_o)$ is the kriged value at location uo, $X(u_i)$ is the known value at location u_i, is the weight associated with the data, is the LaGrange multiplier, and $C(u_i,u_j)$ is the value of the covariance corresponding to a vector with origin in u_i and extremity in u_j.

Values can be calculated by Kriging not only for single point but also for all the node points on a grid. Kriging is a rigorous method for creating maps [18]. In areas beyond the influence of the data points (hard data) the surface is going to smooth out to the mean value of the data. This is going to happen if the variogram range is less than the average interwell distance. The results or maps may look without aesthetics, but from the statistical point of view they will be correct based on the input data [18]. In order to determine the best position of wells to be drilled, in this work production maps are generated along with uncertainty maps associated to production. One important advantage of Kriging over other interpolation methods is the uncertainty maps that can be generated. Standard error maps show the uncertainty related to the predicted values. In order to estimate the uncertainty maps it is required to apply the minimum variance condition:

$$\sigma_E^2 = \mathrm{Var}\left[X(u_o) - \sum_{i=1}^{n} \lambda_i X(u_i)\right] \quad (5)$$

Expanding equation 5:

$$\sigma_E^2 = C(u_o, u_o) + \sum_{i=1}^{n}\sum_{j=1}^{n} \lambda_i \lambda_j C(u_i, u_j) - 2\sum_{i=1}^{n} \lambda_i C(u_i, u_o) \quad (6)$$

The solutions of the above equations are the fundamental principles that were used to determine the best positions of wells based on the Kriging method. In Ref. [1], several cases are analyzed with the above methodology, and compared with the exhaustive methodology. The exhaustive methodology considers the use of ECLIPSE™. The conclusion in Ref. 1 was that by using an alternative methodology, such as Kriging (shortcut method) time and money can be saved, and the results in terms of hydrocarbon recovery is practically the same, concluding that Kriging the production data (3 first months of production) is not a replacement of the robust mathematical algorithms, but it is an alternative one that can be used to propose the well development plan of a field. Then, the applicability of this procedure is important in reclassifying hydrocarbon reserves. For example, in areas where probable or possible reserves are booked, this procedure can be useful in proposing the best position of wells based on the production maps and uncertainty associated. If an area of higher uncertainty is drilled and is successful then the hydrocarbon reserves increases its economic value.

In order to apply the methodology, it is required to have information related to existing exploratory wells and/or initial wells that were drilled previously. For example, if the field which will be developed has sparse information, for example two or three wells already drilled, this information will be used as an input data in our Kriging system. Cumulative production of the first three months is enough to develop our calculations. The first three months of production is a reasonable time to have stabilized production [2], and of course the coordinates of the exploratory and/or first wells drilled in the reservoir.

In this paper three study cases are shown. The first one is the PUNQ (Production forecasting with Uncertainty Quantification) case under some changes in order to take into account primary information and to calibrated our model. PUNQ case is a synthetic reservoir model taken from reservoir engineering study on a real North Sea reservoir operated by Elf Exploration Production [20]. The other two cases are actual cases located in Mexico: Eagle Ford reservoir in Mexico, and an oil field located in the South Region in Mexico called Ayocote. Both of the fields are considered as strategic developments in the portfolio of projects of PEMEX. One of the main objectives is to develop the fields by mitigating the uncertainty. Both fields the Eagle Ford area in Mexico and the one located in the Southern part of Mexico have sparse information, and hydrocarbon reserves need to be developed. The drilling activity in these two Mexican fields has not been as aggressive as in other areas due to the uncertainties associated, as well as the type of reservoir fluid in the case of Eagle Ford (natural gas reservoirs). The above fields will be briefly described.

III. DESCRIPTION OF CANDIDATE AREAS TO APPLY THE METHODOLOGY

PUNQ case

Based on the original data reported in Ref. 21 this field is bounded to the east and south by a fault, and it has a link to the north and west to an aquifer. A small gas cap is located in the center of the dome-shaped structure. The field has six producing wells located around the gas-oil contact. The original objective of the study was to find the cumulative oil production corresponding to a period of 16.5 years. The reservoir model has 2660 (19x28x5) corner point grid blocks, and 1761 blocks are active. Porosity and permeability were generated using the geological/geostatistical model21.

In the present study, only the porosity and permeability distributions were considered, it means that we considered the geological data. Additionally, a modified version of relative permeability curves was assumed. It was considered that no aquifer is present, and it was used a black oil model to study the reservoir. The period of study to prove our methodology was 10 years. Production data were generated by running ECLIPSE^{TM} and data corresponding to the first three years of production were taken as input in our Kriging model. The reason why we selected this case study is because in Ref. [1] several synthetic cases were run and good matching was obtained between the exhaustive methodology and Kriging. In Ref.[1] different permeability distributions were assumed by zones of a squared reservoir and constant porosity distribution was assumed. However, in order to prove this methodology in cases where the distributions of both porosity and permeability are present we chose the PUNQ case to test the performance of the kriged-based method due to the fact that heterogeneity is present in the reservoir, such as paleoslope, paleo water depth, and gross environments of deposition, size and shape of sedimentary bodies, structural trends and style [21]. From the geological interpretation, it is known that the layer thickness is in the order of 5 meters and plays an important role. The idea here was to evaluate the performance of the methodology based on Kriged-production and uncertainty maps, when the first three months of production are known, as well as the location of the first wells previously drilled in the reservoir. The field consists of 5 layers. Layers 1, 3, and 5 correspond to fluvial channel. Layer 2 is marine or lagoonal clay with some distal mouthbar deposits. Layer 4 is a mouthbar or lagoonal delta. Layers 1, 3, and 5 have high-porous sands (porosity greater than 20 percent). Layer 2 belongs to lagoonal shale. They translate into a low-porous media (less than 5 percent). Layer 4 contains mouthbars. This flow unit is expected to have an intermediate porosity region (~ 15 percent). Figure 1 depicts the geometry of the PUNQ field.

Eagle Ford (Mexico)

The purpose is to prove the validity of the methodology in a different scale. For example, in previous works [1, 2], it has been possible to get satisfactory results when the methodology is applied to a synthetic case such as the one described in Ref. 1 and 2. From the geological point of view, Eagle Ford in Mexico is located in the Sabinas Basin, in the limits of the Burgos Basin; geographically it is located 63 kilometers northwest of the city of Nuevo Laredo, Tamaulipas. The geologic column consists of sediments ranging from the formation Buda Cretaceous until Wilcox Formation sediments from the Eocene.

The typical pilot well drilled in this area can reach a total vertical depth of 2,550 meters (in average). In the horizontal type section, the wells explore an average distance of 1,300 meters into the Lower Eagle Ford Cretaceous (Turonian age). The trap is a combination of stratigraphic and structural components. The trap corresponds to the Cretaceous-Turonian, located within homoclinal dipping to Southeast. Shale rock acts as generating and storage rocks, in a simultaneous way. One of the main characteristics of this formation is that it has a high content of organic matter (up 6 percent). This means that the shale rock is very rich with high potential for generating hydrocarbons. The permeability is very low, so that the hydraulic fracturing is necessary to produce hydrocarbons. The reservoir age is cretaceous; and this reservoir has a combination of rich organic matter, maturity, porosity and hydrocarbon saturation. Thermal maturity of the reservoir has values of Ro (Reflectance to vitrinite) ranging from 0.5-1.2 percent, porosity values are from 3 to 7 percent. PEMEX has drilled six wells, confirming the continuation of the Eagle Ford Shale play. Figure 2 shows the geographical location of the Eagle Ford area in Mexico. Drilling activity in Eagle Ford (Mexico) has been modest. Pemex has drilled six wells. Many uncertainties are present and therefore there is sparse information. The area of study is approximately 10,000 km^2 (3861 $mile^2$).

Ayocote Field (Mexico)

The Ayocote field is located in the geological province of Salina del Istmo, and it is part of the Tertiary basins of the Southeast.Theayocote field is located was discovered in November 2013 by the exploration well Ayocote-1 using seismic data and regional geology studies. The well is a producer from the Miocene sands. The structure of Ayocote-1 consists of a system of normal faults with NE-SW that limit the field to the north. Southward there is a seal against salt, and to the SE there is a structural closure by dipping, which is a combined type of entrapment. It has a 3D seismic coverage of high quality. Ayocote field has four main reservoirs that belong to the sandstone formations. The main sandstone body is designated as MS-40, and this is the one we will be analyzing. The petrophysical characteristics of these formations were estimated based on the information provided by the geophysical logs (resistivity, neutron, lithodensity, sonic, RST) and interpretations of petrophysical models: Rock type = sandstone, average porosity = 15-24% and average water saturation = 10-27%, average permeability = 0.01 to 1768 mD.

The field is in its initial stage of development. Since there is sparse information in the field, it will be a good candidate to be studied under the proposed methodology. One of the main objectives of PEMEX's portfolio of projects is to develop this field. Up to now six wells have been drilled in this field. Due to the high economic profitability in the area, the Upper Miocene represents an attractive area to be exploited. Figure 3 depicts the location and the structural map of the Ayocote Field. It is important to mention that in all of these real cases presented in this paper, the cumulative production of the first three months is the input data in our geostatistical scheme of solution.

IV. DISCUSSION OF RESULTS

As it was mentioned in the section of theoretical basis of analysis, the variogram analysis plays an important role in any geostatistical study and is the starting point to develop the Kriging calculations. It is worth to mention that for the PUNQ case, production data were generated by running ECLIPSE^{TM} with the assumptions above described. We just took the heterogeneity information, distributions of permeability and porosity. Unlike the original versionof PUNQ [21], in this work we assumed a different PVT data, no aquifer, and different set of relative permeability curves were considered, the production mode was assumed as constant botomhole pressure, and a period of analysis of 10 years. Field oil production, along with the field pressures are shown in figure 3. Figures 4 and 5 depict the field oil production and field pressure, and the cumulative oil production, respectively. This cumulative oil production is the starting point to develop the variogram analysis. On the other hand, for the fields located in Mexico, production data were taken from the official production data reported by PEMEX [22].

Cumulative production of the first three months was used to analyze and estimate the variograms. The theoretical variogram model that best fitted the information was the spherical model. The spherical model is the most frequently used models type because many geological parameters seem to fit this pattern [23]. As it was mentioned before, this case of study was taken to test the methodology since the distribution of permeability and porosity represents a heterogeneous case. Figure 6 is depicting the semi-variogram analysis for the PUNQ case, the experimental semi-variogram or sample variogram, is a graph of the raw data that shows the lag distance plotted against the semi-variogram. It provides a representation of how the cumulative oil production varies over distance. Figures 7 and 8 show the production and uncertainty maps generated by applying the Kriging-based methodology. Green zones show the best zones in terms of production, while the red ones depict the worst areas to be drilled a well. Uncertainty map shows the uncertainty associated to information we have at the moment when the evaluation has carried out to determine the best position to drill development wells, and in this case uncertainty is giving by the standard errors. These maps of normalized uncertainties depict in green color the zones with the lowest uncertainty is present. From these analyses, it is possible to conclude that under the assumptions previously mentioned, the zone to propose the drilling of infill wells is in the upper corner, where highest production is expected. Additionally, if the strategy is to drill wells in areas where the uncertainty is the lowest, the same areas in green (upper corner) will be the target. It is important to mention that another decision that can be taken is to increase the knowledge of the area, and if this is the objective, the drilling of infill wells can be carried out the middle area of the reservoir.

The main idea of constructing these kinds of maps is that they will help companies to propose a development plan based on the early information that every company has, which is measured every day, the oil and/or gas production data. The point is that production data considers everything related to the reservoir. Let say when a company measures the production data, included in this hard data is everything, permeability, areas, pressure drop, and viscosity. In a nutshell, this proposed methodology is not replacement methodology of the robust algorithms to determine the well placement process; it is an alternative method to be used in the development of a field. In simple words, we are trying to "squeeze" the use of the hard data (information) measured by all the companies, the oil and/or gas production.

These maps are useful because they represent two-dimensional plots of the regions of a field showing their production potential, as well as the uncertainty. It is a two-dimensional representation of the reservoir responses. It is useful in comparing reservoirs or rank stochastic realizations and to incorporate uncertainty into the decision-making process in determining the best positions of wells to be drilled.
The case of study related to Eagle Ford portion in Mexico represents an important option to be developed, because PEMEX, as a strategy has taken the decision to explore and develop this area. In this huge area only 6 wells have been drilled. All the wells have proven that natural gas is present. Even when at present days the price of the commodities is not as attractive as in previous years, for example gas price, this area is important in terms of the company’s strategy. A lot of uncertainties are present, and increasing the knowledge of the area, will increase the economic value of the project. This methodology can help to study the best production zones to propose the drilling of wells. Additionally, uncertainty maps can be generated to help to propose a strategic plan to drill development wells and/or parametric wells (wells to be used to study the reservoir and reduce the

uncertainties). Uncertainty maps can help to visualize the areas where more information needs to be taken to increase the knowledge of the reservoirs. These maps are, by construction, maps that indicate "how good the reservoir area is for production", or in the case of the uncertainty maps, these maps indicate the zones of lower uncertainties, or in other words areas that need to be more explored or more information needs to be taken to reduce our uncertainties. Cumulative gas production data for the Eagle Ford portion of Mexico was used as input data, and then with this information, the semai-variogram was estimated, as it is depicted in figure 9. Figures 10 and 11 are showing the production and uncertainty maps, respectively. Green zones represent areas where the highest productions can be reached, based on the information we have so far. Additionally, red areas are the worst in terms of production, and intermediate areas are in yellow. From these analyses it is possible to conclude that the best zones to propose a more aggressive development plan near the green zones, where hydrocarbon reserves are possible areas or even contingent resources. By drilling wells in these areas, the company can increase the knowledge of the areas, and if the proposed wells are successful in terms of production, then reclassify possible areas into proven reserves, increasing the economic value of the project. If we combine the two maps, production and uncertainties, it is possible to corroborate that the green zones for production and less uncertainties coincide. Uncertainty Map reflects the data locations; it depends entirely on data configuration and covariance modelling of semi-variograms; green zones have less uncertainty while red ones have the highest uncertainty. The prospective resources in Mexico, within the Eagle Ford Shale, are comparable in time to those in the Southeast in USA. Nevertheless, Mexico's coastal shale zone is narrower, less continuous, and from the structural point of view more complex than the equivalent in USA [24].
The same analysis was developed for the Ayocote field (Southen Region of Mexico). This area represents a promising area in terms of production, as wells a good zone to test this methodology. In this field, six wells have been drilled, and it belongs to the geological province of Salina del Istmo. Additionally, Ayocote is part of the Tertiary Basins of the Southeast of Mexico. The Upper Miocene represents the highest economic level in the basin, it has 21 productive plays. Based on the above description, The Ayocote field is a good candidate to test our methodology. There is sparse production information, and it belongs to the portfolio of exploitation opportunities in Pemex Exploration and Production. The reservoir fluid is 34 API, which is an attractive crude oil to be exploited.

The semi-variogram analysis was developed in the same way as the case of PUNQ and Eagle Ford, based on the first three months of production. Figure 12 depicts the semi-variogram obtained. This data is the main source of input in our Kriging solution. Production and uncertainty maps are shown in figures 13 and 14, respectively. The same analysis procedure was considered in this case, as previously described for PUNQ and Eagle Ford (Mexico). Green zones are those reservoir areas where the productions are the best zones to propose the drilling of development wells. Additionally, those areas where hydrocarbon reserves belong to a higher uncertainty can be reclassify to a lower uncertainty category by proposing and drilling in green areas. Areas in yellow represent areas with less uncertainty than those colored in red, and green zones are representing the lowest uncertainty, where there is more information about oil production. As we mentioned before, the uncertainty (standard error) depends on the distance from the observations and not on the observed values (see figure 14). Kriging reproduces the population mean when observations are beyond the range of the semi-variogram, and Kriging uncertainty increases (lower right corner in figure 14). The uncertainty map can be used as a criterion to improve sampling design [17].

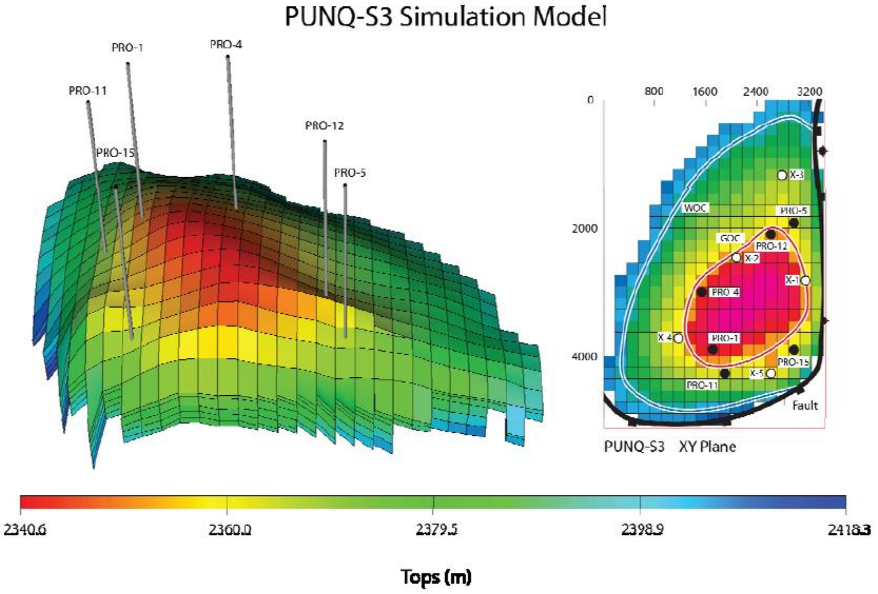

Fig. 1 PUNQ-S3 reservoir model with top surface map and well positions [21]

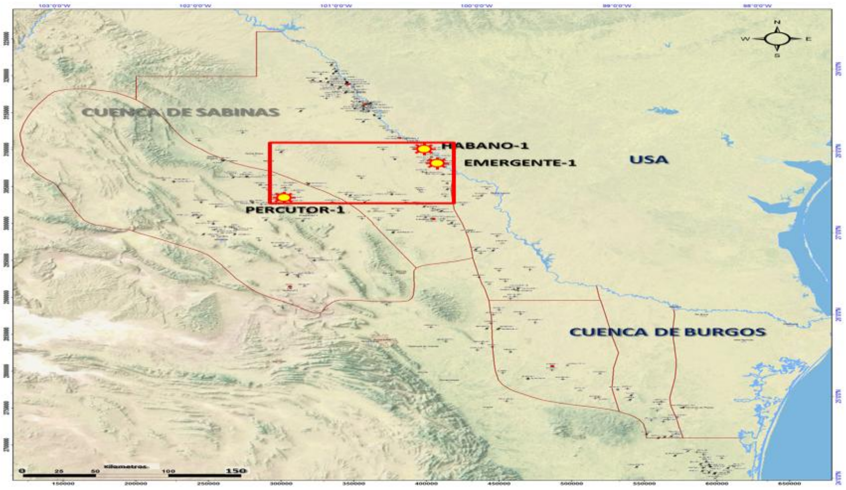

Fig. 2 Location map of Eagle-Ford Portion in Mexico

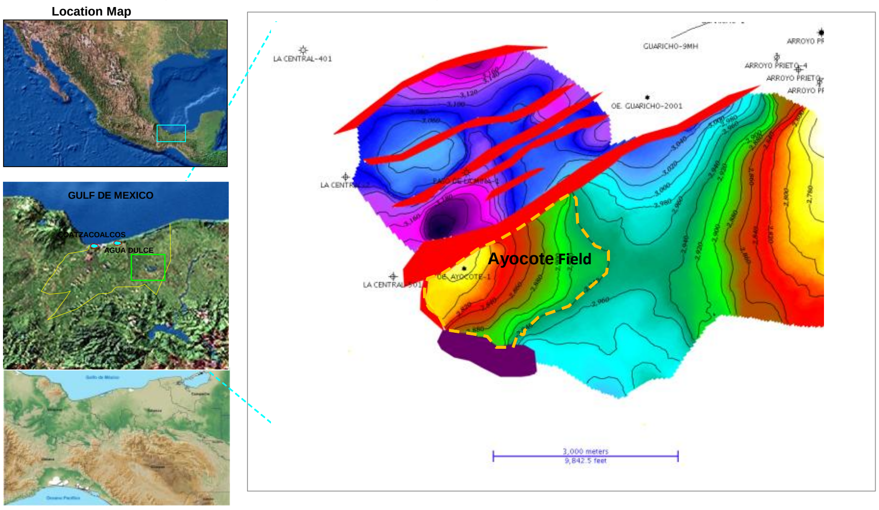

Fig. 3 Location map of the Ayocote Field (México)

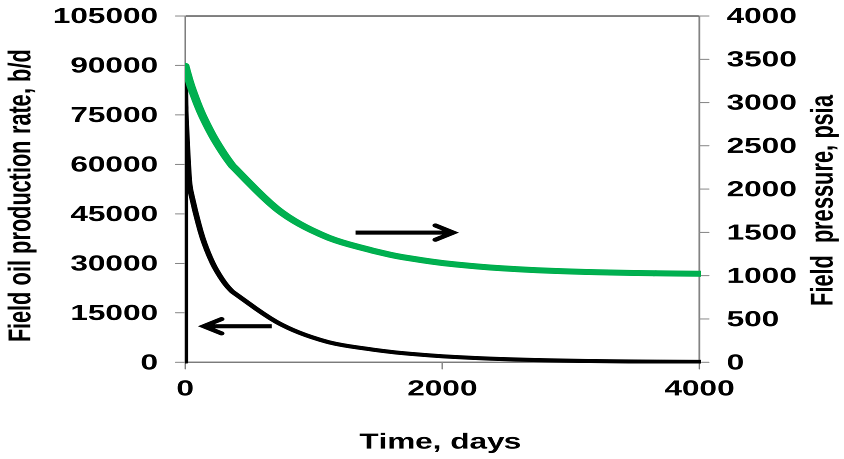

Fig. 4 Field oil production and pressure based on simulation runs. PUNQ case

Table 1 Reservoir fluid system

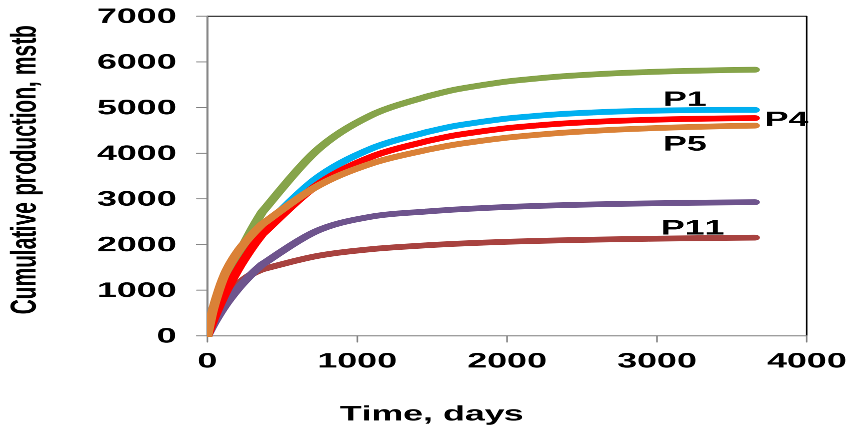

Fig. 5 Cumulative oil production obtained (simulation results). PUNQ case

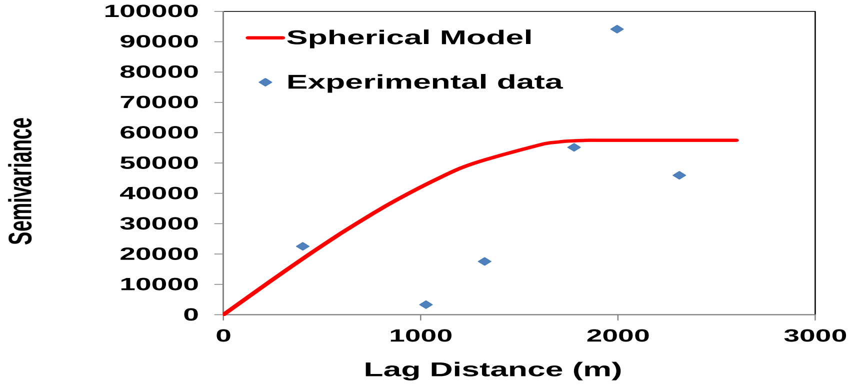

Fig. 6 Semi-variogram of the cumulative oil production, PUNQ case

Fig. 7 Production map, PUNQ case

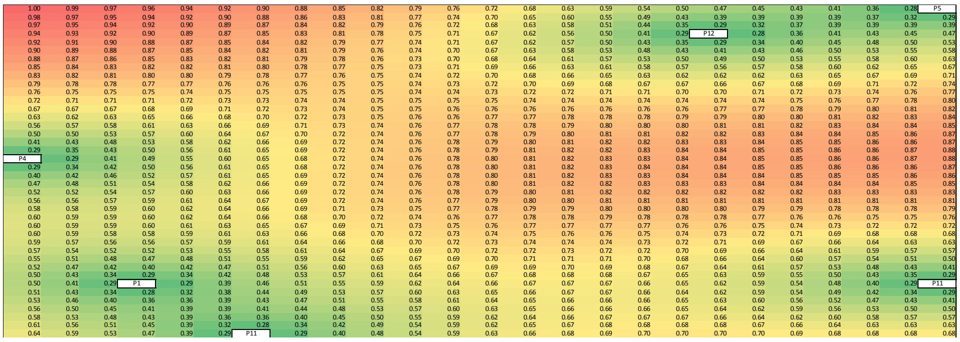

Fig. 8 Uncertainty map, PUNQ case

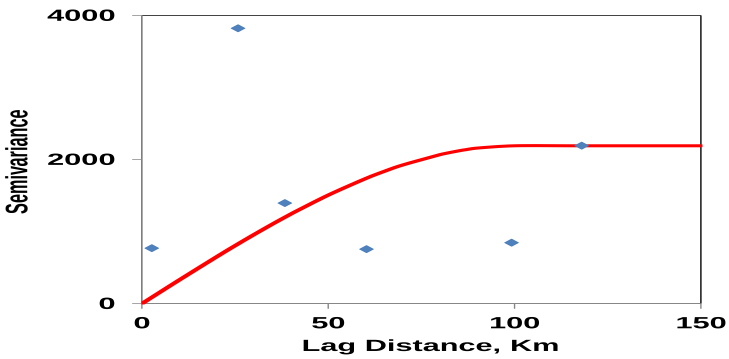

Fig. 9 Semi-variogram of the cumulative gas production, Eagle Ford (México)

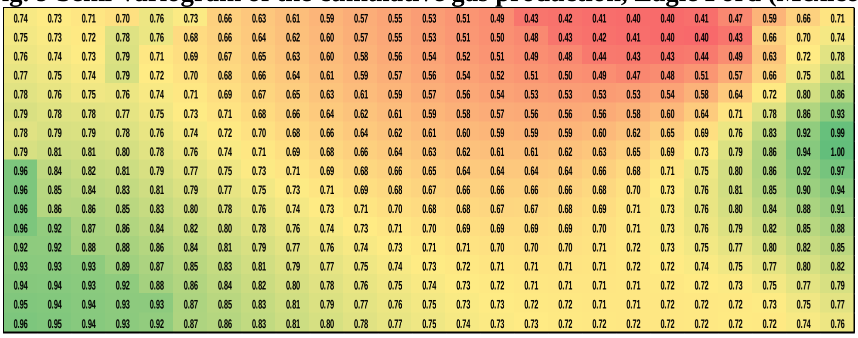

Fig. 10 Production map, Eagle Ford (Mexico)

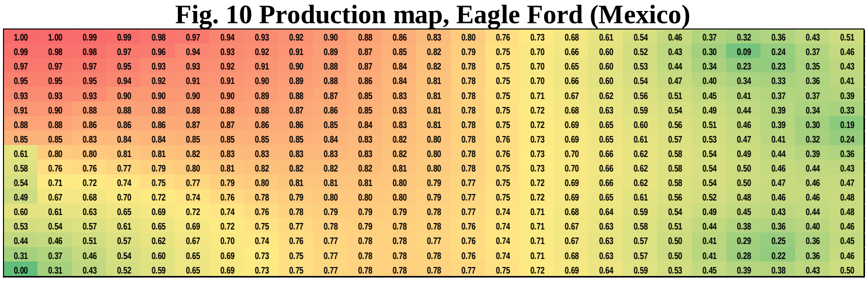

Fig. 11 Uncertainty map, Eagle Ford (Mexico)

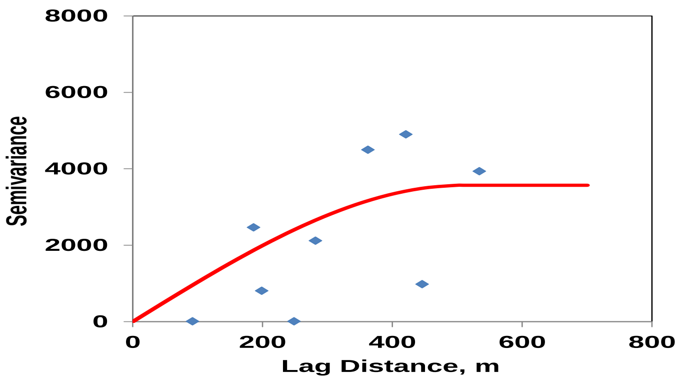

Fig. 12 Semi-variogram of the cumulative oil production production, Ayocote (México)

0.40	0.42	0.44	0.47	0.46	0.49	0.53	0.56	0.59	0.62	0.64	0.65	0.66	0.67	0.66	0.65	0.63	0.60	0.56	0.52	0.49	0.45	0.40	0.36	0.32
0.37	0.39	0.42	0.46	0.46	0.50	0.54	0.58	0.61	0.64	0.67	0.69	0.70	0.70	0.70	0.69	0.66	0.64	0.60	0.56	0.52	0.48	0.43	0.39	0.37
0.35	0.37	0.41	0.45	0.47	0.51	0.56	0.60	0.64	0.67	0.70	0.72	0.74	0.75	0.74	0.73	0.71	0.68	0.64	0.60	0.56	0.51	0.47	0.44	0.41
0.33	0.35	0.39	0.44	0.48	0.53	0.58	0.63	0.67	0.71	0.74	0.76	0.78	0.79	0.79	0.78	0.75	0.72	0.68	0.64	0.60	0.56	0.52	0.48	0.46
0.30	0.33	0.38	0.44	0.50	0.55	0.61	0.66	0.71	0.75	0.78	0.81	0.83	0.84	0.84	0.83	0.80	0.77	0.73	0.68	0.63	0.60	0.56	0.53	0.50
0.28	0.32	0.38	0.45	0.51	0.58	0.64	0.70	0.75	0.79	0.82	0.85	0.87	0.89	0.89	0.88	0.85	0.81	0.77	0.72	0.67	0.65	0.61	0.57	0.55
0.25	0.31	0.39	0.46	0.54	0.62	0.68	0.74	0.79	0.83	0.86	0.89	0.91	0.93	0.94	0.92	0.89	0.86	0.81	0.76	0.71	0.69	0.65	0.61	0.58
0.25	0.33	0.41	0.50	0.58	0.65	0.73	0.79	0.83	0.87	0.90	0.92	0.94	0.96	0.96	0.95	0.93	0.89	0.85	0.79	0.74	0.72	0.68	0.65	0.62
0.33	0.38	0.46	0.54	0.63	0.70	0.78	0.84	0.88	0.91	0.93	0.95	0.97	0.98	0.98	0.97	0.96	0.93	0.87	0.82	0.76	0.75	0.71	0.68	0.65
0.40	0.45	0.52	0.60	0.68	0.76	0.84	0.89	0.92	0.94	0.96	0.98	0.99	0.99	0.99	0.98	0.97	0.94	0.89	0.84	0.78	0.78	0.74	0.71	0.68
0.46	0.51	0.58	0.65	0.74	0.82	0.89	0.94	0.96	0.97	0.98	0.99	1.00	1.00	0.99	0.98	0.97	0.94	0.89	0.84	0.83	0.80	0.76	0.73	0.70
0.52	0.57	0.63	0.70	0.78	0.87	0.96	0.96	0.98	0.99	0.99	1.00	1.00	1.00	0.99	0.98	0.96	0.93	0.89	0.84	0.84	0.81	0.77	0.74	0.71

Fig. 13 Production map, Ayocote Field (México)

0.92	0.89	0.86	0.84	0.80	0.77	0.75	0.74	0.75	0.77	0.79	0.80	0.81	0.81	0.81	0.81	0.81	0.79	0.78	0.74	0.70	0.63	0.54	0.40	0.21
0.86	0.83	0.80	0.77	0.72	0.68	0.65	0.64	0.66	0.69	0.72	0.74	0.75	0.76	0.76	0.76	0.76	0.75	0.74	0.72	0.69	0.64	0.57	0.49	0.45
0.79	0.76	0.73	0.70	0.65	0.59	0.54	0.52	0.56	0.62	0.66	0.68	0.69	0.69	0.69	0.69	0.70	0.71	0.71	0.70	0.69	0.66	0.62	0.58	0.58
0.71	0.69	0.67	0.64	0.59	0.51	0.40	0.34	0.46	0.55	0.61	0.63	0.63	0.62	0.61	0.62	0.64	0.66	0.68	0.69	0.69	0.68	0.67	0.66	0.67
0.62	0.61	0.60	0.59	0.56	0.48	0.35	0.26	0.43	0.53	0.58	0.59	0.58	0.54	0.51	0.52	0.57	0.61	0.65	0.67	0.69	0.70	0.71	0.72	0.74
0.51	0.52	0.55	0.56	0.55	0.51	0.45	0.43	0.49	0.54	0.58	0.57	0.54	0.46	0.35	0.38	0.49	0.56	0.62	0.66	0.69	0.72	0.74	0.77	0.80
0.33	0.42	0.50	0.55	0.55	0.54	0.52	0.52	0.54	0.57	0.59	0.58	0.53	0.44	0.27	0.32	0.44	0.51	0.58	0.64	0.69	0.73	0.77	0.80	0.84
0.23	0.39	0.49	0.54	0.56	0.56	0.55	0.56	0.57	0.59	0.60	0.59	0.55	0.49	0.42	0.39	0.41	0.45	0.53	0.61	0.68	0.74	0.79	0.84	0.88
0.45	0.47	0.52	0.55	0.56	0.55	0.54	0.55	0.58	0.60	0.62	0.61	0.59	0.55	0.49	0.43	0.33	0.33	0.48	0.59	0.68	0.76	0.81	0.86	0.91
0.57	0.56	0.57	0.56	0.54	0.51	0.49	0.52	0.56	0.60	0.63	0.63	0.62	0.59	0.54	0.47	0.34	0.31	0.48	0.61	0.70	0.78	0.84	0.89	0.94
0.66	0.63	0.61	0.58	0.52	0.44	0.39	0.44	0.53	0.60	0.64	0.66	0.66	0.64	0.60	0.55	0.49	0.49	0.56	0.66	0.74	0.81	0.87	0.92	0.97
0.73	0.70	0.66	0.60	0.52	0.40	0.08	0.39	0.52	0.61	0.66	0.69	0.70	0.69	0.67	0.64	0.61	0.62	0.66	0.72	0.79	0.85	0.91	0.96	1.00

Fig. 14 Uncertainty map, Ayocote Field (México)

V. CONCLUSION

This paper presented a methodology that can be applied to develop a field and assumes the use of easily-accessible updated production data. It presented a relatively easy and inexpensive alternative methodology to be applied in the development of an oil/gas field. We would like to emphasize that the proposed methodology is not a replacement of the sophisticated algorithms used to optimize the well-placement process. It is an alternative method to reduce time and money.

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

1. Kriged-production map to select infill-well location assumes as input data the use of only easily-accessible production data that can be updated every three months to feed the model and develop the calculations
2. The single most attractive feature is the use of production data
3. The use of production maps combined with uncertainty maps can help reservoir managers in making their decisions
4. The use of this methodology provides the necessary elements to propose a development plan based on production and uncertainty maps
5. This methodology can be useful not only for the exploitation theme, but also for the exploration area to improve sampling design
6. The contribution is that, the methodology can help companies to save money (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.

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Antonio Sampayo-Trujillo " Early Field-Life Cycle Well Placement and Uncertainty Ranking Using Kriged Production: Application To Real Field Cases" American Journal of Engineering Research (AJER), vol. 7, no. 2, 2018, pp. 24-34.