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Uncertainty Analysis of a Giant Oil Field in the Middle East Using Surrogate Reservoir Model

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Abstract

Simulation models are routinely used as a powerful tool for reservoir management. The underlying static models are the result of integrated efforts that usually includes the latest geophysical, geological and petrophysical measurements and interpretations. As such, these models carry an inherent degree of uncertainty. Typical uncertainty analysis techniques require many realizations and runs of the reservoir simulation model. In this day and age, as reservoir models are getting larger and more complicated, making hundreds or sometimes thousands of simulation runs can put considerable strain on the resources of an asset team, and most of the times are simply impractical. Analysis of these uncertainties and their effects on well performance using a new and efficient technique is the subject of this paper. The analysis has been performed on a giant oil field in the Middle East using a surrogate reservoir model.

The surrogate reservoir model that runs and provides results in real-time is developed to mimic the capabilities of a full field simulation model that includes one million grid blocks and takes 10 hours to run using a cluster of twelve 3.2 GHz CPUs. In order to effectively demonstrate the robustness of Surrogate Reservoir Models and their capabilities as tools that can be used for uncertainty analysis, one must demonstrate that SRMs are competent in providing reasonably accurate results for multiple realizations of the reservoir being studied. In order to demonstrate such robustness and their predictive capabilities as well as their limitations, this paper will examine the performance of the surrogate reservoir models on different geologic realizations of the static model.

Introduction

In two previous SPE papers some of the aspects of the Surrogate Reservoir Models were discussed. In the first paper[1] the idea of Surrogate Reservoir Models was introduced and in the second paper[2] its application in quantifying uncertainties associated with a reservoir simulation study was explored.

The conventional approach for uncertainty analysis in our industry is mainly based on geostatistics. One such method that is often used is Response Surfaces[3-5]. Response Surfaces are statistical interpolations (based on fitting some type of pre-determined models – linear or quadratic –) of model responses to different geological, geophysical and petro-physical realizations[6,7]. Another method that has been used more in other industries is called the Reduced Model. Reduced Models are approximations of full three dimensional numerical simulation models that essentially approach an analytical model for tractability[8].

One of the major advantages of Surrogate Reservoir Models, when compared to conventional geostatistical techniques, is the small number of simulation runs that is required for their development. For example, instead of hundreds of simulation runs that would be required to perform a limited geostatistical study, development of the Surrogate Reservoir Model that is the subject of this paper required only 10 simulation runs. On the other hand, the capabilities of the SRM for analyses are more far reaching than the alternative technique that required hundreds of runs. The reason for being able to do much more with a limited number of simulations runs (about 10 runs as appose to hundreds and sometimes thousands of runs in the case of some geo-statistical analyses) has to do with the efficiency by which SRMs use the resources offered by each simulation run. This efficiency is associated with the way Surrogate Reservoir Models represent the reservoir. The objective of this paper is to demonstrate the approach that is taken by Surrogate Reservoir Models in representation of multiple realizations within a single simulation run. In order to clearly demonstrate this aspect of SRMs, which is a key component in their development, an introduction on the philosophical approach used by the SRM is appropriate.

Surrogate Reservoir Models are prototypes of complete three dimensional numerical reservoir models that are capable of accurately mimicking the behavior of the full field models with all their details and complexity. The word "prototype" is used here in the context of the prototype theory that is defined as "a model of graded categorization, where all members of a category do not have equal status." This definition becomes clearer once the development process of Surrogate Reservoir Model is considered[1].

Given the above definition of Surrogate Reservoir Model, as a prototype of the full field model, the approach used during the development of the Surrogate Reservoir Models fits more appropriately within the approach summarized in the system theory[9] (depicted in Figure 1) rather than the approach commonly used in our industry that is essentially based on geostatistics.

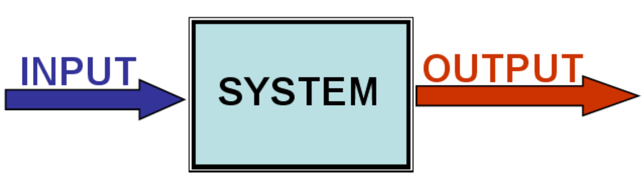

Figure 1. The three components involved in the System Theory, Input, System and Output.

Considering the full field reservoir model within the realm of the System Theory, different reservoir parameters such as permeability, porosity, and capillary pressure, to name a few, from the geologic (static) model are input to the system while the production from the wells is the system output (system being the full field reservoir model as a reasonable substitution for the actual reservoir). When we claim that SRMs are tools that are defined within the real of the System Theory it would mean that the system output reacts to the changes in input. In other words, the Surrogate Reservoir Model is capable of adjust its output as a function of the modeification of the input variables. Moreover, SRMs can perform this task in real-time.

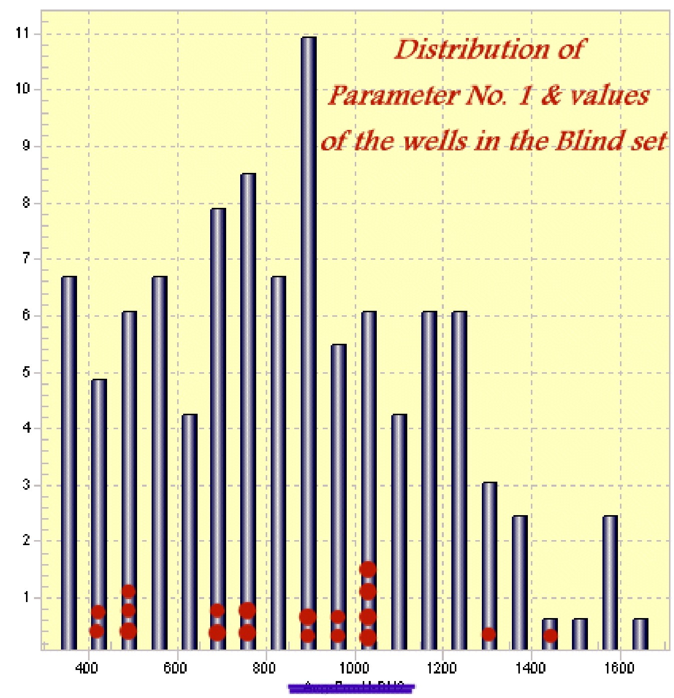

Figure 3. Distribution of reservoir parameter number 1 in the entire reservoir along with the distribution of the 19 blind wells.

During conventional analyses that are categorized as response surface, hundreds of combinations of input parameters are generated (realizations) that upon completion of hundreds of runs, results in hundreds of sets of outputs (production from wells in the field). These outputs are then used to generate surfaces of all the possible responses that can result from the predetermined realizations.

Selection of the realizations is usually made in a way to maximize the coverage of the anticipated range of input parameters while requiring minimum number of simulation runs. Usually, techniques such as Latin Hyper Cube[10] and Design of Experiments[11] are used to optimize this process. Nevertheless most of the serious studies require hundreds of runs to provide meaningful coverage. Furthermore, once the hundreds or thousands of required simulation runs are made and the response surface is created, the input parameters no longer play any role in the process. In other words, the approach mentioned in the System Theory will not be in effect upon completion of the simulation runs and during the development and use of the response surface.

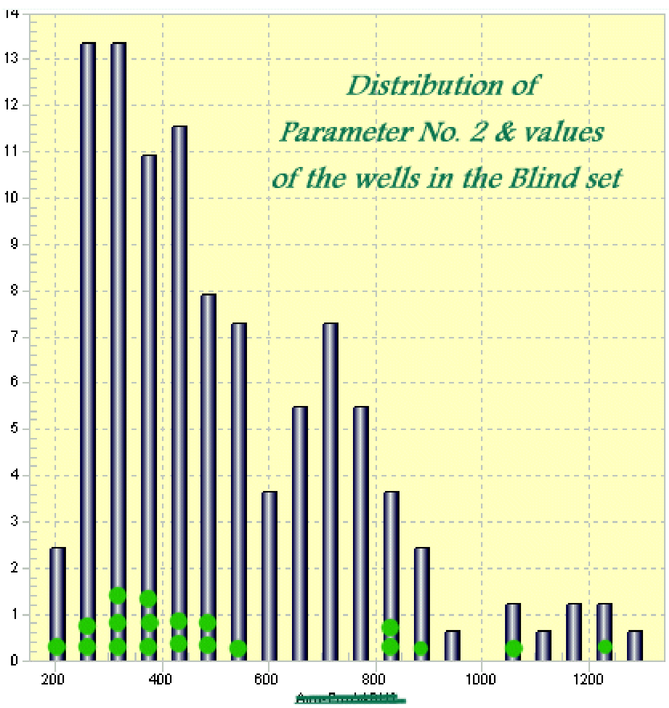

Figure 4. Distribution of reservoir parameter number 2 in the entire reservoir along with the distribution of the 19 blind wells.

Methodology

Figure 2 (at the end of this article) shows the location of the wells in the field along with the approximate drainage area for each well. The approximate drainage areas shown in Figure 2 are identified using the Voronoi Graph theory[12]. During the exercise that is described in this paper the objective is to demonstrate that the Surrogate Reservoir Model can be developed using a certain set of realizations and be validated by another set of independent realizations. In order to do this 19 out of the 165 horizontal wells in the field were randomly selected to serve as the validation wells.

During the remaining parts of this paper, these wells are called the set of blind wells. The validation exercise is performed by predicting the flow behavior in these wells with the Surrogate Reservoir Model that has been developed using the realizations associated with the rest of the wells in the field. The idea is that since the Surrogate Reservoir Model looks at the entire reservoir through the lens of a single well (a representative volume that includes the surrounding area and multiple-layers) then a single simulation run (one realization) actually provides multiple (the total number of wells in the reservoir) realizations. In other words, the realizations that are considered during the development of the Surrogate Reservoir Model include only a segment of the reservoir (the representative volume) rather than the entire reservoir.

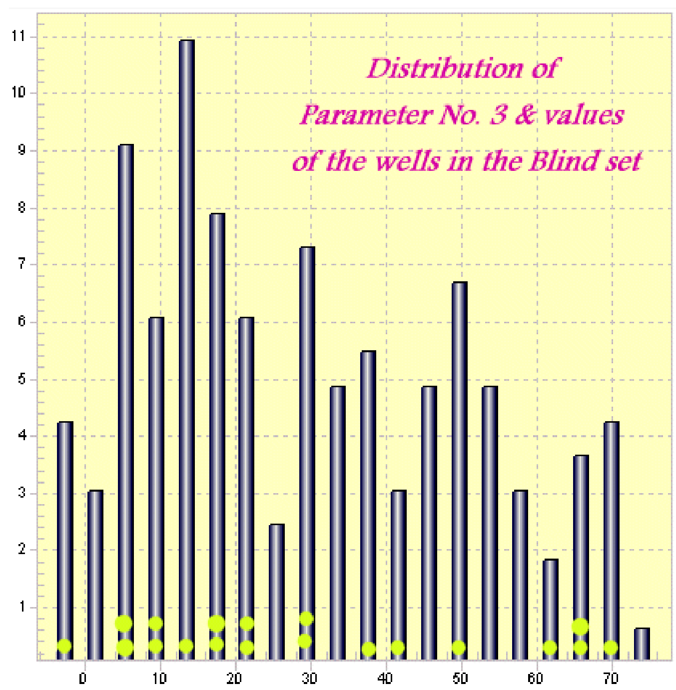

Figure 5. Distribution of reservoir parameter number 3 in the entire reservoir along with the distribution of the 19 blind wells.

Figures 3 through 5 show the distribution of three reservoir parameters in the field along with the values of the set of blind wells identified as small circles in the distribution. It is shown that the values of the parameters for the set of blind wells fall within the distribution of the entire field. Therefore, one may consider that when cumulative oil production and/or water cut for one of the wells in the blind set is predicted by the Surrogate Reservoir Model the model is essentially predicting the behavior of a new realization with a distribution similar to the ones used during the Surrogate Model development.

As mentioned before, the objective is to develop a Surrogate Reservoir Model that is robust enough to be able to predict the well production behavior as long as the reservoir parameters that contribute to the flow fall within a certain distribution. This certain distribution refers to the distribution of each of the parameters for each of the grid blocks in the full field model.

At this point it would be appropriate to mention that Surrogate Reservoir Models are developed based on several different representative volumes. The size of the representative volume is determined by two factors:

1. The objective of the project.
2. The physics and the dynamics of the reservoir.

The representative volume can be as small as the size of one grid block of the actual full field model or so large that it could include multiple wells. The details on how to actually determine the size of the representative volume and how to implement it in the context of developing a Surrogate Reservoir Model as well as the role it plays in the complexity of the Surrogate Reservoir Model is outside of the scope of this paper and will be discussed in a future paper.

Another capability of the Surrogate Reservoir Models that is discussed in this paper is the development of field-wide type curves. Once the Surrogate Reservoir Model is developed it can be used to generate a large number of type curves for the field (reservoir) being studied. Development of such type curves can provide valuable insight into the general behavior of fluid flow in the field (reservoir) and guide future operational development efforts as well as help and direct future analytical and numerical analysis using the full field model.

The type curves are developed by plotting one of the model outputs (in this study 5 year cumulative oil production or water cut) against another parameter while selecting a third parameter for the type curves. By changing the value of the third parameter from minimum to maximum in several steps a set of type curves can be generated. During this operation one can hold the values of all other involved parameters at overall average or select the minimum or the maximum from the entire data set for all the parameters. Some examples of such type curves are presented in the next section.

Results & Discussions

In order to demonstrate that Surrogate Reservoir Models can predict the flow behavior in a reservoir, a set of 19 wells (these wells were not used during the development process) were used as the set of blind wells to validate the performance of a Surrogate Reservoir Models.

The instantaneous water cut generated by the Surrogate Reservoir Model was plotted against the instantaneous water cut generated by the full filed model for comparison. These plots are shown in Figures 6 though 9 for several of these wells. These figures show that results generated by the Surrogate Reservoir Model are quite accurate and acceptable even for wells in the set of blind wells. In these figures when the water cut goes to zero after increasing for several years indicates that the well has been watered out and has been shut down. It is interesting to note that this phenomenon was predicted correctly in every case.

It was shown in Figures 3 to 5 that values of reservoir parameters for the wells belonging to the set of blind wells falls within the distribution of the same reservoir parameters in this field and thus can be counted as a valid realization.

Figures 10-12 show several type curves that were developed for this particular field. Generating such type curves once the Surrogate Reservoir Model has been developed is an easy task and can be accomplished on ly in a matter of seconds.

Furthermore, one can develop such type curves for a particular well as well as the entire reservoir.

These type curves can provide valuable information to the modeling engineers as well as production engineers. They demonstrate the general tendencies and behaviors of the fluid flow in a particular well or in the antire field. As shown in these figures, three parameters are involved in these type curves. Usually the “y” axis is one of the outputs of the SRM and the user can select one parameter for the “x” axis that would change from the minimum to the maximum of its value in the field database. A third parameter is selected to generate the type curves. The value of the third parameter can be any of the numbers between the minimum and the maximum in several steps. While the model is being run hundreds of times to generate the type curves, other involved parameters can assume average, minimum or maximum values. In the case of developing type curves for a particular well, the other parameters are fixed for the values of the well being analyzed

Conclusions

Surrogate Reservoir Models are accurate prototypes of full field models that can run in real-time. They provide instantaneous results and respond to changes in rock, fluid and rock-fluid characteristics that are used in the model. In this article the robustness of Surrogate Reservoir Models was demonstrated by showing their capabilities to predict fluid flow behavior in several different geological realizations. Furthermore, it was demonstrated that Surrogate Reservoir Models can quickly generate a series of type curves for a reservoir that can help engineers in analysis and operational planning of the reservoir.

Acknowledgment

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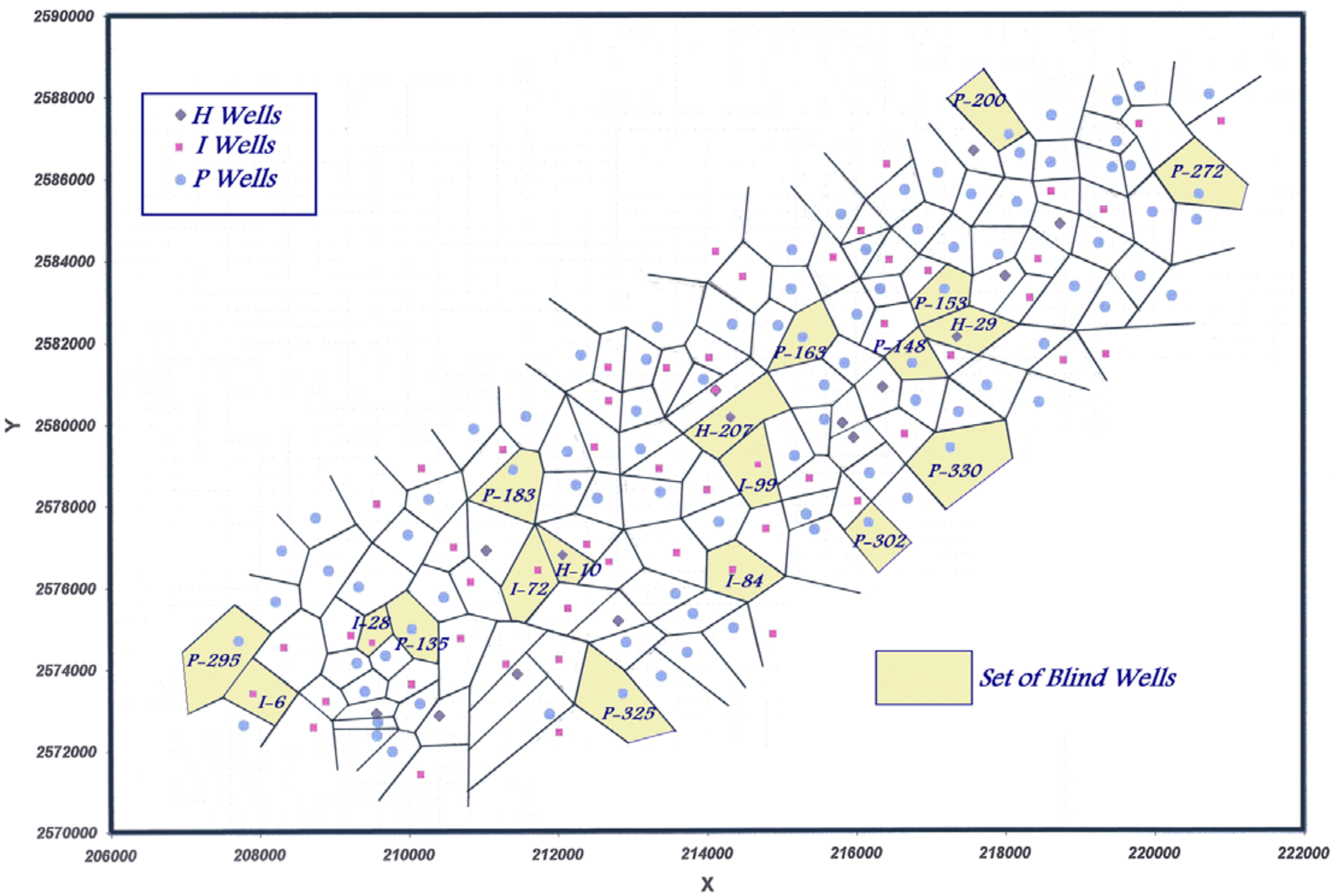

Figure 2. Location of 165 wells in the field. Well identified within colored drainage area are used as blind wells for validation of the analysis.

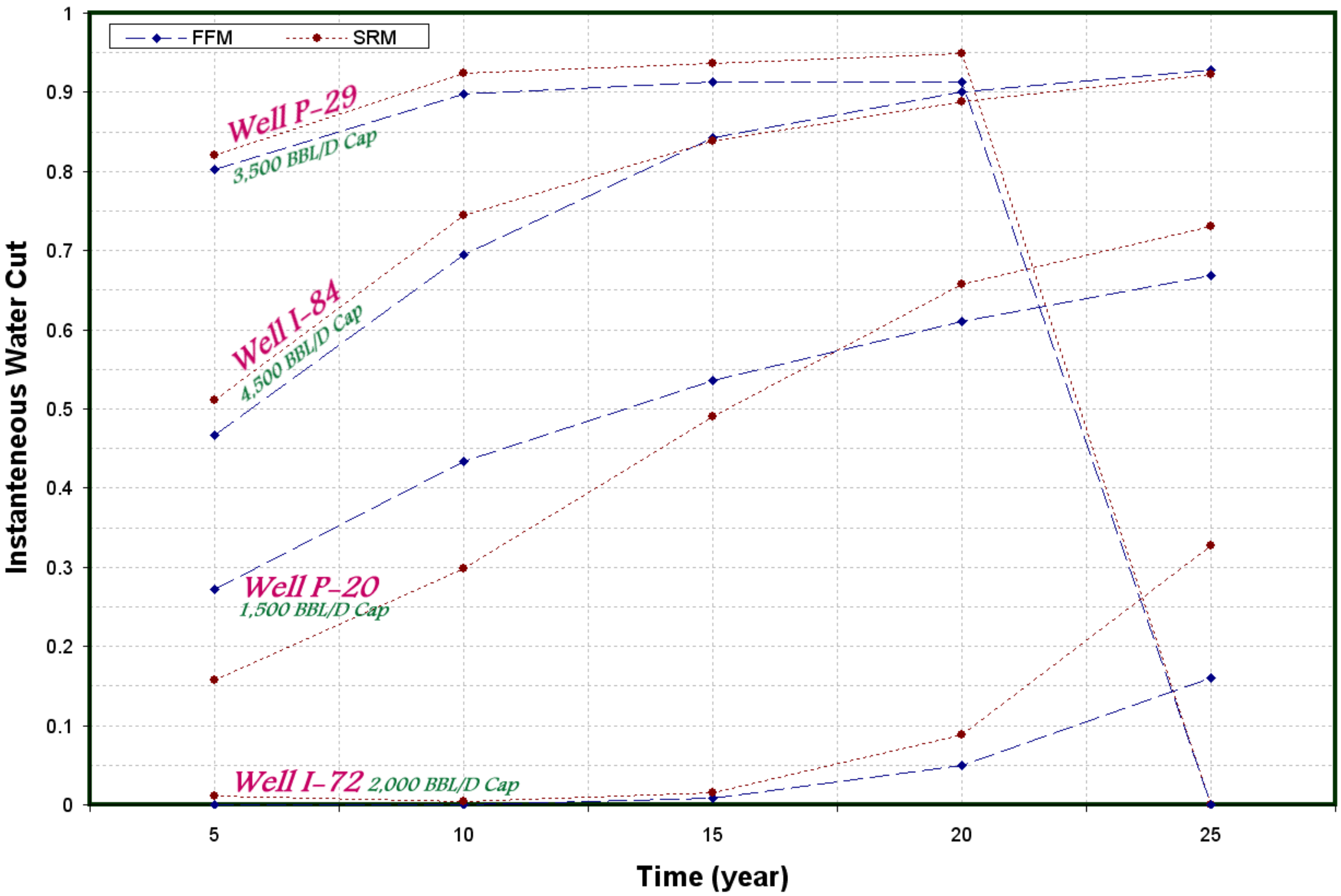

Figure 6. Validation of Surrogate Reservoir Model by comparing the instantaneous water cut as a function of time generated by the full field model (FFM) against those generated by the SRM, for the set of blind wells.

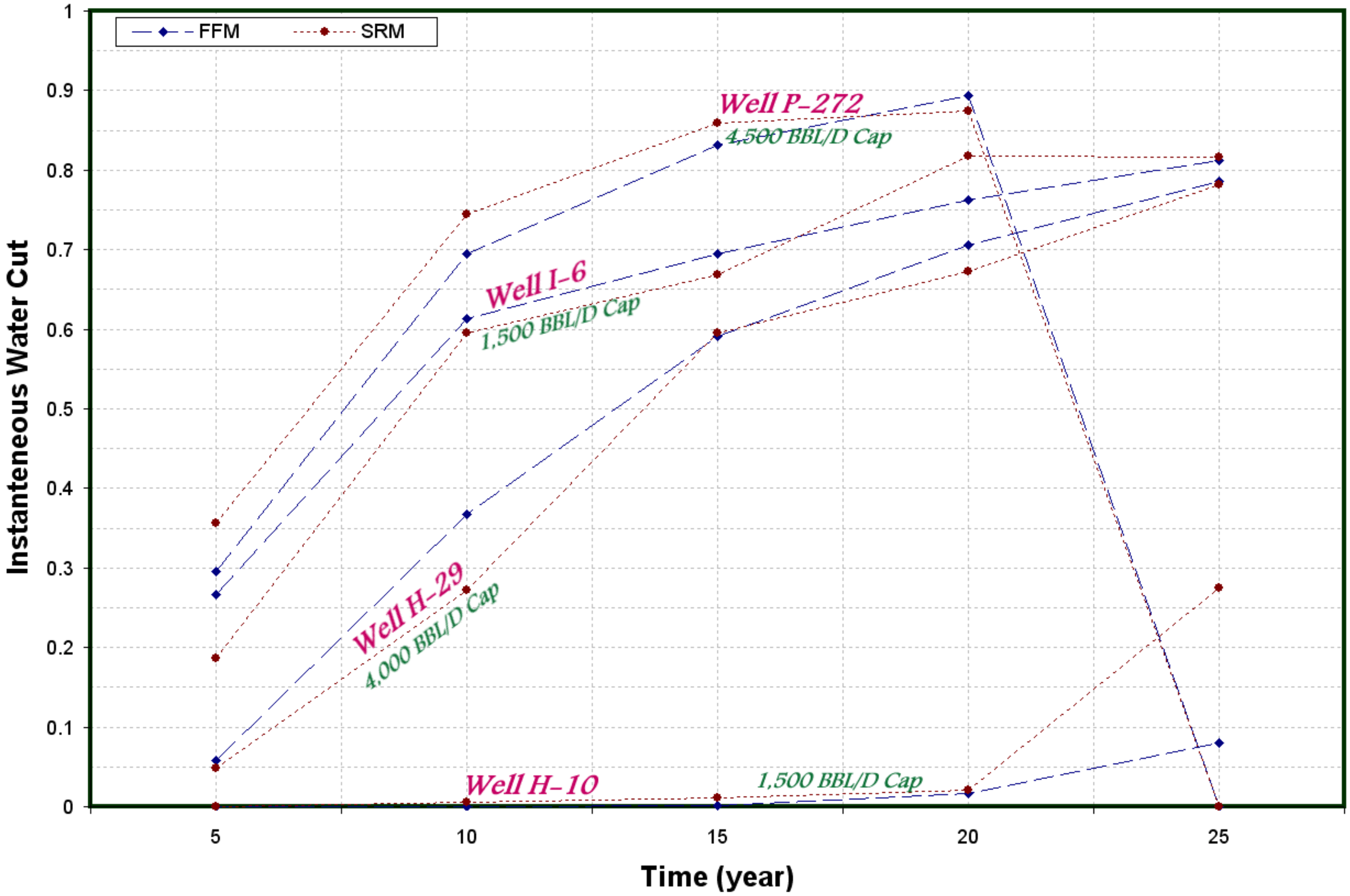

Figure 7. Validation of Surrogate Reservoir Model by comparing the instantaneous water cut as a function of time generated by the full field model (FFM) against those generated by the SRM, for the set of blind wells.

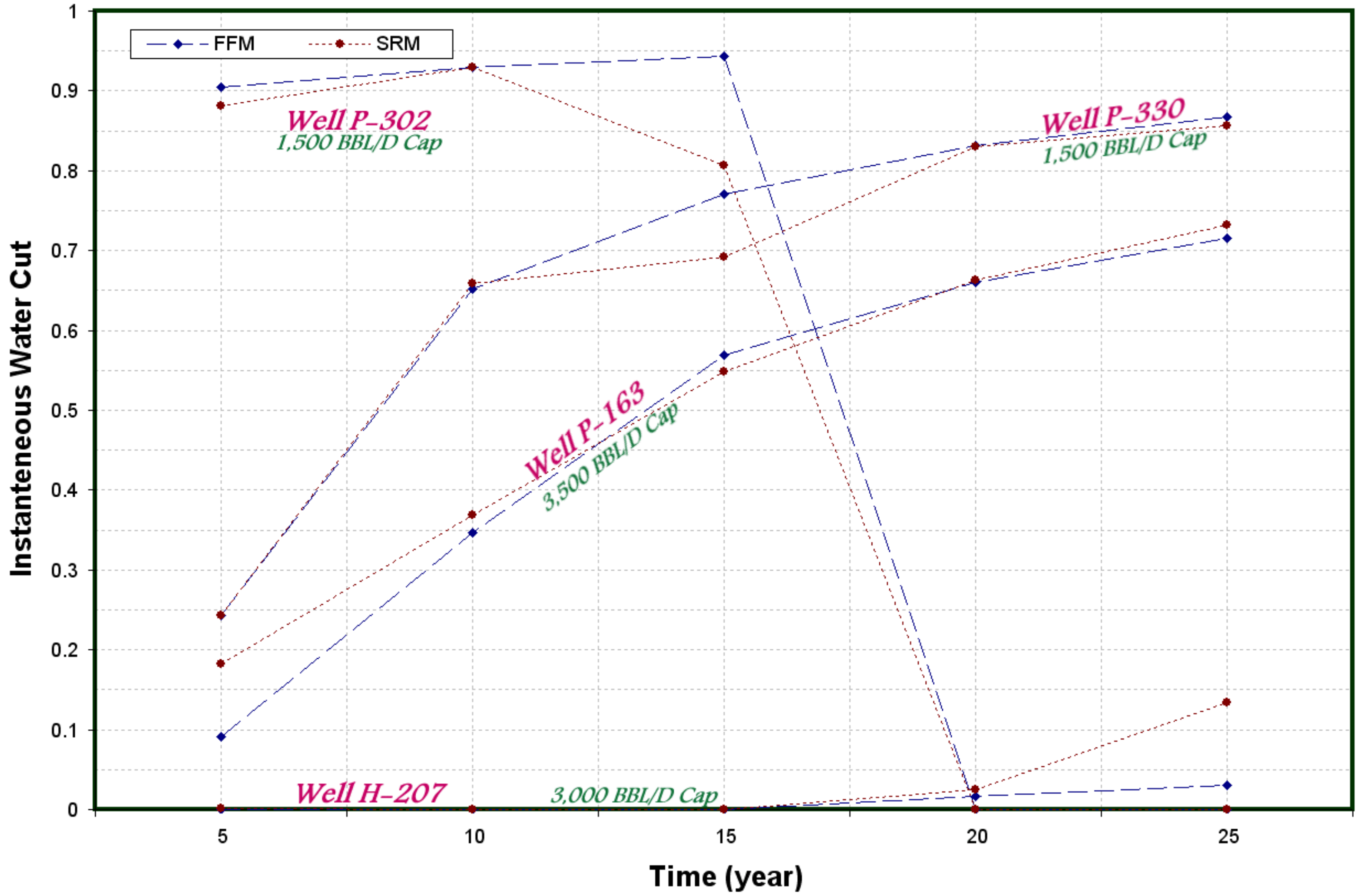

Figure 8. Validation of Surrogate Reservoir Model by comparing the instantaneous water cut as a function of time generated by the full field model (FFM) against those generated by the SRM, for the set of blind wells.

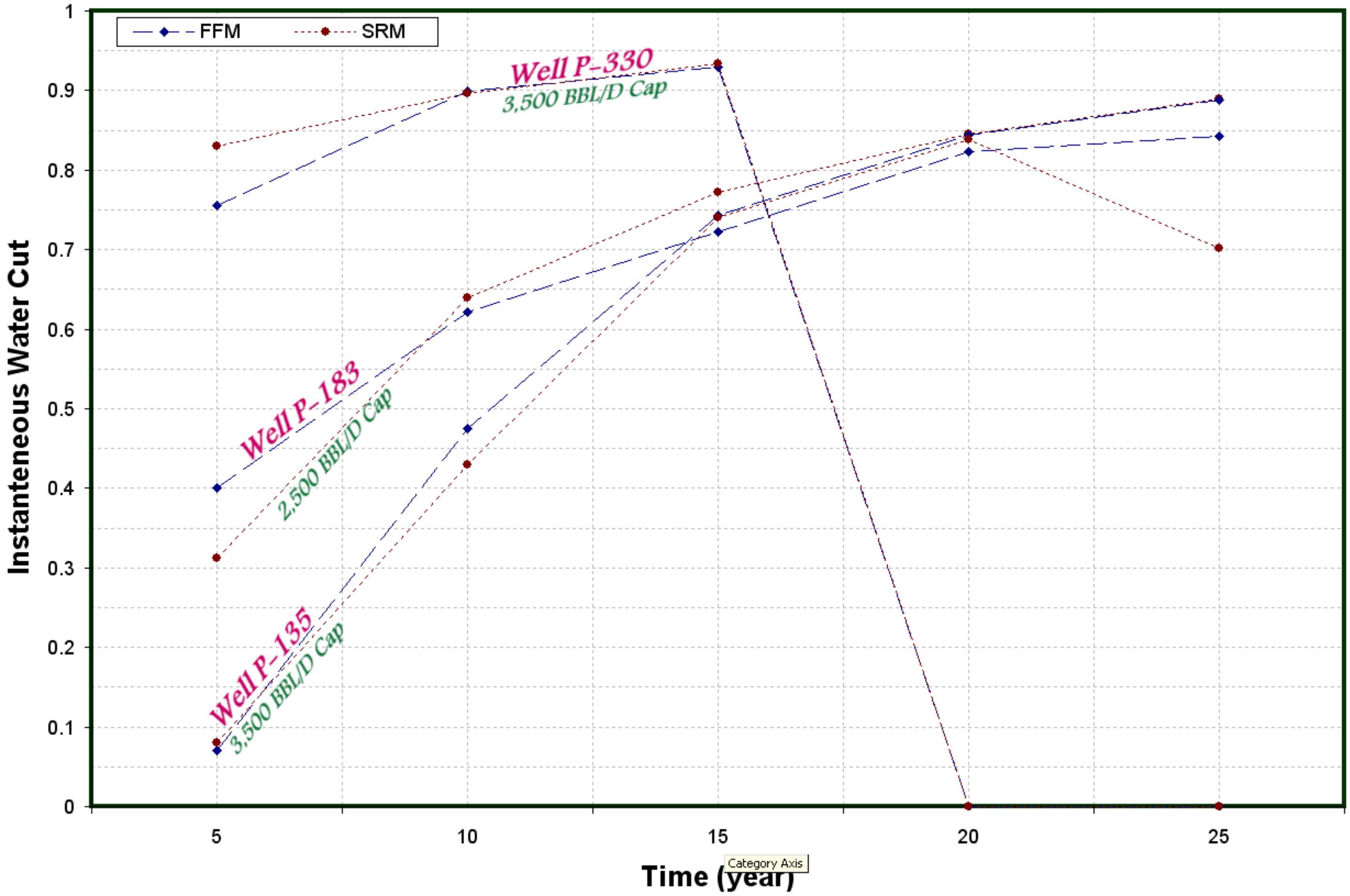

Figure 9. Validation of Surrogate Reservoir Model by comparing the instantaneous water cut as a function of time generated by the full field model (FFM) against those generated by the SRM, for the set of blind wells.

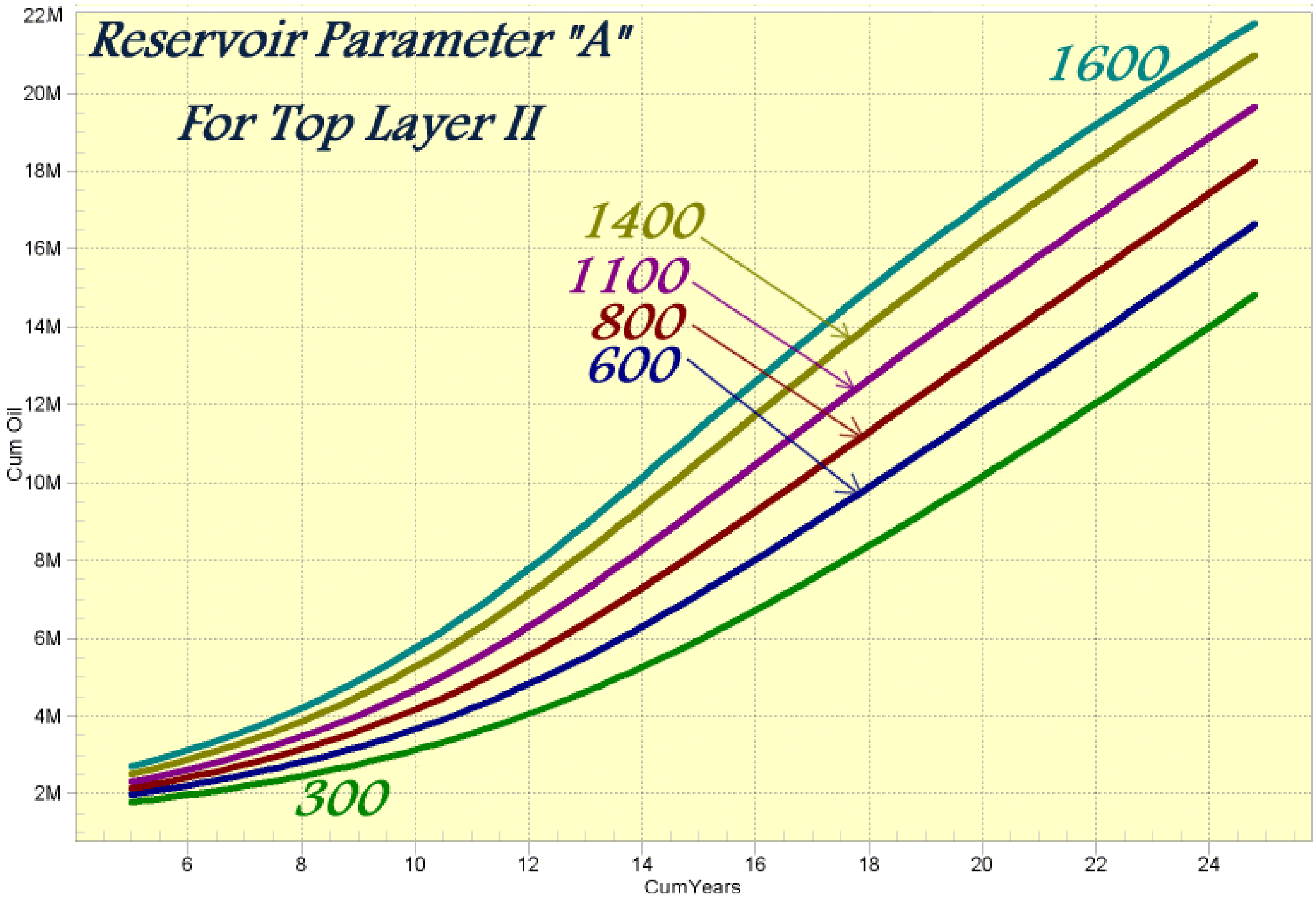

Figure 10. Behavior of 5 year cumulative oil production as a function of time for different values of parameter "A" of Top Layer II. This can be considered as a type curve for this particular reservoir.

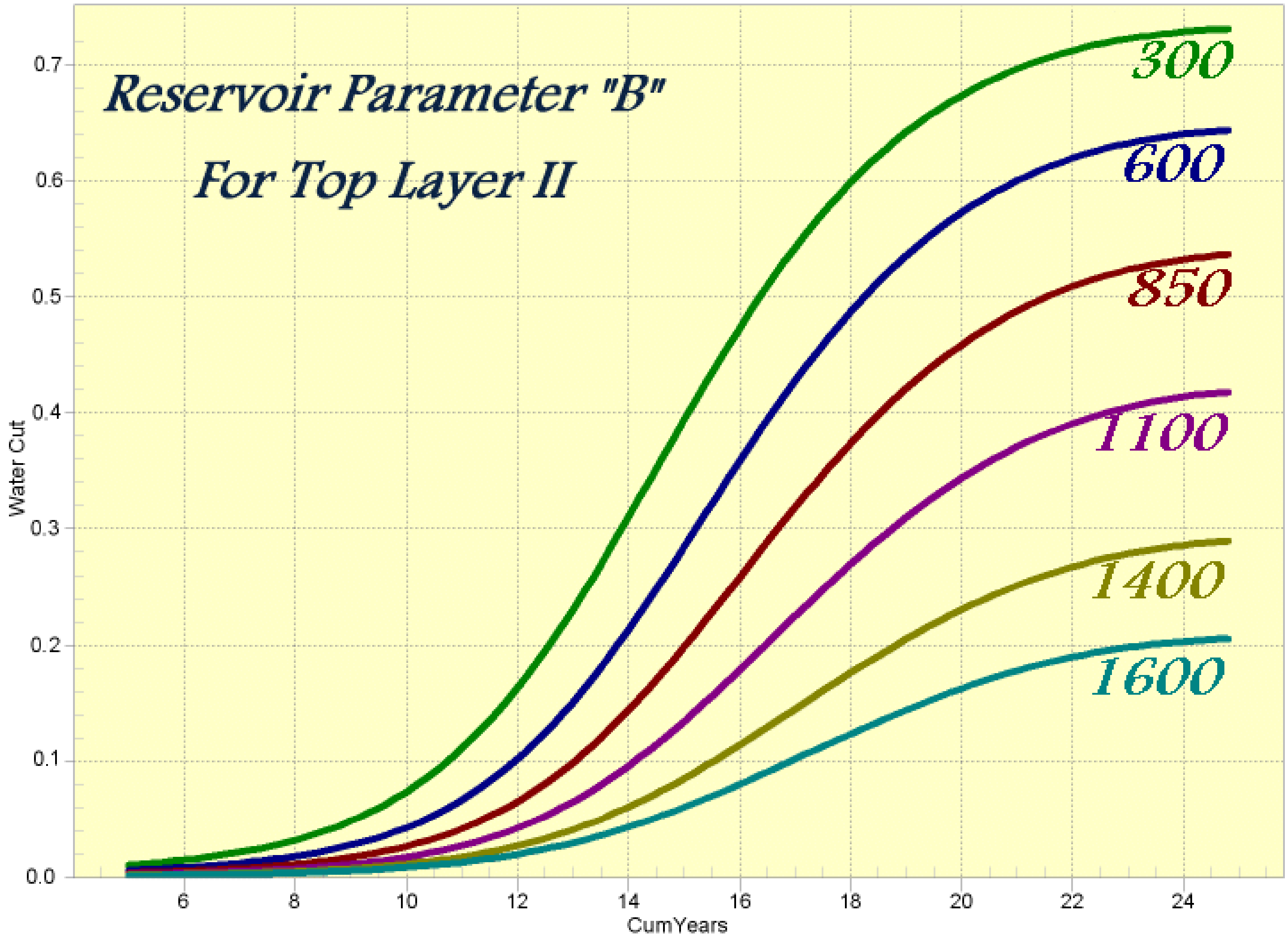

Figure 11. Behavior of instantaneous water cut as a function of time for different values of parameter "B" of Top Layer II. This can be considered as a type curve for this particular reservoir.

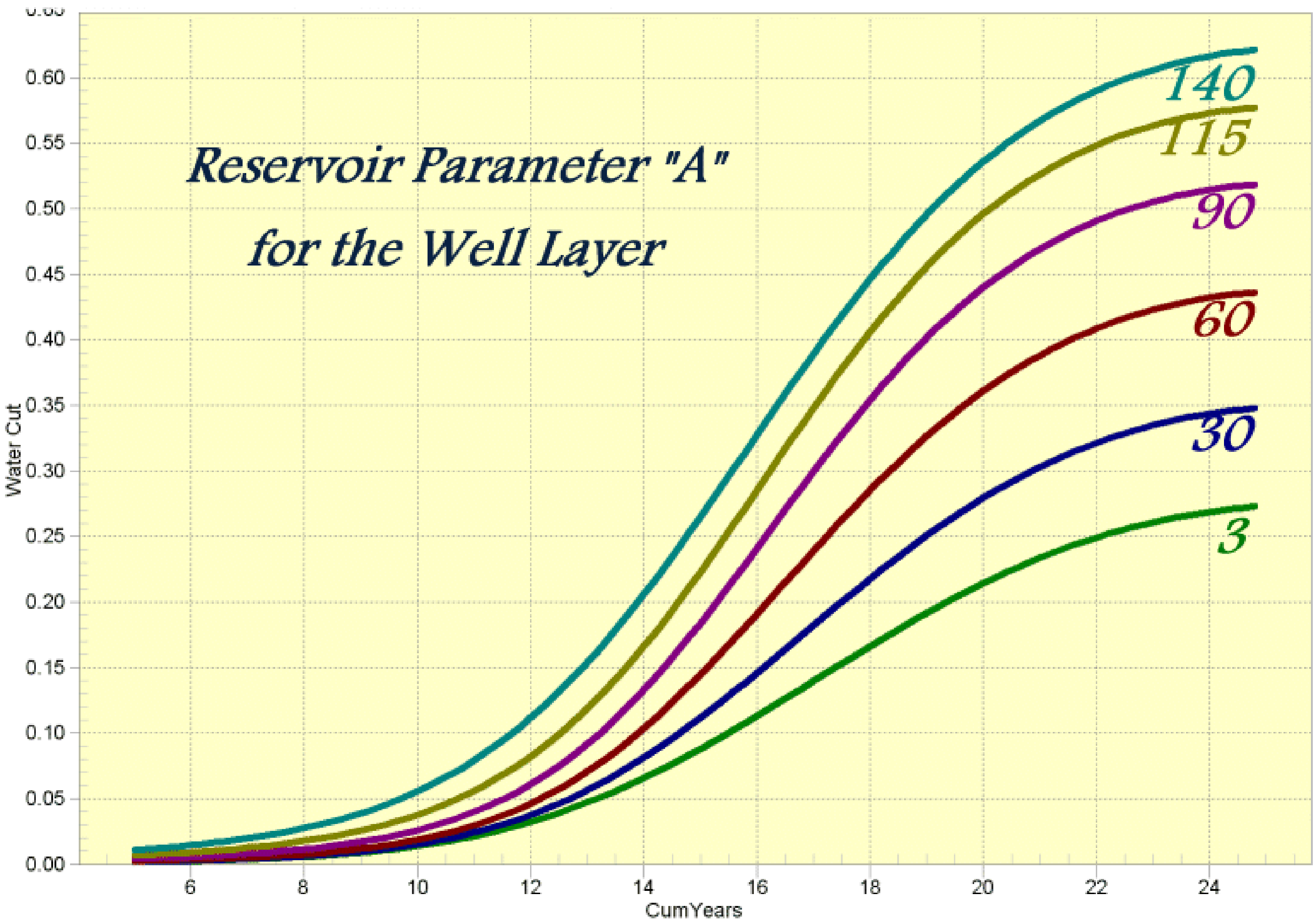

Figure 12. Behavior of instantaneous water cut as a function of time for different values of parameter "A" of Well Layer. This can be considered as a type curve for this particular reservoir.