UNCERTAINTY EVALUATION THROUGH RANKING OF SIMULATION MODELS FOR BOZOVA OIL FIELD

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
MIDDLE EAST TECHNICAL UNIVERSITY

BY

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IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF MASTER OF SCIENCE
IN
PETROLEUM AND NATURAL GAS ENGINEERING

MAY 2011

Approval of the thesis:

UNCERTAINTY EVALUATION THROUGH RANKING OF SIMULATION MODELS FOR BOZOVA OIL FIELD

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ABSTRACT

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May 2011, 100 pages

Producing since 1995, Bozova Field is a mature oil field to be re-evaluated. When evaluating an oil field, the common approach followed in a reservoir simulation study is: Generating a geological model that is expected to represent the reservoir; building simulation models by using the most representative dynamic data; and doing sensitivity analysis around a best case in order to get a history-matched simulation model. Each step deals with a great variety of uncertainty and changing one parameter at a time does not comprise the entire uncertainty space. Not only knowing the impact of uncertainty related to each individual parameter but also their combined effects can help better understanding of the reservoir and better reservoir management.

In this study, uncertainties associated only to fluid properties, rock physics functions and water oil contact (WOC) depth are examined thoroughly. Since sensitivity analysis around a best case will cover only a part of uncertainty, a full factorial experimental design technique is used. Without pursuing the goal of a history matched case, simulation runs are conducted for all possible combinations of: 19 sets of capillary pressure/relative permeability (Pc/krel) curves taken from special core analysis (SCAL) data; 2 sets of pressure, volume, temperature (PVT) analysis data; and 3 sets of WOC depths. As a result, historical production and pressure profiles

from 114 (2 x 3 x 19) cases are presented for screening the impact of uncertainty related to aforementioned parameters in the history matching of Bozova field. The reservoir simulation models that give the best match with the history data are determined by the calculation of an objective function; and they are ranked according to their goodness of fit. It is found that the uncertainty of Pc/krel curves has the highest impact on the history match values; uncertainty of WOC depth comes next and the least effect arises from the uncertainty of PVT data. This study constitutes a solid basis for further studies which is to be done on the selection of the best matched models for history matching purposes.

Keywords: Uncertainty, Ranking, Simulation Models, Factorial Design, Capillary Pressure, Relative Permeability, Water Oil Contact

ÖZ

BOZOVA PETROL SAHASI İÇİN YAPILAN SİMÜLASYON MODELLERİNİN BELİRSİZLİK DEĞERLENDİRMESİ VE SIRALAMASI

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Mayıs 2011, 100 sayfa

Bozova Sahası 1995'ten itibaren üreten ve yeniden değerlendirilmesi yapılacak olan olgun bir petrol sahasıdır. Bir petrol sahasını değerlendirirken yapılan rezervuar simülasyonu çalışmasında takip edilen genel yaklaşım şu şekildedir: Rezervuarı temsil etmesi beklenen bir jeolojik model oluşturmak; rezervuarı en iyi temsil eden dinamik datayı kullanarak simülasyon modelini kurmak; ve tarihsel çakıştırma sağlanmış bir simülasyon modeli elde etmek için en iyi senaryo üzerinde duyarlılık analizi yapmak. Her basamakta çeşitli belirsizliklerle çalışıldığından, her seferinde bir parametreyi değiştirmek tüm belirsizlik uzayını kapsamaz. Sadece her bir tekil parametreye ilişkin belirsizliğin etkisi değil, aynı zamanda bu belirsizliklerin bileşik etkilerinin de bilinmesi, rezervuarı daha iyi anlamaya ve daha iyi rezervuar yönetimine yardımcı olur.

Bu çalışmada, sadece akışkan özellikleri, kayaç fiziği fonksiyonları ve su petrol kontağına ait belirsizlikler derinlemesine çalışılmıştır. En iyi ihtimal senaryosu üzerine çalışılan duyarlılık analizi belirsizliğin sadece bir kısmını kapsayacağından, tam faktöriyel deneysel tasarım tekniği kullanılmıştır. Tarihsel çakıştırma sağlanmış bir senaryo oluşturma amacı güdülmeden, özel karot analizlerinden gelen 19 set kılcal basınç ve göreli geçirgenlik eğrisi; 2 set PVT analizi ve 3 set su petrol kontağı derinliğiyle oluşabilecek tüm olası kombinasyonlar için simülasyonlar

koşturulmuştur. Sonuç olarak, sözkonusu parametrelere ait belirsizliklerin Bozova sahası tarihsel çakıştırması üzerindeki etkisini göstermek amacıyla 114 (2 x 3 x 19) simülasyon sonucundan gelen tarihsel üretim ve basınç profilleri sunulmuştur. En iyi tarihsel çakıştırmayı sağlayan simülasyon modelleri bir amaç fonksiyon hesaplamasıyla belirlenmiş ve simülasyon modelleri uyum iyiliklerine göre sıralanmıştır. Tarihsel çakıştırma değerleri üzerinde en çok etkiye sahip olan belirsizliğin kılcal basınç/göreli geçirgenlik eğrileri belirsizliği olduğu, su petrol kontağı derinliğinin bunu takip ettiği ve en az etkinin PVT datası belirsizliğinden kaynaklandığı bulunmuştur. Bu çalışma, en iyi çakıştırma sağlanmış modeller üzerinde tarihsel çakıştırma amaçlı yapılacak gelecek çalışmalar için sağlam bir temel oluşturmaktadır.

Anahtar Kelimeler: Belirsizlik, Simülasyon Modellerinin Sıralaması, Faktöriyel Tasarım, Kılcal Basınç, Göreli Geçirgenlik, Su Petrol Kontağı

To Schrödinger's cat

ACKNOWLEDGEMENTS

I am sincerely grateful to my supervisor Prof. Dr. Serhat Akın for his valuable suggestions, guidance and support. He has always been accessible and willing to help throughout my work.

I would like to thank related TPAO authorities for allowing me to use the data of Bozova Field which enabled me to complete this study. I also offer my regards to TPAO Production Department Management for their understanding and consideration during my thesis-writing period.

I want to express my thanks to those who worked on developing the geological model of this study; in particular, Melike Özkaya Türkmen for her cooperation, valuable time and precious effort, Ceyda Çetinkaya for her contribution and Yıldız Karakeçe for her substantial guidance throughout the geological modeling process.

Moreover, I wish to thank Murat Demir, Sertuğ Evin, Volkan Üstün, Demet Çelebioğlu and Deniz Yıldırım; the time we spent together has always been a great business experience for me through the years at TPAO. My thanks also go to Fatih Tuğan for encouraging me at the very beginning of this study, and Erkin Gözel for his kind company on working till late hours at the office.

On a personal note, I am heartily thankful to my fiancé Evren, my brother Alper and his joyful wife Neşe, and my parents for their patience, understanding and caring support which has been my source of strength and inspiration. As a result, this tough period became smooth and rewarding for me.

Last but not the least, I want to offer my special thanks to my sisters Feyza, Güneş and Sıla, whose existence and love I feel right beside me all the time, wherever they are. I wish to thank Özlem, Beyza, Demet and Deniz who have always been there for me with their constant moral support, enthusiasm and motivation whenever I need. Having such gorgeous friends, I have always considered myself lucky; they are the true blessings of my life.

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NOMENCLATURE

WOC	: Water oil contact
Pc	: Capillary pressure
krel	: Relative permeability
SCAL	: Special core analysis
PVT	: Pressure volume temperature
FWL	: Free water level
Swir	: Irreducible water saturation
Pce	: Pore entry pressure
RSM	: Response surface methodology
STOOIP	: Stock tank oil originally in place
BHP	: Bottom hole pressure
Pi	: Original reservoir pressure
RMS	: Root mean square

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CHAPTER 1

INTRODUCTION

In the last decades, the high technology has let us to acquire data more easily, accurately and frequently. The accuracy of evaluation of an oil field depends on how all of these data is successfully integrated, for instance in complex numerical reservoir models. However, the data may contain serious errors starting from its acquisition step, to its processing, interpretation and integration steps. The complex numerical model, which is generated by using parameters with significant uncertainties, becomes a model of stacked uncertainties. As a result, the outputs of this reservoir modeling workflow, for example, fluid in places, reserves, production profiles, economic evaluation, etc., will be uncertain (Zabalza-Mezghani, 2004).

The Bozova field, which is studied in this thesis, is a producing oil field of TPAO. There are several reasons why this field is chosen for the study. The first one was the need to re-evaluate the field for reserve estimation purposes. The second reason was the ambiguity of WOC depth. For instance, inspite of the fact that there was no water contact seen in the logs, Bozova-9 started producing 100 % of water 5 months after its production start up. This situation aroused two questions: Is there a possible damage in the casings? Or is there a complex flow mechanism in the reservoir that leads to water production?

Casings are checked with integrity tests showing no indication of damage and according to logs cement bond was of moderate strength. The possibility of a weak casing cement bond interconnecting the perforations and an undetermined water zone was and still is a question subject to this well. It is also useful to mention that the water produced from Bozova-9 and the formation water of Reservoir Level have the same salinity value which again supports the idea that WOC is somehow close to the perforations of Bozova-9. The second question pointed out the importance of flow functions, such as Pc or krel curves, derived from SCAL data.

Under all of these considerations, a geological modeling and simulation study was deemed crucial in order to understand the reservoir behavior thoroughly.

The objective of this study is to evaluate dynamic reservoir uncertainties on the simulation modeling of Bozova oil field and ranking of the simulation models created for uncertainty evaluation. The study covers uncertainties associated only to fluid properties, rock physics functions and WOC depth. Uncertainty of any other type is beyond the scope of this thesis.

The uncertainty range of parameters is not determined by parameter sweeps. In order to reduce the uncertainty range, experimental data is used in this study. The uncertainty of fluid properties is studied through 2 sets of PVT data, samples of which are taken from wells Bozova-1 and 3. The uncertainty of rock physics functions is studied through SCAL data obtained from 19 core plugs, which are taken from Reservoir Level formation of wells Bozova-1, 2 and 3. PVT and SCAL data were analyzed by TPAO Research Center. The uncertainty of WOC depth is studied through 3 different values which are considered to be informative on the determination of the true reservoir description.

In order to address the full range of uncertainty, simulations are run for all possible combinations of these uncertain parameters and simulation models are ranked according to their goodness of fit. Ranking schemes for 114 simulation models are established and compared. The rankings provide an assessment of all possible model responses.

CHAPTER 2

LITERATURE REVIEW

Sources of uncertainties in reservoir engineering are almost infinite and are anywhere within the reservoir modeling workflow. These are static model, upscaling, fluid flow modeling, production data integration, production scheme development and economic evaluation as given in Figure 2.1 (Zabalza-Mezghani, et al., 2004).

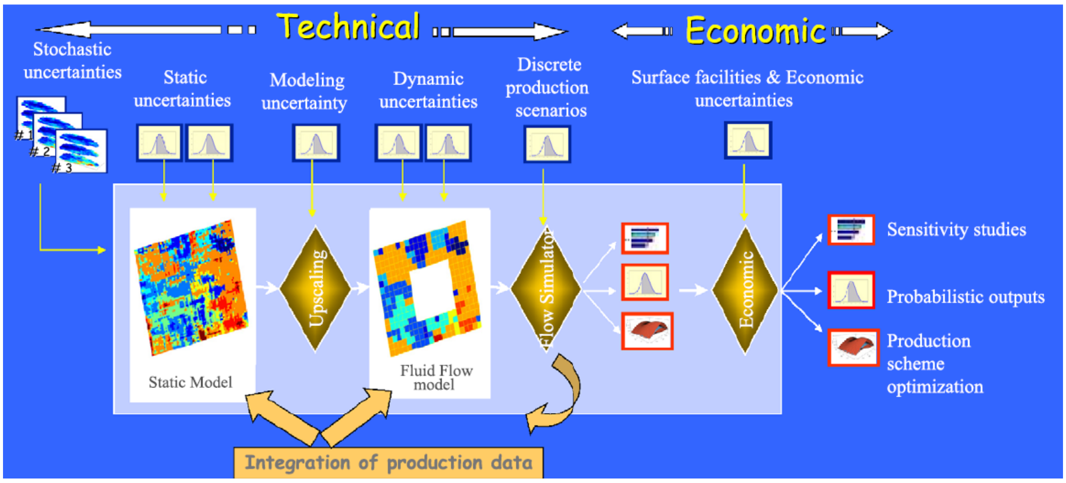

Figure 2.1 Sources of uncertainties in reservoir modeling workflow (Zabalza-Mezghani, 2004)

2.1 Classification of Uncertainties

The evaluation and optimization of reservoirs require complex models which contain many uncertainties. Since there is not a unique methodology that can handle all types of uncertainties, it becomes important to choose the right methodology to take into account each uncertainty. The methodology is selected according to statistical behavior and status of uncertainty.

2.1.1 The Different Uncertainty Statistical Behaviors

As stated by Zabalza-Mezghani et al. (2004) three different statistical behaviors can be used to classify the uncertainties:

Deterministic uncertainty corresponds to a parameter which has a continuous uncertainty range. The parameter may vary between a minimum and a maximum value. This includes, for instance, uncertainty on any average property (average permeability, porosity), correlation length for a geostatistical model, upscaling coefficient between arithmetic and harmonic laws, horizontal well length, etc.

Discrete uncertainty corresponds to a parameter that can take only a finite number of discrete values. This includes, for instance, an uncertainty on a few possible depositional scenarios, the Boolean behavior of a fault which is conductive or not, or the optimal number of new production infill wells to be implemented.

Stochastic uncertainty corresponds to an uncertainty which does not have a smooth behavior on production responses. For instance, a small incrementation of the parameter value may lead to completely different results in terms of production profiles. It also corresponds to an uncertainty that can take infinity of equiprobable discrete values. For instance, infinity of equiprobable structural maps, fracture maps, geostatistical realizations, and history matched models, etc.

2.1.2 The Different Parameters Status

As stated by Zabalza-Mezghani et al. (2004) two different uncertainty status can be used to classify the uncertainties:

Uncontrollable status corresponds to a parameter on which the engineer cannot have any control. This includes typically any physical parameters inherent to the reservoir such as petrophysical values, reservoir structure and geology, etc. For such a parameter, the uncertainty can partially be reduced through additional data acquisition and history matching process but must still be faced using for instance some sampling methods.

Controllable status corresponds to a parameter for which the value is unknown but can be controlled, such as a well location, water injection rate, etc.

2.2 The Importance of Dynamic Uncertainty

The uncertainties of the reservoir properties such as the geological and petrophysical data are very often given more attention than the uncertainties of dynamic reservoir parameters. Input data, such as fluid properties, Pc/krel curves and WOC depth, are very important for the dynamic reservoir simulations as they dictate the accuracy of the simulation prediction. In order to reduce the uncertainty for Pc/krel curves and PVT data, experimental data is used in this study. On the other hand, it should be noted that experimental data may also have significant error or uncertainty.

Pc curve data is a vital input in reservoir simulations. They are used for calculating the volume of oil above free water level (FWL) and in the transition zone (Ferno et al., 2007). Figure 2.2 shows the schematic relationship between a Pc curve and oil accumulation. Irreducible water saturation (Swir) is the water saturation of bound capillary water. Pore entry pressure (Pce) is the threshold pressure required before oil can begin to enter the pore structure. Transition zone is the reservoir interval over which both oil and water will flow (Holmes, 2002).

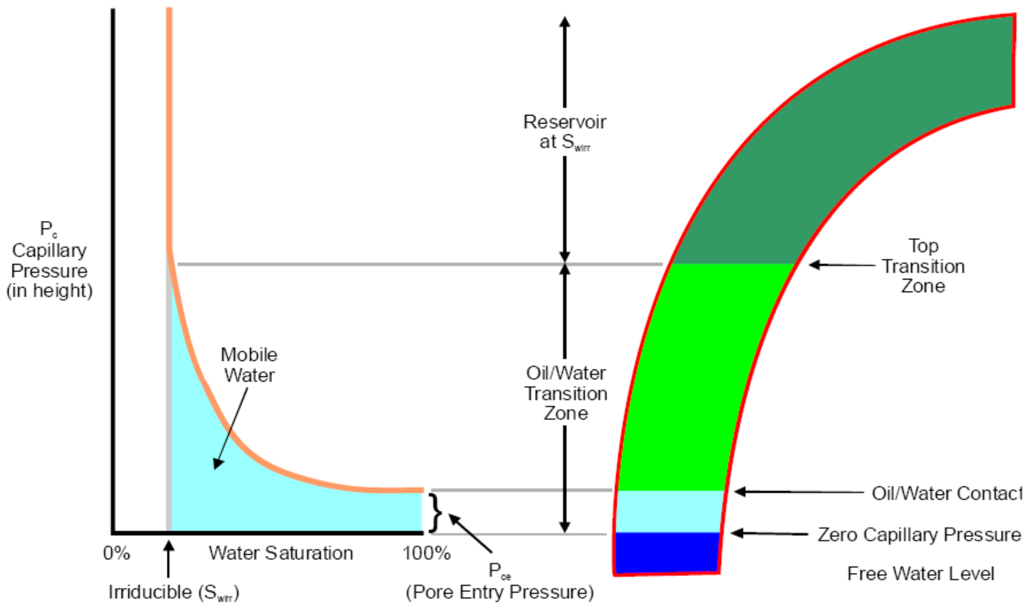

Figure 2.2 Relationship between a Pc curve and oil accumulation (Holmes, 2002)

Salarieh et al. (2004) studied the effect of Pc in a reservoir simulation with three different cases: Without Pc, low Pc and high Pc. The production behaviour of the wells showed the best performance whenever the Pc is zero. The curvatures of the Pc curves are also studied resulting in the low curvature in Pc leads to water coning.

The effect of Pce on oil recovery by gravity drainage was investigated by Li and Horne (2003). They found out that, oil recovery by gravity drainage increases with the decrease in Pce, which depends on permeability, reservoir height, and other parameters.

Relative permeability data variation may introduce significant uncertainty in reservoir simulations. Defining the relative amounts of fluids that will flow when there is more than one fluid phase, it has significant impact on reservoir performance (Holmes, 2002).

By comparing the simulated results to observed data, Mogford (2007) followed a method of adjusting relative permeability iteratively until a good match is obtained. Li and Horne (2003) stated that: Due to the great uncertainty from experimental data, krel is often a parameter set to tune or obtained by history match. However, tuning the krel parameters independently may result in curves that are unphysical or inconsistent with other flow properties.

In addition to the inconsistency from the measurements, fluid sampling is another main source contributing to the accuracy of fluid property data. Zabel et al. (2008) studied the effect of the variation in fluid properties on the dynamic simulation prediction, concluding that; variations in dead and live oil viscosities and oil saturation pressure measurements have significant effects on the primary recovery performance prediction in a typical heavy oil reservoir.

2.3 The Need to Quantify Uncertainty

In the petroleum industry, quantities such as original hydrocarbon in place, reserves, and the time for the recovery process are all critical in the economical aspect. Those quantities play a key role in making important decisions.

The lack of available data in the appraisal stage of a field, or incomplete reservoir description even during the development stage, increases the risks associated with investment decisions. Quantification of these uncertainties and evaluation of the risks would improve decision making (Salomão and Grell, 2001). However, estimating these uncertainties is complicated because it requires an understanding of both the reservoir's static structure and dynamic behavior during production. Even a producing field can result in a financial loss, and even mature fields have uncertainties in the reservoir description (Capen, 1975).

2.4 Uncertainty Quantification Methods

Quantification of uncertainty in reservoir performance is an important part of reservoir management. The uncertainty of a reservoir's performance stems from the uncertainty of the variables that control reservoir performance. The problem is complex since the impact of the variables on the reservoir performance is often nonlinear (Venkatamaran, 2000).

The methods developed for quantifying uncertainties use various techniques such as Monte Carlo, experimental design and response surface, multiple realization tree, relative variation method, and Bayesian rule methods.

Uncertainty analysis method should be able to evaluate the complete range of uncertainties by being able to capture them. It should be able to identify the relevant elements of uncertainty and filter out those that do not matter. Once the key uncertain elements have been identified, it should be able to rapidly know what actions are required to reduce their uncertainty to an acceptable level for decision making (Peterson et al., 2006).

Venkatamaran (2000) have successfully improved the method of parametric analysis for quantifying the uncertainty in production profiles with the use of experimental design in his study.

In reservoir simulation models, generating multiple good history matched models is also used as an uncertainty quantification technique. History matching is an ill-posed inverse problem which means that different combinations of parameters can produce good matches of the observed data. In order to obtain multiple good history matched models, automated history matching techniques are used which exist with a numerous examples in the literature (Hajizadeh et al., 2009). The critical aspect of generating multiple history-matched models is the sampling algorithm used to generate the models. As Mohamed et al. (2009) studied; these can be algorithms such as gradient methods, genetic algorithms and the ensemble Kalman filter. As Rotondi et al. (2006) stated, “Automatic” and “Assisted History Match” techniques automatically vary reservoir parameters until a defined stopping criteria is achieved. In literature they can be divided into three main groups: Deterministic methods, stochastic methods and hybrid methods.

One of the methods to conduct an uncertainty study is an experimental design matrix, which is a method that allows the user to gain maximum information from a series of systematically conducted experiments. The input parameters are predefined by the user as uncertain parameters. A design is a set of parameter value combinations in which responses can be measured, for two level factorial designs each parameter is assigned to an upper and lower limit in all possible combinations. (Al-Shamma and Teigland, 2006).

Once the experiments have been designed and the simulations achieved, engineers need tools to exploit the results. These tools are provided by the Response Surface Methodology (RSM). The aim of RSM is to approximate a process by a simple regression model that fits well the true response surface. Testing the terms of the model leads to identify the influent parameters and to quantify their role in the variability of the response. The final result is a predictive model of the process over the experimental domain.

Manceau et al. (2001) presented an innovative approach called "Joint Modeling Method". It is an experimental design technique coupled with the RSM, providing an efficient and rigorous methodology to accurately quantify the impact of reservoir uncertainties on production forecasts.

Potlog (2003) investigated the advantages and limitations of an experimental design technique when applied to the quantification of uncertainty in a performance production forecast for a real reservoir. A work performed by Leuangthong and Deutsch (2003) describes a methodology to determine a design matrix for sensitivity analysis for any generic case.

Dejean and Blanc (1999), presented a new frame for performing reservoir engineering studies. They quantified the uncertainty on the responses by combining the fitted regression model provided by the RSM and the sampling of the uncertain parameters provided by Monte-Carlo techniques. Integrating these techniques enables to build a simplified model of a process and to estimate the uncertainties on the response predictions.

CHAPTER 3

BOZOVA FIELD OVERVIEW

3.1 General Overview of The Field

Bozova is an oil field located in the South-East Anatolian Region of Turkey (as shown in Figure 3.1). The field is explored in 1995 and the oil producing zone is a bioclastic limestone formation called Reservoir Level. The formation, thickness of which is ranging from 18 to 40 m, is the main target zone in the field. The upper part of Reservoir Level has a porosity of 17-20 %, whereas the lower part is of 7-8 % porosity. The formations below Reservoir Level showed no hydrocarbon potential and are pretty compact throughout the field.

The Bozova structure covers an area of approximately 1.7 km^2 and a total number of 8 wells were drilled in the field between years 1995 and 2002. 5 of the wells (Bozova-1, 2, 3, 8 and 9) were completed as oil production wells, and the others, some of which are drilled outside the reservoir boundary, were abandoned as watery or dry wells. Bozova-9 was abandoned shortly after (11 months later) its water production percentage reaching 100 %. The reservoir drive mechanism is expansion of rock and oil, and water drive.

The cumulative oil production of the field by February 2011 is 1,443,425 bbl. The field is currently producing from 4 wells (Bozova-1, 2, 3 and 8) at a total oil rate of 193 bbl/d, with a water cut of 75 %. The daily oil production graph of the field and the bubble map illustrating the cumulative production of each well is given in Figure 3.2 and Figure 3.3.

Figure 3.1 Geographical location of Bozova field

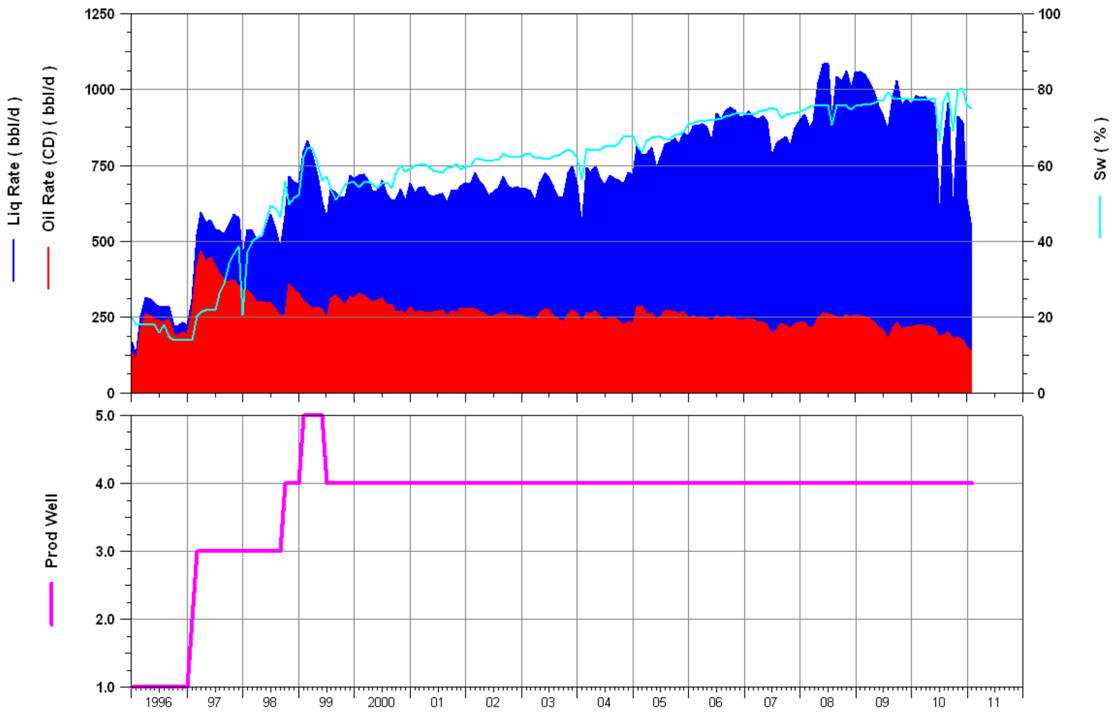

Figure 3.2 The daily oil production graph of Bozova field

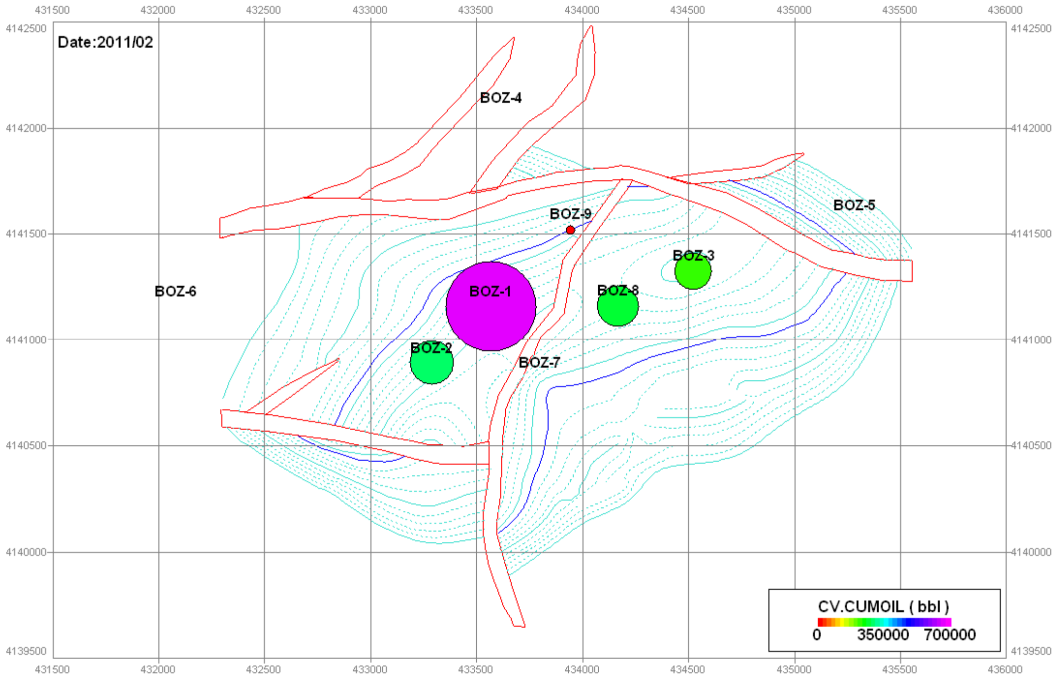

Figure 3.3 The bubble map the illustrating cumulative production of each well

3.2 Geological Description of the Field

3.2.1 Lithological Description of the Reservoir Level

In Bozova field, the oil producing zone is called Reservoir Level. The lithology of this formation is bioclastic limestone and it is in the characteristics of calciturbudites. This unit is formed by the migration from the shelf edge, is settled as small scale channel fills and lenses around Bozova field. This Reservoir Level is so far observed only in this field throughout the South-East Anatolian Region (Evin and Soyhan, 2004).

3.2.2 Structural Geology of the Field

The evolution of Bozova structure is thought to be passed through two tectonic periods, one during Upper Cretaceous and the other one during Miocene (Şengündüz, et al., 2000).

The first tectonic phase (Upper Cretaceous period) is the compression regime formed by subduction of Arabian Plate underneath the Anatolian Plate. This compression regime lead to drifting in northern areas, whereas leading to a deformation (folding and faulting) in southern areas, the effect of which is decreasing towards south. The compression trending northwest-southeast caused formation of folds trending northeast-southwest and structures limited with reverse faults in the south.

The second major tectonic phase is the collision of Anatolian and Arabian Plates which occurred 9 million years ago (Upper Miocene). The effect of this north-east trending event in the northern areas is the overthrusting and drifting towards the south. This effect decreases towards the southern areas. As a result folding, reverse faults trending south and asymmetric anticlines extending east-west forms the dominant topography.

In the formation of Bozova structure, 75 km length and high angled (approximately 85°) Bozova fault, trending northwest-southeast plays a key role. The Bozova fault which has a right lateral throw was previously a normal and then a reverse fault in the past.

Bozova field is an anticline structure limited with normal faults in the north and south. There is a 10 km length fault trending north-south in the middle of the structure. This fault is considered to be permeable.

CHAPTER 4

STATEMENT OF THE PROBLEM

The primary objective of this study is to evaluate the impact of dynamic reservoir uncertainties on the simulation results of Bozova oil field and ranking the simulation models created for uncertainty evaluation. The study covers uncertainties associated only to fluid properties, rock physics functions and WOC depth of the field.

Employing a full factorial experimental design, simulation models will be created for all possible combinations of: 19 sets of Pc/krel curves taken from SCAL data; 2 sets of PVT data obtained from PVT analyses of Bozova-1 and Bozova-3; and 3 sets of WOC depths, which are considered to be informative on determination of the true reservoir description.

Without pursuing the goal of a history matched case, 114 (2 x 3 x 19) simulation models will be run. The results of the simulation runs will be plotted for screening the impact of uncertainties. Following the screening, a history match analysis will be processed on all of the simulation runs; history match values (corresponding to an objective function showing the error between the simulated and observed data) will be utilized to rank the simulation models. After ranking the models according to their goodness of fit, quantification of uncertainties will be performed through two different methods. Thus uncertainty evaluation will be assessed for the simulation models of Bozova Field.

CHAPTER 5

METHOD OF SOLUTION

The commercial seismic-to-simulation software program Petrel is used for the geological modeling; reservoir simulation; and history match analysis studies of Bozova Field. Black oil simulator ECLIPSE 100 is used for the simulation runs.

5.1 Geological Modeling

5.1.1 Data Input, QA/QC

Basic well data including X, Y coordinates, kelly bushing elevation, measured depth, formation depths, digital raw and processed logs of each well is imported into the program. Wells sections illustrating the logs (porosity in the first, water saturation in the second track), status, perforation and DST intervals of the wells are shown in Figure 5.1. The Reservoir Level is the zone between the red dashed lines.

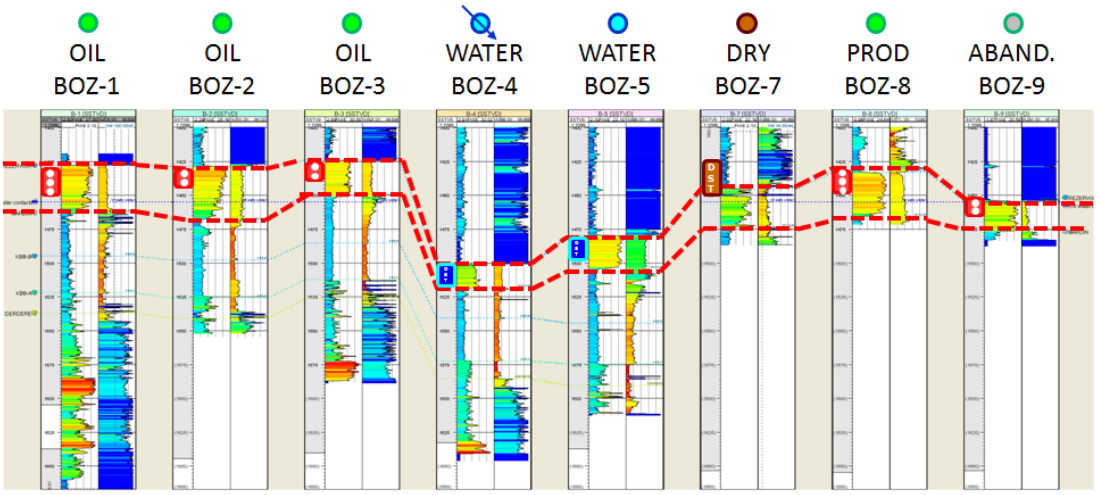

Figure 5.1 Well sections of Bozova field (Log process by Karakeçe, 2009)

The structure contour map on top of Reservoir Level is imported into the program and formations below are derived from this map (Figure 5.2).

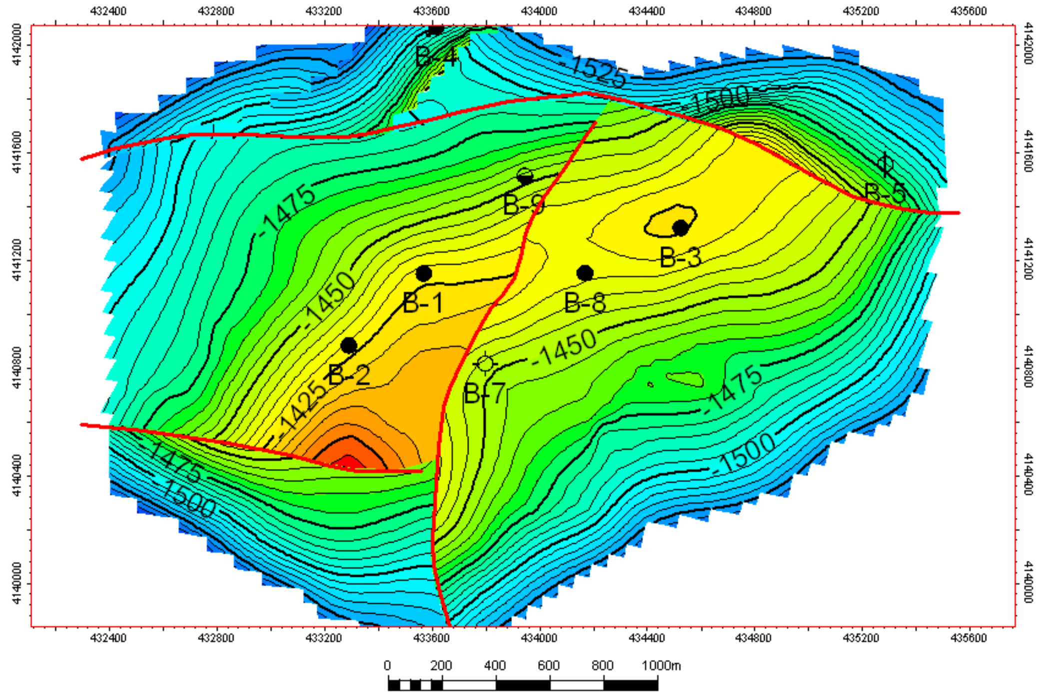

Figure 5.2 Structure contour map of Bozova field on top of Reservoir Level (adapted from Sefunç & Ölmez, 2002)

5.1.2 3D Geological Grid and Petrophysical Parameter Modeling

The size of the grid cells are 50x50x1 m in the X, Y and Z directions respectively. The number of active grid cells is 101,904. Z values ranging from 3 to 15 m are assigned to the formations below the Reservoir Level.

By using Sequential Gaussian Simulation geostatistical method and variogram models porosity values determined from logs are distributed throughout the field. By using the porosity-permeability plot obtained from core data porosity cut-off is identified as 13 % (Figure 5.3). Water saturation values are distributed by using a height dependent function. Porosity and water saturation properties are shown in Figure 5.4 and Figure 5.5.

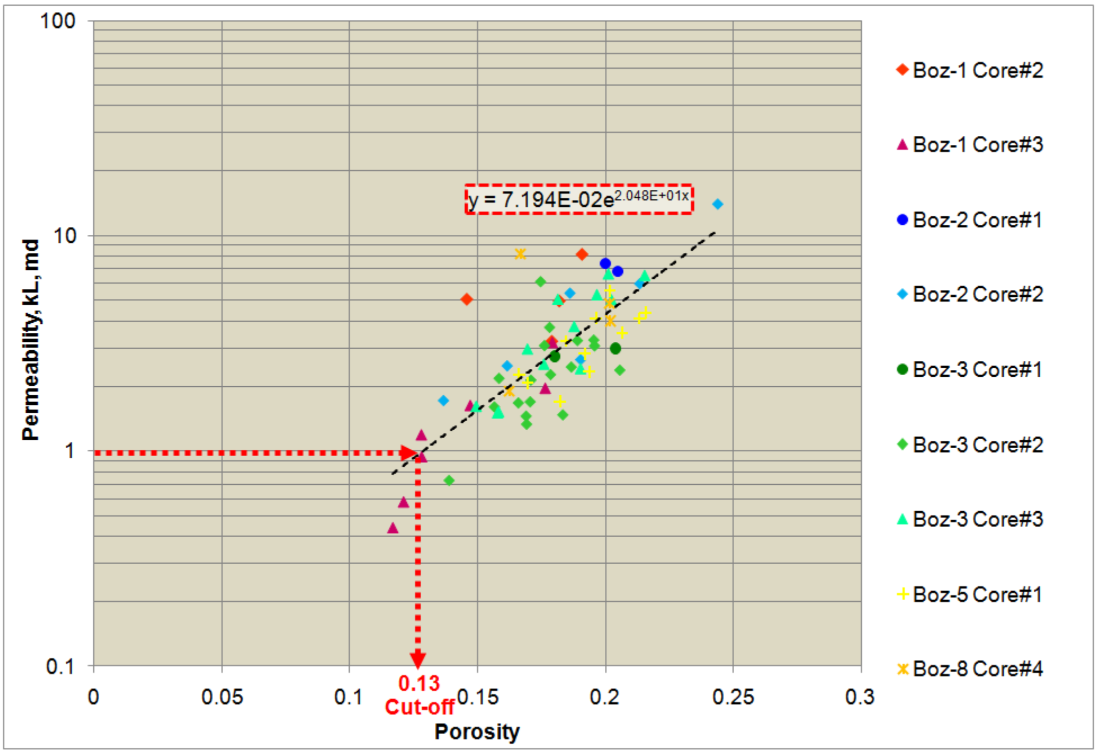

Figure 5.3 The porosity-permeability plot obtained from core data

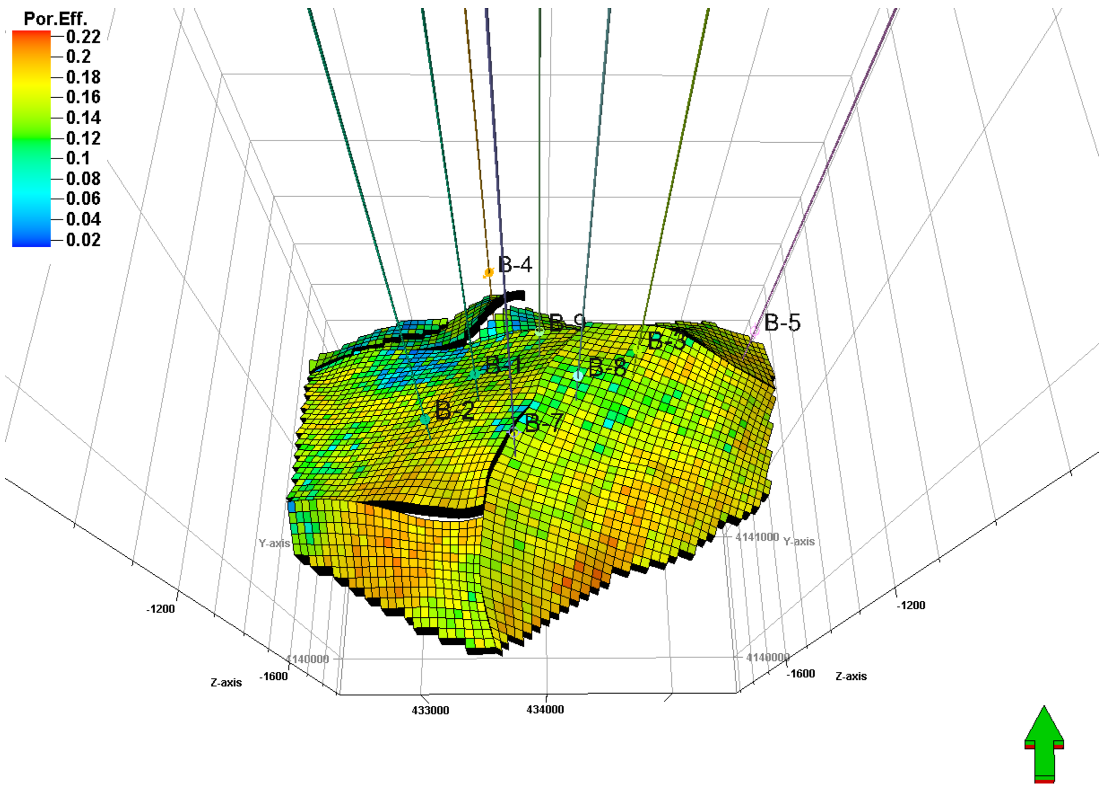

Figure 5.4 Porosity distribution model of the 3D grid

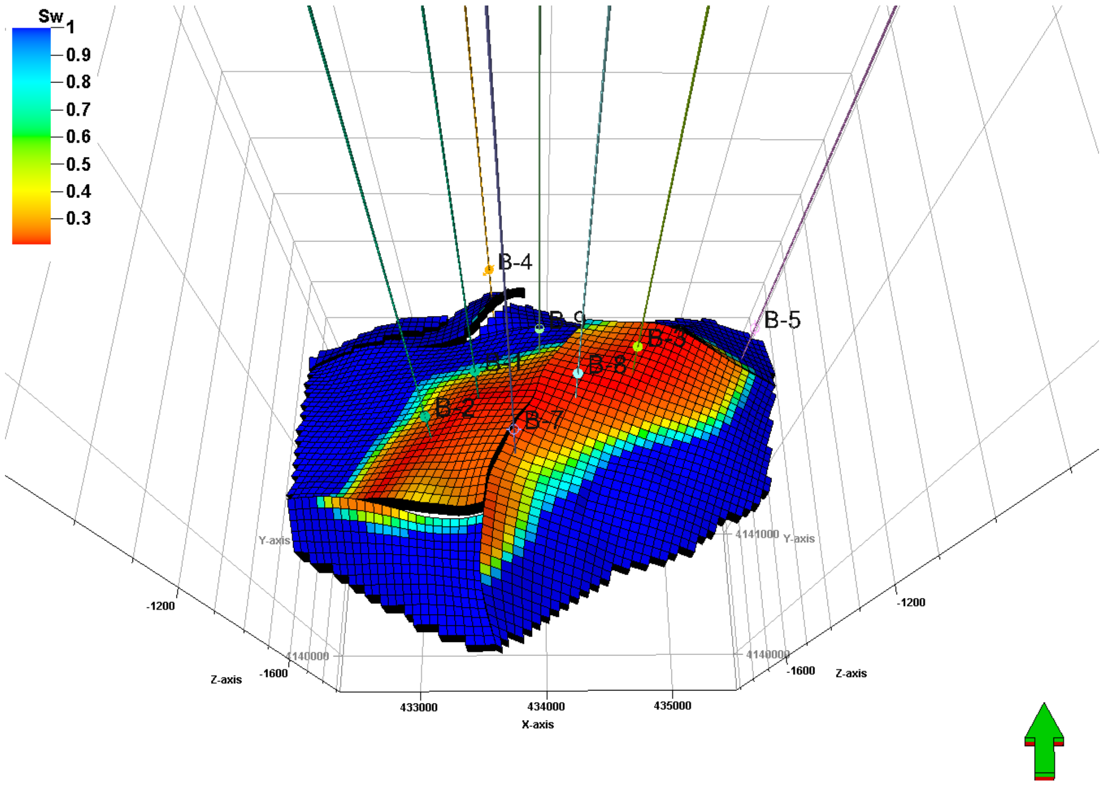

Figure 5.5 Sw distribution model of the 3D grid

5.1.3 STOOIP Calculation from 3D Geological Model

The deterministic reserve calculation is done with 3 WOC depths of 1455, 1468 and 1480 m ssTVD. The stock tank oil originally in place (STOOIP) amounts are volumetrically calculated as 18.5, 28.1, 34.2 million bbls respectively. These values are consistent with the simulation results that are given in the further chapters.

5.2 Basic Reservoir Engineering

This section covers the basic reservoir engineering tasks that are performed in order to understand the dynamics of the reservoir. Before jumping into the simulation, a comprehensive study is performed for collection of basic reservoir engineering data, which is of primary importance in generating the dynamic model accurately. Also determination of uncertainties in WOC, Pc/krel curves and PVT data are performed.

5.2.1 Well Test Interpretations

A total number of 10 open hole DSTs were performed in the Reservoir Level of wells Bozova-1, 2, 3, 4, 5, 8 and 9 between years 1995 and 1998. All of the tests consisted of two flow and two shut-in periods.

Since the bottom hole pressure gauges which are run in hole are mechanical, there may be a significant uncertainty in the BHP values. Calibration of the gauges and the accuracy of calculation of pressure values from the charts are of major importance. Also the flow data were not measured during the tests. They were determined by complex calculations that use the pressure gradient of the recovered fluid, hydrostatic pressure differential during flow period, the related fluid volume in the test string and the duration of the flow. All of these factors bring a certain amount of uncertainty to the calculations of flow rates. The rates are double-checked to see if the derivative of the pressure differentials coming from the 1^{st} and the 2^{nd} shut-in build-up periods were consistent.

Test interpretations are performed by Ecrin Pressure Transient Analysis Module (KAPPA Software). The final shut-in period of the well tests are analyzed by using Log-log and Horner analysis. The reservoir parameters, such as original reservoir pressure (Pi), permeability (k) and skin factor (S) are obtained from these interpretations. Interpreted well test details, parameters used for interpretation and the results are given in Table 5.1. Log-log, semi-log and history plots of all the interpreted well tests are given in Appendix A.

Table 5.1 Bozova DST parameters and the interpretation results

Well	Boz-1	Boz-1	Boz-2	Boz-2	Boz-3	Boz-4	Boz-4	Boz-5	Boz-8	Boz-9
DST No	1	2	1	2	1	1	2	1	1	1
Formation	Res. Level	Res. Level	Res. Level	Res. Lev.	Res. Level	Res. Level	Res. Level	Res. Level	Res. Level	Res. Level
Interval, m	1912.5 - 1926	1930.6 - 1946.5	1912.5 - 1926	1930.4 - 1952	1892.8 - 1908.8	1950 - 1967	1964 - 1987	1955 - 1969	1896.9 - 1916	1911-1932
Date	07.11.1995	09.11.1995	01.01.1997	03.01.1997	30.11.1996	01.09.1997	03.09.1997	08.11.1997	25.09.1998	16.12.1998
Parameters Used										
Well Radius, in	4.25	4.25	4.25	4.25	4.25	4.25	4.25	6.125	4.25	4.25
Gauge Depth, m ssTVD	-1433	-1454	-1417	-1435	-1431	-1506	-1526	-1490	-1448	-1437
Net pay zone, m	6.86	15.85	10.51	17.07	8.53	6.86	22.56	11.74	16.61	12.80
Porosity, %	20.94	18.64	20.29	17.09	19.28	4.34	5.09	19.41	20.55	16.12
Sw, %	17.55	19.25	26.52	31.19	21.58	17.26	15.48	52.28	23.07	30.14
Temperature, ^oF	200	170	170	174	168	178	179	180	172	176
1st Flow Rate, bbl/day	235	240	256	173	190	70	170	540	270	140
2nd Flow Rate, bbl/day	170	110	202	114	130	40	100	320	160	70
Fluid Properties*										
API	22.9	22.9	22.9	22.9	22.9	22.9	22.9	22.9	22.9	22.9
Oil Form. Vol. Fac., rm^3/sm	1.053	1.042	1.042	1.043	1.041	1.045	1.045	1.046	1.043	1.044
Viscosity, cp	5.047	7.793	7.793	7.298	8.062	6.852	6.748	6.646	7.539	7.069
Total Compressibility, psi^{-1}	8.24E-06	6.49E-06	6.81E-06	6.88E-06	6.44E-06	6.96E-06	7.00E-06	6.45E-06	7.18E-06	7.17E-06
Results										
k, mD	12.6	4.9	33.0	4.7	17.1	3.3	2.6	18.6	9.4	3.4
S	0.171	0.160	4.003	0.271	1.351	-0.048	-0.200	0.026	0.352	-0.192
Pi, psia	2579	2612	2325	2387	2578	2623	2648	2776	2156	2245
PI bbl/d/psi										

*At Pi and given temperature.

5.2.2 Bottom Hole Pressure (BHP) Measurements

The BHP of wells Bozova-1, 3 and 8 are measured right before their production start up between years 1995 and 1998. The measurements were made at different levels by running the gauge into the well and pulling it to the next upper level. The gauge was assumed to be kept at each level for an enough period of time that the pressure values were considered to be stabilized. Another set of BHP measurements were made with Spartek digital pressure gauge in wells Bozova-2, 8 and 9 in February 2011. The details of each BHP measurement are given in Appendix B.

5.2.3 Determination of Original Reservoir Pressure (Pi)

The pressure values obtained from DST interpretation results and BHP measurements are shown in Table 5.2. All of the pressure values (corrected at a reference depth of 1455 m ssTVD) are plotted on a date vs. pressure graph in Figure 5.6.

Table 5.2 Pressure values obtained from DSTs and BHP measurements

	Well & BHP Name	Gauge Depth m	BHP psi	Pres. Grad. psi/m	BHP @-1455 m. psi
DST	BOZ-1 DST#1_Nov '95	-1433	2579	1.406	2610
	BOZ-1 DST#2_Nov '95	-1454	2612	1.406	2614
	BOZ-2 DST#1_Jan '97	-1417	2325	1.301	2374
	BOZ-2 DST#2_Jan '97	-1435	2387	1.301	2413
	BOZ-3 DST#1_Nov '96	-1431	2578	1.206	2607
	BOZ-4 DST#1_Sep '97	-1506	2623	1.301	2557
	BOZ-4 DST#2_Sep '97	-1526	2648	1.301	2556
	BOZ-5 DST#1_Nov '97	-1490	2776	1.301	2731
	BOZ-8 DST#1_Sep '98	-1448	2156	1.275	2165
	BOZ-9 DST#1_Dec '98	-1437	2245	1.301	2268
AMERADA (MECHANICAL GAUGE)	BOZ-1 AMRD-1_Dec '95	-1432	2482	1.406	2514
	BOZ-1 AMRD-2_Dec '95	-1432	2454	1.396	2486
	BOZ-3 AMRD-1_Feb '97	-1418	2022	1.215	2067
	BOZ-3 AMRD-2_Feb '97	-1418	1970	1.207	2015
	BOZ-8 AMRD-1_Oct '98	-1439	1729	1.288	1750
	BOZ-8 AMRD-2_Oct '98	-1439	1756	1.275	1777
SPARTEK (DIGITAL GAUGE)	BOZ-2 SPRTK-1_Feb '11	-852	1496	1.408	2345
	BOZ-8 SPRTK-1_Feb '11	-1239	1314	1.409	1618
	BOZ-9 SPRTK-1_Feb '11	-1400	2017	1.368	2092

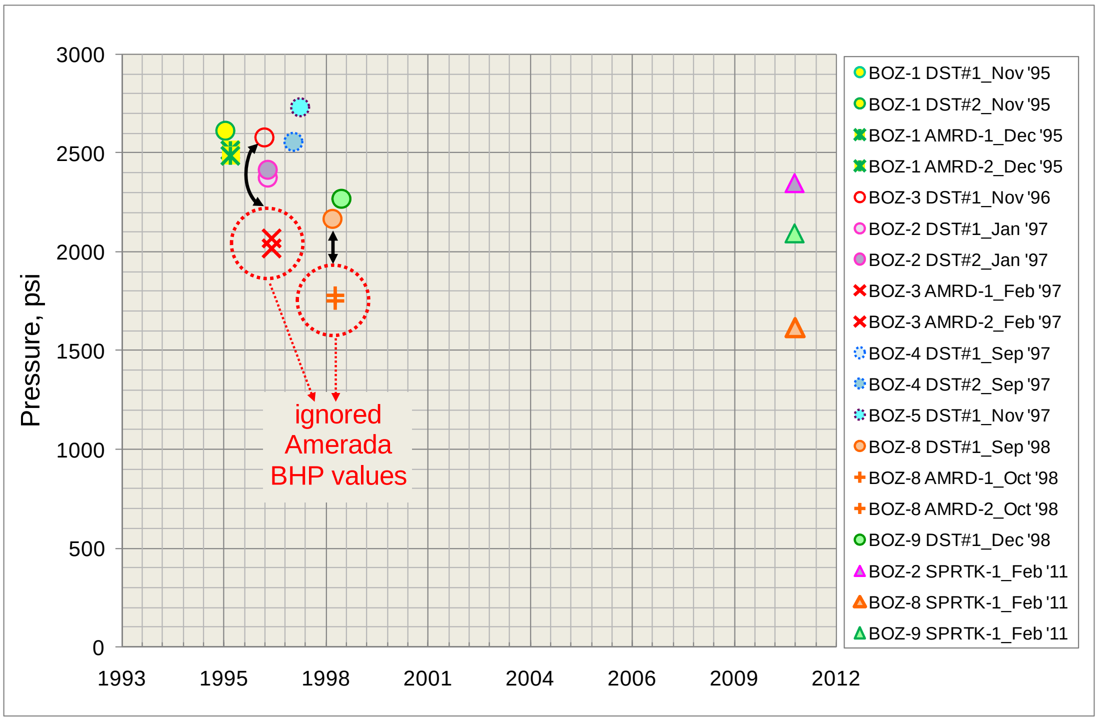

Figure 5.6 Date vs. pressure plot of pressure values corrected @1455 m ssTVD

The Amerada BHP values of Bozova-3 and 8 are much lower than their DST pressure values. This inconsistency may be stemming from the unstabilized pressure readings of the Amerada BHP measurements and because of their questionable reliability they are not taken into account in further steps of this study.

In order to determine the original reservoir pressure (Pi), the pressure values that are measured before the production beginning of wells are plotted on a pressure vs. depth graph in Figure 5.7. As clearly seen in this figure, pressure values show a wide distribution which makes it difficult to decide on Pi and they are examined to identify the ones that should be taken into account and the ones that should be ignored.

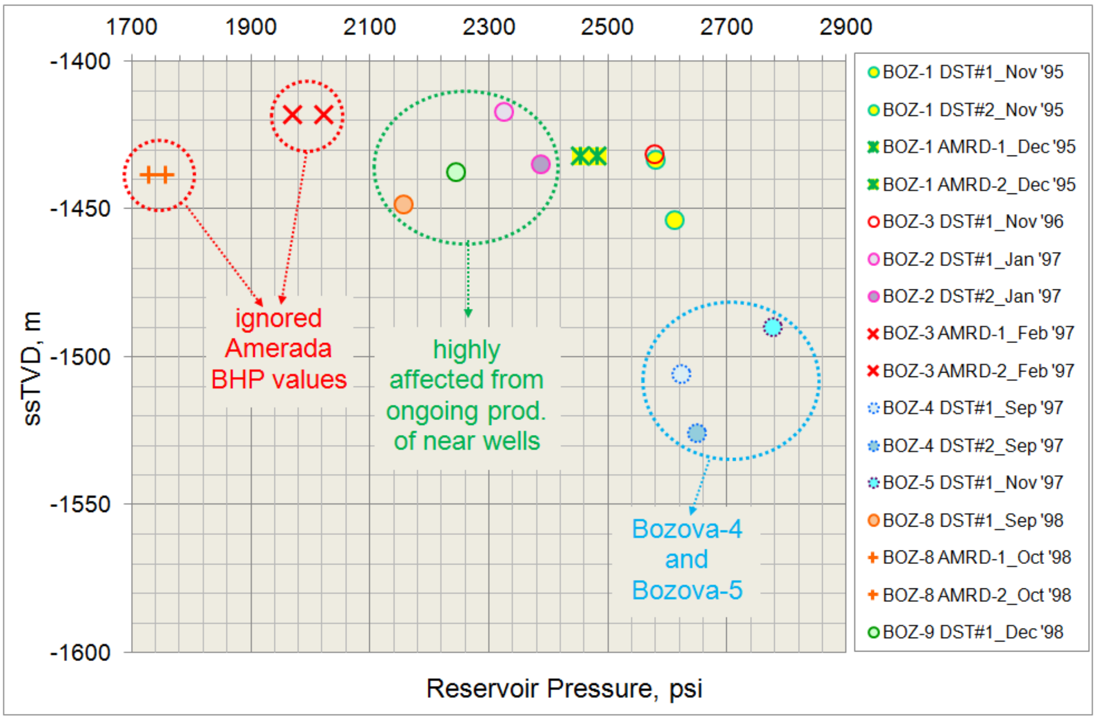

Figure 5.7 Pressure vs. depth plot of DST and Amerada BHP measurements

The pressure values that belong to wells Bozova-4 and 5 are slightly higher and taking these high pressure values in account may be misleading. The faults, which separate Bozova-4 and 5 from the main anticline structure is considered to be impermeable, thus the wells may have a completely different Pi other than the original reservoir pressure.

DST pressure values that belong to wells Bozova-2, 8 and 9 are ignored because they are obviously lower and this supports the idea that they may be highly affected from the ongoing production of near wells like Bozova-1, 2 and 3.

Considering all of these factors, the Pi value is determined as 2610 psi @ 1455 m ssTVD and shown in Figure 5.8. Oil pressure gradient is calculated as 1.301 psi/m.

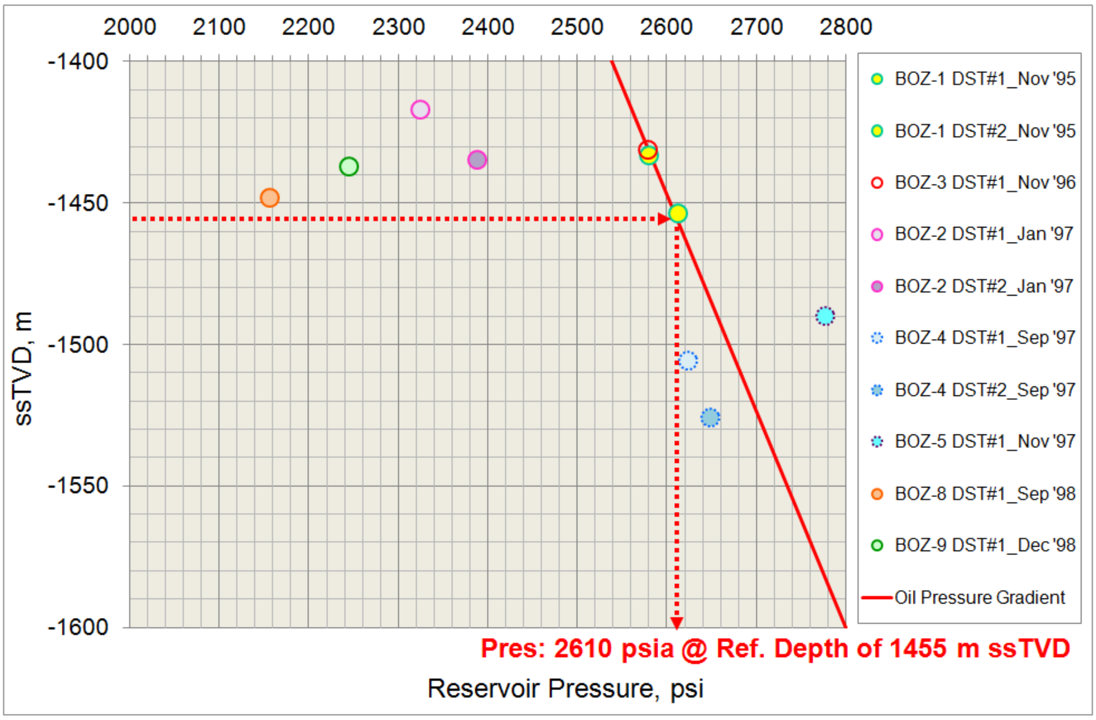

Figure 5.8 Pressure vs. depth plot for determination of Pi

5.2.4 The Uncertainty of WOC

The WOC of Reservoir Level could not be defined precisely by using pressure measurement data, due to several reasons. The pressure readings that are measured in the water bearing zone belong to wells Bozova-4 and 5. Since these wells are considered to be separated from the reservoir area with sealing faults, their pressure values cannot be used to determine where the water pressure gradient line pass and where the WOC is.

Furthermore, because of the capillary effects, the thickness of the transition zone corresponds to the majority of the Reservoir Level thickness, thus oil and water are not separated by a sharp boundary in the vertical direction. Within the transition zone, both oil and water phases are mobile. Thereupon logs do not give a hint about the estimation of WOC.

Leaving pressure measurements and log analysis behind, there remains Bozova-9 to be searched for establishing WOC. As mentioned “3.1 General Overview of The

Field” Bozova-9 was abandoned shortly after (11 months later) its water production percentage reaching 100 %. The tested perforation interval is 1918 – 1930 m, corresponding to 1453 – 1465 m ssTVD. The WOC penetrated in Bozova-9 might be at the depth of (top of perforation) 1453 m ssTVD, or (bottom of perforation) 1465 m ssTVD. Regarding the possibility of “WOC being at the bottom depth for Reservoir Level” and “the perforation gets connected with the WOC after a short period of production” 1477 m ssTVD is also a candidate for WOC.

Taking all of these factors into consideration, the uncertainty of WOC depth is studied through 3 different values which are considered to be informative on determination of the true reservoir description. Rounding and leaving equal intervals between the numbers, WOC depths to be studied in uncertainty analysis are taken as 1455, 1468 and 1480 m ssTVD (Figure 5.9).

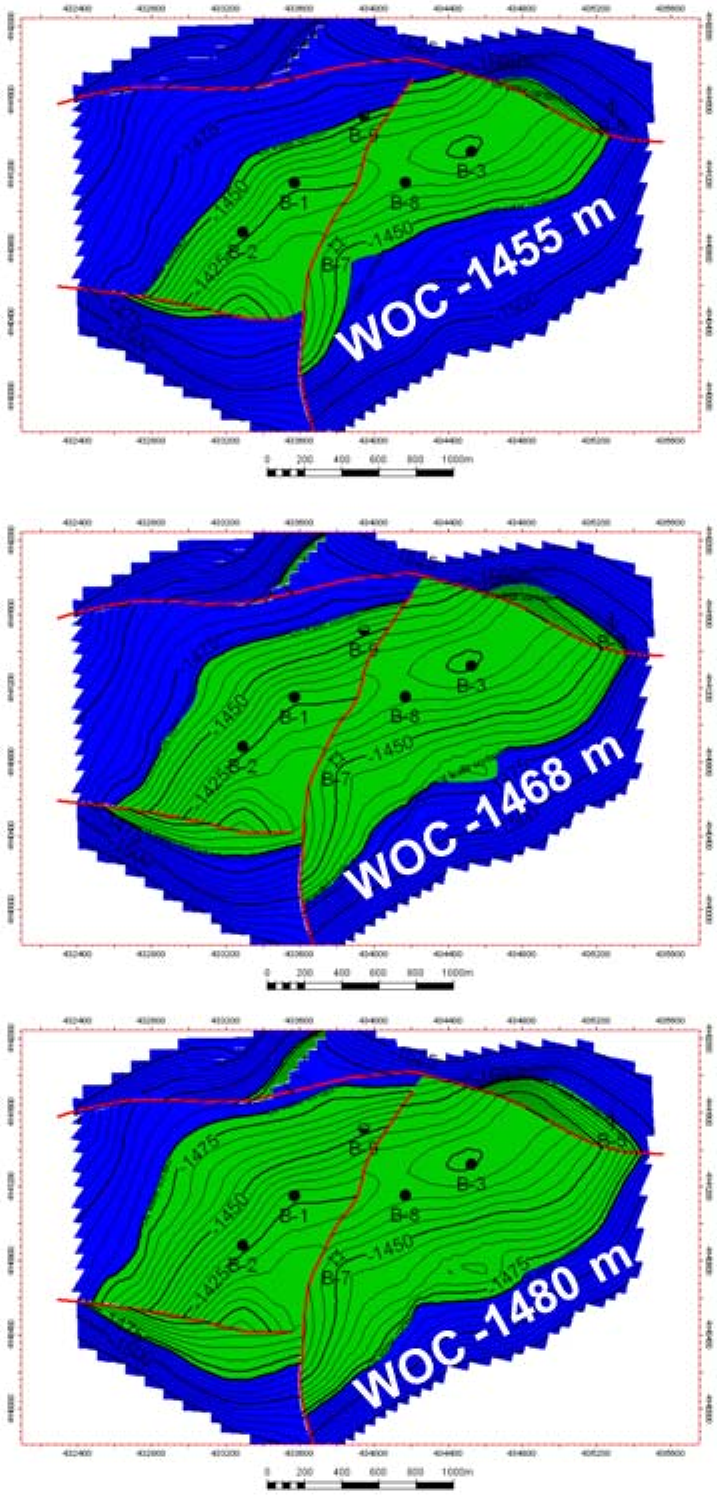

Figure 5.9 WOC depths studied in uncertainty analysis
(1455, 1468 and 1480 m ssTVD)

5.2.5 The Uncertainty in Pc/Krel Curves

There are 72 core plug samples taken from Reservoir Level cores of wells Bozova-1, 2, 3, 5 and 8. The numbers of porosity and permeability measurements are 12, 8, 34, 11 and 7 for wells Bozova-1, 2, 3, 5 and 8 respectively. Porosity-permeability cross plot is drawn for Reservoir Level, including DST permeability results to achieve porosity-permeability correlation. The correlation that is applied to distribute permeability in the simulation model is shown in Figure 5.10. Since the vertical permeability (k_v) and horizontal permeability (k_h) values do not differ in analysis results, the k_h/k_v ratio is taken as 1.

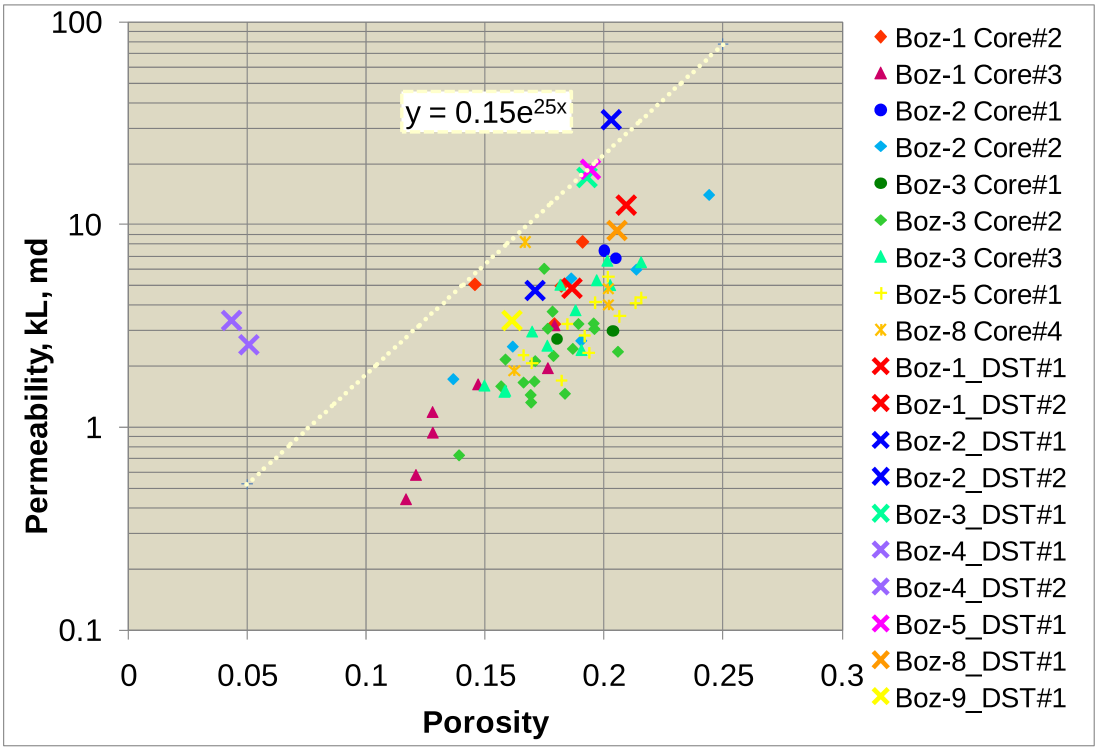

Figure 5.10 Porosity vs. core and DST permeabilities cross-plot for Reservoir Level

Also, special core analyses were conducted on Bozova core samples by TPAO Research Center. There are 19 sets of capillary pressure and relative permeability measurement data that are conducted on the same core plug samples. The capillary pressure curves and relative permeability curves are given in Figure 5.11 and Figure 5.12.

Even though the curves seem to be close to each other, their Swir values show a range between 0.05 and 0.18 and Swir is a key parameter while determining the oil in place. Similarly relative permeability curves assign the fundamental rules of flow functions. In order to investigate the impacts of Pc/krel curves on the simulation results they are studied through 19 sets of data.

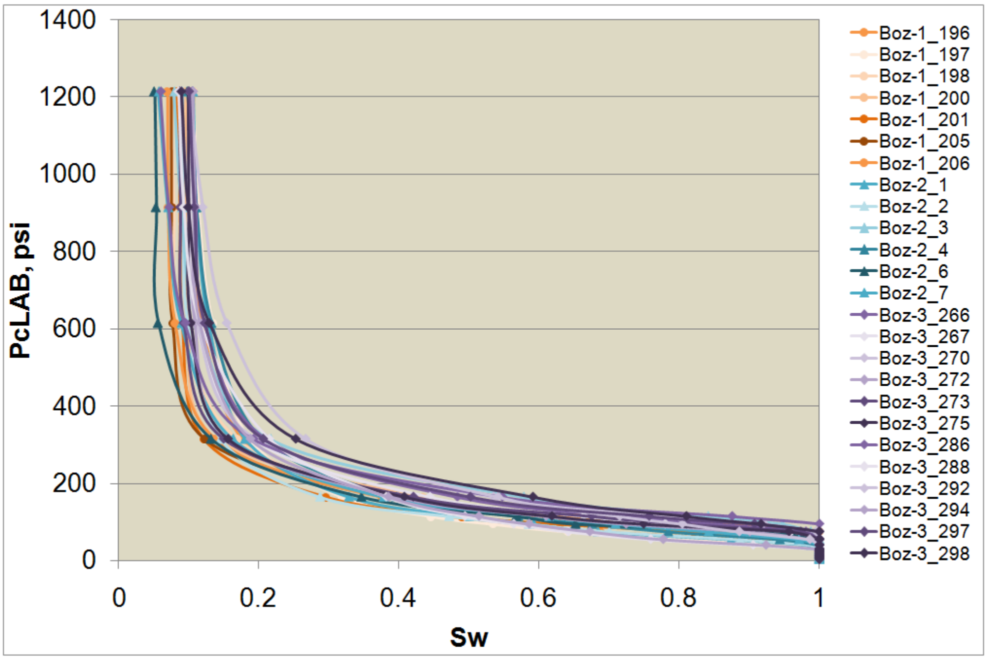

Figure 5.11 Capillary pressure curves for Reservoir Level

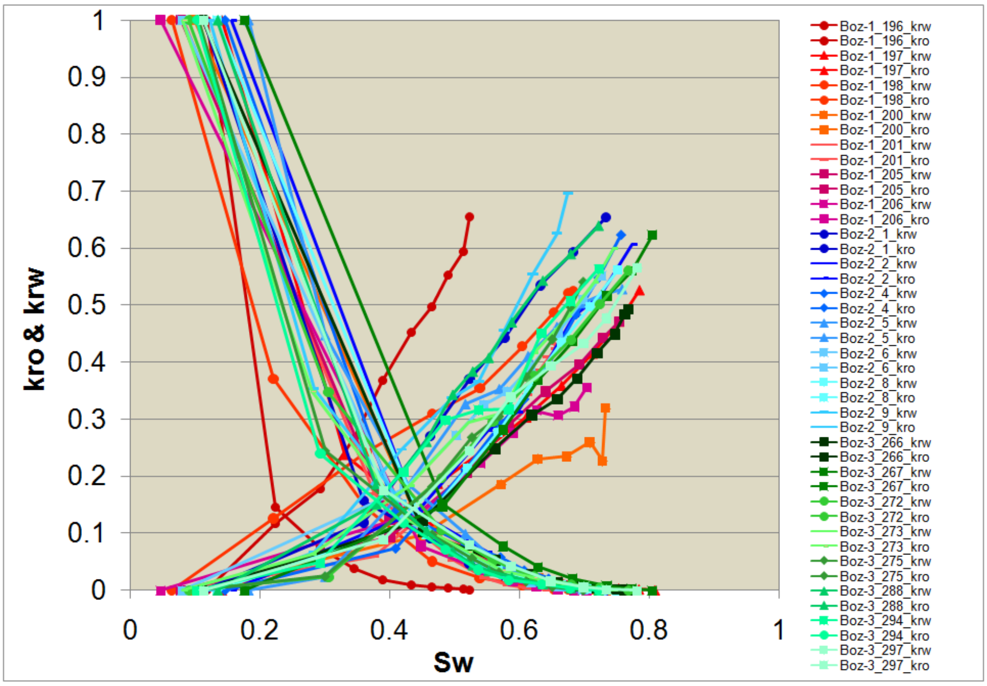

Figure 5.12 Relative permeability curves for Reservoir Level

5.2.6 The Uncertainty in Fluid Properties

The uncertainties of the reservoir properties, such as the geologic and petrophysical data, are often given more attention than the uncertainties of the fluid properties. The uncertainty of fluid property measurements affect the quality of fluid property data which in turn affecting the accuracy of simulation models. In addition to the inconsistency from the measurements, fluid sampling is another main source contributing to the accuracy of fluid property data. Therefore, it is essential to study the effect of the variation in fluid properties, such as oil viscosity, compressibility and bubble point pressure values to generate accurate reservoir simulation models.

There are 2 oil samples taken from wells Bozova-1 and 3. The PVT analysis results are given in Table 5.3 and Table 5.4. In order to investigate the effects of PVT data they are studied through these 2 sets of data.

Table 5.3 PVT analysis results of Bozova-1 sample

WELL	: BOZOVA-1
TEST TEMPERATURE	: 203 F
BUBLE POINT PRESSURE	: 191 PSIG
GOR	: 56.53 SCF/STB
THERMAL EXPANSION COEFFICIENT	: 6.3929 E-04 CC/CC/F

PRESSURE	OIL COMPRESSIBILITY
PSIG	CC/CC/PSIG
2500	5.9209 E-06
2000	6.5737 E-06
1500	7.6645 E-06

PRESSURE	DENSITY	Bo
PSIG	G/CC	BBL/STB
3000	0.8433	1.0806
2500	0.8408	1.0838
2000	0.8383	1.0871
1500	0.8353	1.0909
1000	0.8319	1.0955
750	0.83	1.0979
500	0.8288	1.0995
400	0.8279	1.1007
300	0.8274	1.1014
200	0.8269	1.1022
191	0.8268	1.1023
0	0.8596	1.0601

PRESSURE	VISCOSTY
PSIG	CP
3000	5.91
2500	5.71
2000	5.41
1500	5.12
1000	4.88
500	4.58
250	4.43
191	4.42
140	4.5
50	4.82
0	7.01

Table 5.4 PVT analysis results of Bozova-3 sample

WELL	: BOZOVA-3
TEST TEMPERATURE	: 170 F
BUBLE POINT PRESSURE	: 231 PSIG
GOR	: 59.4 SCF/STB
THERMAL EXPANSION COEFFICIENT	: 6.2620 E-04 CC/CC/F

PRESSURE	OIL COMPRESSIBILITY
PSIG	CC/CC/PSIG
2000	5.9270 E-06
1000	6.2494 E-06
400	6.4640 E-06

PRESSURE	DENSITY	Bo
PSIG	G/CC	BBL/STB
3000	0.8822	1.0476
2000	0.8755	1.0532
1000	0.8719	1.06
500	0.869	1.0636
400	0.8684	1.0643
300	0.8679	1.0648
231	0.8675	1.0653
0	0.8845	1.0449

PRESSURE	VISCOSTY
PSIG	CP
3000	10.2
2000	9.2
1000	8.2
500	7.9
300	7.7
231	7.6
0	10.1

5.3 Reservoir Simulation

The parameters, the effects of which are going to be studied in the simulation modeling, are determined in "5.2 Basic Reservoir Engineering". These are:

1. WOC depth (3 possible values),
2. Pc and krel curves (19 sets of SCAL data),
3. Oil PVT behavior (2 sets of PVT analysis data).

Following a full factorial experimental design, the combination of these parameters will give a total of 114 (3 x 2 x 19) cases to be simulated. The experimental design table showing the combination of uncertain variables and corresponding case names is given in Appendix C.

5.3.1 Making Fluid Model

6 fluid models for 2 PVT and 3 WOC sets are prepared. The factorial design for fluid modeling is given in Table 5.5.

Table 5.5 The factorial design for fluid modeling

Fluid Model	PVT	WOC
FM1	Boz-1	-1455
FM2	Boz-1	-1468
FM3	Boz-1	-1480
FM4	Boz-3	-1455
FM5	Boz-3	-1468
FM6	Boz-3	-1480

Initial conditions are entered into the model as mentioned in "5.2.3 Determination of Original Reservoir Pressure", given in Table 5.6.

Table 5.6 Initial conditions

Ref. Depth, m	Pressure, psia	Temperature, ºF
-1455	2610	177

5.3.2 Making Rock Physics Functions

Relative permeability and capillary pressure data for each core plug sample are entered into the rock physics functions as spreadsheets (Figure 5.13 and Figure 5.14).

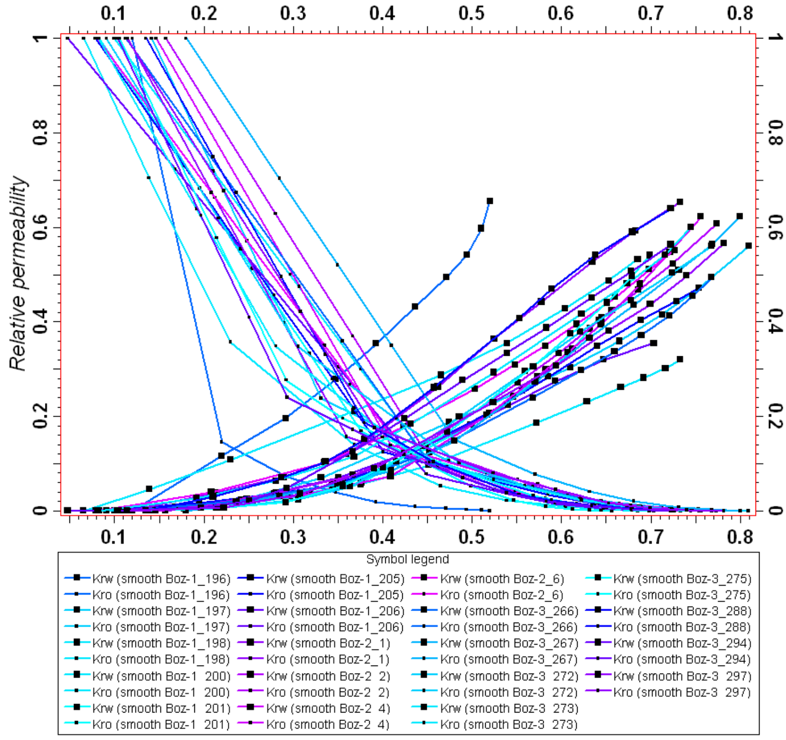

Figure 5.13 Smoothed relative permeability curves taken from SCAL data

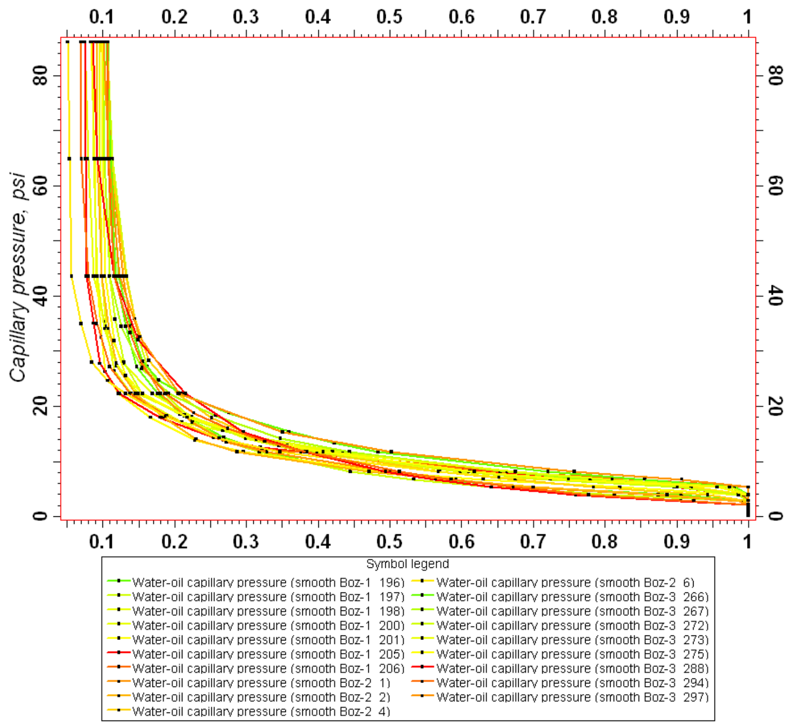

Figure 5.14 Smoothed capillary pressure curves taken from SCAL data

5.3.3 Making Aquifer Model

The need for an aquifer was essential in this reservoir simulation in that, all production values simulated without an aquifer model crashed because of lack of pressure support. In addition to this, after the BHP measurements made in February 2011, it became clear that the pressure decline observed in the field (in a 16-year production period) was very low, indicating the existence of an aquifer (Figure 5.15).

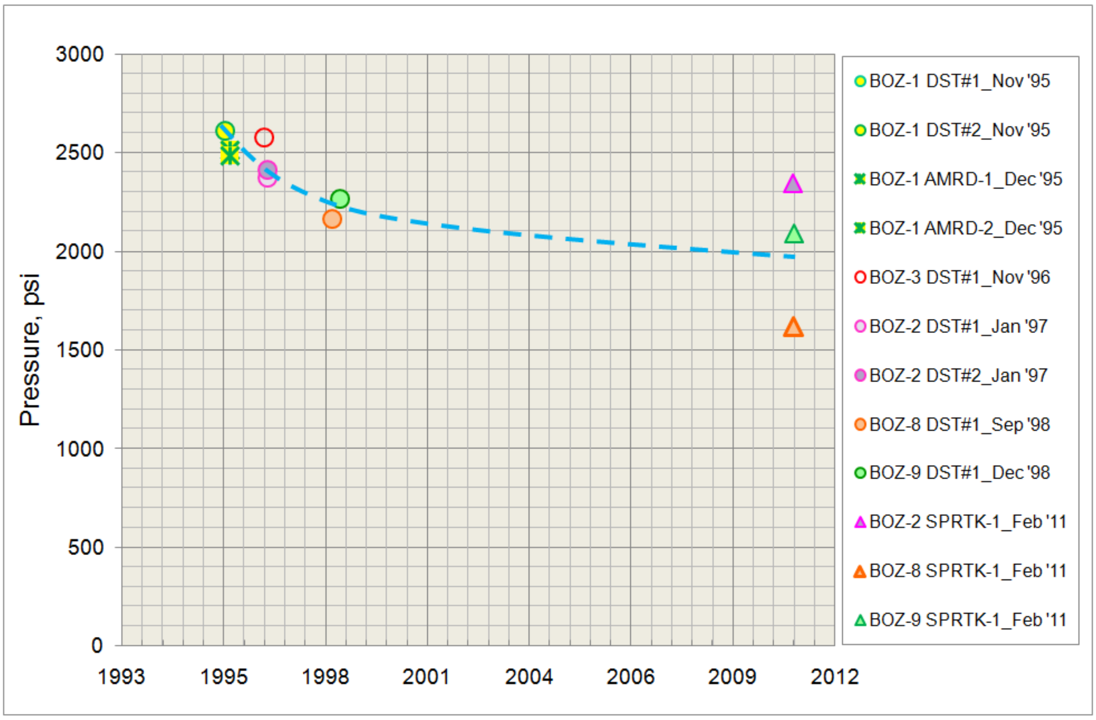

Figure 5.15 Decline in reservoir pressure during production observed in the field

Furthermore, the salinity of the produced water from the wells shows significant changes during the production period and this gives an important clue about the aquifer effect. Taking a closer look, the salinity values (shown as green triangles in the figures) of the wells change as follows: Bozova-1, from 38,000 to 26,000 ppm (Figure 5.16); Bozova-3, from 30,000 to 26,000 ppm (Figure 5.17); Bozova-8, 34,000 to 26,000 ppm (Figure 5.18). This gradual decrease in salinity indicates that, as the wells go on production they are supported by an aquifer of lower salinity. The major salinity changes can easily be matched with major increments in water percentage. It is also observed that, the sudden increase of water production at early stages of production is taken under control successfully by narrowing the perforation intervals in wells Bozova-1 and 3.

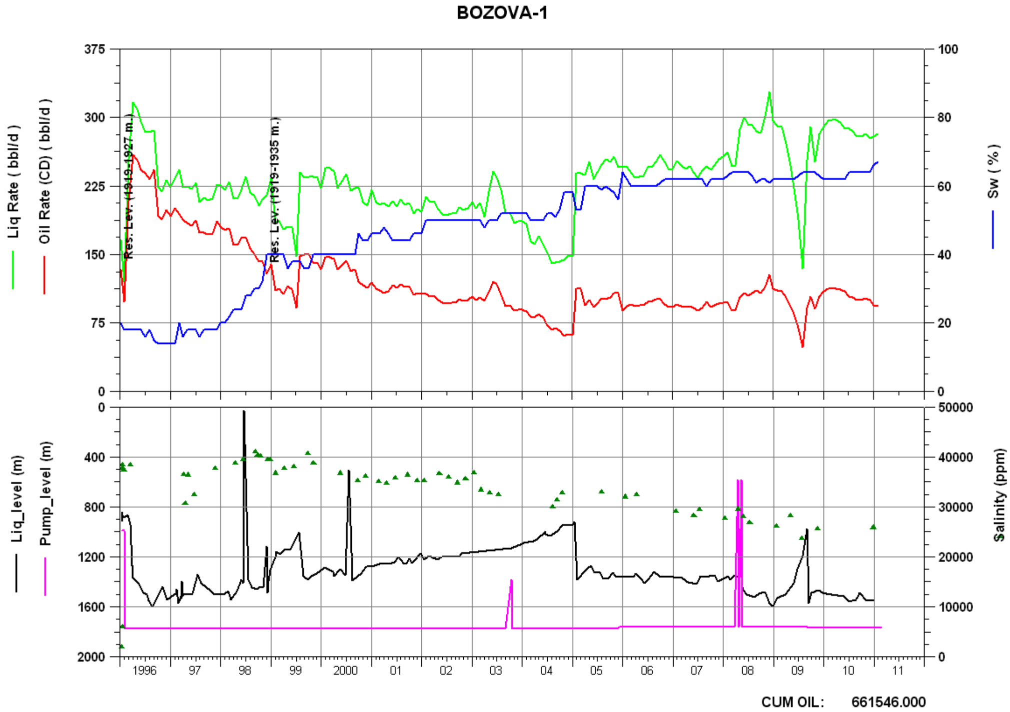

Figure 5.16 Test and production graph of Bozova-1

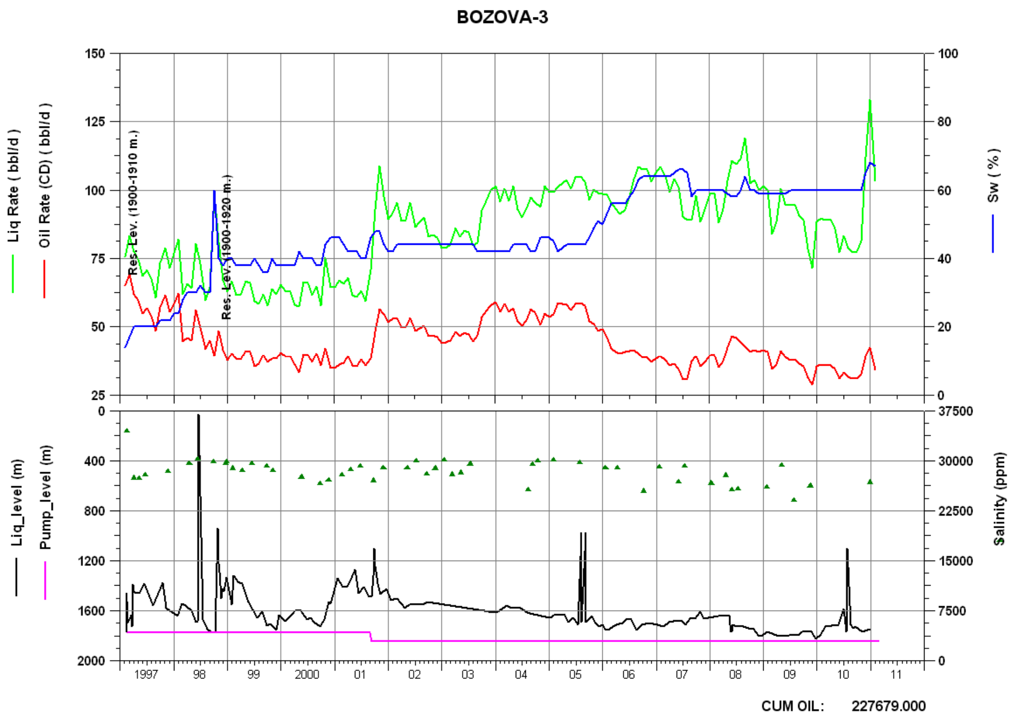

Figure 5.17 Test and production graph of Bozova-3

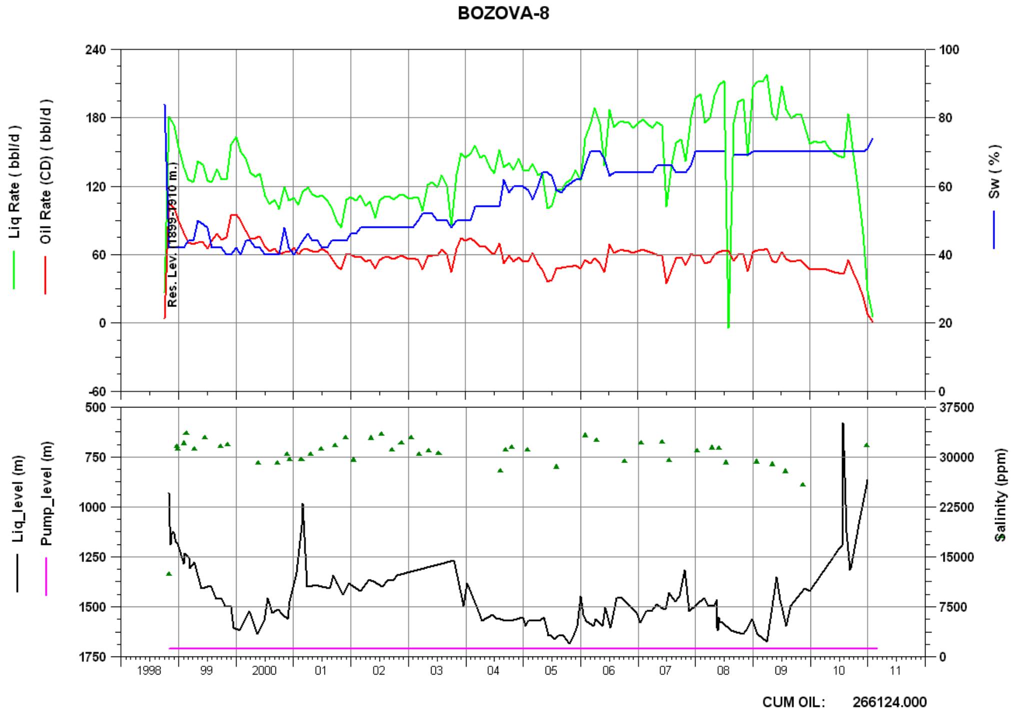

Figure 5.18 Test and production graph of Bozova-8

The only well that produces low salinity water from the beginning of its production is Bozova-2, salinity of which changes only from 5,000 to 3,000 ppm (Figure 5.19).

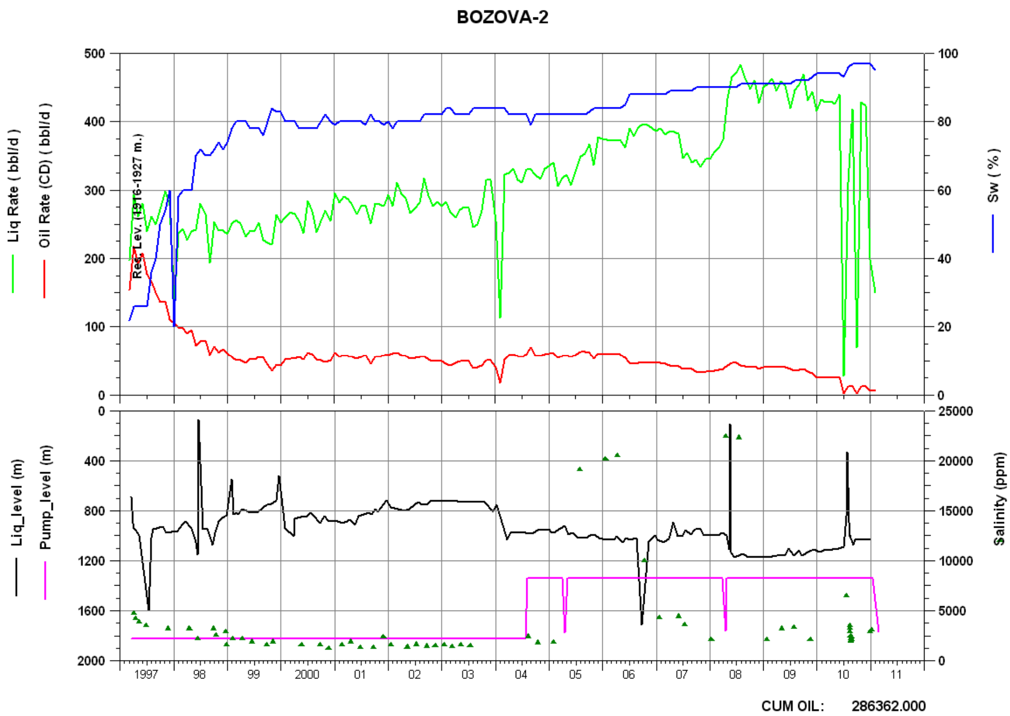

Figure 5.19 Test and production graph of Bozova-2

As a result of all these considerations the aquifer is conceived to be an edge water drive aquifer supporting the field from an area close to Bozova-2, in a direction from south to the rest of the field. After some small scale sensitivity analysis concerning the area and the strength of the aquifer, it is connected to the bottom of Reservoir Level, with a bottom to top and edge drive definition. (Figure 5.20).

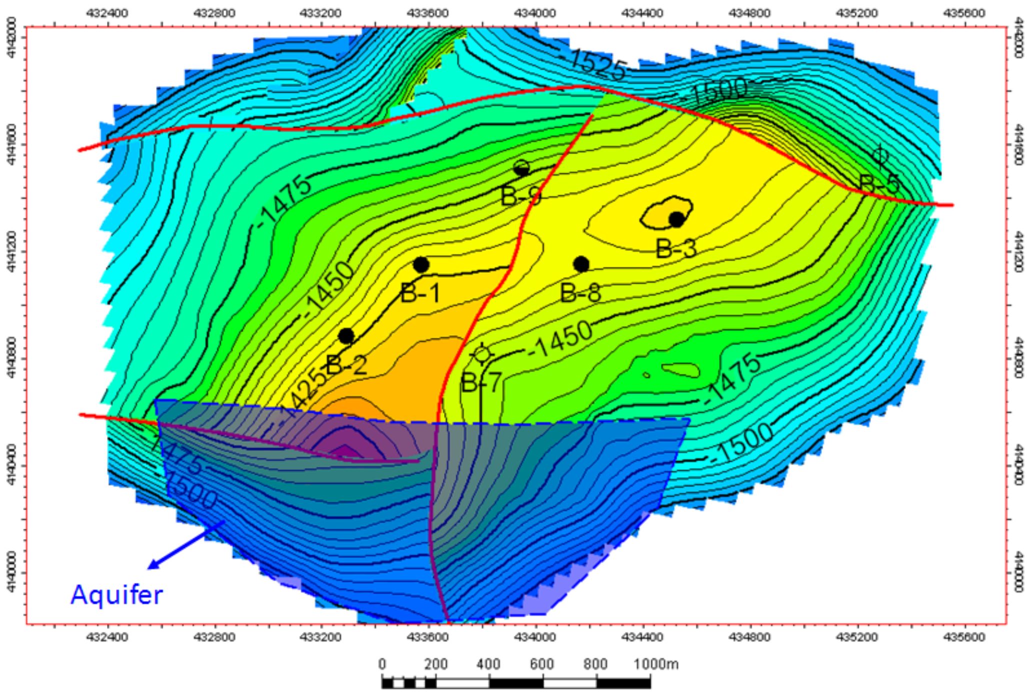

Figure 5.20 Aquifer connected to the bottom of Reservoir Level

5.3.4 Running the Simulation Models

The development strategies are generated for history matching purposes. Oil production rate is chosen as the production control mode. The limiting bottom hole pressure is taken as the bubble point pressure.

The average execution time for a single simulation was about 3 minutes on a computer with an Intel® Core™2 Duo CPU 3.16 GHz processor and 3.48 GB RAM. The total time required to run 114 simulation models is about 6 hours. Since this time period is considered to be moderate, the idea of running all possible cases is applied.

5.4 History Match Analysis

History match analysis is used to quantify how well the simulation models reproduce the observed well data. In order to quantify match values root mean square (RMS) technique is used. RMS signifies the calculated error for every point. The bigger the RMS value the worse the match of the simulation model with the observed well data.

$$M = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(\frac{Si - Oi}{\sigma}\right)^2} \tag{5.1}$$

Where:

M is the match value.

S is the simulated value.

O is the observed value.

N is the number of points (i) that is used to compute M.

σ is a normalization parameter that is used to make sure all the match values are in the same order of magnitude.

The normalization parameter σ is used to assign one vector, or a selection of the vectors, different weighting factors when combining matches. It makes the match unitless and makes the result in a certain normalized range. The "Average (%)" option divides the error (difference between simulated and observed) with the percentage of the average observed value, whereas "Absolute" option uses the specified value. By using an absolute value of 1, the match value will be the un-weighted average error in the original unit.

Sampling frequency is chosen as simulation or observed frequency. Simulation frequency averages the observed data and compares with the simulated data at every time step. Observed frequency compares the simulated values at all observed data points.

Sometimes improving one match can worsen the other. In order to clarify such contradicting match evaluations a combined vector match, which takes all of the vector matches into account, is essential. The calculation for a combined vector is performed in the following way:

$$M_{(combination)} = \sqrt{\frac{\sum\limits_{vectors}\sum\limits_{wells}(M_{(wells,vectors)})^2}{\sum\limits_{vectors}\sum\limits_{wells}(1)}} \tag{5.2}$$

The individual settings specified for the vectors used in this study is shown in Table 5.7.

Table 5.7 Normalization parameters for combined vector match

Vector Match	Normalization	Frequency
Water Cut	Absolute, 1	Simulation
Water Production Rate	Average(%), 10	Simulation
Oil Production Rate	Average(%), 10	Simulation
Water Production Cumulative	Average(%), 10	Simulation
Oil Production Cumulative	Average(%), 10	Simulation
Bottom Hole Pressure	Average(%), 10	Observed

Since it is more reliable to use rates rather than ratios such as water cut, the weight factor for water cut vector is given an absolute value of 1. The remaining vectors are set to an average normalization parameter of 10 %. The only vector, the sampling frequency of which is set to observed, is the BHP.

5.5 Two Level (2^k) Factorial Design Technique as an Uncertainty Quantification Method

For the purpose of obtaining information in an efficient and less time consuming way, statistically designed experiments are used. If the purpose of the experimentation is to determine the important variables, the factorial designs are extremely useful. Factorial designs also provide the combined effect of two or more variables (Saxena and Pavelic, 1971).

In factorial designs, conditions are chosen by selecting a fixed number of levels for each variable and then experiments are run at all possible combinations. A special case of factorial designs is “Two Level Factorial Designs”. These designs are usually written as 2^k designs, where 2 denotes the number of levels of each variable and k is the number of the variables under investigation. The number of experiments that are to be performed for the factorial designs is given in as:

$$\text{Number of experiments} = 2^k \tag{5.3}$$

In order to explain through an example, a 2^k design is constructed and analyzed for three variables: x_1, x_2 and x_3. For all three variables, the effects of which are to be searched, two levels are identified: one as “high” and one as “low”. A coding system is used so that “+1” denotes the high level, and “-1” denotes the low level, just to simplify the design. The 2^k factorial design for the three variables require eight (2^3) tests. The design matrix is given in Table 5.8, which gives the combination of the experiments that are to be performed. After designing the experiment, the tests are performed and the responses (y) are obtained.

Table 5.8 Coded design matrix with results

Test Run No	x_1	x_2	x_3	y
1	-1	-1	-1	y_1
2	+1	-1	-1	y_2
3	-1	+1	-1	y_3
4	+1	+1	-1	y_4
5	-1	-1	+1	y_5
6	+1	-1	+1	y_6
7	-1	+1	+1	y_7
8	+1	+1	+1	y_8

If the three variables are considered as three mutually perpendicular coordinate axes x_1, x_2, x_3, the 2^3 factorial design can be geometrically represented as a cube shown in Figure 5.21.

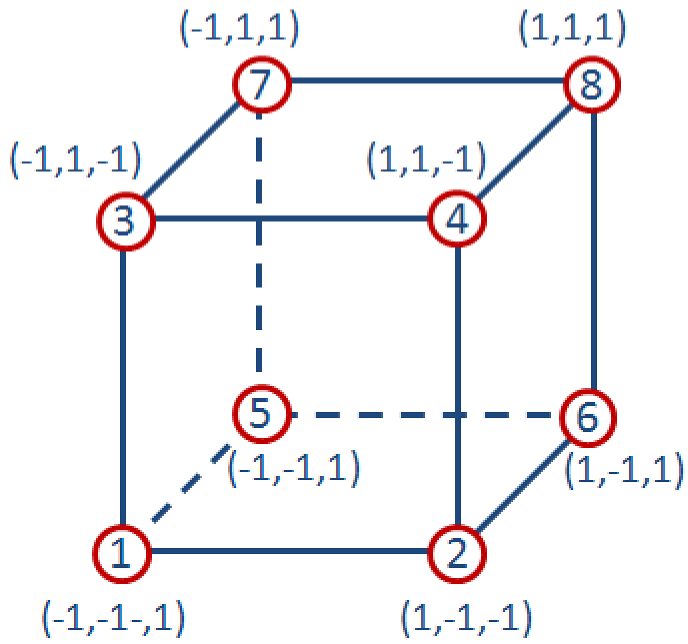

Figure 5.21 Geometrical representation of the 2^3 design (adapted from Saxena and Pavelic, 1971)

Once the tests are performed and the results are obtained, the influence of each variable on the response can be obtained by calculating the average effects. For example; in Figure 5.21, for test number 1 and 2, the conditions of x_2 and x_3 are the same but x_1 conditions are different, i.e., high level of x_1 is used for test 2 while a low level is used for test 1. Similarly, for the pairs of test 3 and 4; 5 and 6; 7 and 8, each pair involves similar test conditions with respect to x_2 and x_3 but different test conditions with respect to x_1. Thus, the difference in the results within each of these pairs reflects the effect of x_1 alone. To calculate the overall average effect of x_1, the four differences are averaged as shown in Equation 5.4.

$$E_1 = \frac{(y_2 - y_1) + (y_4 - y_3) + (y_6 - y_5) + (y_8 - y_7)}{4} \tag{5.4}$$

Geometrically, the average effect of x_1 (E_1) is simply the difference between the average results on a plane at high level of x_1 and the average result on a plane at low level of x_1. The high and low level planes for all variables x_1, x_2 and x_3 are shown in Figure 5.22.

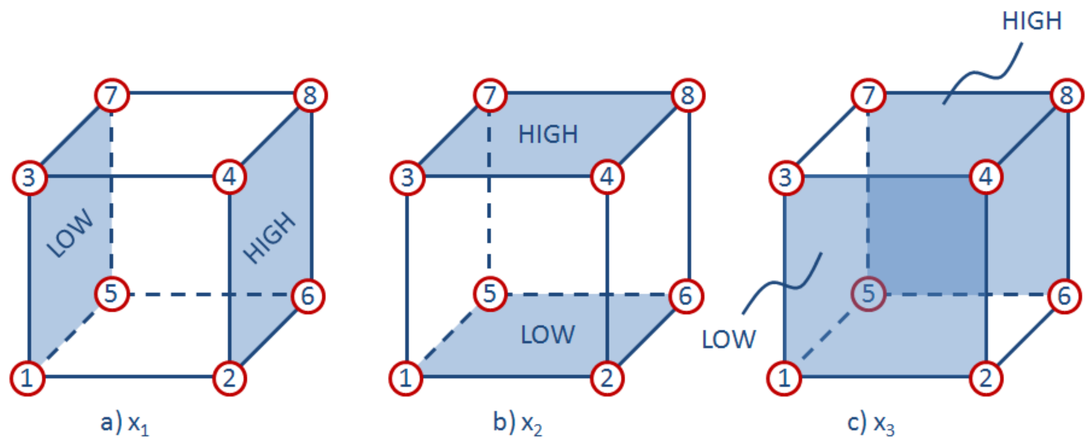

Figure 5.22 The high and low level planes for variables x_1, x_2 and x_3 (adapted from Saxena and Pavelic, 1971)

In general, the average effect is computed as in Equation 5.5.

$$\text{Average Effect} = (\text{Average of y's at high level}) - (\text{Average of y's at low level}) \quad (5.5)$$

In order to calculate the interaction between x_1 and x_2 (E_{12}), compressing the cube in the direction of x_3, the cube is transformed into a square as shown in Figure 5.23. The diagonal representing the high plane includes tests 1, 5, 4 and 8; whereas the low plane consists of tests 2, 6, 3 and 7.

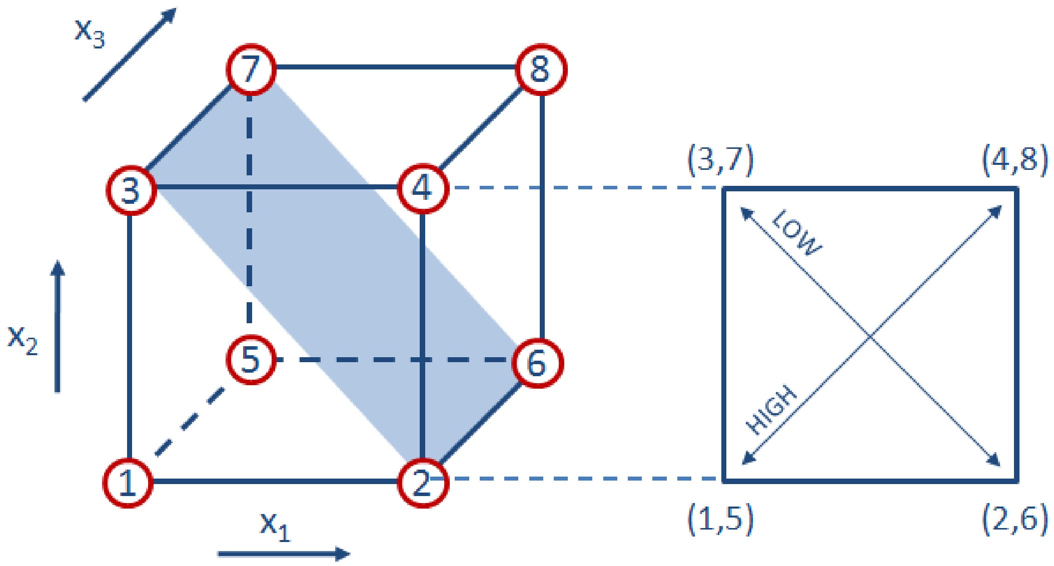

Figure 5.23 The high and low level planes for calculating the interaction between x_1 and x_2 (E_{12}) (adapted from Saxena and Pavelic, 1971)

The interaction between x_1 and x_2 can be calculated by Equation 5.6.

$$E_{12} = (\text{Average of y's at high plane}) - (\text{Average of y's at low plane}) \tag{5.6}$$

There is also a simplified method in order to calculate two and three-factor interactions. The first step is to obtain a calculation matrix from the design matrix. This is done by multiplying all the columns of the design matrix in all possible ways. The multiplication of the columns is done by multiplying the corresponding elements of the columns. For example column x_1x_3 is obtained as:

$$\begin{array}{ccccc} \begin{bmatrix} -1 \\ +1 \\ -1 \\ +1 \\ -1 \\ +1 \\ -1 \\ +1 \end{bmatrix} & x & \begin{bmatrix} -1 \\ -1 \\ -1 \\ -1 \\ +1 \\ +1 \\ +1 \\ +1 \end{bmatrix} & = & \begin{bmatrix} +1 \\ -1 \\ +1 \\ -1 \\ -1 \\ +1 \\ -1 \\ +1 \end{bmatrix} \\ \scriptstyle Column x1 & & \scriptstyle Column x3 & & \scriptstyle Column x1x3 \end{array} \tag{5.7}$$

The complete calculation matrix along with the design matrix and the results y, are shown in Table 5.9.

Table 5.9 Design and calculation matrix; and the results (Saxena and Pavelic, 1971)

Test Run No	x_1	x_2	x_3	x_1x_2	x_1x_3	x_2x_3	$x_1x_2x_3$	y
1	-1	-1	-1	+1	+1	+1	-1	y_1
2	+1	-1	-1	-1	-1	+1	+1	y_2
3	-1	+1	-1	-1	+1	-1	+1	y_3
4	+1	+1	-1	+1	-1	-1	-1	y_4
5	-1	-1	+1	+1	-1	-1	+1	y_5
6	+1	-1	+1	-1	+1	-1	-1	y_6
7	-1	+1	+1	-1	-1	+1	-1	y_7
8	+1	+1	+1	+1	+1	+1	+1	y_8

DESIGN MATRIX CODED

CALCULATION MATRIX

The average effects and the interactions are then computed by multiplying the relevant column with the column y and dividing by the number of plus signs in the column. For example the average effect of E_2 is calculated as follows:

$$E_2 = \left(\frac{1}{Number.of.plus.signs.in.column.x_2} \right) x \underbrace{\begin{bmatrix} -1 \\ -1 \\ +1 \\ +1 \\ -1 \\ -1 \\ +1 \\ +1 \end{bmatrix}}_{Column.x2} x \underbrace{\begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ y_4 \\ y_5 \\ y_6 \\ y_7 \\ y_8 \end{bmatrix}}_{Column.y} \tag{5.8}$$

The three-factor interaction E_{123} is:

$$E_{123} = \left(\frac{1}{Number.of.plus.signs.in.column.x_1 x_2 x_3} \right) x \underbrace{\begin{bmatrix} -1 \\ +1 \\ +1 \\ -1 \\ +1 \\ -1 \\ -1 \\ +1 \end{bmatrix}}_{Column.x1.x2.x3} x \underbrace{\begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ y_4 \\ y_5 \\ y_6 \\ y_7 \\ y_8 \end{bmatrix}}_{Column.y} \tag{5.9}$$

The analysis of the results can be carried out by ranking the effects and interactions according to the absolute magnitudes.

CHAPTER 6

RESULTS AND DISCUSSIONS

6.1 Screening the Simulation Results

A total number of 114 simulation runs are conducted for the uncertainty evaluation, without pursuing the goal of a history matched best case. In order to visualize the results of the simulations according to their goodness of fit, they are viewed in many different aspects. In order to clearly visualize the over-lapping results, the plots are separated in two groups according to the used fluid model; first group as FM1, FM2 and FM3; second group as FM4, FM5 and FM6. First group models (FM-1, 2, 3) use the PVT data of Bozova-1 (which will be named as PVT-1) and the second group models (FM-4, 5, 6) use the PVT data of Bozova-3 (which will be named as PVT-3). The details of fluid models are given in “5.3.1 Making Fluid Model”.

6.1.1 Production Rate Results

The oil and water production rate results for the simulations are shown in Figure 6.1 (PVT-1), Figure 6.2 (PVT-3); and in Figure 6.3 (PVT-1) and Figure 6.4 (PVT-3) respectively. As clearly seen in figures, the results of the simulations that have the same fluid model are grouped as being close to each other. Fluid model is constructed upon combination of 2 items; WOC and PVT properties. When the results of first group (FM1, 2, 3 that belong to PVT-1) is compared to the results of the second group (FM-4, 5, 6 that belong to PVT-3) it is easy to say that uncertainty of PVT data make a minor impact on the results; but it is difficult to decide whether WOC depth is or Pc/krel curves are more determinant on the production rate results. This is an issue to be clarified after history match analysis results.

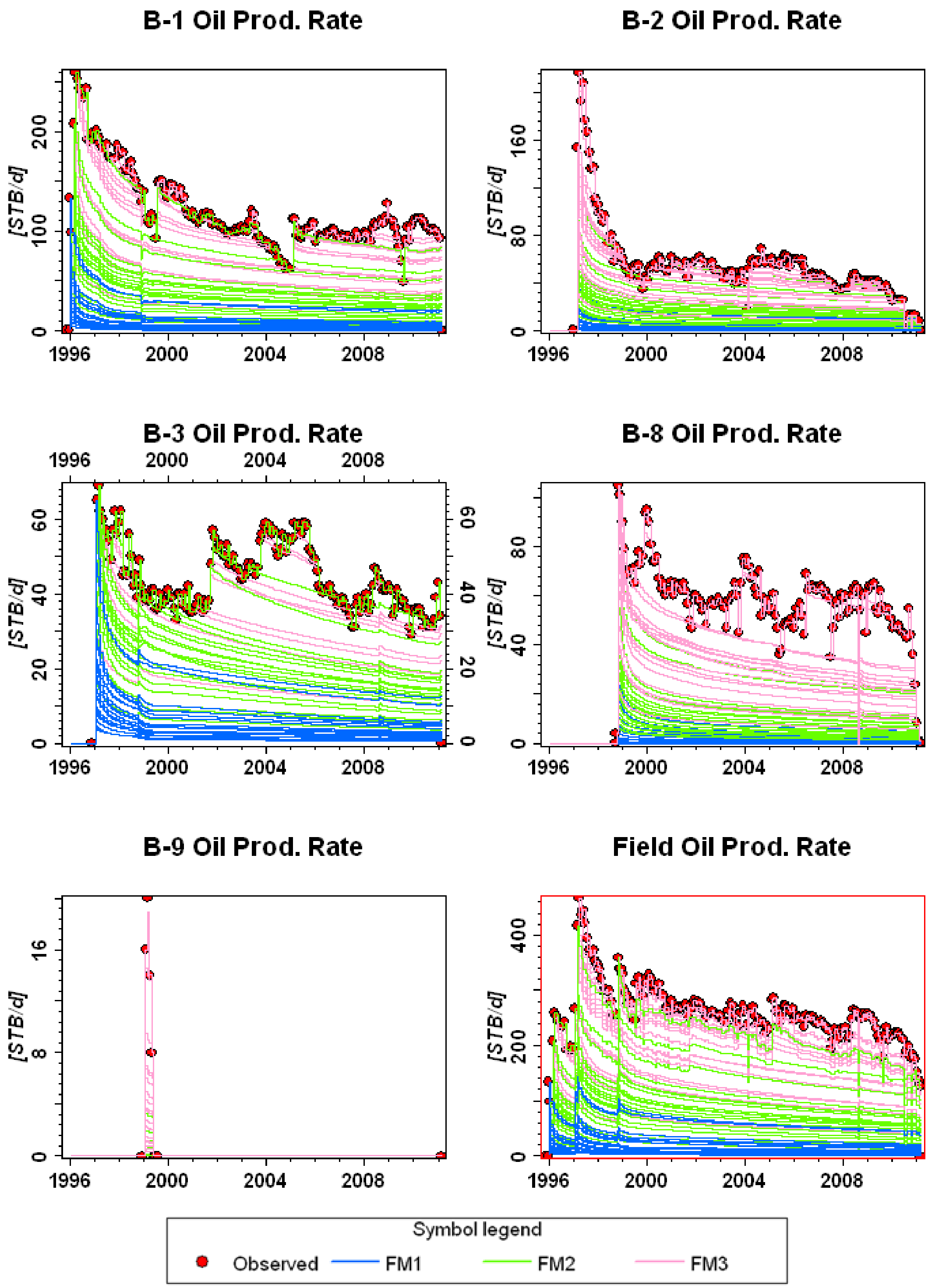

Figure 6.1 Oil production rates of simulation models (PVT-1: FM1,2,3)

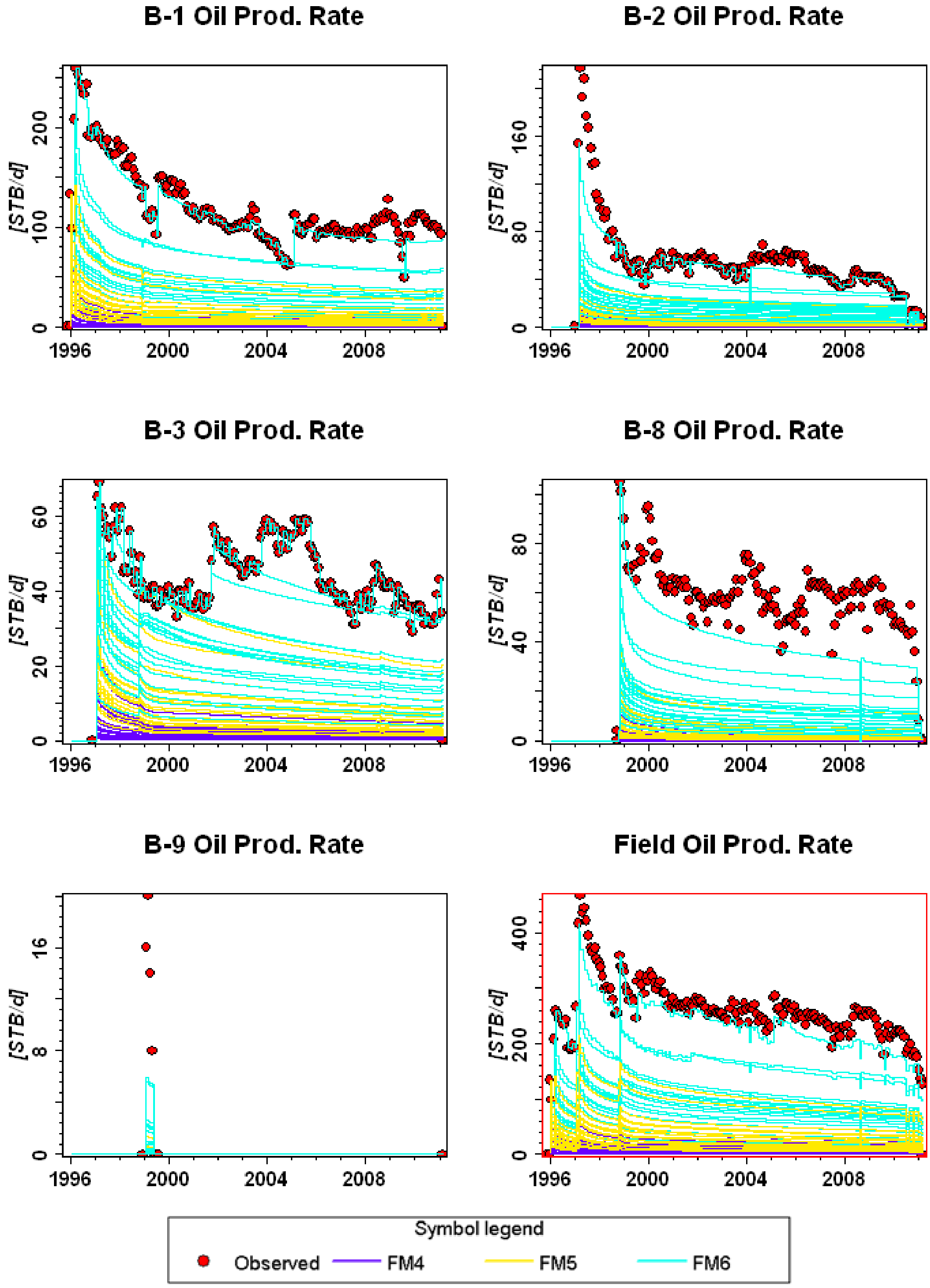

Figure 6.2 Oil production rates of simulation models (PVT-3: FM4,5,6)

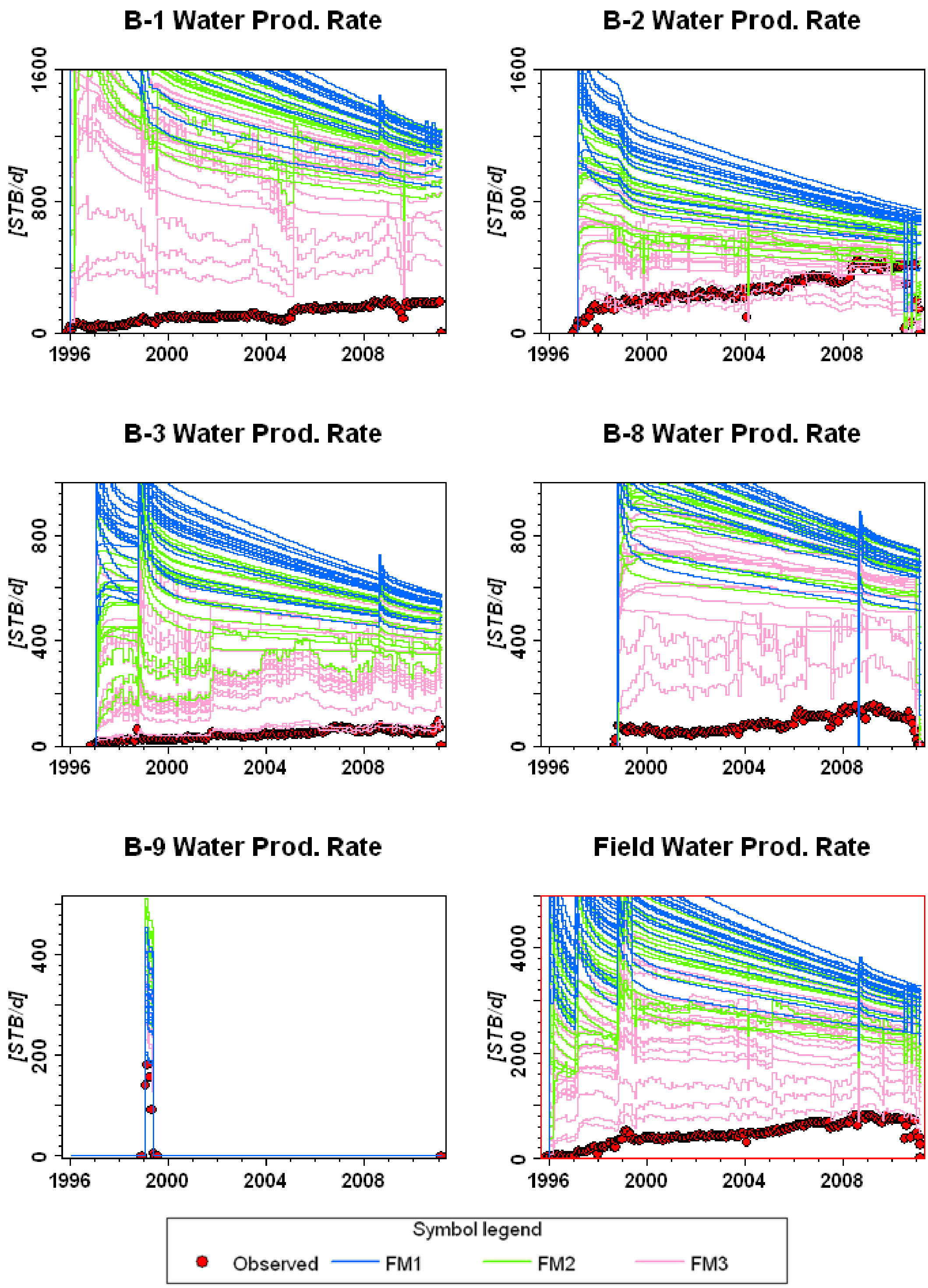

Figure 6.3 Water production rates of simulation models (PVT-1: FM1,2,3)

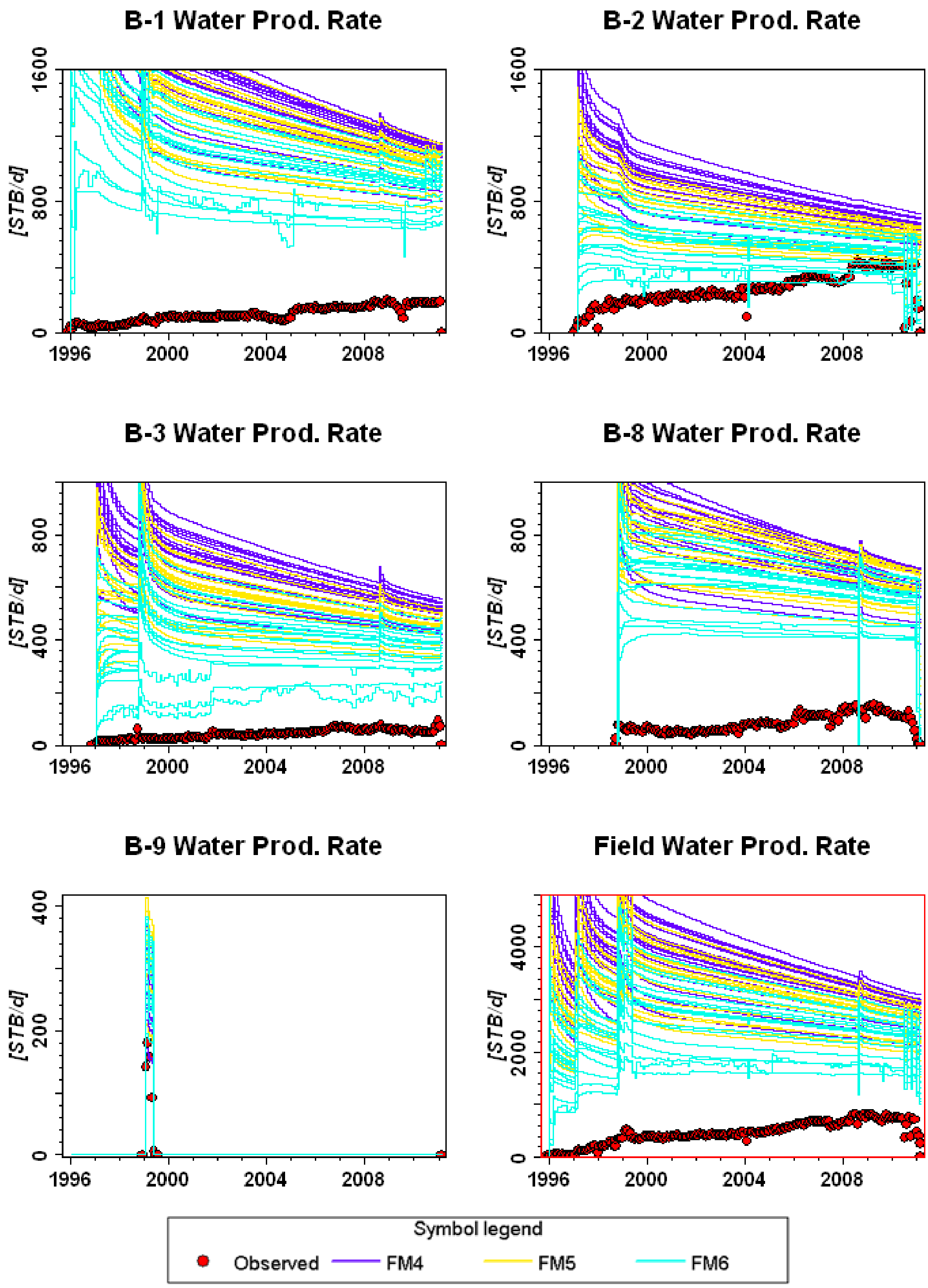

Figure 6.4 Water production rates of simulation models (PVT-3: FM4,5,6)

Indicating a WOC of 1480 m ssTVD, simulation cases of FM3, FM6 are the best matched models. Also FM2, having a WOC of 1468 m ssTVD, shows matched results for some of the wells. The worst matched simulation models FM1 and FM4 are not capable of producing the target oil production rates even if they produce too much water. The goodness of the water production rate results is parallel to the goodness of the oil production rate results in that, as the water production rate results get closer to the observed data, oil production rate results also get closer to the observed data.

The reason why PVT-1 model results show better match depends on the fact that PVT-1 has lower viscosity values than PVT-3. This situation directly affects the mobility ratio of oil. Also higher initial GOR values result in higher oil production because gas enhances the recovery performance. But this is not the main point for the different behaviours of the 2 PVT groups because their initial GOR values do not show a large variation. Another determinant is the oil compressibility value, which is a source of energy for fluid flow in the reservoir. The oil compressibility of PVT-1 is higher than the oil compressibility of PVT-3, which again favors the results of PVT-1 simulation models.

6.1.2 Cumulative Production Results

The cumulative oil and water production rate results for the simulations are shown in Figure 6.5, Figure 6.6 and in Figure 6.7 and Figure 6.8 respectively. The same reasons aforementioned in “6.1.1 Production Rate Results” again explains the matched models. The most effective variables on cumulative production results are depth of WOC level and Pc/krel curves.

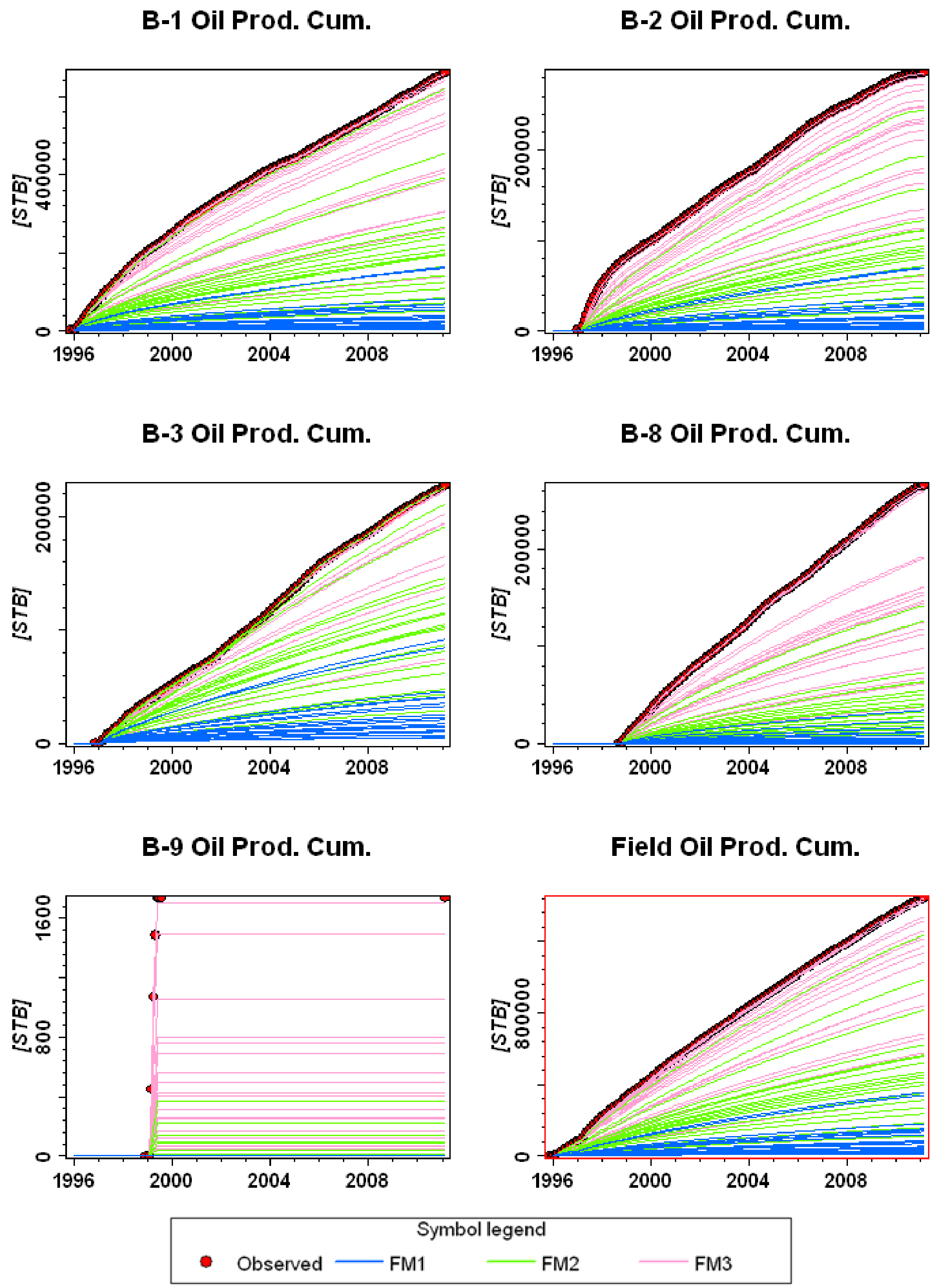

Figure 6.5 Cumulative oil productions of simulation models (PVT-1: FM1,2,3)

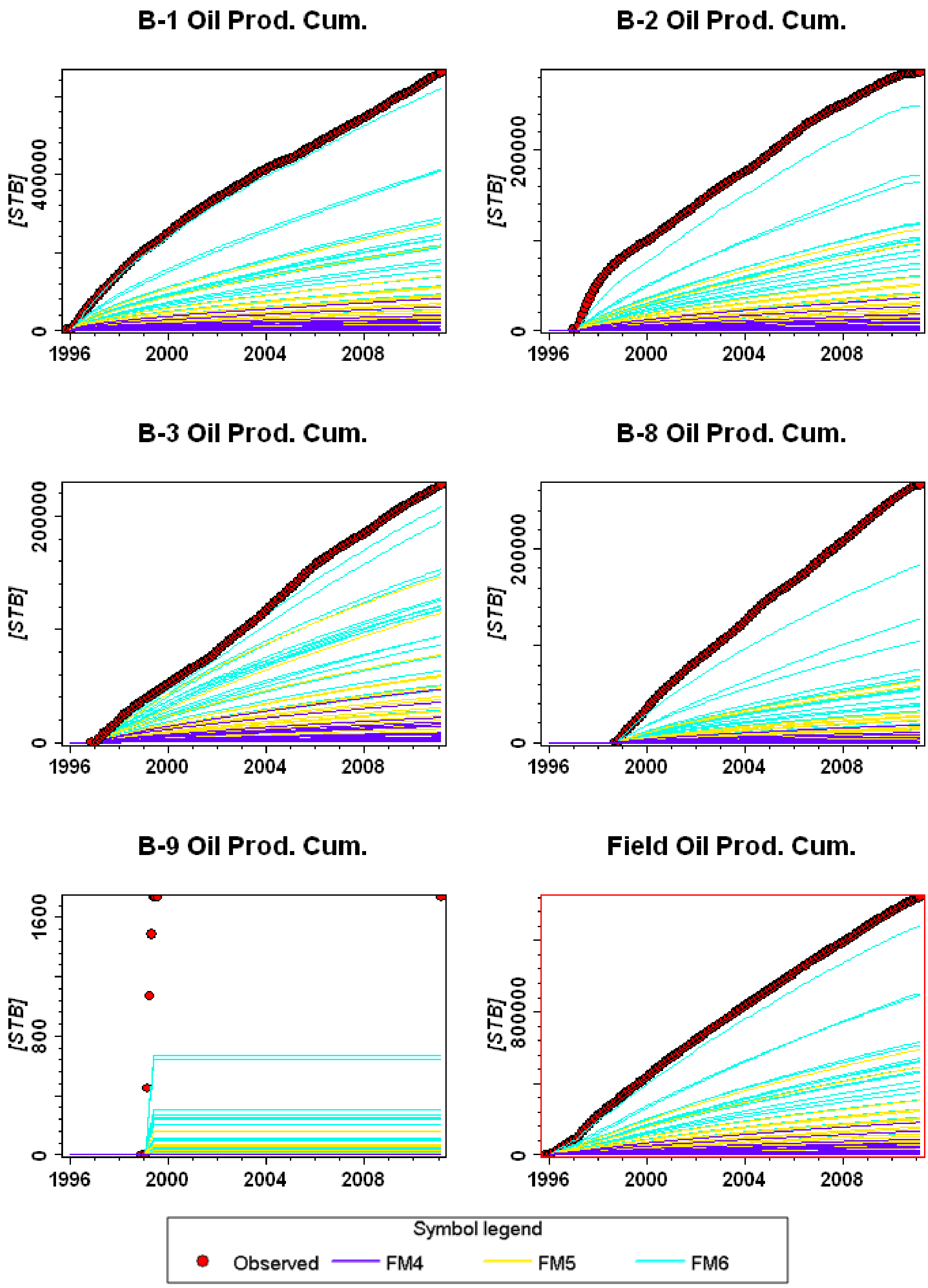

Figure 6.6 Cumulative oil productions of simulation models (PVT-3: FM4,5,6)

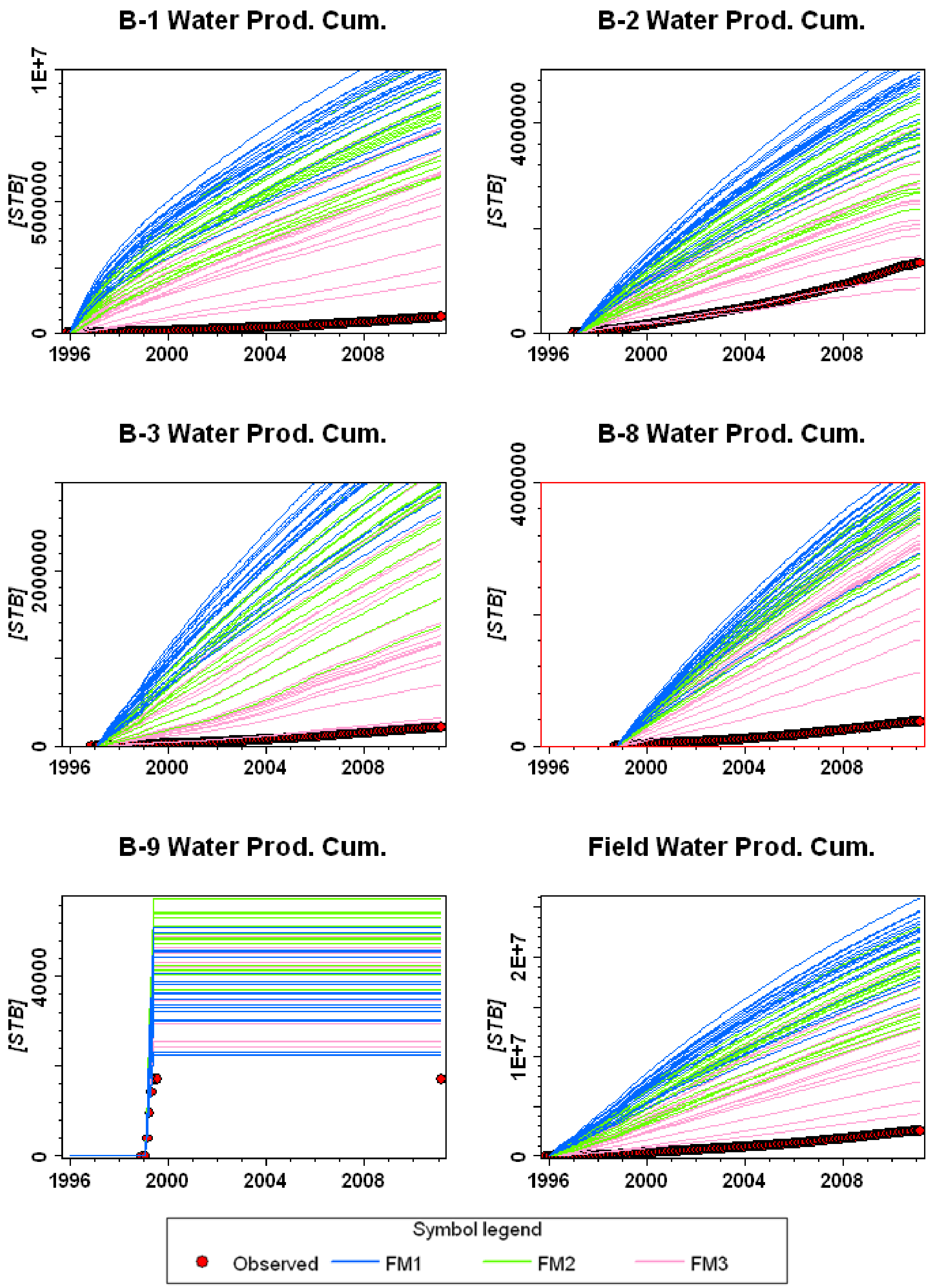

Figure 6.7 Cumulative water productions of simulation models (PVT-1: FM1,2,3)

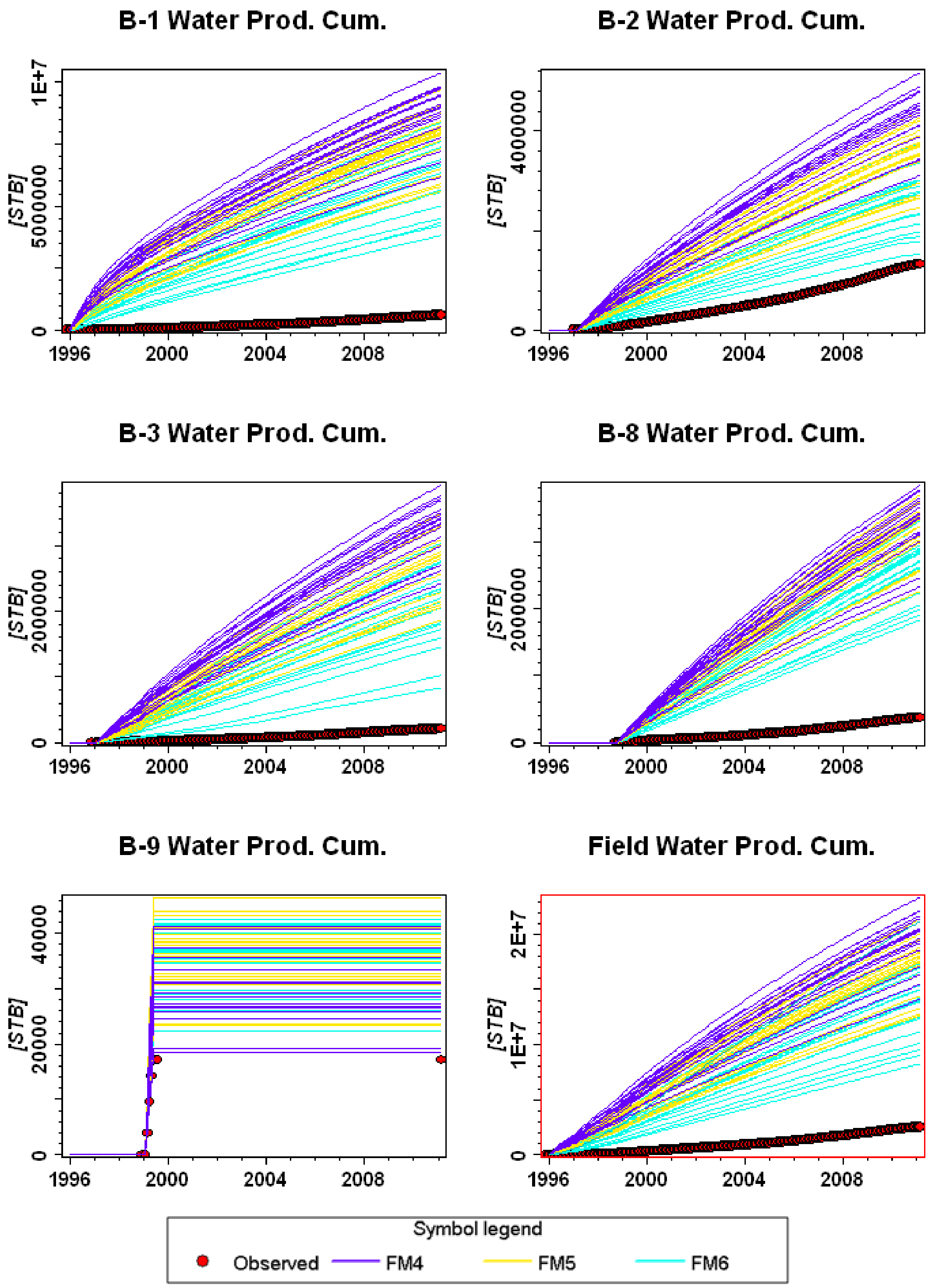

Figure 6.8 Cumulative water productions of simulation models (PVT-3: FM4,5,6)

6.1.3 BHP Results

The BHP results for the simulations are shown in Figure 6.9 and Figure 6.10. Different from the other models, the behaviour of BHP results does not show a parallel trend with oil and water production results. In simple terms, as the BHP values get better, oil and water production values worsen and vice versa.

The model to be matched with observed data requires higher BHP values and lower water productions. This can be provided by a comprehensive study of the aquifer model and/or relative permeability curves etc. There is no doubt that the matches could be improved to provide better results, but this would be beyond the scope of this study.

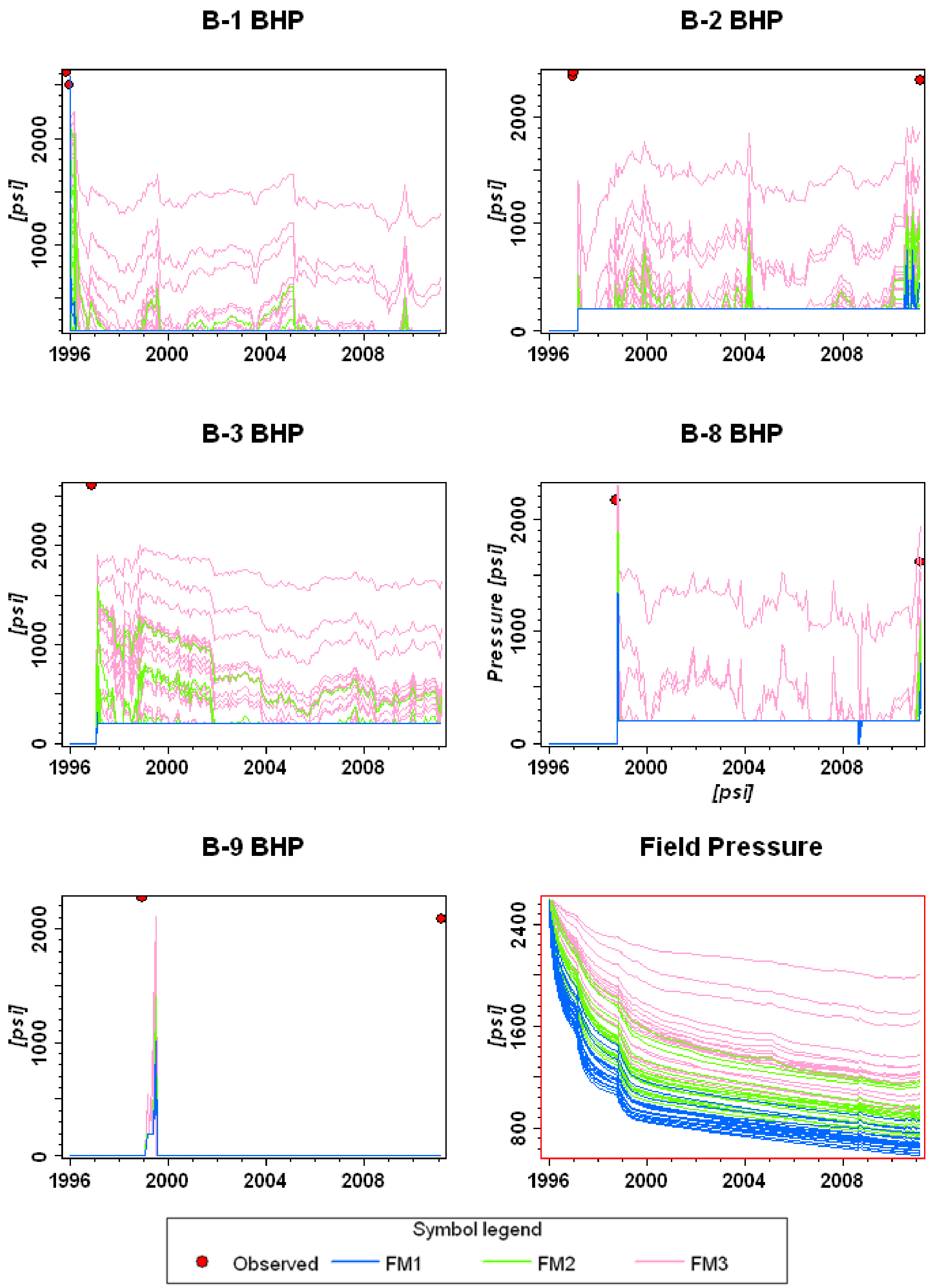

Figure 6.9 BHP of simulation models (PVT-1: FM1,2,3)

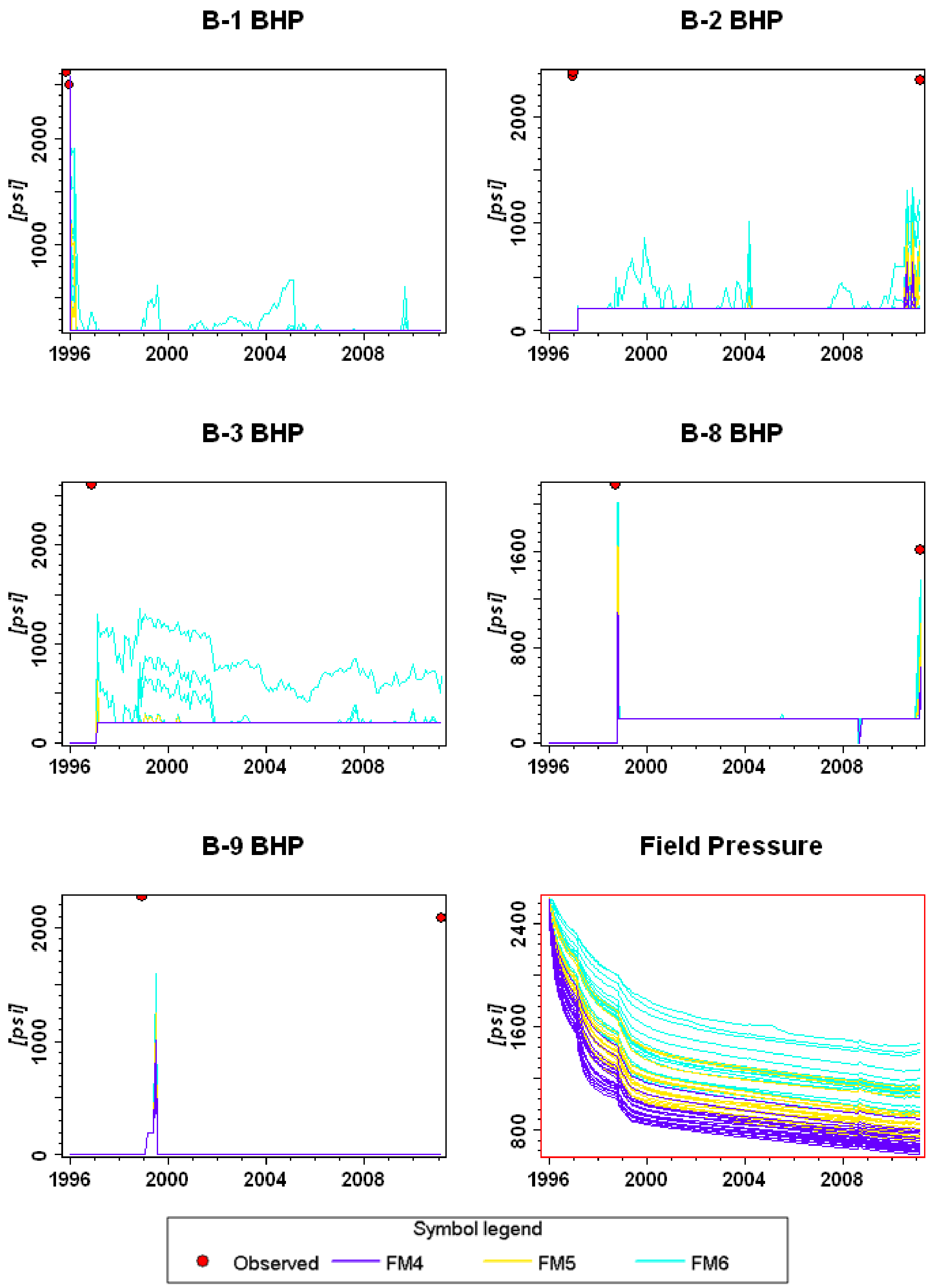

Figure 6.10 BHP of simulation models (PVT-3: FM4,5,6)

6.2 History Match Analysis Results

After the results of the simulation models are plotted, it becomes difficult to verify which case represents a better fit than the other, among 114 cases. Not only the number of the cases but also the number of the vector matches (oil production rate, water production rate, cumulative oil production, cumulative water production, BHP) to be analyzed makes this assessment hard. The “History Match Analysis” process in Petrel is applied to analyze the simulation runs in an easy and quick way.

The first stage of history matching is to rank the cases. As the second stage, the 3 best matching cases for all the wells are examined elaborately in the map view.

6.2.1 Ranking Cases (Case Comparison)

Rather than illustrating each single vector match value for all the cases and for all the wells and field, a combined vector match is used to explore whether the simulated results reproduce the observed production data or not.

From Figure 6.11 to Figure 6.14 the combined match values of all the simulation cases for all the wells and the field are given in two groups (PVT-1 and PVT-3). The color for the best match is chosen as green, the color for the worst match is chosen as red, and the remaining match values are shown in pinkish orange.

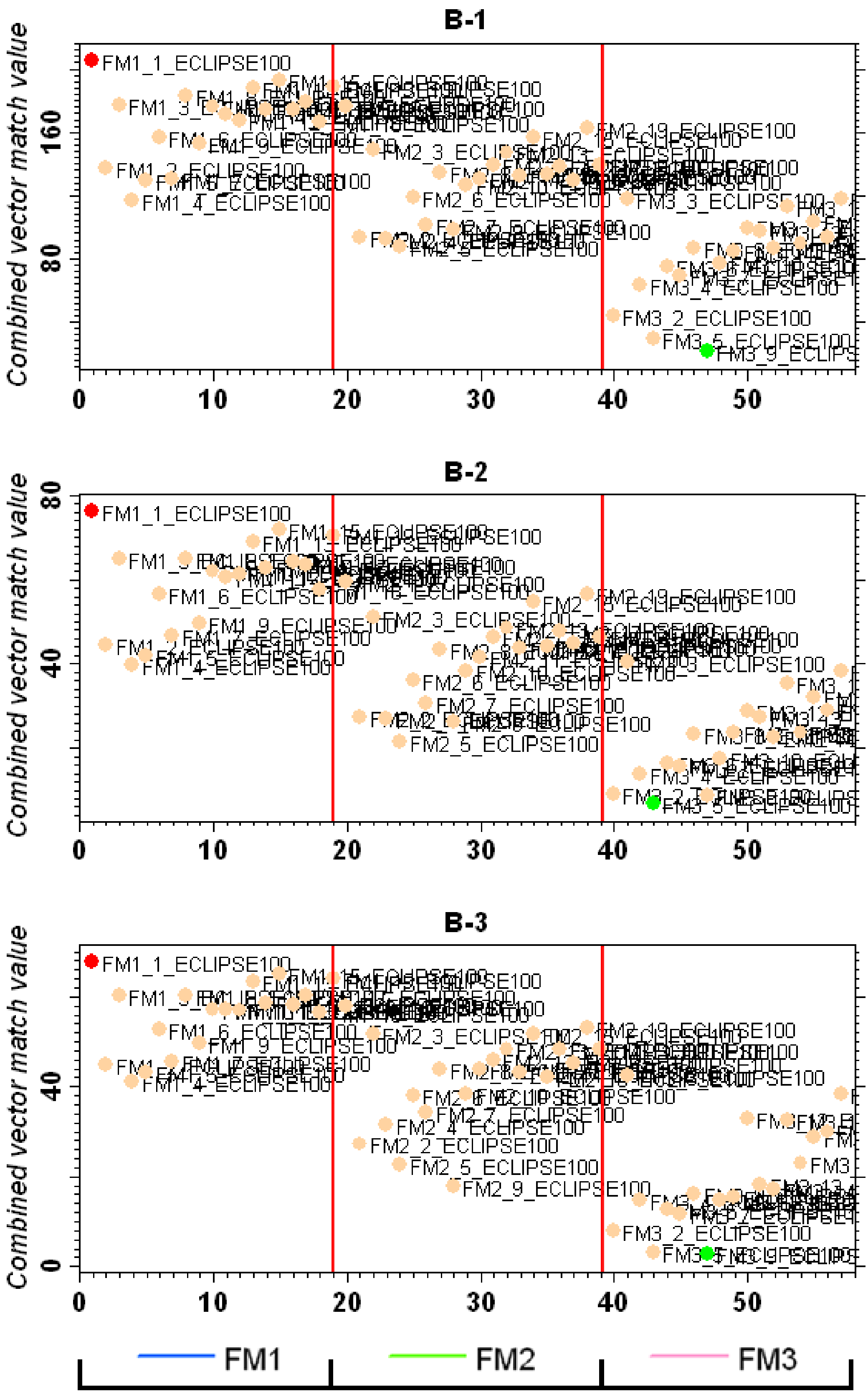

Figure 6.11 Combined vector match values of simulation models FM-1, 2, 3 (Bozova-1, 2, 3)

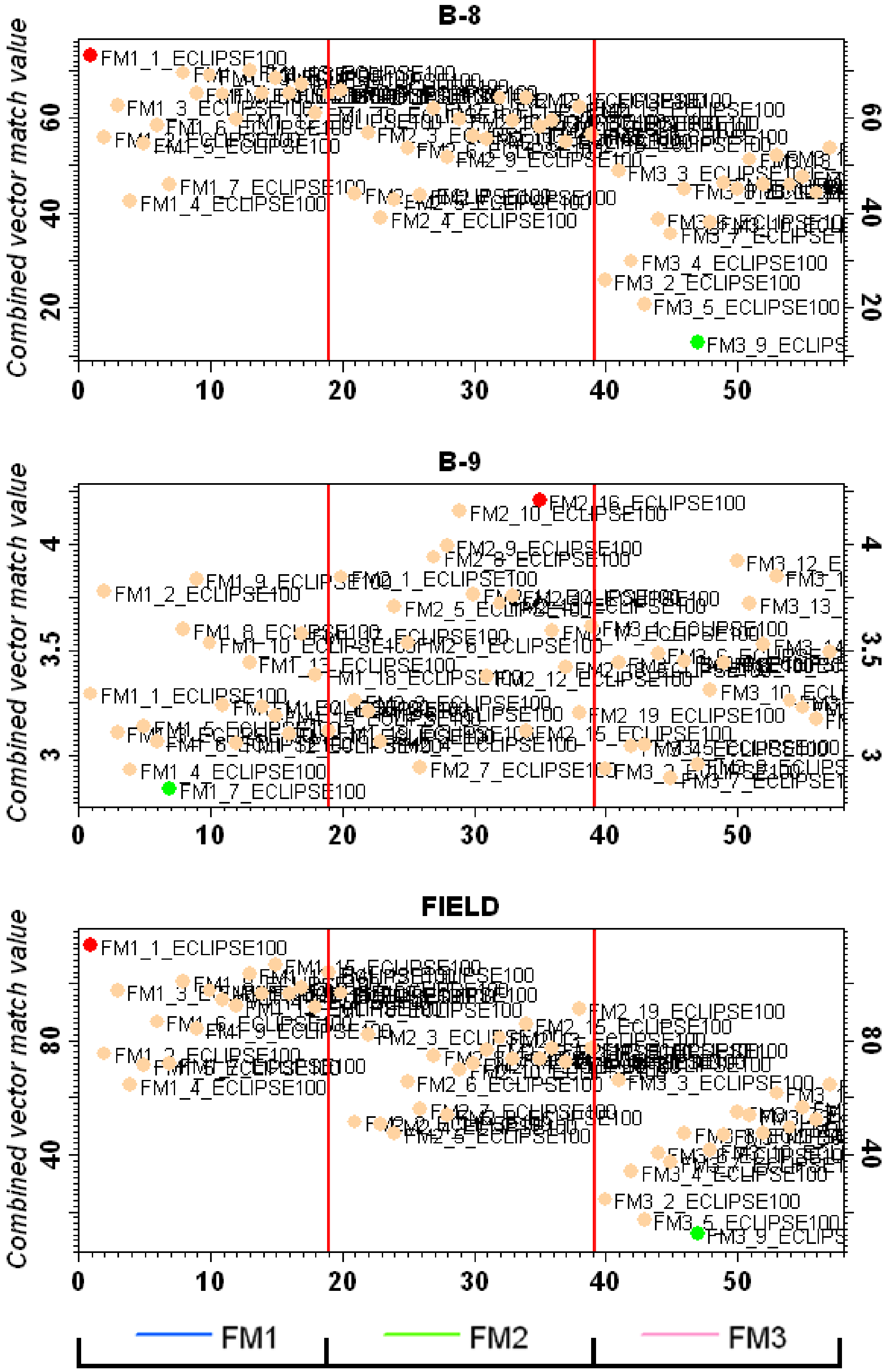

Figure 6.12 Combined vector match values of simulation models FM-1, 2, 3 (Bozova-8, 9, Field)

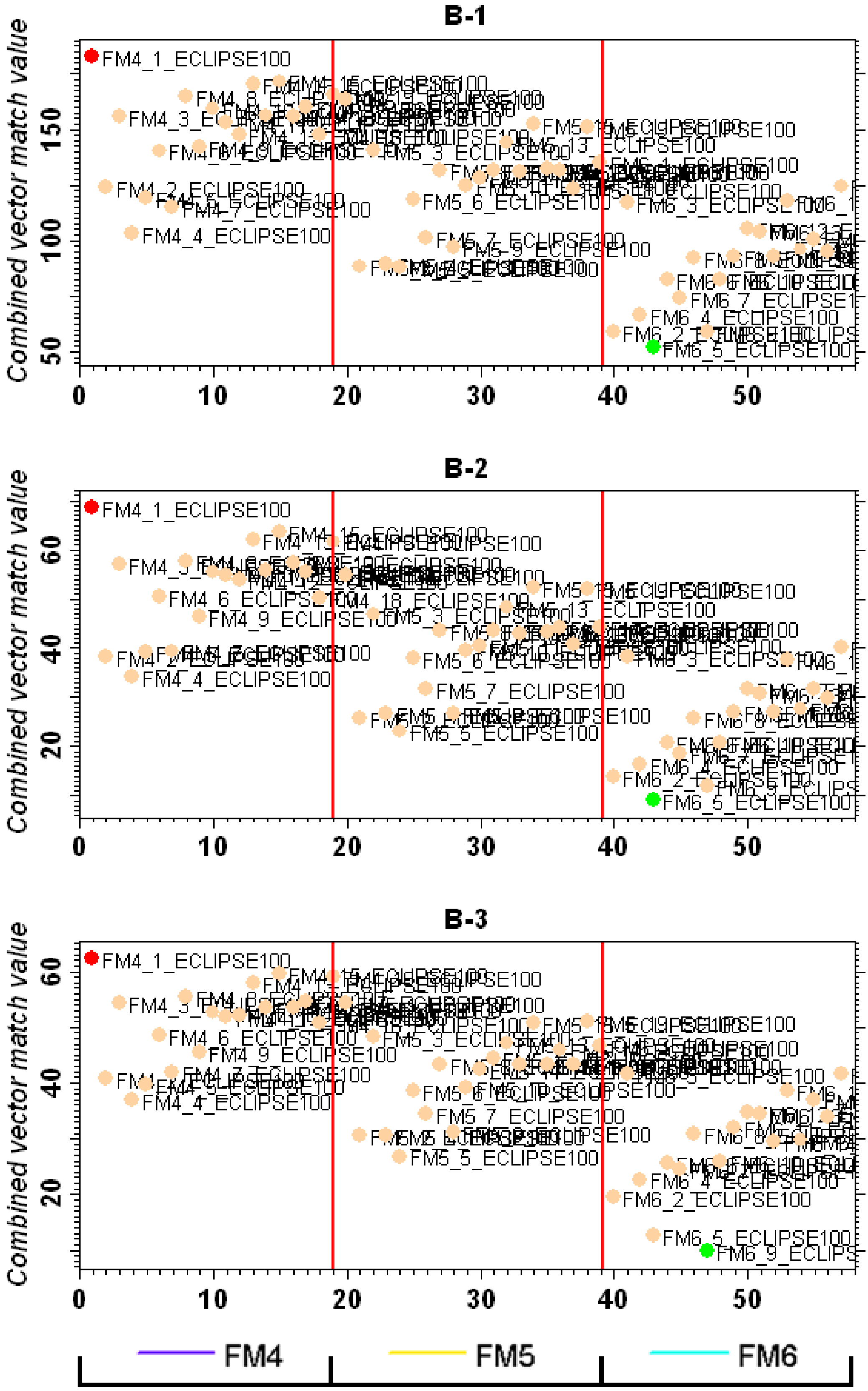

Figure 6.13 Combined vector match values of simulation models FM-4, 5, 6 (Bozova-1, 2, 3)

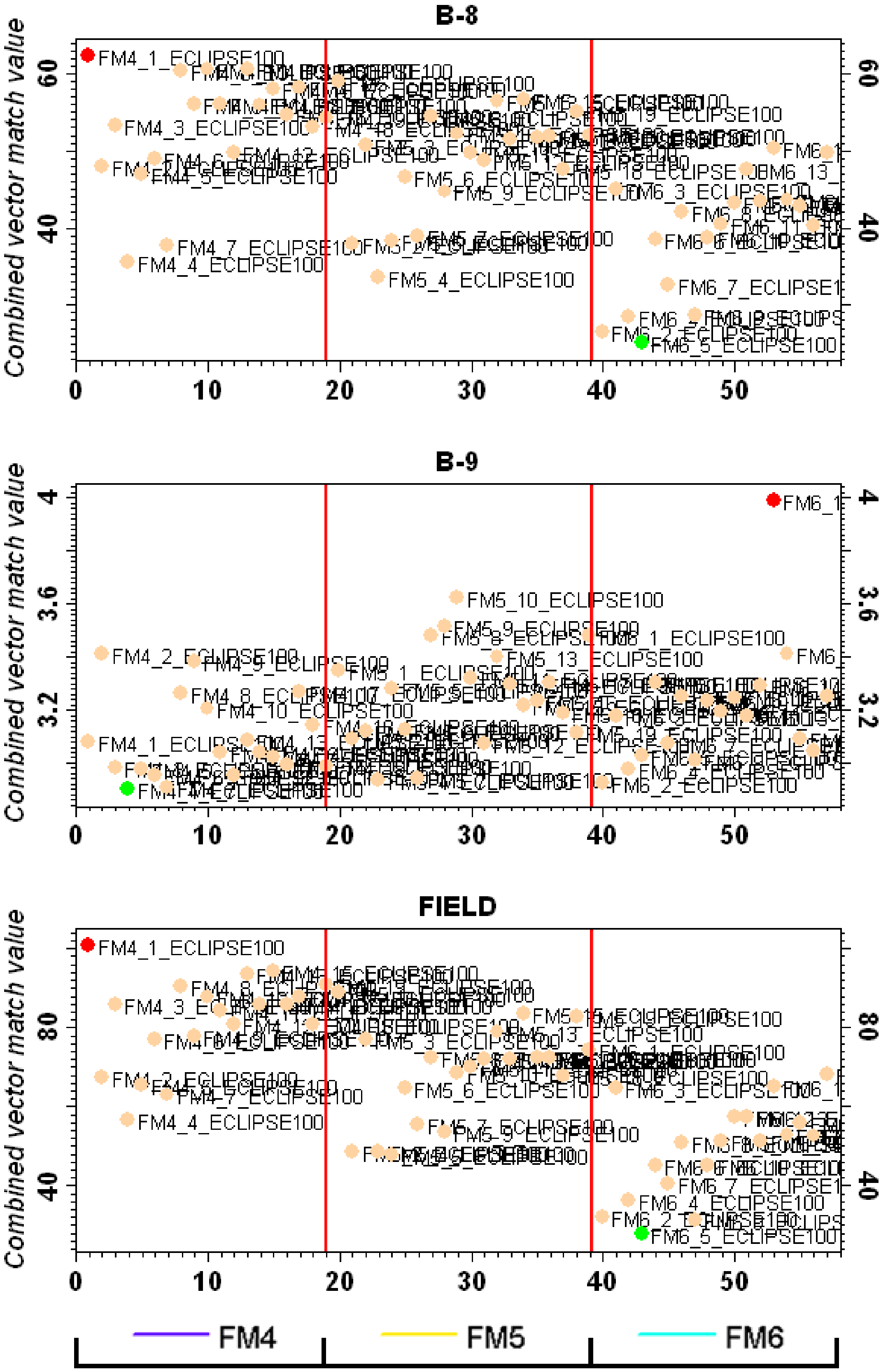

Figure 6.14 Combined vector match values of simulation models FM-4, 5, 6 (Bozova-8, 9, Field)

Table 6.1 shows the simulation models ranked according to their goodness of fit. The smallest match values show the best fit models.

Table 6.1 Ranking simulation models according to their match values

Rank Order	Case Name	Combined Vector Match Value
1	FM3_9	12
2	FM3_5	17
3	FM3_2	24
4	FM6_5	28
5	FM6_9	31
6	FM6_2	32
7	FM3_4	34
8	FM6_4	36
9	FM3_7	37
10	FM3_6	40
11	FM6_7	40
12	FM3_10	41
13	FM6_6	45
14	FM6_10	45
15	FM3_11	46
16	FM2_5	47
17	FM3_8	47
18	FM3_14	47
19	FM5_5	48
20	FM3_16	49
21	FM5_2	49
22	FM5_4	49
23	FM2_2	51
24	FM2_4	51
25	FM6_8	51
26	FM6_11	51
27	FM6_14	51
28	FM3_18	52
29	FM6_18	52
30	FM5_9	53
31	FM6_16	53
32	FM2_9	54
33	FM3_13	54
34	FM3_12	55
35	FM5_7	55
36	FM2_7	56
37	FM3_17	56
38	FM4_4	56
39	FM6_17	56
40	FM6_12	57
41	FM6_13	57
42	FM3_15	61
43	FM4_7	63
44	FM1_4	64
45	FM3_19	64
46	FM2_6	65
47	FM4_5	65
48	FM5_6	65
49	FM6_3	65
50	FM6_15	65
51	FM3_3	66
52	FM4_2	67
53	FM5_10	68
54	FM5_18	68
55	FM6_19	68
56	FM2_10	70
57	FM5_11	70
58	FM1_5	71
59	FM1_7	72
60	FM2_11	72
61	FM2_18	72
62	FM5_8	72
63	FM5_12	72
64	FM5_14	72
65	FM5_16	72
66	FM5_17	72
67	FM2_14	73
68	FM2_16	73
69	FM2_8	74
70	FM6_1	74
71	FM1_2	75
72	FM2_12	76
73	FM2_17	77
74	FM3_1	77
75	FM4_6	77
76	FM5_3	77
77	FM4_9	78
78	FM5_13	79
79	FM2_13	81
80	FM4_12	81
81	FM4_18	81
82	FM2_3	82
83	FM5_15	83
84	FM5_19	83
85	FM1_9	84
86	FM4_11	84
87	FM1_6	86
88	FM2_15	86
89	FM4_3	86
90	FM4_14	86
91	FM4_16	86
92	FM4_10	87
93	FM4_17	88
94	FM5_1	89
95	FM4_8	90
96	FM1_18	91
97	FM2_19	91
98	FM4_19	91
99	FM1_12	92
100	FM1_11	94
101	FM4_13	94
102	FM4_15	94
103	FM1_14	96
104	FM1_16	96
105	FM2_1	96
106	FM1_3	97
107	FM1_10	97
108	FM1_17	98
109	FM1_8	101
110	FM4_1	101
111	FM1_13	103
112	FM1_19	103
113	FM1_15	106
114	FM1_1	113

6.2.2 Simulation and History Match Value Results of the 3 Best Cases

The 3 best and the worst matching cases for each well and the field; their corresponding combined vector match values are given Table 6.2.

Table 6.2 The 3 best and the worst matching cases and match values for each well

Well/Field	Matches							
	Best		2nd Best		3rd Best		Worst	
	Case#	Value	Case#	Value	Case#	Value	Case#	Value
Bozova-1	FM3_9	21	FM3_5	29	FM3_2	43	FM1_1	205
Bozova-2	FM3_5	7	FM3_9	9	FM3_2	9	FM1_1	76
Bozova-3	FM3_9	3	FM3_5	3	FM3_2	8	FM1_1	68
Bozova-8	FM3_9	13	FM3_5	21	FM6_5	25	FM1_1	73
Bozova-9	FM1_7	3	FM3_7	3	FM4_4	3	FM2_16	4
Field	FM3_9	12	FM3_5	17	FM3_2	24	FM1_1	113

Identifying the 3 Best Cases as FM3_9, FM3_5 and FM3_2, their simulation results are given in the following figures (from Figure 6.15 to Figure 6.20) to see more clearly.

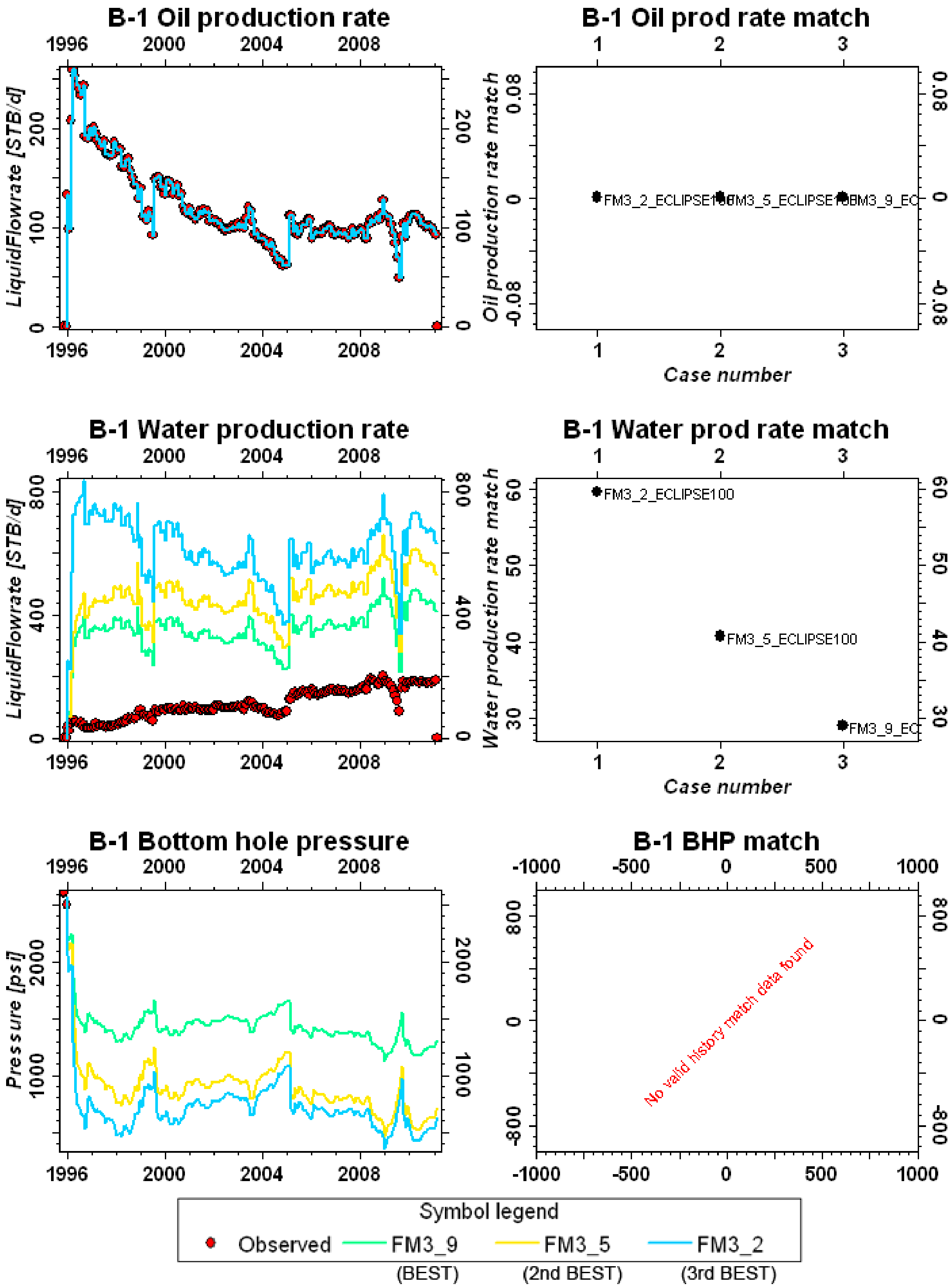

Figure 6.15 Simulation results and vector match values of B-1 for the 3 Best Cases

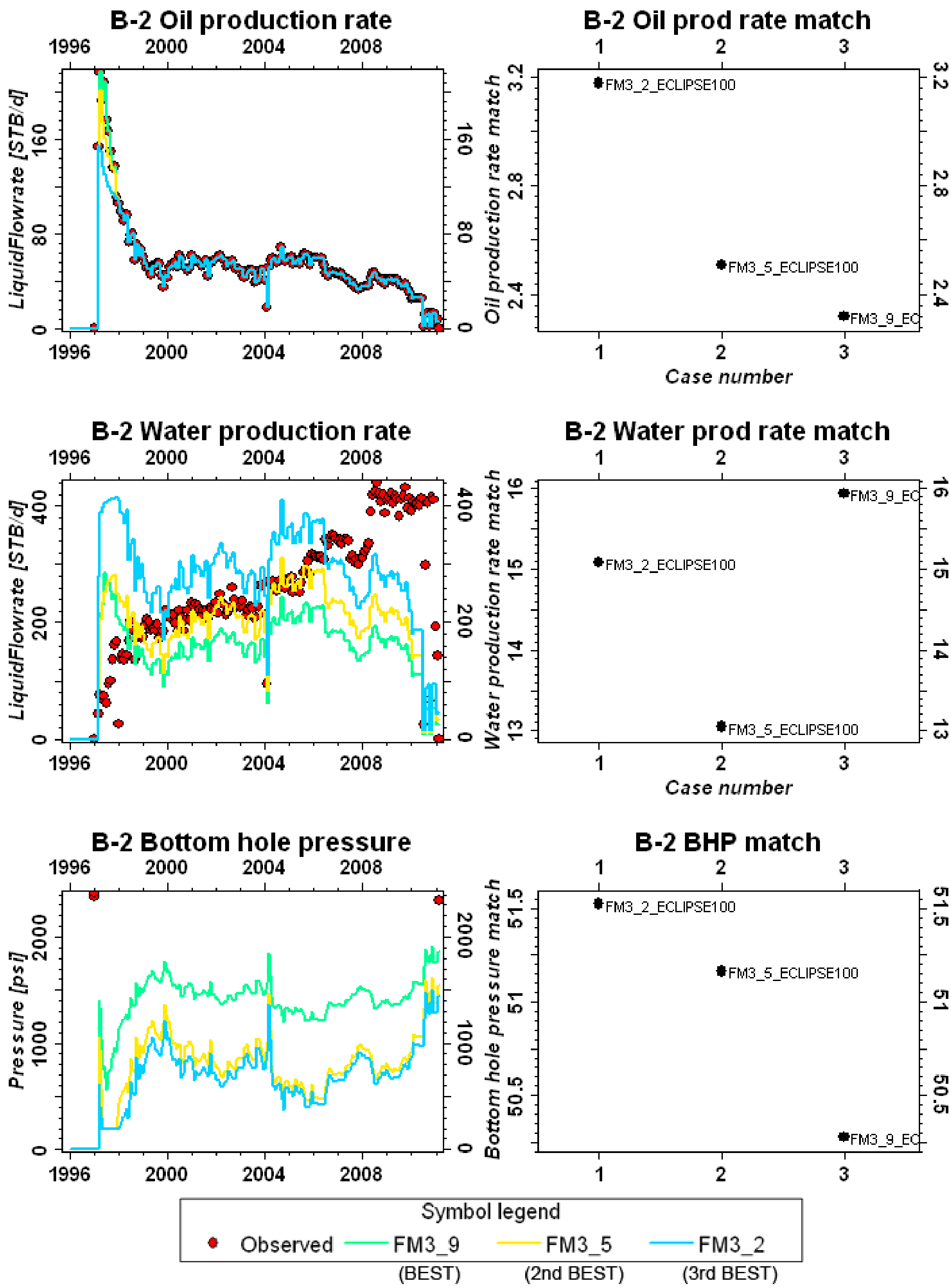

Figure 6.16 Simulation results and vector match values of B-2 for the 3 Best Cases

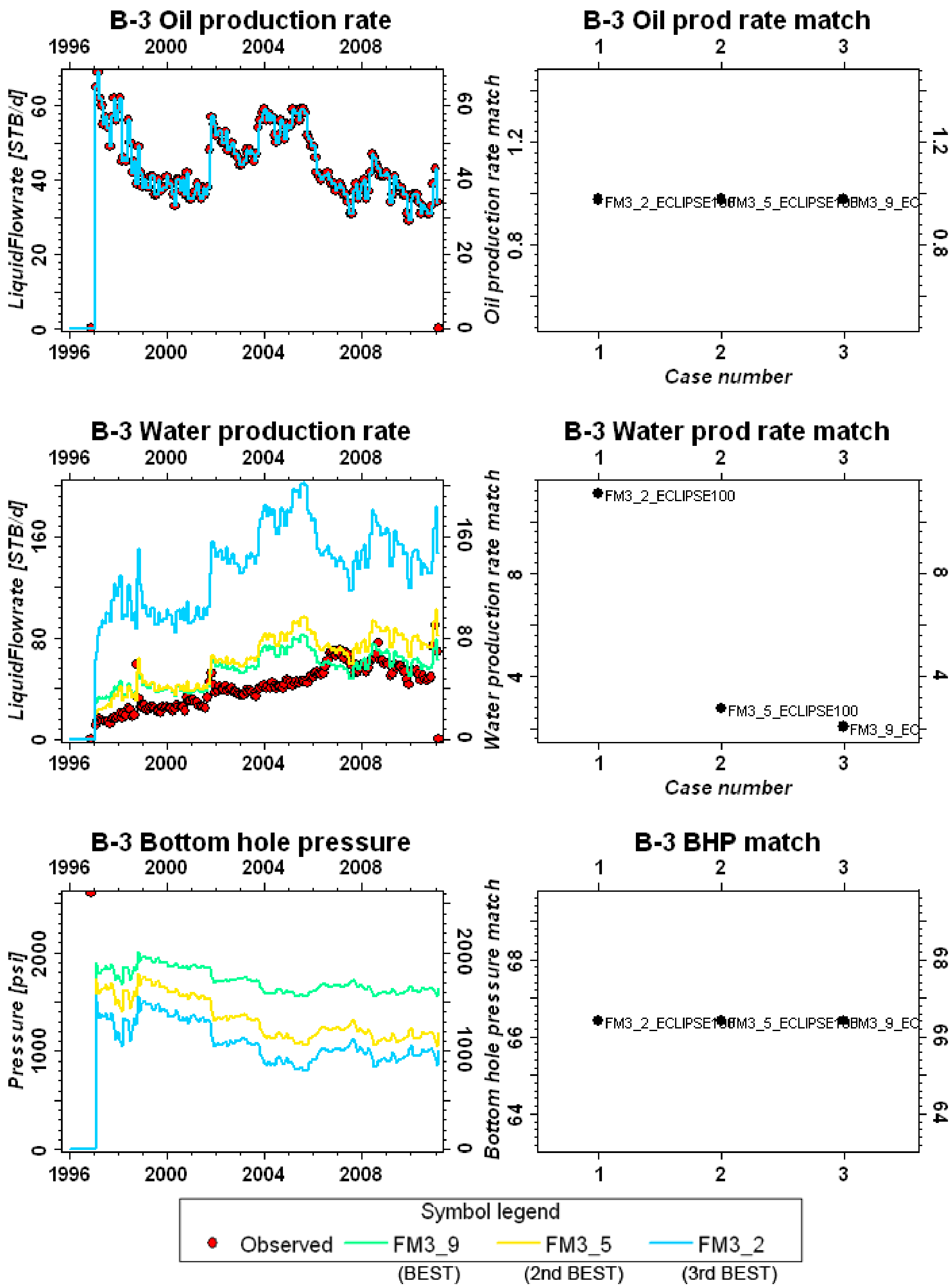

Figure 6.17 Simulation results and vector match values of B-3 for the 3 Best Cases

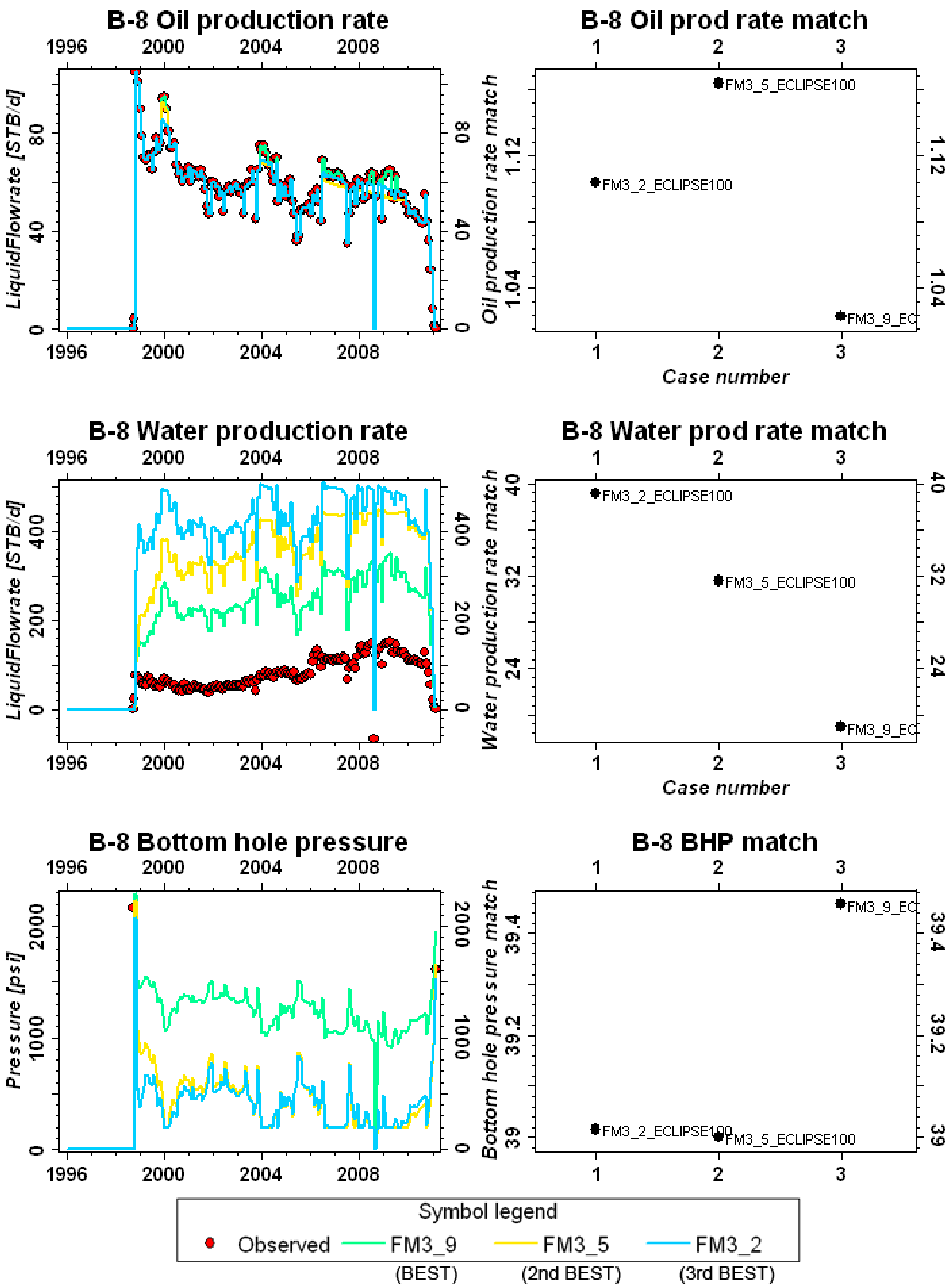

Figure 6.18 Simulation results and vector match values of B-8 for the 3 Best Cases

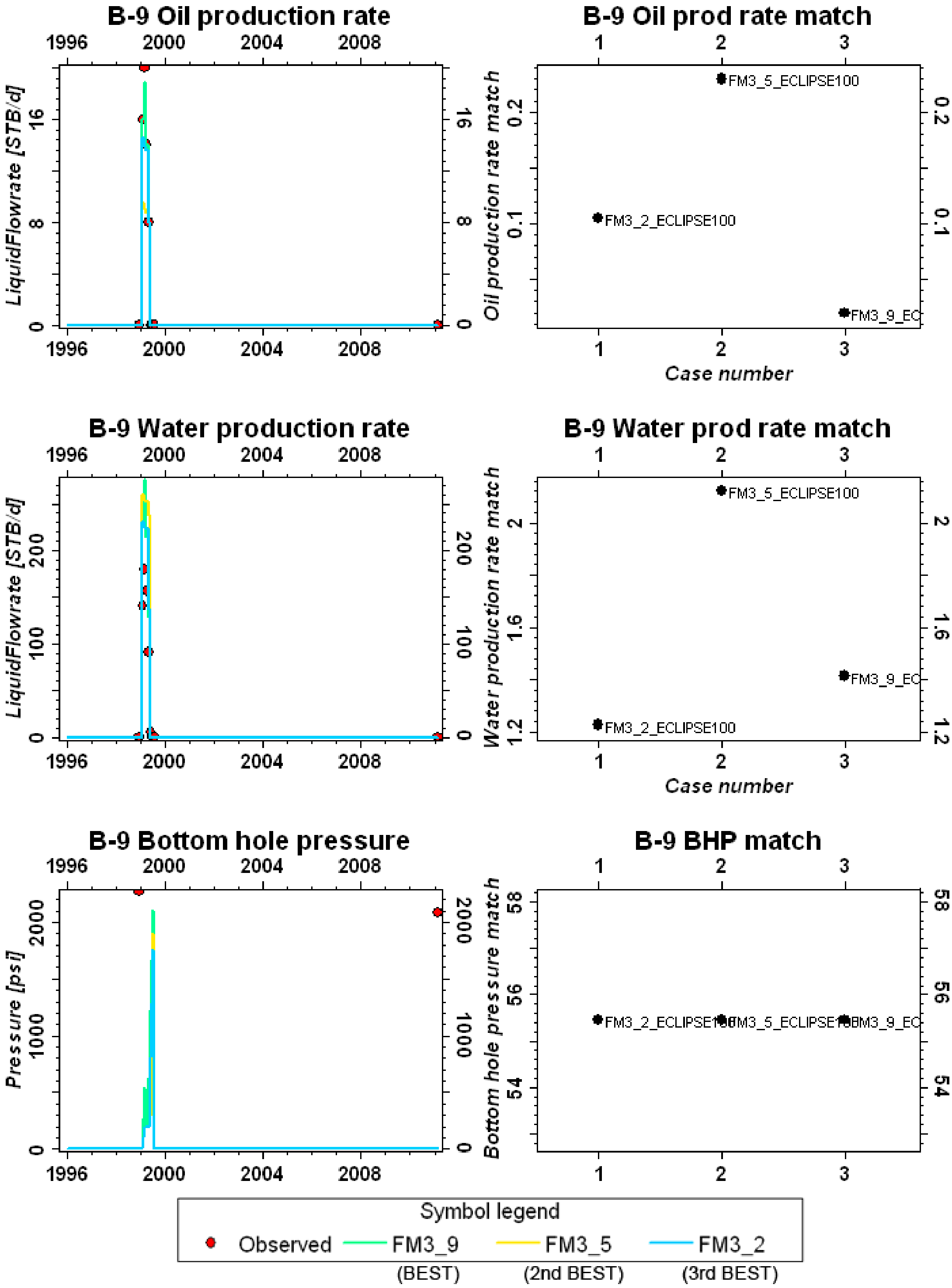

Figure 6.19 Simulation results and vector match values of B-9 for the 3 Best Cases

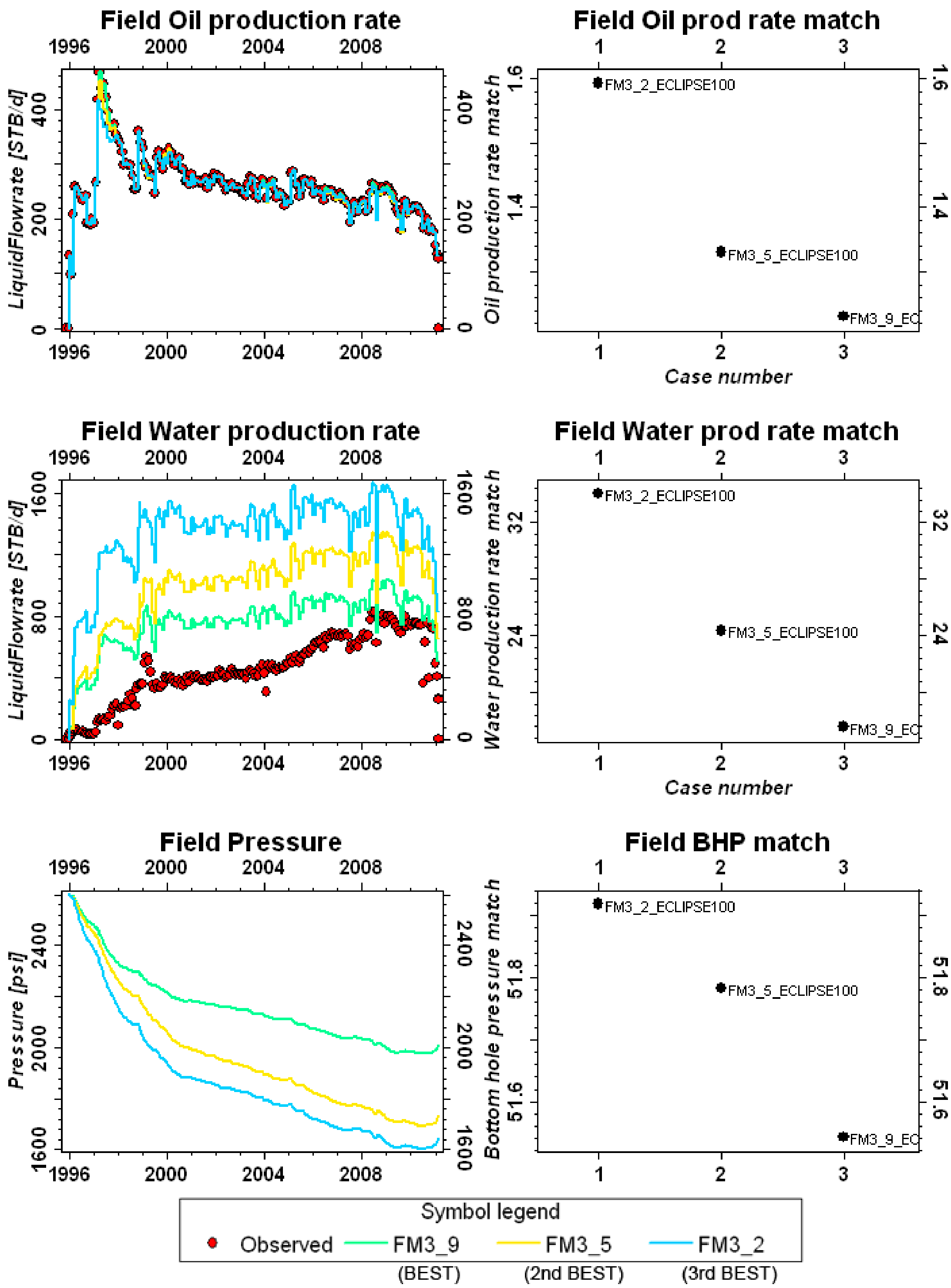

Figure 6.20 Simulation results and vector match values of the field for the 3 Best Cases

All of the 3 Best Case models have a WOC depth of 1480 m ssTVD, and PVT data of Bozova-1. The only different items defined in these models are the Pc/krel curves. Pc/krel curve#9, #5 and #2 belong to plugs named as Boz-2_2, Boz-1_201 and Boz-1_197 respectively. When investigated through the entire Pc/krel curve sets, these curves are not the ones with the lowest Swir values. The end points of krw and kro curves do not give a distinction either. When plotted again, but these 3 best matching Pc/krel curves in yellow color this time (Figure 6.21), one thing draws the attention immediately: The similarity on their threshold capillary pressure (Pc threshold) values being very small. This condition makes the initial water saturation distribution of the model lower than the ones created with the higher Pc threshold curves; thus favoring the simulation models. The reason for these 3 curves matching best is not only the effect of Pc threshold. The krel curves, assigning the fundamental rules of flow functions, are also of vital importance.

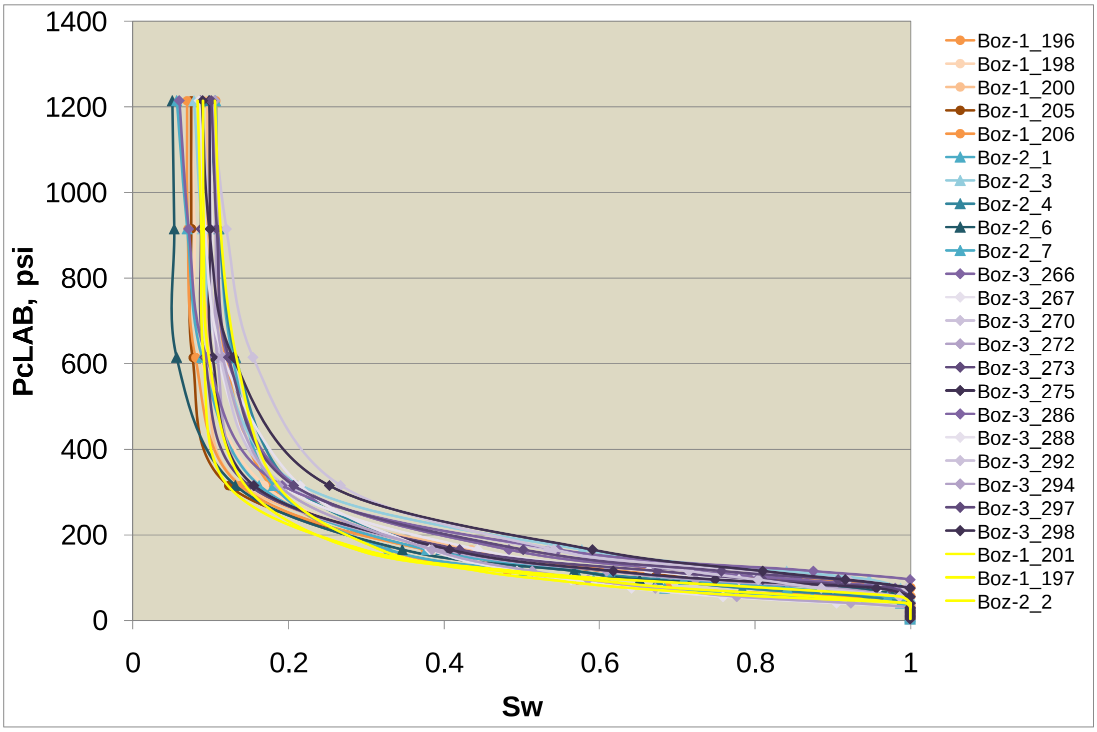

Figure 6.21 Capillary pressure curves emphasizing the 3 best matching curves

The following figure (Figure 6.22) illustrates the match statistics for all wells for the best case (FM3_9) in the map view. The illustrations show the match values in a qualitative perspective, the results are lumped into five categories from “Match” to

"Poor". The bigger the bubbles, the bigger the match values, thus the smaller bubbles show the better matches.

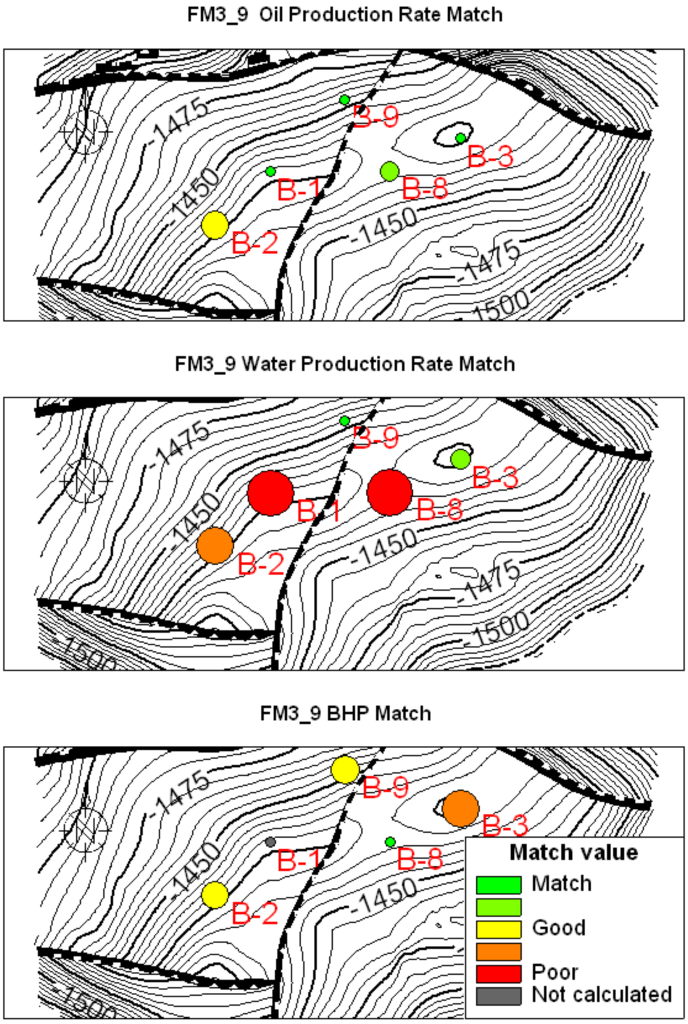

Figure 6.22 Qualitative vector match map for the best case FM3_9

The main issue defining the high match values can be explained by the aquifer support defined to compensate the high percentage water production of Bozova-2. When the aquifer provides the high water production and pressure support as expected in Bozova-2; the water productions of wells Bozova-1, 3 and 8 get worse (resulting in higher water percentages than observed). The solution should be in a way that, while Bozova-1, 3 and 8 get pressure support slowly, Bozova-2 should be in a more direct interaction with the aquifer. A comparative study on the strength of aquifer, the connection area of aquifer, permeability model, kh/kv ratio and krel curves can help working on this problem.

6.3 Uncertainty Quantification Results

Quantification of uncertainty is obtained by following two different evaluation methods. The first method aims to calculate the impact of each variable on each vector match, and to determine the variable whose uncertainty affects the results the most. The second method's objective is the determination of impact of uncertainties only on STOOIP values of the resulting cases. Briefly, the first method provides the impact of uncertainty on dynamic results; whereas the second method focuses on static results of the simulation models.

6.3.1 Uncertainty Quantification by Using History Match Statistics

In order to quantify the impact of uncertainty of each variable, i.e., PVT, WOC and Pc/krel, history match values of the cases are compared in a systematic way. The cases are grouped into classes so that the variable of interest, the uncertainty impact of which is to be investigated, is varied and the remaining variables are kept constant. In each group, regarding the combined and each individual vector separately, a best and a worst matching case is selected. After that, the history match values of these cases are tabulated. The differences between the match values represent the range of effect the variable can create on the result. By this way, the uncertainty impact of each variable on each vector match is calculated, and the variable uncertainty which affects the results the most is determined.

In order to calculate the impact of PVT data uncertainty, 6 classes are formed so that in each class the only changing variable is PVT data. The first table in Table 6.3 belongs to simulation cases with a WOC depth of 1455 m ssTVD and Pc/krel curve#1. Since forming classes for 19 Pc/krel curve sets is tedious; the curves are decreased to 2 representative sets. As Pc/krel curves is not a single numeric value to be determined as minimum and maximum, the most and least matching curves with the results are chosen as Pc/krel curve#1 and #9. In each class, the difference of match value between the best and worst case is calculated as range of effect, which corresponds only to the impact of uncertainty that belongs to the changed variable.

Table 6.3 Tables for calculating the impact of PVT data uncertainty

WOC (-1455) & Pc/k_{rel} # 1		Cases with name FM1_1 & FM4_1				
Well	Match Vector	Best Case	Match	Worst Case	Match	Range of Effect
All Wells	Oil Prod. Rate	FM1_1	15	FM4_1	15	0
All Wells	Water Prod. Rate	FM4_1	149	FM1_1	166	17
All Wells	Oil Prod. Cum.	FM1_1	13	FM4_1	13	0
All Wells	Water Prod. Cum.	FM4_1	168	FM1_1	189	21
All Wells	BHP	FM1_1	56	FM4_1	56	0
All Wells	Combined	FM4_1	100	FM1_1	113	13

WOC (-1468) & Pc/k_{rel} # 1		Cases with name FM2_1 & FM5_1				
Well	Match Vector	Best Case	Match	Worst Case	Match	Range of Effect
All Wells	Oil Prod. Rate	FM2_1	14	FM5_1	15	1
All Wells	Water Prod. Rate	FM5_1	128	FM2_1	137	9
All Wells	Oil Prod. Cum.	FM2_1	12	FM5_1	13	1
All Wells	Water Prod. Cum.	FM5_1	151	FM2_1	165	14
All Wells	BHP	FM2_1	56	FM5_1	56	0
All Wells	Combined	FM5_1	89	FM2_1	96	7

WOC (-1480) & Pc/k_{rel} # 1		Cases with name FM3_1 & FM6_1				
Well	Match Vector	Best Case	Match	Worst Case	Match	Range of Effect
All Wells	Oil Prod. Rate	FM3_1	12	FM6_1	14	2
All Wells	Water Prod. Rate	FM6_1	105	FM3_1	107	2
All Wells	Oil Prod. Cum.	FM3_1	10	FM6_1	12	2
All Wells	Water Prod. Cum.	FM6_1	127	FM3_1	133	6
All Wells	BHP	FM3_1	55	FM6_1	56	1
All Wells	Combined	FM6_1	74	FM3_1	77	3

WOC (-1455) & Pc/k_{rel} # 9		Cases with name FM1_9 & FM4_9				
Well	Match Vector	Best Case	Match	Worst Case	Match	Range of Effect
All Wells	Oil Prod. Rate	FM1_9	12	FM4_9	14	2
All Wells	Water Prod. Rate	FM4_9	110	FM1_9	116	6
All Wells	Oil Prod. Cum.	FM1_9	10	FM4_9	12	2
All Wells	Water Prod. Cum.	FM4_9	133	FM1_9	147	14
All Wells	BHP	FM1_9	55	FM4_9	56	1
All Wells	Combined	FM4_9	78	FM1_9	84	6

WOC (-1468) & Pc/k_{rel} # 9		Cases with name FM2_9 & FM5_9				
Well	Match Vector	Best Case	Match	Worst Case	Match	Range of Effect
All Wells	Oil Prod. Rate	FM2_9	3	FM5_9	9	6
All Wells	Water Prod. Rate	FM5_9	73	FM2_9	74	1
All Wells	Oil Prod. Cum.	FM2_9	2	FM5_9	8	6
All Wells	Water Prod. Cum.	FM5_9	93	FM2_9	94	1
All Wells	BHP	FM2_9	53	FM5_9	53	0
All Wells	Combined	FM5_9	53	FM2_9	54	1

WOC (-1480) & Pc/k_{rel} # 9		Cases with name FM3_9 & FM6_9				
Well	Match Vector	Best Case	Match	Worst Case	Match	Range of Effect
All Wells	Oil Prod. Rate	FM3_9	1	FM6_9	3	2
All Wells	Water Prod. Rate	FM3_9	18	FM6_9	43	25
All Wells	Oil Prod. Cum.	FM3_9	0	FM6_9	1	1
All Wells	Water Prod. Cum.	FM3_9	20	FM6_9	54	34
All Wells	BHP	FM3_9	52	FM6_9	53	1
All Wells	Combined	FM3_9	12	FM6_9	31	19

The same procedure is followed for calculating the impacts of uncertainties that belong to WOC depth and Pc/krel curves. The tables created for the calculations are given in Table 6.4 and Table 6.5. In Table 6.4, variables other than WOC depth (PVT, Pc/krel) are kept constant in each class, whereas variables other than Pc/krel curve (PVT, WOC) are kept constant in Table 6.5.

Table 6.4 Tables for calculating the impact of WOC depth uncertainty

PVT-1 & Pc/k_{rel} # 1		Cases with name FM1_1 & FM2_1 & FM3_1				
Well	Match Vector	Best Case	Match	Worst Case	Match	Range of Effect
All Wells	Oil Prod. Rate	FM3_1	12	FM1_1	15	3
All Wells	Water Prod. Rate	FM3_1	107	FM1_1	166	59
All Wells	Oil Prod. Cum.	FM3_1	10	FM1_1	13	3
All Wells	Water Prod. Cum.	FM3_1	133	FM1_1	189	56
All Wells	BHP	FM3_1	55	FM1_1	56	1
All Wells	Combined	FM3_1	77	FM1_1	113	36

PVT-3 & Pc/k_{rel} # 1		Cases with name FM4_1 & FM5_1 & FM6_1				
Well	Match Vector	Best Case	Match	Worst Case	Match	Range of Effect
All Wells	Oil Prod. Rate	FM6_1	14	FM4_1	15	1
All Wells	Water Prod. Rate	FM6_1	105	FM4_1	149	44
All Wells	Oil Prod. Cum.	FM6_1	12	FM4_1	13	1
All Wells	Water Prod. Cum.	FM6_1	127	FM4_1	168	41
All Wells	BHP	FM6_1	56	FM4_1	56	0
All Wells	Combined	FM6_1	74	FM4_1	101	27

PVT-1 & Pc/k_{rel} # 9		Cases with name FM1_9 & FM2_9 & FM3_9				
Well	Match Vector	Best Case	Match	Worst Case	Match	Range of Effect
All Wells	Oil Prod. Rate	FM3_9	1	FM1_9	12	11
All Wells	Water Prod. Rate	FM3_9	18	FM1_9	116	98
All Wells	Oil Prod. Cum.	FM3_9	0	FM1_9	10	10
All Wells	Water Prod. Cum.	FM3_9	20	FM1_9	147	127
All Wells	BHP	FM3_9	52	FM1_9	55	3
All Wells	Combined	FM3_9	12	FM1_9	84	72

PVT-3 & Pc/k_{rel} # 9		Cases with name FM4_9 & FM5_9 & FM6_9				
Well	Match Vector	Best Case	Match	Worst Case	Match	Range of Effect
All Wells	Oil Prod. Rate	FM6_9	3	FM4_9	14	11
All Wells	Water Prod. Rate	FM6_9	43	FM4_9	110	67
All Wells	Oil Prod. Cum.	FM6_9	1	FM4_9	12	11
All Wells	Water Prod. Cum.	FM6_9	54	FM4_9	133	79
All Wells	BHP	FM6_9	52	FM4_9	56	4
All Wells	Combined	FM6_9	31	FM4_9	78	47

Table 6.5 Tables for calculating the impact of Pc/krel curves uncertainty

WOC (-1455) & PVT-1		Cases with name FM-1_x				
Well	Match Vector	Best Case	Match	Worst Case	Match	Range of Affect
All Wells	Oil Prod. Rate	FM1_2	12	FM1_7	15	3
All Wells	Water Prod. Rate	FM1_4	93	FM1_1	166	73
All Wells	Oil Prod. Cum.	FM1_2	10	FM1_19	13	3
All Wells	Water Prod. Cum.	FM1_4	107	FM1_1	189	82
All Wells	BHP	FM1_2	55	FM1_1	56	1
All Wells	Combined	FM1_4	64	FM1_1	113	49

WOC (-1468) & PVT-1		Cases with name FM-2_x				
Well	Match Vector	Best Case	Match	Worst Case	Match	Range of Affect
All Wells	Oil Prod. Rate	FM2_9	3	FM2_19	15	12
All Wells	Water Prod. Rate	FM2_5	65	FM2_1	137	72
All Wells	Oil Prod. Cum.	FM2_9	2	FM2_1	12	10
All Wells	Water Prod. Cum.	FM2_5	83	FM2_1	165	82
All Wells	BHP	FM2_9	53	FM2_1	56	3
All Wells	Combined	FM2_5	47	FM2_1	96	49

WOC (-1480) & PVT-1		Cases with name FM-3_x				
Well	Match Vector	Best Case	Match	Worst Case	Match	Range of Affect
All Wells	Oil Prod. Rate	FM3_9	1	FM3_1	12	11
All Wells	Water Prod. Rate	FM3_9	18	FM3_1	107	89
All Wells	Oil Prod. Cum.	FM3_9	0	FM3_1	11	11
All Wells	Water Prod. Cum.	FM3_9	20	FM3_1	133	113
All Wells	BHP	FM3_9	52	FM3_1	55	3
All Wells	Combined	FM3_9	12	FM3_1	77	65

WOC (-1455) & PVT-3		Cases with name FM-4_x				
Well	Match Vector	Best Case	Match	Worst Case	Match	Range of Affect
All Wells	Oil Prod. Rate	FM4_2	13	FM4_19	15	2
All Wells	Water Prod. Rate	FM4_4	82	FM4_1	146	64
All Wells	Oil Prod. Cum.	FM4_2	12	FM4_19	13	1
All Wells	Water Prod. Cum.	FM4_4	93	FM4_1	168	75
All Wells	BHP	FM4_2	55	FM4_1	56	1
All Wells	Combined	FM4_4	56	FM4_1	101	45

WOC (-1468) & PVT-3		Cases with name FM-5_x				
Well	Match Vector	Best Case	Match	Worst Case	Match	Range of Affect
All Wells	Oil Prod. Rate	FM5_9	9	FM5_1	15	6
All Wells	Water Prod. Rate	FM5_5	65	FM5_1	128	63
All Wells	Oil Prod. Cum.	FM5_9	8	FM5_1	13	5
All Wells	Water Prod. Cum.	FM5_4	82	FM5_1	151	69
All Wells	BHP	FM5_9	53	FM5_1	56	3
All Wells	Combined	FM5_5	48	FM5_1	89	41

WOC (-1480) & PVT-3		Cases with name FM-6_x				
Well	Match Vector	Best Case	Match	Worst Case	Match	Range of Affect
All Wells	Oil Prod. Rate	FM6_9	3	FM6_1	14	11
All Wells	Water Prod. Rate	FM6_5	38	FM6_1	105	67
All Wells	Oil Prod. Cum.	FM6_9	1	FM6_1	12	11
All Wells	Water Prod. Cum.	FM6_5	48	FM6_1	127	79
All Wells	BHP	FM6_9	52	FM6_1	56	4
All Wells	Combined	FM6_5	28	FM6_1	74	46

So as to see the overall effects more clearly, to see the big picture, the ranges of effects of each class are averaged and are shown in Table 6.6.

Table 6.6 Impact of PVT, WOC, Pc/krel uncertainty on different vector matches

		AVG. RANGE OF EFFECT OF		
Well	Match Vector	PVT	WOC	PC/KREL
All Wells	Oil Prod. Rate	2	7	8
All Wells	Water Prod. Rate	10	67	71
All Wells	Oil Prod. Cum.	2	6	7
All Wells	Water Prod. Cum.	15	76	83
All Wells	BHP	1	2	3
All Wells	Combined	8	46	49

The table demonstrates that PVT data do not seem to noticeably impact the match results when compared to the impact of WOC depth and Pc/krel curve data. The two most dominantly affecting variables, the uncertainty impacts of which are seen on all vector matches (both individually and combined), are Pc/krel and WOC depth data.

Inspecting the Pc/krel uncertainty, due to the fact that it is responsible of the water breakthrough time, its impact, is mostly related to water production rate and water production cumulative results. Following it, impacts on oil production rate and oil production cumulative results comes next with much smaller range of effect values. With close range of effect values, defining the reasons of high water production by a direct relation, impact of WOC uncertainty comes next.

Searching on BHP matches, the effect of Pc/krel and WOC shares the first two rows as the variables having the highest impact, but they are not as determinant as they are on production matches.

6.3.2 Uncertainty Quantification by Two Level (2^k) Factorial Design Technique

In this study, in order to investigate the effects of Pc/krel, PVT and WOC on STOOIP values, a two level design is constructed and analyzed.

As explained in detail in "5.5 Two Level (2^k) Factorial Design Technique as an Uncertainty Quantification Method", the 2^3 factorial design technique is applied in order to quantify the impact of uncertainties on STOOIP values. The coded and uncoded design matrix is as given in Table 6.7. The geometrical representation of the 2^3 design is given in Figure 6.23.

Table 6.7 Coded and uncoded factorial design with results

Test Run No	x_1	x_2	x_3	PC & KREL	WOC	PVT	y (STOOIP)	CASE#
1	-1	-1	-1	MIN	-1455	PVT-3	3,762,259	FM4_19
2	+1	-1	-1	MAX	-1455	PVT-3	15,411,842	FM4_17
3	-1	+1	-1	MIN	-1480	PVT-3	17,238,416	FM6_19
4	+1	+1	-1	MAX	-1480	PVT-3	37,429,903	FM6_2
5	-1	-1	+1	MIN	-1455	PVT-1	5,031,518	FM1_19
6	+1	-1	+1	MAX	-1455	PVT-1	15,412,913	FM1_17
7	-1	+1	+1	MIN	-1480	PVT-1	20,899,394	FM3_19
8	+1	+1	+1	MAX	-1480	PVT-1	38,575,917	FM3_2

DESIGN MATRIX CODED DESIGN MATRIX UNCODED

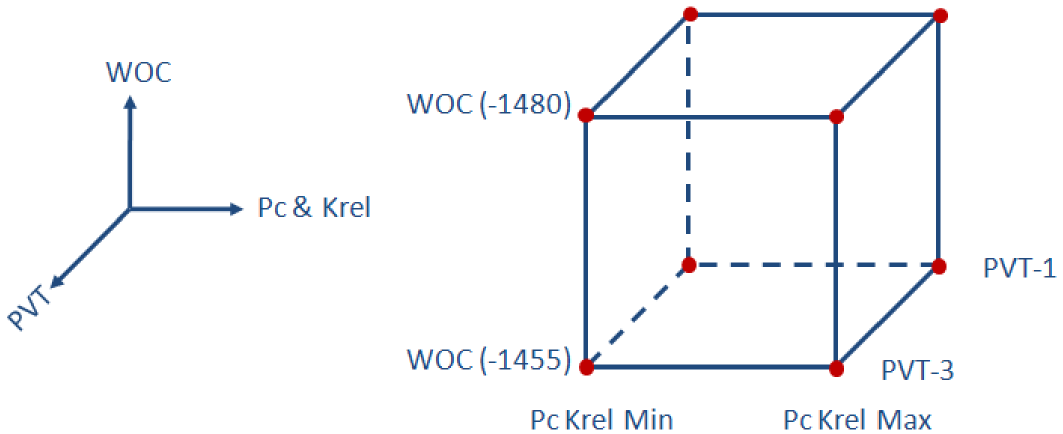

Figure 6.23 Geometrical representation of the 2^3 design

By using the simplified method average effects, two-factor and three-factor interactions are calculated as follows:

E_1 (Average effect of P_C & Krel) = 14,974,747

E_2 (Average effect of WOC) = 18,631,275

E_3 (Average effect of PVT) = 1,519,331

E_{12} (Interaction of P_C & Krel and WOC) = 3,959,258

E_{13} (Interaction of P_C & Krel and PVT) = -945,788

E_{23} (Interaction of WOC and PVT) = 884,166

E_{123} (Interaction of P_C & Krel, WOC and PVT) = -311,694

The analysis of the results is carried out by ranking the effects and interactions according to the absolute magnitudes and given in Table 6.8

Table 6.8 Ranking the average effects on STOOIP

	Average Effect on STOOIP
WOC	18.6×10^6
Pc/krel	15×10^6
WOC & Pc/krel	4×10^6
PVT	1.5×10^6
Pc/krel & PVT	0.95×10^6
WOC & PVT	0.88×10^6
WOC & Pc/krel & PVT	0.31×10^6

When the issue is the determination of STOOIP, the ranking indicates that WOC is the most important variable and Pc/krel effect follows it with a close magnitude of effect. It is also seen that the interaction of WOC and Pc/krel is bigger than the average effect of PVT alone. One should not confuse the interaction with the sum of the effects. The interaction, as the name implies, refers only to the effect that arises from the combination of two items, the results of which are not independent of each other. The remaining two and three factor interactions show that PVT data is quite independent of WOC and Pc/krel.

CHAPTER 7

CONCLUSIONS

This study emphasizes that the uncertainties of dynamic reservoir properties should be given as much attention as the uncertainty of static reservoir properties when modeling an accurate reservoir simulation.

When the results of the simulations are visualized, it is clearly seen that, the dominant factor that affects the match for production rates is the fluid model. Fluid model is constructed upon combination of 2 items; WOC and PVT properties. Screening results do not clarify whether WOC depth is or Pc/krel curves are more determinant on the production rate results.

Screening indicates that, simulation cases of FM3, FM6 (having a WOC of 1480 m ssTVD), are the best matched models. Also FM2 (having a WOC of 1468 m ssTVD), shows matched results for some of the wells. The worst matched simulation models FM1 and FM4 are not capable of producing the target oil production rates even if they produce too much water. The goodness of the water production rate results is parallel to the goodness of the oil production rate results in that, as the water production rate results get closer to the observed data, oil production rate results also get closer to the observed data.

The 3 Best Case models are identified and they all have a WOC depth of 1480 m ssTVD, and PVT data of Bozova-1. The only different items defined in these models are the Pc/krel curves. The similarity on their Pc threshold values being very small, makes the Swi distribution of the model lower than the ones created with the higher Pc threshold curves; thus favoring the simulation models. The reason for these 3 curves matching best is not only the effect of Pc threshold. The krel curves, assigning the fundamental rules of flow functions, are also of vital importance.

Regarding the range of effects the variables can create on the dynamic simulation results, the uncertainty impact of Pc/krel curves is the most affecting variable; the uncertainty of WOC follows it with a close range of effect; and the least effect arises from the uncertainty of PVT data.

When the issue is the determination of STOOIP, it is found that WOC is the most important variable and Pc/krel follows it with a close magnitude of effect. It is also seen that the interaction of WOC and Pc/krel is bigger than the average effect of PVT alone.

CHAPTER 8

RECOMMENDATIONS

Based on the achieved simulation results, there are a number of considerations that must be taken into account in future studies, especially for the history matching process. In addition to the uncertain parameters that are taken into account, parameters such as aquifer strength, aquifer connection area, aquifer influx; kv/kh ratio; permeability model; and Pc/krel curves other than the experimental data should also be considered. As the number of uncertain parameters gets larger, the number of simulation results required also gets larger. Therefore, building a proxy model which connects the results to all influent uncertain parameters may help a more effective uncertainty analysis. In order to identify the actually influent parameters, fractional factorial designs may be used rather than the full factorial experimental designs.

REFERENCES

Al-Shamma, B.R., Teigland, R., 2006, "History Matching of the Valhall Field Using a Global Optimization Method and Uncertainty Assessment", SPE 100946, Presented at the 2006 SPE Annual Technical Conference and Exhibition held in San Antonio, Texas, U.S.A., 24-27 September 2006.

Capen, E.C., 1975, "The Difficulty of Assessing Uncertainty", SPE 5579, Presented at the 1975 SPE-AIME Annual Technical Conference and Exhibition, Dallas, 28 September-1 October 1975.

Çalışgan., H., 1996, "PVT Analysis Report of Bozova-1 Reservoir Oil", Report No 2148, TPAO, Research Center, Reservoir Management, March 1996.

Çalışgan., H., 1996, "PVT Analysis Report of Bozova-3 Reservoir Oil", Report No 2236, TPAO, Research Center, Reservoir Management, February 1997.

Dejean, J.P., Blanc, G.,1999, "Managing Uncertainties on Production Predictions Using Integrated Statistical Methods", SPE 56696, Presented at the 1999 Annual Technical Conference and Exhibition held in Houston, Texas, 3-6 October 1999.

Evin, S., Soyhan, N., 2002, "Reservoir Evaluation Study of Bozova Field", Technical Report, TPAO, Production Department, Reservoir Management, June 2002.

Ferno, M.A., Treinen R., and Graue, A., 2007, "Experimental Measurements of Capillary Pressure with the Centrifuge Technique – Emphasis on Equilibrium Time and Accuracy in Production", SCA2007-22, Presented at the International Symposium of the Society of Core Analysts Calgary, Canada, 10-12 September 2007.

Hajizadeh, Y., Christie, M., Demyanov, V., 2009, "Ant Colony Optimization for History Matching", SPE 121193, Presented at the 2009 SPE EUROPEC/EAGE Annual Conference and Exhibition held in Amsterdam, The Netherlands, 8-11 June 2009.

Holmes, M., 2002, "Capillary Pressure & Relative Permeability Petrophysical Reservoir Models", Technical Report of Digital Formation Inc., Denver, Colorado, U.S.A., 2002.

Karabakal, U., 1998, "Conventional and Special Core Analysis Report of Wells Bozova-1, 2 and 3", Report No 2323, TPAO, Research Center, Reservoir Management, March 1998.

Karakeçe, Y., 1999 "Log Process of Bozova Wells", TPAO, Production Department, Reservoir Management, 1999.

Leuangthong, O., Deutsch, C.V., 2003, "Experimental Design Matrix of Realizations for Optimal Sensitivity Analysis", Technical report, Centre of Computational Geostatistics, University of Alberta, Edmonton, AB, September 2003.

Li, K., Horne, R. N., 2003, "Numerical Simulation with Input Consistency between Capillary Pressure and Relative Permeability", SPE 79716 presented at the SPE Reservoir Simulation Symposium held in Houston, Texas, U.S. A., 3-5 February 2003.

Manceau, E., Mezghani, M., Zabalza-Mezghani, I., Roggero, F., 2001, "Combination of Experimental Design and Joint Modeling Methods for Quantifying the Risk Associated with Deterministic and Stochastic Uncertainties – An Integrated Test Study", SPE 71620, Presented at the 2001 SPE Annual Technical Conference and Exhibition held in New Orleans, Louisiana, U.S.A., 30 September-3 October 2001.

Mogford, M., 2007, "Introduction to Relative Permeability", Presented at the AFES Meeting, Aberdeen, 28 March 2007.

Mohammed, L., Christie, M., Demyanov, V., 2009, “Comparison of Stochastic Sampling Algorithms for Uncertainty Quantification”, SPE 119139, Presented at the 2009 SPE Reservoir Simulation Symposium, The Woodlands, Texas, U.S.A., 2-4 February 2009.

Peterson, R.D., Yawanarah, S., Neisch, D., Tabanou E., and James, S., 2006, “Towards a Framework for Better Decision Making under Subsurface Uncertainty”, SPE 99484, presented at the 2006 Intelligent Energy Conference and Exhibition held in Amsterdam, The Netherlands, 11-13 April 2006.

Potlog, S., 2003, "Uncertainty Quantification and Risk Analysis for Petroleum Exploration and Exploitation Projects", Department of Civil & Environmental Engineering, University of Alberta, 2003.

Rotondi, M., Nicotra, G., Godi, A., Contento, F.M., Blunt, M.J., Christie, M.A., 2006, "Hydrocarbon Production Forecast and Uncertainty Quantification: A Field Application", SPE 102135, Presented at the 2006 SPE Annual Technical Conference and Exhibition held in San Antonio, Texas, U.S.A.,24-27 September 2006.

Salarieh, M., Doroudi, A., Sobhi, G.A., and Bashiri, G.R., 2004, “The Role of Capillary Pressure Curves in Reservoir Simulation Studies”, Technical Report, Research Institute of Petroleum Industry.

Salomão, M.C., and Grell, A.P., 2001. "Uncertainty in Production Profiles on the Basis of Geostatistic Characterization and Flow Simulation", paper SPE 69477, Presented at the SPE Latin American and Caribbean Petroleum Engineering Conference held in Buenos Aires, Argentina, 25–28 March 2001.

Saxena, U., Pavelic, V., 1971, “Factorial Designs as an Effective Tool in Mining and Petroleum Engineering”, SPE 3333, Society of Petroleum Engineers Journal, 1971.

Şengündüz, N., Çoruh, T., İlleez, H., Karabakal, U., and Selvi, B., 2000, “XII. Bölge Bozova, Suvarlı, Araban Sahaları ve Civarının Jeolojik Değerlendirmesi”, Technical Report, TPAO, Research Department, 2000.

Venkatamaran, R., 2000. “Application of the Method of Experimental Design to Quantify Uncertainty in Production Profiles”, SPE 59422, presented at the 2000 SPE Asia Pacific Conference on Integrated Modeling for Asset Management held in Yokohama, Japan, 25-26 April 2000.

Zabalza-Mezghani, I., Manceau, E., Feraille, M., and Jourdan, A., 2004. "Uncertainty Management: From Geological Scenarios to Production Scheme Optimization", Journal of Petroleum Science and Engineering 44, 11-25, 2004.

Zabel, F., Law, D.H.S., Taylor, S., Zuo, J., 2008. “Impact of Uncertainty of Heavy Oil Fluid Property Measurement”, Proceedings of the Canadian International Petroleum Conference/SPE Gas Technology Symposium 2008 Joint Conference, Canada, 2008.

APPENDIX A

WELL TEST INTERPRETATION RESULTS

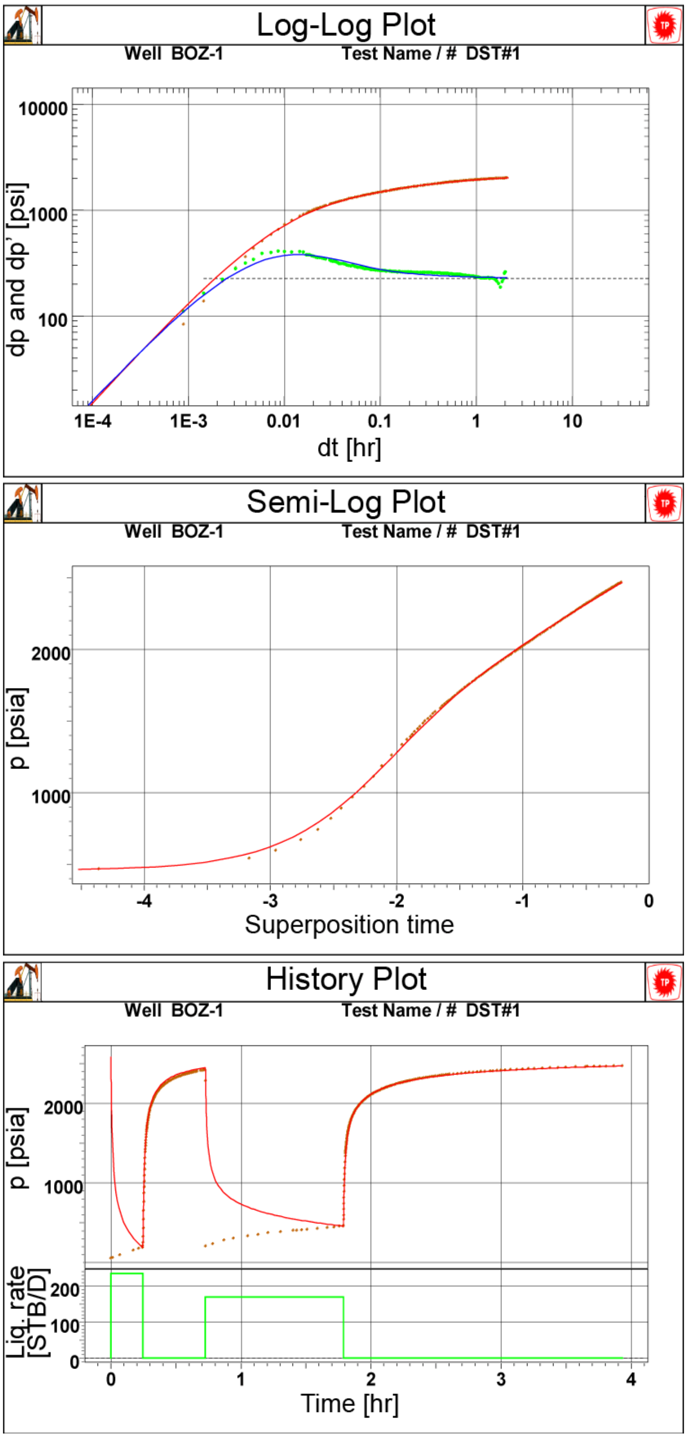

Figure A.1 Well test interpretation plots of Bozova-1 DST#1

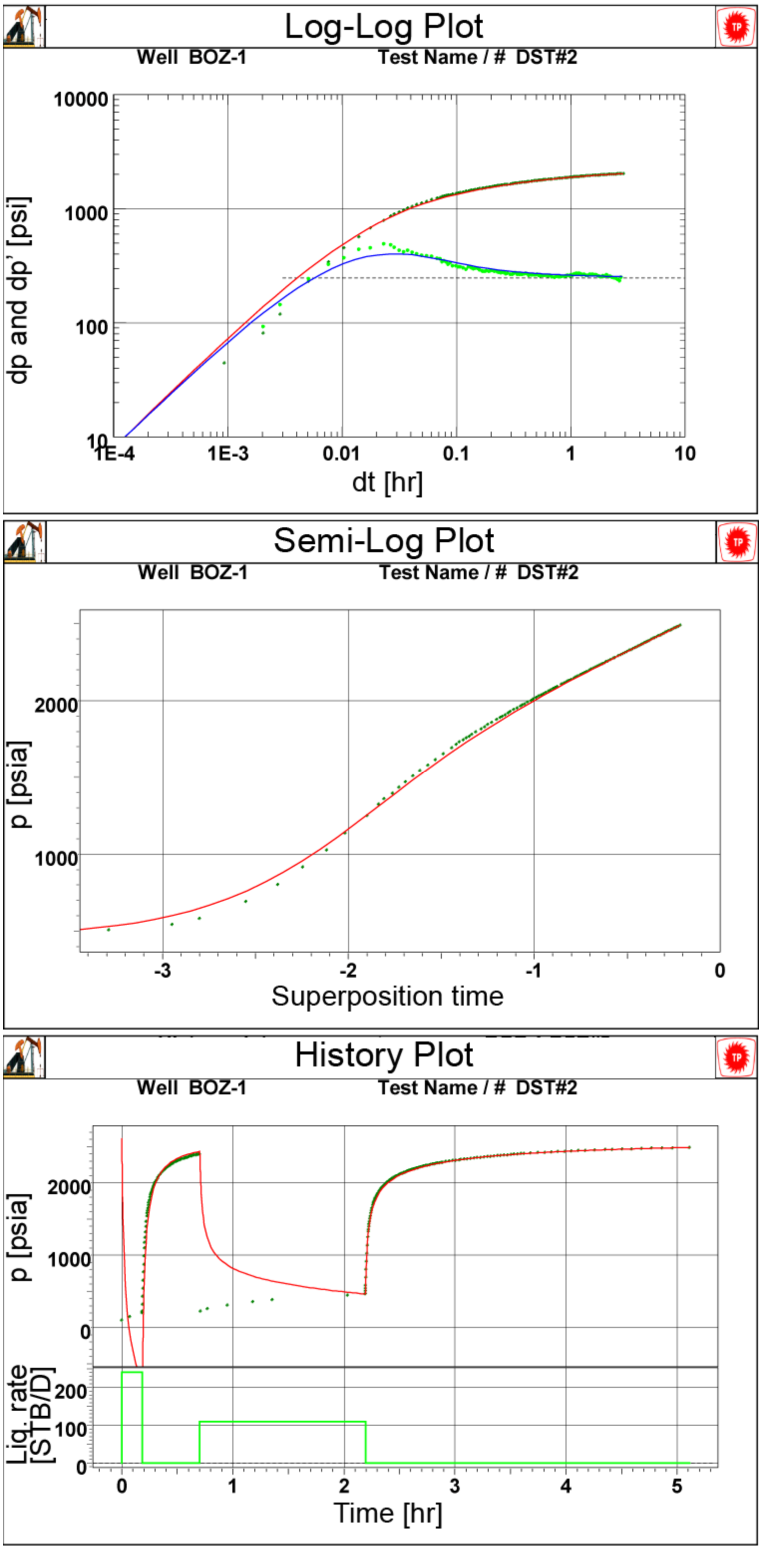

Figure A.2 Well test interpretation plots of Bozova-1 DST#2

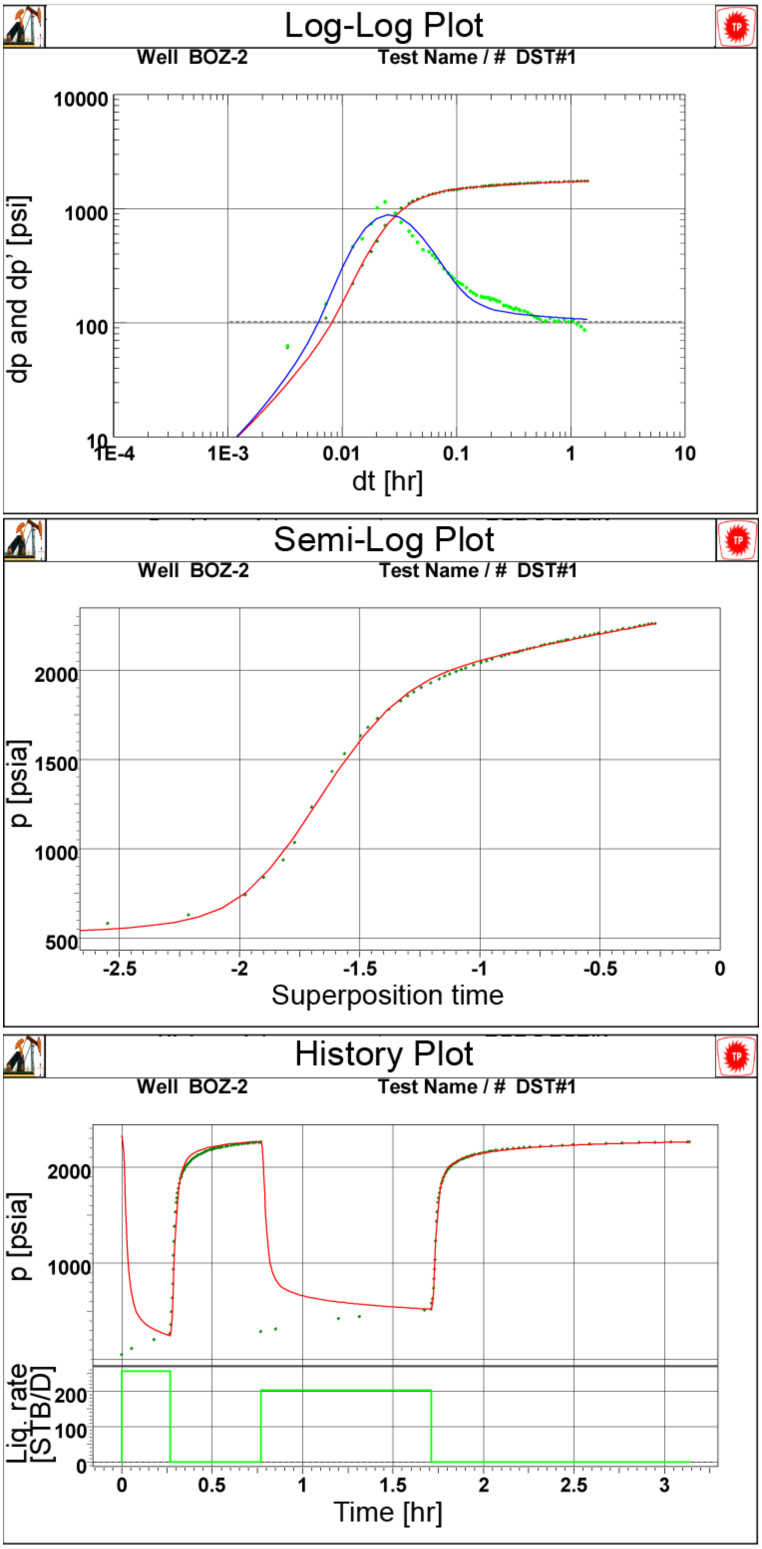

Figure A.3 Well test interpretation plots of Bozova-2 DST#1

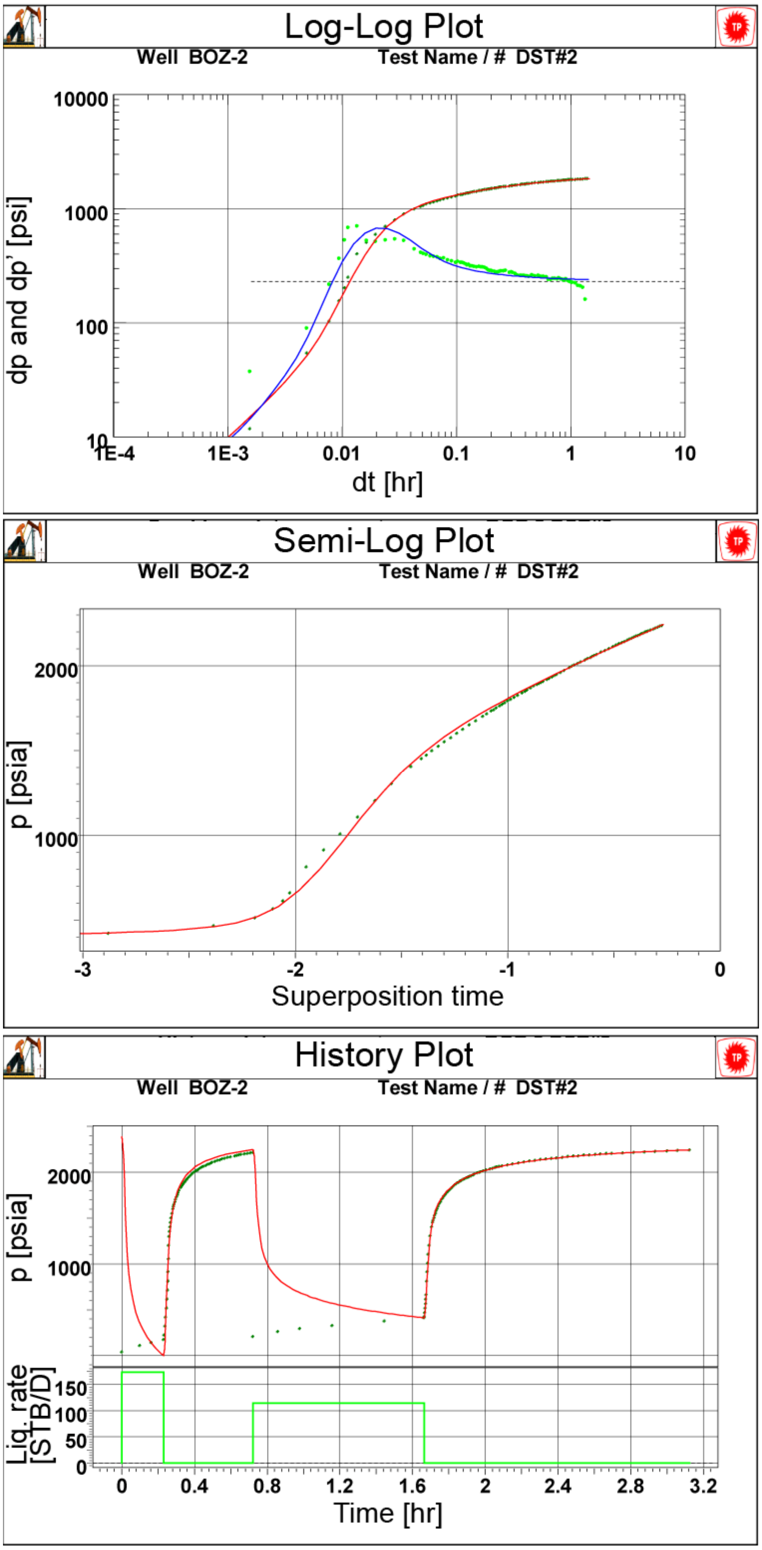

Figure A.4 Well test interpretation plots of Bozova-2 DST#2

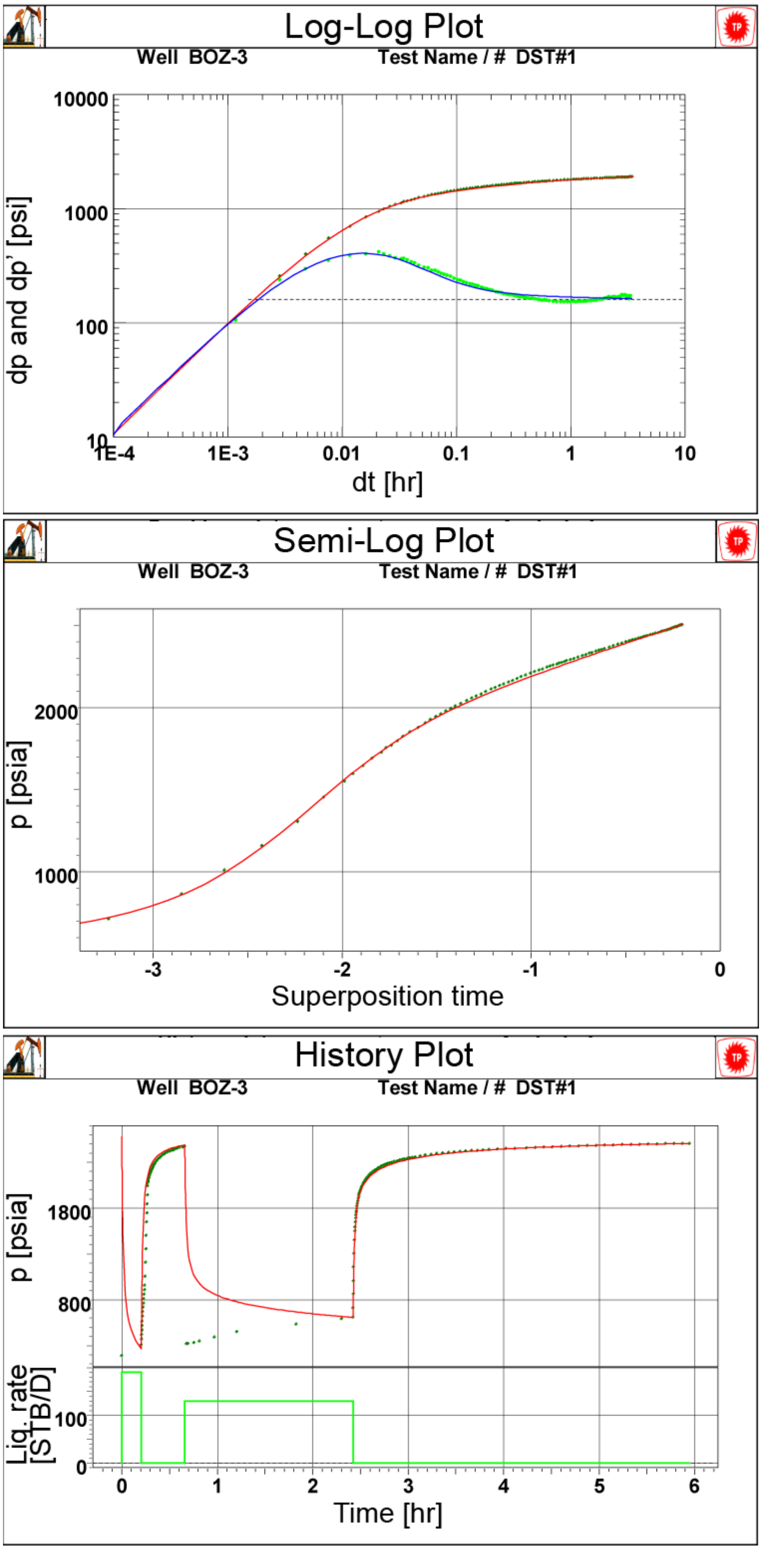

Figure A.5 Well test interpretation plots of Bozova-3 DST#1

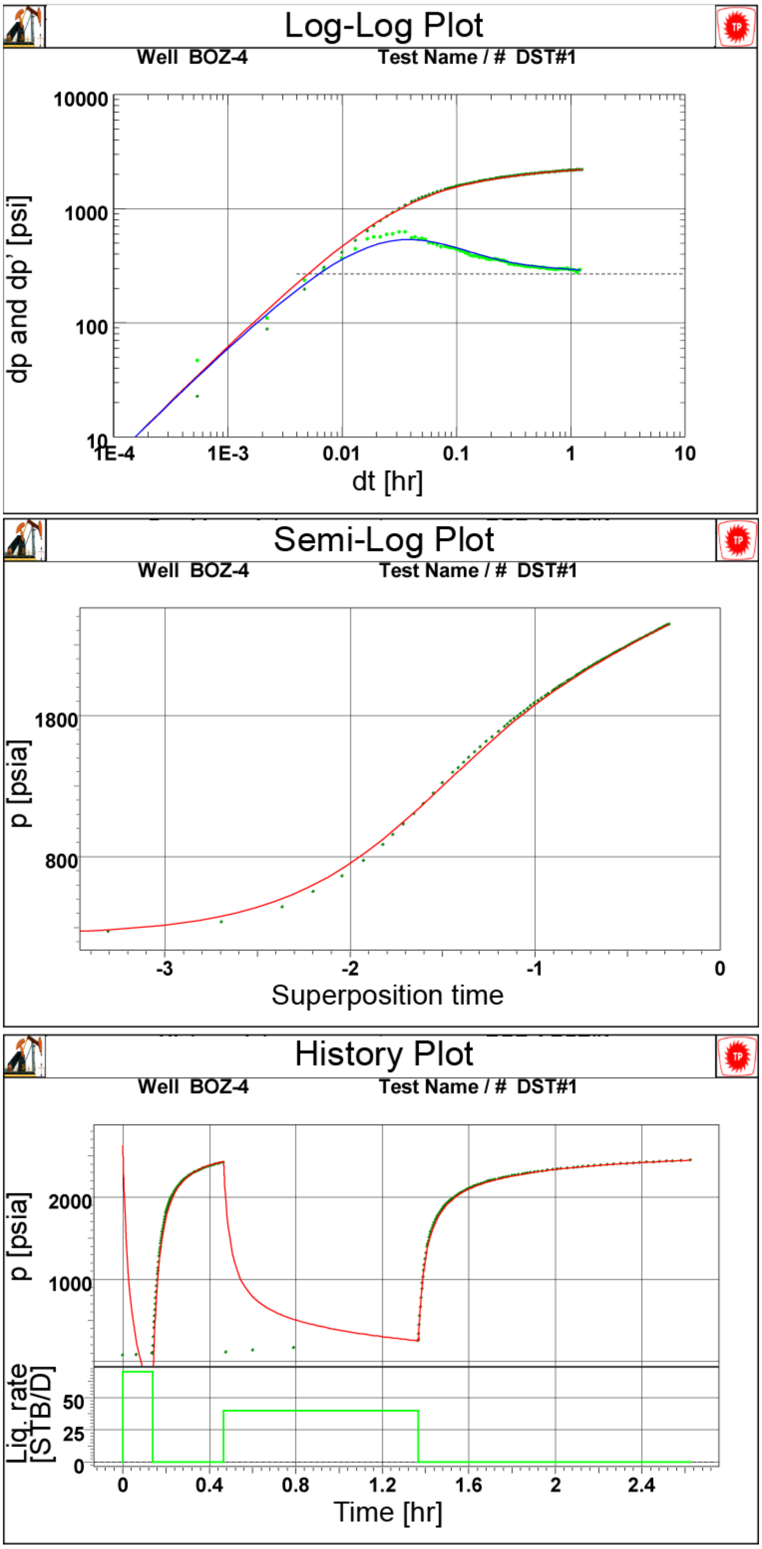

Figure A.6 Well test interpretation plots of Bozova-4 DST#1

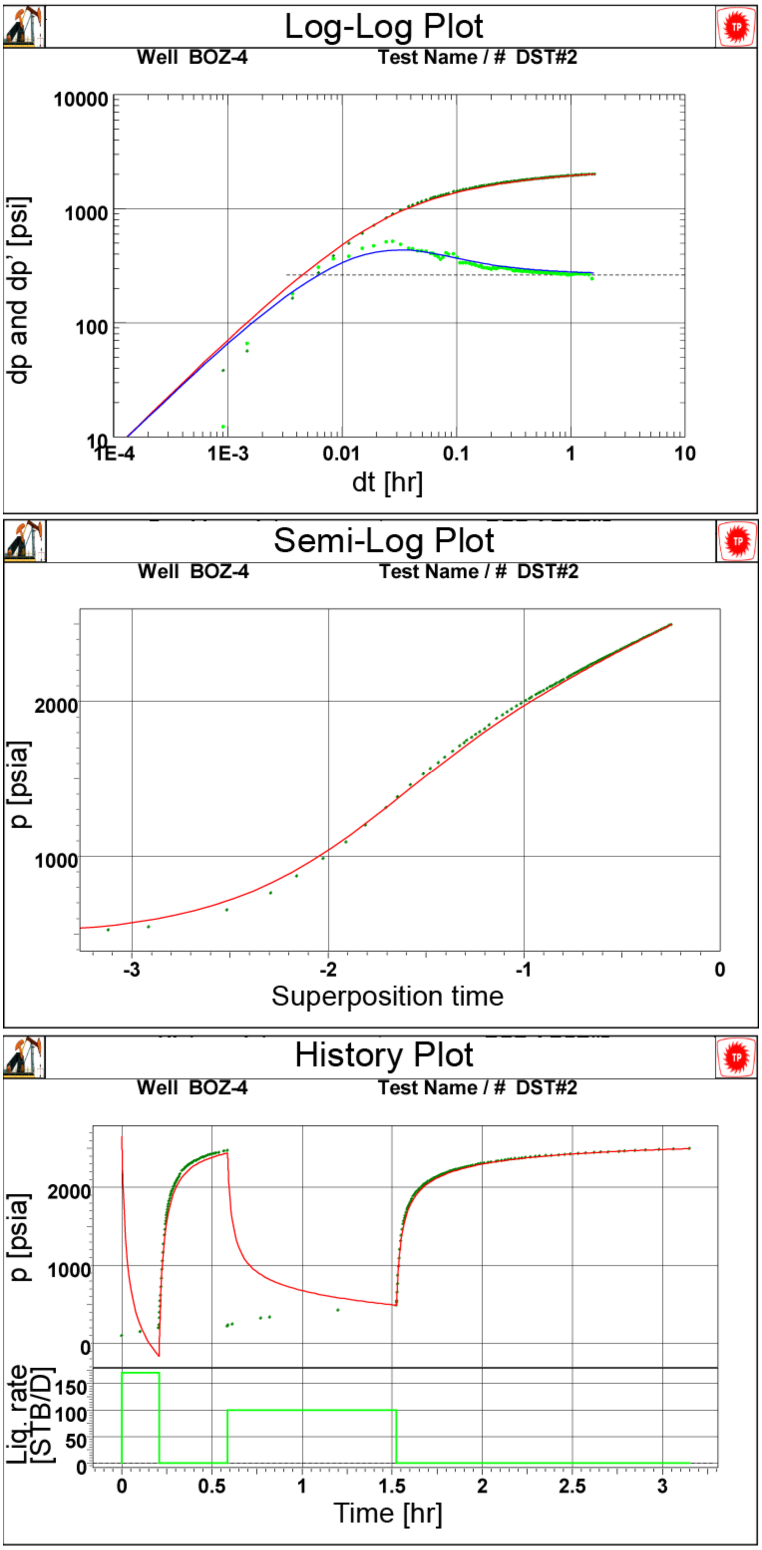

Figure A.7 Well test interpretation plots of Bozova-4 DST#2

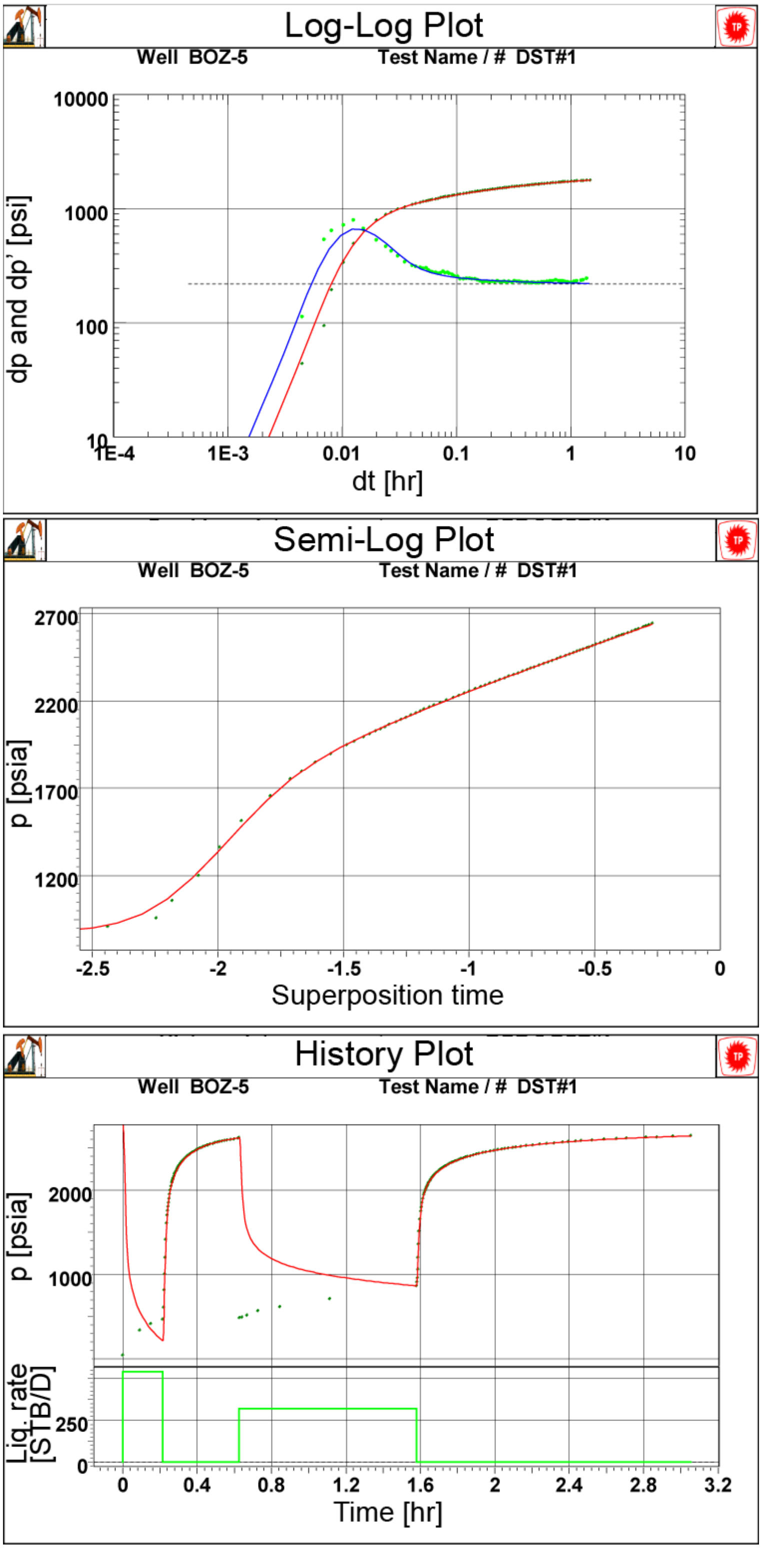

Figure A.8 Well test interpretation plots of Bozova-5 DST#1

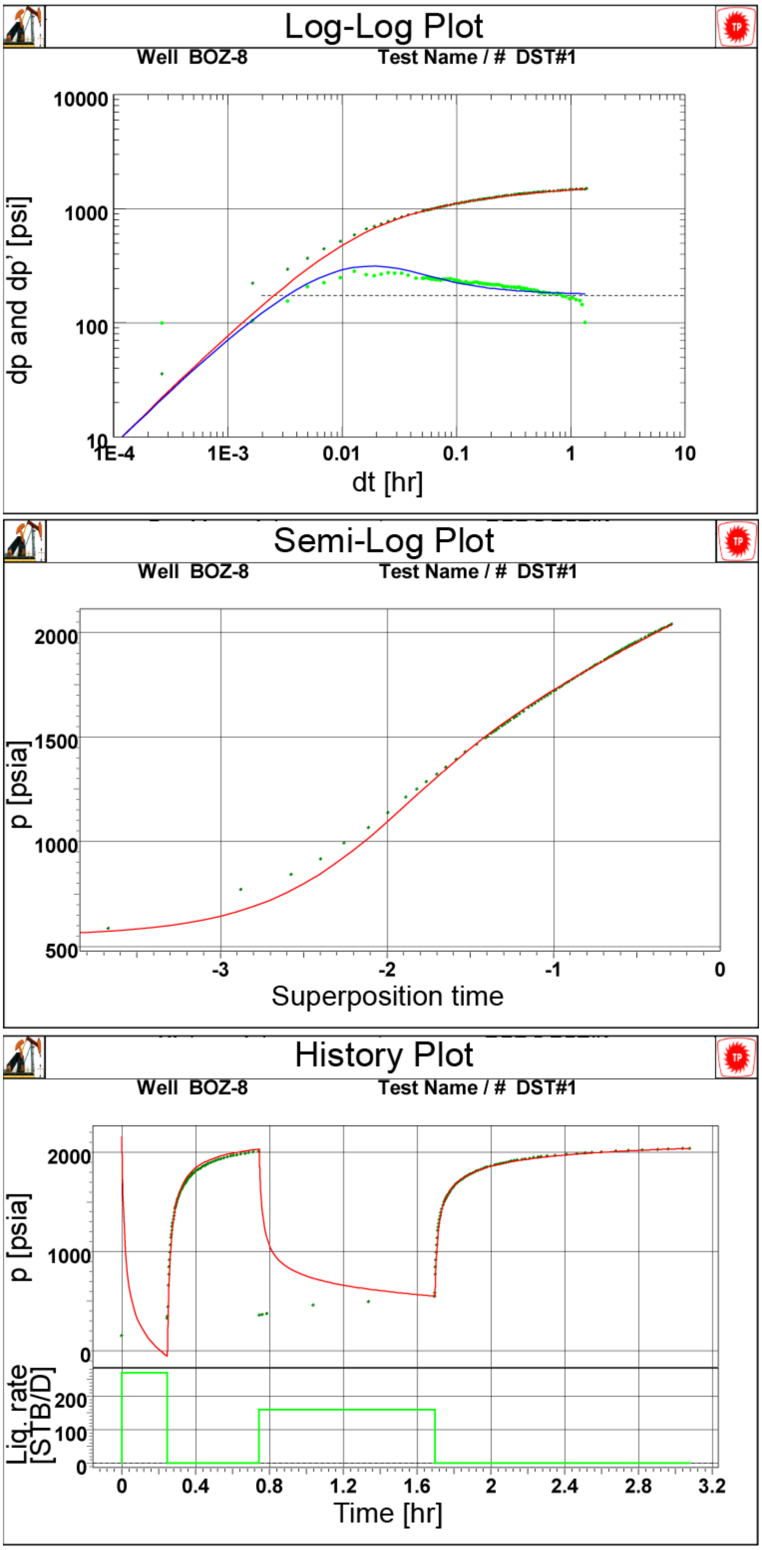

Figure A.9 Well test interpretation plots of Bozova-8 DST#1

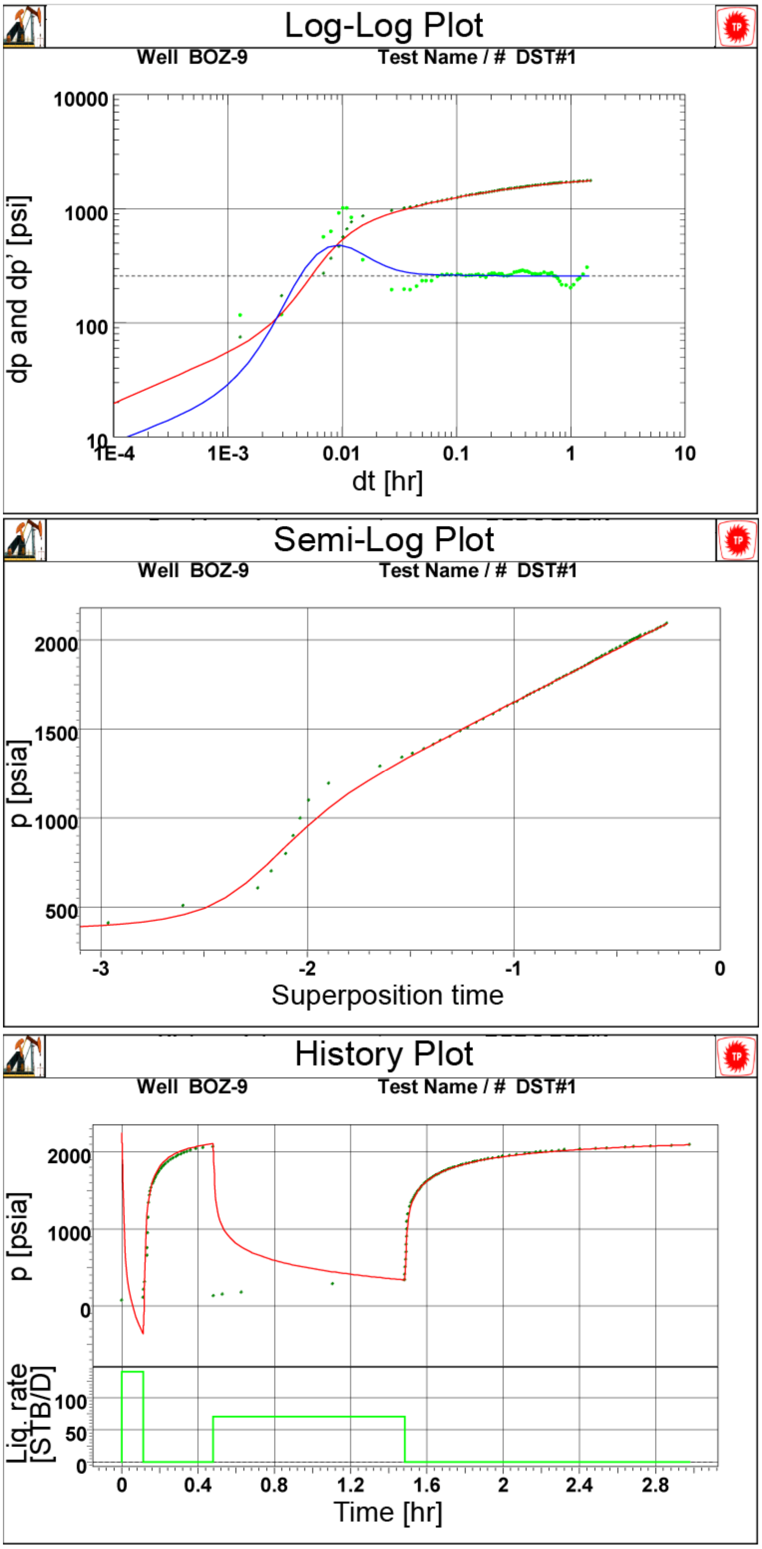

Figure A.10 Well test interpretation plots of Bozova-9 DST#1

APPENDIX B

BHP MEASUREMENT DETAILS

Table B.1 Amerada BHP measurement details (Bozova-1, 3, 8)

Bozova-1 (30.12.1995)				
Level	Depth, m	Elev, m	Amerada1: 58184 Pressure, psi	Amerada2: 80481 Pressure, psi
After RIN	1900	-1409.1	2445	2419
Before POOH	1900	-1409.1	2448	2418
1st Level	1700	-1209.1	2175	2145
2nd Level	1500	-1009.1	1892	1864
3rd Level	1300	-809.1	1605	1589
4th Level	1100	-609.1	1323	1309
5th Level	900	-409.1	1047	1026
6th Level	700	-209.1	760	740

*BHT: 172 ºF

Bozova-3 (06.12.1997)				
Level	Depth, m	Elev, m	Amerada1: 80184 Pressure, psi	Amerada2: 58184 Pressure, psi
After RIN	1850	-1363	1936	1865
Before POOH	1850	-1363	1960	1902
1st Level	1650	-1163	1710	1659
2nd Level	1450	-963	1468	1423
3rd Level	1250	-763	1222	1185
4th Level	1050	-563	975	940
5th Level	850	-363	750	692

*BHT: 174 ºF

Bozova-8 (22.10.1998)				
Level	Depth, m	Elev, m	Amerada1: 80481 Pressure, psi	Amerada2: 10508 Pressure, psi
After RIN	1861	-1395	1635	1678
Before POOH	1861	-1395	1665	1697
1st Level	1661	-1195	1421	1444
2nd Level	1461	-995	1169	1186
3rd Level	1261	-795	915	931
4th Level	1061	-595	653	672
5th Level	861	-395	392	408

*BHT: 172 ºF

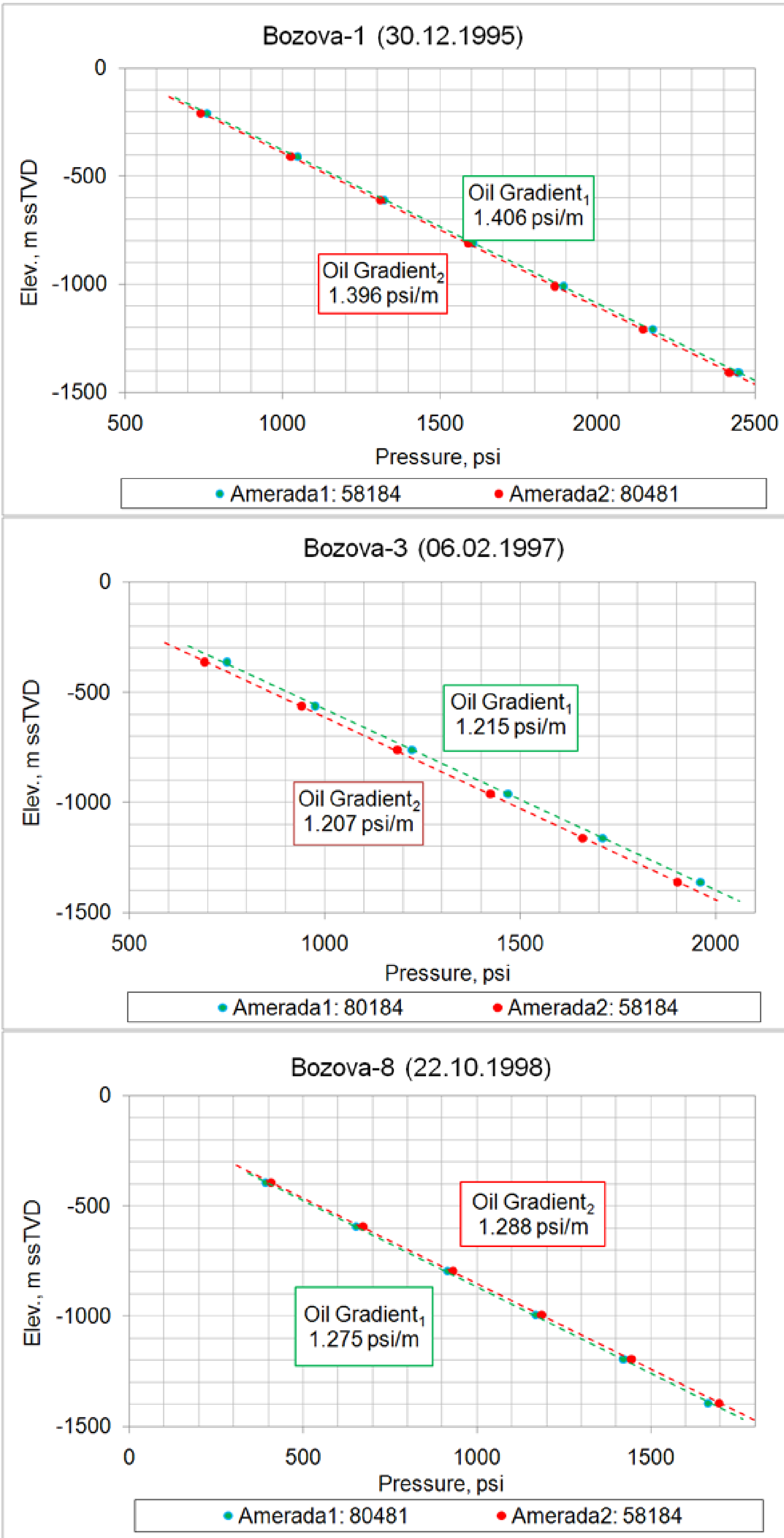

Figure B.1 Pressure vs. depth plots of Amerada BHP measurements (Bozova-1, 3, 8)

Table B.2 Spartek BHP measurement details (Bozova-2, 8, 9)

Bozova-2 (15.02.2011)			
Level	Depth, m	Elev, m	Spartek-1197 Pressure, psi
Before POOH	1335	-852	1496
1st Level	1200	-717	1306
2nd Level	1000	-517	1024
3rd Level	800	-317	741
4th Level	600	-117	458
5th Level	400	83	178
6th Level	350	133	111

*BHT: 150 ºF

Bozova-8 (16.02.2011)			
Level	Depth, m	Elev, m	Spartek-1197 Pressure, psi
Before POOH	1700	-1239	1314
1st Level	1500	-1039	1028
2nd Level	1300	-839	741
3rd Level	1100	-639	454
4th Level	900	-439	193

*BHT: 170 ºF

Bozova-9 (16.02.2011)			
Level	Depth, m	Elev, m	Spartek-1197 Pressure, psi
Before POOH	1860	-1400	2017
1st Level	1700	-1240	1794
2nd Level	1500	-1040	1514
3rd Level	1300	-840	1232
4th Level	1100	-640	949
5th Level	900	-440	683
6th Level	700	-240	423
7th Level	500	-40	164

*BHT: 176 ºF

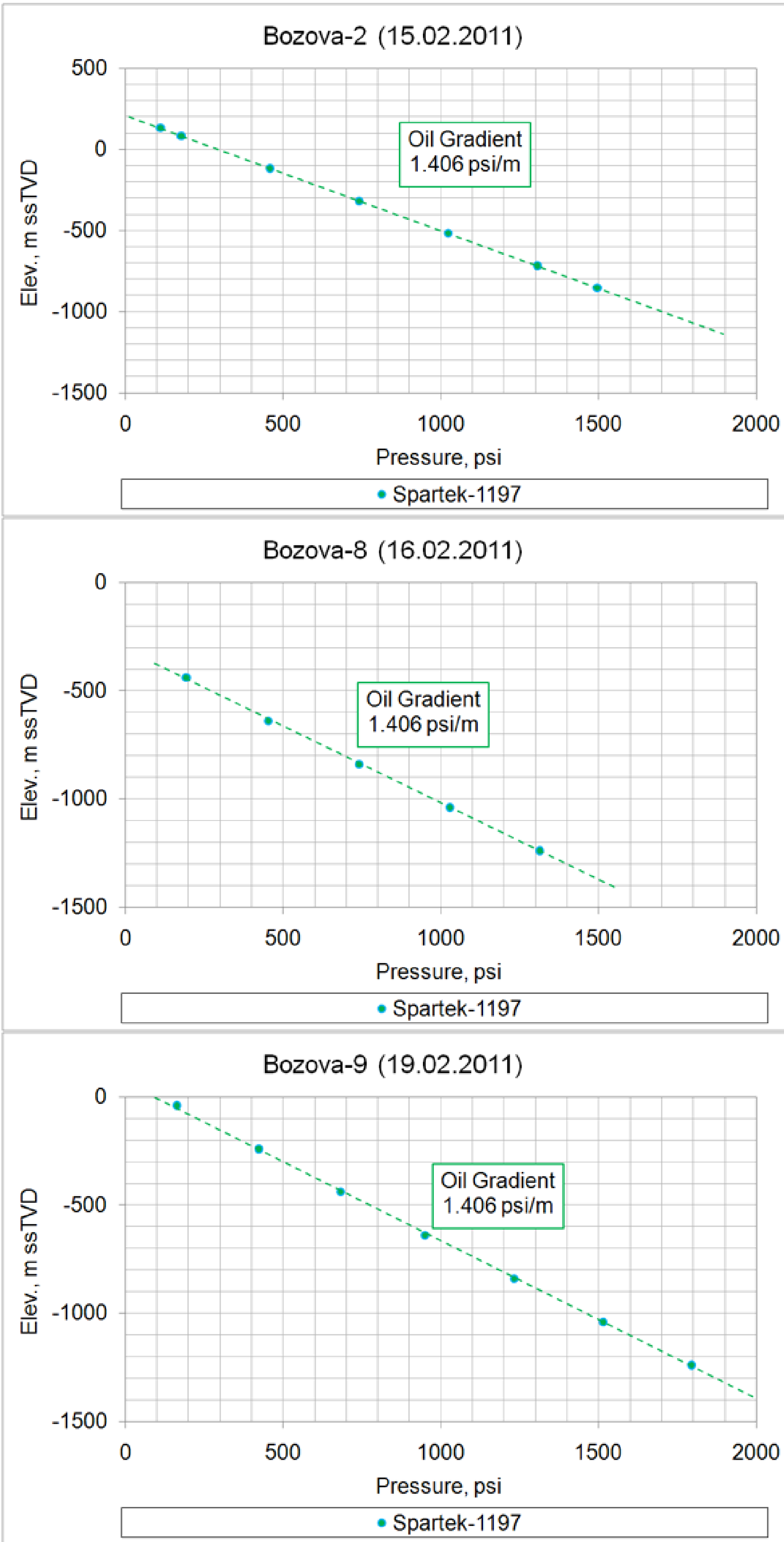

Figure B.2 Pressure vs. depth plots of Spartek BHP measurements (Bozova-2, 8, 9)

APPENDIX C

EXPERIMENTAL DESIGN TABLE

Table C.1 Experimental design used for the simulation runs and STOOIP results

CASE#	PVT	WOC	Pc/krel #		STOOIP	CASE#	PVT	WOC	Pc/krel #		STOOIP
FM1_1	PVT-1	-1455	#1	Boz-1_196	13,733,730	FM4_1	PVT-3	-1455	#1	Boz-1_196	13,037,280
FM1_2	PVT-1	-1455	#2	Boz-1_197	15,373,053	FM4_2	PVT-3	-1455	#2	Boz-1_197	14,970,914
FM1_3	PVT-1	-1455	#3	Boz-1_198	8,372,368	FM4_3	PVT-3	-1455	#3	Boz-1_198	6,988,187
FM1_4	PVT-1	-1455	#4	Boz-1_200	8,027,234	FM4_4	PVT-3	-1455	#4	Boz-1_200	6,861,376
FM1_5	PVT-1	-1455	#5	Boz-1_201	11,629,868	FM4_5	PVT-3	-1455	#5	Boz-1_201	10,385,157
FM1_6	PVT-1	-1455	#6	Boz-1_205	8,327,527	FM4_6	PVT-3	-1455	#6	Boz-1_205	7,011,178
FM1_7	PVT-1	-1455	#7	Boz-1_206	6,836,962	FM4_7	PVT-3	-1455	#7	Boz-1_206	5,242,750
FM1_8	PVT-1	-1455	#8	Boz-2_1	13,730,676	FM4_8	PVT-3	-1455	#8	Boz-2_1	13,134,543
FM1_9	PVT-1	-1455	#9	Boz-2_2	13,935,673	FM4_9	PVT-3	-1455	#9	Boz-2_2	13,174,781
FM1_10	PVT-1	-1455	#10	Boz-2_4	10,855,029	FM4_10	PVT-3	-1455	#10	Boz-2_4	10,006,776
FM1_11	PVT-1	-1455	#11	Boz-2_6	9,364,930	FM4_11	PVT-3	-1455	#11	Boz-2_6	7,995,004
FM1_12	PVT-1	-1455	#12	Boz-3_266	5,921,242	FM4_12	PVT-3	-1455	#12	Boz-3_266	4,689,297
FM1_13	PVT-1	-1455	#13	Boz-3_267	7,273,033	FM4_13	PVT-3	-1455	#13	Boz-3_267	6,026,677
FM1_14	PVT-1	-1455	#14	Boz-3_272	8,900,736	FM4_14	PVT-3	-1455	#14	Boz-3_272	7,710,688
FM1_15	PVT-1	-1455	#15	Boz-3_273	6,974,948	FM4_15	PVT-3	-1455	#15	Boz-3_273	5,617,546
FM1_16	PVT-1	-1455	#16	Boz-3_275	8,050,662	FM4_16	PVT-3	-1455	#16	Boz-3_275	6,723,079
FM1_17	PVT-1	-1455	#17	Boz-3_288	15,412,913	FM4_17	PVT-3	-1455	#17	Boz-3_288	15,411,842
FM1_18	PVT-1	-1455	#18	Boz-3_294	14,608,149	FM4_18	PVT-3	-1455	#18	Boz-3_294	14,472,566
FM1_19	PVT-1	-1455	#19	Boz-3_297	5,031,518	FM4_19	PVT-3	-1455	#19	Boz-3_297	3,762,259
FM2_1	PVT-1	-1468	#1	Boz-1_196	24,521,611	FM5_1	PVT-3	-1468	#1	Boz-1_196	23,299,621
FM2_2	PVT-1	-1468	#2	Boz-1_197	26,489,014	FM5_2	PVT-3	-1468	#2	Boz-1_197	25,672,659
FM2_3	PVT-1	-1468	#3	Boz-1_198	17,532,330	FM5_3	PVT-3	-1468	#3	Boz-1_198	15,148,177
FM2_4	PVT-1	-1468	#4	Boz-1_200	16,501,478	FM5_4	PVT-3	-1468	#4	Boz-1_200	14,292,736
FM2_5	PVT-1	-1468	#5	Boz-1_201	22,462,843	FM5_5	PVT-3	-1468	#5	Boz-1_201	20,387,774
FM2_6	PVT-1	-1468	#6	Boz-1_205	17,406,658	FM5_6	PVT-3	-1468	#6	Boz-1_205	14,890,925
FM2_7	PVT-1	-1468	#7	Boz-1_206	15,670,385	FM5_7	PVT-3	-1468	#7	Boz-1_206	12,711,197
FM2_8	PVT-1	-1468	#8	Boz-2_1	24,346,652	FM5_8	PVT-3	-1468	#8	Boz-2_1	23,138,960
FM2_9	PVT-1	-1468	#9	Boz-2_2	25,079,135	FM5_9	PVT-3	-1468	#9	Boz-2_2	23,657,242
FM2_10	PVT-1	-1468	#10	Boz-2_4	20,239,824	FM5_10	PVT-3	-1468	#10	Boz-2_4	18,663,111
FM2_11	PVT-1	-1468	#11	Boz-2_6	19,126,902	FM5_11	PVT-3	-1468	#11	Boz-2_6	16,769,316
FM2_12	PVT-1	-1468	#12	Boz-3_266	13,216,708	FM5_12	PVT-3	-1468	#12	Boz-3_266	10,880,569
FM2_13	PVT-1	-1468	#13	Boz-3_267	15,431,811	FM5_13	PVT-3	-1468	#13	Boz-3_267	13,163,922
FM2_14	PVT-1	-1468	#14	Boz-3_272	17,946,893	FM5_14	PVT-3	-1468	#14	Boz-3_272	15,792,714
FM2_15	PVT-1	-1468	#15	Boz-3_273	15,287,605	FM5_15	PVT-3	-1468	#15	Boz-3_273	12,746,306
FM2_16	PVT-1	-1468	#16	Boz-3_275	16,884,159	FM5_16	PVT-3	-1468	#16	Boz-3_275	14,544,029
FM2_17	PVT-1	-1468	#17	Boz-3_288	25,652,380	FM5_17	PVT-3	-1468	#17	Boz-3_288	25,297,794
FM2_18	PVT-1	-1468	#18	Boz-3_294	24,694,196	FM5_18	PVT-3	-1468	#18	Boz-3_294	24,097,914
FM2_19	PVT-1	-1468	#19	Boz-3_297	11,906,167	FM5_19	PVT-3	-1468	#19	Boz-3_297	9,406,311
FM3_1	PVT-1	-1480	#1	Boz-1_196	36,374,581	FM6_1	PVT-3	-1480	#1	Boz-1_196	34,738,738
FM3_2	PVT-1	-1480	#2	Boz-1_197	38,575,917	FM6_2	PVT-3	-1480	#2	Boz-1_197	37,429,903
FM3_3	PVT-1	-1480	#3	Boz-1_198	28,348,629	FM6_3	PVT-3	-1480	#3	Boz-1_198	25,142,848
FM3_4	PVT-1	-1480	#4	Boz-1_200	26,887,686	FM6_4	PVT-3	-1480	#4	Boz-1_200	23,597,977
FM3_5	PVT-1	-1480	#5	Boz-1_201	34,738,021	FM6_5	PVT-3	-1480	#5	Boz-1_201	32,015,460
FM3_6	PVT-1	-1480	#6	Boz-1_205	28,603,539	FM6_6	PVT-3	-1480	#6	Boz-1_205	24,993,750
FM3_7	PVT-1	-1480	#7	Boz-1_206	26,773,119	FM6_7	PVT-3	-1480	#7	Boz-1_206	22,677,963
FM3_8	PVT-1	-1480	#8	Boz-2_1	36,218,218	FM6_8	PVT-3	-1480	#8	Boz-2_1	34,495,983
FM3_9	PVT-1	-1480	#9	Boz-2_2	37,492,500	FM6_9	PVT-3	-1480	#9	Boz-2_2	35,581,704
FM3_10	PVT-1	-1480	#10	Boz-2_4	31,016,280	FM6_10	PVT-3	-1480	#10	Boz-2_4	28,770,465
FM3_11	PVT-1	-1480	#11	Boz-2_6	30,548,469	FM6_11	PVT-3	-1480	#11	Boz-2_6	27,372,039
FM3_12	PVT-1	-1480	#12	Boz-3_266	22,396,845	FM6_12	PVT-3	-1480	#12	Boz-3_266	19,052,661
FM3_13	PVT-1	-1480	#13	Boz-3_267	25,352,760	FM6_13	PVT-3	-1480	#13	Boz-3_267	22,142,240
FM3_14	PVT-1	-1480	#14	Boz-3_272	28,702,959	FM6_14	PVT-3	-1480	#14	Boz-3_272	25,653,048
FM3_15	PVT-1	-1480	#15	Boz-3_273	25,625,959	FM6_15	PVT-3	-1480	#15	Boz-3_273	22,007,222
FM3_16	PVT-1	-1480	#16	Boz-3_275	27,464,830	FM6_16	PVT-3	-1480	#16	Boz-3_275	24,198,431
FM3_17	PVT-1	-1480	#17	Boz-3_288	36,890,886	FM6_17	PVT-3	-1480	#17	Boz-3_288	36,184,862
FM3_18	PVT-1	-1480	#18	Boz-3_294	35,952,573	FM6_18	PVT-3	-1480	#18	Boz-3_294	34,869,253
FM3_19	PVT-1	-1480	#19	Boz-3_297	20,899,394	FM6_19	PVT-3	-1480	#19	Boz-3_297	17,238,416