Improvement of Water Flood Performance in NEAG-1 Field in the Egyptian Western Desert

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Abstract: NEAG-1 Field is located in the northern part of the Western Desert in Egypt. Bahariya, the main reservoir, consists of a sequence of thin bedded sandstone with poor lateral extensions. The reservoir heterogeneity is a bit high that the reservoir permeability variation is 0.8 and the reservoir complexity factor is 3.6 (out of 5) so, it is classified as a challenging reservoir. In 2010, the waterflood project has started and the strategy was to adopt a commingle injection and commingle production for all wells. Later on, production and pressure performance proved a high level of heterogeneity and indicated that there are five different flow units in Bahariya which makes numerical prediction and modeling very unlikely. So, this field is better to run and monitor analytically. The decision has been taken to build a tool for waterflood performance monitoring. The first step of the work is to have one database file from different data sources. The second part of this study is to define diagnostic plots that fit NEAG-1 wells, reservoirs and field characters. So, we can have a simple tool that contains all kinds of data and plots for waterflooding monitoring and troubleshooting. It is easy to be updated in daily bases and any one can access and use it from wherever. As a part of the quality control (QC) process, this tool has been developed and validated for NEAG-1 Field with a high accuracy compared to reservoir simulation runs. The results are promising, that the tool has been implemented for three different cases; assisted in Fadl-10 WI workover decisions which saved 0.65 MM$ and added 100 MSTB as an incremental oil reserve. Control of water production which reduced Fadl-1 water cut from 75 to 62% and increased oil production rate by 200 bbl/day. This assisted well planning which helped drill Fadl-47 oil producer with an oil production rate of 500 bpd. In addition to assisting decisions for remedial actions, the tool maximized oil production and optimized the operating cost for lots of cases. The proposed tool can be modified also to fit different fields with different reservoir characters.

Key Words: — ***Water flood Monitoring, Production Optimization, Well Planning, NEAG Field, Western Desert.***

I. INTRODUCTION

North East Abu Gharadig-1 (NEAG-1) field is located in the onshore of northern part of the Western Desert in Egypt [1]. Bahariya formation of Cenomanian Cretaceous age is the main reservoir in NEAG_1 field that is 90% of the Western Desert fields are producing from with several effective and possibly laterally continuous seals [2]. In this field, Bahariya sandstone is found at shallow depth ± 1200 m.ss and consists of a sequence of thin bedded sandstone, shales and siltstone with vertical and lateral heterogeneity [3]. NEAG-1 development lease is a part of North east Abu Gharadig concession, located in the northern part of the Western Desert in Egypt (Figure 1). Badr El Din Petroleum Company (BAPETCO) operates this concession on behalf of the NEAG stakeholders [4]. Bahariya formation in NEAG-1, as well as other formations in other fields in BAPETCO, has been waterflooded using the conventional waterflooding techniques applied in sandstone reservoirs [5]. All injection wells are aligned parallel along major faults trend to force the oil to flow perpendicular to the fracture faults towards a line of production wells [6]. In the past,

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several trials have been conducted to propose different waterflooding monitoring techniques and development plans for Bahariya Unit; however, none of the previous studies have addressed the reservoir characterization and monitoring of the waterflooding project and proposed alternatives of development taking into account the current and future conditions of the reservoir. Consequently, this research aims to present a tool for waterflood monitoring to provide a significant reservoir characterization and evaluate the performance of the waterflooding to provide facts, information and knowledge to obtain the maximum economic recovery from this reservoir. Thus, attempts are made to describe the reservoir, understand its performance under the current waterflooding project, and controlled surveillance will be carried out to improve the field performance.

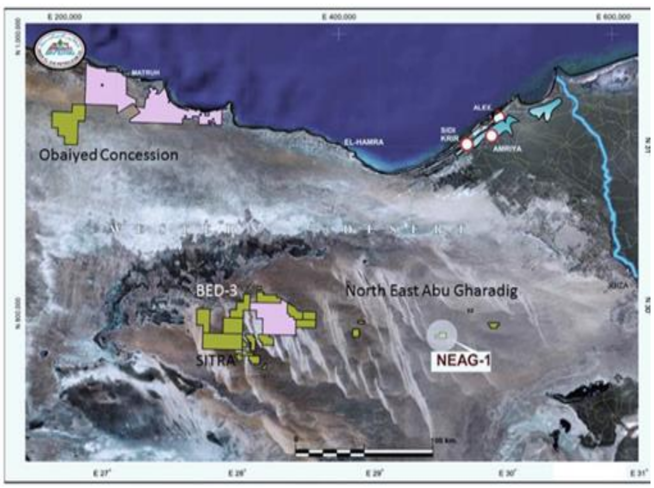


Fig.1. Location map of BAPETCO fields

II. Tool Development

In this part we will go step by step through the different stages of the work to get a waterflood performance monitoring tool ready to be effectively used, starting from raw data preparation and collection from different sources, assembling data into one datasheet, mapping different wells and reservoirs names, calling different data from different tables, preparing different kinds of data representation, plotting and templates for both wells and reservoir and finally how to maximize benefits from this set of templates [7].

A. Data Preparation

The database still one of the biggest challenges that BAPETCO usually faces, many trials to build a robust system database have been done however, big efforts have to be done to get this system effective [8]. The fact is the different kinds of data regarding wells and reservoirs still distributed between different sources. There are three main data sources:

- Local Excel sheets; there are kinds of data like; weekly sample water cut measurements, reservoir pressure measurements, stock tank oil initially in place per block, wells forecasts and reserve, historical events, blocks and pattern definitions, H2S measurements, PVT data, and injection Data before 2012 are stored in an Excel sheet located on the local PC of the team members.
- Access Database; the wells static data like; well name, well coordinate, well completion depth, flow station, field and concession are all stored in a shared access database linked to OFM project.
- EC and OFM database; Energy Component (EC) is the main database used in any petroleum company [9]. The field staff update all the data regarding the wells in daily bases and all technical departments have a limited access to this database. It contains; production data, injection data, production testing data, and artificial lifting data. Figure.2. summarizes the data sources

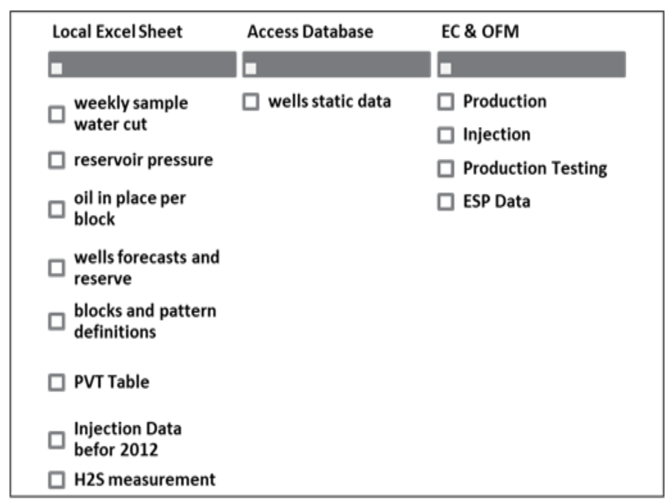


Fig.2. A diagram to show different data sources

B. Data Representation

This is the most important part of the process which is the data representation, it converts the data table to data plot which fits the human mind set and be much easier to be read, understood, and to help in decision making [10]. There are three types of data representations regarding the details level from top view to detailed view as following; field data representation (Dashboard), blocks summary, individual block/pattern data representation and wells data representation. Each visual level of these three levels of data representation will be described separately.

C. Field Data Representation (Dashboard)

Dashboard is visually designed to cover the most important top level performance monitoring parameters [11]. It is designed based on integrated view to contain different elements that makes getting full field view much more clear and easy to recognize, this is very useful for the top managers that they usually like the top view of the field performance so, it fits their purposes dashboard composes of dynamic and static data representation as shown on Figure.3.

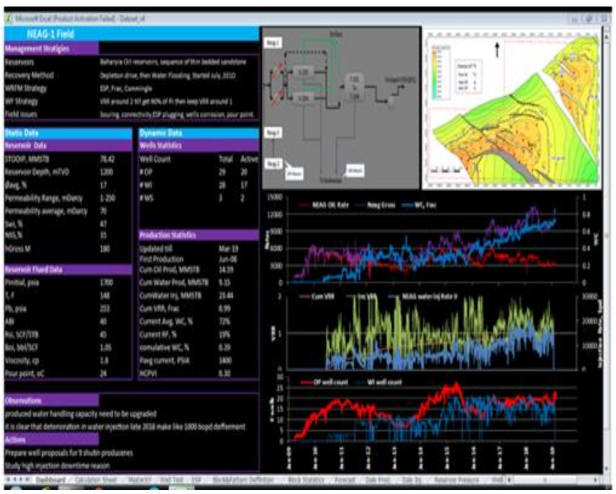


Fig.3. Screenshot of dashboard layout

D. Blocks Performance comparison summary tab

After having a total field overview from the dashboard representation and felt the top field view, strategies, performance, statistics and general field level issues, step down to blocks and pattern level takes place to focus on blocks relative performance as shown on Figure.4. The objective from block performance summary representation is to understand different performances of different blocks compared to each other and compared to analogue fields and benchmarked [12]. So, we can easily focus on low performance blocks and patterns and investigate their performance deeply in detail. Blocks summary representation has a different kind of data, including static data, dynamic data, maps, well logs, summary table and performance comparisons.

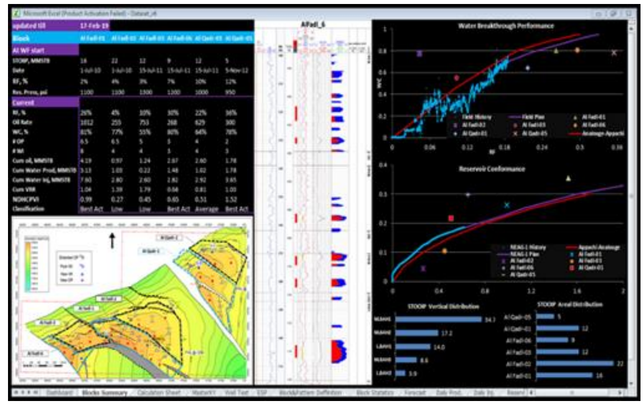


Fig.4. Screenshot of NEAG-1 blocks comparison representations

E. Individual Block Performance Tab

After we got the relative view of the blocks performance, now we are going to have a dedicated block performance overview. The objective from block performance summary representation is to focus on a specific block and understand their performance in detail [13]. This representation contains the key performance indicator for the block such as; block cross section, block statistics table, production and injection performance plots as shown on Figure.5.

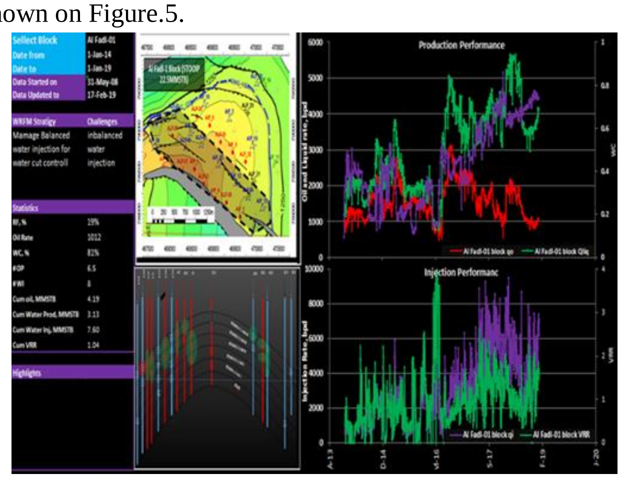


Fig.5. Screenshot of a block performance representations

F. Oil Production Well Performance tab

Now we have reached to the lowest level of details which is the well level where we can focus on individual well performance. In oil production well performance tab, the most critical performance parameters have been clearly shown in both format; plots and tables. They include; current and maximum oil production rate, gross production rate and water cut, workover history for the well, ESP intake and discharge pressure and ESP frequency. In addition to the most important plots like; production performance plot (oil production rate, gross production rate and water cut), Chan plot [14] (WOR and WOR derivative vs. date), ESP performance plot [15] (ESP intake pressure, ESP discharge pressure and ESP frequency) and finally the full history of well intervention as shown on Figure.6.

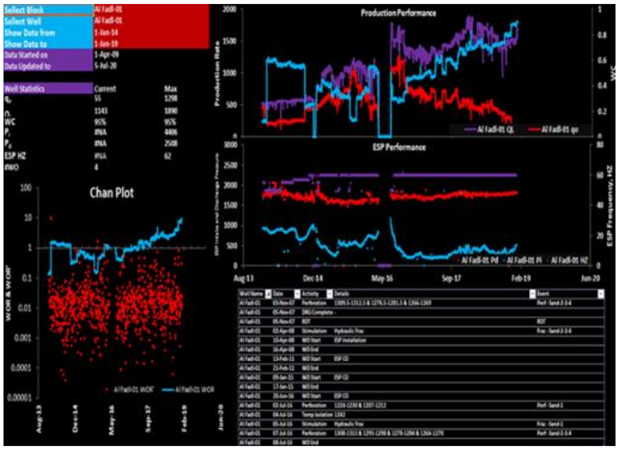


Fig.6. Screenshot of a production well performance tab

G. Water Injection Well Performance tab

This is the last tab where we have reached to the lowest level of details regarding injection well performance, which is the well level where we can focus on individual well performance. In injection well performance tab, the most important performance parameters have been clearly shown in both format; plots and tables. They include; current and maximum water injection rate, injection wellhead pressure and workover history for the well. In addition to the most important plots like; injection performance plot (water injection rate and wellhead injection pressure), Hall plot [16] (cumulative injection pressure time versus cumulative water injection) and finally the full history of well intervention as shown on Figure.7.

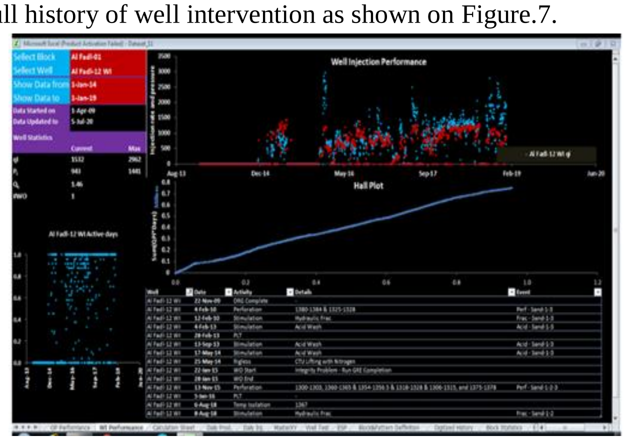


Fig.7. Screenshot of well injection performance tab

H. Workflow and Navigation

The work flow of the tool is built based on funnel view starting from dashboard tab which has the overall field top view image. The next level of details is the blocks performance comparison tab which assists us to rank the blocks based on the key performance indicators. Then we can move to the individual block performance where we can see the block performance in detail. Finally, we can go to the lowest level of details which is the well level where we can find the well performance plots and statistics. To move among different levels of data representation or tabs easy, the tool is opened to dashboard view by default and we can move to blocks performance comparison tab by one click on “blocks comparison” button located on bottom of the tab as shown on Figure.8.

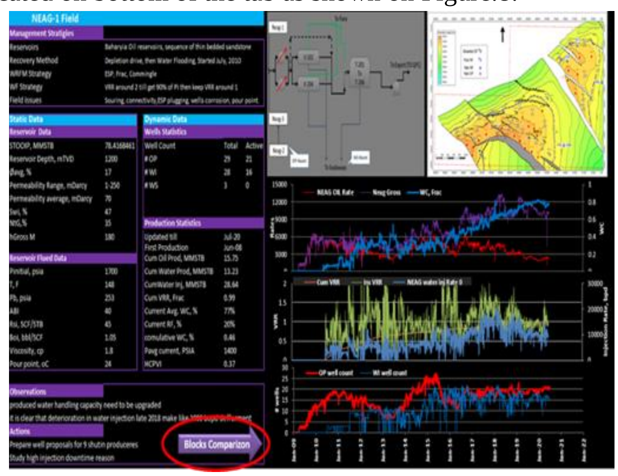


Fig.8. Screenshot for blocks comparison navigation button

Once we finished with block performance comparison tab, we can move to block performance tab by one click on “to block” button located on bottom of the tab as shown on Figure.9.

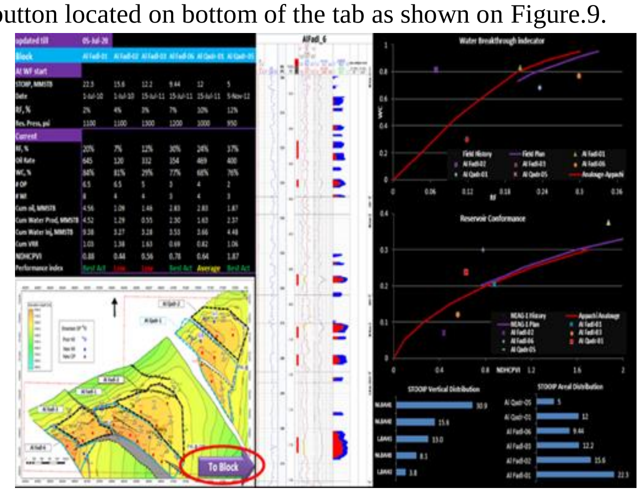


Fig.9. Screenshot for block performance navigation button

Now we are in the block performance tab, on top left corner we can find drop down list to select a specific block to show their performance. Once we finished with block performance, we can move to well performance representation by click on "To OP" button to move to oil producer performance tab or by click on "To WI" button located on bottom left corner of the tab to move to water injection performance tab as shown on Figure.10**.**

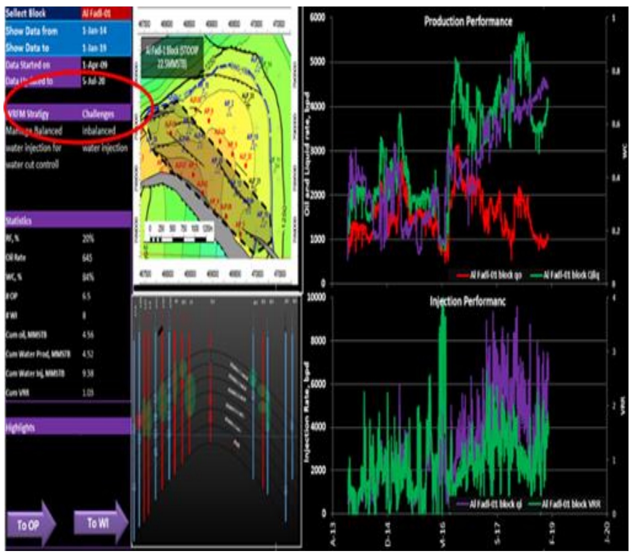


Fig.10. Screenshot for well performance navigation buttons

III. Results And Discussion

In this part we will discuss several challenging cases that are related to well and reservoir management (WRM) and how we used this tool to help monitoring WI performance, trouble shoot WI, maximize oil production and take robust decisions. These case studies are various, including well planning, water production management and water injection optimization. There are lots of these success cases however, three cases have been chosen to show the tool value and capabilities as follows:

- Assist of workover decision for well Fadl-10 WI
- Control of water production of Fadl-1 oil producer
- Assist well planning for oil producer well Fadl-47

Case Study #1: Assist of workover decision for water injection well Fadl-10 WI: - Fadl-10WI is one of Fadl-1 block water injectors. It is perforated and hydraulically fractured in Middle Bahariya #1, #2, #3 and Lower Bahariya #1 (Sand-1, Sand-2, Sand-3 and Sand-4 respectively) to support Fadl-29 oil producer since 2014 as shown on Figure.11. In May 2016 production logging tool (PLT) results showed that more than 90% of the water injection goes to Sand-3. Fadl-41WI is perforated in Bahariya #1 and Bahariya #2 to support both Fadl-29 to the west and Fadl-39 to the east. So, both wells Fadl-10WI and Fadl-41WI are supporting Fadl-29. In July 2016 monitoring Fadl-10WI performance concluded that the well started to perform unexpectedly. It accepted more than 1500 bwpd with zero wellhead injection pressure, which is the only case that we had in NEAG-1. So, tubing testing was conducted and it concluded tubing to annuals communication. The decision was to make workover for the well to change well completion with scab liner and GRE internally coated tubing and the cost estimate was 0.65 MM$.

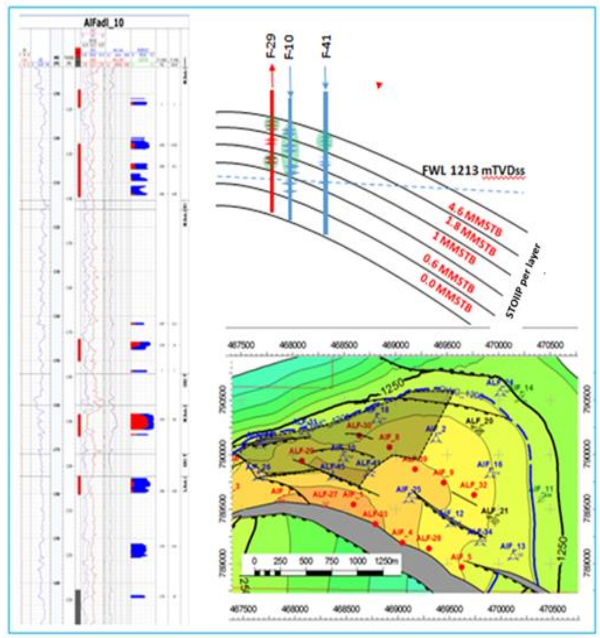


Fig.11. Fadl-10 and 41 well location and Petrophysical log

Analytical Solution to Case #1 using the developed tool: - Fadl-10 WI PLT results show that more than 90% of the water injection goes to Middle Bahariya #3 as shown on **Figure 12**. The cumulative water injection for Fadl-10WI is 1.1 MMSTB which is three times the pore volume of the connected area to the well so, most likely Sand-3 is watered out. There is a clear correlation between the water cut performance in Fadl-29 and the water injection performance in Fadl-41WI especially in the first quarter of 2018. When water injection in Fadl-41WI was decreased, WC in Fadl-29 decreased as shown on **Figure 13**. This proves that there is a good communication between Fadl-41WI and Fadl-29 for middle Bahariya #1&2. Once performance correlation has been understood, we can calculate the remaining reserve for Fadl-29 based on the area between Fadl-10 WI and Fadl-29 as shown on **Figure 14**.

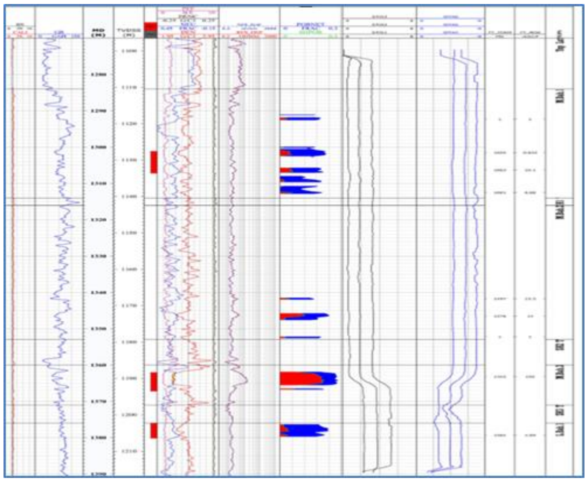


Fig.12. Fadl-10 WI PLT results

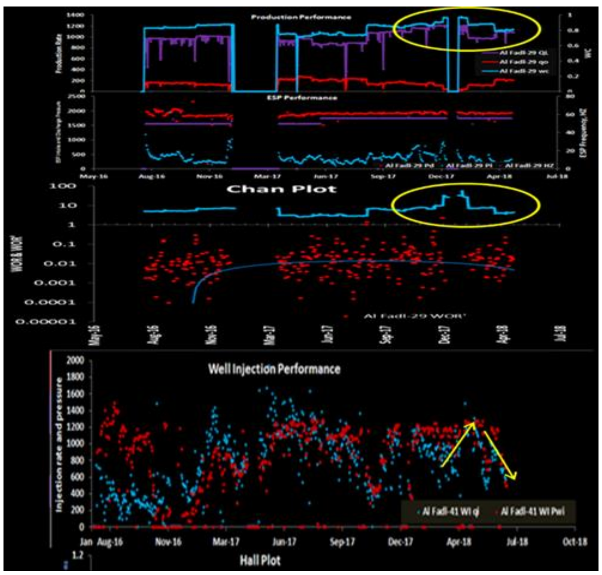
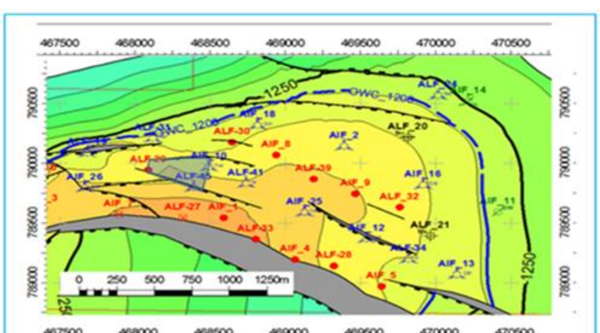


Fig.13. Fadl-29 and Fadl-41WI performance correlation



ZONE	STOIIP between Fadl-10 and Fadl-29
Mb-1	0.33
Mb-2	0.18
Mb-3	0.19

Fig.14. Fadl-29 connected volume and remaining reserve

Oil Recovery for Fadl-29 can be analyzed as following, Fadl-29 cumulative oil production is 0.17 MMSTB from Middle Bahariya #1, 2 &3 as of June 2018. Analog recovery factor for Middle Bahariya #3 is 30% of its STOIIP (0.19 MMSTB) so, cumulative oil production for Middle Bahariya #3 is 0.057 MMSTB (0.19 * 30%).

For Middle Bahariya #1&2, the cumulative oil production (0.113 MMSTB) can be calculated by deducting Middle Bahariya #3 oil production from the oil production of the well (0.17-0.057). STOIIP for Middle Bahariya #1&2 is 0.51 MMSTB So, its current oil RF is 22% (0.113 / 0.51) where the analog ultimate RF is 25% (only 3% is remaining). The remaining reserve is 0.016 MMSTB (0.51* 3%) which is very low. Fadl-10WI is located on the mid-way between Fadl-41WI and Fadl-29 oil producer which creates a high pressure wall that resists the support coming from Fadl-41WI to Fadl-29. Because the area connected to Fadl-41WI is bigger, the communication between Fadl-41WI and Fadl-29 is good. In addition, Fadl-10WI performance (since late 2016) indicates IOOZ and its workover will cost 0.65 MM$ with incremental reserve of 0.016 MMSTB and unit total cost (UTC) is 30 $/bbl which is very high. So, the recommendation was to: - keep close Fadl-10WI to improve the areal sweeping and increase the oil recovery from Fadl-29, isolate Middle Bahariya #3 and stimulate Middle Bahariya #1&2 for both Fadl-29 and Fadl-41. Those WRM actions saved 0.65 MM$ of Fadl-10 WI workover and added 100 KSTB as incremental reserve. In addition, the water cut of Fadl-29 decreased from 90% to 60% as shown on Figure 15. The oil production rate increased by 300 bbl/day and the well is currently running stable and it is one of the highest oil production wells in NEAG-1 as shown on Figure 16.

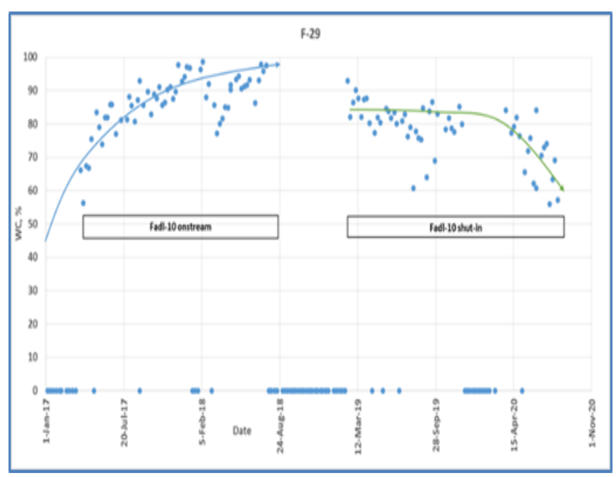


Figure 15. Fadl-29 water cut performance enhancement

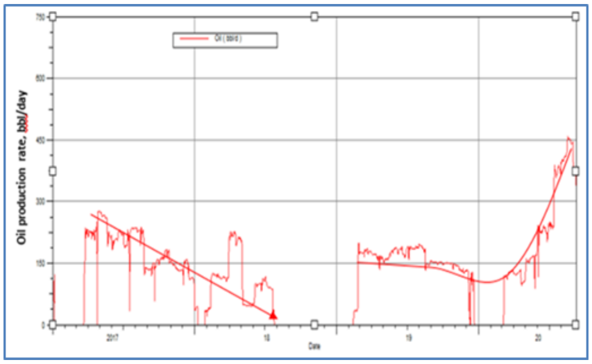


Fig.16. Fadl-29 oil production performance enhancement

Results Validation for Case #1: - To validate these results which have been obtained using the developed tool based on the analysis that we discussed earlier, three reservoir simulation runs have been conducted to compare the three scenarios which are; do nothing, close Fadl-10 WI and keep Fadl-10 WI on stream with shut in Sand-3. The results are very impressive that recommend closing Fadl-10 WI with calculated reserve more or less the same as we calculated analytically using the tool as shown on Figure 17 and presented in Table 1.

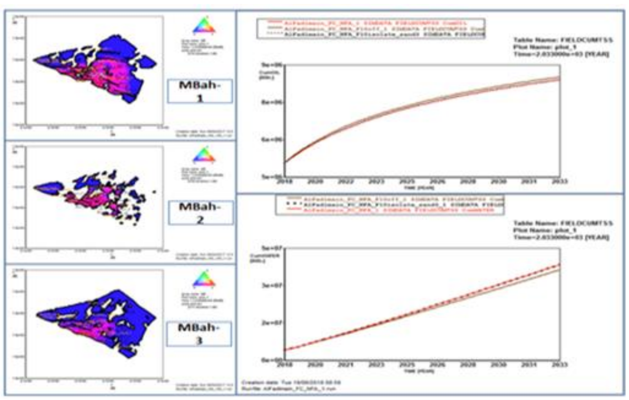


Fig.17. Reservoir simulation results for Fadl-29 oil producer

Table.1. Fadl-29 incremental reserve cases

Case	Simulation Oil increment, MMSTB	Analytical Oil increment, MMSTB	Condition	comment
F-10 off	0.1	0.095		Fadl-10 WI dynamically isolating Fadl-41 WI from F-29
F-10 on	0.015	0.016	Isolate Sand-3 in both Fadl-10 WI and 29	

Case Study #2: Control of water production from Fadl-1 oil producer: - Fadl-1 oil producer takes water injection support from both Fadl-25 and Fadl-45 water injectors. When Fadl-25 failed, the water injection support only came from one direction of the only available well (Fadl-45) just to support reservoir pressure to keep ESP running safely. As a result, Fadl-1 WC increased rapidly due to unbalancing in sweeping from one direction.

Control of the water cut in Fadl-1 by managing WI targets to reestablish the sweeping balance from Fadl-45 and Fadl-12 directions as shown on Figure 18. When Fadl-45 was closed as a safe guard during Fadl-27 workover, a decline in ESP intake pressure was observed then the decline rate was getting decreased from 4 to 2.5 psi/day and going further to stable.

Fadl-1 ESP intake pressure is 380 psi and ESP works within the safe operating envelope. Fadl-27 was back on stream in first week of March, 2018 (transient) and the decline in ESP intake pressure was getting decreased from 16 to 6 psi/day and going to stable zone and the ESP works within safe operating envelope. Updating WI target to achieve balanced injection and better sweeping efficiency was mandatory. After updating the water injection target, we succeeded to decrease the water cut in Fadl-1 from 75 to 62% (liquid production was 1600 bbl/day) which increased the oil production by 200 bbl/day as shown on Figure 19.

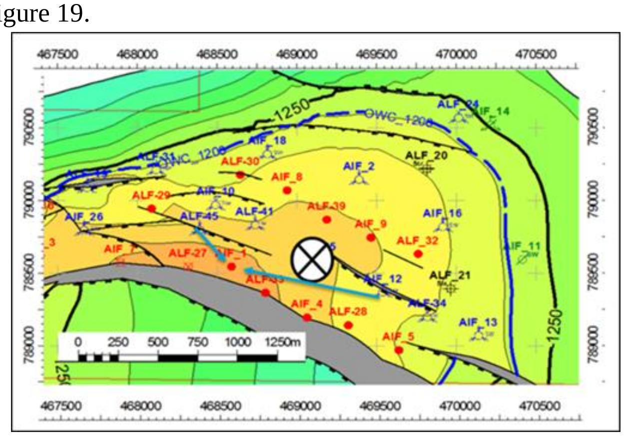


Fig.18. Fadl-1 between two water injectors (Fad-45 & 12)

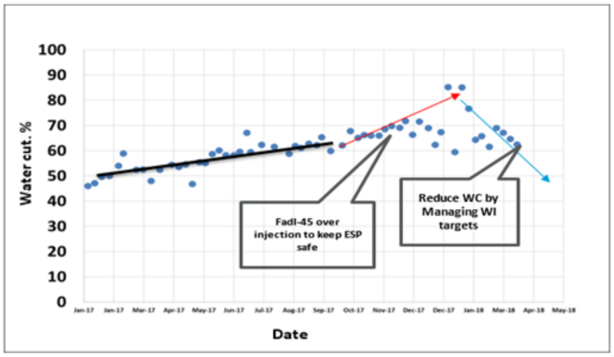


Fig.19. Fadl-1 Water cut control

Water production control exercise has been done for lots of cases with excellent results as shown on Figure.20.

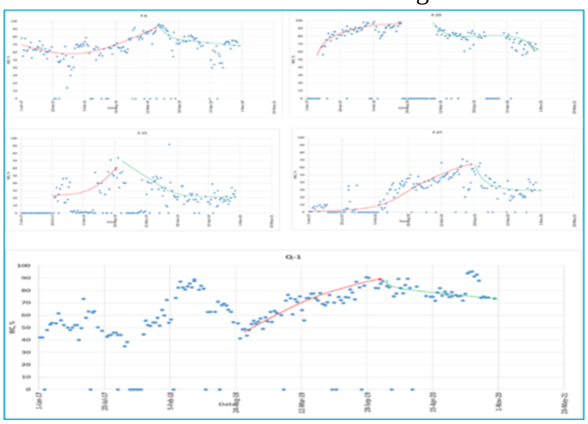


Fig.20. Examples for control of water production

Case Study #3: Assist of well planning for oil producer well Fadl-47: - Fadl-3 block performance is classified as a slow recovery block that the offtake is low compared to the rest of blocks as shown on Figure.21.

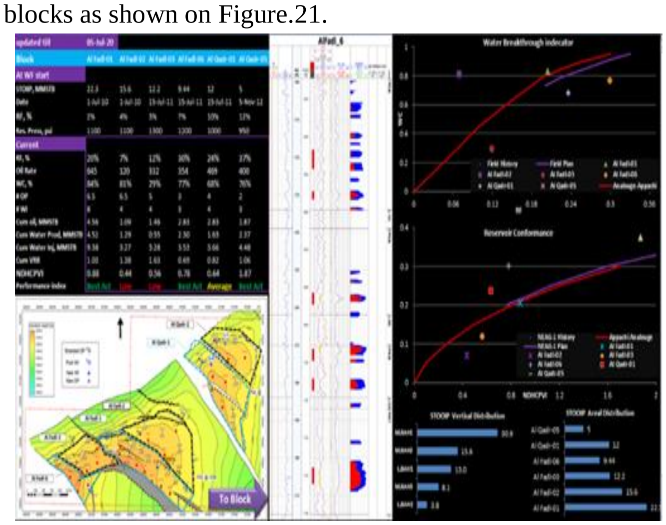


Fig.21. Screenshot for Fadl-3 block in Blocks comparison tab

Analytical Solution to Case #3 using the developed tool: - Fadl-3 block has a slow recovery; the current recovery factor is 12% of the original oil in place which is low compared to the rest of blocks as seen on Figure 22. Therefore, an oil producer well (Fadl-47) has been proposed in the way between Fadl-22 water injector and Fadl-40 oil producer. The estimation of the initial oil production rate and water cut is 500 bopd and 50%, respectively. The objective of the proposed well is to produce from Sand-1 and Sand-2 supported by Fadl-22 and Fadl 42 water injectors. The risk was to have this area been swept or found severe depletion of Middle Bahariya #1 so, the contingency plan was to use the proposed well as a water injector. The well was drilled in and it is very successful that the initial rate of the well was 450 bopd with 50% water cut which are very close to the initial estimate as shown on Figure 23.

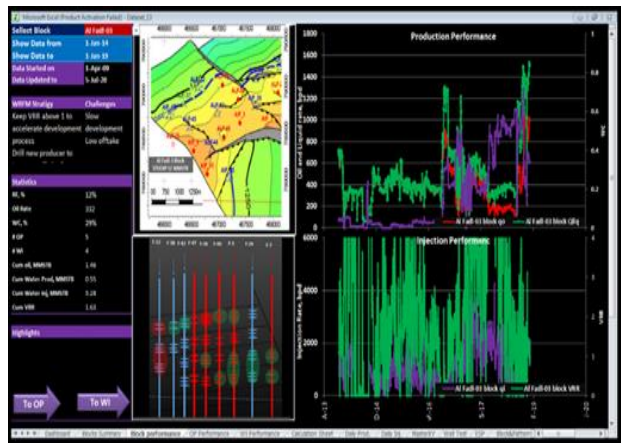


Fig.22. Screenshot for Fadl-3 block performance

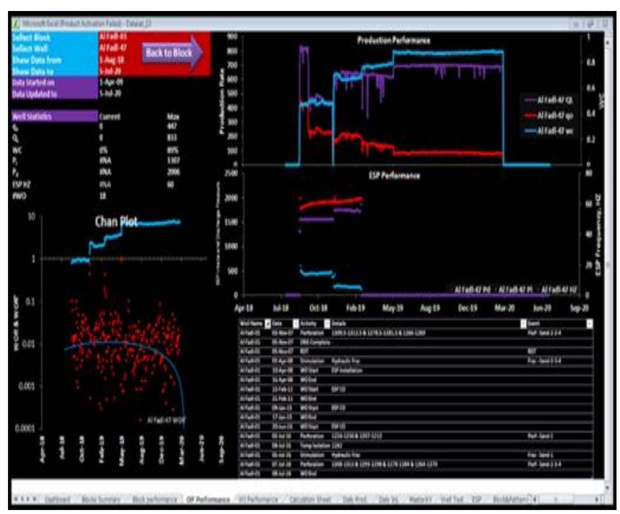


Fig.23. Screenshot for Fadl-47 oil producer performance

IV. Conclusion

From this study, the following conclusions may be drawn:

- NEAG-1 is a challenging field that has a high level of subsurface complexity, the reservoir permeability ranges from 0.5 mD to 700 mD with a permeability variation factor of 0.8 and the reservoir complexity factor is 3.6 (out of 5) which makes numerical prediction and modeling very unlikely. So, this field is better to be run and monitored analytically.
- All of the available completion, pressure, production and injection raw data for wells and reservoirs have been assembled from different data sources and been integrated in one Excel-based interface to have one data source. All diagnostic plots that fit NEAG-1 for different levels of details like; wells, blocks and pattern, reservoirs and field level, and for different data type; static and dynamic were defined. So we have a simple tool that contains all kinds of data and plots for waterflooding trouble shooting. It can be updated in daily bases and all interested persons can access and use it from wherever.
- As a part of the quality control (QC) process, this tool has been developed and validated for NEAG-1 Field with high percentage of efficiency and accuracy compared to reservoir simulation runs. The results are promising, that the tool is very helpful in assisting decisions for remedial actions, maximizing oil production and minimizing the operating cost. For example, for one well (Fadl-29), cost saving of 0.65 MM$ with added reserve of 100 KSTB and increase oil production rate by 300 bopd have been achieved.
- This tool is an Excel-based tool so, it is simple for anyone to use, the capital and running cost is nill compared to the commercial software, it is easy to access and work remotely from home and it will be very effective in pandemic days.
- The developed tool has been built to fit NEAG-1 field and similar fields however, with slight development, it can be fit any field, and can be effectively used for full company fields monitoring.

Nomenclature:

EC: Energy Component software
OFM: Oil Field Manager Software
WI: Water Injector
WC: Water cut
STOIIP: stock tank oil initial in place
RF: Recovery Factor, % of the STOIIP
IOOZ: Injection out of zone
WRM: well and reservoir management
MB-1: Middle Bahariya#1
MB-2: Middle Bahariya#2
MB-3: Middle Bahariya#3
STOIIP: Stock tank oil initially in place

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