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A Doomed Reservoir Surprisingly Became a Mature Reservoir with Potential: Water Dump Flooding Case Study in Boca Field

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Abstract

Water Dump Flooding is less well known for revitalizing mature fields. However, in the Boca Field, specifically Reservoir 95 Y-102, this is exactly what occurred. A periodic review of this mature field suggested abandoning the only producing well in this reservoir, well X-3, because an adjacent well, X-6, located above the dip was known to produce a 99% water cut.

Although other wells were produced in the reservoir, only a 12% recovery was achieved. Therefore, an integrated study to re-evaluate the parameters and properties of Reservoir 95 Y-102 began in 2005. During the well analysis, it was found that the water production of well X-6 was the result of the communication behind the casing of the well with the underlying aquifer 101 and not because of the advancement of the oil-water contact, as initially suggested. Recompletion of well X-3 was recommended because an injection process known as dump flooding was underway. In addition, aquifer support for production over the previous seven years strongly indicated that dump flooding would produce the desired production increases.

Under sub-optimal conditions, accidental Water Dump Flooding rejuvenated the producing well, increasing production to more than 300 BOPD with an acceptable water cut of 61%. The steps followed for the analysis and understanding of the process that occurred and how we took advantage of this accidental Dump Flooding raised the production from nearly zero to over 100,000 barrels produced in a single year. This lays the foundation for using Dump Flooding as a production and development strategy for other projects in the area.

Introduction

Since the early 1970s, water dump flooding or gravity water flooding has been studied as an alternative to conventional water injection. It can be described as an injection process in which water from a high-pressure aquifer flows into a low-pressure oil-producing reservoir. This method is economically attractive because of the absence of injection surface facilities, which reduces initial capital and routine operating expenses (Ofei and Amorin, 2011). This process is known for reservoir pressure maintenance or secondary recovery, but less known for revitalizing inactive mature fields. However, in the Boca Field, specifically in Reservoir 95 Y-102, this was exactly what happened, and motivated us to write this article.

The Boca Field is part of the Chimire-Boca quadrangle located in the Oficina Greater Area in the Eastern Basin in Venezuela. This field contains over 140 reservoirs with proven reserves. Mobil and Menegrande Oil Company operated the Boca Field from the late 1940s until 1975, when the Venezuelan State took control of the oil industry in the country. Since then, some secondary recovery processes have been implemented using gas injection. In 1995, a study to rank mature fields in the Oficina Greater Area gave the Chimire-Boca quadrangle the first spot in production potential, resulting in a drilling campaign executed from 1998 to 1999. However, the low production rates and high decline rates made drilling activity in this area unprofitable.

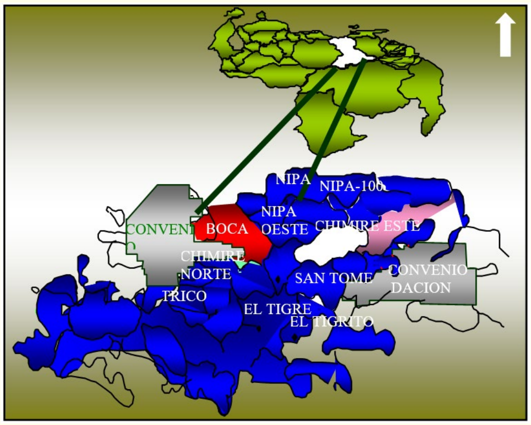


Figure 1: Boca Field location (Molina, 2008).

Reservoir 95 Y-102 was discovered in the early 1950s, and it produced light oil. This reservoir was developed with the completion of three out of 33 wells that were drilled in the reservoir until 1974 and had been inactive since then. A periodic review of this mature field suggested abandoning the only producing well available in this reservoir, well X-3, because an adjacent well, X-6, is located above the dip produced with a 99% water cut.

Although other wells were produced in the reservoir, only 12% recovery was realized, which represented slightly more than half of the estimated primary recovery (20%) of Reservoir 95 Y-102. Therefore, an integrated study to re-evaluate the parameters and properties of Reservoir 95 Y-102 began in 2005.

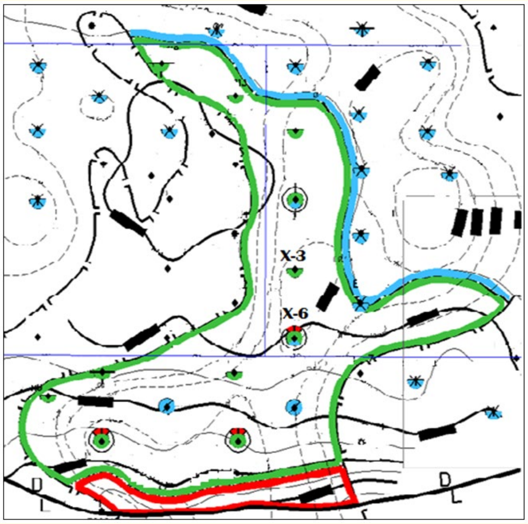


Figure 2: Reservoir 95 Y-102 official map, 2003.

Reservoir Characterization

The static model for both Reservoir 95 Y-102 (Figure 3) and Aquifer 101 was reviewed by structural, stratigraphic, and sedimentological analyses, accompanied by revaluation of petrophysical properties. The main change in the oil reservoir from the previous model was the redefinition of the original oil-water contact because of the reinterpretation of fluid saturations, which now estimates an additional 70 ft down dip. In addition, no primary gas cap was postulated because there was no strong evidence of its existence.

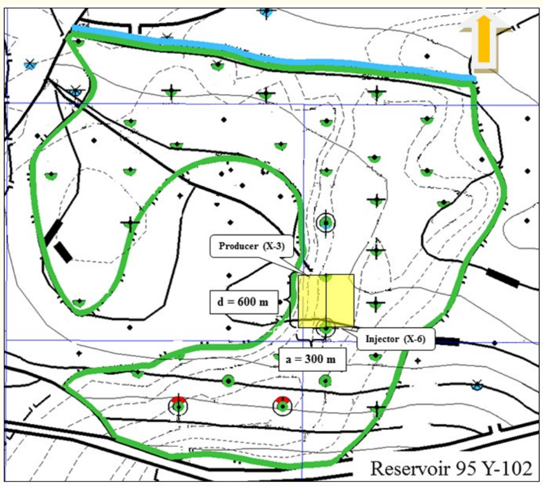


Figure 3: Reservoir 95 Y-102, reinterpreted map (modified after Molina, 2008).

The depositional environment of the reservoir is fluvial and is associated with a meander channel in the N-S direction. There are three main facies: channel, floodplain, and crevasse splay (Molina 2008). Both wells, X-3 and X-6, were found to be in the center of the channel facies (Figure 4), with the best porosity and permeability properties of the reservoir confirmed in the petrophysics evaluation.

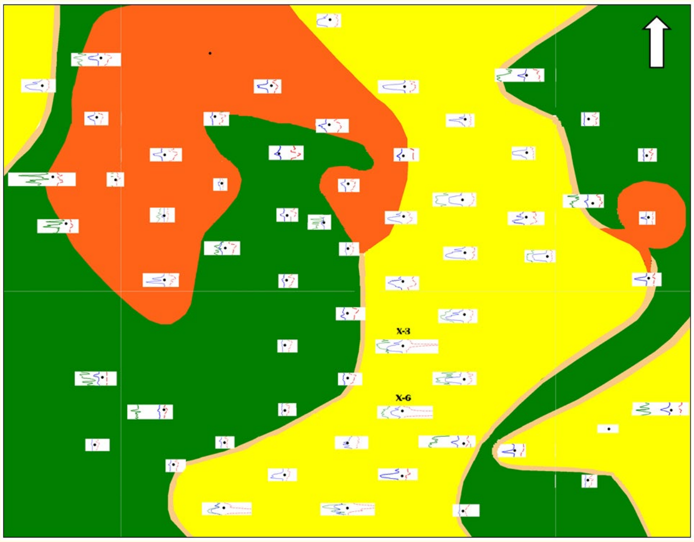
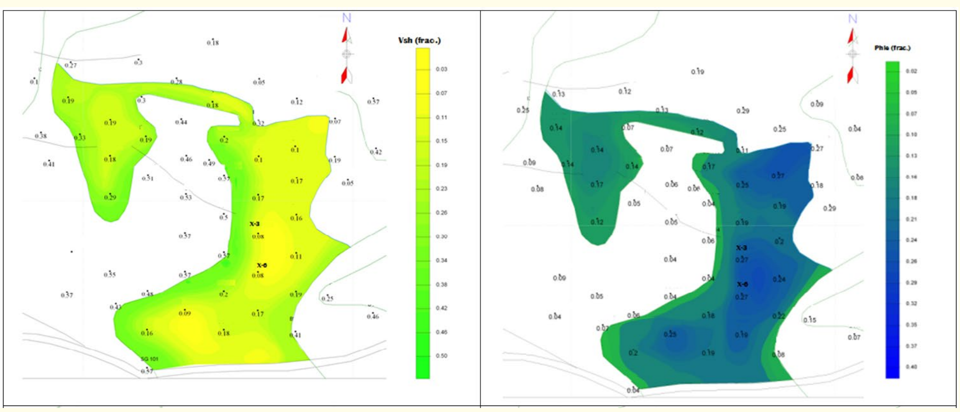


Figure 4: Reservoir 95 Y-102, electrofacies map: yellow shading represents channels facies, green floodplain and orange crevasse splays (modified after Molina, 2008).

Properties such as shale volume, effective porosity, initial water saturation, and permeability were re-evaluated following Acosta and Rosales´ (2006) Petrophysical Model. The evaluation of sixty-eight (68) wells covering the reservoir, associated aquifer, and floodplains were evaluated using four (4) isoproperties maps (Figure 5). Unfortunately, no core analysis was available for calibration, although the excellent correspondence between each other and with the electrofacies map (Figure 4) gave us confidence in the model.



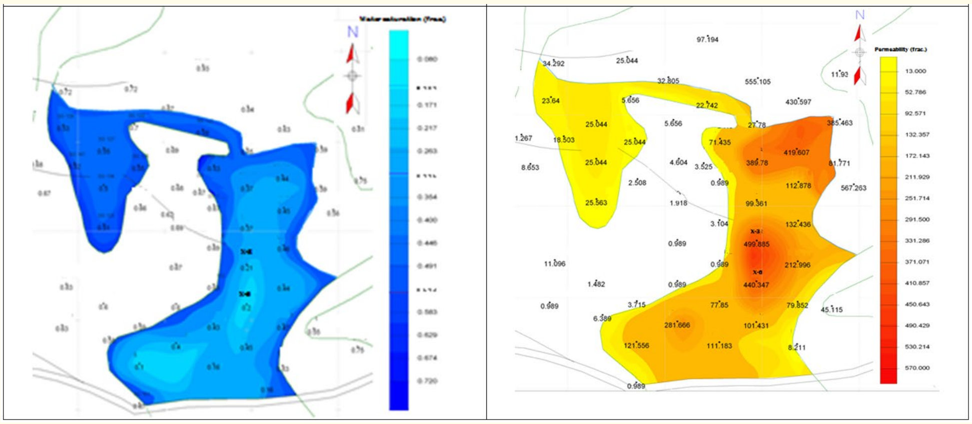


Figure 5: Reservoir 95 Y-102, Petrophysical properties distribution: Volume of shale (upper left corner), Effective porosity (upper right corner), Permeability (bottom left corner) and Initial Water saturation (bottom right corner) (Modified after Molina, 2008).

The main wells of this study, X-3 and X-6, are certainly in the best zone, reporting a very low volume of shale, good effective porosity, low initial water saturation, and very good permeability (Table 1).

Property	***Reservoir 95 Y-102***	***Well X-3***	***Well X-6***
Vsh (%)	17	8	8
Phie (%)	19	27	27
Sw (%)	42	21	20
K (mD)	139	500	440

Table 1: Reservoir 95 Y-102, Petrophysical properties summary.

A flow unit analysis was carried out between wells X-3 and X-6 by applying the modified Lorenz graph and following Acosta and Rosales´s (2006) recommendations. No significant differences were found between the wells that had practically the same flow unit characteristics (Figure 6).

The original oil-in-place stock tank (STOOIP) for the reservoir is estimated in 9.88 MM of STB and the original gas-in-place at 13,844 MM of STCF.

The dynamic model of Reservoir 95 Y-102 consisted of reservoir fluid behavior through the validation of the production and pressure test analysis. A material balance model (tank model) is used to validate the statistical model volumetrics. During the analysis of the well history, it was found that the water production of well X-6 resulted from the communication behind the casing of the well (Figure 7) with the underlying aquifer 101 (Figure 8) and not because of the advancement of the oil-water contact, as initially suggested. The difference in pressure between the aquifer and reservoir (2,000 psia) was estimated to be approximately 750 psia. This and the poor cement quality between them led us to infer that a water injection process known as dump flooding is underway. In addition, aquifer support for production over the previous seven years strongly indicated that accidental water dump flooding would generate the desired production increases because the reservoir's energy should have been revitalized and fluids should have been rearranged by gravity. Based on these facts, the recompletion of well X-3 was recommended.

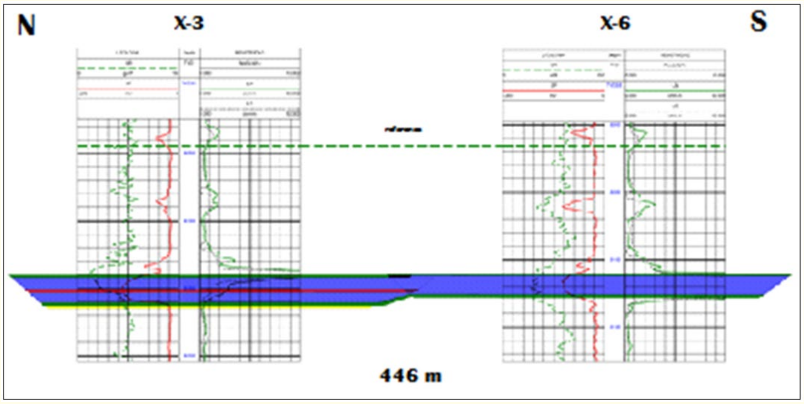


Figure 6: Wells X-3 and X-6 show the flow unit correlation. (Modified after Molina, 2008).

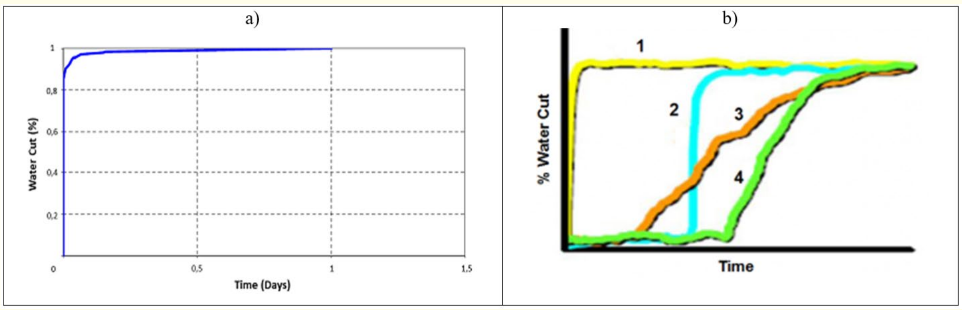


Figure 7: a) Well X-6, Production Water Cut Analysis. b)Conformance problems associated with water cut trends: Casing leaks curves (1) or (2;, Flow behind casing (1); Conning or cresting (3) or (4); Channel from injector (4); High permeability streak (4); Completion near a water zone (1) or (2); Fracturing job went to water (1) or (2) and Watered-out zone (3) or (4). (Kim and Crespo 2013).

Aquifer Characterization

The characterization of Aquifer 101 (Figure 9) enabled the estimation of the porous volume in 169,570.84 ac-ft defining a dimension relation with Reservoir 95 Y-102 of 46.13 (porous volume aquifers / porous volume reservoirs). This dimensional relationship aquifer/reservoir is very important because it will indicate the capacity of the aquifer to supply energy to the reservoir. The fluid compatibility between the aquifer and reservoir is another key characteristic to consider. Because of the proximity of Aquifer 101 to Reservoir 95 Y-102, it was assumed that the water from the aquifer was chemically compatible with that of Reservoir 95 Y-102. This assumption is based on the type of deposition environment of both formations (fluvial), and the fact that only 81 ft separates them.

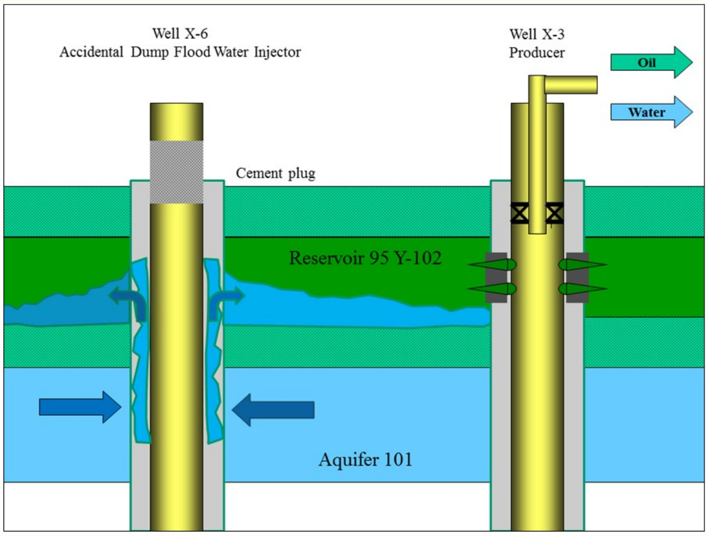


Figure 8: Accidental Water Dump Flood Injection Scheme (bottom).

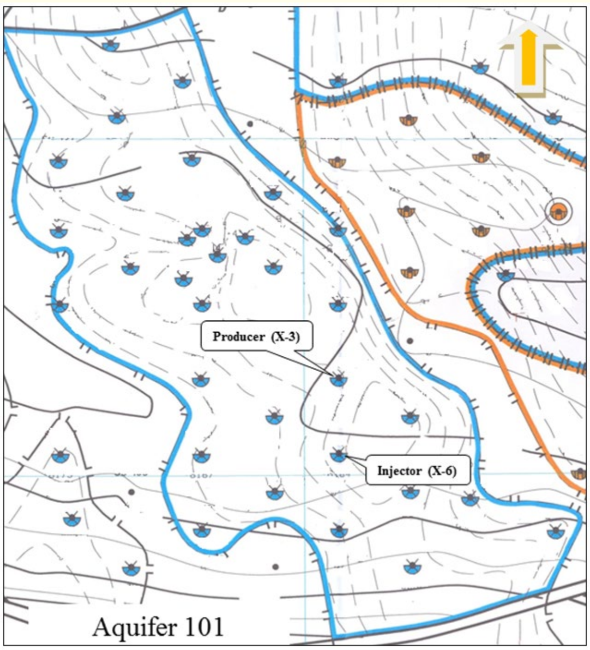


Figure 9: Aquifer 101map (Modified after Molina, 2008).

Accidental Water Dump Flooding

Under sub-optimal conditions, accidental Water Dump Flooding rejuvenated the producing well, increasing production to more than 300 BOPD with an acceptable water cut of 61%. This process increased production from nearly zero to almost 100,000 barrels of oil produced in a single year. From October 2006 to November 2007, well X-3 produced an average of 245 BOPD, 972,000 CFGPD, and 471 BWPD, respectively. Oil production rates during this period are comparable to the first year of production history of Reservoir 95 Y-102, when the average production rate was 362 BOPD (Figures 10, 11, and 12).

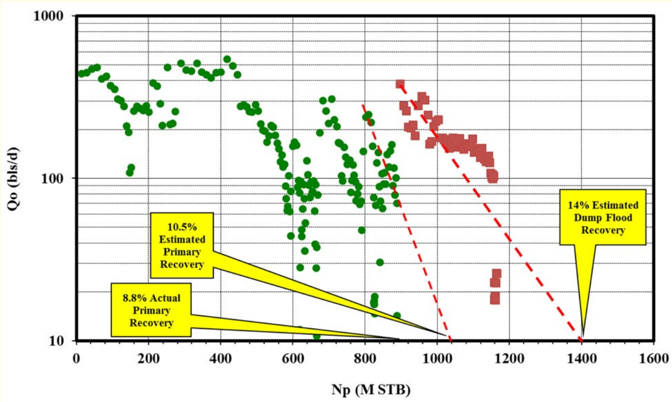


Figure 10: Reservoir 95 Y-102, accumulated oil production versus Oil Rates. (Modified after Molina, 2008).

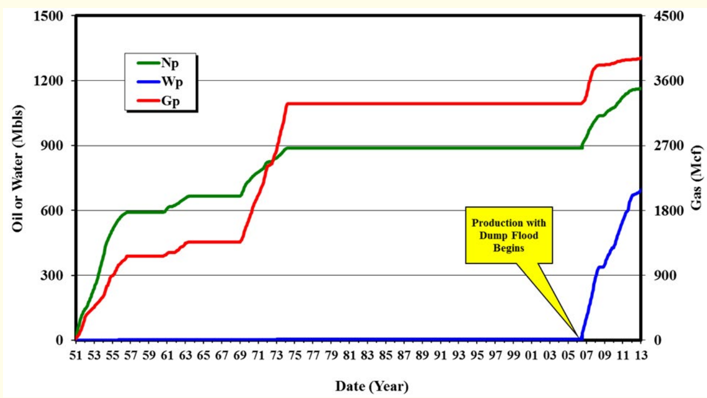


Figure 11: Reservoir 95 Y-102, Accumulated Fluid Production. (Modified after Molina, 2008).

Using decline analysis, the final recovery was estimated to be 14%, approximately 1.4 MM of barrels of oil. The well was shut-in in 2013 due to a high water cut, after a cumulative production of 1.19 MM of barrels of oil. The difference may be explained by many factors from the geoscience point of view (e.g., water channeling between wells), production engineering (e.g., optimization of chokes), or a combination of both.

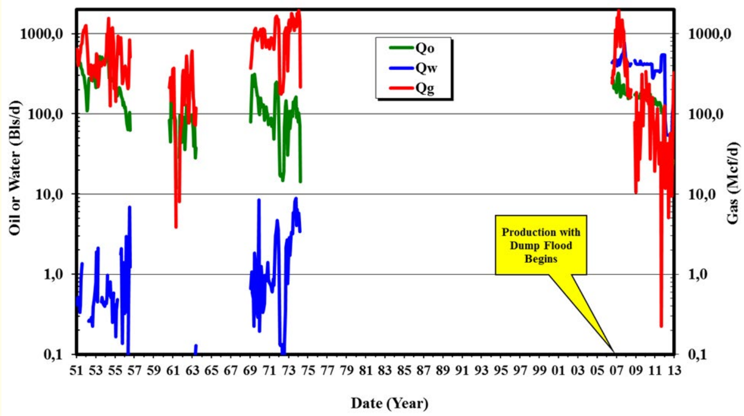


Figure 12: Reservoir 95 Y-102, Production Rates. (Modified after Molina, 2008).

The study of this local case and the analysis of others internationally reported in Kuwait (Rawding, et al., 2008), Oman (Shizawi, et al., 2011), U.A.E. (El-Feky, 1987), Qatar (Al-Siddiqi, 1998), Thailand (Nguyen and Athichanagorn, 2015), Malasia (Bait, 2003), Canada (ARC, 2005), the U.S.A (Witherspoon, 1952), and Equador (Villarroel et al., 2015), and validation for using water dump flooding as a production development strategy for other potential projects in the area. A campaign to promote and search for reservoir candidates in 2007 was found in the Acema 300 Field, a reservoir with ideal characteristics for water dump flooding. The design is currently (Petroven-Bras and RZI, 2008) under review and is being updated. Other reservoirs were identified and are currently in the design phase.

Reservoir Development Strategy

Reservoir 95 Y-102 has two potential production areas. One towards the northeast, where wells X-16 and X-23 (Figure 13) show good properties, where the existence of non-swept remnant oil is suspected. The application of water dump flood arrangements was discarded because these wells are located in a condensate reservoir at the Aquifer 101 level (Figure 14). The other area is towards the south of the reservoir (Figure 13), precisely up-dip of the water dump flood injector (X-6), where petrophysical properties are still good. Considering the success of the completion of well X-3, it is logical to think of studying the completion of the wells above the injector (X-8, Y-111, Y-116, Y-103, and Y-102).

The northeast area might need more study, and it is planned to wait for the results of the update of the model and the simulation. For now, only testing of sand 95 is possible, and depending on the initial potential, it is decided to leave in production.

The initial plan for the southern area, to be executed in parallel with the reservoir´s model update and reviewed according to the results, will be completed after revising the mechanical conditions of wells X-8, Y-111, Y-116, Y-103, and Y-102. If the feasibility of workover jobs in them is established, well X-8 is to be recompleted, taking advantage of the accidental water dump flood injection in well X-6, because it is inferred that a high saturation of oil was created towards well X-8. In parallel, it is considered to complete well Y-111 as a dump flood injector (Aquifer 101) with the purpose of creating high saturation of oil zones towards wells X-8, Y-116, and Y-103, in addition to supporting reservoir pressure revitalization in this area.

When X-8 well has finished its stage as producer (arriving at 85 or 90% water cut), it will be completed as a dump flood injector, including itself as an array with Y-111 well towards well Y-116, which will be completed as a producer. When this well ceases production, it will not be completed as a dump flood injector, as it does not penetrate Aquifer 101 (Figure 14). Well Y-103 was completed as the producer. The sequence of the plan continues with the completion of well Y-102 as the producer and Y-103 as the dump flood injector.

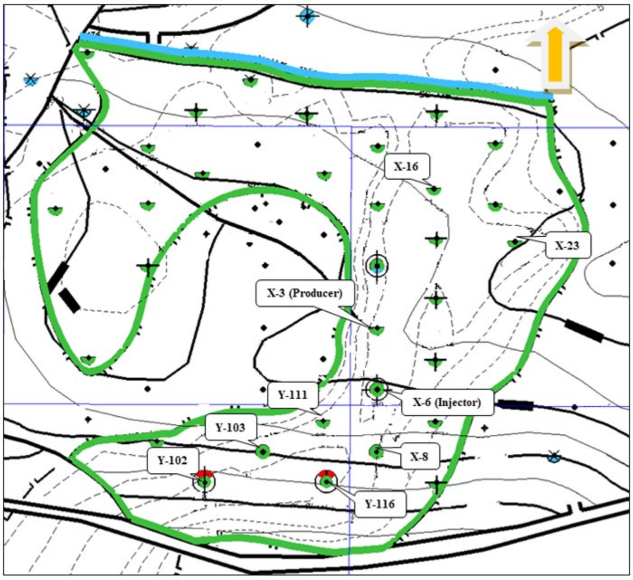


Figure 13: Reservoir 95 Y-102, reinterpreted map (modified after Molina, 2008).

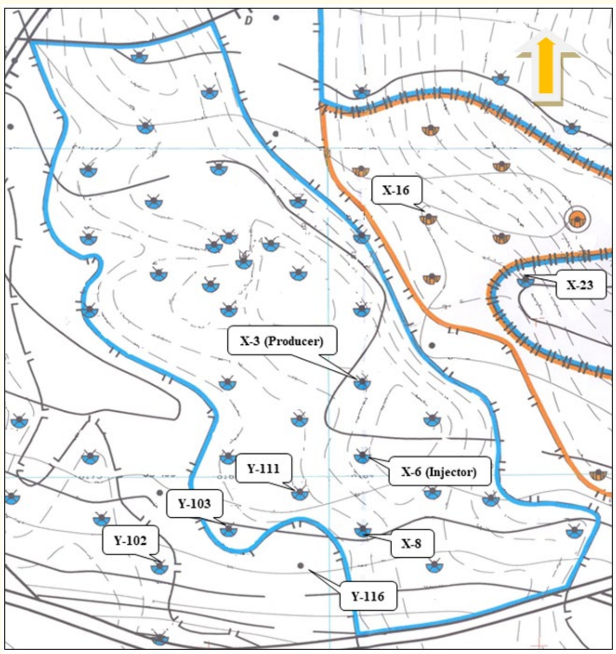


Figure 14: Aquifer 101map (Modified after Molina, 2008).

Towards the reservoir´s attic (Figure 13), there is an area that will probably not be drained. The feasibility of drilling a well should be studied, the computed reserves in the entire geologic column justify it, and the well should be drilled.

Application Water Production Management should be considered by analyzing the current installed capacity to handle the expected produced water volumes. The installation of downhole separator devices (Stuebinger and Elphingstone 2000) (Interstate Oil and Gas Compact Commission and ALL Consulting, 2006) is a solution that allows the reduction of water production at the surface and reinjection of water into Aquifer 101.

Conclusions and Recommendations

A thorough and detailed review of the procedures used for well and/or reservoir analyses to search for production facts is recommended. In the first instance, no option or possibility should be discarded, particularly in mature fields. Perhaps the implementation of the checklist was the most convenient.

Reservoir 95 Y-102´s dynamic model study should be updated, including recent production and considering simulation modeling with the idea of observing hypothetical scenarios, for example, how much production would have occurred if the dump flood had been planned. In addition, the current opportunities for reservoirs should be analyzed.

Considering that the Dump Flood, which occurred accidentally in reservoir 95 Y-102 under suboptimal conditions, was highly beneficial for reservoir production, it is presumed that a planned and designed process tailored for a given reservoir and/or field characteristics should offer even more success than those shown in this study.

Many mature reservoirs in the Oficina Greater Area, specifically in the Chimire-Boca quadrangle, were subjected to gas injection processes; therefore, if they are considered for water dump flood injection, they will become a type of alternate injection project. It is advisable to review and analyze these injection processes.

Promote the Water Dump Flood Injection in the Oficina Greater Area, especially in San Tome District, where a great percentage of the reservoirs go into the category of mature reservoirs, and the implementation of conventional water injections (with surface facilities) are practically impossible due to high costs of construction, maintenance and water management.

Acknowledgments

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Special concepts or terms

In this section, we want to clarify any concepts or terminology of local use that could cause confusion for some readers.

Candidate: Well or reservoir considered for a specific process.

Completion: A process in which a horizon is adapted for placement into production. This necessarily involves a larger job.

Condemned field: field that has very few opportunities to carry out workover jobs in the wells that run through it

Dump flood injection: An injection process in which an aquifer not associated with the hydrocarbon deposit is connected by a well or several wells to use its energy. The name in English "dump flood" does not have a specific translation into Spanish and literally nothing related to what it should mention. The term Endogenous Injection (Inyección Endógena) was created to explain in Spanish in a more appropriate way what the process means at an energetic level within a formation. Also partly at the time it seemed easier to sell the concept.

Dump flood injector: well that communicates the non-associated aquifer and the oil reservoir subjected to the injection process.

Greater Area: determine area of a basin or sub-basin, generally determined by combination of geographic and geological characteristics.

Integrated Study: a study that combines several disciplines related to the characterization of a reservoir or field.

Mature reservoir: reservoir with very low energy, i.e. pressure. For the authors, reservoirs with a current pressure below 80% of their original pressure can be considered mature.

Periodic review: review of the wells and / or reservoirs of a certain area, quadrangle or field in order to locate candidates for workover jobs.

Quadrangle: geographical area determined by the combination of producing fields with similar characteristics.

Recompletion: the same term indicates it, returning to produce a horizon that had already been producer.

Reinterpreted: evaluation or analysis that has been updated or revised incorporating new features initially not considered

Rejuvenate: in the case of reservoirs, it refers to the increase of production potential due to the combination of the increase in pressure and the saturation of oil in the vicinity of the well.

Revitalize: that gains energy. As for the reservoir, it refers to the increase in reservoir pressure due to the introduction of an external energy source, that is, the injection of fluids.

Sweeping: displacement in the reservoir of a fluid by another immiscible.

Well analysis: analysis of current mechanical conditions; historical report of works and, tests and production history of reservoir wells.

Workover: job to complete the well in another horizon.

Nomenclature

ac-ft: acre-foot.
BOPD: barrels of oil per day.
BWPD: barrels of water per day.
CFGPD: cubic feet of gas per day.
ft: feet.
M: thousands.
MM: millions.
mD: millidarcy.
STB: stock tank barrels.
STCF: stock tank cubic feet.

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