Redistribution of wastewater injection as Secondary Recovery method in a Naturally Fractured Carbonate Mature Reservoir

Initiative: First horizontal water injector well in Mexico - Design and expectations

PEMEX ®

POR EL RESCATE DE LA SOBERANÍA

Overview of the Project
Complejo Antonio J. Bermúdez

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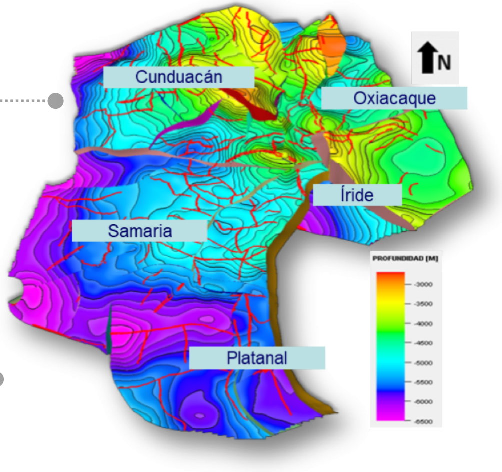
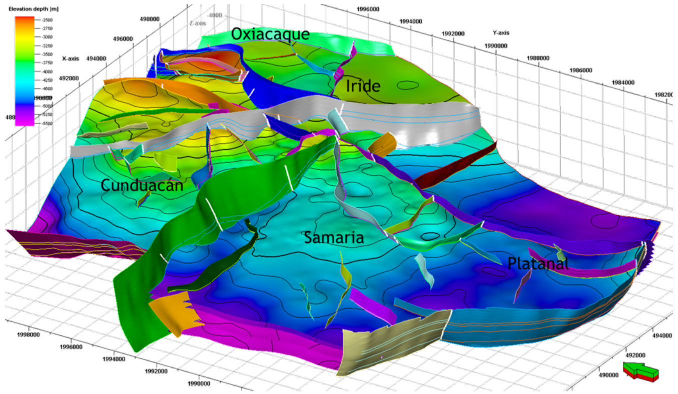
General Characteristics

- **Location:** 20 Km NW from Villahermosa, Tabasco, Mexico
- **Fields:** Samaria, Íride, Cunduacán, Oxiacaque y Platanal
- **Start of Exploitation**: June 1973
- **Type of Reservoir**: Limestone, fractured dolomites
- **Area**: 200.2 km²



- **Rock**: Limestone and Dolomite
- **Porosity**: 4 – 6 %
- **Permeability**: 10 – 250 md
- **Depth**: 3,100 – 5,000 m

- **Type of Oil**: Light black oil
- **Oil Density**: 28 - 31 °API
- **Pressure (kg/cm²):**
  - Initial: 533 kg/cm²
  - Current: 136 kg/cm²
  - Saturation: 318 kg/cm²
- **Temperature**: 125 °C



Current Status of the Project

- **Drilled Wells*: 413**
- Producers: 87 Injectors: 10

- **Current Production*:**
- Oil: 23,300 bbl/d
- Gas: 150.8 mmscf
- **Original Volume:**
- Oil: 8,272 mmbbls
- Gas: 10,440 mmmscf

- **Cummulative Production:**
- Oil: 2,916 mmbbls
- GaS: 4,669 mmmscf
- **Remaining Reserve**
- Oil: 76 mmbbls
- Gas: 189 mmmscf

- **Recovery Factor:**
- **Current** **Final**

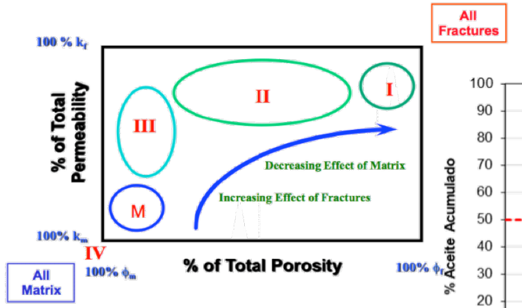
Oil: 35.3 % 36.2 %

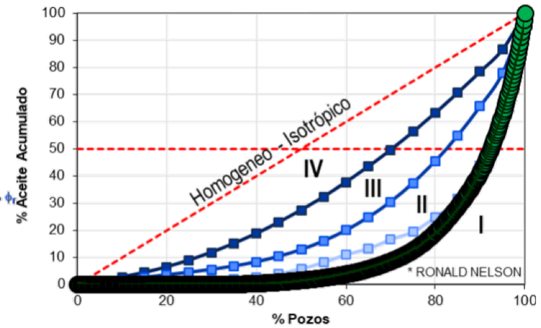
NFR Classification

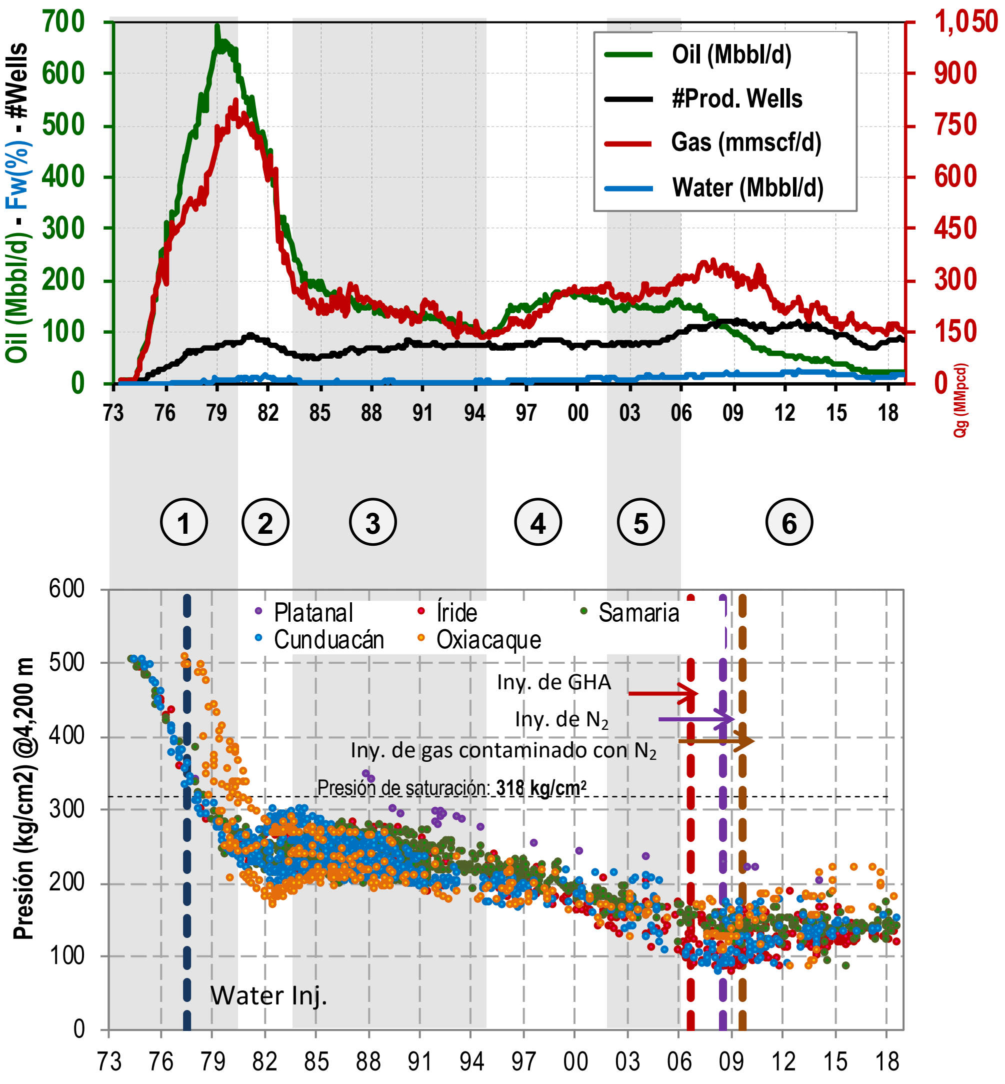
Ronald Nelson's classification for the behavior of naturally fractured reservoirs defines by means of the behavior of production, which medium contributes most to the flow of the reservoir. The description of the 4 types of deposits considered in this classification is shown in the color table.

The behavior of our project is between type I and type II

Type IV	Fractures, perhaps partially filled with cementing agents, act as baffles and barriers to flow in an already producible reservoir and reduce the drainage and sweep efficiency.
Type III	The fractured reservoir is already economically producible (high porosity and permeability in the matrix) and the fractures provide an assist and tend to define the reservoir's flow property anisotropy
Type II	Rock matrix has higher porosity whereas fractures provide the essential flow capacity in a reservoir.
Type I	Fractures provide the essential porosity (i.e. storage capacity) and flow capacity in a reservoir where matrix porosity and permeability are low.







Stage 1 (1973 - 1980)

- Initial development
- Maximum production peak of 693 Mbbls
- Quickly reach saturation pressure
- Started water injection

Stage 2 (1980 - 1983)

- Gas Cap Formation
- Sharp decline (oil production)
- 460 mbbl/d water injection

Stage 3 (1983 - 1994)

- Production platform at 150 mbbl/d until the end of 1992

Stage 4 (1995 - 2001)

- 2nd stage of development
- Deployment of deep gas lift artificial system

Stage 5 (2002 – 2005)

- 3rd stage of intermediate wells
- Waste water injection at 38 mbbl/d

Stage 6 (2006 - Actual)

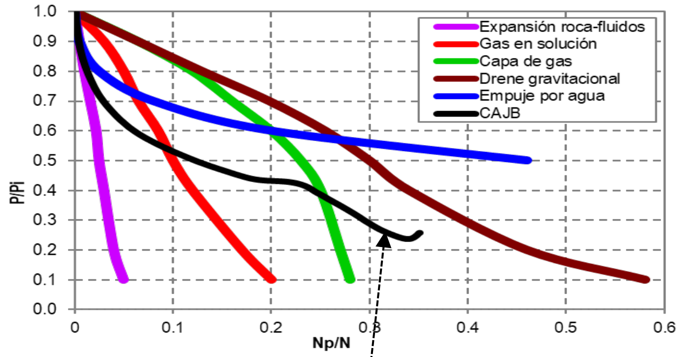
- Bitter gas injection - 60 mmscf/d (Nov/06-nov/12)
- N_2 injection - 190 mmscf/d (Jul/08-Jul/17)
- Contaminated gas injection - 60 mmscf/d (Jul/09)
- Waste wáter injection 60 mbbl/d
- Unconventional Wells
- ESP System (Apr-09)

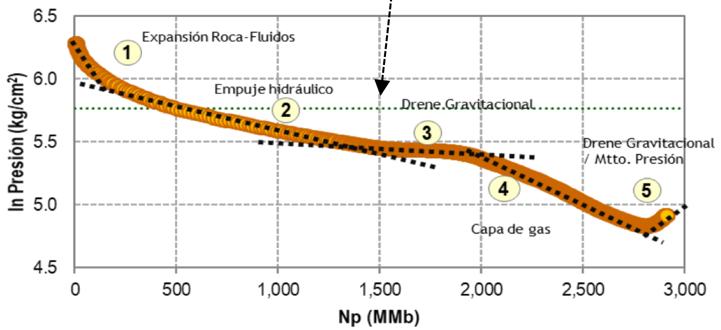
•After 46 years of exploitation, the main mechanism of the deposit corresponds to the Gravity Drainage.

•**In the 80's** a strong water injection was made (maximum iny. 480 mbbl/d) generating a **slight support for water thrust.**

•After reaching the Bp and due to the effects of gas injection, there is a thrust **per layer of gas** in the upper part of the structure.

•Currently, the effects of **pressure maintenance processes**, Bitter gas and Nitrogen injection (2008-2017) **managed to reverse the depression** of the reservoir by production.





Oil & Water Production rates of Samaria Field

Last 10 years of Production vs Pressure & Water injection

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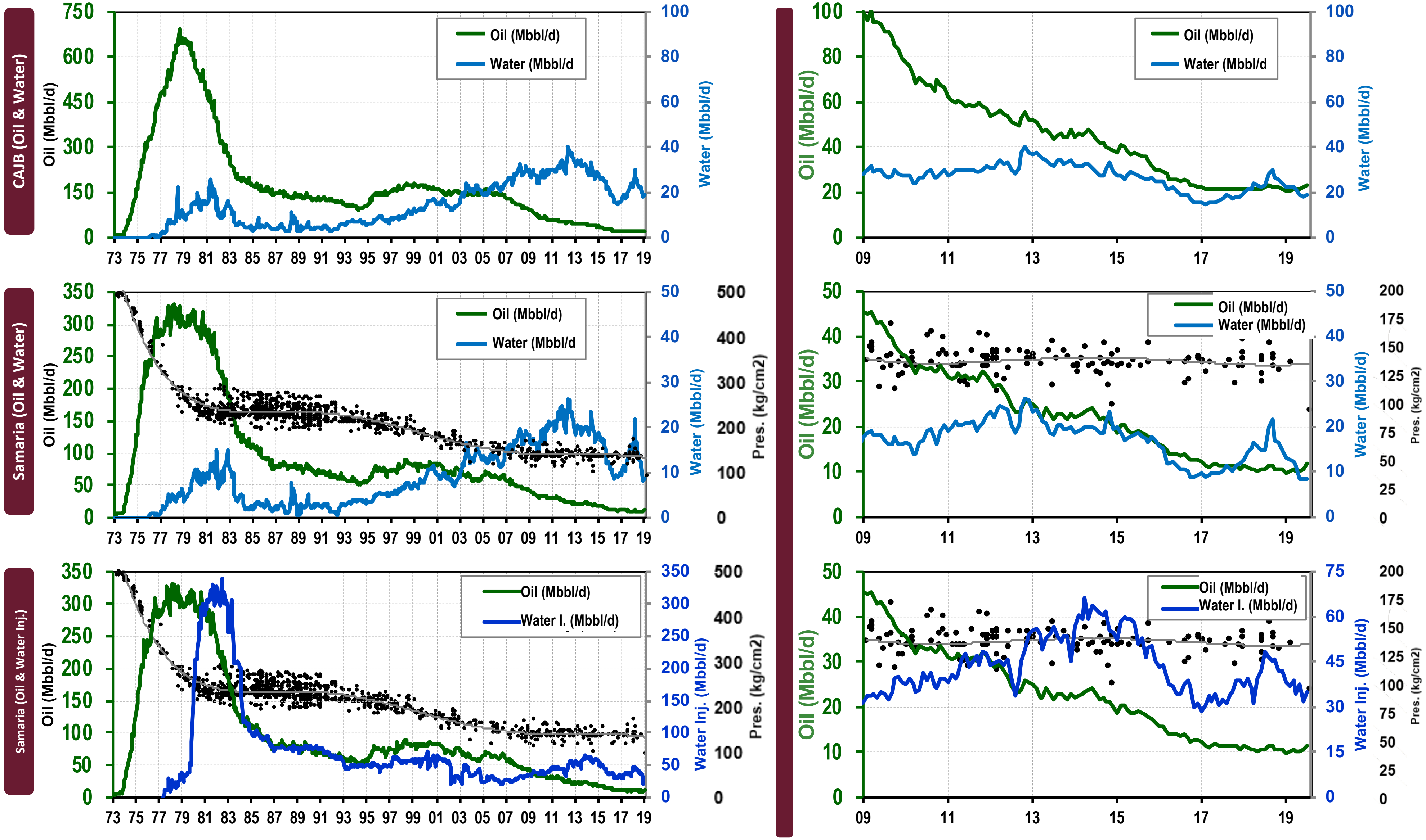
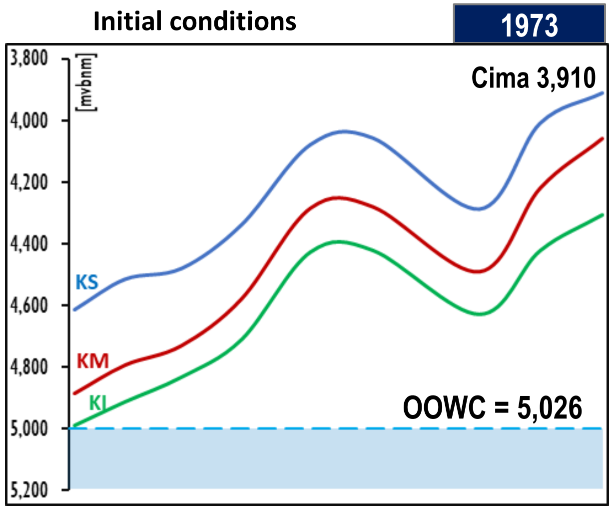


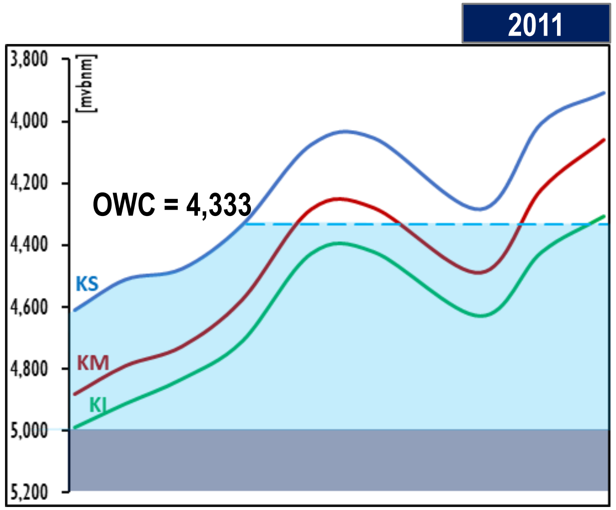
From the fields of the project, the importance of Samaria field can be observed, because 50% of the oil and water production of the project come from this field, in addition it is in this field where most of the wastewater is injected today. Therefore, the behavior in oil production is very similar with respect to the entire project.

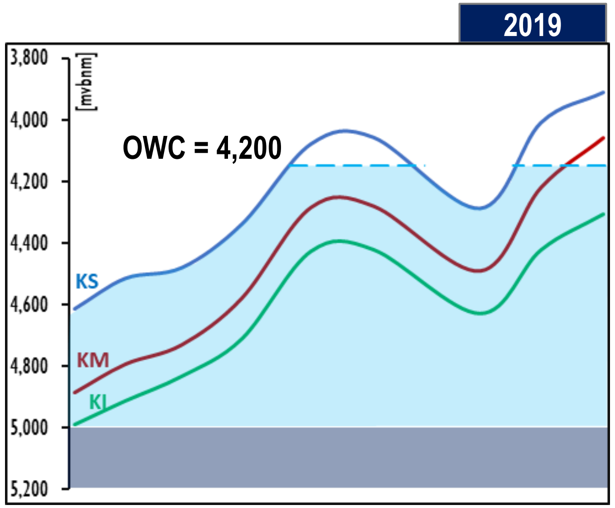
In the last 10 years, there is a pressure maintenance in the Samaria field due to the constant injection of water, this has helped today to be more successful in the new interventions and to counteract the drop in production in the last 3 years .

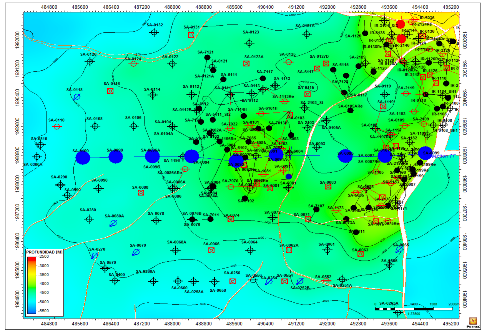
Despite the aforementioned, there is one more problem to which a solution is proposed later

Through the time of the development of the field, the dynamic conditions of the reservoir have been continuously monitored in order to estimate the progress of the OWC and locate the next interventions in the oil window…





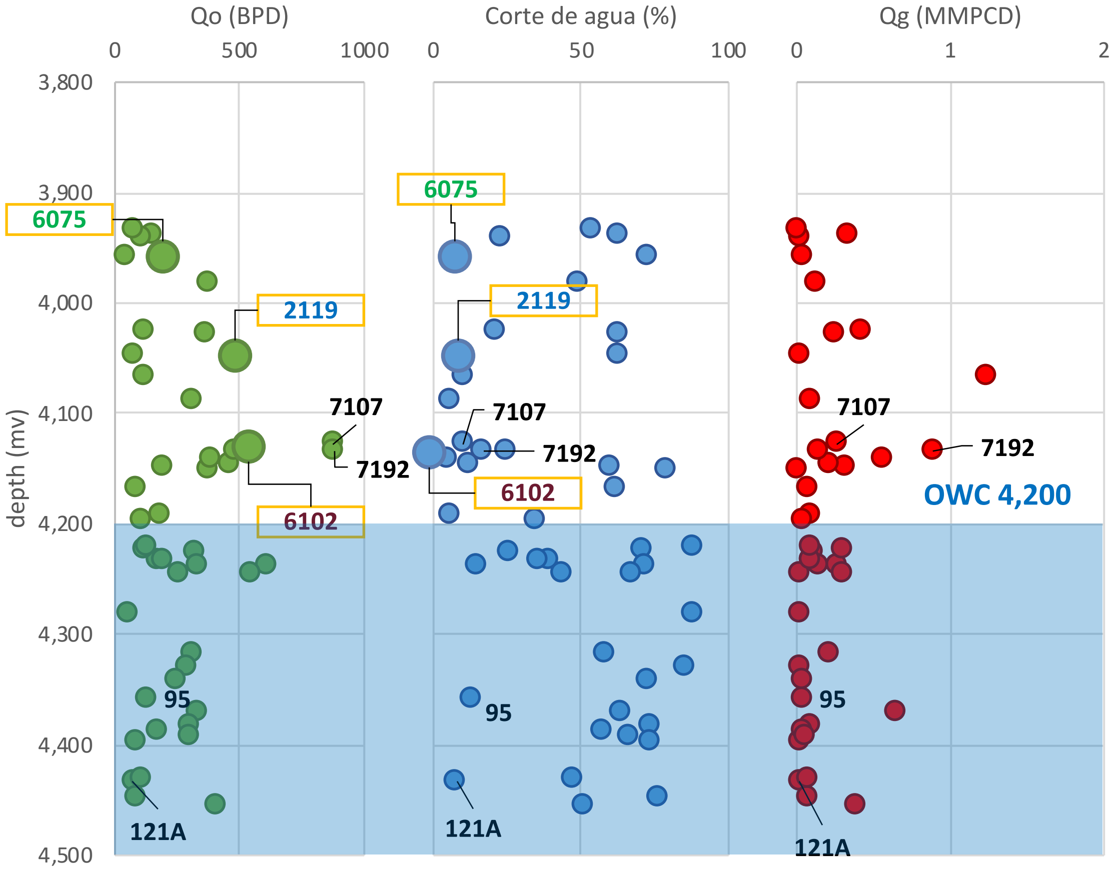




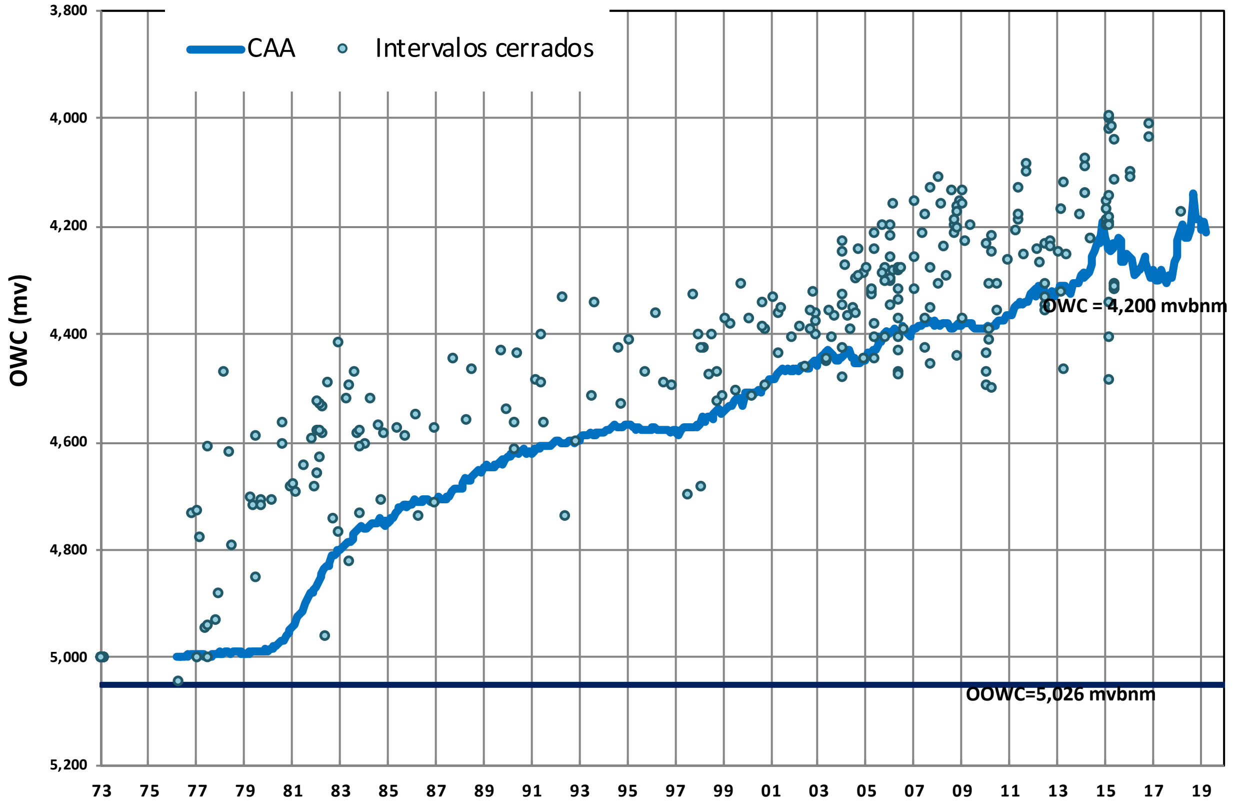
W - E

…but there is a small detail

The fractured nature of Samaria is reflected with a heterogeneous OWC, so the estimation of the contact requires a thorough analysis by area, considering the study of neighboring wells to specifically identify the OWC.



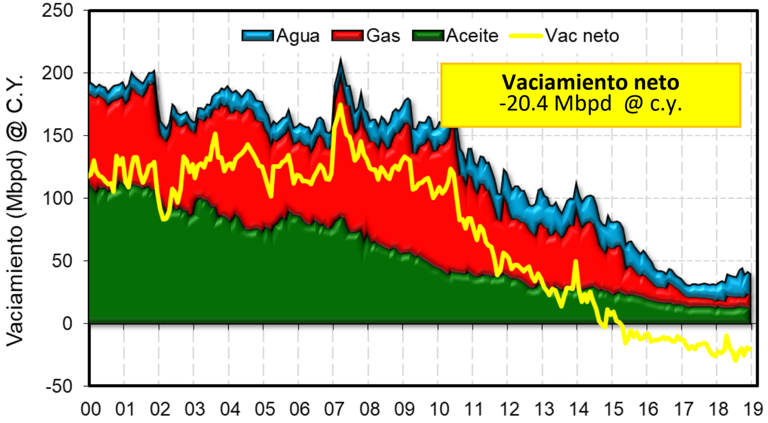
*Gomez, C. & Garcia, J. (2019). Ventana de aceite del campo Samaria. [Gráfico y datos].

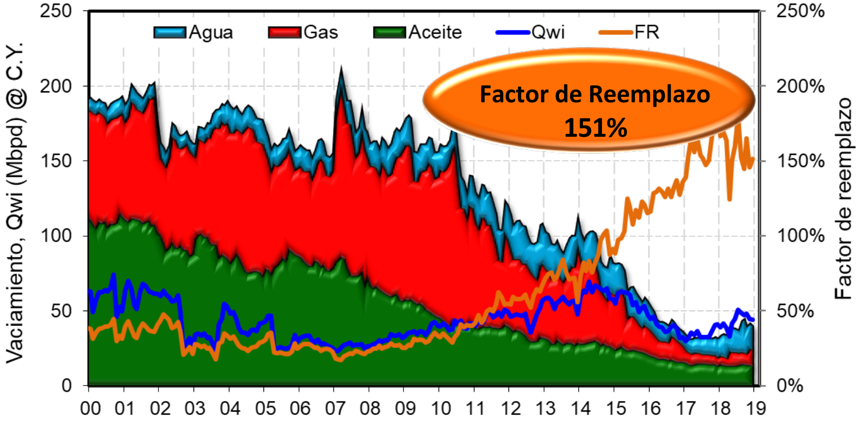


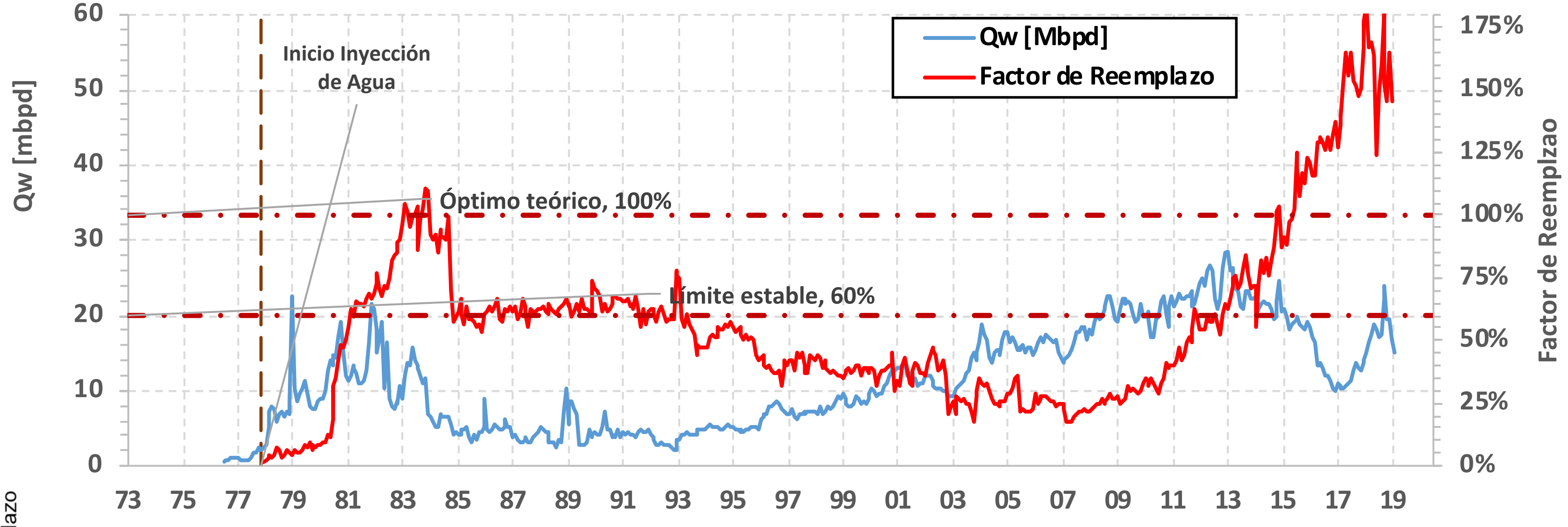
Notwithstanding the high heterogeneity of the field, there is a considerable approximation between the OWC determined by material balance, and the intervals closed by water throughout the history of production

Voidage Replacement Ratio analysis

Current situation in Samaria field



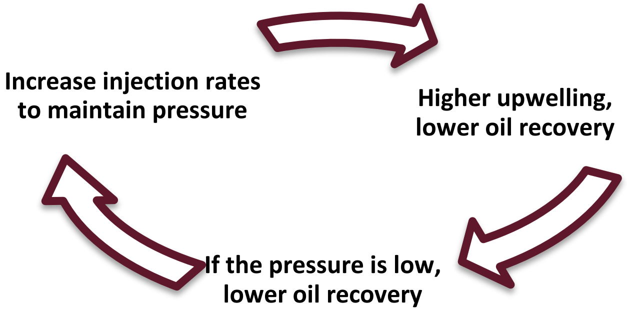




*Colín, G. (2019). Análisis del Vaciamiento y Factor de Remplazo en el campo Samaria. [Gráficos y datos].

- Voidage Replacement Ratio greater than 75%, affected the irruption of water.
- Rates between 60% - 70% kept water production stable despite having low replacement ratio, water production increases since 1991.
- In the 2013-2017 period, wells (ESP) were closed due to high fractional water flow (Water cut).
- High replacement factors lead to water irruptions... But if there is not enough injection, the reservoir pressure decreases considerably .

Acumulado @ c.y. Wi 1,421 MMb* % VP 8.5%**



***Producción @ c.s.**
- Qo 10.5 Mbpd
- Qg 11.4 MMpcd
- Qw 14.8 Mbpd

Producción @ c.y. :
- Qo 13.1 Mbpd (33%)
- Qg 11.0 Mbpd (28%)
- Qw 15.6 Mbpd (39%)
- **Q total 39.6 Mbpd**

***Agua :**
- Qwi 41.9 Mbpd (@c.s.)
- Qwi 44.0 Mbpd (@c.y.
- We 16.0 Mbpd (c.y.)
- **Q iny 60.0 Mbpd** (c.y.)

*Promedio ene/19

** Volumen poroso de CAJB: 17.5 MMMb @ c.y

Negative influence of water injection in southern zone

Problematic: invasion of producing wells due to channeling effects

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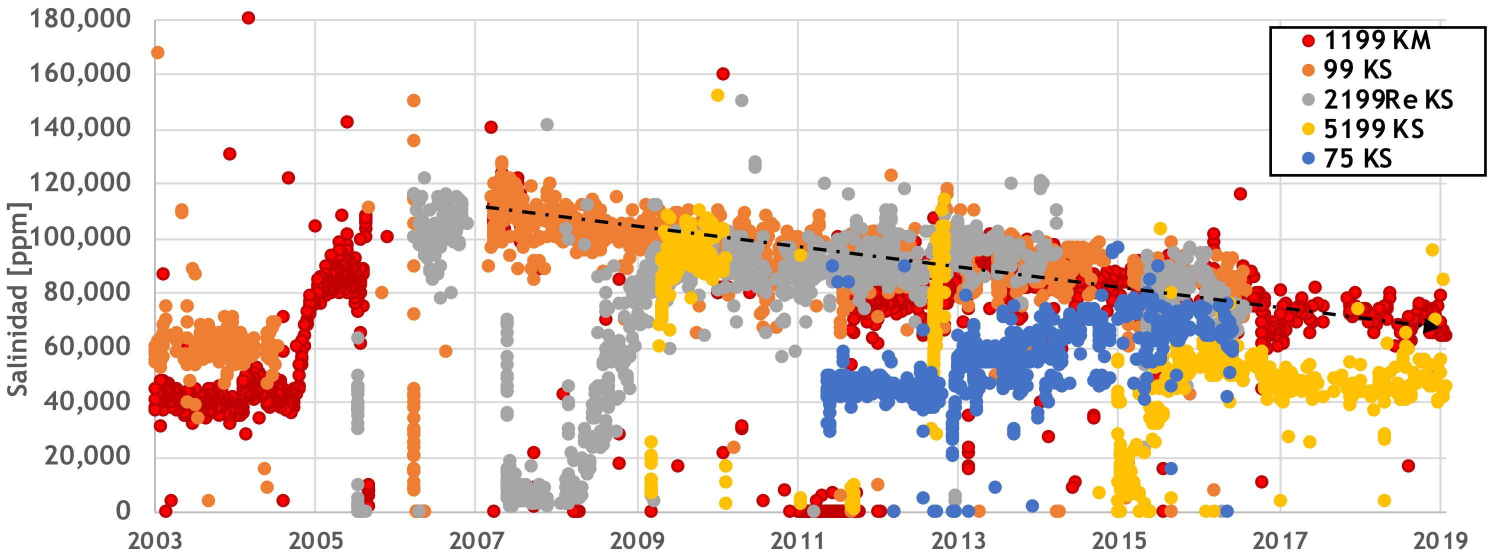
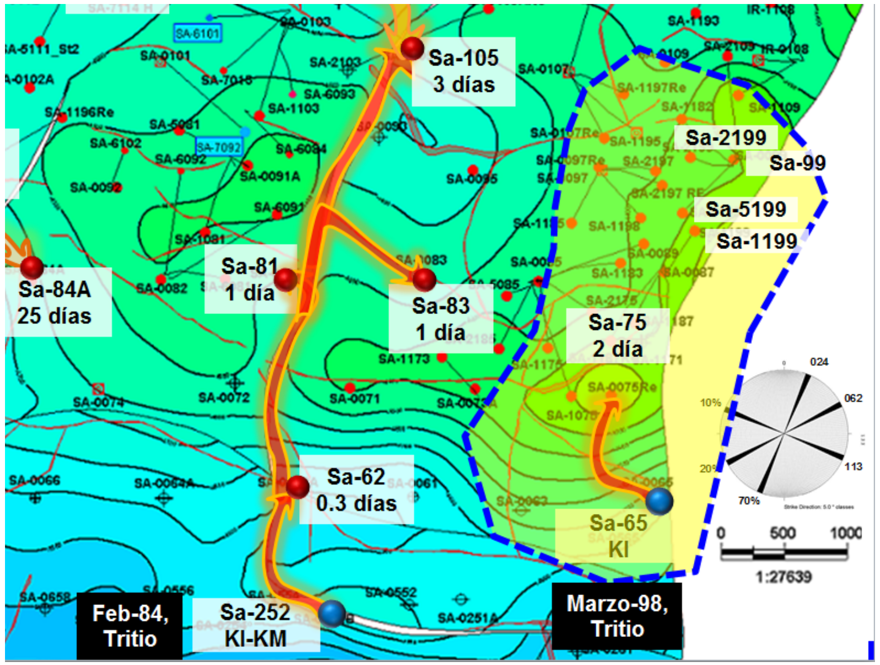
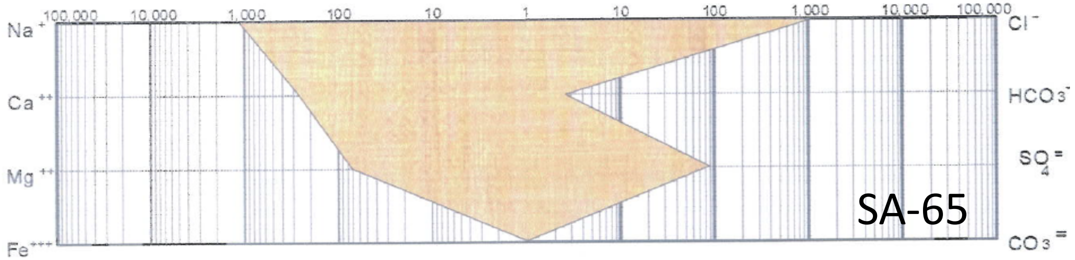
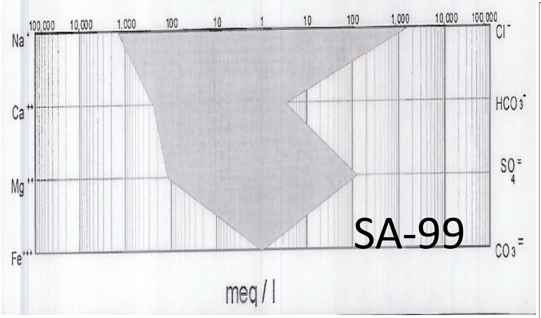
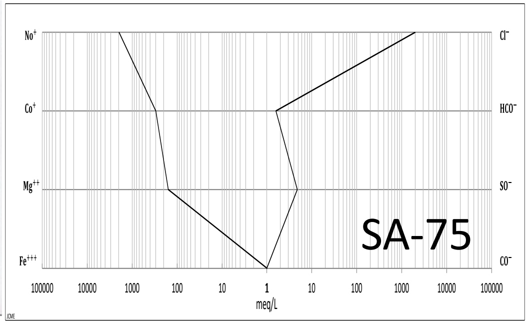






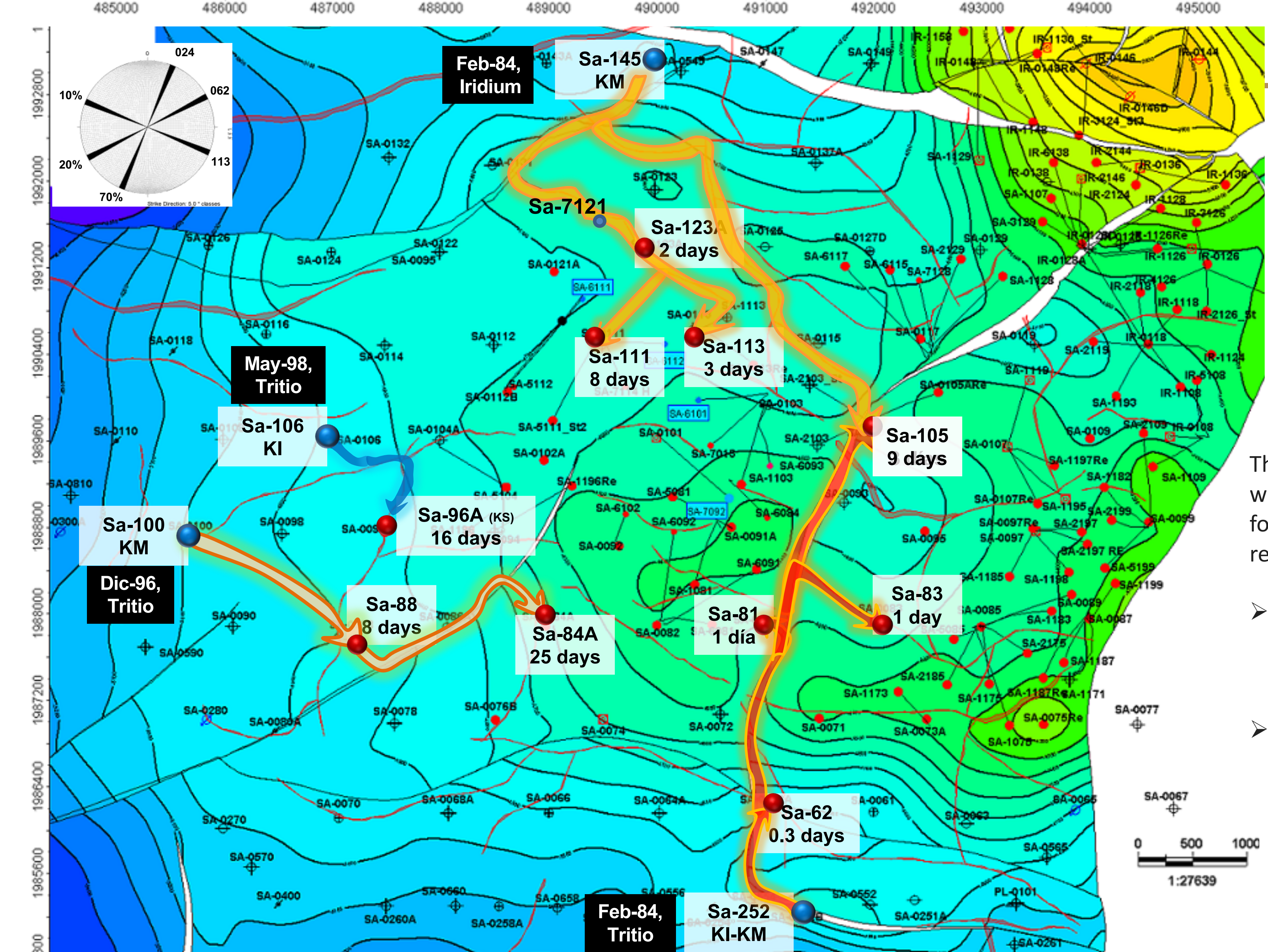




Based on the salinity of SA-65 and the behavior of neighboring wells, the invasion of water injection in the MC and LC is shown.

- This confirms the result of the tracer test carried out before in the field, where the producing wells perceived the tracer fluid immediately.
- In addition, when comparing the stiff plots of the producing wells with the Stiff plot of the injector well, a great similarity was observed between them.

Tracers



The tracers tests indicates that the western part of the field is better suited for water injection for the following reasons :

- The injection is far from most of the producing wells (located in the east and central zone).
- The tracers confirm that injecting sub-perpendicularly to the fractures in the west zone helps to avoid rapid channeling to the producing wells

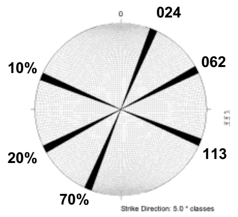
Immediate solution

Redistribution of wastewater injection

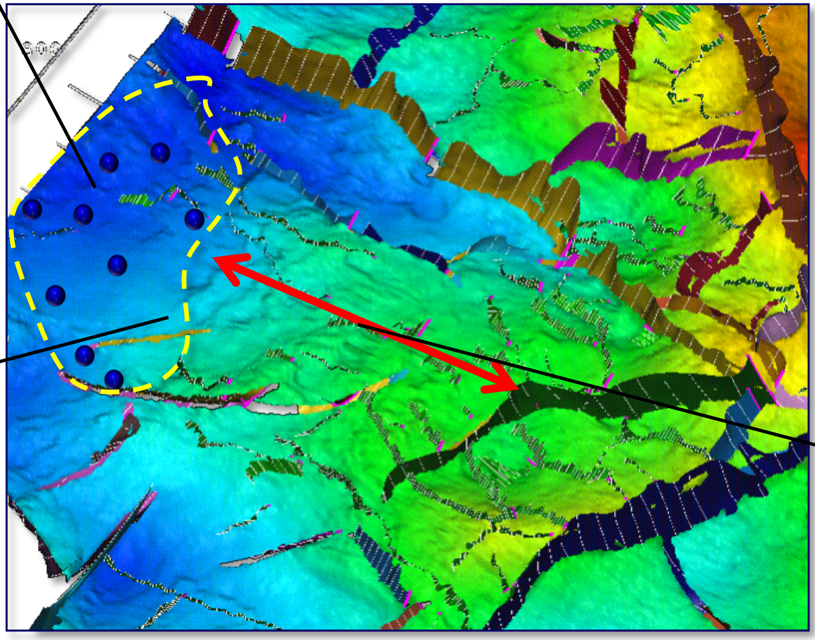
Based on the analysis of the tracers, salinity and Stiff plots, and the result of the fracture study, it is immediately proposed to redistribute the water flooding in Samaria field.

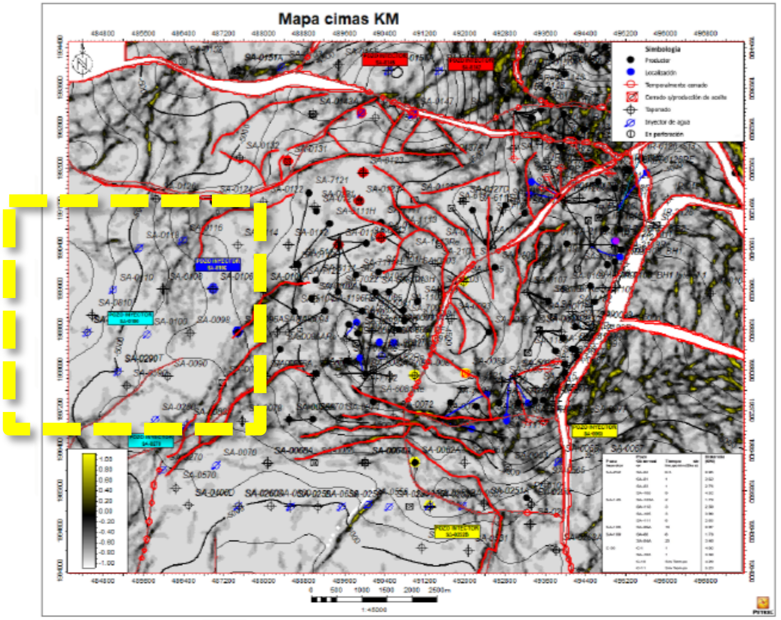
For this, it is necessary to rehabilitate the candidate wells to injectors, guaranteeing their mechanical and surface integrity, as well as the necessary facilities for the management.

Wide area to "flood", retarding the advance of water. Deeper wells



Sub-Perpendicular Injection to the first and second preferential orientation of fractures

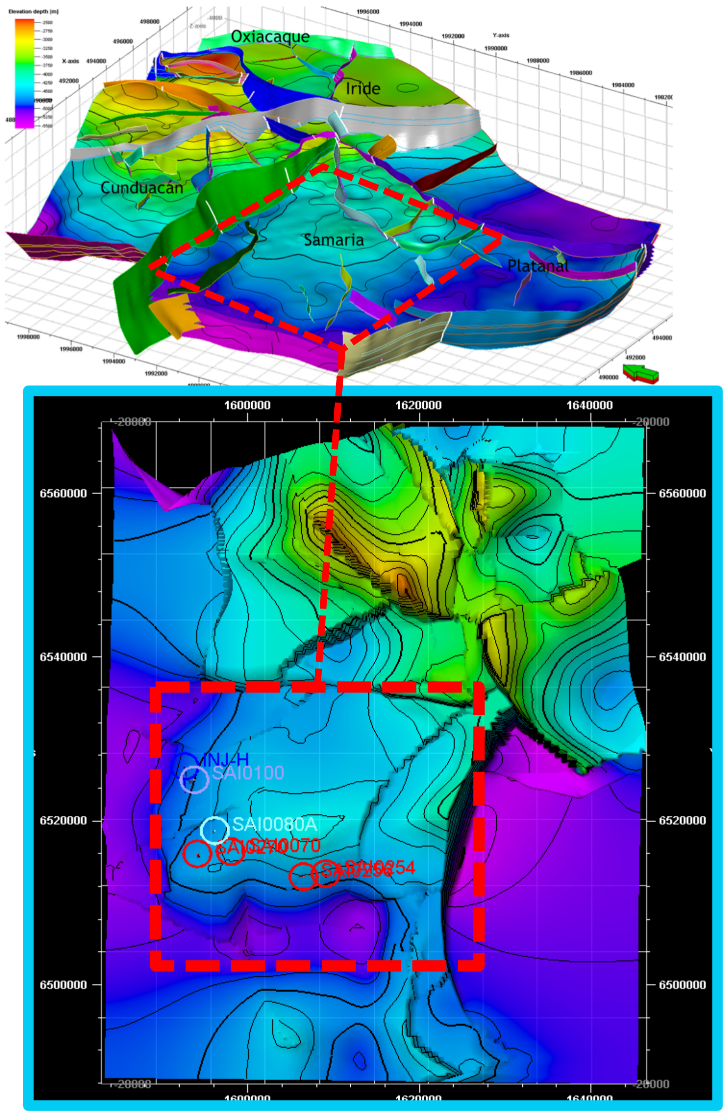


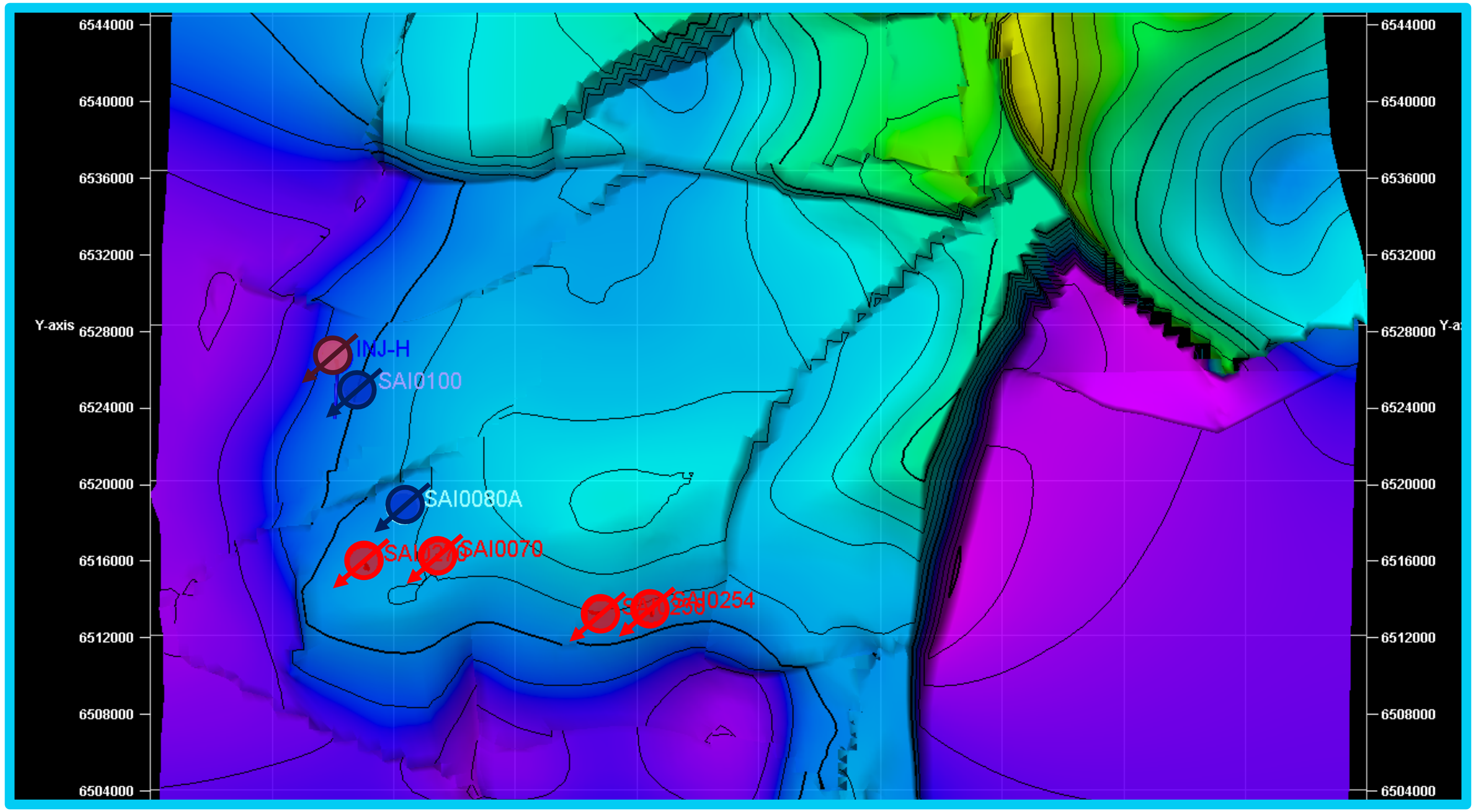


The longest distance to the most important producer block

Injection Analysis

Simulation results





Due to the current situation in which some producing wells of the field are being invaded by injection water, a simulation was carried out in Petrel using the data of the static & dynamic models to define the preferential routes of the injected waste water to through the current injector wells by dividing them into two zones: southern periphery (red wells) and west zone…

In the simulation the proposal of a horizontal injector well was considered

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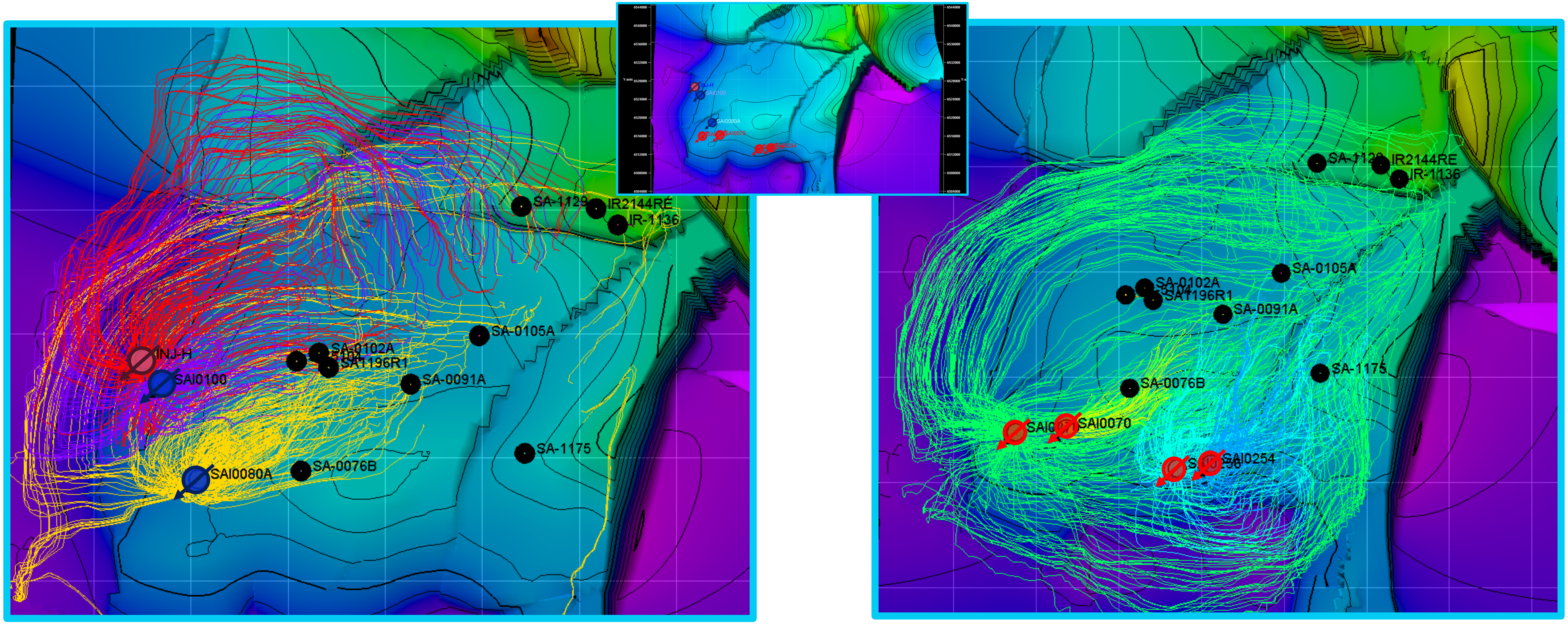
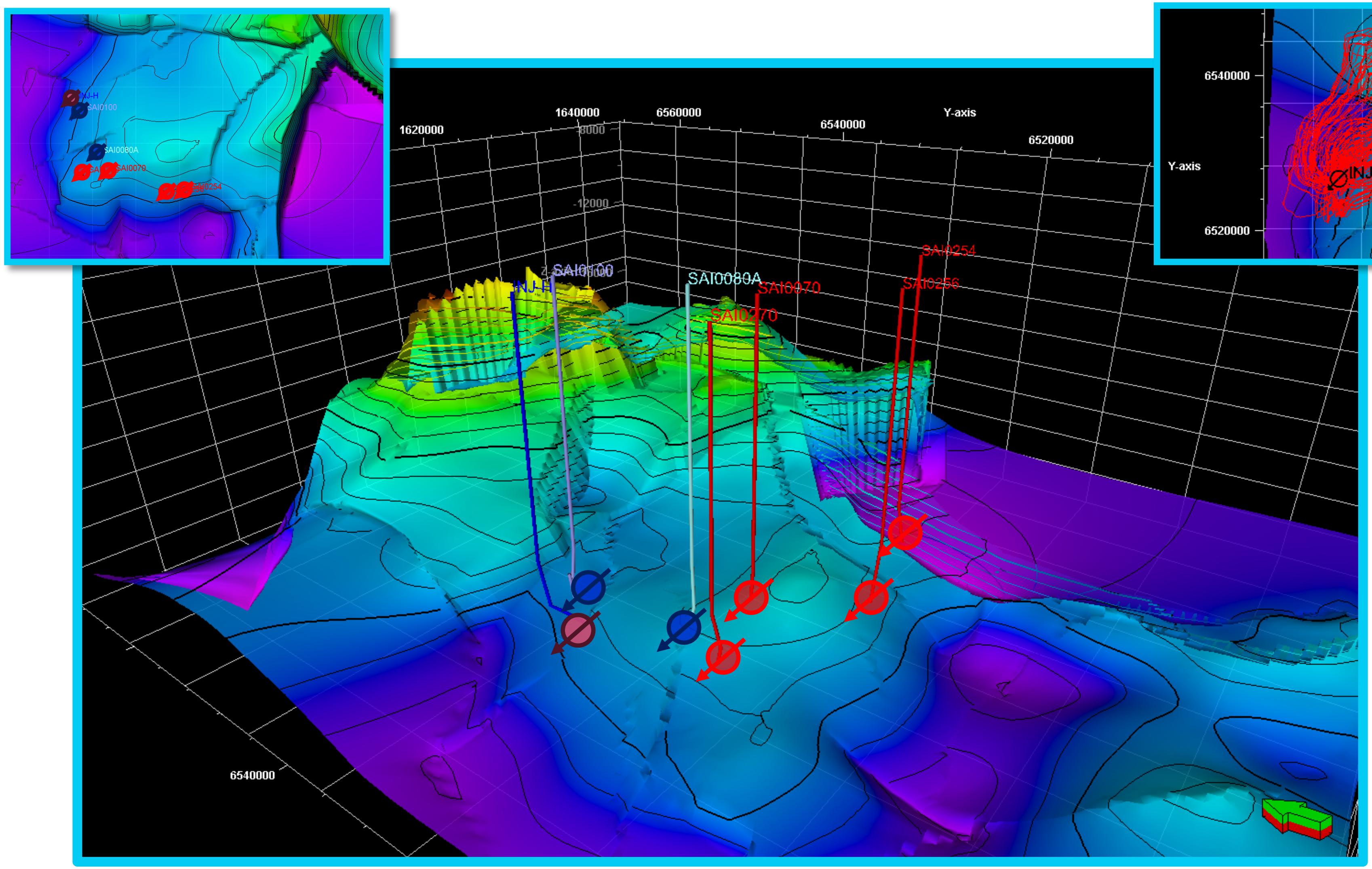


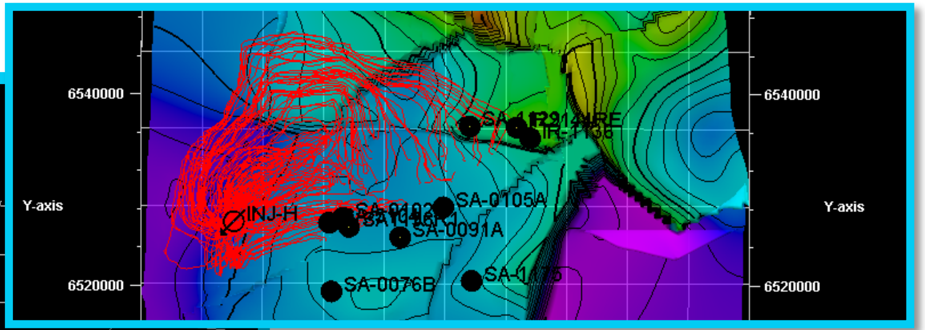
It is clearly seen that the preferential flow routes of the wells located in the southern peripheral zone tend to go towards the central and eastern part of the field, where precisely the highest percentage of producing wells is found, while the preferential flow routes of the Injection in the western zone are directed more towards the northern part, at the same time that they have much less influence in the area of producing wells**.

*** The producing wells located on the map are only for reference to visualize the range of the injection*

Horizontal Injector results

Preferential routes of injection





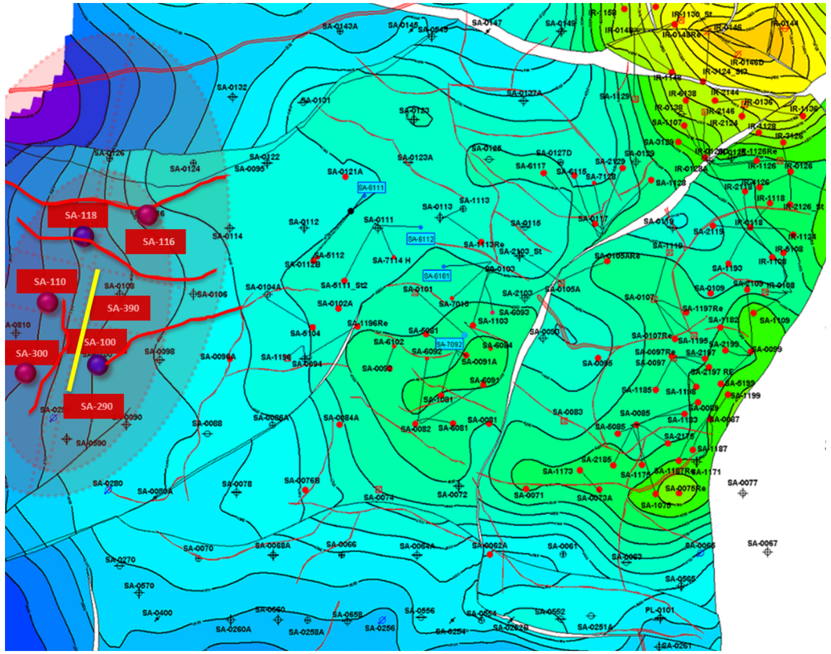
Like the other wells in the western zone, the area where it is proposed to locate the horizontal injector well, has non-invasive preferential routes for producing wells.

And... Why the concern of injecting through a horizontal well?

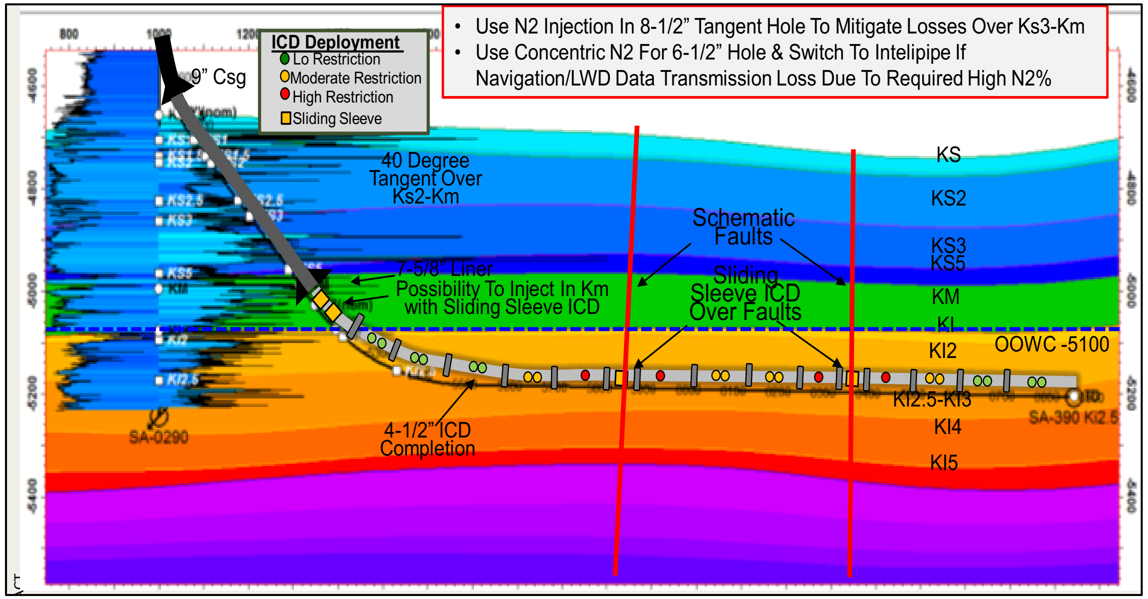
First horizontal water injector well

Design and expectations

- One of the causes of the current high water production is the design and location of water injector.
- All injector wells are vertical, shot in the available section of LC or MC.
- There is no means of controlling the injection and it is done in large volumes.
- Strong upwellings of injected water.



- When injecting through a horizontal well, it is sought to have a more effective injection in an areal way, looking for a better sweep of oil that have been left behind by the channeling of water produced due to the high fracturing of the reservoir.

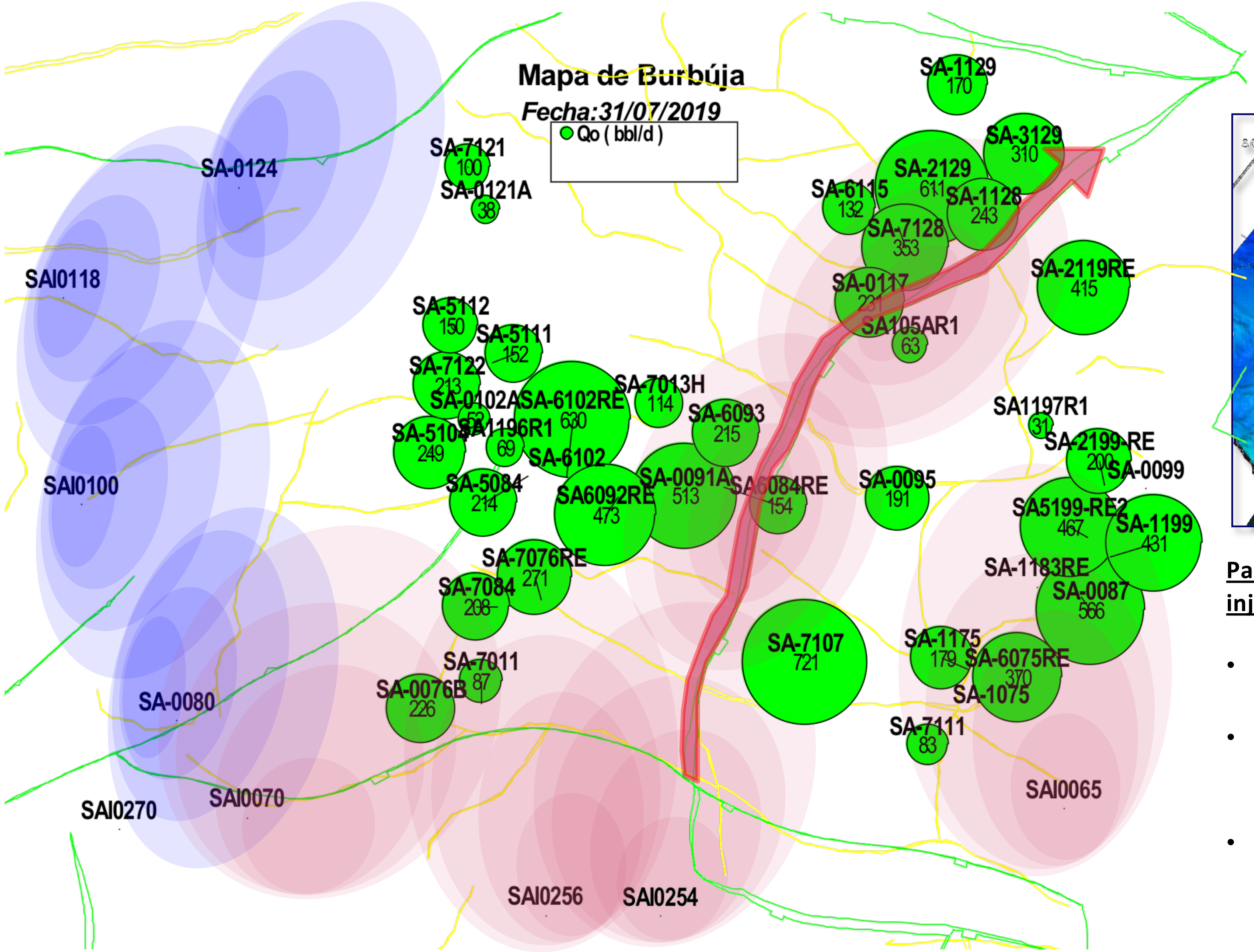


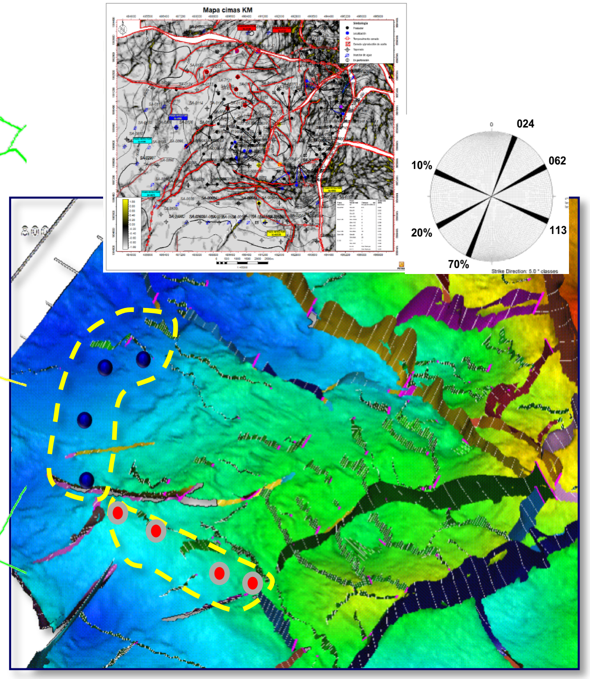
- The flow controllers have capillary tubes with IDs that are defined according to the area and speed of the fluid required. Inflatable packers are used to insulate the areas of permeability variation identified.

With the redistribution of injection to the west zone, an increase in oil production is expected due to better oil sweep and more optimal pressure maintenance, since the injection would be made subperpendicular to the direction preferential fractures

Costo total de intervención (MXN)	Gasto operativo por bpc (MXN/bpce)	Horizonte de producción (meses)
$ 3,800,000.00	$ 110.29	6

Precio de Barril (año referencia)	Precio de Gas (año referencia)
$ 60.48	$ 4.26





Parameter monitoring by deactivating the injection in the southern zone:

- Remarkable results are expected from deactivation in a period of 3 to 6 months.
- One of the expected results is the reduction of the water cut of 10-20% in those directly affected wells.
- Salinity values of produced water will increase.

Redistribution of water injection

Results – Oil Production vs Water cut

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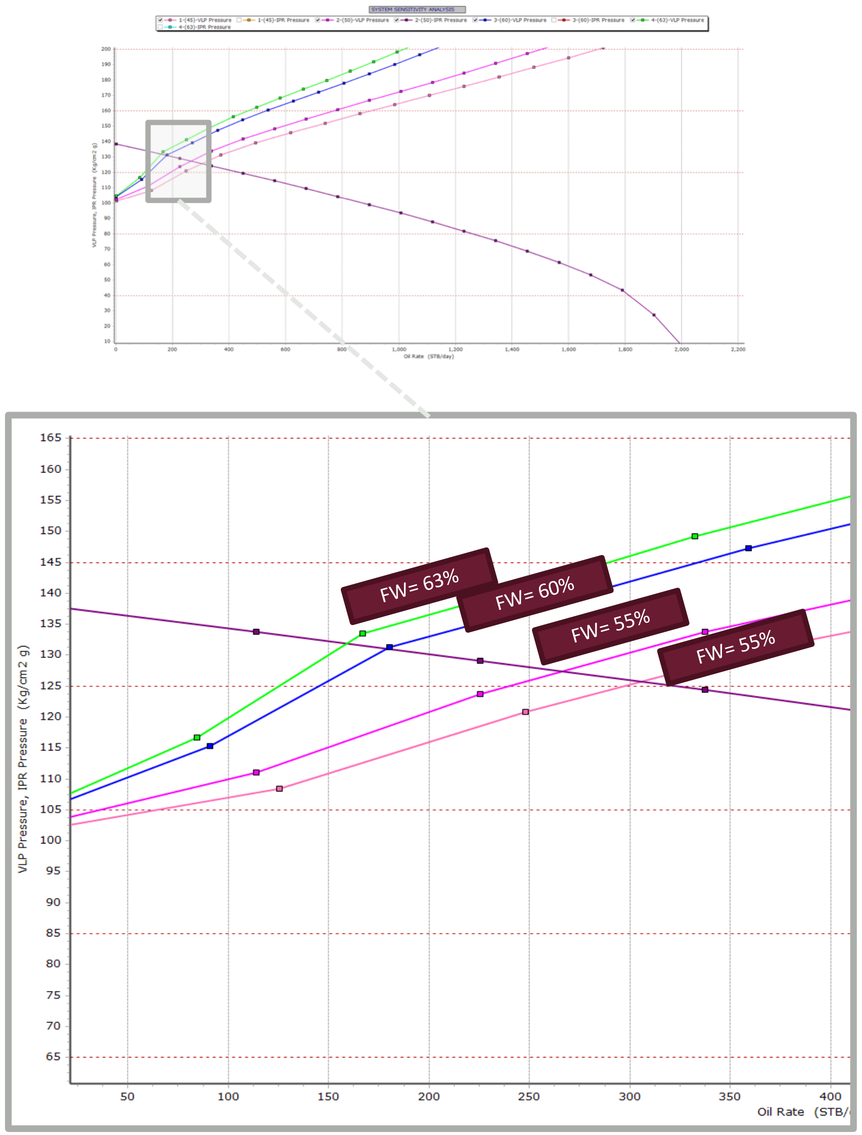
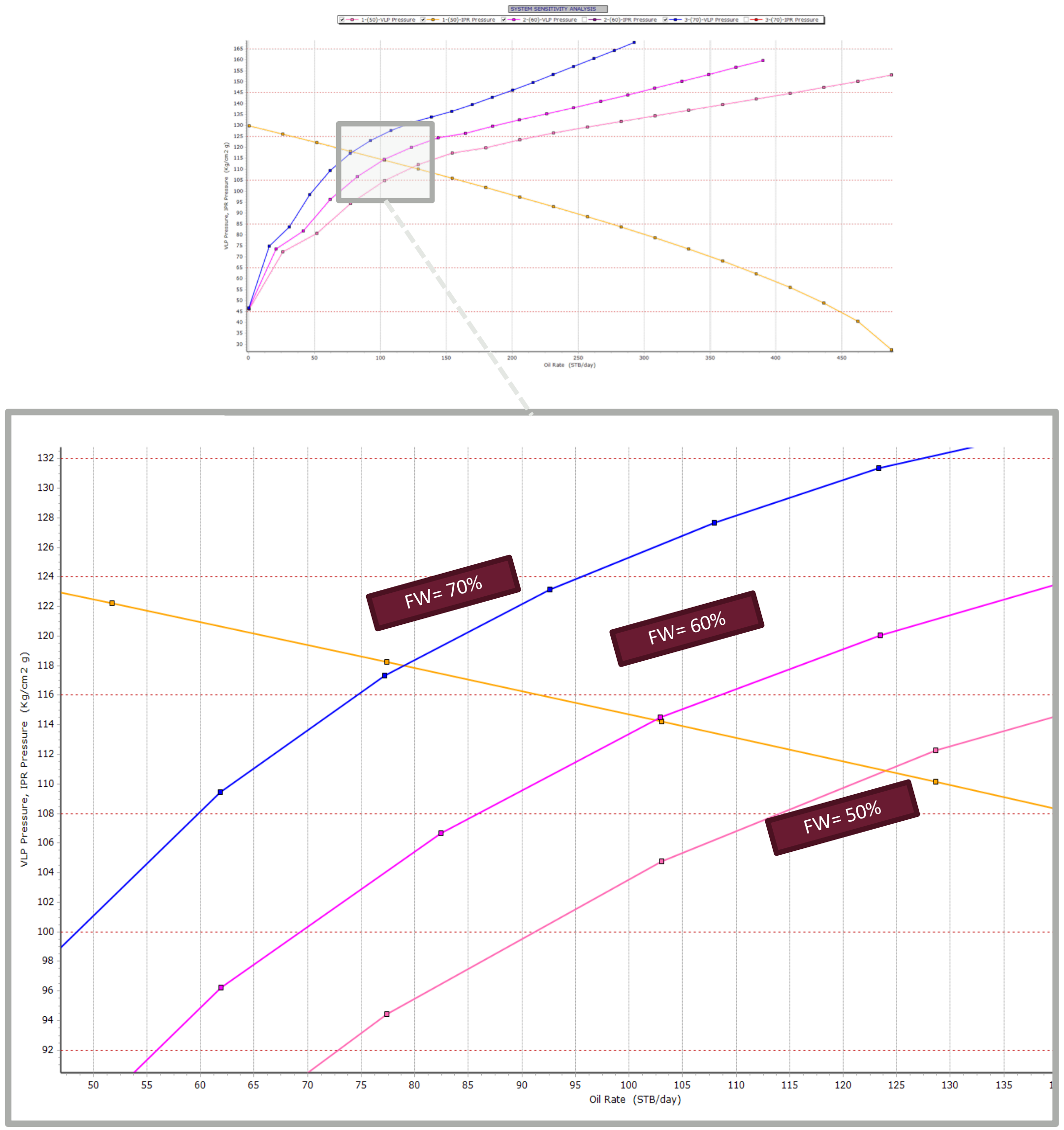


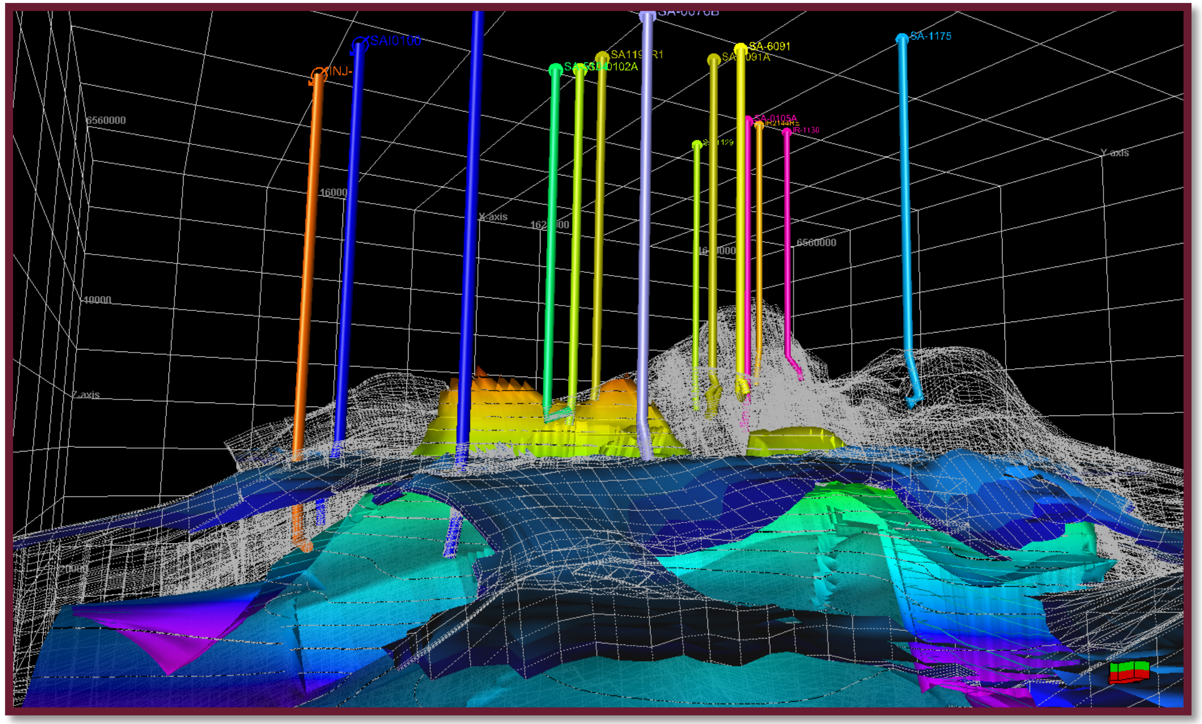


Conclusions

- Continue with the water flooding as long as it is rescued by Reservoir Management, having as emphasis the efficiency of sweeping and critical rates, in order to have greater control over the ranges of increase or maintenance of reservoir pressure having as a priority the effect on it in order to maximize oil recovery.

- It is necessary to increase the simulation analysis with specialized to determine the water contact delimiting the field by study areas, and thus better estimate the oil window considering the high heterogeneity of the reservoir.

- Currently, an information gathering campaign is scheduled to strengthen the dynamic monitoring of contacts, in order to continue identifying new opportunities in areas where they were believed to be invaded by water.



- The horizontal well initiative has advantages over the vertical design in terms of greater reservoir contact, reduction of fracture flow and a greater volume of injection if necessary as long as the control devices in the background are available for correct administration of the injection... although it should be noted that this initiative is not imminent to take immediate actions for the indispensable redistribution of injection