# WATERFLOODING SIMULATOR

Sahara's injection pattern simulator helps to obtain a historic adjustment and a production forecast in considerably shorter times compared to a numerical simulation.

The system has implemented three analytical models based on the Segregated Flow, Buckley & Leverett, and Craig, Geffen & Morse equations, and two empirical models, Statistical Curve and WOR vs Np method. All these models calculate the fraction of water produced according to the cumulative injected water.

The results generated by the simulator can be visualized as production curves for each well, both at well level or layer level, and also for each pattern or group of wells. Injected pore volumes, recovery factors and injection-production balance can also be represented against time. The Map window can display saturation maps, injected pore volumes and recovery factors, among others elements.
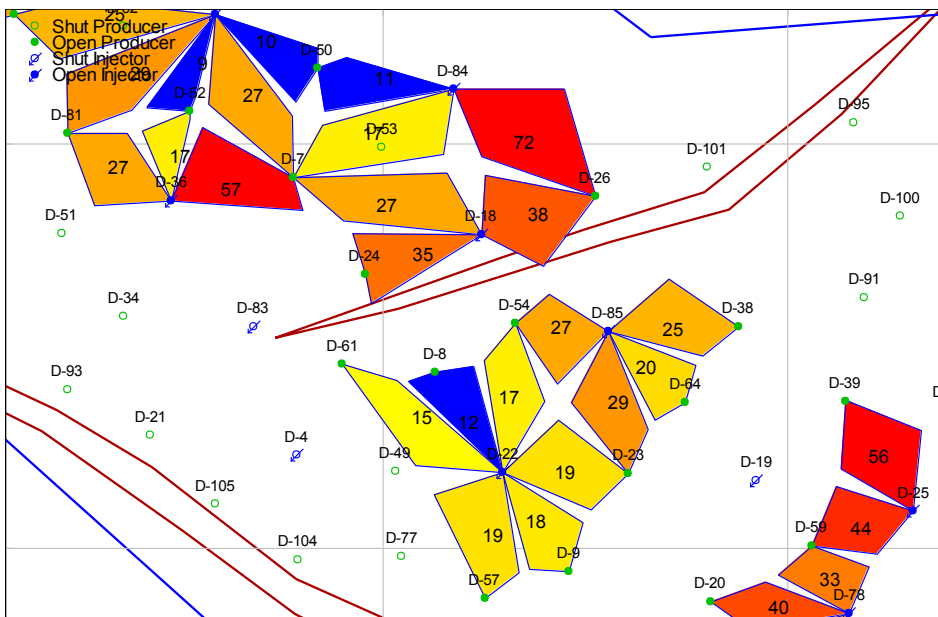
The time required to prepare the data and perform the subsequent calculation is only a few minutes. This is why this tool is powerful not only for the optimization of future injection results, but also for solving situations typical of a secondary recovery project such as anticipating channeling issues or identifying connections among wells that may affect their production response.
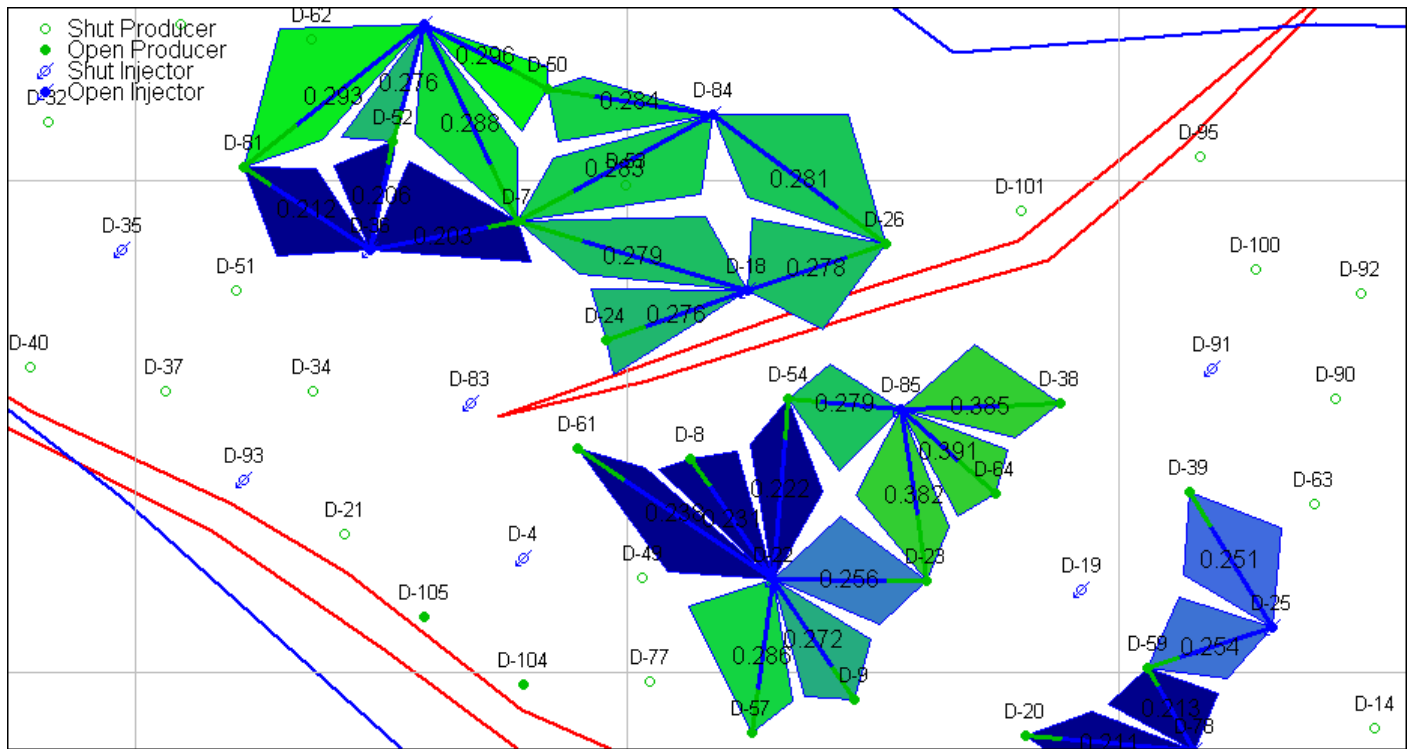
Injection Patterns in the Map Window. Colored injection patterns are displayed according to oil saturation.

The purpose of Sahara's analytical simulator is to represent the displacement of fluids in the reservoir due to the injection of water, once the gas has been produced or redissolved through a multilayer pattern. These injection patterns consist of a group of flow elements connecting each injector well with its neighboring producer wells in each layer. Each flow element represents the reservoir volume where the fluid sweeping from the injector well to the producer well takes place.

The injection patterns are built independently for each layer and can be modified over time to reflect the actual history of water injection. To do it in the most accurate way, it is possible to review the workover historical information, in order to check if each well is open or closed in each of the layers that are in secondary recovery. There is a tool that calculates the well status in each layer and for each date, taking into account the well workover data, such as perforations, cementations and installations that may be leaving closed layers.

By using the simulator, different alternatives of injection patterns can be tested. In this way, in a short period, it is possible to have multiple recovery responses associated with different pattern configurations, to imitate different sweeping schemes, and to assess which is the one that optimizes the project.

To be prepared to perform a simulation, the following information must be available: well conditions, that is, injection and production layers, injection data measured per layer, petrophysical data and PVT tables for the fluids in each of the layers and pore volume maps for each of them. Assuming that all the previous data are known, the last element particularly important for the simulation is the areal injection distribution to each producer well in each layer and each date. The work methodology consists of initially assigning areal distribution coefficients and then modifying them in order to achieve an adequate history matching. To perform the coefficient initialization, Sahara offers different alternatives, with options related to the pore volumes and/or the geometry of the flow elements, and to the production of the wells connected to each injector well. In addition, a Capacitance-Resistance Model (CRM) has been implemented to calculate these coefficients. This model calculates connectivity coefficients over time, which can be interpreted as the areal distribution coefficients, since they represent the fraction of water injected in each injector in each layer contributing to the production of each associated producer well. As an additional parameter, it calculates a response time associated with each injector well.

The time required to prepare the data and perform the subsequent calculation is only a few minutes. This is why this tool is powerful not only for the optimization of future injection results, but also for solving situations typical of a secondary recovery project, such as identifying connections among wells and anticipating channeling issues, among others.

Many of the Sahara tools can help to pre-process the information in order to carry out a simulation. Wellworks, Cross Sections, Logs and 3D windows help to visualize the well status to define their connections. The Pattern Analysis window allows preliminary studies of recovery factors with the purpose of validating sweeping areas, pore volume maps and injected water per layer, among other possibilities.

With Sahara's secondary recovery simulator, the user can get a history matched production forecast for each well, at layer level, in a short time.

Once all the data necessary to perform the simulation have been collected, it is necessary to define the calculation preferences, and most important the calculation model to be used. There are three analytical models based on the Segregated Flow, Buckley & Leverett, and Craig, Geffen & Morse equations, and two empirical models, Statistical Curve and WOR vs Np method. In addition, a fill up curve can be used to represent the production response at the beginning of the secondary recovery, simulating the injected water that compresses and redissolves the

released gas that may exist in the reservoir. Also, it is possible to model a delay in response associated with the time it takes the injected water to have an effect in the producer wells. Another calculation option sets an economic limit to be applied to the flow rates calculated by the simulator. As an additional alternative, for wells or layers that are not in secondary recovery, a decline forecast can be performed in order to be used as a result of the simulation. This last option allows having a forecast for the whole project, even in cases where there are areas with no secondary recovery.

After setting the calculation preferences, the simulator simply takes a few seconds to calculate. It is also possible to make it even faster, by selecting the layers by groups to obtain the history matching.
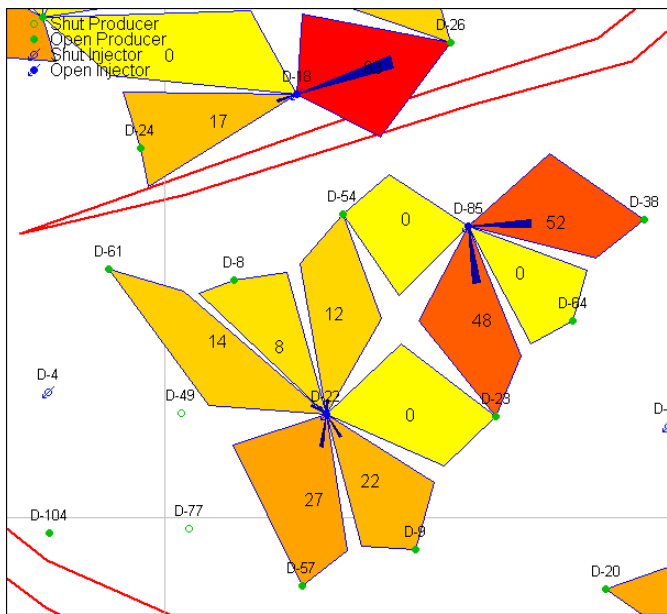

Coefficients Calculated Using the CRM Method. Injection patterns are displayed for a given layer and date, and above the vectors that account for the value of the injection areal distribution coefficients.
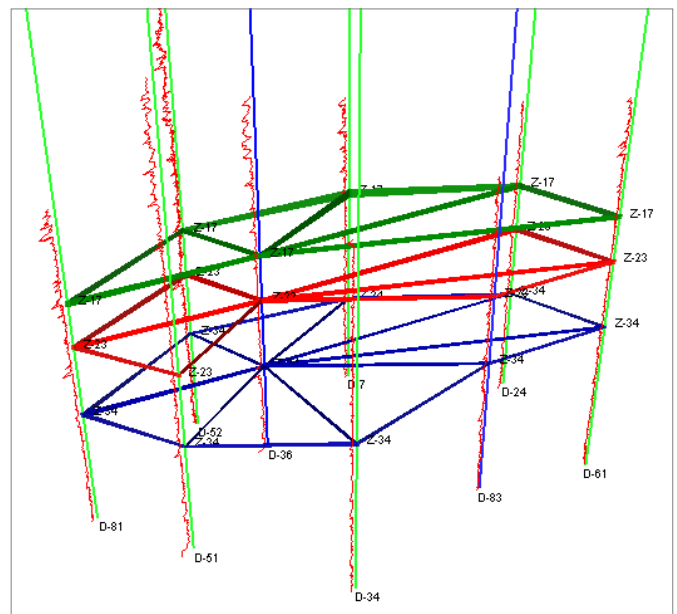

3D visualization of injection patterns.
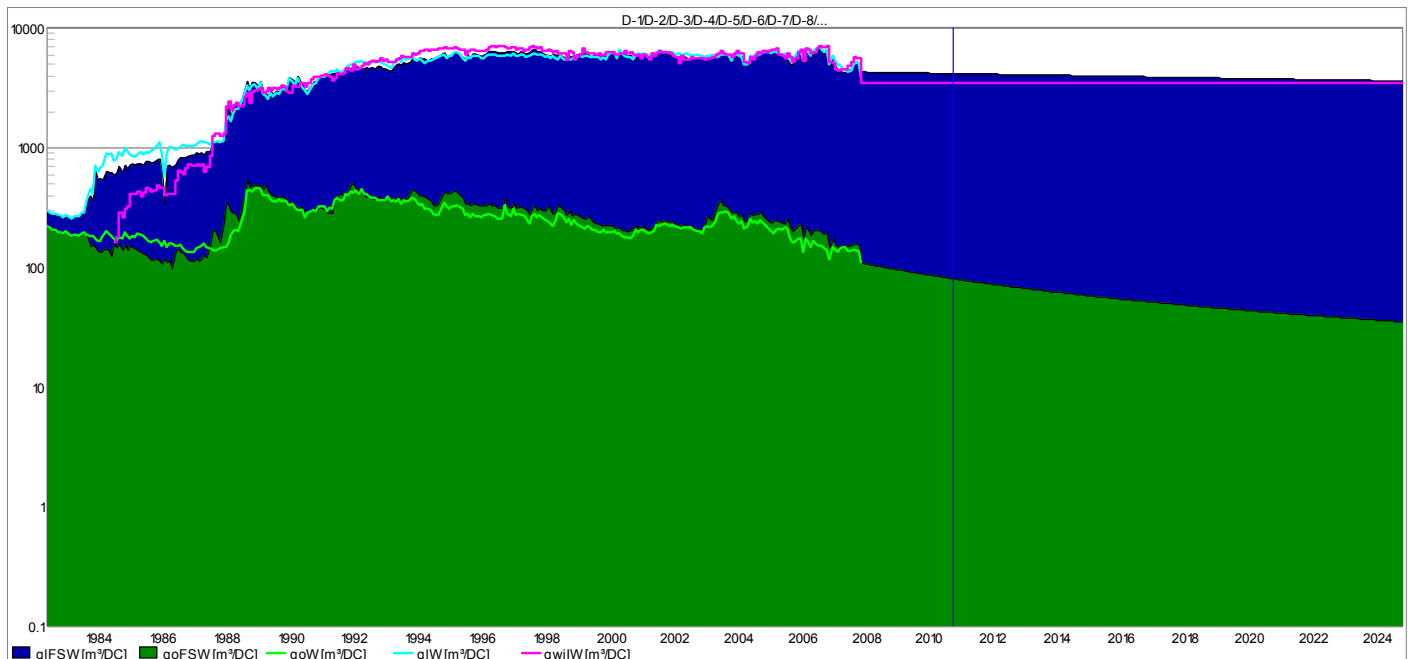
History matching curves. The production forecast curves calculated with the simulator for both oil and liquid are displayed, compared to the actual production curves.
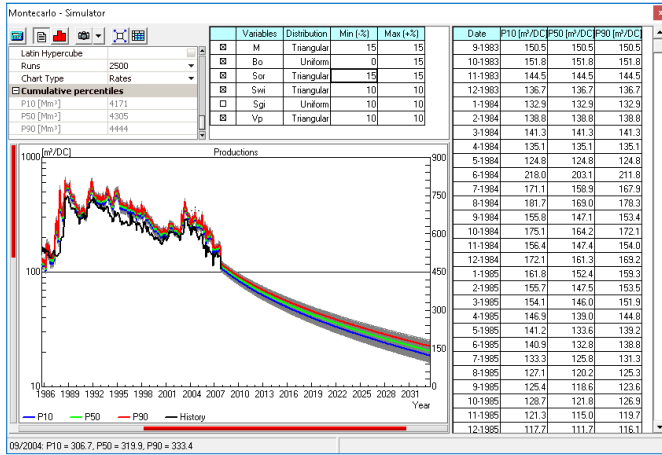
Monte Carlo Simulation window. The image displays the outcome of a 2500-run Monte Carlo simulation using the Segregated Flow equation where a sensitivity analysis was performed with many parameters.
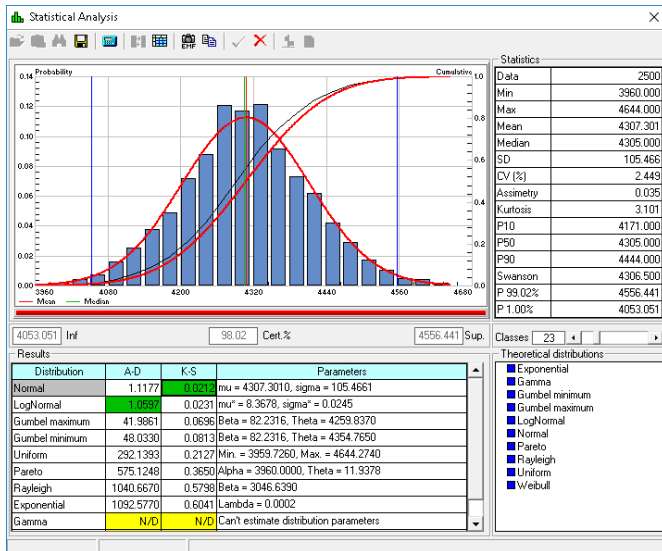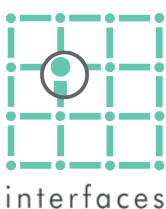

Statistical analysis window. The image displays the result distribution of a 2500-run Monte Carlo simulation using the Segregated Flow equation where a sensitivity analysis was performed with many parameters.

Correlation Matrix

After obtaining an adequate history matching, a Monte Carlo simulation can be run in order to do a sensitivity analysis. The variables available will depend on which model was chosen to perform the calculation. A theoretical distribution and a maximum and minimum value can be assigned to each of them, which will be interpreted in different ways depending on the distribution chosen. In addition, a matrix of correlations can be used to define if there is any correlation linking the variables involved in the calculation, and a tornado chart to assess which of the variables has the most impact on the result. Finally, the number of runs to be performed must be selected. An additional option is to use the Latin Hypercube methodology to take the sampling values. This methodology reduces the number of runs necessary to obtain an acceptable result. After the simulation has been performed, production logs for the 10, 50 and 90 percentiles can be visualized as a table or a chart.