



## A • Introduction

The study case R-1 initially starts as an oilfield with 4 producers. At present time, the field has been on production for a year then shut-in since. The engineer needs to evaluate different field development scenarios to bring back production and improve hydrocarbon recovery.

We are going to first build a model from the existing documentations, history match it using available well history, then consider different development scenarios and generate production forecasts using Rubis, in view of the R-1 field redevelopment.

The field has layers of different permeability and a relatively weak aquifer, in particular there is a high permeability layer that is in partial communication with the others. The upper part of the reservoir has average to good permeability rock and the lower part has average to poor permeability rock. Vertical communication is limited as vertical anisotropy exists. The reservoir is dipping from north east to south west, with an OWC in the south-western leg. It presents north-south faults creating limited communication between the western and eastern part.

## B • Model preparation

Below is a step by step procedure:

The model initialization workflow in Rubis follows a top-to-bottom structure and each step is represented by an icon on your left hand bar.

### B1 • Field infos

Verify that gravity is taken into account. Reference date is set at 1/1/2008, you can enter here the company name and the country name. Field name is R-1.

**B2 • PVT**

The reservoir contains **saturated oil** and **water**.

We have some information regarding the fluid PVT data and the reservoir:

Reservoir and PVT sample Temperature 212 F

Fluid sample test maximum pressure 5000 psia

Fluid GOR 553.806 scf/stb

Water:

Leave the water properties as default. Make sure that correlations used are Spivey for B(w) and Van Wingen Frick for  $\mu(w)$

Gas:

Gas specific gravity is 0.7.

Oil:

Input the constraint for Co (5000psi 212F 3.6E-6)

*Don't forget to match the Co column to the input constraint.*

The back up file is "00 PVT step.krp".

### B3 • Geometry

First we are going to define the boundaries and existing faults. Use the map provided in this exercise to quickly define the boundaries and set the reference at the cross indicated in the map. The yellow dots are the location for the wells that we will define later on. Don't forget to set the scale and the reference point.

The reservoir has 5 layers and a top structure map is provided. Load all the information and make sure that the top depths interpolation is set as **linear**.

The respective thicknesses are:

Layer 1 = 30 ft, layer 2 = 40 ft, layer 3 = 30 ft, layer 4 = 60 ft, layer 5 = 20 ft.

The back up file is "01 geom step.krp".

### B4 • Properties

Initial pressure = 4100 psia @ 6100 ft TVDSS and 212 F

GOC = no "real" one (set above reservoir, for example, @ 5775 ft TVDSS)

WOC = 6392 ft TVDSS

Fluid sampled @ 6100 ft TVDSS, saturation pressure  $P_b = 1931$  psia

Below are the different properties for each layer:

#### Layer 1 (L1):

K = map provided (Kriging interpolation)

Phi = 0.14

N/G = 0.8

No horizontal anisotropy, vertical permeability is 0.6 horizontal permeability

Layer in partial communication with the layer below (0.5 leakage)

Formation compressibility:  $4e-6$  psi<sup>-1</sup>

#### L2:

K = map provided (Kriging interpolation)

Phi = 0.14

N/G = 0.7

No horizontal anisotropy, vertical permeability is 0.8 horizontal permeability

Layer in very limited communication with the layer below (0.01 leakage)

Formation compressibility:  $4e-6$  psi<sup>-1</sup>

#### L3:

K = map provided (Kriging interpolation)

Phi = 0.15

N/G = 0.8

No horizontal anisotropy, vertical permeability is 0.6 horizontal permeability

Layer in limited communication with the layer below (0.5 leakage)

Formation compressibility:  $4e-6$  psi-1

L4:

K = 30 md

Phi = 0.12

N/G = 0.6

No horizontal anisotropy, vertical permeability is 10 mD

Layer in partial communication with the layer below (0.3 leakage)

Formation compressibility:  $4e-6$  psi-1

Layer 5 (rock properties set as default):

K = 30 md

Phi = 0.12

N/G = 0.6

No horizontal anisotropy, vertical permeability is 10 mD

Leakage = 1

Formation compressibility:  $4e-6$  psi-1

Relative permeability:

Water-oil:

Sw residual = 0.15; So residual in water = 0.1

Kr ow = 0.97; Kr wo max = 0.6 ;

Curve shape factor : power 1.85 for krow and 2.48 for krwo

Oil-gas:

Sg residual = 0.04; So residual in gas = 0.1;

Kr og = 1; Kr go = 1;

(Power, 2) for both kr shape factor

**Geometric** relperm is used for 3 phase kr (*actually if you change to stones II there is negligible to no difference, so as you wish, for info on rel perm cf. Gerard's paper*).

Capillary pressure:

Pc max = 0 psia, Pc min = 0 for oil-gas (assume no capillary effect here for oil gas contact); shape factor (power, 2)

Pc max = 1.5 psia, Pc min = 0 for water-oil; shape factor (power, 2.63)

*In terms of front displacement, what could be expected? Which layer is likely to be first depleted? What trend are we observing in terms of areal permeability variation for layers 1, 2, 3?*

*Notice the different possibilities for reservoir properties definition and for property settings.*

**The back up file is "02 rockP step.krp".**

Aquifer:

To activate the option "Aquifer": click on the button "Options" on the "Map" tab, in the dialog 'Run information' tick the checkbox "Allow aquifers".

The field has an aquifer attached to the reservoir below 6392 ft (WOC). Determine correctly for each of the layers the field contour segments that should be attached to the aquifer. We assume here a true numerical aquifer, with a volume of 700 mmstb, in a 14% porosity,  $4e-6$  psi-1 formation compressibility and 30 md permeability rock.

*There is a very simple way to attach the aquifer: go to the 3Dgrid preview dialog, set PV Max/Layer=1 (no sublayering) and select Phi as a property to display in the 'Reservoir Grid'. In the 'Data clipping section' tick the checkbox 'Clip with horizontal plane' at the depth 6392 ft tvd. By doing so we can approximately detect which part of the layers is below the WOC and thus define the segments of the contour at each layer where the aquifer must be attached.*

*Check the different possibilities of aquifer mode for students' interest.*

The back up file is "03 Aquifer step.krp".

## B5 • Well settings

4 wells in total are present for history match. 2 in the western section: W1 (western most well) and W2; 1 in the centre: C1; 1 in the eastern part: E1.

In Edit/QAQC, enter the downhole pressure (MM/DD/YY) and the rate history (duration) for each well (first load all the pressure channels then all the rate channels). Make sure it looks consistent.

All four wells are vertical, and will be controlled by their **oil** production history, with a bottom hole pressure constraint of 2000 psia.

Input additional constraint that will shut-in the well at the condition "QTot(bh)<=0".

*Once defined, it is possible to view to well controls plotted on a timescale for more clarity.*

Define gauge depth: as just above perforations

For wellbore model choose 3 phase drift flux modelling and only above reservoir.

For each well the characteristics are the following:

*You can either choose to type in directly the perforation depth or you can also use the cross section view to draw perforation. Perforations do not need to be absolutely exact. Above reservoir for well intake calculation is ok.*

**Perforation depths can vary depending on user interpolation model. This is not so important since the user just need to create perforation following layering structure.**

E1 perforation: complete the well through layer 1 and layer 2 in two separate perforations. Wellbore storage (WB) = 0.02 bbl/psi, E1 gauge depth: 6069 ft.

C1 perforation: layer 1 (one perforation) and layer 2-3 (one perforation). 6182 – 6209 ft. / 6212- 6281.5 ft. WB = 0.01 bbl/psi, C1 gauge depth: 6181 ft.

W1 perforation: layer 1 completed 6347.3 – 6377 ft. WB = 0.01 bbl/psi, W1 gauge depth: 6347 ft.

W2 perforation: layer 1 and 2 completed with two individual perforations. 6289.61 – 6316 ft / 6319.6 – 6359.6 ft. WB = 0.01 bbl/psi, W2 gauge depth: 6287 ft.

The back up file is "04 wells step.krp".

## B6 • Grid settings

The model will generate automatically all the grid blocks for simulation. To modify the gridding

settings open the "3D grid preview" dialog on the "Map" tab by clicking on  .

*If you uncheck the automatic option for the simulation grid, you can manually select how the grid should be defined, well local refinement, cell density across the field, etc. The most interesting option here is well upscaling. By default it is set to 1, 0.5 would be at Topaze well resolution and 0 would be Saphir's well resolution (good enough to observe pressure transient behaviour).*

*Check for the Automatic layering : the PV max/layer must be 0.2.*

*Click on the button "Update" to preview the grid with build using the new parameters, check the different display settings.*

## **B7 • Model initialization**

The run time is from 01/01/2008 to 31/12/2011. Choose to display Pbar, different recovery factors, surface rates, cumulative, water influx, and recovery factor. Select to plot oil production log for W2.

*In the "Output" tab, the gauge section allows you to redefine which results to save for all wells and for the regions/field.*

Verify that the model is consistent in 3d plot. In particular monitor the water gas saturation. Increase the z scale for better view in 3d map and learn how to make vertical and horizontal cross section (look at the saturation fields at different depths).

**B8 • Model simulation first run**

Make sure that the end of simulation is 31/12/2011.

Check "strictly honour null rate constraints" with minimum duration = 2hrs to make sure that even with fast model approximation shut-ins are not skipped.

Verify that everything is ok and perform the simulation.

*Verify all the wells simulation runs are consistent with history data. What is noticeable?*

The back up file are "05 Hist Match step1 short.krp" and "06 Hist Match step1.krp".

**B9 • Model simulation second run**

We found out later the reason to this problem. After some research on the well completion logs, it was found out that the end of completion status report was missing: we learn from discussion with the former operating company that the well has actually been damaged during the completion stage and that it did not reach true vertical depth as expected. The lowest layer that should have been perforated has been plugged and the remaining perforation has significant skin damage. A well test analysis report provide an estimate of skin value 22 over a perforation across the first layer only, approx. at 6069.33 – 6091.95 ft

Re-run the simulation knowing those information.

*Is the model fully history matched now? What can be said about the water influx? What would happen if all wells continue to produce? Look at W2 oil production log. Are the layer contributions performing along with kh expectations? How much oil has been recovered so far?*

The back up file is "07 Hist Match step2\_E1cor.krp".



## **B10 • Redevelopment plan**

The back up file is "08 Forecast\_starting\_case.krp".

To sum up, the field has a year of production with the 4 original wells in natural depletion. We have 2 wells W1 and W2 in the west flank with one that is close to the water leg. As you have seen in the history matching process, water is breaking through significantly in W1 so the well has been shut in. There is a center well C1 that has limited aquifer support due to fault geometry. And finally E1 is being depleted with almost no pressure support due to its location.

You have been asked to evaluate several field development options. The re-development plan can start from 01/01/2012.

### **B10.1 • Option 1**

The cheapest in terms of facilities overhaul cost would be to use the same facilities at the moment and look for what you can get, but you may expect sub optimal recovery.

Run for 3500 bbl/d oil for each producers. Minimum separator pressure 5 bar = 72.5 psia. How much would you be able to recover if we deplete using current wells with no enhanced recovery technique for the next 10 years?

*Let the students activate the run from 01/01/2012 for 10 years (12/31/2022) and see the outcome.*

*Running the case shows that first your recovery factor is low + how water and pressure depletion comes quickly and kills your production.*

*RF is about 23 % at best with break out in gas that would cause problem in separation facilities along with the water coming in. Cross sections and stratigraphic view 2D see front change shows clearly gas formation. This is not very interesting as we would like to focus on oil recovery.*

*Plateau rates cannot be achieved because of lack of stable pressure support forcing the well to decline.*

*Shows that your layers will be depleted unevenly thus not optimizing the drainage points and you will have cross flows.*

Based on the first option conclusion, what kind of secondary recovery technique would improve the field production?

The back up file is "09 Forecast\_opt1.krp".

**B10.2 • Option 2 & 3**

*Looking from the  $kh$  and  $kv$ , would that be interesting to prefer horizontal producers to vertical ones in an economic perspective?*

*Where would it be interesting to set the new producers?*

After discussion with your team it has been decided that water flooding with extra producers would be an interesting technique for the development of this field.

*What is one possible pattern for efficient reservoir sweep within reasonable timeframe (~10 years)?*

There are two possibilities at this stage that we would like to consider:

- ❖ Option 2: We can try to inject as much as possible and try to maximize production without worrying about the increase of water production as the reservoir is further depleted. This will involve some extra cost for facilities design. Some problems due to low production pressure may appear as well due to continuous decline of water support.

The back up file is "10 Forecast\_opt2\_EOR\_wells\_step.krp" for input.

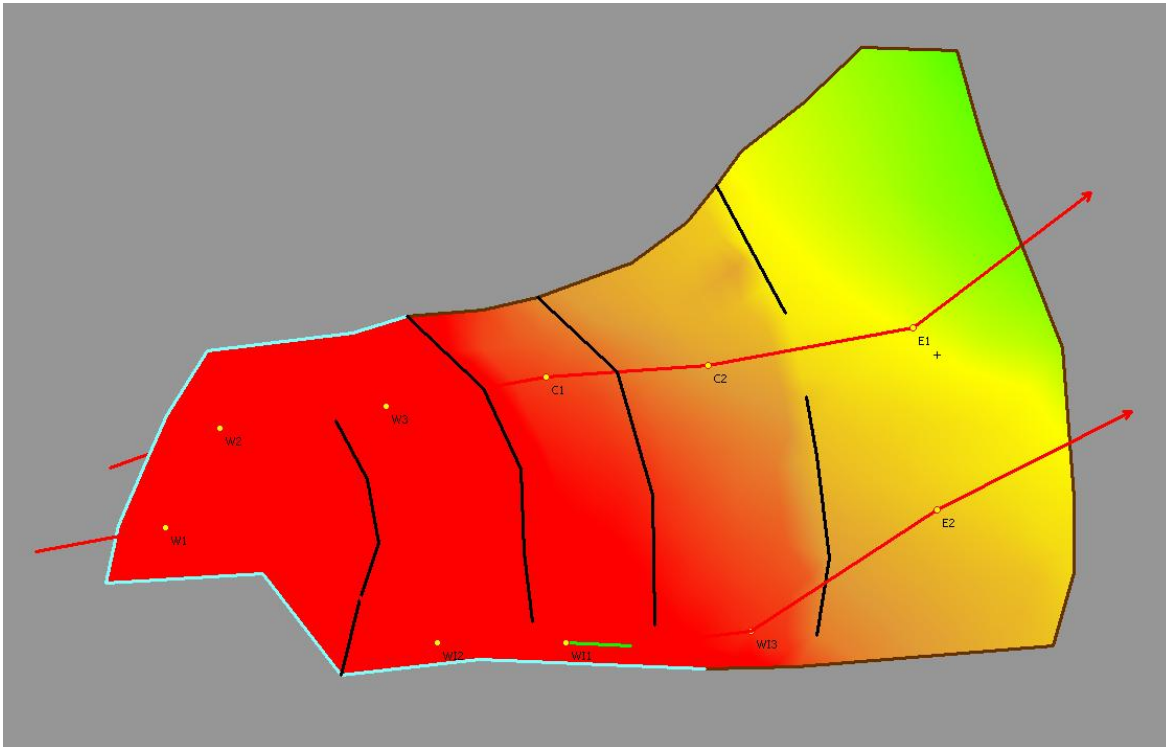
- ❖ Option 3: We can also try to reduce water production by making water shut off at chosen time in order to maximize the oil to water ratio. This scenario will have the advantage of diminishing possible future cost of facilities upgrade and water cycling effect. On the other hand the total recovery would decrease due to flow restriction.

The back up file is "12 Forecast\_opt3\_EOR\_wellstep.krp" for input.

Due to time restriction, in this exercise we will assume one single development plan per option that has been decided based on the above factors:

There will be a plan of adding 3 additional producers on top of current ones, E1 will be worked over to remove skin and get perforated at initially expected reservoir areas and W1 converted to injector. other water injectors have also been planned. The injectors will be situated down flank (with one horizontal injector with 700 ft length) to support aquifer sweep and the producers will be at strategic drainage points.

To get a quick estimate of the placement, just follow the phase 2 map well positioning.



We will need the perforation location (for new wells) and schedule (new & old wells) as well: For all wells set WB = 0.01 bbl/psi and model for "only above reservoir".

E1: set the first perforation skin to be removed after reinstatement by end 2011, create 2 new perforations as suggested and open them by end 2011. Again MD start end are approx. perf#2 is situated at layer 2 and 3, perf#3 for 4 and 5.

| Perf    | Geometry |         |         | Skin | Opening time                        |            |          |
|---------|----------|---------|---------|------|-------------------------------------|------------|----------|
|         | MD start | MD end  | h       |      |                                     |            |          |
|         | ft       | ft      | ft      |      |                                     |            |          |
| Perf #1 | 6069.33  | 6091.95 | 22.6166 | S(t) | <input type="checkbox"/>            | --         | --       |
| Perf #2 | 6104.68  | 6169.33 | 64.6453 | 0    | <input checked="" type="checkbox"/> | 31/12/2011 | 00:00:00 |
| Perf #3 | 6174.62  | 6249.33 | 74.7081 | 0    | <input checked="" type="checkbox"/> | 31/12/2011 | 00:00:00 |

C1: no change.

| Perf    | Geometry |         |         | Skin | Opening time             |    |    |
|---------|----------|---------|---------|------|--------------------------|----|----|
|         | MD start | MD end  | h       |      |                          |    |    |
|         | ft       | ft      | ft      |      |                          |    |    |
| Perf #1 | 6181.93  | 6209.74 | 27.8077 | 0    | <input type="checkbox"/> | -- | -- |
| Perf #2 | 6211.93  | 6281.93 | 70      | 0    | <input type="checkbox"/> | -- | -- |

W2: no change.

| Perf    | Geometry |         |         | Skin | Opening time             |    |    |
|---------|----------|---------|---------|------|--------------------------|----|----|
|         | MD start | MD end  | h       |      |                          |    |    |
|         | ft       | ft      | ft      |      |                          |    |    |
| Perf #1 | 6289.61  | 6316.2  | 26.5937 | 0    | <input type="checkbox"/> | -- | -- |
| Perf #2 | 6319.61  | 6359.61 | 40      | 0    | <input type="checkbox"/> | -- | -- |

W3: create perf#1 for layer 1 and perf#2 for layer 2-3. Again coordinates approx.

| Perf    | Geometry |         |         | Skin | Opening time             |    |    |
|---------|----------|---------|---------|------|--------------------------|----|----|
|         | MD start | MD end  | h       |      |                          |    |    |
|         | ft       | ft      | ft      |      |                          |    |    |
| Perf #1 | 6253.31  | 6277.13 | 23.8218 | 0    | <input type="checkbox"/> | -- | -- |
| Perf #2 | 6285.55  | 6353.31 | 67.7545 | 0    | <input type="checkbox"/> | -- | -- |

C2: create perf#1 for layers 1-2, perf#2 for layer 3, perf#3 for layers 4-5

| Perf    | Geometry |         |         | Skin | Opening time             |    |    |
|---------|----------|---------|---------|------|--------------------------|----|----|
|         | MD start | MD end  | h       |      |                          |    |    |
|         | ft       | ft      | ft      |      |                          |    |    |
| Perf #1 | 6138.92  | 6208.35 | 69.4369 | 0    | <input type="checkbox"/> | -- | -- |
| Perf #2 | 6208.92  | 6238.92 | 30      | 0    | <input type="checkbox"/> | -- | -- |
| Perf #3 | 6242.33  | 6318.92 | 76.5903 | 0    | <input type="checkbox"/> | -- | -- |

E2: create perf#1 for layer 1, perf#2 from mid layer 2 to end layer 3, perf#3 for layer 4-5.

| Perf    | Geometry |         |         | Skin | Opening time             |    |    |
|---------|----------|---------|---------|------|--------------------------|----|----|
|         | MD start | MD end  | h       |      |                          |    |    |
|         | ft       | ft      | ft      |      |                          |    |    |
| Perf #1 | 6110.85  | 6129.85 | 18.9994 | 0    | <input type="checkbox"/> | -- | -- |
| Perf #2 | 6162.55  | 6210.85 | 48.3051 | 0    | <input type="checkbox"/> | -- | -- |
| Perf #3 | 6230.66  | 6290.68 | 60.0178 | 0    | <input type="checkbox"/> | -- | -- |

W1: add perf#2 from below WOC till end of the reservoir. Close the former perforation and open the new one by start of 2012.

| Perf    | Geometry |         |        | Skin | Opening time                        |            |          | Closing time                        |                     |
|---------|----------|---------|--------|------|-------------------------------------|------------|----------|-------------------------------------|---------------------|
|         | MD start | MD end  | h      |      |                                     |            |          |                                     |                     |
|         | ft       | ft      | ft     |      |                                     |            |          |                                     |                     |
| Perf #1 | 6347.13  | 6377.13 | 30     | 0    | <input type="checkbox"/>            | --         | --       | <input checked="" type="checkbox"/> | 31/12/2011 00:00:00 |
| Perf #2 | 6402.85  | 6522.46 | 119.61 | 0    | <input checked="" type="checkbox"/> | 01/01/2012 | 00:00:00 | <input type="checkbox"/>            | -- --               |

W11: go to geometry, set the well to be 700 ft long and at bottom layer where it is under WOC.

| Perf    | Geometry |         |     | Skin |                          |    |              |                          |    |    |
|---------|----------|---------|-----|------|--------------------------|----|--------------|--------------------------|----|----|
|         | MD start | MD end  | h   |      | Opening time             |    | Closing time |                          |    |    |
|         | ft       | ft      | ft  |      |                          |    |              |                          |    |    |
| Perf #1 | 6411.58  | 7111.58 | 700 | 0    | <input type="checkbox"/> | -- | --           | <input type="checkbox"/> | -- | -- |

WI2: perf#1 for layer3-4-5 for about 87 ft, below WOC to be checked.

| Perf    | Geometry |        |         | Skin |                          |    |              |                          |    |    |
|---------|----------|--------|---------|------|--------------------------|----|--------------|--------------------------|----|----|
|         | MD start | MD end | h       |      | Opening time             |    | Closing time |                          |    |    |
|         | ft       | ft     | ft      |      |                          |    |              |                          |    |    |
| Perf #1 | 6395.53  | 6482.3 | 86.7724 | 0    | <input type="checkbox"/> | -- | --           | <input type="checkbox"/> | -- | -- |

WI3: perf#1 for layers 2-3-4-5 for about 137 ft. this injector will be activated later when its region is saturated with water.

| Perf    | Geometry |         |         | Skin |                          |    |              |                          |    |    |
|---------|----------|---------|---------|------|--------------------------|----|--------------|--------------------------|----|----|
|         | MD start | MD end  | h       |      | Opening time             |    | Closing time |                          |    |    |
|         | ft       | ft      | ft      |      |                          |    |              |                          |    |    |
| Perf #1 | 6236.87  | 6374.22 | 137.353 | 0    | <input type="checkbox"/> | -- | --           | <input type="checkbox"/> | -- | -- |

Below is the list of controls for each of the well:

| run no WSO | t@start    | Time    | hr       | Mode     | Target       | Value        | Unit | Constraint   |      |       |
|------------|------------|---------|----------|----------|--------------|--------------|------|--------------|------|-------|
|            | Date       |         |          |          |              |              |      | Type         | Type | Value |
| 1 - W1     | 01/01/2008 | 0:00:00 | 0        | Producer | Q Oil (Surf) | W1 PROD      |      | P Min (BH)   | 2000 | psia  |
| 2 - W1     | 01/01/2012 | 0:00:00 | 35064    | Injector | Q Wat (Surf) | -15000 STB/D |      | P Max (BH)   | 4200 | psia  |
| 3 - C1     | 01/01/2008 | 0:00:00 | 0        | Producer | Q Oil (Surf) | C1 PROD      |      | P Min (BH)   | 2000 | psia  |
| 4 - C1     | 01/01/2012 | 0:00:00 | 35064    | Producer | Q Oil (Surf) | 4500 STB/D   |      | P Min (BH)   | 2000 | psia  |
| 5 - E1     | 01/01/2008 | 0:00:00 | 0        | Producer | Q Oil (Surf) | E1 PROD      |      | P Min (BH)   | 2000 | psia  |
| 6 - E1     | 01/01/2012 | 0:00:00 | 35064    | Producer | Q Oil (Surf) | 5000 STB/D   |      | P Min (BH)   | 2000 | psia  |
| 7 - W2     | 01/01/2008 | 0:00:00 | 0        | Producer | Q Oil (Surf) | W2 PROD      |      | P Min (BH)   | 2000 | psia  |
| 8 - W2     | 01/01/2012 | 0:00:00 | 35064    | Producer | Q Oil (Surf) | 1000 STB/D   |      | P Min (BH)   | 2000 | psia  |
| 9 - WI2    | 01/07/2013 | 0:00:00 | 48192    | Injector | Q Wat (Surf) | -15000 STB/D |      | P Max (BH)   | 4200 | psia  |
| 10 - WI1   | 01/01/2012 | 0:00:00 | 35064    | Injector | Q Wat (Surf) | -15000 STB/D |      | P Max (BH)   | 4200 | psia  |
| 11 - WI3   | 01/05/2014 | 0:00:00 | 55488    | Injector | Q Wat (Surf) | -15000 STB/D |      | P Max (BH)   | 4200 | psia  |
| 12 - W3    | 01/01/2012 | 0:00:00 | 35064    | Producer | Q Oil (Surf) | 4500 STB/D   |      | P Min (BH)   | 2000 | psia  |
| 13 - C2    | 01/08/2014 | 0:00:00 | 57696    | Producer | Q Oil (Surf) | 2000 STB/D   |      | P Min (BH)   | 2000 | psia  |
| 14 - C2    | 01/01/2020 | 0:00:00 | 1.05E+05 | Producer | Q Oil (Surf) | 2000 STB/D   |      | P Min (Surf) | 72.5 | psia  |
| 15 - E2    | 01/07/2013 | 0:00:00 | 48192    | Producer | Q Oil (Surf) | 1500 STB/D   |      | P Min (Surf) | 72.5 | psia  |
| 16 - E2    | 01/08/2015 | 0:00:00 | 66456    | Producer | Q Oil (Surf) | 5500 STB/D   |      | P Min (Surf) | 72.5 | psia  |

The file after run is "11 Forecast\_opt2\_EOR.krp" for option 2.

**For option 3:**

You can duplicate run and add modifications only to gain time.

**E1:** (the first perforation skin will be removed after reinstatement by end 2011)

| Perf    | Geometry |         |         | Skin | Opening time                        |            | Closing time |                                     |            |          |
|---------|----------|---------|---------|------|-------------------------------------|------------|--------------|-------------------------------------|------------|----------|
|         | MD start | MD end  | h       |      |                                     |            |              |                                     |            |          |
|         | ft       | ft      | ft      |      |                                     |            |              |                                     |            |          |
| Perf #1 | 6069.33  | 6091.95 | 22.6166 | S(t) | <input type="checkbox"/>            | --         | --           | <input type="checkbox"/>            | --         | --       |
| Perf #2 | 6104.68  | 6169.33 | 64.6453 | 0    | <input checked="" type="checkbox"/> | 31/12/2011 | 00:00:00     | <input checked="" type="checkbox"/> | 01/07/2020 | 00:00:00 |
| Perf #3 | 6174.62  | 6249.33 | 74.7081 | 0    | <input checked="" type="checkbox"/> | 31/12/2011 | 00:00:00     | <input checked="" type="checkbox"/> | 01/01/2021 | 00:00:00 |

**C1:** perf#2 will be closed to reduce water

| Perf    | Geometry |         |         | Skin | Opening time             |    | Closing time |                                     |            |          |
|---------|----------|---------|---------|------|--------------------------|----|--------------|-------------------------------------|------------|----------|
|         | MD start | MD end  | h       |      |                          |    |              |                                     |            |          |
|         | ft       | ft      | ft      |      |                          |    |              |                                     |            |          |
| Perf #1 | 6181.93  | 6209.74 | 27.8077 | 0    | <input type="checkbox"/> | -- | --           | <input type="checkbox"/>            | --         | --       |
| Perf #2 | 6211.93  | 6281.93 | 70      | 0    | <input type="checkbox"/> | -- | --           | <input checked="" type="checkbox"/> | 01/01/2015 | 00:00:00 |

**W2:** perf#2 will be closed to reduce water

| Perf    | Geometry |         |         | Skin | Opening time             |    | Closing time |                                     |            |          |
|---------|----------|---------|---------|------|--------------------------|----|--------------|-------------------------------------|------------|----------|
|         | MD start | MD end  | h       |      |                          |    |              |                                     |            |          |
|         | ft       | ft      | ft      |      |                          |    |              |                                     |            |          |
| Perf #1 | 6289.61  | 6316.2  | 26.5937 | 0    | <input type="checkbox"/> | -- | --           | <input type="checkbox"/>            | --         | --       |
| Perf #2 | 6319.61  | 6359.61 | 40      | 0    | <input type="checkbox"/> | -- | --           | <input checked="" type="checkbox"/> | 31/12/2011 | 00:00:00 |

**W3:** perf#2 will be closed to reduce water

| Perf    | Geometry |         |         | Skin | Opening time             |    | Closing time |                                     |            |          |
|---------|----------|---------|---------|------|--------------------------|----|--------------|-------------------------------------|------------|----------|
|         | MD start | MD end  | h       |      |                          |    |              |                                     |            |          |
|         | ft       | ft      | ft      |      |                          |    |              |                                     |            |          |
| Perf #1 | 6253.31  | 6277.13 | 23.8218 | 0    | <input type="checkbox"/> | -- | --           | <input type="checkbox"/>            | --         | --       |
| Perf #2 | 6285.55  | 6353.31 | 67.7545 | 0    | <input type="checkbox"/> | -- | --           | <input checked="" type="checkbox"/> | 01/07/2014 | 00:00:00 |

**C2:** perf#2 and #3 will be closed to reduce water

| Perf    | Geometry |         |         | Skin | Opening time             |    | Closing time |                                     |            |          |
|---------|----------|---------|---------|------|--------------------------|----|--------------|-------------------------------------|------------|----------|
|         | MD start | MD end  | h       |      |                          |    |              |                                     |            |          |
|         | ft       | ft      | ft      |      |                          |    |              |                                     |            |          |
| Perf #1 | 6138.92  | 6208.35 | 69.4369 | 0    | <input type="checkbox"/> | -- | --           | <input type="checkbox"/>            | --         | --       |
| Perf #2 | 6208.92  | 6238.92 | 30      | 0    | <input type="checkbox"/> | -- | --           | <input checked="" type="checkbox"/> | 01/01/2016 | 00:00:00 |
| Perf #3 | 6242.33  | 6318.92 | 76.5903 | 0    | <input type="checkbox"/> | -- | --           | <input checked="" type="checkbox"/> | 01/01/2016 | 00:00:00 |

**E2:** perf#2 and #3 will be closed to reduce water

| Perf    | Geometry |         |         | Skin | Opening time             |    | Closing time |                                     |            |          |
|---------|----------|---------|---------|------|--------------------------|----|--------------|-------------------------------------|------------|----------|
|         | MD start | MD end  | h       |      |                          |    |              |                                     |            |          |
|         | ft       | ft      | ft      |      |                          |    |              |                                     |            |          |
| Perf #1 | 6110.85  | 6129.85 | 18.9994 | 0    | <input type="checkbox"/> | -- | --           | <input type="checkbox"/>            | --         | --       |
| Perf #2 | 6162.55  | 6210.85 | 48.3051 | 0    | <input type="checkbox"/> | -- | --           | <input checked="" type="checkbox"/> | 01/07/2016 | 00:00:00 |
| Perf #3 | 6230.66  | 6290.68 | 60.0178 | 0    | <input type="checkbox"/> | -- | --           | <input checked="" type="checkbox"/> | 01/01/2016 | 00:00:00 |

W1:

| Perf    | Geometry |         |        | Skin | Opening time                        |            | Closing time |                                     |            |          |
|---------|----------|---------|--------|------|-------------------------------------|------------|--------------|-------------------------------------|------------|----------|
|         | MD start | MD end  | h      |      |                                     |            |              |                                     |            |          |
|         | ft       | ft      | ft     |      |                                     |            |              |                                     |            |          |
| Perf #1 | 6347.13  | 6377.13 | 30     | 0    | <input type="checkbox"/>            | --         | --           | <input checked="" type="checkbox"/> | 31/12/2011 | 00:00:00 |
| Perf #2 | 6402.85  | 6522.46 | 119.61 | 0    | <input checked="" type="checkbox"/> | 01/01/2012 | 00:00:00     | <input type="checkbox"/>            | --         | --       |

WI1:

| Perf    | Geometry |         |     | Skin | Opening time             |    | Closing time |                          |    |    |
|---------|----------|---------|-----|------|--------------------------|----|--------------|--------------------------|----|----|
|         | MD start | MD end  | h   |      |                          |    |              |                          |    |    |
|         | ft       | ft      | ft  |      |                          |    |              |                          |    |    |
| Perf #1 | 6411.58  | 7111.58 | 700 | 0    | <input type="checkbox"/> | -- | --           | <input type="checkbox"/> | -- | -- |

WI2:

| Perf    | Geometry |        |         | Skin | Opening time             |    | Closing time |                          |    |    |
|---------|----------|--------|---------|------|--------------------------|----|--------------|--------------------------|----|----|
|         | MD start | MD end | h       |      |                          |    |              |                          |    |    |
|         | ft       | ft     | ft      |      |                          |    |              |                          |    |    |
| Perf #1 | 6395.53  | 6482.3 | 86.7724 | 0    | <input type="checkbox"/> | -- | --           | <input type="checkbox"/> | -- | -- |

WI3:

| Perf    | Geometry |         |         | Skin | Opening time             |    | Closing time |                          |    |    |
|---------|----------|---------|---------|------|--------------------------|----|--------------|--------------------------|----|----|
|         | MD start | MD end  | h       |      |                          |    |              |                          |    |    |
|         | ft       | ft      | ft      |      |                          |    |              |                          |    |    |
| Perf #1 | 6236.87  | 6374.22 | 137.353 | 0    | <input type="checkbox"/> | -- | --           | <input type="checkbox"/> | -- | -- |

The schedule is such: we have, compared to option 2, an extra step of shut in for W2 and E2, and a rate reduction for C2 at late time.

| run WSO  | t@start    |         | hr       | Mode     | Target Type  | Value Unit   |      | Constraint   |            |
|----------|------------|---------|----------|----------|--------------|--------------|------|--------------|------------|
|          | Date       | Time    |          |          |              | Value        | Unit | Type         | Value Unit |
| 1 - W1   | 01/01/2008 | 0:00:00 | 0        | Producer | Q Oil (Surf) | W1 PROD      |      | P Min (BH)   | 2000 psia  |
| 2 - W1   | 01/01/2012 | 0:00:00 | 35064    | Injector | Q Wat (Surf) | -15000 STB/D |      | P Max (BH)   | 4200 psia  |
| 3 - C1   | 01/01/2008 | 0:00:00 | 0        | Producer | Q Oil (Surf) | C1 PROD      |      | P Min (BH)   | 2000 psia  |
| 4 - C1   | 01/01/2012 | 0:00:00 | 35064    | Producer | Q Oil (Surf) | 4500 STB/D   |      | P Min (BH)   | 2000 psia  |
| 5 - E1   | 01/01/2008 | 0:00:00 | 0        | Producer | Q Oil (Surf) | E1 PROD      |      | P Min (BH)   | 2000 psia  |
| 6 - E1   | 01/01/2012 | 0:00:00 | 35064    | Producer | Q Oil (Surf) | 5000 STB/D   |      | P Min (BH)   | 2000 psia  |
| 7 - W2   | 01/01/2008 | 0:00:00 | 0        | Producer | Q Oil (Surf) | W2 PROD      |      | P Min (BH)   | 2000 psia  |
| 8 - W2   | 01/01/2012 | 0:00:00 | 35064    | Producer | Q Oil (Surf) | 1000 STB/D   |      | P Min (BH)   | 2000 psia  |
| 9 - W2   | 01/01/2018 | 0:00:00 | 87672    | Producer | Q Oil (Surf) | 0 STB/D      |      | P Min (Surf) | 72.5 psia  |
| 10 - WI2 | 01/07/2013 | 0:00:00 | 48192    | Injector | Q Wat (Surf) | -15000 STB/D |      | P Max (BH)   | 4200 psia  |
| 11 - WI1 | 01/01/2012 | 0:00:00 | 35064    | Injector | Q Wat (Surf) | -15000 STB/D |      | P Max (BH)   | 4200 psia  |
| 12 - WI3 | 01/05/2014 | 0:00:00 | 55488    | Injector | Q Wat (Surf) | -15000 STB/D |      | P Max (BH)   | 4200 psia  |
| 13 - W3  | 01/01/2012 | 0:00:00 | 35064    | Producer | Q Oil (Surf) | 4500 STB/D   |      | P Min (BH)   | 2000 psia  |
| 14 - C2  | 01/08/2014 | 0:00:00 | 5.77E+04 | Producer | Q Oil (Surf) | 2000 STB/D   |      | P Min (BH)   | 2000 psia  |
| 15 - C2  | 01/01/2020 | 0:00:00 | 105192   | Producer | Q Oil (Surf) | 500 STB/D    |      | P Min (Surf) | 72.5 psia  |
| 16 - E2  | 01/07/2013 | 0:00:00 | 48192    | Producer | Q Oil (Surf) | 1500 STB/D   |      | P Min (Surf) | 72.5 psia  |
| 17 - E2  | 01/08/2015 | 0:00:00 | 6.65E+04 | Producer | Q Oil (Surf) | 5500 STB/D   |      | P Min (Surf) | 72.5 psia  |
| 18 - E2  | 01/01/2020 | 0:00:00 | 105192   | Producer | Q Oil (Surf) | 0 STB/D      |      | P Min (Surf) | 72.5 psia  |

*Perform run for both option 2 and 3. Compare different cumulative productions, and observe when option's recovery is significantly better than the other. You can use the browser function to import plots, and then compare them on the same screen. Observe the water front displacement for each layer.*

The file after run is "13 Forecast\_opt3\_EOR.krp" for option 3.