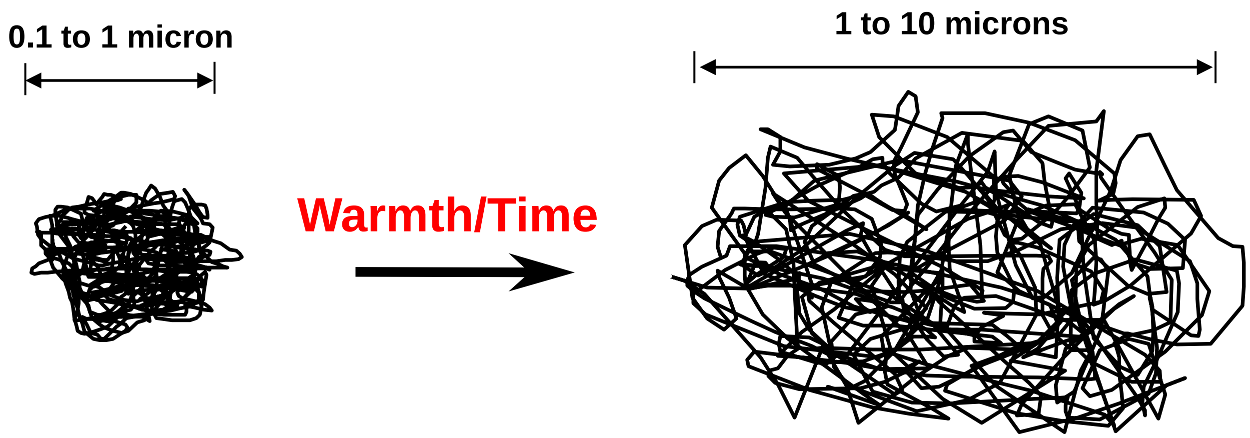
Modelling the field potential of in-depth waterflood diversion with Brightwater

- Mechanism of Brightwater activation and diversion
- Preferred modelling features
- REVEAL/ECLIPSE options

Bright Water Mechanism – pore scale



As manufactured, the Brightwater particles are inert and can move through rock pores with the water flood

Under the influence of heat the polymer particles expand and can interact with the rock and with each other

Popping time at a given temperature is controlled by the number of reversible cross links between the polymers. There are 5 grades with different activation rates. Low levels of permanent cross links prevent the polymer from completely unravelling.

Mixing and Pumping

Bright Water

Surfactant

Pumps located located in an oil resistant bund

Reindeer were curious at first then got bored

Appearance during activation

BrightWater diversion mechanisms

- Treatment needs to have low viscosity during injection so it mostly enters the high perm thief layer or channel

Then:

Diversion mechanism 1

- With time or increased temperature BrightWater gives higher viscosity (highest viscosity in fresh water)
- The viscous polymer diverts the waterflood to other areas

- The viscosity is decreased by dispersion
- If there is a thin thief layer or narrow channel, dispersion is less severe
- But if well-well transit time is long, keeping the high viscosity for deep diversion may require a large treatment tonnage

Diversion mechanism 2

- Swollen BrightWater can adsorb and reduce water flow:
- This can be more effective than viscosity as the effect is longer-lasting
- It is similar to the Residual Resistance Factor observed with polymer floods using hydrolysed polyacrylamide
- With HPAM, value of RRF is usually 2-4
- With the swollen BrightWater particles larger RRF values might be expected
- Less polymer is used in BrightWater ,and the adsorption level can be higher, so the area affected will be more limited
- With BW, the thief layer/channel is not affected near the injector, so injectivity reduction is small and diversion is high

- Adsorption/RRF usually needs to be deep in the reservoir for most effective oil recovery
- Irreversible adsorption will give a longer lasting diversion and will ensure Brightwater does not reach the producers

Adsorption mechanism

- **Monolayer or multilayer of swollen particles**
  - Could give a larger block factor in low perm layers than in high perm
  - However, extent of block would be much greater in high perm as this receives more material and adsorption per cu metre of reservoir is lower
- **Aggregation and retention of swollen particles**
  - Can give a larger block factor
  - Yield point may be expected
  - Reliable measurement in the lab is complicated, prediction for the field is still under investigation

Modelling with ECLIPSE

- Polymer option will allow viscosity to be modelled and also adsorption and RRF
- Thermal option will handle cold water injection in a hot reservoir, but it is not easy to use that to activate Brightwater
- Limitation is that full viscosity and RRF will be present near well during injection so the injection profile will be pessimistic

Tracer option with ECLIPSE

- First model the temperature profile, and use tracer to determine the temperature encountered by the inert Brightwater versus time
- Decide on the likely best distance (time) from the injector for a diverting block
- Select the BrightWater grade that will give this and check adsorption and RRF versus concentration
- Using a restart file, apply a permeability reduction proportional to tracer concentration in all grid blocks containing tracer
- Run sensitivities to activation time, treatment size

ECLIPSE Tracer Limitations:

- BrightWater will not have the same temperature vs time history in all directions or in all layers so it will not all set at the same time
- The BrightWater treatment is moving as it activates: the adsorption level in a grid-block can continue to increase as activating BrightWater continues to enter it
- Adsorbed BrightWater with a significant RRF will divert the following Brightwater

Modelling BrightWater with REVEAL

- Allows dynamic formation of activated BrightWater
- “Gel” is formed from injected inert polymer.
- Reaction can be isothermal or temperature triggered.
- Can specify that no reaction is allowed below a selected temperature or selected concentration
- “Gel” is allowed to adsorb and give a permeability reduction (RRF) which can be permanent or reversible

•Polymer reacts to become BrightWater (gel) at a rate depending on the temperature, concentration of polymer, and a rate constant (Rk).

•A higher value for Rk would be equivalent to the use of a quicker-activating grade of BrightWater

•The activated BW (gel) has a higher viscosity and can adsorb

• Adsorption increases with gel concentration up to a fixed limit

•Permeability reduction is proportional to adsorbed gel level

•A maximum permeability reduction is specified at maximum adsorption

Brightwater adsorption level and block factor

- **Aggregation and retention of swollen particles**
- The adsorption level expected to become high
- In seawater-type salinity the swell factor is around 80
- Pore vol of reservoir is about 250litres/m3.
- Adsorption of 0.4Kg/m3 of reservoir of gel would give about 30 litres of swollen gel per m3 of reservoir (12% of pore volume filled).
- Block factor could be up to 150.
- **"Monolayer" adsorption**
- Lower adsorption and lower potential for blocking than above but still more than standard polyacrylamide
- Maximum block factor (RRF) between 5 and 30

REVEAL Mechanism Limitation

- **In the model** the reaction rate is proportional to the concentration of the (inactive) injected "polymer"
- So when the polymer concentration falls, the reaction rate falls and some polymer remains inactive for a long time and can reach a producer

- **In reality** every injected particle starts to swell at a rate which depends only on the grade selected and on the temperature
- So all the polymer particles in a given area convert to activated "gel" at about the same rate/time
- There will be NO injected material remaining even if it activates at a significant distance from the injector
- No injected material will reach the producer, though activated "gel" may reach the producer if the adsorption level and viscosity are low

Other REVEAL Limitation

- REVEAL has all the features needed for a full-field simulation, but if an ECLIPSE model already exists then starting a new model means a lot of work

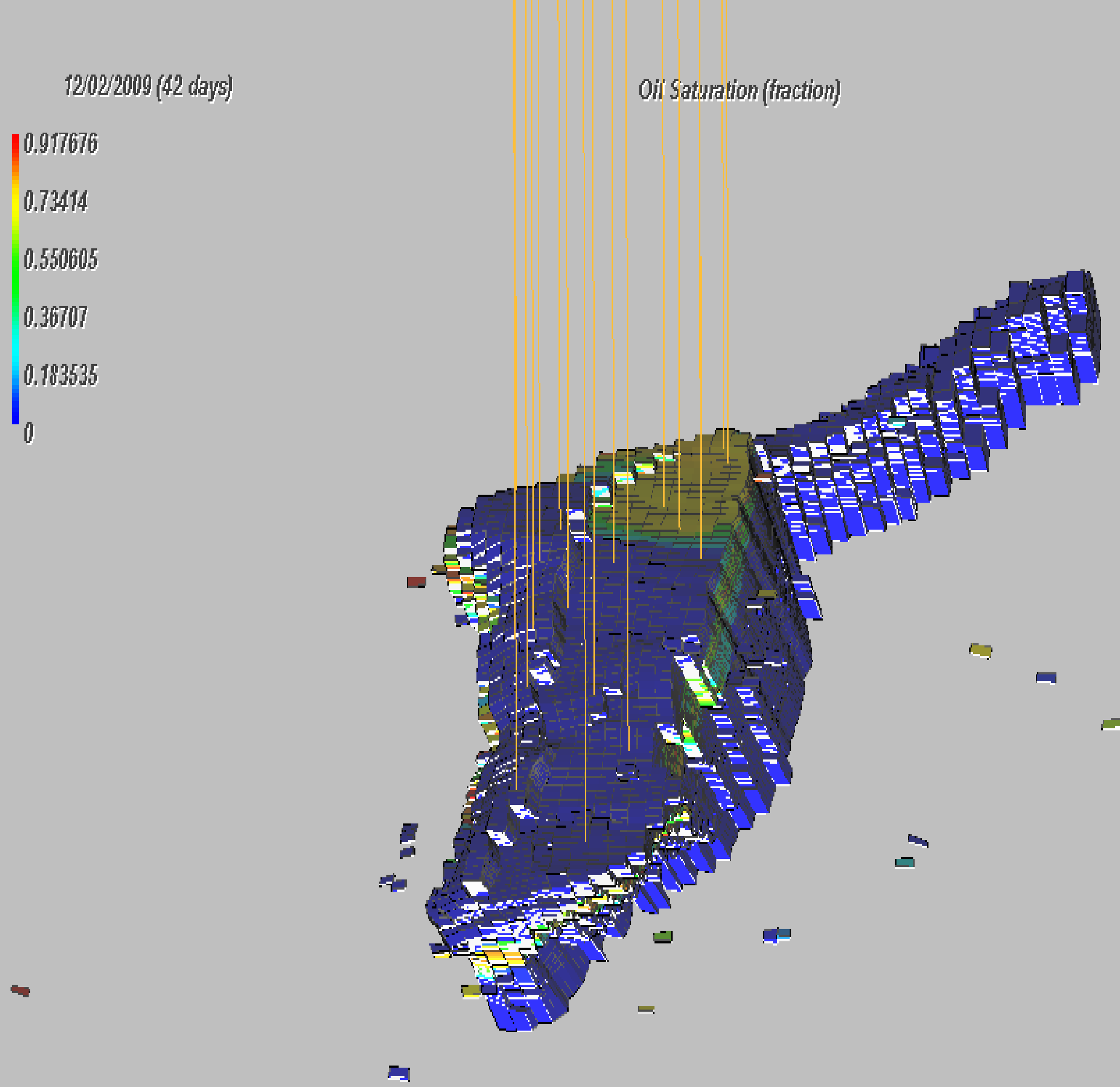
Importing an ECLIPSE model into REVEAL

- The main features can be imported fairly readily (grid permeabilities, porosities etc)
- The wells’ operating schedule cannot be imported.
- Ideally an ECLIPSE Restart file is imported which gives the well locations, completions, saturations and pressures at the Restart time

- If cold water has been injected into the target injector, it will be cooled for a certain distance which must be represented properly in REVEAL
- Only the Thermal Eclipse option will deal with this
- But it is not possible to import a Local Grid Refinement directly from ECLIPSE into REVEAL
- So the Restart file should be at the time cold water starts to be injected into the target injector
- After that the operating schedule will have to be written into REVEAL step by step for all new wells, completion changes, and rate changes

Field Model results

Positive indicators



So: is it a good target or will it eat your lunch?

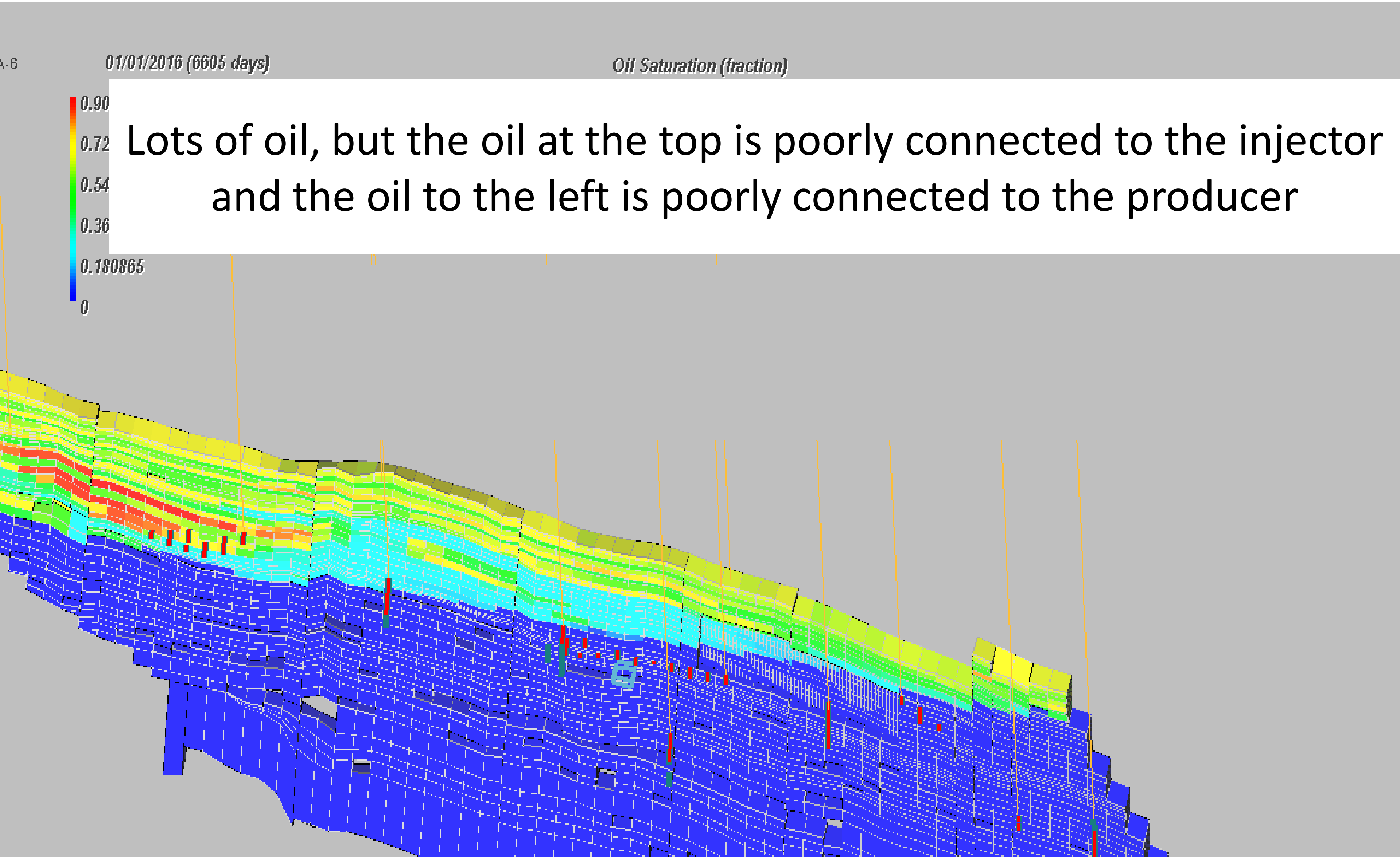
- The first, obvious requirement is significant remaining oil connected to the producer

- But in addition this oil MUST be in pressure communication with the swept zone somewhere near the injector

- So there must be no continuous barriers between the swept “thief” and the unswept oil

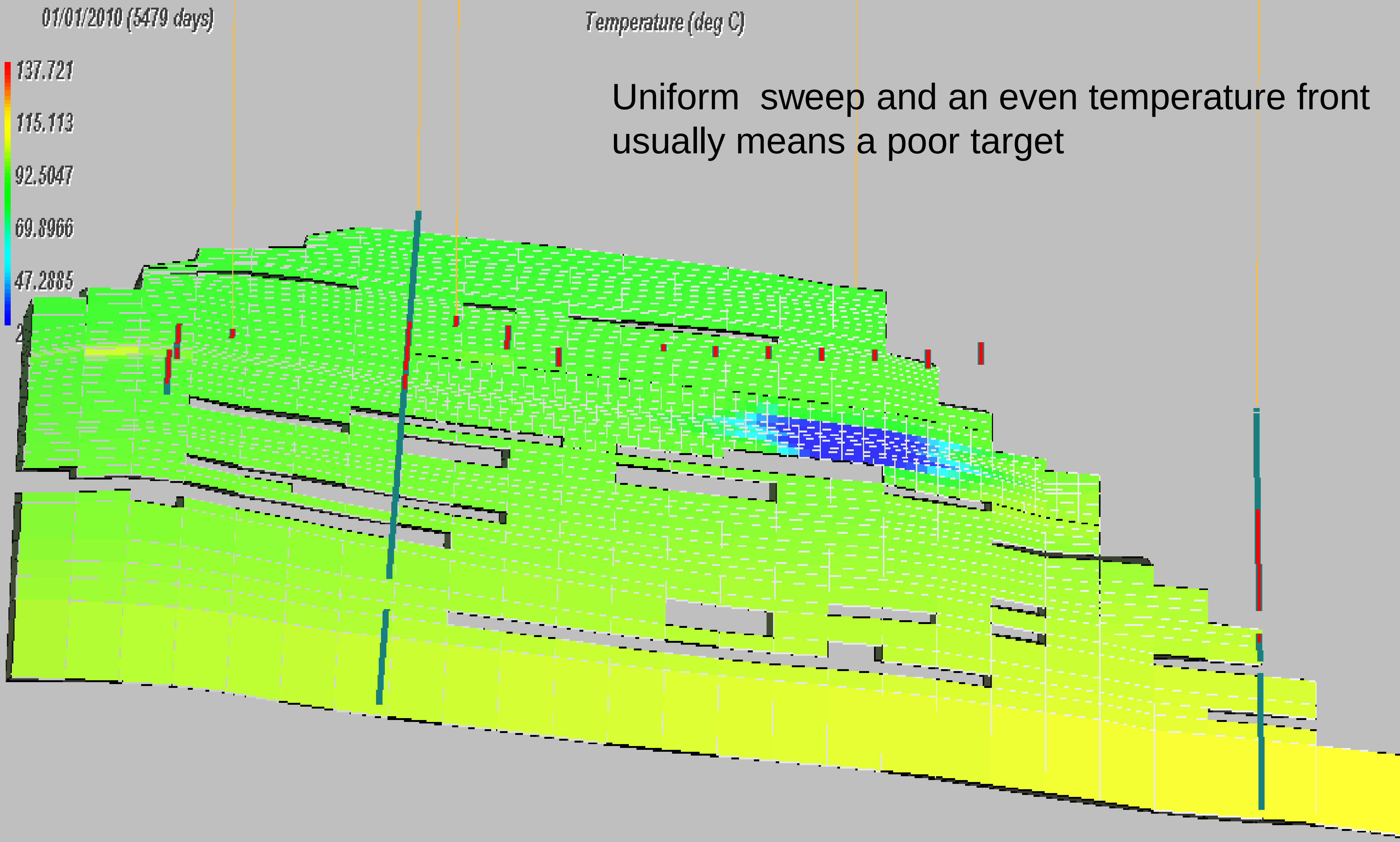
- No large vertical pressure differences seen in the waterflood between swept/unswept areas

Oil saturation at 1/1/2016 in slice X=52 (main grid) and X=28 (LGR)

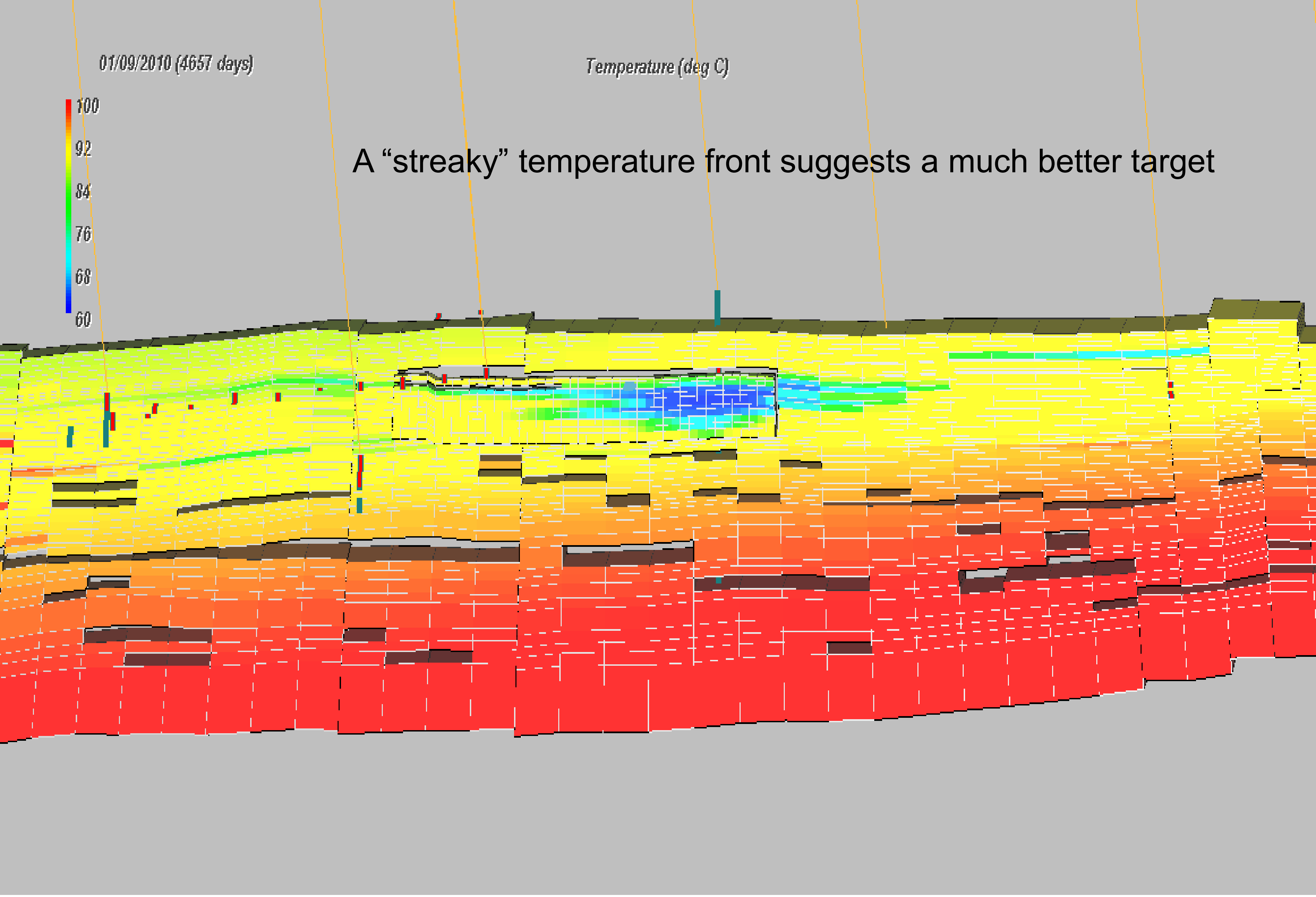


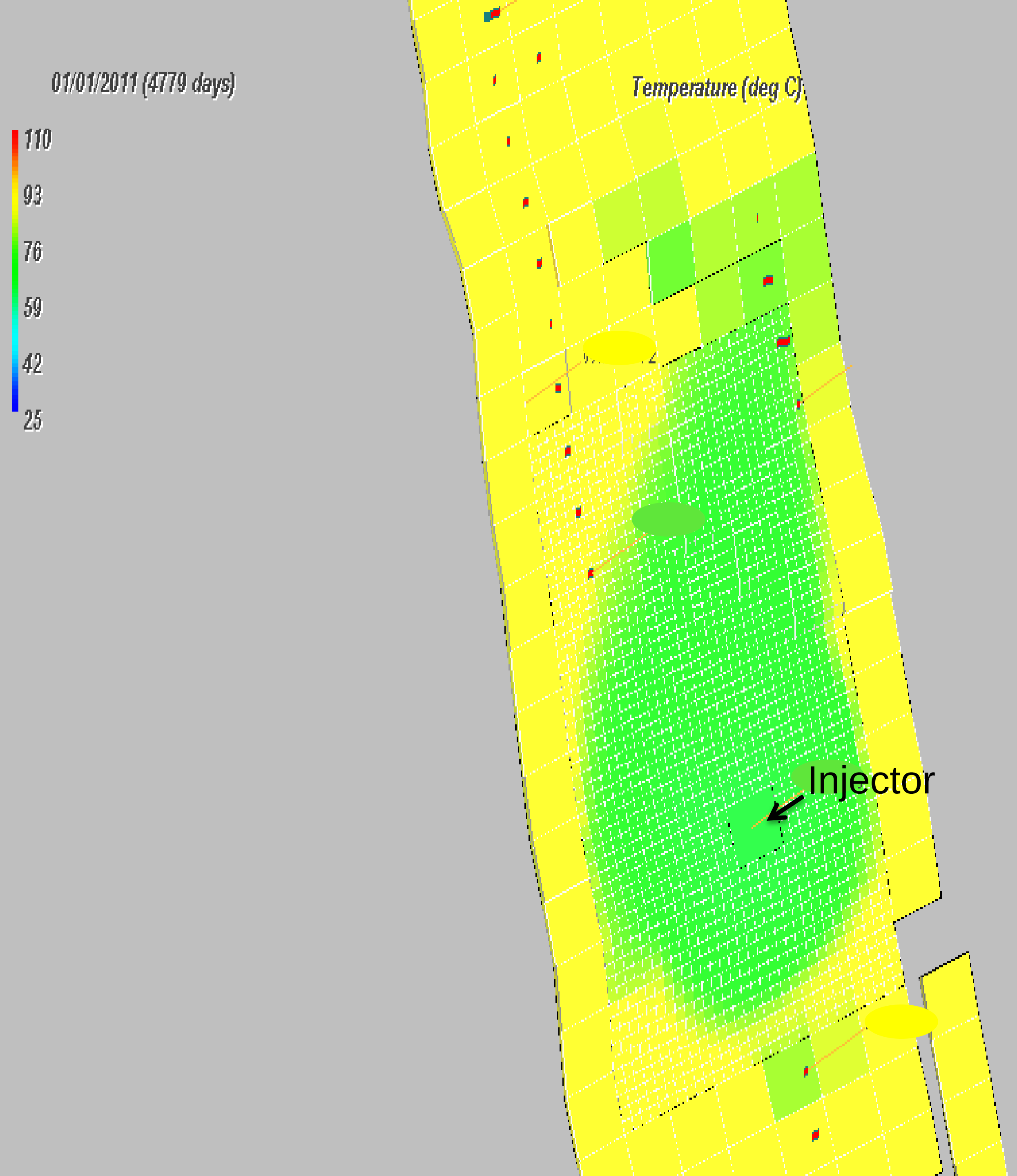
Lots of oil, but the oil at the top is poorly connected to the injector and the oil to the left is poorly connected to the producer

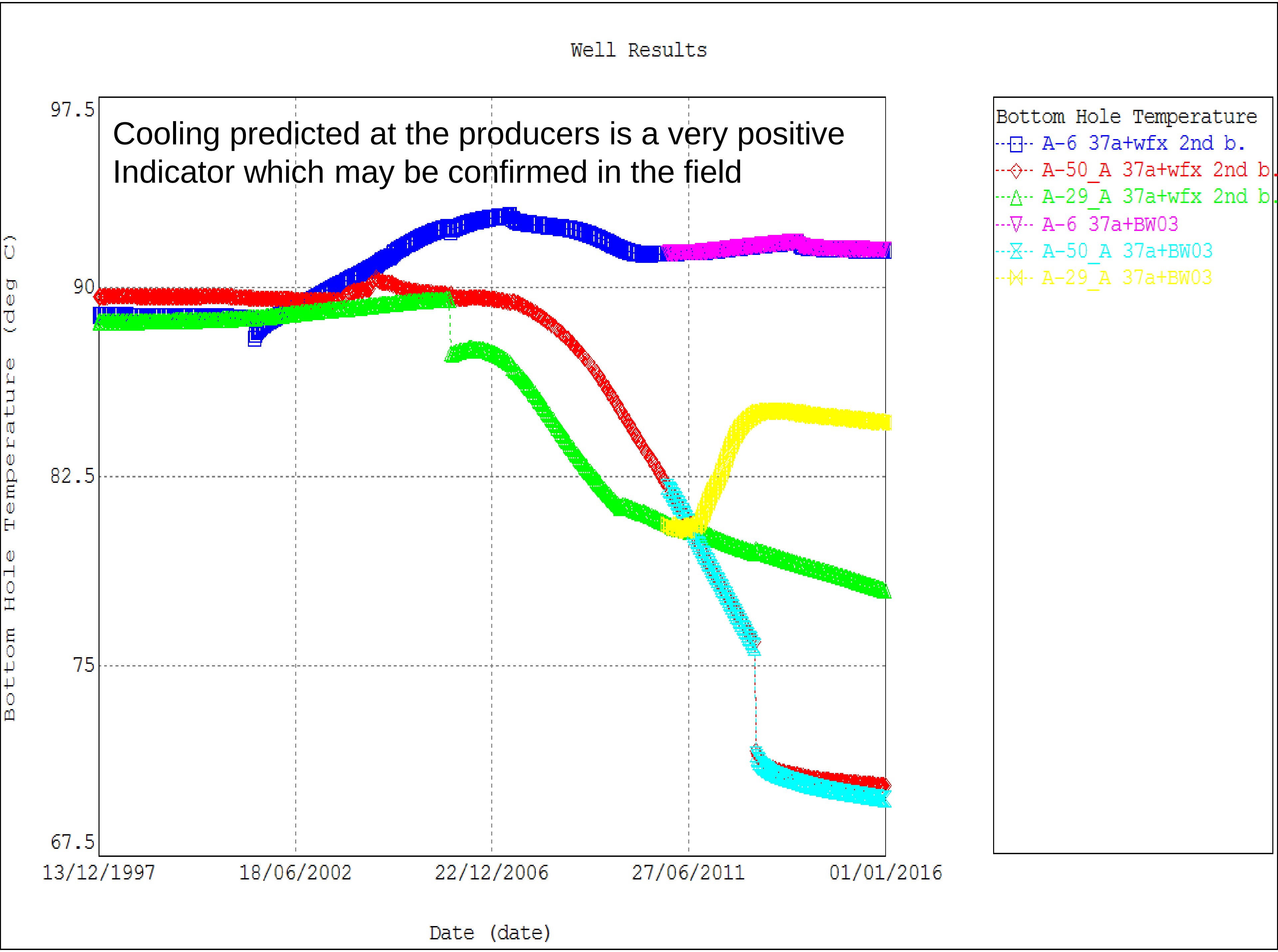
Uniform sweep and an even temperature front usually means a poor target



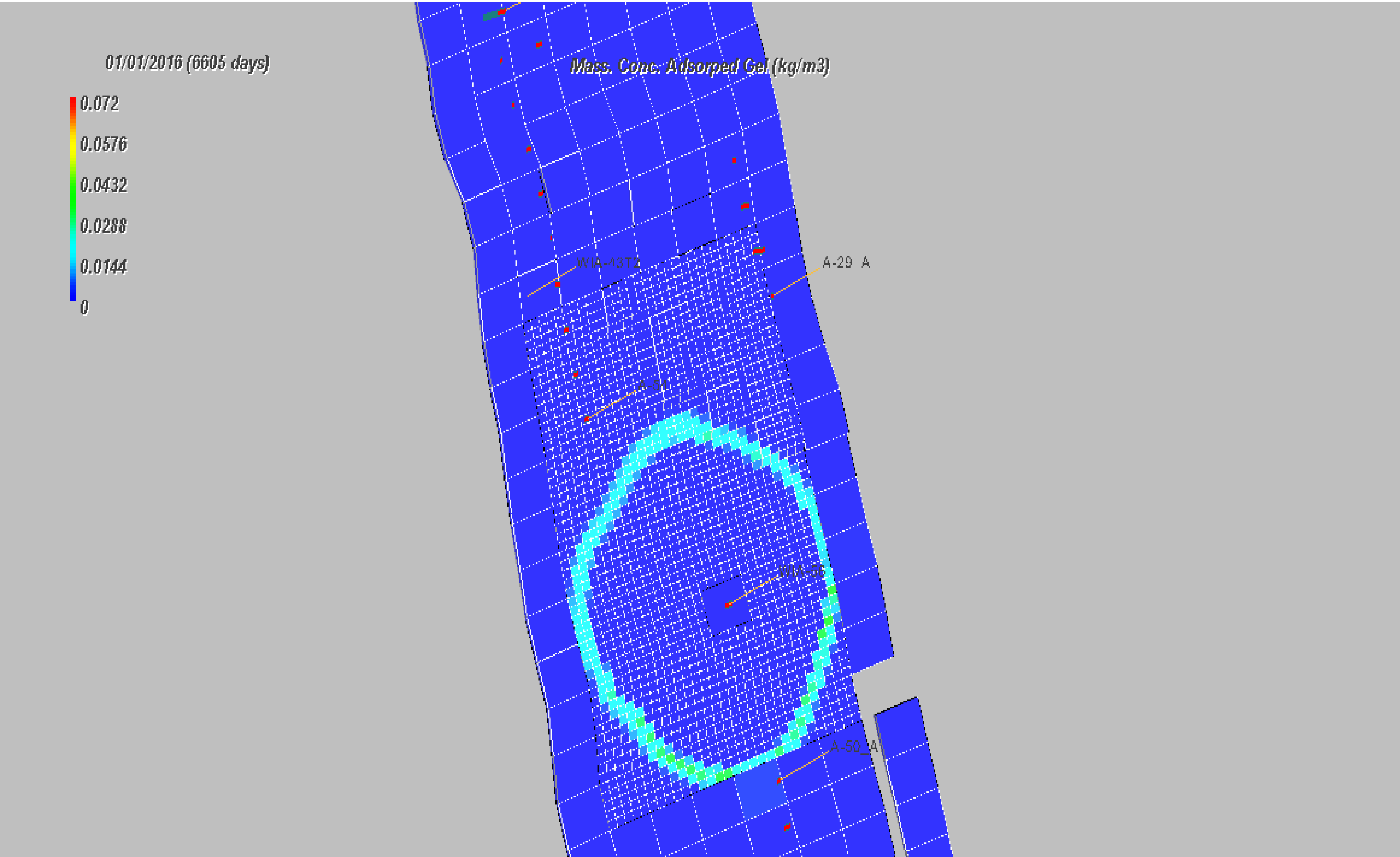
A “streaky” temperature front suggests a much better target



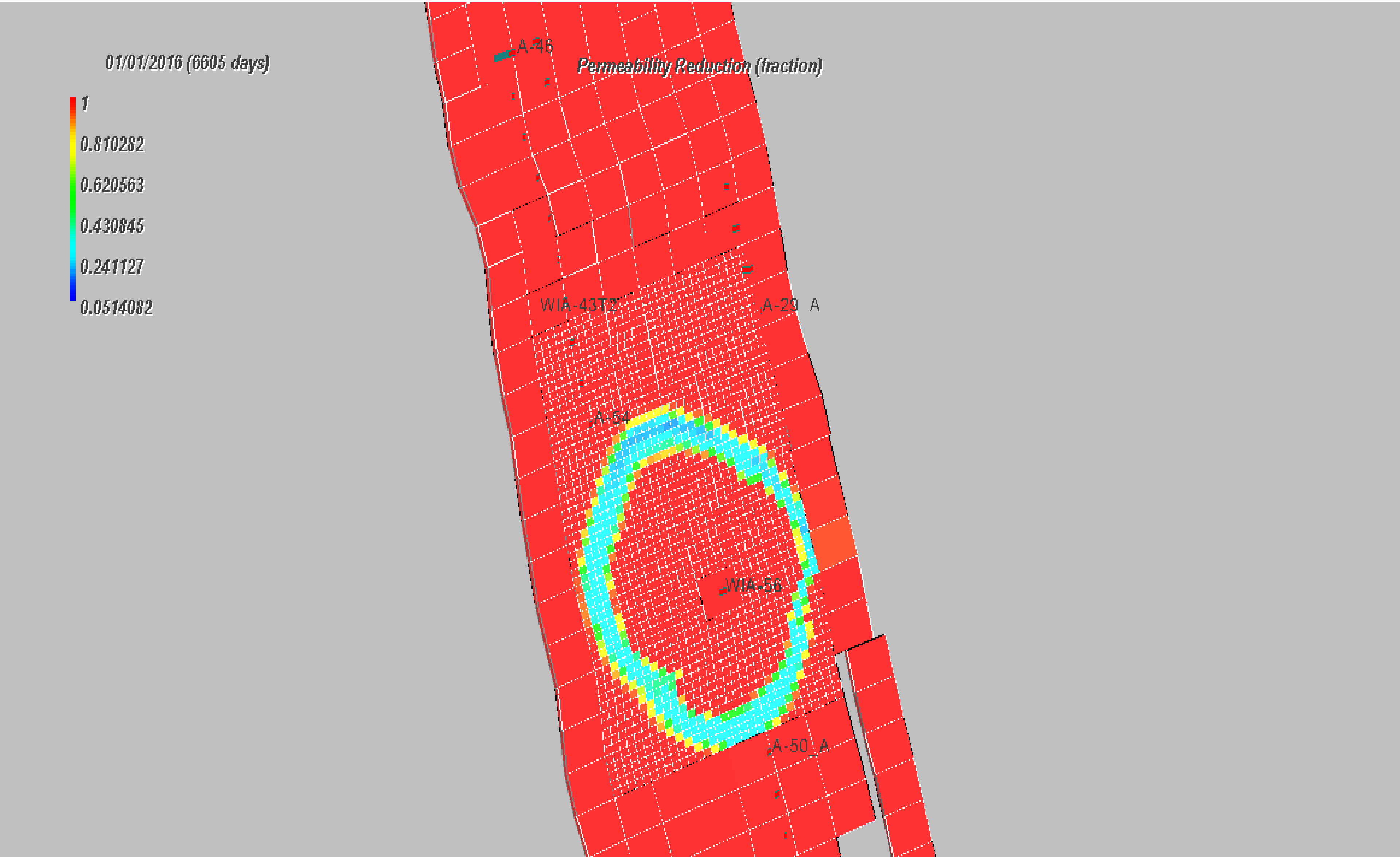

01/01/2011 (4779 days)
Temperature (deg C)
110
93
76
59
42
25
Injector


Well Results
Cooling predicted at the producers is a very positive Indicator which may be confirmed in the field
97.5
90
82.5
75
67.5
Bottom Hole Temperature (deg C)
13/12/1997
18/06/2002
22/12/2006
27/06/2011
01/01/2016
Date (date)
Bottom Hole Temperature
A-6 37a+wfx 2nd b.
A-50_A 37a+wfx 2nd b.
A-29_A 37a+wfx 2nd b.
A-6 37a+BW03
A-50_A 37a+BW03
A-29_A 37a+BW03

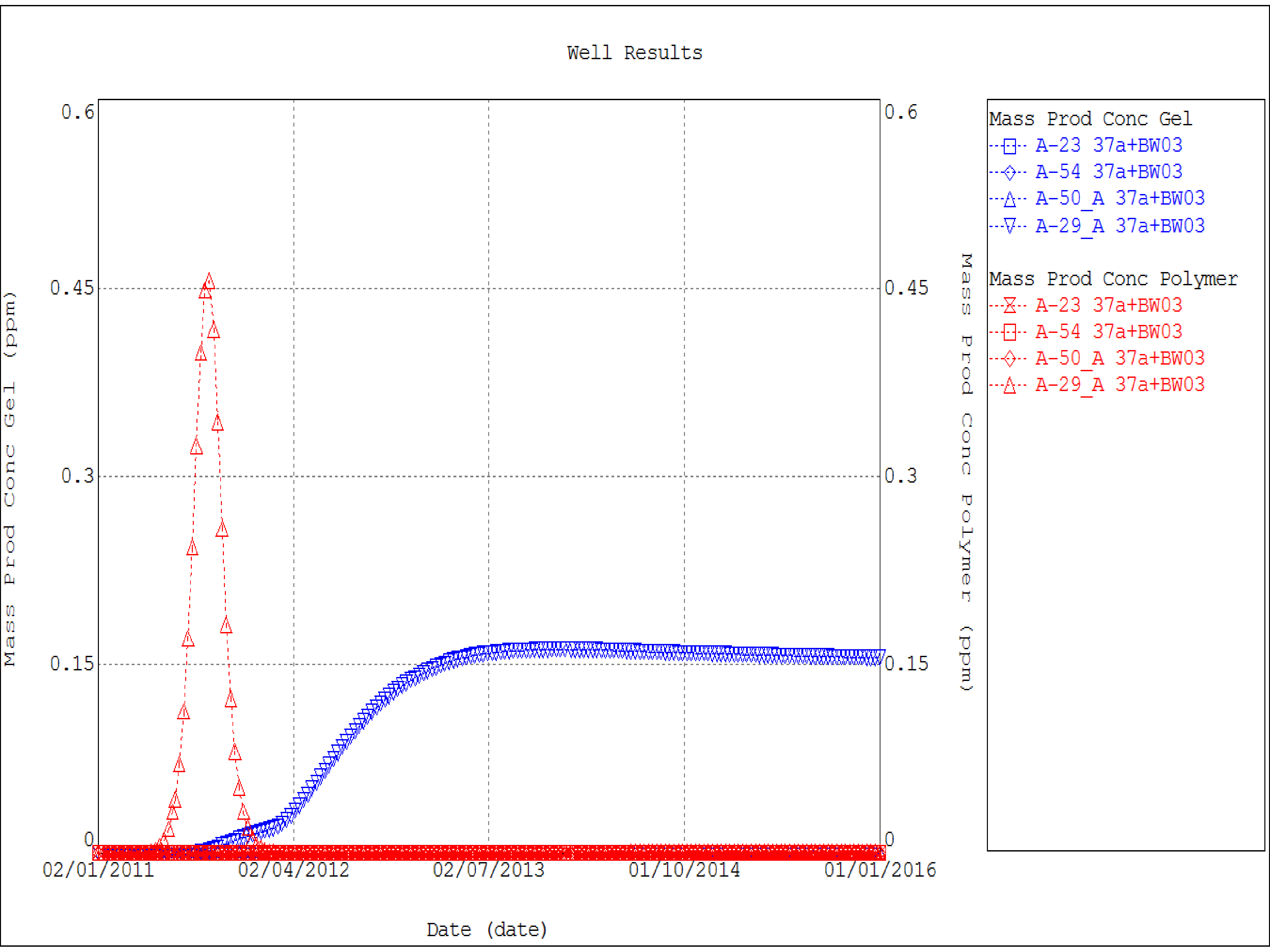
Wf37 BW03 (9 days at 4000ppm active BW = 133.2 tonnes active = 444tonnes as supplied)
Layer 7 (refined grid) and layer 37 (main grid)



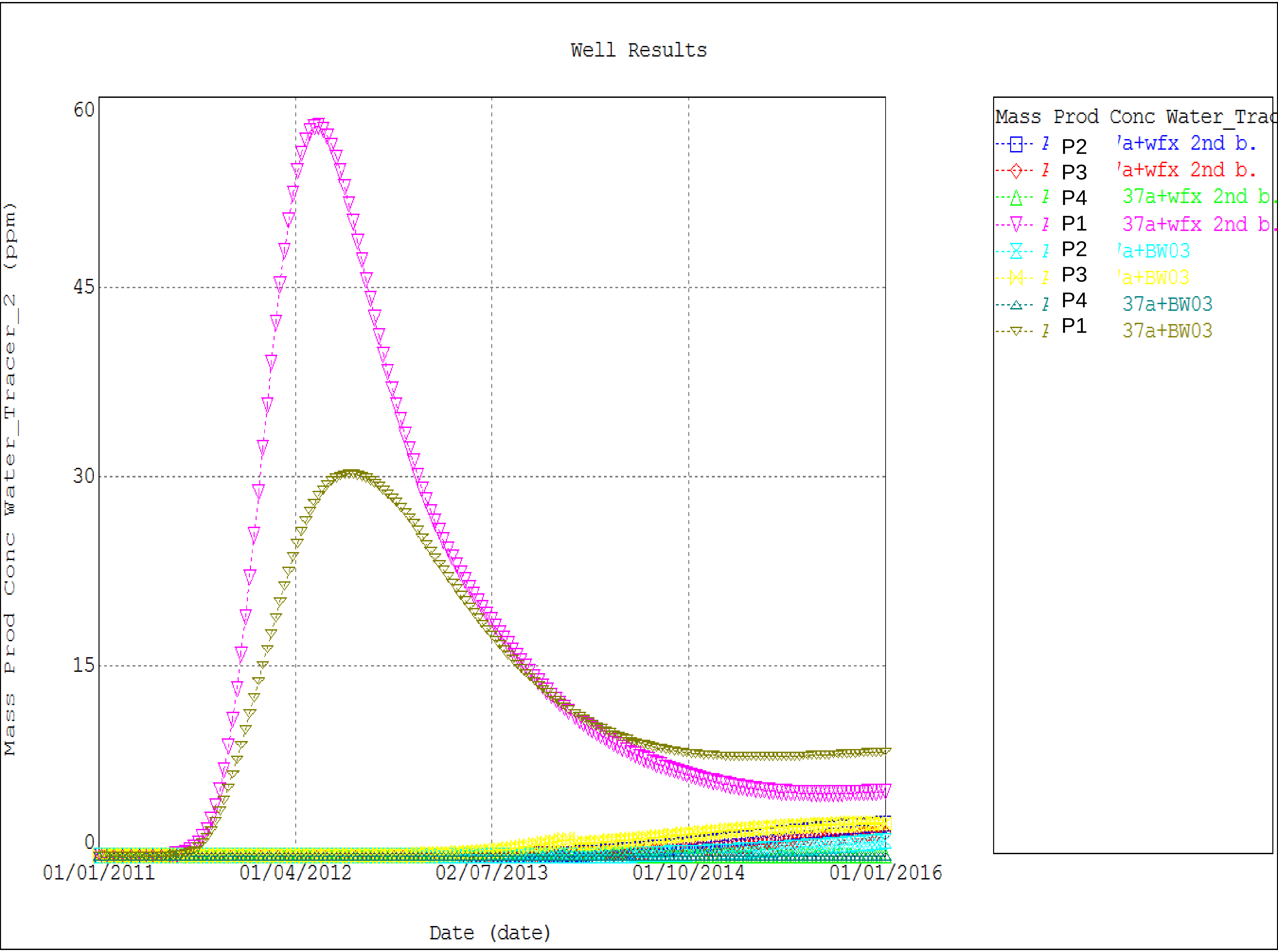
Wf37 BW03: Layer 8 (refined grid) and layer 38 (main grid)

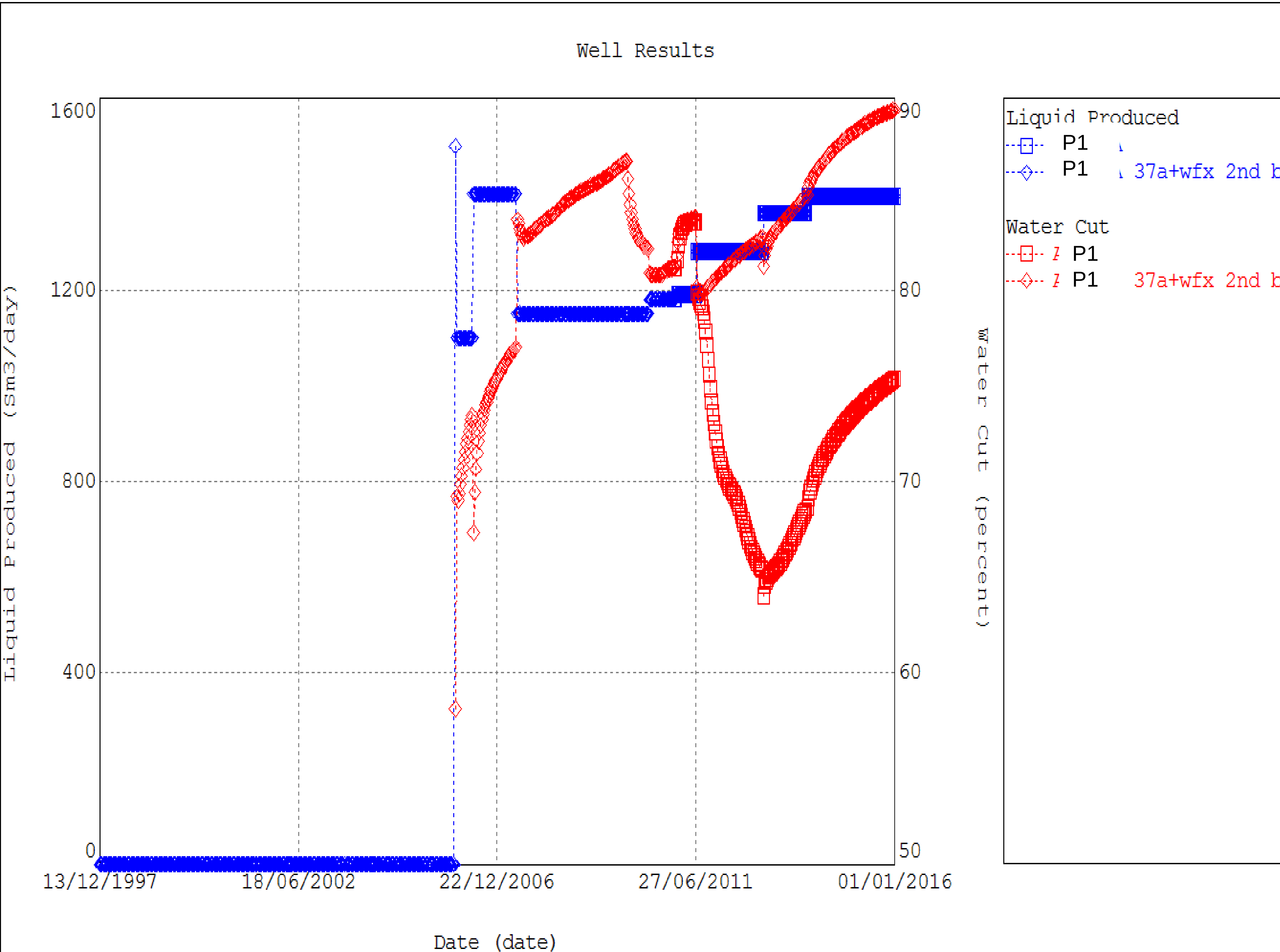


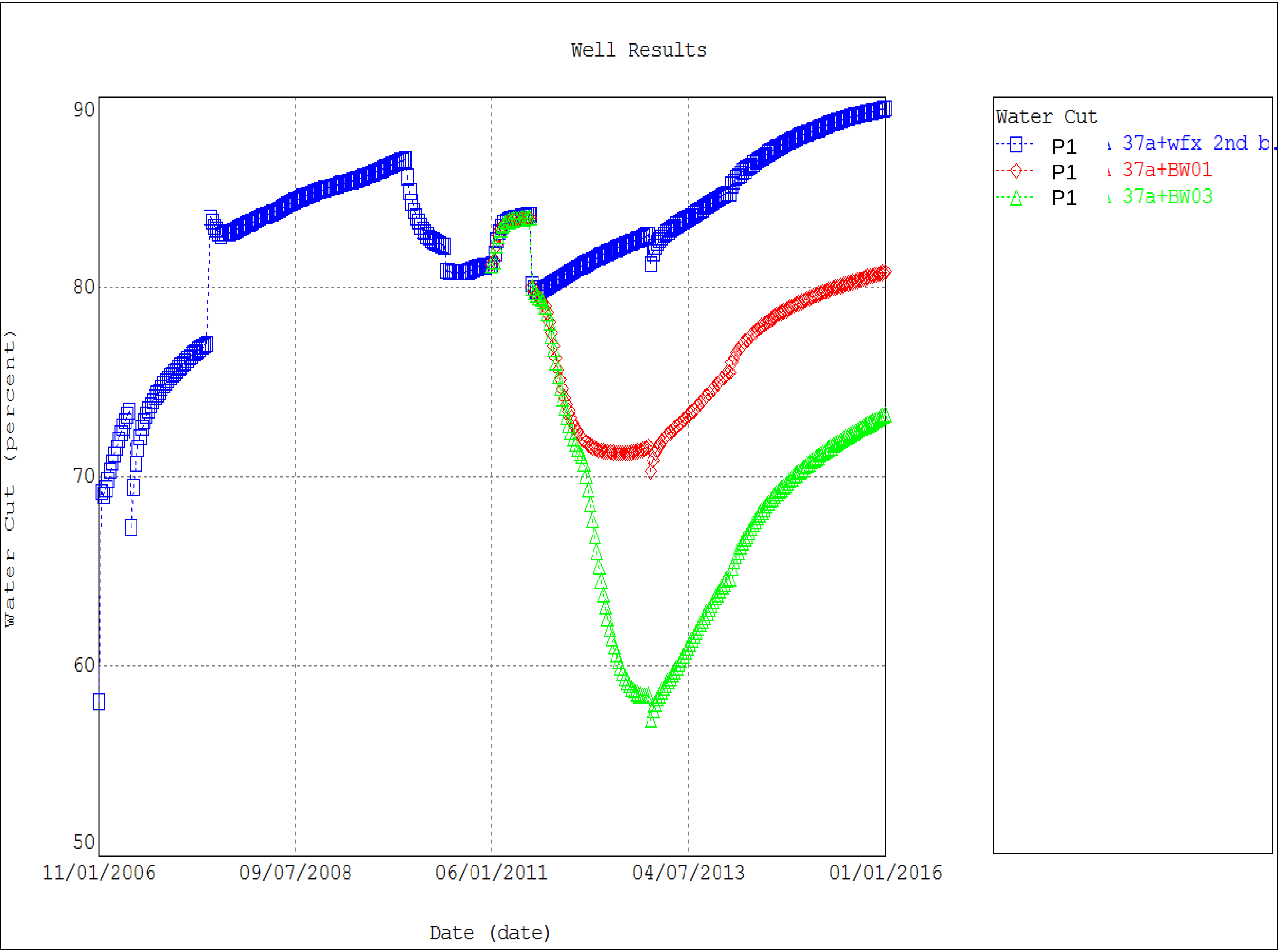
Layer 34 (main) and 10 (LGR)



Well Results
0.6
0.45
0.3
0.15
0
Mass Prod Conc Gel (ppm)
Mass Prod Conc Polymer (ppm)
02/01/2011
02/04/2012
02/07/2013
01/10/2014
01/01/2016
Date (date)
Mass Prod Conc Gel
A-23 37a+BW03
A-54 37a+BW03
A-50_A 37a+BW03
A-29_A 37a+BW03
Mass Prod Conc Polymer
A-23 37a+BW03
A-54 37a+BW03
A-50_A 37a+BW03
A-29_A 37a+BW03


Well Results
Mass Prod Conc Water_Tracer_2 (ppm)
60
45
30
15
0
01/01/2011
01/04/2012
02/07/2013
01/10/2014
01/01/2016
Date (date)
Mass Prod Conc Water_Trac
P2 'a+wfx 2nd b.
P3 'a+wfx 2nd b.
P4 37a+wfx 2nd b.
P1 37a+wfx 2nd b.
P2 'a+BW03
P3 'a+BW03
P4 37a+BW03
P1 37a+BW03

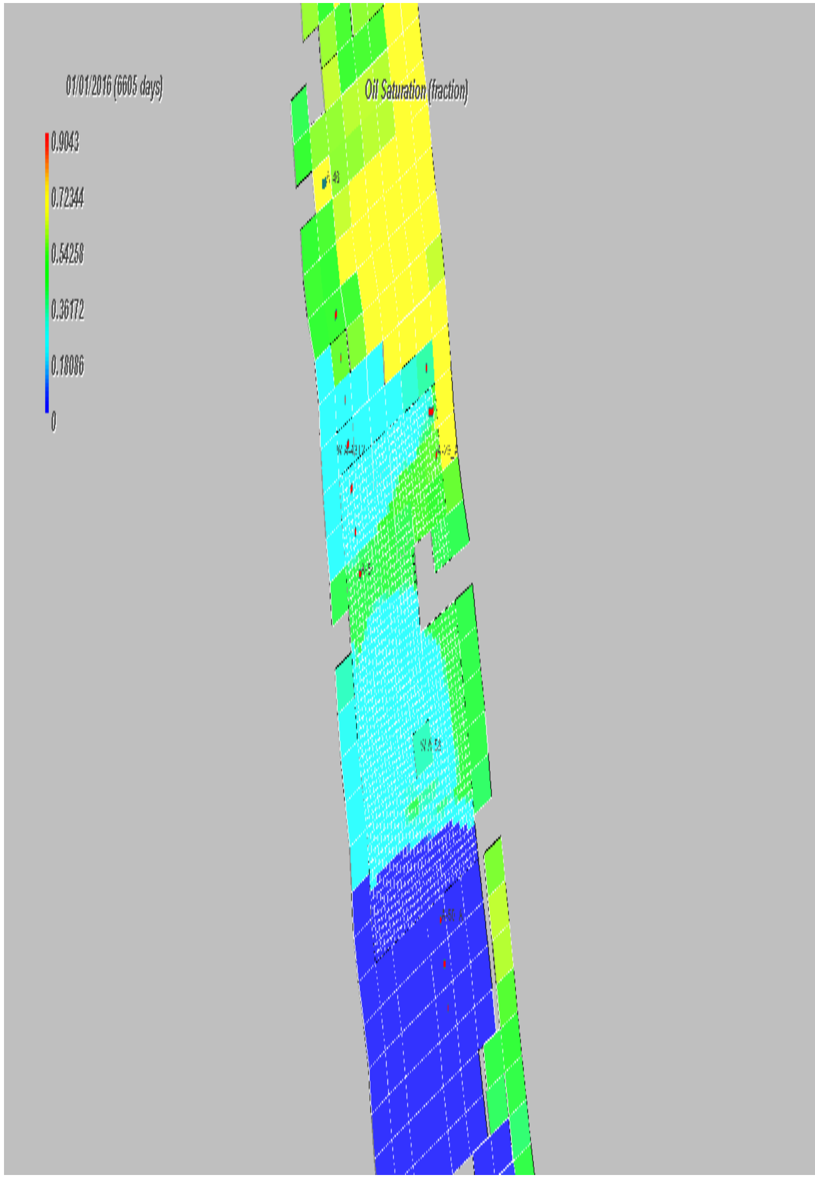

Well Results
Liquid Produced (Sm3/day)
Water Cut (percent)
Date (date)
1600
1200
800
400
0
90
80
70
60
50
13/12/1997
18/06/2002
22/12/2006
27/06/2011
01/01/2016
Liquid Produced
P1
P1 37a+wfx 2nd b
Water Cut
P1
P1 37a+wfx 2nd b


Well Results
90
80
70
60
50
Water Cut (percent)
11/01/2006
09/07/2008
06/01/2011
04/07/2013
01/01/2016
Date (date)
Water Cut
P1 37a+wfx 2nd b
P1 37a+BW01
P1 37a+BW03

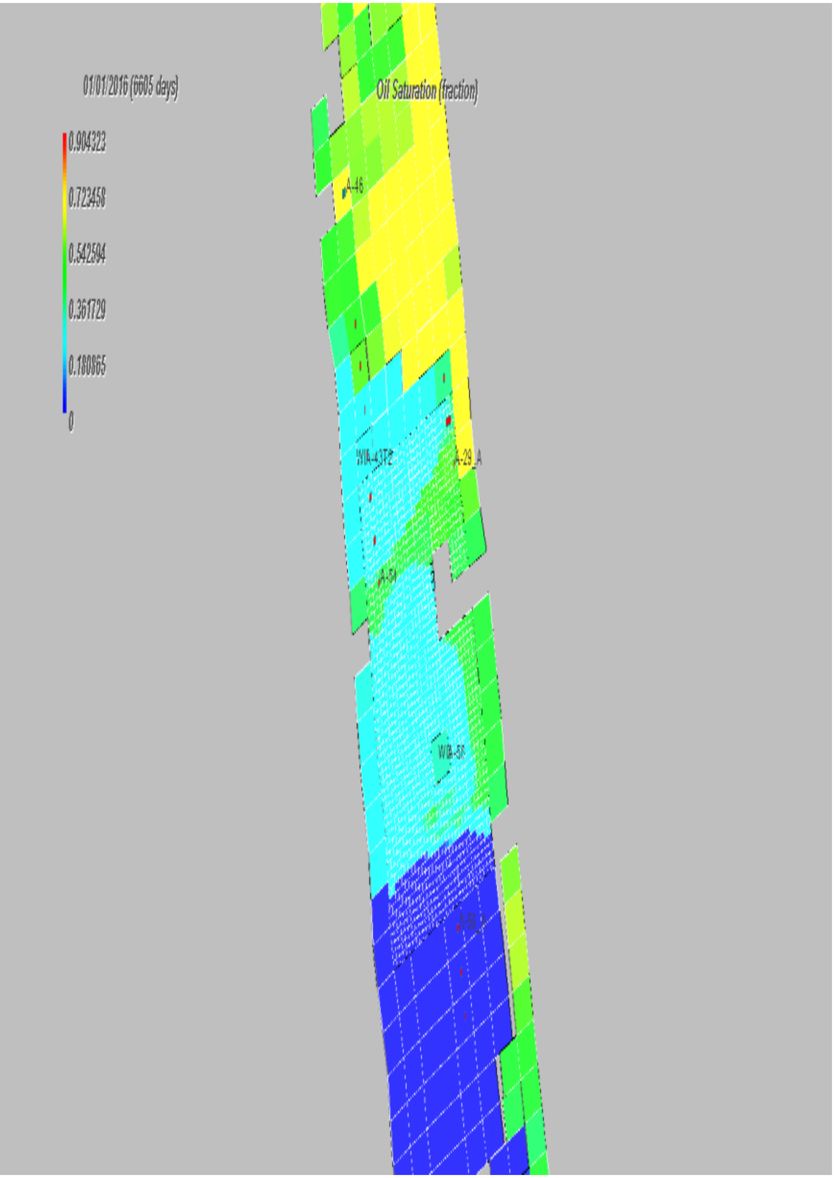
Output from model: summary

- Prediction of cumulative incremental oil and its profile
- Dependence of oil gained on treatment volume
- Effect on injectivity and PI
- Diagnostics expected from activation
- Prediction of chemical reaching producers

Layer1 wfx



Layer 1 BW03



Where is the oil coming from?
Compare saturation slices from waterflood baseline and Brightwater case

```
section mobility

  viscosity model original
  viscosity polymer concentration 275 0 0    !
  polymer salinity off
  viscosity polymer temperature 0    ! deg C

  viscosity gel concentration 15000 0 0 0    ! ppm
  viscosity gel temperature 0    ! deg C

  viscosity shear 100 2    ! 1/sec
  shear_rate_parameter 0.862

  polymer gelation 3_component 5000 -30000 0.05 1e-006 74.5 0 0    ! 1/day deg C
deg C ppm ppm
  polymer gelation below_gelation_threshold off
  degradation polymer
  degradation gel

  ipv polymer 0    ! fraction
  ipv gel 0    ! fraction
```

```
section adsorption

  data for rock_types all
  adsorp ion_exchange off

  adsorp gel isotherm langmuir 900000
  adsorp gel maximum 0.1    ! kg/m3 (polymer content of gel)
  adsorp gel temperature 0 irreversible    ! kg/m3/C
  adsorp gel reversible 0    ! kg/m3
  adsorp gel permeability_reduction 20 all_phase    !
```

```
then
  produce well A-23 rate 1160 gasinj 30     ! Sm3/day 1000Sm3/d
  well A-23 prod_lift_curve file LettAareTab10 type oilgaslift tpd
  produce well A-6 rate 360 gasinj 30     ! Sm3/day 1000Sm3/d
  well A-6 prod_lift_curve file LettAareTab10 type oilgaslift tpd
well A-6 completion range 1 10 skin_factor -3    !
  produce well A-16 rate 490     ! Sm3/day
  produce well A-54 rate 760 gasinj 30     ! Sm3/day 1000Sm3/d
  well A-54 prod_lift_curve file LettAareTab10 type oilgaslift tpd
  inject well WIA-56 type water
  inject well WIA-56 rate 3700 temperature 63     ! Sm3/day deg C
inject well WIA-56 component 8 concentration  5000    ! Ppm water tracer
  inject well WIA-56 component 9 concentration  4000    ! Ppm polymer
  inject well WIA-56 component 10 concentration  10000    ! Ppm crosslinker
inject well WIA-56 rperm standard
  produce well A-50_A rate 1170 gasinj 30     ! Sm3/day 1000Sm3/d
  well A-50_A prod_lift_curve file LettAareTab10 type oilgaslift tpd
  inject well WIA-49 type water
  inject well WIA-49 rate 1350 temperature 25     ! Sm3/day deg C
  inject well WIA-49 component 7 concentration  0    ! ppm
produce well A-29_A rate 1180 gasinj 30     ! Sm3/day 1000Sm3/d
  well A-29_A prod_lift_curve file LettAareTab10 type oilgaslift tpd
  closed well Aquiferinjector    well A-40  well WIA-43T2  closed well A-46
  until time 10/01/2011
```