Exodus Simulation Immiscible Gas Injection Pilot Area

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For Tundra Oil and Gas

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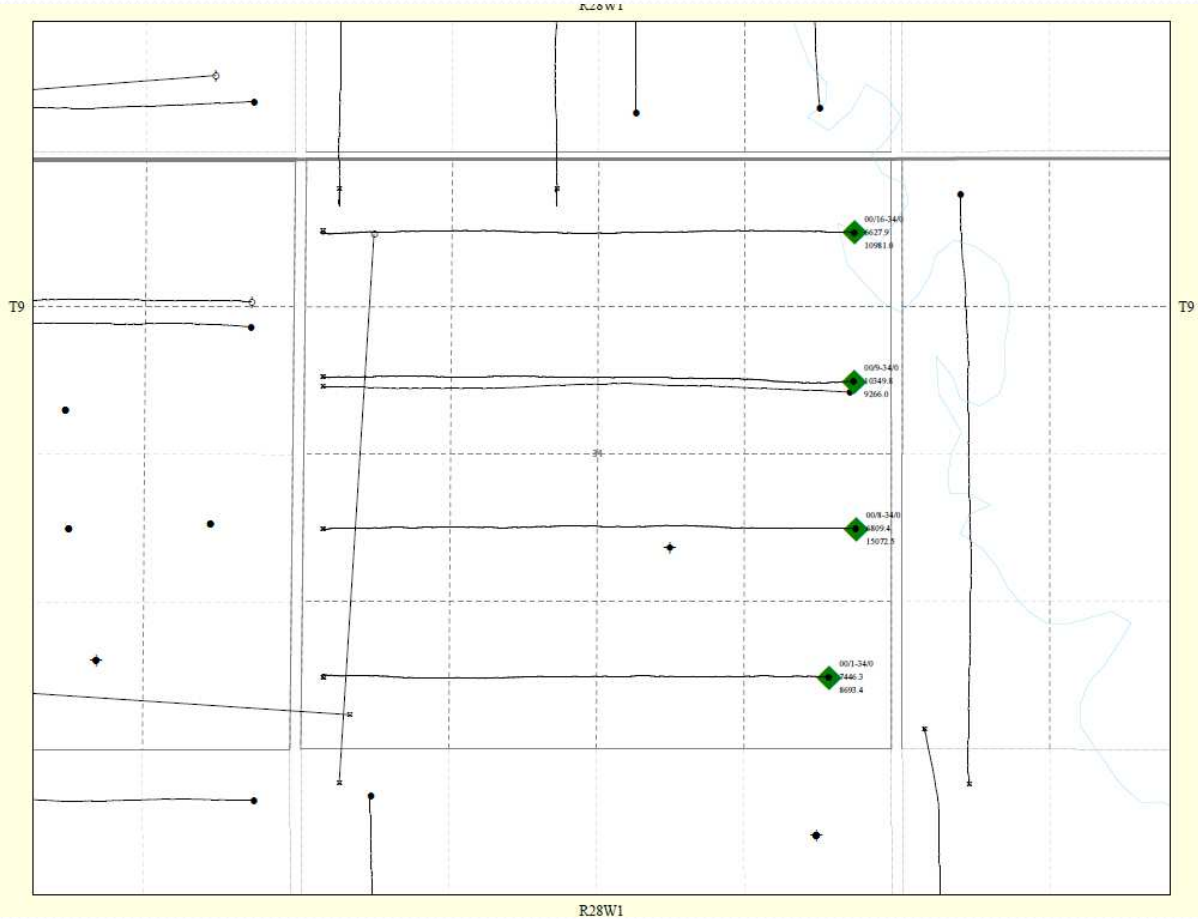
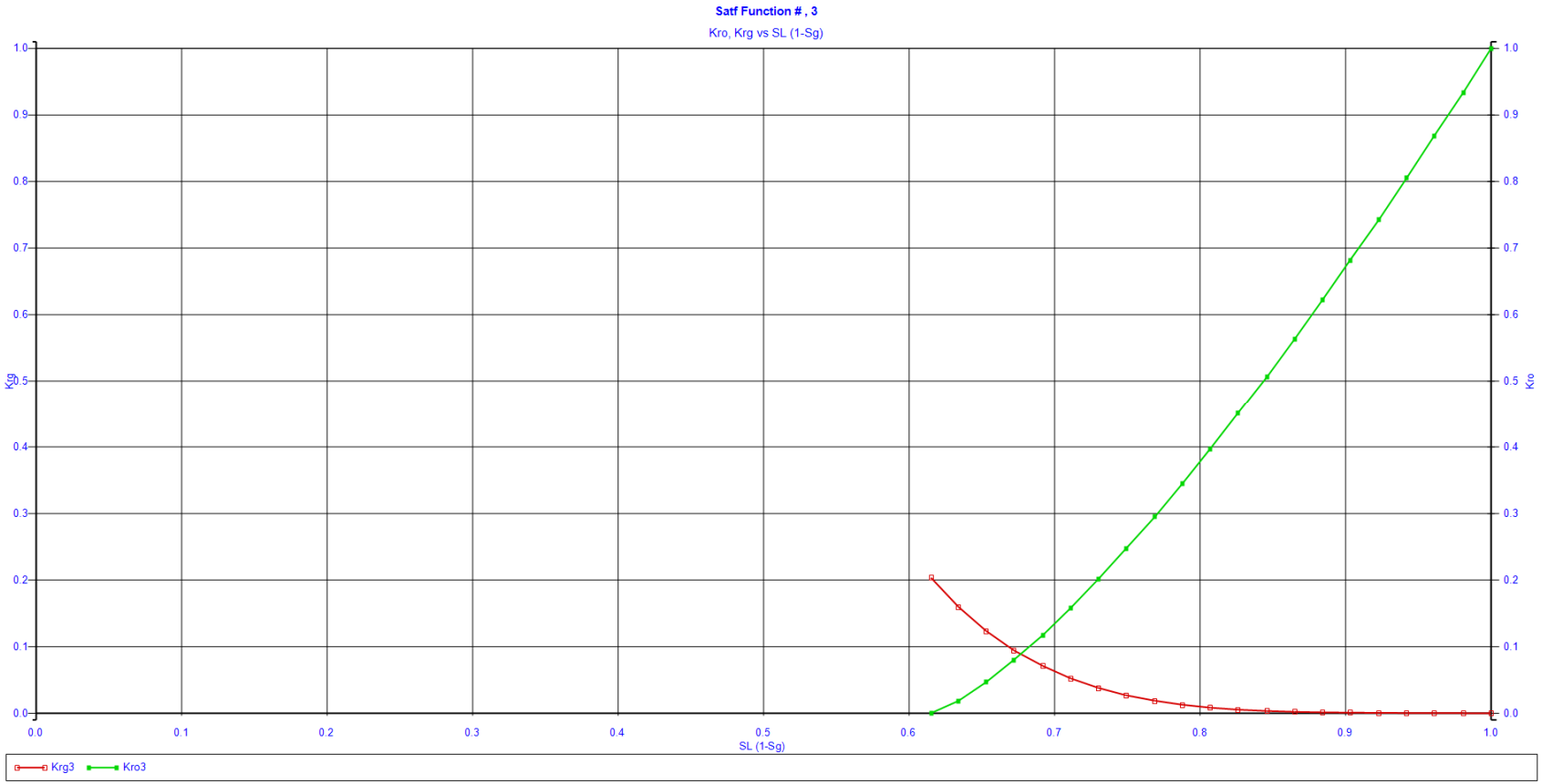
Objectives

- Build a reservoir simulation model of the Bakken in one section, 34-8-28W1, proposed as the site for an immiscible gas injection pilot.
- History match the model to the primary production from four horizontal wells stimulated via multiple hydraulic fractures (MFHWs).
- Introduce available gas-liquid relative permeability curves into the model to forecast performance with immiscible gas injection.

4 Bakken MFHWs in 34-8-28W1



Gas-oil relative permeability from Hycal special core analysis



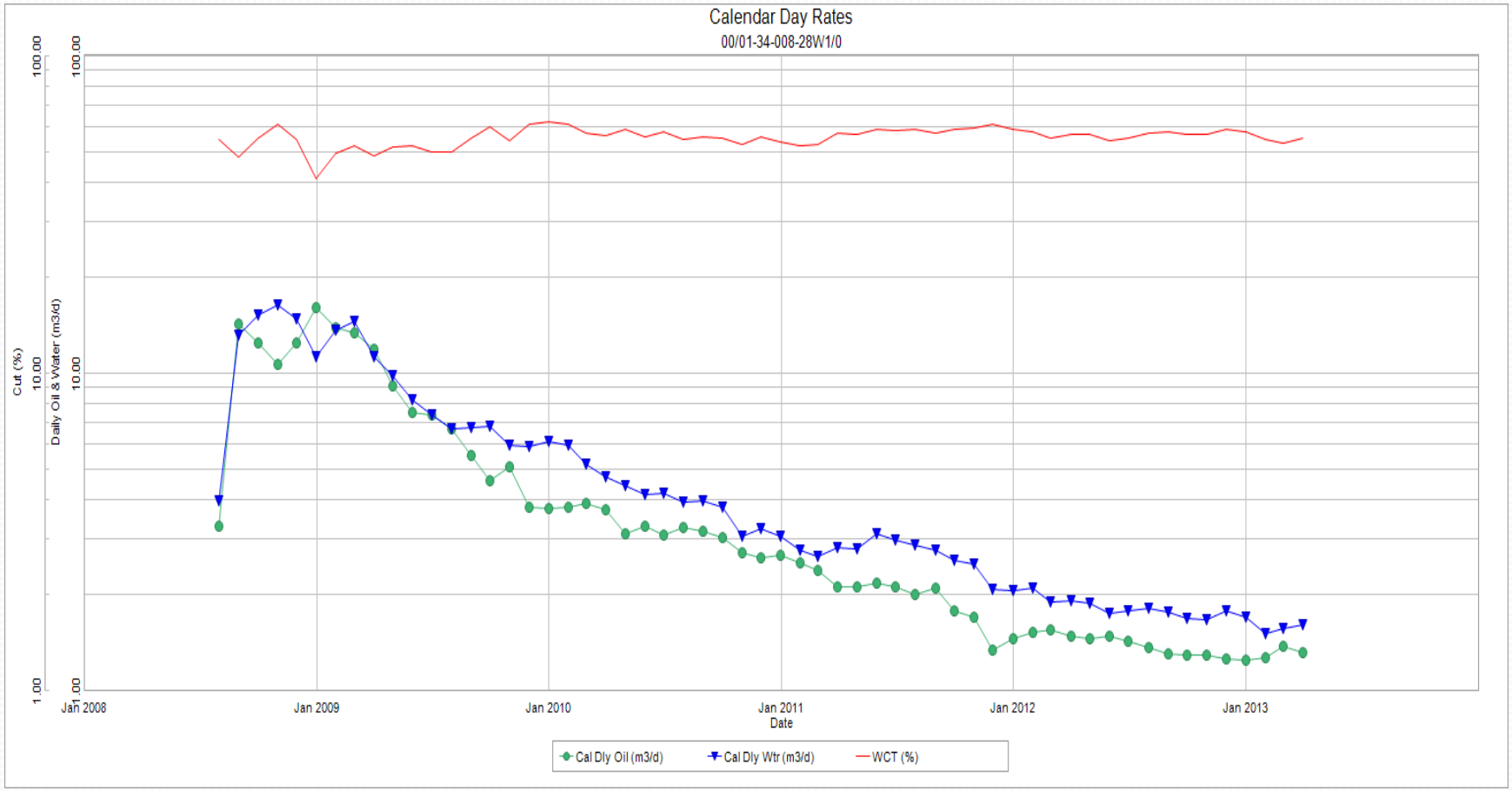
Screening for Immiscible Gas Injection

- In 2012 the Bakken-Lyleton was screened for potential areas which would be most suitable for immiscible gas injection.
- Areas with any core permeability greater than 10 mD were excluded in order to minimize potential for gas fingering.
- Areas with WOR>1 were excluded in order to minimze the chance that communication with the overlying wet, permeable Lodgepole had been established.

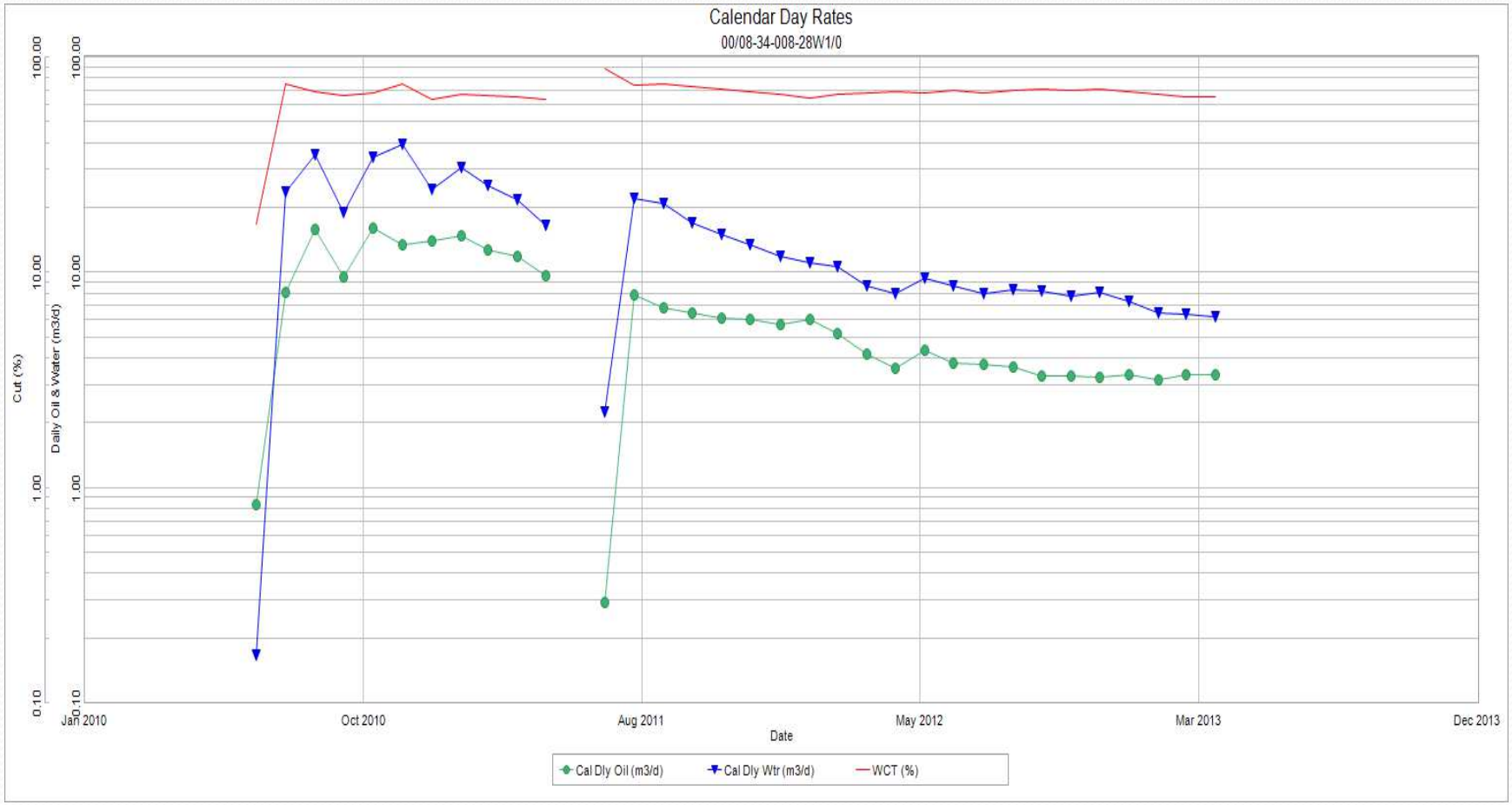
Does section 34-8-28W1 conform with screening criteria?

- The core in well 7-34-8-28W1 has no sample with kmax to air > 10 mD. In fact the highest permeabilities are in two samples with kmax ~ 3.7 mD (to air, ambient). So the core permeability are consistent with the first screening parameter.
- The section is marginal in terms of historical WORs. The range of cumulative WOR's is 0.89 – 2.21.
- The range of recent WOR for the four Bakken horizontal wells in 34-8-28W1 is 0.92 – 1.85

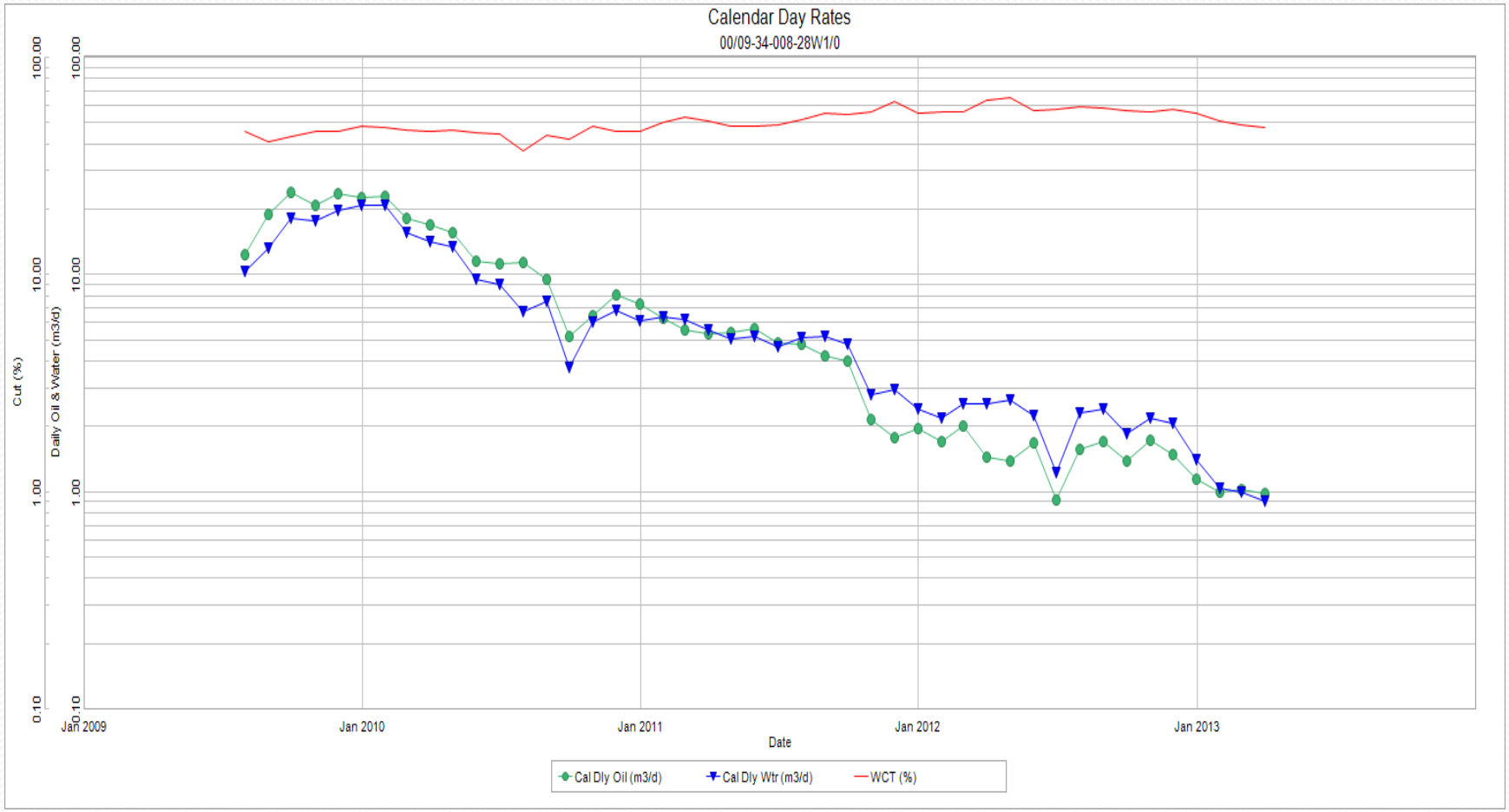
Production Plot: 1-34-8-28W1hz



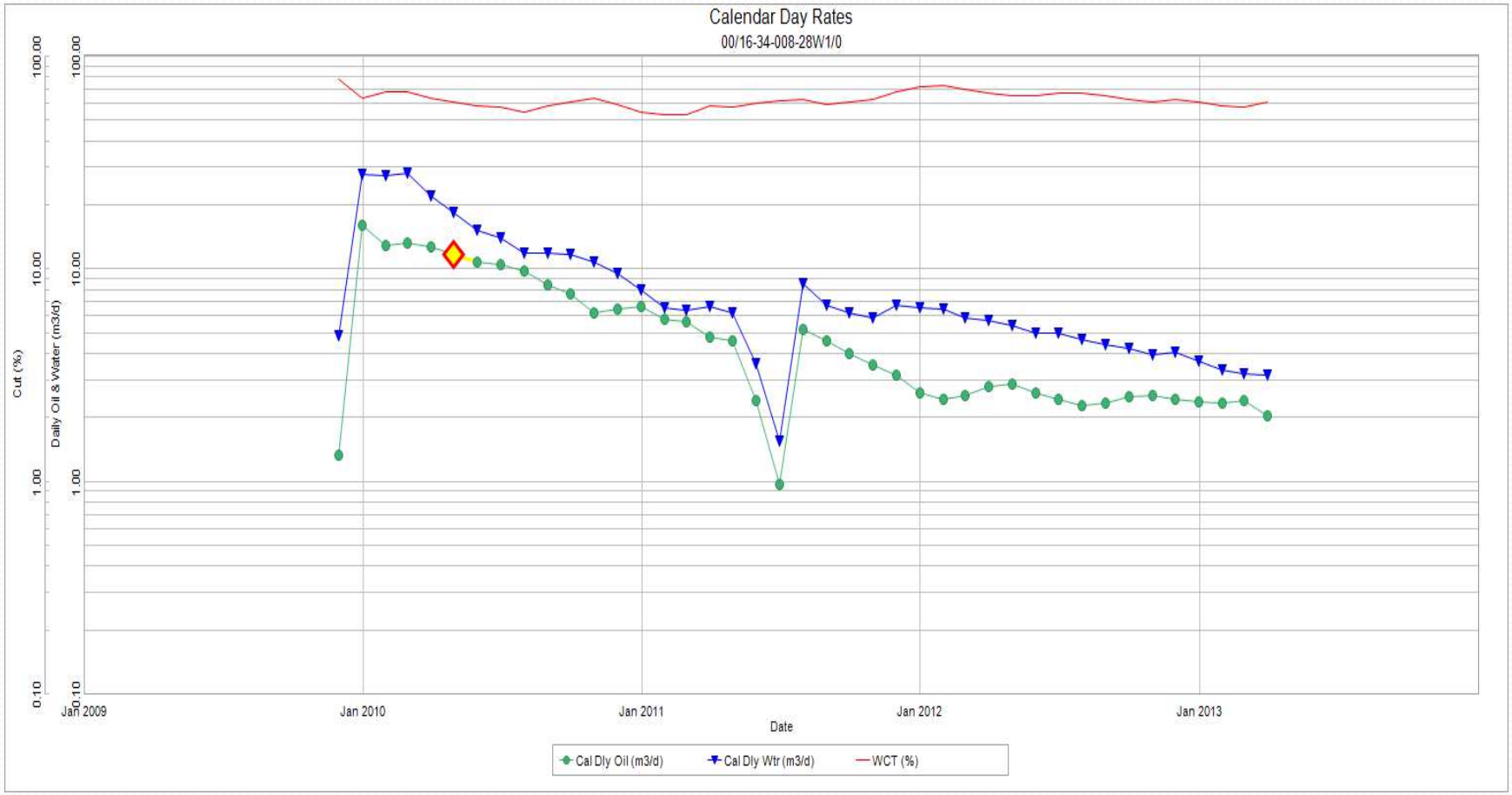
Production Plot: 8-34-8-28W1hz



Production Plot: 9-34-8-28W1hz



Production Plot: 16-34-8-28W1hz



Building the Exodus Model

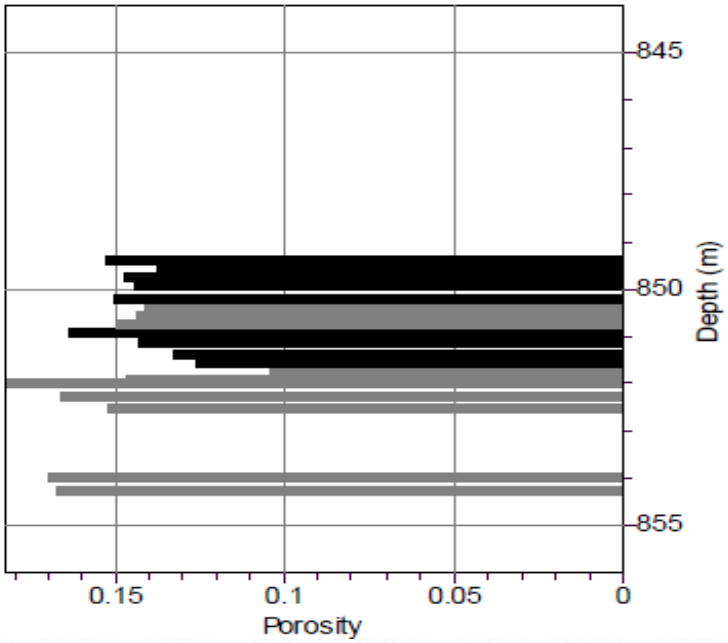
- Bubble point pressure 1900 kPaa, Oil gravity 39.6 API.
- Initially used GOR 4.6 sm3/sm3 at Pb: increased this to 6 sm3/sm3 to increase the energy in the system.
- Conventional core data from well 7-34-8-28W1 were grouped into 6 layers based on kmax.
- Resulting core thickness, porosity and kmax values were applied uniformly in a “layer-cake” model.
- Kmax values were reduced by 50% to approximate in-situ permeability.

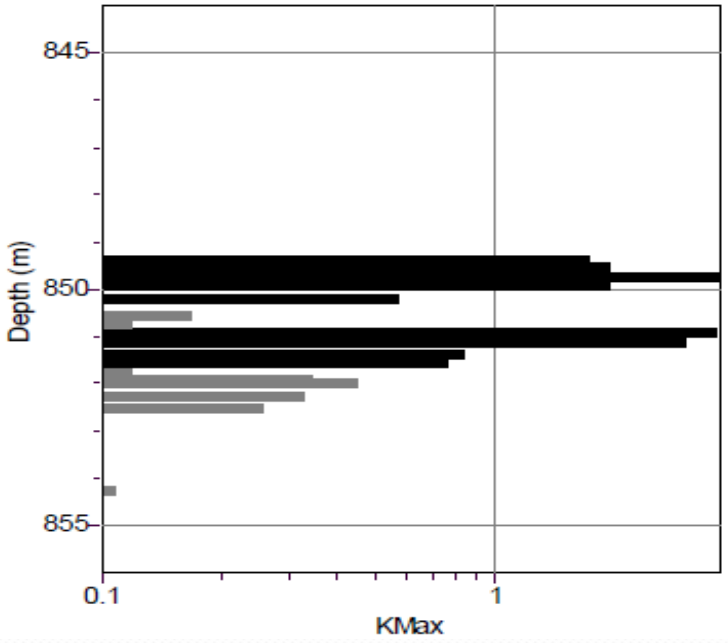
Core Analysis Report

00/07-34-008-28W1/0

Field:	DALY	**KB:**	471.80 (m)	**Rig Rel:**	1986-10-29	**Core Offset:**	0.0 (m)
Pool:	LODGEPOLE DD	**Gr Elev:**	467.70 (m)	**Cores:**	1		
Prod Zone:	LODGEPOL	**Depth:**	870.00 (m)				

			Arith	Geo	Harm		
Tot Thickness:	1.86 (m)	**Avg Km:**	2.02	1.65	1.31	**Filter:**	Kmax >= 0.50
Phi H:	0.27	**Avg Kv:**	0.03	0.02	0.02		
KMax h:	3.76	**Avg Phi:**	0.14	0.14	0.14		
Cored Forms:	BAKKEN						





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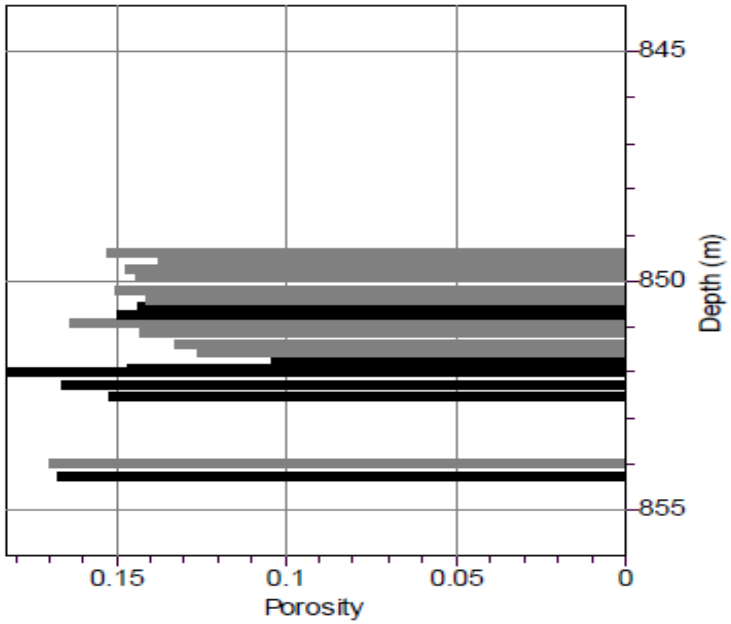
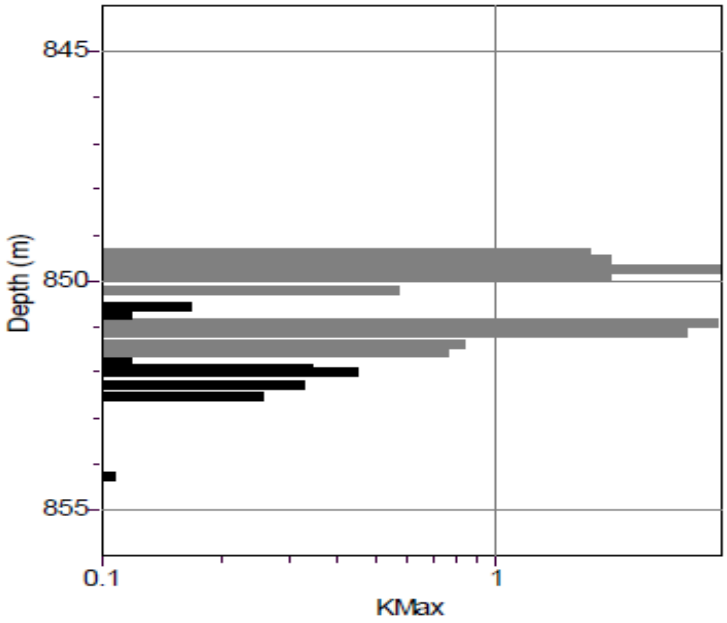
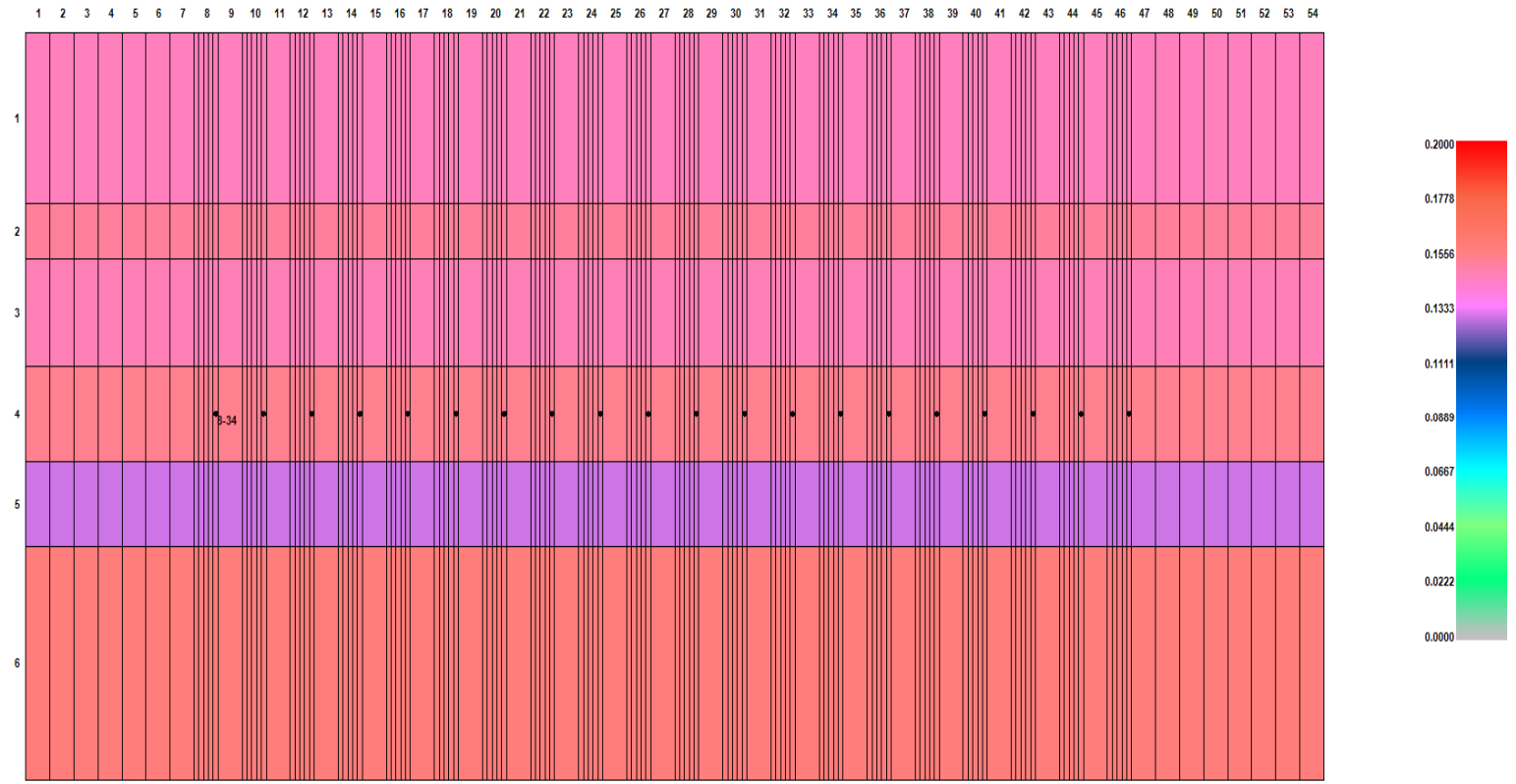
Pool:	LODGEPOLE DD	**Gr Elev:**	467.70 (m)	**Cores:**	1		
Prod Zone:	LODGEPOL	**Depth:**	870.00 (m)				

			Arith	Geo	Harm		
Tot Thickness:	1.60 (m)	**Avg Km:**	0.25	0.22	0.20	**Filter:**	Kmax >= 0.10 AND
Phi H:	0.25	**Avg Kv:**	0.02	0.02	0.01		Kmax < 0.50
KMax h:	0.41	**Avg Phi:**	0.16	0.15	0.15		
Cored Forms:	BAKKEN						





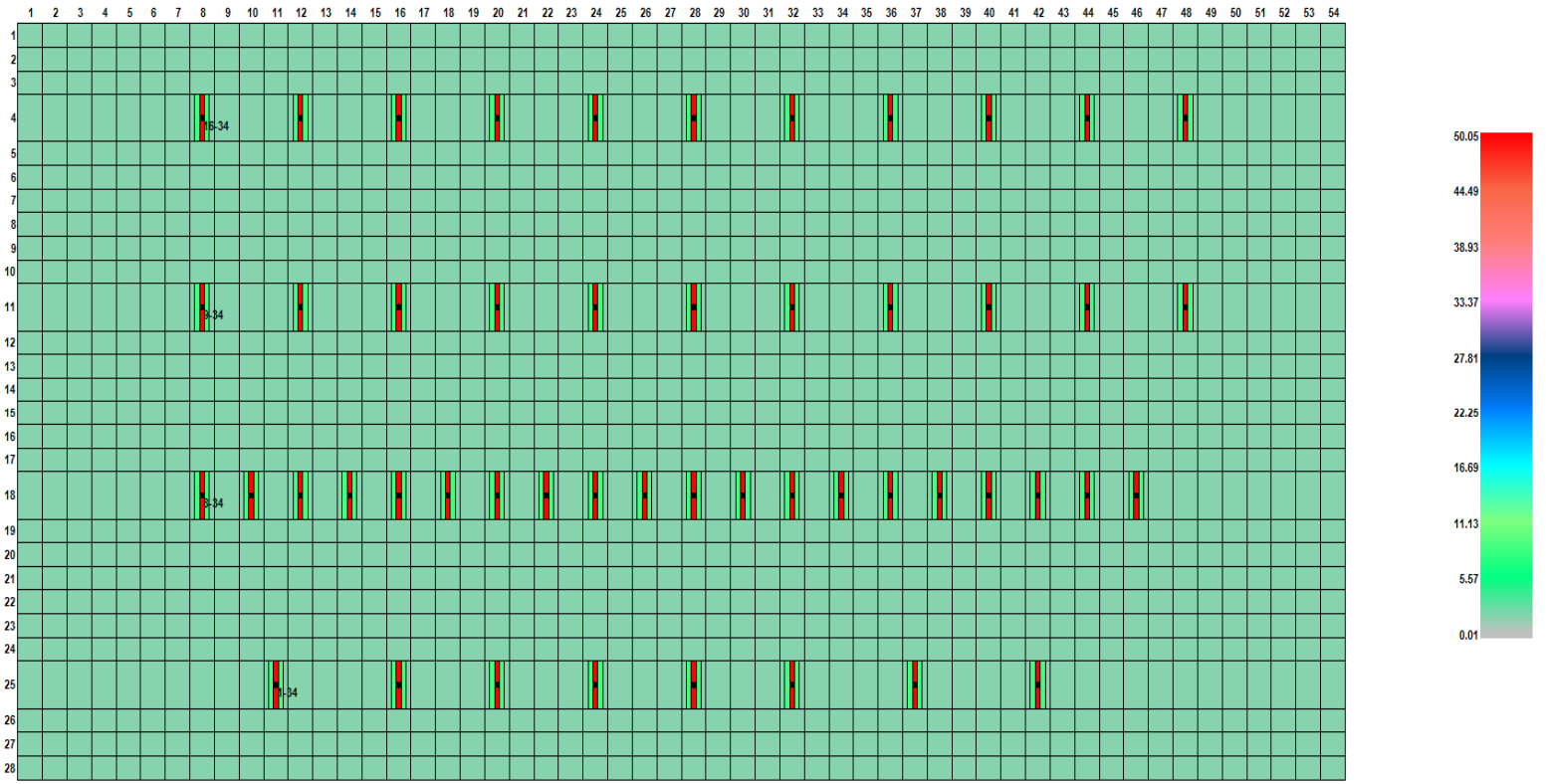
east-west cross-section: porosity



Creating the Hydraulic Fractures

- As in previous Exodus models the hydraulic fractures were represented by using LGR (local grid refinement), subdividing cells in the x direction (perpendicular to the axis of the hz wells).
- The narrow cells were assigned high permeabilities, with the frac itself some 10's of mD and the LGR cells on either side of the fracs improved permeabilities.
- One big impact on the horizontal wells is the good vertical permeability, assumed to be equal to the horizontal permeability within the frac itself.

LGR cells as fracs: kx is plotted



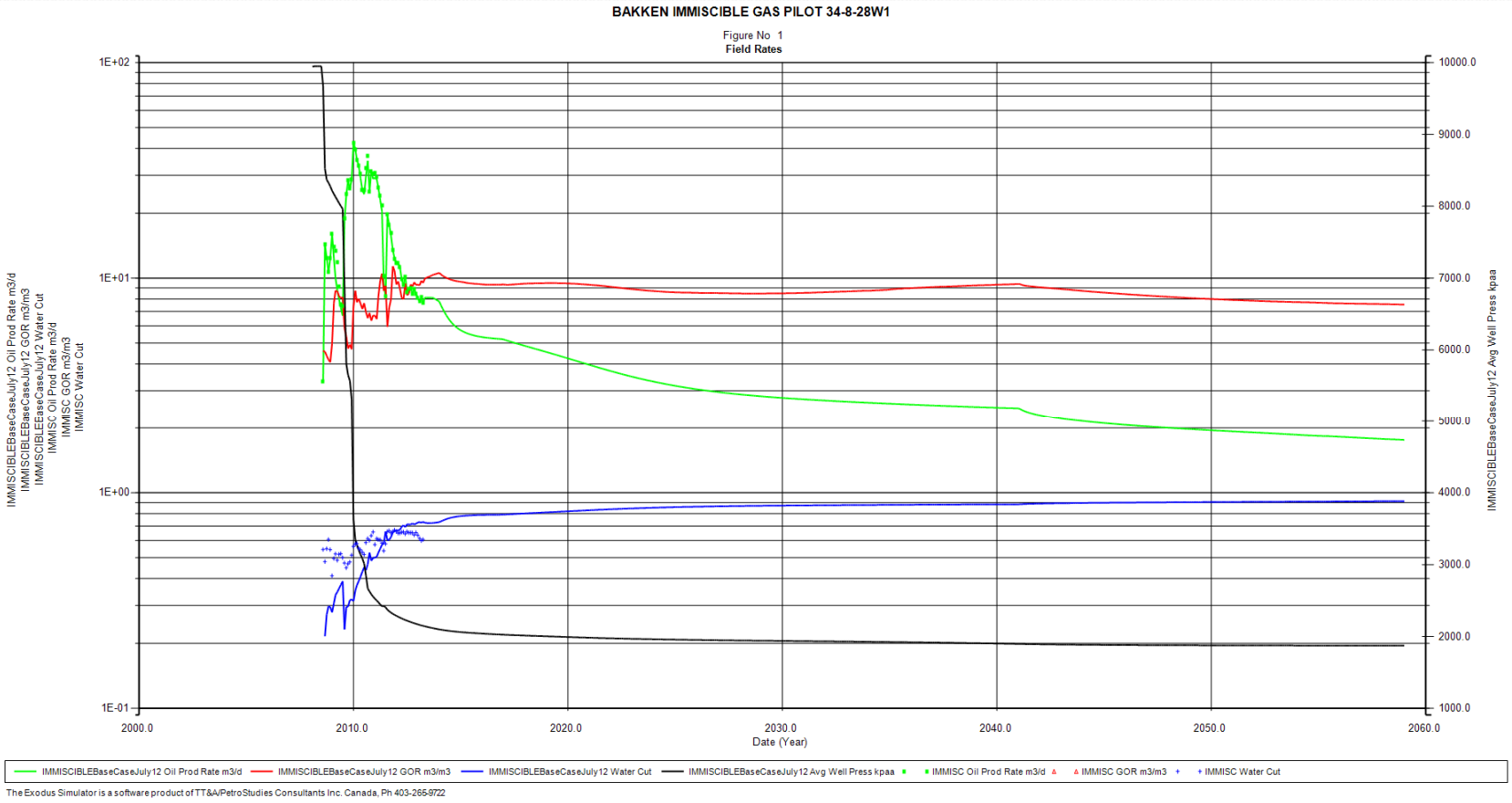
Relative permeability data

- Tundra Oil and Gas have an enviable catalogue of relative permeability analyses conducted on the Bakken-Lyleton in the greater Sinclair area.
- Initially the model was populated with relative permeability data from test conducted by Hycal, as some of these had both water-oil and gas-liquid relative permeability measured.
- Subsequently, when the model would not produce the historical WORs, drastically altered water-oil relative permeability tables were applied…

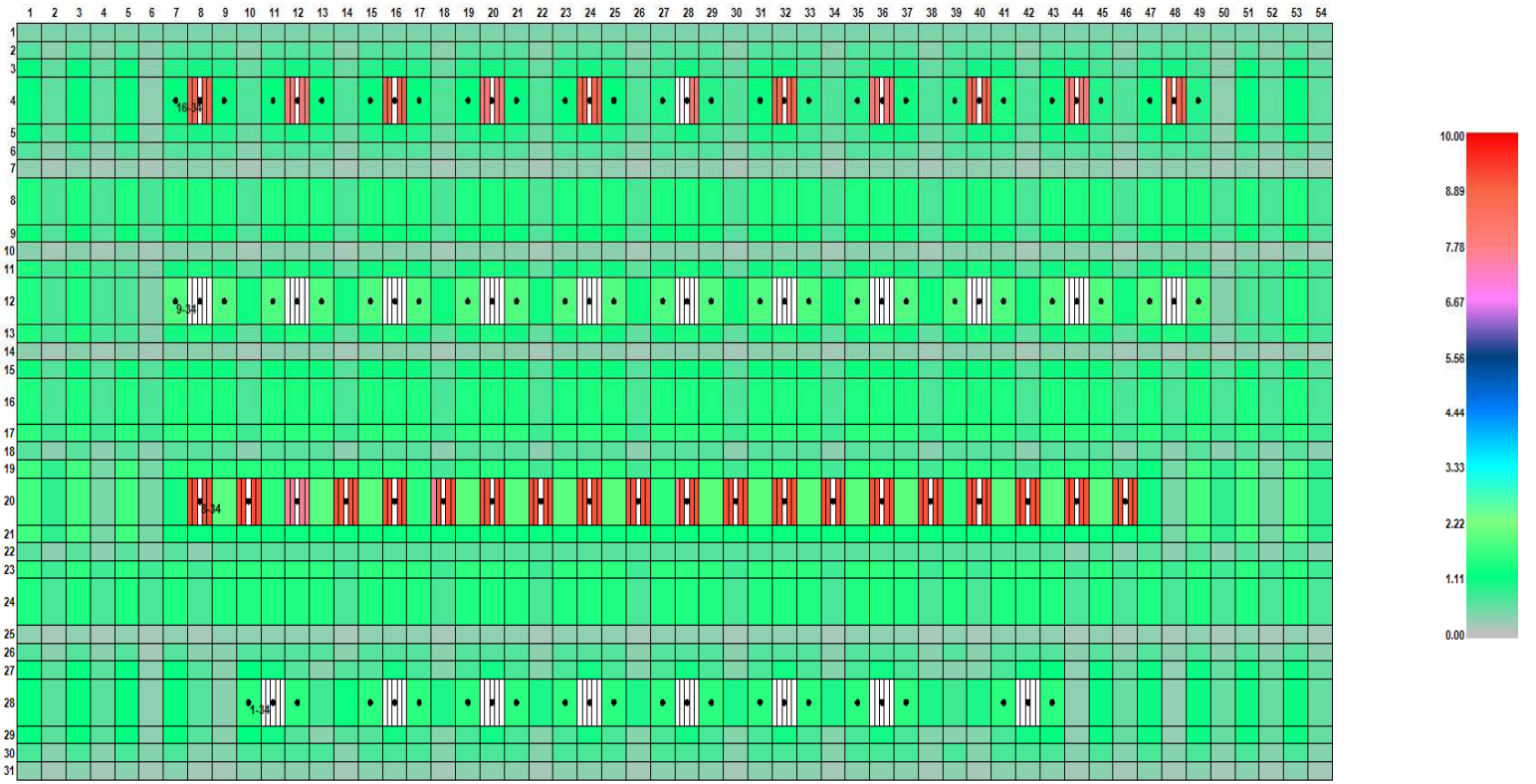
Key Elements of the New Model(s)

- The core and logs from the vertical well 7-34-8-28W1 form the basis for populating the simple “layer-cake” geological model.
- The model is initialized with relative permeability curves from Hycal, which include gas-liquid as well as water-oil relative permeability curves. The gas-liquid curves from the CO_2 pilot model were also available.
- Different oil-water contacts are applied to the Lodgepole and to the Bakken.

Forecast to 2058: BHFP's not changed over time



Permeability Kx, Ky Baffles in layer 4: cells with reduced permeability are grey



Base Case Oil recovery forecast:

- OOIP in the model is 598 e3m3 in one section.
- As of 2013-03 cum oil production (actual) was 31233 m3 from the four wells. This equates to 5.2% oil recovery.
- The model had some slight shortfalls in its oil rate but by July 2013 had produced 31238 m3, again about 5.2% of OOIP.
- Forecast oil production under Base Case from the 4 wells to 2058-12 is a surprisingly robust 78.3 e3m3, or 13.1% of OOIP!

Development Scenarios

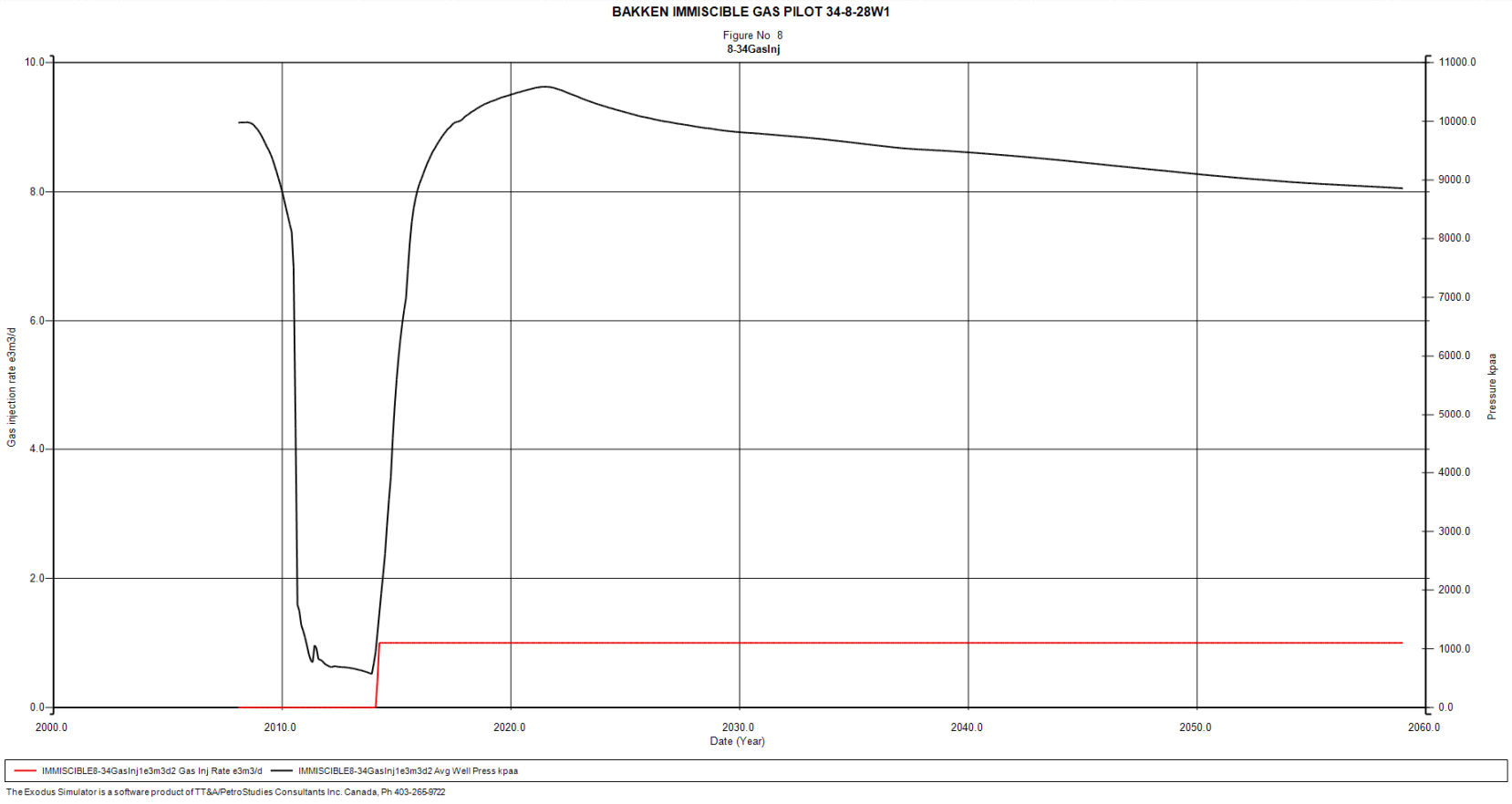
- Several development scenarios are contemplated for this section:

1. Immiscible gas injection via the 8-34 hz well, at 1 e3m3/d, 5 e3m3/d.
2. Immiscible gas injection via an open hole infill hz well between 9-34 and 16-34 at 1 e3m3/d, 5 e3m3/d.
3. Immiscible gas injection via both 8-34 and an infill between 9-34 and 16-34

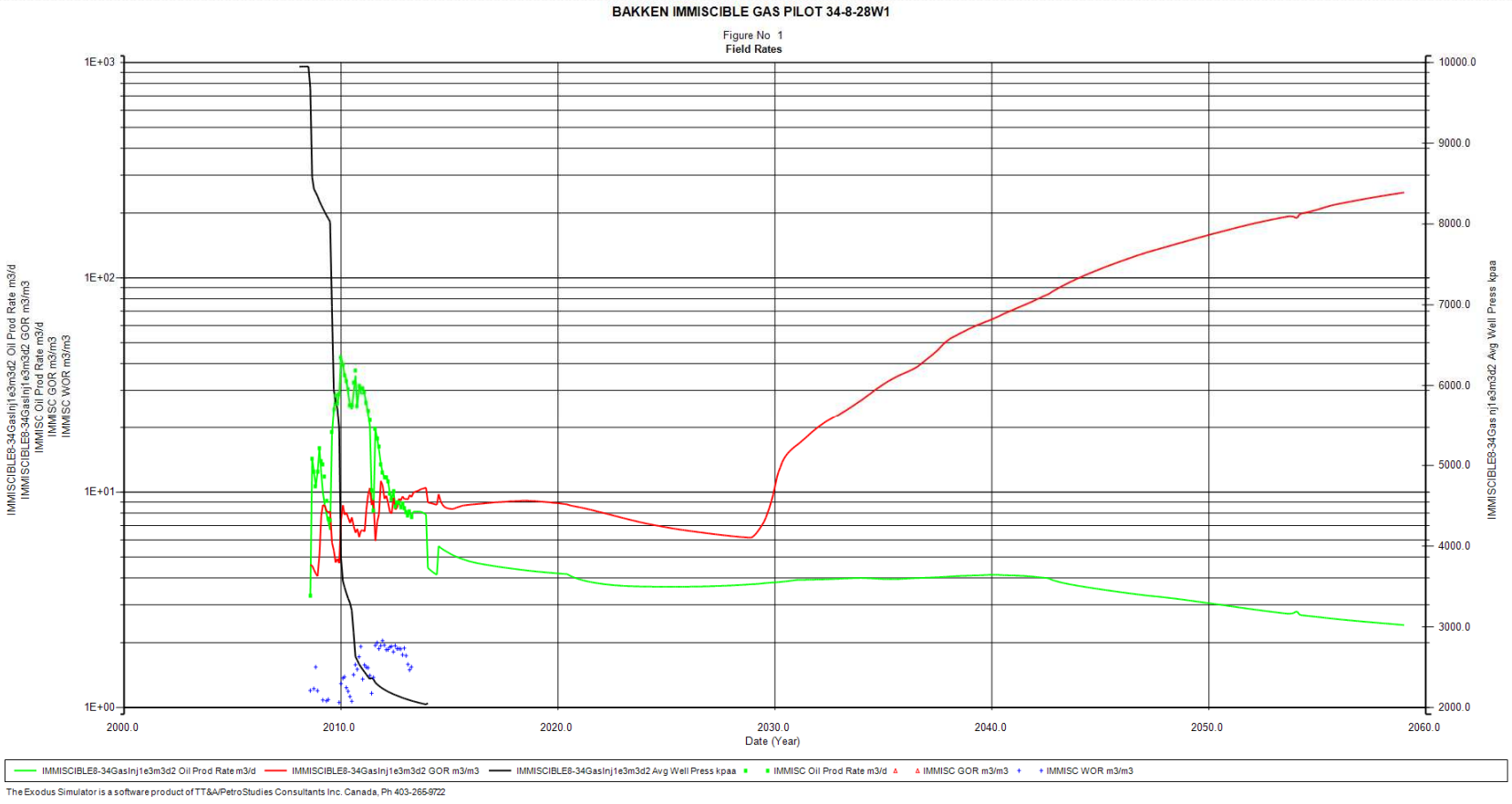
Well controls in gas injection cases

- In the gas injection cases the oil rate targets are increased in mid 2014 from their 2013-04 target rates: if there is improved pressure support they may be able to make these rates, if there is not increased pressure support their oil rates will not increase (much).
- The gas injection rates are increased very slowly in the model, starting at 0.1 e3m3/d, to avoid having the model bomb due to excessive saturation change in the small LGR cells.

8-34 can inject 1 e3m3/d



Group production plot: 8-34 inj 1 e3m3/d. Other well oil rate targets doubled mid 2014



9-34 with 8-34 gas inj. 1 e3m3/d

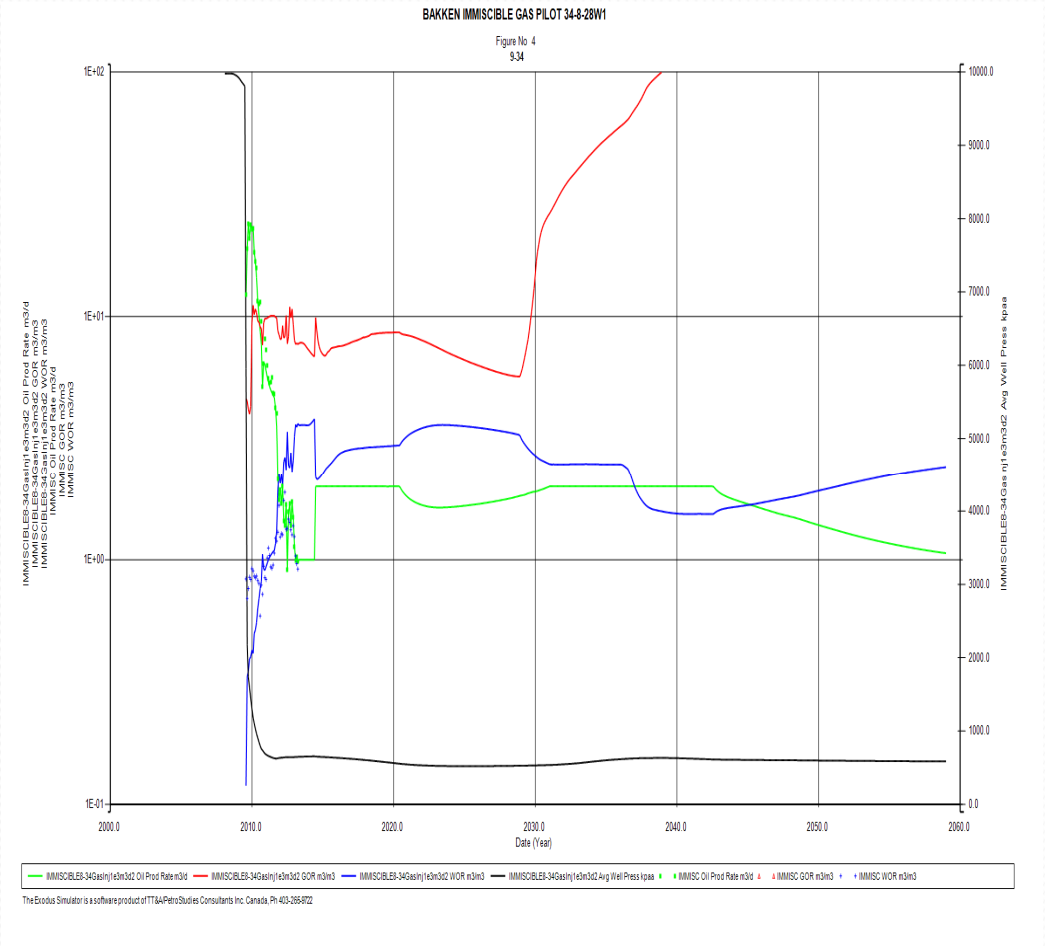
The oil rate target is doubled to 2 m3/d in mid 2014 and the well CAN sustain this for a while…

Note that we think that this well has a mechanical restriction, so it is difficult to match the current low oil rates. With the oil rate increased we reflect that the restriction is removed…

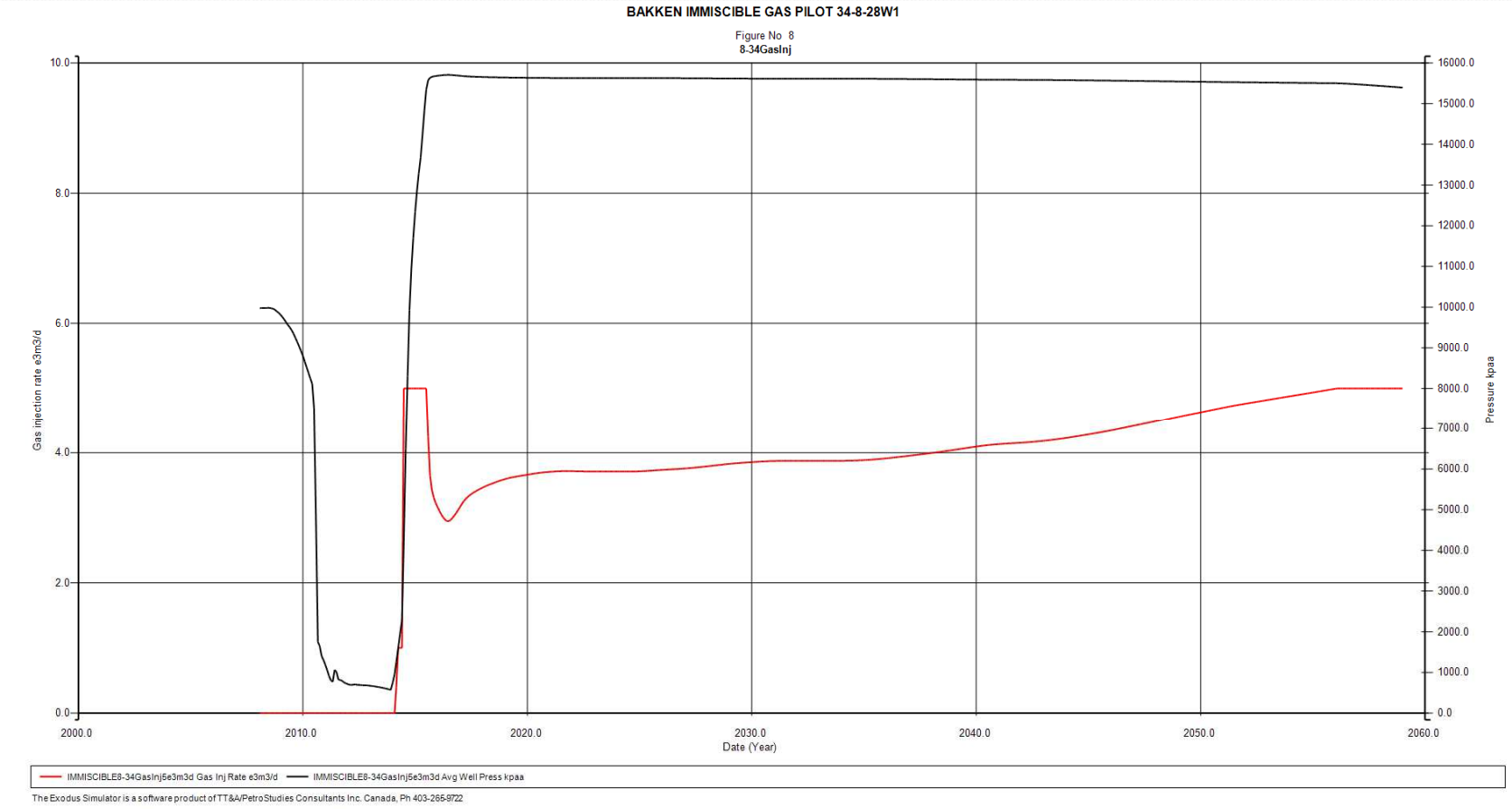
The WOR drops a bit as the oil rate increases.

The GOR actually plateaus until arrival in about 2028, about 5 years before it shows up in 1-34.

Some gas may actually arrive at the producers via the Lodgepole!



8-34 can inject 5 e3m3/d briefly, then pressures up… no need to run cases with higher gas injection rate!

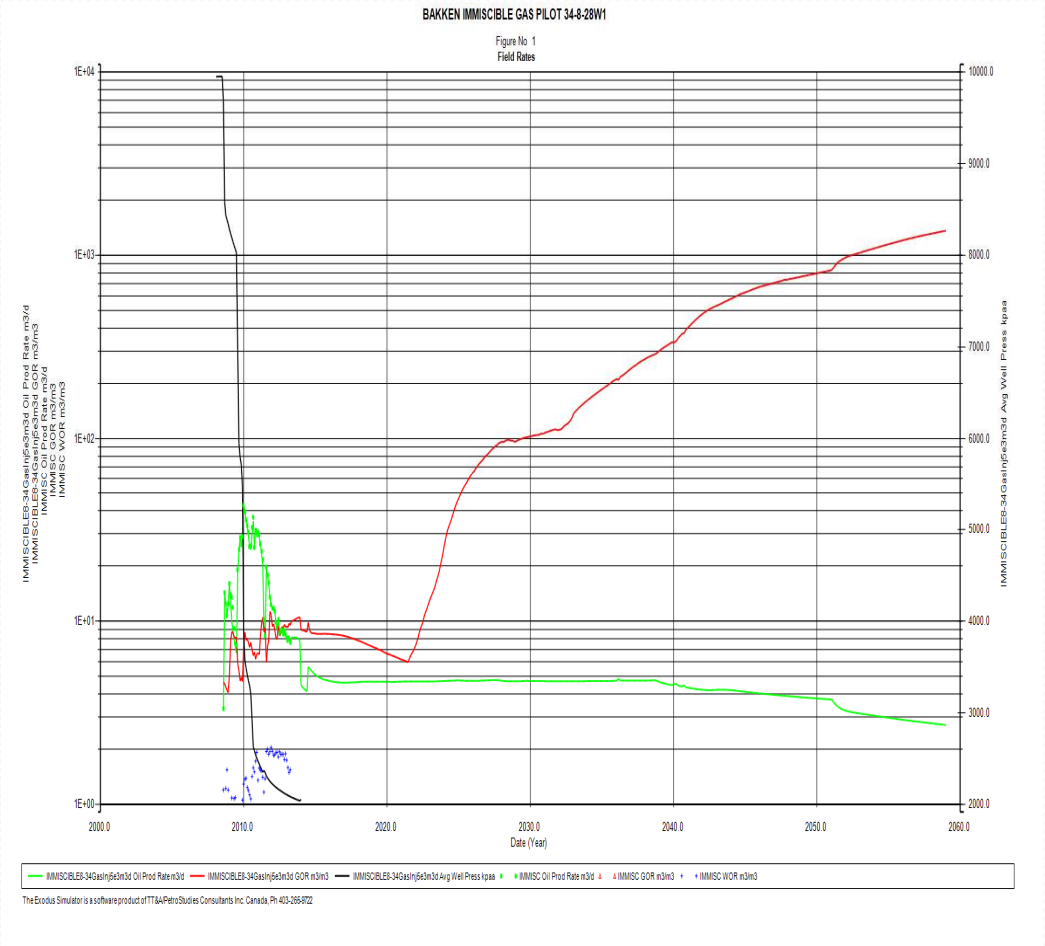


Group plot with 5 e3m3/d gas injection via 8-34hz

The group plot does not present WOR nor pressure.

The oil rate makes a long plateau – it is possible that the target rate could be increased further…perhaps in 9-34 and 1-34.

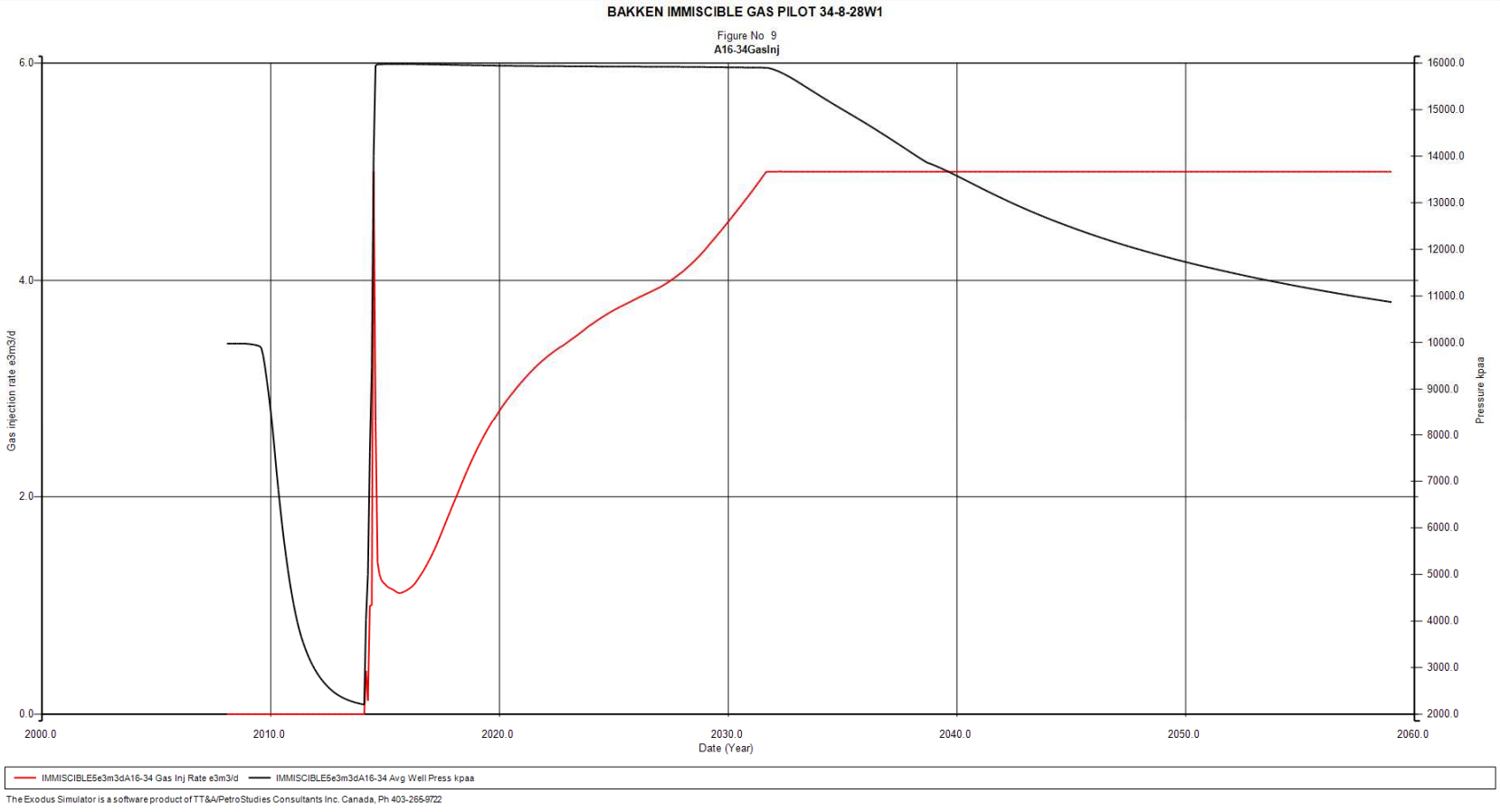
It appears that gas arrives in producers in 2021…



Gas injection targeting 5 e3m3/d via openhole hz A16-34

- In this case the model attempts to inject gas into an un-frac'd open hole hz well landed in the lower permeable layer in the Bakken.
- The hz well runs east-west between 9-34hz and 16-34hz.
- The open hole hz well is not connected via fractures to the Lodgepole.
- The hz well as built cannot initially achieve 5 e3m3/d gas injection.

Gas injection rates (red) A16-34 open hole hz



EUR to 2048 Base and Gas Injection via 1 or 2 hz wells, 8-34 WAG

Case	EUR Oil, e3m3	EUR Gas, e3m3	EUR GasInj, E3m3	Oil RF
Base Case, primary production	78.3	654	0	13.1%
8-34hz inject, 1 e3m3/d gas	90.9	4130	16376	15.2%
8-34hz inject, 5 e3m3/d gas	100.5	24553	67452	16.8%
A16-34 open hole hz inject 5 e3m3/d gas	104.7	66173	70090	17.5%
A16-34 open hole, 8-34frac'd each inject 5 e3m3/d	112.4	70077	115425	18.8%

- Net increase in reserves by going from Base Case to Proposed 2 well WAG gas is 5.7 % (unrisked)
- In running economics, a chance of success of 80% was applied.