GEIE
Route de Soultz
F-67250 Kutzenhausen

Circulation test GPK2/GPK3/GPK4

Test 05jul11

Interpretation with HEX-B

Technical Note

11.08.2006
Ref. TN17.16/CB/TM/TK

GEOWATT AG

S W I S S GEOTHERMAL E X P E R T G R O U P

GEOWATT AG
Dohlenweg 28
CH-8050 Zürich

Tel +41 (0) 44 242 14 54
Fax +41 (0) 44 242 14 58
info@geowatt.ch
www.geowatt.ch

1. Aims

On 11th July 2005 a longterm circulation test has been started. The measured values at the wellhead/surface for pressure, flow rate, density and temperature shall be interpreted with the following aims:

- Calculation of the pressure at the TVD 4500 m in each borehole to determine the injectivity index II, resp. the productivity index PI [l/s/MPa].
- Discuss the pressure difference between the 3 boreholes at the TVD 4500 m

2. Data of the circulation test 05jul11

Figure 2 shows the test data from the thermosyphon test at GPK4. For the following calculations with HEX-B it is assumed the Q_out_separator representing the total liquid flow rate from GPK4.

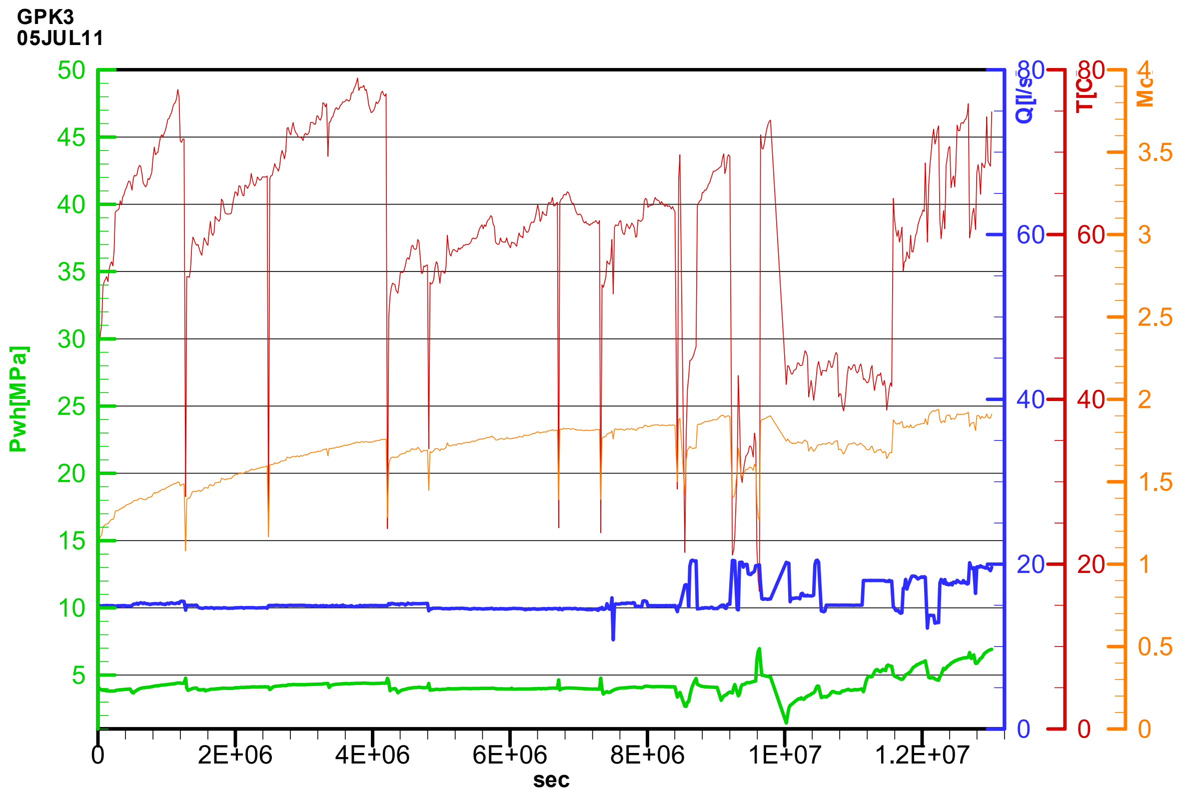


Figure 1: Measured data of test 05jul11,circulation test at GPK3 (Injection)

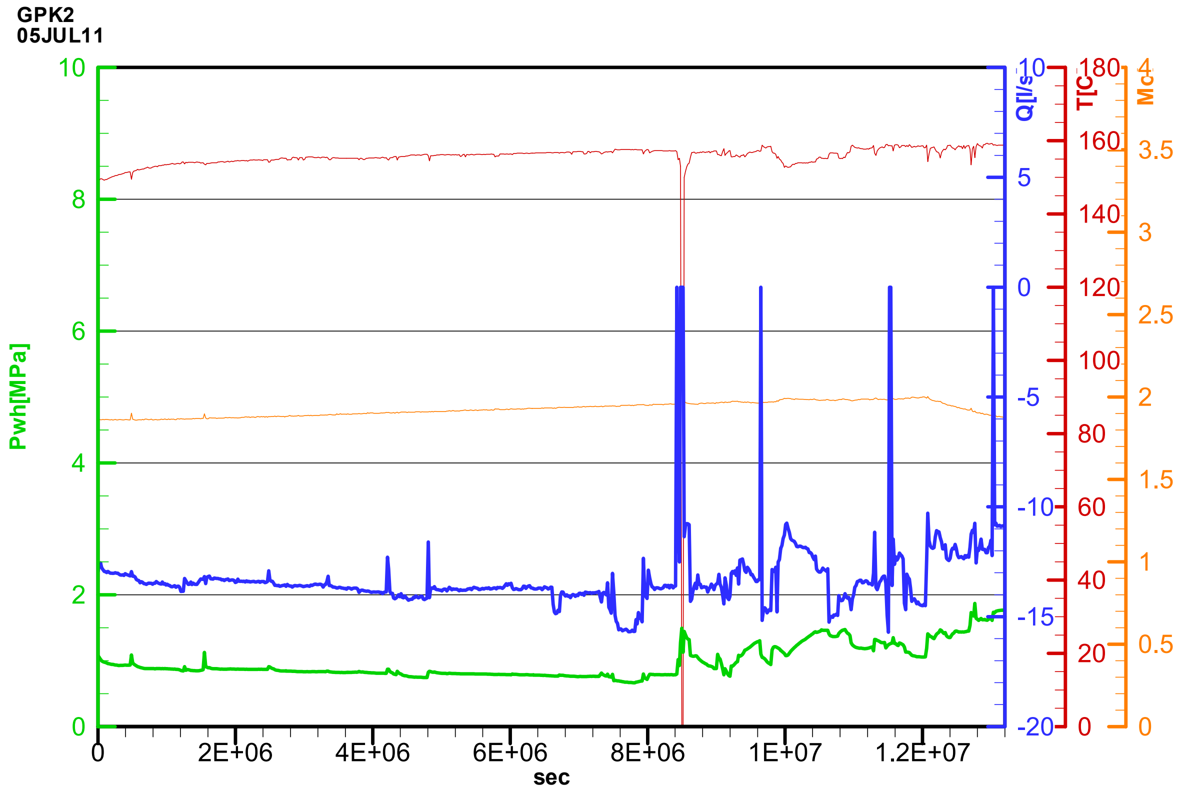


Figure 2: Measured data of test 05jul11,circulation test at GPK2 (Production)

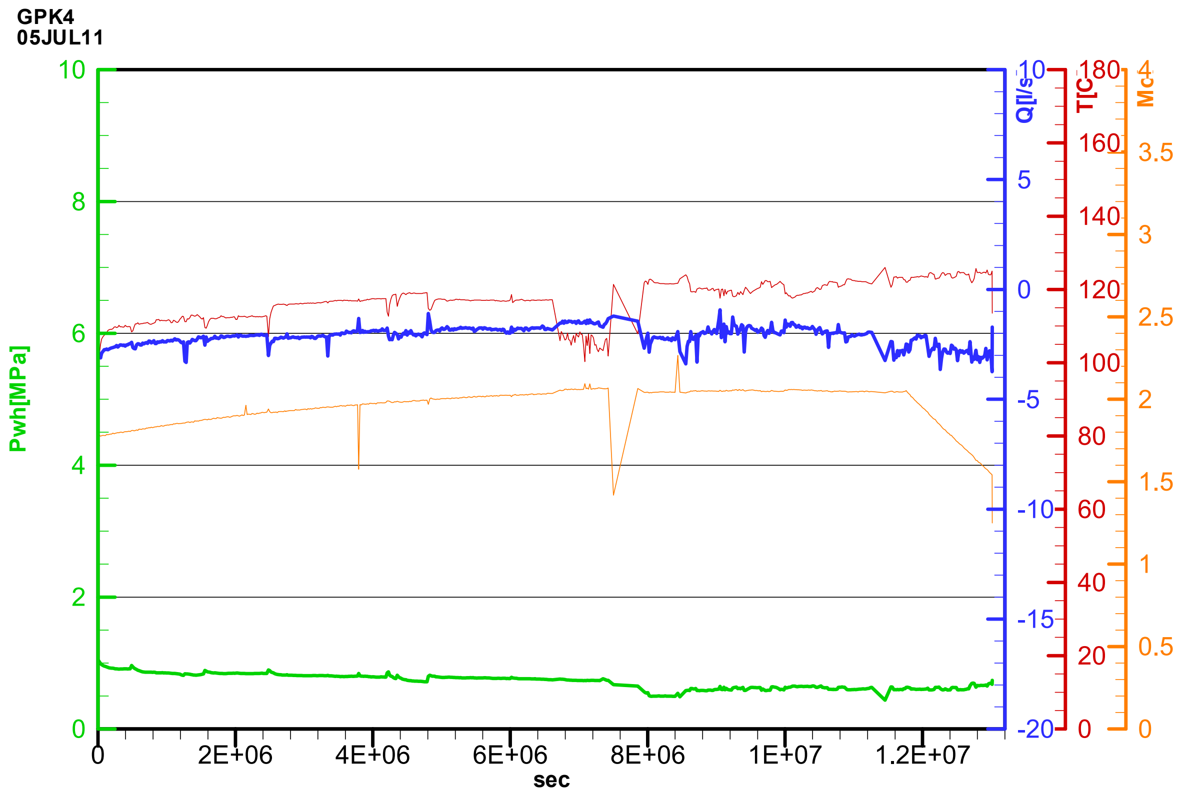


Figure 3: Measured data of test 05jul11,circulation test at GPK4 (Production)

3. HEX-B calculations for GPK2

3.1. Model used

No measured logging values for a calibration of the GPK2 borehole model are available. The model was calibrated with the produced wellhead temperature.

Table 1: Borehole/rock model in HEX-B for GPK2 production well

Bore hole parameters						Rock mass parameters	
Depth section MD [m] Nr	from:	to:	Inner radius [m]	Flow rate [% of injection rate]	Average wall roughness [mm]	Thermal conductivity [W/m K]	Specific heat capacity [J/m^{3}K]
1	0	1500.	0.08	100	0.15	2.4	2.2 10^6
2	1500	3800	0.08	100	0.15	3.2	2.2 10^6
3	3800	4800	0.08	100	0.15	2.4	2.2 10^6

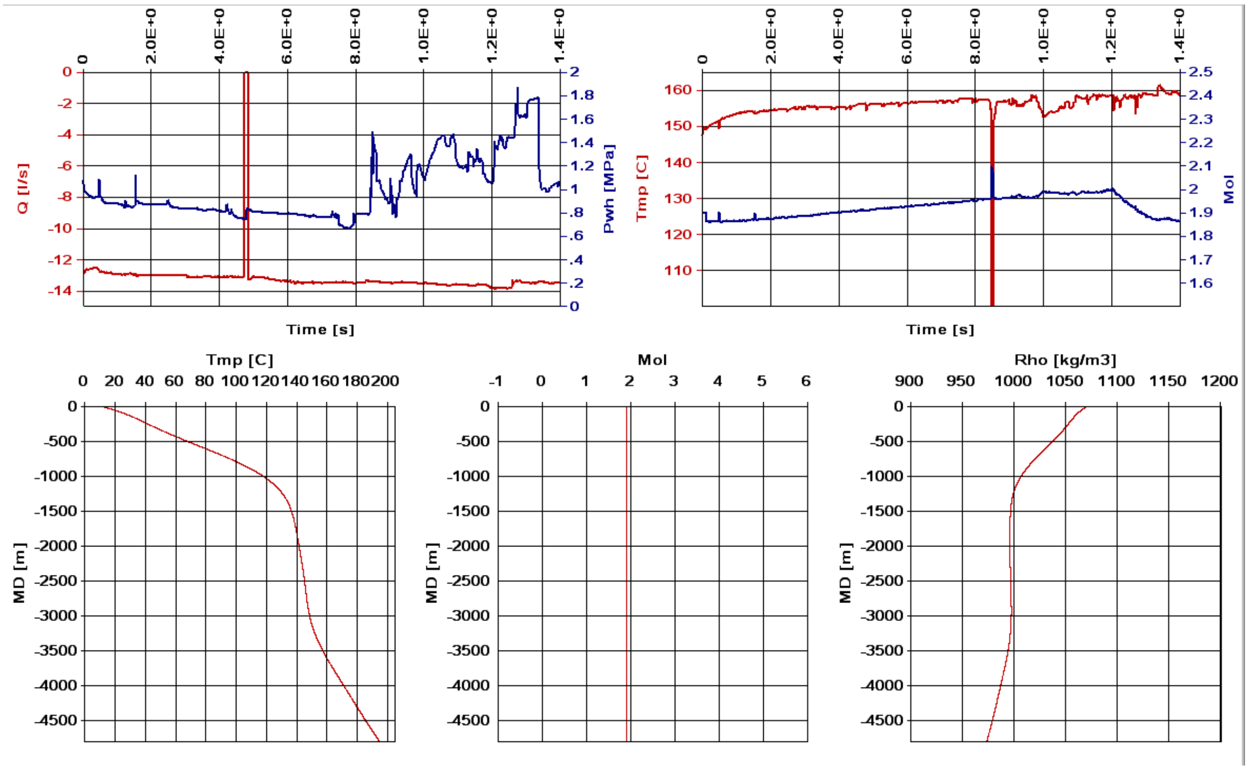


Figure 4: Initial values at the well head and in the borehole of GPK2 used for HEX-B

At GPK2 the TVD 4500 m corresponds to 4538 m MD. Assuming an initial NaCl-molality of 1.9 in the borehole and an initial wellhead pressure of **1.08 MPa** the pressure at 4538 m MD is **45.4 MPa**.

3.2. Results GPK2

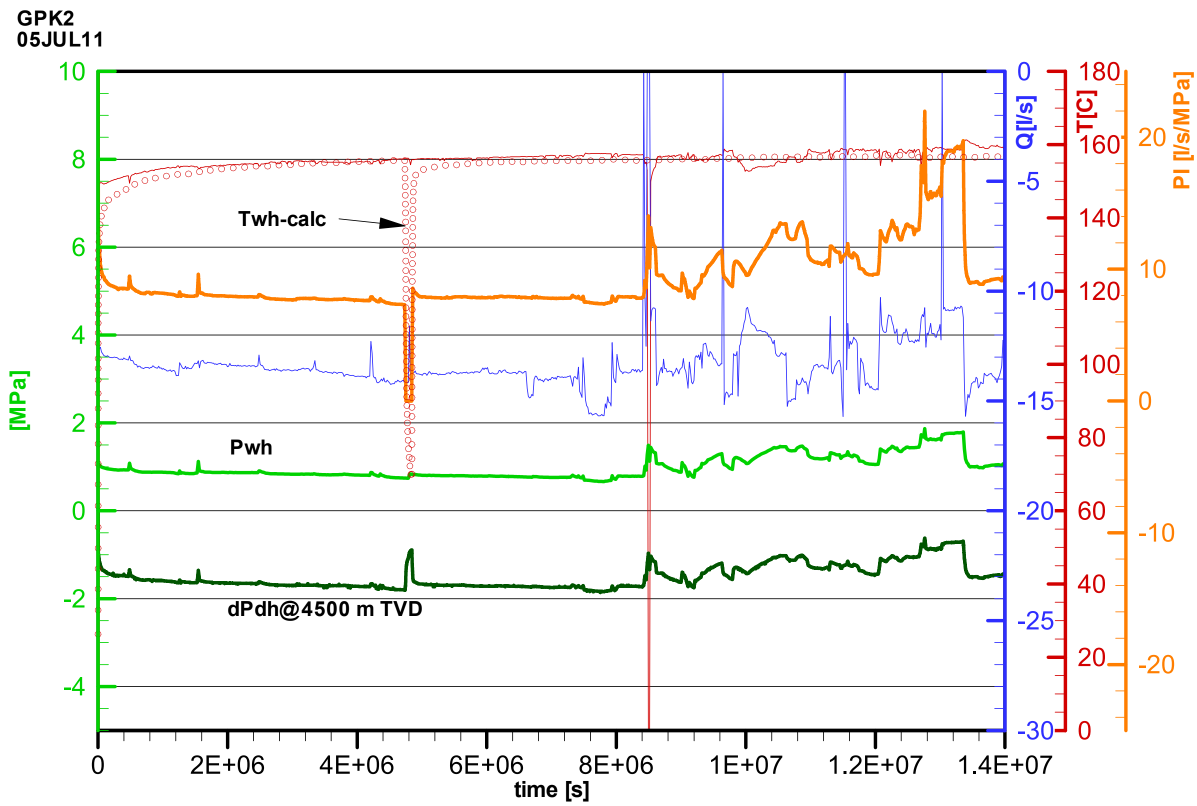


Figure 5: Calculated Productivity Index PI and downhole overpressure dPdh at 4500 m TVD for GPK2. Also indicated the fit of the wellhead temperature (calculated values dotted).

4. HEX-B calculations for GPK3

4.1. Model used

The rock parameters in the vicinity of the GPK3 borehole have been calibrated with measured temperature values 5e6 sec after start of the test.

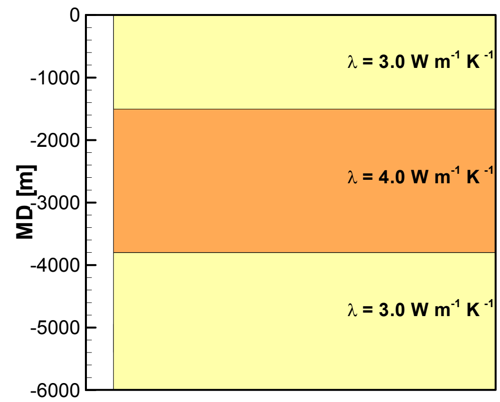
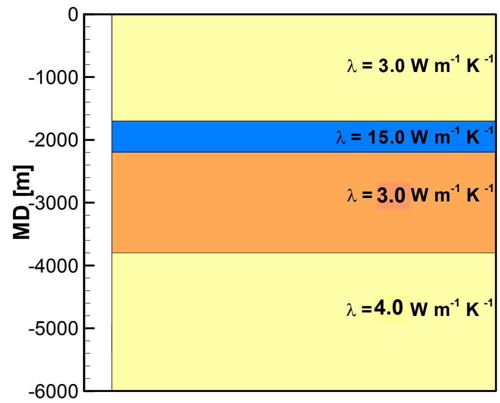
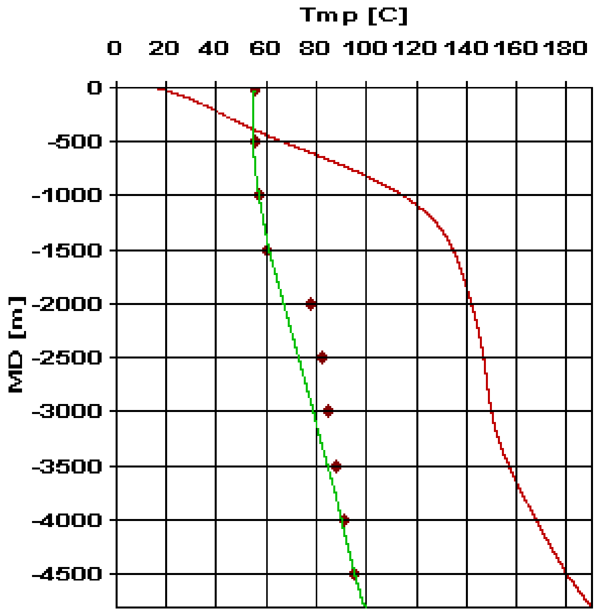
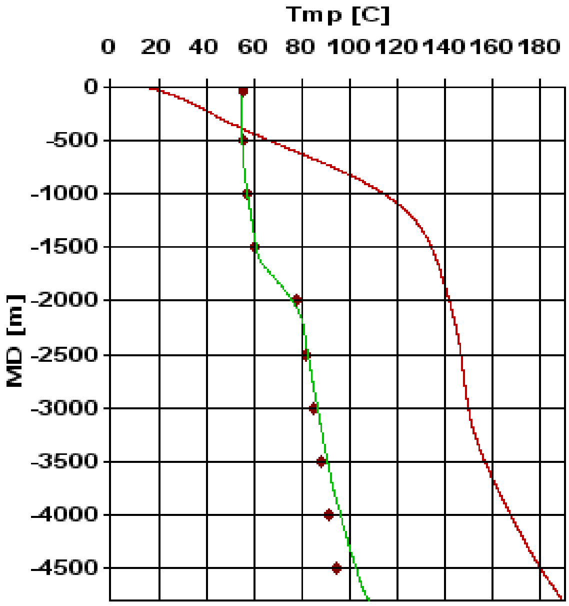
Originally used GPK3 rock model	Calibrated GPK3 rock model
	
	

Table 2: Borehole/rock model in HEX-B for GPK3 injection

Bore hole parameters						Rock mass parameters	
Depth section MD [m] Nr	from:	to:	Inner radius [m]	Flow rate [% of injection rate]	Average wall roughness [mm]	Thermal conductivity [W/m K]	Specific heat capacity [J/m³K]
1	0	1700.	0.11	100	0.15	3	2.2 10^6
2	1700	2200.	0.11	100	0.15	15	2.2 10^6
3	2200	3800.	0.11	100	0.15	4	2.2 10^6
4	3800	4556.	0.11	100	0.15	3	2.2 10^6
5	4556	4768.	0.108	100	1	3	2.2 10^6

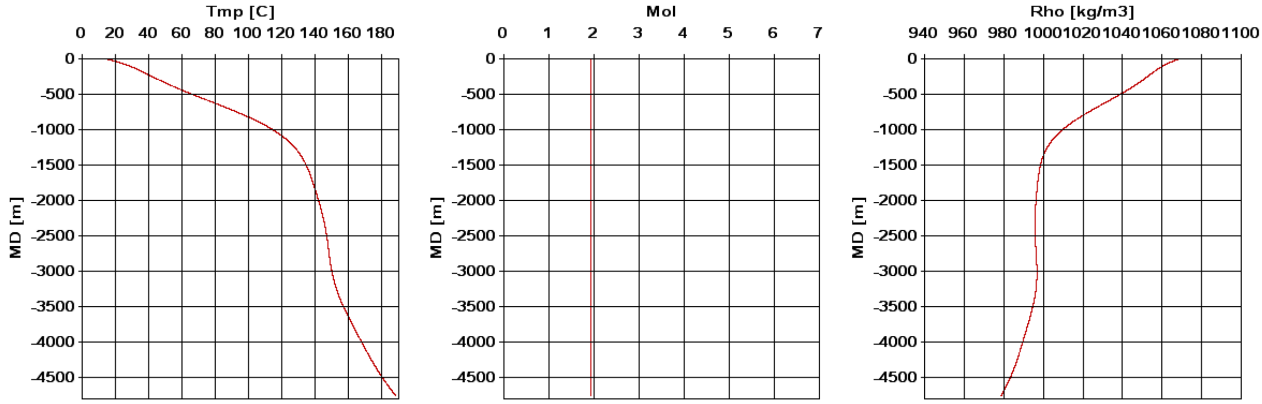


Figure 6: Initial values in GPK3 used for HEX-B

At GPK3 the TVD 4500 m corresponds to 4568 m MD. Assuming an initial NaCl-molality of 1.935 in the borehole and an initial wellhead pressure of **0.1 MPa** the pressure at 4568 m MD is **44.5 MPa**. This value is 0.9 MPa below the value for GPK2 (and also for GPK4).

4.2. Results GPK3

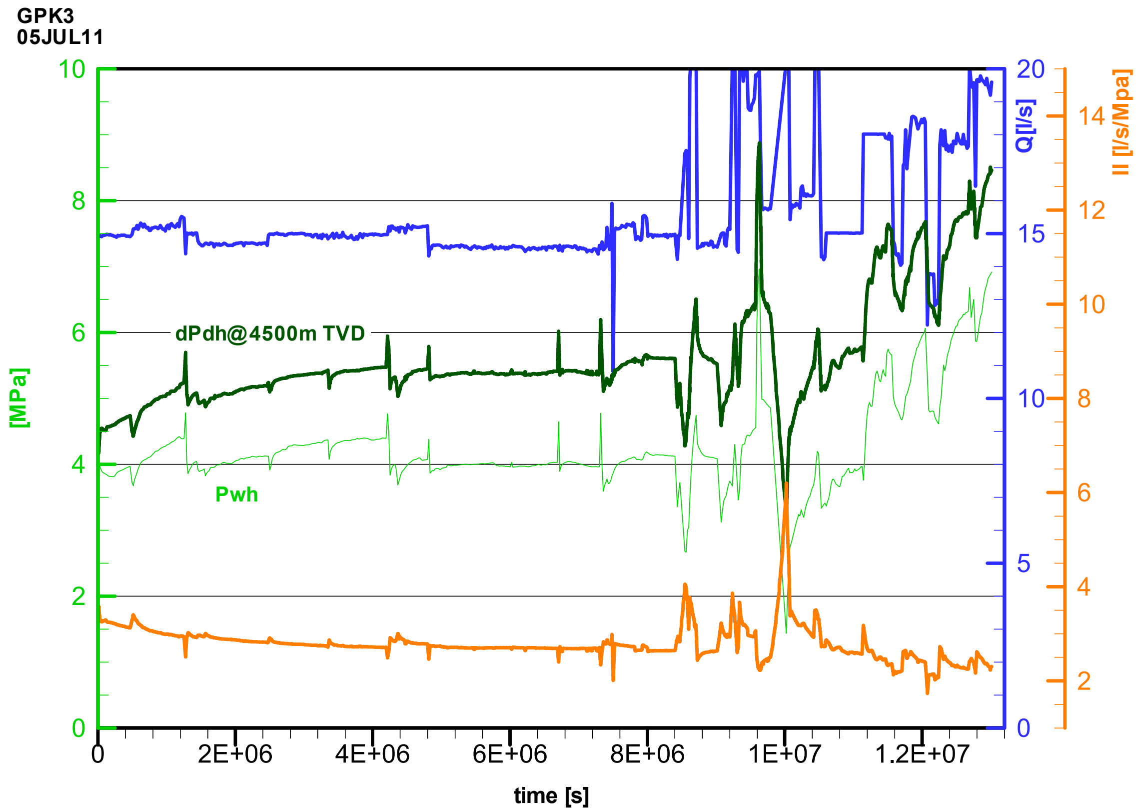


*Figure 7: Calculated Injectivity Index II and downhole overpressure dPdh at 4500 m TVD for GPK3 and an initial pressure at 4500 m TVD of **44.5 MPa***

For a consistent reservoir interpretation, a value of 45.4 MPa has also been used as the GPK3 initial downhole pressure (see chapter 6.)

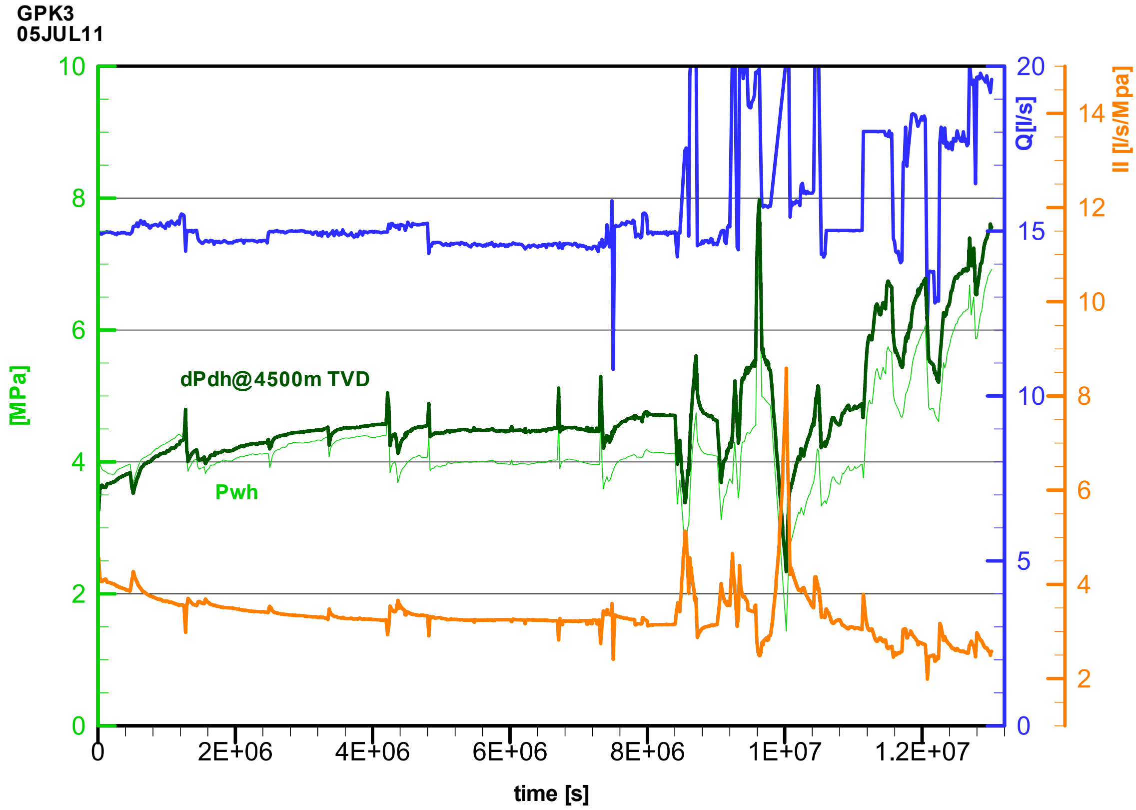


Figure 8: *Calculated Injectivity Index II and downhole overpressure dPdh at 4500 m TVD for GPK3 and an initial pressure at 4500 m TVD of **45.4 MPa***

5. HEX-B calculations for GPK4

5.1. Model used

No measured initial logging values for a calibration of the GPK4 borehole model are available. The pT-profile was logged 5e6 sec after the test started. The model for the rock parameters was calibrated with the produced wellhead temperature.

Table 3: Borehole/rock model in HEX-B for GPK4 production well

Bore hole parameters						Rock mass parameters	
Depth section MD [m] Nr	from:	to:	Inner radius [m]	Flow rate [% of injection rate]	Average wall roughness [mm]	Thermal conductivity [W/m K]	Specific heat capacity [J/m^{3}K]
1	0	1500.	0.11	100	0.15	2.0	2.2 10^6
2	1500	3800	0.11	100	0.15	3.0	2.2 10^6
3	3800	4800	0.11	100	0.15	2.0	2.2 10^6

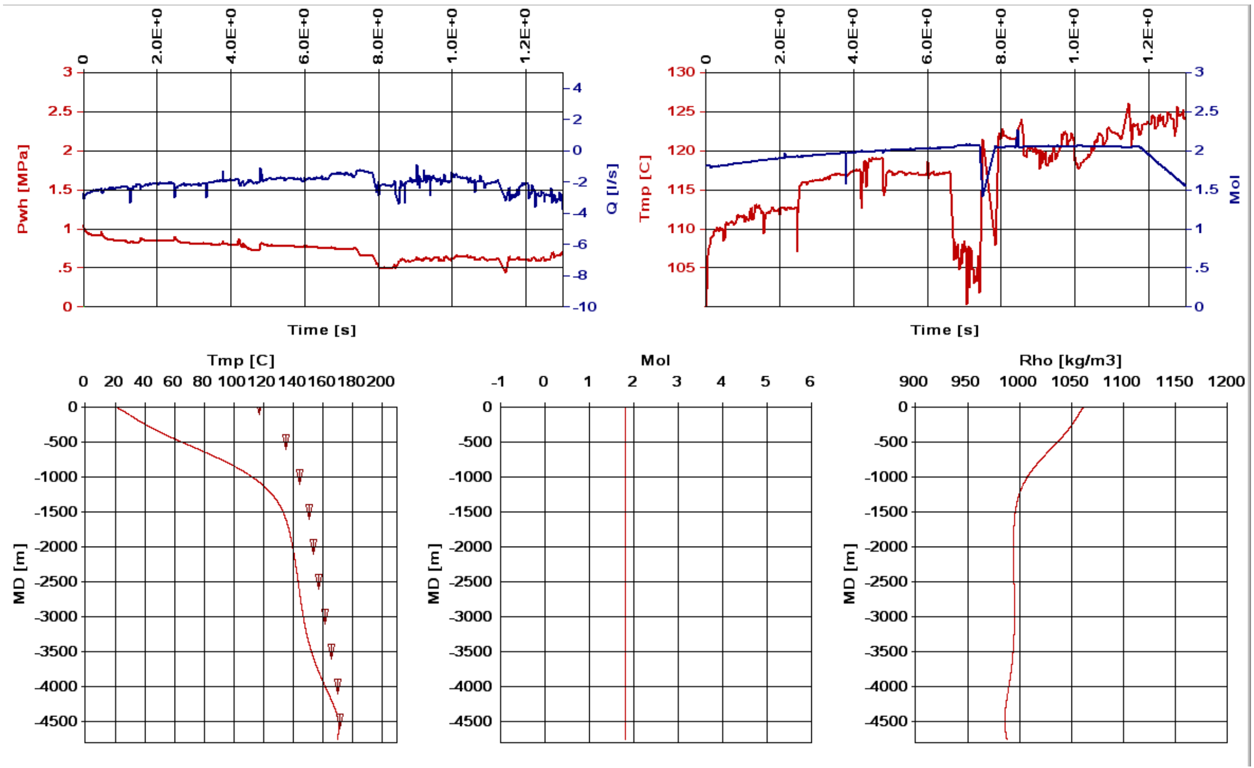


Figure 9: Initial values at the well head and in the borehole of GPK4 used for HEX-B, indicated also the logged temperatures after 5e6 s.

At GPK4 the TVD 4500 m corresponds to 4769 m MD. Assuming an initial NaCl-molality of 1.8 in the borehole and an initial wellhead pressure of **1.05 MPa** the pressure at 4769 m MD is **45.3 MPa**.

5.2. Results GPK4

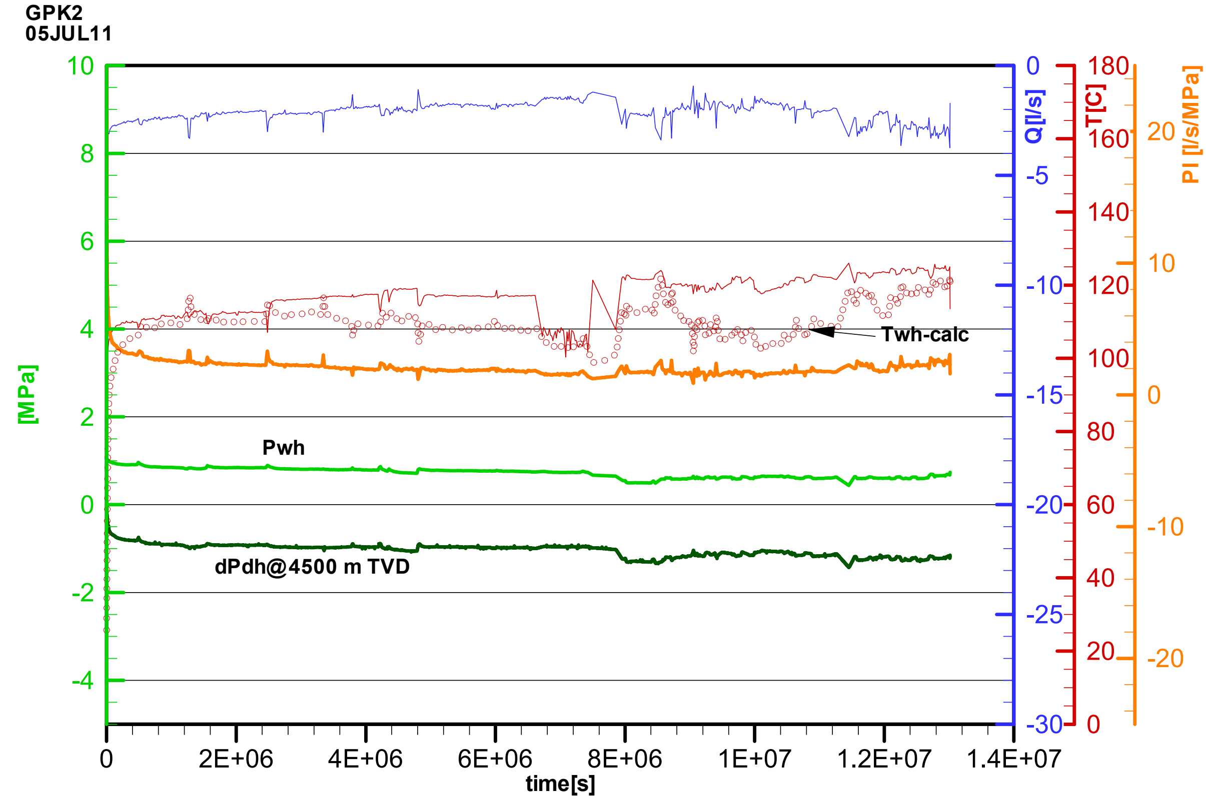


Figure 10: Calculated Productivity index PI and downhole overpressure dPdh at 4500 m TVD for GPK4. Also indicated the fit of the wellhead temperature (calculated values dotted).

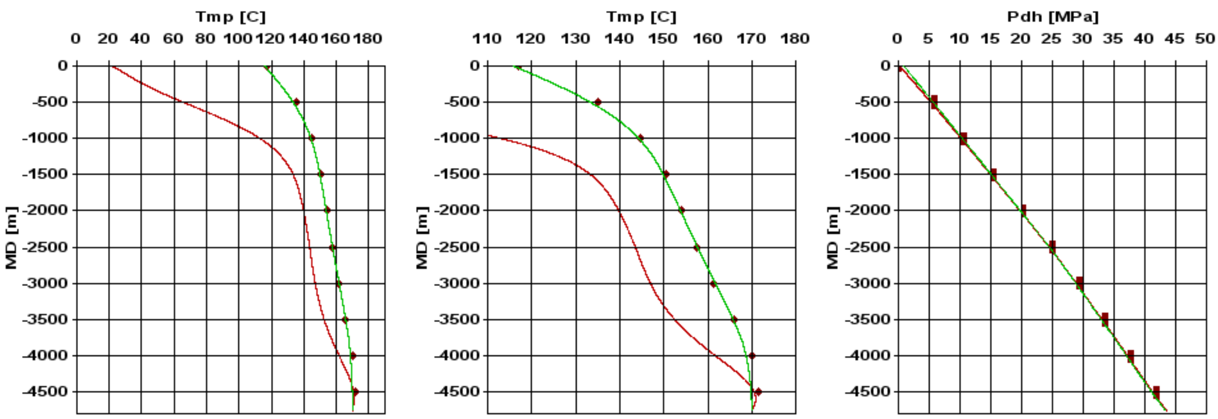


Figure 11: Fit of the temperatures and pressures measured after 5e6 s in GPK4.

6. Summary of results

6.1. Absolute Pressure at 4500 m TVD

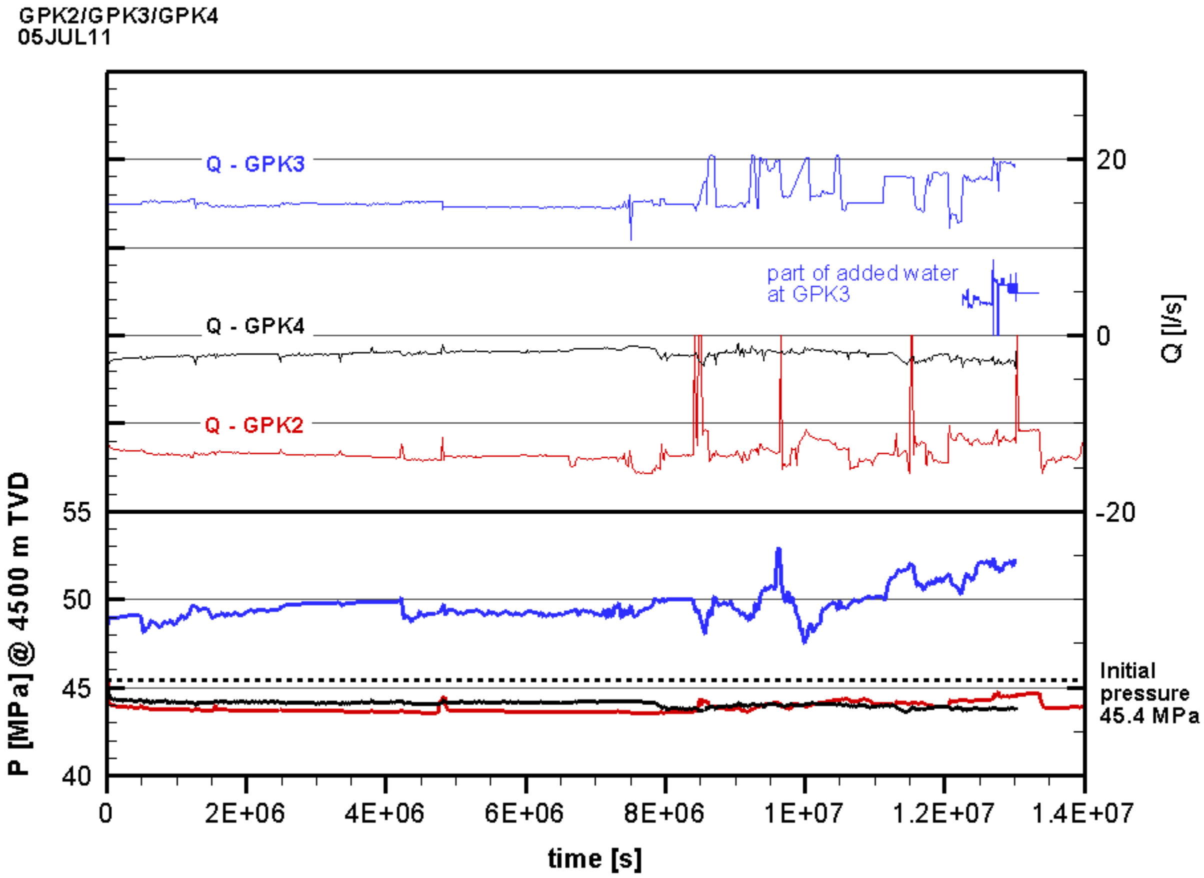


Figure 12: Flow rate and calculated downhole pressure at 4500 m TVD. Negative Q is production.

6.2. Injectivity/Productivity Indices II/PI

The definition of the Injectivity Index II and the Productivity Index PI is:

$$PI = II = \frac{Q}{P_{4500\,TVD,eq} - P_{4500\,TVD,0}} \qquad \text{[l/s/MPa]}$$

	GPK2	GPK3	GPK4
$P_{4500TVD,0}$ [MPa]	45.4	45.4	45.3
$P_{4500TVD,eq}$ [MPa]	43.6	49.9	44.3
$\Delta P_{4500TVD}$ [MPa]	-1.8	4.5	-0.8
Q [l/s]	-13.5	14.5	-1.6
PI / II eq [l/s/MPa]	**7.5**	**3.2**	**2.1**
PI / II all (mean ± σ)	**9.3 ± 3.2**	**3.6 ± 0.5**	**2.1 ± 1.0**

The point "eq" is assumed about at 6e6 sec.

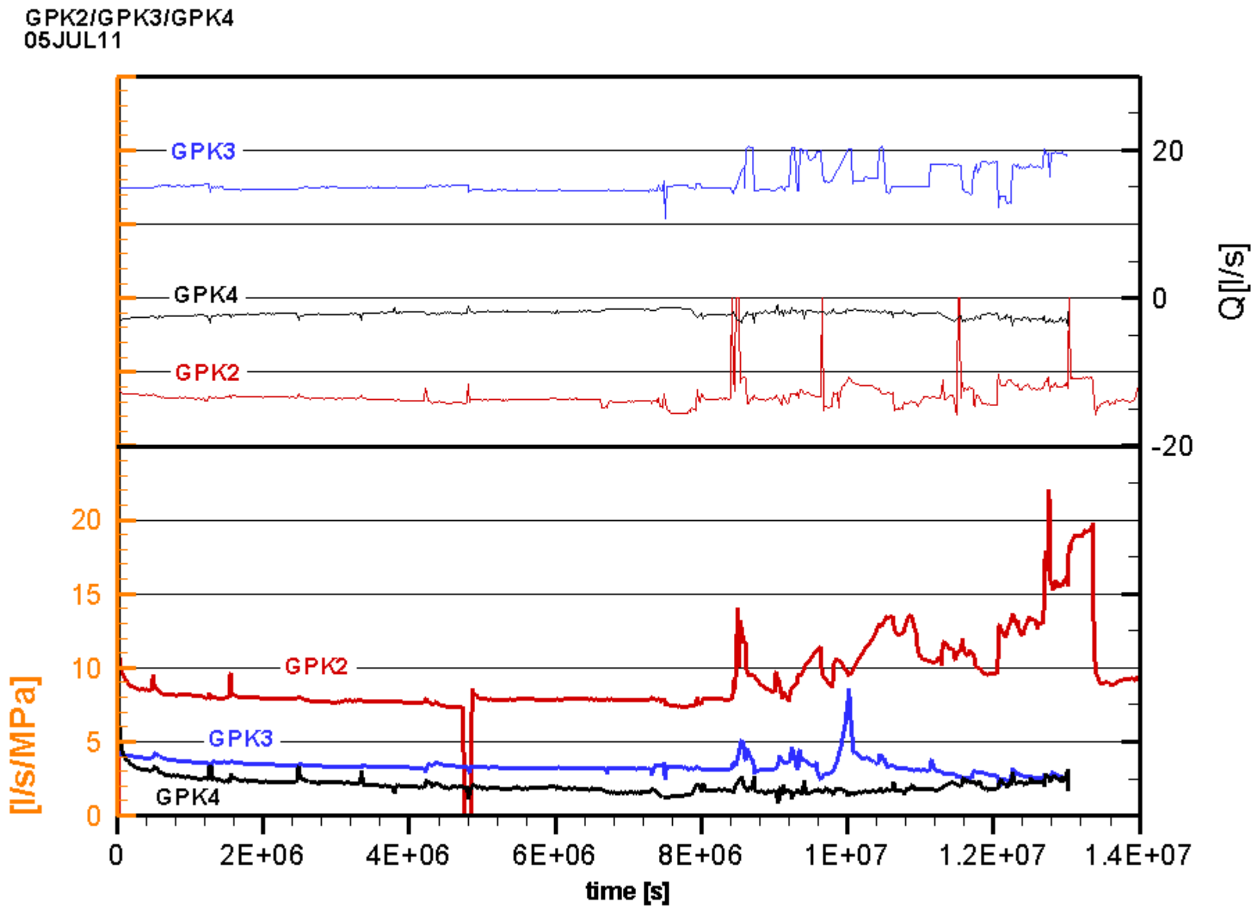


Figure 13: Injectivity/Productivity Index II/PI [l/s/MPa]. Negative Q is production.

6.3. "Reservoir Index" during circulation

An interesting concept that is to be developed is the so-called "Reservoir Index", that can be calculated during circulations. The reservoir Index can be calculated by:

$$RI = \frac{Q}{dPdh_{4500TVD,GPK3} - dPdh_{4500TVD,GPKprod}}$$

Assuming that the produced fluid in production wells corresponds to the injected fluid in GPK3, this index is representative of the properties of the media between injection well GPK3 and the considered production well (Figure 14).

	GPK2	GPK3	GPK4
$dPdh_{4500TVD, eq}$ [MPa]	-1.8	+4.5	-0.8
ΔP to GPK3 [MPa]	6.3		5.3
Q [l/s]	-13.5	14.5	-1.6
"Res. Index" [l/s/MPa]	**2.14**		**0.3**

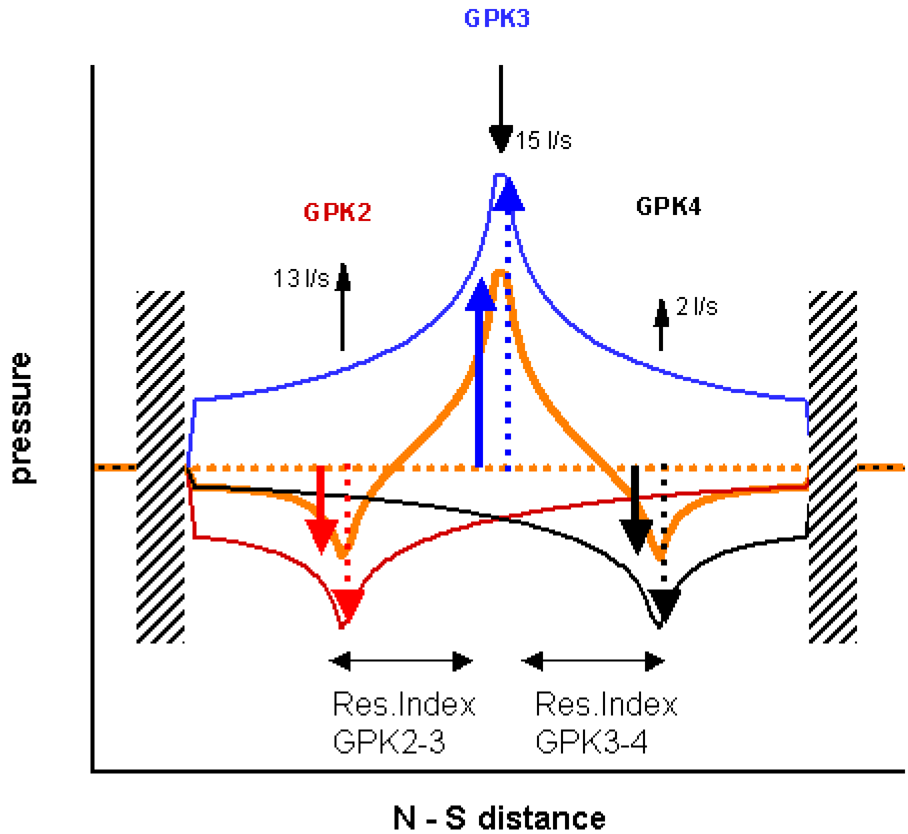


Figure 14: Concept of "Reservoir Index"

7. Observations/Remarks

- The assumed initial wellhead pressures influence directly the initial downhole pressure. At an equilibrium state the initial downhole pressure at 4500 m TVD should be the same at all three boreholes assuming a connection to the same reservoir. The difference in Pwh0 between GPK3 and GPK2 of 1 MPa is also reflected at 4500 m TVD. Assuming the values for Pwh0 are correct, this deviation can be explained as an effect of a slightly different initial profile of the temperature or NaCl-molality. The pressure of **45.4 MPa at 4500 m TVD** is assumed to be the correct value at all boreholes.

- The increase of the injection rate at GPK3 resulted clearly in an increase of the productivity index at GPK2. The increase of the downhole pressure is only minor due to the generally decrease of the production. Therefore the ratio between the flow rate and the pressure difference at reservoir depth (productivity/injectivity index) is an useful parameter to interpret tests.

- No effect due to the change of the injection rate at GPK3 could be observed at GPK4. The hydraulic connection of the two wells is in fact poor.

- Determining the productivity or injectivity of a well means calculating the pressure changes at reservoir depth due to a specific flow rate. The wellhead pressure is heavily superimposed by the varying buoyancy forces in the well due to temperature changes (and concentration changes, at high rates also friction losses) and can therefore not be used directly.