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*Date* : 16-06-2023  
*Subject* : VDB-GT-06 – Maximum injection pressure  
*Version* : v2

### 1. Introduction

The objective of this memo is to provide a flow-dependent maximum injection pressure for VDB-GT-06.

### 2. Well Type

VDB-GT-06 will be drilled as an injection well, forming a geothermal doublet with production well VDB-GT-05.

### 3. Maximum Injection Pressures

Maximum injection pressures (at wellhead level) have been calculated as per the SodM/TNO protocol as displayed in Table 2, Table 3 and Table 4.

#### 3.1 Injection protocol limitations

SodM Protocol (bepaling maximale injectiedrukken bij aardwarmtewinning – v3 Apr 2019), states that a correction for influence of thermal effects on fracture propagation including safety margin should be included with the calculation of maximum injection pressures.

In order to prevent thermal fracturing of the formation, the differential temperature allowance of the injected water in the reservoir is limited. The minimum horizontal stress in the formation is a reaction from the vertical overburden stress distributed by the Poisson ratio. Cooling down the formation affects the formation's Poisson ratio and may increase the potential of thermal fracturing. The effects of viscosity and increased fluid density for cooler fluid temperature may also have an influence, however this is considered very little / neglectable (TNO thermal fracturing report, 2015).

#### Rule of thumb

In case the difference ( $\Delta T$ ) between injection fluids and reservoir temperature exceeds 40 °C, current SodM injection protocol cannot be followed and a reduction in maximum allowable injection pressure may have to be accounted for. A conservative rule of thumb is used where maximum injection pressure is corrected with 1 bar per °C above the 40 °C  $\Delta T$  boundary.

#### VDB specific

Normal reservoir temperature is 66 °C (considering top Delft reservoir at 1755 m and the local temperature gradient of 3.17 °C/100m), therefore, to meet the SodM Injection protocol, maximum injection temperature should not be lower than 26 °C. However, the geothermal system is planned to be complemented with heat pumps, which are in operation when heat demand is high and may cause

lower injection temperatures. The injection pressure at reservoir level must be corrected (reduced) for this.

The injected water encounters friction in the well, causing a dynamic pressure loss. This pressure loss can be added to the allowable injection pressure at wellhead level.

The standard SodM protocol provides a maximum injection pressure of 51 bar at reservoir level for a  $\Delta T$  of up to 40 °C (see Table 2 for calculation). A  $\Delta T$  of 40 °C yields an injection temperature of 26 °C.

- 1) **Case 1:** Table 2, With an injection temperature of 15 °C, 11 °C additional reduction in injection temperature must be corrected for. Therefore 11 bar is deducted from the maximum injection pressure, as per the approved rule of thumb.
- 2) **Case 2:**
- 3) Table 3, With an injection temperature of 25 °C, 1 °C additional reduction in injection temperature must be corrected for. Therefore 1 bar is deducted from the maximum injection pressure, as per the approved rule of thumb.
- 4) **Case 3:** Table 4, An injection pressure of 35 °C falls within a  $\Delta T$  of 40 °C so no reduction in injection pressure is required.

### 3.2 Dynamic Pressure loss

Dynamic pressure loss is calculated for various flow rates up to 450 m<sup>3</sup>/hr. Below graph in Figure 1 shows the calculated pressure loss including the calculated maximum THP (Tubing Head Pressure) as per the SodM/TNO protocol including > 40 °C temperature differential correction of 11 bar and 1 bar.

Input variables:

- Top Delft Sandstone: 1755 m TVD below GL. Source: Detailed design document for wells VDB-GT-05 to 08.
- Brine density: 1.08 g/cm<sup>3</sup> at 20 °C for all VDB wells is considered conservative and representative.

When the injection water temperature is changed from 15 °C to 25 °C and 35 °C, the density and viscosity changes as follows:

| Temperature                 | 15 °C                   | 25 °C                   | 35 °C                   |
|-----------------------------|-------------------------|-------------------------|-------------------------|
| Density of brine injector   | 1.083 g/cm <sup>3</sup> | 1.081 g/cm <sup>3</sup> | 1.078 g/cm <sup>3</sup> |
| Viscosity of brine injector | 1.33 cp                 | 1.12 cp                 | 0.95 cp                 |

Table 1: Changes in input variables with variable injection temperatures.

When the injected water temperature is increased, the density and viscosity decreases at higher temperature. This change in water temperature also affects the dynamic pressure loss as shown in Table 2,

Table 3 and Table 4. However, the difference in dynamic pressure loss is minimal, within 0.24 bar for the well between 15 °C and 35 °C at highest flow rate.

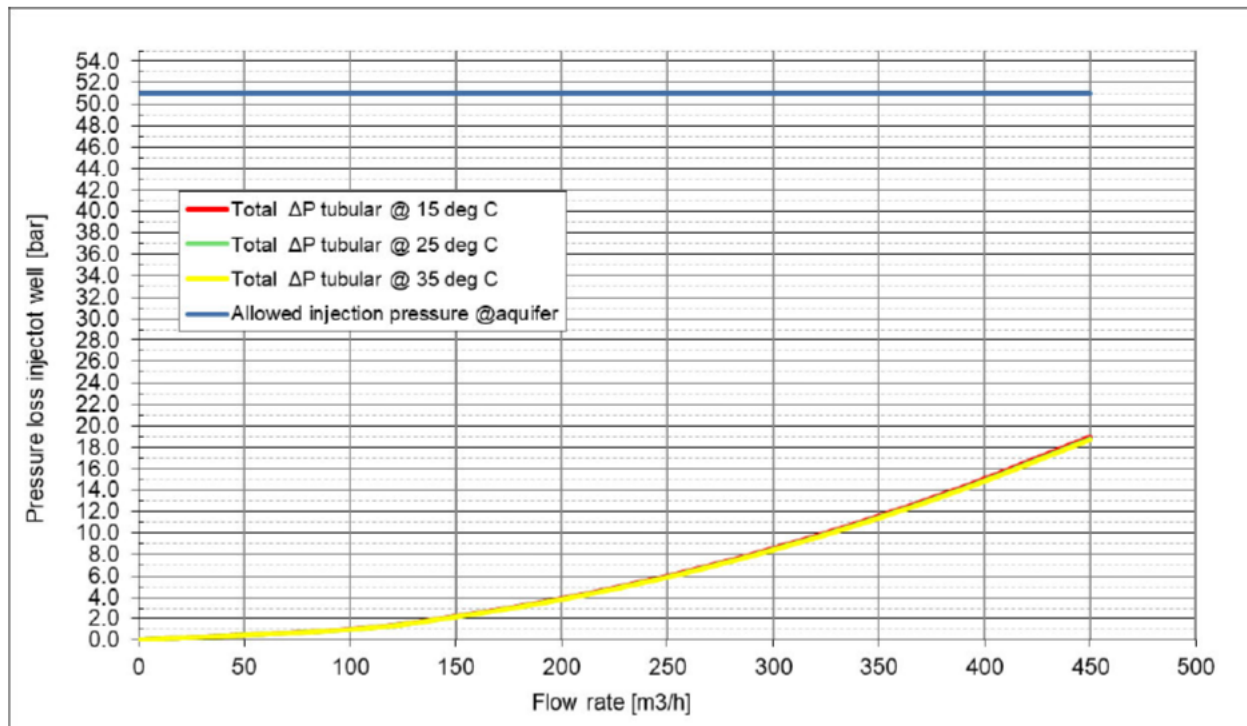


Figure 1: VDB-GT-06 Injection pressure for various flowrates. The blue line represents the calculated maximum injection pressure as per TNO/SodM protocol, minus correction required for more than 40 °C cooling.

The maximum injection pressure (at wellhead level) has been calculated as per the SodM/TNO protocol and is displayed in Table 2,

Table 3 and Table 4 below. The pressure correction (see par 3.1) is deducted from the maximum injection pressure as per the SodM protocol.

Table 2: VDB-GT-06 maximum injection pressures and input variables when water is injected at  $T \approx 15^\circ\text{C}$ .

| Well      | SodM / TNO Protocol    |                     |                                          |                     |                                              |                                                    |                                           | Pressure loss          |                               |                                              |
|-----------|------------------------|---------------------|------------------------------------------|---------------------|----------------------------------------------|----------------------------------------------------|-------------------------------------------|------------------------|-------------------------------|----------------------------------------------|
|           | Top Delft SS (mTVD GL) |                     | Density Brine ( $\text{g}/\text{cm}^3$ ) |                     | Maximum Injection $\Delta P$ @ aquifer (bar) | Correction for $\Delta T > 40^\circ\text{C}$ (bar) | max. Corrected injection $\Delta P$ (bar) | Injection rate (m3/hr) | Dynamic $\Delta P$ well (bar) | Maximum allowed Injection pressure @WH (bar) |
| VDB-GT-06 | 1755                   | $\times (0,135 - ($ | 1,08                                     | $\times 0,0981)) =$ | 51                                           | - 11                                               | 40                                        | 240                    | 5.5                           | 45.5                                         |
|           |                        |                     |                                          |                     |                                              |                                                    |                                           | 265                    | 6.7                           | 46.7                                         |
|           |                        |                     |                                          |                     |                                              |                                                    |                                           | 292                    | 8.1                           | 48.1                                         |
|           |                        |                     |                                          |                     |                                              |                                                    |                                           | 325                    | 10.0                          | 50.0                                         |
|           |                        |                     |                                          |                     |                                              |                                                    |                                           | 359                    | 12.1                          | 52.1                                         |

Table 3: VDB-GT-06 maximum injection pressures and input variables when water is injected at  $T \approx 25^\circ\text{C}$ .

| Well      | SodM / TNO Protocol    |                     |                                          |                     |                                              |                                                    |                                           | Pressure loss                             |                               |                                               |
|-----------|------------------------|---------------------|------------------------------------------|---------------------|----------------------------------------------|----------------------------------------------------|-------------------------------------------|-------------------------------------------|-------------------------------|-----------------------------------------------|
|           | Top Delft SS (mTVD GL) |                     | Density Brine ( $\text{g}/\text{cm}^3$ ) |                     | Maximum Injection $\Delta P$ @ aquifer (bar) | Correction for $\Delta T > 40^\circ\text{C}$ (bar) | Corrected max. injection $\Delta P$ (bar) | Injection rate ( $\text{m}^3/\text{hr}$ ) | Dynamic $\Delta P$ well (bar) | Maximum allowed Injection pressure @ WH (bar) |
| VDB-GT-06 | 1755                   | $\times (0,135 - ($ | 1,08                                     | $\times 0,0981)) =$ | 51                                           | - 1                                                | 50                                        | 240                                       | 5.5                           | 55.4                                          |
|           |                        |                     |                                          |                     |                                              |                                                    |                                           | 265                                       | 6.6                           | 56.6                                          |
|           |                        |                     |                                          |                     |                                              |                                                    |                                           | 292                                       | 8.0                           | 58.0                                          |
|           |                        |                     |                                          |                     |                                              |                                                    |                                           | 325                                       | 9.9                           | 59.9                                          |
|           |                        |                     |                                          |                     |                                              |                                                    |                                           | 359                                       | 12.0                          | 62.0                                          |

Table 4: VDB-GT-06 maximum injection pressures and input variables when water is injected at  $T \approx 35^\circ\text{C}$ .

| Well      | SodM / TNO Protocol    |                     |                                          |                     |                              |                                                    |                                           | Pressure loss                             |                               |                                               |
|-----------|------------------------|---------------------|------------------------------------------|---------------------|------------------------------|----------------------------------------------------|-------------------------------------------|-------------------------------------------|-------------------------------|-----------------------------------------------|
|           | Top Delft SS (mTVD GL) |                     | Density Brine ( $\text{g}/\text{cm}^3$ ) |                     | Maximum Injection $\Delta P$ | Correction for $\Delta T > 40^\circ\text{C}$ (bar) | Corrected max. injection $\Delta P$ (bar) | Injection rate ( $\text{m}^3/\text{hr}$ ) | Dynamic $\Delta P$ well (bar) | Maximum allowed Injection pressure @ WH (bar) |
| VDB-GT-06 | 1755                   | $\times (0,135 - ($ | 1,08                                     | $\times 0,0981)) =$ | 51                           | 0                                                  | 51                                        | 240                                       | 5.4                           | 56.4                                          |
|           |                        |                     |                                          |                     |                              |                                                    |                                           | 265                                       | 6.6                           | 57.6                                          |
|           |                        |                     |                                          |                     |                              |                                                    |                                           | 292                                       | 8.0                           | 58.9                                          |
|           |                        |                     |                                          |                     |                              |                                                    |                                           | 325                                       | 9.8                           | 60.8                                          |
|           |                        |                     |                                          |                     |                              |                                                    |                                           | 359                                       | 12.0                          | 62.9                                          |

The expected injection pressures at surface at different flow rates cannot be calculated at this stage due to the lack of available reservoir properties. The red line indicates maximum allowed injection pressure at surface in the figure below.

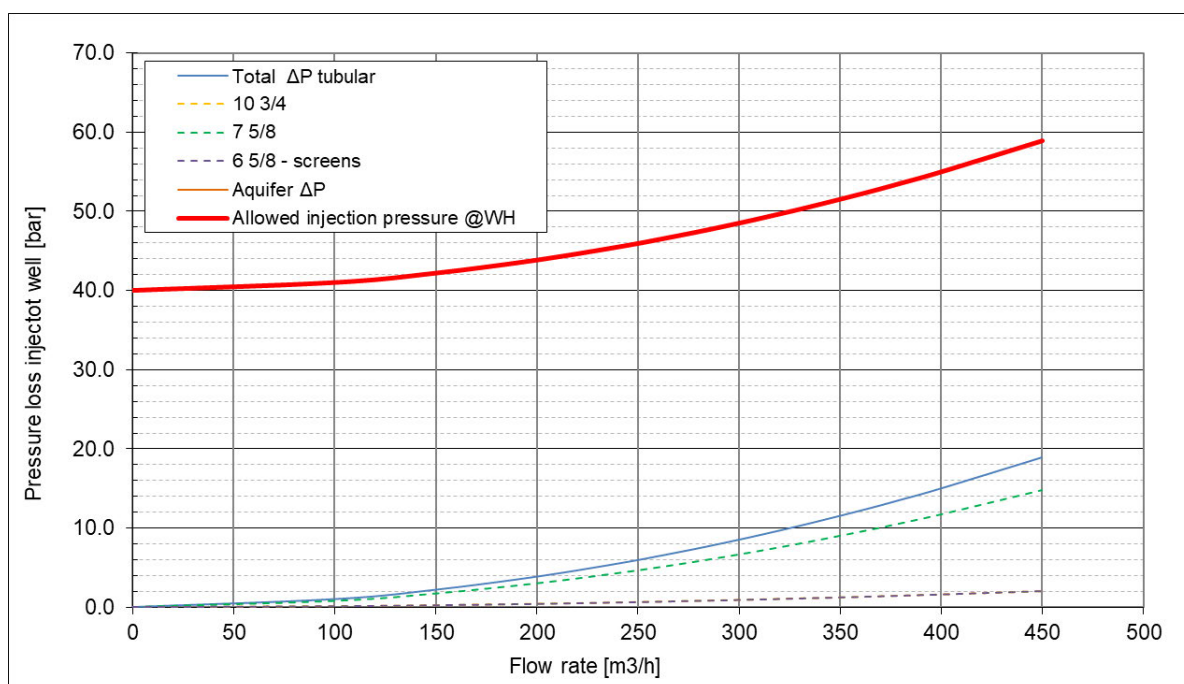


Figure 2: Case-1: When water is injected at  $T \approx 15$  °C. The dashed lines show the dynamic pressure loss per tubular, the blue line the combined tubular dynamic pressure loss, the orange line the expected pressure loss in the aquifer. The red line marks the maximum allowed injection pressure at wellhead level.

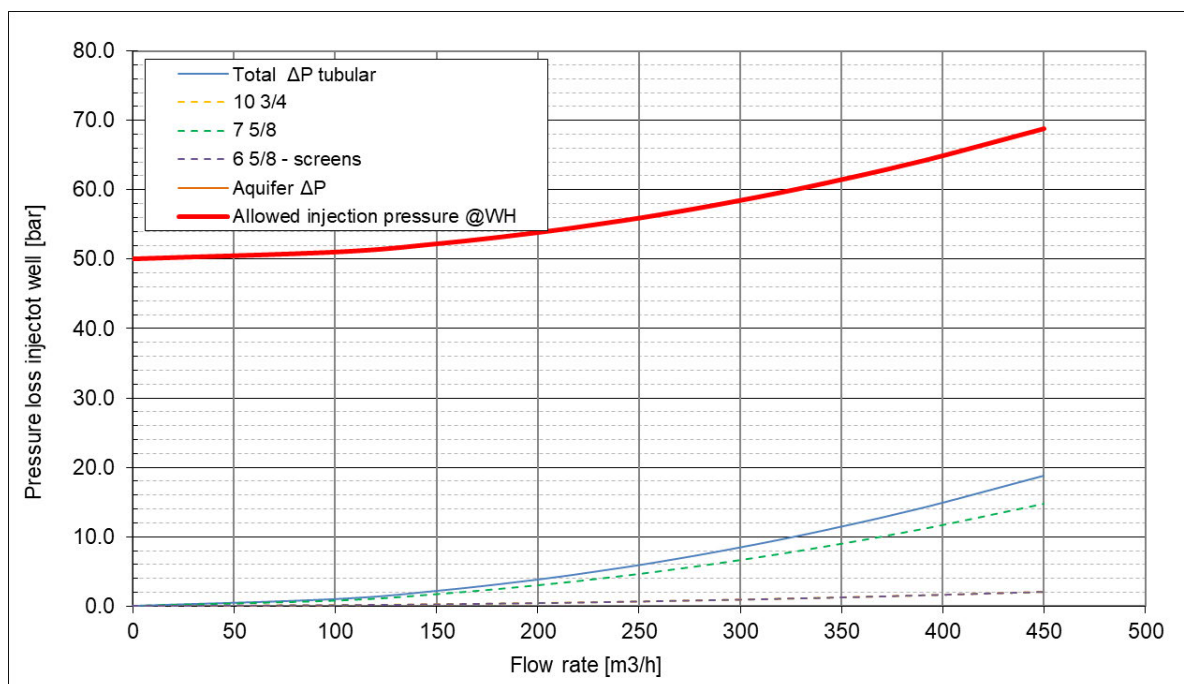


Figure 3: Case-2: When water is injected at  $T \approx 25$  °C. The dashed lines show the dynamic pressure loss per tubular, the blue line the combined tubular dynamic pressure loss, the orange line the expected pressure loss in the aquifer. The red line marks the maximum allowed injection pressure at wellhead level.

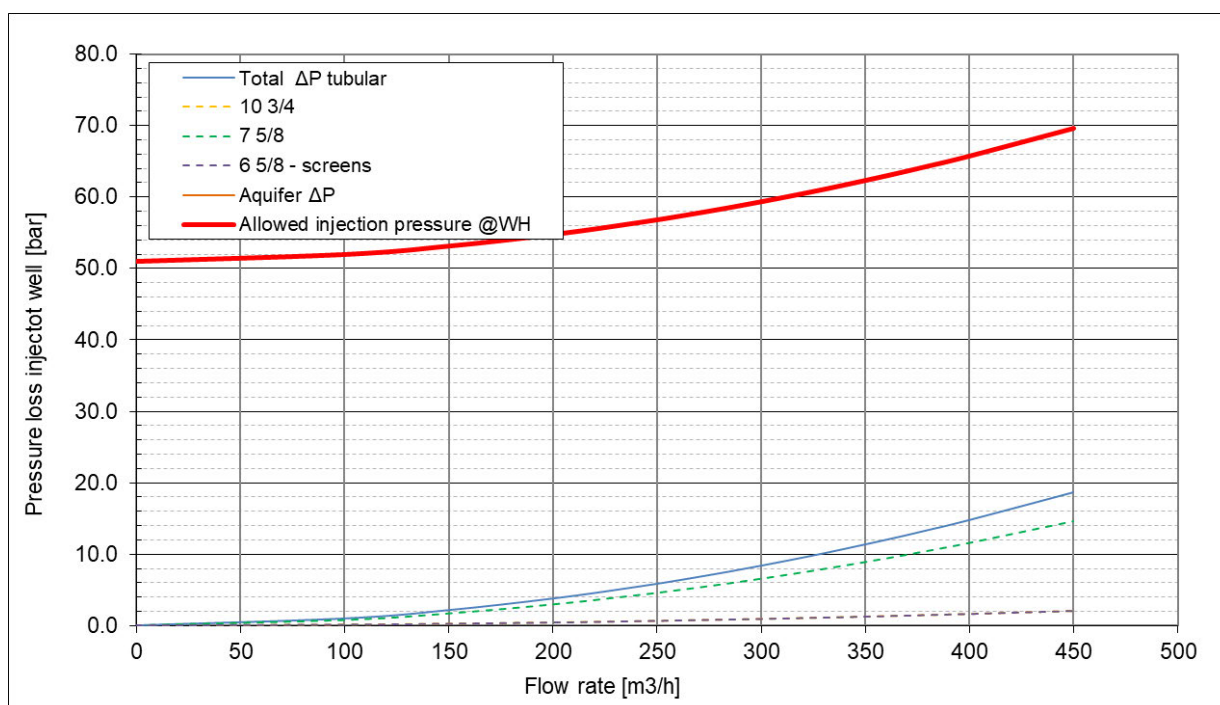


Figure 4: Case-3: When water is injected at  $T \approx 35^\circ\text{C}$ . The dashed lines show the dynamic pressure loss per tubular, the blue line the combined tubular dynamic pressure loss, the orange line the expected pressure loss in the aquifer. The red line marks the maximum allowed injection pressure at wellhead level.

### 4. Conclusion

The maximum injection pressures (at wellhead level) were calculated at different flow rates. From the derived data, it can be concluded that for fixed input of well specifications, the difference in injection pressure is directly related to injected water temperature. With the increase in injection water temperature, the dynamic pressure loss increases.

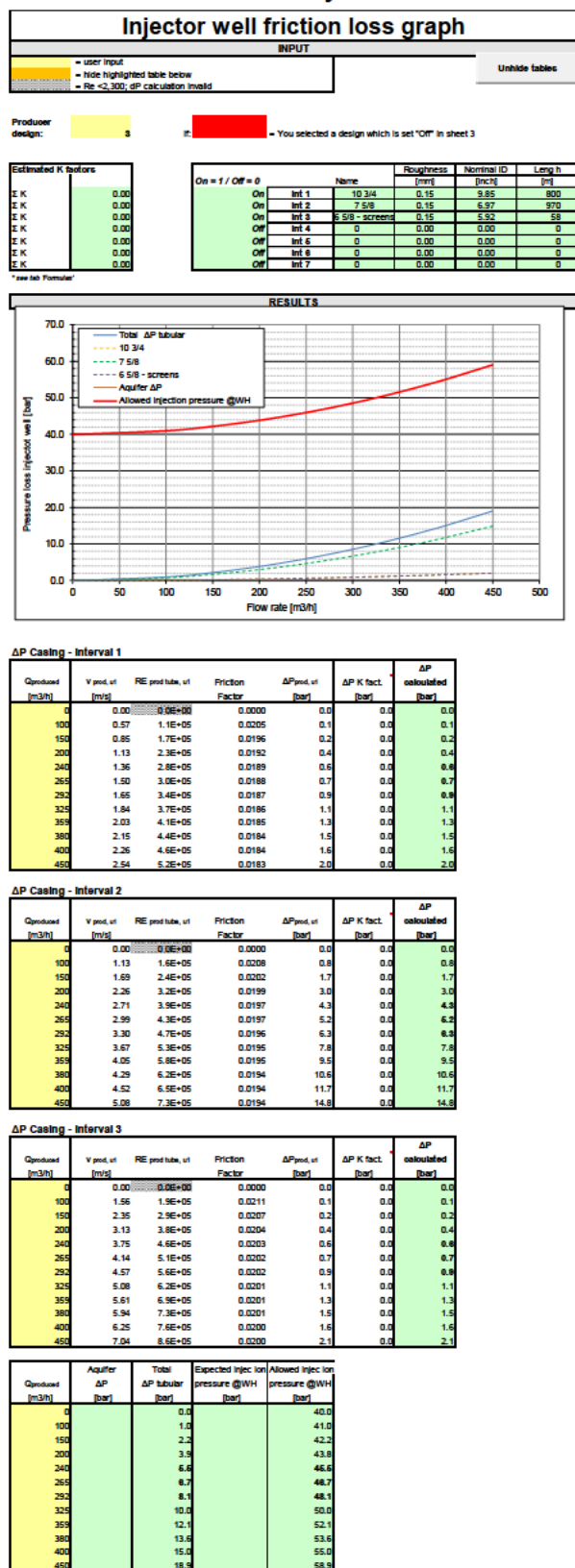
### Attachment: Well schematic

| Nr. | Geothermal Injection Well           | Planned Design VDB-GT-06 | Contingency<br>In case of insufficient production in<br>Ablasserdam | Depth | Depth | Hole | Pipe OD | Collar | Pipe ID | Pipe ID | Geology         |        |                          |                 |
|-----|-------------------------------------|--------------------------|---------------------------------------------------------------------|-------|-------|------|---------|--------|---------|---------|-----------------|--------|--------------------------|-----------------|
|     |                                     |                          |                                                                     | m     | m     | in   | in      | in     | in      | in      | Depth (top) (m) | Member | Formation                | Group           |
|     |                                     |                          |                                                                     | td    | ah    |      |         | (nom)  |         | (drift) | td              | ah     |                          |                 |
| 1   | 20" Conductor                       |                          |                                                                     | 80    | 80    |      | 20.000  |        |         |         | 0               | 0      | Naaldwijk-Perce          |                 |
|     | Kick off Point                      |                          |                                                                     |       |       |      |         |        |         |         | 112             | 112    | Maasvluis                | Upper North Sea |
|     |                                     |                          |                                                                     |       |       |      |         |        |         |         | 263             | 263    | Oosterhout               |                 |
|     |                                     |                          |                                                                     |       |       |      |         |        |         |         | 385             | 388    | Breda                    |                 |
|     | 10 5/8" 51 ppf L-80 13 Cr           |                          |                                                                     |       |       |      |         |        |         |         | 429             | 430    | Ommelanden               | Chalk           |
|     | EOB, at 17.79° inclination          |                          |                                                                     |       |       |      |         |        |         |         | 510             | 515    | Teset Marlstone          |                 |
|     |                                     |                          |                                                                     |       |       |      |         |        |         |         | 541             | 547    | Upper Holland Marl       |                 |
|     | 10 3/4" x 7 5/8" 13 Cr Tie-back X/O |                          |                                                                     |       |       |      |         |        |         |         | 601             | 610    | Middle Holland Claystone |                 |
| 2   | 9 5/8" TOL (Liner Hanger + Packer)  |                          |                                                                     |       |       |      |         |        |         |         | 782             | 800    | Holland                  |                 |
|     | 13 5/8" 61 ppf K-55                 |                          |                                                                     |       |       |      | 16.000  | 13.375 |         | 12.415  | 829             | 850    | Holland Greensand        | Rijnland        |
|     |                                     |                          |                                                                     |       |       |      |         |        |         |         | 901             | 885    |                          |                 |
|     |                                     |                          |                                                                     |       |       |      |         |        |         |         | 910             | 937    | Lower Holland Marl       |                 |
|     |                                     |                          |                                                                     |       |       |      |         |        |         |         | 1040            | 1074   | De Lier                  |                 |
|     | 7 1/8" 26.4 ppf L-80 13 Cr          |                          |                                                                     |       |       |      |         |        |         |         | 1125            | 1164   | Vieland Claystone        |                 |
|     |                                     |                          |                                                                     |       |       |      |         |        |         |         |                 |        | Berkel Sandstone         | Vieland         |
|     |                                     |                          |                                                                     |       |       |      |         |        |         |         | 1469            | 1548   | Berkel Sand/Claystone    |                 |
|     |                                     |                          |                                                                     |       |       |      |         |        |         |         |                 |        | Rijswijk                 |                 |
|     | 11 3/4" x 7 5/8" 13 Cr Tie-back PBR |                          |                                                                     |       |       |      |         |        |         |         | 1770            | 1705   | Rodenrij's Claystone     |                 |
|     | TOL (Liner Hanger + Packer)         |                          |                                                                     |       |       |      |         |        |         |         | 1753            | 1820   |                          |                 |
| 3   | 9 5/8" 40 ppf K-55 Liner            |                          |                                                                     |       |       |      | 12.250  | 9.825  |         | 8.835   |                 |        |                          |                 |
|     |                                     |                          |                                                                     |       |       |      |         |        |         |         | 1755            | 1828   | Delft Sandstone          | Schieland       |
|     |                                     |                          |                                                                     |       |       |      |         |        |         |         | 1867            | 1940   |                          |                 |
|     |                                     |                          |                                                                     |       |       |      |         |        |         |         | 1838            | 1914   | Ablasserdam              |                 |
| 4   | 8 1/2" 24 ppf L-80 13 Cr Base pipe  |                          |                                                                     |       |       |      |         |        |         |         | 2382            | 2477   | Werkendam                | Altena          |
|     | TD 30 m below base Ablasserdam      |                          |                                                                     |       |       |      | 8.500   | 6.625  |         |         |                 |        |                          |                 |

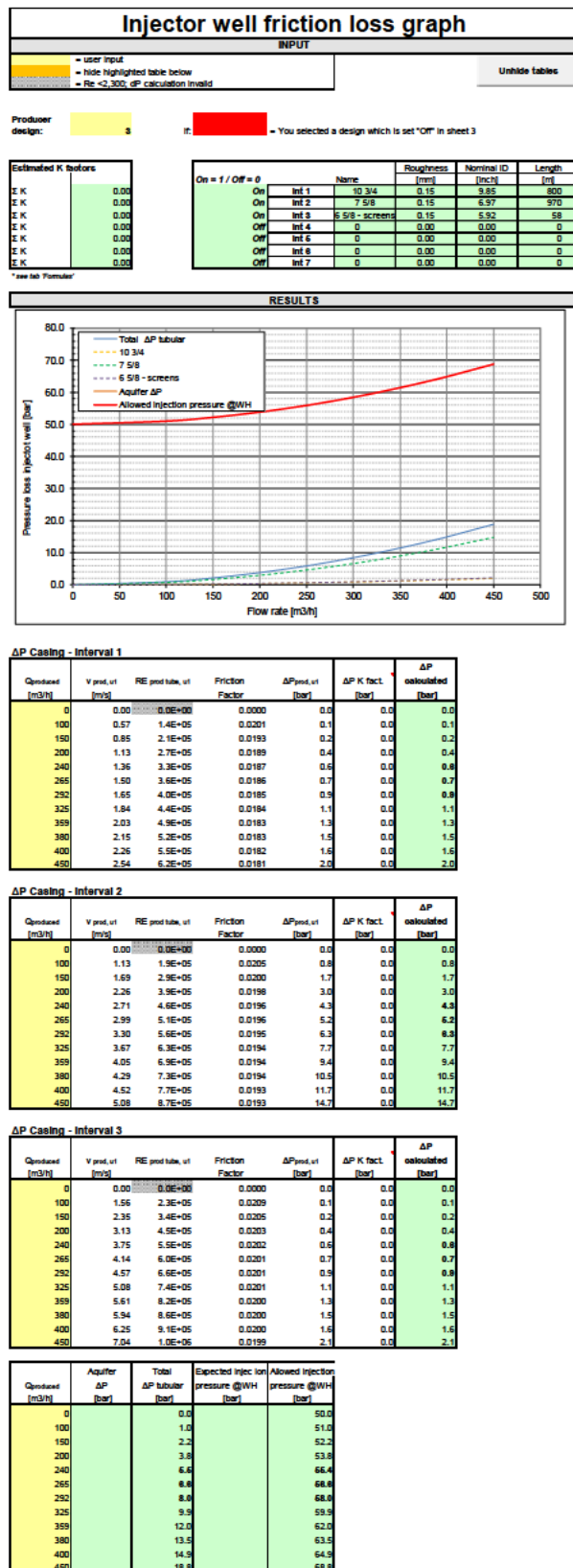
\*Not to scale

### Attachment: Dynamic pressure loss calculation

Case-1: When water is injected at  $T \approx 15^\circ\text{C}$ .



### Case-2: When water is injected at $T \approx 25^\circ\text{C}$ .



### Case-3: When water is injected at $T \approx 35^\circ\text{C}$ .

| Injector well friction loss graph                                                                                                                           |               |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------|
| INPUT                                                                                                                                                       |               |
| <input type="checkbox"/> user input<br><input type="checkbox"/> hide highlighted table below<br><input type="checkbox"/> Re < 2,300; dP calculation invalid | Unhide tables |

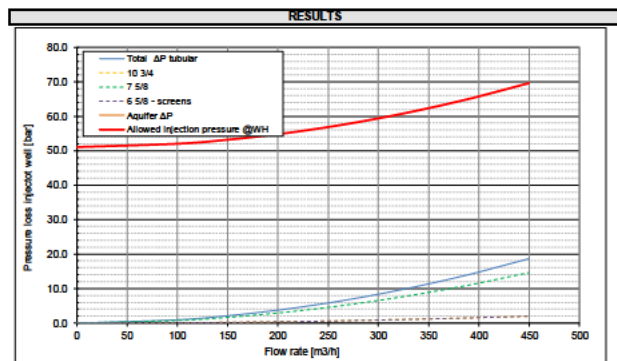
Producer design: 3 If: 3 - You selected a design which is set "Off" in sheet 3

| Estimated K factors |      |
|---------------------|------|
| E K                 | 0.00 |
| E K                 | 0.00 |
| E K                 | 0.00 |
| E K                 | 0.00 |
| E K                 | 0.00 |
| E K                 | 0.00 |
| E K                 | 0.00 |

| On = 1 / Off = 0 |                 |
|------------------|-----------------|
| Name             | Length [m]      |
| Int 1            | 10 3/4          |
| Int 2            | 7 5/8           |
| Int 3            | 5 5/8 - screens |
| Int 4            | 0               |
| Int 5            | 0               |
| Int 6            | 0               |
| Int 7            | 0               |

\*see tab Formulae



AP Casing - interval 1

| Q <sub>produced</sub> [m³/h] | V <sub>prod, u1</sub> [m/s] | RE prod tube, u1 | Friction Factor | ΔP <sub>prod, u1</sub> [bar] | ΔP K fact. [bar] | ΔP calculated [bar] |
|------------------------------|-----------------------------|------------------|-----------------|------------------------------|------------------|---------------------|
| 0                            | 0.00                        | 0.0E+00          | 0.0000          | 0.0                          | 0.0              | 0.0                 |
| 100                          | 0.57                        | 1.6E+05          | 0.0198          | 0.1                          | 0.0              | 0.1                 |
| 150                          | 0.85                        | 2.4E+05          | 0.0191          | 0.2                          | 0.0              | 0.2                 |
| 200                          | 1.13                        | 3.2E+05          | 0.0187          | 0.4                          | 0.0              | 0.4                 |
| 240                          | 1.36                        | 3.8E+05          | 0.0185          | 0.6                          | 0.0              | 0.6                 |
| 265                          | 1.50                        | 4.2E+05          | 0.0184          | 0.7                          | 0.0              | 0.7                 |
| 292                          | 1.65                        | 4.7E+05          | 0.0183          | 0.9                          | 0.0              | 0.9                 |
| 325                          | 1.84                        | 5.2E+05          | 0.0183          | 1.1                          | 0.0              | 1.1                 |
| 359                          | 2.03                        | 5.7E+05          | 0.0182          | 1.3                          | 0.0              | 1.3                 |
| 380                          | 2.15                        | 6.1E+05          | 0.0181          | 1.4                          | 0.0              | 1.4                 |
| 400                          | 2.26                        | 6.4E+05          | 0.0181          | 1.6                          | 0.0              | 1.6                 |
| 450                          | 2.54                        | 7.2E+05          | 0.0180          | 2.0                          | 0.0              | 2.0                 |

AP Casing - interval 2

| Q <sub>produced</sub> [m³/h] | V <sub>prod, u1</sub> [m/s] | RE prod tube, u1 | Friction Factor | ΔP <sub>prod, u1</sub> [bar] | ΔP K fact. [bar] | ΔP calculated [bar] |
|------------------------------|-----------------------------|------------------|-----------------|------------------------------|------------------|---------------------|
| 0                            | 0.00                        | 0.0E+00          | 0.0000          | 0.0                          | 0.0              | 0.0                 |
| 100                          | 1.13                        | 2.3E+05          | 0.0203          | 0.8                          | 0.0              | 0.8                 |
| 150                          | 1.69                        | 3.4E+05          | 0.0199          | 1.7                          | 0.0              | 1.7                 |
| 200                          | 2.26                        | 4.5E+05          | 0.0196          | 3.0                          | 0.0              | 3.0                 |
| 240                          | 2.71                        | 5.4E+05          | 0.0195          | 4.2                          | 0.0              | 4.2                 |
| 265                          | 2.99                        | 6.0E+05          | 0.0195          | 5.1                          | 0.0              | 5.1                 |
| 292                          | 3.30                        | 6.6E+05          | 0.0194          | 6.2                          | 0.0              | 6.2                 |
| 325                          | 3.67                        | 7.3E+05          | 0.0194          | 7.7                          | 0.0              | 7.7                 |
| 359                          | 4.05                        | 8.1E+05          | 0.0193          | 9.4                          | 0.0              | 9.4                 |
| 380                          | 4.29                        | 8.6E+05          | 0.0193          | 10.5                         | 0.0              | 10.5                |
| 400                          | 4.52                        | 9.0E+05          | 0.0193          | 11.6                         | 0.0              | 11.6                |
| 450                          | 5.08                        | 1.0E+06          | 0.0192          | 14.6                         | 0.0              | 14.6                |

AP Casing - interval 3

| Q <sub>produced</sub> [m³/h] | V <sub>prod, u1</sub> [m/s] | RE prod tube, u1 | Friction Factor | ΔP <sub>prod, u1</sub> [bar] | ΔP K fact. [bar] | ΔP calculated [bar] |
|------------------------------|-----------------------------|------------------|-----------------|------------------------------|------------------|---------------------|
| 0                            | 0.00                        | 0.0E+00          | 0.0000          | 0.0                          | 0.0              | 0.0                 |
| 100                          | 1.56                        | 2.7E+05          | 0.0207          | 0.1                          | 0.0              | 0.1                 |
| 150                          | 2.35                        | 4.0E+05          | 0.0204          | 0.2                          | 0.0              | 0.2                 |
| 200                          | 3.13                        | 5.3E+05          | 0.0202          | 0.4                          | 0.0              | 0.4                 |
| 240                          | 3.75                        | 6.4E+05          | 0.0201          | 0.6                          | 0.0              | 0.6                 |
| 265                          | 4.14                        | 7.0E+05          | 0.0201          | 0.7                          | 0.0              | 0.7                 |
| 292                          | 4.57                        | 7.8E+05          | 0.0200          | 0.9                          | 0.0              | 0.9                 |
| 325                          | 5.08                        | 8.6E+05          | 0.0200          | 1.1                          | 0.0              | 1.1                 |
| 359                          | 5.61                        | 9.5E+05          | 0.0200          | 1.3                          | 0.0              | 1.3                 |
| 380                          | 5.94                        | 1.0E+06          | 0.0199          | 1.5                          | 0.0              | 1.5                 |
| 400                          | 6.25                        | 1.1E+06          | 0.0199          | 1.6                          | 0.0              | 1.6                 |
| 450                          | 7.04                        | 1.2E+06          | 0.0199          | 2.0                          | 0.0              | 2.0                 |

| Q <sub>produced</sub> [m³/h] | Aquifer ΔP [bar] | Total ΔP tubular [bar] | Expected injection pressure @WH [bar] | Allowed injection pressure @WH [bar] |
|------------------------------|------------------|------------------------|---------------------------------------|--------------------------------------|
| 0                            | 0.0              | 0.0                    | 51.0                                  | 51.0                                 |
| 100                          | 1.0              | 1.0                    | 52.0                                  | 51.0                                 |
| 150                          | 2.2              | 2.2                    | 53.1                                  | 51.0                                 |
| 200                          | 3.8              | 3.8                    | 54.8                                  | 51.0                                 |
| 240                          | 6.4              | 6.4                    | 58.4                                  | 51.0                                 |
| 265                          | 8.8              | 8.8                    | 60.8                                  | 51.0                                 |
| 292                          | 10.9             | 10.9                   | 62.9                                  | 51.0                                 |
| 325                          | 12.0             | 12.0                   | 64.4                                  | 51.0                                 |
| 359                          | 13.4             | 13.4                   | 65.8                                  | 51.0                                 |
| 380                          | 14.8             | 14.8                   | 66.8                                  | 51.0                                 |
| 400                          | 16.2             | 16.2                   | 67.8                                  | 51.0                                 |
| 450                          | 18.7             | 18.7                   | 69.7                                  | 51.0                                 |

## Roughness factor steel tubulars

Roughness of pipes - Google Chrome

www.pressure-drop.com/Online-Calculator/rauh.html

|                            |                                |                    |
|----------------------------|--------------------------------|--------------------|
| Concrete, Centrifugal-     | new, smooth plastered          | 0.1 - 0.15 mm      |
| Concrete, Centrifugal-     | new, without plaster           | 0.2 - 0.8 mm       |
| Concrete, Steel-           | new, smooth                    | 0.1 - 0.15 mm      |
| Copper, drawn/pressed      | new                            | 0.0013 - 0.0015 mm |
| Copper, drawn/pressed      | used                           | to 0.03 mm         |
| Glass, drawn/pressed       | new                            | 0.0013 - 0.0015 mm |
| Glass, drawn/pressed       | used                           | to 0.03 mm         |
| Plastic, drawn/pressed     | new                            | 0.0013 - 0.0015 mm |
| Plastic, drawn/pressed     | used                           | to 0.03 mm         |
| Rubber                     | new, smooth                    | 0.0016 mm          |
| Steel                      | after long operation cleaned   | 0.15 - 0.20 mm     |
| Steel                      | homogeneous corrosion pits     | 0.15 mm            |
| Steel                      | intensely incrustated          | 2.0 - 4.0 mm       |
| Steel                      | slightly rusty and incrustated | 0.15 - 0.40 mm     |
| Steel, longitudinal welded | new, bituminized               | 0.01 - 0.05 mm     |
| Steel, longitudinal welded | new, galvanized                | 0.008 mm           |
| Steel, longitudinal welded | new, rolling skin              | 0.04 - 0.1 mm      |
| Steel, weldless            | new, comm. size galvanized     | 0.10 - 0.16 mm     |
| Steel, weldless            | new, neatly galvanized         | 0.07 - 0.10 mm     |
| Steel, weldless            | new, pickled                   | 0.03 - 0.04 mm     |
| Steel, weldless            | new, rolling skin              | 0.02 - 0.06 mm     |
| Steel, weldless            | new, unpickled                 | 0.03 - 0.06 mm     |
| Stoneware                  |                                | 0.25 mm            |
| Wood                       | after long operating           | 0.1 mm             |
| Wood                       | new                            | 0.2 - 1.0 mm       |

### Input data

| Injector                               |            |
|----------------------------------------|------------|
| Surface pressure before injection pump | 6 bar      |
| T after heat exchanger                 | 15 °C      |
| Static water level                     | 40 m       |
| NaCl mass fraction                     | 0.11 kg/kg |
| Viscosity brine injector               | 1.33 cp    |
| Pressure (average along well)          | 110 bar    |
| Density brine injector                 | 1.08 -     |

### Used formula's

|                                                                                                                                                                                                                                                                                    |  |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--|
| <b>Pijp drukval berekening (incl wandruwheid)</b>                                                                                                                                                                                                                                  |  |
| Bron: <a href="http://w3.tue.nl/uploads/media/Ptc1-h2.pdf">http://w3.tue.nl/uploads/media/Ptc1-h2.pdf</a>                                                                                                                                                                          |  |
| zodat voor de totale drukval geschreven kan worden                                                                                                                                                                                                                                 |  |
| $\Delta p_{tot} = \rho g(z_2 - z_1) + \left(f \frac{L}{D} + \sum K\right) \frac{1}{2} \rho \left(\frac{4Q}{\pi D}\right)^2$                                                                                                                                                        |  |
| $\Delta p = f \frac{L}{ID} \rho v^2$                                                                                                                                                                                                                                               |  |
| <b>Berekening voor frictiefactor f</b>                                                                                                                                                                                                                                             |  |
| Twee andere ijverige data-verwerkers hebben vergelijkingen opgesteld waaruit f direct als functie van Re en e/D kunnen worden opgelost. Beide uitdrukkingen zijn natuurlijk alleen geldig in het gebied Re > 2300. De vergelijking van Chen luidt                                  |  |
| $\frac{1}{\sqrt{f}} = -2.0 \log \left\{ \frac{\epsilon}{3.7065 D} - \frac{5.0452}{Re} \log \left( \frac{1}{2.8257} \left( \frac{\epsilon}{D} \right)^{1.1098} + \frac{5.8506}{Re} \right) \right\} \quad (2.19)$                                                                   |  |
| De vergelijking van Churchill is                                                                                                                                                                                                                                                   |  |
| $f = 8 \left( \left( \frac{8}{Re} \right)^{12} + \frac{1}{B^{12}} \right)^{1/12} \quad \text{met} \quad B = \left( 2.457 \ln \left( \frac{1}{\left( \frac{7}{Re} \right)^{0.9} + \frac{0.27\epsilon}{D}} \right) \right)^{16} + \left( \frac{37530}{Re} \right)^{16} \quad (2.20)$ |  |

### Lithostratigraphic column

| Lithostratigraphic column VDB-GT-05, VDB-GT-06, VDB-GT-07 & VDB-GT-08 |                       |                          |                              |                                   |                                                                                                                                                                                                                |      | Expected Depth (GL)                                 |      |           |      | Expected Depth (GL) |      |           |      |      |
|-----------------------------------------------------------------------|-----------------------|--------------------------|------------------------------|-----------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|-----------------------------------------------------|------|-----------|------|---------------------|------|-----------|------|------|
|                                                                       |                       |                          |                              |                                   |                                                                                                                                                                                                                |      | VDB-GT-05                                           |      | VDB-GT-06 |      | VDB-GT-07           |      | VDB-GT-08 |      |      |
| Era                                                                   | Group                 | Period                   | Formation                    | Member                            | Lithology                                                                                                                                                                                                      |      | mT05S                                               | mH   | mT05S     | mH   | mT05S               | mH   | mT05S     | mH   |      |
| Cenozoic                                                              | Upper North Sea<br>NU | Quaternary               | Naaldwijk-Peize<br>NUNA-NUPZ |                                   | Continental deposits. Fluvial sand, silt and clays                                                                                                                                                             |      | 0                                                   | 0    | 0         | 0    | 0                   | 0    | 0         | 0    |      |
|                                                                       |                       |                          | Maassluis<br>NUMS            |                                   | Very fine to coarse calcareous sand with some clay streaks.                                                                                                                                                    |      | 112                                                 | 112  | 112       | 112  | 112                 | 112  | 112       | 112  |      |
|                                                                       |                       | Tertiary                 | Oosterhout<br>NUOT           |                                   | Very fine to very coarse sand. Contains shell fragments.                                                                                                                                                       |      | 263                                                 | 263  | 263       | 263  | 263                 | 263  | 263       | 263  |      |
|                                                                       |                       |                          | Breda<br>NUBA                |                                   | Marine glauconitic sands with silty to sandy clays.                                                                                                                                                            |      | 385                                                 | 386  | 385       | 386  | 386                 | 386  | 386       | 386  |      |
|                                                                       | Chalk<br>CK           |                          | Ommelanden<br>CKGR           |                                   |                                                                                                                                                                                                                |      | 429                                                 | 429  | 429       | 430  | 429                 | 430  | 429       | 430  |      |
|                                                                       |                       |                          | Texel<br>CKTX                | Texel Marlstone<br>CKTXM          | White and light to medium grey, chalky marls, in places very silty to very sandy. Bottom section contains some very clayey marls. Glauconitic in places. Traces of shell fragments, glimmer, pyrite and chert. |      | 509                                                 | 514  | 510       | 515  | 510                 | 515  | 504       | 509  |      |
| Mesozoic                                                              | Rijnland<br>KN        | Holland<br>KNGL          |                              | Upper Holland Marl<br>KNGLU       | Light-grey and red-brown marls, characterised by a carbonate content which gradually increases towards the top.                                                                                                |      | 539                                                 | 547  | 541       | 547  | 533                 | 540  | 532       | 539  |      |
|                                                                       |                       |                          |                              | Middle Holland Claystone<br>KNGLM | Grey and/or red-brown calcareous shaly claystone with a distinctly lower lime content than the under- and overlying members.                                                                                   |      | 799                                                 | 843  | 800       | 820  | 778                 | 839  | 775       | 824  |      |
|                                                                       |                       |                          |                              | Holland Greensand<br>KNGLG        | Alternation of greenish grey, very glauconitic, very fine- to fine-grained, argillaceous sandstones.                                                                                                           |      | 873                                                 | 927  | 861       | 885  | 849                 | 929  | 836       | 896  |      |
|                                                                       |                       |                          |                              | Lower Holland Marl<br>KNGLL       | Grey and red-brown marl or calcareous, fissile claystone, frequently with intercalated bituminous claystone beds.                                                                                              |      | 911                                                 | 972  | 910       | 937  | 884                 | 974  | 878       | 946  |      |
|                                                                       |                       | Vlieland<br>KNNS<br>KNNC |                              | De Lier<br>KNNSL                  | Alternation of thin-bedded, very fine- to fine-grained argillaceous sandstones.                                                                                                                                |      | 1065                                                | 1147 | 1040      | 1074 | 1019                | 1145 | 990       | 1079 |      |
|                                                                       |                       |                          |                              | Vlieland Claystone<br>KNNC        | Dark brownish-grey to grey claystone. Mica and very fine lignitic matter are common. Generally, the claystones are only very slightly calcareous.                                                              |      | 1189                                                | 1289 | 1125      | 1164 | 1122                | 1277 | 1082      | 1189 |      |
|                                                                       |                       |                          |                              | Berkel Sandstone<br>KNNS          | Light-grey, very fine- to fine- and medium- to coarse-grained sandstone. Locally gravelly, lignitic, locally glauconitic or with sideritic concretions.                                                        |      | 1538                                                | 1689 | 1489      | 1548 | 1508                | 1767 | 1423      | 1594 |      |
|                                                                       |                       |                          |                              | Berkel Sand/Claystone<br>KNNSC    | Alternation of fine-grained, argillaceous sandstones and brown-grey silty to sandy claystones.                                                                                                                 |      |                                                     |      |           |      |                     |      |           |      |      |
|                                                                       |                       |                          |                              | Rijswijk<br>KNNSR                 | Light- to medium-grey sandstones with a very fine to medium and locally gravelly grain size.                                                                                                                   |      |                                                     |      |           |      |                     |      |           |      |      |
|                                                                       |                       |                          |                              |                                   |                                                                                                                                                                                                                |      |                                                     |      |           |      |                     |      |           |      |      |
|                                                                       | Schieland<br>SL       |                          | Rodenrijs Claystone<br>SLDNR |                                   |                                                                                                                                                                                                                | 1584 | 1742                                                | 1530 | 1591      | 1547 | 1816                | 1460 | 1638      |      |      |
|                                                                       |                       |                          |                              | Delft Sandstone<br>SLDND          | Target Reservoir                                                                                                                                                                                               | 1815 | 2006                                                | 1755 | 1828      | 1698 | 2009                | 1608 | 1813      |      |      |
|                                                                       |                       |                          |                              | Alblasserdam<br>SLDNA             | Target Reservoir                                                                                                                                                                                               | 1898 | 2101                                                | 1836 | 1914      | 1775 | 2106                | 1677 | 1896      |      |      |
|                                                                       |                       |                          | Jurassic                     | Werkendam<br>ATWD                 |                                                                                                                                                                                                                |      | Sequence of grey, slightly marly, shaly claystones. |      | 2402      | 2678 | 2362                | 2477 | 2301      | 2775 | 2139 |
|                                                                       | Altena<br>AT          |                          | TD                           |                                   |                                                                                                                                                                                                                |      |                                                     | 2422 | 2708      | 2386 | 2507                | 2330 | 2811      | 2140 | 2445 |