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RESERVOIR MODELLING STUDY OF GALANTA AREA

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ABSTRACT

The locality of Galanta is situated on the northern rim of the central depression of the Danube Basin in a partial geological structure - the depression of Galanta. The possibility of obtaining geothermal water for the purpose of power utilization in Galanta has been verified by geothermal boreholes FGG-2 and FGG-3 Galanta. Panonian (Neogene) sands and sandstones represent the aquifers of geothermal water. The temperature of the rock environment at depths of 1000 m and 2000 m is 51 °C and 91 °C respectively. The value of the geothermal gradient is 40 °C/km. The average thermal conductivity of the sediments totals 1.94 W/m·K and the value of the heat flow density is 79 mW/m^2. Hydrochemically, the water is of a sodium-bicarbonate type with total dissolved solids in the range of 4.9 - 5.9 g/l. The total gas content in the water ranges from 0.096 to 0.39 m^3/m^3, the highest proportion being represented by carbon dioxide (0.08 to 0.26 m^3/m^3). The bubble point varies within the depth interval of 15 to 110 m, depending on gas content, proportion of particular components and pressure-thermal conditions at the wellhead. The hydraulic parameters of the aquifers are represented by the transmissivity coefficient and the hydraulic conductivity ranging from 4.25 x 10^{-4} to 2.04 x 10^{-3} m^2/s and 4.52 x 10^{-6} to 2.22 x 10^{-5} m/s respectively. The storativity coefficient varies around 1.4 x 10^{-4}. A lumpfit model and a two-dimensional model were used for evaluation of the geothermal resources at the locality. The model was created on the basis of long-term measurements. The total available geothermal power was estimated at 32.1 MW$_t$. Complex evaluation of previous hydrodynamic measurements showed that the demanded regime of the exploitation of geothermal water from the both boreholes could not be secured by the free outflow. Therefore, it has been recommended to immerse the submersible pumps in the boreholes.

1. INTRODUCTION

Galanta is a small town of about 35 000 inhabitants situated about 50 km east of Bratislava (capital of the Slovak Republic).

The possibility of obtaining geothermal water in Galanta has been verified by the research geothermal borehole FGG-2 Galanta. The Dionyz Stur Institute of Geology Bratislava drilled the borehole in the years 1982 to 1983, as a part of exploring the geothermal potential of the central depression of the Danube Basin. The borehole was originally drilled to supply geothermal energy to heat the Town Hospital Complex. Based on the positive results of this borehole, the exploration/exploitation borehole FGG-3 Galanta was drilled in 1984 by the Bratislava branch of the IGHP, s.p. Zilina state company (Franko et al., 1985) and plans were made to extend the use of geothermal energy to include a new apartment housing estate of 1236 apartments. The housing estate was under construction during the years 1981 to 1988. The geothermal water, which is only mildly mineralized and suitable for direct use, was intended to replace the current fossil-fuelled space heating and domestic hot water supply.

The first feasibility report on the geothermal district heating project was prepared by VIRKIR-ORKINT Ltd. (1991). Galantaterm Ltd. - a legal entity - has been formed to provide geothermal energy supply for flats of the Sever housing estate - together with its public service sector, rest home and the Town Hospital of Galanta. A geothermal heat plant with a capacity of 8 MW$_t$ was built in 1996 using geothermal water from FGG-2 and FGG-3 boreholes (Benovsky et al., 1997).

2. HYDROGEOTHERMAL CONDITIONS

The locality of Galanta is situated on the northern rim of the central depression of the Danube Basin in a partial geological structure - the depression of Galanta. It is enclosed by the horst of Inovec from the west and by the horst of Tribec from the east. Both of them are bordered by pre-Panonian faults.

The central depression of the Danube Basin (Figure 1) is enclosed by the Danube river in the southwest between the cities of Bratislava and Komarno, by the Male Karpaty mountains in the northwest, by the Dobra Voda fault (a branch of the Ludina fault) in the northeast, and approximately by the Nitra river in the southeast. A crystalline complex (schists, granitoids) has been identified in the pre-Tertiary base of its northwestern and southeastern part. According to the geological development of the Danube Basin it can be assumed that the whole pre-Tertiary base of the central depression is formed by the Carpathian crystalline. Therefore, there are no suitable sources of geothermal water in the pre-Tertiary base (Franko et al., 1995). The depression is filled with the Quaternary and Ruman gravels and sands, and mixtures of clays or sandy clays and sands to sandstones (Dak, Pont and Panon). The depression developed between the Panon and Pliocene stages and is of a brachysynclinal shape, with the deepest part in the area of Gabcikovo where the geothermal borehole FGGa-1 is situated. The situation of geothermal boreholes in the central depression of the Danube Basin is shown in Figure 2.

The reservoir of geothermal water is overlain by 1000 m of surface deposits and contained laterally and below by a relatively impermeable base with predominant clays (aquiclude) which dips from all sides into the centre where the reservoir probably lies at a depth of 3400 m (FGGa-1 borehole). The main geothermal aquifer is formed by Panon and Pont sands and sandstones. In the central part of the depression, geothermal aquifers are also formed by Dak sands and sandstones. Clays act as an aquiclude (Remsik et al., 1990).

The geothermal boreholes FGG-2 and FGG-3 were completed with 7" casings in the depth interval 1706 to 2032 m. The production intervals are represented by Panon sands and sandstones. The temperature of the rock environment at depths of 1000 m and 2000 m is 51 °C and 91°C.

The water temperature at the wellhead of the FGG-2 borehole with the free outflow of 27.3 l/s is 80°C and at the wellhead of the FGG-3 borehole with the free outflow of 25.0 l/s it amounts to 77 °C. The value of the geothermal gradient is 40°C/km in both boreholes. The average thermal conductivity of the sediments is 1.94 W/m·K and the value of the heat flow density is 79 mW/m^2.

Hydrochemically, the water is of a sodium-bicarbonate type with total mineralization of 4.9 to 5.9 g/l. The total gas content in the water varies within the interval of 0.096 to 0.39 m^3/m^3. The highest proportion is represented by carbon dioxide (0.08 to 0.26 m^3/m^3). The bubble point ranges over the depth interval of 15 - 110 m, depending on gas content, proportion of particular components and pressure-thermal conditions at the wellhead. The proportion of thermal lift and gas lift on the total drawdown, measured during hydrodynamic tests, ranges from 69 to 83 %.

2.1 Hydraulic parameters

The first well tests were performed after drilling was finished in 1983-1984. The relatively short distance between the boreholes enabled each to be used as a piezometer during the test on the other.

Hydrodynamic measurements were carried out in sections 326 m and 368 m thick; the effective thickness of the geothermal aquifers was found to be 92 m and 94 m.

Six well tests were performed on the borehole FGG-2:

Date	Flow rate (l/s)	Drawdown (MPa)
06.02.1983	23.3	0.335
10.02.1983	27.3	0.380
20.02.1983	16.3	0.241
20.06.1995	11.1	0.235
23.06.1995	19.3	0.463
26.06.1995	19.3	0.437

Similar tests were performed on the borehole FGG-3:

Date	Flow rate (l/s)	Drawdown (MPa)
5.08.1984	25.0	0.465
3.09.1984	23.5	0.312
1.07.1995	11.8	0.142
3.07.1995	16.2	0.287
4.07.1995	24.4	0.418
6.07.1995	24.4	0.419

Hydraulic parameters were calculated from the recovery test curves using the Theis equation modified by Jacob transformation. Linear regression analysis was used for division of the graph of drawdown vs. log (time). Individual parts of the semilogarithmic graph were fitted by straight line using the least squares method. The difference between the measured and the fitted value of the hydrostatic pressure also controlled the correct fitting. The representative part for estimation of the hydraulic parameters was selected by the total logarithmic conversion difference. Its utilization is always helpful when results of some hydrodynamic well tests are available. Results of the regression analysis model were used for time t_0 determination which is used for storativity calculation (Fendek, 1997).

The evolution of selected hydrodynamic tests for borehole FGG-2 are shown in Figure 3 and for borehole FGG-3 in Figure 4. Final parts of the hydrodynamic test curves were selected for calculation of hydraulic parameters. No manifestation of any boundary condition was observed; the aquifer could be regarded as infinite. The drawdown curves measured in the observation boreholes during hydrodynamic tests were very similar regardless of the time of their realization. According to this, quite similar values of hydraulic parameters were estimated for all measurements.

Estimates of hydraulic parameters are given in Table 1. Hydraulic parameters of confined aquifers represented by the transmissivity coefficient and the hydraulic conductivity lie within the intervals of 4.25 x 10^{-4} to 2.04 x 10^{-3} m^2/s and 4.52 x 10^{-6} to 2.22 x 10^{-5} m/s, respectively. The storativity coefficient varies around 1.4 x 10^{-4} (Fendek, 1995). Its value enabled estimation of the skin effect for both boreholes. The results showed that the technical condition of the borehole FGG-2 had deteriorated since 1983, which had resulting in a decrease of the free outflow by 17 to 25 %.

2.2 Mathematical modelling

The first step of the mathematical modelling was creation of an analytical model, based on results of the hydrodynamic tests. On the basis of its results, it was clear that the required exploitation of geothermal water from the FGG-2 and FGG-3 boreholes could not be secured by free outflow (Fendek, 1995). Therefore, it was recommended that submersible pumps be installed in the FGG-2 and FGG-3 boreholes at depths of 120 m and 110 m, respectively. The geothermal water could be exploited by pumping for 70 and 150 days per year from the FGG-2 and FGG-3 boreholes respectively, at the time when the exploitation rates planned for the FGG-2 and FGG-3 boreholes lie within the interval of 6 - 15 l/s and 20 l/s, respectively. This is also the time of the highest mutual influence of those boreholes.

The lumpfit model and 2D numerical model were created based on results of long-term measurements. Results obtained from both models were quite similar.

A distributed parameter numerical model for the Galanta geothermal reservoir was created by the AQUA programme package developed by Vatnaskil Consulting Engineers (1992) to solve the groundwater flow and mass transport by differential equations using the Galerkin finite element method with triangular elements. The model is two-dimensional. Seven other geothermal boreholes (FGS-1/A, FGG-1, Di-1, Di-2, HTS-2, VDK-15 and VZK-10, see Figure 2), located in the broader vicinity, were included in the model solution to obtain more representative results. The transmissivity, storage coefficient, anisotropy and porosity were determined by matching observed and calculated reservoir response. The transmissivity in the area covered by the model varied from 6.0 x 10^{-5} to 7.89 x 10^{-3} m^2/s. The lowest value for transmissivity coefficient was obtained for the well HTS-2 in the southeastern part of the modelled area and the highest value for the borehole FGG-3 in Galanta area. The storativity coefficient in the area covered by model ranged from 7.0 x 10^{-5} to 1.0 x 10^{-4}. The highest values were used in the Galanta area.

The results showed that the geothermal water level in the FGG-2 borehole is stabilized at 14.65 m below the surface, at a pumping rate of 15.7 l/s. The water level in the FGG-3 borehole is stabilized at 23.46 m below the surface at a pumping rate of 18.0 l/s. Measured, calculated and predicted drawdowns for FGG-2 borehole are shown in Figure 5. It is very important to mention that the long-term measurements showed a decrease of the geothermal water level below the surface, which was typical for the whole year of 1998 in comparison with the year 1995, in which such a decrease was not evident. The reason is that the exploitation rate during last years is much higher then the recommended values (see Figure 5).

The total exploitation amount of geothermal waters in the modelled area was estimated at 176.0 l/s, which represents a geothermal heat supply of 32.1 MW_t.

3. CONCLUSION

The central depression of the Danube Basin is the best investigated geothermal area in the Slovak Republic. The locality of Galanta is situated on its northern rim in a partial geological structure called the Depression of Galanta. The depression is filled with sediments of Quaternary and Ruman gravels and sands, and Dak, Pont and Panon clays, sandy clays, sands and sandstones. Aquifers are represented by Panon and Pont sands and sandstones. The temperature at depths of 1000 m and 2000 m is 51 °C and 91 °C. The possibility of obtaining geothermal water for the purpose of heat supply in Galanta has been verified by geothermal boreholes FGG-2 and FGG-3.

Water temperature at the wellhead of the FGG-2 borehole with the free outflow of 27.3 l/s is 80°C and at the wellhead of the FGG-3 borehole with the free outflow of 25.0 l/s is 77°C. The bubble point ranges within the depth interval 15 - 110 m depending on gas content, proportion of particular components and pressure-thermal conditions at the wellhead. Therefore it was recommended to set the submersible pumps in the FGG-2 and FGG-3 boreholes to depths of 120 m and 110 m respectively.

Hydraulic parameters of the aquifers represented by the transmissivity coefficient and the hydraulic conductivity lie within the intervals of 4.25×10^{-4} to 2.04×10^{-3} m^2/s and 4.52×10^{-6} to 2.22×10^{-5} m/s respectively. The storativity coefficient varies around 1.4×10^{-4}. Skin effects calculations showed that the technical condition of the borehole FGG-2 had deteriorated since 1983, which resulted in the decrease of the free outflow by 17 to 25 %.

The results of the analytical model (based on results of hydrodynamic tests performed in 1995) showed that geothermal water could be exploited by pumping for 70 - 150 days per year at a pumping rate of 6-15 l/s for the FGG-2 borehole and 20 l/s for FGG-3 borehole. The results of the lumpfit and 2D numerical model showed that the geothermal water level in the FGG-2 borehole is stabilized on the level of 14.65 m below the surface, at the pumping rate of 15.7 l/s. Water level in the FGG-3 borehole is stabilized on the level of 23.46 m below the surface at the pumping rate of 18.0 l/s. On other hand, with higher intensity of exploitation the drawdown would continue to increase.

The total exploitable potential of geothermal waters in the modelled area was estimated on 176.0 l/s, which represents a heat supply of 32.1 MW_t.

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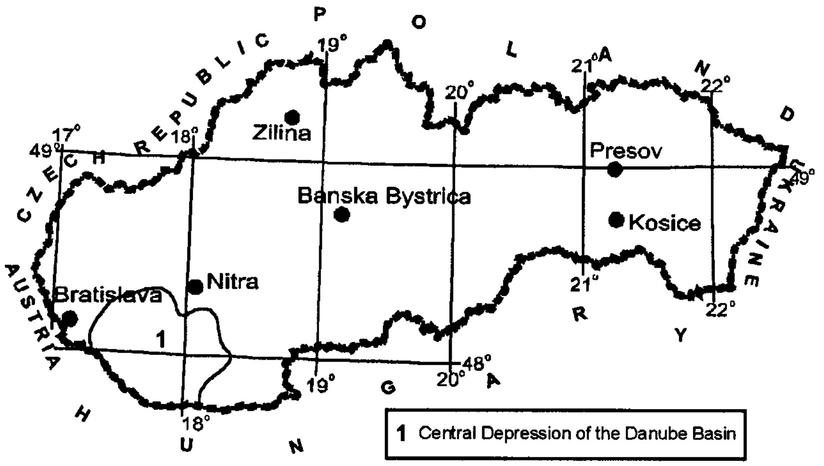

Figure 1. Location of the central depression of the Danube Basin

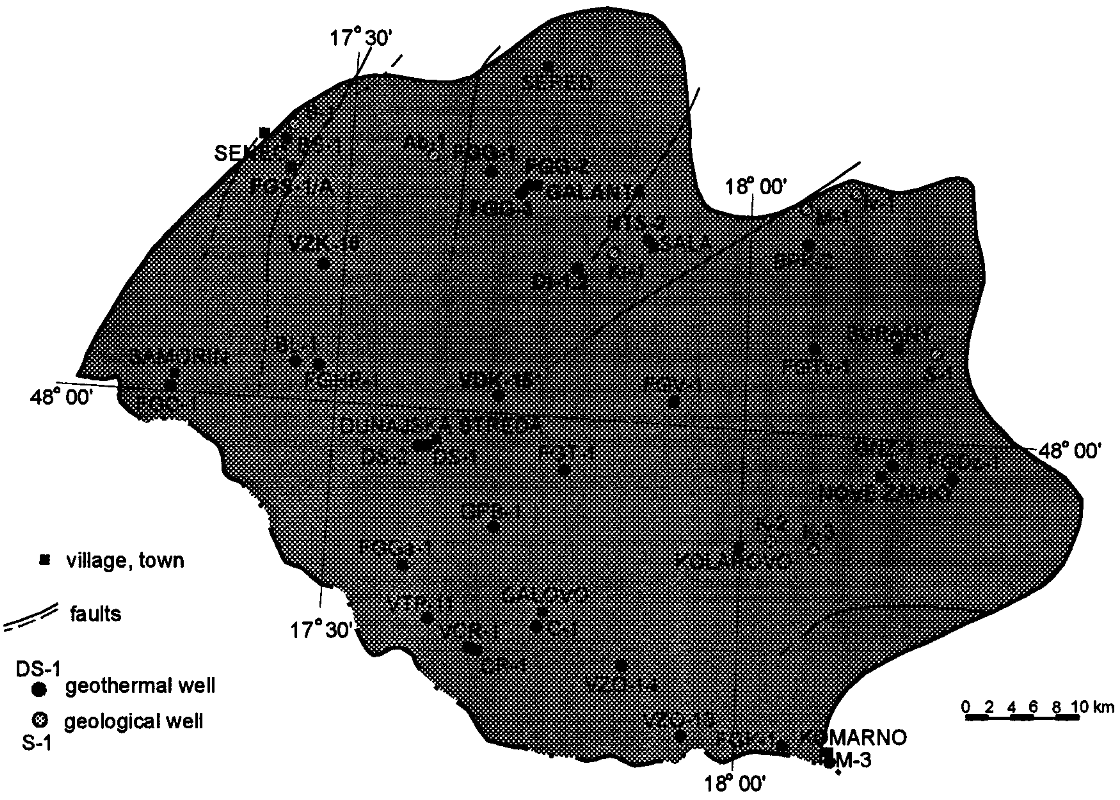

Figure 2. Situation of geothermal boreholes in the central depression of the Danube Basin

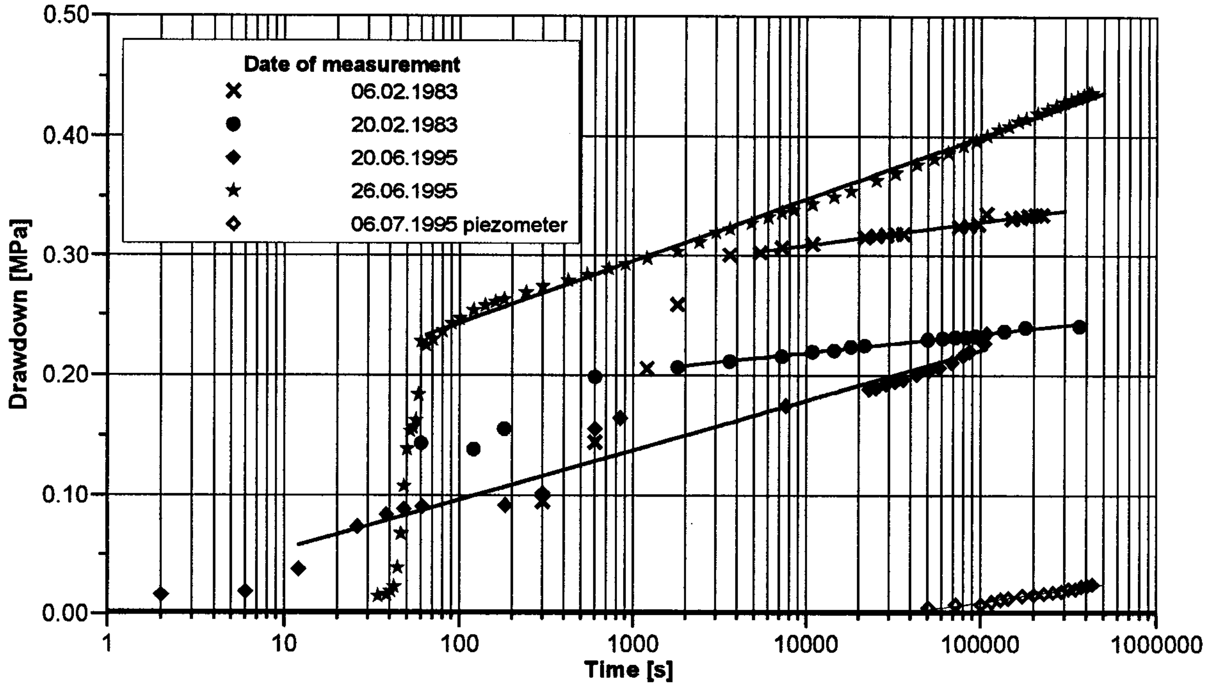

Figure 3. Hydrodynamic tests on the geothermal borehole FGG-2

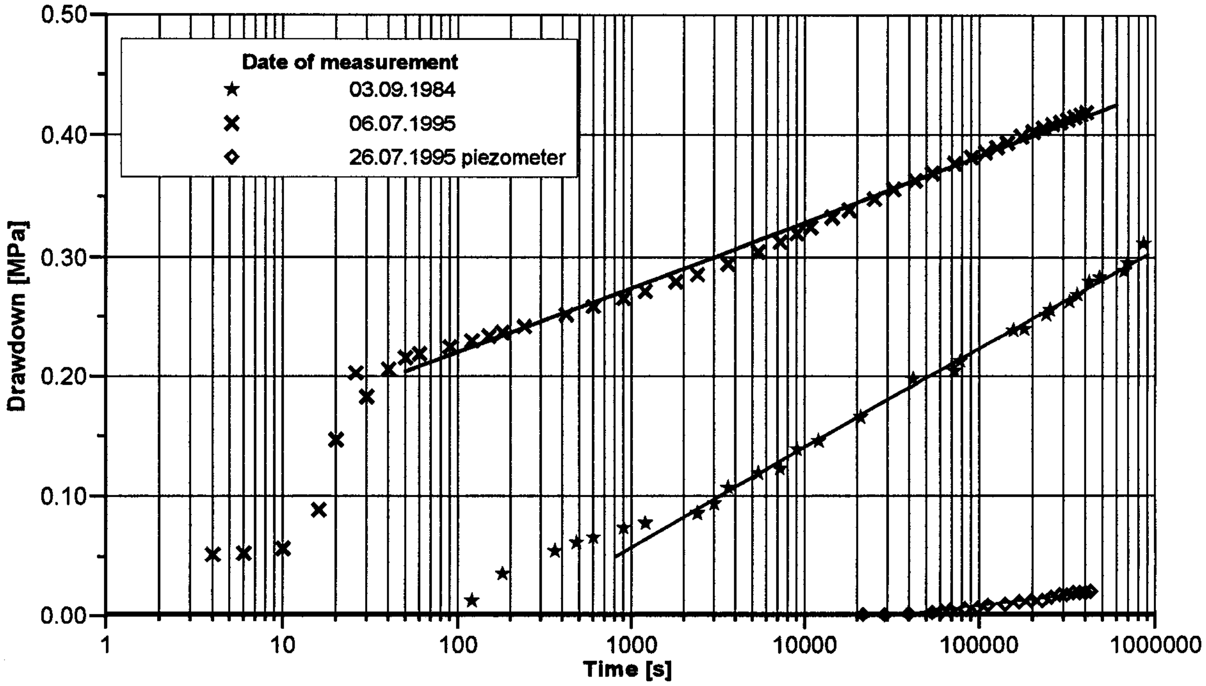

Figure 4. Hydrodynamic tests on the geothermal borehole FGG-3

Table 1 Results of hydraulic parameters estimation

Date	Intrinsic transmis-sivity coefficient x 10^{-11} [m^3]	Transmissivity coefficient x 10^{-3} [m^2/s]	Permeability coefficient x 10^{-13} [m^2]	Conductivity coefficient x 10^{-5} [m/s]	Storativity coefficient
geothermal borehole FGG-2					
06.02.1983	6.869	2.038	7.467	2.215	-
10.02.1983	5.455	1.618	5.929	1.759	-
20.02.1983	6.354	1.885	6.906	2.049	-
05.08.1984	5.992	1.641	6.513	1.783	1.9
03.09.1984	5.368	1.470	5.835	1.597	2.1
20.06.1995	1.618	0.469	1.759	0.510	-
23.06.1995	6.361	1.835	6.914	1.994	-
26.06.1995	2.232	0.647	2.426	0.703	-
06.07.1995	6.782	1.967	7.372	2.138	1.4
geothermal borehole FGG-3					
05.08.1984	1.481	0.425	1.576	0.452	-
03.09.1984	1.742	0.499	1.853	0.532	-
26.06.1995	5.540	1.607	5.893	1.709	1.55
01.07.1995	2.844	0.825	3.025	0.877	-
03.07.1995	3.049	0.887	3.244	0.944	-
04.07.1995	5.743	1.671	6.109	1.778	-
06.07.1995	2.722	0.789	2.895	0.839	-
26.06.1995	5.696	1.657	6.059	1.763	1.4

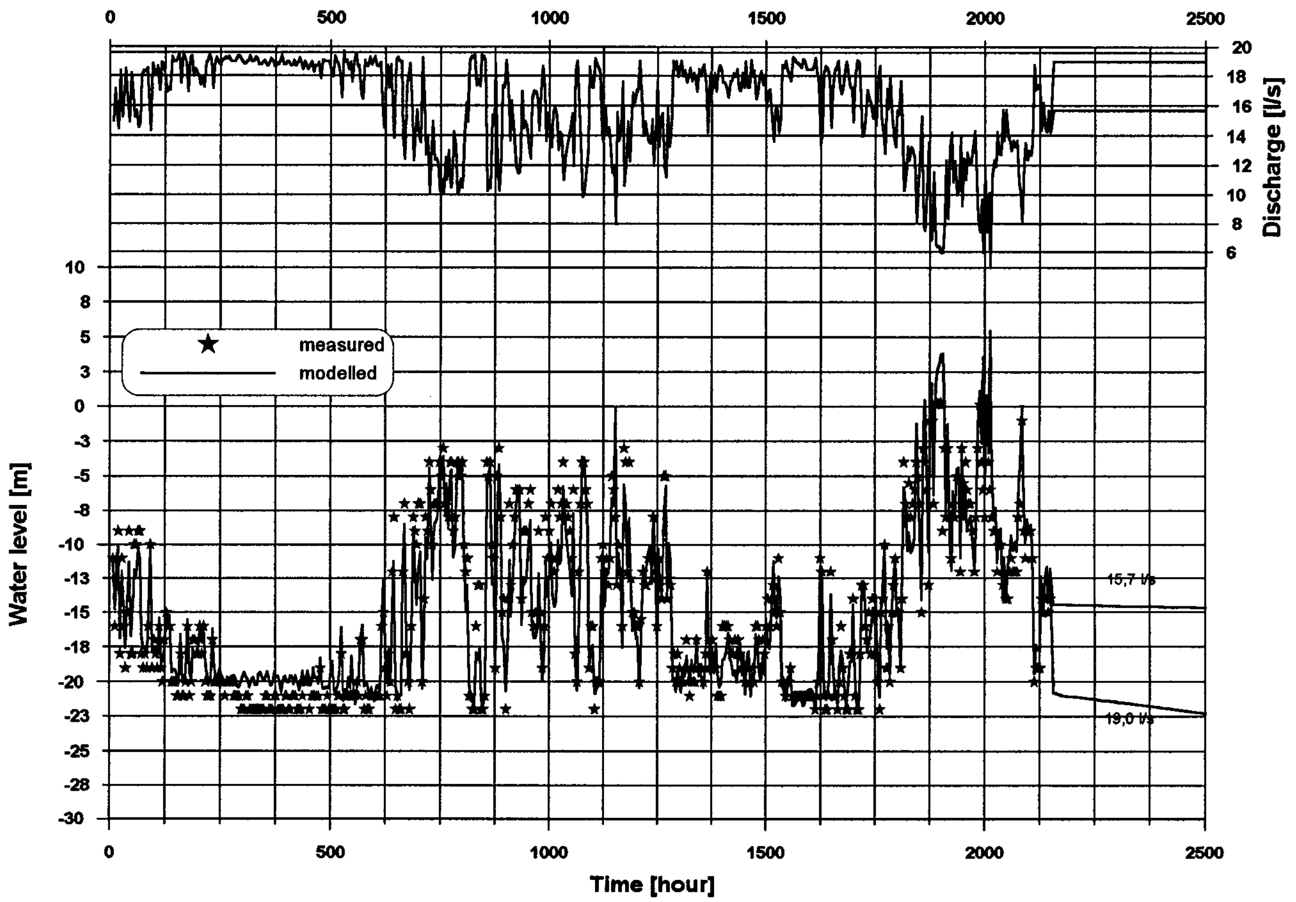

Figure 5. Measured, calculated and predicted drawdown for FGG-2 borehole