A groundwater model of the confined aquifers in the Feistritz valley (Eastern-Styria)

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Previous works

On the basis of hydraulic head records and hydraulic tests already at the beginning of the 1990ies the hydraulic connections of the confined aquifer resources were investigated in the middle Feistritz valley. In the middle Feistritz valley is an extensive confined aquifer located which is developed by four hydraulic connected wells. The hydraulic connection of the four wells was realized through their mutual interference during hydraulic tests. To obtain insights on the recharge of the confined aquifers and the flow conditions in this area a numerical groundwater model was developed by BERGMANN et al. (1993). Based on the hydraulic tests evaluated and hydraulic head data of the test wells lying in the model area (46 km^2) a two-dimensional model was calibrated. In the model area from NW discharge and on the south boundary fix potential was defined (Fig. 1). For the transmissivity distribution a fault zone of low transmissivity along the Feitritz river was assumed. After steady state calibration of the model a withdrawal of 4 l/s from the well Großhartmannsdorf 1 was simulated and the increase of the boundary inflow calculated.
Due to the previous works regarding the development of a numerical model in the middle Feistritz valley and the extended data status was decided to develop the existing model further to a three-dimensional flow model within the scope of the project NANUTIWA (DOMBERGER et al. 2004).

Modelling software

For implementation of the numerical model the groundwater modelling software Visual MODFLOW Version 2.8.2 (WATERLOO HYDROGEOLOGIC INC. 1999) was chosen. The mathematical base of the software for numerical solution of the flow equation is the method of the finite differences. MODFLOW is the most popular groundwater modelling software based on the method of the finite differences. The discretisation follows by a rectangular grid. The software allows the handling of the three-dimensional flow problem and it includes effective algorithms for resolve of large equation systems.

Spatial delimitation of the model area

Since the most information is connected to the wells and these are situated along the Feistritz river the model

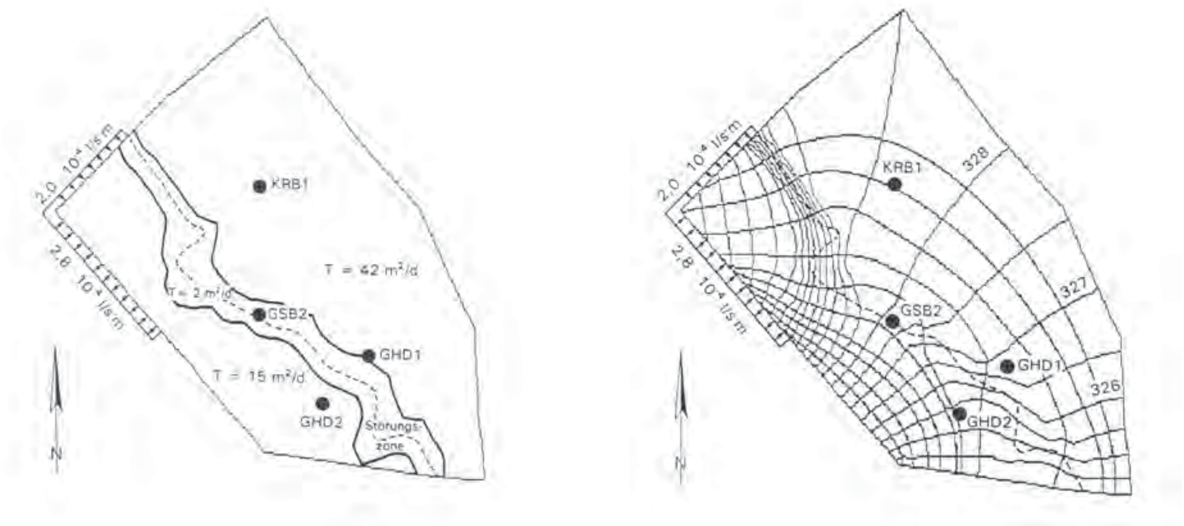

Fig. 1: Transmissivity distribution and boundary inflow (left) and flow net (right) after steady-state calibration (BERGMANN et al. 1993).

Journal of Alpine Geology	52	S. 58-63	Wien 2010

Fig. 2: The model area in the middle Feistritz valley.

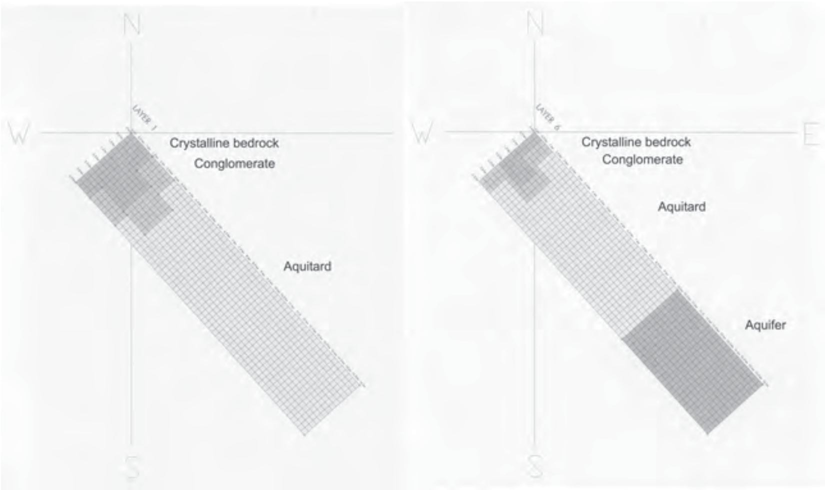

Fig. 3: Representation of the lowermost schematised model layer (left) and of the sixth schematised model layer (right).

boundaries were determined starting from the wells. The model boundaries were defined 1.5 to 2.5 km from the river across to the valley. Since in these boundary areas no hydro-geological information at all is available for model development the boundaries were defined as straight lines. Based on the potential plan of the area was assumed that these boundaries are in accordance with the stream lines and as boundary steam lines they represent impermeable boundary for the model. During the calibration this assumption was partially mitigated and by section boundary inflow and outflow were defined at these boundaries. In the direction of the valley the model boundary was set about 1 km SE from Hainersdorf and 0.5 km NW from Dörfl. The model area is 16 km long along the valley and 3.5 km wide across the valley (Fig. 2).

Vertically the land surface and a surface 300 m under the ground surface were defined as upper and bottom boundary surface of the model area. In this space all the confined groundwater horizons appreciable for questions were included.

Schematisation of the subsurface structures

Because of the complexity and of the interbedding of the horizons known of a few profiles only (Zojer 1987, Schön 1993) the structure of the area was strong schematised.

Thereby the groundwater horizons were synthesised to three aquifer packets. For aquifer packets, afterwards model aquifers, an average thickness was assumed and a permeability determined by the pumping tests was assigned to them. The three model aquifers have following thicknesses: 2.4 m (model layer 6), 11.9 m (model layer 4) and 32.5 m (model layer 2).

At the schematisation the dip of the aquifers was neglected because it is not relevant for the model calculation under confined conditions. The discharge into the aquifer appearing potentially at the pinch out of the horizons was simulated by means of injection wells. In the model seven model layers were defined: the above mentioned three model aquifers and the four aquitards bordering the

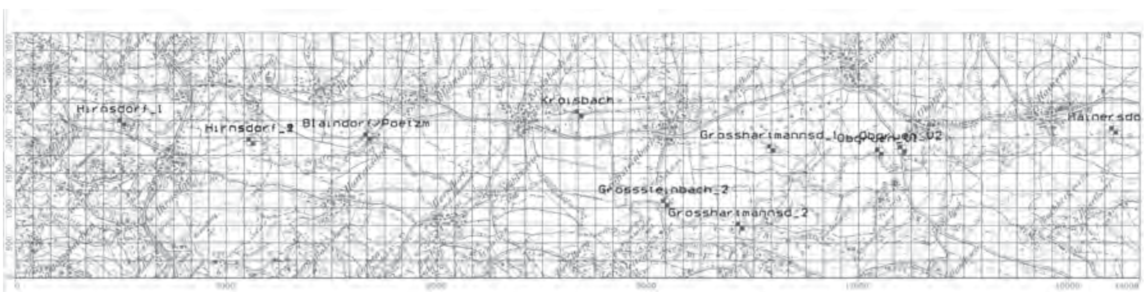

Fig. 4: The model grid and the test wells.

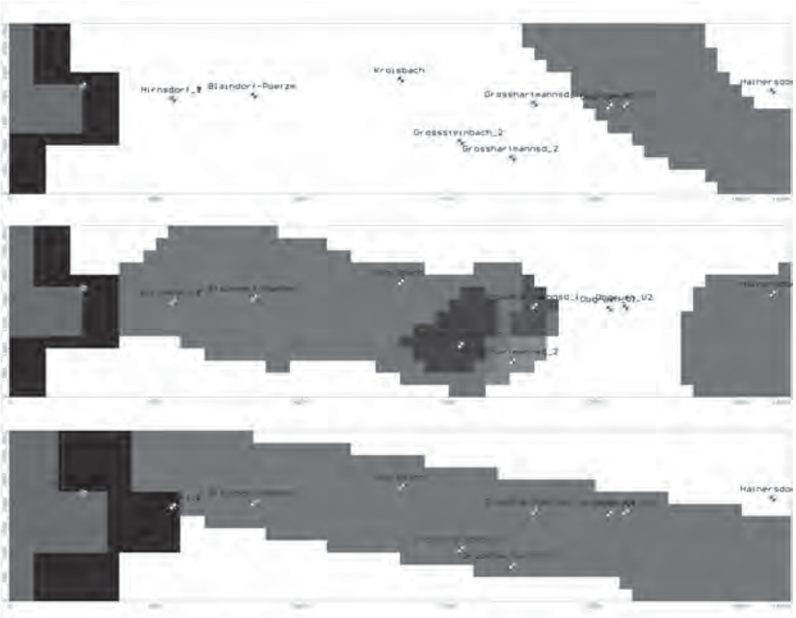

Fig. 5: Permeability distribution of the upper model aquifer (above), the middle model aquifer (in the middle) and the lower model aquifer (below).

aquifers from above and from bottom up. Further according to the stratification three main blocks were determined: the crystalline bedrock, the (partly covered) conglomerate in front of the bedrock and the tertiary sediments of the basin filling which can also be divided into aquifers and aquitars.
The coordinate-wise and height-wise preparation of the model layers and a base map were created in digital form. In Fig. 3 as an example the lowermost schematised model layer (layer 1) and the sixth model layer (upper model aquifer) are presented. In this layer the assumed spread of the lowermost model aquifer is recognizable.

Discretization of the model area

The model area of a surface of 56 km² was discretized by a rectangular grid with constant cell width whereby the cell width amounted to 250 x 250 m (Fig. 4). The cell width represents in comparison to the size of the model area and in view of the data density and the expected statements on the groundwater conditions a sufficient resolution. The model grid was oriented on the average main flow direction whereby the cell sides run parallel to the model boundaries.

Hydraulic properties of the aquifers

To calibrate the model hydraulic properties have to be assigned to all model cells. The most important hydraulic property is the permeability. In the model as first assumption following permeability ranges were defined: crystalline bedrock 1×10^{-8} m/s, conglomerate 1×10^{-7} m/s, aquitard 1 to 5×10^{-7} m/s, aquifer 1×10^{-4} m/s. In the vicinity of wells the permeability coefficients determined by means of pumping tests were taken into account. A definite permeability distribution of the single aquifers could not be assumed because of the minor data density and the lack on additional information. In Fig. 5 the calibrated permeability distributions of the model aquifers are presented. In Fig. 6 a NW-SE vertical profile of permeability distribution through the wells Hirnsdorf 1, Blaindorf and Hainersdorf is shown.

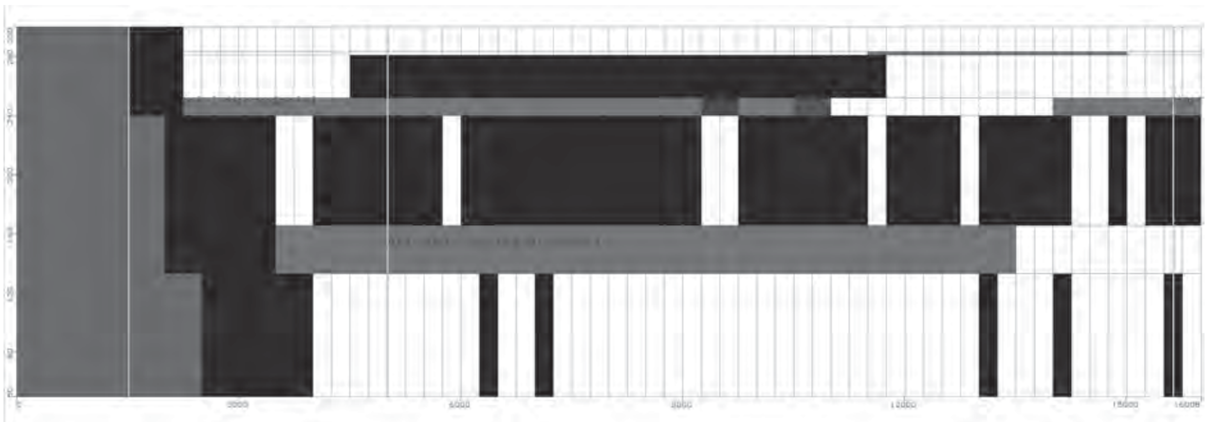

Fig. 6: Profile through the model area (wells Hirnsdorf 1, Blaindorf, Hainersdorf).

Fig. 7: Boundary conditions in the lower model layer.

Boundary conditions

For a three-dimensional flow model the boundary condition of all model layers must be known. In the case of the present model the boundary conditions were barely known therefore had to work with hypotheses. For the SW boundary (near Hainersdorf) a fix potential was defined. The hydraulic head on this boundary was tapped from the potential plan and it was (Figs. 5, 6) linear interpolated between the endpoints of the boundary section. In this way the hydraulic head in SW-NE direction was set between 286 and 300 m a.s.l.

On the surface that is in the lower model layer a recharge of 90 mm/a was assumed on the borderline between crystalline bedrock and conglomerate. In the remaining model area no recharge was specified because it is not relevant for the deep confined aquifers (Fig. 7).

The effective recharge on the aquifer pinch out was realized by injection wells. The recharge related to a cell was considered in the appropriate model layer as lumped inflow (m^3/d).

The Feistritz river as receiving water course in the model area was considered neither as inner potential boundary nor as a river boundary (after leakage concept). Thus the recharge from the Feistritz river was realized by means of injection wells.

Water withdrawal in the model area

In the model the initial hydraulic condition without appreciable water withdrawal was assumed and therefore no pumping wells were set.

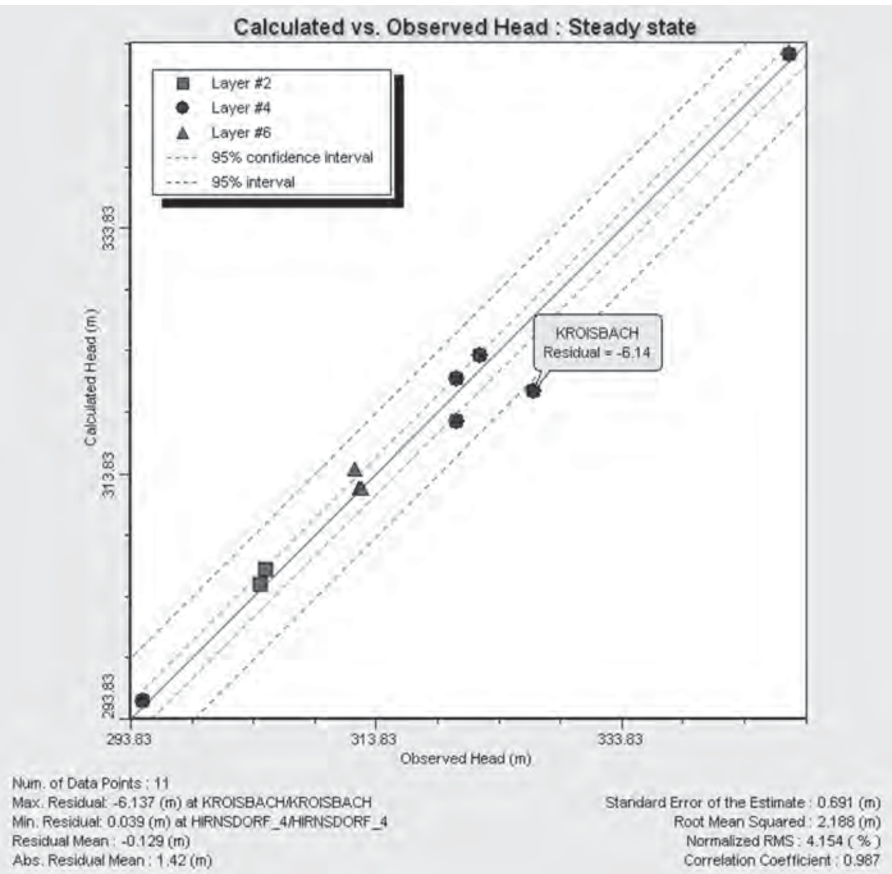

Fig. 8: Comparison between calculated and measured hydraulic heads.

Aquifer	Well	Permeability coefficient [m/s]		Hydraulic head [m a.s.l.]	
		evaluated	calibrated	observed	calculated
lower model aquifer	Obgrün V1	*(1.0x10^{-4})**	1.0x10^{-4}	304.76	306.10
	Obgrün V2	*(1.0x10^{-4})**	1.0x10^{-4}	304.41	304.77
middle model aquifer	Hainersdorf	1.5x10^{-4}	1.0x10^{-4}	294.89	295.26
	Großhartmannsdorf 1	1.3x10^{-4}	8.1x10^{-5}	320.40	318.02
	Großhartmannsdorf 2	2.6x10^{-5}	2.6x10^{-5}	320.43	321.49
	Großsteinbach 2	1.7x10^{-4}	1.7x10^{-4}	322.25	323.38
	Kroisbach	1.1x10^{-4}	1.0x10^{-4}	326.69	320.55
	Hirnsdorf 1	1.0x10^{-6}	1.0x10^{-7}	347.56	347.92
upper model aquifer	Blaindorf-Pötzmühle	4.5x10^{-5}	1.0x10^{-4}	312.05	314.20
	Hirnsdorf 2	1.2x10^{-5}	1.0x10^{-4}	312.43	312.71
	Hirnsdorf 4	9.0x10^{-6}	1.0x10^{-4}	312.65	312.69

* estimated values (no pumping test data)

Tab. 1: Permeability coefficients and initial hydraulic heads in the model area.

Model calibration and water balance

For calibrating the model eleven test wells situated in the model area were used. In these test wells the determined initial hydraulic heads as potential values were taken. The hydraulic heads in the wells characterise different aquifers (Tab. 1).

The calibration of the model was carried out under steady-state conditions by varying of permeability values, their spatial distribution and the boundary conditions of all aquifers. Regarding the calibration process has to be noted that this task was multiple undetermined and for this reason very aggravated. On one side there is no further information about the transmissivity distribution of the aquifers. As it is shown in Tab. 1 in the model aquifers are 2 to 6 values of permeability available which are no uniform distributed as well. On the other side the boundary conditions of the single confined horizons and therefore of the model aquifers are absolutely unknown. The only indirect reference yields the potential plan of the area. From the potential plan the flow direction can be deduced which gives general information on inflow and outflow in the model area.

In spite of the difficulties of model development and calibration in the first step the permeability distribution of the model aquifers was calibrated. In the second step after a rough calibration of the permeability distribution the inflow and outflow were varied, in order to reproduce the course of the potential lines better and to obtain the water balance of the model area in a plausible range. Finally in the third step it was tried to vary the permeability and the inflow and outflow simultaneously in subareas of the model based on the preliminary findings of the first calibration steps. Furthermore was tried to integrate the Feistritz river as inner boundary condition into the model. Over the course of calibration the river section between Großsteinbach and Kroisbach was defined as fix potential. However it led to the problem that the calculated hydraulic heads in the core area were somewhat raised but the hydraulic heads in other subareas were substantial raised, what could not be compensated in regard to a plausible water balance through other measures.

After numerous calibration steps had to be noticed that the core zone of the model area and the wells representing the middle model aquifer can´t be calibrated with a satisfying quality. The comparison between calculated and measured hydraulic heads is illustrated in Fig. 8.

From the eleven calibration points lie eight within the 95% confidence interval and they show a residual less than 2.0 m. These points have a mean residual of -0.13 m. The well Blaindorf with a residual of 2.15 m lies just outside the 95% confidence interval. The central situated wells (Kroisbach, Großhartmannsdorf 1) of the middle model aquifer could be unsatisfying adjusted. The calculated hydraulic heads of these wells have an error of -6.14 m and -2.38 m, respectively. They are significant lower than the measured hydraulic head values. The residual mean

Fig. 9: Calculated isolines of hydraulic head.

Fig. 10: Velocity vectors showing the flow directions in the middle model aquifer.

amounts to 1.4 m, the normalized RMS to 4.15% what indicates according to a rule of thumb (NRMS <5%) a good calibrated model.
The calculated isolines of hydraulic head in the model area are shown in Fig. 9. The course of the calculated isolines presents an acceptable accordance with the plan of hydraulic head isolines constructed from the measuring data. Good accordance can be seen in NW and SE subareas. In the central area of the model the course of the isoline of 320 m height could not be exact reproduced.
The water balance of the model area can be characterized with following figures. The total water balance amounts to 7685 m^3/d (88.9 l/s). The ground water recharge due to precipitation from the bedrock was calculated to be 309 m^3/d (3.6 l/s). The inflow including the recharge from Feistritz river into the middle model aquifer (2950 m^3/d) can be specified with 7330 m^3/d (84.8 l/s). The outflow across the potential boundary arises as a result to 1315 m^3/d (15.2 l/s). The total outflow across the boundaries amounts to 6370 m^3/d (73.7 l/s).

Basic findings of the model development and calibration

As explained above the model calibration could be finished only partially with satisfying quality. The mean residual amounts to 1.42 m indeed, what in respect of the range of hydraulic head values from 304.41 m to 347.56 m can be considered as acceptable error. Two points (well Kroisbach and Großhartmannsdorf 1) feature a significant error what suggests that in the central area of the aquifer system the flow conditions could not be realized completely correct (Fig. 9). In Fig. 10 the velocity vectors show the flow directions in the middle model aquifer.
In the course of calibration the determination of the hydraulic properties and boundaries was focused on the aquifers. The permeability of aquitards between the aquifers is of great importance too. The impact of hydraulic windows that means areas of heightened permeability can essentially influence the hydraulic potential in the aquifers. However the pumping tests yielded permeability coefficients of the aquifers only.
The principal reason for the calibration errors is the moderate data status compared to the complexity of the aquifer system. The data and information available were only partly sufficient to develop a three-dimensional flow model for the middle Feistritz valley. However that does not mean that the groundwater flow in the single horizons could not be simulated with sufficient accuracy by two-dimensional models. Therefore should be tried to realise the aquifers in two-dimensional models and after a successful calibration to connect the horizons in a multi-layer model. In this multi-layer model the aquifers present hydraulically independent pressure systems which communicate with each other by the leakage concept (Fig. 10).
To develop a well-calibrated three-dimensional model, further wells in the single aquifers, pumping tests in these wells, isotope investigations and investigation of the hydraulic connections between Feistritz river and the aquifers pinching out near the river by accurate discharge and water-stage measurements would be needed.
The project NANUTIWA (Domberger 2006) was carried out on behalf of the Land Government of Styria, the Land Government of Burgenland, the Federal Ministry of Economy and Labour and the Federal Ministry of Agriculture, Forestry, Environment and Water Management.

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