Estimation of hydraulic conductivity of the sandstones in the central Baltic Artesian Basin

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Abstract

This study presents the results of the comparative study between hydraulic conductivity, grain size distribution, sediments lithology in the lower Devonian Emsian stage, middle Devonian Eifelian, Givetian stage and upper Devonian Frasnian stage clastic sediments in the central part of the Baltic Artesian Basin in territory of Latvia. The aim of this study was to find characteristic hydraulic conductivity values for each aquifer based on aquifer grain size distribution and lithology on the one hand and pumping test results one the other.

Pumping test results provide a range of at least two orders of hydraulic conductivity values for each aquifer. To characterize the typical values for each aquifer and further subdivide each aquifer into regions of different hydraulic conductivities, pumping test results were correlated with grain size distribution and sediment lithology (Figure 4 – 9).

Figure 1. Boundaries of Baltic Artesian Basin (BAB)

As a limiting factor for the hydraulic conductivity and grain size distribution correlation in the sandstones were chosen the fraction of the fine particles with the size less than 0.05 mm. The correlation of hydraulic conductivity and grain size distribution was carried out by comparing the <0.05 mm fraction and respective hydraulic conductivity values. The results suggest that grain size distribution in general does not correlate with conductivity obtained from the pumping tests. Calculated values in some cases differ from obtained for some units (1 – 3 m/day) but in some cases more than two times, which is connected with uncertainty of existent data and imperfections of the calculation methods. Correlation with the sediments lithology of the aquifer (as described in boreholes) shows better results and allows to subdivide the aquifer into two or more clusters of typical K values.

Data and Methods

All used data are taken from «Latvian Environment, Geology and Meteorology Centre». Data have been provided in rather long time period in geological mapping and geological and hydrogeological survey process. In this study data only from territory of Latvia is used (Table 1.).

Aquifer	K (Number of wells)	Grain size analysis (Number of wells)	K + grain size (Number of wells)
D_3am	66	82	7
D_3gj	152	124	22
D_2br	89	104	17
D_2ar	95	96	14
D_2rz-pr	46	39	5

Table 1. Existing data of hydraulic conductivity (K) values and grain size analysis of Devonian clastic aquifers

First step of this study was estimation of quality of hydraulic conductivity and grain size analysis data. Quality estimations of K data were provided by analysis of wells filter depth and lack of aquitard between current aquifer and upper aquifer, in most cases Quaternary glaciofluvial sediments (Figure 3; 2). Common analysis of hydraulic conductivity and grain size distribution showed insufficient results (Figure 4; 5) for further analysis of these parameters. Gran size distribution data were used for supplement of existent K data range. Calculation of K values from grain size distribution were provided by equation of Hazen and Beyer (Maldavs 1964; Vienken, Dietrich 2011; Fetter 2001):

$$K = C d_{10}^2 (0{,}7+0{,}03\ t),$$

K – hydraulic conductivity (m/day); C – empirical coefficient - varies from 400 (clays) – 1200 (well sorted sands) (Fetter, 2001); *d10* – effective diameter (mm); *t* – water temperature (°C); *(0,7+0,03t)* – temperature correction (Maldavs, 1964).

More valid results showed comparative studies between hydraulic conductivity and sediments lithology. In this case areas with higher K values are almost the same as these with frequent prevalence of coarse grained sandstone (Figure 6; 8; 9).

Estimation of divided areas of characteristic K values was carried out by inverse modeling (Carrera et al 2005) using hydrogeological model of Baltic Artesian Basin (Virbulis et al in print) (Table 2 – 6).

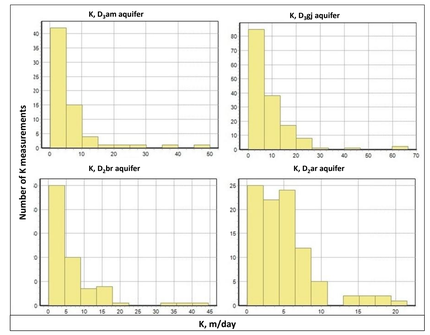

Figure 2. Histograms of K value distribution obtained from well pumping tests of D_3am, D_3gj, D_2br and D_2ar aquifers

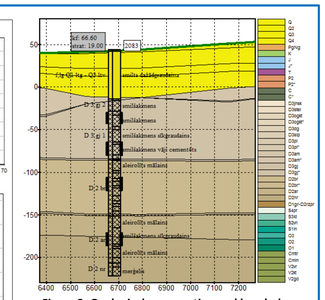

Figure 3. Geological cross section and borehole construction of borehole 2083 (LVĢMC)

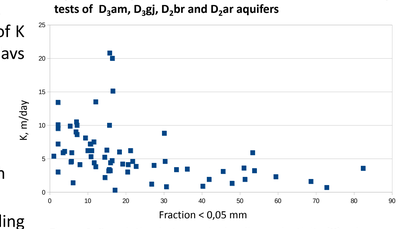

Figure 4. Correlation between hydraulic conductivity (K) values and grain size distribution in Devonian aquifers

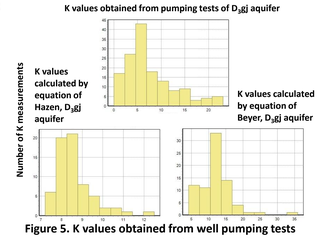

Figure 5. K values obtained from well pumping tests and calculated by equations of Hazen and Beyer

Results

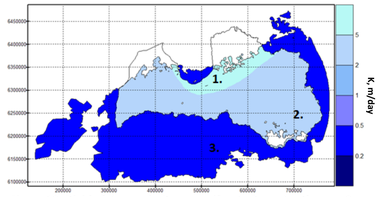

Figure 10. Divided K areas in D_3am aquifer; 1- D_3am North area; 2 – D_3am Latvia area; 3 – D_3am aquifer prevalence in BAB

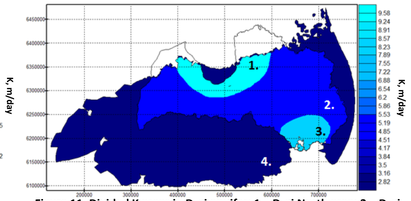

Figure 11. Divided K areas in D_3gj aquifer; 1 – D_3gj North area; 2 – D_3gj Latvia area; D_3gj Latgale area; 4 – D_3gj aquifer prevalence in BAB

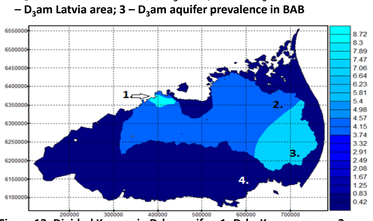

Figure 12. Divided K areas in D_2br aquifer; 1- D_2br Kurzeme area; 2 – D_2br Latvia area; 3 - D_2br Latgale area 4 – D_2br aquifer prevalence in BAB

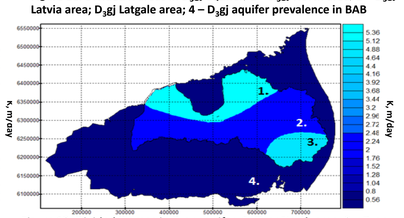

Figure 13. Divided K areas in D_2ar aquifer; 1- D_2ar North area; 2 – D_2ar Latvia area; 3 - D_2ar Latgale area 4 – D_2ar aquifer prevalence in BAB

Aquifer	Number	Values of K (m/day) of divided areas used for target function calculation: D_3am North area	D_3am Latvia area	Total target function of BAB model	Aquifer target function	Disparity of piezometric level in aquifer, m
D_3am	1.	0,32		1170,15	52.52	7,24
	2.	15		1166.82	73.08	8,54
	3.	10		1163.33	69.53	8,33
	4.	4.1		1157.99	62.62	7,91
	5.	5.39	2.72	1154.02	55.34	7,43
	6.	4,0	2,0	1152.98	52.82	7,27

Table 2. Characteristic (No. 5.) and experimental K values of D_3am aquifer and target function calculation results

Aquifer	Number	Values of K (m/day) of divided areas used for target function calculation: D_3gj North area	D_3gj Latvia area	D_3gj Latgales area	Total target function of BAB model	Aquifer target function	Disparity of piezometric level in aquifer, m
D_3gj	1.	2,82			1170,15	132.27	11,50
	2.	20			1244.44	149.0	12,20
	3.	10			1180.05	129.27	11,36
	4.	7,51			1156.06	123.29	11,10
	5.	9.59	5.52	8.34	1144.89	119.46	10,92
	6.	8,0	5,0	6,0	1139.90	118.69	10,89
	7.	5,8	3,8	4,8	1128.80	117.88	10,85

Table 3. Characteristic (No. 5.) and experimental K values of D_3gj aquifer and target function calculation results

Aquifer	N. p. k.	Values of K (m/day) of divided areas used for target function calculation: D_2br Kurzemes area	D_2br Latvia area	D_2br Latgales area	Total target function of BAB model	Aquifer target function	Disparity of piezometric level in aquifer, m
D_2br	1.	0.42			1170,15	36.25	6,02
	2.	20			1341,64	87,93	9,37
	3.	15			1256,96	63,32	7,95
	4.	10			1179,39	40,70	6,37
	5.	5,15			1130.47	26.52	5,14
	6.	8,72	4,06	6,77	1115,60	23,13	4,80
	7.	7,77	3,08	5,77	1113,39	22,74	4,76
	8.	6,72	2,06	4,77	1120,96	24,46	4,95

Table 4. Characteristic (No. 6.) and experimental K values of D_2br aquifer and target function calculation results

Aquifer	Number	Values of K (m/day) of divided areas used for target function calculation: D_2ar North area	D_2ar Latvia area	$D_2arLatgales$ area	Total target function of BAB model	Aquifer target function	Disparity of piezometric level in aquifer, m
D_2ar	1.	0.56			1170,15	31.63	5,62
	2.	20			1361.23	91,67	9,57
	3.	10			1200,23	46,65	6,83
	4.	4,37			1125,06	19,24	4,38
	5.	5,36	1,99	5,02	1119,53	17,86	4,22
	6.	4,36	1,99	4,02	1119,91	17,30	4,15
	7.	2,36	1,09	3,02	1124,58	18,10	4,25

Table 5. Characteristic (No. 5.) and experimental K values of D_2ar aquifer and target function calculation results

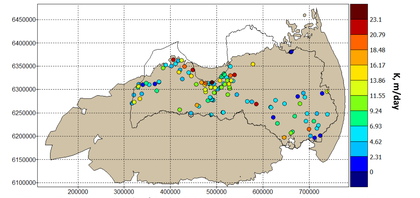

Figure 6. Values of K (m/day) of Devonian Gauja aquifer provided by pumping tests after data quality estimation

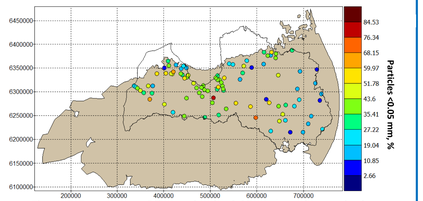

Figure 7. Percentage of fine grained (<0.05 mm) sandstones in the D_3gj aquifer, based on well log data

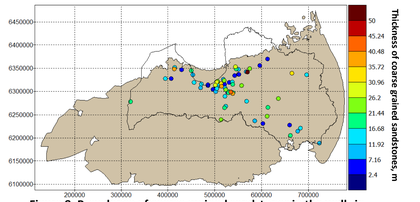

Figure 8. Prevalence of coarse grained sandstones in the wells in D_3gj aquifer and their thickness

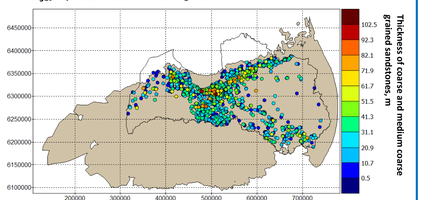

Figure 9. Prevalence of coarse and medium coarse grained sandstones in the wells in D_3gj aquifer and their thickness

Based on distribution of observed values of hydraulic conductivity and sediments lithology characteristic K values for each aquifer were asigned (Figure 10; 11; 12; 13).

Estimation of divided characteristic K values was carried out by inverse modeling using hydrogeological model of Baltic Artesian Basin. Target function (TF) calculation using characteristic K values initially was provided for each aquifer separately to verify reliability of K values and to assess how one aquifer influences all model Table (2 – 5). Subsequently TF calculation was provided using all aquifer K values together (Table 6).

Aquifer	Total target function of BAB model	Aquifer target function	Disparity of piezometric level in aquifer, m
D_3am	1173.73	63,10	7,94
D_3gj		122,88	11,08
D_2br		39,69	6,3
D_2ar		37,77	6,14

Table 6. Total target function calculation results for BAB, including all characteristic K values of each aquifer

Conclusions I

- K values of Upper Devonian Amata aquifer varies from 0,1 – 8,1 m/day, average values is 4,1 m/day and based on K values distribution and sandstones lithology, two areas of characteristic K values – 5,39 and 2,72 m/day can be divided;
- K values of Upper Devonian Gauja aquifer varies from 0,3 – 23,1 m/day, average values is 7,51 m/day and based on K values distribution and sandstones lithology, three areas of characteristic K values – 9,59; 5,52 and 8,34m/day can be divided;
- K values of middle Devonian Burtnieki aquifer varies from 0,02 – 15 m/day, average values is 5,15 m/day and based on K values distribution and sandstones lithology, three areas of characteristic K values – 8,72; 4,06 and 6,77 m/day can be divided;
- K values of middle Devonian Arukila aquifer varies from 0,05 – 13 m/day, average values is 4,37 m/day and based on K values distribution and sandstones lithology, three areas of characteristic K values – 5,36; 1,99 and 5,02 m/day can be divided;

Conclusions II

- Connection observed between lithology and hydraulic conductivity of Devonian clastic sediments are implicit. The influence of the coarse grained sediment on the high values of hydraulic conductivity are indicated by distribution of these parameters in the same prevalence areas;
- Estimation of the values of the hydraulic conductivity by dividing areas of characteristic hydraulic conductivity values, can be considered as objective. Inverse calibration using different and close to pumping tests results values of hydraulic conductivity and calculated target function of the Baltic Artesian Basin model shows better results of calculated target function and difference between calculated and observed piezometric water level. Result of target function and difference between calculated and observed piezometric water levels is less than in case of one average value for all aquifer;
- Estimation of K values of ground water aquifer using mathematical model of Baltic Artesian Basin allows to assess all aquifers as complex system as well as single aquifer and also allows to assess dissociating aquitards.

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