Hydraulic conductivity of sandstones in the Baltic Basin - a comparative study of pumping tests and grain size distribution

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Abstract

This study presents the results of the comparative study between hydraulic conductivity, grain size distribution, sediments lithology of the **lower Devonian Emsian stage, middle Devonian Eifelian and Givetian stage – Arukila (D_2ar) and Burtnieki (D_2br) formation, upper Devonian Frasnian stage – Gauja (D_3gj) and Amata (D_3am) formation in the central part of the Baltic Basin.** The aim of this study was to find characteristic hydraulic conductivity (K) values for each aquifer based on aquifer grain size distribution and lithology on the one hand and pumping test results one the other.

For the calculation of the hydraulic conductivity one has to take into account not only grain size distribution but effective porosity, temperature and kinematic viscosity of the fluid as well, which are lacking in this study.

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

Correlation of the grain size and hydraulic conductivity provided a range of the average hydraulic conductivity values for each aquifer. For example in D_2ar and D_2br aquifers K values varies from 1 - 7 m/day, in D_3gj 1 - 8 m/day and in D_3am aquifer 1 - 5 m/day.

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

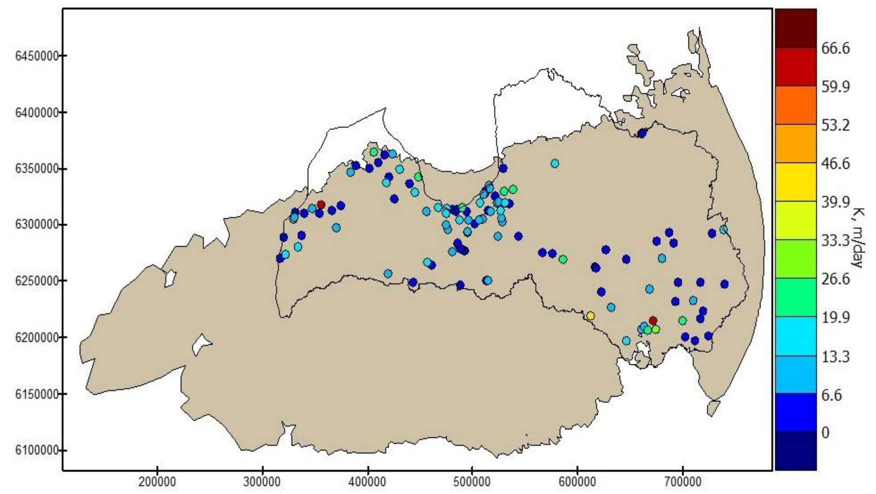

Figure 1. Values of K (m/day) of Devonian Gauja aquifer provided by pumping tests before data quality estimation

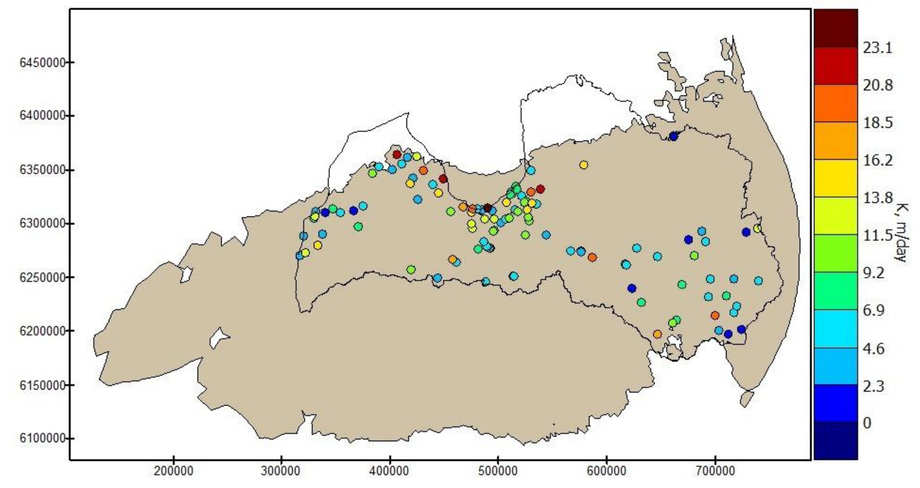

Figure 2. Values of K (m/day) of Devonian Gauja aquifer provided by pumping tests after data quality estimation

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 1; 2). Common analysis of hydraulic conductivity and grain size distribution showed insufficient results (Figure 3, 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 (Maldavs 1964; Vienken, Dietrich 2011; Fetter 2001):

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

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).

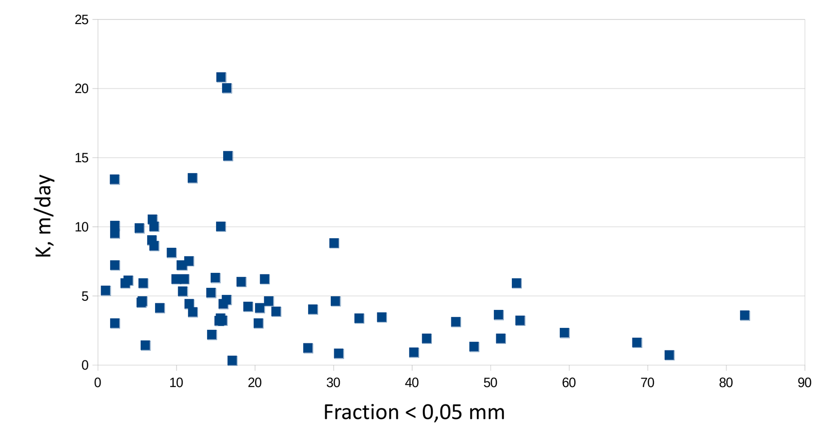

Figure 3. Correlation between hydraulic conductivity (K) values and grain size distribution in Devonian aquifers

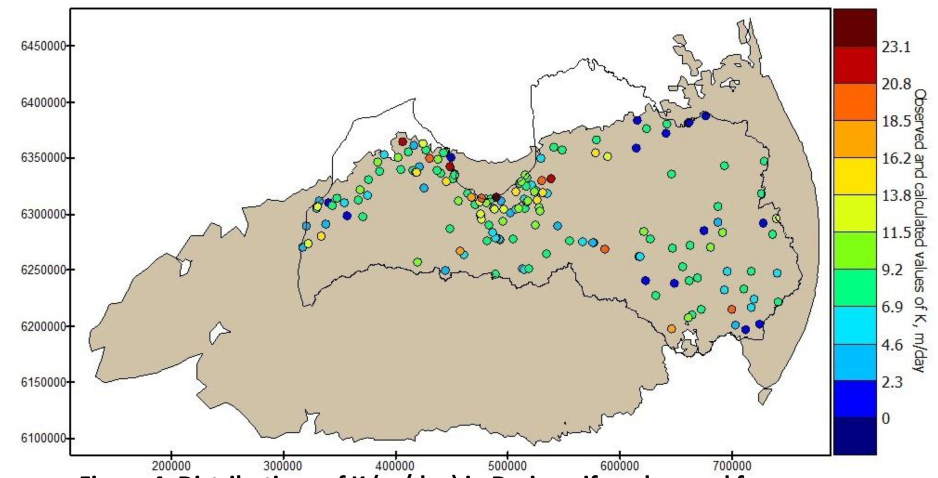

Figure 4. Distributions of K (m/day) in D_3gj aquifer, observed from pumping tests and calculated by Hazen equation

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 5, 6).

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).

From literature studies is known, that hydraulic conductivity as the sediment filtration properties describing parameter , in natural geological systems have different values in vertical and horizontal directions (Hua Chen 2000). Value of hydraulic conductivity that indicates groundwater flow in horizontal direction can be 2 to 20 times larger than value indicating vertical groundvater flow.

In this study relation 1 : 10 between vertical and horizontal hydraulic conductivity values were assumed.

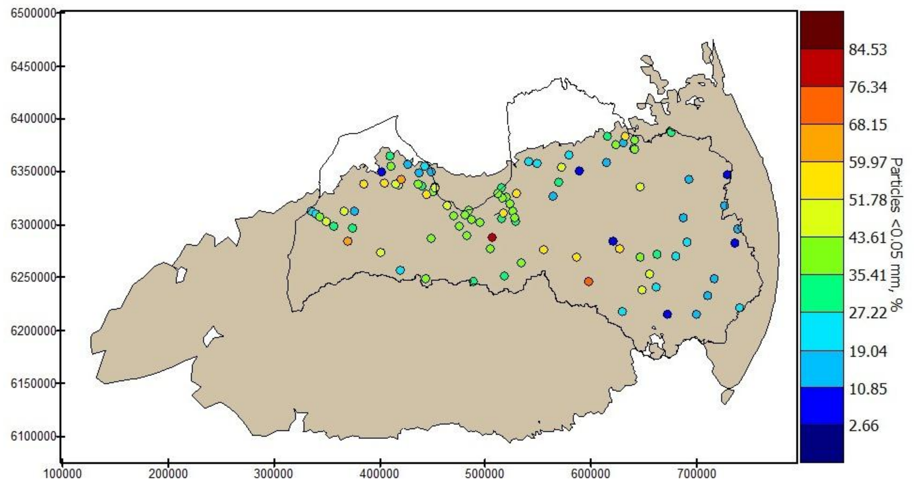

Figure 5. Percentage of fine grained (<0.05 mm) sandstones in the D_3gj aquifer, based on well log data

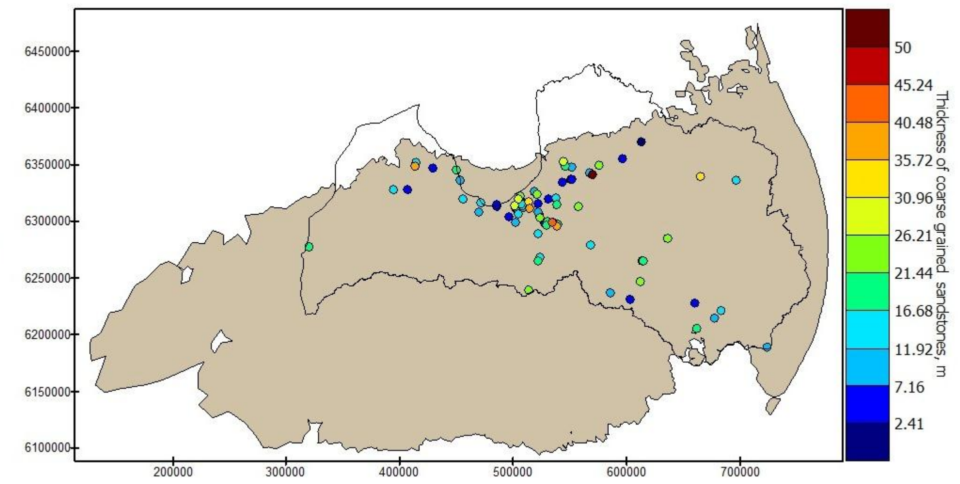

Figure 6. Prevalence of coarse grained sandstones in the wells in D_3gj aquifer and their thickness

Results

Based on distribution of observed and calculated values of hydraulic conductivity, grain size distribution and sediments lithology characteristic K values for each aquifer were assigned. Characteristic average K value for D_3gj aquifer is 7 – 10 m/day, but taking into account the fact of rather high sediment uncertainty (Kursh 1992) there must be divided smaller areas with few characteristic values. In D_3gj aquifer three smaller K value areas can be divided. Other aquifers because of insufficiency of data can be separated in less than three areas.

Estimation of divided 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).

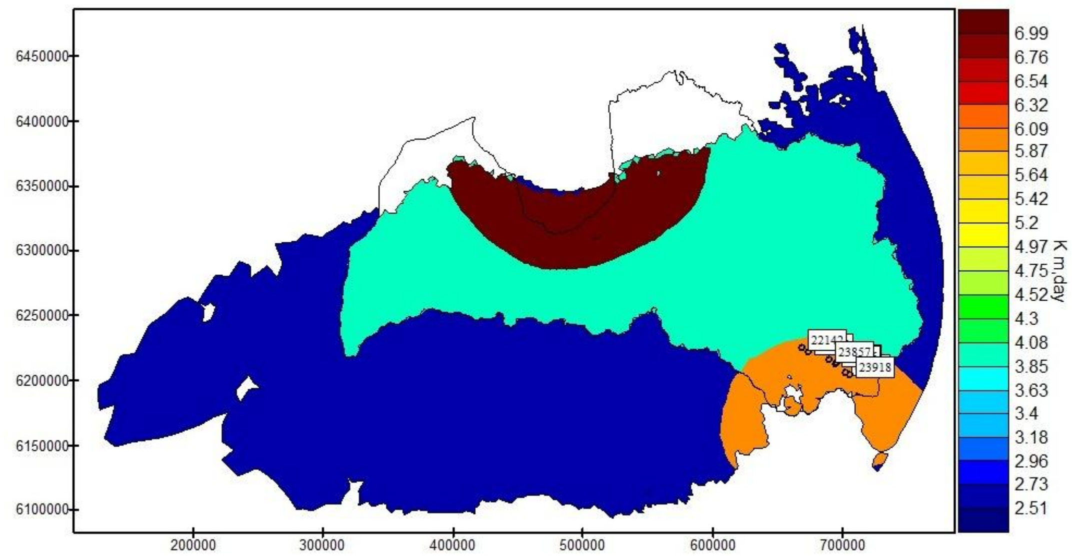

Figure 7. Divided K areas in D3gj aquifer and piezometric level observation wells;
- Riga area, K ~ 7 m/day; - Latvia area, K ~ 4 m/day; - Daugavpils area, K ~ 6 m/day

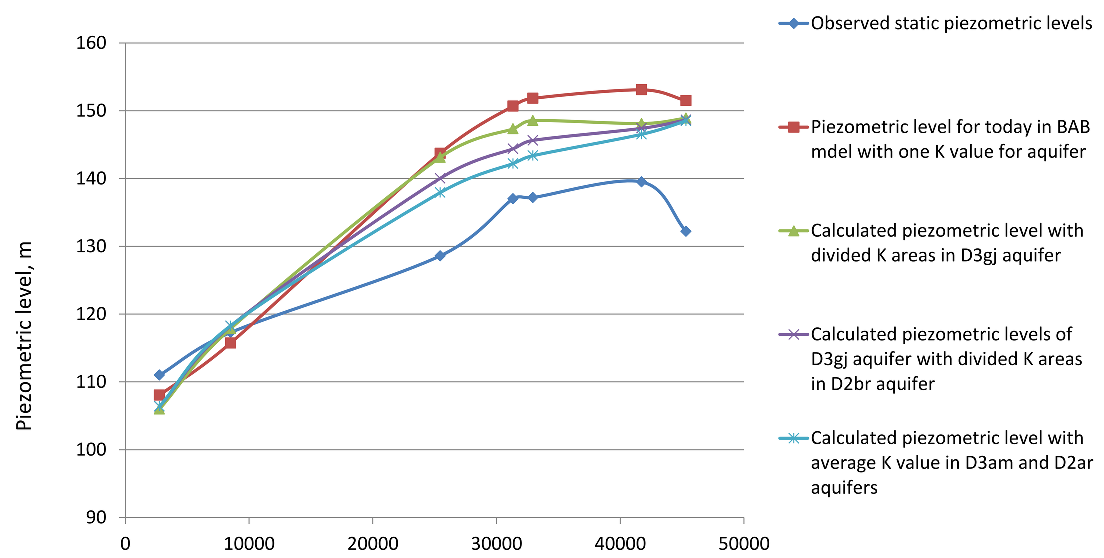

Figure 8. Observed and calculated piezometric levels in D_3gj aquifer

Figure 8 shows differences between piezometric levels in 7 wells (well location see in Figure 7) in Gauja aquifer in Daugavpils area (Figure 7). Piezometric levels are calculated in calibration process of Baltic Artesian Basin, and shows reliability and adequacy of hydraulic conductivity values which have been imparted to studied aquifers.

Figure shows that difference between observed piezometric level and level which is calulated for BAB for today in some observation points is rather large, even more than 10 m. Division of aquifer in smaller areas of characteristic K values reduces level differences. Not only current aquifer division reduces differences, but also value changes in other aquifers. Target function calculatefd in calibration process also shows reduction of piezometric level differences and can be used for description of calculated piezometric level differences between studied aquifers and imparted K values.

Piezometric level differences are not constant in all aquifer, what points to aquitards influence.

Conclusions

- 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;
- In case of defined smaller values of hydraulic conductivity of Gauja and Burtnieki aquifers the total target function of the Baltic Artesian Basin shows better results, what indicates necessity to divide areas of different hydraulic conductivity values in other aquifers of BAB;

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