Geologos 23, 2 (2017): 123–129
DOI: 10.1515/logos-2017-0013

GEOLOGOS

Hydraulic conductivity changes in river valley sediments caused by river bank filtration – an analysis of specific well capacity

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Abstract

Parameters from archive data of the Kalisz-Lis waterworks, located in the Prosna River valley south of Kalisz, have been analysed. Well barrier discharges groundwater from Quaternary sediments which is mixed with riverbank filtration water. The analysis focused on specific well capacity, a parameter that represents the technical and natural aspects of well life. To exclude any aging factor, an examination of specific well capacity acquired only in the first pumping tests of a new well was performed. The results show that wells drilled between 1961 and 2004 have similar values of specific well capacity and prove that > 40 years discharge has had little influence on hydrodynamic conditions of the aquifer, i.e., clogging has either not occurred or is of low intensity. This implies that, in the total water balance of the Kalisz-Lis well barrier, riverbank filtration water made little contribution. In comparison, a similar analysis of archive data on the Mosina-Krajkowo wells of two generations of well barriers located in the Warta flood plains was performed; this has revealed a different trend. There was a significant drop in specific well capacity from the first pumping test of substitute wells. Thus, long-term groundwater discharge in the Warta valley has had a great impact on the reduction of the hydraulic conductivity of sediments and has worsened hydrodynamic conditions due to clogging of river bed and aquifer, which implies a large contribution of riverbank filtration water in the total water well balance. For both well fields conclusions were corroborated by mathematical modeling; in Kalisz-Lis 16.2% of water comes from riverbank filtration, whereas the percentage for Mosina-Krajkowo is 78.9%.

Key words: hydrology, well fields, river valleys, water well balance, clogging, Poland

1. Introduction

Specific well capacity is a factor which combines information on aquifers and technical aspects connected with well construction and further exploitation. Exploitation of wells can cause changes in groundwater parameters which, in turn, can result in worsened filtration conditions, due to clogging of screen, gravel pack and other parts of the aquifer. Thus, while performing an analysis of specific well capacity, the focus can be on different aspects, be it technical (well construction, well aging) or environmental (transmissivity and clogging). The best method of establishing well specific capacity is a pumping test. During such a test, measurements of hydraulic conductivity and aquifer transmissivity are also acquired. Specific well capacity depends upon transmissivity of the aquifer and relationships between parameters are well known and have been described in the literature (Kleczkowski, 1965; Dąbrowski, 1983;Wysocki, 1987; El-Naqa, 1994; Mądrala at el., 2003; Duda & Paszkiewicz, 2007; Witczakat al., 2007).

Specific well capacity can be used to assess changes in hydrodynamic conditions especially in well fields located in river valleys where clogging of river bed and parts of the aquifer occur.

The present note is an analysis of archive data on specific well capacity acquired from the pumping tests in particular wells of different generations of the Kalisz-Lis well barrier and a comparison with the Mosina-Krajkowo well barrier located on the floodplain. The analysis is used in an evaluation of clogging process at sites with different intensities of river bank filtration.

2. Study area

The study area is situated within the Kalisz-Lis well field (Fig. 1) which discharges groundwater from Quaternary sediments in the valley of the River Prosna and, in part, water from river bank filtration. The geological structure of sediments in that valley to the south of Kalisz has been documented well in a number of analyses conducted between the 1950s and the present time (Krygowski, 1952). Analyses are aimed at augmenting our knowledge of the complex Quaternary sediments and their thicknesses (Piszczygłowa, 2010).

Quaternary sediments in the valley rest on a Tertiary series of clays with diversified top portions. Therefore, the thickness of the Quaternary sediments varies from 25 to 88 m (Dąbrowski, 1991). South of Kalisz those sediments have the greatest thickness as they lie in two trenches formed in Tertiary clays (Krygowski, 1952). The complex geological structure of Quaternary sediments in the Prosna River valley reflects its intricate genesis. Accumulation of sediments and infill of the valley, followed by erosion, took place a number of times. Quaternary sediments were laid down by glaciers, lakes and rivers. Even the erosional base of this area changed over time and rivers in the valley flowed in different directions, north and south (Dąbrowski, 1991). On the cross section along the well barrier (Fig. 2) sediments with poor hydraulic conductivity are shown in brown; these occur mainly in the northern part of the well barrier. In the centre, their thickness decreases, creating a hydrogeological window. Alluvial coarse sediments of gravel and sands form zones with the best hydraulic conditions in the Quaternary aquifer.

Two aquifers can be distinguished in Quaternary sediments of the Prosna River valley. The shallow one is in direct connection with the river and comprises mainly fine sand (Fig. 3), while the second one, which is deeper and has a locally confined groundwater table, comprises sand and gravel. The groundwater table in the study area is at 2–5 m below surface (Pleczyński & Przybyłek, 1974; Ziętkowiak, 2000; Kaniecki at al., 2001). The common presence of sediments with low hydraulic conductivity lowers the hydraulic connection between two aquifers but it does not eliminate it, which has

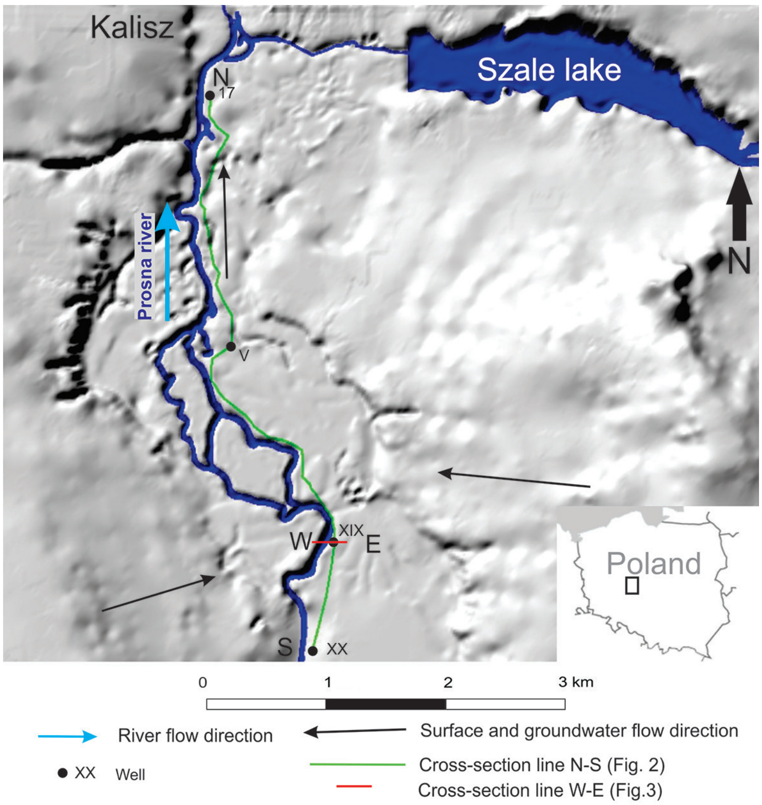

Fig. 1. Location sketch of the Kalisz-Lis well field.

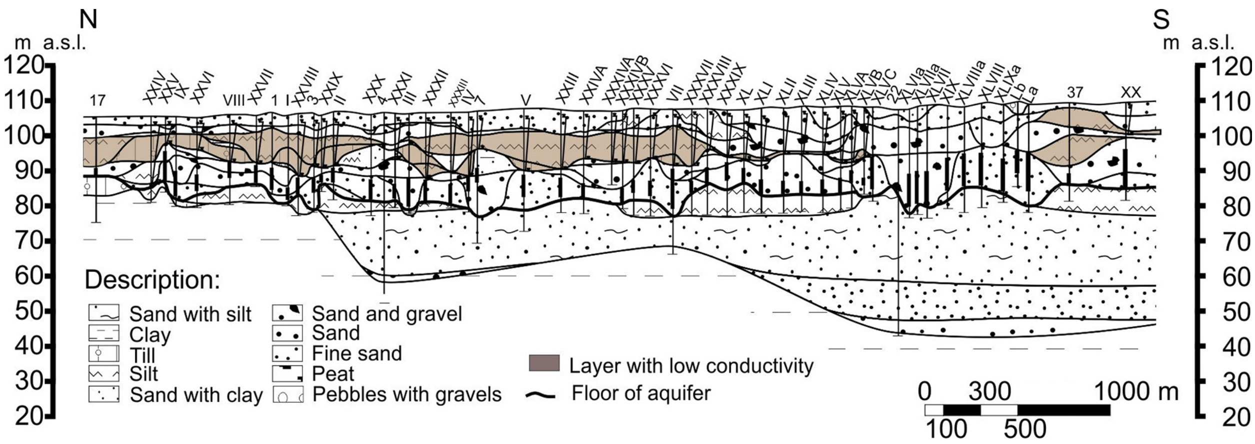

Fig. 2. Hydrogeological cross section along the Kalisz-Lis well barrier.

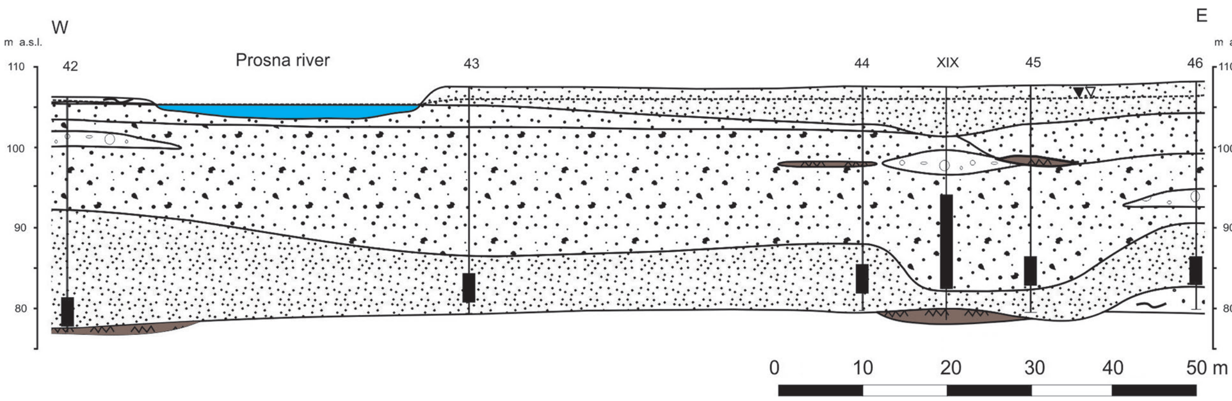

Fig. 3. Hydrogeological cross section across the River Prosna.

been observed during a pumping test by a lowering of the groundwater table in the shallow aquifer, while discharge of the deep one occurred (Karpa & Przybyłek, 1972). In some sections the thickness of this separating layer is less than a metre (Figs. 2,3); thus, in some boreholes it could be washed out by the drilling mud and not recognised in the section. Shallow aquifer recharges the deeper one in the study area as a result of the lower hydrostatic pressure of the latter. The River Prosna is the main local drainage base. Streams and groundwater flow towards the valley and northwards alongside the River Prosna (Fig. 1).

3. Analysis of specific well capacity of successive well generations

The analysis of specific well capacity presented here includes only parameters from the first pumping test that was conducted immediately after the well was sunken. Thus, each well is represented by a single value of specific capacity. Both new and substitute wells of successive generations were analysed. In the analysis it was assumed that well construction did not have significant influence on differences between values of specific well capacity due to a number of similarities amongst wells in the well barrier. The presented order of analysis of specific well capacities allows to exclude influence from well aging and well construction, thus showing only changes of parameters in the aquifer around the well.

A set of wells was chosen for the analysis of the Kalisz-Lis well barrier. Wells with specific capacity in excess of the hydraulic transmissivity were not taken into account, because in such cases values of specific capacities could be exaggerated due to insufficient pumping time and lack of stabilisation of the groundwater table and a maximum depression cone. Hydraulic transmissivity was calculated on the basis of data from well documents. Specific well capacity of wells from the chosen set is presented in graphs for the following generations: the years 1961, 1969 and 1975, plus wells drilled after 1993 (Fig. 4). In 1961 and 1969 wells can be considered as wells drilled at new locations, while the majority of those drilled in 1975 and after 1993 are substitute wells, to replace obsolete ones.

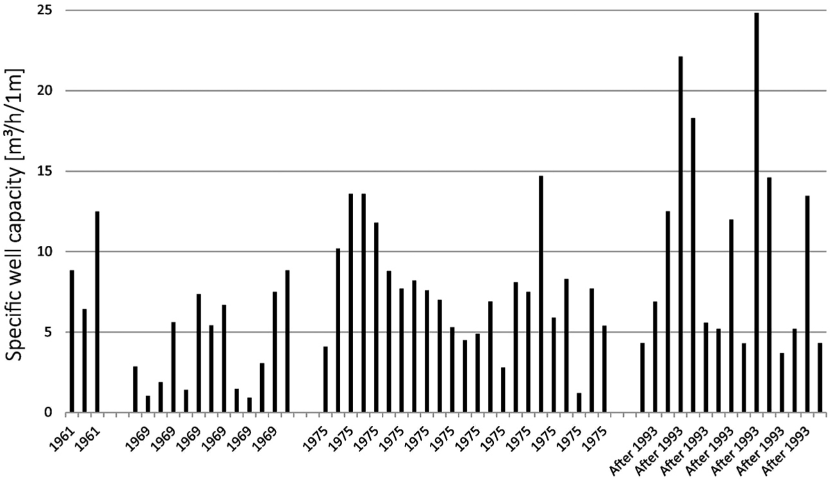

Fig. 4. Specific well capacity of wells in Kalisz-Lis well barrier from 1961 onwards.

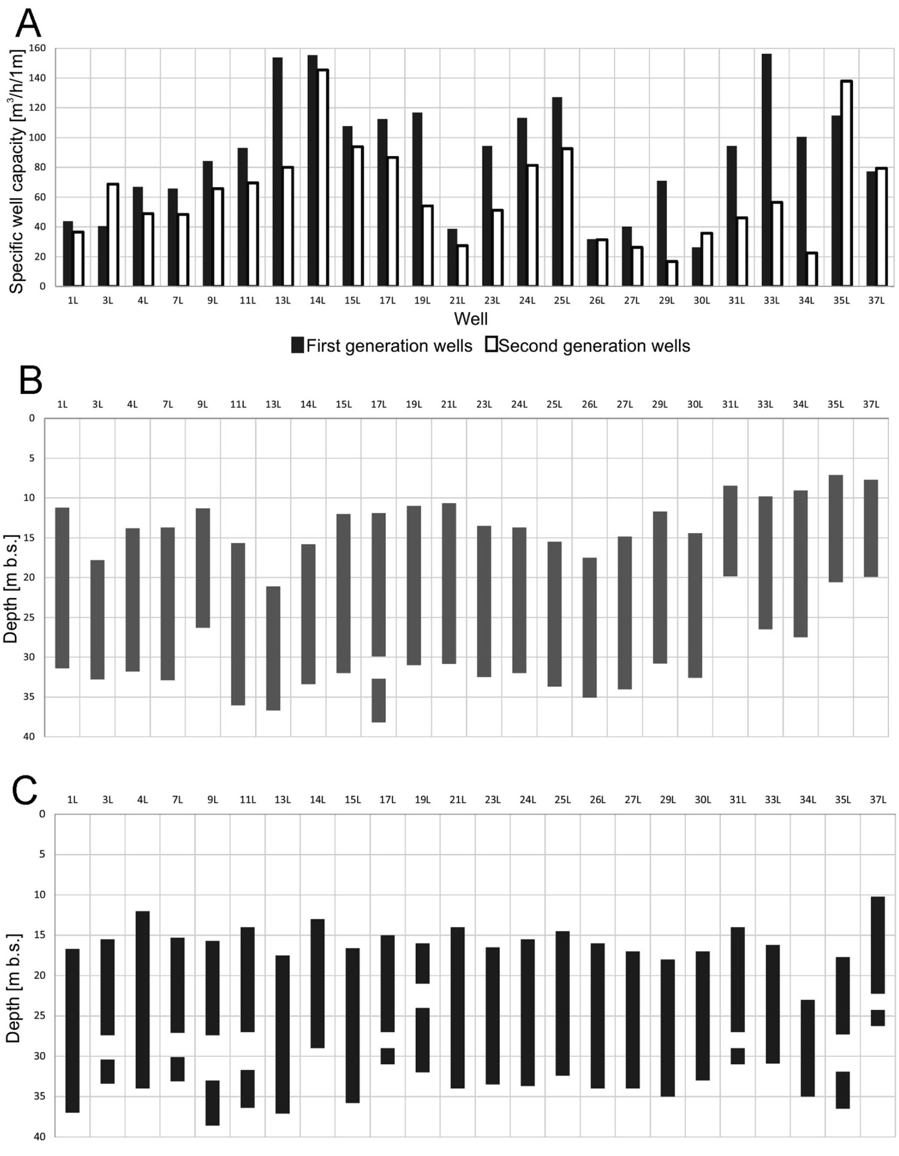

Fig. 5. Specific well capacity and screen position of wells from the Krajkowo well barrier. A – Specific well capacity from the first and second generations; B – Screen position of wells in the first generation; C – Screen position of wells in the second generation.

Values of specific well capacity vary from around 1 $m^3/h*1m$ to 24.8 $m^3/h*1m$ (Fig. 4), which presents high diversification and complexity of hydrodynamic conditions in the Prosna River valley. In the first generation of three wells there is an average of 9.25$m^3/h*1m$. The second generation has the lowest values of specific well capacity, which are caused by screens located in a thin part of the aquifer often in fine sediments with low hydraulic conductivity. In 1975 most of the wells drilled were substitute ones and only a few were drilled at new locations. In this generation of wells we have noted higher values of specific well capacity and an average of 7.64 $m^3/h*1m$. In the last generation of wells, sunken between 1993 and 2004, an average of 10.49 $m^3/h*1m$ is seen. Such an average is caused by the highest two values from the set analysed, from wells which were drilled in the hydrogeological window with favourable conditions. However, over the years a small change in specific well capacity has been noted and substitute wells show similar values to predecessors. The trend of changes in specific well capacity is stable rather than dropping.

A similar analysis of specific capacity of wells was conducted for the well barrier in the well field Mosina-Krajkowo, capturing ground and infiltration water in the Warta River valley. From this well field only the well barrier located on the floodplains was taken into consideration. Both well barriers, Krajkowo and Kalisz-Lis, have similar locations in relation to the rivers. At both sites there are two aquifers, i.e., a shallow one connected with the river and a deeper in which well screens are located. The main difference is the existence of a layer with low hydraulic conductivity at Kalisz-Lis, whereas at the Krajkowo well barrier, two aquifers are in direct connection. Values of specific capacity of wells at the Krajkowo well barrier are presented in a pole chart (Fig. 5A). The wells are subdivided into two generations, drilled between 1975 and 2011. Substitute wells, of the second generation, were drilled around 15 m away from the obsolete, first-generation one. In most cases in second-generation wells a decrease in specific well capacity is seen. In wells 19L, 29L, 31L, 33L and 34L, a drop of 50% was noted. Although in some wells an increase in specific well capacity of substitute wells was recorded, for the whole barrier an average decrease of 76% is noted. Figures 5B and 5C present screen positions of wells of the first and second generations. Most wells have screens at similar depths and of comparable size. In 66% of wells of the second generation screens differ in length for less than 15% in comparison to the first generation. In some wells of the second generation two screens, with separation, were assembled instead of one. A decrease in specific well capacity during the first pumping test in substitute wells 4L, 9L, 13L, 31L and 37L was noted, irrespective of screen length extension in the second-generation wells in comparison to the first generation (Fig. 5A–C).

4. Discussion

Barriers in the Mosina-Krajkowo and Kalisz-Lis well fields present different trends. In the former, during many years of exploitation, a decrease of specific well capacity has been recorded for substitute wells. This indicates an advancing clogging process of the aquifer, worsened filtration conditions and a decrease in hydraulic conductivity coefficient, which is an effect of a large participation of river bank filtration water in the total of discharged water by the well. According to Przybyłek et al. (2004), 78.9% of water in the well comes from river bank filtration. In river bank filtration processes and mixing of ground and surface water a number of physical and chemical process occur, both in the water and in aquifer sediments, between river bed and well. As a result, not only clogging of screens but also clogging of parts of the aquifer and river bed can be noted, which is recorded by a decrease in specific capacity of wells of the second generation in the Krajkowo-Mosina well field.

In the well barrier located at the Kalisz-Lis well field, all wells, both new and substitute, present a similar trend of specific well capacity. From pumping tests in aquifers of limited thickness, or of lower hydraulic conductivity, a lower specific capacity of wells was noted, irrespective of the time of their construction. Wells situated in hydrogeological windows achieve higher values of specific well capacity from the first pumping test. In the well field, aging of wells due to screen clogging has been recorded (Mądrala et al., 2003), but in an analysis of data of the first pumping tests over years of exploitation, the decrease in specific capacity of wells in the Mosina-Krajkowo well field is not present in wells of the Kalisz-Lis well field. Therefore, it can be stated that aquifer clogging between the Prosna River and wells in the well barrier does occurs to a small extent, or not at all. This implies that the participation of river bank filtration in supply of the well field is small. A modelling of ground water flow shows similar results, i.e., river water accounts for 16.2% of the well barrier balance (Matusiak et al., 2008).

The main difference of aquifers at Krajkowo and Kalisz-Lis is the presence of a low conductivity layer between two aquifers. Travel time increases and infiltration speed is reduced. Therefore this layer can also account for the smaller clogging process in the Prosna River valley than in the Krajkowo well field of the Warta River valley.

5. Conclusions

The analysis of the Kalisz-Lis well field presents various situations and illustrates complex hydrogeological conditions in the Prosna River valley. Despite those variations, hydrodynamic conditions do not appear to have deteriorated over time of exploitation, which suggests that hydraulic conditions in the aquifer remain stable. Discharge from the well barrier does not cause clogging of the river bed and aquifer between wells and the Prosna River. The opposite has been recorded from the Mosina-Krajkowo well field where the second generation of wells presented lower values of specific well capacity from the first pumping test, despite extension of screens length in some cases, which indicates clogging of riverbed or aquifer and a reduction of hydraulic conductivity.

The Kalisz-Lis well barrier has been designed as a riverbank filtration site; however, it discharges mainly groundwater from the Prosna River valley sediments and riverbank filtration occurs only in small degree.

Conducted analysis implies that not every well barrier located in close proximity to a river and discharging groundwater from river valley sediments is a riverbank filtration site. Specific well capacities from the first pumping test after well construction, without taking into consideration pumping tests in subsequent years of well discharge, document an impact of aquifer exploitation and changes that occur in aquifer hydraulic conductivity. In the well fields discharging groundwater and water from river bank filtration, such an analysis can be used for qualitative evaluation of the river bank filtration process and an approximation of water balance discharged by the well.

Acknowledgements

I wish to express heartfelt thanks to Professor Jan Przybyłek for academic advice and to Sylwia Obecna and other employees at Kalisz-Lis waterworks for assistance in gathering research data. This paper was completed by analysis supported by the AquaNES project. This project has received funding from the European Union's Horizon 2020 Research and Innovation Program under grant no. 689450.

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Manuscript received 5 April 2017
Revision accepted 29 June 2017