ESTIMATION OF RIVERBED CLOGGING LAYER FILTRATION CHARACTERISTICS BASED ON AQUIFER PUMPING TEST RESULTS

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Summary: *Design of drainage wells is one of the most commonly used methods for groundwater level decrease, where number of wells and their capacity has to be calculated. These parameters depend on aquifer filtration properties, river water level and distance between wells and the river. The effect of the river proximity is reflected in groundwater level increase that may require more wells or bigger well's capacity. Groundwater level reduction is calculated by using the mirror method. Aquifer and riverbed clogging layer filtration characteristic have to be determined when using mirror method. Modification of the mirror method where riverbed clogging layer filtration characteristics are included and methodology for riverbed clogging layer filtration characteristics estimation are presented.*

Keywords: *Groundwater level decrease, well, riverbed clogging layer, mirror method*

1. INTRODUCTION

Construction of the different structure foundations along the rivers is almost always accompanied by decreasing of groundwater level, which should ensure the execution of construction works in the dry foundation pit. The high level of groundwater, which is the effect of river proximity and river water level on whose shore is performed construction of the building, is usually solved by building drainage wells that provide water pumping from underground aquifers and lowering of the groundwater level in this way. The capacity of these wells, as well as their number and arrangement are determined by a series of parameters, where the most significant are proximity to the river, river water level and parameters relating to the filtration characteristics of aquifers. The equations that describe the water flow in porous media when one well or a group of wells works is defined by equations which describe linear, planar or spatial stream. The solution of these equations as the final product have a groundwater level disposition which depends on the filtration properties that need to be known in advance [1].

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Field measurements in the form of pumping tests are the most reliable method for the determination of hydrogeological parameters such as Darcy filtration coefficient, transmissivity and specific yield of aquifer [2]. Besides the above mentioned hydrogeological parameters of the aquifer groundwater level depends on presence of the clogging layer and its proximity, thickness and filtration characteristics. Clogging layer is formed on the bottom of the river as a result of the deposition of organic and nonorganic sediments, carbonate compounds of iron and manganese, and as a result of biological processes [3]. Impact of clogging layer is reflected in the reduction of hydraulic conductivity in the riverbed. The amount of water exchanged between the river and the aquifer depends precisely on the presence of the clogging layer and its characteristics. In this way, the impact of the clogging layer is indirectly transferred to the capacity of the wells that are located near the river. In cases when the groundwater level has to be decreased to allow the execution of appropriate construction works in the presence of dry foundation pit, clogging layer has a positive effect when viewed from the standpoint of the number and capacity of wells, because it is reduced. The second, also very common, case of designing wells near the river refers to drinking water sources. In this case, the presence of clogging layer has a negative effect, as it reduces the capacity of the source. Physical - chemical characteristics of the clogging layers also have a large impact on the quality of groundwater which later can significantly affect the process of purification of drinking water [4]. All the above shows the importance of research on the clogging layer but also the influence of hydrogeological, filtration layer parameters to other processes. Various methods that are based on grain-size composition of samples of the clogging layers are used for evaluation filtration properties [5] which often aren't equal with the results of laboratory research. Since there is still no technical solution to direct estimation of the filtration properties of the clogging layer [3] and because the detailed field research ([12] and [13]) requires a lot of measuring equipment and complex laboratory analysis simple analytical method based on analysis of a pumping test results is proposed in this paper.

2. METHODOLOGY

Simple analytical method for clogging layer filtration characteristics estimation, proposed in this paper, is defined under the assumptions of determined filtration charactersitics of the aquifer, transmisivity and specific yield, as a result of pumping test analysis ([2], [6], [9], [10]).

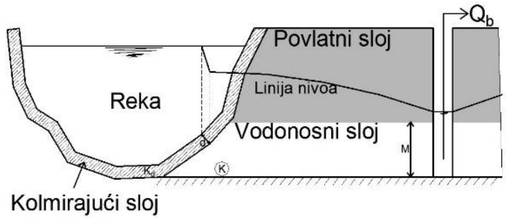

Figure 1. Shematic representation of clogging layer and aquifer with their filtration characteristics: Kd – Darcy's coefficient for clogging layer, d – thickness of clogging layer, K - Darcy's coefficient aquifer, M – thickness of aquifer and Q_w – well flow.

Proposed methodology for analysing pumping test results and clogging layer filtration charactersitics estimation is based on data taken from two monitoring wells. These unknown filtration parametrs can be evaluated by comparing the results of groundwater level changes during pumping test from two monitoring wells and by using analytical methods for calculating groundwater level during pump test.

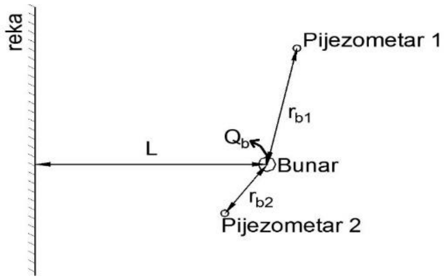

Figure 2. Disposition of two monitoring wells used for pumping tests

Theis' solution [7] was used for calculating groundwater level decrease at any point near the pumping well. This solution was performed under the assumptions of isotropic and unrestricted aquifer with uniform thickness. Theis' solution was modified by using mirror method which includes aquifer limits and appropriate boundary conditions that are present near the river, in this case constant river water level. According to this, groundwater decrease at any point can be calculated by using the equation that superpose impact of pumping well and fictive source on the other side of river boundary obtained by using mirror method [10].

$$s(t) = \frac{Q_w}{4 \cdot \pi \cdot T} \ln\left(\frac{2.25 \cdot t \cdot T}{r_b^2 \cdot S_e}\right) + \frac{Q_s}{4 \cdot \pi \cdot T} \ln\left(\frac{2.25 \cdot t \cdot T}{r_i^2 \cdot S_e}\right) \tag{1}$$

Where *s(t)* is groundwater level decrease, Q_b is well flow, Q_i negative source flow, T aquifer transmisivity, R_b distance between any point and well, R_i distance between any point and fictive source and S_e specific yield of aquifer.

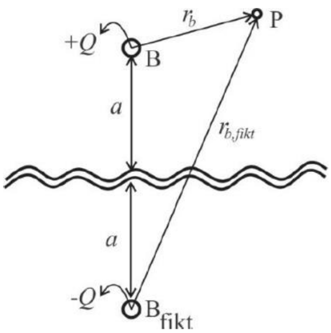

Figure 3. Mirror method for constant head boundary condition

Because it is very common to have clogging layer at riverbed it is necessary to modify analytical solution obtained by mirror method. There are number of difficulties in determining of Darcy's filtration coefficient Kd and thickness d for clogging layer. Because of that ratio Kd/d is used as representative value for clogging layer.
In order to use mirror method for solving described problem it is necessary to adequately present clogging layer effect on groundwater level gradient (Figure 1). This effect can be shown by replacing the clogging layer with layer with the same filtration characteristics as aquifer and creating fictive river boundary (Figure 2.) by moving the real one for additional length *p* which is calculated by equation (2). In oder words, we replace problem with clogging layer with equivalent problem in which pumping well is further from river for additional distance *p* but without clogging layer.

$$p = d \cdot \frac{K}{K_d} \tag{2}$$

Where *p* is fictive additional distance between river boundary and new fictive boundary, *K* is Darcy's filtration coefficent for aquifer, *d* is clogging layer thickness and K_d is Darcy's filtration coefficent for clogging layer.

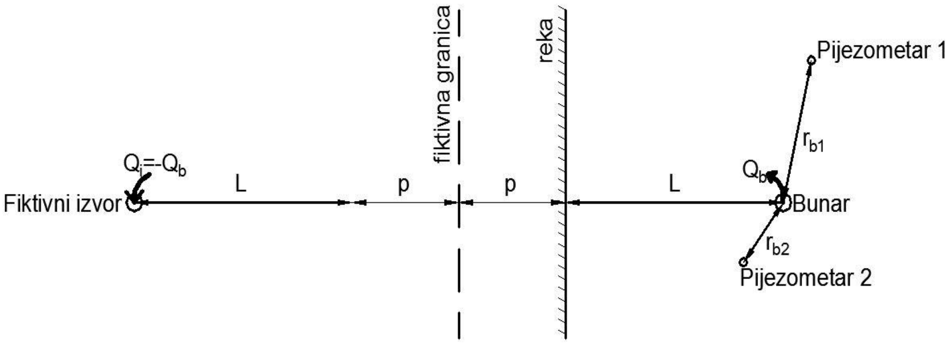

Figure 2. Mirror method when clogging layer is included in river boundary

Well outflow Q_w is equal to source inflow Q_s by intensity but with different „directions", well outflow is pimped out of aquifer and source inflow is flow from river to aquifer. Hence, equation (1). can be writen as:

$$s(t) = \frac{Q_w}{4 \cdot \pi \cdot T} \ln\left(\frac{r_i^2}{r_b^2}\right) \tag{3}$$

Where r_b is distance between monitoring well and pumping well and r_i is distance between monitoring well and fictive source obtained by mirror method.
Value r_i contains unknown fictive distance *p* defined by equation (2). Therefore, equation (2) can be modified by using XY coordinate system:

$$s = \frac{Q_w}{4 \cdot \pi \cdot T} \ln\left(\frac{\left(2 \cdot L + 2 \cdot p + x_{pi}\right)^2 + y_{pi}^2}{x_{pi}^2 + y_{pi}^2} \right) \tag{4}$$

Where L is distance between pumping well and river boundary, p additional fictive distance between real river boundary and fictive river boundary, x_{pi} distance between monitoring well and pumping well in direction X and y_{pi} distance between monitoring well and pumping well in direction Y ($r_b^2 = x_{pi}^2 + y_{pi}^2$).
Equation (4) gives groundwater level decrease when well's radius of influence reaches river boundary when influence of clogging layer is represented by unknown distance *p*. In order do determine value of p results of pumping (aquifer) test from two monitoring wells have to be measured and compared. When radius of influence of pumping well reaches river boundary water head in aquifer recorded in two monitoring wells reaches steady state which depends on clogging layer filtration charactersitics and distance between monitoring wells and pumping well. Hence, ratio between water head decrease in two monitoring wells, s_{p1}/s_{p2} reaches value which is constant. When equation (4) is used for calculating water head decrease at two points, two monitoring wells, ratio between these two values is given by equation (5).

$$\frac{s_{p1}}{s_{p2}} = \frac{\ln\left(\frac{\left(2 \cdot L + 2 \cdot p + x_{p1}\right)^2 + y_{p1}^2}{x_{p1}^2 + y_{p1}^2} \right)}{\ln\left(\frac{\left(2 \cdot L + 2 \cdot p + x_{p2}\right)^2 + y_{p2}^2}{x_{p2}^2 + y_{p2}^2} \right)} = const. \tag{5}$$

Equation (5) contains only one unknown variable, unknown distance between real river boundary and the fictive boundary. This variable is then evaluated by solving equation (5). When fictive distance p is evaluated from equation (5) representative value for clogging layer defined as K_d/d is calculated by using the equation (6).

$$\frac{K_d}{d} = \frac{K}{p} \tag{6}$$

Where K is Darcy's filtration coefficient evaluated by standard aquifer test ([18], [19]).

3. CASE STUDY

Previously described methodology for evaluation of the parameters of clogging, less permeable, layer on the bottom of the river, was tested on data obtained during the pump (aquifer) test for the purpose of pumping underground water drainage project for the construction of buildings on the site Lot14, in Belgrade, near the Sava River.

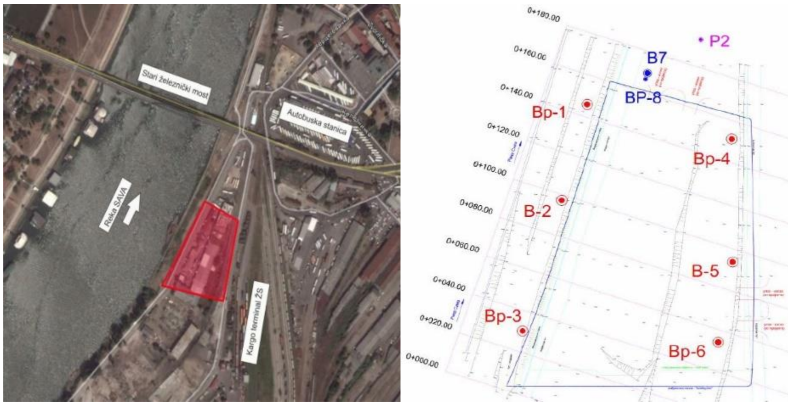

Figure 3. Testing location

Monitoring wells for groundwater level are arranged so that a monitoring well (in the Figure 3. is marked with BP8) is near the well, at a distance of 3 m, while the second monitoring well (in the Figure 3. indicated by P2) is located away from well, at the distance of about 30 m.

Results of lowering ground water level recorded at the monitoring wells BP8 and P2 are given in the Figure , along with their analysis and application of the methodology for determining the parameters Kd / d less permeable layer on the bottom of the river, which is described in the previous section. The test results of the test are recorded in two pumping piezometer BP8 and P2 (in the context of the first example which relates to a method in chapter 2.3) are shown in the figures below.

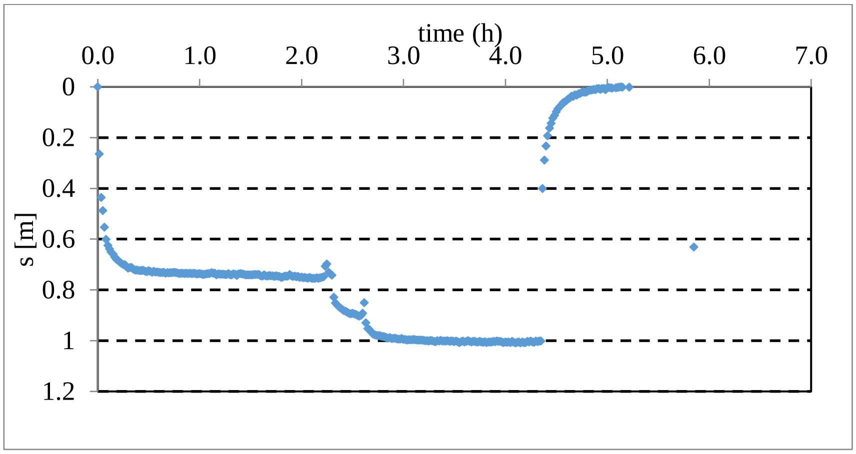

Figure 4. Aquifer test results obtained from monitoring well BP8

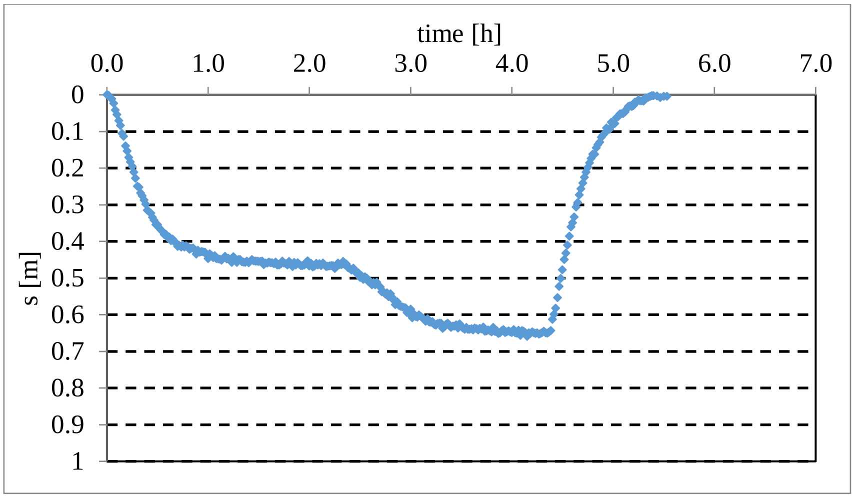

Figure 5. Obtained results from monitoring well P2

4. RESULTS AND DISCUSSION

Obtained data from two monitoring wells are compared by using equation (5) in order to determine if ratio S_{p1}/S_{p2} reaches constant value when radius of influence of pumping well reaches river boundary. Results calculated in this manner are presented in Figure 6. It can be seen that ratio S_{p1}/S_{p2} reaches constan value of 1.642 when radius of influence of well is greater than 300 m. Therefore, solving equation (5) gives the solution of unknown fictive distance p=472.68 m. Implementig solution of p in equation (6) gives the clogging layer filtratation characteristics estimation as K_d/d=1.27·10^{-6} 1/s.

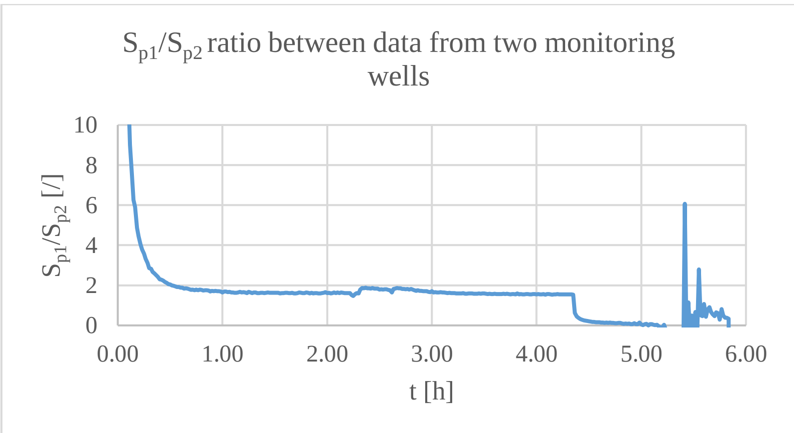

Figure 6. Results by comparing data from two monitoring wells by using equation (5)

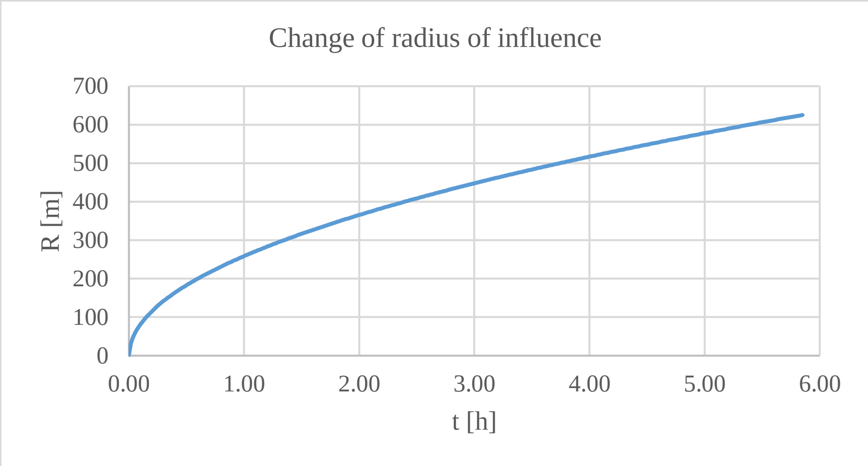

Figure 6. Change of radius of influence

Figure 6. shows that assumption of constant ratio sp1/sp2 is achieved for the most of the time except for the first half hour when radius of influence of the pumping well still hasn't reached river boundary. Other deviations in data from monitoring wells are present beacuse of the statistical errors and flow change durin test period.

5. CONCLUSIONS

Aqifer (pumping) test can be used as a method for determining the filtration characteristics of the aquifer and for determining the filtration characteristics of the clogging, less permeable, layer which has big effect on water head in aquifer when projecting drainage wells near the river.
Results obtained by processing data from the pumping test at the site Lot14 make sense if we look at the nature of less permeable layers. Confirmation of the results would require testing of the proposed methodology to more instances of testing by pumping with the observation level in two piezometers. In addition, it is necessary to emphasize that the nature of clogging layer depends on changes during the year, ie. seasonal, depends on the water level and flow. Therefore, the results should be taken and re-measurement has to be done at the same location in different parts of the year.

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ODREĐIVANJE FILTRACIONIH KARAKTERISTIKA KOLMIRAJUĆEG SLOJA UZ REKU NA OSNOVU REZULTATA TESTA PROBNOG CRPLJENJA

Rezime: *Projektovanje drenažnih bunara je jedan od najčešće primenjivanih postupaka za sniženje nivoa podzemnih voda, pri čemu je potrebno odrediti broj bunara i protok koji se na njima crpi. Ovi parametri zavise od filtracionih karakteristika izdani, nivoa u reci kao i udaljenosti bunara od reke. Uticaj blizine reke ogleda se u tome što ona prihranjuje izdan iz koje se crpi voda što može uticati na povećanje broja bunara ili povećanje kapaciteta pumpi za crpljenje. Sniženje NPV u blizini reke računa se primenom metode ogledalnih slika. Pri upotrebi ove metode potrebno je voditi računa o filtracionim karakteristikama vodonosne izdani ali i kolmirajućeg sloja na dnu reke. Prikazana je modifikacija metode ogledalnih slika koja u obzir uzima i karakteristike pomenutog slabije propusnog sloja i metodologija za određivanje karakteristika kolmirajućeg sloja na osnovu rezultata testa probnog crpljenja.*

Ključne reči: *sniženje NPV, drenažni bunar, kolmirajući sloj, metoda ogledalnih slika*