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HYDRAULIC TESTING OF SPECIALISED WATER PRODUCTION STRUCTURES (HORIZONTAL COLLECTOR WELL) IN RIVERBANK FILTRATION SYSTEMS

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Abstract

One of Hungary's strategic water sectors is the supply of drinking water, which relies heavily on so-called riverbank filtration systems. About 35-40% of the national drinking water supply comes from riverbank filtered aquifers. Today in Hungary, 40% of the population; nearly four million people's daily water needs are met from riverbank filtered aquifers. In the future, 75% of our drinking water sources will be bank-filtered, which means that they will also be of great importance for future water resource management.

The main water abstraction device in these aquifers is the well, or a special type of well, the horizontal collector well (HCW). In our work, we will focus on the hydraulic investigation of these types of wells. Using modern modeling software, the impact of the special design of HCWs on groundwater flow conditions can be well modeled. In our work, the yield distribution between the arms and the impact on the potential relationships are discussed in more detail and the results of this modeling are presented.

Keywords: *horizontal collector well (HCW), riverbank filtration, drinking water supply*

1. Introduction

The relationship between a river and its environment often creates conditions that can be exploited to provide drinking water. So-called riparian filtration systems have hydrogeological characteristics that are suitable for the extraction of large quantities of high-quality drinking water. This is due to the specific characteristics of riverbank filtration, which often have a positive impact on the quality of the water produced (Houben, 2022). During the process of riverbank filtration, the water infiltrated from the river can be purified to drinking water quality by various biological and physical processes before reaching the production wells. Riverbank filtration is of great importance, as 35-40% of Hungary's drinking water supply comes from these systems (Kovács et al., 2016). A frequently used means of producing water from this type of aquifer is the horizontal collector well (HCW). Their advantage lies in the design of the well. The horizontal, multi-directional spudding of the arms increases the useful filtering surface through which large quantities of water can be produced from the well. In our study, we investigate the potential relationships and water flows during the production of these wells.

2. Riverbank filtration systems and horizontal collector wells (HCWs)

The interaction between the river and its environment can create favorable conditions that can be used to produce drinking water. In bank filtration, water is produced using water intake structures installed close to the surface water (mine wells, tube wells, HCWs, galleries), which creates a depression in the well environment (Rózsa, 2000). As a result, the hydraulic gradient changes (K. Tóth, 2017). As the gradient changes, seepage from the river and the background is triggered. If there is a proper basin connection, a higher proportion of recharge (more than 50%) occurs from the river, and this is called riverbank filtration (Ray et al., 2002). The legal definition of a riverbank filtration aquifer is: "a groundwater basin near-surface water where recharge of water produced by abstraction works is derived from infiltration from surface water to a degree of more than 50%" (Government Decree 123/1997 (VII.18.)). This process creates a natural filtration process in the groundwater that can result in the purification of produced water to drinking water quality. The natural purification processes that occur during the riverbank filtration process are:

- hydrodynamic (dilution)
- mechanical (filtration)
- biological (activity of micro-organisms)
- physicochemical (precipitation, adsorption, coagulation, etc.) (Hiscock and Grischek, 2002).

The inventor of the HCW was Leo Ranney, who intended to increase the efficiency of oil wells by using radially arranged horizontal arms. First used as an alternative type of well, this type of well design is now widely used in drinking water supply worldwide, and Budapest is also supplied to a significant extent by such wells (Székely, 2011).

3. The methodology used and well types modeled

One of the most commonly used modeling methods in hydrogeological research is the finite difference method. This numerical method was also used in our work, within the MODFLOW program. The application of the Revised Multi-Node Well (MNW2) package of MODFLOW allowed us to investigate the hydraulic conditions of HCWs. The MNW2 program was originally developed for the hydrodynamic modeling of horizontally drilled and horizontally formed wells but has been shown in previous studies to be suitable for the hydraulic simulation of horizontal collector wells (Nyiri et al., 2019; Székely et al., 2021). With this method, we aimed to determine the distribution of the total yield produced by the horizontal collector well among the arms and to determine the extent of depression in HCWs installed at different distances and its evolution.

Three well types were considered in the modeling. A well type with two, three, and five arms, which is Table 1. are located in a geological medium with characteristic values at a distance of 10-80 m from the river.

4. Results of the modeling

The operating principle for the production of vertically drilled wells is also to produce the well with the same yield, i.e. to subject the well to a nearly constant hydraulic load. In the case of HCWs, the volume of water entering the well along a given length of the arm is not constant but increases exponentially towards the end of the arm (Székely et al., 2021).

Table 1. *Hydraulic parameters of the modeled volume*

Parameter	Value
Hydraulic conductivity (m/d)	150
Model thickness (m)	24
Arm depth (m)	21
Horizontal and collector well yield (m^3 /d)	60 000
Arm length (m)	60
Inner radius of the arm (m)	0,15

This yield distribution is also influenced by the distance of the well from the river. In our study, we wanted to investigate how the yield of the different arms relative to the total yield varies with distance from the river. In the case of HCW with two arms, there is no difference, i.e. both arms produce 50-50% of the total yield. However, the picture is different for the HCW with three (Figure 1.) and five (Figure 2.) arms. As the distance of HCW to the river increases, the production shares nearer to the river show an increasing trend, while the yield share of the parallel to the river, numbers 1 and 3, decreases. This trend changes at 30 m and the two curves start to converge. It can therefore be concluded that in the region close to the river, the yield ratio of the arms shows a balanced pattern, this balance is broken as one moves away from the river and then tends to return to balance at a certain distance from the river. It can therefore be seen that in this case, the yield ratio of the arms at a distance of 30 m is the most unbalanced. At this distance, the river-facing arm produces almost 44% of the total yield, while the other two arms produce 28-28% of the total yield.

A HCW with (Figure 2.) five arms shows the variation in the yield of the arms as a function of distance from the river. Figure 2. shows that the number 1 and 5 arm shows a decreasing and then increasing trend, as in the previous case. For the arms extending towards the river, the yield ratio is shown to increase and then decrease, but the maximum yield ratio is shown at a different location. The maximum drift rate is found at 30 m for the number 2 and 40 m for the number 3.

It has been shown above that the yield produced results in different yield ratios for the arms as they move away from the river. It is therefore important to investigate whether this phenomenon causes this variation in the operating water level and depression.

In our previous works (Székely et al., 2021), the fact that the inflowing yield increases away from the well along the arms of the horizontal well has already been explained. This growth is exponential. The yield flowing along the arm was characterized by the specific yield per unit arm length, which is given by the following relationship.

$$Q_f = \frac{q_{i,j}}{l_{i,j}} \left[\frac{m^3}{day}\right]$$

where,

Q_f: Specific flowrate for unit arm length,

$q_{i,j}$: flowrate of the cell No. i, j,

$l_{i,j}$: length of arm across the cell.

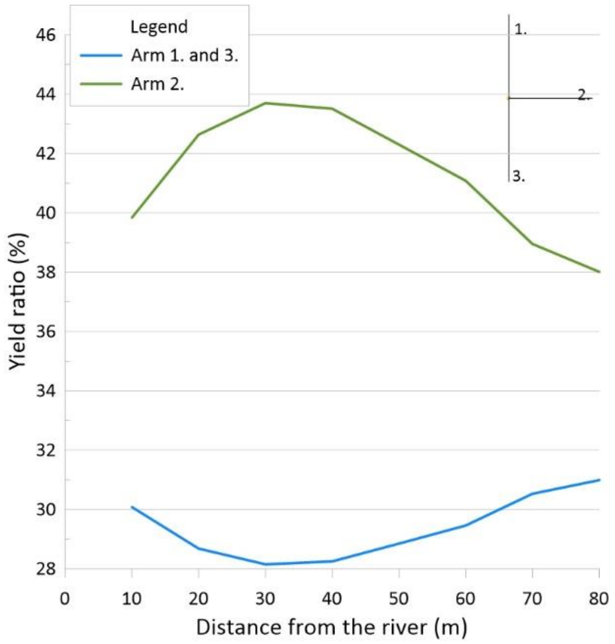

Figure 1. *Evolution of the yield distribution of the arms as a function of distance from the river (well with three arms)*

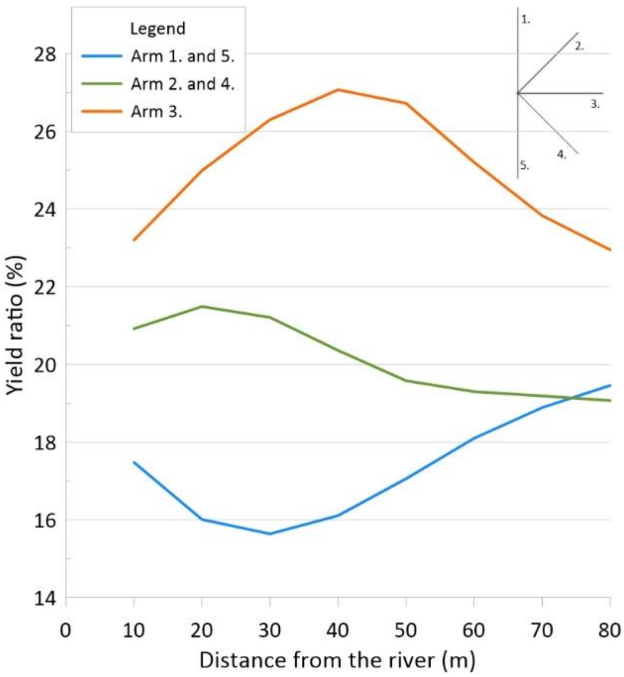

Figure 2. *Evolution of the yield distribution of the arms as a function of distance from the river (well with five arms)*

In the case of a well with two arms, this exponential character can be observed (Figure 3.), however, if additional arms are formed, this exponential character changes near the wellbore.

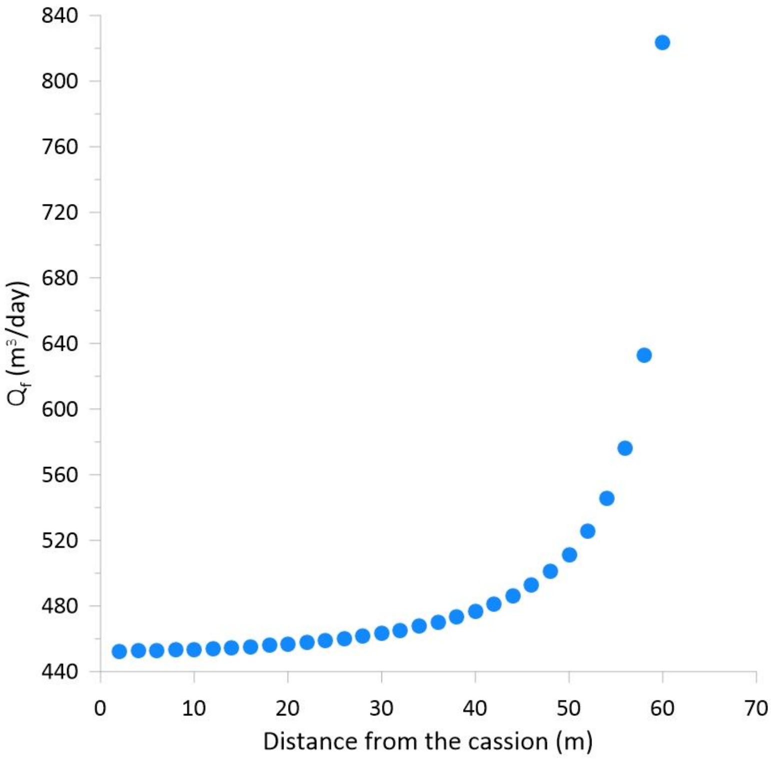

Figure 3. *Specific flowrate change along the arm in the case of HCW with 2 arms*

The reason for this is the effect of the arms on each other. This mutual influence changes the nature of the curve in such a way that the slope of the curve of the yield change is large as it moves from the cassion, then this slope decreases, and finally turns into a large slope again (Figure 4.). In the case of the horizontal collector well with 5 arms, this effect is more pronounced. It can therefore be concluded that the influence of the arms on each other near the well shaft of the horizontal collector well significantly influences the yield distribution along the arm. In the vicinity of the wellbore, the yield decreases for each arm, and increases significantly towards the end of the arm. In the case of horizontal collector wells, it can therefore be said that the hydraulic load on the arms increases from the wellbore towards the end of the arm.

For each of the three types of wells studied, we have determined the degree of depression that develops as a function of distance from the river at constant yield. It can be said that at a given distance from the river, the more arms are formed at a well, the less depression can be expected. This can also be explained physically since the fewer arms used, the smaller the area of space involved in the production, and the greater the depression. Withdrawal of water from a larger surface area implies a reduction in depression. For a given HCW, it can be observed that the depression value increases as one moves away from the river. As you move away from the river, the potential level of the river has less and less impact on the producer well. This means that the depression caused by the producer well increases in the distances we study. The dependence of the depression on distance shows a linear trend over the range studied (Figure 5.).

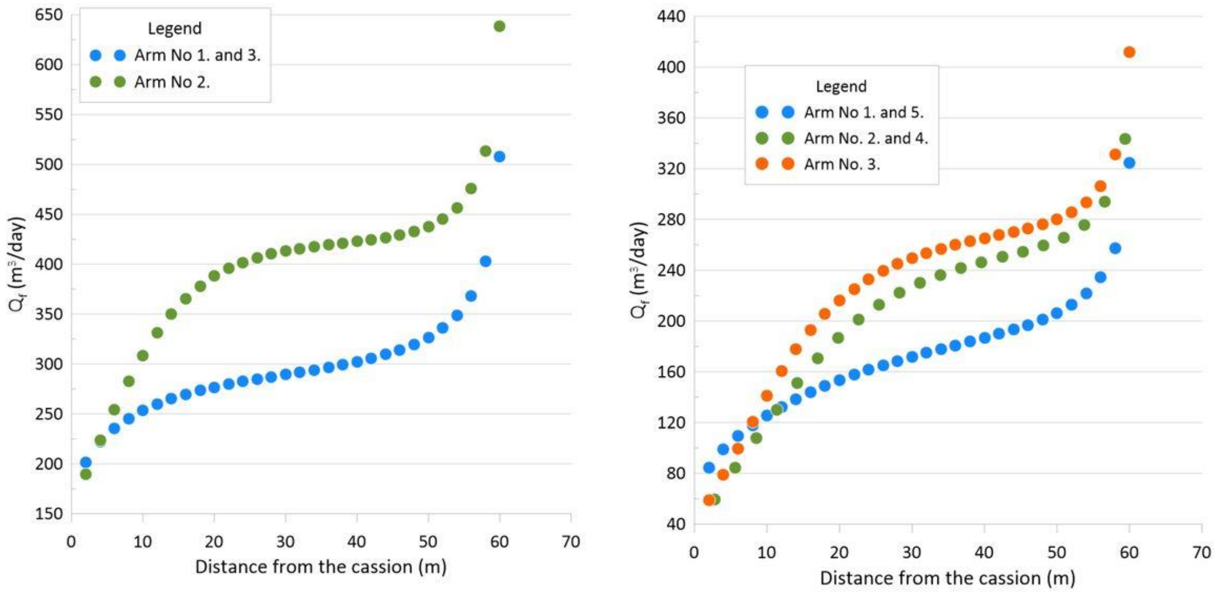

Figure 4. *Change of inflow rate along the arm in the case of HCWs with 3 and 5 arms*

5. Summary

In our work, we investigated the yield distribution and the degree of depression that develops during the production of horizontal collector wells. The results of the modeling indicate that the production of HCW away from the river shows a zone where arms do not produce in a balanced manner. The inflow rates along the arm are highly change if more and more arms are drilled. This phenomenon can give a high amount of hydraulic load to the end of the arms. This information can be important for well operation, as in this unbalanced zone the arms do not receive the same hydraulic load. The depression in the wellbore is not affected by this phenomenon, however, and the depression increases linearly away from the river.

6. Acknowledgments

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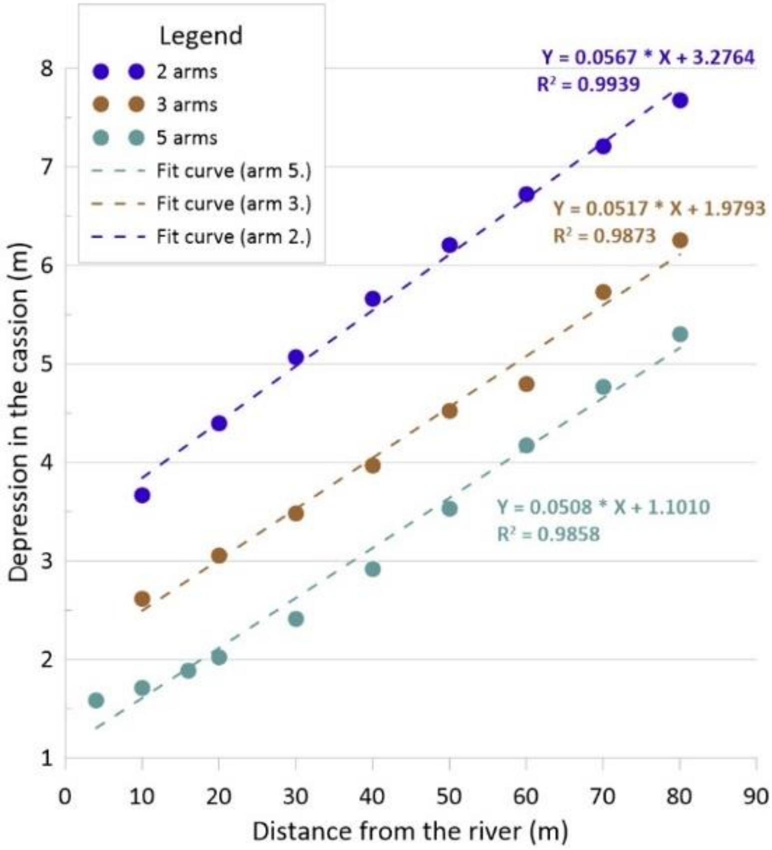

Figure 5. *Depression as a function of the number of arms and distance from the river*

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