Characteristic groundwater level regimes in the capture zones of radial collector wells and importance of identification (case study of Belgrade Groundwater Source)

DjORDjIJE BOŽOVIĆ[1], DUŠAN POLOMČIĆ[2], DRAGOLJUB BAJIĆ[2]

Abstract. Assessment of the operating modes of radial collector wells reveals that the pumping levels in the well caissons are very low relative to the depth/elevation of the laterals, which is a common occurrence at Belgrade Groundwater Source. As a result of such a state of affairs, well discharge capacities vary over a broad range and groundwater levels in the capture zones differ even when the rate of discharge is the same. Five characteristic groundwater level regimes are identified and their origin analyzed using representative wells as examples. The scope and type of background information needed to identify the groundwater level regime are presented and an interpretation approach proposed for preliminary assessment of the aquifer potential at the well site for providing the needed amount of groundwater.

Key words: water supply, radial collector well, groundwater level regime.

Апстракт. Приликом анализирања режима рада бунара са хоризонталним дреновима, уочена је појава која представља готово константу на београдском изворишту подземних вода, а то је да се нивои у бунарским шахтовима налазе веома ниско у односу на дубину/коту утиснутих дренова. Као резултат оваквог стања, капацитети бунара варирају у широком дијапазону, а у непосредном окружењу бунара се формирају веома различити нивои подземних вода, чак и при истом капацитету бунара. Издвојено је пет карактеристичних режима нивоа издани, док су услови њиховог формирања анализирани на примерима репрезентативних бунара. Представљени су обим и врсте подлога којима је потребно располагати у циљу идентификације режима и предложен је приступ његовог тумачења путем ког је могуће прелиминарно дефинисати потенцијал водоносне средине на локацији бунара за обезбеђење потребних количина подземних вода.

Кључне речи: водоснабдевање, бунар са хоризонталним дреновима, режим нивоа подземних вода.

Introduction

Operation of radial collector wells is managed by regulating water levels in the well caisson (i.e. controlling well drawdown). At Belgrade Groundwater Source (BGWS), groundwater levels in the caissons (pumping levels) have for years been low relative to the well laterals. This is primarily a result of a reduced capture capacity of the laterals, caused by multiple decades of exposure to corrosion and colmation (Dimkić *et al*. 2011a, 2011b, 2012; Polomčić 2000). It is safe to say that a large drawdown and modest well discharge capacity are recognizable BGWS features today, as clear indicators of the condition of the wells and the groundwater extraction regime.

The starting point of the research reported in this paper was the observation that maintenance of, as a rule, low pumping levels in the caissons of radial collector wells has resulted in a broad range of discharge capacities (from 3 to 150 l/s), and that as a result of such an operating mode, different groundwater level regimes are formed in the zones of influence of the wells.

It is clear that the discharge capacity of a radial collector well is a function of the number and condition of active laterals, as well as the hydrologic features of the site and aquifer recharge conditions. As such, significant variations in the rates of groundwater extraction between the wells are indicative of large differences in the functional condition of their groundwater capture components and a pronounced heterogeneity of the lithologic composition and filtration characteristics of the porous medium in the near–well region.

Several characteristic groundwater level regimes can be identified with regard to the

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currently intensive operating mode (large well drawdown), such that the wells are grouped accordingly.

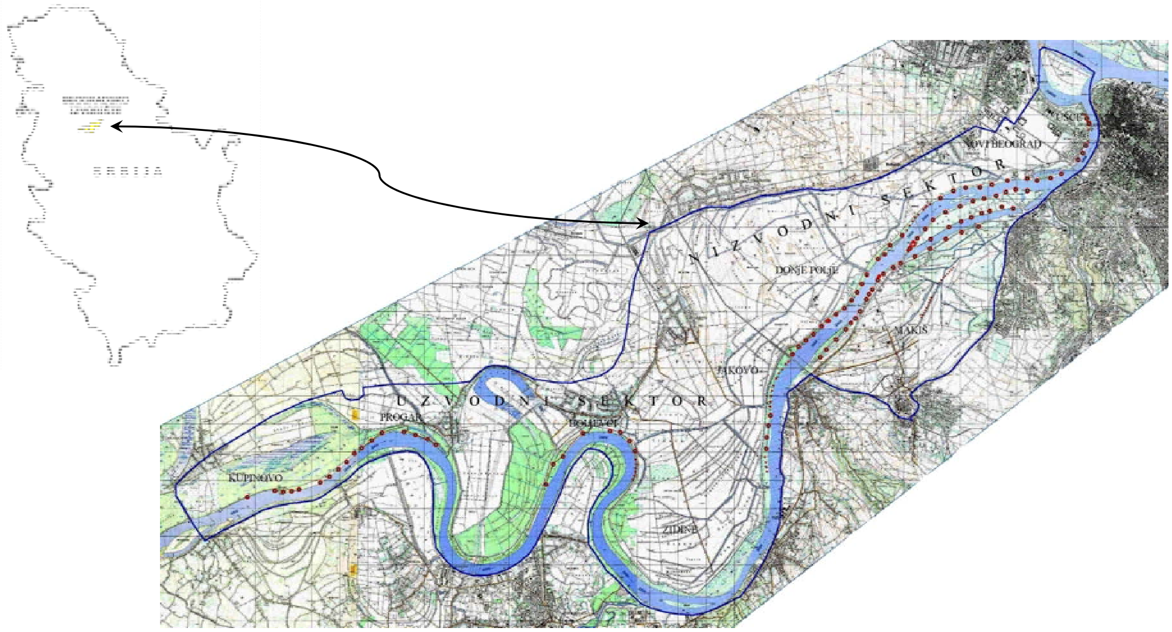

Figure 1: Geographic location of Belgrade Groundwater Source

Geologic framework and hydrogeologic features

Belgrade Groundwater Source (BGWS) is located along the Sava River, in Quaternary fluvial sediments. Its main natural feature is an extremely heterogeneous lithostratigraphic composition and diverse hydrogeologic properties of the sediments (even in a very small space – within the capture zone of the laterals of a single radial collector well). This state of affairs is a result of a highly complex origin, based on current knowledge, associated with intensive tectonic activity in the Late Pliocene and Lower Pleistocene, as well as specific paleoclimate conditions throughout the Quaternary period.

Tectonic activity is manifested by multiple uplifting of the horst of Mt. Fruška Gora to the northwest and the Belgrade hills to the south, along with sinking of the Sava paleo trench between these two formations (Toljić *et al.* 2014). Dramatic global climate change during the Pleistocene is another major initiator of the origin of the characteristic polycyclic framework of the BGWS sediments. This groundwater source corroborates the rule that regional changes in the geologic framework are a result of tectonic activity, whereas local changes are under the influence of climate.

The impermeable aquifer floor formed in fluvial sediments is represented by so–called lacustrine–bog deposits of the Plio–Pleistocene (there are only local older rocks), whose lithologic composition is comprised of clay, sand and silty clay. Their thickness at BGWS has not been determined reliably, but it is believed to be greater than 100 m.

The unconfined aquifer is formed in sediments whose thickness is from 25 to 30 m in the downstream sector of the BGWS and about 20 m upstream from the Ostružnica Bridge. They are comprised of two Quaternary stratigraphic units:

- Lower Pleistocene polycyclic fluvial sediments, and
- Holocene sediments of the contemporary channels of the Sava and its tributaries.

At BGWS, groundwater is tapped from the older Quaternary strata (previously known as the “Makiš layers” or “layers with *Corbicula fluminalis*” and today as “layers with Pleistocene *Corbicula*” – Gaudényi *et al.* 2015). The structure of both old and recent water–bearing sediments is polycyclic, as a result of multiple sedimentation stages of bed–load deposits and floodplain deposits, with frequent formations of oxbow lake deposits.

Common to all cycles is that, as a rule, there are strata of bed–load deposits, comprised of gravel and sand, towards the bottom, which turn sandy near the bed surface and feature different grain sizes.

The final part of each cycle consists of local sediments of floodplain deposits: clay, silty clay and silt. With regard to groundwater extraction and operation of the radial collector wells, the hydrogeologic significance of these ultimate stages of the sedimentation cycles (which are generally referred to as a "semi–permeable interbed") is exceptional. Given that they are semi–permeable rocks, they constitute a barrier for groundwater flow to the laterals. As such, their presence limits and impedes groundwater extraction and operation of the wells.

In the contemporary Sava Valley, Holocene sediments lie discordantly over Lower Pleistocene strata. Middle and Upper Pleistocene fine–grain sediments had previously been severely eroded in the Holocene river channel stage. The average thickness of these strata is 10–15 m.

On the ground surface, there are recent floodplain sediments, which virtually cover the entire alluvial plain of the Sava River. They are comprised of silt, silty sand, and silty and fine sandy clay. They provide sound protection of the aquifer against pollution from the ground surface.

The highly–complex framework of the BGWS fluvial deposits is currently explained most fully by Shantser's model of the constrative dynamic phase of alluvium formation (Nenadić *et al.* 2010), along with the influence of tributaries from the slopes that form the perimeter of the alluvial plain (Knežević *et al.* 2012). However, sudden lateral alternation of sediments featuring different lithologic and geochemical compositions, often only a few meters apart, indicates that this model is simplified but still effectively used to address practical engineering problems (where it is, as a rule, enough to define the vertical lithologic stratification).

Additional exploration is needed to identify the effect of the tributaries on aggradation of the Sava trench in the Pleistocene. Given the past individual efforts and the contributions of those who explored this terrain, a team of explorers from different geological disciplines (along with required resources) is needed to develop a proper geological model of the origin of the BGWS terrain.

Characteristic groundwater level regimes

Regime 1: This characteristic groundwater level regime is found in conditions where the pumping level is at a small height above the laterals, which results in a significant drawdown in the capture zone of the laterals, distinct spatial irregularity of the groundwater levels in the zone of influence of groundwater extraction, and modest well discharge capacity.

A typical example of this groundwater level regime is well RB–46. Over the past five years, the pumping level has been maintained at 55.40 m above sea level (3 m above the laterals), which has resulted in a discharge rate of some 20 l/s (Fig. 2).

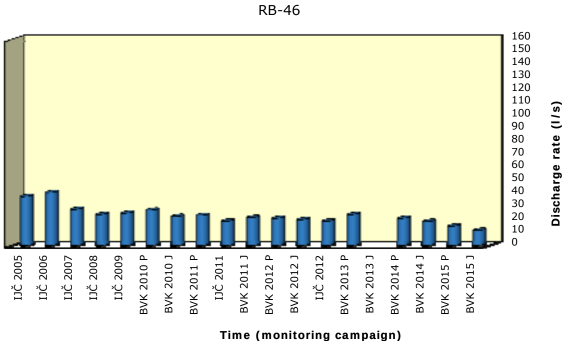

Figure 2: Discharge capacity of well RB–46

(Explanation: IJČ and BVK denote monitoring campaigns undertaken by Jaroslav Černi Institute for the Development of Water Resources and Belgrade Waterworks and Sewerage PUC, respectively; P stands for a spring campaign and J for an autumn campaign.)

The condition of the laterals of well RB–46 is poor. Underwater filming of the inside of the laterals revealed that five of the six active laterals were significantly filled with aquifer material at the very inlet (solid pipe). Since the actual lengths of the laterals could not be determined accurately, all the active laterals were simulated on the hydrodynamic model (Božović *et al.* 2015) as having a screen length of 20 m. Detailed calibration of the hydrodynamic model, which simulated perennial groundwater regime, revealed that only three laterals were actively involved in groundwater extraction.

There are three observation wells (RB–46/P–1, P–2 and P–3) in the capture zone of well RB–46, whose piezometer screens are short and installed at the same depth as the laterals (an important condition in studies of groundwater level regimes in the zone of influence of radial collector wells). The groundwater level differences (Fig. 3) reported by these piezometers are substantial, which leads to the conclusion that they are distinctly a function of distance from the functional laterals. Immediately beyond the capture zone of the laterals, the groundwater levels are not influenced by the well. Instead, they fluctuate according to river stage variation.

This groundwater level regime is determined by modest filtration characteristics of the aquifer in the area of the well. Specifically, the hydraulic conductivity of the layer in which the laterals of well RB–46 are emplaced is $K=1\cdot10^{-4}$ m/s. There is not much of the semi–permeable interbed in this zone. The small difference between the pumping level and the groundwater level at piezometer RB–46/P–1, which is located adjacent to (or in technical jargon "on") lateral #8, indicates that this lateral is not significantly colmated. This has been corroborated by model testing (Božović *et al.* 2015). The considerable aquifer drawdown in the capture zone of the laterals suggests that the filtration properties of the other lithostratigraphic layers (not only those of the layer in which the laterals are emplaced) are modest. As such, the wells in this group cannot be expected to provide substantial amounts of water. This was corroborated by hydrodynamic analysis, which examined the effectiveness of replacing the old laterals of this well by installing six new, 50 m long laterals. Model simulations showed that the discharge capacity of only 35 l/s was to be anticipated (when the stages of the Sava River are low and when the pumping level is 6 m above the elevation of the laterals, according to Božović *et al.* 2016a).

It follows that in this characteristic groundwater level regime, when the pumping level is low, there is a significant aquifer drawdown adjacent to the lateral. As the distance from the lateral increases (even at the center distance between two neighboring laterals), the groundwater level increases progressively and the water table acquires a characteristic three–dimensional pattern (Fig. 4). The discharge capacities of this group of wells are modest even when the laterals are in good condition.

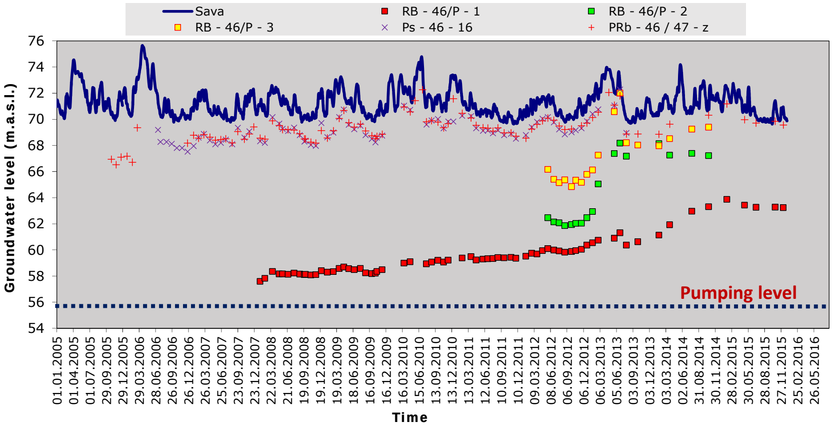

Figure 3: Groundwater levels in the zone of influence of well RB–46

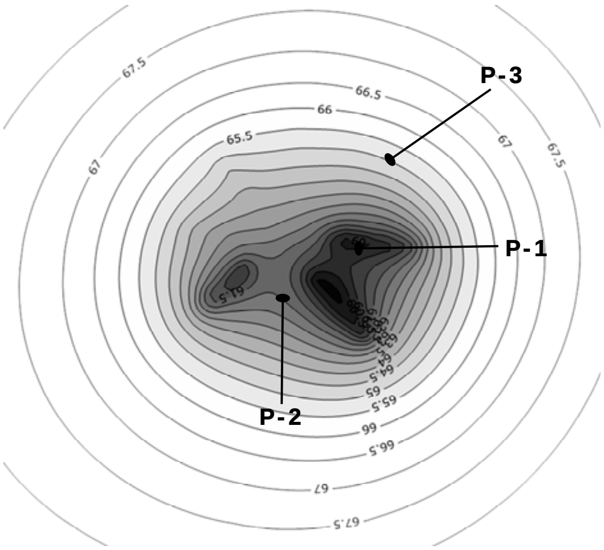

Figure 4: Water table in the zone of influence of well RB–46 (on 25 Oct. 2012, Božović *et al.* 2015)

Regime 2: In this group of wells, when the pumping level is low, the groundwater level in the zone of influence of the well remains high above the laterals (close to the ground surface), which results in a modest well discharge capacity. The reason for this is colmation of the laterals, which reduces the porosity of the screen and filtration characteristics of the skin zone and thus hinders groundwater infiltration into the laterals and prevents a higher discharge capacity of the laterals and the well itself.

Well RB–7m was selected to portray the groundwater extraction and flow conditions typical of this regime. The condition of the laterals of well RB–7m is rather poor. Out of the eight laterals installed in 1978, over the past 20 years only four have remained open but they are so filled with aquifer material that they could not be filmed over a distance of more than a few meters. The presence of boulders and fragments of the aquifer matrix inside the laterals indicates that the screens are severely damaged (by corrosion) and that mechanical rehabilitation is no longer a viable option. Since it will not be possible to increase the discharge capacity of this well while retaining the old laterals, emplacement of new laterals is required.

The laterals of this well are installed at an elevation of 51.50 m.a.s.l. and the pumping level is maintained at about 56.50 m.a.s.l. The well discharge capacity has for years been roughly 20 l/s (Fig. 5).

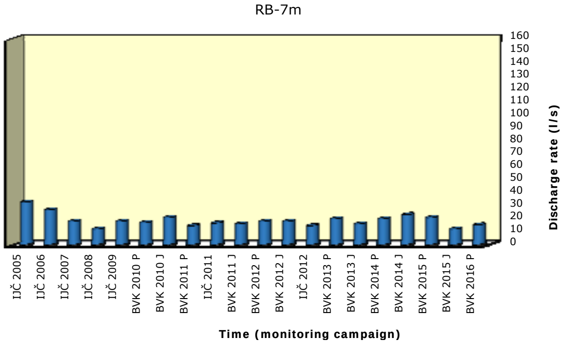

Figure 5: Discharge capacity of well RB–7m

Groundwater levels in the zone of influence of well RB–7m, which is monitored by means of three new piezometers, are under the dominant influence of river stage variations, or rather changes in water levels of a nearby channel which is in hydraulic contact with the river. The drawdown caused by pumping has been tested on several occasions by multiple–day recovery tests and re–starting of the well. The findings were that the aquifer drawdown was virtually negligible relative to the quasi–static groundwater level of the aquifer and that it did not exceed 1 m at the piezometers, while the caisson drawdown was 12–15 m.

In general, the groundwater levels in the area of well RB–7m fluctuated between 67 and 70 m.a.s.l. (Fig. 6). At medium and low stages of the Sava, the difference between the groundwater level and the river stage was about 3 m. It decreased with increasing stages, such that at high stages (above 73 m.a.s.l.), the groundwater level was close to the ground surface, despite pumping.

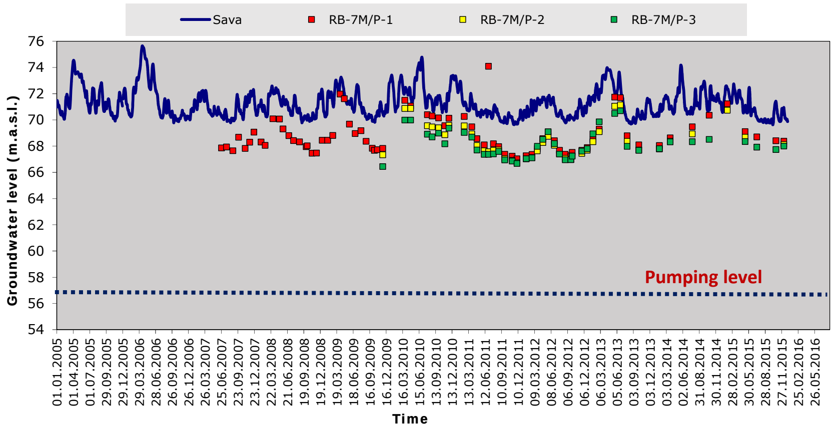

Figure 6: Groundwater levels in the zone of influence of well RB–7m

The fact that at 20 l/s there is a practically negligible aquifer drawdown (contrary to that of well RB–46, which is 10 m at the piezometer closest to a lateral and which registered the lowest levels, at the same pumping rate and similar states of the laterals), indicates that the capacity of the site of well RB–7m is considerable. This was corroborated by hydrodynamic analysis, which showed that installation of five new laterals at the same depth as the existing laterals, with a pumping level of 6 m above the laterals, will result in a discharge of 75 l/s (Božović *et al.* 2016a).

Given that the laterals of this well, like on most BGWS wells, are not installed in the layer that features the best grain–size distribution and filtration characteristics (as a rule, this is the lowest/oldest layer), hydrodynamic modeling was undertaken to test the emplacement of new laterals in that layer, which requires prior reconstruction of the caisson (according to Božović *et al.* 2016b, 2016c). The results suggest that in such a case the achievable rate of groundwater extraction is close to 100 l/s (Božović *et al.* 2016a).

Regime 3: In this case, maintenance of a low pumping level results in a high discharge capacity of the well. A high rate of groundwater extraction at any site is coupled with a considerable drawdown and is achievable only if the functional condition of the laterals is good, if there are many laterals, if they are long enough and if the hydrogeological conditions are favorable. A high discharge capacity of the laterals means that they are hydraulically open (i.e. not colmated), such that the differences between the pumping level and the groundwater level of the aquifer in the capture zone of the laterals are small.

Well RB–23 is an example of this type of groundwater flow and extraction. The well features the highest discharge rate at BGWS. In 2015, the pumping level was maintained at 54.0 m.a.s.l. and the resulting discharge rate was 150 l/s (Fig. 7).

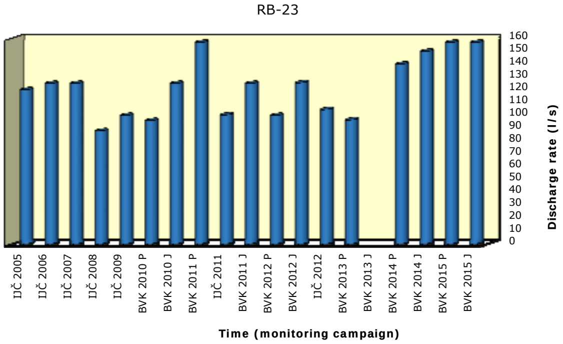

Figure 7: Discharge capacity of well RB–23

Neighboring wells RB–22 and RB–21, located upstream and downstream from representative well RB–23, are also high–capacity wells. In general, this part of BGWS is a zone of a superior mechanical composition, filtration characteristics of the sediments and hydrochemical quality of the groundwater, where average well discharges are higher than in other parts of BGWS. A decline in capacity of a single well (usually due to pumping level increase) boosts the discharge capacity of the neighboring well, leaving the impression of a “well–developed” water–bearing medium.

The laterals of well RB–23 have been emplaced at two elevations. There are eight laterals at 47.80 m.a.s.l. and six at 56.30 m.a.s.l. The lower laterals were filmed by an underwater camera and their length found to be 384 m. It was interesting to note that the laterals were vertically displaced, but pointing downward (to the aquifer floor), which is a rare occurrence given that displacements tend to be in the upward direction. Although the caisson openings are at 47.80 m.a.s.l., the laterals are emplaced at depths ranging from 47.80 to 44.00 m.a.s.l. As a result of displacement, the laterals tap the layer that features the best filtration characteristics (first Pleistocene sedimentation cycle), which has had a favorable impact on the discharge capacity of the well. It is evident that such a capacity of well RB–23 would not have been achieved, even if the condition of the laterals was good, had not the aquifer potential at this location been very high.

The groundwater surface in the capture zone of well RB–23 is typical of a high hydraulic conductivity aquifer: the impact of groundwater extraction spreads far beyond the capture zone of the laterals and the groundwater surface in this zone features a low groundwater level gradient. However, the groundwater levels in the capture zone of this well are low relative to the pumping level, meaning that the groundwater level is not really consistent with that expected in a setting where hydraulic conductivity is high, even with such a substantial well discharge capacity. The actual state of affairs therefore suggests that there is something that causes additional drawdown in the extended area of the well, which requires a more detailed study for a full understanding of the regime.

Exploratory boring revealed the presence of the interbed, lithologically represented by 3 m thick clay, whose spread in this part of BGWS is considerable (and the reason for two levels of laterals). The hydraulic role of the interbed is such that it virtually divides the aquifer into two parts –

shallow and deep. As a result, observation wells are paired. A pair is comprised of a piezometer whose screen is in the lower part of the aquifer and a piezometer in the shallow part (below and above the interbed).

The Sava River has incised its channel shallow in the capture zone of well RB–23 (up to an elevation of 64 m.a.s.l.). The interbed also spreads below the riverbed, corroborated by observation wells drilled from the river surface. The interbed causes active infiltration of surface water only into the shallow part of the aquifer and thus the groundwater levels recorded by the "shallow" piezometers respond more strongly to river stage variation than the "deep" piezometers. The groundwater levels at the deep piezometers are predominantly affected by pumping, such that their response to river stage fluctuations is not as pronounced. The average groundwater level at the shallow piezometers, RB–23/P–2 and RB–23/P–4, over the past ten years has been at 59.94 and 60.78 m.a.s.l., respectively. At the same time, the groundwater level recorded by the deep piezometers (RB–23/P–1 and RB–23/P–3) has been at 57.12 and 58.47 m.a.s.l., respectively. As such, the difference between groundwater levels recorded by the deep and shallow piezometers is about Δh=2.5 m and they are only one meter apart.

The plot of groundwater level fluctuation at the piezometers (Fig. 8) also corroborates a considerable spread of the interbed. The lowest groundwater level is registered by piezometer RB–23/P–1, which is located "on" lateral #1. The difference between this groundwater level and the pumping level is minimal, which is an indication that the lateral is hydraulically open and in good condition. Over the past three years, the difference between the groundwater levels at RB–23/P–1 and the shallow piezometer with which it is paired has been about 4.5 m and is the highest among the piezometer pairs, as expected. This difference is 3.5 m in the case of observation wells RB–23/P–2 and P–4, which are located within the capture zone of the laterals but farther away from the well caisson. However, the differences in groundwater levels between the shallow and deep piezometers of pairs ZNB–1 and ZNB–2 are large (about 2 m), even though they are at a significant distance from the caisson of well RB–23 (150 m and 200 m, Fig. 9). This is attributable to the presence of the semi–permeable interbed, which causes the effect of pumping to be transmitted far from the immediate zone of the well. If that were not the case, the groundwater levels at these observation wells would have been equal.

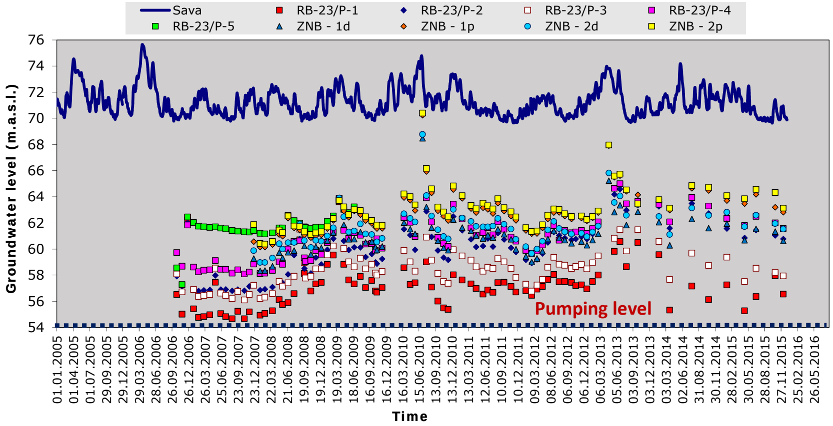

Figure 8: Groundwater levels in the zone of influence of well RB–23

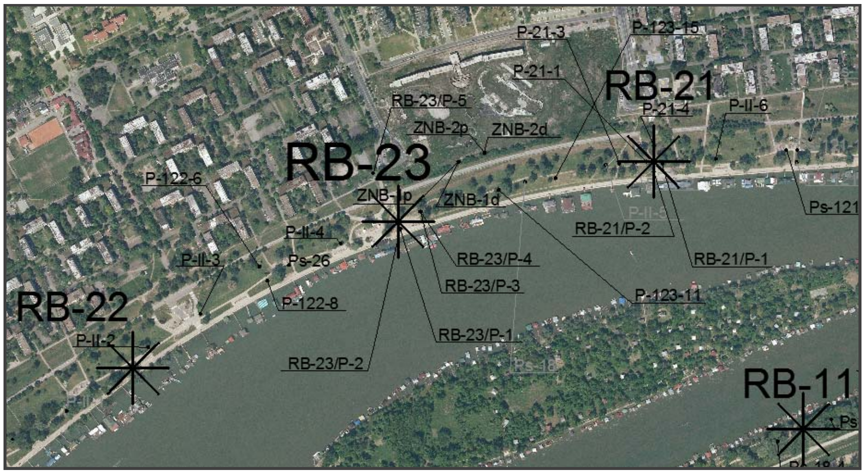

Figure 9: Locations of observation wells in the zone of influence of production well RB–23

Regime 4: In this regime, the pumping levels are low, the well discharge capacity is sound (higher than the present BGWS average) and the drawdown in the capture zone of the laterals is moderate. The wells in this group feature groundwater levels between those of the first and second characteristic regimes. Well RB–41 is an example.

Over the past five years, the discharge capacity of well RB–41 has been 40–45 l/s (Fig. 10). The pumping levels have been maintained at 51.75 m.a.s.l., on average. The laterals are located at 48.25 m.a.s.l., meaning that the pumping level in the well caisson is rather low and only 3.5 m above the laterals.

Compared to the initial state, the current condition of the laterals is such that they are only partly functional. Out of the eight installed laterals, only six are open at present, of which four have retained most of their initial lengths (from 43 to 54 m). The lengths of the remaining two, according to a video recording, are 15 and 20 m. The inside of the laterals was filmed in 2007, showing that corrosion of the screen pipes has caused many of the slots to become enlarged or groups of slots to be joined together. As a result, there is coarse material from the porous medium inside the laterals. Only one lateral exhibits a significant vertical displacement.

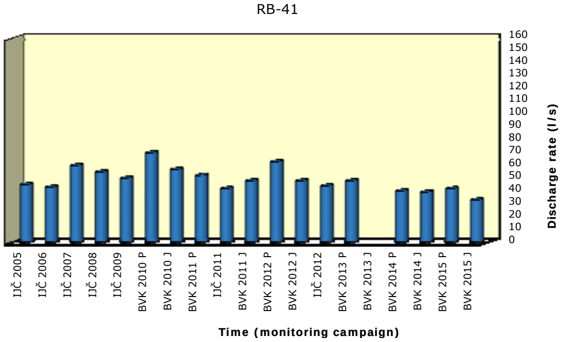

Figure 10: Discharge capacity of well RB–41

In the vicinity of this well there are three old piezometers with 1.5 m long screens at a depth of about 20 m. There are also five new piezometers, two of which form a pair. The screen length of the new deep piezometers is 3 m, generally in the depth range of 24.5–27.5 m. Semi–permeable sediments have been detected only locally, in the zone of piezometer RB–41/P–1.

The groundwater levels recorded at the observation wells fluctuate over a broad range, 60–70 m.a.s.l. (Fig. 11). The groundwater level at the piezometers is a function of their distance from the laterals, which are rather long. At the same time, all the piezometers respond quite strongly to river stage variation.

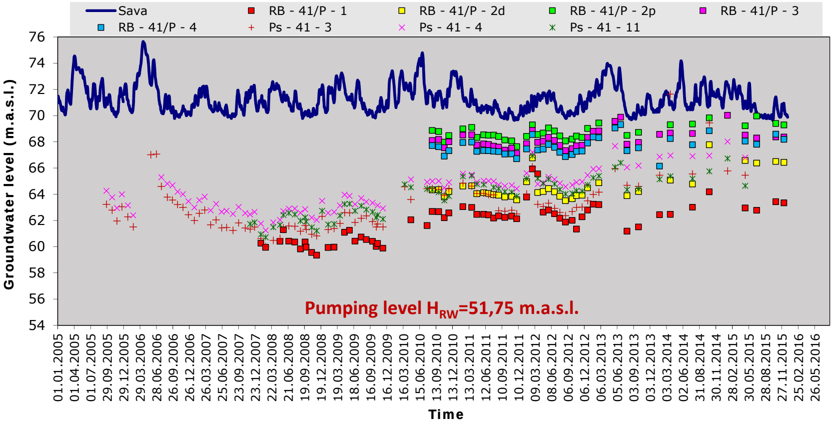

Figure 11: Groundwater levels in the zone of influence of well RB–41

Piezometer RB–41/P–1 registers the lowest groundwater levels. Since it was installed in 2008, the groundwater levels at this location have been in the interval 59.5–63.5 m.a.s.l. However, over the past three years the groundwater levels at this piezometer have been somewhat higher, with a mild upward trend. It has been at 62.80 m.a.s.l., on average, and the river stage participation during that period was about 50% (71.20 m.a.s.l.). As such, river stages did not cause the groundwater levels in the well capture zone to rise. Instead, this state of affairs is indicative of colmation/deterioration of the laterals due to high pumping rates and wear–and–tear.

The aquifer drawdown in the zone of influence of the wells of this group is not very pronounced, which indicates that the filtration characteristics of the aquifer are sound. Additionally, it shows that the groundwater levels are affected by both pumping and river stage fluctuations, given that the river is the main source of aquifer recharge. For this reason it is realistic to expect that replacement of laterals in this group of wells will result in a significant capacity increase (of course, when discharge rates fall to or below the current average).

Regime 5: The last of the characteristic groundwater level regimes pertains to wells whose laterals are exposed to pronounced colmation. Well ageing is a process that leads to a decline in discharge capacity for various reasons (natural, anthropogenic and their synergy). Colmation is one of the specific forms of well ageing, typical of radial collector wells at BGWS. Namely, BGWS wells are often colmated by iron sedimentation (iron concentrations in the groundwater are high, although not evenly distributed over space), due to specific geochemical, hydrochemical, microbiological, lithologic and grain–size conditions of the geological setting and the groundwater, as well as by products of bacterial activity.

As a rule, a decline in well discharge capacity due to biochemical or mechanical colmation is manifested differently from that caused by corrosion. Corrosion leads to degradation of the material from which the screen pipes are made, such that their physical characteristics are altered. Corrosion is initially accompanied by gradual filling of the pipe with aquifer material and once structural integrity is lost, a part of or the entire lateral collapses. This affects the operating mode of the well (i.e. the pumping level) and the rate of discharge declines as a result. In essence, corrosion of screen pipes and colmation of laterals have different causes and manifestations, but the final outcome is the same (Polomčić 2001).

In cases where it is not possible to make a video recording of the inside of the laterals, the effect of the collapse or colmation of a lateral can be identified by analyzing well discharge variations and groundwater level fluctuations in the capture zone. Given that a total or partial collapse of a lateral is nearly instantaneous, the well discharge capacity changes/declines suddenly. Conversely, colmation is a rather slow process and the decline in discharge capacity generally exhibits a uniform trend.

Well RB–42 is a representative example of the group of wells where the decline in capacity is caused by colmation of laterals. The concentration of bivalent iron in this well is about 2.5 mg/l and that of total iron greater than 3.0 mg/l. All the laterals of the well are open, but five are filled at the very beginning. Three laterals (nos. 1, 7 and 8) have retained their original lengths. The laterals are emplaced at an elevation of 50.50 m.a.s.l. The pumping level has for many years been maintained at 53.50 m.a.s.l., and then began to fluctuate around 55.25 m.a.s.l. three years ago. Over the past decade, the discharge capacity declined from more than 50 l/s to less than 10 l/s (Fig. 12), even though the pumping levels had not changed by much.

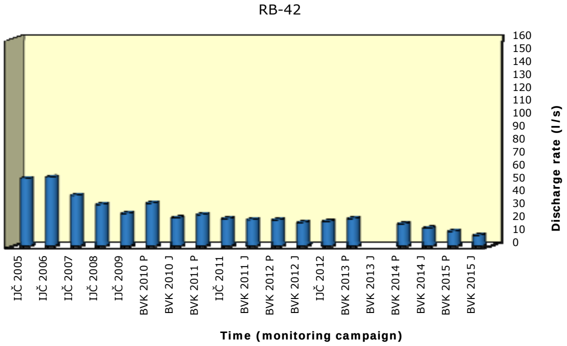

Figure 12: Discharge capacity of well RB–42

There are two piezometers (Prb–42–1 and Prb–42–2) in the capture zone of the laterals and one (Prb–42–z) beyond. When installed, they revealed the presence of the interbed, which explains the large difference in groundwater levels between the capture zone of the laterals and the area beyond (especially at the beginning of the analyzed time period, Fig. 13).

The BGWS management practice is such that when a decrease in well discharge is noted, an attempt is made, as a rule, to compensate by lowering the pumping level in the caisson. Given that the pumping level in well RB–42 has been lowered as far as possible, it is not possible to increase the discharge rate on account of additional drawdown. Mechanical rehabilitation of the laterals would certainly result in damage and collapse of three functional laterals. Consequently, the discharge capacity of this well can only be increased by installing new laterals. A further decline in discharge capacity, and the resulting increase in groundwater levels in the capture zone of this well, can be predicted from Figs. 12 and 13. A total loss of the capture capability of the laterals would equate the groundwater levels at piezometers Prb–42–1 and Prb–42–2 in the capture zone of the laterals with that of piezometer Prb–42–z, which is farther inland.

In the case of wells that exhibit clear signs of colmation, at low pumping levels the discharge capacity gradually declines over time. This decline is manifested by groundwater level variation in the capture zone of the laterals, which rises slowly but continually.

In a certain number of wells in this group, colmation can be slowed down by rehabilitation, although such wells have been fewer from year to year and the effects of rehabilitation less and less notable.

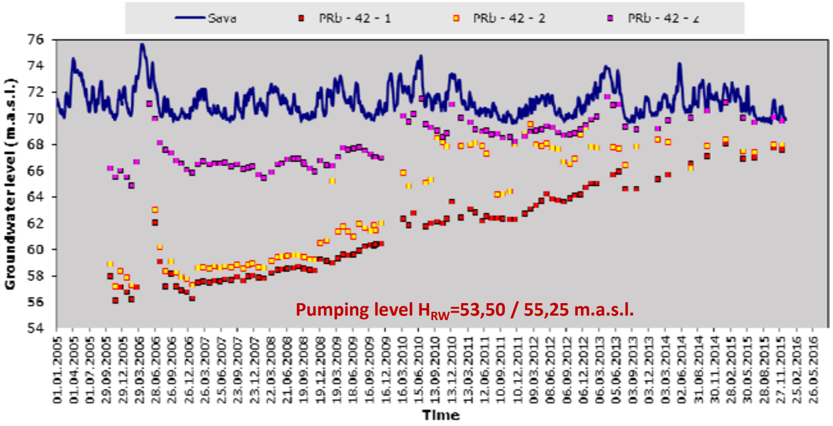

Figure 13: Groundwater levels in the zone of influence of well RB–42

Conclusion

Today, the functional state of radial well laterals has a dominant effect on the well discharge capacity at Belgrade Groundwater Source. The condition of screen pipes and the hydraulic characteristics of the skin zone are the main reasons for the significant decline in pumping levels in the well caissons and modest discharge capacities of the wells.

The present research has shown that assessment of the effect of operation of radial collector wells on groundwater levels in their immediate vicinity needs to be founded upon recognition of the characteristic spatial heterogeneity of the lithologic composition and filtration characteristic of the aquifer layer tapped by this type of wells (usually of Quaternary age and alluvial origin).

In order to analyze the groundwater level regime in the capture zones of radial collector wells, certain information is needed about the condition of the functional laterals, pumping levels, groundwater level fluctuations at suitably designed and located observation wells, and the main indicators of the biochemical composition of the groundwater.

Identification and analysis of the groundwater level regime in the capture zone of a radial collector well constitute a reliable, representative and relatively simple method for gaining insight into the well site potential in terms of groundwater withdrawal and creating conditions for proper selection of wells that need to be rehabilitated or their degraded and non–functional old laterals replaced.

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Резиме

Карактеристични режими нивоа издани у зони бунара са хоризонталним дреновима и значај њихове идентификације (примери београдског изворишта подземних вода)

Управљање режимом рада бунара са хоризонталним дреновима врши се контролисаним снижењем нивоа воде у водосабирном бунарском шахту. Оборени радни нивои, заједно са скромним просечним капацитетом бунара данас представљају препознатљиву одлику београдског изворишта подземних вода и јасан показатељ стања водозахватних објеката и режима експлоатације подземних вода на њему.

Уочено је да одржавање ниских нивоа подземних вода у бунарима има за резултат капацитете чије се вредности крећу у широком дијапазону, од 3 до 150 l/s, као и да се у непосредној зони утицаја бунара/експлоатације подземних вода формирају веома различити режими нивоа издани. Капацитети бунара су свакако функција броја и стања активних дренова, као и хидрогеолошких одлика и услова прихрањивања водоносне средине. Стога, велике разлике у количини захваћених подземних вода између бунара указују на велике разлике у функционалном стању њихових водопријемних делова, као и на изражену хетерогеност литолошког састава и филтрационих карактеристика средине у непосредном окружењу бунара.

Управо се за просторну хетерогеност литостратиграфског састава седимената (чак и на сасвим малом простору – у зони лепезе дренова једног бунара) може рећи да представља основну природну одлику београдског изворишта подземних вода. Овакво стање је резултат комплексних услова генезе, према актуелним схватањима везане за интензивну тектонску активност која се одвијала током краја плиоцена и доњег плеистоцена, као и за специфичне палеоклиматске услове током целог плеистоцена.

У односу на постојећи интензиван режим рада бунара, може се препознати и издвојити неколико карактеристичних режима нивоа подземних вода, због чега се и бунари могу сврстати у више група.

Први издвојени режим нивоа подземних вода је присутан код оних бунара код којих се ниво воде у бунарском шахту налази на малој висини изнад дренова, што за резултат има значајно снижење нивоа подземних вода у издани у зони лепезе дренова, изразито просторно неправилне нивое у зони утицаја експлоатације и скроман капацитет бунара. Разлог за настанак оваквог нивоа издани су скромне филтрационе карактеристике водоносне средине у непосредном окружењу бунара. Ова чињеница указује да се обављањем дренова на бунарима који припадају овој групи не може очекивати захватање значајнијих количина подземних вода.

Код групе бунара који припадају другом издвојеном режиму нивоа издани, при обореном нивоу воде у шахту, ниво подземних вода у зони бунара остаје плитко испод површине терена, односно високо изнад нивоа у шахту, што резултира скромним капацитетом бунара. Разлог оваквог стања је процес колмирања дренова који доводи до смањења порозности филтерске конструкције и прифилтерске зоне, чиме спречава инфилтрацију воде у дренове и остваривање већег капацитета дренова, а самим тим и бунара. У случају када су дренови на бунарима ове групе у лошем функционалном стању (са крупним оштећењима на филтерској конструкцији, зарушени делом почетне дужине, запуњени материјалом порозне средине), механичке регенерације више није оправдано изводити, због чега се капацитет бунара може повратити само утискивањем нових дренова.

Трећој групи припадају они бунари код којих одржавање ниског нивоа воде у шахту има за резултат висок капацитет бунара. Експлоатација значајних количина подземних вода на било којој локацији на београдском изворишту условљава и значајно снижење нивоа издани. Могуће ју је остварити само у случају доброг функционалног стања, већег броја и дужине дренова, уз повољније хидрогеолошке услове. Висок капацитет дренова значи да су они хидраулички

отворени, тј. да нису колмирани, због чега је разлика између нивоа воде у бунарском шахту и нивоа у издани у зони лепезе дренова мала.

Четврти карактеристичан режим нивоа подземних вода је везан за оне бунаре код којих се у условима ниских радних нивоа остварују солидни капацитети бунара (изнад данашњег просека), док је снижење нивоа у зони дренова умерено, односно није значајније изражено. Као такво, оно указује на солидне филтрационе карактеристике водоносне средине. Поред тога, оно указује да се нивои осим под утицајем рада бунара налазе и под утицајем промене водостаја реке као главног извора прихрањивања издани. Из тог разлога се санацијом дренова на бунарима који припадају овој групи у односу на карактеристични режим нивоа, може очекивати остваривање значајнијих капацитета.

Последњи од анализираних режима нивоа издани је присутан код оних бунара на којима је присутан процес колмирања дренова. За разлику од бунара другог карактеристичног режима, овде је он још увек у активној фази. У случају бунара на којима су евидентни ефекти процеса колмирања, при ниском нивоу воде у шахту током времена експлоатације долази до постепеног смањења капацитета бунара. Смањење капацитета се манифестује континуираним променама нивоа подземних вода у зони дренова, тако што ниво издани благо и константно расте.

Услед специфичних геохемијских и литолошких услова геолошке средине и хемијског и микробиолошког састава подземних вода, на бунарима београдског изворишта је често заступљено колмирање изазвано таложењем гвожђа (чији је садржај у подземним водама изворишта висок, мада просторно неравномеран) и продуката активности одређених врста бактерија. Опадање капацитета бунара услед биохемијског или механичког колмирања дренова се по правилу различито манифестује од опадања капацитета које се дешава услед корозије.

Ефекти колмирања се могу идентификовати анализом промене капацитета бунара и осцилација нивоа подземних вода у његовој непосредној зони. Како се зарушавање дела дрена услед корозије филтерских цеви дешава готово тренутно, то се и капацитет бунара нагло мења, односно смањује. Колмирање се, са друге стране, одвија релативно споро, због чега опадање капацитета има генерално равномеран тренд.

На одређеном броју бунара који припадају овој групи, процес колмирања се може успорити спровођењем регенерације, мада је објективно број таквих објеката из године у годину све мањи, а ефекти спроведених мера све дискретнији.

У циљу анализе режима нивоа издани у зони бунара са хоризонталним дреновима, потребно је располагати одређеним информацијама о: стању активних дренова, нивоима вода у шахтовима бунара, осцилацијама нивоа подземних вода у осматрачким објектима адекватне конструкције и позиције у односу на дренове, основним показатељима хемијског и микробиолошког састава захваћених подземних вода.

Спроведено истраживање је указало да анализа ефеката рада бунара са хоризонталним дреновима у смислу формираних нивоа издани у њиховом непосредном окружењу треба бити утемељена на перманентном уважавању карактеристичне просторне хетерогености литолошког састава и филтрационих карактеристика седимената водоносне средине у којима се ови објекти изводе.

Идентификација и анализа режима нивоа подземних вода у зони бунара са хоризонталним дреновима представља репрезентативан и релативно једноставан механизам којим се, на нивоу претходог сагледавања, могу дефинисати потенцијал локације бунара у погледу расположивих количина подземних вода и услови за правилан избор објеката које је потребно санирати, тј. извршити замену дотрајалих и нефункционалних старих дренова адекватним новим дреновима.