Selection of well screen parameters as aspect of water well design

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Abstract. This paper addresses an essential problem within the scope of the issues of optimum design, construction and operation of water supply systems and their elements. The water well is the core element of the groundwater intake structure. The quality of water well design and construction workmanship are pivotal for successful operation of the intake structure in general. Poor well design and errors in well construction result in malfunctioning of the whole water supply system. Selecting an appropriate water well screen to conform to specific geological conditions and to ensure the longevity of the well structure itself is a complicated engineering problem. The estimation of well screen parameters covers such dimensions as length, diameter, open area ratio and aperture (slot) size. Those characteristics must be determined taking into account that the entrance velocities must not exceed the entrance velocity limit for a particular screen, i.e. \( V_{\text{ent}} \leq V_{\text{lim}} \).

1. Introduction

The article presents a methodology for selecting an optimum diameter and length of a groundwater well screen. The methodology has been tried out with the consideration of Kursk region hydrogeological conditions, which is illustrated by an example of obtaining the appropriate well screen characteristics. The estimates have proved that the entrance velocity limit is a key parameter for a successful well design; correct application of this criterion allows for a substantial reduction in the construction costs while ensuring the anticipated well yield and permissible well drawdown.

Due to considerably growing pollution of surface water streams and watercourses in recent years, groundwater supplies have been paid increasingly greater attention. In Russia the amount of groundwater consumption accounts for 13 to 19% of the overall water consumption and over 40% of domestic (household) water consumption [1,2].

The water intake structure is an essential part of the water supply system. It provides for sustainable technical and economic performance and operational reliability of the whole system. Thus, in order that the general problems related to providing potable water from subsurface supplies are successfully solved, much effort has to be expended on proper design, construction procedures and maintenance of water supply systems and their elements.
Well robustness as well as increased time between repairs largely depend on the adequate selection of most appropriate groundwater withdrawal techniques and, in particular, efficient well design solutions. Development of innovative casing and screen design solutions, selection of optimum slot opening and configuration to ensure minimal frictional head losses and colmatage effects is given increasingly greater consideration.

In the South-West University in cooperation with the company "Ekopromservis" was developed a number of core filters with various forms of filter wire [3-12]. Figure 1 shows a diagram of one of the variants of the frame-core structure of the downhole filter.

![Figure 1](image_url)

**Figure 1.** Frame-core design of the downhole filter. 1 – support frame, 2 – wire spiral, 3 – stiffness rods, 4 – upper coupling, 5 – lower coupling, 6 – casing pipe of the drill hole, 7 – centering plates, 8 – lower surface of the upper coupling.

Depending on well design, the cost of a well screen is estimated up to 20-30% of the overall cost of the structure [13]. Screen length and diameter are the key characteristics which determine water well total costs. Advanced pumping equipment makes it possible to use the upper well casing of small
diameter; thus, a well-reasoned choice of a minimal sufficient screen diameter to ensure the anticipated water withdrawal and permissible well drawdown allows obtaining considerable economic effect. For instance, extensively used Grundfos well pumps ensure a wide range of performance and head flow rates even when the outer diameter is small enough.

2. Materials and methods

The pertinent literature by Russian authors deems the vertical flow velocity at the upper section of the screen (where it must not exceed 1.5-2 m/sec) as the criterion recommended to determine screen diameter. Thus, for example, if the vertical flow velocity is an order of magnitude less than that, we adhere to the criterion and, therefore, the choice of an oversize screen diameter and the increased cost of the well structure are substantiated. It is necessary to point out, however, that using the screen of a larger diameter by itself does not result in proportional increase in the productive capacity or specific capacity of the well [13,14].

Russian authors put much emphasis on selection of screen length. However, the existing guidelines mostly consider artesian (confined) aquifers. For unconfined aquifers, the only provision for screen length calculations is that the aquifer thickness has to be reduced by one-half the amount of the anticipated drawdown.

The analysis of different types of well design in a number of unconfined aquifer groundwater intake structures reveals that in many cases screen length is 70 to 80% of the aquifer thickness, and the anticipated well drawdown is insignificant. Temporal decrease in well yield, or production capacity, is accounted for the effects of screen colmatage processes, which may require running the pump into the screened production zone, which is contrary to the currently accepted codes of practice [15,16].

According to a foreign standard, the production zone for unconfined aquifer water wells which has to be screened is located in the lower third of the aquifer [17]. That ensures a sufficient drawdown margin to provide the anticipated well capacity and conforms with the admissible well drawdown which is equal to 2/3 of aquifer thickness. In heterogenous unconfined aquifers with a large saturated thickness the principle of choosing the most permeable interval may be only applied for a deeper section, whereas in confined aquifers the location of such an interval is of no significance.

3. Results

While selecting an optimum screen length it should be taken into consideration that, as V. Alekseev’s studies have shown, screens more than 10m long are not expedient for most hydrogeological conditions. This statement follows from the assumption that the loading on the well screen is uneven along its length, and is substantiated by the field studies of a number of water intake structures [13,14]. For short filters (3-5m long), which are recommended for unconfined 10 to15m thick aquifers, such a likelihood is not even considered by Russian well designers due to the absence of the relevant practice and the methods for its justification. For this reason we deem it appropriate to regard foreign practices in this field which have been presented in a number of guides, standards as well as in the pertinent literature.

In most foreign countries the entrance velocity limit is used as a criterion to justify the length and the diameter of the water well screen. It is defined by the following formula:

\[ V_{\text{ent}} = \frac{Q}{F} = \frac{Q}{\pi D L_{\text{scr}} \eta}, \]

where \( F \) is aperture (slot) size area, \( L_{\text{scr}} \) — screen length, \( m \); \( D \) — screen diameter, \( m \); \( \eta \) — open area ratio.

The criterion of the entrance velocity is viewed as most instrumental for developing a successful water well design to provide a significant reduction in the construction costs and at the same time to ensure high well performance. The entrance velocity limit of 0.03 m/s is most frequently cited in the literature [17].
The American Water Works Association (AWWA) standards on water supply wells specify the recommended entrance velocity of 0.03 to 0.46 m/s; it is however pointed out that the upper limit has to be set with regard to the actual hydrogeological conditions and the practice of water well design and construction in a particular region.

The design of a water well involves the following successive steps: carrying out a grain size analysis of the representative samples from the water-bearing formation, definition of the screen interval, specification of the type of a gravel pack, definition of the screen-slot size and screen diameter.

The selection of the screen slot sizes is based upon the aquifer or the filter pack material grain size distribution. The maximum screen slot size is selected so that it will not exceed the minimum diameter of gravel-pack material particles sampled from the production zone, according to Table 1 shown below.

| Minimum grain diameter | 0.5 | 0.75 | 1.0 | 2.0 | 3.0 | 5.5 | 8.0 |
|------------------------|-----|------|-----|-----|-----|-----|-----|
| Maximum grain diameter | 1.0 | 1.5  | 2.0 | 3.0 | 5.5 | 8.0 | 16.0|
| Mean grain diameter    |     |      |     |     |     |     |     |
| Maximum screen slot size, mm | 0.5 | 0.75 | 1.0 | 2.0 | 3.0 | 4.0 | 4.0 |

The entrance velocity criterion is applied after the well screen length and its open area rate have been specified. Then, given the minimum entrance velocity value of 0.03 m/s, screen diameter may be defined by the formula shown below:

\[ D = \frac{Q}{F} \cdot \frac{Q}{\pi V_{out} L_{out} \eta} \]  

The final decision must be made with regard to the actual hydrogeological conditions. At that, it is necessary to take into account that the reduction in screen length will result in increase in well imperfection due to partial penetration, i.e. increase in well drawdown.

4. Discussions

Below we present an example to illustrate the process of selection of well screen length and diameter to suit the hydrogeological conditions of Kursk. At present about 61% of the overall groundwater intake in the region is provided by the Albian and Senomanian aquifer. This type of aquifer prevales regionwide, except the areas surrounding river valleys where the aquifer deposits are washed out. It appears as the upper-level water-bearing formation throughout most of the region area. It is generally accepted that the aquifer is essentially a monolithic hydraulically bound sequence of formations dated to the Quarternary-Senomanian-Aptian [18].

The Quaternary deposits which appear as fine sands are inferior in their filtration properties to K1+2al+cm sands of the Senomanian stratum. It should be pointed out that since the water well is in operation, the dynamic level in the water intake zone is close to the aquifer bottom, and it is even lower in the water well. Thus, in order to choose a proper zone for well screen installation, it is advisable to regard the Senomanian water-bearing sand deposits as the production aquifer level, since they gain water from both the upper Quarternary and the lower Aptian layers. This water-bearing formation is about 15m thick [18- 20].

According to the theoretically justified and practically approved well construction standards the aquifers of this type must be screened in their lower portion (within the limit of 2/3 of their thickness), which is approximately equal to 10m.
On the other hand, the dimensions of a well screen are selected depending on aquifer permeability, sand granulometric composition and well operation conditions. A number of the dimensions, such as internal screen size, anticipated well production capacity, well drawdown, are defined empirically. Consequently, screen transmitting capacity, or maximum permissible well discharge, and permissible transmitting velocities are viewed as pivotal screen characteristics.

Screen transmitting capacity is defined according to the formula:

$$Q = F \cdot V_{scr},$$

where $F$ is the overall screen area, m$^2$; $D$ – screen diameter, mm; $l_{scr}$ – screen length, m; $V_{scr}$ – transmitting velocity limit, m/day.

The permissible transmitting velocity is limited by the effects of suffosion and is defined according to the formula for friable filter-pack material:

$$V_{scr} = 1000 \cdot K \left( \frac{d_{so}}{D_{so}} \right)^2,$$

where $K$ is the coefficient of transmissibility, m/day; $D_{so}$ is a mean size of the filter-pack particles, mm; $d_{so}$ is a mean size of the ground particles, mm.

In this case the mean value of the coefficient of $V_{scr} < 1.5$ transmissibility is defined as $\approx 10$ m/day:

$$V_{scr} = 1000 \cdot 10(1/10)^2 = 100 \text{ m/day}.$$

If the permissible transmitting velocity is calculated another way, e.g. by using Abramov’s formula, we receive a larger $V_{scr}$ value of 140 m/day. Let us assume $V_{scr} = 120$ m/day. At a well yield of 50 m$^3$/hr the daily well production comes to 1200 m$^3$/day. Let the borehole size be defined as 273 mm.

With the given $Q$ and $V_{scr}$ the screen length is

$$l_{scr} = \frac{1200}{3.14 \cdot 0.273 \cdot 120} = 11.5 \text{ m}$$

At a minimal velocity given 0.03 m/s and the same production of 50 m$^3$/hr (0.014 m$^3$/s) let us define the screen diameter for a wire-wrapped screen with 2 mm slot opening and 20% open area ratio.

$$D = \frac{0.014}{3.14 \cdot 11.5 \cdot 0.2 \cdot 0.03} = 6.4 \text{ mm}$$

However, the value obtained is unacceptable, firstly, because it does not satisfy the limiting condition that the permissible vertical flow velocity at the upper screen section is $V_{scr} < 1.5$ m/s. Secondly, the recommended minimum screen diameter is 150 mm, which is required due to the conditions of water well development and regeneration.

Assuming screen diameter as 150 mm, let us assure that the condition $V_{scr} < 1.5$ m/s is satisfied, and the entrance velocity does not exceed the recommended value and is equal to 0.015 m/s. Upon that, the reduction of screen length is admissible. At $D = 0.15$ m and $V_{ent} = 0.03$ m/s the optimum screen length ($l_{scr}$) works out at 5 m.

5. Conclusion

Thus, at a well screen length of about 5 m, 150 mm diameter and a mean coefficient of transmissibility of 10 m/day, the water well provides a yield of 50 m$^3$/hr. However, in the zone of installation of the screen sand granulometric composition is characterized by a large particle size, and has a higher coefficient of permeability than a standard coefficient value for the Quarternary-Senomanian
formation. In relation of the problem of groundwater withdrawal by means of a well structure, this formation is difficult to use as a single whole due to the absence of uniformity in its geological structure and permeability in depth. The saturation of the stratum with groundwater is much more intense in the zone of screen location, which provides for a large margin of screen transmissibility.

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