ACTA SCIENTIARUM POLONORUM
aspa.sggw.edu.pl
content.sciendo.com/aspa

Acta Sci. Pol.
Architectura 21 (2) 2022, 55–61
ISSN 1644-0633 eISSN 2544-1760 DOI: 10.22630/ASPA.2022.21.2.14

ORIGINAL PAPER

Received: 26.03.2022
Accepted: 25.05.2022

LOWERING WATER LEVEL IN AN EXCAVATION FOR A MULTI--FAMILY RESIDENTIAL BUILDING IN URBAN DEVELOPMENT

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ABSTRACT

The paper concerns lowering water level in excavations for residential buildings in a dense urban development. The construction and protection of excavation walls as well as the methods of lowering the water level and its impact on the surroundings were discussed. An excavation dewatering system is presented on the example of a multi-family residential building with one underground floor, built in dense urban development. The excavation executed in the sandy subsoil below the groundwater level and encased with walls made of steel sheet piles was analysed. Two concepts of lowering the water level in the excavation were considered: the first with use of a wellpoint system, the second with use of a well with pumps. The conducted calculations showed that when using a wellpoint system to lower the water level in the excavation for analysed multi--family residential building, a system consisting of 260 wellpoints with a spacing of 1.0 m should be made. The efficiency of a single wellpoint is 12.25 $m^3 \cdot d^{-1}$, and the efficiency of the entire installation is 3,185.69 $m^3 \cdot d^{-1}$. When draining the wells, a system consisting of 9 wells should be made, with a unit capacity of 375.58 $m^3 \cdot d^{-1}$ and efficiency of the total installation 3,380.22 $m^3 \cdot d^{-1}$.

Key words: groundwater, water level, drainage of subsoil, well, wellpoint, multi-family residential building

INTRODUCTION

Nowadays, a significant civilization leap has contributed to the rapid development of urban areas in particular, what poses huge challenges for engineers. Investors increasingly decide to make investments located on small plots of land in strict urban development or in areas with difficult soil and water conditions. The location of investments with deep foundation in difficult areas usually requires drainage for the time of foundation works. Correctly applied dewatering systems depress groundwater to the level assumed by the project until the earthworks and foundation works are completed.

Currently, there are many techniques for making foundations in areas with high groundwater levels. It is up to the designer to choose the appropriate technology based on an analysis of soil and water conditions, the type of an investment, its location, a method of making and securing the excavation, a degree of urbanization of the surroundings and construction costs (Driscoll, 1986; Pujades, Vàzquez--Suñé, Carreraa & Jurado, 2014; Calin, Radu & Bica, 2017).

When carrying out construction excavations, it is particularly important to ensure the stability of its slopes. The slope's stability is ensured by making an appropriate inclination depending on its height and a type of soil in the subsoil, or by making an appropriate retaining structure. The designer who determines the safety of the excavation slopes should in particular take into account the type of soil in which the excavation will be made, loads in the slope area, approximate time of use of the excavation and the effects of possible loss of stability by the slope (Son & Cording, 2005). During the execution of temporary excavations,

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it is permissible to make vertical slopes only in situations where the depth of an excavation does not exceed:
- 1.00 m: in non-watered sands, weathered rocks, rubble, cracked rocks;
- 1.25 m: in cohesive soils, however, it is allowed to increase the depth of the excavation up to 1.50 m for compactly cohesive and very cohesive soils;
- 4.00 m: in mechanically separated solid rocks.

In other cases, excavations should be made with slopes with a safe inclination or with use of retaining structures (Kotowski, 2011; Farzi, Pakbaz & Aminpour, 2018).

Investments carried out in deep excavations, and above all those located in highly urbanized areas, require design of an excavation support. The designer choosing the type and technology of the excavation support must take many factors into account. The basis for the designer is the documentation of subsoil, where the soil and water conditions in a given area are determined. After planning an initial technical solution for the excavation and taking the hydrogeological conditions into account, values of extreme terrain displacements in a deep excavation impact zone are estimated. If the predicted displacements are greater than the permissible ones, a change of the adopted design solution should be considered. The most popular types of excavation supports are: diaphragm walls; walls made of steel sheet piles; palisade of piles or micropiles; and walls made of columns by jet grouting. It is also allowed to use mixed structures protecting excavation walls.

In the case of a high groundwater level in the subsoil, only the excavation with diaphragm walls does not require water removal during construction works. However, due to construction costs of this type of structure, it is mainly used in tall office buildings. In the case of the construction of residential buildings, walls made of steel sheet piles, palisade of piles or micropiles, walls made of columns by jet grouting are most often used, therefore there is a need for continuous removal of water from the excavation during construction works. Wellpoints or wells with pumps are most often used to lower the water level in the excavation during the construction works.

Lowering the water level in the construction excavation leads to changes in hydrogeological conditions around the investment. The lowered water level changes the stresses in the subsoil, namely increases them, and this in turn may contribute to a settlement of adjacent buildings. Therefore, when lowering the water level in the construction excavation, structures limiting a formation of depression around the excavation should be used and the surroundings should be monitored. In the case of works carried out in urban areas, a significant problem is also the management of water from the conducted drainage works, if there is no watercourse nearby (Matusiewicz, 2005; Wrzesiński, Kowalski & Miszkowska, 2018; Wrzesiński, 2020).

However, the most important thing is to take into account consequences of the selected construction technology and to consider negative effects that it may cause. The above shows how many components determine the selection of the appropriate method of building a foundation excavation with a high groundwater level. A properly selected drainage system will have a positive effect on the implementation of the foundation excavation as well as the foundations themselves. Construction quality will be higher, construction time and costs will be reduced.

The paper analyses methods of drainage of the foundation excavation on an example of an excavation for a multi-family residential building with an underground storey located on a small plot of land in close urban development. Two concepts for the lowering the water level in the excavation were considered, the first with use of a wellpoint system, the second with use of a well with pumps.

SITE CHARACTERISTICS

The study analyses an area located in Warsaw, where the construction of a multi-family residential building is planned (Fig. 1). The planned investment is adjacent to the existing buildings and located north of a stream. The thickness of the designed foundation slab will be 40 and 70 cm and it will be made on a base concrete layer of approx. 100 mm. The designed foundation level is below the groundwater level.

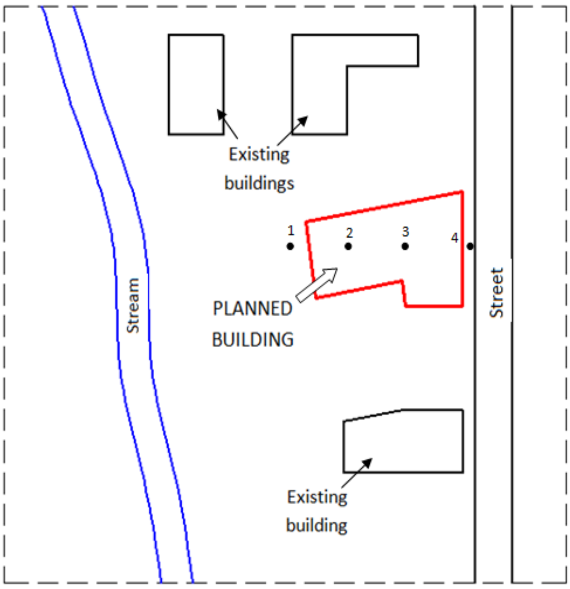

Fig. 1. Analysed area: 1, 2, 3, 4 – borehole numbers

The article considers the excavation with use of sheet piling as a protection of the excavation walls. It is planned to construct the underground part of the building in the technology of waterproof concrete. In the analysed area, field and laboratory tests were carried out, which allowed to determine the soil and water conditions. For the purposes of the analysis, 4 boreholes were made to a depth of 12.0 m and 4 cone penetration tests (CPT) to a depth of 12.0 m. Location of the test boreholes is shown in Figure 1, and cross-section of the subsoil in the place of the planned building in Figure 2. According to the performed research, anthropogenic soils are in the subsoil to a depth in the range of 1.00–2.00 m. Below, there are medium--compacted sands (FSa, FSa/MSa, MSa) of different granulation with the index density I_D = 0.40–0.60. The index density (I_D) increases with the depth below ground surface. Cohesive soil clSa occurs locally. No layer was drilled to the depth of the exploration that would enable the water to be cut off to the construction excavation. The research shows that the groundwater level is about 0.60–0.65 m above the foundation level of the foundation slab.

The foundation of the building is planned on the foundation slab. Both the foundation slab and the foundation walls are made of waterproof concrete. The waterproof concrete diagram used for the foundation slab and foundation walls of the building is presented in Figure 3. The construction of the slab and walls of the foundations of the building with use of the waterproof concrete requires excavation below the groundwater level. In the analysed case, the excavation will be made with use of sheet piling, because the use of sheet piling ensures the excavation stability and reduces the size of the resulting depression cone. The sheet piling and a method of connecting individual elements is shown in Figure 4.

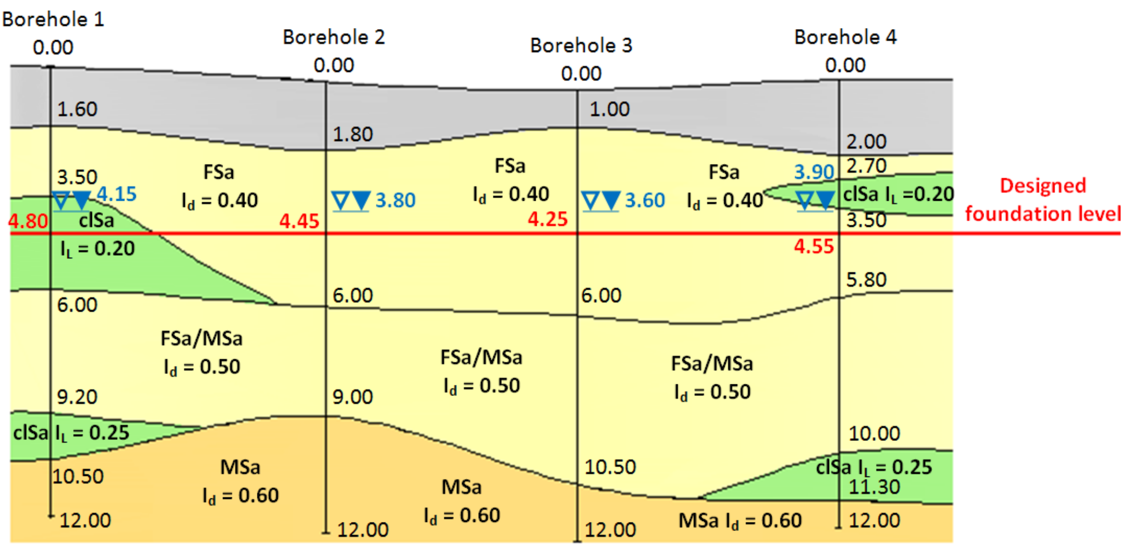

Fig. 2. Subsoil in the place of the planned building

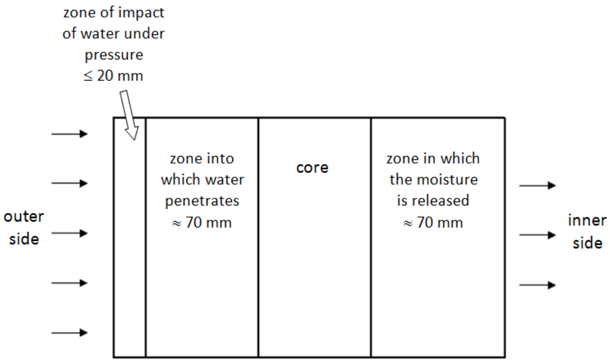

Fig. 3. Waterproof concrete used for the foundation slab and foundation walls of the building

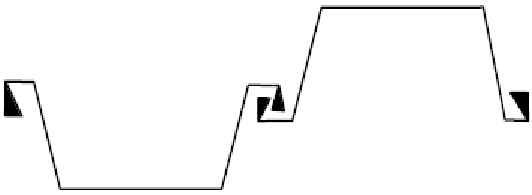

Fig. 4. Sheet piling and method of connecting individual elements

CONCEPTS OF LOWERING WATER LEVEL

Due to the water level above the designed foundation level, it is necessary to lower the water level in order to enable the works to be carried out. For this purpose, calculations for installation wellpoints and calculations for installation wells were performed.

General calculations

Depression range (R):

$$R = 10.2 \cdot S_0 \sqrt{k}\ [\text{m}], \tag{1}$$

where:
S_0 – required lowering the groundwater level in the excavation centre [m],
k – permeability coefficient [m·d^{-1}].

The lowering value of the groundwater level in the excavation centre was assumed 0.5 m below the excavation bottom, i.e. $S_0 = 1.15$ m. The value of k was determined on the basis of the analysis of the consolidation process using the Taylor method: $k = 28.85$ m·d^{-1}.

$$R = 10.2 \cdot 1.15 \cdot \sqrt{28.85} = 63.00\ \text{m}.$$

Calculation radius (r_0) of the great well:

$$r_0 = m \cdot \frac{(L+B)}{4}\ [\text{m}], \tag{2}$$

where:
m – coefficient depending on the value of B/L [-],
L – excavation length [m],
B – excavation width [m].

Excavation length (L) is equal to 100 m, excavation width (B) is equal to 40 m, so the coefficient depending on the value of B/L was determined based on Sokołowski and Żbikowski (1993) and is equal to 1.18 m.

$$r_0 = 1.18 \cdot \frac{(100+40)}{4} = 41.30\ \text{m}.$$

Calculations for wellpoint installation

Thickness of the active zone (H_{0z}):

$$H_{0z} = \alpha \cdot (S_{cz} + l_f)\ [\text{m}], \tag{3}$$

where:
α – factor depending on the ratio $S_{cz} / (S_{cz} + l_f)$ [-],
S_{cz} – assumed reduction of the groundwater level outside the wellpoints [m],
l_f – length of active filter [m].

The factor α was determined based on Sokołowski and Żbikowski (1993) and is equal to 1.88, the reduction of the groundwater level outside the wellpoint (S_{cz}) was assumed 3.15 m, and the length of the active filter (l_f) was established on 0.60 m.

$$H_{0z} = 1.88 \cdot (3.15 + 0.60) = 7.05\ \text{m}.$$

Up to the subsoil recognition depth equal to 12.00 m mainly non-cohesive soils occur. Therefore, in the calculations, the value determined from the formula was adopted as the active zone thickness of 7.05 m.

Permissible water velocity (v_d) for the wellpoint:

$$v_d = 130 \cdot \sqrt[3]{k}\ [\text{m} \cdot \text{d}^{-1}], \tag{4}$$

$$v_d = 130 \cdot \sqrt[3]{28.85} = 398.71\ \text{m} \cdot \text{d}^{-1}.$$

Permissible water velocity (P) for the wellpoints:

$$P = 2 \cdot \pi \cdot r_0\ [\text{m·d}^{-1}], \tag{5}$$

$P = 2 \cdot \pi \cdot 41.30 = 259.50 \text{ m·d}^{-1}$.

Number (n) of wellpoints in the system:

$$n = \frac{P}{\sigma} \ [-], \tag{6}$$

where:
σ – distance between the wellpoints [m].

In the analysed installation, the distance between wellpoints was assumed to $\sigma = 1$ m.

$$n = \frac{259.50}{1} \approx 260.$$

Efficiency (q) of a single wellpoint with the required reduction value for the excavation:

$$q = \frac{1.36 \cdot k \cdot S_0 \cdot (2 \cdot H_{0z} - S_0)}{n \cdot \lg \frac{R}{r_0}} \ [\text{m}^3 \cdot \text{d}^{-1}], \tag{7}$$

$$q = \frac{1.36 \cdot 28.85 \cdot 1.15 \cdot (2 \cdot 7.05 - 1.15)}{260 \cdot \lg \frac{63.00}{41.30}} = 12.25 \text{ m}^3 \cdot \text{d}^{-1}.$$

Total efficiency (Q_{total}) of the wellpoint installation:

$$Q_{\text{total}} = q \cdot n \ \ [\text{m}^3\text{·d}^{-1}], \tag{8}$$

$$Q_{\text{total}} = 12.25 \cdot 260 = 3{,}185.69 \text{ m}^3\text{·d}^{-1}.$$

Calculations for well installations

Thickness (H_{0z}) of the active zone:

$$H_{0z} = \alpha \cdot (S_{cz} + l_f) \ [\text{m}], \tag{9}$$

where:
α – factor depending on the ratio $S_{cz} / (S_{cz} + l_f)$ [-],
S_{cz} – assumed reduction of the groundwater level outside the well [m],
l_f – length of active filter length [m].

The factor α was determined based on Sokołowski and Żbikowski (1993) and is equal to 1.64, the reduction of the groundwater level outside the well (S_{cz}) was assumed 3.15 m, and the length of the active filter $l_f = 1.20$ m.

$$H_{0z} = 1.64 \cdot (3.15 + 1.20) = 7.13 \text{ m}.$$

Up to the subsoil recognition depth equal to 12.00 m mainly non-cohesive soils occur. Therefore, in the calculations, the value determined from the formula was adopted as the active zone thickness of 7.13 m.

Permissible water velocity (v_d) for the well:

$$v_d = 65 \cdot \sqrt[3]{k} \ [\text{m} \cdot \text{d}^{-1}], \tag{10}$$

$$v_d = 65 \cdot \sqrt[3]{28.85} = 199.35 \text{ m} \cdot \text{d}^{-1}.$$

Water flow (Q) from the excavation:

$$Q = \frac{1.36 \cdot k \cdot S_0 \cdot (2 \cdot H_{0z} - S_0)}{\lg \frac{R}{r_0}} \ [\text{m}^3 \cdot \text{d}^{-1}], \tag{11}$$

$$Q = \frac{1.36 \cdot 28.85 \cdot 1.15 \cdot (2 \cdot 7.13 - 1.15)}{\lg \frac{63.00}{41.30}} = 3{,}225.58 \text{ m}^3 \cdot \text{d}^{-1}.$$

Water flow (q) from a single well:

$$q = 2\pi r \cdot l_f \cdot v_d \ [\text{m}^3 \cdot \text{d}^{-1}], \tag{12}$$

where:
r – well radius [m].

$$q = 2 \cdot \pi \cdot 0.25 \cdot 1.20 \cdot 199.35 = 375.58 \text{ m}^3\text{·d}^{-1}.$$

The well with a radius of $r = 0.25$ m was adopted for a drainage system.

Number of wells (n):

$$n = \frac{Q}{q} \ [-], \tag{13}$$

$$n = \frac{3{,}225.58}{375.58} = 8.59 \approx 9.$$

Total efficiency of the wells installation (Q_{total}):

$$Q_{\text{total}} = q \cdot n \ [\text{m}^3\text{·d}^{-1}], \tag{14}$$

$$Q_{\text{total}} = 375.58 \cdot 9 = 3{,}380.22 \text{ m}^3\text{·d}^{-1}.$$

The performed calculations enabled to determine the number of wellpoints and the number of wells for the considered systems of lowering the water level in the analysed excavation. Plans of the foundation excavation with wellpoint and well installations are presented in Figures 5 and 6 respectively.

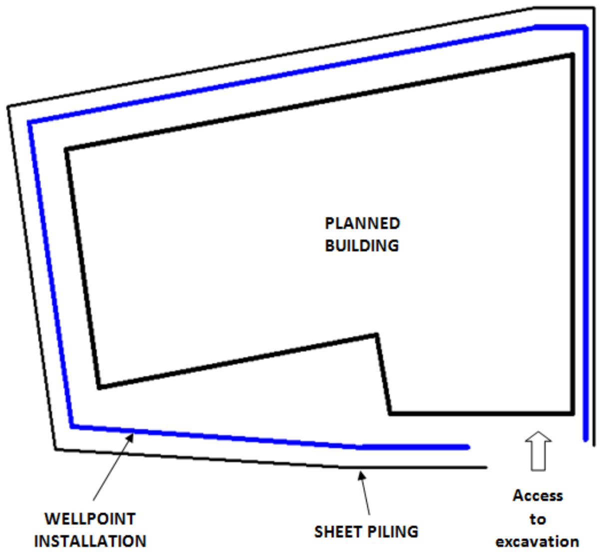

Fig. 5. Plan of the foundation excavation with wellpoint installation

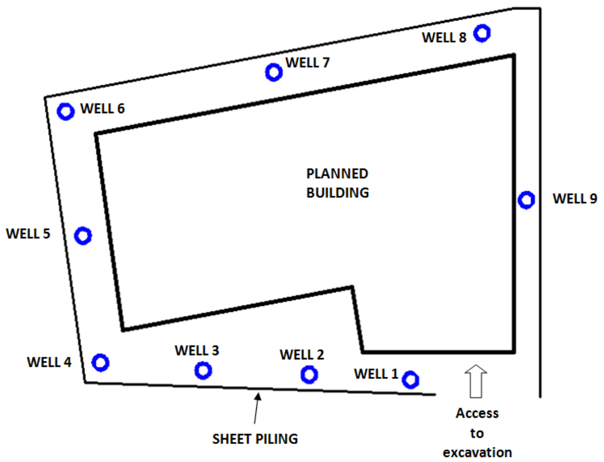

Fig. 6. Plan of the foundation excavation with well installation

In the analysed case, it is possible to use both a wellpoint system and a drainage well, because there are sandy soils in the subsoil. In the case of alternating cohesive and non-cohesive soils in the subsoil, wells should be used to lower the water level in the excavation. The wells could be rinsed deeper and the active part of the filter could be used at a greater depth, which would allow drainage over a larger area of the subsoil.

SUMMARY AND CONCLUSIONS

Investments carried out in areas where the groundwater level is above the foundation of the facility require the use of appropriate water level lowering systems enabling the performance of construction works. When choosing a drainage method, the designer must take into account the issues related to the occurrence of negative phenomena caused by the water level lowering and the effects that they may occur. The selection of an appropriate excavation protection along with proper drainage guarantees safety at the investment site and in its surroundings.

The article presents the concept of lowering the water level in the excavation for a multi-family residential building with one underground floor in urban development. The foundation of the building is planned on the foundation slab with the use of waterproof concrete. Construction of the underground part of the building requires lowering the water level by 1.15 m compared to the level determined during the tests.

As a solution to the problem of high groundwater level, the article considers two drainage concepts: with the use of wellpoints and with the use of wells. It was possible to use the two mentioned drainage systems, because there are sandy soils in the subsoil. The conducted analyzes showed that when using a wellpoint system to lower the water level in the excavation, a system consisting of 260 wellpoints with a spacing of 1.0 m should be made. The efficiency of a single wellpoint is 12.25 $m^3 \cdot d^{-1}$, and the efficiency of the entire installation is 3,185.69 $m^3 \cdot d^{-1}$. When draining the wells, a system consisting of 9 wells should be made, with a unit capacity of 375.58 $m^3 \cdot d^{-1}$ and efficiency of the total installation 3,380.22 $m^3 \cdot d^{-1}$.

Both drainage of excavations with wellpoints and wells are effective methods by which it is possible to lower the groundwater level. It is difficult to clearly determine which method is better. The choice of the drainage method should be preceded by a detailed analysis of subsoil and water conditions, calculations of the drainage system and the possibility of installing individual drainage systems in the field.

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OBNIŻENIE POZIOMU WODY W WYKOPIE POD BUDYNEK MIESZKALNY WIELORODZINNY W GĘSTEJ ZABUDOWIE MIEJSKIEJ

STRESZCZENIE

Artykuł dotyczy wykonywania odwodnienia wykopów pod budynki mieszkalne w gęstej zabudowie miejskiej. W artykule omówiono wykonywanie i zabezpieczanie ścian wykopów oraz sposoby obniżania zwierciadła wody i ich wpływ na otoczenie. Odwodnienie wykopu otwartego przedstawiono na przykładzie budynku mieszkalnego wielorodzinnego z jedną kondygnacją podziemną, wznoszonego w gęstej zabudowie miejskiej. Rozpatrzono wykop wykonanywany w podłożu piaszczystym poniżej zwierciadła wody gruntowej w obudowie ścianek szczelnych. Jako odwodnienie wykopu na czas prowadzenia robót zaproponowano i przeanalizowano dwa sposoby: za pomocą igłofiltrów oraz studni wpłukiwanych. Przeprowadzone obliczenia wykazały, że dla analizowanego przypadku, stosując system igłofiltrowy do obniżenia poziomu wody w wykopie, należy wykonać system składający się z 260 igłofiltrów w rozstawie 1,0 m, przy wydajności pojedynczego igłofiltra 12,25 $m^3 \cdot d^{-1}$ oraz całej instalacji 3185,69 $m^3 \cdot d^{-1}$. Stosując odwodnienie studniami, należy wykonać system składający się z 9 studni z pompami o wydajności jednostkowej 375,58 $m^3 \cdot d^{-1}$ i wydajności całej instalacji 3380,22 $m^3 \cdot d^{-1}$.

Słowa kluczowe: woda gruntowa, zwierciadło wody gruntowej, odwodnienie podłoża, studnia, igłofiltr, budynek mieszkalny wielorodzinny