Method of reducing the level of underground waters

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Abstract: A method is proposed to calculate water irrigation rates for crops that considers hysteresis in the volumetric water content (θ)-water pressure head (ψ) relations, including scanning paths, by the method of point approximation. Three θ(ψ) models are described and computational experiments were carried out using data from literary sources on the hydrophysical properties of soils with different textures. The error analysis of the point approximation of the main branches and the predictive calculation of the scanning branches of the hysteresis loop were carried out. The practical significance of the research lies in the possibility to calculate the precise irrigation rates for crops. The use of such standards minimizes unproductive spending of irrigation water, fertilizers, ameliorants and plant protection products, as well as prevents the pollution of natural waters with agrochemicals and reduces the risk of eutrophication of water sources.

1. Introduction

According to the sources, developers of previous reconstruction projects have already encountered the problem of flooding basements. Information about flooding was obtained by the authors during a survey of workers in the complex of buildings of the Stables Department. According to them, in the absence of pumping of incoming water by pumps, the water level in the basement of one of the buildings reaches about 1 meter from the basement floor. In this paper, authors consider the possibility of lowering the groundwater level in the complex by arranging an annular vertical drainage.

The aim of this paper was to develop proposals for a system for draining two objects on the territory of the Stables Department. The first of these facilities is the basement of the eastern corps (Manege) (system #1). The second is the foundation pit, which was realized as a result of lowering the level of the territory by the thickness of the cultural layer around the surviving fragment of the building of the architect Gerbel, the oldest building in the complex (system #2).

The water-reduction system proposed by the authors consists of two rows of drainage wells (wells) located along the long sides of the perimeter of the drained sites. Wells placed in this way intercept groundwater along the entire contour of the drained area and can be considered as an annular vertical drainage.
2. Material and methods

A water-reducing installation [1-3] from a system of separately located wells has several advantages over other types of drainage. The choice of vertical drainage in this paper is due to the following factors:

- necessity of the large depth of groundwater table lowering;
- It is necessary to lower the groundwater level by approximately 3.5 meters from the surface of the earth and in the basement of the Eastern Corps, and in the area occupied by the foundation pit around the Gerbel corps, to maintain the selected objects in a “dry” state. Such a decrease during the usage of the horizontal drainage is practically not feasible [4].
- close location of the water intake;
- The territory of the Stables Department is washed by the Moika River from the north, and by the Griboedov Canal from the east (the canal is located 15 meters from the Eastern Corps). The filtration flow coming from the streams, constantly maintains the piezometric pressure of the aquifer. Due to the chain of water-reducing wells, the depression funnels that form around each well will close together, thereby constantly lowering the groundwater level throughout the coastal area.

- the ability to change the power of the installation.

During the operation of the water-retention [5-8] system, it is possible to change the power consumed by it by turning on or off the existing wells. Because the water reduction system in this paper will be calculated on the increased groundwater level during the surge events in the Gulf of Finland, most of the time it will not work at full capacity. Power control will save energy when using only part of the pumps [9-11].

The authors consider the calculations of the characteristics of vertical drainage using the example of the water system of the Eastern Corps. Calculation of the water reduction system in the area occupied by the foundation pit of the Gerbel building is carried out according to the same scheme.

The following initial data were taken as the basis for calculating the system of lowering the site of the Eastern Corps.

- The size of the drained site is 40 x 31 m. The mark of the territory is 3 mbs;
- Mark of a stopper (loam) (-6) mbs;
- Information about soils located above the stopper is given in Table 1;
- The groundwater level corresponds to the water level in the watercourses taking into account surge phenomena and is assumed to be 1.8 mbs;
- Basement bottom mark 0 mbs;
- The groundwater level should be lowered to the level of (-0.5) mbs, to protect the basement of the building from flooding, which corresponds to the required drainage rate in St. Petersburg of 0.3 m [2];
- The radius of the well r = 0.25 m (adopted based on experience in the design of such systems).

### Table 1 Layers of soil located above the stopper

| Layer number | Soil type     | Filtration coefficient k, m/day | Layer power, m |
|--------------|---------------|---------------------------------|----------------|
| 1            | Bulk soil     | 8                               | 1              |
| 2            | Dusty sands   | 1                               | 1              |
| 3            | Medium sands  | 10                              | 7              |

The decrease level in the center of the site on which the Manege building is located is defined as the difference between the groundwater level mark and the mark on the drainage rate (\(S=1.8-(-0.5)=2.3\) m). The thickness of the aquifer \(H\) is the distance between the groundwater level mark and the mark of water resistance. In our case \(H=1.8-(-6)=7.8\) m.
Since the foundation pit is cut through by heterogeneous formations consisting of layers of different permeability [12-13], the reduced value determined by the Equation 1 is taken as the filtration coefficient $k$:

$$k = \frac{(h_1K_1)+(h_2K_2)+...+(h_nK_n)}{h_1+h_2+...+h_n}$$

(1)

Further calculations are performed according to the dependences given in [3]. The radius of action of the drainage $R$ is found by the Equation 2:

$$R = 2S\sqrt{K} + r$$

(2)

The depth of water in the soil from the center of the square to the stopper is calculated by the Equation 3:

$$y_0 = H - S$$

(3)

The radius of the circle, the equal area of the rectangle - the territory of the drained site, calculated by the Equation 4:

$$x_0 = \sqrt{\frac{F}{\pi}}$$

(4)

where $F$ is the area of the drained site, $m^2$. Determination of preliminary flow rate of annular vertical drainage (Equation 5):

$$Q_{prelim} = \pi \times k \times \frac{(2H-S)\times S}{\ln R - \ln x_0}$$

(5)

Determination of water-retention capacity of a well (Equation 6):

$$Q_{WRC} = 2\pi \times y \times V_{altw}, m^3/day.$$ 

(6)

where $V_{altw}$ – allowable rate of water filtration when leaving the soil, determined by the dependence (Equation 7):

$$V_{altw} = 65\sqrt{k}$$

(7)

where: $r$ – well radii ($r=0.25$ m); $y$ – water level in well (counted from the mark of the stopper to the mark of the surface of the water in this well). The number of wells is determined so that the conditions are met (Equation 8,9):

$$Q_{WRC} \times (n-2) < Q_{prelim}$$

(8)

$$Q_{WRC} \times n > Q_{prelim}$$

(9)

where $y_n$ – preliminary average required water level in the wells with the number of wells $n$, calculated by the Equation 10. The solution to the system of Equations 8,9 is the number 8.9. Therefore, authors choose the number of wells nearest even large. The number of wells was set as $n=10$. 


\[ y_n = \sqrt{y_0^2 - \frac{Q_{\text{prelim}}}{\pi kn} \ln \frac{x_0}{r}} \] (10)

Check the accepted number of wells \( n = 10 \) according to the Equation 8. The resulting number of wells is evenly distributed around the perimeter of the drained site every 10 m. Authors measured the distance from the center \( O \) to individual wells according to the plot plan and calculate the adjusted flow rate according to the Equation 11, to determine the specified flow rate [14].

\[ Q = \pi \cdot k \cdot \frac{(2H-S) \cdot S}{\ln R - \ln \frac{10}{\sqrt{x_1 \cdot x_2 \cdots x_{10}}}} \] (11)

3. Results and discussions
Authors calculated the groundwater levels for groups of wells that are in the same conditions according to Equation 12. For this, it is necessary to draw up a diagram of all symmetrically located wells and calculate the distances from the selected well to others. For the selected well \( x_n = r = 0.25 \) m was accepted. The calculation results of the above-described model of water-retention are summarized in Table 2.

\[ y_{ni} = \sqrt{H^2 - \frac{Q}{\pi k} \left( \ln R - \ln \frac{10}{\sqrt{x_1 \cdot x_2 \cdots x_{10}}} \right)} \] (12)

| k; m/day | R; m | \( y_0; \) m | \( x_0; \) m | \( Q_{\text{prelim}}; \) m³/day | \( V_{\text{ahv}}; \) m³/day | \( y_u; \) m | Q; m³/day |
|----------|------|-------------|-------------|-------------------------------|----------------|-------------|----------|
| 8.8      | 38.4 | 5.5         | 19.87       | 1285.3                        | 134.2          | 3.15        | 1319.7   |

After calculating the main characteristics of the annular drainage, water levels were calculated for the groups of wells. Wells were divided into three groups according to their location in plan relative to each other. The first group consisted of wells 1,5,6,10; the second - 2,4,7,9; the third - 3,8 (Figure 1). The obtained values of water levels in the wells were summarized in Table 3.
Figure 1 Well distribution along the contour of the site at n = 10

Table 3 Design values of the levels in the wells and in the center of the site. System #1

| Point | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 |
|-------|----|----|----|----|----|----|----|----|----|----|
| Water level, m | | | | | | | | | | |
| 1.2   | 4.18 | 3.85 | 4.18 | 5.12 | 5.12 | 4.18 | 3.85 | 4.18 | 5.12 | 5.50 |

The groundwater level on the territory of the drained site, as mentioned above, should not exceed the level of -0.5 mBS. The mark of the bottom of the wells corresponds to the mark of the water-resistant layer -6 mBs. Thus, the water level mark in each well, increased relative to the mark of water confinement in accordance with the values in Table 3, does not exceed the maximum permissible calculated value of -0.5 mBs, which means that the groundwater level ensures non-flooding of the basement.

The calculation of the water-retention system around the architect Gerbel’s building, with the exception of the initial data, has some other minor differences from the calculation of the first system. Due to the lack of basements, the calculation of the required level of lowering groundwater was carried out relative to the base of the building foundation. It should also be noted that due to the decrease in the size of the drained site, the drainage rate is assumed to have changed downward, so the authors reduced the radius of the wells to an optimal size of 0.2 m, at which a pump can be placed in the well.

The results of calculations of the water-retention system around the building of the architect Gerbel are summarized in Table 4 and 5.

Table 4 The main design characteristics of ring drainage. System #2

| k; m/day | R; m | y0; m | x0; m | Qprelim; m^3/day | V_aw; m^3/day | yu; m | Q; m^3/day |
|----------|------|-------|-------|------------------|---------------|-------|------------|
| 2.9      | 24.8 | 7.5   | 13.65 | 610.3            | 92.8          | 3.04  | 706        |
Table 5 Design values of the levels in the wells and in the center of the site. System #2

| Point | Wells | 1 | 2 | 3 | 4 | 5 | 6 | Point O |
|-------|-------|---|---|---|---|---|---|---------|
| Water level, m |       | 5.67 | 5.67 | 4.31 | 5.67 | 5.67 | 4.31 | 7.50 |

In order to maintain the required water level in vertical drainage wells, it is necessary to select a pumping unit. The authors propose to choose a Grundfos Unilift AP drainage pump to drain drainage wells for the following reasons:

- The impeller allows free passage of particles up to 50 mm in size;
- The ability to operate the pump in automatic mode using a float switch;
- The compact overall dimensions of the pump, in particular the small diameter, allow it to work in wells designed by the authors.

The pump is selected according to two parameters - pressure and flow. The required pump supply $Q_{n1}$ is taken equal to the flow rate of one well: $Q_{n1} = 131.97 \text{ m}^3/\text{day} = 5.5 \text{ m}^3/\text{h} = 1.53 \text{ l}/\text{s}$, where $131.97 = Q/n = 1319.7/10 \text{ m}^3/\text{day}$ – corresponding to the flow rate of one well. Next, authors determined the design head of the pump according to the Equation 13 [4]:

$$H_{c1} = H_{g1} + \sum h_p,$$

where $H_{c1}$ – project pressure of the pump (pump station), $H_{g1}$ – geometric pressure, $\sum h_p$ – total pressure loss (conventionally assumed equal to 30% of geometric pressure). Authors found the geometric pressure as the difference between the elevation of the earth’s surface and the elevation of the water level in the well with the lowest water level from the table [1]. $H_{g1} = 3 - (-6+3.85) = 5.15 \text{ m}$. Then the calculated pump pressure is equal to $H_{p1} = 1.3 \times 5.15 = 6.7 \text{ m}$.

The appropriate drainage pump from the catalog [5] Grundfos Unilift AP 12.40.04.A1 with the following characteristics (Fig. 2):

Figure 2 Pump performance Grundfos Unilift AP 12.40.04.A1
As can be seen from the operating characteristics of the pump, this model provides with some margin the necessary pressure for the estimated flow rate of the drainage well during the surge phenomena in the Gulf of Finland.

It is necessary to carry out its correct installation, ensuring the constancy of the design location of each pump, to ensure stable and safe operation of the pumping equipment. The authors proposed their own scheme for installing pumps in wells. Pumps are mounted by hanging with a cable for the special holder provided in the pump design. The length of the cable controls the exact design position of the pump along the height of the well to maintain the design level of water in the well. The pump casing should be fixed through the sealing gum with three fixing lights, which ensure the immobility of the pump in the plane of the casing. The system for pumping water from wells can operate autonomously. When the water level in the well rises, the pump turns on automatically, due to the presence of a float switch in its design. The installation diagram of the pump in the well is shown in Figures 3,4.

![Figure 3](image3.png)

**Figure 3** Pump layout; view from above

![Figure 4](image4.png)

**Figure 4** Pump layout; side view
4. Conclusion
According to the calculation results, the optimal number of drainage wells was selected, as well as their location so that the design values for lowering the levels in all wells provide the necessary groundwater level, ensuring the absence of flooding of the building foundations. It has been established that the best system providing a “dry” state of selected objects is vertical drainage, which is a series of wells equipped with submersible pumps. It was determined that the highest level of groundwater will be implemented in the center of drained sites. It is shown that uninterrupted pumping of water from wells can be ensured by the installation system of submersible pumps proposed by the authors.

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