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Mitigating groundwater rise in Fergana city: a comprehensive analysis and drainage strategy

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Abstract. This article analyzes the problems of raising groundwater in the city of Fergana and their impact on buildings, structures and utilities. The hydrogeological state of the area was studied, a drainage scheme was selected depending on the geodetic height and the location of buildings and structures on the site, in other words, a general plan of the site was developed. Hydrogeological calculations determined the flow rates of drainage water and depression lines. Hydraulic calculations are based on water permeability, water velocity, pipe diameter and slope. Hydraulic calculations of closed horizontal drains to lower the groundwater level were performed. The Bernoulli equation was constructed for a siphon pipe, and the vacuum at the highest point was determined by applying the continuity equation to this equation. The maximum height of the siphon was found using the given equations.

1 Introduction

Increasing the level of groundwater in the city will have a negative impact on the infrastructure of the city. It leads to the failure of underground engineering communications, which leads to a decrease in their performance and reliability parameters. In addition, it complicates the construction process in the city.

The rise in the level of groundwater has a negative impact on the technical condition of buildings and structures in urban areas. Therefore, determining the effective method of lowering the level of groundwater is an urgent issue of today[1]. In 1920-1930, Professor I.P. Kusakin [2] developed a method of hydraulic calculation to substantiate the project of artificial dewatering.

In 1937, the American scientist M. Bucket**[3]** published a book on the theory of filtration, and in his scientific work he was able to find a clear solution for a hydrodynamically imperfect well.

In hydrogeology and hydrology, the finite number method was first used in 1943 by GN Kamensky [4]. The formation of modeling is described in detail in the monograph of I.K. Gavich [5] "Theory and practice of using modeling in hydrogeology."

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Groundwater levels are now rising in most cities around the world[6]. T.G.Snarman has done a lot of work on modeling the movement of underground water. In 2022, Z.E. Abdulhayev defended it at the Ph.D. In 1975, A.J. Muftakhov [7] developed a hydrodynamic basis for the forecasting of changes in groundwater in complex hydrogeological conditions and the filtration calculations of protective drainage. In 1991, a group of scientists led by Professor A.J. Muftakhov[8] published the normative rules of construction, which contains analytical solutions to the theory of filtration. In addition to the filtration calculations in the normative rules of construction, sections on preventive measures, drainage structures and their maintenance are included.

2 Problem statement

In recent years, rising groundwater levels in many parts of the world have caused many problems. Buildings in these cities are having a negative impact on utilities. The same situation is observed in Fergana. To solve this problem, water is collected in horizontal open drains, but lowering the groundwater level in this way has a negative impact on the city's infrastructure[9], [10].

Studies show that the use of closed horizontal drains to reduce the groundwater level in Fergana is the best way to solve the problem. The Margilan River, which runs through the center of Fergana, is considered a catchment area because it runs through the deepest part of the city [11]–[15].

The following works are carried out for the design of drains:
- the hydrogeological condition of the area will be studied;
- the geodetic height of the area and the location of buildings and structures located there, in other words, the general plan of the area is drawn up.

Fig. 1. Scheme of drainage of groundwater collected into the Margilan River.

In the hydraulic calculations of the drains, the flow of water was determined using the J.Dupy equation[16]. The flow of water flowing into the side drain is determined by the following formula:

$$q_i = \frac{K}{2L}(h_1^2 - h_2^2) \tag{1}$$

Assuming that the groundwater flow from the side to the gallery is q_2, the pressure height is $Z = h_1 - h_2$ because the water flowing into the receiving structure is pressurized. Given the inflow of water from half the diameter of the pipe, we can write the following formula:

$$q_2 = kzq_r \tag{2}$$

$$\frac{q_2}{kz} = q_r$$

here, Z- pressure height, m.

q_r- the amount of specific consumption received m^2/sec.

Coefficients α and β are determined from the graph of R.R.Chugaev[13]:

$$\alpha = \frac{L}{L+r}; \quad \beta = \frac{L}{T}$$

Total specific water consumption for horizontal drainage:

$$q = q_1 + q_2 \tag{3}$$

The total water consumption along the length of the drainage collector is determined as follows:

$$Q = 2qL \tag{4}$$

The calculation of horizontal closed drainage is carried out in two stages:

- Hydrogeological calculation, which results in the flow of water to the drain, determines the condition of the depression surface;
- Hydraulic calculation, in which the water velocity for the water transfer capacity is to determine the pipe diameter and laying slope to reduce the high pressure.

Hydrogeological calculations are usually performed by the sampling method. In subsequent years, graphs built as a result of experiments and on the basis of analytical calculations are used to facilitate such calculations.

To carry out hydrogeological calculations, a special scheme is created based on the hydrogeological conditions of the area, based on this scheme. It depends on the hydrogeological conditions of the foundation and the method of construction of drainage. To choose a calculation scheme, it is necessary to take into account the specific conditions of the area: In this case, it is necessary to determine the following parameters.

- groundwater source and drainage system;
- drainage type: perfect and imperfect;
- the structure of the area where groundwater is reduced (soil homogeneity, permeability);
- state of the aquifer (pressurized, non-pressurized);
- groundwater characteristics (direction, strength, slope).

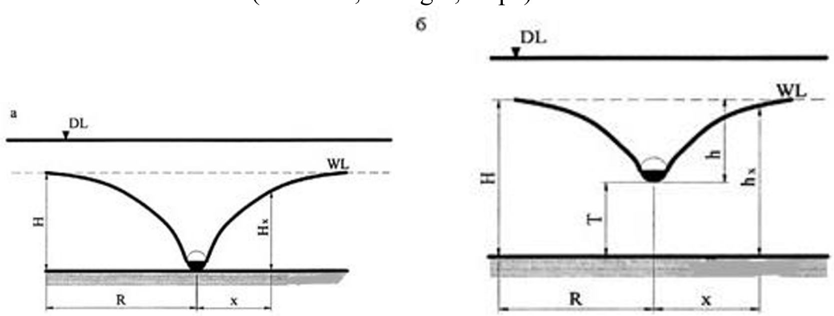

Fig. 2. Calculation scheme of single-line drainage: *a-perfect drainage, b-imperfect drainage.*

If it is not possible to obtain the filtration coefficient of the area where the groundwater is being reduced on an experimental basis, the data will be taken from the data table based on experiments depending on the condition of the construction site. Due to the different soil conditions in the area under consideration, it is necessary to select the values in the data table

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in a precise manner. In cases where the water permeability is different, an average filtration coefficient is used, which is determined by the following formula[17]–[19]:

$$K_{o'r} = \frac{K_1 m_1 + K_2 m_2 + \cdots + K_n m_n}{m_1 + m_2 + \cdots + m_n} \tag{5}$$

here $K_1, K_2 \ldots K_n$- filtration coefficient, m/day;

$m_1, m_2 \ldots m_n$- the strength of the layers, m.

In this case, the use of formula (5) is limited and the number of different layers should not exceed 20:

$$K_n : K_1 < 20$$

We select the scheme of the drainage pipe from Figure 3. If the drainage pipe is lowered to the impermeable layer, the perfect drainage is called imperfect drainage if it is located in the permeable layer. Given the fact that the water flow in the improved drainage flows from both sides, the specific water consumption is found from the following formula:

$$Q_0 = \frac{KH^3}{R} \tag{6}$$

If water flows from only one side, the specific consumption is found as follows:

$$Q_0 = \frac{KH^3}{2R} \tag{7}$$

here R- depression radius, m;

$$R = h\sqrt{\frac{K}{2W}} \tag{8}$$

The following formula is used to construct the depression curve:

$$H_x = H\sqrt{\frac{X}{R}} \tag{9}$$

The specific water consumption for an imperfect single-line closed drain is determined as follows:

$$Q_0 = Kh\left[\frac{h}{R} + \frac{\pi}{ln\frac{T}{\pi r_d} + \frac{\pi R}{2T}}\right] \tag{10}$$

$r_d = \frac{1}{2}b$ - radius of depression.

here b- the width of the drainage ditch, m.

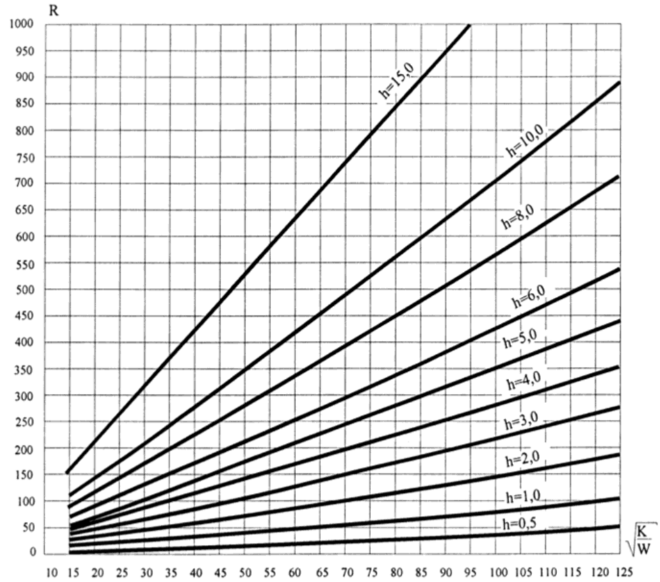

Fig. 3. Graph for determining the radius of depression

The water consumption along the length of the drain is determined by the following formula:

$$Q = Q_0 L \tag{11}$$

The radius of depression R can also be determined from the graph in Figure 3. The depression curve is determined analytically using the following formula[20]:

$$h_X = \frac{Q_0}{K} \cdot \left[\frac{\ln(1-e^{\frac{\pi X}{H}})}{\pi} - \frac{(R-X)}{2H} \right] + H \tag{12}$$

here H- the height of the groundwater table above the waterproof layer, m;
h- elevation of groundwater level from drainage, m;
T- height from waterproof layer to drainage, m;
H_X- the height of the groundwater level at a distance of X, m;
W- intensity of absorption of external atmospheric water, m/day.

Depending on the different schemes, the water consumption in a perfect contour system drainage (Figure 2a) is determined as follows:

$$Q = \frac{\pi K H^2}{\ln\frac{R}{r_0}} \tag{13}$$

Since $r_0 > R$, the denominator of the formula can be assumed to be 1. In this case, the radius r_0 is determined by the following formula:

$$r_0 = \sqrt{\frac{F}{\pi}} \tag{14}$$

The radius of depression R is defined as:

$$R\sqrt{lgR - lgr - 0.217} = 0.66\sqrt{\frac{Kh^2}{W} - 0.5r_0} \tag{15}$$

here F- limited contour area, m^2.

The height of the groundwater level in the contour:

$$H_X = \sqrt{\frac{Q \ln\frac{X}{r_0}}{\pi K}} \tag{16}$$

It can be assumed that $ln\frac{X}{r_0} = 1$ for $X < r_0$.

Water consumption in imperfect drains is determined as follows:

$$Q = \pi K h \left[\frac{h}{\ln\frac{R}{r_0}} + \frac{2\pi T r_0}{T \ln\frac{8r_0}{rg} + 2\varphi r_0} \right] \tag{17}$$

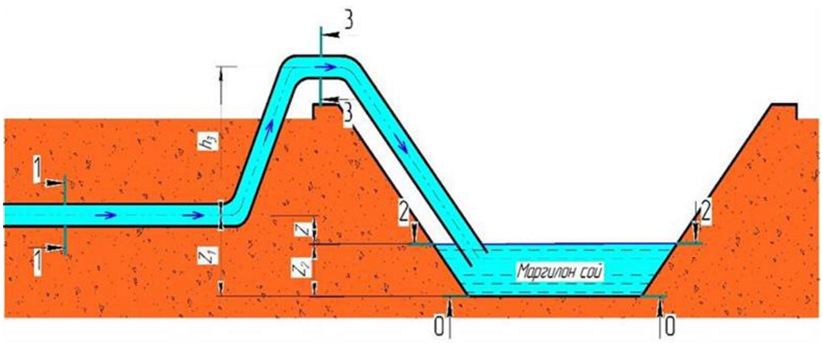

Fig. 4. Siphon drainage

3 Solution method

For the hydraulic calculation of a siphon-shaped pipe, the Bernoulli equation for sections $1-1$ and $2-2$ in Figure 4 is constructed [17]:

$$Z_1 + \frac{P_1}{\rho g} + \frac{\alpha_1 v_1^2}{2g} = Z_2 + \frac{P_2}{\rho g} + \frac{\alpha_2 v_2^2}{2g} + \Sigma\Delta h \tag{18}$$

here $\Sigma\Delta h = (\lambda\frac{l}{d} + \Sigma\xi)\frac{v^2}{2g}$ - the sum of the pressure losses in the pipe, m;

$v_1 = v_2$ - since the diameters of the pipes are the same, the velocities at sections $1-1$ and $2-2$ of the pipe are equal due to the continuity equation for fluid flow.

Using $Z = Z_1 - Z_2$, Equation (18) can be reduced to:

$$Z + \frac{P_1 - P_2}{\rho g} = (\lambda\frac{l}{d} + \Sigma\xi)\frac{v^2}{2g} \tag{19}$$

Considering the fluid continuity equation, the fluid velocity for cylindrical pipes can be found by the following formula:

$$v = \frac{4Q}{\pi d^2} \tag{20}$$

By substituting formula (20) instead of velocity in equation (19), we can make the equation look like this:

$$Z+\frac{P_1-P_2}{\rho g}=(\lambda\frac{l}{d}+\Sigma\xi)\frac{4Q^2}{g\pi^2 d^4} \tag{21}$$

According to Equation (21), the fluid flow rate Q is found as follows:

$$Q=\sqrt{\frac{g\pi^2 d^4}{8(\lambda\frac{l}{d}+\Sigma\xi)}(Z+\frac{P_1-P_2}{\rho g})} \tag{22}$$

here λ - x is the coefficient of hydraulic friction resistance, which depends on the Reynolds number (Re) and the roughness of the pipe ($\kappa_э$), i.e. $\lambda=f(\mathrm{Re},\ \kappa_э)$.

Typically, λ is determined from the Altshul formula:

$$\lambda=0.11\left(\frac{\kappa_э}{d}+\frac{68}{\mathrm{Re}}\right)^{0.25} \tag{23}$$

here $\Sigma\xi$ -is the sum of the local resistance coefficients, which can be derived from an experiment or table, depending on the type of local resistance.

4 Results

To ensure proper operation of the siphon pipe, it is necessary to determine the pressure at the farthest point of the pipe. A vacuum is created at the top of the siphon tube. The value of this vacuum should not exceed the saturated vapor pressure of the liquid. To determine this vacuum, the Bernoulli equation is constructed for sections 1-1 and 3-3, and the vacuum at the highest point is determined by applying the continuity equation to the equation:

$$P_3=P_1-\rho g h_3-\frac{\rho}{2}\left(\frac{Q}{\omega}\right)^2\left(1+\lambda\frac{l_{1-3}}{d}+\xi_{1-3}\right)>P_s \tag{24}$$

here ω - the cross-sectional area of the pipe is defined as follows:

$$\omega=\frac{\pi d^2}{4}$$

P_1 - pressure in section $1-1$, Pa;

h_3 - the height of the siphon, m;

l_{1-3} - pipe lengths in sections $1-1$ and $3-3$, m;

ξ_{1-3} -the sum of the local resistance coefficients in the range 1-1 to 3-3.

Using the above equations, the maximum height h_3 of the siphon can be determined as follows:

$$h_3 = \frac{P_1 - P_3}{\rho g} - \frac{1}{2g}\left(\frac{Q}{\omega}\right)^2 \left(1 + \lambda \frac{l_{1-3}}{d} + \xi_{1-3}\right) \quad (25)$$

Imperfect drainage is used to carry out construction work in the area. This is due to the fact that the depth of the impermeable layer varies from region to region, making it impossible to use perfect drainage.

Siphon pipes are used in the discharge section to increase the efficiency of groundwater collection. These pipes create a vacuum in the system and increase the efficiency of water collection.[20-26] The siphon drain works as shown in Figures 3 and 4.

5 Conclusion

In this article, the ecological and hydrogeological conditions of the area will be improved by reducing groundwater, and the negative impact of groundwater on buildings and structures will be reduced. In the city of Fergana, when the water collected through horizontal drainage is discharged into the Margilan River waterworks, it will be possible to increase the water resources needed for irrigation in agriculture. The water flows into the Southern Fergana Canal via the Margilan River and is used for irrigation in the Altiyarik and Qoshtepa districts of the region.

Calculations show that the use of such horizontal drainage will reduce groundwater levels in the central part of Fergana, "Bahor", "Yormazor" and "Joydam". Allows additional water resources to be used by collecting runoff from drains. The above proposals are complex and expensive, but the damage to the strength of buildings and structures and underground communications will be reduced several times due to rising groundwater. By using siphon drains in the area, the efficiency of closed horizontal drains increases, that is, when the pressure inside the drain decreases, which leads to an increase in the consumption of water collected in the drain. and will have a source of water necessary for industry. Research shows that in siphon drainage, it is effective when the height of the siphon part of the network is raised at a distance of (1÷1.5) d from the main pipe. A large increase in height will fill the siphon xtab leads to the appearance of an air cap in it, and at a small value, the presence of a vacuum decreases.

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