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Filtration calculation to reduce the construction impact on hydrogeological conditions in the city

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Abstract. The paper presents the results of the research conducted to justify construction works within the intensively developed and still developing city area. The study area was located structurally and tectonically within the lowered part of the grabens bounded by regional gaps. The second from the surface aquifer was confined. The aim of the research was to evaluate the effect of lowering of the water table during construction work and laying utility lines on the filtration properties of soils, as well as on existing buildings and highways. Analytical dependencies for the infinite linear perturbation source scheme in an infinite soil layer were proposed and improved. The conducted modeling showed that the estimated maximum depression at the design point under the multi-storey non-residential administrative building was 4.4 m, which was less than the maximum allowable deformations. It was revealed that the maximum water inflows were observed at lowering of water table over the entire limited area of 20–40 m length simultaneously; therefore, the obtained analytical solution should be increased by 22.4 %. It was found that the average discharges depend proportionally on the amount of subsidence in the water table lowering area, with the relationship between the average discharges being linear regardless of the design scheme. The building subsidence due to water table lowering was calculated and a model for geofiltration calculations was developed in Microsoft Excel. The model calculations showed that the maximum subsidence of the soil at the design point of the multi-storey non-residential administrative building did not exceed the maximum allowable deformation values.

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1. *Introduction*

The studied area is structurally and tectonically located within the lowered part of the grabens bounded by regional gaps.

The constructed site is located within the valleys of small rivers flowing through the city. In particular, on the site along the construction of the city highway, there are also small basins of small rivers. It should be noted that within the floodplains of small rivers, with shallow bedding of the moraine roof and insignificant thickness of fluvioglacial deposits, the area becomes waterlogged. Therefore, the problem of assessing and predicting changes in the filtration properties of soils in conditions of intensive urban development is relevant.

When considering the situation in the modern scientific community, it is revealed that the closest to this issue are the researches of Prof. V.V. Vedernikov in the field of water regime forecasting in the aeration zone. In our study, in contrast to the above study, differential nonlinear equations with specified parameters of the range of application area are used [1].

As an aside from the previously considered hydrogeological conditions of urban areas development (M.V. Bolgov et al.), large megapolis with dense building are characterized by more intensive development and frequent reconstruction of both roads and buildings, which must be taken into account when calculating filtration flows in construction [2].

Most works in the considered research area (S.F. Aver'anov, I.S. Pashkovskii, etc.) consider agricultural areas and the impact of irrigated and drained meliorations on filtration flows in soils without an emphasis on built-up areas [3, 4].

Various types of construction work, civil engineering and laying of utility lines substantially affect changes in hydrogeological conditions and, in particular, the water regime, which, in turn, has a significant impact on the subsidence and deformation of buildings [5–8]. This is especially relevant when laying utility lines in urbanized areas. One of the most important problems and practical tasks at construction sites and when laying utilities, when designing hydraulic structures, linear engineering systems, etc. is the prediction of the water regime in the aeration zone and the groundwater regime. Therefore, the assessment of the filtration calculation to reduce the factors of the impact of utility lines on hydrogeological conditions within the urban districts is relevant, especially in the constantly changing conditions of urban development and reconstruction of cities.

The aim of the research is to evaluate the filtration calculations of water lowering during construction works on utility lines in the watersheds of the small rivers within the built-up urban area to reduce the factors of the impact of utility lines on the hydrogeological conditions within urban districts.

Such tasks as modeling to reveal patterns of changes in the subsidence of buildings depending on the water table were considered.

2. Material and Methods

The research was conducted to justify construction works in the territory of megapolis on the example of some districts of Moscow.

This structural depression includes structural-erosive valleys of the Moscow River of different ages [9–13]. Geomorphologically, the area under consideration lies within the plain of fluvioglacial interfluves. This part of the upland is characterized by smooth relief forms with indistinct watersheds of small rivers, with absolute surface elevations of 150–190 m and relative elevations above the flat depressions of 5–10 m, which were previously waterlogged.

The hydrogeological conditions of the area under consideration within the upper part of the section are characterized by the presence of three aquifers: supra-moraine, Upper Jurassic and Upper Carboniferous (Fig. 1).

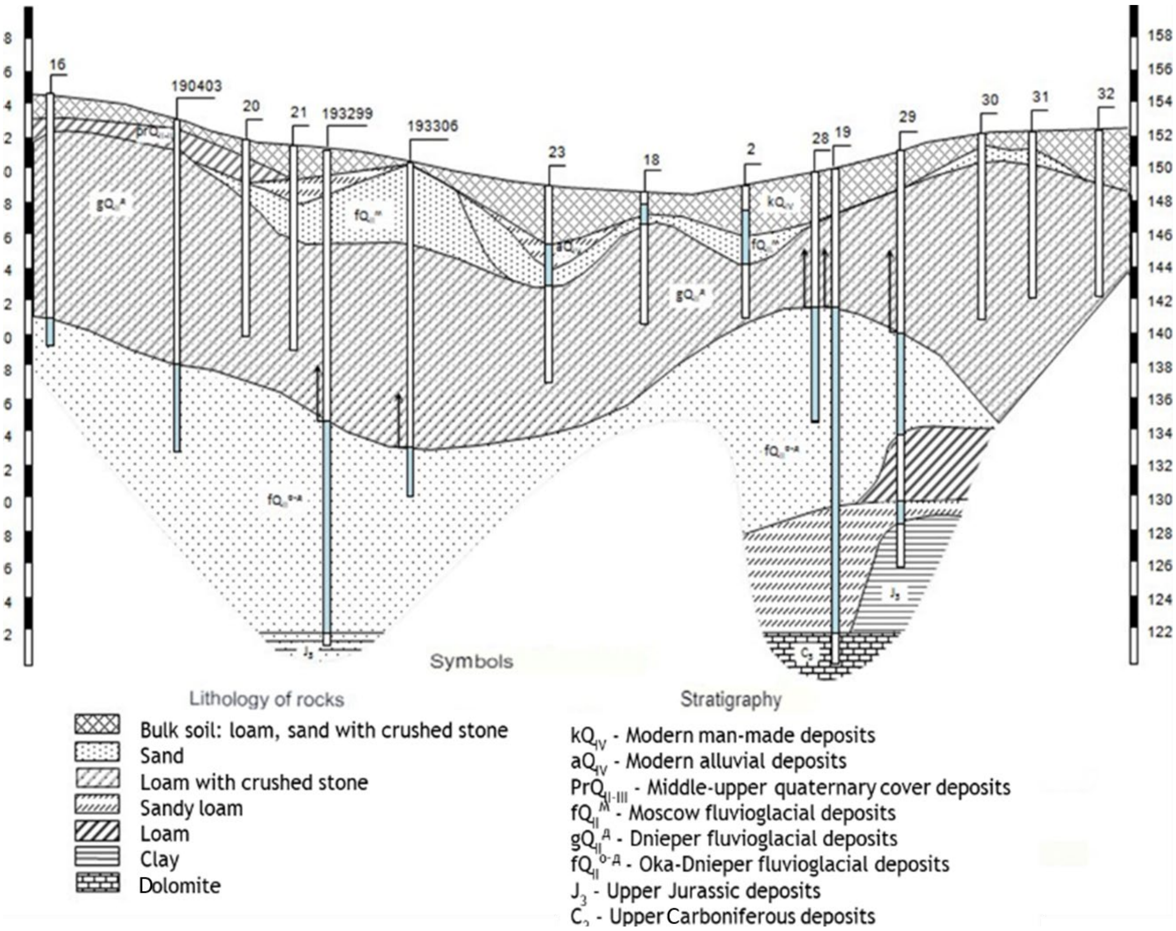

Figure 1. Geological and hydrogeological cross-section (the figure was compiled by the authors based on the results of some studies, expertise and other data from various free resources).

The upland aquifer is the first from the surface at a depth of 1–4 m, is partially distributed and is characterized by sandy deposits above the upper part of moraine and low filtration properties of moraine deposits. The thickness of the horizon is 0.3–5.0 m, water conductivity varies from 1 to 20 m^2/day. The water-retaining foundation is loams 3–15 m thick.

The Upper Jurassic aquifer, widespread throughout the area under consideration, is the second from the surface and is a confined aquifer. The filtration structure of the groundwater in the aquifer is rather complex due to the irregularity of the infiltration supply and the heterogeneity of the underlying water-bearing Jurassic clays. The total thickness of the aquifer is 10–20 m, the filtration coefficient is 2 m/day, the water permeability is 20–40 m^2/day. The water-bearing foundation is clayey deposits of the Upper Jurassic.

The analysis showed that the technical and moral deterioration of fixed assets at almost all operating construction sites, expiration of the standard service life of technical facilities and utility lines, reduction in the volume of reconstruction and repair work, force one to improve the existing ones and look for new ways to reduce the environmental hazard of techno-natural system functioning.

Analytical methods for solving differential equations of groundwater filtration are used to assess the impact of construction work on hydrogeological conditions. When predicting changes in groundwater levels, it is advisable to use the basic differential nonlinear steady-state filtration equation for planar-flat flow [14, 15]:

$$\frac{\partial}{\partial x}\left(T\frac{\partial H}{\partial x}\right)+\frac{\partial}{\partial y}\left(\frac{\partial H}{\partial y}\right)=0, \tag{1}$$

where H is the hydraulic head, m; T is the reservoir conductivity, m^2/day; x and y are the coordinates, m.

The general solution of equation (1) is represented as [16, 17]:

$$H\left(x,t\right)=H_e+\Delta H\left(x,t\right), \tag{2}$$

where H_e is the head of the original steady-state flow; $\Delta H(x,t)$ is the change in the head caused by the disturbance boundary.

In order to solve equation (1), the condition of theoretically instantaneous filling of the channel and instantaneous onset of undercut filtration stage is assumed, i.e. the following initial and boundary conditions:

$$\Delta H(x,0)=0 \quad \text{and} \quad \Delta H(0,t)=\Delta H^0. \tag{3}$$

For an instantaneous level change at the boundary, the calculation formula (solution) has a general form [18, 19]:

$$\Delta H=\Delta H^0 \times F(x;t), \tag{4}$$

where ΔH is the change in groundwater level at the distance x (m) from the boundary of the flow disturbance after the time period t (days); ΔH^0 is the value of the change in the horizon level at the line of the well contour, m; $F(x,t)$ is a special function, depending on the nature of the flow disturbance and boundary conditions, whose values are given [20, 21].

For a semi-constrained flow with an imperfect boundary, the value of additional hydrodynamic resistance must be taken into account by lengthening the flow ΔL_t by the time-dependent value t during unsteady flow. When solving the problem in this way, the equation has the following form [22, 23]:

$$\Delta H=\Delta H^0 \times erfc\left(\frac{x+\Delta L_t}{2\sqrt{at}}\right). \tag{5}$$

Enter the designation:

$$\lambda=\frac{x}{2\sqrt{at}},\ \theta=2\sqrt{at}/\Delta L_t, \tag{6}$$

where $erfc\,\lambda$ is the special tabulated error function; $a=T/\mu$ is the conductivity coefficient, m²/day; T is the water conductivity of the horizon, m²/day; μ is the gravity capacity coefficient, shares of unites.

The dependence $\theta=f(\Delta L_t/\Delta L)$ is presented in Fig. 2.

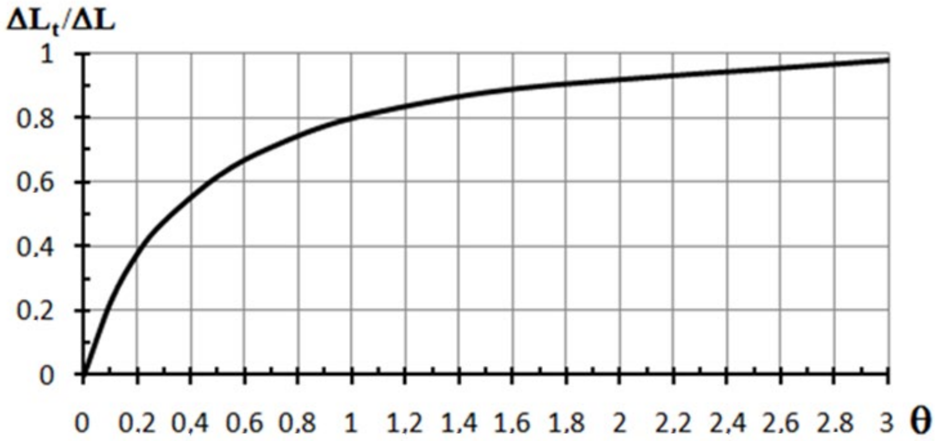

Figure 2. Dependence of $f(\Delta L_t/\Delta L)$ on θ.

With a high degree of accuracy, with a pairwise correlation coefficient of r = 0.9997, the value ΔL_t can be expressed by a regression equation:

$$\Delta L_t = \Delta L \times \left(\frac{1}{0.904 + \frac{0.353}{\theta}} \right). \quad (7)$$

Given the value of ΔL_t, the equation (7) can be presented as follows:

$$\Delta H = \Delta H^0 \times erfc \left(\frac{x + \Delta L \left(\frac{1}{0.904 + 0.353/\theta} \right)}{2\sqrt{at}} \right). \quad (8)$$

The magnitude of the change in specific two-way inflow (flow rate per linear meter) is determined by the relationship:

$$\Delta q = \frac{4T\Delta H^0}{\sqrt{\pi \times at}} \times \exp - \left(\frac{1}{2\sqrt{at}} \times \frac{\Delta L}{0.904 + \frac{0.353 \times \Delta L}{\sqrt{at}}} \right). \quad (9)$$

The average flow is determined by numerical integration. For trenches and horizontal drainage, the value ΔL can be expressed through the parameter $L_{ld}\left(\Delta L = 2L_{ld}\right)$. For a drain located in a homogeneous reservoir, L_{ld} is determined by the formula [24, 25]:

$$L_{ld} = 0.73 \times \lg \frac{2d}{\pi d_d}, \quad (10)$$

where d_d is the calculated drain diameter, $d_d \approx 0.56 \cdot P_d$; P_d is the wetted perimeter of the drain; m_d is the power of the flow under the drain.

For a two-layer reservoir, consisting of a slightly conductive top layer m_n with filtration coefficient k_n and a lower aquifer, with a drain in the top layer, we obtain:

$$ld = 0.73 \frac{T}{k_n} \cdot \lg \frac{8m_n}{\pi d_d}. \quad (11)$$

Analytical solutions according to dependencies (8, 9) are considered for the scheme of infinite linear source of disturbance in an infinite reservoir. However, in real conditions during construction dewatering, open laying of utilities, work is carried out at limited intervals. In this case, dewatering is carried out either at once on the entire interval (trench) – about 100 m, or on a limited section of 20–40 m long, which moves as the pit is dug. The flow pattern gradually becomes radial as it moves away from the source of disturbance.

The analytical values were compared with the numerical values obtained for typical hydrogeological conditions in order to adjust the limitations of the dewatering areas. The averaged discharges appear to be proportionally dependent on the decrease in the level in the dewatering site $\left(S_c\right)$, so the relationship between the average discharges is also linear, regardless of the design linear scheme. Using this relationship, the analytical solutions Q_a were refined:

- when dewatering occurs throughout the entire interval during the entire period of work:

$$Q_o = 1.2244 \cdot Q_a; \quad (12)$$

- when the dewatering section shifts in time:

$$Q_v = 1.0332 \cdot Q_a. \quad (13)$$

It is obvious that the result of analytical solution is practically no different from the result of the numerical solution in the case of section mobility and can be accepted without corrections, since the accuracy is about 3 %. However, the maximum water inflows are observed with a simultaneous decrease in the level over the entire interval, therefore, the obtained analytical solution, according to (12), should be increased by 22.4 %.

3. Results and Discussion

During construction work on laying utility lines, the geological environment will be changed by removing soil from open trenches and pits, as well as under the influence of a number of measures aimed at changing the hydrogeological conditions to prevent flooding in the area of the small river basins. The main impacts on the geological environment during construction is dewatering, which will be carried out in the areas of urban and storm sewerage and water supply systems [26–29].

The input data and calculation results for water inflows into the building drainage system are shown in Fig. 3.

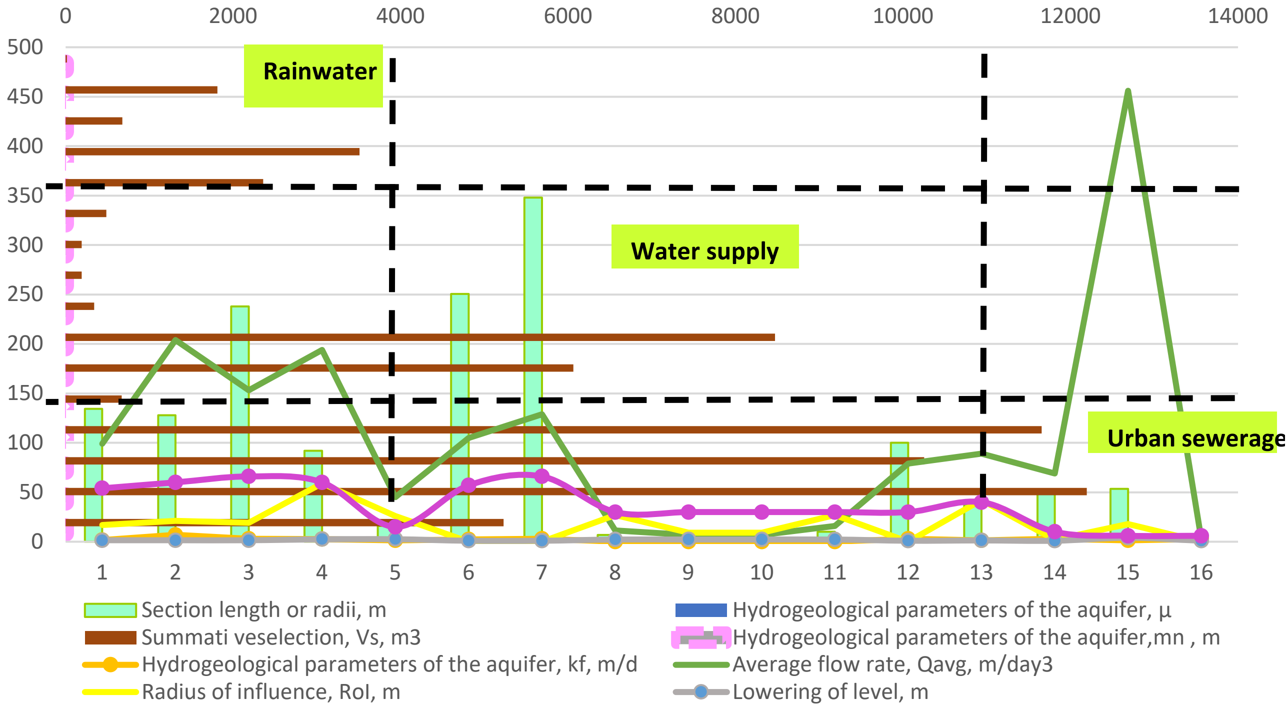

Figure 3. Calculation results of water inflows in the building drainage system.

The studies have shown that the level drop in the supra-moraine aquifer at different areas ranges from 1 to 4 m. The water-bearing rocks of the horizon are upper quaternary deposits, represented by sands and sandy loams; the water yield coefficient is taken to be 0.07–0.15. As the calculations have shown, the average groundwater discharge during the period of level decrease will vary for each calculated area from 2 to 456 m^3/day. At the same time, the total volume of water withdrawal will be 64112 m^3. When determining the size of the zone of influence of the level decrease in the aquifer, a level decrease of 1 m is taken as the boundary, which corresponds to the amplitude of natural fluctuations in the groundwater level. The maximum zone of influence from the conducted dewatering will be 59 m in the storm sewer zone.

Calculations of building subsidence as a result of lowering the water table have been made using the recommendations given in [30, 31] and the dependencies of moisture transport in the aeration zone [18, 32].

In order to assess the filtration calculations of dewatering, a model of the filtration calculations was developed and carried out in Microsoft Excel. During the model calculations, it was found that the depression funnel from construction dewatering with a groundwater subsidence of more than 1 m would include non-residential buildings in the industrial area, where the maximum subsidence under them would be 2 m (Fig. 4).

Table 1

Baseline data for the calculation of precipitation at the RT 1 design point

Absolute ground mark, m	148,6	Number of water-tightness layer:	6
Baseline groundwater he=	146,1	Deep, m	2,5
Level reduction value	2	Horizontal wrinkle m =	2,8

№	lytology of Rocks	Mark Note of the bottom of the layer, m	Engineering and geological parameters density of skeleton, g/cm3	Coef, porosity, d.d.	Maximum molecules, moisture-intensive, d.e.	Capillar, tower, m	Deformation module, Mpa
1	PesGlSm	145,1	1,46	0,65	0,07	0,7	3,5
2	black Ql	144,1	1,7	0,72	0,16	1,4	8
3	p.m./s al	142,8	1,52	0,75	0,02	0,5	13
4	black Ql	142,4	1,7	0,72	0,16	1,4	8
5	p.s./s. al	141,3	1,62	0,7	0,02	2	20
6	сугл.qQII	132,4	1,79	0,45	0,12	1,4	25

Table 2

Results of the sediment calculation at RT 1

(excluding the distribution of humidity and the capacity of the compressible column of the non-conforming capacity of the aquifer)

№	Lithology	Power	Density	Nature characteristics of the ground			The crime of a lower level			Module	Change	Sprout in
ned of the	of the design layers	of the design layers, m	skeleton, g/cm3	Humidity.	Ge density	Pressure, Pe	Wet., Ws.	Density Gs	Pressure, Ps	E, Mpa	pressure dP	layer, dS, mm
1	PesGlSm	1,00	1,46	0,39	0,85	4,50	0,18	1,46	5,11	3,50	0,30	0,87
2	black Ql	1,00	1,70	0,42	1,12	5,62	0,34	1,70	6,81	8,00	0,90	1,12
3	p.m./s al	1,30	1,52	0,43	0,95	6,86	0,43	0,95	8,04	13,00	1,19	1,19
4	black Ql	0,40	1,70	0,42	1,12	7,30	0,42	1,12	8,49	8,00	1,19	0,59
5	p.s./s. al	1,10	1,62	0,41	1,03	8,44	0,41	1,03	9,63	20,00	1,19	0,65
6	сугл.qQII	8,90	1,79	0,31	1,10	18,23	0,31	1,10	19,42	25,00	1,19	0,00

With total pressure change dP= 1.187458

The area of influence will be H = 7.30006 m

The draught shall be dS = 4.421056 mm

Figure 4. Calculation results of geotechnical parameters and building settlement.

The modeling has revealed a pattern of changes in building settlement depending on the water table. The plot of building settlement in the area of PT-1 at different depths of the water table H_e and its different geotechnical parameters and building settlement S_o is shown in Fig. 5.

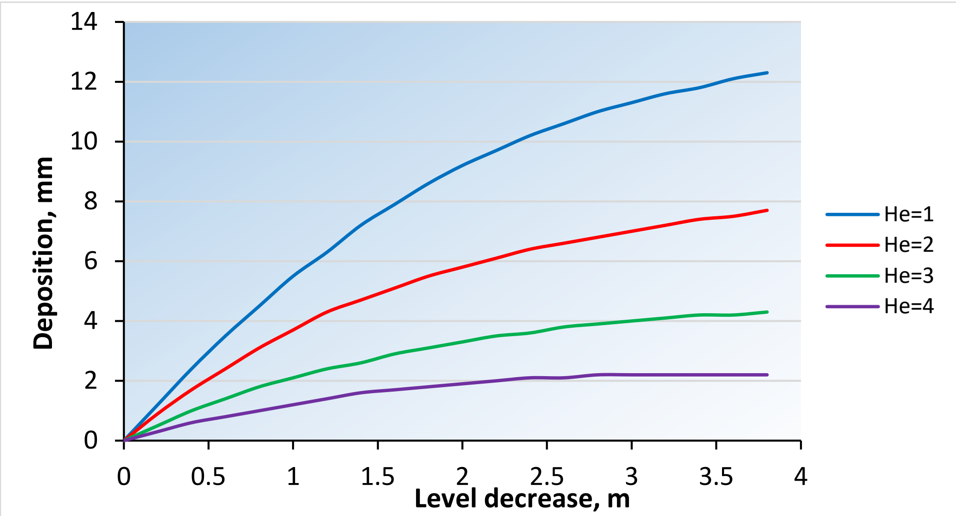

Figure 5. Dependence of deposition on lowering and depth of groundwater level.

The modeling showed that the estimated maximum subsidence at the design point PT-1 under the multi-storey non-residential administrative building was 4.4 m, which is less than the maximum permissible deformations.

4. Conclusions

Dependencies for estimation of filtration calculations of dewatering in the area of construction of utility lines and laying of urban and storm sewers in the territory of the highway construction zone are proposed.

It was revealed that the main factor influencing the hydrogeological conditions of the area of construction of utility lines, where minor catchments of small rivers are located, is dewatering.

Analytical dependencies for the infinite linear perturbation source scheme in an infinite soil layer were proposed and improved.

It was found that the average discharges appear to be proportionally dependent on the amount of the drawdown at the dewatering site, with the relationship between the average discharges being linear regardless of the design linear scheme.

The conducted modeling showed that calculations on estimation of maximum depression at the design point under the multi-storey non-residential administrative building was 4.4 m, which was less than the maximum allowable deformations. It was revealed that the maximum water inflows were observed at lowering of water table over the entire limited area of 20–40 m length simultaneously; therefore, the obtained analytical solution should be increased by 22.4 %.

The building subsidence due to water table lowering was calculated and a model for geofiltration calculations was developed in Microsoft Excel. The model calculations showed that the maximum subsidence of the soil at the design point of the multi-storey non-residential administrative building did not exceed the maximum allowable deformation values.

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