Modeling of changing hydrogeological conditions during construction of pier foundations on the Kama river bank

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Abstract. The article presents the results of hydrogeological studies carried out within the area of the Kama river bank in Perm city. It proposes the hydrodynamic model by means of which a number of forecasting issues have been addressed. The possible scenarios of changes in filtration flow, i.e. water rise before the obstacle and water drop behind the obstacle due to groundwater filtration blockage, have been described [2]. The allowable changes of hydrodynamic conditions within the study area have been outlined.

1. Introduction

The relevance of the study is due to the need to improve flood forecasting methods and corresponding warning techniques. City development, development density, underground utility systems, and changes in natural relief dramatically affect geological environment within the territory under construction. Due to a number of factors (city development, rock compaction caused by overburden engineering load), new perched aquifers form.

The purpose of the current research is to study and provide a long-term forecast of geological, hydrogeological, and hydrodynamic conditions when constructing additional pier foundations for the Kama river bank protection.

Today, flood events appear to become an urgent issue throughout the entire country [9], which, in its turn, brings devastating consequences and can have effects on the economy and environment. This fact urges to carry out a more detailed study aimed at improving flood forecasting methods and protection techniques [7].

2. Materials and methods

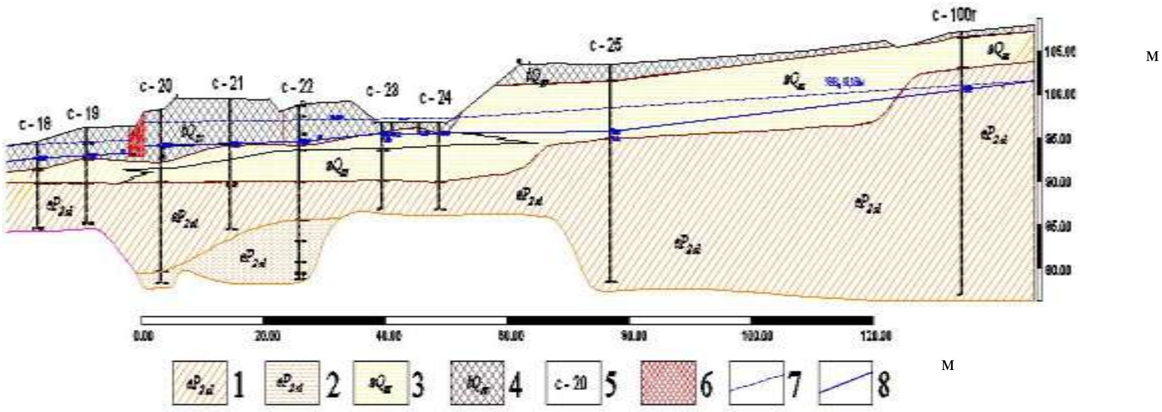
The data for the research were taken from “Sibgiprotransput”, which had been collected by the author of the article in 2013…2014 when studying hydrogeological conditions. In the course of this work, 66 wells were drilled (including four slant wells and two horizontal ones), 20 pit-holes were made, and more than 600 samples were collected. In field investigations, static and dynamic zoning was applied. The soils were sampled and tested using rotating method (static loads). To provide reliable estimate of the filtration parameters, the pumping tests within a two-well cluster and five individual wells were carried out. Hydrogeological survey was done, more than 50 observation points being described. In lab conditions, the full scale of physic-mechanical properties of soils was determined. The filtration capacity was defined for conventionally compacted rocks above the water table. To estimate the impact of the newly constructed pier foundations or changes in groundwater recharge conditions, the numerical modeling was mainly used, including solution of differential equation of nonstandard planned filtration based on the finite-difference technique [2]. Surfer and AutoCad were used as pre-processing programs.

3. Results and discussion

In 2013, the Institute "Sibgiprotransput" (Novosibirsk) with direct involvement of the author of the current research carried out geoengineering studies in Perm city. This study was urged by the need to reconstruct the motor over-bridge crossing the railway line Perm 1…Perm 2. During the study period (03.08…24.11.2013), geoengineering and hydrogeological conditions of the area were investigated in detail.

Within the hydrogeological cross-section of the study site and according to its geological structure [6], the following aquifer systems were identified: Quaternary Aquifer System (pore-ground) and Upper Perm Sheshminsky Aquifer System (eP2sI) (fractured-porous), as well as waters found in technogenic deposits. The aquifers are interconnected and sporadically distributed within the study area.

Within the study area, the depth of the groundwater table is 91.50…104.76 m. The groundwater depth ranges within 0.5…12.2 m. The elevation difference is 13.26 m. The filtration flow is directed to the riverbed, with the hydraulic slope being 0.0608 (Figure. 1).



1 – Sheshminsky complex of fractured argillite; 2 - Sheshminsky complex of fractured sandstone; 3 Quaternary alluvial deposits of II and III terraces above-the-floodplain; 4 – technogenic soils 5 – well, its number; 6 – pier foundation; 7 – estimated groundwater level; 8 – groundwater level in October, 2013

Figure 1. Hydrogeological cross-section of the study area.

At the time of the study, the level of the surface water in the Kama river altered within 87.69…87.72 m. The highest values were identified within the motor over-bridge area, i.e. 93.48 m. In that case, a part of the Kama river valley was flooded, the river stages were water backed over a considerable distance [3].

To obtain reliable estimates of aquifer filtration parameters, a number of tests for underground waters flow were carried out. Such tests were an obligatory part for further estimates of the expected changes in hydrogeological conditions (Table 1).

Table 1. Data of pumping tests (individual wells).

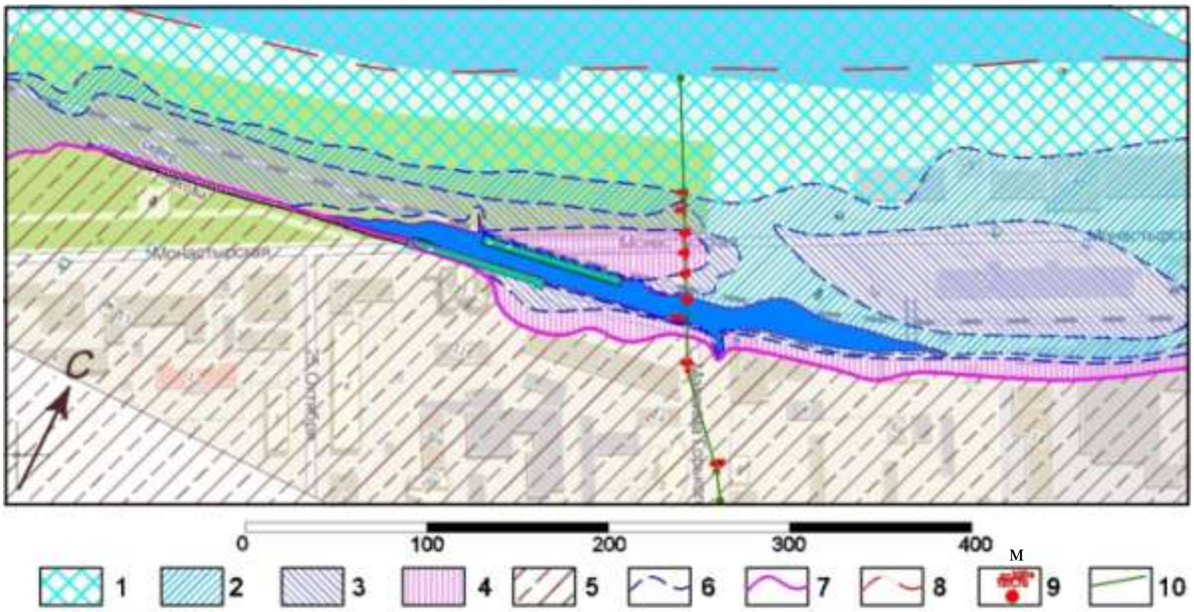
Well number	Test interval, from … to m	Pumping parameters			Average filtration coefficient, m/day	Calculated filtration coefficient at a=0.98 (+)	Calculated filtration coefficient at a=0.98 (-)
		Flow rate, l/sec m^3/day	Draw-down м	Specific capacity, l/sec*m m^3/day*m			
C-18	1.9…10.0	0.036	2.05	0.018	0.33	0.39	0.28

	8.1	3.11		1.52			
C-25	8.5…25.0	0.800	6.45	0.124	1.36	1.51	1.21
	16.5	69.12		10.72			
C-56	10.9…15.0	0.180	2.18	0.083	1.57	1.75	1.39
	4.1	15.55		7.13			
C-59	6.6…10.0	0.370	1.20	0.308	5.94	6.28	5.59
	3.4	31.97		26.64			
C-100г	8.8…30.2	0.170	3.40	0.050	1.39	1.57	1.22
	20.4	14.69		4.32			
	Average				*2.12*	*2.30*	*1.94*
	Min.				*5.94*	*6.28*	*5.59*
	Max.				*0.33*	*0.39*	*0.28*

Due to the complex hydrogeological conditions, estimation of groundwater level change induced by rise of surface water level in the Kama river up to 93.936 m (1 % flow duration curve) was carried out by numerical hydrodynamic modeling in the simulation system Processing Modflow [1].

Gauging of filtration model [5] simulating the increase in the Kama river water level involved determination of the conductivity values and filtration coefficients of the underflow and adjacent deposits, respectively.

As the result of model gauging based on the fitting criteria of real and modelled values (well pressure), the problem of inverse filtration was solved. The field of natural head distribution was modeled, by means of which the flood hazard and risk map of the study area was developed (Figure2).



1 – flood subzone; aeration capacity for 2 zone – 0…0.5 m; 3 zone – 0.5…2.0; 4 zone – 2.0…4.0; 5 zone – slow increase in groundwater level; 6 – boundaries of minor flooding zone; 7 – boundaries between zone of seasonal (annual) flooding and zone of long-term increase in groudwater level; 8 – boundary of the Kama river, 26.10.2013; 9 – well; 10 – crosssection line.

Figure 2. Schematic flood hazard and risk map.

Slope protection for further construction of pier foundations could increase the risks of technogenic floods due to the damming effect that can occur during installation of the pier foundation base below the groundwater level [4]. To eliminate such a scenario, it is necessary to define the optimal depth of pier foundation grid installation. Considering complexity of the hydrogeological conditions, it is essential to use the methods of numerical modeling [8] in order to estimate the groundwater level changes during pier foundation base construction. In this case, the conventional hydrodynamic calculations are not efficient as they rarely make it possible to fully consider the complex nature of water-bearing foliation system interacting with the adjacent layers characterized by different hydrogeological conditions [9].

The forecast of groundwater levels involves two design options which are different in the absolute elevation of pier foundation grids. According to the first design, the absolute mark of pier foundation base is 92.0 m (Figure 3), while the second design option suggests 94.5 m.

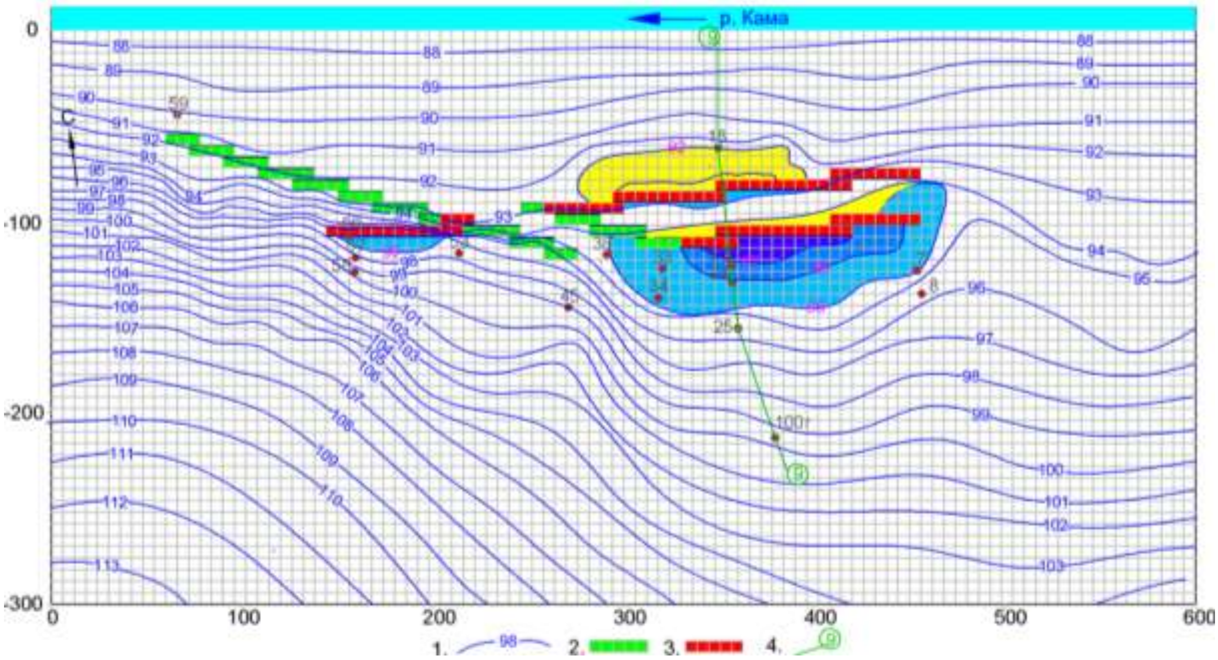


Figure 3. Forecast model of groundwater level changes during pier foundation base embedment up to 92.0 elev.m.: 1 – line of equal heads; 2 – existing pier foundations; 3 – designed pier foundations; 4 – cross-section line.

While the pier foundation base embedded up to the elevation mark 94.5 m, the filtration behavior changes insignificantly. The groundwater level rise around the pier foundations does not exceed 0.3…0.5 m against its standard level restored by means of epignose modeling (Figure 4).

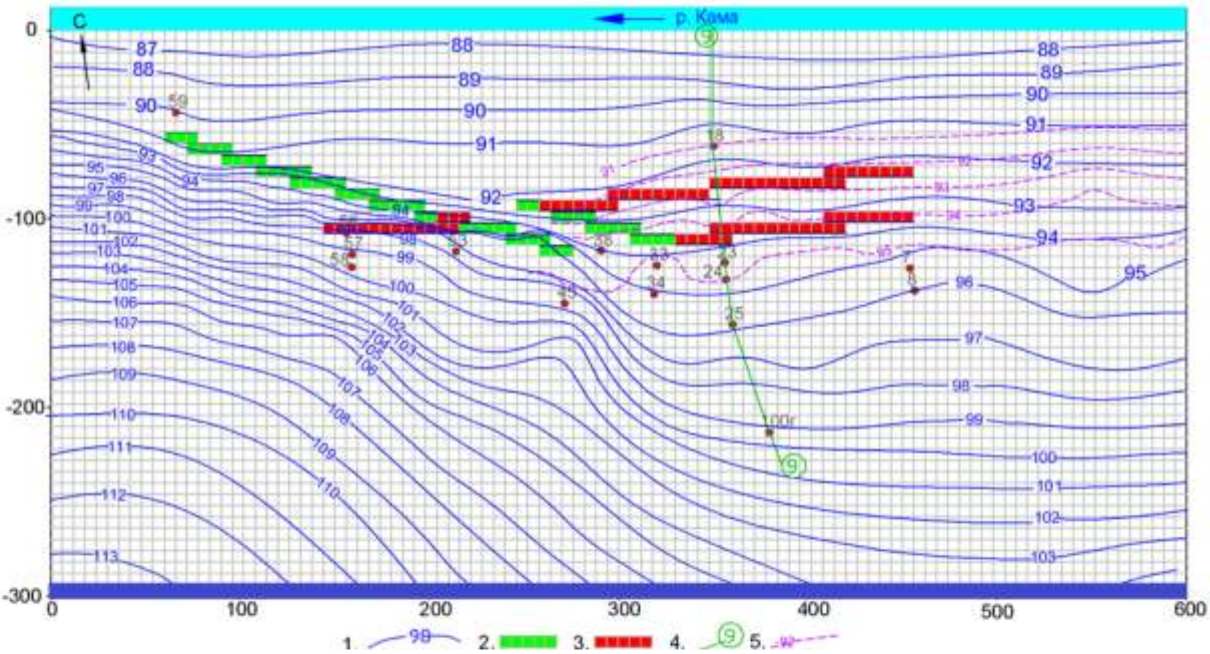


Figure 4. Forecast model of groundwater level changes during pier foundation base embedment up to 94.5 elev.m. 1 – line of equal heads; 2 – existing pier foundations; 3 – designed pier foundations; 4 – cross-section line; 5 – isolines of natural flow.

4. Conclusion

1. The hydrodynamic model to forecast the changes in groundwater levels with regard to maximum possible flood marks (93.94 m) of the surface waters in the Kama river was developed in the software package PMWIN.

2. The flood hazard and risk map of the study area was compiled in accordance with the rules and regulations of geoengineering studies SP 11-105-97 (part 2). The entire area is divided into two zones: zone of seasonal (annual) flooding and zone of long-term increase in groudwater level. The first zone is also divided into four subzones within which groundwater level is projected in line with the maximum level of flood waters in the Kama river. These subzones are identified on the basis of aeration capacity within the four graduation lavels: 0 m; 0.0…0.5 m.; 0.5…2.0 m; 2.0…4.0 m.

3. The forecast of groundwater level change was carried out by means of numerical modeling considering two options of pier foundation base embedment. According to the first design option, the absolute mark of pier foundation base (92.0 m) results in insignificant rise of groundwater level. In the second case (94.5 m), groundwater level rise around the pier foundations does not exceed 0.3…0.5 m against the natural conditions.

References

[1] Chiang Wen-Hsing and Kinzelbach Wolfgang *3D – Groundwater Modeling with PMWIN* (Germany: Springer) p 346

[2] Bukaty M B 2002 Software engineering for the solution of hydrogeological problems *TPU Bulletin Geology, Prospect and Exploration of Mineral Resources in Siberia* Vol 305, **6** 348–365

[3] Burtsev Yu G et al. 1978 *Otchet o rezul'tatakh rabot po izucheniyu dinamiki inzhenerno-geologicheskikh protsessov na beregakh Kamskogo i Votkinskogo vodokhranilishch v 1977-78* (Perm: Sylvenskaya gidrogeologicheskaya partiya) p 212

[4] Gavshina Z P and Dzektser E S 1982 *Usloviya podtopleniya gruntovymi vodami zastraivaemykh territoriy* (Moscow: Stroyizdat) p 116

[5] Zhernov I E and Pavlovats I N 1976 *Modelirovanie fil'tratsionnykh protsessov* (Kiev: Vysshaya shkola) p 192
[6] Lekhov M 2013 Hydrogeological surveys and modeling for urban construction: critical comments *Engineering Survey* **1** 24-29
[7] Muftakhov A Zh 1975 *Gidrodinamicheskie osnovy prognoza podtopleniya promploshchadok i fil'tratsionnye raschety zashchitnogo drenazha v slozhnykh gidrogeologicheskikh usloviyakh: avtoref. dis. d-ra tekhn. Nauk* (Moscow: VNII VODGEO) p 44
[8] Popov V K, Lukashevich O D and Korobkin V A 2004 *Tekhnogennoe podtoplenie: otsenka, razvitie, preventivnye mery* (Irkutsk) pp 24–27
[9] V D Pokrovsky, E M Dutova, K I Kuzevanov, D S Pokrovsky and N G Nalivaiko Hydrogeological Conditions Changes of Tomsk, Russia URL: http://iopscience.iop.org/article/10.1088/1755-1315/27/1/012031