Hydrogeological Conditions Changes of Tomsk, Russia

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Abstract. The hydro-geological conditions of Tomsk are determined by both natural factors and the impact of the urban infrastructure. Important impact on subsurface water flows involves the complex hydraulic relationship of several geological layers and the ancient and modern relief. Increasing groundwater abstraction has generally led to lowered piezometric heads in the deeper aquifer horizons, while in the uppermost horizons, rises in the water table and formation of new perched water tables are experienced due to leaking pipes and impedance of groundwater flow by deep foundations. In this paper special attention is paid to the Quaternary aquifer complex. Barrage effects of pile foundations and the intensive development of perched water distributed on flat surfaces of the watersheds and high terraces, complicated conditions for the construction and operation of facilities, leading in some cases to emergency situations.

1. Introduction

One of the actual problems of the urbanisation is a technogene underflooding of the newly developing territories. It is manifested in the raise of the subsoil waters level, the formation of new aquifers and upper layers of ground water. These processes lead to getting wet and stability loss of the soils of the foundations, flooding of underground components of buildings and constructions, changing exploitation conditions, breakdowns and out -of – action engineering communications. They are the reason of the ecological and social situation degradation.

From the beginning of the 70-s (20th century) great attention has been paid to underflooding in Russia. Since 1972 regular conferences on this problem have been conducted, in which the representatives of scientific design, prospecting and building-exploitation organizations took participation. During the last decades a large amount of factual material has been stored, theoretical conceptions and investigation methods of hydro-geological conditions within urban territories have been worked out, as well as prevention and straggle with negative underflooding consequences [1–3]. At the same time, this problem remains open because of the variety of natural and technogene circumstances, complication of different and often diverse direct factors. At present, in Russia hundreds of large cities are under underflooding influence by underground waters, as well as many rural settlements and large industrial enterprises within the European territory, in the Urals, in Siberia, in the Far East. Tomsk is not an exclusion.

Since 1932 the hydro-geological conditions in Tomsk have been studied by M.I. Kuchin, later on by his followers V.A. Nudner, B.V. Plotnikov et al. The authors turned to this problem in 1979, generalizing the materials of the engineering-geological prospecting for building purposes. The scientific report of 1981 was the result of this work, which became the basis for future hydro-geological prospecting on the territory of the city by different organizations. Later on, the works on this theme were continued by such authors as [4–8]. The formed ideas about the directionality of the hydro-geological processes are given below.

2. Situation and Natural Conditions

Tomsk, an ancient student, cultural and industrial city, is situated in a redundantly humidified taiga zone of West Siberia, on the river Tom, the right tributary of the Ob River (figure 1). Its area embraces 295 km2, including a weakly developed left-bank part and a green zone. The W-N-W relief is complicated by terracing complexes of the Tom River and Ushaika, Kirgizka and Basandaika valley tributaries. The relief involves watersheds in the southern part of up to 190-210 m, lowering to 120-150 m in the northern part. The gently sloping terrace ledges smoothly accompanied by the watershed and often confined by slopes of different steepness inclining from 5-10 up to 50-60 degrees, and exceeding up to 50-60 m. The minimum relief is marked by the water cut in the Tom River of up to 68-70 m (absolute height). The historical central part of the city is mainly of ancient two- and three-storey wooden houses, neighbouring with five- and fifteen- storey buildings in residential micro-districts, being densely populated.

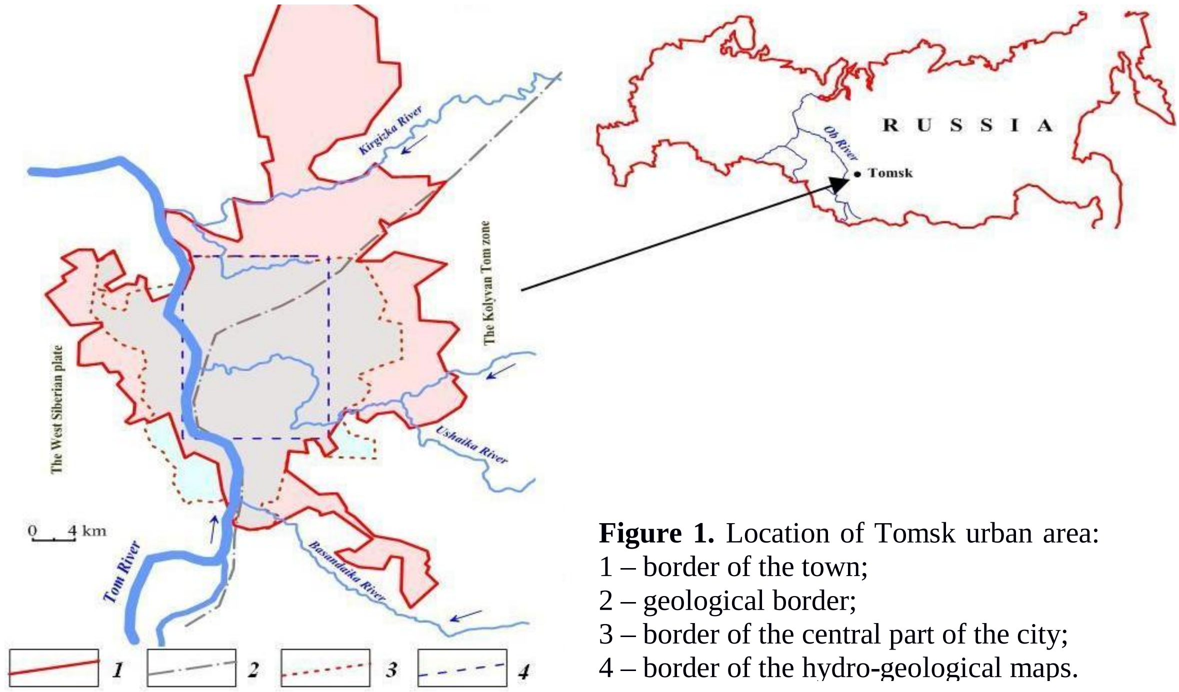

Figure 1. Location of Tomsk urban area:
1 – border of the town;
2 – geological border;
3 – border of the central part of the city;
4 – border of the hydro-geological maps.

3. Hydro-geological Conditions

Hydro-geological features of the territory are determined by its location in the joint of the Kolyvan-Tomsk folded zone and West Siberian platform. The peculiarities of this geological area are defined as a two-level hydro-geological territorial structure.

Water-bearing rocks of the Palaeozoic folded substructure, forming the low hydro-geological level mainly include agrillaceous slates, to a less extent, sandstones. The rocks of the substructure are exposed in the course of the River Tom, in the southern part of the city and in the central area within Ushaika River valley. Water-bearing zones of regional crushing with a thickness of 20-80 m, developed in the upper parts of this section. Within the top of Palaeozoic deposits, the clay weathering crust is developed, which serves as a reliable aquifuge and separates the lower hydro-geological level from the upper one. Waters are of a confined ground nature. Water tables are fixed at the depths of 30-35 m. Water abundance of the deposits is irregular and, on the whole, it is not significant. Specific discharges of the boreholes vary from thousands` up to 0.2 l/sec. Areas with the highest water abundance are within the zones of crushing, also in zones of structural eluvium developed by the widths of a sandy content. In the northern and north-western directions the rocks of the substructure are immersed. They occur at the depths of 80-100 m and more within the bounds of the city.

Loosen formations of the cover, forming the upper geological level, involve aquiferous complexes of Quaternary, Palaeogene and Cretaceous deposits. The Quaternary complex deposits include aquifers (flood-plain and the first terrace), high terraces (the second, the third and the fourth on flood-plains) of the river Tom and its tributaries, watershed and its slopes. The levels of the flood lands are widely developed

4. Changing hydro-geological conditions

The territory of Tomsk is exposed to dangerous engineering-geological processes, where flooding is the most significant one. The development characteristics of this process are determined by the complex influence of both artificial and natural factors. The most important of which are intensity of additional groundwater supply above the natural conditions, structure of the geological section in the zone of influence and the drainage of the area. One of the leading places sources is the additional groundwater recharge to the water supply systems. The urban area receives volumes of water from the external surface and underground sources that are comparable to the intensity of rainfall. In addition, the city has about 200 wells, which capture a considerable amount of water from the regular aquifer and moving to the upper level, promoting the development of flooding. The intensity of technogenic impact on the geological environment is largely determined by density and condition of engineering networks. An extremely widespread engineering infrastructure via water communications and their long-term exploitation contribute to the formation of large quantities of leaks. Taken into account the nature of the construction and condition of the water communications, the calculations show that the intensity of the additional infiltration, in ordinary cases, is 150-200, and in some places up to 1000 – 1500 mm per year, i.e. a higher order of magnitude than in the case of natural ones.

Analysis of the geological structure and lithological variability rocks allows to select one-, two-, and three-layer filtration slit models defining a predisposition of the territory to the flooding process development. This selection is based on the ratio of good and low permeable layers.

One layer section: F-type I-1 classified the soils with high filtration properties (gravel-pebble deposits, sand, sandy loam, bulk soils, as well as loess-like loam top loessial soil). These soils exist in various relations and have a total capacity of more than 15 m.

F-type I-2 classified sections consisting of soils with low filtration properties (loamy soils in all categories except for the area of the upper horizon, clay, uliginous difference between rocks and argillaceous products of the weathering crust) to a depth of 10-15 m.

Two-layer sections: F-type II-1 are soils with high filtration properties, deposits with a width from 2 to 10-12 m, low permeable undersoils and waterproof horizons.

F-II- 2 is characterized by the development of low permeable soils at the top of the section. At depths of 5, sometimes more meters, soils with high filtration properties are deposited.

Three-layer sections: F- type III-1 includes soils with high filtration properties, which have a discrete layer of aquitard with the width 2-6 m. F-type III-2 involves soils with low filtration properties, including good permeable layer with the width 5-6 m.

According to generally accepted criteria, taking into account the ratio of hypsometric location of the underground water supply and discharge areas and the extent of the relief dissection, this territory is well – drained. In general, underground water of the lower hydro-geological and Quaternary alluvial deposit horizons have good drainage. Top soils of sandy and clayey horizons, flooded once in a while, are characterized by very low drainability. This determines the possible active flooding development. Increased levels caused by the development of new areas and reconstruction of old ones are identified by the geomorphologic elements. They are visible in the watershed areas composed of different types of cross-sections, inclined to the formation of flooding processes. First of all, the formation of perched water should be noted in a number of areas which it has not been previously described.

The technogenic impact results on the water imbalance (drainage deterioration, filtration losses from water supply and sewage networks, regimentation of surface runoff, etc.), formation of perched water, and developed flooding. The worsening drainage conditions caused by the barrage effect during the construction of buildings on pile foundations cause the flooding of watershed and transit sites of ground flow. Pile foundations of planned and existing buildings can play an important role in the formation of the damaged structure of seepage flows, especially in the case of mass building. Barrage effect of pile foundations, without taking account underground water movement direction, was repeatedly described in literature. In 1981 this effect was described concerning the possible underground water level rise in some areas of Tomsk. This was also confirmed recently. The scheme of building foundations interaction on one of Tomsk construction sites is described. This site is located on the surface of the second terrace over flood-plain of Tom River, directly near its border. Two major aquifers are allocated in the cross-section. The non-pressure aquifer is located from the surface to depths of 2.3-3.7 m. Pressurized aquifer is opened at depth 16.4 m. The depth of perched water in the backfill soil of near-surface cross-section ranges from 1.2 to 2.8 m.

Based on field studies results aquifer of Quaternary deposits located within reach of the pile foundation is sited in the zone of engineering structure interaction. In the area of the construction site, there is a regional groundwater flow, N-W oriented to the Ushayka River valley which is a natural drain. Analysis of hydro-geological conditions showed that the building foundations existing in the area of the construction site are under the influence of the groundwater flow. This creates favourable conditions for the barrage effect. Modeling of the hydro-geological conditions of this site was performed (figure 2a).

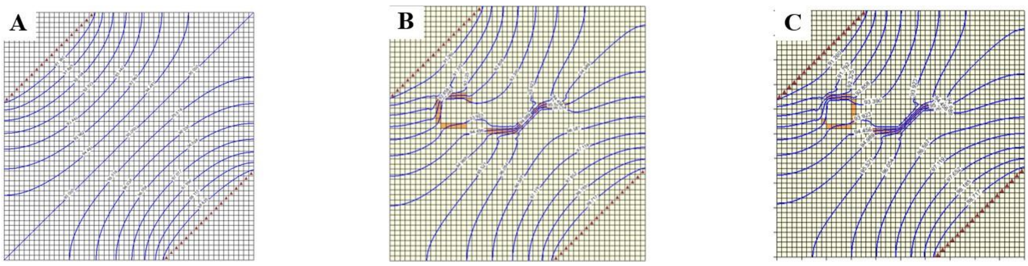

Figure 2. Modeling results of groundwater flow:

A – under natural conditions of the aquifer with homogeneous filtration properties;
B – under disturbed conditions, reducing the filtering coefficient of piles field in 100 times
C – under disturbed conditions, reducing the filtering coefficient of piles field in 100 times. The planning design of building site was changed.

An illustrative example is the design of piles field configuration disregarding the hydrodynamic characteristics of the geological cross-section (figure 2-B). The courtyard represents a "trap" for the regional filtration flow. Within this area the drainage will be completely impossible, but the flow of underground water from the South-East will continue. It can be stated that construction site on a pile foundation in combination with the existing buildings could drastically worsen the conditions of natural drainability, leading to a redistribution of filtration flows and the rise of groundwater levels.

After analysing the results of numerical simulation (figure 2-C), the proposed design solution dramatically reduces the risk of a sharp rise of groundwater levels. Alternative construction project of the residential house was adopted to implement the proposed recommendations. This example shows the importance of considering the characteristics of hydro-geological conditions in the development planning of any urban territory. The study of other technogenic influenced areas in the analysis of the water flows structure can also be very useful.

This can be illustrated by examining the pollution processes. Zoning of the city territory under terms of run-off was proposed. This scheme is as following: the eastern part of the subdistrict A-I-1 (figure 3) embraces modern multi-storey buildings, which affect the groundwater discharge along Tom River high terraces. The western part of the subdistrict embraces old two-three storey buildings in so-called private sector and characterized by the underdevelopment of the sewerage and water supply. The northern part of the subdistrict A-I-2 experiences a complex impact of mixed ancient urban building, including the low-rise part of the private sector along the western border. Technogenic load is reduced to a minimum southward. Area B-II is subjected to the complex nature of pollution. The effect of high-rise modern building is prominent along the southern boundary. In the northern part of the territory the influence of the industrial zone is increasing.

The effect of various kinds of technological factors is pronounced within valleys of permanent watercourses, which are tributaries of the first order Kirgizka River and are treated as separate sections (not shown on the map).

Subdistrict C-I-1 on the right bank of the Ušajka River valley is mainly influenced by high-rise multi-storey building construction development. Subdistrict C-I-2 combines three tributaries of the Ušajka River, forming separate areas within the valleys, vary by relative shares of watershed development. The types of economic development are approximately similar for all three valleys. Subdistrict C-I-3 is characterized by Northwest direction of runoff and has a direct impact on modern buildings. Subdistrict C-I-4 is defined by South-East direction of surface run-off and reflects a mixed impact of modern building with elements of individual construction.

Subdistrict C-II-1 undergoes a mixed influence of urban building. The underground water discharge from the bed of Ušajka River is more prone to the old two-three storey construction. Subdistrict C-II-2 is influenced by two-three storey construction development. Subdistrict C-II-3 is characterized by mainly North direction of surface run-off and by limited influence of technogenic load because of the weak development of the territory in the areas of groundwater supply.
Area D corresponds to the drainage basin of Basandjak River and occupies an insignificant area within the administrative boundaries of the central part of the city.

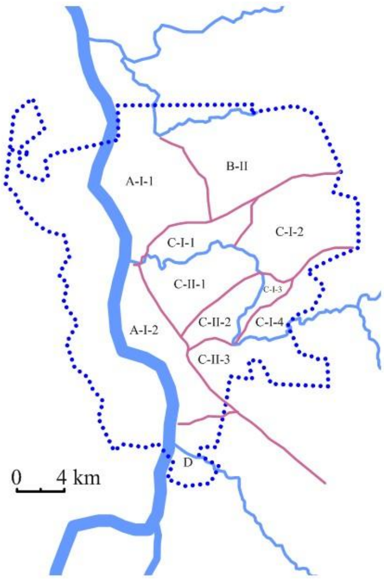

Figure 3. Zoning of the central part of Tomsk territory according to the surface discharge conditions.

Performed zoning allows obtaining analysis basis showing the development of pollution processes. The possible differentiated approach in analysing the potential sources of pollution in urban area became evident. It is possible to determine the major type of pollution, emerging as a result of new multi-storeyhigh-rise or old two-three storey buildings. This is crucial for Tomsk, which was historically developed without considering zoning in the construction residential and industrial areas.

5. Conclusion

The territory of the city as a whole is not prone to the intensive development of the groundwater flooding processes. High hypsometric marks of the area, rugged river network and logs, the presence of powerful horizons of sandy soil create favourable conditions for drainage. At the same time, the intensive development of perched water distributed on flat surfaces of the watersheds and high terraces, complicate conditions for the construction and operation of facilities and, in some cases, to emergency situations. Barrage effects of pile foundations in areas with near deposition of ground waters are pronounced.

1. structure of the regional natural underground water flow does not change in time. The supply and the drainage areas keep their position in space.
2. urbanized territories local seepage flows structure is formed not only under control of natural factors but largely has been restructuring under the influence of technogenic impact, among which, the most important are the additional supply of underground water and direct impact, that are expressed in terms of barrage effect of underground engineering constructions.
3. impact of cities on the deep aquifers can be seen in the lowering levels of underground water; their hydrodynamic regime has no effect on the conditions of construction.
4. areas of the city within the development of low terraces are the natural flooded condition.
5. main reasons of flooding are the rising value of additional underground water supply through leaks from water communications and the deterioration of drainage in the terms of the accepted system of the construction.

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