Causes and consequences of flooding of urban agglomerations on the example of Perm

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Abstract. The process of flooding on the territory of large cities caused by both natural and technogenic causes. On the example of Perm urban agglomeration, the causes and nature of flooding of built-up areas are identified. Natural causes include the location of the city districts on the low floodplain terraces of the Kama River, widespread weakly permeable clay soils, low degree of relief fragmentation. According to many years of research, a significant role in flooding has a technogenic effect. Based on stock hydro-geological materials and engineering-geological surveys conducted in different districts of the city, the analysis and assessment of the impact of natural and technogenic factors on the flooding processes was carried out. This is due to an increase in groundwater level as a result of loss of natural drainage of the territory, siltation of small rivers, and backfill of ravines. The increasing density of buildings also contributes to the flooding process.

1. Introduction
Man has become the largest geological force, often determining the appearance of the upper part of the lithosphere. The most significant changes in the geological environment occur in the territories of urban agglomerations, where sources of additional artificial soil moistening often arise, as a result of which an technogenic high water forms in initially dry soils. In the process of engineering and economic activity, the areas and capacities of anthropogenic deposits grow, which from sporadic collectors often turn into huge flooded lenses, distorting the natural hydro-geological situation. One of the unfavourable hydro geological and engineering-geological processes is flooding, in which the built-up areas, as a result of technogenic impact, are subjected to undesirable re-wetting of soils and rise of groundwater level.

The natural conditions of the flooding process are the presence of poorly permeable soils in the aeration zone, the proximity of local water confines, poor drainage of the territory, and a shallow groundwater table. Technogenic factors of flooding are new sources of groundwater supply caused by leaks from water-bearing communications, violation of the conditions of natural unloading of groundwater, moisture condensation under the base of buildings, structures and under asphalt coverings, inefficiency of storm sewers, backfilling of ravines with clay soils, construction of buried underground structures.

The task of this research is to identify the causes and factors of flooding in the Perm urban and industrial agglomeration.
2. Research results

In the Perm urban agglomeration, flooding is also associated with both natural conditions (widespread development of poorly permeable clay deposits and significant areas of the low terraces of the Kama Valley), as well as high rates of various construction, disruption of natural surface water runoff, leaks from sewer and water supply networks (reaching 10-15% from water supply), watering green spaces and streets. Not only does the ground water plate rise, but its chemical composition changes. Water often acquires aggressive properties. The humidity and salt regimes of groundwater in the aeration zone are changing [1, 2].

The connection between flooding and the degree of dissection of the relief is noted. A high degree of groundwater flooding is characterized by the watershed of the Yegoshikhinsk-Danilikhinsk interfluve, the Permnefteorgsintez site-the Mulyanka and Pyzha interfluve, where the highest rise in the water table is recorded at 6-10 m (figure 1).

This type of geological section is characterized by the presence of water-resistant clay; at the beginning, a “high water” is formed, as it accumulates in the section of water, it acquires all the features of the groundwater horizon. At the same time, the second horizon located below the water-resistant clay, with poor water supply, unloading into local erosion bases, experiences a decrease in water levels.

One of the reasons for raising the groundwater plate is the loss of natural drainage of the territory due to backfilling of ravines.

![Figure 1. Scheme of flooding in the watersheds.](image)

The construction of Kama reservoirs had a great impact on changing the ground water balance and as a result, the scale of hydraulic connection of surface and underground waters increased. The creation of the Votkinsk reservoir increased the low water plate of the Kama river in the city on 1.5-2 m, caused the rise or retention of ground water, flooding and water-logging of construction sites [3, 4].

Hydro alluvium of sand and gravel sediments with a thickness of 4-5 m in the Kama Valley in the 80s of the last century for the construction of the micro-district led to the formation of a technogenic groundwater horizon (figure 2).

The peat deposit with a thickness of 3-7 m for which hydro-alluvium was carried out is represented by forest, forest-marsh, and marsh peat. It was established that, as peat was compacted as a result of hydro-alluvium, its porosity and filtration properties decreased. The maximum compaction of peat occurred in the first year of 80-90%, the remaining part was condensed (consolidated) in the next 6-12 years. So, when compaction of forest peat from 0.25 kg/cm² to 1.0 kg/cm² the values of the filtration coefficient decreased from 0.026 to 0.00041 m/day (the filtration properties of other types of peat also changed) [5]. The peat deposit became a water barrier. In alluvial soils, a technogenic groundwater horizon has formed with a depth of 0.5-1.0 m that is not associated with the lower horizon of alluvial
sand and gravel deposits and the surface waters of the Kama river. The lower horizon before the alluvium of the non-pressure has acquired a weak pressure character, with the height of the pressure to 4.0m with the corresponding rise of water in the reservoir.

![Diagram of flooding scheme on the I floodplain terrace of the Kama river](image)

**Figure 2.** Flooding scheme on the I floodplain terrace of the Kama river.

The effect of the Votkinsk reservoir on natural groundwater levels within low terraces are recorded at a distance of 500 m from the edge.

The largest distribution in the territory of the city Perm has processes such as processing the banks of the Kama and Votkinsk reservoirs, flooding, waterlogging, landslide and suffusion processes, and gully erosion.

Flooding is one of the most common and dangerous engineering and geological processes. In the Perm agglomeration, about 40% of the territory is flooded or potentially flooded [6].

Flooding develops according to three principal hydrogeological schemes, different in the mode, conditions of formation and nature of the distribution of underground water (table 1).

**Option 1** - the rise of the first plate from the surface of a non-pressure aquifer, which experiences significant seasonal and long-term fluctuations, in territories where the depth of the underground water plate in most cases is small (usually does not exceed 5.0 m); soils are mainly clay composition, filtration properties of soils are low, territories are undeveloped (parks, forests) when flooding occurs, the main type of underground water mode is observed.

**Option 2** - the rise of the underground water plate with the formation of the initial period of high water in the aeration zone, and then its confluence. This occurs in areas where the level of the first from the surface of the aquifer lies at a shallow depth (usually no more than 7-10 m), the soils of the aeration zone are represented by soils of clay and sand composition. During flooding there is a natural-technogenic type of groundwater mode.

**Option 3** - rise in water plate due to the influence of exclusively technogenic factors (barrage, constant leaks from water-carrying communications, flooding during the creation of reservoirs). The depth of groundwater is more than 10m. With flooding, a technogenic type of mode is observed.

Consider the causes of flooding of some buildings and structures in Perm.

The building of river station. Located along the embankment of the Kama River. The deep laying of strip foundations (3-4 m) causes a partial flooding of the basements of the building, due to the discharge of ground and surface waters from the side of the watershed slope during heavy rains and spring
snowmelt. Also, a barrage from the Kama side is created in the case of underground water is backed up which caused by rising levels in the Votkinsk reservoir. On this site, two aquifers are opened: quaternary pore-soil and Lower Perm-Sheshmink crack-pore, as well as the high water of technogenic deposits. All aquifers are interconnected. Groundwater levels are subject to fluctuations, the appearance of water is noted at a depth of 3.5-4.5 m, and when the foundation was opened, the level was fixed at a depth of 1.3-4.3 m, the amplitude of the level rise was 0.6-1.5 m.

Administrative building in the central part of the city Perm, Krasnova str., 24 is subject to flooding due to the construction of a new multi-storey residential building with underground parking (5.0 m). Alluvial-deluvial quaternary deposits and Sheshmink-lower Perm bedrock deposits, represented by sandstones, siltstones, mudstones, are common on the site. The upper aquifer is confined to silty loams to a depth of 2.5-3.0 m. The main source of water supply for this aquifer is atmospheric precipitation, to a small extent, recharge from the underlying aquifer occurs. The construction of a residential building with underground parking began with the construction of an underground building envelope consisting of rows of injection piles, then excavation of the foundation pit of the pile field were carried out. More than 250 piles 10-12m long were driven into the foundation pit. During the construction process, water reduction was carried out - pumping water. After the construction of foundations and underground parking, the underground water level rose from the side of Krasnov st., which led to flooding of the basement of the old building, wave-like deformation of the floor and walls with the formation of cracks. These processes caused a barrage effect expressed in the rise of the water level by 1.5-2.0 m from the initial one and the deterioration of the physical and mechanical properties of the foundation soils and basement floor.

Table 1. Types of groundwater regime during flooding.

| Types of groundwater regime during flooding | Causes of flooding | Water levels before and after flooding, m | The processes caused by the flooding |
|--------------------------------------------|--------------------|------------------------------------------|------------------------------------|
| Natural                                    | Climatic conditions, clay type of section, low filtration properties of soils | up to 5.0m/0.3-0.4m | Groundwater level rise, waterlogging. |
| Natural and technogenic                    | Redevelopment of territories, filling in natural drains, covering with asphalt, leaks from water-carrying communications | Up to 7-10m/0.5-1.5m | Change in the physical and mechanical properties of soils, suffosion, |
| Technogenic                                | Deep foundation laying, surface redevelopment, leaks from water-carrying communications | More than 10m/up to 1-2m | Barrage, suffosion, unequal settlement of foundations |

To evaluate the barrage effect, a planned quasi-three-dimensional problem was modeled based on the finite difference method using the specialized MODFLOW filtering simulation software.

The nature of the surface of the groundwater (hydroisogypsum map, figure 3) indicates the influence of the enclosing concrete wall on the filtration of groundwater with the occurrence of a barrage effect.

The construction of high-rise buildings on Engels St. on pile foundations with underground parking provoked a barrage effect. Three ascending springs with a flow rate of 0.3 to 1.5 l/s appeared in the pit with a depth of -2.0 m, which led to partial flooding, and necessitated the construction of drainage and water drainage. Pile field blocked the flow of groundwater.
3. Conclusions
In the Perm urban and industrial agglomeration, flooding is caused by both natural and technogenic causes.

The territory of the central part of Perm in the 30s of XX century. belonged to the almost unsinkable, 80-90s according to the research of VerkhnekamTISIZ it is attributed to almost flooded [7]. Currently, intensive development of high-rise buildings in the central part of the city leads to large-scale changes in hydro-geological and engineering-geological conditions. Almost any construction in the city is currently impossible without the use of measures to organize water reduction and the installation of drainage structures. Flooding has a significant impact on the deterioration of the physical and mechanical properties of soils, which requires the development of special measures to strengthen the foundations of old buildings.

Since the 50s of the last century, the Department of Dynamic Geology and Hydrogeology of PGNIU has been conducting operational monitoring of the levels and chemical composition of groundwater. On the territory of the city, sources of additional artificial nutrition often arise, as a result of which anthropogenic high water forms in initially dry soils. In the process of engineering and economic activity, the areas and capacities of anthropogenic deposits grow, which from sporadic collectors often turn into huge flooded lenses, distorting the natural hydro-geological situation.

To resolve issues on the forecast of flooding of the city, it is necessary to conduct annual integrated regime observations.

References
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Figure 3. Map of gypsum with a simultaneous effect on the groundwater filtration of the pit and fencing with injection piles below the building under examination along the groundwater flow.
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