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PRINCIPLES OF CALCULATIONS AND ARRANGEMENT OF LOCAL DRAINAGE SYSTEMS IN PRIVATE BUILDING TERRITORIES

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Abstract. *Abnormally heavy rains in the first two spring months of 2023 revealed the unpreparedness and lack of protection of many settlements in the Kyiv region from excessive moisture and inundation. Among them, is Novi Petrivtsi village, where the natural conditions for surface runoff and precipitation infiltration (lack of visible surface slopes and poorly permeable cover sediments) are unfavourable and significantly complicated by buildings, and a network of highways. The long-term retention of water on the surface, the rise of groundwater levels, and the layered structure of the upper part of the geological section provide grounds for the use of combined local drainage systems with compliance with drainage standards of at least 3.0 m. Since the high density of buildings often does not allow for contour drainage around residential buildings, it is necessary to lay single-line horizontal drainage to a greater depth than for a conventional contour drainage of 3.5 meters or more. However, the lack of roadside ditches and other water intakes and means of orderly drainage do not allow homestead drainage systems to work as efficiently as possible. This requires the creation of an orderly system of water intakes (trenches and closed collectors) on the scale of the village. Foreign experience convinces that the rational planning of such systems is possible under the conditions of establishing the character of rainfall distribution with a resolution of 1–5 minutes in time and a step of 500 m across the area. Meteorological radar is used to record radar images of rain and study its intensity. An effective solution to the water drainage problem is impossible without detailed engineering and geological investigations. Due to them, litho-facies inhomogeneities in the aeration zone and water-saturated stratum, which lead to the retention and support of groundwater, were discovered in the local area. Taking into account the spatial boundaries of these engineering and geological elements allow drainage more efficiently. Drainage capacity is substantiated by forecasts of changes in the maximum amount of precipitation per day and two days in a row. Due calculating the drainage capacity, it should be taken into account that the maximum amount of precipitation in the future period will have a guarantee of 0.5–2.0 % less than the actual maximum values. In the calculation part, the main attention is paid to the selection of equations for determining the width of influence of a single horizontal drain. Five formulas have been selected that can be used to solve similar problems. The time of onset of the established mode of operation of a single drain was calculated. Future research should focus on the collection of high-resolution rainfall and local urban runoff data, as well as the implementation of urban drainage models.*

Key words: *drainage, groundwater level, flooding, private construction, inundating, precipitation, provision, sewerage, climate change*

Relevance of research. The high density of private buildings in small settlements of the Kyiv agglomeration, and the unpredictability of weather anomalies are increasingly exacerbating the problems associated with the harmful effects of water and forcing the search for optimal means of countering flooding and inundation.

There is a noticeable increase in the amount of precipitation associated with the beginning of the high-water cycle after the end of the abnormally low water cycle of 2009–2020. According to the forecast scenarios of changes in the amount of precipitation in the third decade of the 21st century, there will be an increase in the amount of precipitation in the winter (according to three executed scenarios) and spring (two out of three scenarios) seasons in the greater territory of Ukraine [19]. Moreover, the increase in the amount of spring precipitation is determined by the frequency of heavy daily precipitation. Compared to the period of 2001–2010, the maximum precipitation of the spring season of the 20s (the third decade) will increase by 45–92 mm (according to the three executed scenarios).

Although it is doubtful that such an increase is justified in the Ukrainian Polissia zone, it has been recorded that the precipitation in April 2023 at the Vyshhorod weather station (68.6 mm) had a rather low coverage of 13.5 % and was higher than the average values of 2001–2010 by 31.5 mm (85 %), and in 2011–2020 by 39.6 mm (137 % of the average value for the compared period). Since the maximum value of spring precipitation for the third decade has probably not yet been reached, it can expect an increase in the amount of spring precipitation until 2030 and an increase in the risks of flooding and inundation of poorly drained areas. The main problem will be related to the significant unevenness of precipitation when short-term showers with a supply of less than 10 % will create a large load on sewerage systems, which will force them to increase their carrying capacity. This prompts the search for ways to quickly drain a large amount of water in a short period of time.

Analysis of recent research and publications. A review of the current state of rainwater drainage systems in the territories of the newest private buildings in Ukraine gives the impression of neglecting the problem of centralized drainage. The attitude to this issue in Ukraine is especially contrasted with the rainwater sewerage control system in settlements abroad [24, 29]. As a result of the artificial overlapping of the natural surface, small urban and village catchment basins are characterized by fast runoff processes and a short response time to precipitation. Due to this, they are extremely sensitive to the spatial and temporal variability of precipitation (in cities, this variability is significant even on a small scale) [26, 27]. The development of urban construction leads to the planning and overlapping of zones of the natural flow of excess stormwater [24]. In addition, runoff problems in urbanized areas are created due to the clogging of storm drains, collectors, and hidden riverbeds. Separate studies demonstrate an increase in the amount of precipitation in large urban agglomerations, compared to their periphery, which may be associated with raised evaporation of moisture from impermeable surfaces due to increased temperature and boosted updrafts [25]. Services that control stormwater drainage have concluded that high-resolution precipitation information is needed to manage urban runoff processes [28]. Increasing the temporal resolution of rainfall has a greater impact on the results of hydrodynamic modelling than increasing the *spatial* resolution [29]. A theoretical study by Schilling (1991) suggests that rainfall data with a resolution of at least 1–5 min in time and 1 km in distance should be used for urban drainage modelling. Bern et al. (2004) investigated the temporal and spatial scales of various urban catchments and established the required temporal and spatial resolution of rain measurements for urban hydrological applications. The spatio-temporal resolution proposed by [30] (1–5 min in time and 100–500 m in space) is used for detailed modelling of sewage systems in European cities. Using a geostatistical approach, an analysis of variograms of non-zero precipitation is performed. Periods of rain are recorded by the Treier meteorological radar, which provides radar images of rain with a high level of spatial resolution (250 × 250 m) and instantaneous temporal resolution [26]. In addition, the UKCEH Gridded Estimates of Areal Rainfall (CEH-GEAR) at 1 km resolution is available for many countries, particularly the UK.

In Ukraine, more attention is paid to the flooding of settlements as a result of the load from buildings, the crossing and support of natural streams by underground structures, operational and emergency losses of water from urban water supply and sewage networks, etc. [14, 20, 22, 23].

The main task of drainage systems in flooded built-up areas is to ensure the necessary reduction in the level of groundwater (LGW), which is determined by the deepening of basements, communications, and other underground structures. To avoid flooding of buildings in populated areas, drainage should intercept and divert at least 45 % of the amount of precipitation [24]. When protecting buried structures from underground water, the lowered LGW should be below the base of these structures at least to the height of the capillary rise of water in draining soils [13]. The type of drainage that can be applied is horizontal, vertical, or combined, including radial, depending mainly on the lithological composition and structure of the drained soils, and the degree of density and character of the building [15]. From experience, on draining areas with poorly permeable soils on the surface, collector-drainage systems are well known [6], and draining poorly permeable rocks at depth, vacuum drainages are effective, the water-receiving part of which is sealed and a vacuum is maintained in it with using of a vacuum pump, which allows the removal of only free, but also bound (capillary) moisture. The discharge of drainage water is carried out into open watercourses, reservoirs, ditches, and in their absence into absorbing wells and boreholes or into water receivers (pre-chambers) of pumping stations through dead pipelines [2–4]. The optimal option in terms of economic indicators is when water flows by gravity to the water intake. However, if the settlement is located on a lower terrain, forced pumping of water is resorted to.

Although the tasks of the drainage system on agricultural land and in built-up areas are different, the requirement for optimization of drainage parameters is common, which consists of determining such values for which capital investments in construction would be minimal, while ensuring that the groundwater level is below critical depths and norms drying [7, 9]. The approaches and principles of drainage calculation are also similar. In one case, the load on the drainage is formed as a result of infiltration of atmospheric precipitation, irrigation water, and filtration losses from channels (for irrigation systems) or infiltration of precipitation and lateral inflow (for drainage systems), in the other atmospheric precipitation, lateral inflow from the higher territory and possible losses from sewage facilities and septic tanks.

Therefore, for the calculations of local sewerage systems, it is possible to rely on the fundamental works on determining the optimal parameters of the operation of horizontal and vertical drains [1, 10, 11, 13]. The principles of modelling drainage systems formulated by Polyakov [12], allow the development of reliable algorithms for drainage engineering calculations. The method of calculating water inflow to horizontal drainage proposed in [8] is quite simple and therefore attractive.

However, despite the high level of existing methods for determining the main parameters of drainage and a large number of calculation options [7, 8, 10–13], which is associated with significant variability of hydrogeological conditions and a large list of agricultural and technical tasks, there is a lack of rational approaches to calculation substantiation of the method of drainage of small built-up areas, where the arrangement of contour drainage is impossible. For this, in most cases, it is necessary to use the formulas for single drains, while the possibility of the existence of drainage in neighboring areas should be taken into account, which is mostly designed without taking into account the combined operation (superimposed action of the drainage).

When substantiating and calculating drainage, special attention is paid to additional infiltration feeding of groundwater. The intensity of this feeding in the Kyiv region is quite high and, in some areas, reaches 10^{-2} m/day, on average it ranges from $5 \cdot 10^{-3}$ to $5 \cdot 10^{-4}$ m/day [5, 21], increasing significantly during the spring snow melting. However, in Ukraine, there is a complete absence of the application of a geostatistical approach using meteorological radars, which would ensure the differentiation of the territory of populated areas by the frequency of maximums and amounts of precipitation and would allow for the rational distribution of rainwater drainage systems.

The purpose of the research is to select the optimal calculation models and constructive and technological solutions for local drainage systems in modern conditions of climate change (taking into account changes in the amount of precipitation) in the territories of private development.

Asking the question and justifying the research methodology. It would seem that the Novi Petrivtsi village in Kyiv region, located much above the level of the Dnipro River, has no prerequisites for crises during high floods and high waters. However, the naturally low drainage in the greater part of its territory, associated with the uneven topography and poorly permeable sediments from the surface, is currently significantly complicated by dense buildings and the lack of an orderly drainage system. In the yard of a private house on Nova Kyivska Street is periodic flooding of basements with groundwater and retention of meltwater and rainwater on the surface (Fig. 1). There is no natural open drain within a radius of at least 1.0 km from the site. There are also no artificial drainage ditches along the roads that pass from the southwest and northeast of the house.

Briefly will consider the main characteristics of natural conditions, which are important from the point of view of identifying the causes of flooding and calculating drainage parameters.

Characteristics of the research object. The research territory is located on the high (watershed) territory of the right bank of the Kyiv Reservoir. The surface is very poorly drained, and flat. The main drain of the Dnipro River is located approximately 3.2 km to the east. In terms of geomorphology, the area belongs to the moraine-zandr plain, which is connected with the distribution of heavy glacial loams. Only loose sedimentary rocks are present in the geological structure of the overburden. Up to a depth of at least 8.0 m, they are represented by modern, upper- and middleneopleistocene eolian-diluvial, as well as moraine and hydroglacial light sandy loams with the inclusion of pebbles and gravel of crystalline rocks (Fig. 2) and supramoraine and submoraine fluvioglacial sands (the depth of the sole is about 9.0–9.5 m). Below are Pliocene eluvial-diluvial brown clays, which gradually turn into variegated Miocene clays, with a total

Fig. 1. Inundation roads (a) and yards (b) in Novi Petrivtsi village, April 2023

thickness of 18–22 m [16, 21]. Of course, in the zone of draining influence of the Dnipro River, the aquifers of the Neogene and Paleogene do not have significant pressure. Therefore, the flow from the bottom to the first aquifer from the surface of the pressure less aquifer can be neglected.

The level of groundwater (LGW) at the time of searches (end of October to the beginning of November) was 1.95–2.15 m from the surface. In wet periods of the year, the LGW can rise by an additional 1.0 m (to a depth of 0.9–1.1 m from the surface). After reconnaissance and a thorough study of the engineering-geological and hydrogeological conditions of the site, it was possible to establish ***the main reasons for water retention and flooding of the territory:***

1) climatic conditions – the territory belongs to the zone of sufficient moisture (in the case of poorly permeable cover soils, a layer of runoff is formed on the surface or water is retained in micro depressions of the terrain);

2) the flat topography causes very weak natural drainage of surface sediments; the presence of an elevation in the central part of the site and significant built-up of the territory significantly complicate the runoff of meltwater and rainwater;

3) lack of channelized drainage of stormwater runoff and meltwater runoff, which, after flowing from the roofs of 4 buildings and artificial surfaces (tiles), is localized in depressions or enters the surface of lawns and gardens;

4) occurrence of poorly permeable sediments from the surface, whereby a layer of fluvioglacial

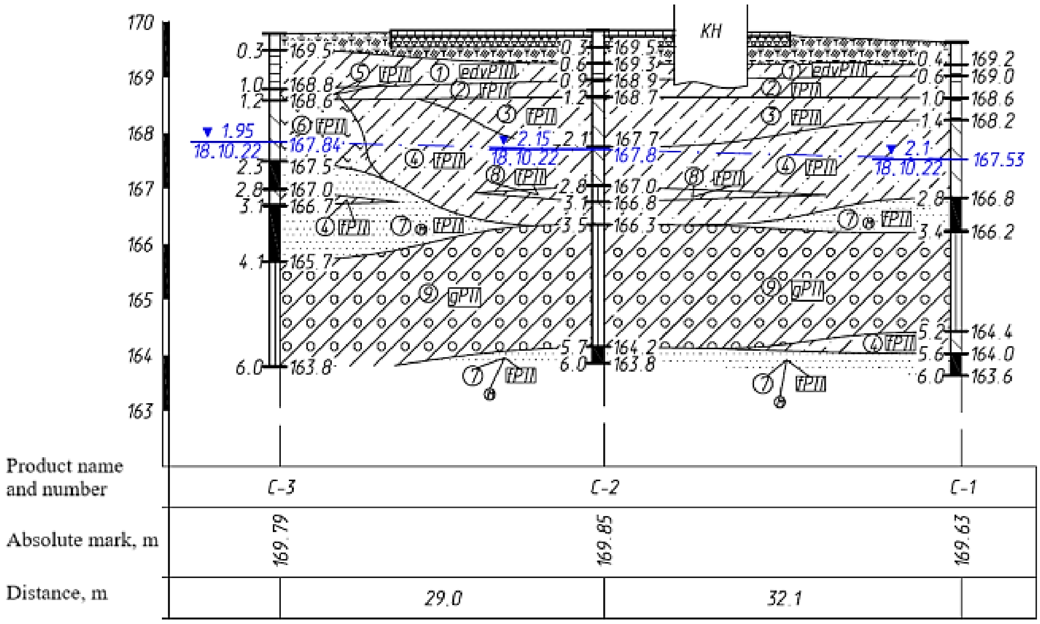

Fig. 2. Engineering-geological section along a private area in Novi-Petrivtsi village for drainage design

loam builds up power inversely to the general, very weak slope of the surface and the direction of the flow of groundwater (toward the Dnipro River), which contributes to the local support of the local flow of perched, which is seasonal (during the melting of snow) is formed close to the surface;

5) wedging of a layer of fluvioglacial sands in the middle part of the section and the area with its replacement by less permeable sandy loam with a layer of light loam, which creates filtration resistance and groundwater support downstream, as evidenced by a significant *decrease in the flow gradient* in the upper part (I = 0.00137) compared to the lower I = 0.0084 on the northeastern edge of the site;

6) the shallow location of the local relative aquifer – a layer of moraine loams – at an average depth of 3.5 m with its roof approaching the surface in the direction of the groundwater flow, which also slows down their natural filtration downstream;

7) a filtration well in the upper part of the natural flow of groundwater creates an additional dome of water spreading (as evidenced by a higher LGW), which is slowly activated due to the peculiarities of the geological structure of the upper part of the section and weak drainage.

In addition, pressure feeding of the upper water-saturated layer of sand and sandy loam is possible due to the formation of its pressure in the submoren sand layer, which will reduce the efficiency of horizontal drainage. Undoubtedly, the choice of water-lowering method will also be influenced by the lack of possibility of discharge of drainage water outside the site.

If the fight against flooding and / or inundation is carried out at the level of an entire settlement, then in each specific case, factors are ranked, which allows for the development of generalized recommendations for the prevention or elimination of inundation [17]. At the same time, it is necessary to be guided by *the principle of maximum use and even return of the natural conditions of the runoff,* which have been changed as a result of economic activity, in certain areas of the territory. However, in the built-up area, it can only use the natural landscape conditions to the maximum to ensure gravity drainage of excess water, and geological and hydrogeological conditions to transfer excess moisture into aquifers with better collector properties and accelerated unloading.

Technological solutions should be aimed at ensuring the drainage of rain and melt runoff, lateral inflow of groundwater, and lowering their level. To eliminate the causes of flooding according to 2 and 3, it is expedient to ensure the drainage of surface rain and melt runoff from the roofs of buildings through the storm collector to the absorbing well; and according to 4 and 5 lay two links of linear horizontal drainage with discharge into the intake borehole.

Results and their discussion. At the beginning, it is advisable to calculate the total load on the receiving drainage collector and, accordingly, determine its hydraulic parameters.

Assessment of the load on the drainage (*Fd, m^3/m^2*) allows establishing the drainage flow module *qp*, m^3/day from 1 m^2 the main indicator of the efficiency of the drainage [7], which combines hydraulic and filtration calculations and can defined as:

$$q_p = Fd / t, \tag{1}$$

where *t* is the duration of the settlement period, days. *Fd* can be determined by the formula modified for local drainage on a built-up plot with a garden when the collector combines the functions of sewerage, drainage, and storm (rain) drainage:

$$Fd = V_P + V_e \pm V_Y \pm V_{ver}, \tag{2}$$

where V_P is the infiltration supply of groundwater by atmospheric precipitation; V_Y is the difference between inflow (from building roofs) and outflow of surface water, m^3; V_e is water loss from the septic tank, m^3; V_{ver} is the vertical water exchange of the balance layer with the groundwater located below, m^3, which can be neglected under the given conditions.

First, the total maximum load on the drainage is determined due to infiltration on the open surface, rain and melt runoff from roofs and artificially covered surface, as well as losses from the filtration well.

The capacity of drainage collectors and the speed of water movement in them is calculated or selected according to the formulas of uniform water movement and when the pipes are completely filled can be calculated according to the Chesy formula: $Q = S\ V$, where

$$S = \frac{\pi \cdot d^2}{4}, \tag{3}$$

The Chesy coefficient (*C*) for drainage pipes is taken according to the formula:

$$C = \frac{70\sqrt{R}}{n' + \sqrt{R}}, \tag{4}$$

where $$R = \frac{\pi \cdot r^2}{2\pi \cdot r} = \frac{d}{4}, \tag{5}$$

If assumes a collector diameter of 110 mm, then the desired flow rate in the pipe will be equal to 3.33 l/s (at a roughness of 0.08). In a day, at such costs, the drainage can pass 287 m^3, which fully satisfies the need to remove the maximum possible daily load on the drainage of 167.0 m^3/day (corresponds to a provision of 0.1 %). Most of the components of the total amount of water to be diverted are predictable. The largest volumes are caused by water consumption and its removal through the sewer to the septic tank, from which the water enters the groundwater through the filtration well. That is, the greatest load will be on the closed part of the drainage. Obviously, to reduce this load, surface runoff should be intercepted and diverted through a separate rain collector.

Calculations of stormwater sewerage taking into account climatic changes. As is known, in built-up areas the percentage of surface runoff in the water balance increases (the share of infiltration decreases accordingly) compared to natural surfaces. The collector should be calculated for costs that will be higher by 4.4 % than the actual spring precipitation for the period 2001–2010 (according to forecasts), or the actual maximum precipitation of the summer season (according to all variants of the forecasts, summer precipitation in the third and fourth decades is not will increase, and most likely will decrease [19]). In fact, in 2023, frequent and significant precipitation in April led to surface flooding and inundation of buildings. According to the Vyshhorod weather station, the amount of precipitation for this month was 68.6 mm, which, according to the analysis of data from 1971 (53 values), corresponds to a supply of 14.4 %. The coverage for each member of the series was calculated according to the equation:

$$P = \frac{m - 0,3}{n + 0,4} 100\%, \qquad (6)$$

where m is the ordinal number of a member of the series of studied values, arranged in decreasing order; n is the total number of members of the series.

Since the empirical curve ends at a value of 122.3 mm, which corresponds to a coverage of 1.3 %, a theoretical curve was constructed, according to which a coverage of 1 % corresponds to a sum of precipitation of 131 mm. However, more important is the maximum amount of daily precipitation, as well as precipitation during two consecutive days. The first value for April in the period 1976–2023 is 42 mm (1987) ($P = 1.4$ %), for the period 2001–2010 is 22,3 mm ($P = 13.8$ %), the second respectively, 73 mm (1976) and 25.2 mm ($P = 20$ %). Precipitation with a 10 % guarantee will amount to 28.3 and 38.7 mm, respectively. According to forecasts, these values are expected to increase to 29.6 and 39.2 mm, which should be foreseen in the projects. The maximum daily precipitation for April 2023 amounted to 32.2 mm ($P = 7.6$ %), which significantly exceeds the forecast (increase by 4.4 %) relative to the maximum value of 2001–2010. In fact, the maximum daily precipitation at the beginning increased by 44 % in the third decade.

The maximum daily amount of precipitation in the warm period of 2001–2010 consists of 62.9 mm (May 2002), which corresponds to a coverage of 6.7 %. Since these are precipitations of the spring period, they can increase by 4.4 %, that is, reach 65.7 mm, which corresponds to 6.1 % of security. Therefore, the storm collector should be calculated for costs derived from the amount of precipitation, which corresponds to a provision of no more than 5 %.

According to the results of the wavelet analysis of daily precipitation for the period of 1976–2002, a significant increase in the frequency of minimum and maximum daily precipitation was established: before 1991, the maxima alternated with a frequency of about 10–11 years, and after 1991 with a frequency of 5.4–5.5 years.

According to the dynamics of precipitation recorded at the Kyiv weather station, the largest amount of precipitation in September-October, when 34–40 mm can fall per day. The biggest risk is heavy precipitation for 2 days in a row. Such cases have been recorded in Vyshhorod weather station for the past 12 years in June and August, in particular, on June 26 and 27, 2011, 42.1 and 61.8 mm fell, respectively, and on August 13 and 14, 2012 of 48.9 mm, respectively and 38.5 mm of precipitation, which confirms the validity of the forecasts made in 2010 [11]. Based on the maximum daily precipitation of 62 mm, the consumption will be 21.2 m^3/day.

It should be noted that the calculations of rainfall are necessary not so much to justify the diameter of the collector (the set of standard pipe diameters is limited and a diameter of 110 mm with a margin meets the needs of local drainage), but to account for the total load on the collector network of the built-up area of the village. A pipe with a diameter of 110 mm at a slope of its laying of 0.002 and working with a full cross-section at a roughness of $n = 0.1$ provides a throughput of 3.08 l/s, which fully satisfies the requirements for the removal of high storm runoff.

Calculations of closed horizontal drainage. Since the drain must be laid from the wall (foundation) at a distance exceeding the minimum L_{min}, formula [1] should be used to determine it:

$$L_{min} = l_f + l_d / 2 + \Delta h / tg\varphi, \qquad (7)$$

where l_f is the protrusion (lower extension) of the foundation, l_d is the width of the drainage trench, φ° is the angle of internal friction of the drained soil; Δh is the vertical distance from the base of the foundation to the horizontal axis of the tubular drain.

The determined distance was 3.15 m, which meets the necessary conditions.

Taking into account the *area of the required drain*, it can determine the total costs for a perfect drain (in this case, 200.5 m^3/day). At the first variant of an imperfect drain, they amount to 113 m^3/day, which also satisfies the hydraulic parameters of linear drainage (3.33–3.77 l/s).

The most important indicator of the efficiency of the drainage is the width of the spreading zone of water lowering from a horizontal narrow drain which can be approximately calculated using the formula for the period of the unstable filtration regime for the time of the formation of the depression funnel:

$$L = H\sqrt{\frac{k}{2\omega}\left(1 - \exp\left(-\frac{6\omega \cdot t}{\mu H}\right)\right)}, \qquad (8)$$

where t is draining operation time, day; ω is infiltration, m/day; k is filtration coefficient, m/day; μ is the water yield coefficient.

If the infiltration supply will be 0.01 m/day, and the actual pressure $H = 7.5$ m (from the water table), then according to formula (8), the width of the water lowering zone will be about 23.6 m, which is typical for the values of the inter-drain distances for similar hydrogeological conditions. At the same time, the drainage flow module can be about 0.03 l/s per ha. That is, in one direction from the drain, the water lowering extends for almost 12 m. The practically identical value of 24 m is obtained from equation (9), which does not take into account infiltration over the area, which corresponds well to the conditions of construction and artificial covering of the surface and drainage of rain runoff by a separate overflow collector:

$$L = 1.73\sqrt{\frac{kHt}{\mu}}. \qquad (9)$$

The total maximum distance to which the action of the drain should extend ensuring the drainage rate (2.5 m) should be 14.55 m.

It should be taken into account that although the zone of influence of a single drain can be greater than the inter-drain distance under the same parameters of two parallel drains, the reduced LGW at a distance of $L_d/2$ from a single drain will be higher than under the influence of two drains.

In order to estimate the total distance over which the influence of the drain extends in one direction, we determine the dynamics of the spread of the influence and the limit of this influence (where the reduction of LGW becomes infinitely small) on the tenth day of operation of the drain in a quasi-steady (or unstable) mode using the formula of I. N. Pavlovtsia:

$$L_t = 3.16 \cdot \sqrt{a_y \cdot t}, \qquad (10)$$

where

$$a_y = \frac{k(3h_L + h_д)}{4\mu}, \qquad (11)$$

According to calculations, at $h_L = 1.7$ m (natural LGW), $h_д = 0.5$ m – water pressure above the drain, the coefficient of conductivity a_y will be equal to 38 m^2/day, and the influence of the drain in one direction will extend to a distance of 61.6 m, and with compliance of drainage norm by 20 m (Fig. 3).

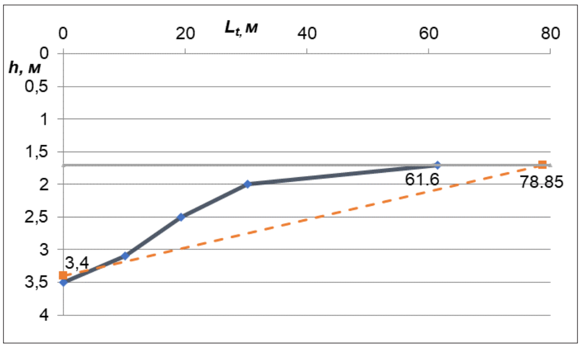

Fig. 3. Spread of water lowering (pressure line) in one direction from the drain on the 10th day under an unstable regime (solid line) and on the 17th–18th day under a stable regime (when the drain is operating in full section) (dashed line); the horizontal line of 1.7 m is the natural level from the surface at the edge of the drain

Since the construction area is located practically on a watershed with a slight slope of the soil flow and the absence of an obvious contour of the area of supply and pressure formation, the unstable mode of filtration in the zone of influence of the drain can continue for a long time. If the unstable regime continues for up to 30 days, the influence of the drain can spread to 105–106 m.

Let's assume that after a certain time, a stable filtering regime will be established and the contours of the depression funnel and the zone of influence of the drain will stabilize. The width of the influence zone in one direction from the horizontal drain can be roughly calculated using the equation:

$$L_{\partial} = \sqrt{\frac{k(H_L^2 - h_{\partial}^2)}{2 \cdot w}}, \qquad (12)$$

where k is the filtration coefficient (2.31 m/day); t_P is the natural pressure from the aquifer at the edge of the drain, or the natural capacity of the aquifer for the depth of laying the drain 3.5 m and LGW = 1.7 m equals 1.8 m; h_{∂} – pressure in the drain from the water resistance (taken to be equal to 0.2 m); w – infiltration supply (about 0.0006 m/day). Hence, L_{∂} under the established filtration regime will be equal to 78.5 m. Provided that the pressure does not exceed the limits of the drain, i.e. $h_d = 0.1$ m, L_{∂} will change insignificantly, increasing only to 78.85 m (Fig. 3), the zone with compliance with the drainage norm, will be about 40 m. Based on the values of L_{∂}, which can be obtained from equation (13), it can be assumed that the steady state will come on the 17th–18th day of operation of the drain.

$$L_{\partial} = 2 \cdot \sqrt{\frac{k t_p h_1 h_2}{\mu(h_1 - h_2 \alpha) + P - e}}, \qquad (13)$$

where k is the filtration coefficient, m/day; t_p is the estimated (or normative) time for the reduction of LGW to the drainage norm h_n at a distance of $L_{\partial}/2$ from the drain. For conditions when the main volume of water comes from the filtration well, which is located next to the septic tank, t_p is taken equal to 2 days; $h_1 = h - h_{\min}$, where $h_{\min}$ is the depth of LGW from the surface during a typical wet period or under natural flooding conditions, taken as equal to 1.5 m; $h_2 = h - h_n$.

Therefore, in order to prevent the flooding of the plot with a residential building, it is necessary to lay a single-line horizontal drainage to a depth of at least 3.5 m, which makes it conditionally perfect. It is necessary to maintain a distance from the foundation of the house to the drain of 3.0–3.15 m. This drainage link (D-1) is laid with a slope of at least 0.002 and extends to the absorption well (Fig. 4), crossing the area of natural support of the soil flow (due to facial replacement, see Fig. 2).

The fourth and fifth causes of flooding are eliminated due to the arrangement of the closed tubular drain D-1 and the absorbing borehole. The 6.3 m deep well is drilled to the lower water-saturated sand layer with better reservoir properties than the wedged upper layer. It is equipped with a pump to ensure the removal of excess water during peak periods of rain and snowmelt in the event of a rise in the LGW above 2.0 m (to eliminate the cause of flooding № 6). Its purpose is to divert water coming from the horizontal drain and reduce the pressure level of the sub-pressure horizon in the submoren sands. Drainage of the pumped water through the pipeline (T-1) to the rear edge of the site with distribution over the garden area is carried out using 5 underground sprinkler pipes (Fig. 5) with a diameter of 40 mm.

The necessity for the equipment of an absorbing inspection well (K) in the rear part of

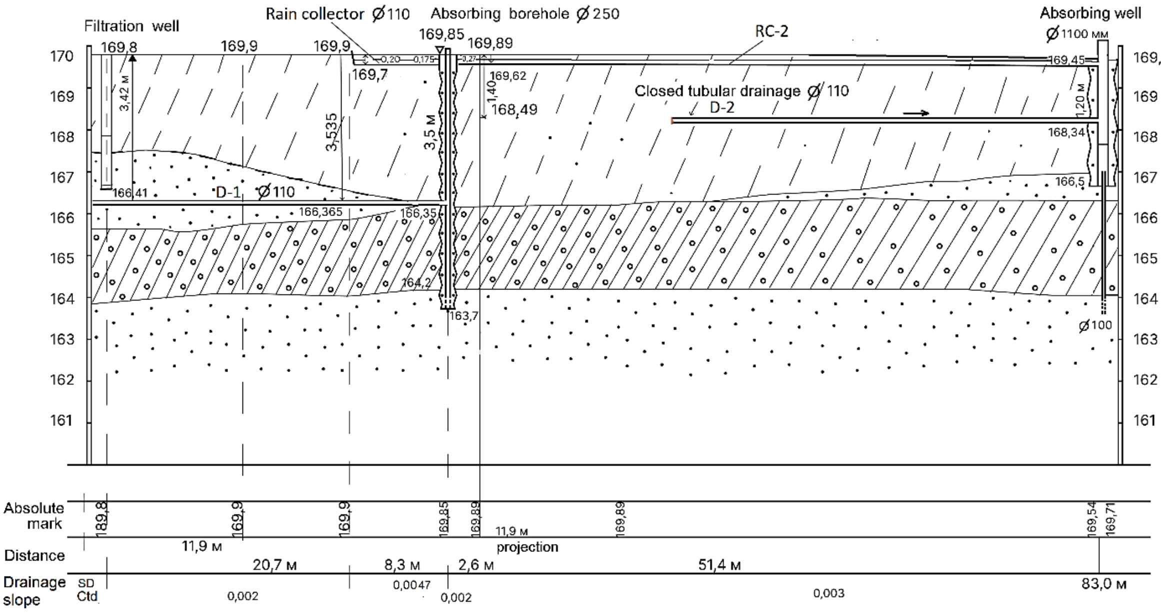

Fig. 4. Section along the plot of a private building with removal of drainage means

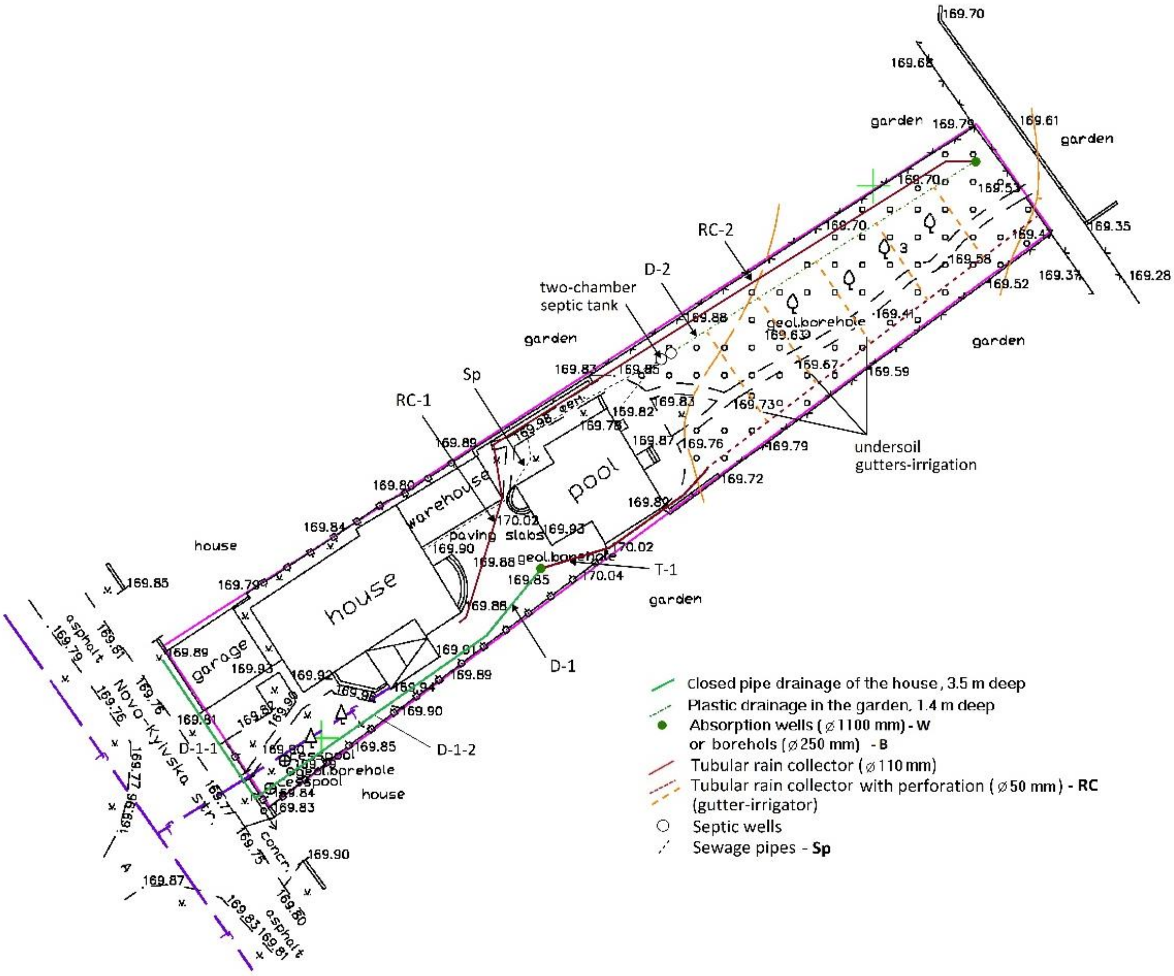

Fig. 5. Plan of the local drainage design site

the site (Figs. 4, 5) is due to the lack of natural and artificial means of accelerated water drainage near the site of works (including beams, ravines, roadside ditches, centralized storm sewers). In compressed building conditions, it is advisable to use polymer sand wells, which are assembled from individual rings 0.2 m high, 1100 mm in diameter, and weighing 44 kg. An absorbing well is drilled through the bottom of the well; a working column is installed, the bottom 40 cm is perforated, and the bottom is covered with a metal mesh and geotextile or fiberglass. A thread is cut in the upper part of the head, which will allow the well to be tightly covered with a lid in case of pressure feeding from below (from a layer of submoren sand).

Conclusions. Unfortunately, the problem of lack of orderly drainage in built-up areas subject to periodic flooding is systemic. It is obvious that it would be more rational to design centralized water lowering and drainage systems (at least to the level of lateral collectors and main ditches) simultaneously with the general development plan of villages and small cities. After dense construction, it becomes almost impossible to lay optimal drainage routes. The algorithm proposed by us for substantiating measures to combat inundation and flooding under the following conditions includes: a) zoning of the territory of the settlement according to the nature of the distribution of precipitation and storm runoff based on radar imaging of rain by a meteorological radar with a high level of temporal (1–5 min) and spatial resolution ability (500 × 500 m); b) calculations of the capacity of the storm network based on radar observations and forecasts of seasonal rainfall, taking into account artificial surface covering; c) detailed study of engineering and geological conditions; d) diagnosis of the causes of flooding and water retention in individual areas, highlighting meteorological, geomorphological, hydrogeological, geological and anthropogenic factors; e) storm water drainage calculations based on actual and forecast data; f) selection of technological scheme and calculations of closed drainage.

The design and construction of the drainage system, even in small areas, should be preceded by detailed engineering and geological investigations to a depth of 6–8 m. In the presence of several interconnected aquifers (horizons), the nature of their interaction should be clarified (the presence of pressure feeding of the upper horizon).

The capacity of the collector for the removal of atmospheric precipitation must be substantiated on the basis of climatic forecasts. However, the current changes in the amount of extreme precipitation, in particular the maximum daily precipitation in April 2023, exceed the predicted values by more than 40 % (compared to the period 2001–2010). When calculating the drainage capacity, it should be taken into account that the maximum amount of precipitation in the future period will have a guarantee of 0.5–2.0 % less than the actual maximum values.

In the conditions of dense construction, if it is impossible to arrange a contour drainage, a single-line horizontal drainage at a depth of 3/5 m can be effective enough to reduce high LGW. Calculations of the zone of influence of the drainage can be performed according to the equations for the inter-drain distances in conditions of unstable and steady inflow regimes. It was established that the influence of the drain in fluvioglacial sand-clay deposits extends in one direction for a distance of about 60 m in an unstable regime, and about 80 m in a stable regime. The technological drainage solution, in our case, included an absorbing well, which was determined by the peculiarities of local conditions: the wedging of the main water-permeable collector in the upper part of the cut and the absence of an open water receiver.

Future research should focus on the collection of high-resolution rainfall and local urban runoff data, as well as the implementation of urban drainage models and the development of compact and efficient drainage facilities.

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ПРИНЦИПИ РОЗРАХУНКІВ ТА ОБЛАШТУВАННЯ ЛОКАЛЬНИХ СИСТЕМ ДРЕНАЖУ НА ТЕРИТОРІЯХ ПРИВАТНОЇ ЗАБУДОВИ

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Анотація. *Аномально рясні дощі за два перші весняні місяці 2023 р. виявили непідготовленість та незахищеність багатьох населених пунктів Київщини від надмірної кількості вологи та затоп-*

лення. Серед таких і с. Нові Петрівці, де несприятливі природні умови для поверхневого стоку та інфільтрації опадів (відсутність видимих ухилів поверхні та слабопроникні покривні відклади), істотно ускладнені забудовою та сіткою автошляхів. Тривала затримка води на поверхні, підйом рівнів ґрунтових вод та шарувата будова верхньої частини геологічного розрізу дають підстави для застосування комбінованих локальних систем дренажу з дотриманням норм осушення не менше 3,0 м. Оскільки висока щільність забудови часто не дозволяє облаштовувати контурний дренаж навколо житлових будинків, доводиться закладати однолінійний горизонтальний дренаж на більшу, ніж для звичайного контурного дренажу глибину – 3,5 і більше метрів. Проте, відсутність придорожніх канав та інших водоприймачів та засобів впорядкованого водовідведення не дозволяють працювати присадибним системам дренажу максимально ефективно. Це потребує створення впорядкованої системи водоприймачів (траншей і закритих колекторів) в масштабах селища. Закордонний досвід переконує, що раціональне планування таких систем можливе за умов встановлення характеру розподілу дощових опадів із роздільною здатністю 1–5 хвилин за часом і кроком в 500 м по площі. Для запису радіолокаційних зображень дощу та вивчення його інтенсивності використовується метеорологічний радар. Ефективне вирішення проблеми водовідведення неможливе без детальних інженерно-геологічних вишукувань. Завдяки ним на локальній ділянці було виявлено літолого-фаціальні неоднорідності в зоні аерації та водонасиченій товщі, які зумовлюють затримання і підпір ґрунтових вод. Врахування просторових меж цих інженерно-геологічних елементів дозволяє розташувати дренаж більш ефективно. Пропускну здатність дренажу обґрунтовано прогнозами змін максимальної кількості опадів за добу і дві доби поспіль. При розрахунках пропускної здатності дренажу слід враховувати, що максимальна кількість опадів майбутнього періоду матиме забезпеченість на 0,5–2,0 % меншу, ніж фактичні максимальні значення. В розрахунковій частині головна увага приділена підбору рівнянь для визначення ширини впливу одиночної горизонтальної дрени. Підібрано п’ять формул, які можуть бути застосовані для вирішення подібних завдань. Вирахувано час настання усталеного режиму роботи одиночної дрени. Майбутні дослідження мають бути зосереджені на зборі даних про опади високої роздільної здатності та місцевий міський стік, а також на реалізації моделей міського дренажу.

Ключові слова: *дренаж, рівень ґрунтових вод, підтоплення, приватна забудова, затоплення, опади, забезпеченість, водовідведення, кліматичні зміни*