Determination of design layer of rainfall for design of treatment facilities of surface runoff

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Abstract. The article assesses the influence of the initial data and the duration of observations on the calculated value of the sediment layer, which determines the performance of treatment facilities of surface runoff. At design of these constructions drain volume from a settlement rain is found. The error introduced by the grouping of initial data depending on the accepted gradation of intervals is determined. The daily layer of precipitation from low-intensity frequent rains with a period of a single excess of the calculated intensity of 0.05-0.1 years was determined (for the conditions of Samara). Recommendations on the choice of initial data in the design are given.

1. Introduction

Surface wastewater contributes significantly to water pollution [1-18] and requires pre-treatment before discharge [3,16,17].

When designing treatment facilities for surface wastewater, it is necessary to determine the amount of runoff from the design rain. It depends on the maximum precipitation layer ($h$) for rain, from which the runoff is cleaned in full [3].

For residential areas and industrial enterprises (runoff from the territory of which the composition of impurities is close to the surface runoff from residential areas and does not contain specific substances with toxic properties), the value of $h$ is taken to be equal to the daily layer of precipitation from low-intensity frequent rains with a period of one-time excess of the calculated intensity $P = 0.05-0.1$ years, which in most cases provides reception for cleaning at least 70% of the annual volume of surface runoff [19,20].

2. Relevance

To determine the value of the calculated precipitation layer ($h$), the following reference values may be used [3,19-22]:

- data of long-term observations of weather stations for precipitation in a particular area (not less than 10-15 years);
- observations at the nearest representative weather stations (a meteorological station can be considered representative of the considered runoff area if the following conditions are met: the distance from the station to the catchment area of the object is less than 100 km; the difference...
between the elevation of the catchment area above sea level and the weather station does not exceed 50 m).

In the absence of long-term observations (long series of observations of rainfall) for specific areas in the calculation is allowed to use statistically processed data of climate directories. Baseline values can have a significant impact on the design sediment layer, and therefore on the volume of control tanks (which account for most of the cost) and the performance of facilities. The relevance of the work is due to a significant number of planned for the design of treatment facilities of surface runoff and the need to optimize the cost of their construction.

3. Research Theory
To assess the influence of the initial parameters of the indicators, the calculation of the value of $h$ with periods of single excess of the calculated intensity of rain $P_1 = 0.05$, $P_2 = 0.1$ and $P_3 = 0.075$ years in Samara.

Observations of atmospheric precipitation in Samara began in the late 19th century at the meteorological station at the Real School on Kazanskaia street (now A. Tolstoy street, 31). Only the total precipitation over 24 hours was measured. These observations had noticeable omissions and as a result in engineering calculations they were not taken into account.

In addition, observations were carried out at the station of the II category "Tomashev Kolok", located seven versts North-East of the city (currently the territory of Samara). During the first 8.5 years of observations, the average annual precipitation layer height was 466.17 mm and the average monthly 38.85 mm.

As initial indicators we will use data on daily amount of atmospheric precipitation in Samara since 1936. On the chosen number of observations statistical characteristics of distribution are defined: average value – 4,37, a standard deviation of $\sigma = 6.2$ and the coefficient of asymmetry – $A = 3,25$, kurtosis – $E = 18,29$ and the coefficient of variation – $Cv =1,42$. Absolute and relative errors of these indicators are calculated. The analysis of the obtained distribution estimates allows us to consider the sample representative of the General population.

As a result of data processing, the number of days with precipitation of different sizes was determined (Table 1).

| Month | $\geq 0,1$ | $\geq 0,5$ | $\geq 1$ | $\geq 5$ | $\geq 10$ | $\geq 20$ | $\geq 30$ |
|-------|------------|------------|---------|---------|---------|---------|---------|
| I     | 17,9       | 12,1       | 8,8     | 2,5     | 0,7     | 0,1     | 0,0     |
| II    | 13,5       | 9,0        | 6,6     | 1,9     | 0,7     | 0,1     | 0,0     |
| III   | 11,8       | 8,4        | 6,5     | 1,8     | 0,4     | 0,1     | 0,0     |
| IV    | 9,1        | 7,5        | 6,3     | 2,3     | 0,9     | 0,2     | 0,0     |
| V     | 9,3        | 7,7        | 6,2     | 2,4     | 1,1     | 0,2     | 0,0     |
| VI    | 10,3       | 8,3        | 6,8     | 3,0     | 1,5     | 0,4     | 0,2     |
| VII   | 10,7       | 8,9        | 7,4     | 3,3     | 1,6     | 0,6     | 0,3     |
| VIII  | 9,0        | 7,4        | 6,2     | 2,7     | 1,4     | 0,3     | 0,1     |
| IX    | 10,3       | 8,4        | 7,0     | 2,7     | 0,9     | 0,2     | 0,1     |
| X     | 12,7       | 10,0       | 8,3     | 3,4     | 1,3     | 0,2     | 0,0     |
| XI    | 14,9       | 10,3       | 8,1     | 2,7     | 1,0     | 0,2     | 0,0     |
| XII   | 18,2       | 11,7       | 8,6     | 2,4     | 0,9     | 0,1     | 0,0     |
| Year  | 147,8      | 109,7      | 86,7    | 31,4    | 12,4    | 2,7     | 0,8     |

From the data of Table 1 it follows that in Samara, an average of 147.8 days with precipitation of more than 0.1 mm. Since positive average monthly air temperatures are observed in the period from April to October, it can be said that rainy days with precipitation of more than 0.1 mm are observed on
average 71.5. However, it should be noted that in fact, despite the positive temperature, in April and October there are precipitation in the form of snow, and in May and September – mixed precipitation (Figure 1).

![Figure 1. Changes in species composition of precipitation during the year.](image)

Interestingly, if we compare these data with the data obtained for the first 170 months of observations (Table 2), it is clear that the number of days with high rainfall has decreased significantly. For example, initial observations show an average of 25 days with precipitation of 15 mm or more, and table 1 shows an average of only 12.4 days with precipitation of 10 mm or more.

**Table 2. Number of days with precipitation of different magnitude.**

| Precipitation, mm | ≥ 15 | ≥ 17 | ≥ 20 | ≥ 25 | ≥ 30 |
|-------------------|------|------|------|------|------|
| 25                | 18   | 11   | 7    | 3    |

In the absence of data of long-term observations, the value of $h_1$ is allowed to be taken within 5-10 mm. For our conditions, we obtain that during the warm period there are 19.8 days with precipitation of 5 mm or more, and 8.7 days with precipitation of 10 mm or more.

4. Results

For our conditions at $P_1 = 0.05$, the probability of a daily layer of liquid precipitation will be 72.0%, at $P_2 = 0.1 – 86.0\%$ and at $P_3 = 0.075 – 81.2\%$. According to the graph of the probability distribution function, the values of the daily layers of liquid precipitation $h_1$ with the corresponding period of a single excess were determined: $h_1 = 6.6$ mm, $h_2 = 4.7$ mm, $h_3 = 3.0$ mm. As can be seen from the data, only with a period of a single excess of more than 0.075, the calculated values are in the recommended area of 5-10 mm.

The influence of the length of a number of observations on the calculated values of precipitation layers is estimated. For this purpose, calculations have been made for shortened series of observations, taking into account the available recommendations on their duration.
The calculation results are presented in Table 3. The greatest dispersion of values is characteristic for the period of single excess of $P = 0.1$ (reaches 1.5 times) and with decrease of $P$, the difference in layers of precipitation also decreases.

**Table 3.** Estimation of the influence of the duration of observations on the calculated daily precipitation layer using the variation series.

| Period of single excess, $P$, years | The daily layer of $h$, mm / definition error, %, during the observation period, years |
|-----------------------------------|----------------------------------------------------------------------------------|
| 0.1                               | 6.6 / 26.7 9.0 / 0 7.4 / 17.8 6.7 / 25.6 |
| 0.075                             | 4.7 / 35.6 6.7 / 8.2 5.4 / 26.0 4.9 / 32.9 |
| 0.05                              | 3.0 / 38.8 3.8 / 22.4 3.3 / 32.7 3.2 / 34.7 |

The calculation of the grouped data makes the results of additional errors, the so-called grouping errors. In our case, we use the variation series with the gradation adopted in the climatic reference book, while the intervals themselves for the task are extremely unsuccessful, since we are interested in the layers of precipitation in the range of about 5-10 mm, and as can be seen from the Table. 4 they are included in one gradation (Option 1).

To determine the size of the grouping error, the initial data is grouped according to the gradation given in table 4 (Option 2, Option 3). The calculated data are used to plot the probability distribution function (Figure 2) and to determine the precipitation layer at $P = 0.1$. Depending on the accepted gradation of intervals, the layer of precipitation varies from 6.6 to 7.5 mm.

**Table 4.** Coordinates of the probability distribution function of the value of the daily rain layer, depending on the division of the interval scale.

| The boundaries of the interval, mm | The middle of the interval, mm | Probability of non-exceedance, % | The boundaries of the interval, mm | The middle of the interval, mm | Probability of non-exceedance, % | The boundaries of the interval, mm | The middle of the interval, mm | Probability of non-exceedance, % |
|-----------------------------------|-------------------------------|---------------------------------|-----------------------------------|-------------------------------|---------------------------------|-----------------------------------|-------------------------------|---------------------------------|
| 0.1                               | 0.3                           | 18.6                            | 0.1                               | 1.05                          | 49                              | 0.1                               | 1.05                          | 49                              |
| 0.5                               | 0.75                          | 32.6                            | 2                                 | 4                             | 76.3                            | 2                                 | 6                             | 65.9                            |
| 1                                 | 3                             | 72.1                            | 6                                 | 9                             | 91.1                            | 4                                 | 5                             | 76.3                            |
| 5                                 | 7.5                           | 87.7                            | 12                                | 16                            | 96.8                            | 6                                 | 7                             | 83.2                            |
| 10                                | 15                            | 96.8                            | 20                                | 25                            | 98.9                            | 8                                 | 9                             | 87.7                            |
| 20                                | 25                            | 98.9                            | 30                                | 36                            | 99.5                            | 10                                | 11                            | 91.1                            |
| 30                                | 42                            | 98.9                            | 42                                | 98.9                          | 99.5                            | 12                                | 98.9                          | 99.5                            |

In order to preserve the asymptotic property, which is very important for climatic generalizations, the integral distribution should be built on the initial, simple statistical series. We evaluate the effect of the length of a number of observations on the calculated daily precipitation layer. For this purpose, calculations on the initial and shortened series of observations (Table 5).

The results show that the calculation of the initial series for the period of single excess $P = 0.05-0.1$ daily precipitation layer is in the range of 4.9-9.0 mm, which practically corresponds to the data [19-22], and the use of short series of observations introduces an error in the calculated values, which can reach about 15%.
Figure 2. Graphs of the probability distribution function of daily precipitation layers.

Table 5. Assessment of the effect of the duration of a number of observations on the calculated precipitation layer.

| Period of single excess, $P$, years | The daily layer of $h$, mm, / definition error, $\%$, when the duration of a series of observations, years |
|------------------------------------|--------------------------------------------------------------------------------------------------|
| 0,1                                | 9,0 / 9,85 / 9,4 / 9,4 / 8,97 / 0,3                                                                |
| 0,075                              | 7,3 / 8,0 / 9,6 / 7,4 / 7,2 / 1,4                                                                |
| 0,05                               | 4,9 / 5,6 / 14,3 / 5,0 / 4,8 / 2,0                                                                |

5. Conclusion
The research yielded the following conclusions:
1. The definition of the layer precipitation, the runoff from which is given to cleaning that should be possible using data from long-term observations on the basis of simple statistical series.
2. The use of grouped reference data leads to an error in the determination of the daily precipitation layer of the order of 35-50%, and the use of short series of observations – up to 15%.
3. For conditions of Samara daily layer of precipitation from low-intensity frequent rains with a period of single excess of the calculated intensity $P = 0,05$-0,1 years is $h = 4,9$-9,0 mm.

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