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# PRESENT CONDITION ANALYSIS AND DESIGN OF SEWER COLLECTOR RECOVERY

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**Abstract:** The aim of the study is to assess the hydraulic capacity of the sewer network and sewer collector recovery in the urban catchment area of Trnava.

The analysis focuses on the evaluation of situations with different precipitation frequencies. Elaboration consists of modeling the current state of the assessed sewer collector B and subsequent loading of this collector by several block rainfalls. Based on the results of the analysis, the recovery of the sewer network proposed.

**Keywords:** Combined sewer network, Hydraulic capacity, Sewer network recovery

## 1. Introduction

The last decades characterize the population redeployment, urbanization, and urban infrastructure development. To negative impacts of urbanization belong to the increase in the impermeable areas and population concentration [1]. The sharp rise in urbanized regions contributes to the deterioration of the urban microclimate. The reduction of greenery in the cities and the land-use changes lead to the Urban Heat Island (UHI) effect. UHI causes extreme weather changes in urban areas. It creates long periods of drought in cities and then extreme rainfall events [2]. The high level of urbanization threatens the water environment of cities. It affects an increase in the risk of floods, degradation of habitats, and deterioration of water quality [3].

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The new urbanization trend is causing a fast increase in the volume of municipal wastewater and rainwater [4]. The usual method of rainwater management in cities bases on the concept of the quickest drainage of rain from the urbanized area [5]. However, an unexpected increase in the amount of wastewater causes a threat to the functioning of sewer [6]. Therefore, this concept needs to review in light of current conditions. Sewer networks regularly loaded with high-intensity rainfall and short duration. In many cases, local floods occur due to insufficient capacity of sewer networks [7].

Most Slovak cities and villages have built combined sewer networks, which at the time of design and construction fulfilled the essential purpose. Over time, however, there was an increase in the number of connected inhabitants to individual parts of sewer networks and an improvement in the area of the given drainage basin. Concerning the age and condition of individual sewer networks, it is necessary to proceed with reconstruction and recovery. The new concept dedicates to the implementation of nature-friendly measures in the sewerage system. It uses infiltration and retention devices to reduce surface runoff. These devices can decrease and flatten the rain flow in the sewers [8], [9].

## 2. Methodology

### *2.1. Study area*

The study carried out on the part of Trnava City. The city of Trnava situated on the edge of the Western Slovak Lowland between the Váh River and the Low Carpathians Mountains in the Danube Lowlands (*Fig. 1*). It located on the river Trnávka, in the center of the Trnava Uplands. The city center is at an altitude of 146 m. The population is 63,924 inhabitants, and the population density is 894 inhabitants/km$^2$ (31.12. 2018) [10].


*Fig. 1.* City location, on the basis of [10]

The city divided into six parts: Trnava Center, Trnava East, Trnava North, Trnava West, Trnava South, and Modranka, and it currently covers an area of almost 72 square kilometers [11].

*Sewer network in city of Trnava*

Wastewater discharge in Trnava solves by a combined sewer network. This network drains both wastewater and rainwater from this area. The total length of the sewer network is 111,236 km. The number of inhabitants connected to the public sewerage system and the wastewater treatment plant is 612,315 inhabitants (*Fig. 2*).

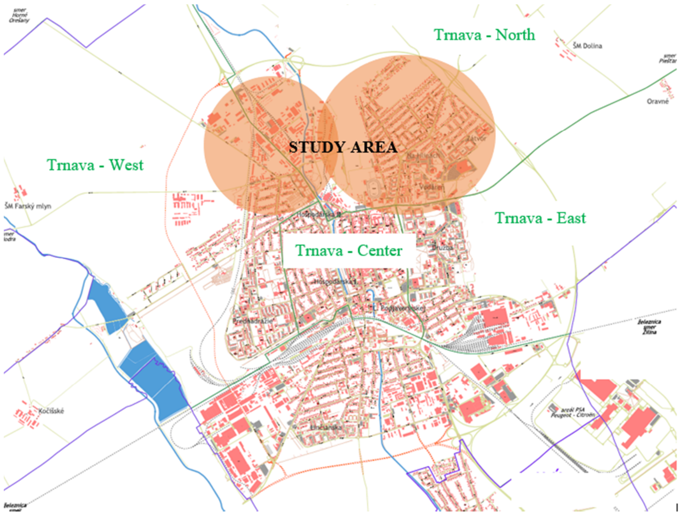


*Fig. 2*. Study area, on the basis of [12]

The primary drainage collector keeps on the right bank of Trnávka. It drains wastewater from the connection of collectors B and A in the southern part of the urban area to the Wastewater Treatment Plant (WWTP) Trnava - Zeleneč. Sewage collector A led on the left bank of Trnávka, draining the eastern part of the urban area. Collectors I, II, III, V in the central part of the urban area lead to collector A. Sewer collectors D, C drain the northeastern part of the urban area. Collectors A9a, AN2, AN collect the wastewater from the eastern part of the urban area into the combined sewer overflow CSO 01.

The western part of the urban area drained by the sewerage collectors B, G. Sewer network unloading is provided by 20 combined sewer overflows, which discharge the storm-water during the heavy rainfalls to the receiving water body. The receiving medium of the discharged wastewater is the river Trnávka. The CSO chambers load the recipient in a ratio of 1:4. The city center sewer network is already outdated and hydraulically undersized. These conditions create difficulties in operation, limits the development of the city, and the possibility of connection [12].

*Present conditions of the assessed sewer network*

The assessment was devoted only to part of the sewer network in Trnava. The analysis deals with 42 sewer collectors located northwest and northeast of the city center. The total surface of the assessed area is approx. 3 $km^2$, and the full length of the analyzed sewer network is 30,808.5 m. The inventory of sewage collectors is shown in *Table I.*

*Table I*

Inventory table of sewerage collectors

| SCO | Length of SCO (m) | SCO | Length of SCO (m) | SCO | Length of SCO (m) | SCO | Length of SCO (m) | SCO | Length of SCO (m) |
|---|---|---|---|---|---|---|---|---|---|
| C | 2170.65 | C10 | 134.92 | D8 | 1427.86 | B | 606.00 | B75 | 305.40 |
| C1 | 3204.70 | C100 | 84.34 | D9 | 245.02 | B26 | 1610.70 | B77 | 668.00 |
| C2 | 1370.94 | D | 1487.52 | D10 | 212.35 | B26A | 521.30 | | |
| C3 | 45.41 | D1 | 4555.39 | VD | 685.81 | B27 | 651.20 | | |
| C4 | 80.08 | D2 | 691.75 | VD2 | 109.01 | B28 | 357.20 | | |
| C5 | 859.28 | D3 | 1233.26 | VD3 | 116.36 | B29 | 287.00 | | |
| C6 | 314.55 | D4 | 1268.23 | VD4 | 116.57 | B63 | 437.40 | | |
| C7 | 361.39 | D5 | 224.95 | VD5 | 666.47 | B72 | 141.00 | | |
| C8 | 295.91 | D6 | 1319.63 | VD6 | 221.90 | B73 | 319.30 | | |
| C9 | 235.05 | D7 | 242.12 | VD7 | 743.00 | B74 | 179.50 | | |

*SCO - Sewerage Collector

The pipe diameter of the individual collectors ranges from DN 300 at the beginning of the sections up to DN 1000 at the point of connection to the combined sewer overflow. The combined sewer overflows locate on the collectors B28 (CSO 09 B), B26A (CSO 08 B), and D (CSO 01 D).

The study area consists of built-up areas, transport and parking areas, non-built-up areas, playgrounds, and green areas. According to the surface area of the site were used the runoff coefficients. For a given site, these are the coefficients of the following categories: Open housing ($\psi$ = 0,35), Medium housing ($\psi$ = 0,6), dense housing ($\psi$ = 0,8), flats ($\psi$ = 0,8), dense commercial land use ($\psi$ = 0,9), and open green spaces ($\psi$ = 0,15-0,2). The slope of the terrain is mostly flat. The allocation of runoff coefficients depends on the slope of the terrain and the land use.

## *2.2. Description of SeWaCAD software system*

SeWaCAD software was used to assess the combined sewer network of the study area. This program was developed in the Department of Sanitary and Environmental Engineering at the Faculty of Civil Engineering, STU in Bratislava. This software was developed for the design and assessment of sewer networks. It works based on integrated procedures, which enable to solve complex hydrological and hydraulic problems of urbanized areas. To appraisal input data of sewer network are absolute altitude and attitude data of the region, profiles, roughness of existing pipelines, size of sewerage districts, and runoff coefficients. Also, to the characteristics of the study area, the calculation includes rain data and a component of the block rain curve for the given site. The software works with several subroutines to work with rain data, to perform hydro-technical calculations or to present results. The output is a set of hydro-technical calculations, evaluation of sewer pipe profiles, drawings of longitudinal profiles, and hydro-technical situations [13]. All program outputs comply with Slovak standard STN EN 75 6101 gravity sewerage systems outside buildings.

### *2.3. Rainfalls*

The rainfall events vary according to their duration (*t*), the height of the rainwater column (*H*), the average intensity (*i*) and the variability, the time position of the absolute peak, and the temporal and spatial variability of these characteristics. Each rain event is unrepeatable and unique [6], [14].

The assessment of the sewage networks shall apply to load-bearing or design rainfalls. The design rainfall is an idealized intense profile of rain with a statistically determined frequency (*p*) or a return period (*T*). The most frequently used design rainfalls are the individual model rainfalls and the time series of historical rains. It divides the individual model rains into:

- Block rainfalls with constant intensities;
- Synthetic rainfalls with variable intensity;
- Historical rain;
- Real rainfall [6], [14], [15].

### *Determination of block rainfall for Trnava City*

For the design and assessment of the sewer networks using the rational method, it calculated using the design block rain. The periodicity of the block rainfall depends on the measurement of the study area. The block rain is defined by constant intensity during the rainfall and creates a block unit. It has the most straightforward and least real shape - rectangular shape. The specific rainfall unit yield decreases in increasing its duration. The annual frequency (periodicity) is the probable number of occurrences of the block rains per year [6]. The mathematical expression of the block rain curves shall be determined based on the Slovak block rainfall data and the equation for calculating the block rainfall unit yield. The block rainfall data present in *Table II*. *Fig. 3* illustrates the progress of the block rains curves for the periodicity in question.

*Table II*

Local parameters of block rain

| *p* | 0.2 | 0.5 | 1 | 5 |
|---|---|---|---|---|
| *K* | 3637.4 | 2744.9 | 2157.9 | 1038.5 |
| *B* | 4.37 | 3.81 | 3.44 | 2.71 |
| *a* | 0.947 | 0.93 | 0.918 | 0.89 |

where *p* is annual frequency (periodicity), *K, B, a* are the parameters of block rain curve [-].

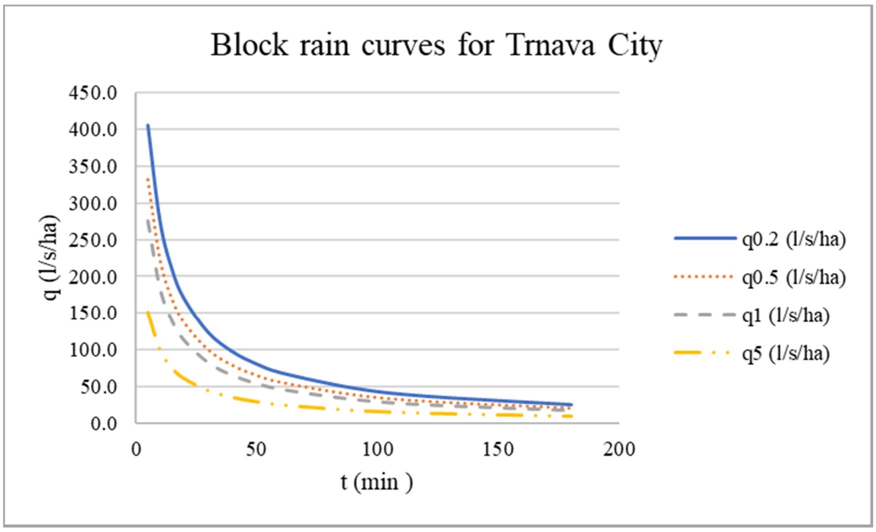


*Fig. 3*. Block rain curves for Trnava City
where $q$ is rainfall unit yield (l/s/ha); $t$ is rainfall duration (min); $q0.2$ is block rainfall curve for periodicity $p = 0.2$; $q0.5$ is block rainfall curve for periodicity $p = 0.5$; $q1$ is block rainfall curve for periodicity $p = 1.0$; $q5$ is block rainfall curve for periodicity $p = 5.0$.

## 3. Results

Mathematical models of collectors C, D, and B were created in the SeWaCad program. Based on the results of the hydraulic assessment, sections with unsatisfactory capacity were detected. Mathematical models of collectors C, D of the gravity zone of the combined sewer overflow chamber CSO 01 D were the subject of previous research. Under a load of block rain with periodicity $p = 0.5$ of the total length of the collector (24,724 m), 11,134 m (45%) were overloaded. This article focuses on collector recovery based on the previous assessment.

### *3.1. Hydraulic assessment of sewer collector B*

The collector B was loaded with block rain with a periodicity of $p = 5.0$, $p = 0.5$, and $p = 0.1$. One of the most important steps was to determine the runoff coefficients corresponding to the surface finish of the site. The catchment area of collector B also includes objects of combined sewer overflow chambers CSO 07 B, CSO 08 B, and CSO09 B. The last assessed section ends in CSO 07 B.

The precipitation frequency $p = 5.0$ corresponds to the rain occurring five times a year. The *Fig. 4* shows the overload situation of the sewer network at $p = 5.0$. The assessment found that of the total length of the assessed network (6,084 m), 1,799.1 m of congested sections found, and 4,284.9 m complied with the assessment. 100-150% overload occurs at 13.7% of the collector length. 15.8% of the total length of the collector overloaded up to 150-200%.

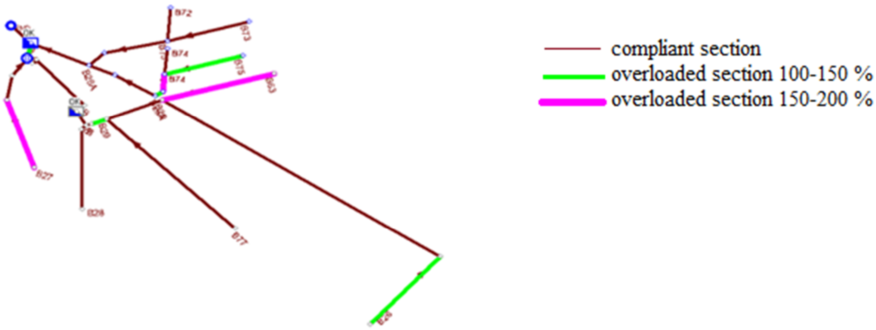


*Fig. 4*. Collector B overload at precipitation frequency p = 5.0

The precipitation frequency $p = 0.5$ corresponds to the rainfall occurring once every two years. All sections except three were overloaded under a model rainfall load of precipitation frequency $p = 0.5$. The assessment found that of the total length of the sewer network under consideration (6,084 m), 5,660.7 m were overloaded, and 3,51.2 m complied with the evaluation. The full range of the sewer is 14.3 % overloaded to 100-150%, 46.6% of the network length is overloaded to 150-250 %, 31.2% of the total length is overloaded to 250-500 % and 1.0 % is overloaded to 500 %. *Fig. 5* shows the situation of the sewer network congestion.


*Fig. 5*. Collector B overload at precipitation frequency $p = 0.5$

The precipitation frequency $P = 0.1$ corresponds to rain occurring once in 10 years. Up to eleven of the twelve sewer collector sections were overloaded. The total length of sewer B, 5.1% of the span is overloaded to 150-200%, 10.7% of the length is overloaded to 150-200%, 59.91% is overloaded to 250-500%, and 11.02% of length the collector is overloaded by more 500%. Only 5.8% of collector length complies with the assessment. *Table III* summarizes the results of the evaluations and presents the lengths of congested sections at collector B.

*Table III*

Overview of hydraulic assessment results

| Precipitation frequency | Length of congested section | | | | Length of matching parts 0-100% (m) |
|---|---|---|---|---|---|
| | 100-150% (m) | 150-200% (m) | 250-500% (m) | > 500% (m) | |
| $p = 0{,}1$ | 310.3 | 651 | 3644.9 | 670.7 | 351.2 |
| $p = 0{,}5$ | 868.3 | 2837.6 | 1895.7 | 59.1 | 351.2 |
| $p = 5$ | 834.9 | 964.2 | 0 | 0 | 4414.2 |

### *3.2. Design of sewer network recovery*

Methods for the recovery of sewer networks define the standard STN EN 752 – 5 as a repair, renovation, reconstruction, reconstruction, or replacement. Replacement means the design of a new sewer network to improve the functionality of the old sewer [16]. The recovery of the sewer network (collector B, C, and D) design based on an assessment of hydraulic capacity with a load of 15 minutes of block rain with a periodicity of $p = 0.5$.

As a renewal of the assessed sewer network, it proposes to replace pipelines on congested sections with larger profiles. Under current conditions, a replacement of 54% of the total length of the collectors required. Collector B needs a recovery of 94% of its range. The assessments of collectors C and D indicate the need to recover 45% of the length. The following tables (*Table IV* - *Table VIII*) show the congested sections, their profiles (Dj) and the design of new profiles (DN).

*Table VIII* summarizes the overloaded sections of collector B. The second column represents the length of the sections. The third column (Dj) describes the size of the cross-section in a given part. The last column (DN) specifies the proposed cross-section.

*Table IV*

Design of new profiles - Collectors C and D

| Collector [-] | L [m] | Dj [mm] | DN [mm] | Collector [-] | L [m] | Dj [mm] | DN [mm] |
|---|---|---|---|---|---|---|---|
| C | 373.05 | 400 | 500 | C | 60.53 | 800 | 1200 |
| C13 | 275.94 | 300 | 600 | C | 61.22 | 800 | 1400 |
| C1 | 221.16 | 300 | 800 | C | 62.77 | 800 | 1400 |
| C14 | 201.6 | 300 | 400 | C5 | 101.58 | 300 | 400 |
| C15 | 135.68 | 300 | 400 | C5 | 19.59 | 300 | 400 |
| C1 | 74.11 | 600 | 1000 | C5 | 62.07 | 800 | 1000 |
| C19 | 279.19 | 300 | 400 | C | 34.15 | 800 | 1600 |
| C19 | 138.86 | 400 | 500 | C | 168.92 | 800 | 1600 |
| C1 | 163.75 | 600 | 1200 | C | 70.66 | 900 | 1600 |
| C | 63.55 | 800 | 1200 | C | 129.98 | 1000 | 1600 |

*Table V*

Design of new profiles - Collectors C and D

| Collector [-] | L [m] | Dj [mm] | DN [mm] | Collector [-] | L [m] | Dj [mm] | DN [mm] |
|---|---|---|---|---|---|---|---|
| C | 74.32 | 1000 | 1600 | C | 37.63 | 1100 | 1600 |
| C7 | 182.14 | 300 | 400 | C | 68.86 | 1100 | 1600 |
| C7 | 23.36 | 300 | 800 | VD | 69.33 | 300 | 600 |
| C | 109.57 | 900 | 1600 | VD5 | 50.54 | 300 | 400 |
| C8 | 147.81 | 300 | 400 | VD52 | 120.64 | 300 | 500 |
| C8 | 115.89 | 300 | 400 | VD5 | 100.75 | 300 | 800 |
| C | 164.08 | 900 | 1600 | VD | 79.84 | 600 | 1000 |
| C9 | 91.61 | 300 | 400 | VD6 | 46.95 | 300 | 400 |
| C | 110.13 | 1000 | 1600 | VD7 | 81.31 | 300 | 500 |
| C | 11.9 | 1100 | 1600 | VD7 | 213.28 | 300 | 600 |

*Table VI*

Design of new profiles - Collectors C and D

| Collector [-] | L [m] | Dj [mm] | DN [mm] | Collector [-] | L [m] | Dj [mm] | DN [mm] |
|---|---|---|---|---|---|---|---|
| VD7 | 99.26 | 300 | 600 | D142 | 46.3 | 400 | 600 |
| C | 151.28 | 1100 | 1600 | D1422 | 473.12 | 300 | 500 |
| D | 259.81 | 500 | 600 | D1422 | 184.98 | 300 | 600 |
| D1 | 89.31 | 700 | 1200 | D1422 | 101.74 | 300 | 600 |
| D14 | 465.91 | 300 | 600 | D1422 | 27.84 | 300 | 600 |
| D14 | 214.68 | 400 | 600 | D142 | 41.09 | 400 | 800 |
| D14 | 66.64 | 400 | 800 | D14 | 91.26 | 400 | 1000 |
| D1421 | 466.32 | 300 | 500 | D14 | 137.06 | 400 | 1000 |
| D1421 | 218.78 | 300 | 600 | D1 | 142.98 | 800 | 1400 |
| D1421 | 95.03 | 300 | 600 | D | 84.1 | 800 | 1400 |

*Table VII*

Design of new profiles - Collectors C and D

| Collector [-] | L [m] | Dj [mm] | DN [mm] | Collector [-] | L [m] | Dj [mm] | DN [mm] |
|---|---|---|---|---|---|---|---|
| D2 | 371.12 | 500 | 600 | D8 | 268.43 | 400 | 600 |
| D21 | 74.72 | 300 | 400 | D8 | 72.29 | 400 | 800 |
| D | 97.7 | 1000 | 1600 | D8 | 93.59 | 500 | 800 |
| D | 84 | 1000 | 1800 | D | 96.13 | 1600 | 2000 |
| D4 | 38.57 | 500 | 800 | D9 | 246.02 | 300 | 500 |
| D4 | 403.09 | 500 | 800 | D | 93.14 | 1600 | 2000 |
| D | 64.18 | 1600 | 1800 | D10 | 213.32 | 300 | 500 |
| D | 93.56 | 1600 | 1800 | D | 168.81 | 1600 | 2000 |
| D | 44.25 | 1600 | 2000 | D | 181.97 | 1600 | 2000 |
| D | 90.63 | 1600 | 2000 | C | 192.6 | 2400 | 2600 |
| | | | | C | 128.09 | 1600 | 2600 |
| | | | | C | 128.09 | 1600 | 2600 |

*Table VIII*

Design of new profiles - Collector B

| Collector [-] | L [m] | Dj [mm] | DN [mm] | Collector [-] | L [m] | Dj [mm] | DN [mm] |
|---|---|---|---|---|---|---|---|
| B26 | 369.09 | 500 | 800 | B27 | 102.75 | 400 | 600 |
| B26 | 1241.59 | 600 | 800 | B27 | 93.00 | 500 | 600 |
| B63 | 437.38 | 500 | 1000 | B | 66.96 | 400 | 600 |
| B29 | 227.94 | 600 | 1000 | B73 | 319.25 | 600 | 800 |
| B77 | 668.01 | 600 | 1000 | B72 | 140.98 | 500 | 400 |
| B29 | 59.14 | 600 | 1200 | B73 | 243.48 | 600 | 1000 |
| B | 22.61 | 800 | 1200 | B73 | 79.06 | 600 | 1000 |
| B28 | 333.26 | 600 | 800 | B75 | 305.39 | 400 | 600 |
| B28 | 23.93 | 600 | 800 | B74 | 108.12 | 400 | 400 |
| B | 68.00 | 800 | 1200 | B74 | 71.39 | 400 | 800 |
| B | 36.31 | 400 | 300 | B74 | 34.32 | 400 | 800 |
| B | 262.58 | 400 | 500 | B26A | 173.65 | 600 | 1000 |
| B | 21.94 | 400 | 500 | B26A | 108.85 | 600 | 1000 |
| B | 25.78 | 400 | 500 | B26A | 238.66 | 1000 | 1200 |
| B27 | 455.37 | 300 | 600 | B | 102.12 | 400 | 300 |

The design of sewerage pipeline renewal is based on the mathematical model of the sewer network. In the SeWaCad program evaluated the new pipeline profiles based on the design flow rates associated with the load case $p = 0.5$. Table *VI* - *Table VII* present the results of the design of the recovery of collectors C and D.

## 4. Conclusion

The high degree of urbanization causes a lack of porous areas, which ensure a reduction of the surface runoff coefficient and maximum flood flow. The conclusion of the work was a hydraulic assessment of sewer collector B in the area of interest Trnava. Concerning the age and condition of individual sewer networks, it is necessary to proceed with reconstruction and renewal. When designing these measures, it is now required to consider the new concept of sewerage of towns and municipalities - the original idea dedicated to the implementation of nature-friendly measures in the sewerage system.

The results of the hydraulic assessment of sewer collectors indicate that the collectors are no longer able to perform their function even in average rain. Rains were analyzed sequentially with a periodicity of $p = 5.0$, $p = 0.5$ and $p = 0.1$ in SeWaCAD. Subsequently, the impact of individual rainfall on the congestion of the assessed sewer network depicted. Five sections of collector B overloaded by more than 500% at the periodicity $p = 0.5$. At the precipitation frequency, $p = 0.5$ overloaded in all sections. Only 5.8% of collector B length complies with the assessment at the precipitation frequency $p = 0.1$. The percentage distribution of congestion of collector sections B at $p = 0.5$ is as follows: 6% of the length of the collector complies with the hydraulic assessment, and 94% fails the evaluation. The recovery of the sewerage network was designed based on the load state evaluation $p$ = 0.5. For a given load case, it is necessary to replace 94% (5,660.7 m) of the collector B length and 45% (11,299.3 m) of the collectors C and D.

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