DOI:10.22337/2587-9618-2023-19-1-23-31

ASSESSMENT OF WEIGHT OF SEDIMENT FORMATION DEPOSIT IN MUNICIPAL COLLECTOR SYSTEM (MCS)

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Abstract: The main purpose of this work is to provide calculations of annual weight of sediment formation deposit in Municipal Collector System (MCS). The article considers two-phases flow in the collector. The storm water collector is small culvert for storm water (rainwater) or for removing the river (creek, stream, flow) underground. The article defines the solid particles in flow as sand, clay, stones, silt, etc. It was found that in case of signif\icant flow rate, then all solid particles move in the pipe. If not, they settle to the bottom and sediment is formed. In this paper, total weight of sediment formation in Moscow collector system is calculated at average annual values. On this ground a consideration can be made that sediment deposit reduces efficiency of the system partially or completely.

Keywords: storm system, storm water pipes, sewage pipes, solid particles, sewerage system, sediment formation

ОЦЕНКА МАССЫ ОТЛОЖЕНИЙ, ФОРМИРУЮЩИХСЯ В ГОРОДСКОЙ КОЛЛЕКТОРНОЙ СИСТЕМЕ

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Аннотация. Основная цель настоящей работы расчет массы отложений, формирующихся в городской коллекторной системе ежегодно. Поток в коллекторе рассматривается как двухфазный. Коллектор представляет собой малое водопропускное сооружение (труба) для пропуска ливневой (дождевой) воды или для отвода реки (притока реки или ручья) под землю. В статье рассматриваются твердые частицы такие как галька, песок, глина, ил и т.д. двигающиеся с потоком, в случае значительного расхода воды, и оседают на дно коллектора (образуется осадок), если энергии потока недостаточно. В данной работе общая масса отложений, формирующихся во всей московской коллекторной системе, рассчитана по среднегодовым значениям. На основе полученных данных сформулирован вывод, что образование осадка снижает полностью или частично эффективность работы городской коллекторной системы.

Ключевые слова: система коллекторов, ливневые трубы, канализационные трубы, твердые частицы, канализация, образование отложений

INTRODUCTION

With the increase of urbanization in cities, problems due to storm water become more and more important: floods, overflows, pollution of receiving waters, high exploitation costs due to sediment deposits [1,4,5]. Since the mid-20th Century, the fundamental research of “solid transfer in sewers” has been carried out for improvement urban environment [7, 13].

On the territory of Moscow, the total length of the river network is more than 600 km. About 295 km of them (more than 160 rivers) flow underground (Fig. 1) in tube under industrial and civil constructions and have become part of municipal storm system.

The storm water system is separated from sewer systems in Moscow. The volume of transport and sedimentation inside tubes relates to the concentration and types of solid particles shed into the water or ground.

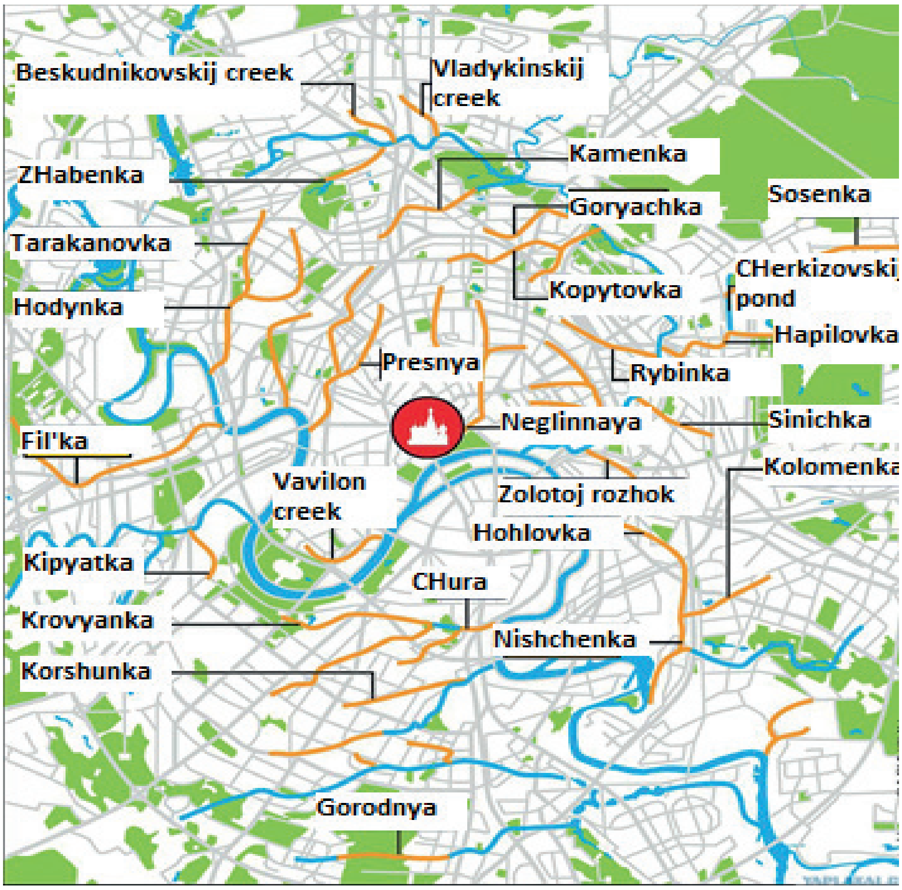

Figure 1. Moscow underground rivers map

As storm water covers streets and other waterproof surfaces, it transports pollutants such as oil, chemicals, pathogens, and sediments. This pollution is carried by storm water and discharged directly into local waterways, which has a negative impact on water quality. The pollution levels of Moscow consist of four zones: transport, residential, park and industrial. The studies have shown [3,9,11,14] that the main pollutant of surface runoff is suspension and dissolved petroleum products, the source of which is transport and collapsing asphalt road surfaces. The main pollutants arising from the operation of roads are oils, lubricants, propellants, tars, silicones, exhaust gases produced by the fuel combustion, abrasive products of broken car discs and tires, asphalt, ashes, dusts, organic bituminous ingredients, and remnants provided after the maintenance of roads in winter [15,17]. The infrastructure (roads, sidewalks, commercial and residential structures) added during urbanization process is designed to collect storm water in Moskva river water channels. The quality of water is influenced by river suspended particles and pollutants collected on impervious surfaces and that are carried by urban storm water runoff. The flow is caused by the slope. Flows in collectors can be unsteady, irregular with variable roughness coefficient and two-phases with wide list of solid particles [8, 18].

The literature review [2, 4, 6,10,12,16] presents the modern concerning sediment sewer transport

modeling. After a description of solid particles found in tubes and in storm water, the different steps considered in models are described: a transfer through model and a model of deposition (sediment formation) and erosion in sewer pipes.
The design Moscow Collector System (MCS) consisted of two tasks: the main one was protection of floods and the secondary was self-cleaning support.
On the regulation basis, the condition in the tube can be self-cleaning. However, Mosvodostok (Moscow engineering system) removes the main part of sediment deposition manually or mechanically. The main purpose of this work is to provide calculations of annual weight of sediment formation deposit in MCS.

METHODS

At the turn of the 19th-20th century, the city's (municipal) sewerage system appeared in Moscow. Also problems with the storm water collection and water irrigation were solved. Most of now operating collector systems were built in period of 60-80 years of the 20th century. Collectors are used for:

- Storm water collection (to protect the territory from flooding)
- City's development (increasing the territory and district connection)
- Ecological goal (reduced entering pollution from the water flows)

Collector system is extensive, complex net (network) of tubes (tree like), where tubes of smaller diameter are connected to tubes of large diameter. There are two types of collectors in MCS, with or without connection to the sewage treatment plants. In the current work we take into account the collectors with connection straight to the river.
The Data Base (DB) consists of characteristics of 2421 collectors (outlet tubes) of MCS. DB allows us to evaluate the efficiency of work of the whole municipal storm system. The working array was built in eight columns and 2421 lines:

$$\left[S_i^n\right],\left[D_i^n\right],\left[C_i^n\right],\left[R_i^n\right],\left[Q_i^n\right],\left[V_i^n\right],\left[H_i^n\right],\left[P_i^n\right] \quad (1)$$

where S_i^n – water catchment area for runoff tube, D_i^n – local runoff outlet tube diameter, range 100 to 5000 mm, C_i^n - cross-section parameter – "rectangular" or "round"; R_i^n – ratio – part of water catchment area for local runoff tube (percent):

$$\left[R_i^n\right]=\frac{\left[S_i^n\right]}{S}\cdot 100\% \quad (2)$$

S – Moscow water catchment area (m^2) = 83.5 acre; D – diameter runoff tube (m), Q_i^n part of rate in local runoff tube (m^3/s), Q – water rate in MCS:

$$\left[Q_i^n\right]=Q\frac{\left[S_i^n\right]}{S} \quad (3)$$

V_i^n - average flow velocity (m^2/s) and H_i^n – depth flow in tube, P_i^n - condition execution "yes" or "no" parameter. In current work, we used the following condition based on state regulation: "If the flow in collectors has average velocity less than recommended self-cleaning velocity, V_{sc}, solid particles will settle in the bottom and the sediment is formed".
The output rectangular cross-section occurs in 2% of cases (45 pieces) and round in 98% of cases (2376 pieces). The total average annual flow rate can be obtained from the water balance of the Moskva river. The water balance of river catchments is the ratio of the arrival and flow of water over a period of time (Table 1).

Table 1. The total annual water balance of Moskva river

RATE	mln m^3 per year	m^3/s
Storm water	600.00	19.29
Moskva river at the entrance to the city (data collected at the Karamyshevskaya dam)	1 144.76	36.80
Tributaries (Yauza, Setun, Gorodnya, Skhodnya, Nishenka, Desna)	353.32	11.36
Irrigation water	10.00	0.32
Leaks through the tube	-256.23	-8.24
Removal of water from the city, Moskva river (data collected at the Perervinsky dam)	-2 680.56	-86.18
Unaccounted tributaries	828.71	26.64
Balance	0.00	0.00

A part of the flow rate (Q) – average annual flow rate in collectors – is flow rate entering the collector system and is taken as the main calculated flow rate (average annual) passing through the entire collector system (Table 2).

Table 2. Estimated average water rate in MCS

RATE	mln m^3 per year	m^3/s
Storm water (30% of total 600.00)	181.56	5.84
Tributaries in tube (Setun, Gorodnya, Skhodnya, Nishenka)	157.7	5.07
Irrigation water (100% of total 10.00)	10.00	0.32
TOTAL	349.26	11.23

For the average annual flow rate passing through the MCS, 11.23 m^3/s is accepted in this work.

Taking into account the pipeline diameter, the bottom slope and the wall roughness (Chezi formula) for all possible depths of the pipeline, it is possible to plot the dependence of the flow rate (and, consequently, the velocity) on the relative depth H_i^n. Therefore, if the flow rate in each local collector is known, then the average velocity in each one is known.

The process of application of the overall methodology is illustrated in a Fig. 2.

The self-cleaning velocity is in range of 0.7 – 1.6 m/s., and detection condition $V_{sc} > V_i^n$ for average annual flow rate (flow rate in MCS is 11.23 m^3/s in Table 3). In the UK BS 80056 (British Standard) recommends a full pipe velocity of 1 m/s in order to ensure that a velocity of 0.75 m/s is exceeded at least once each day on average [5].

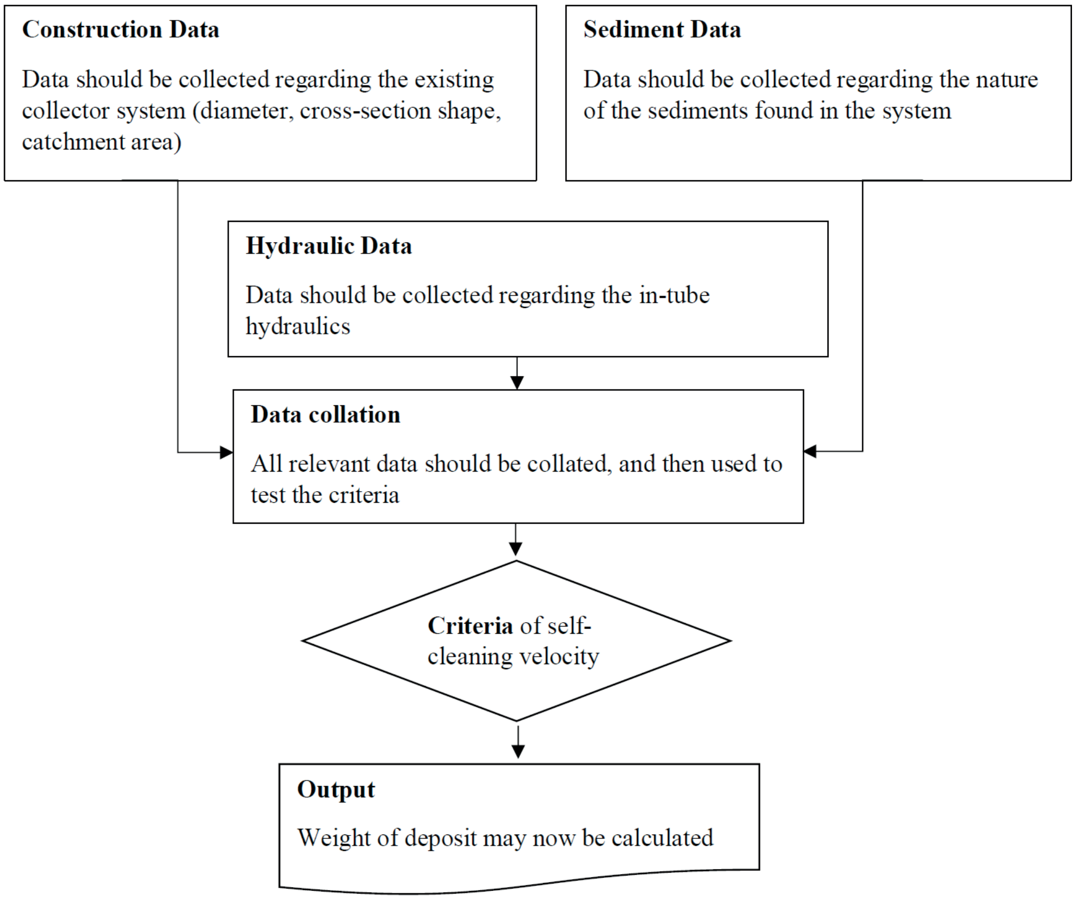

Figure 2. Schematic application of the calculation procedure

Table 3. Velocity analysis

Diameter range mm	Quantity of tubes	Maximum flow rate, m^3/s	Average velocity, V_i^n, m/s	Quantity of tubes with self-cleaning velocity conditions
below 300	513	0.016	to 1	3
from 300 to 400	678	0.03	to 1.5	7
from 400 to 500	165	0.008	to 0.008	2
from 500 to 600	153	0.1	to 2	9
from 600 to 800	132	0.13	to 2.33	7
from 800 to 1000	263	0.23	to 2.72	15
from 1000 to 1200	91	0.13	to 2	12
from 1200 to 2500	122	0.4	to 2.95	10
from 2500 to 5000	304	0.6	to 1.6	10
TOTAL	**2421**			**75**

For the average annual flow rate (in the MCS), the data was estimated as 11.23 m^3/s and for particles brought into the collector system from the outside:

- 97% of solid (silts) particles (diameter up to 5 mm), will settle to the bottom.
- 87.6% of the suspended solids will settle to the bottom.

RESULTS

In 2346 out of 2421 collectors, there is a condition not sufficient for transporting solid particles. Therefore, suspended solid particles deposit in button (in other words, the collector works as a sewage treatment facilities). The condition of calculation can be seen in Table 4.

Table 4. Conditions of calculation

Condition	Setting
Geometry	Cross section shape (circle or rectangular) (0.3 – 5.0) m x (0.3 – 5.0) m
Roughness coefficient	Concrete: 0.011
Slope	0.005
Soil	Density: 2650 kg/m^3 Particle diameter: < 50 mm Concentration: suspended particles 20.78 mg/l petroleum products 0.58 mg/l
Water	Density: 1000 kg/m^3 Dynamic viscosity: 0.001004 Pa·s

The calculation was made to estimate the weight of solid particles depositing in MCS (Table 5).
Particle diameter is maximum inlet diameter, regulated by the standard. Concentration date is based on average actual data for 2019 on the volumes of suspended particles entering the sewage plants (Berezovaya Alley, Ivanovskoe, MKAD No.7, Yurlovskaya). Cleaning efficiency is average for Moscow sewage plants used as deposit process parameter.

Table 5. Weight sediment deposit

No	Parameter	Unit	Formula	Quantity
1	Volume of the storm water flow	mln. m^3 per year		254.52
2	Concentration of suspended solid particles	mg/l		20.78
3	Weight of solid particles moving in the flow	thsd. tons	3 = 1*2	5.29
4	Cleaning efficiency	percent		65.83
5	Collectors with low self-cleaning velocity conditions	percent		87.6
6	Weight of suspended solid particles deposit in the bottom	thsd. tons	6 = 3*4*5	3.05
7	Concentration of petroleum products	mg/l		0.58
8	Weight petroleum products particles moving in the flow	thsd. tons	8 = 1*7	0.15
9	Cleaning efficiency	percent		62.16
10	Collectors with low self-cleaning velocity conditions	percent		87.6
11	Weight of petroleum products particles deposit in the bottom	thsd. tons	11 = 8*9*10	0.08
12	Volume of the 4 big branches (tributaries) of the Moskva river	mln. m3 per year		157.7

13	Average solid particles (silt) concentration in rivers	mg/l		369.4
14	Weight of solid particles in rivers	thsd. tons		58.25
15	Cleaning efficiency	percent		65.83
16	Collectors with low self-cleaning velocity conditions	percent		97
17	Weight of particles from rivers settled in the bottom	thsd. tons	17=14*15*16	37.20
18	TOTAL weight of sediment deposit	thsd. tons	18=6+11+17	40.33

CONCLUSIONS

The estimation of the average annual weight of solid particles deposited at the bottom of the tubes in collector system of Moscow is 40.33 thousand tons (based on the average annual level of water consumption, turbidity and dry sediment).

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