METHODOLOGY OF GREEN RUNOFF DRAINAGE DESIGN FOR URBAN STREETS

Trofimenko Yu.V.[1], Nemchinov D.M.[2], Evstigneeva N.A.[1], Lobikov A.V.[1], Evstigneeva Yu.V.[1]
[1] *Moscow Automobile and Road Construction State Technical University (MADI), Russia*
[2] *TransIngProekt LCC, Russia*

Abstract

The main provisions of the methodology for calculating and designing a “green drainage system” of surface runoff from the road network of settlements that are not equipped with an underground drainage and treatment system are given. Requirements for the “green drainage system” of surface runoff from urban streets that are not equipped with an underground drainage system are formulated. The requirements include the treatment degree of surface runoff, filtration rate, comfort of the visual environment, safety and convenience for pedestrians and bicyclists, technologies of winter maintenance. The main pollutants of surface runoff for different categories of Russian streets are identified. The composition and depth of filtration media, its operating life, types of green plants are determined depending on the composition of pollutants, their typical concentrations, the collection area of surface runoff and the composition of native soils. Examples of the most effective design solutions for the “green drainage system” and treatment of surface runoff from the road network are given.

Keywords: urban street, stormwater, rain garden, design, methodology

1 Introduction

The task of collecting and treating of surface runoff from the road network of settlements that are not equipped with an underground drainage system is extremely important for Russia. In Russia the water quality in most rivers is unsatisfactory and does not conform sanitary and hygienic standards. This is the result of the negative impact of uncontrolled sources, including stormwater. The flow of untreated stormwater to the relief leads to the accumulation of significant volumes of pollutants in soils and grounds [1]. Road dust, wear products from road surfaces, tires, brake pads, car discs, emissions from car engines and anti-icing materials for road ice prevention are the main pollutants in storm runoff. According to article 65 of the Water Code of Russian Federation the water protection zones and coastal protection zones are assigned to surface water bodies (seas, rivers, streams, canals, lakes, reservoirs). A special regime for the implementation of economic and other activities is established within these zones in order to avoid pollution of water bodies. In the absence of an underground drainage system the Water Code prescribes equipping transport infrastructure facilities with local treatment facilities (hereinafter - LTF). LTFs allow to the treat rainwater, watering and meltwater to ensure the most stringent standards established for water bodies of fishery importance. However, LTFs that are recommended by the industry road guidance document ODM 218.8.005-2014 [2] for roads are not suitable for the road network of settlements because LTFs require sufficient free space for their placement, their appearance does not match with the architectural environment of street space.

DOI: https://doi.org/10.5592/CO/CETRA.2020.1050

In addition, the existing experience of operating LTFs on Russian roads has shown their low efficiency due to errors in design, construction and violation of the periodicity of routine maintenance [3], [4]. The listed circumstances require new designs of treatment facilities. These structures should fit harmoniously into the urbanized area, have high treatment efficiency and minimal costs for design, construction and operation.

2 Perspective LTFs for urban streets

2.1 Bioremediation LTFs

The practice of foreign countries are shown that LTFs are based on bioremediation technologies are the most perspective for the road network of settlements. Such facilities include filter strip, bioswale and a rain garden. The principle of operation of these constructions is based on the filtration of stormwater through a layer of soil (native or improved) and the plants. However, the construction of filter strip and bioswale requires favorable local relief. Moreover, the efficiency of surface runoff treatment by these LTFs is not high enough (40 ... 70 %) [5]. In addition, according to Russian set of rules SP 32.13330.2012 “Sewerage. Pipelines and wastewater treatment facilities” the open drainage of surface runoff is permissible only for settlements with low-rise residential buildings and for park areas and settlements in rural areas. In connection with the above, rain gardens should recognized as the most attractive and promising for urban streets. They have a high efficiency of storm water treatment (70...100 %) and do not have requirements for the relief [5].

2.2 The principal construction of rain gardens

The rain garden is a depression in the relief, which is designed to receive surface runoff and filled by a filtration media with planted moisture-loving higher plants that are able to restore the throughput of the filter (Fig. 1).

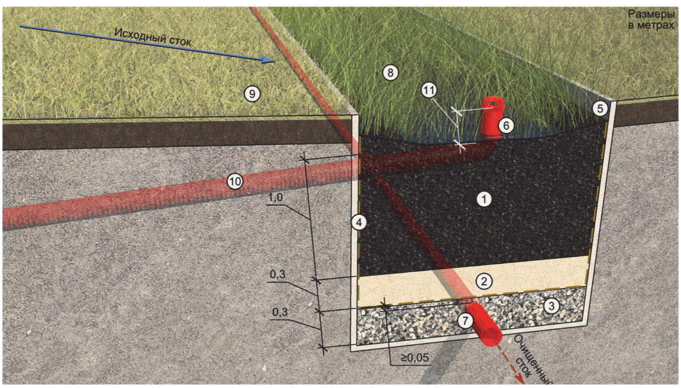

Figure 1 Rain garden operating principles [6] (1 - filtration media (native or improved soil), 2 - sand bed (optional), 3 - crushed stone, 4 - impermeable liner, 5 - geotextile, 6 - overflow pipe, 7 - drainage pipe, 8 - plants, 9 - drainage surface, 10 - outlet pipe, 11 - depth of the retention zone)

The catchment area is not more than 0.1 ha [6]. The surface runoff enters in the space provided by the rain garden design above the filtration media. This space serves for the temporary retention of water. The recommended depth of the retention zone is 0.3 m [6], [7], [8]. The incoming stormwater should not be in the retention zone for more than 24 hours for sanitary reasons [6], [8]. Stormwater slowly passes through a rain garden. Treatment is provided by passing in the filtration media together with bioretention provided by the plants. After passing through the rain garden, water is discharged either by infiltration to underlying soil, or is collected in a pipe and discharged into a storage system or sewer network. Maximum time of runoff water infiltration through the rain garden is 72 hours [7].

2.3 Adaptation of the rain garden design to Russian conditions

The use of rain gardens in Russia is constrained by the lack of guidelines for their construction and operation under local conditions. Simple copying of foreign guidance manuals for using is impossible due to differences in climate, soil, native plants and rhizosphere microorganisms. Russia is characterized by a clear division of the year into warm and cold periods, significant temperature fluctuations, and a stable snow cover is formed in most regions of the country during the cold season.Therefore, it is impossible to ensure efficient operation of the rain garden at low temperatures without introducing of sorption and ion-exchange materials into its filtration media [9]. Used plants should be native, perennial, moisture-loving, fast-growing, easy to care for, resistant to wintering, have a large biomass and thick deep roots, and have the ability to hyperaccumulate metal ions in the green mass. The most perspective solution is the combined use of plants and rhizosphere microorganisms (symbiotic plants and rhizosphere complexes) in LTFs [10], [11].

3 Methodological approaches of rain gardens design on urban streets in Russia

A rain garden designing must include specific steps.

3.1 Definition of main site parameters

The main parameters of the road network section include:
- urban street category;
- individual features of the section (plan elements, longitudinal and transverse profiles, number of lanes in each direction, width of lanes, width of the dividing strip, width of shoulders);
- soil types;
- weather and climate conditions.

According to [12] the weather and climatic characteristics of the area are determine from statistically processed data of long-term (at least 10...15 years) observations of meteorological stations in specific settlements or at the nearest representative meteorological stations.

3.2 Determination of the composition and concentration of pollutants in the surface runoff

At the design step of LTFs according to ODM 218.8.012-2019 [13], the predictive assessment of the concentration of pollutants in surface runoff from roads is performed for suspended solids, lead and oil and petroleum products in accordance with Table 1.
During the operation period of the road network section a qualitative and quantitative assessment of storm runoff for the presence of suspended solids and chemical pollution is carried out by sampling.

Table 1 Concentration of pollutants in the surface runoff from roads and urban streets [13]

Pollutant	Concentration of pollutants C [mg / dm³]	
	in rainwater	**in meltwater**
Suspended solids	390	810
Lead	0.084	0.09
Oil and petroleum products	7.2	7.8
Note: The table data may be specified depending on local conditions and for individual types of pollution.		

3.3 Assessment of runoff infiltration into the soil

The treated runoff can be discharged into the native soil under the rain garden (infiltrating rain gardens). If native soils have low water permeability or if other limitations exist, then rain gardens should designed with impenetrable walls, bottom and drainage infrastructure (non-infiltration rain gardens).

At the design stage, it is recommended to consider the possibility of partial or full use of treated storm water for household needs (for example, for road washing or plant watering) [12]. In this connection, it is advisable to design non-infiltration rain gardens for settlements.

3.4 Determination of the necessity for stormwater treatment

In accordance with ODM 218.8.012-2019 [13] the determination of the necessity for stormwater treatment should carried out by calculating of maximum allowable discharge in water body (MAD) for each pollutant separately, Eq. (1):

$$MAD(i) = q \cdot C_{\max}(i) \text{ kg/year} \tag{1}$$

q – stormwater vollume for treatment during a year, thousand m^3 / year;
$C_{max}(i)$ – maximum allowable concentration of the i-th pollutant, mg/dm^3 (It has been set by regulatory legal act of Russia).

A predictive assessment should be carried out for a prospective period. According to the Russian set of rules SP 34.13330.2012 “Automobile roads” this period is 20 years. The initial year of the calculated prospective period is the year when the road (or an independent section of the road) was put into operation. Therefore, effective treatment of stormwater by a rain garden without replacing the filtration media should be ensured during 20 years. Then during the calculation period the rain garden must hold a certain amount of pollutants from the surface runoff:

$$\Delta M_{20}(i) = 0.02 \cdot \left[q \cdot C(i) - MAD(i) \right] \text{ t/ period,} \tag{2}$$

C(i) – concentration of the i-th pollutant in the surface runoff, mg/dm^3 (according to Table 1).

3.5 The calculation of the rain garden parameters

Calculation of the media area S is made by the following formula (3):

$$S = \frac{W}{h} \cdot 10^3 \quad m^2 \tag{3}$$

W – volume of the estimated rain or the estimated daily volume of meltwater is discharged for treatment (maximum value of them is accepted), m^3. The calculation is made according to metod [11];
h – maximum rain precipitation, mm.

The shape of the rain garden in the plan is chosed arbitrarily, based on considerations of harmonious fit into the street space. The LTF productivity Q is determined by the maximum infiltration time (24 hours), Eq. (4):

$$Q = \frac{W}{24} \quad m^3/h \tag{4}$$

Next, it is necessary to determine by calculation the composition and depth of the filtration media in the rain garden, select plants and rhizomicrobial associations, which together can provide the required treatment of stormwater for 20 years. Such calculations should be based on the results of own or others experimental research. The results of experimental research [8] can be recommended. They allow to determine the operating time of the rain garden before replacing the filtration media.It should be noted that the research [8] does not take into account the presence of rhizosphere microorganisms, which make it possible to increase the efficiency of stormwater treatment from oil products and heavy metals [11].

3.6 Comparative technical and economic assessment of the options for the technological scheme of stormwater treatment

When a technological scheme of rain garden is developed, it is advisable to consider several of its options. This will allow to choose the optimal scheme in the future. This choice is based on a comparison of the technical and economic indicators for different schemes in the conditions of construction and operation of LTF.

3.7 Development of the rain garden design and the requirements for its operation and maintenance

Based on the selected technological scheme, a LTF design is developed for the selected section of the street. Finally, the requirements for the operation and maintenance of the rain garden are determined, including the control of the infiltration rate.

4 Conclusion

The use of “green system” for drain and treatment of stormwater from urban streets without an underground drainage system is environmentally and economically viable. Such systems based on bioremediation technologies have already found application in many countries (USA, Canada, New Zealand, etc.). But these systems are not yet being developed in Russia, although there is a regulatory and methodological framework for this. The main technical issues preventing the widespread use of rain gardens for treatment of stormwater in Russia include defining the optimal filtration media composition and parameters, and selecting of plants, suitable for the climatic conditions of Russia. More research is also needed on the use of microbiota in rain gardens and the search for the optimal composition of plant and rhizomicrobial complexes for operating in various regions of Russia.

References

[1] State report: On the state and use of water resources of the Russian Federation in 2017, http://www.mnr.gov.ru, 20.02.2020.

[2] ODM 218.8.005-2014: Guidelines for the maintenance of treatment facilities on roads (ROSAVTODOR), https://rosavtodor.ru, 25.02.2020.

[3] Trofimenko, Yu.V, Grigoryeva, T.Yu: Development of a methodology for assessing environmental risks associated with the treatment of surface runoff from roads: a report on research, Moscow Automobile and Road Construction State Technical University (MADI), Moscow, 2013.

[4] Veremeev, A.M., Tomilov, A.A., Ruchkinova, O.I.: Surface wastewater from roads, Modern technologies in construction. Theory and practice, 1 (2016), pp. 393-402

[5] Melekhin, A.G., Schukin, I.S.: Analysis of existing bioengineering facilities for surface runoff treatment and the possibility of their application in the conditions of the Western Urals, Bulletin of PNIPU, Construction and architecture, 2 (2013), pp. 40-50

[6] On-site stormwater devices: description and standard design steps: On-Site Stormwater Management Guideline, New Zealand Water Environment Research Foundation. Wellington, New Zealand, October 2004, https://ru.scribd.com/, 29.01.2020.

[7] Stormwater Retrofit Guidance Manual, Philadelphia Water Department, https://www.phila.gov, 31.05.2019.

[8] Schukin, I.S.: Purification of surface wastewater using phytofilters, Dis. Cand. Tech Sciences: 05.23.04, Perm national researched Polytechnic un-t Permian, 2019.

[9] Melekhin, A.G., Schukin, I.S.: The use of bioengineering facilities for the treatment of storm and melt water from urban areas, Vestnik PNIPU, Construction and architecture, 1 (2012), pp. 122-132

[10] Evstigneeva, Yu.V., Trofimenko, Y.V., Evstigneeva, N.A.: Bioremediation technologies for runoff treating from the road network of settlements, European Journal of Natural History, 1 (2020), pp. 81-87

[11] Trofimenko, Yu.V., Lobikov, A.V.: Biological methods for reducing roadside pollution, Overview information. Car roads, 5 (2001), pp. 1-96

[12] Recommendations on the calculation of collection systems, diversion and treatment of surface runoff of residential areas, sites of enterprises and determining the conditions for its release into water bodies: method. guide (FAU FCC), https://www.faufcc.ru, 25.02.2020.

[13] ODM 218.8.012-2019 Guidelines (guidance) on the predictive assessment of environmental impact during the construction and operation of public roads (ROSAVTODOR), https://rosavtodor.ru, 25.02.2020.