УДК 628.35, 628.387
DOI: 10.17277/voprosy.2015.02.pp.034-040

TECHNOLOGY OF URBAN STORMWATER TREATMENT AND ITS USE IN A COLD CLIMATE

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Keywords: rain garden; stormwater treatment; stormwater use.

Abstract: Typical industrial stormwater treatment facilities are characterized by high costs for construction and maintenance in cold conditions. A good alternative is bioengineering facilities, particularly rain gardens. Furthermore, rain gardens can be used to store stormwater and snowmelt with a view to further use. Technology for treatment and use of stormwater and snowmelt in cold climate conditions, based on a rain garden, has been developed by the author. Several variations of the rain garden model for industrial, municipal and residential areas are shown. Main principles of calculations of rain gardens for treatment and use of stormwater are presented.

Around the world today, much attention has been paid to the ecology of urban areas. One of the topical issues is the treatment of stormwater and snowmelt from municipal and industrial areas. Reducing the use of energy and resources required by water supply and sewage systems is important too.

Typical industrial facilities providing mechanical and physics-chemical stormwater treatment are often used in Russia. These facilities are characterized by high costs for construction and maintenance in cold conditions. The aim of the research is to propose an alternative concept of the stormwater treatment system. A literature review of the bioengineering facilities, particularly rain gardens, used for stormwater treatment was undertaken. They do have not the construction and technological disadvantages of typical industrial treatment facilities. For stormwater, they can reduce the total amount of suspended solids by up to 98 %, petroleum hydrocarbons by 95 %, nitrogen by 73 %, phosphorus

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by 90 %, heavy metals by 90 % and pathogens by 80 % [1 – 3]. Rain gardens can be used to store stormwater and snowmelt with a view to further use.

Technology based on the use of rain garden has been developed by the author for treatment and use stormwater and snowmelt. The rain garden (Fig. 1) is a shallow surface depression with filtration media (*4*) containing zeolite and planted with specially selected vegetation (*5*) to capture and treat stormwater runoff. When it rains, a water layer (*1*) is created, which exists until full infiltration. After percolating through the top of the rain garden, the water enters the tank, which contains poured bulk deformable media (*6*), where the treated water is stored. Coarse sand, gravel and crushed stone can be used as poured bulk deformable media.

This construction is not affected by freezing because it is deformable. It can store a high volume of water. The use of deformable media allows year-round storage and the water can be harvested in a warm period. Stored water can be removed using the pump (*8*) submerged in the well (*9*). Between rainfalls, the rain garden looks like a green area in the urban landscape.

Zeolite is added to the filtration media to treat the water during non-vegetative periods in the spring and autumn. Stormwater pollutants, such as heavy metals, nutrients and petroleum hydrocarbons, accumulate in the zeolite during that time. The uptake, transformation and destruction of pollutants from the zeolite by plants and soil microorganisms occur during the vegetative period. Application of the zeolite as meliorative material to the filtration media can be explained by its moderate price with high adsorbtion and ion exchange ability to petroleum hydrocarbons and heavy metals [4 – 6]. Zeolite addition has a positive influence on plants growth in consequence of soil air-water balance sustentation [7]. The novelty of the model of a rain garden for treatment and use of stormwater is confirmed by Patent for invention No 2540620 (RU). Several variations of the rain garden model have been developed, which are suitable for industrial, municipal and residential areas.

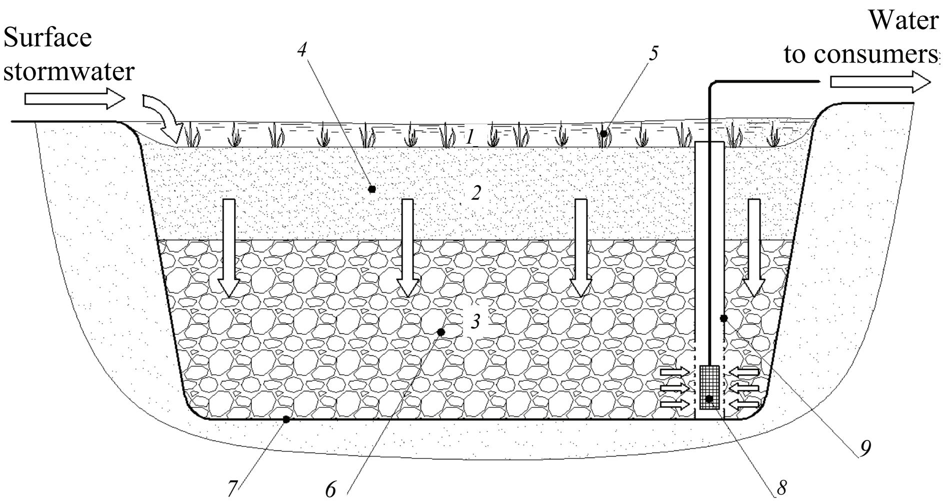
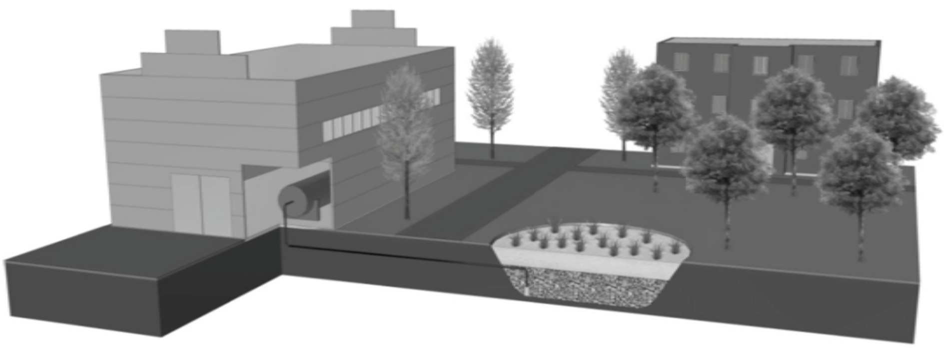


Fig. 1. Rain garden for stormwater treatment and use:
1 – raingarden bowl; *2* – treatment module; *3* – storage module; *4* – filtration media; *5* – vegetation; *6* – poured bulk deformable media; *7* – impermeable liner; *8* – submerged pump; *9* – well

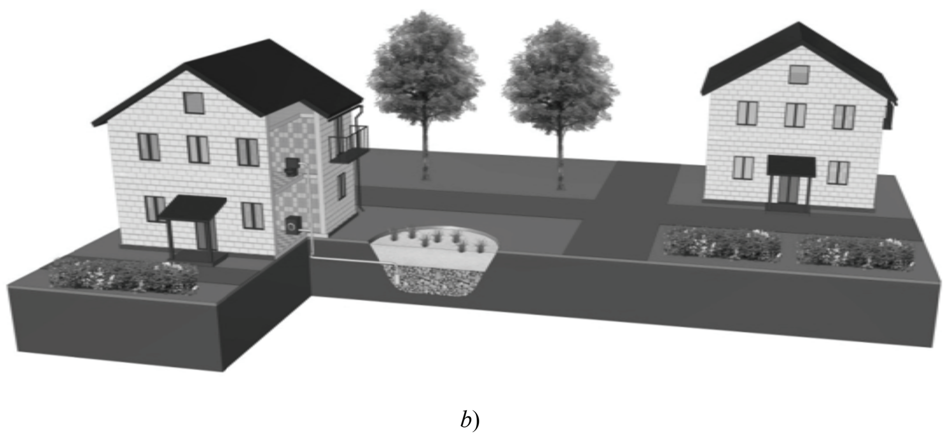
Harvesting and storing of stormwater and snowmelt in industrial areas (Fig. 2, *a*) are with a view to using the water for processing, territory washing and green watering. Soft stormwater can be used for various processes. The problem of discharging stormwater where there is no drainage system has been solved. In residential areas near houses (Fig. 2, *b*), stormwater can be used all year for household needs.

On average, every person in Russian Federation uses around 200 – 250 liters of water per day. The elements (micro components) of the average demand for water in measured households are: 30 % Toilet flushing, 35 % Personal washing, 20 % Clothes washing, 5 % housecleaning and only 10 % dishwashing, drinking and food concoction [8]. Also water can be used for car washing and green irrigation. Thereby stormwater harvesting for domestic uses could potentially reduce the amount of average daily tap water demand up to 90 %.

Potential water quality issues include atmospheric pollution, bird and possum droppings, insects e.g. mosquito larvae, roofing material, paints and detergents. The rain garden can reduce concentration of roof pollutants down to accepted for technical water value. As part of maintenance, an annual flush out (to remove built up sludge and debris) and regular visual inspections should be carried out [9].



a)



b)

Fig. 2. Rain garden for stormwater treatment and storage in industrial (*a*) and residential (*b*) areas

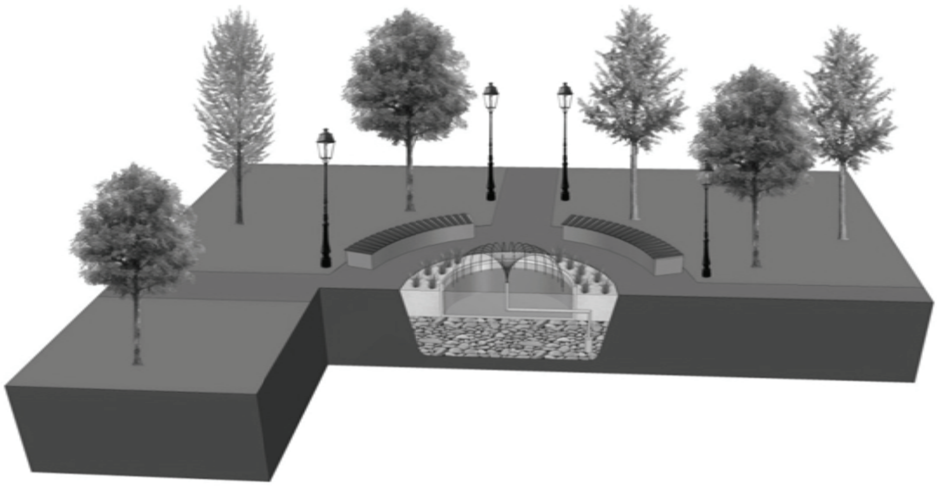


Fig. 3. Rain garden for stormwater treatment and storage in parks and squares

In cities, rain gardens in parks and squares can be combined with fountains (Fig. 3). This technical solution has several advantages: it is highly decorative, it allows supporting a filtration media moisture, Water is removed from the system by evaporation and water is entrained in the form of spray.

Methods of the rain garden design have been developed. The size of the tank with poured bulk deformable media definition is based on monthly water balance of the rain garden during a year. The monthly water balance can be defined

$$W = Q - E_{tr} - E_{ev} + V, \qquad (1)$$

where W – stormwater runoff volume during a month, m^3; V – accumulated stormwater volume in tank, which contains poured bulk deformable media, m^3; Q – water use, m^3; E_{tr} – vegetation transpiration water loss, m^3; E_{ev} – surface evaporation water loss, m^3.

The stormwater runoff volume W is defined according to methods [10], by monthly precipitation layer taking into account general runoff coefficient of catchment basin ψ

$$W_n = \frac{F_{catch} h_n \psi}{1000}, \qquad (2)$$

where W_n – stormwater volume during n-th month, м^3; F_{catch} – catchment area, m^2; h_n – n-th month precipitation, mm [11]; ψ – general runoff coefficient, that can be defined as follows:

Catchment basin surface type:

Impermeable areas (roofs, roads etc.) .... 0,6…0,8
Pavement roads and sidewalks .... 0,4…0,6
Square, avenue, parks .... 0,2…0,3
Grass, green 0,1

Total evaporation (sum of the surface evaporation E_{ev} and the vegetation transpiration E_{tr}) is defined by monthly potential evaporation maps shown in [12].

Presence of water for every month is ensured when is satisfied.

$$V_n = V_{n-1} + W_n - Q_n - (E_{tr} + E_{ev}) > 0, \quad (3)$$

where V_n – water volume remain after n-th month, m^3; V_{n-1} – water volume remain after $(n - 1)$-th month, m^3; Q_n – water use during n-th month, m^3.

Maximum water volume that must be stored V_{max} is defined by difference between V_n^{max} and V_n^{min} during a year.

Then volume of poured bulk deformable media is defined by its hollowness

$$V_{media} = \frac{V_{max}}{P_{media}}, \quad (4)$$

where V_{media} – media volume, m^3; W – stored water volume, m^3; P – media hollowness (packed), %. Hollowness of sand, gravel and crushed stone [13] are presented below:

Media type:

Sea sand 29
River sand 28,75
Mountain sand 32,75
River gravel 28,8
Crushed stone 32,5

The area of the tank with poured bulk deformable media is defined

$$F_{tank} = \frac{V_{media}}{h_{media}}, \quad (5)$$

where h_{media} – height of the tank, 2 – 3 m.

After defining the size of the tank it is necessary to check the hydraulic conductivity of the rain garden with predicted maximum stormwater flow, which should not be less than 12.5…50.8 mm hr^{-1}, according to recommendation of guidances [14, 15].

Conclusion

The technology for treatment and use of stormwater and snowmelt in cold climate conditions has been developed by the author. Stormwater storage and use may be appropriate for industrial, municipal and residential consumers. Methods of the rain garden size calculation are based on monthly water balance during a year. The main advantages of the methods include using reliable and available initial data, which based on long-term meteorological observations results.

The main technical issues preventing the widespread use of rain gardens for treatment of stormwater in Russia include estimating the treatment and hydraulic load given the climate, defining the optimal filtration and storage media composition and parameters, and selecting plants suitable for cold regions that can survive in a rain garden.

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Технология очистки и использования поверхностного стока с урбанизированных территорий в условиях холодного климата

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Ключевые слова: использование ливневых вод; очистка поверхностного стока; фитофильтр.

Аннотация: Традиционные сооружения очистки ливневых вод характеризуются высокой стоимостью строительства и эксплуатации в условиях холодного климата. Хорошей альтернативой для них могут служить биоинженерные очистные сооружения, в том числе фитофильтры, которые могут быть использованы для накопления ливневых и талых вод в целях дальнейшего использования. Разработана технология очистки и использования ливневых и талых вод с урбанизированных территорий, основанная на фитофильтрации. Показаны возможные варианты реализации указанной технологии на городских, промышленных и частных территориях. Приведены основные принципы расчета сооружений по предлагаемой технологии.

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