Improving the systems for surface runoff treatment

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Abstract
The issues of improving the treatment of surface runoff (SRO), generated on the territory of communities of various functionality, in particular, the design of flow-type local facilities for surface runoff treatment are considered. It is noted that SRO generated on the territory of cities and communities is an intensive source of technogenic pollution of water bodies and affect the ecological safety of the urban environment. Herewith, to the front burner go the issues of developing advanced process systems for SRO treatment that provide for applying the latest developments of the sectoral research; as well as of upgrading the existing process schemes for SRO treatment, with account of the new approaches to the regulation of the pollution discharge into water bodies. The paper discusses the principle of decentralization of surface runoff treatment systems using biological treatment facilities. Based on experimental studies of the SRO composition the paper presents a list of the priority pollution indicators needed for designing SRO treatment systems. The recommended classification of flow-type SRO treatment facilities widely used in the engineering design, is given. The paper describes a new design of a flow-type SRO treatment plant developed as a result of the experimental studies with real SRO with a utility patent obtained.

Keywords: surface runoff, system, treatment, design, improvement

Introduction

Surface runoff generated on the territory of the Russian cities and communities during atmospheric precipitation has been an intensive source of the technogenic pollution of the environment, primarily, water bodies. [1,2]. Most communities in the Russian Federation, lack or cannot operate (owing to the high wear and tear of the networks and structures) the systems for surface runoff handling [3]. This produces a negative impact on the sanitary and ecological state of the natural water bodies; so that during steady and heavy rainfall

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emergency situations occur associated with flooding of territories and transport infrastructure facilities [4]. Surface runoff refers to the category of wastewater that falls within the scope of all the requirements to wastewater discharge of into water bodies. The main documents justifying the need for the construction of systems for their removal and purification are RF Water Code No.74-FL, and CP 32.13330.2018 "SNiP 2.04.03-85 "Sewerage. External networks and structures" with amendments No. 1 and No. 2.

Designing facilities for SRO handling is built on the estimation of the average annual and daily volume of the runoff, flow rate in storm sewers, as well as the data on the qualitative characteristics of SRO from the territory of residential areas, transport infrastructure and industrial sites; and on the conditions of SRO discharge to the public wastewater disposal systems of communities, urban districts, and into water bodies [5,6,7,8,9,10]. However, at present, designing systems for SRO handling in the water industry of Russia, is based on the averaged data. The approximate (averaged) values of only four integral pollution indicators (suspended solids, oil products, BOD_5, COD) have been included into Table 15 of CP 32.13330.2018 as priority (monitored) indicators of SRO pollution. This practice does not meet the current requirements of the RF Environmental Legislation and regulatory legal acts of the recent years that provide for the transition of the discharge regulation system to the principles of the technological regulation based on the process indicators of the Best Available Technologies (BAT); besides it does not take into account possible presence of pollutants in SRO, that are subject to the state regulation provisions established by the order of the RF Government No. 1316-r of 07/08/2015. [11]. Thus, the values of pollution indicators given in these documents are somewhat approximate; they do not apply to all design objects and need updating for quite some time now, both in terms of the list of indicators and values (updating has not been carried out for more than 30 years). Obviously, designing new or adapting existing systems to the climate changes involves accounting for the impact of the current and also future climate changes due to the long technological lifespan of the sewer networks [12,13,14,15].

The relevance of research in the field of improving and optimizing the operation of SRO treatment systems is determined by the fact that, on the one hand, the organization of harvesting and treatment of SRO from residential areas is the most important requirement for the improvement of communities for preventing negative consequences from flooding of residential areas and industrial facilities during heavy rainfall, and snowmelt; on the other hand, it is an environmental measure aiming at ensuring the ecological safety of the urban environment, i.e., preventing a negative impact on water bodies by reducing the discharge of technogenic pollutants.

In this regard, a comprehensive study of the composition and properties of SRO generated on the territory of various functional purposes is needed. This is the basis for substantiating the priority list of monitored indicators of SRO pollution and methods for their quantitative analysis and SRO treatment technology development, as well as for designing treatment facilities (plants).

Methods

Numerous studies have established that surface runoff generated in cities, as a rule, contains [16,17,18,19]:

- mineral and organic matter of natural origin resulting from the absorption of gases from the atmosphere and soil erosion including dissolved organic and mineral substances, as well as coarse impurities (particles of sand, clay, humus);

- substances of technogenic origin in various phase-dispersive states: oil products, leachable components of roadway paving, heavy metal compounds, synthetic surfactants and other components depending on the business profile of the local industrial enterprises and sanitary-technical condition of the territory;

- bacterial pollution entering the drain as a result of the unsatisfactory sanitary and technical state of catchment areas and sewer networks.

The performed studies of the composition and properties of the surface runoff generated on the Moscow territories of various functional purposes (residential buildings, industrial zones, highways and adjacent territories) was the basis for substantiating the priority list of monitored indicators of SRO pollution and methods for the quantitative analysis and development of SRO treatment technology; as well as for designing treatment facilities (plants) using composite materials. The list of priority indicators of SRO pollution should include:

- suspended substances, solid residue, oil products, COD, BOD_5 and phosphorus;
- lead, nickel, strontium (2nd hazard class, may be present in the surface runoff of highways), chromium;
- iron, copper, zinc, manganese, ammonium ion, nitrate-ion, nitrite-ion, chlorides, sulfates, anionic surfactants, ethylene glycol (state regulation measures are applied).

For the effective treatment of SRO generated in residential areas (for further reusing or discharging the effluent into water bodies in compliance with the regulatory requirements), various process flow schemes are used based on the SRO characteristics, including mechanical, physical, chemical and biological methods of purification and tertiary treatment. As a rule, multistage treatment schemes are used that combine various methods of pollution removal or destruction [21].

Figure 1 presents the classification of SRO treatment facilities widely used in designing the systems for the disposal and treatment of surface runoff generated in urban and rural communities.

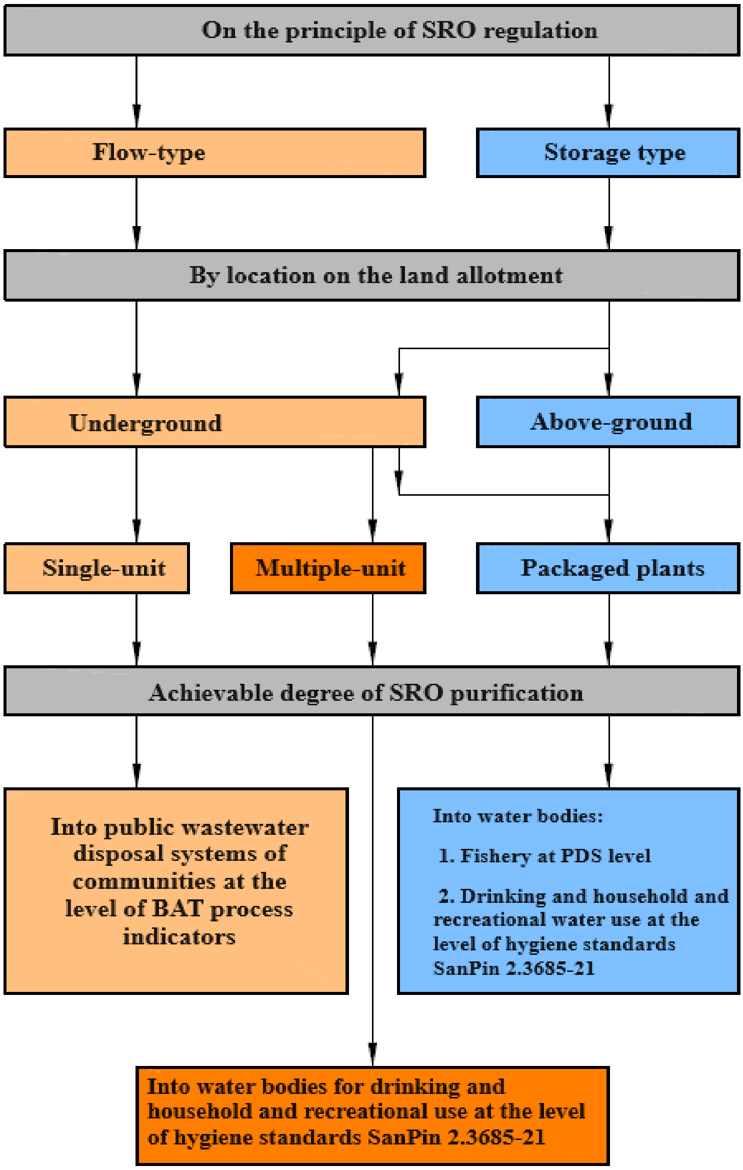


Fig. 1 Classification of SRO treatment facilities

Depending on the principle of regulation of surface (rain) runoff subject to treatment, all known local treatment facilities (LTFs) are divided into two types: storage and flow-type.

Both types of structures have their own area of application depending on the capacity and achieved effect of SRO treatment in terms of the main pollution indicators. Flow-type LTFs – turnkey packaged plants, are less cost-intensive, however, troubled in operation.

At present, due to the large-scale construction of highways, transport infrastructure facilities, as well as owing to the needs of a number of capital construction projects with a small catchment area, a trend emerged of expanding the scope of application of surface runoff treatment facilities of the "flow" and "storage" types of small capacity with different process flow schemes that provide for meeting the regulatory requirements to the effluent quality to be discharged into public sewers or water bodies (at a level of process indicators of the best available technologies (BAT), sanitary and hygienic standards or permissible discharge standards (PDS), calculated on the basis of maximum permissible concentrations for fishery water bodies (MPC fishery).

Since imported plastic and fiberglass tanks had appeared on the domestic market and later, when they were replaced by similar domestic products, manufacturing flow-type surface runoff treatment facilities (LTFs) on their basis became one of the areas of their application.

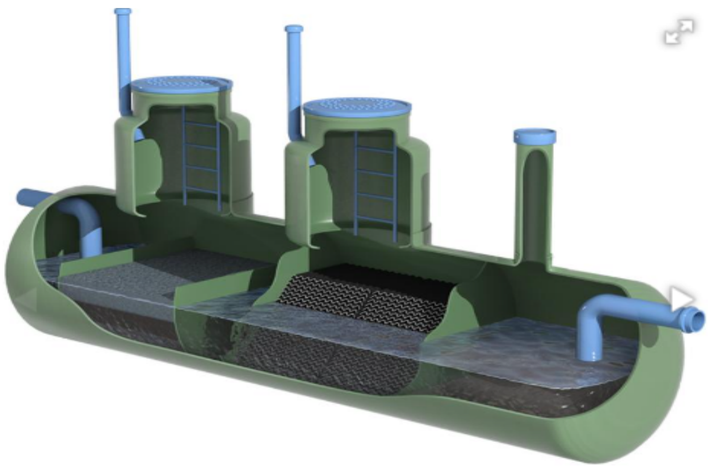


Fig. 2. Flow-type LTF manufactured by Polyplastic Group, LLC

Their widespread acceptance during the initial implementation stage was explaind not only by the above objective advantages of plastic containers, but also, to a large extent, by combative advertising of flow system suppliers promising a high wastewater treatment effect at low capital and operating costs compared to traditional treatment facilities of storage type, designed and manufactured in accordance with the environmental legislation of the Russian Federation and design code.

Indeed, relatively low capital costs declared by the suppliers, ease of operation and minimum operating costs, in the eyes of laymen, served as significant advantages of flow-type treatment systems. In addition to the above, no construction of storage tanks and buildings for the treatment facilities is needed; no need for electricity, treatment chemicals and other consumables; and maintenance, as follows from the advertisement, is reduced to replacing filters.

However, studies have shown that the claimed degree of SRO purification in terms of the residual concentration of only three pollution indicators (oil products, suspended solids and BOD_5) at the level of MPC of pollutants in fishery water bodies is insufficient to obtain a permission from the environmental authorities to discharge effluents into water bodies. As a rule, the list of regulated pollution indicators contains 10-13 items and may include indicators of chemical oxygen demand (COD), surfactants, metals, nitrogen and phosphorus salts, which are scarcely removed in flow-type plants.

The retention time of polluted SRO in the sedimentation sections of these plants (even in the absence of sludge in the bottom part) is from 1.5 to 20 minutes. Given that the rainfall runoff contains mainly finely dispersed suspended solids, during this time only coarse solid particles precipitate. At the same time, the actual efficiency of retaining suspended solids in the sedimentation sections of these plants is at most 15 - 20%.

The service life of existing flow-type systems (plants) for SRO treatment is limited to one or two design rains of medium intensity.

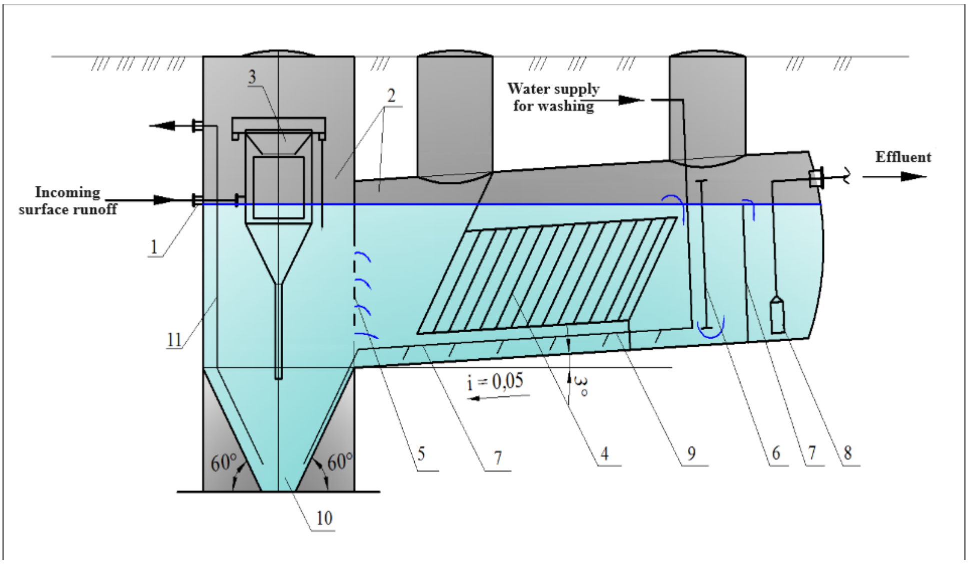
Results

The Water Supply and Wastewater Disposal department of the National Research University MGSU conducted experimental studies with real SRO at a local plant and simulated the process of SRO treatment by sedimentation and filtration-sorption method in filters with various filter media in the modes of mechanical, sorption and ion-exchange treatment with or without chemical surface runoff pre-treatment. The studies were aiming at expanding the boundaries of the use of flow-type and storage facilities for the SRO treatment.

The studies showed that the promising areas for improving the process flow schemes and designs of small capacity flow-type and traditional storage-type plants (with storage tanks made of plastic containers) for SRO treatment were as follows:

- structural modification of the units for mechanical pretreatment of SRO (underground version) to increase the efficiency of separating coarse and fine mechanical impurities and oil products with a hydraulic particle size of 0.2 mm/s or less;
- retrofitting underground facilities with effective systems for collecting and removing oil products (free), as well as with the systems for hydrowashing and removing the separated mineral sludge for dewatering (utilization);
- fabricating housings of flow-type plants and other capacitive treatment equipment (accumulation tanks, collectors, mixers and filters) from advanced, chemical and corrosion-resistant materials with high strength characteristics and a long service life;
- developing basic process flow schemes for the SRO disposal and treatment both flow-and storage-type that provide for meeting the current regulatory requirements to the composition of effluents to be discharged into public wastewater disposal systems (combined, storm and composite), as well as into water bodies (at the level of the process indicators of BAT, health-based exposure limits or permissible discharge standards based on $MPC_{fishery}$).

The new design of the flow-type SRO treatment plant [22] is shown in Figure 2.



Legend: 1 – SRO to treatment, 2 -combined tank-settler, 3 -hydrocyclone, 4 -lamellar sedimentation module, 5 – deflector baffle, 6 - baffle, 7 -weir, 8 -submersible pump for effluent discharge, 9 -sludge hydrowashing system, 10 -sludge collecting hopper, 11 – sludge removing pipeline

Fig. 3. New design of a flow-type SRO treatment plant

The unit is a combined structure designed to separate (remove) coarse and fine mechanical impurities (suspended substances and oil products) from SRO that does not contain specific pollutants with toxic properties while being discharged into public wastewater disposal systems (stormwater, combined sewer, composite) or water bodies. The housing of the plant is made of large diameter pressure fiberglass pipes (from 2000 to 3000 mm).

In terms of design the plant consists of two sections - a vertical one with a hydrocyclone and a conical sludge hopper, and an inclined one (at an angle of less than 3^0) with a lamellar sedimentation module separated by a vertical deflector baffle.

Besides, the plant can be used for mechanical treatment of surface runoff generated on the territory of industrial zones where facilities (enterprises or their individual production) are located, classified as category III or IV facilities according to the criteria of negative environmental impact.

A patent for Utility model RU 207 418 U1 “Device for surface runoff treatment” was obtained for the developed flow-type plant made of fiberglass materials for mechanical pretreatment of SRO [23].

Biological treatment is an alternative both in Russia and overseas for the decentralization of the system for removing dissolved organic substances (including specific pollutants of technogenic origin), as well as nitrogen and phosphorus salts, from surface runoff. [24,25].

One of the promising areas under development in the field of biological SRO treatment is bioengineering facilities designed for biological treatment of wastewater in natural conditions eliminating the use of chemicals and expensive equipment. They are as follows:

- gabion filtration treatment facilities (GFTF);
- phyto-purification facilities with forced aeration (PhPF);
- underground storage and infiltration facilities.

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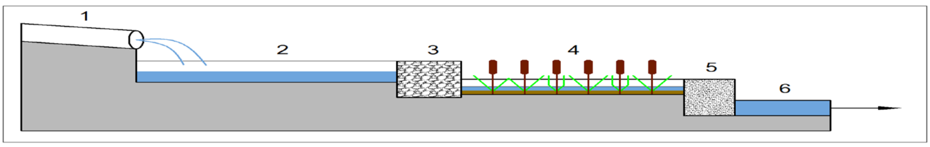
Advanced gabion filtration treatment facilities (GFTF) usually consist of two sections each having 4 treatment stages:

- a storage sedimentation tank with more than 1 day retention time;
- a filtration chamber with granular media (gravel and coarse sand);
- a bioplateau, a shallow nature-like water body planted with native species of macrophytes;
- a filtration chamber with a sorbent agent (modified alumina silicate).

GFTF are gravity facilities of open type, Figure 4.

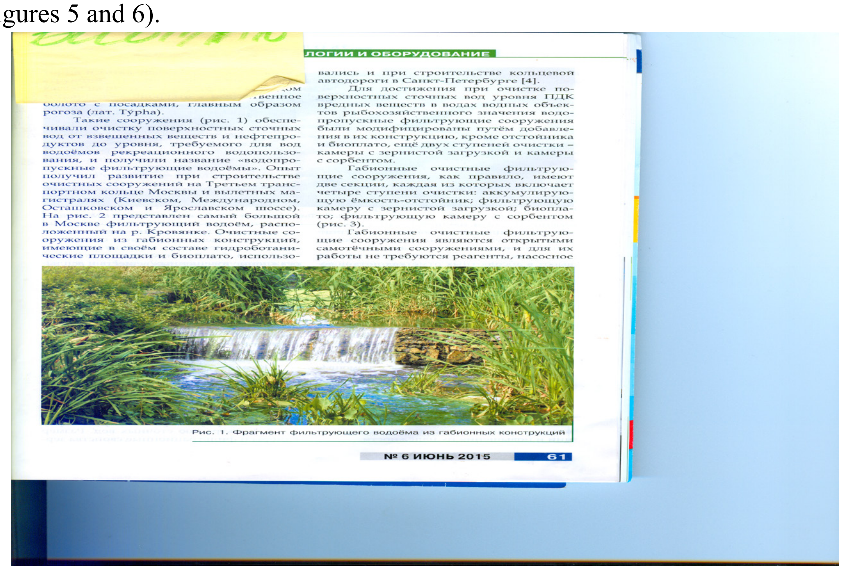


1 – storm sewer (or feeding channel); 2 – sedimentation tank;

3- filtration chamber with granular media; 4 - bioplateau; 5 – filtration chamber with a sorbent agent; 6 – effluent discharge.

Fig. 4 General layout of gabion filtration treatment facilities (GFTF)

Recently, a fairly large number of them have been designed and built in Russia for the purification of SRO generated on highways, industrial sites, in technology and industrial parks (Figures 5 and 6).



ЛОГИИ И ОБОРУДОВАНИЕ

...болото с посадками, главным образом рогоза (лат. Týpha).

Такие сооружения (рис. 1) обеспечивали очистку поверхностных сточных вод от взвешенных веществ и нефтепродуктов до уровня, требуемого для вод водоёмов рекреационного водопользования, и получили название «водопропускные фильтрующие водоёмы». Опыт получил развитие при строительстве очистных сооружений на Третьем транспортном кольце Москвы и вылетных магистралях (Киевском, Международном, Осташковском и Ярославском шоссе). На рис. 2 представлен самый большой в Москве фильтрующий водоём, расположенный на р. Кровянке. Очистные сооружения из габионных конструкций, имеющие в своём составе гидроботанические площадки и биоплато, использовались и при строительстве кольцевой автодороги в Санкт-Петербурге [4].

Для достижения при очистке поверхностных сточных вод уровня ПДК вредных веществ в водах водных объектов рыбохозяйственного значения водопропускные фильтрующие сооружения были модифицированы путём добавления в их конструкцию, кроме отстойника и биоплато, ещё двух ступеней очистки – камеры с зернистой загрузкой и камеры с сорбентом.

Габионные очистные фильтрующие сооружения, как правило, имеют две секции, каждая из которых включает четыре ступени очистки: аккумулирующую ёмкость-отстойник; фильтрующую камеру с зернистой загрузкой; биоплато; фильтрующую камеру с сорбентом (рис. 3).

Габионные очистные фильтрующие сооружения являются открытыми самотёчными сооружениями, и для их работы не требуются реагенты, насосное

Рис. 1. Фрагмент фильтрующего водоёма из габионных конструкций

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Fig. 5 Fragment of a filtration pond built of gabion structures

The treatment capacity of GFTF with a bioplateau can reach 20 thousand m^3/day of surface runoff from a catchment area of up to 200 ha. At the same time, the size of the bioplateau as part of the gabion treatment facilities can be from 30 to 50% of the territory occupied by GFTF.

The main conditions for designing GFTF is the difference in elevations of the supply and drainage pipelines, the availability of large areas for the treatment facilities construction, as well as favorable climatic conditions, i.e., a fairly warm climate (they are not effective at low temperatures).

Phyto-purification facilities with forced aeration (PhPF) occur widely in all countries of the world, being quite popular in Europe. These are domestic wastewater biological treatment (tertiary treatment) facilities with artificial aeration (Figure 6).


Экология Производства

Рис. 2. Фильтрующий водоём на р. Кровянке в Москве

оборудование, электричество, строительство служебных помещений. Основные условия работы сооружений:

1) не менее чем метровый перепад высот в абсолютных отметках лотков водоподводящей и водоотводящей труб. Абсолютная отметка последней определяется положением точки сброса очищенных сточных вод в водный объект, в который они отводятся;

2) участок, имеющий достаточную площадь для размещения ГОФС соответствующей производительности. Форма сооружения и рельеф участка могут быть любыми.

Для защиты грунта от инфильтрации загрязнённого поверхностного стока всё сооружение гидроизолируется с помощью плёночных материалов. Для реализации технологической схемы в ГОФС используются геомембраны, удобные при монтаже в сочетании с габионными конструкциями.

Ещё одно достоинство ГОФС – с появлением новых материалов и сорбентов они легко могут быть модифицированы в целях снижения стоимости эксплуатации и повышения их надёжности.

Аккумулирующая ёмкость-отстойник имеет глубину отстойной части не менее 1 м, а глубину рабочего объёма – 1–3 м. В отстойнике происходит осаждение взвешенных веществ и всплытие свободных нефтепродуктов. Положение уровня воды определяется конструкцией камеры с зернистой загрузкой и высотной отметкой лотка водоподводящей трубы. Скорость движения воды в аккумулирующей ёмкости-отстойнике определяется конструкцией фильтрующей камеры с зернистой загрузкой и, как правило, имеет значение менее 0,01 м/с. Расчёт рабочего объёма производится с использованием действующих нормативных документов [5–7].

Камера с зернистой загрузкой используется в качестве естественного фильтра и представляет собой ёмкость между двумя рядами габионов, заполненную щебнем и крупнозернистым песком. Указанная конструкция камеры по принципу действия обеспечивает напорную вертикальную (сверху вниз) фильтрацию сточных вод. Размер камеры и фильтрационные свойства зер-

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Fig. 6. Filtration pond on the Krovianka Creek in Moscow

Wastewater biological treatment is carried out in a subsurface horizontal, as a rule, semiburied phyto-purification lagoon, equipped with a forced aeration system. At a high level of groundwater, the phyto-purification lagoon is arranged in an embankment. A special mulching (peat) layer is spread over the surface of the structure that provides for maintaining the required temperature regime all year round in the subsurface wastewater layer under treatment. The wastewater treatment process includes mechanical pretreatment, a phyto-purification lagoon and, if required, a tertiary treatment (disinfection) stage.

The advantage of PhPF is the low cost and operating expenditures compared to the traditional treatment facilities (with activated sludge and biofilters). Attractive design with green vegetation on the surface blends into any landscape.

The main problem with PhPF is the lack of experience in applying phyto-purification technology in Russia, both for domestic wastewater and surface runoff treatment.

Conclusions

1.While designing a system for surface runoff harvesting and treatment in the city of Moscow, it is essential, alongside with the construction of large-scale cluster treatment facilities with the traditional technology, to implement the decentralization principle using local biological treatment facilities to the extent possible.

2. A comparative analysis of the characteristics of flow-type SRO treatment plants both domestic and foreign- made shows that these facilities being currently introduced do not comply with the design standards in force in the Russian Federation and do not meet the

regulatory requirements for the degree of wastewater treatment established by the environmental and water legislation (in fact, they only imitate treatment processes).

3. While developing process flow schemes for the disposal and treatment of surface runoff from the territory of cities and communities in Russia, it is essential to consider:

- meeting various regulatory requirements to the degree of SRO purification to be discharged into public sewers or water bodies;
- up-to-date information on the qualitative characteristics of SRO generated on the territory of residential and industrial zones, as well as transport infrastructure and adjacent areas;
- the amount, intensity and probabilistic nature of precipitation at the design objects to be developed.

4. At present, all designing engineers of the country use “outdated” climatic parameters of 50 years old while making hydraulic calculations of surface runoff disposal systems. It is essential to update the climatic parameters for performing hydraulic calculations while designing storm sewer networks using the “limit intensities” method.

5. An independent engineering certification of local flow-type treatment facilities shall be conducted, since almost all of the proposed designs of these facilities do not comply with the established SRO treatment standards; nevertheless, they have compliance certificates.

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