Conceptual approach to the creation of “smart” sewerage system for city surface runoff

Elena Vialkova, Svetlana Maksimova, Elena Malyshkina, Andrey Voronov, Marina Zemlyanova and Lev Maksimov

Industrial University of Tyumen, Volodarskogo street, 38, Tyumen, Russia, 625000

E-mail: vyalkova-e@yandex

Abstract. Creation of comfortable living conditions for people in urban areas it is requires the "smart" infrastructure, designed to divert surface runoff: rainwater, meltwater and sprinkling water. Organization of the deleting diffuse surface runoff from urban areas is one of the main sources of industrial pollution and degradation of the water bodies, located in the city. To reduce the anthropogenic impact on water bodies need in high-quality treatment of surface runoff during the year. The existing technological schemes for treatment the surface urban runoff, as it turned out, do not fully take into account changes in the quantity and quality of surface wastewater. This is associated with increasing the proportion of waterproof coverings in residential areas and the appearance of new types of anthropogenic pollution depending on the season. This report presents a conceptual approach to the development of a new local wastewater treatment plants is able to automatically change the parameters (time, intensity, dose and type of reagents, temperature, etc.), add or delete the necessary treatment stages with considering of quality seasonal changes of rainwater, sprinkling and melt waters. The results of the conducted researches allows to develop new technological schemes of surface runoff treatment on the basis of nature-like technologies taking, to determine the most effective methods and the main stages of treatment, choose the optimal composition of facilities and equipment, calculate the technological parameters of local treatment stations. New technological schemes provide the possibility of remote management and control.

1. Introduction

One of the strategic priorities of the Russian Federation in the urban development field is the modern complex engineering development of cities and other settlements, ensuring environmental safety and people comfortable living. In this regard, the proposed list of construction fundamental problems until 2030 identifies the particularly important environmental problems in the context of the formation of a healthy city habitat [1].

The current state of affairs is such that an imperfect rainwater sewage system that collects rain and meltwater from the urban areas is one of the main industrial pollution sources and degradation of water bodies located within the boundaries of settlements. According to many authors, rain and thawed sewage, which contribute at least 50% of pollutants, are major factor in the unsatisfactory quality of water bodies [2-4]. As a rule, it is worsens the sanitary condition of water sources for drinking purposes and creates conditions for decreasing the population epidemiological well-being. To create the normal living conditions in urban areas, a smart engineering infrastructure is required. This smart drainage system should be designed for effective collection, transportation and qualitatively
treatment of the surface runoff. This new drainage system should be able to reduce the anthropogenic impact on the water bodies.

2. Review

The traditional ways of organizing of the surface runoff sewage systems are as follows: collection, joint transportation and treatment of the surface runoff and domestic sewage drains (the common sewage systems); separate collection and discharge of the rainwater runoff into the water sources without treatment as conditionally clean; rain accumulation in natural water ponds for partial infiltration into the ground and evaporation from the surface; accumulation and use of conditionally clean runoff for technical purposes without treatment.

The most progressive rainwater drainage systems are: the installation of special local purification systems only for rain and meltwater with subsequent discharge into the body of water in order to replenish water resources (Russia); purification and reuse for industrial or economic purposes (Malta); irrigation of the urban green areas (Hungary); irrigation of the vertical and horizontal landscaping systems of buildings (Singapore); application of bioengineering technologies for surface water treatment (Russia: Moscow, St. Petersburg; China); high-quality water treatment to drinking standards and further using for stand-alone water supply facilities (the experience of Switzerland).

On some authors’ opinion, development of water resources is also feasible by means of green infrastructure. So far, quality protection zones in Debrecen (Hungary) are marked outland designated for limiting certain polluting activities. The purpose of the researches was to expose the high potential of the Green Infrastructure (GI) elements application to water resource development in areas which is requiring protection. This study also focus on the GI-systems usefulness as a finding method the primary places for the GI-elements practice with intention of water resources development [3].

On the example of Singapore, Under the ABC Water Program, design-building features can be categorized under the following elements: rooftop, sky garden or terrace, balcony, planter box, ground level greenery and green wall or vertical green field. Other than enhancing the buildings aesthetic, these green elements are cooling the surrounding air temperature, reduce the groundwater level, clean and treat the rainwater runoff through natural purification processes before reaching the ground. The using of green treatment system is continuing inside the building including water self-sufficiency through rainwater-collection and rainwater reuse for both plant irrigation and toilet flushing [5].

As a result of the aiming to reduce operating costs for surface runoff treatment in many countries around the world, the development of bio- and phytotechnologies for rainwater treatment, including biofiltration canals, bioplatos and phyto-filters, has been developed. All these structures are artificial or natural water bodies planted with special plant species, in which the incoming flow is purified through the natural soil layer and the root system. These technologies have found wide application in China (PCF - phyto-cleaning facilities). Currently, more than 2.5 thousand exploited bioplatforms in various countries of the world are already known. Bioplatos have become widespread in Europe and America. More than 200 bioplatos structures have been built in Denmark, Germany and England. In the United States, since 1988, several hundred bioplatos facilities have also been in operation, and technological procedures for the "Constructed Wetland" bioplatos type have been specially developed [6].

In Moscow, the system of collection and surface runoff treatment is considered the most organized in Russia. This system represents a complex of structures that consist of the following facilities: settling ponds including rough mechanical cleaning, oil traps, and mechanical thin-layer filters. At the first stage, large debris, suspended solids and oil products are captured by grids, lattices and oil traps. At the second and third stages, thin-layer filters are used to purify water from medium and fine dispersed suspended matters, as well as from oil products. At the fourth stage, the post-treatment of surface runoff occurs at phytotechnology facilities [7].

In Russian North conditions, where the climatic is harsher and the air temperature might be -40°C and lower, the winter has a high duration, the ground freezes by 2 and more meters, and the snow cover reaches 65 cm high or more, the application of phyto-cleaning water facilities will be practically
impossible or high energy-consuming. After severe winters, the north vegetation active growth begins only from May to June and finishes in August. This is sufficient only for treatment the summer rainwater. Therefore, the Programs of the Western Siberia settlements Development plan to provide for the construction of local modular treatment facilities for receiving rain and snowmelt runoff, followed by discharge into the reservoir or reuse.

In the reference book (ITS 10-2015) [8] it is proposed to use two kinds of wastewater treatment plants for surface runoff: flowing and storage. The composition of the technological scheme is quite simple and includes a first mechanical treatment, sedimentation, filters and, if necessary, disinfection. According to the Russian handbook [8], about 56% of all Moscow surface runoff treatment plants refer to technologies that use the filtering process. Only a third part (19%) can be attributed to modern high-tech facilities. The SUE "Vodokanal of St. Petersburg" operates only 4 of these facilities, and at 3 objects, pressure filtration through granular layers is provided, on one - technology with peat filtration.

In 2014, recommendations were issued in which an effective technological scheme of surface runoff treatment facilities is presented. Recommendations are based on the experience of operating such structures [7]. Rainwaters collected from the surface of the catchment in trays and pipelines, and then transport by gravity or pressure collectors to local wastewater plant for surface runoff treatment with the using control tanks. On the inlet manifolds, there are overflows and regulating chambers for discharge, bypassing local WWTP, surface runoff during high intensity rains, and slightly contaminated sewage. To reduce the productivity of a local water treatment plant, there are equipped with accumulation tanks and sedimentation tanks. Then wastewater is treated and disinfected on treatment facilities, the approximate composition is as follows: 1. Mechanized gratings with clearances not exceeding 10 mm; 2. Sand traps with sand washing unit from organic impurities; 3. Accumulating reservoirs - sedimentation tanks; 4. Pumping station; 5. Post-treatment of surface runoff (clarifying filters with sandy, and two steps of carbon filters); 6. Disinfection of purified water with ultraviolet radiation.

In addition to the above, in the authors' opinion [9], biological treatment stage may be included in the WWTP. This solution is advisable to use at a high concentration in the surface runoff of biologically oxidized contaminants (BOD), as well as biogenic elements (nitrogen, phosphorus). For deeper treatment and intensification of the processes of surface runoff clarification, it is recommended to use reagent treatment with coagulants and (or) flocculants. With a proper justification it is advisable to apply flotation before filtration.

As for treatment the surface runoff from specific contaminants, several options are considered: sorption and membrane filters, reagent methods. Adsorption methods are widely used for deep qualitative water purification from dissolved organic (mineral oil) and mineral matters (metal ions, sulfates, hardness salts) [10-13].

One of the effective methods of water purification from soluble impurities is treatment by reagents. The use of "lime milk" (Ca(OH)₂ - solution) as a coagulant is due to the fact that calcium is an active metal that displaces heavy metals from soluble compounds, transforms them into insoluble compounds, and also precipitates various salts, including phosphates, sulfates and chlorides [14].

Membrane technology is quite promising for use at the stage of qualitative deep-water treatment. Fine membrane filters remove the salt and metals from the water. However, the big expenses for the equipment, operation and regeneration of units require taking measures to reduce the price of this technology [15].

There are interesting specific methods of wastewater treatment and disinfection using microwave electromagnetic technologies and ozonization [16].

3. Problem

It is generally recognized that surface waters are formed in an unstable regime. The non-permanent nature of the surface runoff effect on the state of a water body is complicated by the variability of the concentration of substances in the surface runoff dynamics. The list of pollutants has a wide spectrum
and ranges from easily soluble substances to heavy conservative impurities that have accumulative ability and form insoluble complexes. At the same time, the regulation of the pollution discharge should be carried out taking into account the change in water consumptions and pollutant concentrations [2, 17].

The issue of surface wastewater treatment was not given enough attention. It was believed that the pollution concentrations in rainwater is high only in the first 15-20 minutes of rain, so it does not damage the environment. However, in reality, the pollution concentration in these waters depends significantly on the construction area, the soil composition, geological conditions, and industrial development of the cities, climate and season [18]. It must be recognized that with the urbanization growth, the increase in the road transport intensity and the urban industry development, the quality of surface runoff has changed significantly. Surface waters include the toxic contaminants that are washed off the motorways - oils, carboys, fuel oil, chlorides, sulfates, iron, lead and other heavy metals [19].

In the study of the problem of water management and surface runoff treatment from the territory of Russian cities revealed that the purification process is most organized and regulated in the metropolitan cities.

The snow contaminations depend on the time of its staying on the roadway and the timing of subsequent removal. This is probably due to the periodic partial melting of snow with the preservation of most of the pollutions in it. Comparison of the mass of chlorides supplied with melt water, with the total amount of anti-ice reagents used in the city of Moscow (about 90 thousand tons by chloride), shows that about 15% of the anti-ice reagents enter to the snow-melting plants. The concentration of heavy metal ions in the meltwater runoff is higher than in the rainwater surface runoff: approximately 5 times higher for copper and zinc, and more than 10 times higher for lead, aluminum and petroleum products. When such flow enters the municipal sewerage for 4 or more months in a year, it is necessary to recognize that the quality of surface runoff in the winter period and the period of active snowmelt differs from the quality of "summer" surface runoff [20, 21].

The proposed treatment schemes and local wastewater treatment plants, unfortunately, do not take into account the climatic features of surface runoff formation, the difference between the qualitative and quantitative characteristics of rain and meltwater, the content of specific pollution associated with seasonal features of urban operation.

A technical analysis of more than 10 domestic local treatment plants was conducted. The fact has been detected, that the plants are not able to change the parameters of the operating mode and stages of the technological scheme depending on inlet water parameters.

Typical wastewater treatment schemes, mainly aimed at achieving the effects of rainwater purification, they do not have technological flexibility and therefore, as a rule, are not effective and even useless. In connection with the above problems, in Western Siberia, new runoff treatment plants for surface runoff are needed that can automatically change the process parameters (processing time, stirring intensity, dose and type of reagents, temperature, etc.). New smart-plants are able to work in the automatic mode, include or exclude the necessary water treatment steps, taking into account qualitative and quantitative characteristics of urban surface runoff.

4. Research and results

In connection with the above problems, surface runoff is selected as the object of research, which is formed on the territory of the city of Tyumen at different times of the year. Tyumen is a modern Western Siberian city, with a population of about 700 thousand people, it has developed infrastructure, transport, industry and its municipality is characterized by high social activity. The climate in the Tyumen city is boundary between Humid continental and Subarctic; therefor quantity and quality of urban surface wastewater formed depend substantially on the year season.

At the Department of Water Supply and Wastewater (Industrial University of Tyumen, Russia), calculations of the quantity and quality of rain, watering and melting surface sewage of certain urban areas were made. The main calculations and studies results are shown.
The quantitative characteristics of urban surface runoff are presented. The character of precipitation and the intensity of snow melting depend on climatic factors and are predictable only with a certain degree of probability. For comparison, the surface wastewater consumptions for some cities of the Tyumen North were calculated. In Table 1 it is presented that rainfall is the determining factor in the quantity, which can be formed in 2-4 times more than snowmelt water.

| Settlement | Surface wastewater consumptions (cubic meters from hectare per day) |
|------------|-------------------------------------------------------------------|
|            | Providing 63% (the period of a single excess of 1 year)            |
|            | Rain water | Melt water | Rain water | Melt water |
| Tyumen     | 243.3      | 96.0       | 131.1      | 48.0       |
| Tobolsk    | 270.6      | 76.8       | 134.5      | 38.4       |
| Surgut     | 237.2      | 76.8       | 152.3      | 38.4       |
| Salekhard  | 193.4      | 57.6       | 105.4      | 28.8       |

Table 1 – Surface wastewater consumptions [7]

Obviously, the sewage treatment regime depends on the kind of atmospheric precipitation, snow cleaning and snow removal, availability of snow melting plants and their productivity. In the main, if the snow accumulates in the dumps during the whole winter, then the input intensity of thawed waters into the sewage system will be determined by the time of spring snowmelt in the day warm hours. In this case, sewage will not come to the local treatment facilities in winter. If there is a snow melting plants in the settlement, it will be able to reduce the peak load on the rainwater drainage system in the spring. However, at the same time rain sewage and local treatment plants will work with a more or less constant supply of surface runoff sewage.

The qualitative characteristics of urban surface runoff are presented. To determine the quality indicators, the various parts of the urban area were chosen: the main roads with intensive traffic (group A) and the roadsides of secondary roads with less intensive traffic (group B). The obtained diagrams showing the seasonal variation in the concentrations of some surface runoff pollutants (suspended matters, chlorides and COD - chemical oxygen demand) are shown in Figures 1-3. To determine water quality indicators, standard laboratory methods and modern devices were used. The frequency of sampling of atmospheric precipitation was determined by the studies objectives, variability degree of the components concentrations and meteorological conditions.
Figure 1 – Suspended matters content change (mg/dm$^3$)

Figure 2 – Chloride content change (mg/dm$^3$)
The analysis results of seasonal variations of urban surface runoff for individual city area are shown in Figure 4. Comparing the different quality indicators of rainwater and meltwater runoff, the dirtiest is the melt runoff formed during the winter-spring snowmelt. The content of suspended solids in the snow cover exceeds the content in rain and sprinkling waters by 12-15 times, COD by 1.5-4 times, total iron by 23-32 times, chlorides by 76-103 times. The amount of oil products on the contrary falls by 50%, since the decrease in roads traffic in winter.

5. Discussion
The possible solutions of problem is proposed for discussion. In the operation process of local plants for water treatment, it is necessary to change flexibly technological schemes and modes of surface runoff treatment depending on the year season. A new concept of a functional scheme for the automation of such a purification station under northern climatic conditions are presented below (Figure 5).
Figure 5 - The example of a functional scheme of sewage treatment facilities for surface runoff

D1, D2 - dosing devices; MCh - mixing chamber; mF1, mF2 - mechanical filters; sF1, sF2 - sorption filters; CB1 - CB5 – control blocks

These intelligent engineering solutions will reduce the anthropogenic impact on the surrounding urban environment; increase the efficiency of treatment and the quality of water at the outlet from the WWTP.

This functional scheme includes separate cleaning stages for "summer" and "winter" surface runoff. The main differences at the stages are different types of reagents and their doses, various filter sorbents. For this, it is not necessary to provide additional capacitances and parallel filters. Perhaps, in certain periods (approximately 2 times a year), reagents and filtering charges should be replaced during operation. The change of cleaning parameters (for example, sedimentation time of suspended substances, filtration rate, reagent doses, etc.) should be performed automatically.

Obviously, this additional options and automated control of the wastewater plants make the treatment processes more expensive. However, if it takes into account the prevented damage to the urban environment, and especially to the water bodies - the sources of drinking water, then such high costs for the "smart" drainage system of surface runoff justify themselves.

Until the design stage, such local treatment plants require a more thorough study of the issue, including a technical and economic feasibility study in each case. This approach to the automation system should generate a sufficiently large amount of data of scientific and practical interest.

6. Conclusions

The solution of the qualitative treatment problem of surface runoff will help to preserve the quality of water bodies located in the urban environment. In northern climatic conditions, local treatment plants for cleaning rain and melt sewage must take stock the sudden change in quantity and quality depending on the season. It is also necessary to provide for the specific impurities purification (oil products, chlorides, metal ions and others). It is possible if the station automatically changes the
technological steps and water treatment parameters. The proposed functional scheme of a flexible sewage treatment plant is one of the variants of the conceptual approach to solving the indicated problem. Such a circuit should operate in two modes, using remote control capabilities and modern sensory equipment.

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