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Investigation of Rainwater Infiltration with Emphasis on Hydro-geological as well as Hydrological Conditions

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Abstract. Urban drainage has become one of the most important aspects of urban development. Ensuring long-term functioning of sewer systems and waste-water treatment plants is associated with constantly rising costs, and it is clear nowadays that the contemporary method of urban drainage cannot possibly be implemented worldwide because of the financial burden. The existing method of urban drainage continues to threaten the status of water flow and water sources. Urban hydrology has evolved to improve the way urban run-off is managed for flood protection, public health and environmental protection. The essence of the future solution resides in finding an acceptable compromise or an alternative solution for rainwater drainage from urban areas. The content of this paper is research focused on the infiltration of water from surface run-off and comparison of ground testing, laboratory analysis and numerical analysis of filtration coefficient. The foundation for improving the effectiveness of urban drainage will be created through the proposal and comparison of infiltration conditions. The topic of the paper emerged because of insufficient information about infiltration systems in the Slovak technical regulations and the lack of support for water infiltration from surface run-off. This paper points out the fundamentals, principles and development of proposals for infiltration facilities. The aim of the paper was to expand the body of scientific knowledge in research and solutions for infiltration of water from surface run-off with emphasis on the infiltration capacity of the selected area and intensity of precipitation.

Keywords: infiltration facilities, rainwater, hydrology, hydrogeology.

Conference topic: Water engineering.

Introduction

Urbanisation is typically accompanied by increases in impervious surfaces such as roofs and roads, construction of hydraulically efficient drainage systems, compaction of soils, and modifications to vegetation. This results in increased flood flows and stream erosion, and the potential for decreased base-flow (Paul, Meyer 2001; Elliot, Trowsdale 2007). Currently, there is a new trend in the approach to the development of schemes of run-off and water quality with increasing interest and recognition that restore the natural water balance and contribute to a healthier environment and improve the quality of the urban landscape. Previously rainwater was considered only a nuisance, but now it is considered with increased interest as a resource. Despite this progress, there are still many uncertainties in urban hydrology. Further research is required into the space-time dynamics of urban rainfall, particularly in order to improve short-term forecasting of rainfall.

Drainage systems are needed in developed urban areas because of the interaction between human activity and the natural water cycle. This interaction has two main forms: the abstraction of water from the natural cycle to provide water supply for human life, and the covering of land with impermeable surfaces that divert rainwater away from the local natural system of drainage (Butler, Davies 2011).

All the issues and challenges of uncertainty are masked by climate change, which imposes an obligation to ensure that rainwater management systems are adaptable and open to change. Urban hydrology plays an important role in solving these problems. The science of urban hydrology was developed to improve urban water management for public health and sanitation, flood protection, and the protection of the environment and urban life (Krejčí *et al.* 2002; Hlavínek, Stránsky 2010). Management of urban run-off involves several disciplines: engineering, environmental science, public health or sociology. Urban hydrology is far from simple and requires the development of new technologies which can deal with technical problems in the cities, and that address the needs of urban communities. The ability to measure and model the hydrological variables and processes depends on the ability to measure and predict rainfall at a high level of temporal and spatial precision. This requirement is especially relevant in the case of towns. This has led to many innovations in measuring precipitation, such as the use of digital rain gauges and development of rainfall models for the simulation of rainfall run-off processes in urban environments.

In many urban areas, drainage is based on a completely artificial system of sewers: pipes and structures that collect and dispose of run-off water. In contrast, isolated or low-income communities normally have no main drainage. Waste water is treated locally (or not at all), and storm water drains naturally into the ground. These sorts of arrangements generally exist where the extent of urbanisation has been limited. Recent thinking towards more sustainable drainage practices encourages the use of more natural drainage arrangements wherever possible (Butler, Davies 2011). In the last few decades it has developed a wide range of approaches to mitigating hydrological impacts as well as impacts on water quality as a result of urbanization. However, significant controversy persists over the best approach to dealing with drainage of precipitation and storm water in urban areas and it is still a complex and complicated area of research. There is a new trend towards a more integrated approach to coping with changes in flow regime as well as water quality, including trying to treat rainwater as a resource, a means to an end, and not a waste product that should be discarded. Development of integrated models to predict and assess the effectiveness of alternative approaches to rainwater drainage in cities, considered to be part of the wider urban water cycle, has thus recently attracted considerable attention.

This paper deals with the issue of urban hydrology and the management of rainwater. It presents the results of research into related problems carried out by the Faculty of Civil Engineering at the Technical University of Košice in Slovakia.

Material and Methods

The purpose of the research is to draft conditions of percolation, based on analysis of rainfall and a geological survey of the site for the needs of urban drainage. The methods used are based on practical experience as well as lessons learned from available literature and consultation with experts dealing with this topic in practice.

The research is designed in line with Slovak law, specifically Law no. 364/2004 Coll. (the Water Law) as amended by Law no. 394/2009 Coll., Government Regulation no. 269/2010 Coll. laying down the requirements to achieve good water status, and Decree no. 397/2003 Coll. establishing the details of measuring the amount of water supplied by public water supply and the amount of discharged water, dealing with the method of calculating the amount of waste water and water pollution from surface run-off, and guide figures for consumption of water. The research takes into account the existing foreign directives and standards, for example German standard DWA-A 138E covering the design, construction and operation of facilities for infiltration rainwater, or Czech standard 75 9010 regulating the acquisition of devices for percolation.

The aim of the research is to expand the body of scientific knowledge in the field of research and addressing the drainage of water from surface runoff with emphasis on the retention capacity of the selected area and intensity of rainfall. The research is directed to the following Zeleňáková, Rejdovjanová 2011; Zeleňáková *et al*. 2011; Markovič *et al*. 2014):

- design of intensity and periodicity of rainfall as an input value for infiltration facilities proposal;
- description of the scope of geological survey for the purposes of rainwater infiltration;
- solving and research of the relationship of rainfall intensity and drainage of water from surface runoff;
- set the conditions for infiltration facilities of rainwater.

The research has included various methods. Field trials used real measurements of rainfall parallel with rainwater infiltration. Laboratory analysis determined the grading curve and subsequent filtration coefficient and numerical analysis included the modeling of infiltration. Numerical analysis included empirical relationships and dimensional analysis. A detailed description of the research methods is given in (Hudáková 2015). The result of the research is design of conditions for infiltration.

The aim of the research is to expand the body of scientific knowledge in the particular field, and address the drainage of water from surface run-off with emphasis on the retention capacity of the selected area and intensity of rainfall. The research focuses on the following:

1. design values for the amount of rain water monitoring data;
2. description of the scope and modalities of implementation of geological exploration for drainage of rainwater;
3. investigation of the relationship between intensity of rainfall and drainage of water from surface run-off;
4. setting the conditions for infiltration of rainwater.

As is apparent from the scheme of Fig. 1, four methods of research are proposed: Field trials using real measurements of rainfall infiltration; Laboratory analysis determining the grading curve and subsequent filtration coefficient, and numerical analysis of the modelling. Numerical analysis includes empirical relationships and dimensional analysis. A detailed description of the research methods is given in [1]. The result of the research is the designation of conditions for infiltration.

Results

Research results include field measurements of precipitation totals and their comparison with the design values – intensity, duration, frequency (IDF) curves (Fig. 1). Rainfall during the reporting period did not exceed the totals in Kosice with a periodicity of 0.2, which is used in accordance with German standard DWA-A 138 or Czech standard CSN 75 9010 for the design of infiltration facilities. We calculated minimum and maximum rainfall intensities from rainfall events for Košice, which we compared with design tables issued by the Slovak Hydro-meteorological Institute (SHMÚ) for the Košice-Barca rain gauge station. They were exceeded only by rainfall intensity with frequency 5 (Fig. 2). The rainfall intensity during the reporting period of three years did not exceed the intensity and frequency of 0.2; 0.5; 1; and 2 at the Košice-Barca rain gauge station. It follows that the use of the frequency of rainfall intensities 0.2 for sizing the infiltration devices is also suitable in Slovakia. The duration of block rain prepared by the SHMÚ for rain gauge stations in Slovakia is useful, despite the time of processing the tables (year 1968). Fifty year old tables are still valid and also applicable nowadays, although the time of climate change is still ongoing.

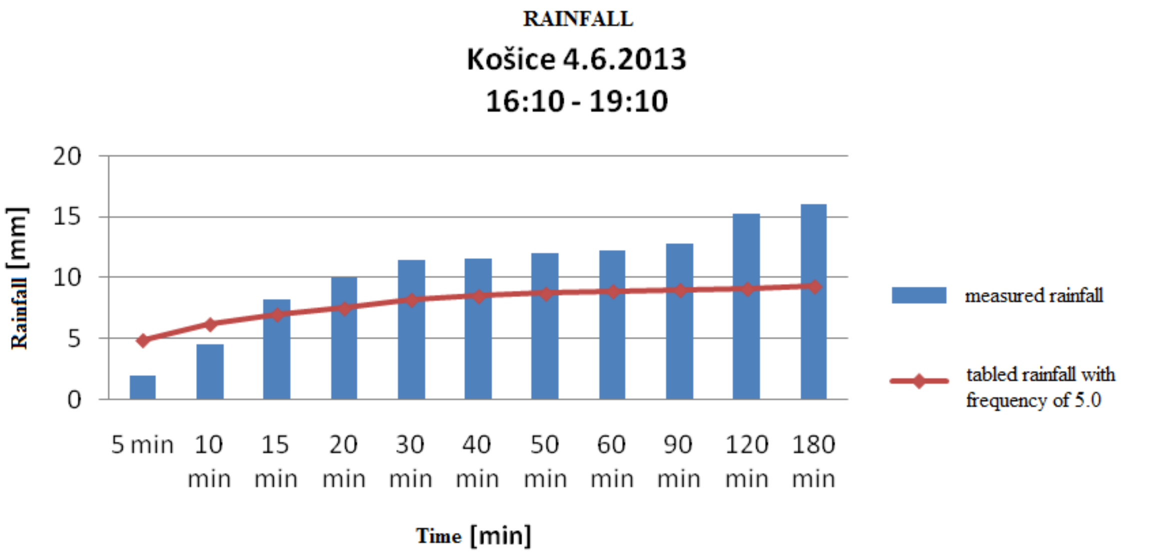

Fig. 1. Comparison of measured rainfall (4.6.2013) and tabled rainfall with frequency of 5.0

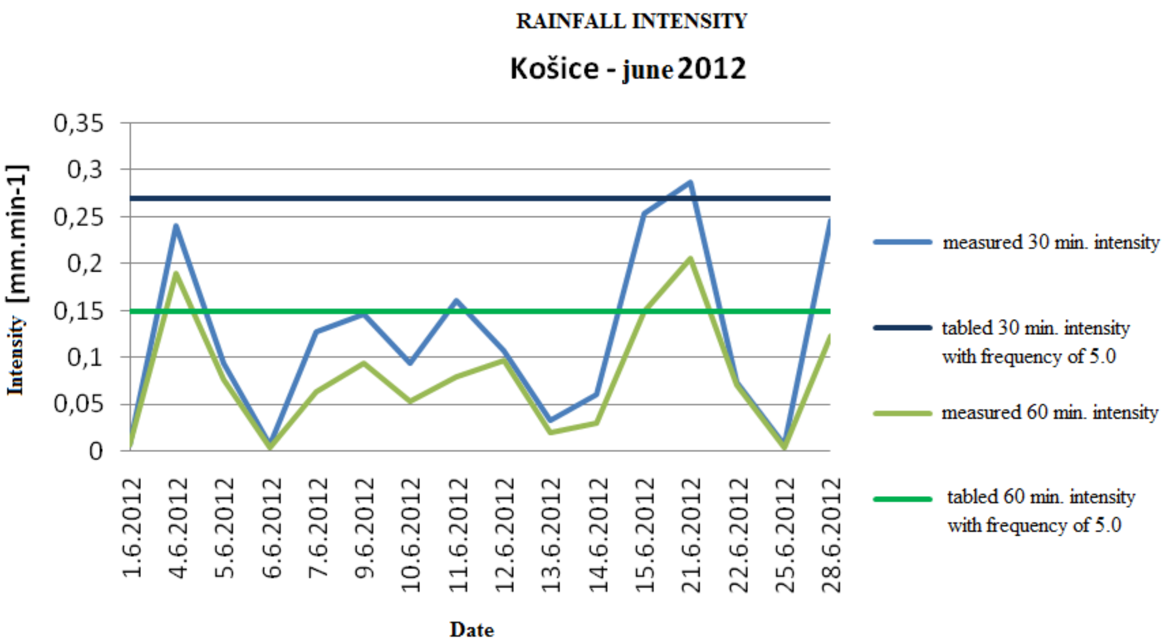

Fig. 2. Comparison of measured and tabled rainfall intensity (IDF curves), with frequency of 5.0

One of the main conditions of applying the percolation device is effective slow and gradual emptying, which must not exceed 72 hours according to CSN 75 9010, or three days according to DWA-A 138E. This was confirmed for the monitored rainfall events. Within the research we designed a model to calculate the duration of emptying which may be used in variations of the area of the percolation device.

This requirement is closely related to soil parameters and the hydro-geological conditions in the subsoil. According to the available standards the bottom of the percolation facility should be located at least 1.0 meters and in the case of infiltration shafts at least 1.5 meters above the maximum groundwater levels (CSN 75 9010), and the filtration layer should be in the range of the filtration coefficient (k_f) of 5.10^{-3} to 5.10^{-6} ms^{-1}.

The bottom of the infiltration shaft which is located in the area of the university campus in Košice is located in a layer of gravel with a share of fine-grained soils in which $k_f = 1.10^{-3}$ and 1.10^{-4} m s^{-1} (Fig. 3). These are neogene sediments, creating favorable conditions for the concentration of large amounts of groundwater. For this reason the spring months state is maintained at the bottom of the well and the water flows very slowly. Most certainly this has to do with the moving water table, which is usually higher in the spring after the snow melts, as well as the location of the bottom of the well, and also the engineering-geological profile, where the layer of gravel admixture of fine-grained soils (symbol GF, class G3) is clayed gravel (GC class G5), in which the filtration capabilities are lower.

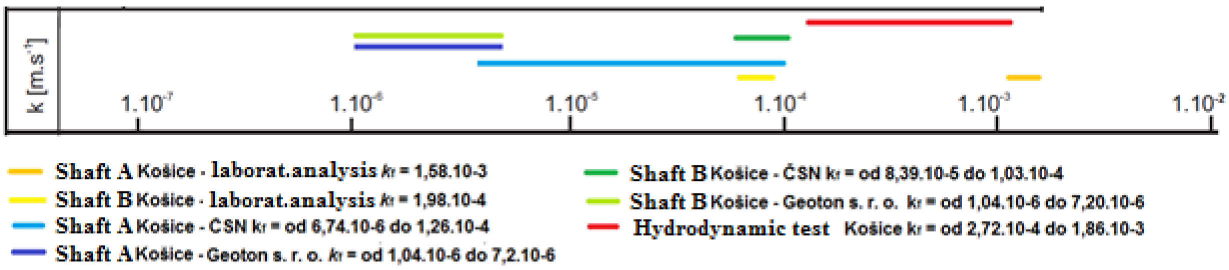

Fig. 3. Scheme of filtration coefficient results in Kosice determined by various methods

Hydrodynamic test results in some cases coincide with CSN 75 9010, the Final Report by Geton s.r.o., as well as laboratory analysis.

Conclusions

Urban drainage presents a classic set of modern environmental challenges: the need for cost-effective and socially acceptable technical improvements in existing systems; the need for assessment of the impact of those systems; and the need to search for sustainable solutions. As in all other areas of environmental concern, these challenges cannot be considered as being the responsibility of one profession alone. Policy-makers, engineers, environment specialists, together with all citizens, have a role to play. Moreover, these roles must be played in partnership. Engineers must understand the wider issues, while those who seek to influence policy must have some understanding of the technical problems (Butler, Davies 2011).

This research provides information addressing the issue of urban drainage. The research issue becomes the subject of a solution resulting in establishment of the design parameters of percolation/ infiltration facilities. The importance of this work lies mainly in the draft of conditions for percolation/ infiltration facilities in the Slovak Republic. The conclusions will form the basis for further research in the field of urban drainage, as the need for drainage of rainwater is still increasing.

For the proper proposal of any rainwater drainage system, the most important criterion is the quality of surface water and suitability of the ground for rainwater infiltration. For the design and construction of percolation facilities the following are certainly critical (Hudáková 2015):

- diagnostics of wider relations to assess the impact of groundwater on the ecosystem,
- configuration of the terrain,
- direction of groundwater flow,
- depth of groundwater level,
- hydraulic gradient calculated as the distance from the nearest construction,
- direct distance of recipient (water flow).

In conclusion, it is clear that the basis of an optimally designed infiltration system certainly lies in good geological and hydrological surveys. Accurate measurement is important with regard to the filtration rate of the filtration layer, but also other flow properties of the soil. The particular merit of accurately establishing these characteristics lies crucially in the calculation of discharge times of infiltration devices, contributing to the optimal design of the devices themselves. In the case of inaccurate data, in times of extreme rainfall there is the risk of overflow of the shaft.

The problem seems to be that we lack effective legislation that would precisely define the entry requirements for the design of infiltration facilities in Slovakia. New legislation should therefore be addressed not only to establishing the conditions of drainage of rain water, but should specify the extent and manner in which the hydrological, geological and hydro-geological surveys have to be done.

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