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Petr Hlavínek
Martina Zeleňáková *Editors*

# Storm Water Management

## Examples from Czech Republic, Slovakia and Poland

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Editors
Petr Hlavínek
Faculty of Civil Engineering
Technical University Brno
Brno
Czech Republic

Martina Zeleňáková
Technical University of Košice
Košice
Slovakia

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# Preface

The aim of the publication "Storm Water Management, Examples from Czech Republic, Slovakia and Poland" is to provide a knowledge and experience mainly for professionals, researchers, lecturers and academics in the field of storm water management. The importance of this topic in the time of climate change is growing. There is increasing emphasis these days on storm water management mainly in urban areas. The publication deals with the topic of incorporating rainwater back into the natural water cycle as close as possible to its source. This solution is hydrologically and technically meaningful and may be advantageous in terms of the national economy. The publication aims to familiarize candidates with the procedures and principles of the use, retention and infiltration of rainwater mainly from point of view of the experts from V4 countries. Rainwater management measures applied to individual property are among those that can be described as measures applied at the source. These measures are usually not only technically effective but also cost-effective. We hope that professionals and scientists in the field of interest covered in the book will find it a useful reference source. The publication is output of International Visegrad Fund's Strategic Grant No. 31210009. The support of International Visegrad Fund is greatly appreciated.

Brno, Czech Republic — Petr Hlavínek
Košice, Slovakia — Martina Zeleňáková

# Contents

# Contributors

Vojtech Bares Faculty of Civil Engineering, Czech Technical University in Prague, Prague, Czech Republic

Józef Dziopak The Faculty of Civil and Environmental Engineering, Rzeszów University of Technology, Rzeszów, Poland

Lenka Gernešová Faculty of Forestry and Wood Technology, Mendel University in Brno, Brno, Czech Republic

Petr Hlavínek Faculty of Civil Engineering, Brno University of Technology, Brno, Czech Republic

Ivana Kabelkova Czech Technical University in Prague, Faculty of Civil Engineering, Prague, Czech Republic

Daniela Kaposztásová Faculty of Civil Engineering, Technical University of Košice, Košice, Slovakia

Sabina Kordana The Faculty of Civil and Environmental Engineering, Rzeszów University of Technology, Rzeszów, Poland

Gabriel Markovič Faculty of Civil Engineering, Technical University of Košice, Košice, Slovakia

Jana Marková Faculty of Forestry and Wood Technology, Mendel University in Brno, Brno, Czech Republic

Petr Pelikán Faculty of Forestry and Wood Technology, Mendel University of Brno, Brno, Czech Republic

Miloslav Šlezingr Faculty of Forestry and Wood Technology, Mendel University in Brno, Brno, Czech Republic

Daniel Słyś The Faculty of Civil and Environmental Engineering, Rzeszów University of Technology, Rzeszów, Poland

Agnieszka Stec The Faculty of Civil and Environmental Engineering, Rzeszów University of Technology, Rzeszów, Poland

David Stransky Faculty of Civil Engineering, Czech Technical University in Prague, Prague, Czech Republic

Zuzana Vranayová Faculty of Civil Engineering, Technical University of Košice, Košice, Slovakia

Martina Zeleňáková Faculty of Civil Engineering, Technical University of Košice, Košice, Slovakia

Adéla Žižlavská Faculty of Civil Engineering, Brno University of Technology, Brno, Czech Republic

# Stormwater Management in Urbanised Areas

Petr Hlavínek

## 1 Introduction

Presently, stormwater in built-up areas and other areas with closed surfaces can hardly find a natural path to reach the natural water cycle. This may result in gradual, long-lasting changes in soil structures and water regimes, entailing a reduction in the natural local groundwater replenishment and impacts upon the chemical and biological conditions over and under the ground. Furthermore, harmless drainage of surface runoffs, in particular extreme runoffs during heavy rain events, calls for substantial technical and financial considerations during the stage of designing, construction and operation of sewer systems and wastewater treatment plants. However, despite all technical measures, some extreme runoffs do reach surface water. This may result in flood events, or increased pollution in small water courses in catchment areas with a major share of urban development. Considering the potential pollution that may be released in the drained area, the reintroduction of stormwater into the natural water cycle as close as possible to the point of its impact is an objective that is meaningful in environmental, water management and technical terms, and may also be advantageous in terms of the national economy. Therefore, while taking into account the local conditions, it is vital to primarily pursue the surface runoff reduction and its local infiltration, and, secondly, resort to conveying stormwater in sewer systems.

In anthropogenically intact country, up to 99 % of stormwater gets infiltrated, is absorbed by plants or evaporates. The expanding housing development and road construction for the growing number of people, and management of forest and agricultural land have changed the natural hydrological cycle. Vast stretches of land consist of hard standing surfaces (roads, pavements, built-up areas) which prevents

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P. Hlavínek ( & )
Faculty of Civil Engineering, Brno University of Technology,
Zizkova 17, 602 00 Brno, Czech Republic
e-mail: hlavinek.p@fce.vutbr.cz

 
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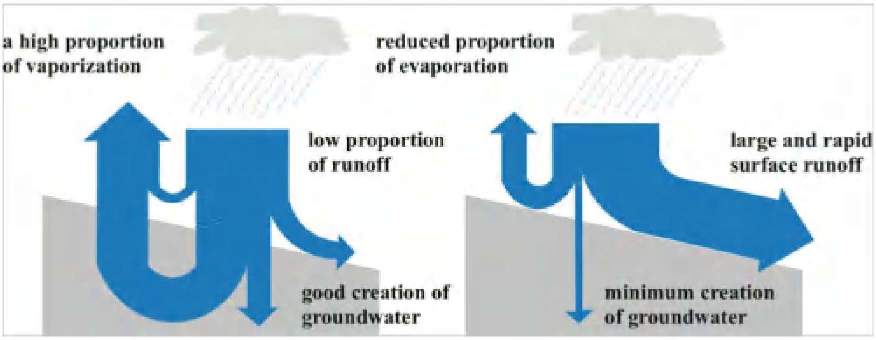


Fig. 1 Water regime in permeable and hard standing surfaces

from stormwater infiltration back into the soil and thus disables groundwater replenishing. Instead, most of the stormwater is conveyed by sewers to the nearest receiving bodies of water. This water washes off impurities from the hard standing surfaces and therefore shows quite substantial pollution. The different runoff ratios are shown in Fig. 1. As regards roofs and surfaces made of asphalt and concrete, the runoff reaches 90–100 %.

The increasing share of hard standing surfaces results not only in rising surface runoff but it also entails a reduced rate of groundwater recharge. At low flow rates, there is a growing gap between the excessive flood situations and drying out streams. This may generate a number of problems such as floods, erosion, pollution, lowering groundwater levels (Fig. 2). The movement between groundwater and surface water depends on the relative position of the water table. Groundwater increases the basic discharge in free flowing water or the water level in lakes, if the groundwater level is higher than the surface water level and, on the contrary, surface water infiltrates into the ground if the groundwater level is lower. In this case, it may happen that weak water streams dry out and only carry water during rain events. Plants and animals depending on humid environment then lose their natural habitats. The lower groundwater level, lower soil moisture content and missing vegetation may also change the regional climate (Krejčí et al. 2002).

Stormwater retention and infiltration on site has also a positive effect on the operation of wastewater treatment plants. Combined systems that convey stormwater along with sewage water often result in increased influent to the wastewater treatment plants during rain events and their hydraulic overloading. Treatment plants fitted with activation tanks may experience turbidity in the effluent.

Stormwater retention and infiltration on site may also reduce the rate of loading the water course by the combined and separate sewerage. In combined sewerage, the potential cause of toxic pollution of water courses is mainly rainfall of a low intensity. In such a situation, wastewater that is relatively little diluted overflows into the receiving body of water.

Reducing the runoff volumes and flow peaks entails lower capex and opex of urban drainage systems (Geiger and Dreiseitl 2001).

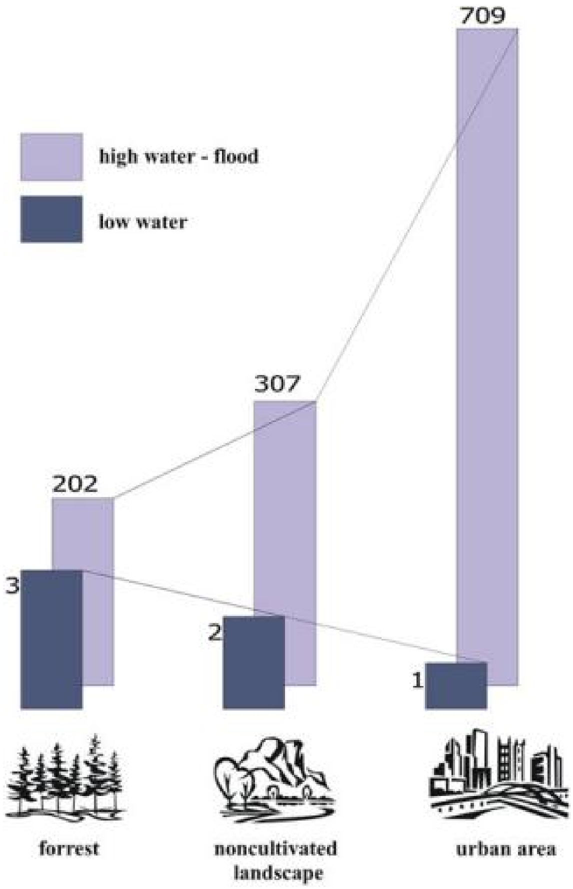


Fig. 2 Runoff volume [l $s^{-1}$ $km^{-2}$] at high and low water level for various soil utilisation

## 2 History of Stormwater Management

Various solutions to the urban drainage systems date back to antiquity. The so-called "cisterns"—underground reservoirs with a capacity up to 1000 $m^3$ were built already in the ancient times, storing stormwater for various needs of the society at that time (Garbrecht 1987).

- 3000 BC, many meters deed shafts were dug up in Babylon to infiltrate stormwater and wastewater from kitchens and baths in houses and palaces (Geiger and Dreiseitl 2001).
- Thanks to loosely connected stone blocks, the Roman streets enabled stormwater infiltration(Fig.3); however, they were also often connected to sewerage through storm drains. Water retention space was defined by high shoulders. Walkable stones were used to cross the streets (Geiger and Dreiseitl 2001).

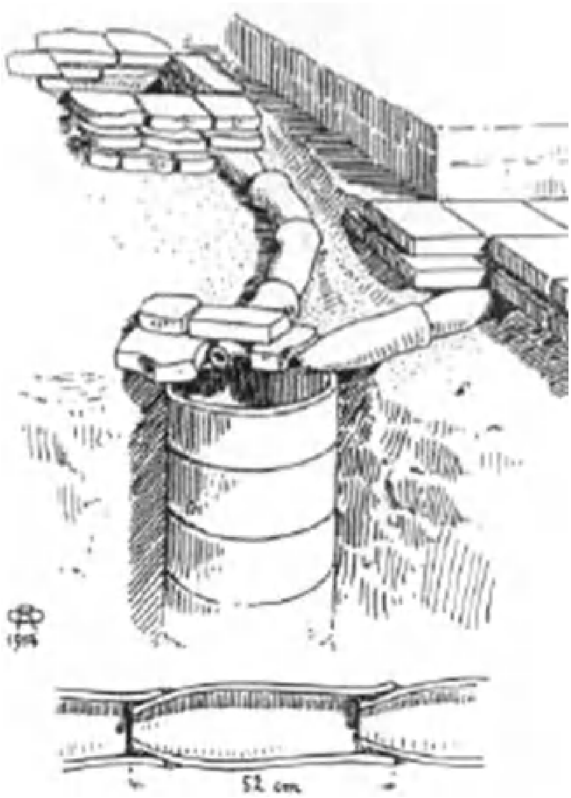


Fig. 3 Infiltration shaft with an inlet

- Many residential houses in the Roman Empire were fitted with open water reservoirs in open atriums which collected stormwater from roofs. Overflows drained into underground cisterns protecting water from evaporation and pollution, while maintaining its relatively low temperature. At the beginning, the systems were not central, and later on, the central systems were established.
- Excavation sites in Pergamon (Asia Minor) reveal a total of 80 cisterns with a capacity between 10 and 130 $m^3$ covering an area of 8 ha. The cisterns were carved in rock, were pear-shaped and their narrow necks were covered with stone plates.
- One of most famous examples in the world is Masada, a rock massif, located in a desert west of the Dead Sea. This system is unique as to its type and size. At the top of the rock there is a plateau that is 650 m long and 300 m wide. Approximately 100 BC, a number of cisterns were built here for the fortress and palace to retain occasional but heavy rains. The two largest cisterns have a capacity of 750 and 1000 $m^3$.
- The largest stormwater reservoir in the Middle Ages was probably a cistern in Constantinople with a volume of 80,000 $m^3$ (ground plan of 140 × 70 m with a

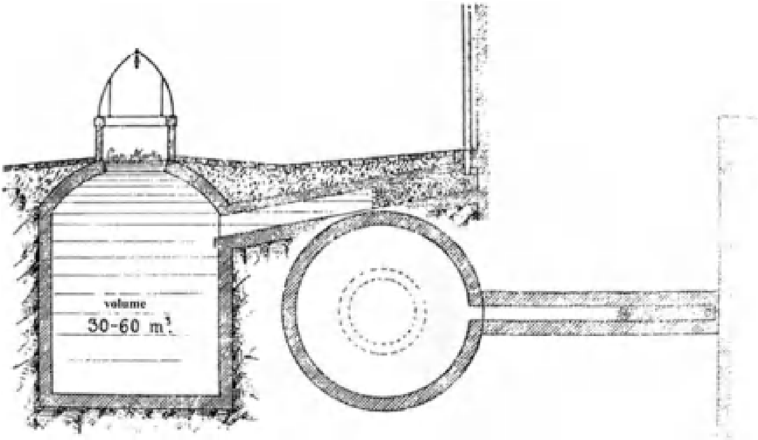


Fig. 4 Cistern with inlet filtration at the railway buildings

number of decorated marble columns), which is presently a tourist attraction called the "cathedral under water" (Garbrecht 1987).

After the fall of the Roman Empire, a great part of the ancient knowledge fell into oblivion. Catastrophic hygienic conditions in the fast-growing cities resulted again in the construction of public as well as private facilities for water storage with simple water treatment. Stormwater cisterns formed important elements of these systems, and were fitted with simple filtration systems

- Before introducing a central drinking water supply system in the 19th century, there were over 4500 stormwater cisterns in Venice (Fig.4), every third of them used to supply drinking water. Cisterns installed at railway houses (e.g. the route from Ljubljana–Trieste from the mid-19th century) are also well known (Schmidt 1986).
- The use of cisterns is still common in scarcely populated areas and in areas with extreme time—related distribution of rainfalls.
- The use of cisterns is still common in scarcely populated areas and in areas with extreme time—related distribution of rainfalls.
- Berbers in Tunisia use cisterns with a capacity of several thousands litres per family (Krejčí and Kol 2002).

## 3 Supporting Data and Planning Assumptions

By transposing the European legislation into the Czech system of technical standards, a new philosophy of urban drainage and water course protection has been established. The objective of this new approach to urban drainage is to control or, possibly, reduce the volume of stormwater runoff, reduce the frequency of property flooding, mitigate the total conveyed pollution and minimise the impacts on the receiving bodies of water while preserving the water courses and groundwater resources in a condition which will make it possible to fulfil their other functions while achieving sustainable development of towns and municipalities.

The deepening knowledge of the mutual interactions between sewerage systems, wastewater treatment plants and water streams results in the main feature of the new drainage conception (Geiger and Dreiseitl 2001):

- reduce the direct runoff through stormwater.
- fag store stormwater runoff incapable of direct infiltration in the individual houses and ensure slow infiltration or delayed discharge into the water course,
- store stormwater runoff incapable of direct infiltration in the individual houses and ensure slow infiltration or delayed discharge into the water course,
- utilise stormwater,
- store and clean unavoidably polluted water.

There are many approaches to technical utilisation and integration of these facilities in urban systems. In particular, stormwater must be retained and infiltrated on site (Geiger and Dreiseitl 2001):

- if new construction sites are to be developed,
- if it is necessary to reconstruct the existing sewerage and reduced runoff may result in smaller profile diameters so that the new pipe may be pipe jacked into the damaged sewers,
- if the sewerage is hydraulically overloaded, and stormwater infiltration may reduce the peak runoffs to such an extent that the existing pipe diameters will be sufficient,
- if wastewater treatment plants get overloaded during rain events,
- if the ratio of low water level medium flow rate to medium flood discharge rate exceeds 1:20.

## 4 Possibilities of Stormwater Management Given the Type of Development

Various types of development offer different possibilities of stormwater management (Emschergenossenschaft 1993) shrubs.

### 4.1 Localities with Existing Buildings

Additional implementation of stormwater management facilities in existing housing estates is restricted by the structure of the residential districts (Geiger and Dreiseitl 2001).

### 4.1.1 City Centres

City centres feature high density of urban development, which entails the highest degree of hard standing surfaces. In these densely populated central zones with closed blocks of flats on the outskirts and various use of land the infiltration of stormwater is almost impossible due to the lack of vacant spaces. The degree of hard standing surfaces is usually between 95 and 100 %. Green roofing which provides an alternative possibility of stormwater retention given the high degree of hard standing surfaces can only be implemented in a limited scope in the existing urban development. Green roofing (based on the season and layers of vegetation) retains 50–70 % of the rainfalls. It is then also possible to use water cisterns for stormwater reuse.

### 4.1.2 Municipal Residential and Mixed Localities

Residential and mixed localities near the city centres also feature high density of urban development due to the prevailing blocks of flats on the outskirts (degree of hard standing surfaces between 60 and 80 %). Therefore, the possibilities of stormwater infiltration are substantially restricted here, too. There are subject to ownership rights and divided into very small plots, with a partial commercial use of the ground floors and inside the blocks and with large-size garages. These boundary conditions make the specific solutions and conceptions unifying the land ownership rights for the purposes of constructing reservoirs and infiltration facilities difficult.

### 4.1.3 Municipal Residential Zones

There is a growing size of municipal residential zones with closed blocks of flats on the outskirts and rows of detached houses the yards of which are used as gardens. The degree of hard standing surfaces here is from 50 to 80 %. Given suitable soil conditions, local measures are possible, which can be coordinated on the basis of the heterogenic structure of ownership. If the buildings are in possession of owners such as housing associations or housing co-operatives, the removal of hard standing surfaces in the internal spaces may provide larger vacant spaces. Before taking measures in the vicinity of the residential zones it must be verified to what extent any of the stormwater infiltration methods may be applied.

### 4.1.4 Detached Houses

Localities with detached houses are characterised by open housing development (degree of hard standing surfaces of 20 %) and generously conceived private free spaces with a major share of gardens. Given the large scope of free spaces, this offers good conditions for the individual stormwater infiltration facilities as well as for solutions going beyond the borders of the plots of land.

### 4.1.5 Commercial Zones

Commercial zones have a major share of hard standing surfaces, wide hard standing roads, hall and paved and asphalt external spaces which leave little room for greenery. This is also reflected in the high degree of hard standing areas between 80 and 95 %. This necessitates a different analysis of the conditions of stormwater infiltration. Strongly polluted water must discharge into sewerage. Harmless polluted stormwater from hard standing surfaces can be, for example, infiltrated through a vegetation layer. It is usually necessary to plan measures to check the storage of substances that endanger groundwater during incidents or fires.

### 4.1.6 New Housing Development

With respect to new housing developments it is possible to integrate a different approach to stormwater in the municipal urban plan conception from the very start. Potential measures include:

- to use loose programmes for hardstand surface treatment, which gradually reduces the share of current impermeable hard standing surfaces,
- to use technical methods encouraging infiltration for stormwater drainage from impermeable areas and to make sure that the stormwater runoff is reduced to a level of the natural runoff,
- to generally prefer stormwater drainage from the land along the surface. This is enabled by various types of ditches, gullies and trenches and (enabling partial infiltration—and also by soil filtration and sedimentation of settleable substances),
- to use contour furrow to drain stormwater from parks (natural ditches with a meandering route), possibly with dams and small lakes,
- to infiltrate stormwater in the plots of detached houses,
- to install stormwater storage tanks to retain floating sediments upstream the stormwater sewerage outlet or a combined system overflows discharging into a water course,
- to protect water courses from pollution related to potential infiltration of undesirable substances by installing stop logs shutting off the discharge into the water stream and boosting infiltration of retained water,
- to use permeable materials for hard standing surfaces where there is no risk of water pollution. Discharges from parking lots and lay-bys should be conveyed via systems eliminating oil products and oils.

# 5 Design Data

To develop a design, valid planning supporting data must be available. shrubs.

## 5.1 Type of Catchment Area

The possibilities of using various stormwater management systems differ as to the type of urban development in the relevant locality (residential, mixed, industrial, etc.).

- Map data
  - Layout
  - Urban plan
  - Drainage plan (for the existing development)
  - Altimetry
- Geological and hydrogeological data
  - Soil structure
  - Soil infiltration capacity
  - Distance of the groundwater level
  - In areas experiencing subsidence, landslides following erosion, in undermined localities and if there is a risk of scouring effect it is necessary to examine the effect of infiltration on geological stability.
  - Old environmental pollution

### 5.1.1 Hydrological Conditions

Hydraulic calculations require information about the course of the rain event or, potentially, design rain. Rainfall intensity changes in dependence of a number of factors. Altitude has a substantial effect on the average yearly rain precipitation. As some of the factors (for example, the occurrence of rain shadows) cannot be captured in general, it is always recommended to draw upon long-term measuring conducted by local hydrometeorological stations.

- Type of hardstands (types of impermeable surfaces) to determine the runoff coefficient of the relevant surface
- Survey into the quality of surface water and groundwater
- Concentration of stormwater pollution
  Determination of ownership rights

## 6 Volume of Retained Stormwater

The volume of retained stormwater $Q_d$ depends on the rainfall in the relevant locality, size of the area and the runoff coefficient.

$$Q_D = w \cdot A \cdot H_N \left[\mathrm{m}^3\ \mathrm{year}^{-1}\right]$$

where

$\psi$ runoff coefficient as an index number [−]

$A$ ground area (horizontal projection) [$m^2$]

$H_N$ yearly rainfall [mm $rok^{-1}$ = l $m^{-2}$ $year^{-1}$]

## 7 Inputs to Select Materials

Stormwater reaches surfaces made of various materials. The choice of suitable materials for the surfaces and roofing may result in reduced runoff pollution by contaminants.

The most important materials for roofing, roads, spaces and streets and their hazard potentials are described below, potentially with their cleaning effect. The supporting data should be used to indicate the design considerations.

### 7.1 Roofs

Selection of roof materials for stormwater reuse and infiltration is most important. A green roof may filter off pollutants that reach water from the air. Discharged water is usually very clean but it can contain particles of soil. Concrete partially neutralises “acid rain”, but it can also contain some substances representing a load. Asbestos cement liberates lindane into water. Copper, zinc and lead are materials that are a source of a certain quantity of heavy metals in water (Bullermann et al. 1989) (Table 1).

### 7.2 Roads and Public Spaces

Roads, pavements, park pathways, play grounds, private or little frequented car parks and similar zones should be made of materials capable of infiltration so as to drain as little water as possible. Commonly used materials are shown in Table 2. Grassy layers form especially good filtration zones for polluted stormwater, which

Table 1 Potential of various roof material pollution (Bullermann et al. 1989)

| Roofing, waste pipes | Potential pollution |
|---|---|
| Roof grassing | None |
| Glass | None |
| Fired tile | None |
| Concrete blocks | Low |
| Man-made materials | Low |
| Asphalts | Medium |
| Fiver-reinforced concrete | Medium |
| Asbestos cement | High |
| Copper | High |
| Zink | High |
| Lead | High |

Table 2 Pollution potential and cleaning capacity of road and public space materials (Pietsch and Kamith 1991)

| Cover | Potential pollution | Cleaning capacity ability |
|---|---|---|
| Grass and plants | None | Treatment by biological degradation and organic Processing |
| Gravel and grass | None | |
| Turf block | None | |
| Water retaining surface | None | Mechanical cleaning |
| Paved surface | None | |
| Asphalt | Low | None |

applies both to pollutants in the air as well pollution caused, for example, by vehicles in parking lots. Little frequented parking lots, fire routes and tertiary roads may be grassed over, for example, by using turf blocks. Sandy joints of paved roads have a mechanical cleaning effect. These roads are usually made of granules of natural stone and do not endanger groundwater in any manner. Asphalt releases bituminous particles; however, these only result in a low groundwater pollution potential (Pietsch and Kamith 1991).

## 7.3 Roads

Roads exposed to heavy traffic (trucks) and public parking lots have a much higher share of pollutants endangering discharged stormwater than pavements and little frequented roads.

Therefore, pre-treatment before infiltrating water from roads is suitable. In many cases, a simple flowing through a grassy layer of soil is enough to eliminate and retain pollutants. This is sufficient to treat water from little frequented roads in residential areas, or commercial zones, which are comparable as to the share of harmful substances. For example, drained water may be pre-treated by being passed through natural wastewater treatment plants, or separation systems with post-treatment, e.g. a vegetation passage. Installation of such treatment systems in highly frequented roads and strongly polluted industrial zones is vital (Golwer and Schneider 1982).

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# Review of the Implementation Process of Sustainable Stormwater Management in the Czech Republic

David Stransky and Ivana Kabelkova

Abstract The paper describes a process of implementing sustainable stormwater management in the Czech Republic, including motivations behind the process, the situation in stormwater management before the implementation, actions undertaken during the preparation of a national stormwater concept, obstacles and the current status of implementation. The first large scale pilot study is given as an example of the process and lessons learned are summarized in order to give the experience to other countries.

## 1 Introduction

Sustainable urban drainage systems (SUDS) are systems promoting good practice leading to sustainability in the sector of urban drainage. Application of SUDS demands both philosophical and technical changes that must be incorporated in all forms of urban re/development and represents a shift from the traditional approach to an adaptive, participatory and integrated approach (Brown and Farrelly 2009). It means that SUDS implementation is not a task for water branch only, but an all-society task.

The process of SUDS implementation in the Czech Republic was delayed compared to the most developed countries. The reasons were: (i) the international isolation of the Czech Republic during the second half of the 20th century and (ii) the transition to capitalism after the revolution in 1989, which was in the first phases much more oriented on economical issues rather than on environmental and social ones. Till 2007, virtually no SUDS techniques were applied with exception

D. Stransky (&) · I. Kabelkova
Czech Technical University in Prague, Faculty of Civil Engineering,
Thakurova 7, 166 29 Prague, Czech Republic
e-mail: stransky@fsv.cvut.cz

I. Kabelkova
e-mail: kabelkova@fsv.cvut.cz

 
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of individual projects of environmental enthusiasts and EU financed projects (e.g. INTERREG IIIB CADSES project RainDROP, code: 5C052).

At the beginning of the year 2007, the situation in the Czech Republic was as follows:

- No decentralized stormwater management systems. In the past, most sewer systems in the Czech Republic were built as combined systems. Later, separate systems were constructed at the outskirts of municipalities. Decentralized systems for the retention and infiltration of stormwater were used only rarely.
- A lack of political will to implement sustainability principles in stormwater drainage. Other environmental issues, such as recycling of home wastes, highway construction in sensitive areas and industrial development projects, were considered more critical.
- An underestimation of urban drainage problems, a lack of awareness in society. The discharge of sewer systems and pollution in receiving water are often not visible, and thus these problems are underestimated by the public and politicians. A series of 10 floods in the rivers between 1997 and 2010 accompanied by casualties initiated a discussion on water in the society; however, most people do not relate the impacts in receiving waters to urban drainage. Major projects were directed towards flood protection.
- No legislation encouraging sustainability principles, no technical standards. The majority of engineers design traditional urban drainage concepts (see later); thus there is no need for technical standards regarding best stormwater management practices. The legal status of stormwater runoff and combined sewer overflows (CSOs) is not specified (CSOs overflows are not considered to be wastewater).
- Conservatism of engineers. Before the political changes in 1989, the urban drainage, as with other specializations, had lost contact with international research and development. During that period, many senior engineers were educated and started their work.
- Stormwater fees exist for only a minority of stormwater producers. Stormwater fees are regulated by Czech legislation and only apply to some impervious surfaces connected to combined sewers (mainly associated with companies) with many exemptions such as roads, rails, households and recreational buildings. The stormwater fee from impervious surfaces drained by storm sewers is not prescribed by law, i.e. the municipalities can regulate it themselves. However, no municipality yet collects this fee.
- Information and experience from abroad. Some of the community of engineers is aware of the problem and looks for information abroad (mainly from Germany). They have started to hold regular seminars on SUDS topics. Also, foreign manufacturers of artificial infiltration devices have started to advertise their products on the Czech market.

Increasing rate of urbanization and expected climate change have become the main driving forces for implementing sustainable stormwater management in the Czech Republic. These forces are manifested through an increased frequency of local floods (due to overloaded sewer systems or receiving waters), water quality deterioration, biodiversity degradation and decreased quality of living, with increased mitigation costs as a consequence.

The rapid urbanization occurred in the Czech Republic after the political changes in 1989. According to The Report on Environment (Ministry of Environment of the Czech Republic 2009), the annual urbanization of agricultural land increased from 0.02 % in 1994 to 0.18 % in 2009 (Fig. 1), i.e. nearly 14 ha are converted daily. Today, the urbanized area in the Czech Republic approaches 5000 $km^2$, i.e. 6.5 % of the country. Considering the mean rainfall height of 640 mm per year, and assuming an increase in surface runoff volume from original 10 % for a natural catchment to 35 % for an urbanized catchment (Paul and Meyer 2001), the natural annual flow volume from the Czech Republic to neighboring states has increased by 0.8 $km^3$ (about 6 %). Continuing the current trend of urbanization, this number could increase by a factor of 2 by the year 2050.

According to the National Program to Abate Climate Change Impacts (Ministry of Environment of the Czech Republic 2004), a small change of annual rainfall depth is predicted for the Czech Republic. However, a significant change is expected in the distribution of rainfall activity throughout the year, together with increases in temperatures and evapotranspiration. In consequence, more frequent heavy storm events (as well as flash floods) and prolonged periods of drought may appear.

In reaction to the situation in 2007, a specialists group on Urban Drainage (SGUD) was established under the Czech Water Association (CzWA), the national member of the International Water Association. The goal of this group is to promote the transition from current urban stormwater drainage systems to sustainable ones based on experience from abroad (esp. Germany, Switzerland, UK, Canada, USA and Australia). The actions of the SGUD are not primarily oriented toward research and technology, but rather how to implement sustainable stormwater management in Czech conditions.

The goal of this paper is to describe the paradigm change regarding stormwater in the Czech Republic, the motivation behind it, the process of implementing necessary changes aimed at sustainable stormwater management, and the restrictions and obstacles to implementation. We also present a pilot study from the city of

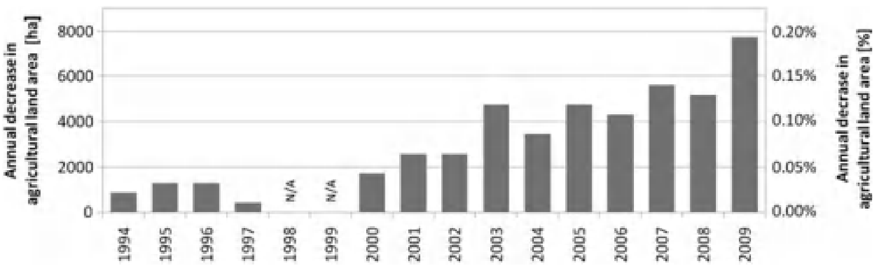


Fig. 1 The annual decrease of total agricultural land area in the Czech Republic (Ministry of Environment of the Czech Republic 2009)

Hradec Kralove. The experience that the Czech Republic has had with implementation can serve as a useful example of the transition towards sustainability for other countries facing similar problems.

# 2 Methods: Strategy of Implementation

## 2.1 Background

The Plan of Main River Basins (Ministry of Agriculture of the Czech Republic 2007) as a national planning document introduced a framework for implementing sustainable stormwater management. Due to harmonization with the EU water policy (Directive 2000/60/EC), increased stress was put on stormwater infiltration, runoff attenuation and reuse, instead of connections to combined sewer systems. The Plan also requested that a National Concept of Stormwater Management in Urbanized Areas be created. Using this Plan as a starting point, the SGUD (on contract with the Ministry of Agriculture) created a Background document for the Concept (Czech Water Association—SGUD (2007), which proposed:

- In newly developed areas—to shift the obligation for managing stormwater on the originator, i.e. the owner of the property where runoff originates,
- In existing urban areas—to create an economic motivation, i.e. a property owner who wants to improve the current state (to disconnect surface runoff from the combined sewer) should profit economically (e.g. by a decreased or eliminated stormwater fee).

## 2.2 Implementation

The background document was followed by an Implementation strategy document (Czech Water Association—SGUD 2009) which specified a set of necessary changes in the legislation, proposed new technical standards and methodical approaches, and stressed the need for education, research and dissemination of information related to sustainable stormwater management.

## 2.3 Legal Framework, Methodologies and Technical Standards

First, a legal framework creating a basis for implementing the Concept must be formed. In the Czech Republic, these changes concern mainly the Water Act, the Building Act and delegated legislation (implementing regulations). The most important is: (i) specification of the legal status of stormwater runoff and priorities regarding stormwater management; (ii) definition of the legal status of CSOs; (iii) elaboration of an impacts-based guideline on CSOs and (iv) declaration of general liability of the property owner for stormwater.

In specific areas, the following actions were proposed:

- Setting priorities of stormwater management in newly developed areas. Stormwater management on ground plots must take into account applicability, feasibility and economical adequacy. Priorities concerning the choice of recipient (groundwater, surface water, sewer system) must be given. Polluted and unpolluted stormwater runoff must be defined and permissible infiltration method must be specified, taking into consideration soil and groundwater protection. A maximum specific discharge from newly urbanized sites must be set as a basis for the design of devices.
- Introduction of economical motivation. Exemptions from stormwater fees must be minimized. In addition, a methodology for runoff quantification should be specified.
- Incorporation of sustainable stormwater management into city planning. Changes at the level of municipal legislation concern the City Development Plan, where conditions for the retention, infiltration and utilization of stormwater must be created through setting limits of stormwater discharge from areas with site-specific local conditions (type of development, hydrogeological conditions, recipient availability/capacity, etc.). Rules on how to set these limits and how to introduce SUDS must be specified in a methodical guidance publication produced by the Ministry for Regional Development.
- Creating technical standards for the design, operation and maintenance of SUDS. Technical standards must be created to ensure technical quality and safety of SUDS devices including their design, operation and maintenance on the state-of-the-art level.

## 2.4 Education and Research

The implementation strategy document suggests the following:

- To create courses for officials (esp. for Building authority and city administration)
- To launch a broader education program "Stormwater in the city and landscape", informing children and teenagers (through school and after-school activities) about the role of stormwater, its function in the hydrological cycle and its function in cities
- To support related topics through grant agencies and systems (e.g. analysis of the socio-economic effects of stormwater fees, the effect of stormwater infiltration on

different subsoil types, treatment efficiency for different soil profiles, the effect of decreased discharge in combined sewers caused by disconnecting stormwaters on sedimentation)

# 3 Methods: Strategy of Implementation

## 3.1 Newly Developed Areas

### 3.1.1 Implementation

The implementation itself started in 2009 by a parallel novelisation of the Water Act and the Building Act. The Water Act (Act 254/2010 Coll.) newly defines stormwater as a special category of water, obliging its sustainable management by developers. A developer must ensure infiltration or retention with regulated discharge, i.e. a direct connection to the combined sewer is no longer allowed. A revised regulation (Regulation 501/2006 Coll., novelized 2009) to the Building Act (Act 183/2006 Coll.) further specifies the rules of stormwater management (Table 1). The basics for SUDS were created.

In 2012 and 2013 two new Czech technical standards were published. The first one (CSN 759010 2012) deals with soakaways, the second one (TNV 759011 2013) covers the whole field of sustainable stormwater management obeying the priorities given by Table 1 (Fig. 2).

### 3.1.2 Obstacles

Despite these updates to the Water Act and the Building Act, many obstacles still limit the full implementation of these new principles:

- Time needed by the engineers and officials to get acquainted with the two new Czech technical standards and to use them properly.
- The low level of stormwater-related education for many officials, resulting in situations where they often do not know what to demand and how perform controls.

Table 1 Priorities of stormwater management in the regulation to the Building Act (Act 183/2006 Coll.)

| Priority | Stormwater management |
|---|---|
| 1 | Infiltration, pre-treatment in the case of polluted runoff. If not possible, then: |
| 2 | Retention and regulated discharge to the surface waters (directly or by a separate storm sewer system), pre-treatment if needed. If not possible, then: |
| 3 | Retention and regulated discharge to the combined sewer system |

- The efforts of (some) developers to evade the rules, e.g. they consider a whole development area (often tens of hectares) as one building site. Then, a central rather than decentralized retention system is built, despite the fact that the site will be later parceled (Fig. 2).
- Poor understanding by other professions (architects, city planners, road engineers and even civil engineers). The new approach to stormwater is considered to be a complication.

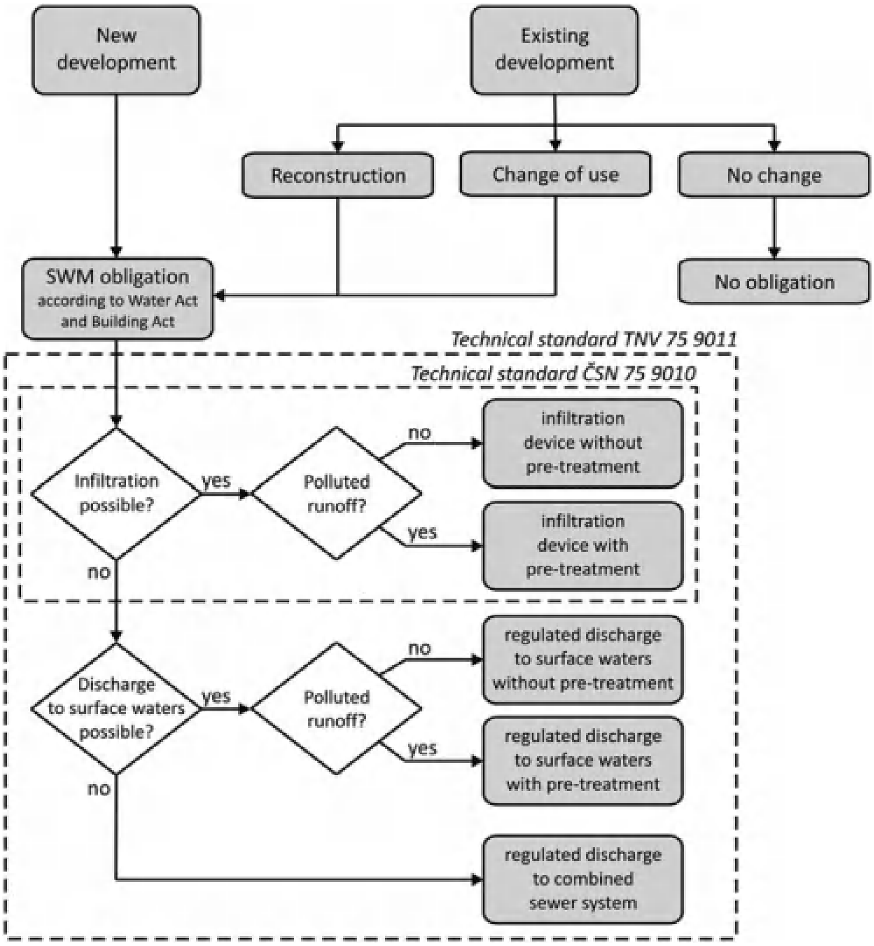


Fig. 2 Stormwater management rules in the Czech legislation and the scope of the technical standards

### 3.1.3 Pilot Study

The city of Hradec Kralove (96,000 inhabitants in 2010) was planned as a green city before the Second World War by architect Josef Gocar. Today, it is still an excellent example of clever urban planning. Stormwater drainage was solved as a first priority before starting planning the urbanization itself. Gocar designed a system combining natural water bodies and open vegetated channels. Moreover, infiltration systems were created in some areas. However, in the past few decades, Hradec Kralove has suffered from massive urbanization resulting in overloading of water bodies, open channels and of the sewer system. In response, the city ordered a Stormwater Drainage Area Plan (SDAP) in 2008 (DHI and JVPROJEKTVH 2011), focusing on sustainable stormwater management and its relation to urban planning. The project went beyond the requirements of current legislation.

The SDAP incorporates hydrodynamic modeling of the sewer system (mainly combined), water bodies, artificial open channels, underground waters (JACOBS 2010) and SUDS elements. Limits on the areas to be urbanized were implemented by:

- Defining areas of natural water retention (due to a high underground water level; less than 1 m bellow surface) and areas of flood risk, where urbanization is forbidden,
- Setting a maximum specific regulated discharge of 3 l $s^{-1}$ $ha^{-1}$ for a 5-years storm event for individual developments (scattered),
- Demanding recalculation of the water regime in terms of the hydraulic capacity of the sewer system, water bodies and artificial channels, and of groundwater level changes in the case of extensive individual developments or large development projects.

The above mentioned rules will be incorporated into the new City Development Plan and into the administration of new development by the Building Authority. Boundary Conditions Sheets (Table 2) for individual planned development areas were elaborated where possibilities of stormwater management are evaluated respecting priorities set in Table 1.

## 3.2 Existing Urban Areas

### 3.2.1 Implementation

The implementation of necessary changes has not made as much progress as in the case of new development. The cancellation of stormwater fee exemptions was discussed in 2012 during the revision of the Water Distribution and Drainage Act (Act 274/2001 Coll.) and most recently rejected by officials. One positive point is

Table 2 Example of a boundary conditions sheet for planned development (DHI and JVPROJEKTVH 2011)

| | | | |
|---|---|---|---|
| Development area | No. 3 | Za Metelkou, Drtinova Street | |
| General information | | | |
| Identification of areas | | Acreage of areas | Functional type |
| 6-9/6, 7-9/14, 7-9/30, 6-9/4 | | 18,013 m$^2$ | Suburban low-storey development |
| 6-9/7 | | 5487 m$^2$ | Multi-storey dwellings |
| Studies and regulation plans | | No | |
| Areas of special water regime | | | |
| Natural water retention area | | No | |
| Flood risk area | | No | |
| Inundation area | | No | |
| Adjacent recipients | | | |
| Groundwater | Groundwater level | 2–5 m below surface | No limitations for infiltration |
| | Hydraulic conductivity | $\geq 1 \times 10^{-6}$ m/s | |
| | Ecological burden | No | |
| Available receiving surface waters/storm sewers | | Melounka Brook (Identification No. 10101505, Hydrological catchment No. 1-03-01-005) | |
| Available combined sewers/foul sewers | | Combined sewer B (DN 500)—Petra Jilemnického Street | |
| | | Combined sewer B 18 (DN 300)—U Drevony Street | |
| | | Combined sewer B 19 (DN 300)—Predmericka Street | |
| Drainage concept for stormwaters | | | |
| Groundwater | | Decentralized infiltration devices recommended (detailed hydrogeological survey necessary) | |
| Receiving surface water / storm sewer | | Melounka Brook recommended for overflows from infiltration devices | |
| Combined sewer | | – | |
| Drainage concept for foul waters | | | |
| Combined sewer system, sewers B, B18 or B19 | | | |

that the updated Water Act is valid not only for new development, but also for reconstruction and changes to building uses (e.g. changes from housing to administrative purposes) (Fig. 2).

### 3.2.2 Obstacles

The government did not accept ending the stormwater fee exemptions, considering this to be politically hazardous. Thus, the SGUD is promoting not to introduce a new fee for stormwater producers with exemptions, but rather to divide the current sewage fee (collected according to drinking water consumption) into two fees—a decreased sewage fee and a stormwater fee. The explanation is backed by the following arguments:

- The sewer operator maintains the sewer system draining both sewage and stormwater.
- The operator collects an amount of money sufficient to maintain the system, therefore:
  - A certain stormwater fee is hidden in the sewage fee; i.e. sewage producers pay for stormwater drainage according to their drinking water consumption instead of according to the runoff volume originating from associated impervious areas. This system is inequitable, as exemplified by the following: a household with a high consumption of drinking water and a small roof per inhabitant (as in a typical block of flats) pays a considerably higher hidden stormwater fee than a single-family house with a lower drinking water consumption and a larger roof area per person.
  - Due to the exemptions from the stormwater fee, subjects obliged to pay the fee also pay the costs of stormwater drainage for other producers (also an inequitable system).

### 3.2.3 Pilot Study

The economical motivation cannot be introduced by the SDAP (DHI and JVPROJEKTVH 2011), as it does not comply with the national law. However, the city wants to serve as an example and disconnect selected areas from the combined sewer system. These areas were selected by a detailed field survey according to the following criteria (Table 3):

- the area must have potential to infiltrate or to delay stormwater runoff (e.g. sufficient green areas, suitable hydrogeology),
- this potential must be available (i.e. under city ownership).

By disconnecting these areas, the city can reduce the area of impervious surfaces connected to the combined sewer system by 15 % within the next 30 years.

## 4 Discussion on Further Actions

The SGUD oversees the implementation and attempts to overcome the obstacles described above through discussions with authorities, creating new methods and technical standards, and organizing conferences, seminars and education for

Table 3 Example of a boundary conditions sheet for planned development (DHI and JVPROJEKTVH 2011)

| | | | |
|---|---|---|---|
| Streets | Pod Zameckem, Milady Horakove, Prostejovska, Fricova, Urxova | Local part | Trebes |
| | | Acreage | 35 ha |
| | | Hydrological catchment No. | 1-03-01-002 |
| | | Trunk sewer | C |
| Criteria | | Classification | |
| Information on the development | Prevailing development | City centre | 5 % |
| | | Multi-storey dwellings | 95 % |
| | | Low-storey dwellings | |
| | | Industrial area | |
| | | Traffic infrastructure | |
| | Ecological burdens | Yes | |
| | | No | • |
| | Stormwater infiltration | No limitations | 10 % |
| | | Conditionally suitable | |
| | | Difficult | 90 % |
| | | Impossible | |
| Technical potential of infiltration | Presence of areas suitable for stormwater infiltration | Yes | • |
| | | No | |
| | Prevailing slope of surface | <3 % | • |
| | | ≥3 % | |
| Available potential of infiltration | Owner of buildings | City | • |
| | | Other | |
| | Owner of adjacent areas suitable for stormwater infiltration | City | • |
| | | Other | |

officials, engineers and the public (including children). In the next stage, dissemination will be focused on local administrators, land-use planners, architects and the public.

It is crucial to create a methodical guideline for the Building authority that should enforce the priorities required by law. This guideline must include criteria under what conditions the infiltration (or regulated discharge to receiving waters) is possible, how to document it and how to control it. The guideline should be supplemented by educational training for Building authority employees.

Future actions will also focus on implementing the economic motivation. First, it must be demonstrated how the stormwater fee affects different owners of properties (private, city, region, state). A project studying social and economic effects is currently being prepared.

## 5 Conclusion

Launching SUDS principles in areas to be developed is much easier than in existing urban areas as clear rules can be given. However, the experience from the pilot study in Hradec Kralove confirms foreign experience that it is possible (Moore et al. 2011) and has a promising potential of upgrading living and health standards of urban citizens.

During the transformation of the stormwater management in the Czech Republic, many obstacles were faced and still are not overcome. Some obstacles we identified are similar to those in countries, which have already implemented SUDS principles (e.g. Brown 2008).

Experience gained in the Czech Republic can be transferred to countries with similar political, social and economical background, i.e. mainly to Central and East European countries. However, some findings can be useful generally, as stated in the following points:

- Paradigm changes regarding stormwater management require a substantial change of thinking at all levels (engineers, land-use planners, architects, officials and local, regional and national authorities).
- It is relatively easy to change the thinking of water engineers (the only problem is learning new methods), it is moderately easy to convince local and regional authorities (since they need to solve problems at a local level) and it is very demanding to convince national authorities (e.g. regarding the stormwater fee), land-use engineers and architects (as they are used to their practices, i.e. water is solved at the end of the process).
- Demonstrating examples from abroad is not as efficient as actual examples in the country of interest.
- The sustainable water management lobby is not very powerful compared to much stronger lobbies driven by financial interests (e.g. big developers companies).
- It is not possible to introduce new rules without explaining them thoroughly as people have to understand the reasons behind them. This should be mainly the role of the state.
- Transition to sustainable stormwater management must be coordinated from the national level in order to prevent problems between the actors of the process having often contradictory interests.

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# Storm Water Quality

Petr Hlavínek

## 1 Introduction Quality

Since rain clouds develop through evaporation, storm water could be in fact distilled water, i.e. pure water with no dissolved solids. However, already in the atmosphere, this water comes into contact with various chemical substances, and its quality is therefore markedly affected by air pollution in this environment. After having passed through the Earth's atmosphere, storm water shows a pH value of about 5.6 because it bounds to—among other things—$CO_2$, contained in the air.

Pollution of the already retained storm water is of triple origin (Krejčí et al. 2002)

- Dissolved and suspended solids in atmospheric precipitation,
- Pollution, which settles on surfaces during t dry spells and is carried away with storm water during rain events,
- Pollution induced by storm water contact with materials on the ground surface.

Establishing the magnitude of pollution in runoff, we need to know the length of dry weather period, intensity of atmospheric precipitation and runoff volume. Nearly all loads by polluting matters occurring in runoff exhibit higher concentrations at the beginning than in its further course (the so-called "first flushing" effect). This is because during the beginning of a rain event, atmospheric pollution is washed out and dry sediments are mobilised together with the corrosion products developed since the last rain. Separation of the first flushing (approx. 1–3 mm of rain) usually considerably reduces BOD load in the intercepted storm water.

P. Hlavínek (&)
Faculty of Civil Engineering, Brno University of Technology, Zizkova 17, 602 00 Brno, Czech Republic
e-mail: hlavinek.p@fce.vutbr.cz



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## 2 Pollution in Atmospheric Precipitation

Polluting substances in the atmosphere are one of the reasons for runoff pollution namely in cities and industrial areas. During rain events, air pollutants are washed out and the atmosphere is purified. Thus, rain water is not a clear condensate; it reflects both the natural background of the Earth's surface (sea salts, soil erosion), and anthropogenic pollution, especially by flue gases and traffic. Substances contained in the atmosphere can be transported to a large distance. This is why storm water features effects of remote areas as well as local pollution (Krejčí et al. 2002)

Acids and acid-forming substances (sulphuric acid, nitric acid and hydrochloric acid), originating mainly from the anthropogenic pollution sources, prevail over basic substances (calcium carbonate, magnesium carbonate and ammonia nitro-gen) originating in particular from the natural environment (Garbrecht 1987).

Sources of acids are mainly sulphur compounds (namely $SO_2$ and $H_2S$) and nitro-gen ($N_2O$, NO, $NO_2$) compounds from the incineration of fossil fuels, from motor vehicle exhaust gases as well as from microbial denitrification in soils and water. Chlorine compounds are produced during the incineration of plastic materials with the content of PVC (municipal and industrial incinerators). Sources of alkaline substances are agriculture (ammonium ions in fertilizers) and the natural background (carbonates). Other substances include heavy metals (emissions from industrial operations and incinerators), organic substances (namely hydrocarbons from motor vehicle exhaust gases) and plant nutrients (e.g. phosphorus and am-monium ions) (Table 1).

## 3 Roof Runoff Pollution

Knowledge of the material composition of roof runoff is one of present-day topical issues because runoff from roofs is considered primarily for storm water reuse. Runoff from roofs is as a rule much less polluted than runoff from urban traffic surfaces.

Table 1 Chemical composition of rain in the Czech Republic—average concentrations (Czech hydrometeorological Institute)

| Chemicals | Ca | Mg | Na | K | $NH_4^+$ | $SO_4^{2-}$ | $Cl^-$ |
|---|---|---|---|---|---|---|---|
| mg $l^{-1}$ | 0.37 | 0.06 | 0.25 | 0.19 | 0.9 | 1.7 | 0.31 |

| Chemicals | $NO_3^-$ | Fe | Mn | Pb | Zn | F |
|---|---|---|---|---|---|---|
| mg $l^{-1}$ | 2.4 | 0.017 | 0.007 | 0.002 | 0.007 | 0.012 |

### 3.1 Pollution Accumulated on Roofs During Dry Weather Periods

Storm water is the only way for roofs to become clean. Storm water running off a building roof contains a high share of dissolved oxides ($CO_2$ and $SO_2$) and a variable proportion of organic substances (pollen, sticks, foliage, bird droppings, dust and germs). Nevertheless, the hitherto experience shows that this pathogenic load of water is negligible, and cannot represent a risk for human health if storm water is managed responsibly.

### 3.2 Pollution Generated by from Storm Water Contact with Various Materials

Water quality also depends on the type of surface from which it runs off. By coming into contact with the roofing, downspouts etc., the water becomes polluted.

Degradation of civil structures (effect of sun, water, frost and rain) results in the release of small particles of roofing, bricks, concrete, metals, dyes, asphalt, glass etc. These particles form a considerable part of runoff pollution. The extent of the pollution depends on the condition of buildings and on materials used.

The variable amount of particles released from roof and gutter paints depends once again on local conditions (paint age and state, paint material used and technique of paint finish). Rain gutters and other metal parts of roofs corrode and release toxic substances such as copper, chromium or zinc.

After a longer-lasting dry weather period, asbestos cement emanates lindane into water, which exhibits a range of both acute and permanent effects on human health. Pursuant to Government Regulation no. 258/2001 Sb., lindane is classified as a toxic substance dangerous for the environment.

A considerably important role in the replacement of inappropriate materials may be played by regulations stipulating obligatory pretreatment of rain runoff from roofs that contains a large proportion of pollutants, e.g. copper and zinc. In these cases, the builder is willing, resp. indirectly forced to use substitute, if possible inert materials.

## 4 Pollution of Runoff from Streets and Roads

Pollution of streets and roads is caused by

- Motor vehicle traffic
  Vehicular traffic affects decisively the degree of runoff pollution and hence soil pollution near roadways. Pollution from the means of transport includes solid

particles and polyaromatic hydrocarbons released from unburned fuels, lead compounds from fuel additives, and hydrocarbons released from oils and lubricants. Zinc and hydrocarbons are released due to tyre wear. Iron, chromium, lead, copper, nickel and zinc are released from the corrosion of vehicles. Various particles such as hydrocarbons, tar, emulsifiers, carbonates and metals become released due to roadway surface wear.

- Salt application on roads
  The application of salt on roads in winter is responsible for a considerably increased content of chlorides in storm waters. Salt contains other impurities, too, which causes the increased content of solids on roadways in the winter period. The presence of salt accelerates corrosion of transport means and metal installations on the road. The use of inert spreading (sand, gravel, cinder etc.) increases the amount of solids transported by storm water, and if the particle composition is unsuitable (cinder, ash), harmful chemicals leach into the storm water [2].
- Erosion of paved surfaces
  Through the process of gradual ageing, particles of diverse size and composition become released from paved surfaces.
- Litter
  Urbanised areas are polluted by large amounts of thrown away trash of all kinds. This pollution is caused mainly by poor discipline of people (Fig. 1).

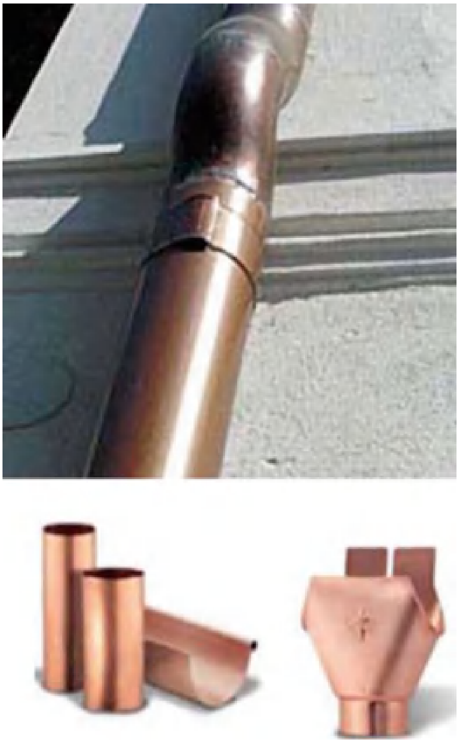

Fig. 1 Metal gutters are affected by corrosion and release toxic substances into storm drain

- Animals
  Urine and excrements of animals on pavements, roads, in parks and on other surfaces represent a source of bacteriological pollution, pollution by organic substances and ammonium ions. Animals killed on the road or dead animals may represent a source of infections and diseases.
- Vegetation
  Urbanised areas are also polluted by dead vegetation and by residues from vegetation treatment. Sticks, leaves or mown grass may cause mechanical problems, e.g. blocking of street drains, if flushed by storm water.
- Release of pollutants from surfaces of buildings and other civil structures

Table 2 Average concentrations of substances in runoff (VSA 2002)

| Indicator | Size | Slanted roof | Flat roofs with gravel-sand layer |
|---|---|---|---|
| pH | | 5.5–7.7 | 5.5–7.9 |
| TOC | $mg\ l^{-1}$ | 5–10 | 5–10 |
| TSS | $mg\ l^{-1}$ | 15–40 | 2–5 |
| Cl | $mg\ l^{-1}$ | 0.3–1 | 0.5–1 |
| $SO_4$ | $mg\ l^{-1}$ | 2–6 | 2–8 |
| $SiO_4$ | $mg\ l^{-1}$ | 0.3–0.4 | 1–2 |
| $NO_3$ | $mg\ l^{-1}$ | 0.3–0.7 | 2–5 |
| $NO_2$ | $mg\ l^{-1}$ | 0.05-0.1 | 0.1–0.15 |
| $NH_4$ | $mg\ l^{-1}$ | 0.4-2 | 0.01–0.07 |
| $N_t$ | $mg\ l^{-1}$ | 1.5–5 | 3–5 |
| $P_t$ | $mg\ l^{-1}$ | 0.08–0.15 | 0.02–0.05 |
| Ca | $mg\ l^{-1}$ | 1.5–2.5 | 10–25 |
| Mg | $mg\ l^{-1}$ | 0.2–0.7 | 0.7–1 |
| Na | $mg\ l^{-1}$ | 0.2–0.3 | 0.2–0.3 |
| Cr | $mg\ l^{-1}$ | 0.5–0.8 | 0.3–0.6 |
| Mu | $mg\ l^{-1}$ | 5–12 | 5–12 |
| Fe | $mg\ l^{-1}$ | 90–1000 | 100–200 |
| Cu | $mg\ l^{-1}$ | | |
| Roof without $Cu^-$ | | 15–30 | 15–25 |
| Roof with $Cu^-$ installations | | 100–300 | 100–300 |
| Cu-roof | | 800–2000 | |
| Zn | $mg\ l^{-1}$ | | |
| Roof without $Zn^-$ | | 20–70 | 10–40 |
| Roof with $Zn^-$ | | 50–200 | 50–200 |
| Titanium-Zn-roof | | 1000–4000 | |
| Pb | | | |
| Roof without $Pb^-$ | | 10–30 | 2–10 |
| Roof with $Pb^-$ | | 100–300 | |
| Pb-roof | $mg\ l^{-1}$ | 5000–7000 | |
| Cd | $mg\ l^{-1}$ | 0.1–0.5 | 0.05–0.1 |

Table 3 Average concentrations of pollutants in street runoff (VSA 2002)

| Indicator | Size | Average concentration |
|---|---|---|
| PH | | 7.4 |
| TOC | mg $l^{-1}$ | 16 |
| TSS | mg $l^{-1}$ | 240 |
| Cl | mg $l^{-1}$ | 150 |
| $SO_4$ | mg $l^{-1}$ | 40 |
| $NO_3$ | mg $l^{-1}$ | 6 |
| $N0_2$ | mg $l^{-1}$ | 0.4 |
| $NH_4$ | mg $l^{-1}$ | 0.4–2 |
| Pt | mg $l^{-1}$ | 0.7 |
| Fe | mg $l^{-1}$ | 6 |
| Pb | mg $l^{-1}$ | 0.3 |
| Zn | mg $l^{-1}$ | 500 |
| Cr | mg $l^{-1}$ | 15 |
| Ni | mg $l^{-1}$ | 40 |
| Cu | mg $l^{-1}$ | 150 |
| Cd | mg $l^{-1}$ | 4.5 |

Degradation of civil structures and other structures (effect of rain, sun, frost) results in the release of small particles of bricks, roofing, concrete, metals, dyes, asphalt and glass. The pollution extent depends on the condition of buildings and on materials used.

Metal structures (fences, benches, rain gutters) corrode and release toxic substances such as copper, chromium and zinc.

- Industries

  Pollution occurs at handling and processing raw materials, chemicals in industrial operations, in construction industry (washing of machines, oil leakages), in transport (chemicals to control icing on aircrafts, pesticides) (Tables 2 and 3).

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# Pretreatment of Stormwater

Petr Hlavínek

## 1 Storm Water Pretreatment Facilities

Storm water pretreatment is difficult to design as a general solution due to the complex character of mutual interactions. This is why it is useful to evaluate each individual case separately.

Pursuant to ATV-DVWK A 138, runoff from paved surfaces is classified in terms of its content of pollutants and possible impact on groundwater into the following three categories.

### 1.1 Harmless

Example can be storm water from the roofs (with the exception of roofing made of copper or zinc-coated metal sheets), walkways and green areas.

### 1.2 Tolerable

Tolerable is rainwater originating from residential-industrial areas, villages, parking lots and roads. Runoff can be infiltrated after suitable pretreatment (e.g. with using purification processes in the infiltration facilities). Infiltration through the greened surface may be sufficient in dependence on catchment area characteristics and

P. Hlavínek ( & )
Faculty of Civil Engineering, Brno University of Technology, Zizkova 17,
602 00 Brno, Czech Republic
e-mail: hlavinek.p@fce.vutbr.cz



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retention time within the infiltration space. Physical, chemical and biological processes taking place there can inhibit even greater quality fluctuations of runoff water before reaching the groundwater horizon.

## 1.3 Intolerable

Intolerable is rainwater from very busy roads, from unsheltered storage areas and transhipment points of harmful and noxious substances. Rainwater runoff should infiltrate only after a suitable pretreatment or be drained into the sewer system (Fig. 1).

Functional principles forming a general base of facilities for rainwater pretreatment are as follows.

## 1.4 Sedimentation

Sedimentation exhibits a very good purification capacity since many pollutants occur in the form of particles. Moreover, during the sedimentation of suspended particles, dissolved solids are caught too. A prerequisite for sedimentation is the least possible water turbulence. Sediment stir-up due impact load needs to be prevented by proper dimensioning and maintenance. Important is to minimise turbulences by constructive measures on inflow and outflow from settling pits and pools (Geiger and Dreiseitl 2001).

## 1.5 Filtration

Filtration takes place through natural surfaces, through water permeable pavement, mineral concrete and drainage asphalt. As to suspended solids, the purification capacity of such facilities is very good (Geiger and Dreiseitl 2001). Massive accumulation of solids occurs on the surface and in the upper 30 cm of soil.

Fig. 1 Inlet trash-rack before the drainage pipe is a necessary and efficient element for catching coarse dirt taken away by water flowing down from communications and outdoor surfaces

Suspended solids from runoff are mechanically bound in the soil. Soils with fine pores can filter even very small particles (<0.2 m) (Scheffer and Schachtschabel 1992). Filtration capacity is given by the diameter of water path pores and by their continuity. Filtration capacity decreases in the course of time due to the accumulation of particles.

## 1.6 Adsorption

Adsorption takes place due to electrostatic or covalent forces on charged and uncharged surfaces. Binding of heavy metals is caused by adsorption on exchangers (exchange of adsorbed ions (cations) for cations from the soil solution at equivalent proportion). In adsorption, it is necessary to distinguish between non-specific adsorption occurring on the surface of exchangers due to Coulomb forces, and markedly stronger specific adsorption. Connection power increases from Cd, through Ni, Zn, Cu and Pb. Lead exhibits the strongest specific adsorption in the soil. While substances bound by specific adsorption occur in the soil are relatively firmly bound, non-specific adsorption gives a possibility for substances to move and for soil to release. Long-term stabilisation of metal ions takes place due to the incorporation into the crystal lattice of clay materials. The most important exchangers of cations in soils are clay minerals and humic substances (Geiger and Dreiseitl 2001).

## 1.7 Chemical Processes

Chemical processes play a decisive role in the deposition and elimination of harmful substances in the soil. If free dissolved oxygen is available in the soil, oxides of metals and hydroxides of metals become disintegrated similarly as other difficult-to-disintegrate bonds. Sulphides of heavy metals develop to a limited extent. Inorganic substances forming complex compounds with heavy metals play a significant role in bedrock purifying processes. In addition, organic complexes such as fulvic and humic acids take part in the decontamination of harmful substances (Geiger and Dreiseitl 2001).

## 1.8 Biological Processes

Microorganism such as bacteria and fungi eliminate organic harmful substances from the soil by transforming them partly into inorganic substances. The elimination occurs through intermediate stages and ends with carbon oxides and water. A prerequisite for efficient microbiological disintegration is sufficient oxygen content in the soil. Plants can remove harmful substances from the soil, too.

By means of roots, they take up namely Cd, Cu, Ni and Zn. High concentrations of heavy metals can disturb microbiological life in the soil for a long time and even permanently. Respiration capacity is reduced immediately after heavy metals get into the soil and after some time – depending on soil characteristics and the kind of metal – it reaches its active level again. Toxicity of heavy metals to microorganisms decreases in the order from Cd-Ni-Zn-Pb (Scheffer 1998).

Biological pretreatment of storm water is achieved as a rule in combination with mechanical processes. The purification capacity of soils and substances is based on physical, chemical and biological processes.

### 1.8.1 Settling Pit

Settling pit (Fig. 2) is used to pretreat precipitation water with a high proportion of settleable substances during low flushes. Pits are very modest as to area requirements.

Rainwater is purified mechanically by way of sedimentation in pit elements with the concrete bottom. Floating and lightweight substances are caught on the scum board. A disadvantage may be turbulence preventing the capacity of sedimentation. However, this can be avoided by the installation of settling pits with stopping plates to prevent turbulence.

In the first approximation, settling pits can be extended to 10 m$^3$ ha 1 of relevant area – for volume calculation (Geiger and Dreiseitl 2001). Trapping of impurities pursuant to DIN 1221. Target parameter is the required volume of sedimentation zone, the sedimentation volume being governed by inflow characteristics and by the required degree of sedimentation.

### 1.8.2 Drain Well with the Bottom Mud Trap (Fig. 3)

This is a combination of settling pit and drain well. The lower part of the well is compact and impermeable to create a settling space. It is used for the pretreatment of precipitation water with a high proportion of settleable substances. Drain wells have only low requirements for area and investment costs are low too. Limited possibilities of maintenance may be considered a disadvantage.

Purification capacity is good thanks to sedimentation. The share of suspended particles in the filtering gravel is further reduced thanks to the drain well lining with geotextile filters.

### 1.8.3 Geotextile Filter Bag for Drain Wells (Fig. 4)

Non-woven filter bags are used for the pretreatment of runoffs with prevailing suspended solids in urban areas with small available surfaces.

The textile (special geotextile made of 70 % PES and 30 % PP-fibres) is sewed into a bag with respect to drain well size. Water is purified thanks to the mechanical filtering properties of the textile (permeability coefficient kf = $10^{-3}$ m $s^{-1}$). Advantage of the textile is a possibility of multiple uses after cleaning, and a simple installation thanks to a divisible tension ring (Fig. 5).

Area requirements of drain wells are very low; the wells can be used also if impermeable layers occur nearby the terrain. A disadvantage may be poor trapping of dissolved solids.

Approximately 70 % of dust and clay particles are caught by the muddy fraction, which has a very good purification capacity. The trapping capacity improves with accumulated soil particles without impact on permeability (Miehling and Gartung 1988).

## 1.9 Design

Target design parameter is the required storage and settling volume of the well (based on its high permeability coefficient, the inserted filter bag has no pronounced effect on the maximum level height in the well).

Distances to be adhered to in the design are as follows (ATV-DVWK A 138):

- Groundwater table has to be at least 1 m below the well bottom
- Distance of drain facility from the construction pit foot should not be smaller than 1.5-multiple of the construction pit depth
- Spacing between the wells >10 m (Figs. 2, 3, 4 and 5)

### 1.9.1 Separator of Lightweight Solids

Apart from the treatment of wastewater from technological processes, separators of lightweight solids are as a rule used in sewer systems draining precipitation water from paved surfaces with existing great probability of contamination by oil products,

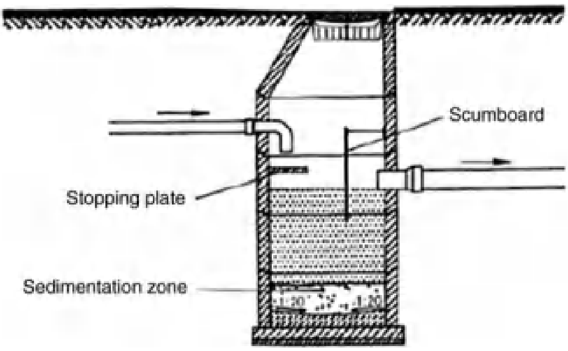


Fig. 2 Settling pit

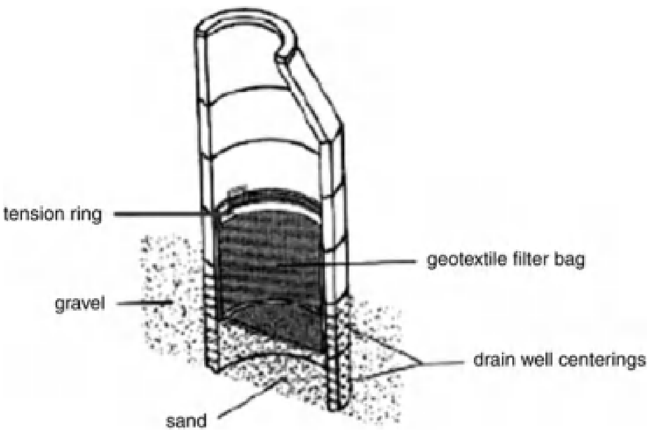


Fig. 3 Drain well with mud trapping on deep lying well bortím

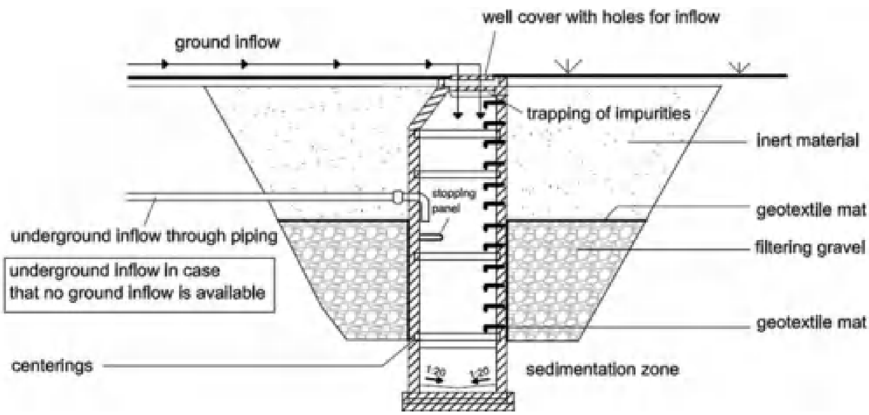


Fig. 4 Geotextile filter bag for drain wells

i.e. for the pretreatment of runoff from production areas with increased degree of contamination by fuels and mineral oil products (roads, parking lots).

Purification capacity is high in lightweight solids; low efficiency in the case of impact load (Geiger and Dreiseitl 2001).

Separators of lightweight solids (OLK) (e.g. motor gasoline, diesel oil, fuel oil) usually contain sludge storage space, separator proper (class I or class II), and a space for sampling where necessary. In some cases, separators of lightweight solids can have a sorption part.

Fig. 5 Spillway shaft with a filter bag

- Sludge storage space is a part of the installation, which is situated on the inlet end of the separator and which is intended for the sedimentation of solid materials, i.e. sludge, mud and sand.
- Separator itself is a part of the installation, in which lightweight liquid is separated from wastewater and stored.
- Sorption part is a part of the installation, which serves to trap finely dispersed drops of lightweight liquids.

Design can be implemented according to ČSN EN 858-1 Separators of lightweight liquids (e.g. oil and gasoline) – Part 1: Principles for designing, construction and testing, designation and quality control and according to ČSN EN 858-2 Separators of lightweight liquids (e.g. oil and gasoline) – Part 2: Nominal size selection, installation, operation and maintenance.

Information important for design:

- Nominal size (NS) – a dimensionless number indicating verified capacity of catch pit function to trap lightweight liquids at a corresponding flow rate.
- Evaluation of the selection of suitable nominal size and sludge storage space size.

The method for calculating OLK nominal size and for establishing the size of sludge storage space is stipulated by ČSN EN 858-2.

Result of the design is a suitable nominal size and a correctly selected type of the installation with the corresponding sludge space. Roughly, we can say that for stormwater flowing from road shoulders and parking lots the nominal size of the separator equals flow rate at design rain intensity.

- Depending on the required performance capacity, which is ruled by the inflow mode and volume as well as by the required degree of clarification, prefabricated separators of lightweight solids can be selected by choosing corresponding nominal size.
- The separators can be used both as underground and ground installations. In case they are built in the field, care should be taken of ground space being treated so that inlet holes cannot be flooded by torrent rains.
- Final parameter of the design is the required separator volume.
- It is advised that records are taken about the facility operation (operating diary).

### 1.9.2 Settling Pond

Settling ponds are used for the pretreatment of precipitation water with a high proportion of settleable solids in peripheral areas with large available surfaces, and they contribute to climate improvement in urban areas. Settling ponds are sealed from the bedrock. They function both purely mechanically as sedimentation basins, and biologically as natural clearing lagoons.

Settling pond has good purification capacities for both suspended and dissolved solids as well as good possibilities of purification control. At choked outflow, accumulation space for precipitation water is created. If the holding time is sufficiently long, it has good settling capacity for particles with $d > 0.1$ mm. In the reservoir, biological degradation occurs due to aerobic and anaerobic processes. Additional purification processes may occur in dependence on the structure of plantations (Geiger and Dreiseitl 2001).

Disadvantage may be high requirements for area and maintenance as well as a possible danger for playing children (fencing is recommended).

Important information for design:

- Slope gradients according to lining $<1:1.5$; the lowest pond volume $V > 300$ m$^3$.
- Settling zone in the inflow area is deep ($h0 > 1.5$ m) and elongated.
- For even and smooth inflow distribution, it is possible to include a division trench.

### 1.9.3 Vegetation Passage

Rainwater flows mostly in horizontal direction through an earth body with plants, which is sealed from the bedrock.

Vegetation passage is useful for additional purification of rainwater severely polluted by organic substances. It can also be incorporated as a biotope in urban and housing areas (without bad odour load) (Geiger and Dreiseitl 2001).

Vegetation passage has good clearing capacities namely of dissolved solids and good possibilities of purification control.

Purification capacity is high due to anaerobic and aerobic degradation processes. At the same time, mechanical cleaning occurs due to the filtration of harmful substances in the earth body, and physical and chemical binding (adsorption) of harmful substances onto soil particles. In winter, the biological cleaning capacity decreases by ca. 20 %.

Maximum efficiency degree is achieved only with the continual inflow; this is why retention spaces have to be included upstream. An upstream-situated clarification facility for the sedimentation of suspended solids is appropriate. The facility has high area requirements.

## 1.10 Design

A sedimentation space (e.g. settling pond) is usually incorporated upstream to remove coarse matter. It is useful to use gravel 8/32 to suppress hydraulic impact due to heavy rain. Soil compaction (e.g. during tending measures) has to be prevented (Geiger and Dreiseitl 2001).

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# Stormwater Management and Retention in Urban Catchment

Józef Dziopak and Daniel Słyś

**Abstract** Rising costs of traditional precipitation wastewater disposal are connected with increasing urbanization. This unfavorable situation enforces to apply local rainwater management wherever possible. The urgent matter is to search for alternative solutions which guarantee effective rainwater management in the area of precipitation occurrence. The sustainable development within the framework of created wastewater management systems should be realized multidirectionally when it comes to rainwater. Starting with natural methods of rainwater management through the use of existing and constructed sewage systems equipped with artificial storage reservoirs and devices for regulation of the rainwater flow capacity.

## 1 Introduction

When we compare total annual volume of domestic wastewater to storm water, which are discharged from urban catchments of European cities the relation equals approximately 4:1. The situation is completely different when it comes to dimensioning of sewer diameter, since canals are dimensioned for critical flows which are short and characterized by high intensity. Critical flow of storm water exceeds dozens of times, and in extreme cases hundredfold, the maximum flow of domestic wastewater. After analysis of coefficients characterizing the efficiency of constructed storm water and combined sewage systems it is safe to state that they are very low. It is due to the fact that the use of total diameters of these canals is seldom, happens maybe once in a few years, depending on assumed level of reliability of sewage system.

J. Dziopak ( & ) · D. Słyś
The Faculty of Civil and Environmental Engineering, Rzeszów University of Technology,
Al. Powstańców Warszawy 12, 35-959 Rzeszów, Poland
e-mail: jdziopak@prz.edu.pl

D. Słyś
e-mail: daniels@prz.edu.pl



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Sewage drainage systems are among the most expensive, hard to construct and modernize systems in the whole complex of urban underground infrastructure. Costs of their construction are at least four times higher than investment outlays intended for building of sewage treatment plant. The main part of costs is spent for transport of storm water in storm and combined sewage systems.

Technical condition of the majority of exploited sewage net in Poland and many countries abroad enforces the renovation, modernization or replacement of canals in order to take into account the current operating conditions and readjust to present needs. Hydraulic overload of collectors is the second problem. It manifests itself by collectors flooding or/and working under pressure. In practice there is a need to solve these two engineering issues at the same time.

## 2 Topicality and Importance of the Subject

Along with urbanization of cities there is radical change of runoff intensity of storm water observed, what influences significantly the functioning of urban infrastructure and water recipients. It enforces to take actions which aim is to manage rainwater in the area of its formation and apply different methods of effective retention.

The problem of stormwater management in urban areas is currently the priority, what is proved by design concepts in connection with progressive urbanization of the cities. Based on projections, it is estimated that in the year of 2025 60 % of the whole human population will be living in the cities and over 400 cities will be inhabited by at least 1 million people (Roesner 1999).

Problems which occur currently when it comes to construction and development of drainage infrastructure as well as precipitation wastewater management are the result of interference in natural water balance of catchments. The key problems are: functioning of hydraulically overloaded sewage systems and sewage treatment plants (Dziopak 2000), often flooding of cities caused by sewage systems, larger flood waves and local reduction of ground waters level.

These relations are shown in Fig. 1 in form of exemplary hydrograms of stormwater outflows from urbanized catchment and natural catchment.

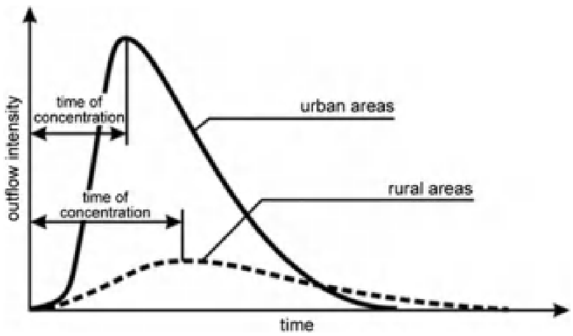



Fig. 1 The examples of typical hydrograms of stormwater outflows from urbanized and rural catchments

The observed difference in the volume of surface runoff results from the fact that the significant percent of rainwater in the area covered by natural vegetation infiltrates to the ground and flows slowly to water courses.

In the urbanized areas times of concentration of the rainwater runoff are short and characterized by very high dynamics. Along with the decrease of amount of water percolating to the ground and lower roughness coefficient the surface runoff becomes torrential and leads to overloads of sewage networks and as a consequence also water courses which are receivers of stormwater from urban areas. Water level rises fast very often and the frequency of raised water stages is higher.

The most destructive factors influencing the natural rainwater runoffs include development of residential, commercial and industrial areas as well as widely developed road infrastructure. In practice, it causes the necessity of providing substitute routes for rainwater runoff, significant investment outlays and areas for temporary accumulation of rainwater excess.

Currently, the most popular solution of rainwater management in Poland is collecting rainwater during the precipitation and discharging it from the catchment in the system of underground conduits, which are the part of rainwater and combined sewage systems. However the mixed sewage system is the most common in Poland.

The issues of modern rainwater management with the use of different technical solutions, retention processes and effective utilization of rainwater are the subject of research conducted in many countries (Bettmann and Ostrowski 1997; Jonasson 1984; Novotny 1984; O'Loughlin et al. 1995; Schelling 1986) including Poland (Dziopak 1992, 2004; Dziopak and Słyś 2007; Nowakowska-Błaszczyk and Błaszczyk 2003; Słyś 2009a; Słyś et al. 2012). It should be emphasized that concepts concerning effective rainwater retention are the leading subject for many authors. These issues are consistent with the wider subject of sustainable development of urban areas. Implementing innovative solutions and methodologies of their dimensioning have significant impact on modern infrastructure of the cities in system approach.

The superior aim of created concepts is to retain rainwater near to the area of precipitation with simultaneous counteracting phenomena which cause sudden, intensive and cumulated rainwater disposals to the surface waters.

The sustainable development within the framework of created wastewater management systems in relation to rainwaters can be realized multidirectionally. Starting with natural methods of rainwater management within the catchment through the use of existing and constructed sewage systems equipped with artificial storage reservoirs and devices for regulation of the rainwater flow capacity.

Figure 2 shows a diagram which illustrates the system approach to the problems, occurring in connection with urban areas planning with consideration of rainwater modeling and management principles.

Currently implemented strategy of system approach to the sustainable rainwater management in urban catchments is oriented towards a series of activities that include the issues related mainly to:

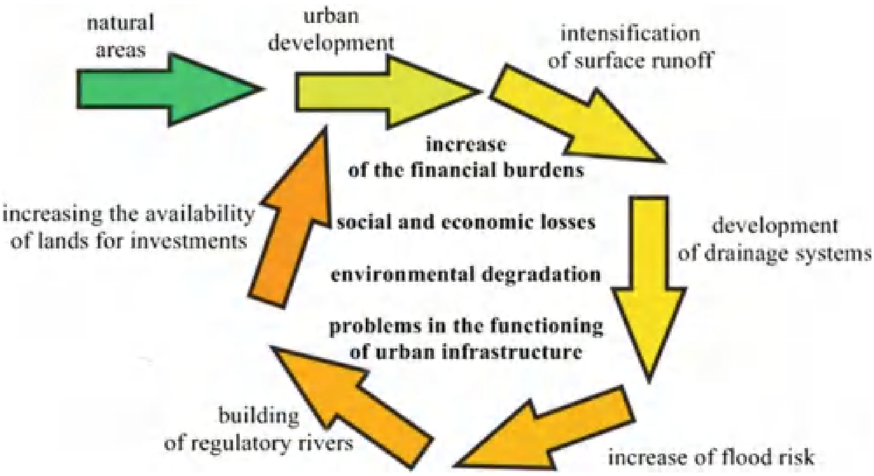



Fig. 2 System approach to the problems of urban areas in terms of rainwater management

- reduction of rainwater's discharge from the catchment by underground sewage systems as a result of it detention in devices and objects which are used for local rainwater management through terrain retention and infiltration into the soil,
- using the retention capacities of sewage systems and storage reservoirs serving to reduce the intensity and frequency of rainwater discharge into the recipients,
- improvement of technical condition of rainwater drainage systems and combined sewage system to eliminate and minimize the phenomenon of infiltration of the groundwater into the sewage systems,
- reduction of pollutants loads discharged to the recipients on the way of pre-treatment in natural and artificial purification devices,
- exploitation of deep sewage systems in areas which demand high level of security and reliability, such as highways, motorways, airports, urban city centers,
- discharge of the particularly polluted rainwater into deep sewage systems and wastewater treatment plants,
- using diffusive introduction of rainwater into the receiving water body to counteract the low level of water and disappearing flow, particularly in the small watercourses.

## 3 The Methods of Rainwater Runoff Reduction and Retention of Storm Water in Sewage Systems Introduction

The most important process affecting the course of surface water runoff is infiltration of rainwater into the soil, which depend on the surface sealing, ground sloping and the type of soil. Water percolating into the soil environment feeds the groundwater reservoirs and reduces the inflow to the watercourses.

When dimensioning the systems of rainwater discharge and management, one of the important parameter used is the coefficient of surface runoff. It determines the volume of rainwater flowing down from the surface to the elements of this system in relation to the total volume of water, which appear after the precipitation on a specified catchment surface. Urban catchments due to its specificity are characterized by significant diversity of management methods. In such cases an average value of runoff coefficient should be determined. It must be noted that runoff coefficient plays a very important role in determining of the mass balance of rainwater runoff. Its corrected designation is difficult and sometimes affected by errors. In many cases it is based on the intuition of the designer. Even relatively small errors in estimating of its actual value can lead to faulty determination of the required cubature of network, facilities and devices of sewage system.

Taking into account current international scientific and technological achievements as well as basing on own technical solutions for precipitation wastewater retention within the sewage network and reduction of the amount of rainwater discharged from the urbanized catchment it is necessary to run detailed technical and economic analysis before deciding on suitable design concept. The analysis should be conducted for particular local conditions and with balance of wastewater taking into account in order to choose optimal investment variant. Hydraulic overloads of networks, especially combined sewers, which occur in many cities in Poland, force to consider different methods of reduction of rainwater runoff volume in sewage networks.

Surface or terrain retention is the first and most recommended stage of holding rainwater on its way to the sewage system. Such actions should always go before channel and reservoir retention. Therefore, different methods of rainwater retention need to be taken into account and only after that, having the wastewater balance determined, sewage network flow capacity can be calculated. On the basis of such data complete analysis of the whole sewage system can be conducted and efficient concepts of modernization may be discussed. They should include various forms of rainwater retention. The use of properly selected technical solutions for rainwater accumulation enables to divide effectively into stages the investments realized within constructed, developed or modernized sewage networks.

Another simple and effective solution, when it comes to the problem of rainwater excess in urban catchment, is collecting it in natural pits and basins. It is realized in a form of natural ponds or developed open reservoirs, which at the same time are the crucial part of urban recreational areas. Such natural reservoirs are emptied by partial or total drainage, which is a result of collected rainwater infiltration to the ground. This process is dependent on many factors including the amount of accumulated rainwater, water level in the reservoir, hydrogeological conditions of the area, dry weather periods and many others. It is highly recommended to avoid catchment sealing. What is more, efforts at providing conditions for sustainable rainwater management should be aimed. In practice it can be obtained by construction of parking areas made of lattice paving blocks, permeable walkways and roads, infiltration of rainwater from the roofs to the ground, designing and arranging urban recreational areas next to the open reservoirs collecting rainwater and accumulating its excess during intense precipitation periods.

Taking into account diversity of functions of storage reservoirs in gravitational sewage systems and in reference to current opinions on the meaning of reservoirs and their influence on effective and efficient designing of systems transporting urban sewage and trade effluent it is reasonable to divide these reservoirs into three basic groups (Dziopak 2004).

1. Reservoirs which hydraulically relieve the network and its elements. They can function as flow reservoirs or they can have bypass. Such reservoirs are applied for outflow regulation, mainly when it comes to precipitation wastewater as well as trade effluent due to its amount and quality. Pollution collected in the reservoir during the sewage accumulation is discharged with the sewage in the stage of the reservoir emptying or when it is already empty by applying various methods of cleaning. This type of reservoir does not reduce the pollution load in the sewage. However, in practice efforts are taken to transport all pollution to the sewage treatment plant.
2. Averaging storage reservoirs which aim is to collect and hold the highly polluted precipitation wastewater formed periodically. Reservoirs of this type do not reduce the pollution load in the sewage. However, due to cooperation with sewage treatment plant, they have significant influence on hydraulic relief and averaging pollution concentration in sewage flowing to the plant and a receiver.
3. Reservoirs which work as sedimentation tanks for treatment of precipitation wastewater, combined sewage and trade effluent (mixed with precipitation wastewater) in the process of suspended matter sedimentation. Initially cleaned wastewater flows from cleaning overflow to outflow channels and is considered mechanically purified. Such a wastewater can be discharged to the surface waters of the receiver. Sediments collected on the bottom are removed from the reservoir and directed to channels through which they flow to the sewage treatment plant. Reservoirs of this type have additional overflow, which works similarly to these used in typical sedimentation tanks.

Considering this division it can be stated that the purpose of the storage reservoir depends mainly on its main function within the sewage network. Therefore, defining the aim that is to be achieved is priority. The choice of particular solution and the type of the reservoir should be preceded by detailed research of available and possible to design solutions of reservoirs with the analysis of sewage accumulation processes.

## 4 Rainwater Management in Urban Catchment

Rainwater is the part of the whole water resources, which remains in continuous and natural circulation, what guarantees that surface and underground water resources are renewable. With regard to this, these waters undergo legal protection against degradation. It should be properly managed as natural resource, especially as generally available source of tap water.

In order to reduce and counteract negative changes in natural environment connected with rainwater drainage it is required to change the thinking of rainwater and solve a number of problems—legislative ones as well as social, mental and, above all, technical (Ward et al. 2013; Minkley 2013). However in Poland people still believe that rainwater in urban areas is useless wastewater, which should be drained completely from the catchment as soon as possible. Such approach is unreasonable, especially taking the fact that our country will have to face periodical water deficiencies more often and what is more obligatory Directive of the European Parliament (DIRECTIVE 2000/60/EC…[1]) orders to apply rainwater management consistent with the philosophy of sustainable development.

Well known and superior idea, which should be put into practice within the framework of sustainable rainwater management is holding rainwater and utilization in the catchment area along with reduction of rainwater surface runoff to rivers and lakes.

Rainwater management may be conducted in different stages and at first it consists in collecting and holding rainwater in the catchment in the largest possible amount. Only the reminding part runs to sewage systems and is transported as precipitation wastewater, which in certain conditions should be treated.

Rainwater management should be analyzed in a wide range, taking into account the whole water balance in the city area or particular catchment with system approach as a priority.

Incorporated elements in the form of objects and devices can be part of distributed rainwater management system or integrated rainwater management system depending on their purpose and the scale of incorporation. In the first case they work independently and are rather objects and individual devices used within the plots of particular investors. Example of such case can be infiltration wells and installations for rainwater harvesting and utilization.

In integrated system its particular parts are located directly in the sewage network or organized rainwater management is conducted within the sewage network which encompasses larger areas as cities' districts and residential areas. Such an example can be the system of network storage reservoirs with properly determined dimensions.

However the most beneficial from financial, economic and environmental point of view is the solution which combines the both systems and in practice is usually applied as mixed system.

In distributed rainwater management systems there are different objects and devices applied in order to reach the goal of water infiltration and retention. These are:

- perforated pavements,
- green roofs,
- infiltration wells,
- absorptive basins,

[1]Ramowa Dyrektywa Wodna Unii Europejskiej 2000/60/WE.

- rainwater harvesting and utilization systems,
- rigolas and infiltration drainages,
- ponds.

Elements included in integrated rainwater management systems, which purpose is to infiltrate and retain, are:

- storage reservoirs,
- storage and filtration reservoirs,
- absorptive basins and infiltration ponds,
- settling tanks,
- evaporation tanks.

## 5 Systems of Rainwater Discharge and Management

The main task of organized drainage systems is, first of all, the collection and utilization, then discharge, and in certain situations, an efficient purification of rainwater. Transportation of rainwater sewage is carried out mainly by sewage systems and, in some cases, surface watercourses. In dependence on the way of transport of rainwater, domestic and industrial wastewaters two basic gravity systems are used i.e. combined sewage system and separate sewage system. In almost all textbooks the half-separate sewage system is considered more theoretically, because in Poland such solution is scarcely used. While considering in details the operation of half-separate sewage system it should be noted, that it differs little from the combined sewage system, and even imitates it. The only difference is that the composition of combined wastewater, discharged by storm water overflow, is characterized on average as 10–15 % of domestic wastewater. However, at the moment of rainwater discharge to the recipient its quality often does not deviate from the quality of combined wastewater discharged by storm water overflow. Annually the volume of municipal wastewater discharge through storm water overflows from the combined sewage system to the recipient is much less than one per mill and takes place only a few times a year. Analysis of these data brought to an important conclusion, that half-separate sewage system is ruled out because of huge construction costs with dubious or meanly effects.

Choice of rainwater utilization system in the catchment should be preceded by a detailed analysis of local conditions and guidelines for the design bases and the requirements, that are placed on the planned drainage solution taking into account the financial efficiency of the investment. The important factors that should be taken into account at the stage of construction, as well as the flexibility of the system, and the factors influencing on the choice of rational solutions are primarily (Słyś and Stec 2009):

- intensity of rainwater inflow into the system,
- intensity of the reduced outflow from the system,

- quality of rainwater and the required level of treatment,
- groundwater level,
- availability of land for building equipment and facilities,
- coefficient of soil filtration,
- safety of people staying in the vicinity of equipment,
- financial aspect solution.

For small single-family housing areas, the soakaways, rigoles, small trough-flow or infiltration boxes are used. For large quantities of rainwater the devices with relatively high retention and infiltration capacity are used: mainly infiltration tanks and underground infiltration systems in the form of boxes and infiltration chambers.

The major problem of urban areas is the lack of availability of land for construction of storm water utilization facilities that require large surfaces. Reduction of the building surface requires the design of objects with greater heights of water storage. However, it is disadvantageous for operational reasons and ensuring the safety of surroundings. Surface devices used in urban areas at depths greater than 0.3 m require fencing in order to secure them from accessing people.

Rainwater containing many pollutants may be discharged to the ground under condition that it will be preserved by the minimum distance of 1.0 m, from the bottom of the distribution device in the ground water to the highest level of groundwater (Geiger and Dreiseitl 1999; Słyś 2008). This factor is also crucial when choosing a technical solution of rainwater management because of contamination danger and their transport to the lower-lying aquifers. Low level of ground water requires the use of alternative concepts, which include the tanks and troughs localization. In the case of soils situated on impervious layers it occurs such high groundwater levels that exclude the usage of any infiltration device.

It should be noted that the main parameter affecting the intensity of rainwater percolation process, and thereby the required geometry of the equipment and investment expenses, is the coefficient of soil filtration $k_f$. It characterizes the ability of soil to absorb and transmit the water through a particular type of soil, and its value depends mainly on the composition of soil, its particle size and porosity. The value of filtration coefficient changes with time of devices' exploitation as a result of the silting of infiltration equipment and soil filter. It brings to the reduction of rainwater flow intensity through the porous of soil medium, causing also the reduction of infiltration process efficiency. The use of rainwater infiltration devices is especially recommended in the areas which are characterized by the value of soil filtration coefficient $k_f$ in the range of $10^{-3}$ to $10^{-6}$ m/s.

In the case of surface equipment covered by vegetation the maximum period of water detention should not exceed an average of 1–2 days and depends on the adopted vegetation. Longer detention of rainwater conducive to the phenomenon of plants' dying, causing also an operational and aesthetic problems.

From the other side, the grounds with high filtration coefficient value $k_f > 10^{-3}$ m/s are not recommended for rainwater infiltration processes because of too high water flow rate through the soil structure. In practice, it results in low efficiency of water purification by soil biological membrane and vegetation on the ground.

Both investment construction expenses and operating costs incurred in different variants of applied rainwater management systems are usually of individual character, because of crucial importance of the existing local conditions.

# 6 Retention of Rainwater

## 6.1 Introduction

Rainwater runoff from the drained surfaces is a random phenomenon, which at higher intensities of rain usually has a rapid course. In some cases, intensity of rainwater flow exceeds the hydraulic capacity of sewage network and facilities, infiltration and purification devices. The reason of this phenomenon may be the inappropriate dimensioning, adverse changes of wastewater balance, and most commonly, the occurrence of precipitation intensity exceeding designed value.

In many justified cases it is rational to use the cubature objects for the intended retention of rainwater. Their task is to transform the unfavorable course of the function describing time variability of rainwater flow on the way of their hydraulic transport by sewage networks, which is characterized by high, instantaneous flow rate and short duration. The use of retention allows getting more advantageous, and therefore flattened hydrograph of their flow with smaller intensity, but longer duration. The described course of retention objects operation is shown in Fig. 3.

The basic retention objects and retention equipment have different constructional solutions, scope of application, efficiency of wastewater treatment, and they perform different functions and tasks. They are now used to regulate the flow rate of precipitation water in urban catchments and rain wastewaters in sewage systems and include mainly:

- filtration troughs,
- retention and filtration tanks,
- storage reservoirs,
- retention channels.

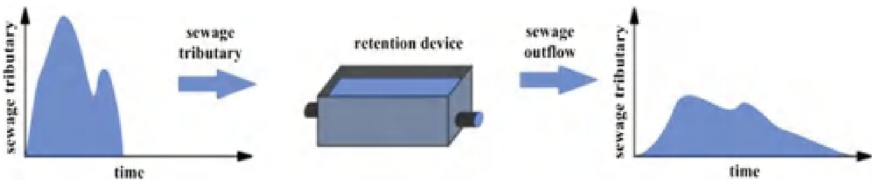



Fig. 3 The idea of retention object operation

## 6.2 The Filtration Troughs

The object of rainwater retention with relatively simple structure is the filtration trough, which is the modification of technical solution of the absorption trough. The top layer of the filtration trough is fertile ground of minimum thickness 0.2 m, which is planted with vegetation. Its task is to treat the accumulated rainwater during in the phase its percolation. Below this layer there is a water-permeable soil constituting the ground filter, where rain water is purified in a filtration process and biological decomposition of pollutants. The ground filter should be characterized by a significant porosity, where free spaces between the grains have a large share and provide the possibility of rainwater storage.

Filtration trough solutions with surface layer from mineral ground material which is not planted with vegetation (Geiger and Dreiseitl 1999).

In the bottom part of the ground filter the drainage is made, which is arranged with a slope of about 0.5–2.0 % in the direction of the outflow. Its task is to collect and discharge the filterable water into the collecting wells, from which it flows then into the surface recipient or is directed to the devices providing its infiltration into the ground.

The use of filtration basin is justified in cases where the certain conditions are met, namely: (1) below the ground filter it is a layer of impermeable soil and there is no possibility of draining rainwater into the ground, (2) the rainwater cannot be discharged into the ground due to the high level of ground water and (3) rainwater cannot be discharged into the ground due to its significant pollution.

However, in the case of high ground water level the devices must be sealed against ground water by the impervious soil partition or geosynthetics and foils.

Under the limited possibility of filtrated water discharge into the sewage system, receiver, or infiltration devices, it is recommended to use suppressing devices in collecting well.

## 6.3 Retention and Filtration Tanks

Retention and filtration tanks belong to engineering facilities which are equipped with devices for retaining and pretreatment of large volumes of significantly contaminated surface runoff. In contrast to filtration troughs it is characterized by higher levels of stored water, more durable construction larger dimensions. Its location in residential areas usually requires the implementation of a fence around the accumulation reservoir chamber.

The thickening of soil layer up to at least 0.2 m is recommended, and the slope of the embankments should be proper to ensure the lasting stability of construction. Necessary conditions for water retention time must be provided and accumulation parts of reservoir must be adapted to the type of plants inhabiting the bottom and slopes. The retention and filtration tanks without the active soil layer, but they have definitely less purification efficiency. The choice of granulometric content and the height of filter layers in retention and filtration reservoirs should take into account rainwater contamination characteristics. In the case of precipitation runoff from the surface of roadways, the ground filters with various constructions and outer casing are recommended, depending on the country of their application.

# 7 Storage Reservoirs

## 7.1 Introduction

Design solutions of storage reservoirs are closely related to their function (functions) in a specified sewage system and existing local conditions. Having regard to the high availability of various types of technical solutions, storm water storage reservoirs are the dominant option of efficient cubature objects, providing the required control of rainwater flow level. The role of storage reservoirs is the flattening of rainwater wave and temporary accumulation of water flow, exceeding the assumed intensity, before its discharge to the network or recipient and called the reduced flow.

The choice of storage reservoir location is an important decision taken by designer and should be justified by an analysis of many factors. It includes the assessment of sewage system capacity, the impact of sewage discharge on quality of receiving water, topographic conditions, type of land management and development of areas intended for the construction of reservoir, as well as hydrogeological conditions.

Possible location of rainwaters storage reservoirs must be chosen with consideration of areas meeting certain favorable conditions, thus (Słyś 2013):

- outside areas of the intense building,
- not interfering with the communication systems and underground network,
- does not require the expropriations,
- on the land with soils of the low grade,
- places with possibility to use the existing local and natural terrain hollows for adaptation for natural reservoirs,
- especially in areas with a favorable decline of the terrain and high altitude,
- areas served by the gravitational sewage system,
- in a specific section of the sewage system where it is a possibility to use retention volume of the inflow collector and sewerage network, located above the reservoir in direct neighborhood with overflows, separators and connecting chambers,
- outside the flood zone reach,
- in the area easily accessible to the operating departments,
- areas guaranteeing work security during construction, as well as the subsequent operation,

- areas, where there is no risk of adverse impact of wastewater collected in reservoir on the quality of groundwater intake and on the exploitation of adjacent areas, buildings and underground utilities.

The storage reservoirs due to the functions performed in the system, the variety of their construction, the solutions of hydraulic systems, their locations on the network, and other factors can be classified in various configurations.

Accordingly to their location relatively to the surface storage reservoirs can be divided into surface storage reservoirs and underground storage reservoirs. Underground reservoirs can be divided into open reservoirs and closed reservoirs.

While considering the construction of the reservoir one can distinguish the ground reservoirs (terrain); reinforced concrete reservoirs, prefabricated and monolithic; steel reservoirs and pipe reservoirs made of ready-made sections of a pipe.

However, their main classification criterion is the hydraulic system of chambers reservoirs, which allow to classify them into a single-chamber reservoirs (classic) and multi-chamber reservoirs.

Taking into account their functions and localization, the storage reservoirs in sewage system are usually defined as:

- network reservoirs which take hydraulic load of sewage system and objects interacting with it,
- averaging reservoirs with the function of stabilization of hydraulic parameters associated with the wastewater flow to the treatment plant or other facilities,
- storm reservoirs, localized before storm overflow or on the storm channels, whose task is reducing the volume of waste water discharged to the recipient,
- reservoirs temporarily accumulating the total volume of wastewater to be emptied after a certain time.

Due to the position of reservoir relatively to the sewage collector there can be distinguished the storage reservoirs located within sewage collector, storage reservoirs located on the by-pass or storage reservoirs on the sewage pumping stations.

Another important division of the reservoirs is based on configuration of hydraulic system of wastewater retention in relations: inflow—accumulation—outflow from the tank and there can be distinguished:

- gravitational reservoirs,
- pump-gravitational reservoirs,
- pumping reservoirs
- vacuum-gravitational reservoirs.

## 8 Storage Reservoirs Functions and Their Localization

Combined and stormwater sewage systems are characterized by very large variation of flow intensity during wet and dry weather. Comparing the annual quantity of municipal wastewater to the amount of rain wastewater discharged at the same time, it turns out that for most European cities, the ratio is about 4:1 (Dziopak 2004). While, taking into account the actual flow volumes the situation is quite different. Then the momentary flows of wastewater originated from the rain exceed tens and hundred times the volume of municipal and industrial wastewater in the periods of dry weather. Therefore, the character of rainwater flow requires the use of channels of large diameters and have adversely affect not only on sewage system operation, but also technological processes in sewage treatment plants. In dry weather periods the quantity and quality changes of wastewater primarily affect the course and efficiency of biological wastewater treatment processes.

From the technical and economic reasons it is advisable to limit the temporary flows rain water sewage by their retention.

Taking into account the tasks and functions which the storage reservoirs perform in sewage systems they can be divided into three basic groups (Dziopak 1992, 2001a, b):

- reservoirs which hydraulically relieve the sewage network,
- reservoirs averaging intensity of the inflow of wastewater to the treatment plant,
- reservoirs purifying wastewater as a result of the classic or supported sedimentation processes.

Reservoirs which hydraulically relieve the sewage network and cooperating objects are usually used in the form of network reservoirs. Their task is to retain certain volume of wastewater in order to reduce effectively the large momentary flow of wastewater. These tanks can be located within the channel or may operate beyond, in the form of by-pass. The location of the tanks which relieve the stormwater sewage network and the combined sewage system are shown in Figs. 4 and 5.

In the design practice the consideration of retention tank for sewage network relief is of particular importance, especially when new designed catchment is attached to the existing sewage system.

The group of relieve reservoirs includes the storage reservoirs, which are located before the storm overflows or/and on storm water canal transports the combined wastewater from overflows into the recipient. In the first of the following cases the storage reservoir causes a decrease in number and volume of discharges of combined sewage to the receiver per year and simultaneously provides an increasing amounts of wastewater transported to wastewater treatment plant. In the second case, the reservoir reduces the temporary level of discharged pollution loads but do not influence the number of discharges. Performing of such important function by the tank is important because of the changes in the existing legislation in Poland, which limits the variable number of possible discharges. The problem of interaction

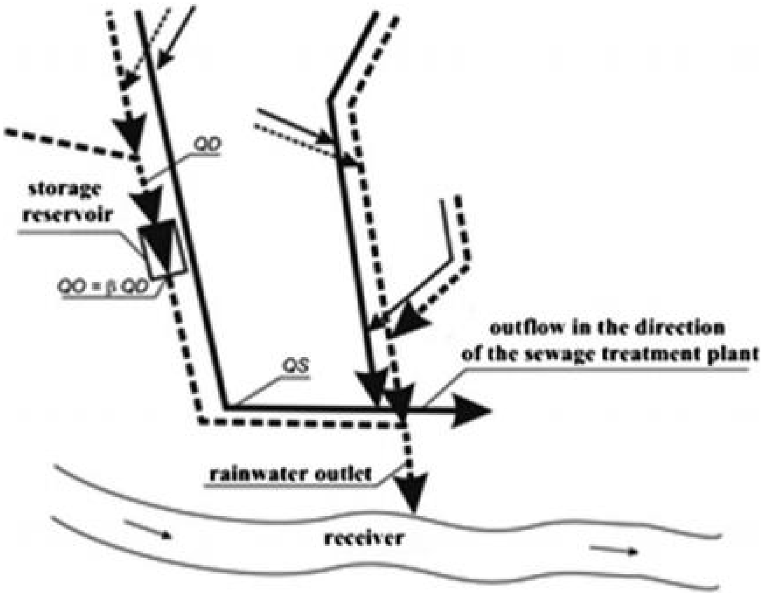



Fig. 4 Location of the tank, which relieves hydraulically the storm water network

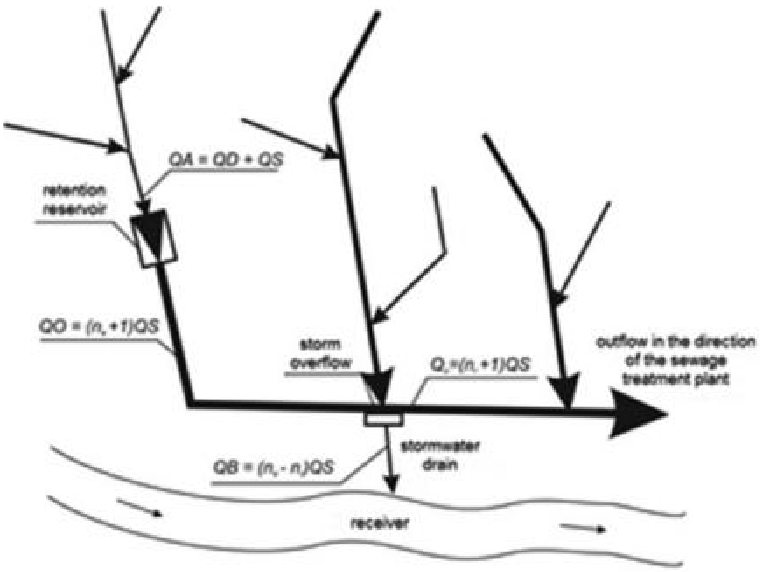



Fig. 5 Location of the tank, which relieves hydraulically the combined sewage system

of storm overflows with storage reservoirs has been widely discussed in publication (Słyś 2009b). In Figs. 6 and 7 the schemes of storage reservoir arrangement within the storm canal before the discharge outlet into the recipient for separate and combined sewage system are shown.

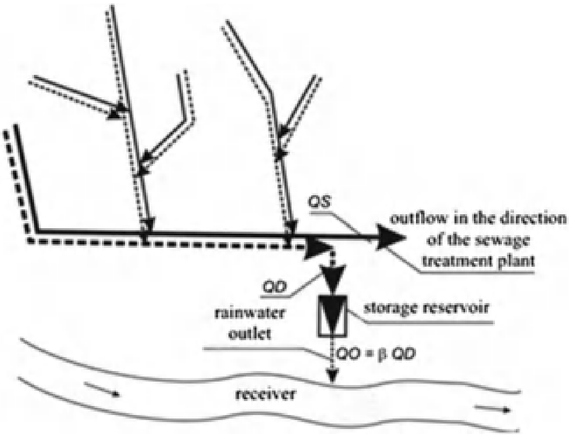



Fig. 6 Location of the tank, which relieves hydraulically wastewater recipient within separate sewage system

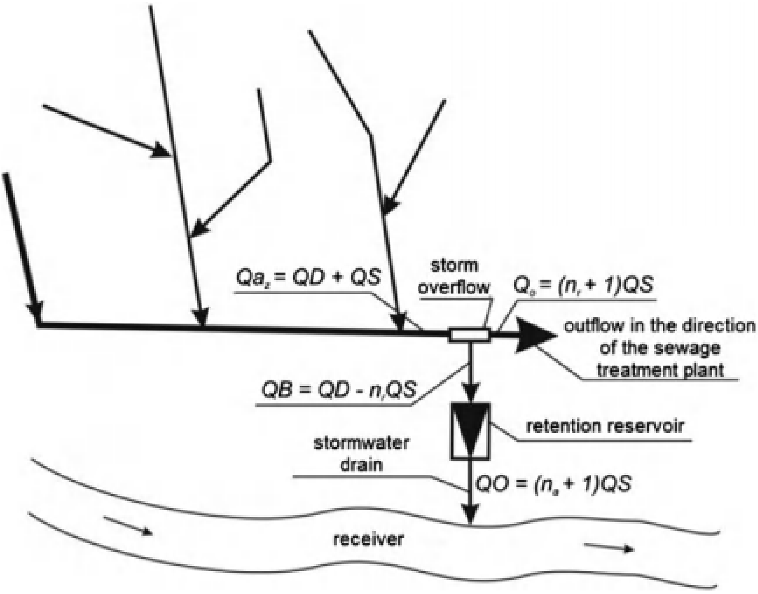



Fig. 7 Location of the tank, which relieves hydraulically the wastewater recipient within combined sewage system

The task of the averaging storage reservoir, which is localized before wastewater treatment plant in the combined and mixed sewage systems, is to stabilize the hydraulic parameters of combined sewage at the inlet to the treatment facilities (reduction of intensity of inflowing wastewater) and indirectly, also the pollutant load which is directed to the treatment plant. The averaging storage reservoir reduced temporary inflow into the equipment and facilities of the wastewater treatment plant and stabilizes hydraulically its action in periods of the increased inflow of rain waters. This reservoir indirectly also reduces the negative effect of the phenomena associated with “the first wave of runoff”, which contain the significant load of pollutants rinsed out of the channels, after the sedimentation in during dry periods. The variability of wastewater inflow intensity into the wastewater treatment technological facilities adversely affects on the maintenance of its design parameters (Zawilski and Brzezińska 2003; Myszograj and Panek 2007). This particularly relates the catchment of increased sealing and increased participation of rain water and demands the use of the averaging tanks. In modern systems of wastewater treatment the averaging tank is the required element, an example of which is a German guideline. It imposes the need of averaging tanks use before the treatment of combined wastewater and it determines the basis of their dimension, including the maximum amount of the combined sewage as a multiple of the municipal wastewater from period without precipitation.

Operation diagram of the averaging storage reservoir in combined sewage system, situated below the inflow of wastewater to treatment plant, shown in Fig. 8.

In contrast, purification tanks play the role of sedimentation tank. Simultaneously they can serve also as retention reservoirs. Sediments accumulated on the bottom of the tank can be discharged gravitationally or under pressure to

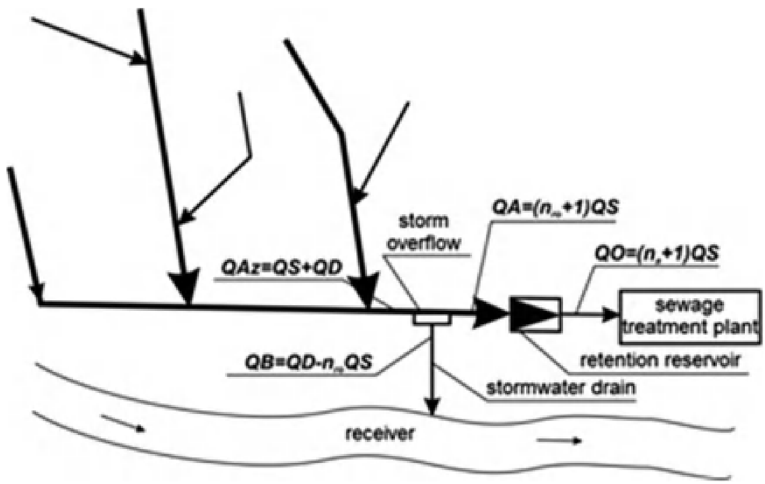



Fig. 8 The location of storage reservoir averaging wastewater inflow into the treatment plant

wastewater treatment plant, while pretreated wastewater usually is transported gravitationally directly to the recipient (Dziopak 1992; Kalinowski 1987).

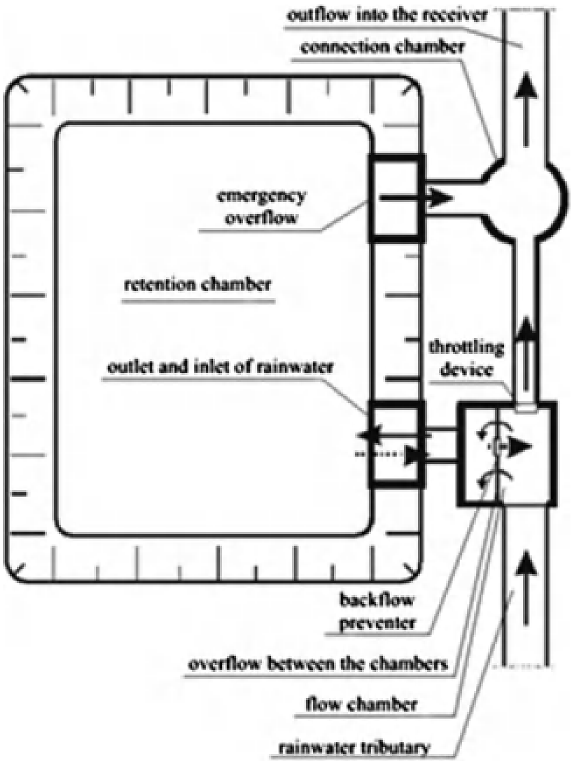
## 8.1 The Terrain Tanks

Terrain tanks belong to rain-and-wastewater storage facilities, which have not been mixed with municipal and industrial wastewater. Such facilities are aimed to collect rainwater, which characterized by suspended and dissolved pollutants, which does not constitute a risk for the public health.

These types of facilities are often built as single-chamber tanks, although they may also interact with the overflow chambers. In such variants, it should be designed in accordance with the methodology used for multi-chamber tanks. The example of the reservoir cooperating with separating overflow, which discharges the rainwater excess into accumulation chamber is shown in Fig. 9.

The rainwater flow into the terrain tank is transported by canal which is located on the ground or as a natural surface runoff fortified or not fortified trough, in dependence on local and landscape conditions.

Fig. 9 Horizontal projection of terrain tank cooperating with separating overflow



In the case of tanks of through-flow character localized on water streams the flow trough, connecting the inlet and throttled outlet of the tank, can be executed in order to carry smaller flows (Słyś 2008).

Retention reservoirs for rainwater have a various construction and can be made as drying tanks, in which all the collected rainwater is discharged to sewage system, recipient and infiltration devices or non-drained reservoirs, where part of rainwater remains in retention chamber and is used for development of wetland vegetation. In the case of non-drained tanks it should be assumed the execution of adequate cavity and sealing which prevents the outflow of rainwater from the trough into the ground, or such outlet location that ensure minimum filling of the reservoir in dry periods. However, in drained tanks where the vegetation is not of swampy character, the time of water retention should be set up in such way to avoid the loss of vegetation. For the most plants this period should not exceed two days.

## 8.2 The Pipe Reservoirs

Operation of the typical tubular reservoir is based on single-chamber tank model where the cubic chamber of a defined surface and height is replaced by filling pipe section of determined diameter and length. Modifications of these reservoirs are known, which are based on typical two-chamber tank of Contract type with changed geometry (Dziopak 1992). Storage reservoirs of tube profile are located as single object or a system of parallel located objects (Fig. 10), which get an excess of

Fig. 10 Example pipe retention tank construction

rain waters flowing in rain collectors or collectors of combined sewage system and dose it in respective amounts to the recipient or into network located below. Capacity of the retention tank significantly depends on local conditions, which determine the length of the profiled sections of the canals of certain diameter and slop.

The combination of wastewater canal of predetermined diameter with accumulation canal should be implemented with the largest possible difference of ordinates. In practice they will be connected by the ceilings. The canal placed in the direction of the drain hole of calculated diameter and located at the opposite end of the tank in the near-bottom part. The proper intensity of sewage outflow is obtained at the maximum level of tube retention, and its value is determined according to the capacity of discharge canal on the base of flow coefficient, or flow intensity adopted to modernized or newly designed sewerage system.

Such solutions of storage canals is characterized by a number of advantages, which are the following: fast and easy installation of unitary construction, highly corrosion-resistant material, completely tight connections, high abrasion resistance and the smoothness of the inner walls of canal, that eliminates sedimentation and silting.

It is quite widely used solution, also in Poland and was included in many of the design concepts, including Rzeszów and Jasło.

## 9 Studies on Concepts of Water Management Including Hydrodynamic Modelling

Significance of the influence of various methods of urban area development and rainwater management was revealed, among others, in Stec and Słyś (2012). The authors conducted detailed analysis of impact that various ways of land development have on functioning of existing sewage system in Przemyśl. The research was carried out on a number of variants, from the existing state to a few hypothetical concepts of water management in the area of Zasanie quarter in Przemyśl. For simulation research there was hydrodynamic model of catchment used, which was worked out on the basis of the data enclosed in the Study of Conditions and Directions of Spatial Development of the City of Przemyśl (Study of Conditions…).

Currently, the areas planned to be annexed to the city are unpaved wastelands covered with vegetation. This kind of surface is the reason why the rainwater runoff volume in comparison to precipitation volume in a given areas is minor.

As a result of planned urbanization of new areas their sealing degree will grow. It will cause the growth of rainwater runoff capacity transported in existing urban sewage system. Figure 11 shows analyzed city quarter with the plan of sewage system and with areas to be annexed selected (Dziopak 2000; Słyś and Dziopak 2012).

Fig. 11 Scheme of analyzed catchment and sewage system of Zasanie district in the city of Przemyśl together with new areas planned to be drained by existing sewage system (areas planned to be annexed are in dark grey)

Simulation research describing the conditions of sewage system functioning was carried out with the use of real precipitation data for existing sewage network and for proposed variants of urban development of Zasanie quarter.

Two different concepts of land development of new areas were reviewed with two different models of rainwater management taken into account.

Variant 1, where the urbanization would include traditional rainwater management model.

Variant 2, with the urbanization that includes sustainable rainwater management model.

On the basis of research it was proved that after joining new areas and their urbanization radical change of volume of rainwater surface runoff would occur. The other result would also be the prolongation of sewage transport in storm drain to the receiver as well as higher volume of sewage disposal from the overflow relieving the sewage system in this part of the city.

In order to examine the influence of the change in catchment development on sewage flow in existing sewage network there was conducted the analysis of the variant where rainwater in annexed subcatchments is managed according to principles of sustainable development (Słyś and Stec 2012), which assumes that the part or the whole rainwater is hold in the area of precipitation.

Present-day methods of rainwater management should consist mainly in natural processes of retention and infiltration to the ground. Accordingly, the devices for temporary rainwater storage and infiltration, such as absorptive basins and green roofs, were designed within the subcatchment area. Additionally, impervious concrete and asphalted pavements were exchanged for perforated and lattice pavements wherever it was possible for exploitation reasons.

The results of conducted research showed significant differences in runoff volume from annexed subcatchments where rainwater was managed in accordance to principles of sustainable development in comparison to the same subcatchments from which total rainwater amount was directed to the municipal sewage network. Limited rainwater runoff results mainly from the decrease of catchment sealing degree obtained by increasing retention surface of the area and rainwater infiltration to the ground.

The analysis of obtained results in terms of flow capacity in main channel which takes in rainwater in current state and after annexing new subcatchments (Stec and Słyś 2012): (1) with traditional rainwater management and (2) sustainable rainwater management is presented in Fig. 12.

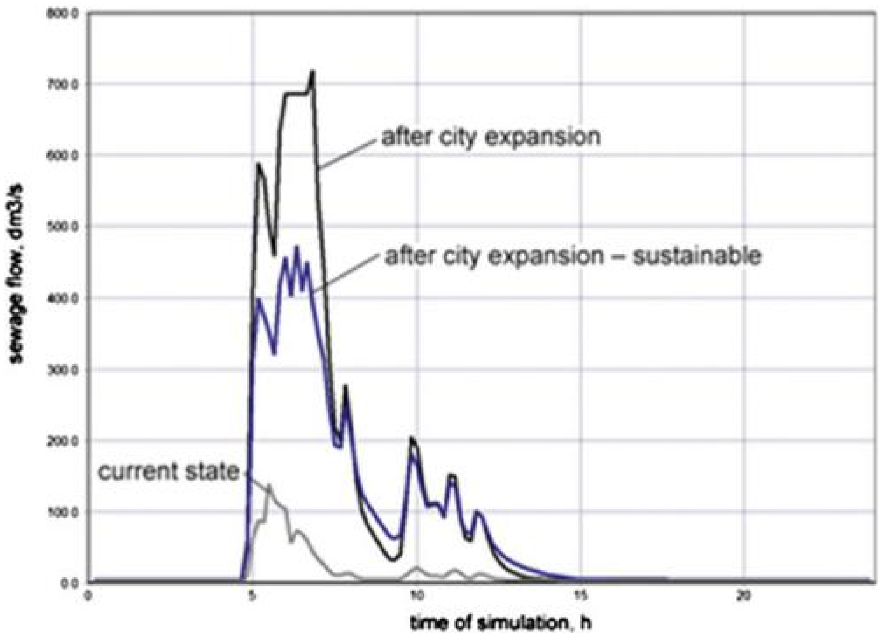



Fig. 12 Variation of sewage flow in canal L37 in existing catchment and for two variants of rainwater management applied in annexed subcatchments (analyzed precipitation data from 24 August 2008)

When sewage flow capacity in case of traditional rainwater management was compared to sustainable rainwater management average flow reduction coefficient of 34 % was obtained.

Other benefits resulting from sustainable city development should also be mentioned. Besides from economic advantages and improvement of sewage systems' functioning creating such objects as green roofs or absorptive basins has positive influence on landscape and quality of life in the city.

This tendency and above mentioned relations are also confirmed by research results, which were presented in unpublished work (Słyś and Dziopak 2012), conducted by the author as a part of scientific project connected with flood protection of Special Economic Zone in Przemyśl (Study of Conditions…).

## 10 Conclusions

Rising costs of traditional storm water disposal are connected with increasing urbanization. Their unfavorable influence on drained areas and receivers enforce to apply local rainwater management. The urgent matter is to search for alternative solutions which guarantee effective rainwater management in the area of precipitation occurrence. A number of realized objects and positive experiences can be mentioned here. Moreover, implementing new law regulations makes it easier to apply sustainable development principles in water management of urban areas. The approach to the choice of technical solutions should be multivariant. Measurable effect can be determined by analysis of costs, which are important in terms of economy and environment.

Taking into account the influence of sewage retention in the sewage networks on regulation of precipitation wastewater flow is important from economic, practical and operational point of view. It causes the reduction of investment outlays intended for construction and modernization of sewage networks and sewage treatment plants. It is confirmed by results of researches conducted in many urban catchments.

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# The Analysis of Possibilities of Using the Rainwater Harvesting Systems in Residential Buildings in Poland

Daniel Słyś, Agnieszka Stec and Józef Dziopak

**Abstract** This publication discusses results of hydrological and financial analysis for rainwater harvesting system (RWHS) for a residential buildings located in South-Eastern Poland. In this paper, the findings are presented on the basis of which a possible reduction in tap water use was determined for a residential building in Polish conditions as well as the financial ratios for the RWHS installed in this facility.

## 1 Introduction

The water resources of our planet are huge and could theoretically satisfy the needs of the Earth's entire population; however, their non-uniform distribution and irrational water management by humankind mean that in many countries the supply of this basic material is an immense problem.

The current annual demand for fresh water all over the globe is about 4500 $km^3$, while the spatial diversification of the scale of needs does not coincide with the distribution and availability of water resources, and causes water deficits in many countries. Moreover, according to some scenarios of economic growth, the annual demand for fresh water will increase to 6900 $km^3$ in 2030 and may lead to a shortage of 40 % in the total global water supply (2030 Water Resources Group 2009). The water deficit is most painfully felt by the countries of the North and Central Africa, South America and Mid Asia. However, many European countries, including Poland, also have to deal with a water shortage.

D. Słyś (&) · A. Stec · J. Dziopak
The Faculty of Civil and Environmental Engineering, Rzeszów University of Technology,
Al. Powstańców Warszawy 12, 35-959 Rzeszów, Poland
e-mail: daniels@prz.edu.pl

A. Stec
e-mail: stec_aga@prz.edu.pl

J. Dziopak
e-mail: jdziopak@prz.edu.pl

 
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Poland is one of the most water-deficient European countries and is ranked 26th in Europe considering the quantity of water resources which are characterized by high seasonal fluctuations and a non-uniform territorial distribution. In Poland the per capita ratio of water resources is 1660 $m^3$/year while the European average per capita value is estimated at 4560 $m^3$/year.

One method for reducing use of water resources is the economic utilization of rainwater. Systems for collecting and using this water are also used in other countries. Depending on climate conditions and the type of building where the rainwater system is installed, a saving on the demand for tap water is obtainable at different levels.

Rainwater cannot be used for consumption or sanitary purposes but it can be successfully used as a substitute for the tap water consumed in toilet flushing, car washing, laundry, agricultural irrigation and green area watering systems (Coombes 2003; Furumai 2008; Ghisi et al. 2009; Imteaz et al. 2011; Jones and Hunt 2010; Mourad and Berndtsson 2011; Villarreal and Dixon 2005). Most commonly, the rainwater is used to flush toilets in residential buildings (Fewkes 2000; Ghisi and Ferreira 2007; Ghisi and Oliveira 2007; Ghisi 2006).

In Poland, the economic use of rainwater utilization systems is rare. The findings of analyses conducted on the potential utilization of these systems for residential housing have been presented in (Słyś 2009).

## 2 Simulation Model

The computational model comprises the system of collecting, storing and utilization of rainwater. Its operation is determined by such factors as: occurrence of precipitation, size of retention tank, volume of water collected in the tank, size of the roof surface and runoff coefficient as well as demand for water of lower quality. The model is presented schematically in Fig. 1.

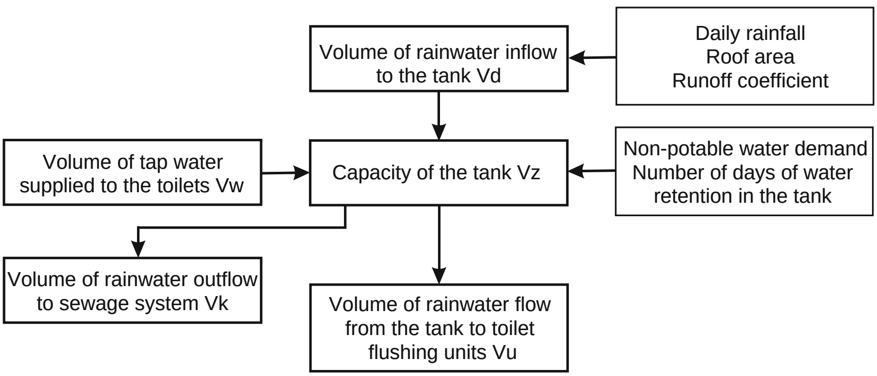


Fig. 1 Model of the system for utilization of rainwater

## 3 Case Study

In order to determine the applicability of rainwater harvesting systems (RWHS) under Polish conditions the studies were conducted for two types of dwellings: single-family and multi-family building. The analyzed buildings were located in the city of Rzeszów, which is located in the south-eastern part of Poland.

The studies identified not only the possibility to reduce the consumption of mains water, but also there were performed the calculation of financial indicators showing the cost-effectiveness of the use of rainwater utilization systems in the analyzed buildings.

### 3.1 Single-Family Residential Building

In order to determine the course of the system as it functioned in conditions similar to reality, computation simulations were performed on the basis of data of daily precipitation level measurements from the meteorological station located in the area of Jasionka airfield near Rzeszow. The calculations were based on historical data for rainfall rates during 10 years (1968–1977). Average annual precipitation in the period was 612 mm.

Figures 2, 3 and 4 show the amount of daily precipitation for 3 years from the selected for the analysis period.

The study covered the analysis of operation of the rainwater usage systems for various roof surface areas, different water demands for toilet flushing. On the basis of data published concerning water usage for WC flushing in Poland, which agrees well with the data from other European countries, the average daily water consumption for this purpose was assumed as 35 $dm^3$ per day, per person. A situation

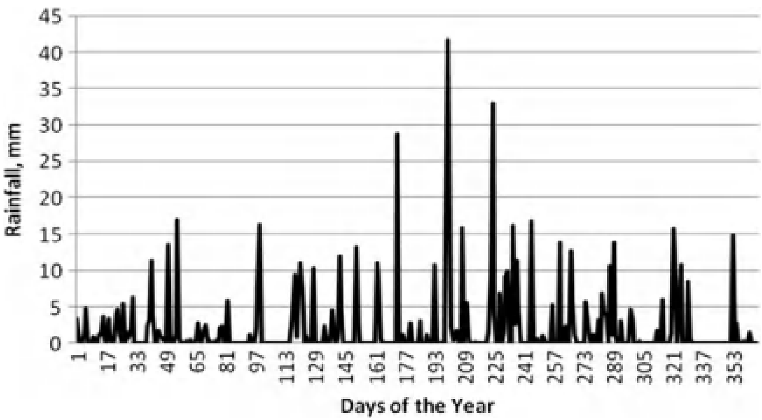


Fig. 2 Daily precipitation in the year 1968

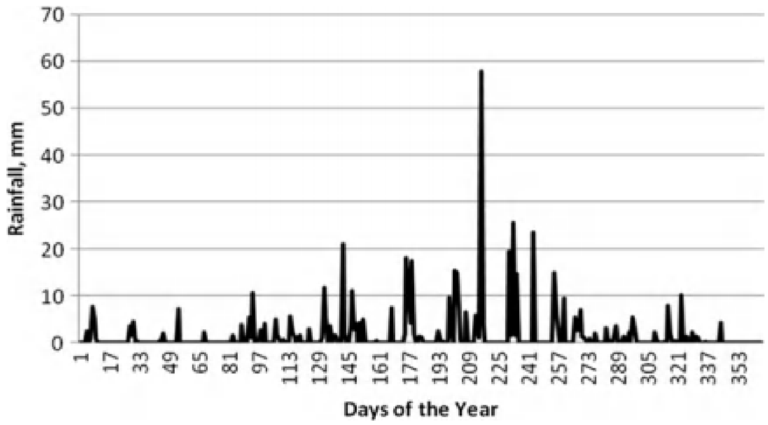


Fig. 3 Daily precipitation in the year 1972

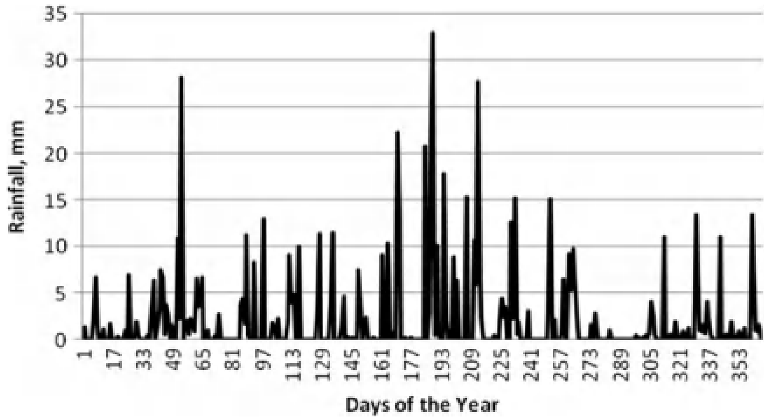


Fig. 4 Daily precipitation in the year 1977

in which the rainwater usage system serves for 2, 4 and 6 people was analyzed. The roof areas assumed for the analysis were: 100 and 150 $m^2$, respectively. Based on the simulation model developed calculations were carried out for 10 years.

The savings E of tap water used for flushing toilets were determined. The results of the calculation for roof surface areas 100 and 150 $m^2$, as well as water used for flushing toilets, are presented in Figs. 5 and 6, respectively.

As may be seen from the relationships presented in Figs. 5 and 6, there is a certain, precisely defined volume for a storage tank, Vz, which, when exceeded, does not show any noticeable growth in tap water savings. This value is closely correlated with rainwater demand and with the roof area.

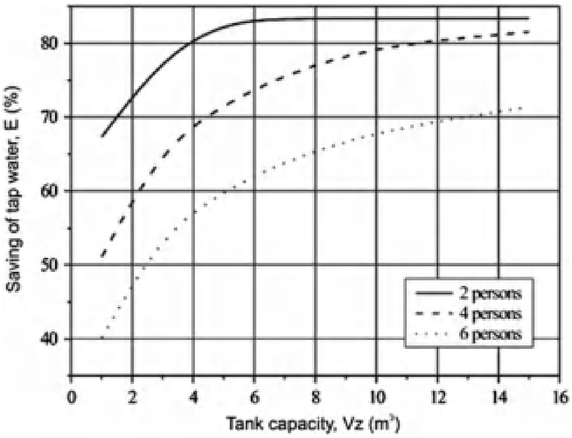


Fig. 5 Savings of tap water when collecting rainwater from roof surface of 100 m$^2$, depending on tank capacity for different numbers of users and different water consumption for toilet flushing

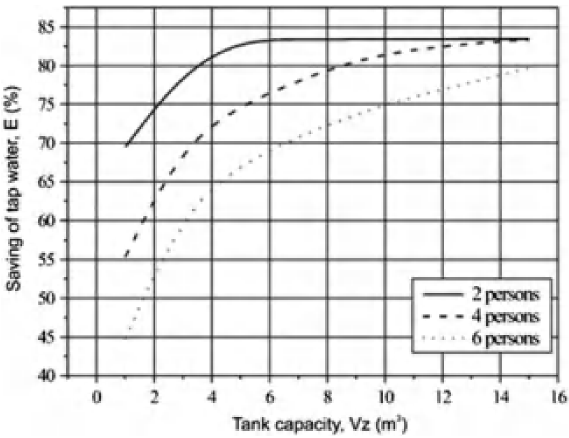


Fig. 6 Savings of tap water when collecting rainwater from roof surface of 150 m$^2$, depending on tank capacity for different numbers of users and different water consumption for toilet flushing

This is a very important observation that implies a formula enabling the calculation of an optimum capacity of the storage tank. The calculations performed indicate a considerable potential for rainwater to substitute potable water for flushing toilets. Depending on the number of people using toilets, the saving effectiveness for a roof of a surface area of 100 m$^2$, ranges from 40 % for a tank of 1 m$^3$ capacity and 6 people to as much as 83.4 % for tank of 7 m$^3$ capacity and 2 users.

The growing number of users and areas to be watered with rainwater by a system of specific rainwater collection area affects the effectiveness of system functioning. A clear improvement of this parameter takes place with growing rainwater collection area.

The next significant research task, affecting the potential of application of such systems in practice, was to determine the areas of their economic effectiveness on the basis of the market price of tap water as supplied to recipients in Poland.

The analysis of water prices in European countries leads to the conclusion that the purchasing cost of tap water in Poland is comparable with the price level in other countries of central-eastern Europe and it is clearly lower than the price for potable water in Western Europe. In the economic analysis of a functioning system, it has been assumed that in Polish conditions the average price per 1 $m^3$ of delivered tap water is about 1 Euro.

Simultaneously, average capital costs of rainwater collection and usage systems for single-family houses offered by manufacturers in Poland have been analysed. Depending on system size, these prices range from 2450 Euro for a system equipped with tank of 2 $m^3$ capacity to 5300 Euro for a system based on a tank with a storage capacity of 20 $m^3$. These are mean capital costs, which comprise the purchase of tank, pump, filter, controls and water-supply piping, as well as the cost of system assembling in single-family house.

Having in mind the above considerations, the ROI (return-on-investment) period (in years) for construction of systems with tanks of various capacities, was determined. Figure 7 presents selected results of calculations of the ROI (return-on-investment) period for construction of system to be used by 2, 4 and 6 users for toilet flushing. The relationship describing the ROI period versus storage tank size has the character of a convex function and reaches its minimum at the point, where the ROI period is the shortest. In this computational case, the return on investment shall take place after a period ranging from 59 to over 100 years, depending of water demand, and tank capacity Vz. It is clear evidence of no economic justification for using such systems in single family residential building in the present Polish macro-economic conditions.

A similar study was carried out for systems using rainwater for both toilet flushing and watering land areas of 2000 $m^2$. Depending on demand for water of reduced quality, the period of return for such systems ranges from 31 to 62 years. The shortest period of return on investment was obtained for a tank of 11 $m^3$ capacity used by 6 users. The results of the calculations are presented in Fig. 8.

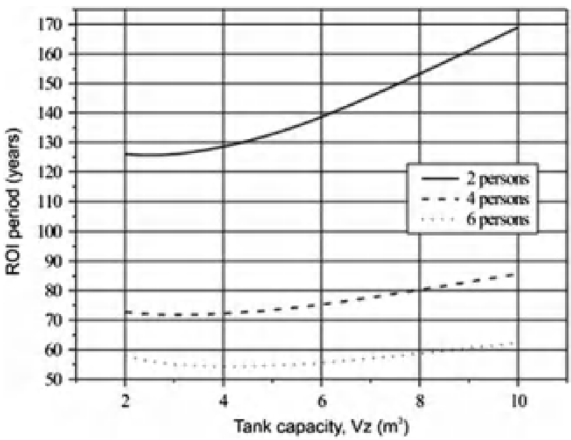


Fig. 7 The return-on-investment (ROI) period for a RWHS collected rainwater from roof area of 150 $m^2$, depending on tank capacity for various numbers of users using it toilet flushing

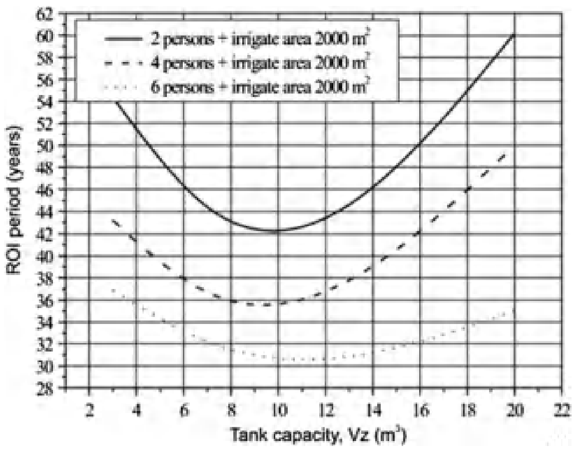


Fig. 8 The return-on-investment (ROI) period for a RWHS collected rainwater from roof area of 300 $m^2$, depending on tank capacity for different numbers of users using it for toilet flushing and for watering a land lot area of 2000 $m^2$

Generally, it may be said that climatic conditions in Poland enable the highly effective functioning of systems for rainwater collection and usage, as confirmed by the results of studies simulating such systems. Despite that, the economic analysis indicates very long ROI (return-on-investment) periods for such systems in single-family houses and low cost effectiveness of constructing such systems in Polish conditions. It is also confirmed by the relatively low level of interest in utilizing systems of this type in Poland.

## 3.2 Multi-family Residential Building

The multi-family building is a 4-story structure with a basement and it consists of two segments. The flats are arranged in the following way: in both segments there are 3 flats per floor on the ground, first and second level; on the third floor there are 2 flats in segment I and 3 flats in segment II.

The analysis of the adopted options for water supply scheme in the above building was based on the following essential data:

- number of residents: M = 81,
- roof surface: 455 $m^2$,
- average unit water demand for toilet flushing qs = 0035 $m^3$/Md,
- runoff coefficient $\psi$ = 1,0,
- number of days of water retention in a tank during a period of drought t = 7 days,
- demand for water for flushing toilets in the building: 2.835 $m^3$/days.

The calculations were based on historical data for rainfall rates in Rzeszów during 10 years (1968–1977).

On the basis of the characteristics of the test object, and meteorological data the required volume of a storage reservoir, which amounted to 22 $m^3$ was calculated.

Based on the developed simulation model and the available data on the amount of daily precipitation, the operation of the sanitary system using rainwater for flushing toilets in the apartment building was analyzed. Figure 9 presents a graph showing the process of filling the tank with rainwater water during the period of 10 years. And Fig. 10 shows the process of water consumption from the retention tank to be installed in one of the selected year.

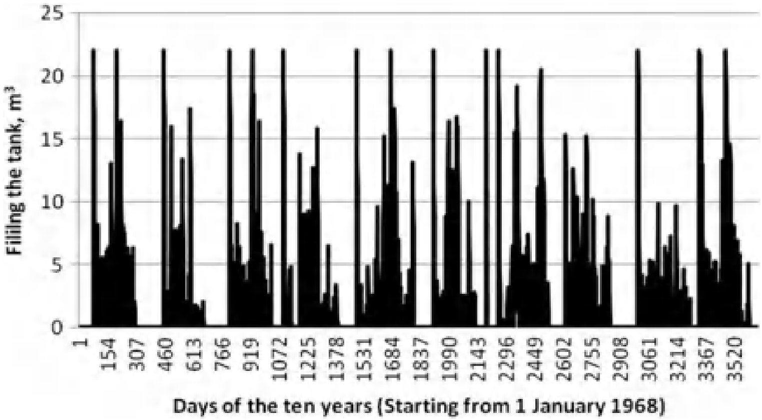


Fig. 9 Filling the storage tank for the multi-family residential building in the years 1968–1977

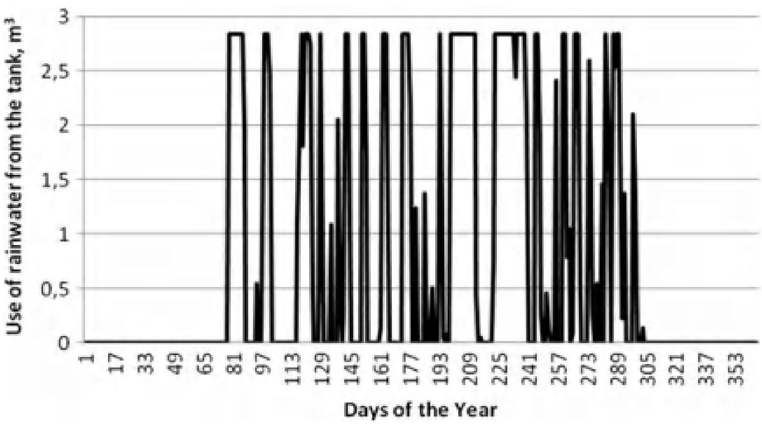


Fig. 10 Use of rainwater from the tank for toilet flushing in 1968

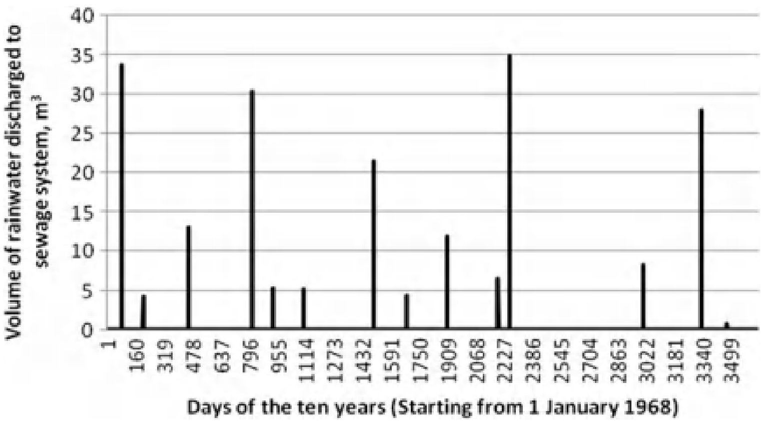


Fig. 11 Volume of an excess of rainwater discharged to sewage system from the tank in the year 1968 and 1977

While analyzing the operation of the RWHS system in apartment building within 10 years the incidences of discharge of the excess of rainwater from the storage reservoir to drain were observed. This process is shown in Fig. 11.

Based on the obtained results, it was found that the rainwater running off from the roof is not able to replace total daily demand for water for flushing toilets in the apartment building. Average savings of tap water in 10 years was 25.8 %.

In order to determine the cost-effectiveness of the use of RWHS in the analyzed apartment building the financial analysis was carried out for two variants of water supply. In studies, the methodology of Life Cycle Cost was applied.

In accordance with LCC methodology the calculations were performed taking into account the complete life cycle of the building, including the initial investments designated for constructing the water supply system and the costs connected with its use. Results of LCC analysis can provide valuable information and facilitate decisions in the process of assessing and comparing alternative solutions. Due to the above, the present article describes tests which make it possible to estimate the costs of building and operating RWHS systems in multi-family residential building. For each of the water supply options envisaged by the study for the multi-family building and for the assumed life of the building in question, the LLC costs were determined according to (1):

$$LCC = K_I + \left[\sum_{t=1}^{T}(1+r)^{-t}\right]\cdot K_E \qquad (1)$$

where: $K_I$—financial investment, Euro; $K_E$—operation costs, Euro; $T$—duration of LCC analysis, $T = 30$ years, r—constant discount rate, $r = 0.05$, $t$—successive year of using the building [–].

LCC analysis was conducted for the following options concerning transport of water to the installation designed for flushing toilets in the residential facility in question:

- Option I—providing the internal installation exclusively with water supplied by the mains,
- Option II—providing the internal installation additionally with water collected from the building's roof and stored in a tank located in the basement.

For the first option, the operation costs $K_{EI}$ included costs of purchasing water from the water supply network and the costs of discharging all stormwater from the roof to sewers. These costs were calculated following formula (2).

$$K_{EI} = K_{ZWW} + K_{OWD} \tag{2}$$

where: $K_{EI}$—operation costs for Option I water supply system in the building, Euro; $K_{ZWW}$—cost of purchasing water for flushing WCs, Euro; $K_{OWD}$—cost of discharging rainwater to sewers, Euro.

The second case took into account operation costs $K_{EII}$ connected with the purchase of mains water necessary for filling up the tank if the flow of rainwater from the roof does not cover the demand for water needed for flushing toilets, and the costs of discharging excess rainwater to sewers. Additional costs were connected with the transport of water from the tank, via pumps to water-closet bowls. The calculation of operation costs $K_{EII}$ was based on formula (3).

$$K_{EII} = K_{ZWW} + K_{OWD} + K_{PW} \tag{3}$$

where: $K_{EII}$—operation costs for Option II water supply system in the building, Euro; $K_{PW}$—cost of transporting water from the tank, via pumps to water-closet bowls, Euro.

Additionally calculation of operation costs for each water supply option envisaged for the building took into account annual increase in prices of purchasing mains water and electricity as well as costs of discharging rainwater to sewers. Based on projections, the following values were determined:

- increase in purchase prices for water from water mains, $r_w = 0.08$;
- increase in purchase prices for electricity, $r_e = 0.07$;
- increase in prices for discharging rainwater to sewers, $r_d = 0.04$.

The calculations of the total costs of construction and using the installation transporting water for flushing WCs additionally took into account the following data:

- purchase price for 1 m$^3$ of mains water, $c_w = 1$ Euro;
- price for discharging 1 m$^3$ of rainwater to sewers, $c_{wd} = 0.77$ Euro;
- annual volume of water transported to toilets: 1034.78 m$^3$;

Table 1 Comparison of costs for the envisaged options of water supply in a multi-family building

| Water supply option | Capital expenditures NINW (Euro) | $K_{ZWW}$ (Euro) | $K_{OWD}$ (Euro) | $K_{PW}$ (Euro) | LCC (Euro) |
|---|---|---|---|---|---|
| Option I | 47,800 | 48,427.6 | 4905.8 | – | 101,133.4 |
| Option II | 65,348 | 36,931.4 | 414.1 | 338.5 | 103,032 |

- annual volume of rainwater transported via pumping systems to water-closet bowls: 245.8 $m^3$;
- purchase price for electricity, $c_{en}$ = 0.14 Euro/kWh.

The applied simulation model of installation designed for domestic use of rainwater to flush toilets in the building in question, as well as the LCC cost analysis conducted for two options of water supply in that building, showed that for the data taken into account in the calculations the traditional method of providing the building with water exclusively from the mains is a cheaper alternative. The obtained findings are shown in Table 1.

Analysis of the findings allows for the conclusion that Option I is characterised by initial capital expenditure which is 27 % lower than Option II. On the other hand, Option I operation costs exceed Option II operation costs by 30 %. The greater value of investments in the latter option results from the necessity to use additional components, such as storage tank, pumping system, fittings and ducts, which are not applicable in the standard installation. The most capital-intensive component of the installation designed for domestic use of rainwater is the storage tank.

However, given the LCC costs, the findings show that the cost of Option II is less than 2 % higher if compared with Option I. Therefore, in the long-term perspective overall costs of both options are similar.

## 3.3 Dormitory

The studies, which were performed on the developed simulation model of the installation of rainwater utilization in a dormitory building were carried out using actual rainfall data. The data on daily rainfall heights derived from the meteorological station Rzeszów-Jasionka. For the simulation tests there was used data from the years 2003–2012, for which the annual rainfall is shown in Fig. 12. The multi-year average sum of precipitation was also pointed out.

The analysis of the performance of the economic use of rainwater utilization system for the “Ikar” dormitory was carried out with a simulation model based on the following input data:

- Canteen roof surface $F_S$ = 1714 $m^2$;
- Roof surface $F_D$ = 731.9 $m^2$;
- Total drained surface $F$ = 2445.9 $m^2$;

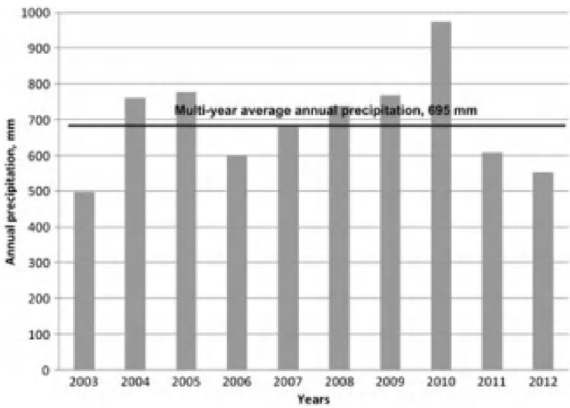


Fig. 12 Annual precipitation between the year 2003 and 2012

- Number of inhabitants (students) M = 600 persons;
- Average unit water demand for toilet flushing $q_s$ = 0.035 $m^3$/Md;
- Daily water demand for toilet flushing $V_s$ = 21 $m^3$/day;
- Runoff coefficient of a drained surface $\psi$ = 1.0;
- Number of days of water retention in a tank during a period of drought t = 7 days.

On the basis of these input data and design recommendations from the producers of rainwater tanks "Tank A's" capacity was determined at 90 $m^3$.

On the basis of the prepared simulation model and possessed daily precipitation data the analysis of the performance of the economic use of rainwater utilization system for the chosen university facility. Figure 13 shows a graph illustrating filling

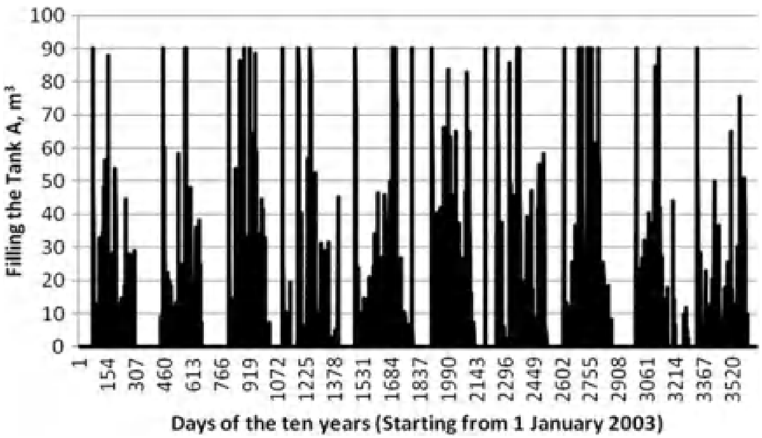


Fig. 13 Filling the tank of rainwater for the "Ikar" dormitory with a tank capacity of 90 $m^3$ and a period between the 2003 and 2012

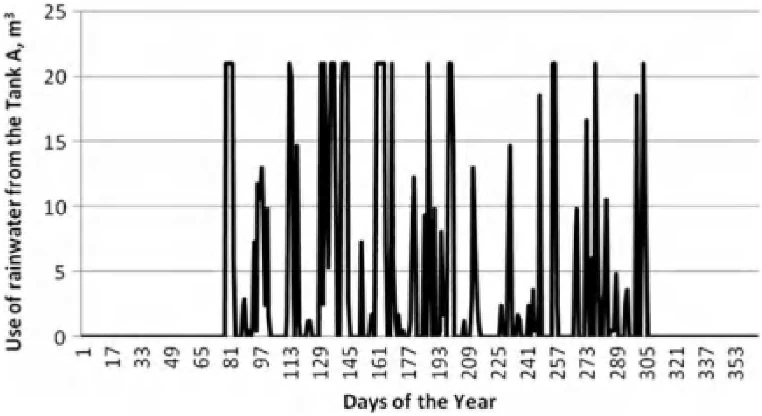


Fig. 14 Use of rainwater from the storage tank for toilet flushing in the "Ikar" dormitory with a tank capacity of 90 $m^3$ in 2003

trends in a period of 10 years in the "Tank A". Figure 14 shows the collection process for rainwater from this tank on specific days of the chosen year.

Despite of considerable capacity of the retention "Tank A", which enables the rainwater downflows from a roof to be effectively retained in it, within the analyzed period some incidents were observed when the excess of rainwater was discharged to a sewage system. The discharging process of the excess of rainwater out of the system is shown in Fig. 15.

In the study it was also analyzed the influence of a retention tank size on efficiency of the economic use of rainwater utilization system for the "Ikar" dormitory. For the purposes of the analysis, tank capacities of 30 and 60 $m^3$ was assumed.

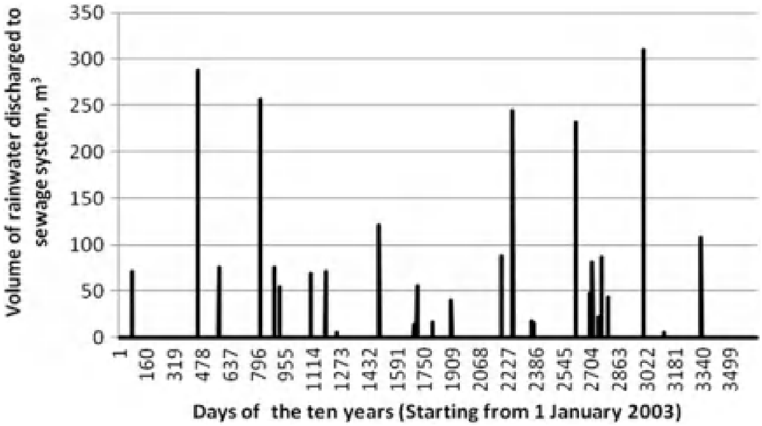


Fig. 15 Volume of an excess of rainwater discharged to sewage system from the tank between the year 2003 and 2012

Analyzing a period of 10 years it was found out that the rainwater downflows from a roof coating cannot fully substitute the tap water needed to satisfy the daily demand for toilet flushing. The high proportion of tap water in the water demand for toilet flushing resulted from the undersized roof surface and the irregular occurrence of precipitation within the year. On the basis of these findings, for each analyzed variant of retention tank capacity, the percentage share of rainwater in the total water demand for toilet flushing in the "Ikar" dormitory was calculated.

Depending on the retention tank capacity, an average saving on lower quality water was 11–22 %. This low system efficiency in the case of a multi-storey building such as the "Ikar" building is a consequence of the undersized roof surface from which the rainwater is collected and, also of the considerable water demand from the large number of inhabitants.

First and foremost, the economic effect of the use of a rainwater utilization system depends on the possible savings on tap water, and capital expenditures and operating costs borne during the system's operation.

The results of the simulation study obtained for different variants of retention "Tank A" capacity enabled us to assess the financial effectiveness of an investment in the possible utilization of rainwater for toilet flushing in the analyzed university facility, and define an optimum variant for the capital project. For this purpose, for the analyzed variant the financial ratio have been determined: the Discounted Payback Period (DPP).

The Discounted Payback Period (DPP) was calculated using mathematical relation (4). This financial ratio determines the number of years after which the discounted incomes from a realized undertaking compensate for the capital expenditures (Ehrhardt and Brigham 2011).

$$\mathrm{DPP_k} = \mathrm{Y_k} + \frac{|\mathrm{NPV_{kY}}|}{\mathrm{CF_{k(Y+1)}}} \tag{4}$$

where: $\mathrm{DPP_k}$—Discounted Payback Period determined for a variant k, in years; $\mathrm{Y_k}$—number of full years before a total payback of expenditures determined for a variant k, in years; $\mathrm{CF_{k(Y+1)}}$—discounted cash flow in a year (Y + 1), determined for a variant k, in Euros; $\mathrm{NPV_{kY}}$—unrecovered expenditures determined at the beginning of the year (Y + 1), determined for a variant k, in Euros.

The Discounted Payback Period was calculated for three analyzed variants of rainwater retention tank capacity in the economic use of a precipitation water utilization system in the "Ikar" dormitory. The findings are presented in Table 2.

Table 2 Discounted Payback Period for analyzed variants of the rainwater utilization system

| Tank capacity ($m^3$) | Discounted Payback Period (years) |
|---|---|
| 30 | 23.25 |
| 60 | 21.86 |
| 90 | 22.00 |

On the basis of the findings obtained, it can be seen that in no analyzed variant of rainwater retention tank capacity did the payback period exceed the one which was assumed for the system's operational life in the building. In the most profitable of the analyzed variants, i.e., the tank of 60 $m^3$ capacity, the DPP is 21.86 year. This means that this tank is the optimum solution for the rainwater utilization system in the analyzed dormitory. Whereas the variant with the tank of 90 $m^3$ capacity enables greater savings to be gained which result from the reduction in tap water use and reduced water volumes discharged to the sewage system, but, consequently, it requires higher capital expenditures. This is translated into a payback period longer than in the case of the 60 $m^3$ tank. Nonetheless, taking into consideration the fact that the DPP values for these two variants are similar and in the further time horizon it would be possible to gain greater savings, it would be reasonable to consider whether the variant with the 90 $m^3$ tank could be the optimum solution. It could also be supported with criteria other than merely financial, for example the criterion of natural environment resource protection.

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# Research of Infiltration Facility Efficiency and Quality of Rainwater Harvested from Surface Runoff in Real Conditions

Gabriel Markovič, Martina Zeleňáková, Zuzana Vranayová and Daniela Kaposztásová

**Abstract** Disposal, respectively safe drainage of rainwater runoff is a problem of almost every new building in an urban area and in area with undersized sewage systems. Design and use of infiltration facilities as a sustainable method of rainwater runoff disposal become an integral part of the drainage management and projects of sewerage system of buildings or other paved surfaces. The permeability of infiltration zone is an essential qualitative and quantitative prerequisite for infiltration of rainwater. Permeability is represented by a filtration coefficient $k_f$, which represents the effectiveness of infiltration facilities, respectively ability of subsoil infiltrate incoming rainwater. Therefore, the most important design parameter of the infiltration facilities is to determine the filtration coefficient $k_f$ on-site. With the correct design, realization and maintenance of infiltration facilities, it should be operation of this device fluent and without complications. It is therefore necessary that the designer of the infiltration facilities known hydrogeological conditions in the interest area. This article aims to provide an overview of the measured data of infiltration systems at the campus of Technical University of Košice and describes the effectiveness of infiltration facilities—infiltration shafts in real conditions.

G. Markovič (&) · M. Zeleňáková · Z. Vranayová · D. Kaposztásová
Faculty of Civil Engineering, Technical University of Košice, Vysokoškolská 4, 042 00 Košice, Slovakia
e-mail: gabriel.markovic@tuke.sk

M. Zeleňáková
e-mail: martina.zelenakova@tuke.sk

Z. Vranayová
e-mail: zuzana.vranayova@tuke.sk

D. Kaposztásová
e-mail: daniela.kaposztasova@tuke.sk

 
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# 1 Introduction

Infiltration of rainwater runoff as a disposal method of rainwater runoff, become an integral part of rainwater management.

Waste-water disposal system is very often overloaded with water coming from heavy rainfall which means that it cannot be used for the purpose of rainwater management. Higher disposition of manhole covers helps to keep sewerage water within safe level and minimize the risk of endangering sensitive ecosystems. Waste-water disposal systems, sewage treatment plants and recipients of water flows are overloaded and the risk of floods grows. This represents another reason for waterworks companies to have the possibility of forbidding the disposal of rainfall water from surface detention into the waste-water disposal system already during the creation and fulfilment of the development plan. For this reason, it is appropriate to design infiltration systems, which not only solve a technical problem that partially relieve a sewer network, but also contribute to the ecological stability of ecosystems, and also reduce expanse for disposal of surface water from rainfall runoff into a waste-water disposal system.

# 2 Rainwater Infiltration

Urban stormwater must be controlled in order to avoid flooding and to safeguard human health and enterprise. Traditionally, urban storm drainage systems have been designed for hydraulic efficiency to transport stormwater from the built environment as quickly as possible (Semadeni-Davies and Bengtsson 2000).

Urban drainage systems can be divided into two most commonly used; combined sewer system and separate sewer system. Combined sewer systems convey stormwater and waste water away in one pipe. Where there are combined systems, there is a risk of combined sewer overflows (CSO) which represents transfers of untreated waste water to receiving waters (Semadeni-Davies and Bengtsson 2000). Whereas separate sewer system carry stormwater and waste water in separate pipes, usually laid side-by-side (Butler and Davies 2011).

## 2.1 Positive Aspects of Rainwater Infiltration Systems

A serious problem in recent years of waterworks praxis has appeared to be the one with growing necessity for surface water detention (Vranayová 2003). Continuous growth of natural terrain coverage for building construction, industry, free time activities and transport reasons leads to widening of the area of build surface and lack of natural terrain with capability of natural rainfall water infiltration. This causes serious damage to natural water cycle. In case rainfall water falls on natural

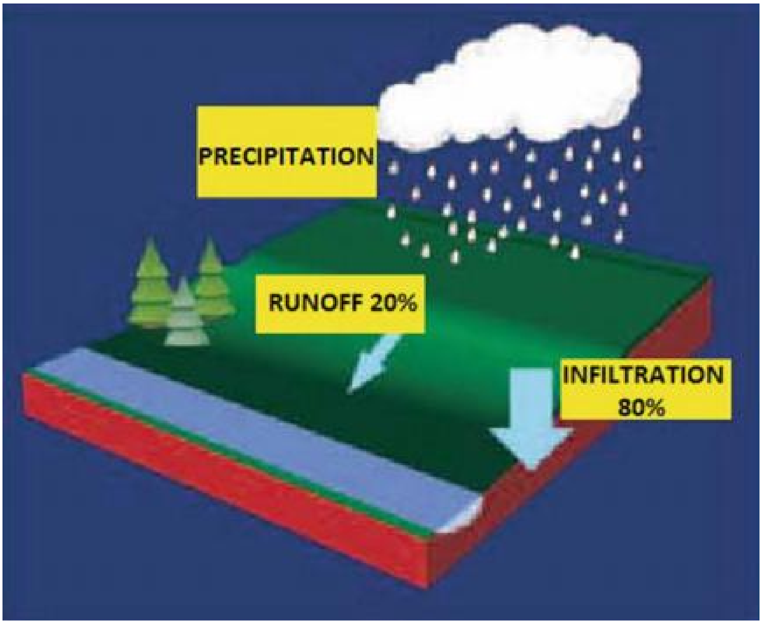


Fig. 1 Cycle of rainwater in nature (Wavin 2006)

terrain, most water soaks in the soil and becomes a part of subsoil water. Only about 20 % of rainfall water comes to rivers or is carried to stormwater drainage (Fig. 1).

As a consequence of a continuous growth of building construction and urban development, natural terrain is replaced by compact soil for example roofs of industrial, residential, commercial or other buildings, road network, car parks etc. When rainfall water reaches these surfaces almost 80 % of this water flows to wastewater disposal system or rivers and only 20 % soaks to the soil (Fig. 2).

This leads to ecological damages as floods, torrential rain, and decline of subsoil water level, local soil dehydration and endangering of sensitive ecosystems. It is necessary to build and develop not only urban constructions but also artificial regulation of water circulation in nature, which contribute to maintenance of ecological stability of chosen location.

Rainwater infiltration system brings also economic advantages especially when prices of water rate and sewage charges grow constantly (Słyś et al. 2012). The reason for forcing these prices up is growth of expenses for drinking water purification and wastewater treatment. Other reasons are declining level of subsoil water and lack of drinking water resources. In years to come the situation won't change or it will be even worse. The prices will grow continuously. Implementation of rainwater infiltration system on private property will help the owner to reduce expenses for conducting rainwater to wastewater disposal system (Fig. 3).

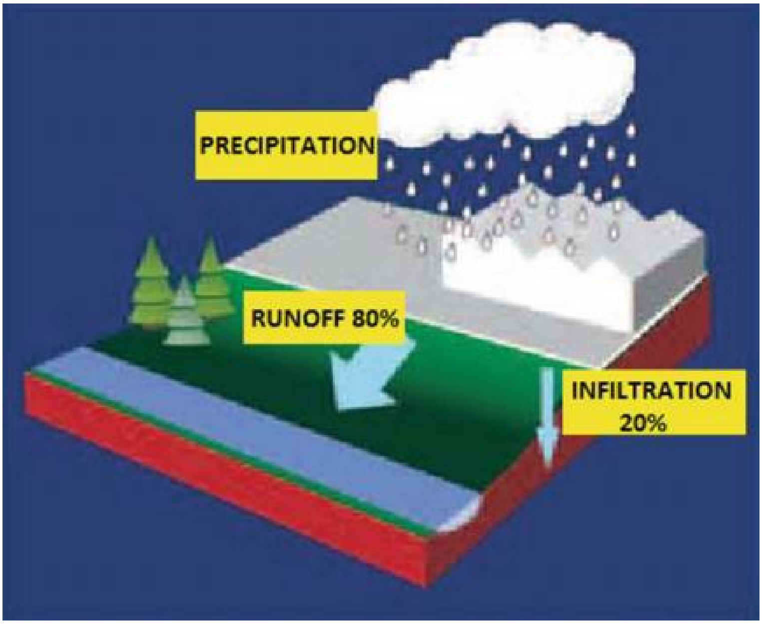


Fig. 2 Cycle of rainwater in urban area (Wavin 2006)

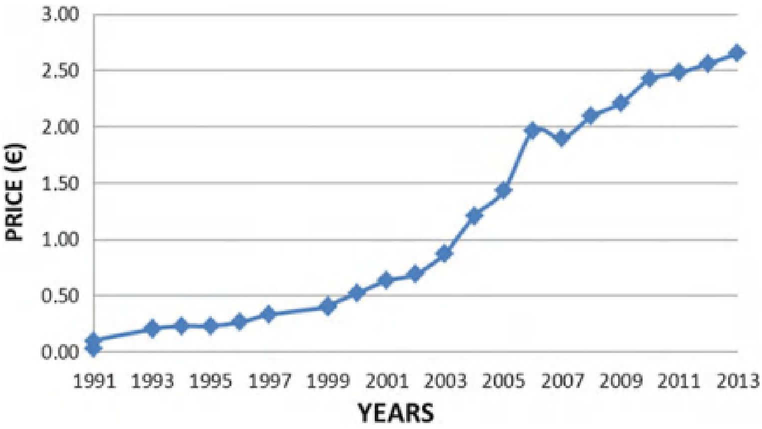


Fig. 3 Price trend of water and sewage charges for households in Košice (Markovič and Zeleňáková 2014)

## 2.2 Main Design Principles of Infiltration Facilities

Design and use of infiltration facilities as a sustainable method of rainwater runoff disposal become an integral part of the drainage management and projects of sewerage system of buildings or other paved surfaces. Infiltration facilities are devices designed for fluent and natural infiltration of rainwater from the roofs of buildings and paved surfaces.

The basic principle and function of all types of infiltration facilities as quickly as possible to divert rainwater to infiltration zone and there it infiltrates into the surrounding soil.

Main technical solutions for infiltration facilities are:

- Surface infiltration
- Swale infiltration
- Swale Trench infiltration
- Infiltration trench and pipe infiltration trench
- Shaft infiltration
- Basin infiltration
- Undergroud infiltration blocks

A very important design parameter of infiltration facilities is to determine the infiltration coefficient $k_f$ in the interest area. Infiltration coefficient $k_f$ generally represents an efficiency of infiltration facilities, respectively infiltration capability of the soil to absorb inflow water.

Permeability of the infiltration zone is a main qualitative and quantitative requirement for rainwater infiltration. Permeability of loose rock depends primarily on the size and distribution of the particles and compactness, in soils is critical soil structure and water temperature and is given by the infiltration coefficient. Permeability of loose rock varies in general between $1 \times 10^{-2}$ and $1 \times 10^{-10}$ m/s (Fig. 4). The $k_f$ values apply to the process of infiltration water in the saturated

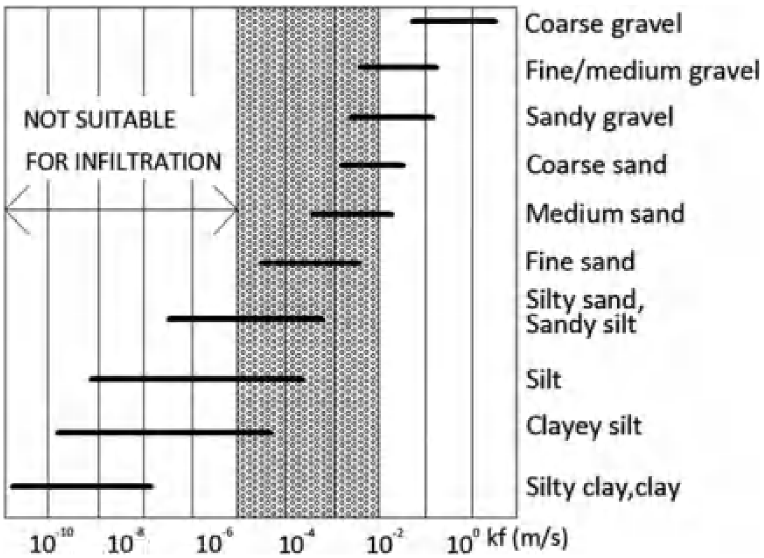


Fig. 4 Recommended values of the infiltration coefficient (Standard DWA-A 138E 2005)

zone. The range of values for the filtration coefficient for technical drainage ranges from $1 \times 10^{-3}$ and $1 \times 10^{-6}$ m/s (Vrána 2010).

The $k_f$ values greater than $1 \times 10^{-3}$ m/s cannot be reached for rainwater runoff and low depth of groundwater level the sufficient pretreatment through chemical and biological processes. If the $k_f$ values are smaller than $1 \times 10^{-6}$ m/s, the percolation facilities are loaded very long time. For this reason, anaerobic processes in the unsaturated soil, which resulting in adverse effects on retention and capacity capabilities of the soil can occur.

Therefore, the most important design parameter of the infiltration facilities is to determine the filtration coefficient $k_f$ on-site.

The infiltration facilities can't cause any damage to buildings or other facilities. Therefore, it always should be respected a minimum distance from buildings, basement of the buildings and the average amount of groundwater levels. These dimensions can vary from a few decimetres to several meters.

Figures 5 and 6 represent minimum distance from buildings. The same rules apply for underground infiltration facilities.

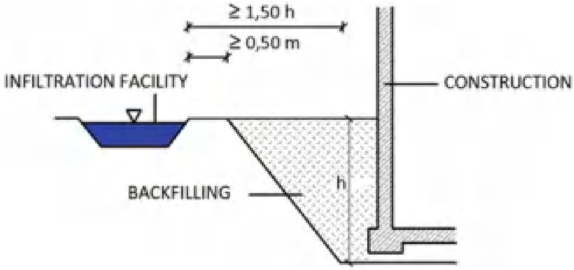


Fig. 5 The minimum distance of the decentralized infiltration facilities from building without waterproofing (Standard DWA-A 138E 2005)

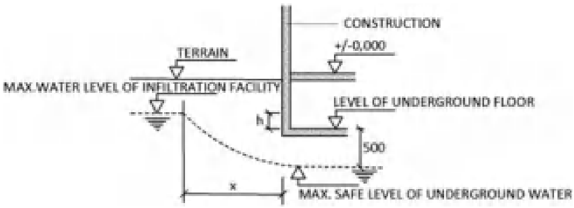


Fig. 6 Required separation distance from buildings (Žabička 2010)

# 3 Experimental Research of Quality and Quantity of Rainwater in the Campus of TU Košice

The project APVV SUSPP-0007-09 relating to quality and quantity of rainwater, taking place at the Faculty of Civil Engineering in Košice-city. The sources tested are located in the premises of TUKE (Technical University of Kosice—Fig. 7). The resources that provide us information about the quality and quantity of rainwater are located in the campus of Technical University of Kosice. First is rain gauge (Fig. 8) located on the roof of University library, second is real school building PK6 (Fig. 19) third are two model tanks located on a roof of University library too (Fig. 30).

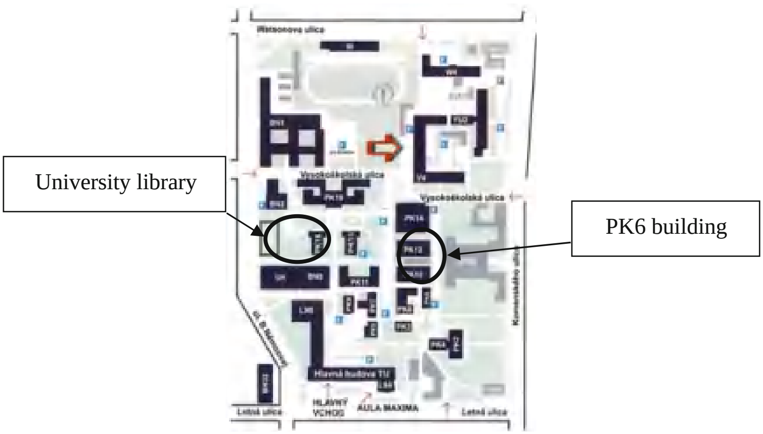


Fig. 7 Location of the research points in the premises of TUKE (Ahmidat et al. 2013)

Fig. 8 Rain gauge on the roof of University library

## 3.1 Measuring Devices

The rain gauge is located at the campus of the Technical University of Košice on the roof of University Library which is flat and provides good access. Rain gauge is joined with its own concrete foundation using a steel rod. Flat roof helped us fixing the rain gauge into horizontal position which is the first condition for receiving correct data.

Rain gauges are the most common device for measuring rainfall. Non-recording gauge collects rain falling on a standard area over a known period of time and the volume of stored rainfall is measured manually, compared to recording gauges which are able to provide continuous record of precipitation.

We use recording heated rain gauge for all year round measuring. There are known unheated rain gauges as well used for limited part of year when the temperatures aren't so low. Heated rain gauge is used for measuring liquid precipitation (rain) and solid precipitation (snow) as well. Rain gauge (Fig. 8) is made of stainless material.

Rain gauge's round catchment area is 200 $cm^2$ and its function is based on tipping bucket mechanism. Tipping bucket is located inside the rain gauge body right under the funnel outlet. Rain or snow fall down the funnel outlet into the divided bucket. The bucket does not move until it is filled with calibrated 0.2 mm amount of water, then it tips and second half of bucket can be filled with rain water. When the bucket tips it empties the liquid from the half of the bucket into a drainage hole. Tipping bucket is made of plastic with very thin layer of titanium and it is hanged on stainless steel axial holder. Tipping continues according to the length of rainfall (Uhmannová et al. 2013).

Initial measurement start and continue in infiltration shaft A since March 2011, when began to measure the inflow of rainwater runoff from the roof of the building PK6.

Headquarters, respectively a control/data unit for generating of measurement data, is a universal data unit M4016, which is situated in the infiltration shaft A (Fig. 9). Infiltration shaft B, respectively devices located in this shaft, are also connected to the control unit.

Registration and control unit equipped unit M4016 includes universal data logger, telemetric station with build-in GSM module, programmable control automat and multiple flow meter if M4016 is connected to an ultrasonic or pressure level sensor (Fig. 4) (Markovič 2012).

Under inflow, respectively rain outlet pipe in the shaft, there are measurement flumes for metering of inflow rainwater from the roof of a building PK6 in both of infiltration shafts (Fig. 10). Rainwater from the roof of the building PK6 is fed by rainwater pipes directly into measurement flumes, which are placed under the ultrasonic level sensor which transmitting data of the water level in the measurement flumes to the data unit M4016 (Markovič 2012).

The unit M4016, in which the signal transmitted from the ultrasonic level sensor is preset up to 14 equations or the most used sharp crested weirs. Flow rate

Fig. 9 Data unit M4016 in shaft A (Markovič 2012)


Fig. 10 Measurement flume with ultrasonic level sensor in shafts (Markovič and Vranayová 2013)

calculation from relationship water level/flow rate. For the purposes of our measurements is to calculate the instantaneous and cumulative flow, calculated from water level used by predefined profile—Thomson weir (Technical documents of Fiedler-magr—Manuál M4016 2012).

Thomson weir consists of two overflow edges with an angle of 90°. Axis of this angle must be vertical (Fig. 11) (Mosný 2002).

The measurement of inflow rainwater was later extended of the other parameters, especially the effectiveness of infiltration shafts for infiltration of rainwater at the shaft bottom, respectively, infiltration rate of the inflow water.

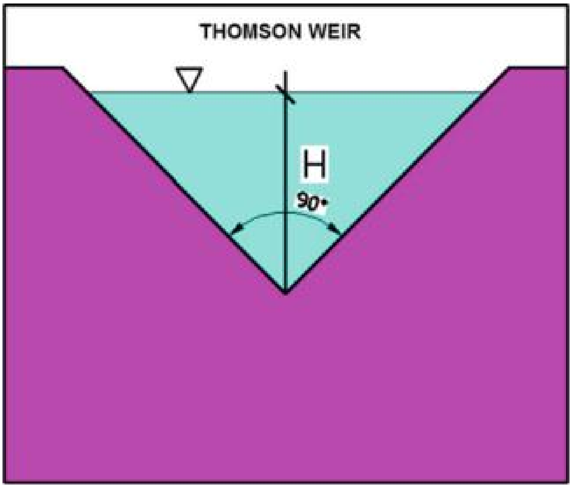


Fig. 11 Thomson weir

Fig. 12 Pressure sensor for measuring of the water level at the bottom of infiltration shaft (Markovič and Vranayová 2013)

Measurement of the inflow of rainwater volume runs on the bottom of infiltration shafts, where are located pressure sensors type LMP307 which monitoring water lever (Fig. 12).

Sensors are placed in a metal container at the bottom of shafts and are used for continuous measurements of water levels and infiltration capabilities of shafts. The pressure sensor is made of stainless steel with protection IP 68 (Technical documents of Fiedler-magr LMP307 2012) and is connected with data communication cable to control unit M4016 where the measured data is also sent in minute interval, like data of rainwater inflow, sent directly to the server.

## 3.2 Experimental Research of Quantity of Rainwater – Infiltration Shaft Efficiency

### 3.2.1 Infiltration Shafts

One of the types of infiltration facilities are percolation/infiltration shafts. It is a vertical underground infiltration facility which is usually made from concrete rings with the filter layer on the bottom (Fig. 13).

Rainwater from the catchment area is transported with system of vertical and horizontal rain pipes in underground space for infiltration.

Infiltration shaft is a facility where the largest dimension is depth, so that design of this shaft depends of the highest water level in the shaft and also of the groundwater level in the interest area. The design of shafts must take into the account protection of groundwater and infiltration capability of shaft which is represents by infiltration coefficient on site.

The design of shafts must take into the account protection of groundwater and infiltration capability of shaft. German standard DWA-A 138 indicates that it is necessary to place the bottom of the infiltration shaft a filter sack which is located above the filter layer. The total volume of inflow rainwater must pass through the filter sack before infiltration into the soil. The filter sack is absorbing all of the settle able and filterable solids and filter sack should be flushed or replaced (Standard

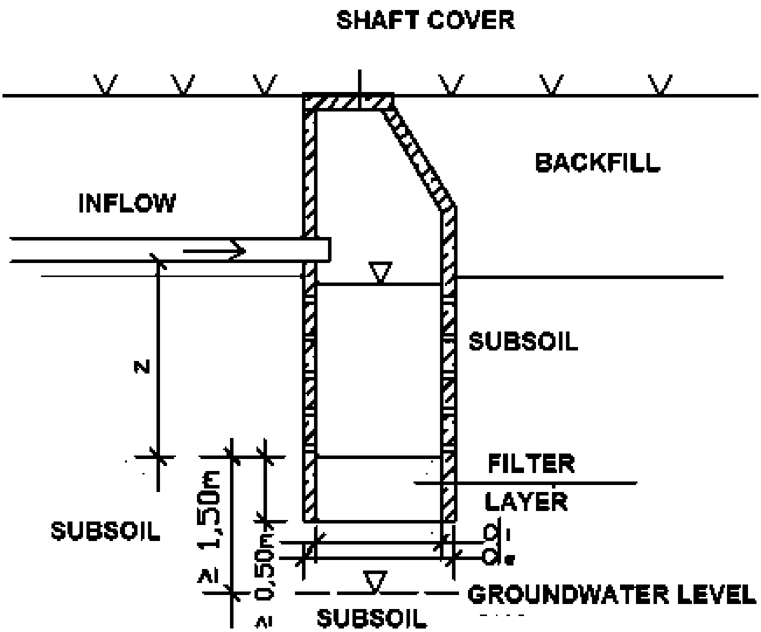


Fig. 13 Infiltration shaft

DWA-A 138E 2005). Czech standard for infiltration indicates that on the bottom layer is placed layer of gravel at least 300 mm. On this layer is placed geo-textile, which is recommended to protect with the gravel-sand layer (ČSN 75 9010 2012).

### 3.2.2 Local Conditions in the Interest Area

As was already mentioned above, the most important parameter of design not only for infiltration shafts, but in general infiltration facilities, is to determine the infiltration coefficient $k_f$ in the interest area.

Morphology of the interest area is formed by alluvial plains of the river Hornád. The surface of the site is formed from anthropogenic sediments (fills). Under this layer are located fluvial sediments of river Hornád and under this layer are sediments of neogene age (Záverečná správa geologických prieskumných prác pre objekt Technicom 2010).

The fills of the interest area consist mostly of gravel clays, a building waste and natural gravels. Through the exploratory bores was to verify the thickness of these fills from 0.5 to 0.6 m. Under the fills were verified fluvial sediments of the river Hornád. Immediately under the backfill was verified continuous layer of clay with a thickness of 4.0–4.5 m. Under flood sediments were verified fluvial gravel sediments with a thickness of 5.0–7.0 m, and its gravels blended with fine-grained soil. The bottom layer consists of clay-gravel with a thickness of 0.7–2.7 m (Záverečná správa geologických prieskumných prác pre objekt Technicom 2010).

Validation of the hydrogeological survey of the site, respectively verify the infiltration coefficient $k_f$ of the soil in studied infiltration shafts near the PK6 building was made by taking samples of soil from the bottom of the infiltration shafts. Through the laboratory tests, the samples were evaluated as gravel blended with a fine-grained soil and infiltration coefficient set at $10^{-3}$ m/s, what confirming the hydrogeological survey of the site made for object Technicom in the campus of TU Košice.

### 3.2.3 Theoretical Calculation of Infiltration Shaft Efficiency

Theoretical analysis of infiltration shaft efficiency respectively of the time required for infiltration of inflow rainwater from the roof of the building was processed for the studied infiltration shaft A and its real dimensions:

Locality: Campus TU Košice, PK6 building
$A_{imp}$—area of roof for shaft A: 212 $m^2$
$d_e$—outer diameter of shaft: 1.0 m
$d_i$—inner diameter of shaft: 0.8 m
$k_f$—infiltration coefficient: $1 \times 10^{-3}$ m/s
$r_{D(0.5)}$—rainfall intensity for duration D and frequency n.

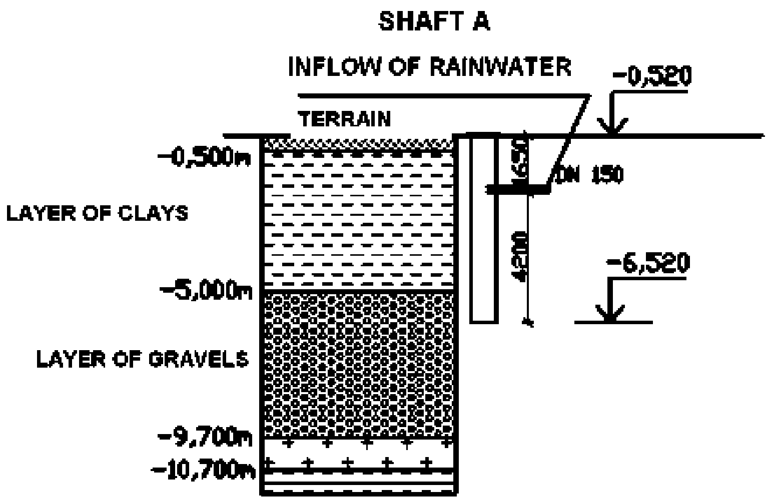


Fig. 14 Infiltration shaft A near building PK6 with geological cut

Before the calculating of infiltration shaft efficiency respectively of the time required for infiltration of inflow rainwater to the soil on the bottom of shaft is necessary to calculate the required depth and accumulation volume of infiltration shaft (Fig. 14).

As was already mentioned above, the most important parameter of design not only for infiltration shafts, but in general infiltration facilities, is to determine the infiltration coefficient $k_f$ in the interest area. Therefore, the calculation was processed for a range of infiltration coefficients from $10^{-2}$ to $10^{-7}$ m/s for presentation as infiltration coefficient depends for design of infiltration shaft resp. facilities (Tables 1 and 2; Figs. 15 and 16).

Last calculation is to determine the time required for the infiltration of total volume of inflow rainwater.

As a result from theoretical calculation (Table 3; Fig. 17), the efficiency of infiltration shaft respectively time required for infiltration of rainwater inflow in studied infiltration shaft would be ranges of minutes.

Table 1 Required depth of infiltration shaft depending of the infiltration coefficient (Markovič 2012)

| Infiltration coefficient | Rainfall intensity | z (shaft depth in m) |
|---|---|---|
| $k_f = 10^{-2}$ | $r_D(0.5)$ | 0.32 |
| $k_f = 10^{-3}$ | $r_D(0.5)$ | 2.97 |
| $k_f = 10^{-4}$ | $r_D(0.5)$ | 7.51 |
| $k_f = 10^{-5}$ | $r_D(0.5)$ | 12.47 |
| $k_f = 10^{-6}$ | $r_D(0.5)$ | 14.46 |
| $k_f = 10^{-7}$ | $r_D(0.5)$ | 14.73 |

Table 2 Required accumulation volume of infiltration shaft depending of the infiltration coefficient (Markovič 2012)

| Infiltration coefficient | Rainfall intensity | V (accumulation volume in $m^3$) |
|---|---|---|
| $k_f = 10^{-2}$ | $r_D(0.5)$ | 0.16 |
| $k_f = 10^{-3}$ | $r_D(0.5)$ | 1.49 |
| $k_f = 10^{-4}$ | $r_D(0.5)$ | 3.77 |
| $k_f = 10^{-5}$ | $r_D(0.5)$ | 6.26 |
| $k_f = 10^{-6}$ | $r_D(0.5)$ | 7.27 |
| $k_f = 10^{-7}$ | $r_D(0.5)$ | 7.40 |

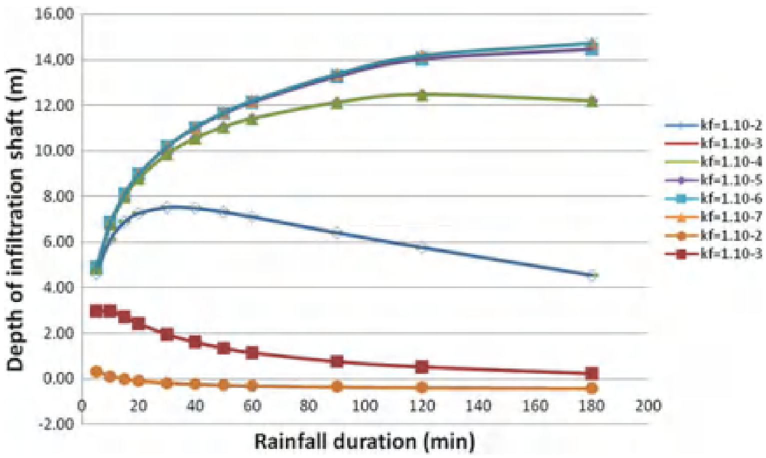


Fig. 15 Graph of required depth of infiltration shaft depending of the infiltration coefficient corresponding to each rainfall intensity for duration D and frequency $r_{D(0.5)}$

It should also be noted that the infiltration coefficients suitable for infiltration by infiltration facilities ranges between $10^{-3}$ and $10^{-5}$ m/s.

### 3.2.4 Infiltration Shaft Efficiency in Real Conditions

All rainwater runoff from roof of building PK6 is flow into the two infiltration shafts (Fig. 19). Roof area of the PK6 building is 548.55 $m^2$ (Fig. 18).

It should be noted that the project of building drainage and project of design and realization of infiltration shafts is not available. All data, whether the parameters of infiltration shafts or a drainage concept of rainwater from the building, were investigate on site (Fig. 20).

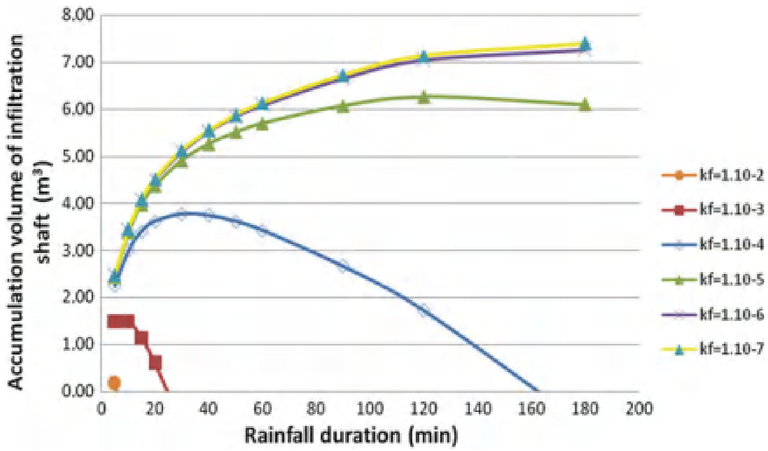


Fig. 16 Graph of required accumulation volume of infiltration shaft depending of the infiltration coefficient corresponding to each rainfall intensity for duration D and frequency $r_{D(0.5)}$

Table 3 Required time for rainwater infiltration in shaft A depending of the infiltration coefficients from theoretical calculation (Markovič 2012)

| Infiltration coefficient | Rainfall intensity | z (shaft depth in m) | V (accumulation volume in m$^3$) | t (time of infiltration in hours) |
|---|---|---|---|---|
| $k_f = 10^{-2}$ | $r_D(0.5)$ | 0.32 | 0.16 | t = 0.05 |
| $k_f = 10^{-3}$ | $r_D(0.5)$ | 2.97 | 1.49 | t = 0.13 |
| $k_f = 10^{-4}$ | $r_D(0.5)$ | 7.51 | 3.77 | t = 1.4 |
| $k_f = 10^{-5}$ | $r_D(0.5)$ | 12.47 | 6.26 | t = 14 |
| $k_f = 10^{-6}$ | $r_D(0.5)$ | 14.46 | 7.27 | t = 143 (6 days) |
| $k_f = 10^{-7}$ | $r_D(0.5)$ | 14.73 | 7.40 | t = 1432 (60 days) |

Both infiltration shafts are located at the east side of the building PK6. The shafts are realized from concrete rings with the outer diameter of 1000 mm. Parameters of infiltration shafts are shown in Table 4.

Real values of infiltration shaft efficiency respectively of the time required for infiltration of inflow rainwater from the roof of the building PK6 in campus of the Technical University of Kosice are shown in Figs. 21 and 22 (Markovič and Vranayová 2013).

Figures 2 and 3 represent 2 selected rainfall events from every year of research showing the process of inflow rainwater into the infiltration shaft, calculated volume of inflow rainwater and process of water level change at the bottom of infiltration shaft A. The time for infiltration of rainwater at the bottom of shaft basically follows the process of precipitation, respectively inflow of rainwater into the shaft.

As resulting not only from Figs. 21 and 22, but also from the overall measured data during the research, the total infiltration of rainwater in the infiltration shaft, take place at the time of termination of rainfall events, respectively short-time after,

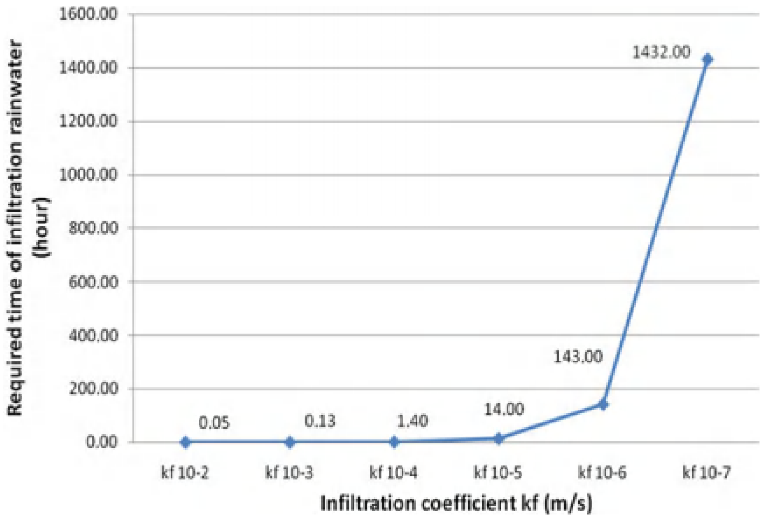


Fig. 17 Graph of required time of infiltration rainwater depending of the infiltration coefficient

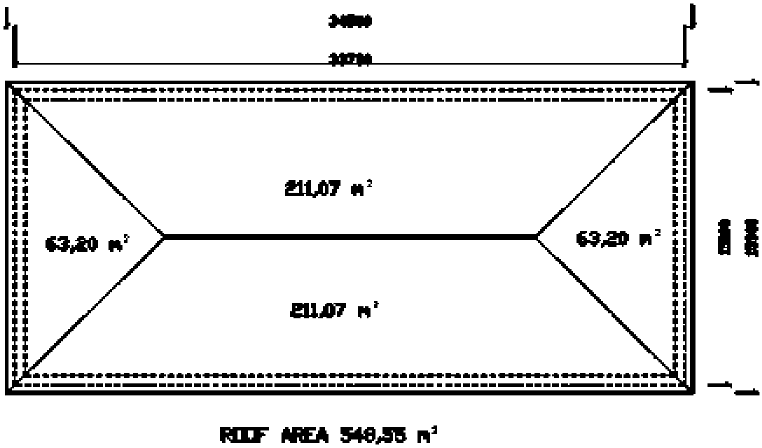


Fig. 18 Ground plan of PK6 roof

which represent a high infiltration rate of this shaft, given by the coefficient of infiltration of soil at the bottom of shaft. Therefore, despite the smaller surface for infiltration of infiltration shafts with comparison to other types of infiltration facilities, the infiltration coefficient of surveyed infiltration shafts $k_f = 1 \times 10^{-3}$ m/s ensures safe disposal of surface runoff. The maximum water level at the infiltration shafts are shown in Figs. 23 and 24 (Markovič and Vranayová 2013).


Fig. 19 Location of infiltration shafts near building PK6 (Markovič and Vranayová 2013)

## 3.3 Experimental Research of Quality of Rainwater Runoff

The aim of our research is to identify factors that affect the quality of rainwater harvested from surface runoff (hereinafter RHSR), such as surrounding environment in which the system of RHSR is located, impact of rain periods (rainfall periods or periods without precipitation) and the impact roofing materials have on the quality of RHSR. Main goal of the research is to obtain information about RHSR collected from roofs of various roofing materials and, based on this information, identify roofing material which appears to be the most suitable material for the monitored area of Košice.

Assessment of individual quality indicators of RHSR follows the Regulation of the Slovak Republic No. 269/2010 Z. z., effective May 25th, 2010, laying down the requirements for achieving good water status results.

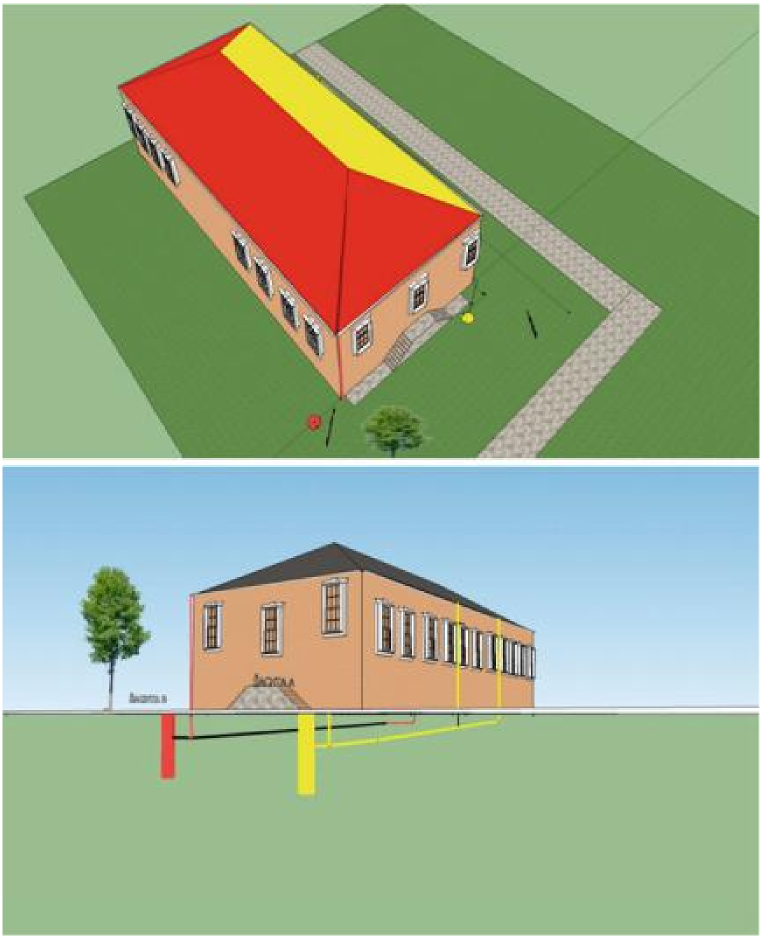

Fig. 20 Drainage of rainwater from roof of building PK6 (Markovič and Vranayová 2013)

Table 4 Parameters of infiltration shafts (Markovič and Vranayová 2013)

| | Shaft A | Shaft B |
|---|---|---|
| The outer diameter of shaft | 1000 mm | 1000 mm |
| The inner diameter of shaft | 800 mm | 800 mm |
| Shaft depth | 6.0 m | 5.9 m |
| Depth of inflow | 1.65 m | 1.5 m |
| DN of inflow pipe | DN 150 | DN 125 |
| Infiltration coefficient at the bottom | $1 \times 10^{-3}$ m/s | $1 \times 10^{-3}$ m/s |
| Drainage area of roof | 212 $m^2$ | 336 $m^2$ |
| Accumulation volume | 2.11 $m^3$ | 2.18 $m^3$ |

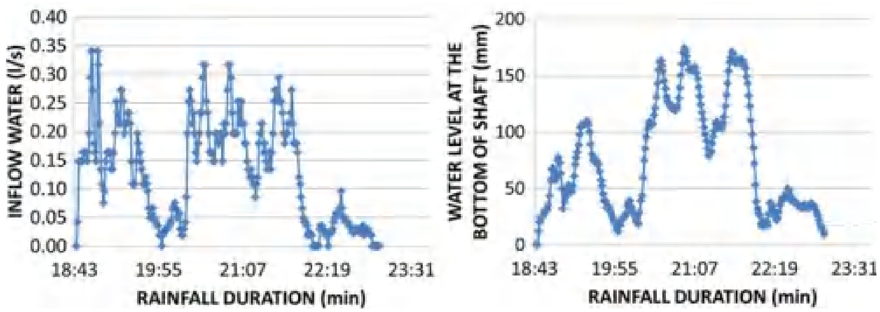


Fig. 21 Volume of rainwater inflow and water level changes at the bottom of shaft during rainfall 7 October 2011 (Markovič and Vranayová 2013)

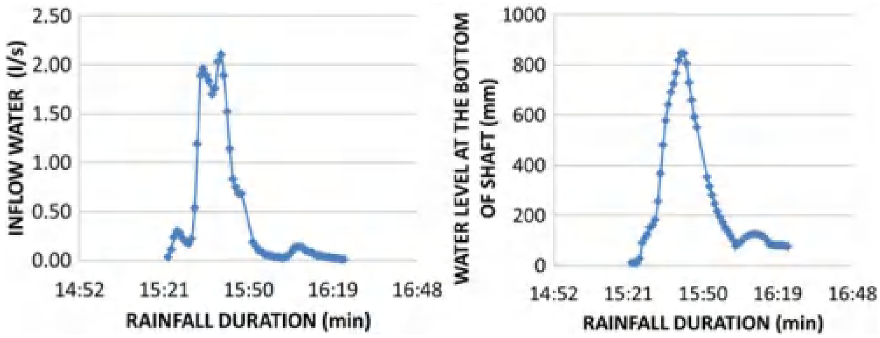


Fig. 22 Volume of rainwater inflow and water level changes at the bottom of shaft during rainfall 1 September 2013 (Markovič and Vranayová 2013)

One of the basic elements of environment affecting the quality of rainwater is atmosphere. Polluted atmosphere is an important factor that degrades the quality of materials and affects the occurrence of acid rain. Each material gives different response depending on the material composition and other characteristics. Most of the materials exposed to atmosphere show sensitivity to the effect of sulfur compounds, chloride aerosols and acidity of atmospheric precipitation. Degree and type of environment contamination need to be considered when choosing materials and protective coatings. Pollution level is a decisive parameter in the estimation of objects lifetime, their components and surface finish (SAŽP 2002; Fargašová 2011).

Quality of air in Košice and its surroundings is predominantly affected by industry structure which is represented mainly by metallurgical, chemical and processing industry. The area is also a place of production of heat energy and electric power characterized by high energy demands of technologies used that, moreover, produce significant emission leakage which ultimately has a negative impact on the quality of air. Increasing car traffic is becoming a more significant source of air pollution, centred mainly on the main transport corridors on the

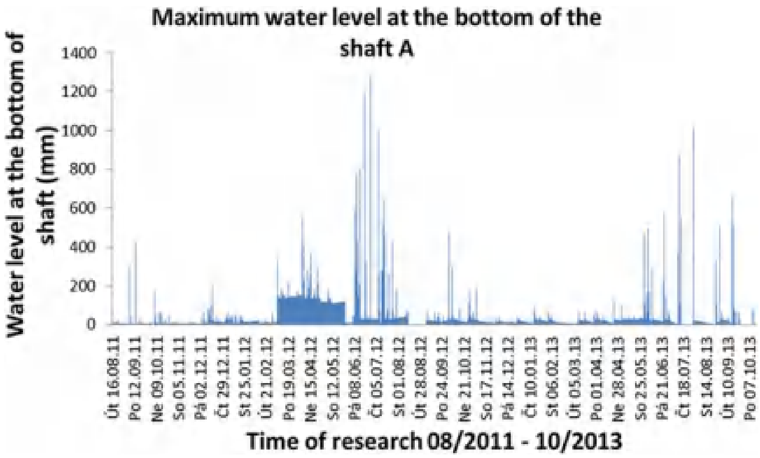


Fig. 23 Values of maximum water level at the bottom of the shaft A from August 2011 to October 2013 (Markovič and Vranayová 2013)

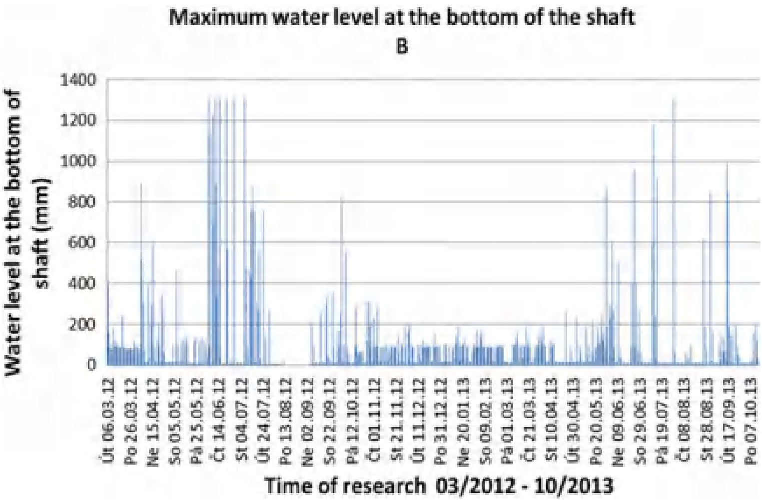


Fig. 24 Values of maximum water level at the bottom of the shaft B from March 2012 to October 2013 (Markovič and Vranayová 2013)

entrance to the city and in the "canyons" of the streets in the central part of the city. The growth in road traffic intensity increases the area-wide road burden and increases the amount of exhaust fume emissions and secondary dust. Dominant source of air pollution in the area is U.S. Steel Košice. Within the regions of Slovakia, long-term production of major pollutant emissions, groups of inorganic gaseous pollutants and heavy metals is centered right in the city of Košice and its surroundings.

Quality of rainwater can be influenced by the selection of appropriate roofing. When choosing suitable roofing material, the material must comply with the following conditions:

- it does not contain toxic substances,
- it ensures immediate drainage of rainfall,
- wash-away of "Runoff" (such as dissolving of metal in the form of ion and its wash-off from roofing) is minimal,
- pollution catchment is low,
- intact roof drainage (gutters and waste pipe)
- easy maintenance (identification of parts which require frequent maintenance, easily accessible cleaning catchment areas)

In the past, rainwater harvested from surface runoff (hereinafter RHSR) in Slovakia was used mainly for irrigation of gardens. These days, systems for collecting RHSR are built in mainly in buildings like supermarkets, stadiums, etc. where RHSR is used for toilets flushing. Only negligible number of Slovak families use RHSR for household needs (washing, flushing, etc.). RHSR can become widely used in everyday life in the near future once systems for RHSR collecting are installed to houses, schools or office buildings. This water could partially replace precious drinking water. For RHSR use in households it is essential that collected water complies with both health and hygienic requirements and also meets quality requirements (Očipová et al. 2010).

Drinking water quality is evaluated according to basic indicators:

- microbiological and biological indicators (coliform bacteria, thermotolerant coliform bacteria and faecal streptococci),
- physico-chemical parameters (pH, conductivity, levels of heavy metals and chemicals that could harm human health),
- sensorial characteristics (taste, odor, color)

Factors affecting the quality of RHSR are:

- environment in which the system for SWR operates (proximity of roads, traffic density, proximity of the manufacturing and construction industries, heavy industry, housing sector, agriculture),
- meteorological conditions (temperature, amount of rainfall periods and dry periods, course of fronts), SWR system (material used, its sustainability, filtration),
- human factors (proper sizing, regular maintenance, information about the operation of system as a whole and also about individual components)

Measuring of qualitative parameters began in late 2011 using multi-parameter water sensor, type YSI 600 XL, placed in a infiltration shaft (Fig. 25), pH and conductivity measurements took place continuously (Ahmidat and Vranayová 2010).

Fig. 25 Multi-parameter water sensor for RHSR quality measurement, type YSI 600 XL, and its location in a concrete shaft

Measurements of qualitative parameters (pH and conductivity) by multiparameter water sensor started at the end of 2011. Multiparameter water sensor is situated at measurement flume (Fig. 25). pH and conductivity values are being measured continually. Box-Plot graph on Figs. 26 and 27 depicts pH values of water during 2012 and 2013. Figures show that the average value of pH varies each month. Evaluation of respective indicators is carried out basing on the government regulation of Slovak Republic (Slovak Government Regulation 2010) which sets the requirements for optimal state of water. In accordance with the regulation the value of pH should fit into the interval from 6 to 8.5. In June and October pH values are below the limit what mean that RHSR is acid (Ahmidat et al. 2013).

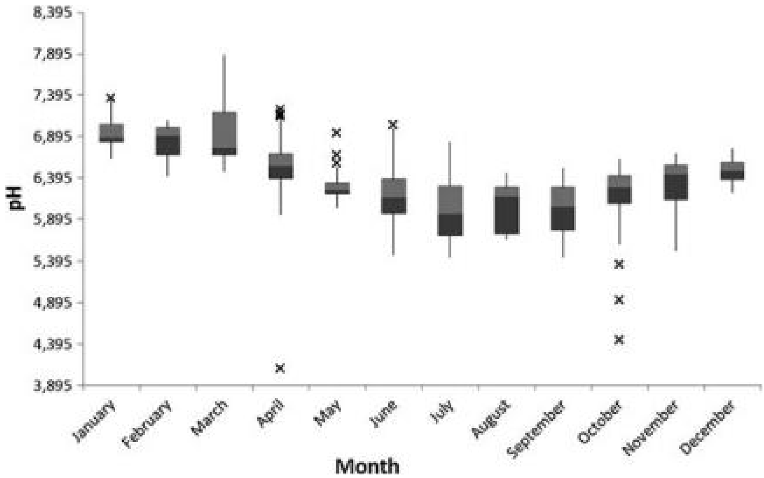


Fig. 26 pH values of rainwater from PK6 Building during 2012

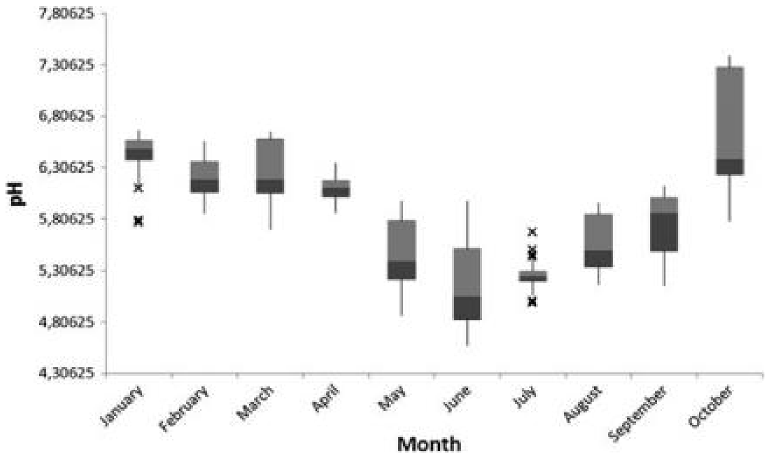


Fig. 27 pH values of rainwater from PK6 Building during 2013 (Ahmidat et al. 2013)

Another indicator of the quality of water collected from PK6 building is conductivity. Conductivity, like pH values, is also measured continually using a multiparameter sensor.

Conductivity stands for approximate rate of concentration of electrolytes in water. According to the regulation (Slovak Government Regulation 2010) conductivity limit for potable water represents 100 mS/m what equals 1000 mg/L. Under optimal conditions, potable water should contain less soluble substance, i.e. 200–400 mg/L (about 25–50 mS/m). Conductivity values of rainwater during 2012 and 2013 are shown in the Box-Plot graph on Figs. 28 and 29. From the graphs we can see that the average value for each month varies, but in most months it is optimal. During periods of rainfall the limit was exceeded, however, conductivity was mostly of the standard value and sometimes even optimal. The only exception was the month of September where the limit was exceeded.

On May 10th, 2011, single-shot sampling for chemical analysis in laboratory was done. The samples should have confirmed in-site measurements. The following parameters were set: pH, conductivity, alkalinity, hardness, nitrites, iron, phosphates, molybdenum and turbidity. Individual indicators were assessed just as the parameters measured by a multi-parameter instrument measuring quality and in the compliance with laws of the Slovak Republic (Slovak Government Regulation 2010). Most of the water quality parameters evaluated were of normal values, only the lower limit of pH was exceeded. Basing on the selected indicators, the stormwater we monitored (Table 5) is suitable for irrigation and, after treatment and disinfection, also for drinking purposes.

Monitoring of the quality of RHSR from the model with ceramic roof tiles started in June 2012. Two parameters were evaluated, pH and conductivity. Water sample was taken always on the 3rd, 15th and 30th day of month from 300 L plastic

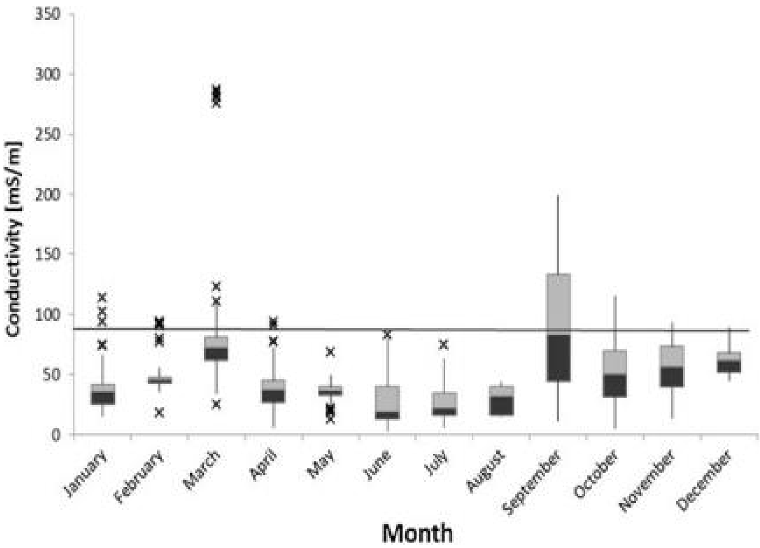


Fig. 28 Conductivity values of rainwater from the PK6 building during 2012

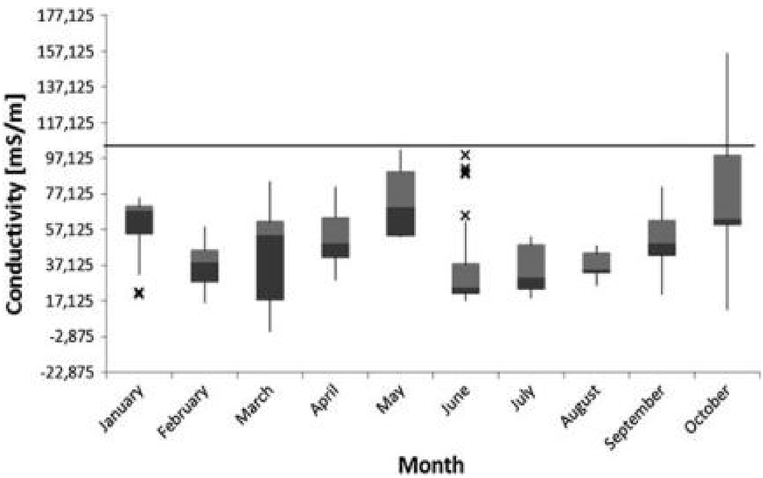


Fig. 29 Conductivity values of rainwater from PK6 Building during 2013 (Ahmidat et al. 2013)

water tank. There are two identical models with different roof materials (ceramic, organic coated metal roof) located on the roof of university library (Fig. 30). Measurement and analysis of the quality of stormwater in these models began in June 2012 on ceramic roofing material and in October 2013 on the roofing organic

Table 5 Quality parameters of SWR collected from PK6 Building (laboratory) (Ahmidat et al. 2013)

| | Parameters | Value |
|---|---|---|
| 1. | Appearance | Clean |
| 2. | pH (pri 25 °C) | 5.82 |
| 3. | Conductivity (μS/cm) | 60 |
| 4. | m-alkality (mmol/l) | 0.2 |
| 5. | p-alkality (mmol/l) | 0 |
| 6. | hardness (mg $CaCO_3$/l) | 50 |
| 7. | Ca hardness (mg/l $CaCo_3$) | 27.5 |
| 8. | Ca (mg/l Ca) | 20 |
| 9. | Iron(mg Fe/l) | 0 |
| 10. | Phosphates (mg $PO_4^{3-}$/l) | 0.18 |
| 11. | Silicates (mg $SiO^2$/l) | 1.3 |
| 12. | Molybdenum (mg Mo/l) | 0.5 |
| 13. | Turbidity (FAU) | 8 |

Alkalinity: 100 mg/l $CaCO_3$ = 2 mval/l = 2 mmol/l
Hardness: 100 mg/L $CaCO_3$ = 2 mval/l = 1 mmol/l = 5.6

Fig. 30 Location of models on the roof of university library building. Left hand model with ceramic roof tiles, right hand model with organic coated metal roofing (Ahmidat et al. 2013)

coated metal roof. For the analysis purposes, stormwater samples are taken from two places, i.e. from the place of “first flush” and from the 300 L plastic tank collecting RHSR (Fig. 31). The analysis of the quality of rainwater is made on the spot by means of a multi-parameter water quality sensor HANNA HI 991301 (Fig. 32). Control measurements are performed in laboratory using a pH and conductivity meter WTW pH/cond 340i (Figure 9).

Fig. 31 Samples from water tanks collecting RHSR

Fig. 32 Analysis of water quality on the spot using multi-parameter water quality sensor HANNA HI 991301

### 3.3.1 Roof Material: Ceramic Roof Tiles

These were obtained by sampling and subsequent chemical analysis of water samples. pH values of water in tank during 2013 are outlined in box-plot graph on Fig. 33. In 2013, average pH value equaled 7.5, maximum pH was 8.6 and minimum value reached 6.89. According to the regulation (Slovak Government Regulation 2010), pH value should range from 6 to 8.5 (Ahmidat et al. 2013).

Water conductivity values during 2013 are shown in box—plot graph on Fig. 34. In 2013, conductivity values are optimal, not exceeding 50 mS/m.

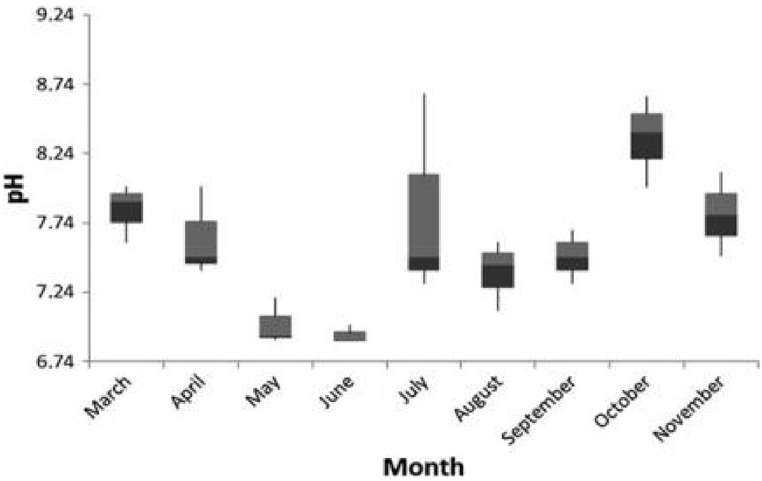


Fig. 33 pH values measured in 2013—model with ceramic roofing

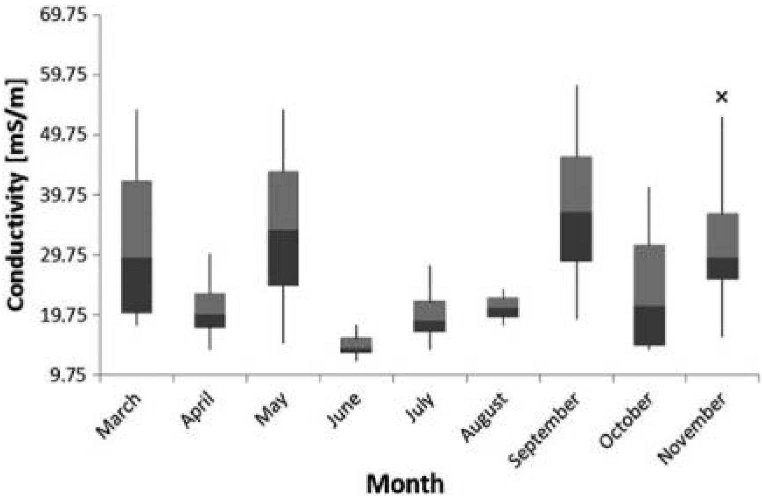


Fig. 34 Conductivity values measured in 2013—model with ceramic roofing

### 3.3.2 Roof Material: Organic Coated Metal Roof

Measuring of qualitative indicators for the model with organic coated metal roof began in October 2013. Water samples were collected from the "first flush" and from the tank. Samples were taken at the 3rd, 15th and 30th day in month and after large precipitation events. Figure 35 shows pH values during the monitored periods in 2013 displayed in box—plot graph. Average pH value recorded was 8, maximum pH was 8.6 and minimum 7.6.

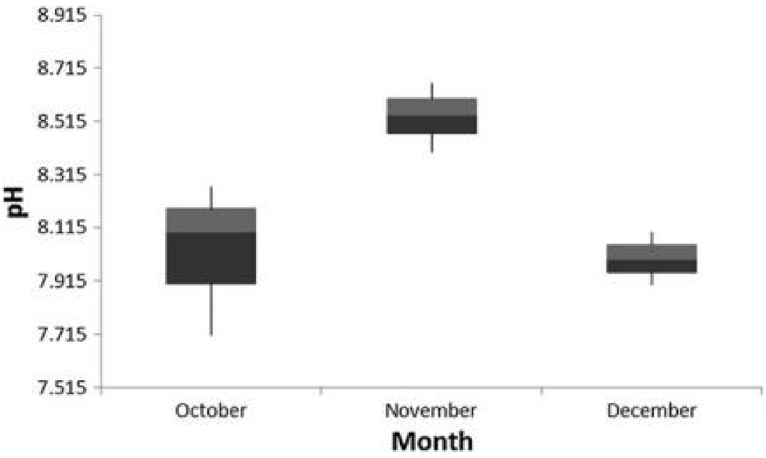


Fig. 35 pH values of rainwater from the model with organic coated metal roofing during the monitored period in 2013

Water conductivity values during the monitored period in 2013 are shown in box graph on Fig. 36. During the 2013 monitored period, conductivity values were optimal and did not exceed 50 mS/m. Average conductivity value was 17 mS/m, maximum value reached 42 mS/m and minimum was 3 mS/m.

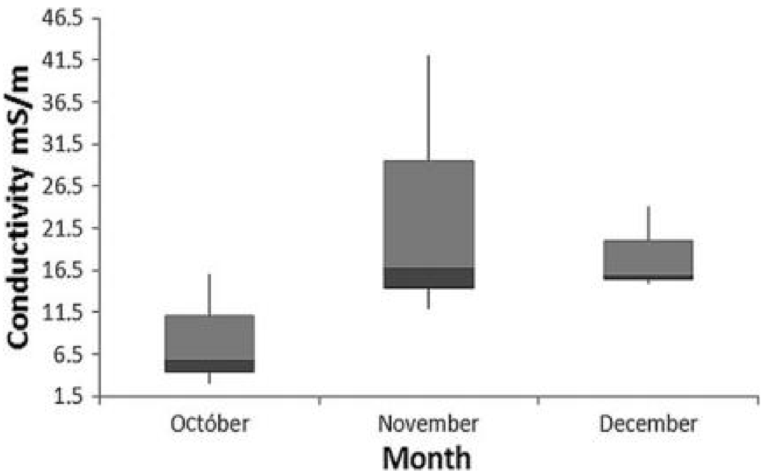


Fig. 36 Water conductivity values during the monitored period in 2013 for the model with organic coated metal roofing

## 4 Conclusions

Infiltration facilities must be designed correctly. There are a number of cases, when from the incorrect design of infiltration facilities insufficiently or only partly fulfil their function, and in many cases there has been damage of property.

Permeability of infiltration zone is qualitative and quantitative prerequisite for infiltration of rainwater in infiltration facility.

Permeability is represented by the infiltration coefficient $k_f$, which represent efficiency of infiltration facility, respectively ability of subsoil infiltrate incoming rainwater.

It is always necessary to consider from the view of local conditions about suitability of rainwater infiltration solutions. Therefore, in each case, it is to be considered carefully, which drainage concept in combination with the percolation of precipitation is ecologically sensible, technically possible and economically justifiable (Standard DWA-A 138E 2005). As resulting not only from the overall measured data during the research, the total infiltration of rainwater in the infiltration shaft take place at the time of termination of rainfall events, respectively short-time after which represent a high infiltration rate of this shaft given by the coefficient of infiltration at the bottom of shaft. As is apparent from the theoretical calculation values as well as the values obtained from measurements during research, times required for infiltration of surface runoff at infiltration shaft vary in the range of minutes, which means that the results obtained by calculation and the results obtained by experimental measurements in real conditions for the area of infiltration respectively for infiltration shaft correlate with each other. Therefore, despite the smaller surface for infiltration of infiltration shafts compared to other types of infiltration facilities, the infiltration coefficient of surveyed infiltration shafts $k_f = 1 \times 10^{-3}$ m/s ensures safe disposal of surface runoff.

With the correct design, realization and maintenance of infiltration facilities, it should be operation of this device fluent and without complications. It is therefore necessary that the designer of the infiltration facilities known hydrogeological conditions at the interest area.

Research on the roofing materials used proves that organic coated metal roofing appears to be the most advantageous roofs for the collection of RHSR in the given area of Košice. Qualitative parameters of RHSR from ceramic roofings comply with the requirements on drinking water. Incorporation of “first flush” system into RHSR collecting system has significant effects on the final quality of RHSR. RHSR from “first flush” is more acidic and with higher concentration of pollutants. RHSR from model tanks meet high quality requirements on drinking water. RHSR from real building PK6 with fibrecement roof coating is, on the basis of selected indicators, suitable for irrigation and, after treatment and disinfection, also for drinking.

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Záverečná správa geologických prieskumných prác pre objekt Technicom–Areál TU Košice 2010

# Stormwater Management in Compliance with Sustainable Design of Buildings

Zuzana Vranayová, Daniela Kaposztasova, Martina Zeleňáková and Gabriel Markovic

**Abstract** Stormwater management is quite a new topic in Slovakia as well as other countries of V4. There is no legal framework as well as standards or guidelines how to apply sustainable stormwater management techniques. As a consequence of repeated floods we are aware of a need for more effective stormwater handling. There are numerous techniques and approaches known around the world how to support sustainable stormwater management, especially in the urban areas, where the stormwater can cause significant damages. Nowadays we are more open to implement these new approaches especially in cases, where the effort is sustainability in stormwater management such as protection against floods and mitigation of pollution. The aim is to manage stormwater as close to source as possible which is also called source control covering number of measures. Rainwater harvesting as a part of the source control measures could contribute to the sustainability in stormwater management as well, by supporting potable water conservation and sustainability in water management in general. This part of the publication describes comprehensive stormwater management approaches as well as legislative framework. It contains brief overview of the source control techniques as well as examples of rain water use for non-potable purposes. Authors also described the risk analysis as valuable method for SWH system evaluation. We were able to collect helpful information from the questionnaires that helped us later in the risk identification as well as risk assessment phase along with the help of the brainstorming method within the team of experts. The results from the risk analysis led us to those parts of the system which need to be maintained with higher attention.

Z. Vranayová (&) · D. Kaposztasova · M. Zeleňáková · G. Markovic
Faculty of Civil Engineering, Technical University of Košice, Vysokoškolská 4,
042 00 Košice, Slovakia
e-mail: zuzana.vranayova@tuke.sk

D. Kaposztasova
e-mail: daniela.kaposztasova@tuke.sk

M. Zeleňáková
e-mail: martina.zelenakova@tuke.sk

G. Markovic
e-mail: gabriel.markovic@tuke.sk



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Appropriate risk management will hopefully eliminate potential risks to the minimum and prevent potential material or health damages. The output from the risk assessment is a checklist available for users of such systems, enabling them to use the list of questions to perform regular self-control of the system, inform users about their system and serving also as a tool for prevention. The results from the risk analysis were verified by the AHP and empirical multilevel comprehensive evaluation, which was found to be useful as well. The information from questionnaires also gave us a plenty of ideas which way we need to direct our attention in the field of rainwater harvesting in our conditions in the future.

## 1 Introduction

This part of the publication deals with contemporary knowledge in stormwater management (SWM). This current topic is significant nowadays because in our conditions we face unsustainability in water management in general and there are also many countries around the world being confronted by new approaches and changes of paradigms in the stormwater management. This chapter should give the stormwater management overview, necessity of changing our current practices and the sustainable stormwater management measures description.

The chapter is divided into three sections. Section 2 provides general overview, previous and present state and sustainable approaches in the stormwater management. Section 3 describes sustainable measures helping to reduce volume and speed of stormwater runoff, improve quality of receiving waters and introduce blue-green structures to the urban areas. SWH technique creates more added values than any other stormwater management measure. It supports sustainable water use, helps to conserve potable water consumption and contributes to the integrated water cycle as well.

Section 4 shortly describes risk management as a highly comprehensive topic. We can find risk analysis methods in many fields of science, practice or social life. The advantages of rainwater harvesting systems are well known. It is the same with other areas where according to risk management principles, some events could be categorized as risk prone events. Therefore one of the objectives of risk analysis is to identify potential risks, compile a list of them, prioritize them and find out how to prevent or eliminate hazardous events (Ashley et al. 2007).

The “water topic” is one of the most important topics around the world and through this chapter, authors would like contribute to the sustainable water management and use in conditions of V4.

## 2 Stormwater Management Overview Development

There are several definitions of stormwater management regarding different approaches. According to Marsalek and Chocat (2002), stormwater management is a process employing various non-structural and structural measures to control stormwater runoff with respect to its quantity and quality.

In principle, Debo and Reese (2003) defined fundamental purpose of the stormwater management as keeping people from the water and the water from people, and to protect or enhance the environment while doing so. At the beginning it is important to define what the stormwater is. Stormwater as an all-inclusive term refers to any of the water running off of the land's surface after a rainfall or snowmelt event (Minnesota Stormwater Manual 2008).

Urban stormwater must be controlled in order to avoid flooding and to safeguard human health and enterprise. Traditionally, urban storm drainage systems have been designed for hydraulic efficiency to transport stormwater from the built environment as quickly as possible (Semadeni-Davies and Bengtsson 2000).

Drainage systems are needed in developed urban areas because of the interaction between human activity and the natural water cycle. We distinguish two types of water; wastewater and stormwater which require to be drained away from urban areas (Butler and Davies 2011).

Water conveyance from urban areas is performed by drainage systems. Times have changed and so have the approaches in the urban drainage systems, as we have to face different challenges in the urban environment.

Urban drainage systems can be divided into two most commonly used; combined sewer system and separate sewer system. Combined sewer systems convey stormwater and waste water away in one pipe. Where there are combined systems, there is a risk of combined sewer overflows (CSO) which represents transfers of untreated waste water to receiving waters (Semadeni-Davies and Bengtsson 2000). Whereas separate sewer system carry stormwater and waste water in separate pipes, usually laid side-by-side (Butler and Davies 2011).

Stormwater runoff, snowmelt runoff, and surface runoff, all resulting from precipitation, that either runs off from the surface into a stream, is captured by a storm or combined sewer, or percolates into the soil (Adrien 2004).

Prior to development, stormwater is a small component of the annual water balance. However, as development increases, the paving of pervious surfaces with new roads, shopping centres, driveways and rooftops all adds up to mean less water soaks into the ground and more water runs off. Overall, 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 (Butler and Davies 2011).

Majority of drainage systems in Slovakia are combined as well as in the UK, France and Germany, where about 70 % of total drainage system length is combined, according to Butler and Davies (2011). Nowadays we know that this kind of system is economically and environmentally inefficient and in many cases causes overloading sewerage systems and treatment plants as more frequent floods prove it. It is essential that we introduce new sustainable approaches in urban drainage systems in V4 countries as well.

## 2.1 Stormwater Management – Past and Present

There were a lot of different approaches in stormwater management used in the past which can now be called as paradigms. A paradigm is what we think is true and right about a certain subject. Whether our paradigm is, in fact, true and effective, is not the point. We believe it is. And, we only reluctantly change our ways and agree to agree with someone else's paradigm (Debo and Reese 2003). According to Debo and Reese the early stormwater paradigms were:

#1—Run It In Ditches
#2—Run It In Pipes
#3—Run It In Stormwater Pipes
#4—Keep It From Stormwater Pipes
#5—Well, Just Do Not Cause Flooding

The problem of older paradigms was that they solved only the immediate problem or solved the problem of previous one. This should be changed and the approach should be more integrated. As Debo and Reese stated we are facing new paradigms now:

#6—Do Not Pollute
#7—It Is The Ecology
#8—Water Is Water Is Watershed
#9—Green And Bear It

Most of the early paradigms were driven by the demands of the citizens to solve pressing problems. Many of the later ones are driven by regulations and local response to them (Debo and Reese 2003).

SWM faces a lot of challenges nowadays. There are approaches from the past still significantly widespread in the SWM in Slovakia and we should design new properties considering all aspects, to provide sustainability in the SWM. We can sum up contemporary SWM theory into 10 basic principles:

1. Managing stormwater as a resource;
2. Preserving and utilizing existing natural features and systems;
3. Managing stormwater as close to the source as possible;
4. Sustaining the hydrologic balance of surface and ground water;
5. Disconnecting, decentralizing and distributing sources and discharges;
6. Slowing runoff down, and not speeding it up;
7. Preventing potential water quality and quantity problems;

8. Minimizing problems that cannot be avoided;
9. Integrating stormwater management into the initial site design process
10. Inspecting and maintaining all BMPs (Pennsylvania Stormwater BMPs Manual 2006).

There are at least two very important facts which need to be considered when dealing with the SWM. It is increasingly changing climate, resulting in short term but more intensive precipitation in one hand and increasing droughts in some countries in the other. The second fact is increasing urbanization over the last years which has changed the natural water processes and increased the urban runoff significantly. These facts have influenced urban drainage and it is assumed that they will influence it even more in the future.

## 2.2 Climate Changes

Climate changes have been one of the most discussed topics all around the world over the past years. Observed climate warming is consistently associated with changes in the hydrological cycle and hydrological systems such as: changing precipitation patterns, intensity and extremes; widespread melting of snow and ice; increasing atmospheric water vapour; increasing evaporation; and changes in soil moisture and runoff. Widespread increases in heavy precipitation events have been observed, even in places where total amounts have decreased. These increases are associated with increased atmospheric water vapour and are consistent with observed warming (e.g., Peterson et al. 2002; Griffiths et al. 2003; Herath and Ratnayake 2004) (Bates et al. 2008). This tendency we can see on Fig. 1.

Scientists and engineers face a lot of challenges and questions how climate changes will affect different aspects of our life. Increases in the occurrence of heavy precipitation have been observed across Europe and North America (Klein Tank and Können 2003; Kunkel et al. 2003; Groisman et al. 2004; Haylock and Goodess 2004; Bates et al. 2008). We have witnessed heavy precipitation resulting in severe urban floods throughout Slovakia recently; therefore the "water topic" becomes more and more important.

Seasonality of changes varies with location: increases are strongest in the warm season in the USA, while in Europe changes were most notable in the cool season (Groisman et al. 2004; Haylock and Goodess 2004; Bates et al. 2008). Flood risk is projected to increase throughout the continent. Regions most prone to a rise in flood frequencies are Eastern Europe, then northern Europe, the Atlantic coast and central Europe, while projections for southern and south-eastern Europe show significant increases in drought frequencies. In some regions, both the risks of floods and droughts are projected to increase simultaneously (Bates et al. 2008).

There are a lot of predictions for each country; therefore we should take climate changes into account in the process of designing urban drainage and related facilities as well.

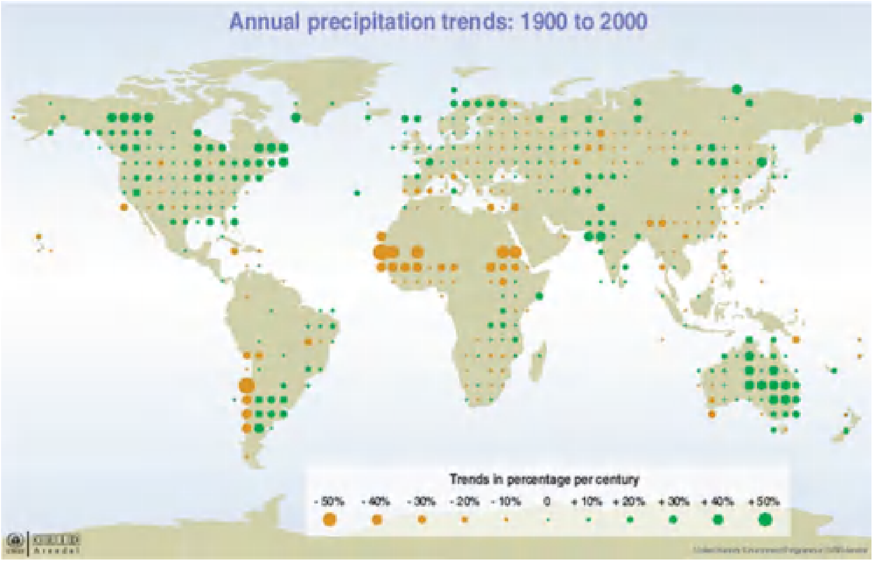


Fig. 1 Annual precipitation trends: 1900–2000 (United Nation Environment Programme 2005)

Climate change predictions have also been released for Slovakia and The Fifth National Communication of The Slovak Republic on Climate Change presented all observed changes and discussed them. As this document sums up, average annual temperature increased by approx. 1.6 °C from 1881 to 2008 and the annual precipitation decreased by approx. 3.4 % in Slovakia. Precipitation decline is more significant in the southern Slovakia where recorded decrease was more than 10 %, whereas in the north and northeast of Slovakia, the increase was up to 3 %. Relative humidity decline was also recorded. Snow cover decrease was registered up to the altitude of 1000 m and the increase in higher altitude. The air temperature rise will significantly increase the water vapour, leading to extremes in precipitation during strong thunderstorms in the warm half-year. It is supposed that heavy precipitation events will be more frequent than in the past by approx. 25 up to 50 %. Winter precipitation is expected to rise by 30 % in the north of Slovakia and highlands and temperature will increase by 4 °C. According to various climate scenarios, runoff decrease can be expected despite the possibility of a slight annual precipitation increase in the large portion of Slovakia. One of the main sources of uncertainty in the water management is the potential runoff change due to expected climate changes. It is important to mention that all results should be interpreted very carefully because of uncertainties in the scenarios and methodology; however the trends of changes are very probable (The Fifth National Communication of The Slovak Republic on Climate Change 2009).

## 2.3 Urbanization

The problems associated with urbanization originate in the changes in landscape, the increased volume of runoff, and the quickened manner in which it moves. The changes in the landscape occurred during the transition from rural and open space to urbanized land use (Minnesota Stormwater Manual 2008).

Urbanization causes a shift from sub-surface pathways dominating stream flow generating processes to overland flow as vegetation is removed and soils become compacted or covered with impervious paving or roofs. Stormwater runoff is largely caused by rain falling on asphalt or roofs and storms (Semadeni-Davies and Bengtsson 2000).

Figure 2 show how the development of urban areas has changed infiltration and evapotranspiration processes and how the runoff has increased up to 55 % due to impervious surfaces.

Impervious surfaces are the results of new developments as well as further developments within existing areas and lead to increased stormwater runoff (see Fig. 3). It is not only the volume of runoff but also the speed of runoff what increase (Stahre 2006). This means that the flow will both arrive and die away faster, so

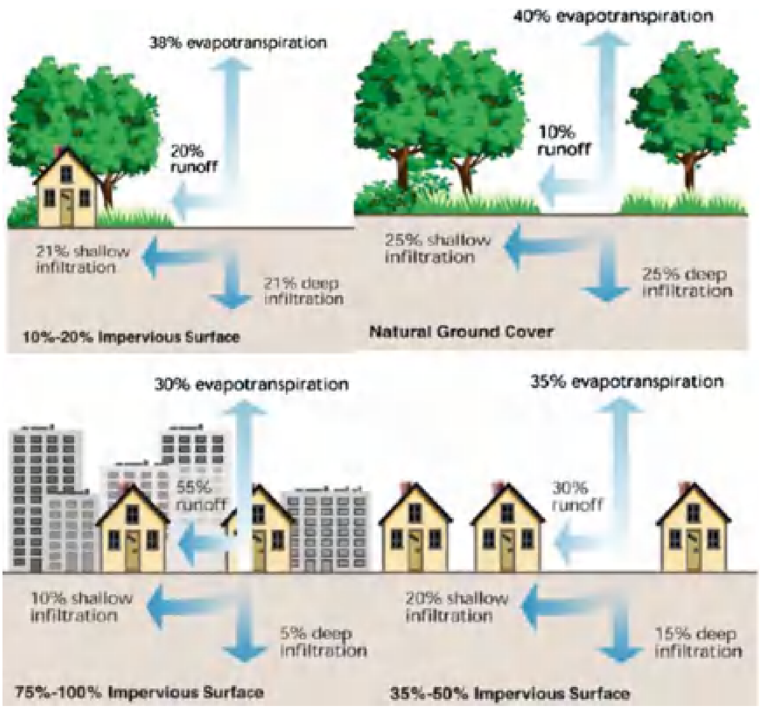


Fig. 2 Relationship between impervious cover and surface runoff (FISRWG 1998)

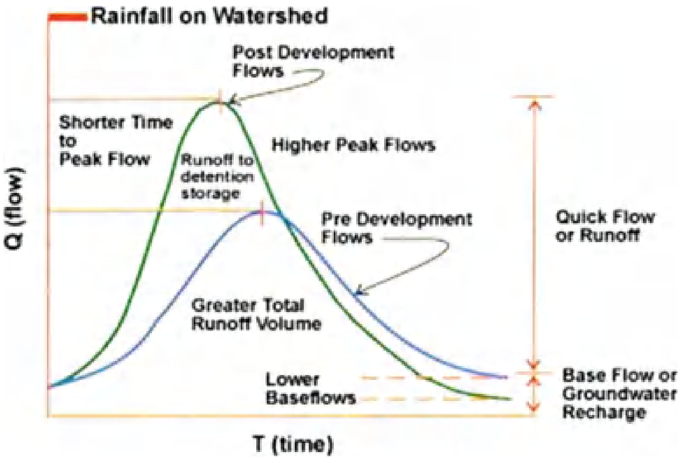


Fig. 3 Runoff changes (MELP (now WLAP) & MMA 1994)

therefore the peak flow will be greater and it also means reduced infiltration what cause poorer groundwater recharge (Butler and Davies 2000).

Growth of urban areas increases velocity and amount of stormwater runoff. As a result of such growth, existing storm drainage systems are sometimes exceeded. This is especially the case of larger cities with combined sewer systems. Heavy rainfall can cause temporary overloading of the system (Stahre 2006).

Also the rapid runoff especially from the urban environment is likely to cause pollutants and sediments to be washed off from the surface to the receiving water. In the urban areas, there are more pollutants in the air and on the catchment surfaces (roads, paths, roofs, parking lots etc.), than in the natural environment (Butler and Davies 2011).

Pollutants from the waste water also enter receiving water bodies through the combined sewer overflow (CSOs) during the heavy or longer lasting precipitation events, what affects water quality significantly.

When we know what affect water in general, we can understand the importance of conserving water and helping to protect it from pollutants. It is even more important when we realise that demand is continuously increasing also because of urbanization and development. It is up to us therefore to ensure that the Water Framework Directive (the main EU water directive, will be more described below) is implemented effectively, that there is enough water for future generations and that this water meets high quality standards (The Water Framework Directive 2002).

## 3 Legislation Frame for Stormwater Harvesting

This part provides basic information about the legislation in water industry in general. Stormwater management issues are part of the complex water management issues. Most of the directives deal with water quality, since the main target of all legislations and standards is to obtain sustainable water quality globally. The main directive in Europe is The Water Framework Directive (WFD 2000) which establishes a legal framework to protect and restore clean water across Europe and ensure its long-term sustainability (WISE 2008). It is the most far-reaching piece of environmental legislation ever introduced by EU and will change the way in which water is perceived and managed in Europe forever (Gray 2010).

This directive also sets rules for groundwater and according to Butler and Davies (Butler and Davies 2011), implementation of the directive has more uncertainties, for instance, what implications will a prohibition of discharge to groundwater have on infiltration—based sustainable drainage systems.

The document similar to European WFD is the Clean Water Act (CWA) in the United States which was implemented in early 1970s and has resulted in significant efforts to improve the quality of water bodies, much of which has included improvements to stormwater management (Ashley et al. 2007). Other related European directives or "WFDs daughters" are The Urban Waste Water Treatment Directive 91/271/EEC, The Groundwater Directive 2006/118/EC, The Bathing Water Directive 2006/7/EC and The Flood Directive 2007/60/EC. DWA-A 138E, Planning, construction and operation of facilities for the percolation of precipitation water developed in Germany is aimed at designing infiltration facilities (DWA-A 138E 2005).

The water legislation in Slovakia is covered by following acts and regulations. The first is the Water Act, Act No. 364/2004 Coll. on Water Sources and on amendment of the Act of the Slovak National Council No. 372/1990 Coll. on offences in wording of latter provisions. Water Act is the basic legal framework regulating water protection in Slovakia.

The Government Regulation No. 296/2005 Coll. establishes qualitative objectives for surface waters and limit rates of waste water and special waters pollution indicators.

The Act No. 442/2002 Coll. on Public Water Systems and Public Sewage Systems and on amendment and supplement of the Act No. 276/2001 Coll. on Regulation of Network Industries, states that the owner of sewage system can deny connection of property to public sewage system if for example the capacity of system or WTP is already exceeded or is possible to dispose runoff water (stormwater) out of public sewage.

Regulation of a Ministry of Environment No. 684/2006 is about technical requirements of design, project documentation and public water supply and public sewage construction.

Regulation of the Ministry of Environment No. 397/2003, this regulation setting out details about measuring the amount of supplied water and quantity of discharged waste water and surface runoff.

Act No. 7/2010 Coll. on Flood Protection establishes measures how to prevent floods.

The government approved The Programme of Landscape Revitalization and Integrated Watershed Management in Slovak Republic by the decree No. 744/2010. The objectives of this programme regarding the topic of the thesis are floods protection and retention of stormwater in the country and support of stormwater management projects.

## 3.1 Stormwater Management in Context of EU Projects

"Water topic" is one of the most discussed topics within the environmental issues. There are a lot of platforms, projects, associations and organizations involved in this area. This section provides only a short overview.

The Water supply and sanitation Technology Platform (WssTP) which was initiated by the European Commission in 2004 to promote coordination and collaboration of Research and Technology Development in the water industry, worked out the Strategic Research Agenda (SRA). The SRA was updated in 2010 and contains 6 pilots:

Pilot 1: Mitigation of water stress in coastal zones.
Pilot 2: Sustainable water management inside and around large urban areas.
Pilot 3: Sustainable water management and agriculture.
Pilot 4: Sustainable water management for industry.
Pilot 5: Reclamation of degraded water zones (surface water and groundwater).
Pilot 6: Proactive and corrective management of extreme hydro-climatic events.

We consider principles of Pilot 2 and Pilot 4 as the base for our research work.

Pilot 2: Enhancing urban water services through efficient water management. More than 50 % of the world population lives in urban areas. Urban areas, especially large or densely inhabited ones, raise specific issues with regard to water management. Urban areas require developments to manage efficiently the water services, safeguarding the public health while protecting the water resource and the aquatic ecosystems and reducing the energy consumption and the carbon emission of the system (WssTP, Strategic Research Agenda 2010).

Pilot 4: Promoting a sustainable management of water in all industries. The industrial sector is of great economic importance, where water related cost can reach up to 25 % of the total production cost. The main challenges are to promote a sustainable use of water in industries processes while ensuring efficient management and possible recovery of other resources required in the production such as raw materials or energy (WssTP, Strategic Research Agenda 2010).

6th Framework Programme SWITCH—Managing Water for the City of the Future, is aims to bring about a paradigm shift in urban water management towards a more coherent and integrated approach. The vision of SWITCH is sustainable urban water management in the 'City of the Future'.

SWITCH research includes 6 themes:

- Urban water paradigm shift
- Stormwater management
- Efficient water supply and use
- Waste water
- Water planning
- Governance and Institutions (SWITCH 2010)

Each of research themes includes Work packages. Theme Stormwater management include next work packages:

- Technological options for stormwater control under conditions of uncertainty
- Decision-making processes for effective urban stormwater management
- Environmental change studies for stormwater control and reuse options.

6th framework programme proves that the stormwater management topic of this thesis is very up-to-date and should be also presented more in the conditions of the Slovak republic as well as other V4 countries.

The last programme mentioned below shows the necessity of appropriate use of water in the industry. Ideas of the 7th Framework Programme called Aquafit4use will author exploit in the next work. Main aim of the programme is use of appropriate water quality for the production processes in the industry. Objectives of the programme are:

- Reduction of fresh water needs (30 %)
- Less environmental impact (energy, emissions, sludge)
- Water fit-for-use (increasing productivity, safety, health)
- Closing the water cycle (Aquafit4use 2010).

## 3.2 Sustainability in Stormwater Management

In general, we can say that we have to move towards sustainability in all areas of human activity and the SWM is no exception. Sustainability, or better long-term sustainability was specified by Agenda 21 in 1992 and all of us should take a responsible attitude to our environment.

Characteristic feature of sustainable urban drainage is that quantity and quality issues are handled together with various social aspects of the drainage (Stahre 2006).

There are different names for more sustainable drainage mechanisms in different countries. In the United States and other countries, these methods are called BMPs or “Best Management Practices”. General expression “water sensitive urban design” is used in Australia whereas in the United Kingdom term SUDS or “Sustainable Urban Drainage Systems” is used (Butler and Davies 2011). Other known concepts are LID or “Low impact development”, Integrated catchment planning, Ecological stormwater management (Stahre 2006). As Ashley et al. (2007) summarized, there is a movement towards new 'more natural' stormwater management approaches, BMPs, LIDs, SUDS and "source controls" in general in the USA and EU as well.

A new approach to urban drainage sustainable SWM carries many benefits in comparison with conventional systems:

- Protect water and air quality;
- Reduce stormwater treatment costs (capital infrastructure, maintenance and operating costs);
- Promote aquifer recharge;
- Reduce peak flow and pipe capacity costs;
- Reduce stormwater runoff/pollution/flooding and erosion risk;
- Reduce degradation of rivers, lakes, beaches and bays;
- Reduce landscaping maintenance costs;
- Enhance natural environment, community aesthetics and recreational opportunities;
- Attract wildlife;
- Promote a safer/healthier community and encourage social interaction (SWITCH 2007).

The benefits of the new approaches are unquestionable but there are major obstacles in the process of adopting these systems in many EU countries, due to urban density, regulatory inadequacies and institutional constraints according to Ashley et al. (2007). New ideas and versatile systems are needed to meet also requirements of the WFD (Ashley et al. 2007).

Sustainable approach to urban drainage according to Stahre (2006) can be divided into four parts of where we dispose stormwater:

- Source control
- Onsite control
- Slow transport
- Downstream control.

Source control means that handling of stormwater takes place on private land and covers different types of facility for local disposal or detention of storm water, according to Stahre (2006). We can say that it is private responsibility (Stahre 2006) and it is one of 10 SWM principles to managing stormwater as close to the source as possible.

Examples of source control:

- Green roofs
- Infiltration on lawns
- Permeable paving
- Stone fillings percolation
- Local ponds
- Rainwater harvesting etc.

Experience from the United States has shown, as Ashley et al. (2007) states, those evapotranspiration techniques such as green roofs, water gardens and/or disconnecting existing inputs to major drainage systems can collectively provide significant benefits to managing local and downstream water quality and quantity, what is also widely accepted fact. From US practice is also apparent that benefits are most effective where the stormwater costs are clearly identifiable within charging schemes (Ashley et al. 2007).

Review of the Use of Stormwater BMPs in Europe (ADSS 2002) shows, the most common types of BMPs in Germany are swales and infiltration trenches, retention basins along with porous paving with reservoir structures are used widely for stormwater control in France. In the cold climate countries, retention ponds, swales and infiltration basins are used to control both storm water and melted snow. The swales also offer additional storage for snow as well. According to the report, the use of BMPs in Southern European countries, such as Greece, Italy, Spain and Portugal, is limited.

Concern over SWM sustainability has been increasing over the past years also due to climate changes, growing urbanization and unsustainable water management in general thus sustainable practices such as SUDS, BMPs, LID, etc. are becoming more and more popular around the world. Another reason is also existing local stormwater discharge restrictions to the combined sewers.

Comparison of conventional and sustainable stormwater drainage system see in Table 1.

Table 1 General comparison of conventional and sustainable systems (Revitt et al. 2003)

| | Conventional system | Sustainable system |
|---|---|---|
| Cost to construct | May be equivalent but potential of multifunctional use of BMPs may reduce overall cost | |
| Cost to operate and maintain | Established | Unclear for some systems: further work required |
| On-site flood control | Yes | Yes |
| Downstream erosion and flood control | No | Yes |
| Potential for water re-use | No | Yes |
| Potential for groundwater recharge | No | Yes |
| Potential for pollutant removal | Low | High |
| Public amenity benefits | No | Yes |
| Educational benefits | No | Yes |
| Performance lifetime | Established | Not established for some systems: further work required |

## 4 Rainwater Harvesting and Associated Risks

The rainwater harvesting system as a well-known system all around the world is still not well established in our conditions of V4 countries. There was no need to looking for a new alternative water sources for domestic or commercial use because of good water sources in Slovak Republic for years. And there are still some voices around that are saying that it is unnecessary in our conditions. But overloaded sewerage systems, overloaded water treatment plants, urban floods or water scarcity make us thing more about the sustainable usage of water sources all around the world and about proper water quality usage for different purposes (Adrien 2004).

The English term "Rainwater Harvesting" has been internationally widely accepted (König and Sperfeld 2007) but in the Slovak language there is no appropriate word for it. So let's start with the explanation what the rainwater harvesting is.

Principle of this very simple system, used for many years all around the world is collecting the rainwater and/or stormwater in the tanks (under or above ground) and storing it until it is used. The system is much more sophisticated nowadays since our demand is higher and necessity of water quality is taken into consideration. We usually collect water from impervious surfaces such as roofs, paths and parking lots etc. It is further transported by gauges and downpipes through filter/screen to prevent organic material particles and debris reaching the system. Very important part of the system is the first flush device which retains initial runoff because of the stored water quality. In addition, it is possible to install different types of filters and treatment devices. The level of treatment of the stored water depends on purpose for what the water will be used. There are disinfection devices using for instance UV radiation, chlorine or activated carbon filters. Pumps and pipes, necessary for transporting the water to the consumer, are of course inseparable parts of the system and cannot be interconnected with potable water network.

Harvesting rainwater and urban stormwater for safe reuse has many potential benefits. It can help to reduce the impact of urban development on water quality and stream flow, and can also help to meet water conservation objectives. Rainwater and stormwater reuse schemes are commonly used in water sensitive design strategies for new urban developments (National Water Quality Management Strategy 2009).

Systems using alternative water sources are well known in many countries. There are many case studies aimed not only at rainwater and storm water usage, they are concerned in recycling and reuse e.g. of gray water and combined systems of rainwater and gray water or respectively and its reliability and economic effectiveness as performed (Ghisi and Ferreira 2007; Ghisi and Mengotti de Oliveira 2007).

Based on foreign case studies, it is possible to figure that household's savings of potable water could rise up to 60 % for family houses and apartment houses. In the apartment houses, water consumption increases in dependence on number of dwelling units and surrounded areas needed to be irrigated. This particular case study is for example form Norrköping in Sweden, where different alternatives of rainwater usage had also been considered (Villarreala and Dixon 2005).

More and more case studies apply rainwater harvesting for other kinds of buildings instead of residential buildings. Very interesting example is from the capital of Brazil, where the usage of rainwater at petrol station for car washing could save from 7.4 to 57.2 % of water (Ghisi et al. 2009).

Nowadays, the rainwater collection system is a common part of new architectural designs of the buildings such as "The bird's nest" (Beijing National Stadium), The Millennium Dome in Greenwich London, Daimler Chrysler buildings in Berlin and sport facilities for winter Olympic games 2010 in Vancouver. Most of the buildings use harvested water for toilet flushing and irrigation.

Figure 4 shows types of buildings suitable for rainwater harvesting. The arrow deliberately widens towards the commercial use. According to authors' opinion, rainwater and storm water harvesting potential increases in commercial sphere. Author would focus on new industrial parks and logistics centres, where the potential to accumulate rainwater not only from roofs but also from the surrounding areas is quite significant.

Ward et al. (2010) elaborated financial analysis as a part of their study and calculated that RWH systems, installed inside large commercial buildings may be financially more viable than smaller domestic systems (Ward et al. 2010).

Rainwater could replace potable water in the following cases: flushing toilets, maintenance and cleaning, irrigation, washing vehicles, process water or fire water. It's needless to say that rainwater and storm water can't fulfil all water demand which is possible to replace. That is the reason why it is necessary to decide for what purposes will the rainwater be used. Before designing the system, it's necessary to define the rainwater demand and then determine storage capacity regarding effectiveness, reliability and total cost.

Table 2 shows water reuse matrix for commercial purposes adapted from Hauber-Davidson.

It is necessary to choose appropriate purposes for using this water to meet water availability and economical effectiveness of all systems.

Fig. 4 Rainwater harvesting usage

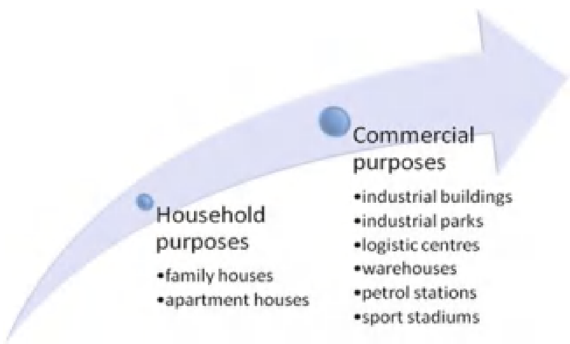

Table 2 Rain and storm water reuse matrix for commercial purposes, according to Hauber-Davidson (2009)

| Purpose | Commercial purposes | |
|---|---|---|
| | Rainwater from roofs | Stormwater from roofs and surrounding areas |
| Bathroom | Acceptable | Not recommended |
| Kitchen | Possible | Not applicable |
| Hot water system | Acceptable | Not recommended |
| Toilet flushing | Acceptable | Possible |
| Laundry | Acceptable | Not recommended |
| Irrigation | Acceptable | Acceptable |
| Washing vehicles | Acceptable | Acceptable |
| Cooling tower | Acceptable | Acceptable |
| Pools | Acceptable | Not recommended |
| Other process water | Acceptable | Possible |

Acceptable ● (green) Possible ● (blue) Not recommended ● (orange) Not applicable ● (red)

Rain and stormwater harvesting contribute to the integrated management of urban water cycle. It has direct impact on volume and quality of stormwater runoff than reduction in flows to wastewater treatment plants (WWTP) and it of course conserves drinking water (Scholes 2007).

That is the reason why we are interested in this topic and why we would like to increase awareness on this topic on our conditions as well. As all of the human activities also this system could potentially be risky in some cases. Risk management has its place in science and our everyday life as well. Water management in general comprises wide range of problems especially in recent years we see increasing need to dispose rainwater on decentralized way. That means to use different systems of infiltration or percolation or another way is to reuse this water. Generally it's called rainwater harvesting—RWH.

It is undisputed that rainwater harvesting systems brings a lot of benefits but it is the same with other areas that according to risk management some events can be categorized as risk events.

Risk management programs generally cover five main components:

- Context—What is at risk and why?
- Risk identification—What and where are the risks?
- Risk analysis—What is known about them?
- Risk evaluation—How important are they?
- Risk treatment—What should be done about them? (Aquafit4use 2010).

Effective risk management requires identification of potential risks/hazards as described in methodology bellow. The methodology is designed in accordance with Water Safety Plan and WSP Manual step-by-step and comprises following stages:

- Form a team of experts
- Description of RWH system
- Risk identification
- Risk assessment
- Determination and evaluation of control measures (Aquafit4use 2010).

RWH systems and others sustainable urban drainage systems undoubtedly bring many benefits, but it is same as in the others areas that some events can be categorized as risky events from the perspective of the risk management. The objective of risk analysis is to detect these potential risks, summarize them, determine their importance and find out the solution how to prevent or eliminate them.

## 4.1 Questionnaire as a Tool for Risk Analysis

Questionnaire was completed by designers and construction companies in Slovakia and it should give us plenty of ideas, opinions and experiences of the design process as well as from construction and operation of such systems. They helped us identify and assess risks.

The questionnaire was filled in by 33 respondents. But not all of the respondents felt knowledgeable enough to answer all of the questions and the last part of the questionnaire focused on the risks in RWH, described below, was assessed by 20 respondents. At the beginning of questionnaire there were a couple of basic questions about respondent, such as number of years of experience, position and what is his/her opinion about RWH. Second group of questions was focused on practical experiences for example: when did you do your first design, what problems you faced during design process, have you seen increased demand for RWH in recent years, what standards or manuals do you use for your designs, etc. And the target of the last group of questions was to obtain information about risks in RWH. This part is strongly subjective based on respondent experiences and opinions. In this section we will introduce a few results of the last group of questions from the

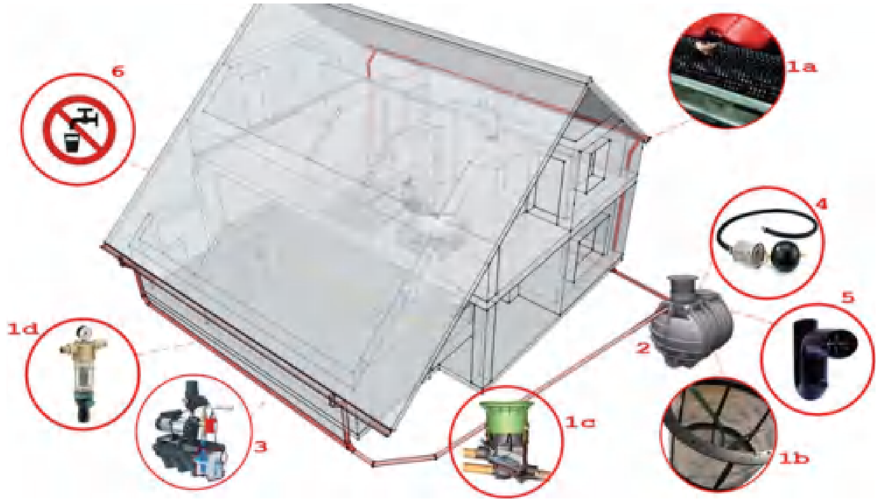


Fig. 5 Experimental family house and its main parts: 1—filters; 2—tank; 3—pump and regulating unit

questionnaire where respondents assigned values from 1 to 10 (1 for the lowest risk 10 for the highest risk) for the main parts of the system (Fig. 5) depending on the significance of the risk. The results show that the riskiest parts of the system according to questionnaire are: the pump, the filter, the tank. According to the questionnaire, we can say that the greatest attention should be paid to the design, installation and maintenance of these three parts of the system. Approximately half of the respondents think that there is a lack of the information about the system maintenance and water usage of users what rivets our attention to this kind of risk as well. We can say that the questionnaire is a good example how to obtain relevant information from practice about the design process, experiences and opinions for the risk analysis steps like risks identification a risk assessment.

## 4.2 Risk Analysis – Aims and Methods

The aim was to prepare a general risk analysis methodology for rainwater harvesting systems. This methodology can especially be applied for small scale projects such as family houses; in our case we applied it for a newly constructed family house with the RWH system (Fig. 5). Installed system is brand new, supplied with 4 $m^3$ underground water tank. Rainwater is used for flushing toilets, irrigation, and maintenance and potentially for washing machine as well.

One of the aims of the risk analysis is to prepare a check-list for this type of user. Check list should serve as a tool for the regular self-control of the system which can eliminate various types of risk events and inform user about the system as well. The methodology was designed in accordance with Water Safety.

Quantitative or qualitative methods can be used for the risk evaluation. The semi-quantitative methodology was selected for RWH evaluation of our experimental system. Semi-quantitative risk assessment is a system for sorting out risks, focusing on the big issues, and managing the entire risk portfolio better. The scoring system is inherently imperfect, but so is any other risk evaluation system (Ashley et al. 2007).

By using the semi-quantitative risk assessment, the team of experts who is carrying on the evaluation can calculate a priority score, for each identified hazard. The objective of the prioritisation matrix is to rank hazardous events to provide a focus on the most significant hazards. The likelihood and severity can be derived from the team's technical knowledge and expertise, historical data and relevant guidelines (Aquafit4use 2010).

The RWH system was divided into 4 parts according to Fig. 6 for the purpose of risk identification and assessment. These four parts has divided our system into 4 main evaluation folders. Each part was then divided into sub-systems. Sub-system are the main system components where can be identified all sorts of potential hazards from the minor ones to the most important. There is whole list of these potential hazards and it is the last level of our evaluation hierarchy. The list is not presented at this article.

The objective of our work was to prepare risk analysis methodology especially for small scale RWH projects. The methodology was applied on experimental family house with RWH system where rainwater will be used for flushing toilets, irrigation and potentially for washing machine as well.

Determination of risk score according to semi-quantitative methodology is made according to this formula (Bates et al. 2008):

$$\text{Risk} = \text{likelihood of occurrence} \times \text{severity of consequence}$$

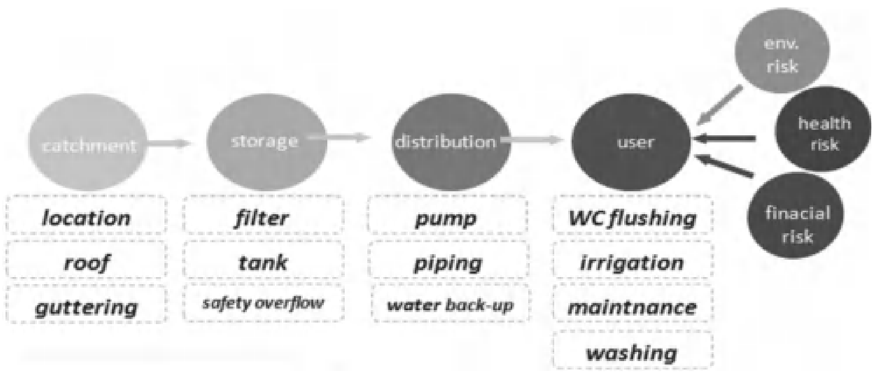


Fig. 6 Flow diagram

Table 3 Table of risk scores as a result from semi-quantitative risk matrix (WSP 2009) (Bates et al. 2008)

| Risk score | 1–3 | 4–6 | 8–10 | 12–16 | 20–25 |
|---|---|---|---|---|---|
| Risk score | Very low | Low | Medium | High | Very high |

The risk is determined by multiplying these two values. This allows us to distinguish serious risks to the minor ones and to determine priorities for their prevention or elimination (WSP 2009) (Table 3).

All potential hazards with the risk score higher than 9 were taken into further consideration. The value of risk score 9 is our point of division. This value was chose be the team of experts according to their knowledge and is rather subjective value.

The team can choose whatever point of division or can consider all of potential hazards but we have chosen this value and we have taken for further consideration and evaluation only the potential hazards with the risk score higher than 9. These potential hazards can be found in Table 4.

We have found out that the riskiness of the system is not high at all. What is the most important part in RWH system evaluation is good and regular system revision and maintenance and good knowledge about the system function by users.

The result of semi-quantitative risk analysis was verified by other mathematical methods and questionnaire. The questionnaire helped us with the risk identification as well as risk assessment process. According to respondents (construction companies and professionals) the parts of the RWH system most prone to the risks are the pump, the filters and the tank. We can find this parts in the results of our risk analysis as well.

The mathematical method was useful in this process as well. The most objective and appropriate method from the mathematical methods is AHP (Analytic

Table 4 Identified potential hazards with the risk score higher then 9

| Subsystem | Potential hazards |
|---|---|
| Location | Microbiological contamination |
| | Dustiness |
| | Drought |
| Guttering | Revision and maintenance |
| Filters | Revision and maintenance |
| Tank | Under sizing |
| | Over sizing |
| | Microbiological contamination |
| | Revision and maintenance |
| Pump | Clogging |
| WC flushing | Toilet lid closing |
| | Bathroom joint with toilet |
| | Inhalation of dangerous microbes |

Hierarchy Process). The highest weights according to this method were attributed to the location, pump, filter and tank. The verification methods show that the results from semi-quantitative method can be considered as suitable. Based on that we can design easy to use control measures for the RWH systems in order to reduce or eliminate potential hazards to minimum even if the system can be considered as not risky.

### 4.3 Risk Analysis – Conclusions

What is important to mention is that even if we focus our attention only on some parts of the system the other parts of the system are important as well because the system is connected and omission of maintenance of one part can lead to some potential risks in the another part. Good knowledge of the used system is very important as well (Bengtsson et al. 2005).

It is very important to mention that even if we work with the numbers and methods which can be considered objective the interpretation of evaluation and the evaluation inputs are subjective and based on team of experts knowledge. In this kind of evaluation there is not possible to exclude some subjectivity level (Butler and Davies 2011).

The output from the risk assessment is a checklist available for users of such systems, enabling them to use the list of questions to perform regular self-control of the system, inform users about their system and serving also as a tool for prevention (Debo and Reese 2003).

Systems using rainwater are well known, although not enough widespread in our country yet. The use of this alternative water resource, as well as the others, definitely brings many benefits but the risks should not be ignored as well. The risks are associated with any activity we do in our everyday life. Early risk identification allows us preventing potential hazardous events, which is crucial for proper system function and satisfaction of user. In conclusion we can state that the parts of RWH most prone to the risk events are pump, filter, tank and location itself. The target is to design easy to use risk management to prevent potential hazardous events, especially for the small scale RWH projects according to this experimental one.

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# Protection of Slopes Against Erosion by Flowing Rain Water

Miloslav Šlezingr, Petr Pelikán, Jana Marková and Lenka Gernešová

**Abstract** Protection of slopes (river banks) before flowing rainwater provides riparian vegetation. The text describes the basic functions of riparian vegetation. The objective of planting is to create vertically distributed and diversified stands occupying the maximum space in the floodplain. Within the design of vegetation species structure, we should not forget shrubs, which have their indisputable place, and vital grassland, which is basic protection against the occurrence and development of erosion on the bank slope. The result is the protection of the shore (slope) before the occurrence of erosion.

## 1 Basic Functions of Bankside Trees and Shrubs

Bankside trees and shrubs are one of the building blocks of territorial systems of ecological stability (TSES) (Šlezingr and Úradníček 2002a). It is part of an ecologically balanced landscape, a form of spread green vegetation growing outside integrated forest complexes. It is created by tree species and herbs growing along streams. In relation to stream regulation, linear building along water streams etc.,

M. Šlezingr (&) · J. Marková · L. Gernešová
Faculty of Forestry and Wood Technology, Mendel University in Brno, Zemedelska 3, 613 00 Brno, Czech Republic
e-mail: miloslav.slezingr@mendelu.cz

J. Marková
e-mail: markova@node.mendelu.cz

L. Gernešová
e-mail: gernesova@node.mendelu.cz

P. Pelikán
Faculty of Forestry and Wood Technology, Mendel University of Brno, Zizkova 17, 602 00 Brno, Czech Republic
e-mail: pelikan@node.mendelu.cz



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a lack of riparian and accompanying stands started to manifest negatively. We can say that only once it decreases, will we start to realise its indispensability in our landscape (Šlezingr and Úradníček 2002b). The following paragraphs deal with the basic functions of bankside trees and shrubs (Begon et al. 1986).

## 1.1 Erosion and Abrasion Control Functions

Protection against the effects of running waters, drifting of ice, waves etc. (Fig. 1).

If we consider tree species growing on banks, it is important to notice the effect of underground and aboveground parts. The root system grows through the soil profile and binds soil particles, thus reinforcing riverbed banks. Roots also grow into the zone of continuous flooding where they are a sought-after refuge for water fauna. The aboveground parts of plants relieve the pressure of running water, protect banks against direct effects of waves, drifting of ice and in combination with nonliving reinforcing structures they act as long-term, durable and reliable stabilisation of banks. Protection against water flowing into the stream from adjacent land is very important, too. Banks may also be damaged in rainstorms when runoff is concentrated into one or more main currents, or when water flows back into the riverbed after overflowing onto the flood plain (Raplík et al. 1989).

By stabilising banks by means of grassland in combination with tree species, we can prevent riverbed banks from being damaged by erosion rills that can have a very unfavourable impact on the stability of riverbed slopes (Tichá and Úřadníček 2004).

## 1.2 Anti-deflationary Function

Protection against silting up of a riverbed or a reservoir with material transported by wind from adjacent land is significant especially in intensively cultivated

Fig. 1 Absence of streamside protection and accompanying stands results in the impairment of banks, the occurrence of scours

Fig. 2 Anti-deflationary function

agricultural plains. Along with fine dust particles, organic residuals, plant seeds, excessive fertilisers, preservative agents etc. are also transported here (Fig. 2).

A fully-grown, sufficiently involved accompanying stand (mostly trees) and riparian stand (mostly shrubs) acts as a “protective wall” and is able to intercept much of the transported material. According to the width and quality of bankside trees and shrubs, we can speak about a similar function as a semi-permeable windbreak. Its importance in the protection against the effects of side wind is also demonstrated in inland navigation, especially in the navigation of empty ships.

## 1.3 Protective Function

Protection against riverbed overgrowth and silting (Fig. 3).

A direct incidence of sunrays on the water surface causes intensive warming of water in riverbeds. Since the intensity of sunshine is highest in summer months when the water level is also very low, water flora grows more. Irrigation channels

Fig. 3 Overgrown riverbed of Říčanský potok

and shallow reservoirs are most endangered. The final effect of a fast growth of hydrophytes in warm water, well provided with nutrients from adjacent agricultural land, may be an increasing oxygen deficit with all its unfavourable consequences for fish in the reservoir (pond). In addition, it should be emphasised that an overgrown riverbed does not have to be capable of higher flow in case of rainstorms, thus causing a flood, albeit only a local one.

An increased occurrence of hydrophytes in the riverbed results in increased bottom roughness and a lower flow profile. The speed of running water reduces and, consequently, more particles are deposited. Especially smaller streams with a minor bottom slope are endangered. By means of hydrophytes, such deposits are stabilised and the flow profile gradually reduces, increasing the risk of overflows.

Appropriate bankside trees and shrubs, especially with smaller streams, prevent excessive access of direct light, partially shading the surface and very effectively preventing conditions suitable for the rapid growth of weed hydrophytes.

## 1.4 Water Quality Function

Impact on self-cleanability of water streams (Fig. 4).

The pre-condition for self-cleanability to develop is a sufficiently aerated water stream and the presence of organisms in the water. Organisms colonising uneven places on the bottom, roots penetrating into the stream, parts of plants etc. participate, to the maximum extent, in the removal of organic pollution in the stream (its natural transformation into inorganic substances). It is riparian vegetation, its surface and underground parts that have a considerable share in the enhancement of self-cleanability of water streams. However, it should be pointed out that full shading of the surface is undesirable. The more the surface is shaded, the more its self-cleanability is reduced.

Fig. 4 Water quality function

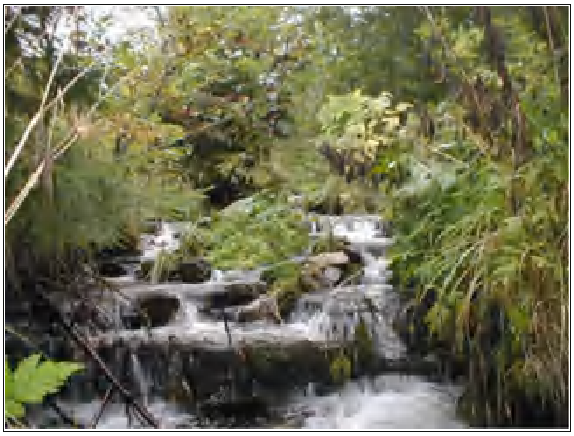

Fig. 5 Scheme of the triangular ditch

## 1.5 Function of a Refuge for Fauna Living Near Waters

Both riparian and accompanying stands are home to many animals and, considering the trend of unification of small fields into larger units and consequential elimination of bosks, scattered green vegetation, derelict land etc., they became an important part of systems of ecological stability. As habitats of predators, they can significantly share in farm crop yields on neighbouring land (reduction in the number of rodents), in the maintenance of good health condition of stands in the whole area (elimination of insect pests) etc. (Fig. 5) (Chmelař and Meusel 1986).

This function may best be fulfilled by natural stands or by newly created stands whose species structure and spatial arrangement correspond to the natural structure of bankside trees and shrubs. Newly designed stands cannot be interchanged with park planting, which does not necessarily have to fulfil the essence of bankside trees and shrubs even with a suitable park arrangement. Attention should also be paid to the planting of gradually flowering tree species, tree species corresponding to the relative forest type, autochthonous tree species—so as not to introduce alien species but in particular to pay sufficient attention and care to planting and consequential tending.

## 1.6 Multi-family Residential Building

Bankside trees and shrubs are an important element in landscape enhancement. Within stream regulation, we should try to propose necessary interventions to the river profile and its closest surroundings with maximum respect for existing vegetation. Having carried out technical adjustments, it is necessary to propose, in liaison with competent specialists, and to provide for the implementation of new planting, or reconstruction of riparian and accompanying stands (Fig. 6).

Fig. 6 Scheme of the triangular ditch

The planting of and the consequential care for bankside trees and shrubs should not be underestimated as unplanted areas within natural succession become overgrown with self-seeding species whose unsuitable location and species structure may impair the stability of slopes, flow ratios in the riverbed and, even in aesthetical terms, they do not have to necessarily make a good impression (Šimíček 1999).

Fully-grown, maintained bankside trees and shrubs are a dominant element in flatlands and their impact on the overall character of the area is appreciable.

## 1.7 Multi-family Residential Building

This function of bankside trees and shrubs cannot be overlooked in our overview. According to Water Plan information, in the Czech Republic there are almost 37,000 km of water streams with a catchment of over 5 km$^2$. To calculate the possible amount of dendromass, it is important to know the average width of accompanying stands. This value depends, to a great extent, on the width of the stream and, according to information from the conference entitled “Functions of riparian stands in the landscape” held in 1987, 7–10 m per bank can be considered an average value. However, it should be noted that not every riparian stand can be used for the production of quality wood; therefore, volume estimates in these areas differ (Fig. 7).

According to data from Lesprojekt from 1975, the value for the former Czechoslovak Republic is indicated at approx. 2,100,000 m$^3$. Although felling in these areas accounts for only a few percent of the overall felling volume, this area is a valuable wood resource as well.

Fig. 7 Productive function

## 1.8 Function of Creating a Natural Bio-corridor

Streamside trees and shrubs act as a natural bio-corridor, connecting line, migration route between forest units. From an eco-biological point of view, bankside trees and shrubs are an integral part of the river biotope and its closer and remoter surroundings (Fig. 8) (Kolibáčová et al. 1999).

## 1.9 Recreational Function

Bankside trees and shrubs are a precondition for creating rest areas near streams in the vicinity of towns and cities; in the case of reservoirs used for recreation they are

Fig. 8 Bio-corridor

Fig. 9 Recreational function—river Svratka in Brno

a pre-condition for its development; by supporting the good condition of fish in streams and reservoirs, it helps in the development of sports fishing, etc. (Fig. 9).

## 1.10 Sanitary Function

Riparian and accompanying stands play an important sanitary function, too. A fully-grown stand is able to intercept dust particles, to act as a partial noise barrier and it creates an overall positive impression by means of which green vegetation influences the human mind etc. (Fig. 10).

Vital bankside trees and shrubs also considerably contribute to:

- the retardation of runoff from stream banks,
- increased soil infiltrability on stream bank slopes,

Fig. 10 Sanitary function—capture the dust from transport

- a reduction in extreme discharges,
- an increase in minimum discharges (in the areas of wetlands, cut-off stream branches, …),
- stream protection against water contamination by risk elements,
- optimal development of zoocoenosis and biocoenosis.

The next part deals in particular with the quality of streamside trees and shrubs; aspects of the technical solution of a particular stream regulation are thus not described in detail. Further, attention will be paid to tree species creating streamside vegetation, although we have to take into consideration that riparian stands are also created by a herb layer.

## 2 Assessment of the Current Condition of Riparian and Accompanying Stands

Prior to deciding on the manner and methods of new planting or reconstruction of riparian and accompanying stands, it is vital to assess the current condition of the riverbed and its closest surroundings from the following points of view:

- necessary future technical interventions to the river profile (whether more extensive building intervention is expected in the particular locality, e.g. weir construction, riverbed capacitating through continuous regulation, construction of a parallel road in close proximity to the stream, construction or reconstruction of buildings in close proximity to the stream etc.)
- building modifications performed in the past (details concerning possible stream regulation, documents concerning the proposed planting of trees and shrubs within the performed stream regulation, materials concerning the original riparian stands (photo-documentation, eyewitness information), or to try to find out reasons why planting had not been performed, etc.)

It is always suitable and very important to inspect such areas with representatives from the stream administration, Agency for Nature Conservation and Landscape Protection of the Czech Republic, representatives of the environmental department of the competent municipal authority, or other environmental organisations and to assess the condition of stands near the stream, or to compare the existing condition with the designed one.

At a meeting called in relation to the relative problem requirements of interested authorities and organisations, land and company owners, etc. with respect to future modifications, their extent, manner and time of performance, including other steps necessary to solve the task with success, must be clarified.

## 2.1 Method of Assessment of the Condition of Trees and Shrubs

Within stream regulation, great attention is also paid to programs in the area of landscape ecology and environmental engineering, aroused by efforts not to irreversibly disturb (through proposed construction complexes) the ecological balance of the system. (Ecological balance is a dynamic condition of the ecosystem and is the main feature of ecological stability of the system. Ecological stability is then the ability of the ecosystem to endure the effect of stressors and, after they subside, to return to the initial condition.)

Within hydraulic engineering, revitalisation and eco-biological constructions (but only here), it is vital to initially become acquainted with the current situation of the locality which will be more or less affected by proposed modifications or building interventions.

Within the evaluation of the current condition of riparian and accompanying stands, subjective opinions often prevail and, from the point of view of the technical public, due assessment of the condition of stands prior to building or another modification is often underestimated. Due inspection, including a related record, is important information for the proposal for such part of project documentation that solves the incorporation of the construction into the landscape after its completion.

This was one of the reasons why effort was aimed at facilitating initial assessment of riparian and accompanying stands by proposing a method not requiring detailed dendrological, biological or ecological knowledge. The basic principle of the proposed method is simplicity, comprehensibility and explicitness—thus wide usability. A detailed inspection of the interested location, in our case the assessed part of the bank, is necessary and inevitable. The assessment is then carried out directly within the inspection of the current condition of the territory.

The assessed sector shall be divided (if it is necessary due to its extent) into sub-sectors approx. 100 m long, which are assessed separately. Due marking of sectors in the situation is important. Each bank of the stream (reservoir) shall be assessed separately.

The assessment itself is based on scoring (marking) the fulfilment of particular criteria: 1 = the best condition, 3 = the worst condition, and consequential categorisation of the sector. The categories clearly show in what condition the stand was prior to starting building or other works in the concerned locality. Along with photo-documentation, this assessment may serve to demonstrate related facts if there are problems with incorporating the construction into the landscape within its completion.

# 3 Method of Assessment of the Current Condition of Bankside Trees and Shrubs

| Assessment criterion score | | |
|---|---|---|
| A. % damaged or unsuitable[a] species | Up to 30 % | 1 |
| | Up to 60 % | 2 |
| | Over 60 % | 3 |
| B. Number of vegetation layers | 1 vegetation layer | 3 |
| | 2 veg. layers | 2 |
| | 3 veg. layers | 1 |
| C. Width of the vegetation zone (from the approximate level $Q_a$) | Up to 7 m | 3 |
| | 7–10 m | 2 |
| | Above 10 m | 1 |
| D. Species diversity | Up to 3 species | 3 |
| | 4–6 species | 2 |
| | 7 and more species | 1 |
| E. Relative density of stands: | | |
| – a continuous vegetation stand with local vistas of the water surface | | 1 |
| – medium and large groups of stands | | 2 |
| – no vegetation stands, small groups, solitaires | | 3 |

[a]By unsuitable species, such species, exotic species etc. mean those that are unsuitable for that particular site
The assessed sector shall be categorised according to the score obtained
5–6 points—vegetation in good condition
7–8 points—the sector needs adjustments, additional planting
9 and more points—necessary extensive interventions, or overall recovery

After such assessment has been performed, it is possible to objectively evaluate the assessed condition of stands also after a lapse of time. Further possible specification and proposal of necessary interventions should be left to competent specialists. The assessment record completed with photo-documentation could be used as important material in the future as well.

## 3.1 Use of Self-seeding Species and Naturally Spreading Vegetation

After stream regulations or weir construction, new conditions for vegetation growth on its banks are created, in particular in the area of the eulitoral zone. Since it is very important to ensure the stability of banks already at this stage, we try to use naturally spreading vegetation as well. Unfortunately, water and bog vegetation naturally spreads especially on banks with only slight natural inclination that are least endangered; no particularly intensive protection is thus necessary (Jandora and Uhmannová 1999).

However, in steep areas (inclination 1:1 and higher), or already disturbed banks where protection is especially necessary, we cannot rely on natural stabilisation. The finest particles and nutrient components are washed from the soil due to intensive erosion activity; only coarse gravel and stones remain, which is not a suitable soil for self-seeding (or pioneer) species. On the contrary, already fully-grown vegetation dies and bank material is further washed. Bank scours thus appearing cannot be reinstated only by using vegetation elements.

Species suitable also for reclamation, cover planting etc.

Many species called "weed species" are of great help in reclamation, re-vegetation of unexploited barren areas where they outdo many valuable species due to their low living condition quality requirements and vitality. Species that are able to successfully survive in such environment are called "pioneer species".

These species include for instance:

Elderberry bush: Land after building interventions, waysides, barren farm-tracks etc. Heavy spreading must be taken into account. It also tolerates salts.
European red elder: A similar use as elderberry bush, it can also be planted in dry sites with direct sunshine, barren land.
White birch: Used after extensive improvement works on devastated, barren land, bedrock. It prevents the spread of undergrowth.
Pea tree: Used for planting in built-up areas, between paved surfaces, on barren land after building interventions.
European hornbeam: It can be suitably used for cover purposes near old walls, unattractive supporting walls etc. It covers well thanks to its thick foliage, partially also in winter, dry leaves last long.
Flowering ash: Suitable for extremely dry sites on limestone, forestation of karst areas.
Tartar maple: If it has sufficient humidity, planting in barren, unproductive soils along streams, slag heaps, near dumps etc. is possible.
Swedish whitebeam: Suitable for planting on devastated or less fertile soils.
Rowan tree: It is able to quickly cover devastated areas, does not tolerate saline soil.
Small-leaved lime: It can be used as a pioneer species on hillsides, rocky sites. Considerable litterfall helps to fertilise soil well.
Grey alder: Besides others, it can be used for planting in less fertile soils, after building interventions on stream banks, after regulations, reinforcement of extreme slopes, etc.
Common alder: Suitable for the reinforcement of extreme slopes, for planting in industrial environments, suffers in dry soils.
Sea buckthorn: Possible planting on exposed slopes, devastated soils, slag heaps, dumps etc.
Common buckthorn: Possible planting on barren land after building interventions, to re-vegetate sunny slopes, debris.
Ninebark: Possible planting on land with a high groundwater level, on less fertile soil, slopes.

Aspen: It can be planted in barren open areas, rubble heaps, devastated areas.
Black locust: Possible planting on steep slopes, re-vegetation of gullies, relatively infertile areas.
Sandbar willow: Suitable planting after the excavation of gravel, sands, very good vegetative propagation.
Grey willow: It avoids acid soils and peat, prepares living conditions for more demanding species in waterlogged bog soils.
Willow (Salix dasyclados): It also prospers in heavy, little aerated soils, bogs, dumps, embankment dams. Cuttings take roots fast and easily.

Of course, this list is not comprehensive but it can be a guide in the preliminary design or assessment of tree species vegetation in a particular area. More detailed information on the above-mentioned and other species can be obtained in the section entitled Alphabetical List of Species and, especially, in professional literature related to this theme. See above.

## 3.2 Grassland

The grassland of a stream bank slope reinforces soil surface and, to a great extent, prevents the occurrence and development of erosion. When proposing suitable grass mixtures, we work on recommendations based on which the following criteria should be fulfilled:

- production of a sufficient quantity of aboveground mass in the shortest possible time
- a continuous production of aboveground mass within further development of grass carpet should not exceed 180 $g/m^2$
- resistance to illnesses and pests
- resistance to climatic variations common in the Czech Republic's geographic latitude
- resistance to flooding
- ability to create a thick root system concentrated in the subsurface soil zone
- resistance to the stress caused by running water in the riverbed

## 3.3 Establishment of Grassland

It is necessary to realise that grassland composition, its endurance, overall involvement and consequential viability depends on the number of created and sufficiently developed individuals in the first two to three months after seeding. Although seeding is the most common method of establishing grassland, it is not the only one.

(a) Establishment of Grassland by Seeding

Prior to seeding, the laying of a humus layer on disturbed planed stream bank slope is expected. The follow-up seeding is manual, or mechanisms may be used, from early April to late August. Seeds need to be fertilised in the soil by rolling. If possible, watering in the first month and top dressing are important. To prevent the undesirable development of weed, one or two weeding treatments are necessary after approx. 8–12 weeks of seeding. The protective function of stands starts to work within only 2–3 months of seeding (Herynek 1997).

(b) Establishment of Grassland by Sodding

For fast and almost immediate effective grassing of banks, so-called sodding may be used. Sods can best be obtained from an adjacent site (meadow, pasture) that has approximately the same site conditions as the locality being reinforced. Sods shall be taken by means of special knives, cutting strips approx. 40–50 cm wide. Separate the strips from subsoil using a shovel to achieve optimal sod thickness. Thus removed grass strips shall be divided into squares with sides of 40–50 cm. The produced sod should immediately be placed on the site being reinforced.

(c) Establishment of Grassland by Hydro-seeding

This is a hydraulic method of seeding when a mixture of seeds, water, fertiliser, organic substance and anti-erosive additives are sprayed under pressure. In this way, inaccessible slopes and other places can be re-vegetated. Within seeds, the prescribed grass mixture or seeds of tree species can be used.

| | kg/ha | % share |
|---|---|---|
| Grass mixtures for the eulitoral zone | | |
| Smooth meadow grass | 31 | 25 |
| Swamp meadow grass | 19 | 10 |
| Annual ryegrass | 5 | 2 |
| Reed canary grass | 50 | 55 |
| Meadow foxtail | 17 | 8 |
| Grass mixture for the supralitoral zone | | |
| White clover | 15 | 11 |
| Swamp meadow grass | 12 | 9 |
| Red fescue | 20 | 15 |
| Timothy | 10 | 7 |
| Annual ryegrass | | 5 |
| Smooth meadow bluegrass | 25 | 18 |
| Creeping bentgrass | 6 | 5 |
| Meadow fescue | 30 | 20 |
| Perennial ryegrass | 15 | 11 |

(continued)

(continued)

| | kg/ha | % share |
|---|---|---|
| Grass mixtures with a high erosion control effect | | |
| Smooth meadow bluegrass | 40 | 40 |
| Red fescue, cultivar Tamara | 38 | 25 |
| Chewing's fescue | 28 | 15 |
| Perennial ryegrass | 30 | 20 |

(d) Other technologies

In addition, pre-planted grass carpets, especially wherever an immediate aesthetic and stabilisation effect is requested, divided stabilisation strips, slope stabilisation by means of coconut or jute nets placed on the seeded area (prevents erosion) etc. can be used.

Examples of Composition of Grass Mixtures (Kutílek)

Of course, grass mixtures may be modified according to particular conditions, or specific requirements and purpose of grassing. Details can be found, for instance, in the publication Vegetace v úpravách vodních toků a nádrží, L. Novák a kol.

## 4 Final Recommendations

It is extremely important to mention that all works in the recovery of bankside trees and shrubs could misfire if we fail to ensure at least basic after-planting care. First of all, it is watering and protection against forest weed, especially at an early stage of growth, further protection against browsing, against inadequate anthropogenic intervention, etc. Care for stands is always necessary, not only at the moment of planting or tending interventions. Regular checks after winter months, topping, etc. should be among the routine activities of administrators of individual streams.

However, it is necessary to consider not only recommendations by professionals but also possibilities of stream administrators who are often not able, with the best will in the world, to provide for due and continuous care of riparian and accompanying stands (Loew 1995).

In addition, it should be pointed out that in the case of more extensive interventions in the accompanying vegetation, project documentation of the intervention concerned must be developed in liaison with professionals from related fields. If the recovery of stands is performed within stream regulation, this project should be part of the project documentation concerning the stream regulation itself. Again, we have to remember that the accompanying vegetation includes the herbs layer as well. Suitable grass mixtures are able to protect the slope against water erosion to a great extent (Marhoun 1991).

The Project Being Developed Should Include:

A. Project documentation of felling works, which contains:

1. Technical report
2. Industrial taxation statement
3. Budget, statement of areas
4. Overall catchment situation 1:50,000
5. Detailed situation 1:1000, 1:2000
6. Provincial Recovery Plan, time schedule of works

B. Project documentation of recovery and completion of stands:

1. Technical report
2. Recap of the necessary planting material
3. Budget, statement of areas
4. Planting situation 1:500, 1:1000
5. Planting scheme 1:100, 1:200
6. Provincial Recovery Plan, time schedule of works

Basic Requirements for Planting Material and Process:

Planting shall be started in early spring; in the case of deciduous trees (which is the case in riparian and accompanying stands) autumn is also possible. The common method is hole planting with triangular or square spacing.

Mature plants, three to six years old, are the most suitable planting material. Under extremely favourable conditions, transplanted plants two to three years old may be used. For group planting, saplings approx. 1 cm high, with line planting up to 1.5 m, are sufficient. In unfavourable sites (stony, gravel ground), it is suitable to provide at least the minimum amount of humic soil.

Plants shall be shaped in planting: to ensure better growth, plants should be provided with poles; in endangered localities, plants should be protected against browsing.

In the case of species with the ability of vegetative propagation (e.g. willow, poplar, etc.), cuttings, osiers or globular plants can be used as planting material. For details on this part, see professional literature (bibliography at the end of this publication).

## Glossary Terms

| | |
|---|---|
| Abundance | Number |
| Autochthonous | Indigenous |
| Autotrophic | (Organism) = nourishing through mineral substances, it is a primary producer of organic substance |

| | |
|---|---|
| Benthos | A community of invertebrates living on beds of waterways |
| Biocoenosis | An association of vegetal and animal organisms living in a community |
| Biocentre | A nature segment enabling long-term existence of indigenous plant and animal communities |
| Biogeocoenosis | Biocoenosis including the surrounding environment |
| Bio-corridor | Space connecting biocentres and enabling migration |
| Biotope | Environment enabling development of a community |
| Biomass | Organic substance |
| Riparian stands | Stands on riverbed and reservoir banks whose main function is the stabilisation of banks |
| Coenosis | Plant and animal community |
| Dendrology | The study of trees |
| Accompanying stands | Stands near water streams fulfilling various functions (anti-deflationary, aesthetic, water surface shading etc.) |
| Ecobiological stream regulation | Regulation which, only in necessary cases, results in a change of horizontal and vertical alignment, longitudinal slope or a significant change of cross-section of the bed. The regulation is carried out with minimal interventions to the original bed condition, using riparian and accompanying stands as the stabilisation element of the riverbed and its vicinity |
| Ecology | The science dealing with the relationship between living organisms and their surroundings |
| Ecological stability | Ability of the system to resist extrinsic effects |
| Ecosystem | A functional system of living and nonliving components of the environment interconnected by the mutual exchange of substances, energy flow and information exchange which influence each other and develop in a certain space and at a certain time |
| Ecotope | Abiotic (nonliving) environment of biocoenosis |
| Eutrophication | Nutrient enrichment |
| Phytocoenosis | Vegetal component of biocoenosis |
| Frequency | Frequency of occurrence |
| Heterotrophic | (Organisms) = obtaining nutrition from organic substances |

| | |
|---|---|
| Climax | The most advanced community that can develop in a considered area |
| FAZ | Forest altitudinal zone |
| Revitalization | Recovery of vital functions, return to a condition similar to the condition prior to anthropic interventions |
| Reclamation | Recovery of productivity, fertilization |
| Relic | A relict, unique species |
| Systematic stream regulation | This term shall mean such effected stream regulation within which mostly horizontal and vertical alignment, longitudinal slope of the bottom, cross-section of the riverbed and its following stabilisation is changed. It can be expected in this stream regulation that most bankside vegetation will be cleared and replaced with new planting |
| Succession | Spontaneous changing of vegetal communities |
| Synusis | Vertically differentiated components of biocoenoses, includes the whole plant |
| TSES | Territorial System of Ecological Stability |
| Zoocoenosis | Animal component of biocoenosis |

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# Classification, Resources and Elimination of Xenobiotics in Stormwater

Petr Hlavínek and Adéla Žižlavská

Abstract Advanced analytical technologies related to stormwater reveal the presence of various hazardous substances such as heavy metals, PAH, DEHP and other persistent xenobiotic organic compounds. Releases of these substances into stormwater is a result of the fact that stormwater comes into contact with synthetic materials and elements during the run-off process. These elements can be found deep inside the earth and they are extracted to the surface through anthropogenic activities, which leads to the migration of these compounds in the environment. It has been proved that most of these substances have an impact on human health. This chapter is focused on the classification, sources and elimination of xenobiotics in stormwater.

## 1 Introduction

Chemical characterisation of stormwater depends directly on the nature of surface with which it comes into contact. During the run-off process, various types of micro-pollutants are releases into the body of water due to anthropogenic activities in the catchment area. This brings about various impacts on the aquatic environment and, if stormwater is reused, it may potentially adversely impact the end-costs.

These micro-pollutants are called xenobiotics (from Latin xenos-foreign, bios-biologic) due to their "foreign" origin compared to common pollution.

Xenobiotics are a group of substances including a variety of substances such as pesticides, detergents, lays, pharmaceuticals, metals and many others (Fatta-Kassinos et al. 2010). These substances have concentrations within a range of ng/L–μg/L, but they are more dangerous than common organic pollution as they can have mutagenic

P. Hlavínek (&) · A. Žižlavská
Faculty of Civil Engineering, Brno University of Technology, Zizkova 17,
602 00 Brno, Czech Republic
e-mail: hlavinek.p@fce.vutbr.cz

A. Žižlavská
e-mail: zizlavska.a@fce.vutbr.cz

 
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effects, cause cancer, reproduction changes and many other effects. In addition, these effects can manifest themselves in the next subpopulations that were not in contact with them.

Xenobiotics are resistant to common biological degradation processes and according to recent studies, there are complex interactions among these substances, which reinforces negative effects, e.g. during the runoff process this may result in the formation of new transformation products that can be even more hazardous than the parent compounds.

In recent years there has been an increasing tendency to utilise storm-water in households (for example, for toilet flushing), irrigation and even for some industrial process.

In many larger cities, surface water is used as alternative sources for fountains, man-made lakes and natural swimming pools. The chemical composition is strongly affected by the stormwater sewerage inflow composition and sudden flood events.

Toxicity tests of stormwater (Denmark, Germany) indicate the presence of xenobiotics in stormwater intended for reuse. These were xenobiotics with demonstrated negative impacts on aquatic environment biota, such as some of the heavy metals, polycyclic aromatic hydrocarbons (PAH), pesticides, phthalates, alkylphenol ethoxylates, dioxins, furans, polycyclic chlorinated biphenyl's (PCB).

Reviews performed by Makepeace et al. 1995 (Caliman and Gavrilescu 2009) and Eriksson et al. (2007a, b) show that at least 78 metals and other inorganic elements and 385 XOCs have been observed/quantified in stormwater. The major sources of these compounds are building materials, traffic-related releases (exhaust fumes from vehicles, tires, brakes, road material, painting markers on roads, use of de-icing agents), human activities (application of pesticides, car washing, disposal of paint, oil etc. in the stormwater sewers) as well as wet and dry air deposition.

With regard to the above mentioned, an analysis and assessment of the potential danger of xenobiotics in stormwater is needed.

The implementation of the Water Framework Directive (WFD) in the European Union has further stressed the need for evaluating potential chemical hazards in stormwater and to identify efficient and sustainable source control options. Among the possible source control options are actions to be taken to limit the release of XOCs to the urban environment (legislation, regulations, and substitution) and to implement the fundamental direction of stormwater disposal.

## 2 Protection of the Environment Against Xenobiotics, Legislation

The main European strategy for the protection of surface water against hazardous pollutants is contained in the Water Framework Directive (WFD) 2000/60/EC. Directive 2008/05/ES amending the WFD establish environmental quality standards for the first 33 priority hazardous substances (and others 8 substances).

The European Union, within the framework of water policies reorganisation, adopted the Water Frame Work Directive (WFD) (2000/60/EC) in September 2000. More recently, the European Commission included environmental quality standards (EQS) of priority pollutants to the WFD (in July 2007). The Environmental Quality Standards (EQS) on priority pollutants must be achieved by 2015 in every member state in order to ensure a "satisfactory chemical status for surface water".

Besides this, biota standards for these substances are established to provide better and understandable monitoring of the PBT substances (PBT—persistent, biocumulative, toxic) and to create control mechanisms. Their aim is to establish a review list of priority hazardous substances on the basis of WISE monitoring. The EU will assess and update the list of priority hazardous substances every 4 years. In the next 20 years (from December 2008), the priority hazardous substances will be excluded from all production processes and the EU will aspire to reduce, check and control the emissions, discharges and leakage of the PBT to the bodies of water.

Within the framework of the international co-operation, the PBT substances are controlled with the help of UNEP (UN Program for the Environment) established in 2001 through the Stockholm convention requesting the elimination of the most dangerous persistent organic substances (POPs). Nowadays, a total of 22 substances are on the list of the Stockholm convention ratified by 174 states all over the world including the Czech Republic and the European Union.

On 22nd March 2007, the European Environment Agency along with the European Commission (DG Environment, Joint Research Centre a Eurostat) and EU member states launched the WISE system (Water Information System for Europe) that collects data about the physical, chemical and biological condition of surface and ground water in the EU from 54,000 surface waster monitoring stations and 51,000 groundwater monitoring stations.

The European Council for Enterprise and Industry established the REACH regulation concerning the registration, evaluation, approving and restricted use of chemical substance. It came into force on 1st June 2007. It simplifies and improves the previous Framework Directive concerning handling of chemical substances in the European Union. The objective of REACH si to improve human health and environmental protection through a better and easier identification of the chemical composition of products used on the production of various industrial products.

It is also used indirectly as a tool for innovating chemical substances used in the European market and thus improves the competitive advantages of the European market.

Given the continuous development in the xenobiotics research and their impact on the environment we can expect future changes in the EU law related to the environmental protection and a likely extension of the list of priority hazardous substances.

## 3 Xenobiotics Observed in Stormwater

The first test of stormwater was performed at Environmental Engineering and Science Institute, Department of Civil Engineering, University of Alberta, by David K. Makepeace, Daniel W. Smith and Stephen J. Stanley in 1995. These test revealed the presence of metals and other inorganic trace elements as well as xenobiotic organic compounds (XOC) e.g. polycyclic aromatic hydrocarbons (PAH), pesticides, phthalates, alkyl phenol ethoxylates, dioxins, furans, polycyclic chlorinated biphenyl's (PCB). Samples of stormwater, appropriate for reuse, were collected from roofs, roads, parking lots, impervious urban areas, green or recreational areas and specific local sites e.g. airports

In 2002, prof. Ledin et al. (2002) at the Technical University of Denmark, Institute of Environment and Resources performed similar tests which detected 27 metals and inorganic trace materials and 352 XOCs (Table 1). In 2007, Eriksson and the team observed at least 78 metals and other inorganic elements and 385 XOCs in stormwater (Eriksson et al. 2007a, b).

In 2002, prof. Anna Ledin and co-workers at Institute of Environment and Resources, Technical University of Denmark, performed similar tesst, which reveal 27 metals and inorganic trace materials and 352 XOC's (Table 1) and in 2007,

Table 1 Number of compounds that have been identified in collected stormwater (Ledin et al. 2002)

| Compound group | Identified in stormwater |
|---|---|
| Metals and inorganic trace elements | 27 |
| Xenobiotic organic compounds | |
| Aliphatic amines | 0 |
| Alkanes | 18 |
| Aromatic hydrocarbons | 7 |
| Chlorophenyls | 0 |
| Dioxins and furans | 34 |
| Ethers | 8 |
| Halogenated aliphatic hydrocarbons | 27 |
| Halogenated aromatic hydrocarbons | 12 |
| Organolead compounds | 9 |
| Organotin compounds | 0 |
| PCBs | 14 |
| Pesticides | 118 |
| Phenols | 27 |
| Phthalates and adipates | 8 |
| Polycyclic aromatic hydrocarbons (PAHs) | 45 |
| P-triesters | 3 |
| Miscellaneous | 25 |
| Total | 382 |

Eriksson and co-workers observed even at least 78 metals and other inorganic elements and 385 XOC's in stormwater (Eriksson et al. 2007a, b).

A similar research project was conducted at Paris University in France (Gasperi et al. 2009). Since 2007, these studies have detected the occurrence and concentration of PPs along a heavily urbanized stretch of the Seine River in the Paris region (France). A large spectrum of the PPs were observed in settleable particles and, to a lesser extent, in the surveyed water.

A total of 18 PPs, including 15 priority hazardous substances, were detected in surface water, yet the concentrations rarely exceeded the limit for quantification. In fact, only diuron, DEHP, fluoranthene and para-tert-octylphenol were observed on a frequent basis, with concentrations ranging from 0.01 to 1.0 μg/L. As regards the Environmental Quality Standards (EQS), 10 substances or groups of substances were found in surface water exhibiting concentrations above the annual average value, while only the benzo (a) pyrene concentration exceeded the maximum permissible level.

As for the Canadian Sediment Quality Guidelines, settleable particles collected in the Seine River appear to be heavily contaminated since most samples contain PP levels above the guideline values (18 PPs) and, in many cases, above the probable effect levels (15 PPs), which underscores that the levels of metals, PAHs and PCBs in settleable particles constitute a potential risk to freshwater organisms.

On three catchment areas in Sweden (Björklund et al. 2009), the conducted studies focused on determining the occurrence of nonylphenol, nonylphenol ethoxylates and eight phthalates in urban stormwater and stormwater sediments. Stormwater sampling was performed in two urban residential areas in Stockholm, Nybohov and Skarpnäck, and one catchment area dominated by the E6 highway in Gårda, Göteborg (all in Sweden). The sediment samples were collected from the E6 from sediments, from a series of seven underground chambers passing under the motorway. The study confirmed that the concentrations of nonylphenol and its ethoxylates in the sample from Gårda exceeded the Canadian water quality guideline for the protection of aquatic life (no Swedish guidelines exist) of 1.0 μg/L.

In July 2001, November 2001 and January 2002, rain and snow sampling was conducted in different urban, suburban and rural areas in Germany and Belgium. High concentrations of 4-NP in rain and snow (Fries et al. 2004) were observed in this study.

As regards urban stormwater runoff from two catchments in Dunedin, significantly higher concentrations of A16PAH (sum of the 16 USEPA priority listed PAHs) and heavy metals were present in the runoff from the urban catchment (as compared to a local river (the Leith) that has 83 % of its catchment in rural areas but also receives stormwater discharges from several small urban sub-catchments.

The above mentioned studies and many other studies all over the world (Norway, UK, Switzerland etc.) reveal increasing pollution caused by priority pollutants, hazardous pollution and potential priority pollutants in stormwater.

In the European Union, the EU Plant Protection products Directive 91/414/EEC introduces corrective using of pesticides in land management, but a study conducted on the Nil River in Belgium reveals extremely dynamic pesticides concentrations (such as atrazine, simazine, diuron, etc.) in surface water during rainfall events (Seuntjens et al. 2008).

A solution appropriate for the protection of surface water is to develop tools for risk assessment and planning of stormwater discharges in the framework of the WFD as well as methodologies for assessing the removal of pollutants and structural stormwater treatment systems or best management practices (BMPs).

## 4 Xenobiotics in Stormwater (Sources, Pathways, Types)

The most frequent xenobiotics in stormwater are metals, inorganic trace elements, polycyclic aromatic hydrocarbons (PAH), pesticides, phthalates, alkylphenol, ethoxylates, dioxins, furans, polycyclic chlorinated biphenyls (PCB) etc. The major sources are compounds released from building materials, traffic related releases (exhaust fumes from vehicles, tires, brakes, road material, painting markers on roads, use of de-icing agents), human activities (application of pesticides, car washing, disposal of paint, oil etc. in the storm water sewers) as well as wet and dry air deposition. Combined system overflows may also contain pharmaceuticals, chemicals from household and chemicals from various industries.

Xenobiotics are released into stormwater from point sources, which is mainly related to metals and de-freezing agents but they can also be released from area sources, such as pesticides. Frequently observed elements are metals such as Cd, Cr, Cu, Pb and Zn, and as well PAU and pesticides.

The reviews conducted by Makepeace et al. (1995) and Eriksson et al. (2007a, b) show that the concentration levels of the pollutants vary significantly within one rain event, between events at the same site, and between representative concentrations established at different sites. This can in part be attributed to differences in urban environment and land-use.

A common problem is the analysis of stormwater for reuse where it is very difficult to determine what substances the tests should focus on.

### 4.1 Classification of Harmful Substances (Health Threatening) in Stormwater

The chemical character of stormwater depends on the nature of surfaces (roads, roofs etc.) with which it comes into contact during the runoff process as well as natural processes and anthropogenic activities in the catchments.

The level of stormwater pollution is generally defined as follows (Hlavínek et al. 2007):

- slightly polluted—stormwater run-off from residential areas (streets, bicycle tracks, pavements, green areas, etc.).

- normally polluted—water from residential-industrial areas, villages, parking lots and roads.
- strongly polluted—water from motorways, heavy traffic, primary roads, and open warehouses for harmful and poisonous substances.

### 4.1.1 Metals

Sources of metals are motor vehicle emissions, crankcase oil leaks, vehicle tire wear and asphalt road surfaces, these are diffuse sources of chemical contaminants in urban environments. During rainfall, these contaminants are washed from roofs, roads and other surfaces into the stormwater system and then discharged into surface waterways. Pb, Cr, Cu, Zn, Cd, Hg, Ni, Pt are often monitored in stormwater run-off from urbanised areas. Strong contribution from runoff is highly correlated with the heavy metal contamination of roof runoff. High concentration of Zn (658–1137 mg l-1), Cu (86–134 mg l-1) and Pb (46–175 mg l-1) were observed in combined sewer overflows in Paris. The majority of roofs within the Paris city have been fitted with metal materials, such as lead fittings and zinc sheets, thus leading to high metal concentrations (Zgheib et al. 2012).

Effect of metals on human health: Lead can damage the blood system, nervous system, kidneys, immunity reaction, heart muscle, digestive and reproduction systems. Copper is an accumulative xenobiotic, stored first in the liver and in bone marrow. Soluble salts of copper may induce hyphaemia, cause damage to liver, kidneys, indigestion or bleeding into the digestive tract and Wilson illness. There is a proven teratogenic and mutagenic effect of cadmium ions resulting in chromosomal aberration. Mercury effects the nervous system, kidney, lungs, skin. Most toxic are chromium compounds, chromium trioxide, chromate and dichromate. These are major carcinogens inducing lung cancer, some of them have mutagenic effects, affect liver and kidney and induce internal hemorrhage. They can also irritate skin and mucous membrane, result in skin ulcers, affect stomach and duodenum.

Repeated contact with these compounds results in damage to the heart muscle, kidneys, allergies and erosion of the nasal septum.

### 4.1.2 Polycyclic Aromatic Hydrocarbons

Diffuse sources of PAHs include domestic fire emissions, spillage or deliberate dumping of waste oil and corrosion of roofing materials. Specific point sources, such as electroplating workshops, gasworks and commercial incinerators may also exist in urban catchments (Gasperi et al. 2009) Naphthalene* (N), acenaphthalene (Acen), acenaphthylene (Acyl), fluorene (F), phenanthrene (P), anthracene* (A), fluoranthene (Fluo), pyrene (Pyr), benzo[a]anthracene (B(a)A), chrysene (Chry), benzo[a]pyrene* (B(a)P), benzo[b]fluoranthene* (B(b)F*), benzo[k]fluoranthene*

(B(k)F*), dibenz[ah]anthracene (D(ah)A), benzo[ghi]perylene (B(ghi)P*), and indeno[cd]pyrene (IP*) are commonly monitored in stormwater, and stormwater contains higher PAH concentrations than wastewater. For example, stormwater has a PAH concentration between 0.77 and 6.14 mg $L^{-1}$ (with the median at 1.36 mg $L^{-1}$), while the concentrations found in wastewater are in a range of 0.20–1.22 mg $L^{-1}$ (median: 0.47 mg $L^{-1}$) (Zgheib et al. 2012).

Many polyaromates are mutagenic and carcinogenic. Animal tests indicated unfavorable effects on the skin and haemopoiesis, damage to respiratory and immunity system, reproduction system etc.

### 4.1.3 Pesticides

Pesticides may be harmful to humans, animals and the environment as they can induce cancer, mutagenic changes, endocrine disruption and many others adverse effects. Pesticides enter the surface water via (Seuntjens et al. 2008):

- Diffuse source—run-off, run-off flow, atmospheric deposition and ground water
- Point source—run-off, run-off flow, combined system overflows and direct discharges

The concentration of pesticides in stormwater depends on their leaching on impervious surfaces. Utilization of pesticides is regulated by the EU Plant Protection Products Directive 91/414/EEC. Majority of stormwater researches monitor al-drin, atrazine, desethylatrazine, simazine, dieldrin diuron, isoproturon, aminotria-zole, glyphosate and amino methyl phosphonic acids.

The current research work attributed more negative effects to pesticides besides endocrines disruption such as a decline in bees population, contamination of surface water, Parkinson's disease, etc. Many of the substances on the Stockholm convention list are pesticides.

### 4.1.4 Phthalates

Phthalates are mainly used as plasticisers in PVC products such as coated panels and cables. Vehicle components and regenerated asphalt have also been identified as potential sources. DEHP is the most frequently detected phthalate found at the highest concentrations in urban environments.

Tests conducted on animals indicate that DEHP is characterised as a toxic substance endangering the reproduction ability (damaging male and female reproduction organs), inductive inborn disorders (e.g. skeletal disorders, eye disorders, embryo nervous system disorders nervous), cardio—vascular disorders and dustiness. DEHP also damages kidneys and livers.

### 4.1.5 Nonylphenols

NPEO concentrations in stormwater originate from car washing using detergents which contain NP/EOs, from agents in concrete and from lubricant, paint and sealant production. In a current study, the highest NP/EO detection frequency and the highest water concentrations were reported in high-density traffic catchments (Fries et al. 2004). NPEO imitate the effects of natural oestrogenic hormone, disrupt DNA and human lymphocytes, bioaccumulate in living tissues and are toxic to water organisms.

### 4.1.6 Polychlorobiphenyls

The main sources of PCBs in water are the residues of atmospheric deposition and runoff on urban surfaces. The presence of PCB was detected in sealants used in the construction of buildings. Some of these sealants are suspected to contain up to 20 % of pure PCBs They can be eroded or degraded so that PCBs are released into the environment (air and soils) (Rossi et al. 2004) PCB causes liver diseases, blood circulation disorders and fatigue.

Fish exposed to a long time to water contaminated with trace concentration of PCB have a thousand times higher concentration in the tissues than in water. At the same time, the PCB concentration in the fish bodies was unevenly distributed.

### 4.1.7 Organotins

Organotin compounds found in stormwater are tributyltin (TBT), dibutyltin (DBT) and monobutyl (MBT) Organotins are generally applied industrial pesticides used in agriculture, as wood preservatives, for industrial water cooling towers, and in many types of PVC applications. High concentrations of MBT and DBT in stormwater are caused by leaching from PVC materials and house paints (Gasperi et al. 2012). Tributylcin blocked conversion of testosterone to estrogens. Excessive production of testosterones in females may result in male characteristic features. In extreme cases, this may result in infertility.

### 4.1.8 Volatile Organic Compounds (VOC′s)

Tetrachloroethylene, ethylbenzene, toluene, xylene and trichloroethylene are occasionally detected in stormwater. According to US-EPA, methylene chloride is used in various industrial processes, spanning many different industries including paint stripping, pharmaceutical manufacturing, paint remover manufacturing and metal cleaning and degreasing. Similarly, owing to its excellent degreasing properties, tetrachloroethylene is a widely preferred degreasing agent and solvent, therefore explaining its presence in numerous household products (automobile cleaners, paint removers, strippers, etc.). The main concentrations of VOC enter the surface water trough overflows in combined sewer system during storm events (Gasperi et al. 2012). Frequent exposure to tetrachlorethylen may cause serious damage to brain, eyes, kidneys, liver, skin, larynx and evidence shows that this substance may be carcinogenic.

People working in laundries and exposed to tetrachlorethylen for a long time often suffer from frequent cases to the nervous system disorder and women face a higher risk of abortion and menstrual cycle changes.

### 4.1.9 Chloralkanes

Chloroalkanes are also called short-chain, chlorinated paraffin. These compounds are used as lubricants and additives, as well as flame retardants. Concentrations of chloralkanes in the environment are caused by combustion in incinerators, leaching of dyes in water (pools, basins,) Chloralkanes cause dermatitis, respiratory system disorders and are retained in the organism tissues. The mixture of post chlorinated saturated hydrocarbon C12 with 60 % chlorine is assessed by the IARC as a potential human carcinogen, highly toxic for aquatic organisms, causing long-term adverse effects on aquatic environment. Toxicity in aquatic organisms was demonstrated in a concentration range of 0. 12–1.45 ug/L (MŽP ČR 2004).

### 4.1.10 Dioxins

The main source of dioxins in water is incineration of waste containing chlorinated substances or they are produced as a by—product in chemical production where chlorine is used (production of pesticides, paper bleaching, etc.) Dioxins result in hormonal disorders, they endanger animal reproduction including humans, and are responsible for immunity system disorders. Some of them are carcinogenic.

## 4.2 Method of Classification and Risk Analyses

In the European Union, the Institute for Health and Consumer Protection has established a technical handbook for risk analyses (issued in 2003), which introduces three possible to approaches to evaluation:

- Quantitative PEC/PNEC environmental analyses of the substance diversification estimates comparing the individual concentrations (PEC—predicted environmental concentration), whether it is below the limit of the so-called no-effect concentration—PNEC (predicted no-effect environmental concentration), which is a concentration of these substances that has no adverse effect on water biota.

- Qualitative environmental risk analysis of the substances,
- PBT estimate, persistency estimates, bio—storage potential and toxicity.

The PEC values are derived from already measured data or from model calculations. The PNEC are obtained on the basis of laboratory tests and, in several cases, from derived modelling calculations.

However, according to the team of Danish researchers from the Danish Technical University (A. Baun, E. Eriksson, a. Ledin, P.S. Mikkelsen), these methods are unsuitable for stormwater and surface water intended for reuse. Therefore, they developed two methods in 2009—the RICH process (Ranking and Identification of Chemical Hazards) and in 2007 the CHIAT process (Chemical Gambling Identification and Assessment Tool). These methods calculate the hazard values to be taken into the account in the final test of the total effect of xenobiotics on the water ecosystem.

Generally, it is necessary to define and assess potential chemical hazards in stormwater, validate the sustainable qualities of stormwater sources before it infiltrates into groudnwater or surface water as identification of diluted xenobiotics in a body of water body is impossible. In many cases, the input concentrations are too low or, on the contrary, retention processes may inadequately increase the residual concentrations. Therefore, it is necessary to consider the recorded quantitative analysis to assess the specific substances.

Currently, the knowledge of the potential effects, or transformation process that xenobiotics can cause in stormwater is limited.

The principal element in designing of stormwater treatment is the methodology to identify priority pollutants in stormwater systems. Analysing of xenobiotics is financially exacting and therefore is necessary estimate what type these substances might be included to runoff (Eriksson et al. 2007a, b). The CHIAT (Chemical Hazard Identification and Assessment Tool) methodology is best-known assessment tools for stormwater. The CHIAT procedure was inspired by the approach advocated by the European technical guidance document for risk assessment of chemicals as well as the approaches used in environmental risk assessment of chemicals by governments, chemical industry, scientific communities, environmental organisations, and institutions responsible for issuing eco-labels (Eriksson et al. 2007a, b).

The CHIAT has been developed in collaboration with end-users and is expected to be used by end-users in the future. The tool includes a number of hazards that need to be taken into account when evaluating the impact from micropollutants on aquatic systems. These are both acute and long-term effects to living organisms e.g. toxicity, bioaccumulation, carcinogenicity, mutagenicity, reproduction hazards and endocrine disrupting effects, as well as the ability to promote allergic reactions in humans.

The CHIAT-procedure consists of five steps:

1. source characterisation,
2. recipient, subject exposure and criteria identification,
3. hazard and problem identification,
4. hazard assessment
5. expert judgment/stakeholder involvement.

Another complicated problem related to the disposal of xenobiotics from stormwater is the complex d interactive relationship between these compounds, and analysing sample of water on the basis of the concentrations of single substances is not suitable. A possible solution to the testing is in vitro bio—tests that may analyse the total potential effects of the sample, assess the ability of the substance to influence wastewater organisms living in the water body e.g. based on the estrogenic or androgenic potential.

## 5 Problems Related with the Presence of Xenobiotics in Stormwater Intended for Reuse in Households, Irrigation or Other Commercial Use

With regard to increases in the prices of potable water m the stormwater harvesting seems highly advantageous in economic terms. At present, stormwater from vast urbanized areas with a high area of concrete and asphalt impermeable surfaces may seriously endanger the groundwater quality (possible sources of drinking water) due to xenobiotics contamination.

In local conditions, stormwater is largely utilised in households where up to s 50 % of drinking water can be replaced with waste stormwater e.g. for toilet flushing, cloth washing, irrigation and cleaning (Hlavínek et al. 2007).

However, stormwater may be used not only in households but also in larger blocks of flats, in commercial buildings (hotel, administration building) as an alternative source for urban water elements such as fountains, channels, man-made lakes and to raise groundwater level, natural lakes and rivers. Toxicity tests of storm water (Denmark, Germany) reveal the presence xenobiotics in water intended for these purposes.

### 5.1 How to Estimate the Risks and Potential Problems with the Presence of Xenobiotics in Stormwater for Reuse?

The most important step to identify the risk and problems is to determine the sources of stormwater and purposes of its reuse. The best sources of stormwater for its reuse is water from roofs, roadways, parking lots, airports, impervious urban areas, green areas and recreational areas. Nowadays, stormwater is mostly reused for toilet flushing, washing machines, cleaning, irrigation and in fountains, man*-made lakes and channels.

Table 2 shows the potential risks and issues related to the specific type of reuse.

## 5.2 Environmental Hazards

The adverse effects on the environment include bioaccumulation of the compounds in tissues or sediments, mutagenic effects, toxicity, endocrine disruption and others dangerous influences of xenobiotics causing irreversible changes.

As regards the environmental persistence criteria, the compounds are divided into four groups: not degradable (N), degradable (Y) and no information found (NI). Mobility is categorised into mobile constituents (M), constituents that show some mobility (m) and immobile (im) (Table 3). In stormwater samples, 467 compounds were classified and of these, 190 were categorised as mobile (M), 84 as slightly mobile (m) and 193 as immobile (im) (Table 3). Mobility is a parameter characterizing the ability of a compound to leach into the soil and groundwater. Halogenated aliphatic hydrocarbons, pesticides and phenols are highly mobile and therefore they pose a potential risk to the groundwater.

Bioaccumulation is expressed by the bioaccumulation factor and presents the ability of compounds to be bound to the tissues, sediments and plants. The BCF parameter for stormwater was identified with tests of algae, fish and c crustaceans. The PAHs groups contained the highest volume of bioaccumulation compounds.

Toxicity is expressed as EC50/LC50, which is the medium effective concentration (EC50), a statistically derived concentration of a substance in a natural environment expected to produce a certain effect in 50 % of test organisms in a given population under a defined set of conditions (IUPAC definition). LC50 is a lethal dose expressed as the mass of substance administered per unit mass of test subject when the effect is the death of the tested subject. Pesticides contain the highest quantity of toxic compounds, for example, EC50/LC50 < 0.1 mg/L was found in 102 pesticides. Tested samples indicate that the values of toxicity increased from < 0.1 to < 1 mg/L, the number of compounds classified as hazardous increased twice.

## 5.3 Human Health Hazards

Xenobiotic have diverse effects on human health such as worsened allergic reaction, cancer, reproduction changes and etc. According to Ledin et al. 2002:

Table 2 Identification of hazards and problems associated with different types of reuse (Ledin et al. 2002)

| | Exposure pathway | Potential hazard problem | Type of hazard/problem |
|---|---|---|---|
| Toilet flushing | Inhalation of aerosols | Allergies | Health |
| | | Infectious diseases | |
| | Skin contact | Allergies | Health |
| | | Infectious diseases | |
| | Others | Colouring | Aesthetic |
| | | Foaming | Aesthetic |
| | | Odour | Aesthetic |
| | | Precipitation | Technical |
| | Exposure pathway | Potential hazard problem | Type of hazard/problem |
| Laundry wash | Skin contact | Infectious diseases | Health |
| | | Allergies | |
| | | Cancer | |
| | | Mutagenic effects | |
| | | Reproductive effects | |
| | Others | Colouring of cloth | Aesthetic |
| | | Corrosion | Technical |
| | | Odour | Aesthetic |
| | | Precipitation | Technical |
| | | Whitening of cloth | Aesthetic |
| Cleaning | Inhalation of aerosols | Allergies | Health |
| | | Infectious diseases | |
| | Skin contact | Infectious diseases | Health |
| | | Allergies | |
| | | Cancer | |
| | | Mutagenic effects | |
| | | Reproductive effects | |
| | Others | Corrosion | Technical |
| | | Odour | Aesthetic |
| | | Precipitation | Technical |
| Local treatment | Biofilter | Toxicity | Technical |

(continued)

Table 2 (continued)

| | Exposure pathway | Potential hazard problem | Type of hazard/problem |
|---|---|---|---|
| Irrigation—local infiltration | Soil and soil living organisms | Accumulation | Environmental |
| | | Deteriorating quality (e.g. changes in soil structure) | |
| | | Toxicity | |
| | Groundwater | Deteriorating quality | Environmental |
| | | Mobilisation to the groundwater | |
| Utilisation | Exposure pathway | Potential hazard problem | Type of hazard/problem |
| Discharge into fountains, canals, lakes | Surface water, water living organisms | Accumulation | Environmental |
| | | Deteriorating quality | |
| | | Toxicity | |
| | Swimming | Allergies | Health |
| | | Cancer | |
| | | Mutagenic effects | |
| | | Reproductive effects | |

It was found out that 73 out of the 599 compounds potentially present in collected rainwater could give rise to allergic reactions, 78 compounds may cause cancer, 13 compounds are known to be mutagenic and 32 can affect reproduction Some of the compounds have more than one of these properties for example pesticides, halogenated or aromatic compounds.

The classification of risks is based on available information about biodegradation, toxicity and bioaccumulation. However, stormwater has not been sufficiently examined yet in this respect and, currently, we have more information about pesticides than about other compound groups.

Although not enough information is available about a majority of xenobiotics in stormwater, we can state that stormwater poses a potential hazard to the environment and human health if the water is used without previous treatment (Erikson et al. 2007a, b).

The main technical problem related to discolouring of clothes or the toilet bowl is caused by the presence of metal-(hydr)—oxides, or natural organic matter such as humic and fulvic acids.

Table 3 Inherent properties of the constituents observed and potentially present in rainwater (Ledin et al. 2002)

| Hazard classification | No. | Persistent | Bioacumulative (BCF) | Toxicity (mg/L) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | N | D | NI | >2000 | >100 | NI | <0.1 | <1 | NI |
| Metals and trace el. | 30 | 29 | 0 | 1 | 3 | 7 | 16 | 10 | 15 | 12 |
| Aliphatic amines | 6 | 0 | 4 | 2 | 0 | 1 | 2 | 0 | 0 | 3 |
| Alkanes | 24 | 3 | 2 | 19 | 3 | 4 | 18 | 2 | 2 | 19 |
| Aromatichc. | 27 | 3 | 12 | 12 | 3 | 9 | 9 | 1 | 7 | 9 |
| Chlorophenyls | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 |
| Dioxins and furans | 28 | 1 | 0 | 27 | 6 | 7 | 21 | 3 | 3 | 25 |
| Ethers | 13 | 1 | 0 | 12 | 0 | 1 | 11 | 0 | 0 | 11 |
| Halo. aliph. hc | 37 | 12 | 13 | 12 | 1 | 3 | 9 | 4 | 5 | 10 |
| Halo. arom. hc | 32 | 2 | 12 | 18 | 3 | 16 | 11 | 4 | 12 | 12 |
| Miscellaneous | 149 | 12 | 29 | 108 | 9 | 15 | 105 | 1 | 5 | 107 |
| Organolead compound | 12 | 0 | 0 | 12 | 2 | 2 | 0 | 1 | 2 | 10 |
| Organotin comp. | 9 | 0 | 1 | 8 | 1 | 1 | 10 | 2 | 2 | 7 |
| PCBs | 22 | 0 | 0 | 22 | 6 | 6 | 8 | 5 | 6 | 16 |
| Pesticides | 102 | 15 | 21 | 66 | 15 | 28 | 16 | 38 | 43 | 49 |
| Phenols | 47 | 6 | 18 | 23 | 5 | 12 | 47 | 4 | 11 | 21 |
| Softeners and plasticizers | 9 | 0 | 8 | 1 | 2 | 4 | 22 | 2 | 5 | 1 |
| PAHs | 48 | 4 | 8 | 36 | 13 | 18 | 1 | 6 | 12 | 35 |
| P-triesters | 3 | 0 | 3 | 0 | 1 | 2 | 29 | 1 | 2 | 0 |

## 5.4 Aesthetic Problem

Foaming, odour and discolouring are frequently aesthetic problem of stormwater. Foaming is a result of the presence of organic compounds with a lipophilic and hydrophilic moiety e.g. detergents, fatty acids, proteins etc. Odour and discolouring are caused by growth of microorganisms.

## 5.5 Summary of Stormwater Reuse

The sources and pathways of xenobiotics in stormwater are very diverse, and classification of these sources and pathways creates the basis for effective pollution management. There are many potential approaches to classifying risks and problems with stormwater reuse but it always depends on actual available data collection and analyses of stormwater. Nevertheless, currently we do not have enough information about their detailed composition (Fatta-Kassinos et al. 2010). A new possibility is forensic source tracking involving the systematic monitoring and evaluating of physical, chemical and historical information regarding the sources of pollutant emissions.

## 6 Stormwater Treatment Option

Professor Robert Pitt from the University of Alabama, Department of Civil, Construction and Environmental Engineering, Tuscaloosa in the USA, conducts research and evaluation of wastewater treatment technologies in terms of xenobiotics removal.

As part of this research he issued several publication focuses on treatment and utilisation of stormwater. The Department of Civil Engineering at the university of Alabama in cooperation with U.S. Environmental Protection Agency created the International BMP Database (http://www.bmpdatabase.org/, accessed 07/18/2011), which collects data from several hundreds of stormwater studies and makes statistical evaluation of its effects.

Prof. R. Pitt assessed the effects of wastewater treatment technologies for selected priority pollutants present in stormwater runoff, see Table 4.

### 6.1 Factors Affecting Degradation of Xenobiotics

As mentioned above, xenobiotics represent a relatively wide spectrum of substances, which do not always have the same physical-chemical properties, and we can therefore infer that various treatment technologies will have different impacts on the level of their degradation.

When designing wastewater treatment plants it is therefore necessary to know the detailed treated wastewater analysis while respecting possible mutual interactions among the specific compounds.

Recent studies indicate that he rate of natural degradation of xenobiotic substances depends on several factors: season, temperature, intensity of sun radiation, hydraulic retention time. As regards water resources management it is necessary to select efficient treatment technologies so as to avoid any risk to surface water. Biological wastewater treatment methods provide various results of degradation depending on the particular type of substances (as per value log $K_{ow}$).

The TCPP derivate released in stormwater, primarily from the building industry—has strong hydrophobic characteristics and therefore the biological degradation methods using activated sludge do not have any effect on decreasing its concentrations

Table 4 Maximum permissible values of the inclination of the bottom of the road ditch with no strengthened scarps and bottom in Poland (based on: PN-S-02204:1999P)

| Pollutant | Treatment process | Design notes |
| --- | --- | --- |
| Lead | Ion-exchange<br>Chemically-active media filtration | Lead attaches strongly to solids. Substantial removal by sedimentation and/or physical filtration of solids to which lead is attached. Lead < 0.45 mm may be ionic and could be removed using ion-exchange with zeolites, but filtered, ionic lead is usually at very low concentrations and it would be unusual to require treatment. Lead complexes with hydroxides and chlorides to a certain extent. Removed in media with variety of binding sites (peat, compost, soil) |
| Copper, Zinc, Cadmium | Chemically-active filtration | These metals can attach to very small particles, with attachments being a function of the particulate organic content, pH, and oxidation-reduction conditions (filterable fractions vary from 25 to 75þ %). Physical filtration may be limited depending on size association of the pollutants. These metals complex with a variety of organic and inorganic ligands to create soluble complexes of varying valence charges (2 to þ2). Small amount of ionic species (metal as þ2 ion only) reduces ion-exchange effectiveness. Complexes require variety types of sorption/exchange sites. Organic complexes may be removed by GAC. Peat, compost and soil will remove most inorganic and organic complexes. Concern about background contamination of media with metals |
| Mercury | Chemically-active filtration with organic media | Mercury reacts with both organic and inorganic compounds to form complexes, plus it methylates to form methylmercury (log KOW ¼ 1.7e2.5), which is somewhat soluble in water. Complexes require multiple types of sorption/exchange sites. Organic complexes and methylmercury may be removed by GAC. Other potential media include peat, compost and soil. Reducing mercury to very low levels with filtration may be difficult if parent material has mercury contamination. Hyperaccumulating plants have been successfully used for reducing Hg from sediments and soils (requires harvesting and plant management) |
| Volatile Organic Compounds (VOCs) | Air stripping<br>Chemically-active filtration | Passive air stripping can be accomplished using step aeration or by passing runoff over packing balls or other air entrainment mechanisms as the water enters the treatment device. See below for filtration |

(continued)

Table 4 (continued)

| Pollutant | Treatment process | Design notes |
|---|---|---|
| PAHs/Oil and Grease (O&G)/ Dioxin | Chemically-active filtration | These compounds have high KOW and low KS and are strongly associated with particulates. Sedimentation's effectiveness is function of particle size association. Preferential sorption to organic media, such as peat, compost, soil. Some O&G components can be microbially degraded in filter media. Reductions to very low levels with filtration may be difficult if parent material is contaminated. If low permit limits, may have to use clean material such as GAC |
| Organic Acids and Bases | Chemically-active filtration | Tend to be more soluble in water than PAHs and more likely to be transported easily in treatment column. Need media with multiple types of sorption sites, such as peat, compost and soil. GAC possible if nonpolar part of molecule interacts well with GAC or if GAC has stronger surface active reactions than just van der Waals strength forces. |
| Pesticides | Chemically-active filtration | Tend to be soluble in water and need multiple reaction sites to be removed. Breakdown time in biologically-active filtration media is compound-dependent. Breakdown has the potential to restore surface-active sites, and may result in more soluble daughter products, which may or may not be more toxic. Organic media such as peat, compost, soil, GAC likely to be most effective since size of compound will exclude substantial removal in ion-exchange resins such as zeolites |

in stormwater. Therefore, it is better in some cases to use prosperous innovation treatment technologies such as advanced oxidation process, membranes technology, and others.

The best systems for stormwater treatment are decentralised systems of stormwater and snow retention as they compensate for uneven flows.

The decentralized systems include the Best management practices (BMPs) and Sustainable urban drainage systems (SUDs), which are widely used to reduce urban runoff peak flows as well as the amount of pollutants entering into the water environment.

Structural BMPs can be categorised into four main groups (Eriksson et al. 2007a, b):

- filter strips and swales;
- infiltration systems (soakaways, infiltration trenches and infiltration basins);
- storage facilities (retention basins, retention ponds, lagoons),
- alternative road structures (porous paving, porous asphalt surfaces).

## 7 Conclusion

Stormwater is one of the major pathways for the introduction of xenobiotics into the water cycle. Analyses of samples from stormwater reveal the presence of xenobiotics compounds such as metals, inorganic trace elements, polycyclic aromatic hydrocarbons (PAH), pesticides, phthalates, alkylphenol, ethoxylates, dioxins, furans and polycyclic chlorinated biphenyls (PCB).

Many of these are listed in Annex 10 of the Water Frame Directive as being hazardous or potentially hazardous. Generally, it is necessary to assess the potential chemical hazards in stormwater, sustainable source control and to treat stormwater runoffs before it infiltrates into the groundwater or into the receiving body of water.

Identification of the impacts of xenobiotics on water bodies is often a problem as in many cases the input concentration is too low but during retention and degradation processes in the system the resulting concentration in the receiving body of water may increase. Therefore, it is necessary to consider whether water testing based on the values of quantitative analyses of the individual substances is perfectly suitable.

Currently there is very limited knowledge of the potential effects of xenobiotics in stormwater. This is related both to the identification of the compound present in the stormwater and to the degradation mechanisms and their transformation products.

Therefore it is necessary to encourage more research studies focusing on the xenobiotics in stormwater.

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# Basic Principles of the Czech Technical Standard on Sustainable Stormwater Management

Ivana Kabelkova, David Stransky and Vojtech Bares

**Abstract** The paper introduces basic principles of a new Czech technical standard in the field of stormwater management (TNV 75 9011 Sustainable Stormwater Management). It describes the procedure of the selection of the drainage concept, when individual approaches (stormwater infiltration, drainage to the surface waters, drainage by the combined sewer system) have to be subsequently examined as to their admissibility and feasibility. Within the detailed drainage design, focus is put on the hydraulic loading of infiltration devices determining their pollutants removal efficiency and on the stormwater pre-treatment techniques suitable for the removal of individual pollutant categories before infiltration or discharge to the surface waters. The standard gives also an overview of stormwater management structures and devices together with the rules for their technical and hydraulic design, construction, operation and maintenance.

## 1 Introduction

The Czech technical standard Sustainable Stormwater Management (TNV 75 9011 2013) provides technical support to the Czech legislation regarding stormwater management (SWM) (details see Stransky and Kabelkova 2015). The standard is

I. Kabelkova (&) · D. Stransky · V. Bares
Faculty of Civil Engineering, Czech Technical University in Prague, Thákurova 7, 166 29 Prague, Czech Republic
e-mail: kabelkova@fsv.cvut.cz

D. Stransky
e-mail: stransky@fsv.cvut.cz

V. Bares
e-mail: bares@fsv.cvut.cz



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based on similar technical standards and methodical guidances used in Germany (Arbeitsblatt DWA-A138 2005; DWA-Merkblatt M153 2007), Austria (ÖNORM B 2506-1 2000; ÖNORM B 2506-2 2003; ÖWAV-Regelblatt 35 2003), Switzerland (VSA 2002) and Great Britain (CIRIA 2007). Its subject matter covers:

- instructions on the selection of an appropriate stormwater recipient (i.e. the drainage concept) respecting priorities given by the legislation and on the selection of the corresponding drainage technique,
- technical design of individual SWM structures and devices (description of their function and construction including their schemes),
- hydraulic design of the SWM structures accompanied by several computational examples,
- construction, operation and maintenance requirements.

This paper concentrates first of all on the explanation of the principles of the selection of the drainage concept and its technique. The other parts of the technical standard are discussed in less detail.

# 2 Conceptual Drainage Design

## 2.1 Stormwater Recipients

Stormwater recipients can be the atmosphere (via evaporation and evapotranspiration), the ground water (via infiltration), surface waters (by the means of open channels or storm sewers) and the combined sewer system.

The standard recommends at least 30 % of the built-up surface of the land plot to enable evapotranspiration, e.g. by the means of vegetated grounds, roofs or facades.

Next to the rain water harvesting (e.g. in the household or in the garden) and decreasing stormwater runoff (e.g. by permeable surfaces), the selection of the stormwater recipient follows priorities given by the Czech legislation (Act 183/2006 Coll.; Regulation 501/2006 Coll.):

1. Infiltration, pre-treatment in the case of polluted runoff. If not possible, then:
2. Retention and regulated discharge to the surface waters (directly or by a separate storm sewer system), pre-treatment if needed. If not possible, then:
3. Retention and regulated discharge to the combined sewer system.

## 2.2 Stormwater Measures Management Train

SWM devices may also be placed in series to increase the robustness and safety of the system (Fig. 1). A following sequence of measures and devices supporting sustainable stormwater management is recommended as follows:

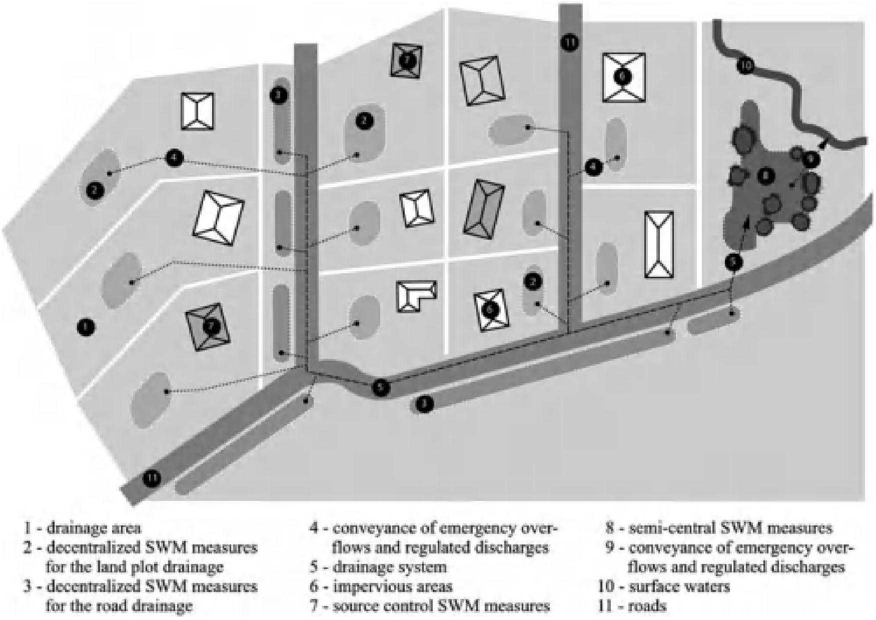


Fig. 1 Series of stormwater management measures (management train)

- source control measures (e.g. minimising impervious surfaces, application of permeable and semi-permeable surfaces, green roofs, regular cleaning of the surfaces, rain water harvesting),
- decentralized stormwater structures at the plot of land to be drained or at the plots adjacent to the roads and streets (e.g. swales, infiltration trenches, dry wells),
- semi-central stormwater structures shared by more plots of land (e.g. drainage of regulated discharges and emergency overflows from decentralized devices to infiltration basins, detention basins, stormwater wetlands etc.).

### 2.2.1 Stormwater Pollution Aspects

The stormwater should be treated according to the degree of its pollution. It is not suitable to mix low polluted and heavily polluted waters or waters with different types of pollutants requiring different pre-treatment. The standard provides an overview of typical pollutants and quantifies the expected degree of pollution of the stormwater runoff from individual surface types (Table 1).

Table 1 Expected degree of pollution of the stormwater runoff from individual surface types

| Surface type | | Litter, sediments | Fine particles | Heavy metals | Hydrocarbons | Organic substances | Nutrients | Pathogenic microorganisms | Chlorides |
|---|---|---|---|---|---|---|---|---|---|
| Roofs | Green-extensive | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| | Green-intensive | ○ | ○ | ○ | ○ | ● | ● | ○ | ○ |
| | Inert | ● | ● | ○/● | ○/● | ○/● | ○/● | ○/● | ○ |
| | With the area of untreated metal parts less than 50 $m^2$ | ● | ● | ● | ○/● | ○/● | ○/● | ○/● | ○ |
| | With the area of untreated metal parts 50–500 $m^2$ | ● | ● | ●● | ○/● | ○/● | ○/● | ○/● | ○ |
| | With the area of untreated metal parts more than 500 $m^2$ | ● | ● | ●●● | ○/● | ○/● | ○/● | ○/● | ○ |
| Grassed areas | | ●/●●● | ●/●●● | ○ | ○ | ● | ● | ○/● | ○ |
| Foot and cycle pathways | | ●● | ● | ○/● | ○/● | ● | ● | ● | ○/● |
| Parking areas | With light traffic (passenger cars) | ●● | ● | ● | ● | ● | ● | ● | ● |
| | With heavy traffic (passenger cars and buses) | ●● | ●● | ●● | ●● | ● | ● | ● | ●● |
| | Lorries[d] | ●●● | ●●● | ●●● | ●●● | ● | ● | ● | ●● |
| Roads | With light traffic[a] | ●● | ● | ● | ● | ● | ● | ● | ● |
| | With medium traffic[b] | ●● | ●● | ●● | ●● | ● | ● | ● | ●● |
| | With heavy traffic[c] | ●● | ●●● | ●●● | ●●● | ● | ● | ● | ●●● |

(continued)

Table 1 (continued)

| Surface type | Litter, sediments | Fine particles | Heavy metals | Hydrocarbons | Organic substances | Nutrients | Pathogenic microorganisms | Chlorides |
|---|---|---|---|---|---|---|---|---|
| Commercial and industrial zones | ●/●●● | ●/●●● | ●/●●● | ●/●●● | ● | ● | ● | ●/●● |
| Roads and parks at farms | ●●● | ●●● | ●● | ●● | ●●● | ●●● | ●●● | ○/● |

○ Unpolluted stormwater
● Slightly polluted stormwater
●● Medium polluted stormwater
●●● Highly polluted stormwater
[a]<300 cars per 24 h, e.g. in the residential zone
[b]300–15 000 cars per 24 h
[c]>15 000 cars per 24 h, usually highways
[d]Parking lots not a part of public roads

# 3 Detailed Drainage Design

The local feasibility and admissibility of the drainage to the different stormwater recipients (including the necessity of stormwater pre-treatment) have to be studied in the sequence of the prescribed priorities and determine the resulting drainage concept and its detailed design.

The examination of the local feasibility proves the technical possibility to discharge stormwater to the selected recipient.

The assessment of the local admissibility of the drainage concept answers the question if the stormwater quality may endanger the recipient. It focuses on the protection of soil, groundwater and surface waters.

## 3.1 Infiltration

### 3.1.1 Feasibility

The technical feasibility of infiltration depends on two aspects:

Geological conditions

- infiltration capacity (hydraulic conductivity) of the soil determining the size of the device,
- depth of surface layers with low permeability effecting the construction of the device,
- groundwater level limiting the depth of the infiltration device.

Spatial conditions and slope of the area

- spatial conditions limiting the possibility to build a surface infiltration device,
- slope of the terrain excluding surface infiltration,
- spatial conditions determining the size of the infiltration device and of the retention volume.

### 3.1.2 Admissibility

The admissibility to infiltrate stormwater is given first of all by:

- its expected pollution decisive for whether the stormwater is allowed to be infiltrated at all, which technique may be used and if pre-treatment is required,
- hydraulic loading of the infiltration device (given by the ratio of the connected effective impervious area $A_{eff}$[1] and of the infiltration area $A_{inf}$) determining its pollutants removal efficiency.

[1] $A_{eff} = A_{imp} \cdot C$ , where $A_{imp}$ is the impervious drainage area and $C$ the runoff coefficient.

Special attention must be devoted to roofs made of untreated metals (Cu, Zn) or with considerable portion of metal parts such as gutters. These metals may be washed out by stormwater and endanger groundwater. Similarly, heavy metals and other significant pollutants are contained in the stormwater runoff from roads and parking lots with heavy traffic (Table 1). Thus, direct infiltration of these waters to the sub-soil is prohibited and only surface infiltration through the grassed humus layer adsorbing these pollutants is allowed (if necessary accompanied by further efficient pre-treatment of the whole runoff volume).

Infiltration at sites with old ecological burdens is prohibited.

### 3.1.3 Infiltration Techniques

Recommended infiltration techniques regarding the expected stormwater runoff pollution from different surface types and the hydraulic loading of the infiltration device are given in Table 2. The table also shows when pre-treatment is needed. The pre-treatment is further specified in Table 3.

The priority infiltration technique is the surface infiltration through a continuous humus layer with grass, either low loaded areal infiltration ($A_{eff}/A_{inf} \leq 5$) or decentralized infiltration in a swale or in a swale combined with a trench ($5 < A_{eff}/A_{inf} \leq 15$). This technique is suitable for the removal of most of the typical stormwater pollutants.

Pollution removal by infiltration through a discontinuously grassed area of an insufficient humus layer depth (such as concrete pavers with voids filled with grass) or through a surface without the grassed humus layer (such as porous asphalt or gravel) is low. Thus, permeable surfaces should be used only for the at site reduction of the stormwater runoff and no stormwater from other surfaces should be infiltrated on them.

The hydraulic loading of infiltration basins or of the system of swales and trenches is higher ($A_{eff}/A_{inf} > 15$), thus the pollution removal ability is lower. In the case of highly polluted stormwater runoff, pre-treatment is needed, especially suspended solids removal.

The soakaways with direct infiltration into deeper permeable layers without passing through the grassed humus layer are recommended only for the least polluted stormwaters and should be only an exceptional choice. Linear and areal soakaways (filter drains and spaces filled with gravel or perforated plastic structures) should be preferred to point devices (dry wells). The soakaways must be protected from input of suspended solids and other pollutants.

In the case of an insufficient infiltration capacity of the soil, infiltration must be combined with regulated discharge to surface waters or to the combined sewer system.

Table 2 Recommended stormwater infiltration techniques

| | Infiltration technique | | | | | | |
|---|---|---|---|---|---|---|---|
| Surface type | Surface infiltration | | | | | Soakaways | |
| | Through a continuously grassed humus layer | | | Through a discont. grassed humus layer | Without grassed humus layer | | |
| | Areal $A_{eff}/A_{inf} \leq 5$ | Decentral $5 < A_{eff}/A_{inf} \leq 15$ | Central $A_{eff}/A_{inf} > 15$ | Areal | Areal | Linear and areal | Point |
| | Broad areas and ditches | Swales and swales with trenches | System of swales, infiltration basins | Concrete pavers with voids | Permeable surfaces | Filter drains spaces filled with gravel or perforated plastic structures | Dry wells |
| Green roofs-extensive | ++ | ++ | ++ | o | o | ++ | ++ |
| Green roofs-intensive | ++ | ++ | ++ | o | o | – | – |
| Roofs and terraces made of inert materials | ++ | ++ | ++ | o | o | ++ | + |
| Roofs with untreated metal parts less than 50 $m^2$ | ++ | ++ | + | o | o | + | + |
| Foot and cycle pathways | ++ | ++ | + | + | + | + | – |
| Parking areas with light traffic | ++ | ++ | + | + | + | – | – |
| Roads with light traffic[a] | ++ | ++ | + | + | + | – | – |
| Roofs with untreated metal parts between 50 and 500 $m^2$ | ++ | ++ | + | o | o | – | –– |

(continued)

Table 2 (continued)

| | Infiltration technique | | | | | | |
|---|---|---|---|---|---|---|---|
| Surface type | Surface infiltration | | | | | Soakaways | |
| | Through a continuously grassed humus layer | | | Through a discont. grassed humus layer | Without grassed humus layer | | |
| | Areal $A_{eff}/A_{inf} \le 5$ | Decentral $5 < A_{eff}/A_{inf} \le 15$ | Central $A_{eff}/A_{inf} > 15$ | Areal | Areal | Linear and areal | Point |
| | Broad areas and ditches | Swales and swales with trenches | System of swales, infiltration basins | Concrete pavers with voids | Permeable surfaces | Filter drains spaces filled with gravel or perforated plastic structures | Dry wells |
| Roads with medium traffic[b] | ++ | ++ | + | −− | −− | −− | −− |
| Parking areas with heavy traffic | ++ | + | + | −/−− | −/−− | −− | −− |
| Roofs with untreated metal parts more than 500 $m^2$ | ++ | + | + | o | o | −− | −− |
| Roads with heavy traffic[c] | ++ | + | + | −− | −− | −− | −− |
| Roads and parks in commercial and industrial zones | +/−/−− | −/−− | −− | −− | −− | −− | −− |
| Roads and parks at farms | +/−/− | −/−− | − | −− | −− | −− | −− |
| Lorry parks[d] | −− | −− | −− | −− | −− | −− | −− |

++ Admissible, + Usually admissible, as the case may be pre-treatment recommended, o Not used, − Problematic, pre-treatment necessary, −− Inadmissible
[a,b,c,d]See Table 1

Table 3 Stormwater pre-treatment mechanisms before infiltration and their efficiency for each pollutant category

| Pollution removal mechanism | Device | Litter, sediments | Fine particles | Heavy metals | Hydrocarbons | Organic substances | Nutrients |
|---|---|---|---|---|---|---|---|
| Litter and sediment trapping | Inlet grids | ++ | −− | −− | −− | −− | −− |
| | Debris traps | ++ | −− | −− | −− | −− | −− |
| | Screen bars | ++ | −− | −− | −− | −− | −− |
| | Mesh screens, sieves | +, o | −− | −− | −− | −− | −− |
| Infiltration through a grassed humus layer (filtration, ad-sorption, biological treatment) | Swales<br>Swales and trenches<br>Infiltration basins | ++ | ++ | ++ | ++ | ++ | ++ |
| Gravitational separation (sedimentation and flotation) | Sediment sumps<br>Sedimentation tanks | ++ | ++ | ++ | ++ | −− | −− |
| | Oil separators with a sediment forebay | ++ | ++ | + | ++ | −− | −− |
| Mechanical filtration | Sand and gravel filters | ++ | ++ | + | −− | −− | + |
| | Geotextiles | ++ | ++ | + | −− | −− | −− |
| Filtration through an adsorbent matter | Active coal, coke | o | o | ++ | ++ | ++ | −− |
| | Zeolites | o | o | ++ | ++ | + | −− |
| | Iron and aluminum hydroxides | o | o | ++ | −− | −− | −− |
| | Oil adsorbents | −− | −− | −− | ++ | −− | −− |

++ Suitable, + Conditionally suitable, o Combined with other pre-treatment steps, − Rather unsuitable, −− Unsuitable

## 3.2 Regulated Discharge to Surface Waters

### 3.2.1 Feasibility

The feasibility of the regulated discharge from the drained area to surface waters is assessed regarding the distance of the drained site to a suitable connection to the surface water either directly or via an existing open channel or a storm sewer. Further aspects are the surface elevation, topology and legal relationships.

### 3.2.2 Admissibility

The admissibility of the regulated discharge to surface waters depends on:

- the type and degree of the stormwater pollution,
- the required protection of the receiving water body (e.g. sensitive region, fish waters, drinking water sources),
- the hydraulic stress in the receiving running water body caused by the stormwater discharges.

The standard provides an overview of requirements on the pre-treatment of stormwater runoff from different types of surfaces with respect to the discharge into the surface waters (Table 4). The pre-treatment mechanisms including their efficiency for each pollutant category are further specified in Table 5.

As to the stormwater quantity, the recommended value of the discharge from one land plot (i.e. one SWM device) is calculated based on the maximum specific discharge $3\ l\ s^{-1}\ ha^{-1}$ from the whole plot area, which is a value approaching the

Table 4 Pre-treatment requirements before discharge of stormwater to surface waters

| Surface type | Pre-treatment |
|---|---|
| Green roofs; roofs made of inert materials; roofs with untreated metal parts $<500\ m^2$; foot and cycle pathways; parking areas with light traffic; roads with light traffic[a] | Not required |
| Roads with medium traffic[b] | Minimum requirement: simple mechanical pre-treatment – oil and sediment collector; if possible enhanced for mechanical filtration |
| Parking areas with heavy traffic | |
| Roofs with untreated metal parts $>500\ m^2$ | Filtration through a grassed humus layer or filtration through heavy metals adsorbents |
| Roads with heavy traffic[c] | Minimum requirement: advanced mechanical pre-treatment – oil separator, sedimentation tank with a scum board; if possible enhanced for mechanical filtration and filtration through heavy metals adsorbents |
| Roads and parks in commercial and industrial zones | |
| Roads and parks at farms | |
| Lorry parks[d] | |

[a,b,c,d]See Table 1

Table 5 Stormwater pre-treatment mechanisms before discharge to surface waters and their efficiency for each pollutant category

| Pollution removal mechanism | Device | Litter, sediments | Fine particles | Heavy metals | Hydrocarbons | Organic substances | Nutrients |
|---|---|---|---|---|---|---|---|
| Gravitational separation (sedimentation and flotation) | Sediment sumps sedimentation tanks | ++ | ++ | ++ | ++ | −− | −− |
| | Stormwater tanks | ++ | ++ | ++ | ++ | −− | −− |
| | Hydrodynamic separators | ++ | + | + | - | −− | −− |
| | Oil separators | ++ | ++ | + | ++ | −− | −− |
| Sedimentation and biological treatment | Wet ponds, wetlands | +,o | ++ | ++ | −,o | ++ | ++ |
| Mechanical filtration | Sand and gravel filters | ++ | ++ | + | −− | −− | + |
| | Geotextiles | ++ | ++ | + | −− | −− | −− |
| Filtration and biological treatment | Vegetated sand and gravel filters | +,o | ++ | ++ | − | ++ | ++ |
| | Swales and trenches Bioretention | +,o | ++ | ++ | ++ | ++ | ++ |
| Filtration through an adsorbent matter | Active coal, coke | o | o | ++ | ++ | ++ | −− |
| | Zeolites | o | o | ++ | ++ | + | −− |
| | Iron and aluminum hydroxides | o | o | ++ | −− | −− | −− |
| | Oil adsorbents | −− | −− | −− | ++ | −− | −− |

++ Suitable, + Conditionally suitable, o Combined with other pre-treatment steps, − Rather unsuitable, −− Unsuitable usual pre-urbanization conditions. However, in the case of small land plots where the calculated maximum permissible discharge would be lower than 0.5 l $s^{-1}$, the minimum regulated discharge from one SWM device is allowed to be 0.5 l $s^{-1}$ because of the technical feasibility of the flow control.

### 3.2.3 Drainage Techniques

To convey stormwater runoff, vegetated open channels are preferred to storm sewers in order to encourage evapotranspiration and flow attenuation.

Both detention basins/tanks and retention basins/tanks can be used for stormwater storage. Regarding the esthetical function and support of evapotranspiration, ponds with grassed banks should be preferred to the underground tanks. Part of the storage volume can be planted to provide biological treatment. Very suitable are also artificial wetlands treating the stormwater biologically and increasing evapotranspiration. All retention structures must be equipped with a flow control device and an emergency overflow. At the sites with prohibited infiltration (e.g. contaminated sites), the technical design must ensure no leakage to the underground.

## 3.3 Regulated Discharge to the Combined Sewer System

### 3.3.1 Feasibility

The feasibility of the regulated discharge from the land plot to the combined sewer system is assessed regarding the distance of the drained site to a suitable connection to the sewer, surface elevation, topology and legal relationships.

### 3.3.2 Admissibility

The admissibility of the connection of the stormwater runoff from the land plot to the combined sewer system from the pollution point of view is given by the requirements of the Sewerage code. Pre-treatment preventing the input of suspended solids and of oil should be applied.

The recommendations for the calculation of the admissible discharge from the land plot are the same as in the case of the discharge to the surface waters. However, in addition, the sewer system capacity has to be checked (so as not to exceed the design frequency), the fulfilment of the emission criteria and environmental quality standards for combined sewer overflows should be newly assessed and the free WWTP capacity should be proven. The necessity of the assessment (e.g. as recalculation of the Urban Drainage Masterplan) depends on the newly to be connected drainage area and can be required by the sewer system owner or operator in order to allow or reject the new connection.

### 3.3.3 Drainage Techniques

Again, open channels are preferred to closed circuits for the connection of stormwaters. The technical design of retention structures is similar to the previous drainage concept, too.

## 4 Structures and Devices

Source control

- green roofs and gravel roofs
- permeable surfaces

Rainwater harvesting
Infiltration (without and with regulated discharge)

- surface infiltration (areal infiltration, swales, trenches, infiltration basins)
- soakaways (filter drains, spaces filled with gravel or perforated plastic structures, dry wells)

  Regulated discharge to surface waters and to the combined sewer system

  - detention basins and tanks
  - retention basins, stormwater wetlands

Pre-treatment

The technical standard gives a general description of individual SWM techniques, structures and devices and specifies their technical design and construction. The subject matter covers:

Flow control devices

Flow control devices are the key elements effecting the long-term efficiency of SWM structures, thus, a lot of attention should be paid to them. As the values of the regulated discharge are usually in the order of magnitude of decimals of litres to litres per second, orifice plates and small vortex throttles are recommended.

It is very important to prevent the flow control device blockage. Thus, first litter and suspended solids have to be removed from stormwater (by infiltration of stormwater through soil or through filter layers) and only afterwards it can come to the device. All flow control devices have to be regularly maintained and cleaned.

## 5 SWM Structures Hydraulic Design

The design method depends on the size of the catchment area and on the complexity of the drainage system. The standard specifies when simple (rational) methods for the design of SWM structures can be used. In all other cases, a more detailed

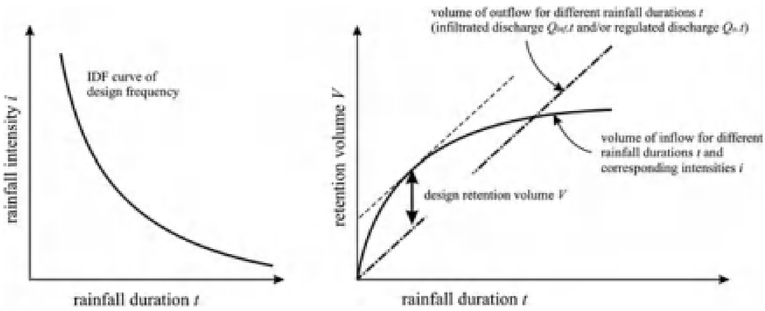


Fig. 2 Principle of the retention volume design by a simple method

long-term simulation of the rainfall-runoff process with the help of mathematical models is required.

Simple methods can be used in the following cases:

- individual infiltration devices or retention structures not connected in series,
- the drainage area connected to one infiltration device with retention volume smaller than 3 ha,
- individual retention structures with the catchment area $A < 200$ ha and flow concentration time $t_c < 15$ min.

The design procedure is based on balancing stormwater input and output for the SWM structure performed for various rainfall durations of the design frequency. The required retention volume is determined by the largest difference between the inflow and outflow volumes (Fig. 2).

The standard provides simple hydrological balance equations for different SWM structures respecting relevant equation terms (Table 6).

The design storm frequency is 0.2 and the time to empty the retention volume should be less than 24 h.

## 6 Construction, Operation and Maintenance Requirements

Construction, operation and maintenance requirements cover:

- basic construction rules to avoid future operational failures (e.g. proper schedule and performance of individual activities, supervision),
- content of the documentation,
- procedure of handing the device over to the user, content of the user manual,
- maintenance schedule for individual SWM devices (required actions and frequency of regular and occasional maintenance, remedial actions).

Table 6 Hydrological balance equations for different SWM structures

| Device | Inflow | = | Outflow | | | | |
|---|---|---|---|---|---|---|---|
| | Volume of stormwater inflow | = | Volume of infiltrated water | + | Retention volume | + | Volume of regulated discharge |
| Surface infiltration without retention | $i \cdot (A_{eff} + A_{inf}) \cdot t/1000$ | = | $3600 \cdot Q_{inf} \cdot t$ | + | 0 | + | 0 |
| Surface infiltration with retention | $i \cdot (A_{eff} + A_{inf}) \cdot t/1000$ | = | $3600 \cdot Q_{inf} \cdot t$ | + | $V$ | + | 0 |
| Surface infiltration with retention and discharge | $i \cdot (A_{eff} + A_{inf}) \cdot t/1000$ | = | $3600 \cdot Q_{inf} \cdot t$ | + | $V$ | + | $3600 \cdot Q_o \cdot t$ |
| Soakaways with retention | $i \cdot A_{eff} \cdot t/1000$ | = | $3600 \cdot Q_{inf} \cdot t$ | + | $V$ | + | 0 |
| Soakaways with retention and discharge | $i \cdot A_{eff} \cdot t/1000$ | = | $3600 \cdot Q_{inf} \cdot t$ | + | $V$ | + | $3600 \cdot Q_o \cdot t$ |
| Retention tanks | $i \cdot (A_{eff} + A_{ret}) \cdot t/1000$ | = | 0 | + | $V$ | + | $3600 \cdot Q_o \cdot t$ |

$i$ Rainfall intensity (mm/h), $t$ Rainfall duration (h), $A_{eff}$ Effective impervious drainage area ($m^2$), $A_{inf}$ Infiltration area ($m^2$), $A_{ret}$ Area of the storage volume ($m^2$), $Q_{inf}$ Infiltrated discharge ($m^3/s$), $Q_o$ Regulated discharge ($m^3/s$), $V$ Retention volume ($m^3$)

## 7 Conclusions

The technical standard TNV 75 9011 Sustainable Stormwater Management is a tool supporting ecologically as well as economically sustainable stormwater management, which is being introduced by the Czech legislation since the year 2009.

Basic principles governing the stormwater management are:

- priorities of stormwater recipients required by the Czech legislation,
- technical feasibility of individual drainage concepts,
- admissibility of individual drainage concepts with respect to the protection of soil groundwater and surface waters,
- equality of builders irrespective of the size of the impervious area of the drained land plot.

The standard focuses mainly on the new development, however, its principles and technical solutions are applicable in the existing development, too, e.g. for retrofitting and disconnection of the drained areas from the sewer system.

It is highly recommended to coordinate the drainage concept with the city planning in the new development in order to keep enough space for the stormwater management measures and their series.

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# The Law Regulations on the Subject of Rainwater Management in Poland

Daniel Słyś, Sabina Kordana and Józef Dziopak

Abstract The increase of hardscapes causes number of problems associated with the rainwater harvesting. It requires the realization of sustainable rainwater management, which would be in line with the law. This paper analyses the law regulations on rainwater management in Poland.

## 1 Introduction

In natural areas with large amount of vegetation part of rainwater percolates or evaporates and the other part runs off towards water-courses. Development of civilization and progressive urbanization contribute to the increase of hardscapes, what implicates that along with the increase of sealing degree of area the amount of rainwater absorbed by the ground decreases. In contrast to undeveloped areas—the urban areas must comply with certain technical standards and ensure appropriate levels of security.

By definition stated in the Water Law Act of 18 July 2001 (Journal of Laws of 2001c), the Environmental Protection Law Act of 27 April 2001 (Journal of Laws of 2001a) and in the Act on the Collective Water Supply and Collective Wastewater Disposal of 7 June 2001 (Journal of Laws of 2001b) rainwater and meltwater which ran off from polluted areas with impervious surface is considered wastewater. It concerns above all rainwater coming from cities, airports, harbors, roads and parking lots as well as industrial and commercial areas and transport bases.

D. Słyś (&) · S. Kordana · J. Dziopak
The Faculty of Civil and Environmental Engineering, Rzeszów University of Technology, Al. Powstańców Warszawy 12, 35-959 Rzeszów, Poland
e-mail: daniels@prz.edu.pl

S. Kordana
e-mail: sk@prz.edu.pl

J. Dziopak
e-mail: jdziopak@prz.edu.pl



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The increase of the precipitation intensity, which has been one of the most noticeable effect of climate change in recent years, causes number of problems, which may be considered on technical, economic as well as ecological side. Technical problems result from insufficient flow capacity of existing sewage systems. The economic aspect is connected with the lack of clear financing of rainwater management, whereas the ecological problem concerns above all the negative consequences observed in sewage receivers and drained areas. It necessitates the implementation of sustainable rainwater management, which would be in accordance with the law, since only such approach enables to reduce negative impact of rainwater.

## 2 Basic Law Regulations in Subject on Rainwater Management

The most important legislation in Poland, which is regulated in a comprehensive storm water management issues in the technical and environmental aspects are:

- Water Law Act of 18 July 2001 (Journal of Laws of 2001c),
- Environmental Protection Law Act of 27 April 2001 (Journal of Laws of 2001a),
- Act on the Collective Water Supply and Collective Wastewater Disposal of 7 June 2001 (Journal of Laws of 2001b),
- Construction Law Act of 7 July 1994 (Journal of Laws of 1994),
- Public Roads Act of 21 March 1985 (Journal of Laws of 1985).

The Water Law Act is primary legal regulation concerning rainwater management in Poland. It presents methods of rainwater management, which are in line with principles of sustainable development (Art. 1 Sec. 1). It also states the main goal of water protection, which is its quality maintenance or improvement as well as keeping the biological balance in water and wetlands (Art. 38 Sec. 2).

Art. 37 and Art. 122 Sec. 1 p. 1 of this act indicates that special water use, which includes introducing rainwater and meltwater do the environment, requires water legal permit. The scope of this document and its granting procedure is described in details in the unit VI of the Water Law Act.

Art. 29 Sec. 1 of the act, in turn, states that the land owner is prohibited from both changing the state of the water within his plot and discharging sewage and water to the neighboring areas. At the same time the act orders to discharge rainwater from water intake protection zones in a way which prevents it from penetrating water collection devices (Art. 53 Sec. 2).

Art. 39 Sec. 1 of the act forbids to introduce wastewater directly to underground waters as well as surface waters located in the bathing areas and public beaches situated by the water or in maximum of 1 km distance from them. This prohibition applies also for the same distance from lakes and their tributaries, it however concerns only the situation when the time of sewage inflow to the lake is shorter then 24 h.

Section 2 describes also cases when derogation from the given regulations is possible. They concern, above all, rainwater and meltwater and water coming from overflows of rainwater drainage systems. Point 1 states the possibility of discharging these wastewaters to the ground or surface waters in case when the distance from beaches and bathing areas is shorter than 1 km. Point 2 informs in turn that introducing rainwater and meltwater to the lakes and their tributaries is even acceptable when the flow of rainwater to the lake lasts shorter than 24 h.

In Art. 45 Sec. 3 of discussed act the recommendation is stated, in the light of which discharging rainwater coming from the overflows of combined and rainwater sewage systems to the ground or water is possible only after meeting the requirements of proper regulation, which, as of today, is the Regulation of the Minister of Environment of 24 July 2006 on conditions to be met for the introduction of sewage into the water or ground and on substances particularly harmful to the aquatic environment (Journal of Laws of 2006b).

Legislator adduces the principles of sustainable development also in the Environmental Protection Law. According to Art. 71 Sec. 1 of this legal act these principles are the base for preparing plans and concepts of land development on various levels of the administrative division of the country.

The unit III of title II states in turn the necessity of water protection, which aim is to gain high quality of water. Realization of this aim is possible, among others, by reducing the influence on areas feeding underground waters, what can result in reducing the hazard of polluting these waters. The mentioned aim may be also gained by maintaining the balance of ground water resources (Art. 98 Sec. 1).

Additionally, Art. 100 Sec. 1 states that influence of prepared ventures on aquatic environment in the given area should be reduced to the minimum and in case of causing change in this environment necessary actions should be taken to restore initial state of the environment as soon as possible (Art. 100 Sec. 3).

The Environmental Protection Law forces the need of paying regular fees for using the environment, what includes discharging sewage directly to waters or ground (Art. 273 Sec. 1 p. 2). Implementing act in this case is the Regulation of the Council of Ministers of 14 October 2008 on payments for use of the environment (Journal of Laws of 2008). Current rates, collected, among others, for polluted hardscapes, from which rainwater and meltwater is discharged to waters or ground, are presented in the Announcement of the Minister of Environment of 13 August 2013 on charges for the use of environment for the year of 2014 (Official Journal of the Republic of Poland "Monitor Polski" 2013).

According to Art. 9 Sec. 1 of the Act on the Collective Water Supply and Collective Wastewater Disposal it is forbidden to introduce rainwater to sanitary sewer systems. Additionally, it is also against the law to transport trade effluent as well as sewage coming from household sanitary facilities and public utility buildings in rainwater sewage systems.

This act regulates also the issue of fees for discharging rainwater in sewage systems. Implementing act is the Regulation of the Minister of Construction of 28 June 2006 on determining rates, application pattern and conditions of collective water supply and collective wastewater disposal (Journal of Laws of 2006a). The aim of introducing the fees is raising capital for self-financing of water and sewage companies as well as profit. The other aim is to encourage recipients of services to use water in reasonable way and reduce sewage pollution (§13.2).

Legal base concerning sustainable rainwater management is also stated in the Construction Law Act of 7 July 1994 (Journal of Laws of 1994). According to Art. 5 Sec. 1 of this act building should be designed and constructed in a way to assure that usage conditions of given building are congruent with its purpose. It concerns, among others, the discharge of rainwater and sewage. In the other part of this act (Art. 29 Sec. 1) legislator abolishes duty of applying for permission to build such structures as household swimming pools and ponds, which surface does not exceed 30 $m^2$.

The conditions mentioned in the act are discussed in details, among others, in the Regulation of the Minister of Infrastructure of 12 April 2002 on technical specifications that buildings and their location should comply with (Journal of Laws of 2002) and the Regulation of the Minister of Transportation and Maritime Economy of 2 March 1999 on technical conditions that public roads and their location should comply with (Journal of Laws of 1999).

Another act which concerns the issue of natural environment including surface and underground waters as well as soils, what is directly connected with rainwater management, is the Public Roads Act of 21 March 1985 (Journal of Laws of 1985). In accordance with Art. 20 of the act administrator of the road is obliged to counteract unfavorable changes that can arise in the environment as a result of construction and maintenance of roads.

## 3 Environmental Requirements

The main implementing regulations governing the details of, inter alia, the functioning of drainage systems and the conditions which they must satisfy are:

- Regulation of the Minister of Environment of 24 July 2006 on conditions to be met for the introduction of sewage into the water or ground and on substances particularly harmful to the aquatic environment (Journal of Laws of 2006b),
- Regulation of the Minister of Infrastructure of 12 April 2002 on technical specifications that buildings and their location should comply with (Journal of Laws of 2002),
- Regulation of the Minister of Transportation and Maritime Economy of 2 March 1999 on technical conditions that public roads and their location should comply with (Journal of Laws of 1999).

Basic regulations concerning rainwater introduction to the environment is covered by §19 of the regulation (Journal of Laws of 2006b). In Sec. 1 the particular areas are listed for which it is required that pollutants content should not exceed 100 mg/$dm^3$ when it comes to all suspensions in general and 15 mg/$dm^3$ of petroleum derived hydrocarbons. There are mentioned, above all, industrial and storage areas, transportation depots, docks, airports, cities, railway buildings, national and local roads, parking areas which surface exceeds 0.1 ha and contaminated pavements intended for fuel storage and distribution. In the latter case, the rainwater which is a result of the rain lasting longer than 15 min, occurring once a year and discharged in stormwater drainage is required to be treated. It should be also taken into account that the amount of rainwater, which have to meet the particular requirements, cannot be lower than the amount caused by the rain of intensity of 77 $dm^3/(s\ ha)$. In other cases, recommendations concerning the content of pollution in stormwater refer to the amount which is a result of the rain of intensity equal at least to 15 $dm^3/(s\ ha)$.

In §19.2 it is stated that in case of rainwater and meltwater which comes from other types of surfaces that mentioned above it is allowed to discharge it without previous treatment. It is the same in case of precipitation characterized by parameters higher than ones defined in the regulation. The exceed of rainwater may be in such case discharged directly to the receiver without verifying its quality and the device intended for treatment of rainwater needs to be protected from the rainwater inflow of intensity higher than nominal flow capacity of such devices (§19.3). This recommendation may be realized by using separators with bypasses.

It should be emphasized that lawmaker limited the number of stormwater quality indicators to two in mentioned regulation. Concentration of other compounds and elements, including chlorides and heavy metals, which have significant impact on the condition of natural environment is not mentioned in the regulation.

Discussed regulation specifies however conditions of wastewater disposal from overflows of rainwater and combined sewage systems. In case of the first system, the lawmaker states that when the number of wastewater disposal from overflows does not exceed 5 in one year it is allowed to discharge it to lakes and their tributaries, other reservoirs in which inflow and outflow of surface water is continuous as well as reservoirs located in watercourses (§19.4). In other part of the regulation the legislator determines maximum number of stormwater disposals from overflows of combined sewage systems. It equals 10 and can be reduced in case when as a result of direct analysis it is proved that the change of water quality precludes its use in accordance with the purpose (§20).

In further part of the document there is information about the procedures used in tests conducted in order to examine whether the rainwater and meltwater quality standards stated in the regulation are fulfilled.

The regulation states also that meltwater and rainwater mixed with other types of sewage can be discharged to the ground only in case of specific location conditions and when there are no other solutions available. In a given situation, concentration of all suspension matter in rainwater before mixing cannot exceed 100 and 15 $mg/dm^3$ of petroleum derived hydrocarbons (§11).

The Regulation of the Minister of Infrastructure of 12 April 2002 on technical specifications that buildings and their location should comply with (Journal of Laws of 2002) defines biologically active area. According to the definition it is the area covered with vegetation as well as surface water located within the plot. 50 % of the sum of flat roofs and terraces of 10 $m^2$ minimum surface, which are constructed as permanent lawns or flower beds on a substrate enabling their natural vegetation can also be called biologically active area. The regulation determines also the requirements when it comes to the share of such type of surface in total plot surface. This share depends mainly on the type of land development.

In case of areas intended for multi-family residential units, healthcare (except for health centers) and education, it equals 25 %. However when there is one building permit for the whole complex of multi-family residential units issued, it is necessary to design areas for playgrounds and recreation 30 % of which should comprise biologically active area (§39, §40.1). In both cases it is obligatory to take into account land development guidelines, which are of primary importance.

In other part of the regulation the lawmaker states that roofs and terraces of buildings as well as niches in their outside walls need to be equipped with installation draining rainwater to the rainwater or combined sewage system. When there are no such systems available rainwater should be discharged in own non-hardened area, to absorption devices or storage reservoirs. It is forbidden to discharge rainwater on other plots. In case, when rainwater is used in household it is necessary to apply an installation intended for this purpose. Such an installation cannot be connected with water supply system.

According to the Regulation of the Minister of Transportation and Maritime Economy of 2 March 1999 on technical conditions that public roads and their location should comply with (Journal of Laws of 1999), devices used for roadway drainage, as well as for discharging rainwater collected this way into the receiver, and their treatment from harmful substances resulting from road use are classified as technical equipment of roads.

Collection and discharging of rainwater from the drained surface can be done using surface and underground devices. In §101.1 of the regulation, the legislator indicates the need for dimensioning of equipment for surface drainage of road lanes in such a way so as to enable effective drainage of rainwater. Sec. 2, in turn, states the probability of rainfall that must be taken for the calculation of drainage systems depending on the class of road. The probability of rainfall $p$, whose value is expressed as a percentage, informs about the minimum number of precipitation occurrences of the given intensity and duration over 100 years. Table 1 shows values for this parameter recommended by the legislator.

Hydraulic calculations of devices for drainage of road lanes should be carried out in accordance with the guidelines contained in the Polish Standard (§101.3). The

Table 1 Values of probability of rainfall $p$ recommended for calculations of road drainage systems in Poland (based on Journal of Laws of 1999)

| Class of road | The probability of rainfall $p$ (%) |
|---|---|
| A—motorways | 10 |
| S—expressways | 10 |
| GP—fast-traffic main roads | 20 |
| G—main roads | 50 |
| Z—local distributor roads | 50 |
| L—local roads | 100 |
| D—access roads | 100 |

regulation does not specify clearly which norms apply to the recommendation, however, the document currently in force in this field, is the standard: Roadways—Roads drainage (PN-S-02204 1999P).

Equipment used for draining and discharge of runoff rainwater from roads includes, among others, road ditches, which, according to the §8.2 (Journal of Laws of 1999) are among the elements that make up the width of the road. The shape of the cross section of a drainage ditch can be designed as streamlined, trapezoidal or triangular (§102.1). It should be taken into account that the use of particular solutions is conditioned by the class of road.

The streamlined ditches are used mainly on highways and expressways. In addition, their use is allowed on fast-traffic main roads, provided that they are situated in a trench (§102.2). It is advisable that the width b of such a ditch is not less than 1.5 m, and its depth h—maximum 20 % its width (§102.3). The standard (PN-S-02204 1999P) indicates that the roadside ditches characterized by a streamlined cross-sectional shape should have a depth h, designated as the distance from the bottom of ditch to the lower edge of the upper ditch, and in the range from 0.3 to 0.5 m. The bottom of the ditch and its upper edges must be constructed as rounded circular curve with a radius equal to appropriately $r_1 = 2.0$ m and $r_2 = 1.0$–2.0 m, while buttresses of device should have adequate declines, as shown in Fig. 1.

To drainage of roads of classes A, S and GP one can also use ditches with a triangular cross-sectional shape. The legislator (Journal of Laws of 1999) recommends that the steepness of the slopes of this element of road infrastructure does not exceed 1:3 on his inner side and 1:5 on outer side. In turn, the depth of the triangular ditch should be adapted to the method of drainage of the corpus of the road (§102.4). At the same time the standard (PN-S-02204 1999P) indicates that the outer escarpment of the triangular ditch should be shaped with a slope in the range of 1:3–1:10, and its depth h, calculated as in the case of the streamlined ditch, should not be less than 0.3 m and greater than 1.5 m. Experience shows, however, that the depth of this ditch generally does not exceed 0.8 m (Edel 2009; Strycharz et al. 2009). The Polish Committee for Standardization (PKN) recommends also that the bottom of the triangular ditch should be done as a rounded circular curve with a radius $r_1 = 0.5$ m (PN-S-02204 1999P). The diagram of a triangular ditch is shown in Fig. 2.

The trapezoidal ditch can be used as a drainage system of roads of any class. In case of highways and national roads its use, however, depends on locating the extreme protective barrier on the crown of the road (§102.6). Additionally, in case of dewatering of the upper part of the corpus of the road by using the drains or a

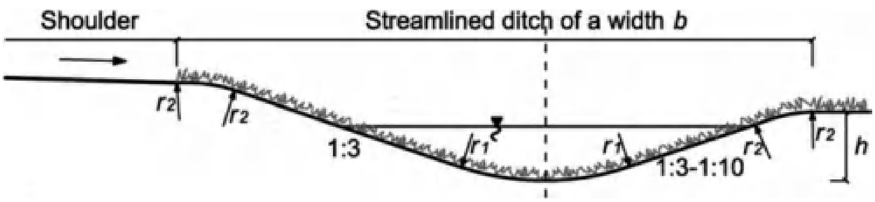


Fig. 1 Scheme of the streamlined ditch (based on Strycharz et al. 2009)

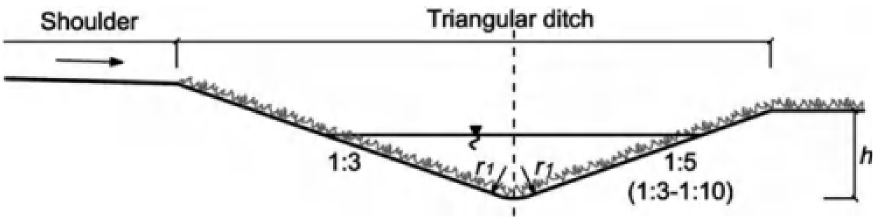


Fig. 2 Scheme of the triangular ditch (based on Strycharz et al. 2009)

filtering layer, the bottom of the trapezoidal ditch must be located at least 0.2 m below the level of the outlet of these devices (§102.5).

The legislature has determined that the minimum width of the bottom of the trapezoidal ditch a should be at 0.4 m, while the minimum depth h is 0.5 m (§102.5). The regulation does not give unequivocally the upper limit of depth of a ditch which has a cross-sectional shape of trapezoid, therefore it is usually assumed on the basis of the guidelines contained in the (PN-S-02204 1999P) as equal to 1.2 m. In the technical literature (Słyś 2013) one can also find recommendations, according to which standard acceptable depth of the trapezoidal ditch refers to the ditches made in soils of impermeable sort. In case of permeable ground it should be reduced to 0.7 m. In contrast to the data recommended by the legislature (Journal of Laws of 1999), in the standard (PN-S-02204 1999P), the minimum depth of the trapezoidal ditch has been defined at 0.3 m. This document also specifies the recommended slope of the ditch scarps, which is 1:1.5-1:3. Cross-section of a trapezoidal ditch is presented in Fig. 3.

In case of the road of the public transport localized below the slopes of the mountain there is a need to protect them against the inflow of rainwater flowing from the area located above them. For the intake and drainage of rain water one can use the ditches on the slope, which are constructed as ditches of trapezoidal cross-sectional shape and inclination of scarps exceeding 1:1.5 (§102.8) (Journal of Laws of 1999). Ditches on the slope also perform a series of additional functions among which one should distinguish, above all, the protection of slopes against the effects of surface erosion, the hydraulic strain relief of roadside ditches, as well as countering landslides and blurring the scarps (Strycharz et al. 2009).

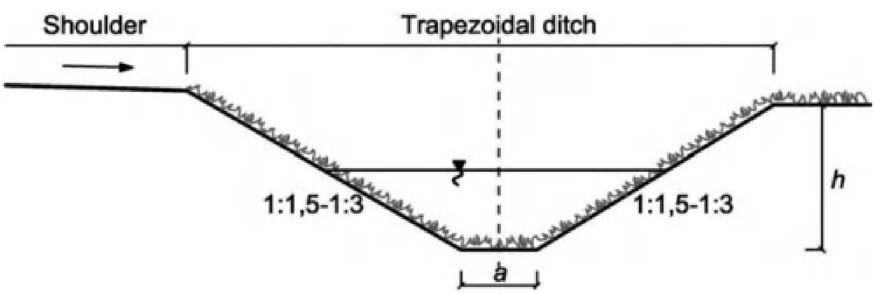


Fig. 3 Scheme of the trapezoidal ditch (based on Strycharz et al. 2009)

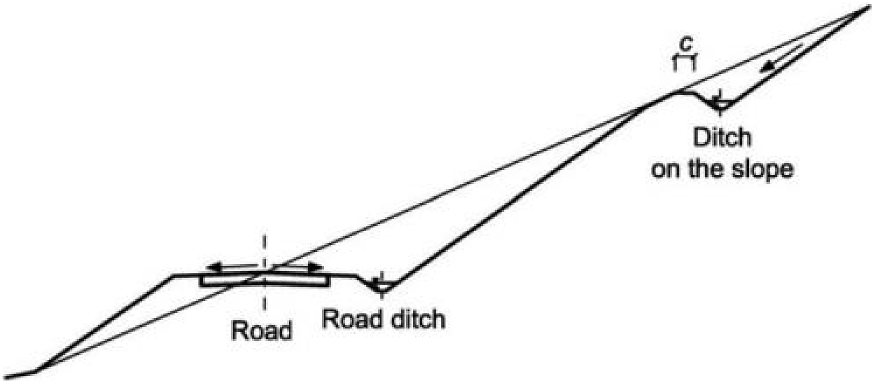


Fig. 4 Scheme of location of the ditch on the slope (based on Strycharz et al. 2009)

Location the ditch on the slope is determined mainly by the minimum required distance from the edge of the escarpment road c, which, in accordance with the regulation (Journal of Laws of 1999) (§102.8) is it 3.0 m. The standard (PN-S-02204 1999P) also states that this distance is sufficient only if the ground is dry and compact. However, when a ditch on the slope is made in other types of ground, the distance should be increased to 5.0 m.

The locations of a ditch on the slope in the scarp located above the road is shown in Fig. 4. In case of the negative impact of the infiltrating rainwater on stability of the scarp, one should design the seal of the bottom of the ditch or move the device away from the escarpment.

The minimum fall of the bottom of a road ditch was defined by the legislature (Journal of Laws of 1999) as equal to 0.5 %. Lesser values of the slope are acceptable only in special cases, which relate mainly to conducting a ditch in flat ground. The fall of the bottom of the device should not, then, be less than 0.2 or 0.1 % depending on water-permeability of the soil in which the ditch has been made. The maximum permissible values of the inclination of the bottom of the ditch were defined in the Polish Standard and equal 1.5–10.0 % if the ditches are not reinforced and 2.0–15.0 % when the bottom and scarps of the device have been reinforced (Journal of Laws of 1999). Value limits of the decline oblong of the bottom of the road ditches are summarized in Tables 2 and 3.

Table 2 Maximum permissible values of the inclination of the bottom of the road ditch with no strengthened scarps and bottom in Poland (based on PN-S-02204 1999P)

| The soil types | The permissible value of the decline oblong of the bottom of the road ditch (%) |
|---|---|
| Sandy soils | 1.5 |
| Dusty soils, sandy-clayey soils, clayey and loamy soils | 2.0 |
| Clayey and loamy soils | 3.0 |
| Rocky soils | 10.0 |

Table 3 Maximum permissible values of the inclination of the bottom of the road ditch with strengthened scarps and bottom in Poland (based on PN-S-02204 1999P)

| The type of reinforcement of bottom and scarps of the ditch | The permissible value of the decline oblong of the bottom of the road ditch (%) |
|---|---|
| Grassy mat | 2.0 |
| Sod | 3.0 |
| Fascine | 4.0 |
| Dry pavement | 6.0 |
| Concrete elements | 10.0 |
| Pavement for ballasted cement–sand with a thickness of min 20 cm | 15.0 |

Another device defined in the regulation (Journal of Laws of 1999) included in the road drainage system is sewer. Sewers are used mainly in places where there is a risk of damaging part of the road by rainwater. Additionally, they can be used also in case of inability to drain the collected water directly to the receiver (§103.1).

Sewers are usually used for draining rainwater from the road elements such as: roadway, cured shoulders and sidewalks, bike paths and separating lanes. In addition, these devices must be designed to drain the edge of the road crown situated in the rocky excavation or at the retaining wall, as well as to strengthen the bottom of a ditch (§103.1).

Depending on the location of a sewer, its usable properties and constructions sewer devices can be divided into flat, also called devices at the kerb, tray and indoor devices (§103.2). The standard (PN-S-02204 1999P) introduces yet another division, according to which these devices are divided into sewers at the curb which are placed on the edge of the road or on the edge of parking spots, surface sewers (gutters) localized within the area of car parks and roadside sewers (moguls) performing the function of roadside ditches. All of the described types of sewer devices may be designed as devices with a triangular or troughs cross-sectional shape. In case of sewers at the curb and surface sewers one should take into account additional need for implementation of non-absorbent material (PN-S-02204 1999P).

In accordance with the regulation (Journal of Laws of 1999) minimal fall of the bottom of sewer should be taken as equal to 0.5 %. The only exception are devices situated in flat land where it is possible to reduce the required drop of the longitudinal bottom of the sewer to 0.2 % (§103.6). In this way the designed device has the task to drain the collected rainwater to the well, where they will be directed to the sewage system or into roadside ditches. In both cases, as an additional intermediary element one should design the house drain which connects sewer to another device (§103.3). Distances between points, from which rain water transported by the sewer is discharged to other devices, are mainly determined by the amount of water. A significant role is also played by the oblong drop of the bottom and fill of the sewer. When they develop the device with a minimum fall in the flat

0.2 % then the maximum allowable distance between the points of discharge of stormwater from the sewer is 50 m (§103.7).

Devices designed for surface drainage areas, as in the case of systems whose function is to bring and drain water from the road surface, should ensure effective drainage of rain water from the dewatered area (§104.1). The regulation (Journal of Laws of 1999) states also that one well cannot be discharged with rainwater flowing from an area exceeding 800 $m^2$ (§104.2), and the minimum slope of the drainage area in the direction of water flow is equal to 4 ‰ (§104.3). In order to meet the above conditions within squares one should form partial basins, within which one should make a sewer conveying runoff water to wells (§104.4).

In a situation where the task of the road drainage system is to drain rainwater from the base of the corpus of the way one should design devices for deep road drainage (§105.1), whose parameters should be chosen on the basis of the properties of the soil and ground water (§105.2).

Devices for deep road drainage are mainly used in situations where there is a need to lower the groundwater level, and if it is necessary to drain water flowing from the road surface to the soil and drain filtering layer (§105.3). In the first of these cases one primarily uses drains which can be arranged in a dividing strip or under the bottom of a ditch or a sewer (§105.4).

Another element defined in the regulation is a rainwater drainage system, the use of which is subject to the inability to drain rainwater using surface equipment or other regulations (§106.1). The legislator points out that a design of this rainwater management method should take into account the location of other underground and surface infrastructure facilities, if they have deep foundations (§106.2). In addition, the legislature states that in case of dual carriageway roads, sewer pipes should be located in a dividing strip. It is also permissible to locate sewer lines in another place, outside the road, however, it must be justified in terms of technology. Where the investment concerns the single carriageway roads, rainwater drainage system can be situated under the sidewalk, shoulder or green belt. In some cases it is also possible to locate it outside the crown of the road (§106.3).

On the local distributor roads, local roads and access roads it is also possible to locate the rainwater channel under the roadway. This solution is also permissible in case of main roads and fast-traffic main roads which are being repaired or rebuilt, but this applies only to those sections of road which are located on the built up area (§106.4).

The regulation states, moreover, that the depth of arrangement of rainwater sewage systems pipes, starting from the ground level to the vault of channel should be greater than the depth of frost penetration of the ground. In a situation where, due to local conditions, this requirement is not possible insulation of the pipes should be applied (§106.5).

The diameters of the sewer pipes should be determined on the basis of the intensity of rainwater flowing to the sewage system and the adopted drop of the channel while maintaining appropriate flow speeds. It should be taken into account that the minimum diameter of the collector is equal to 0.3 m whereas in case of laterals it is possible to use pipes with diameters of 0.15 m. In accordance with the regulation flow speed of the stormwater in a sewer pipe should not be less than 0.5 m/s, while the maximum value is determined on the basis of the material data of the cable. In addition, it is necessary to take into account limit values of the longitudinal inclination of the channels specified by the legislator. In case of cables having a diameter of 0.3 m, the maximum drop of the cable is equal to 3.0 %, and at a diameter of 1.0 m—1.0 %. At intermediate diameters one should use an interpolation (§106.6).

The document (Journal of Laws of 1999) also mentions the need to use inspection chambers. These objects should be used when changing the diameter, drop and direction of conducting conduit, as well as on all ramifications (§106.7). In addition, they should be located in such a way as to be exposed to the vehicle wheels as little as possible (§106.4). Additional guidance on the location of the inspection chamber is described in the Polish Standard (§106.7).

The standard (PN-S-02204 1999P) states that the use of inspection chambers is required mainly because of the need for revision of the technical sewer systems, as well as to allow for cleaning and renovation of channels. In case of non-excavation wires, it is such that the inner diameter does not exceed 800 mm, PKN (PN-S-02204 1999P) recommends that inspection chambers are placed at 50–70 m. In addition, all well connections can be considered as inspection chambers.

Regulation of the Minister of Transportation and Maritime Economy of 2 March 1999 on technical conditions that public roads and their location should comply with (Journal of Laws of 1999), describes the individual solutions for devices whose task is rainwater intake and rainwater drainage from the road. These devices are mainly used in case of occurrence of adverse ground and water conditions, in mountain areas, landslides or mining, as well as in protected areas (§107.1). The legislator recommends using solutions such as: tight cross-section of road crown or ditch which drains surface water, scarps drainage, sewer made of flexible pipes, screens clays, partitions whose function is to reduce the discharge flow velocity of water, as well as a vertical drains and absorbing wells and drainage wells (§107.2).

In accordance with §108.1 of the regulation (Journal of Laws of 1999) stormwater discharged from the roads to the receiver should meet the requirements of their quality.

As a rainwater drainage device one can also use a drainage ditch or collector. In the first of these cases, in order to clean the water, one can design a grassy ditch, often with baffles whose longitudinal bottom slope should be no greater than 0.5 %. In a situation where water from road drainage is discharged into a receiver of water by the collector, one must apply additional rainwater treatment devices (§108.2). Another point of the regulation states that rainwater purification is necessary also when it is not possible to drain the rainwater flowing out of the way with the excluding of this process. Devices which must be designed to protect the environment against pollution flowing down from road, along with guidelines for their use, are shown in Table 4.

Table 4 Statement of devices used to treatment of rain water from the drainage of road in Poland (based on Journal of Laws of 1999)

| Type of device | Guidelines for the use of the device |
|---|---|
| The retention and infiltration reservoir | Used to delay the outflow of water or completely stop it |
| The infiltration reservoir | Used when the filtration velocity at a depth of 1.5 m below the bottom of the reservoir does not fall below 1.25 cm/h; it is also the minimum depth of the position of the ground water level |
| The infiltration ditch | Used when the filtration velocity at a depth of 1.5 m below the bottom of the reservoir does not fall below 0.7 cm/h; it is also the minimum depth of the position of the ground water level |
| The grassy ditch | Used alone or in combination with other purifying devices; the device should be covered with a dense and high mowed grass, and filtration velocity below the unit should not be less than 1.25 cm/h |

The solutions of devices designed to purify rainwater from roads listed in the table should be located at a distance of at least 8 m from the buildings. In addition, these devices should be guaranteed access to efficient technical service (§108.5).

## 4 Conclusions

Regulations concerning rainwater management in Poland are present in a number of legislative acts, regulations and decrees issued by appropriate ministers.

In many cases, implementation of mentioned recommendations enables rational use of natural environment resources, which is in the line with principles of sustainable development.

Some of these regulations are however inexact, especially when it comes to fees for rainwater disposal. It forces the change of applicable law regarding this issue. The modifications should aim at clarification of ambiguous provisions of the law and elimination of jurisdictional conflicts in Polish law.

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