Development and Changes in Characteristics of Infiltration and Retention Facilities for Transport Infrastructure and Paved Area Surface Run-off Treatment

M. Rozkošný*, R. Novotný, D. Beránková
T.G.M. Water Research Institute, p.r.i., Mojmirovo nam. 16, Brno
**Corresponding author: milos_rozkosny@vuv.cz*

M. Kriška
Brno University of Technology, Faculty of Civil Engineering, Žižkova 17, Brno

T. Hudcová
Dekonta, a.s., Dřetovice 109, Stehelčeves

DOI: 10.2478/trans-2014-0015

ABSTRACT: The paper presents the results of water quality monitoring of road and parking surface run-off, which was done in the city of Brno in 2008-2009 and 2013-2014. The main results of the effectiveness of retention and infiltration facility treatment for PAH, petroleum substances, chlorides and selected heavy metals are presented, too. The system of facilities was built for a parking place located in Brno-Bohunice (Masaryk University campus). A retention basin was built near a shopping centre in Brno. The results of analyses and field measurements allow for comparing the evolution and changes of the filtration media characteristics, treatment effectiveness and changes in pollution. The aim of the evaluation is to provide information for the proper maintenance of retention, infiltration and treatment facilities for the surface run-off source of pollution of water bodies.

KEY WORDS: Transport infrastructure, surface run-off, water pollution, water retention, infiltration.

1 INTRODUCTION

The article presents the results of the research aimed at monitoring the retention, treatment and infiltration of surface run-off from transport infrastructure and paved areas (urban roads and car parks) in the Brno city area between the years 2008 and 2014. The conclusions from the analysis of the cleaning effect of selected facilities for the retention of pollutants from the group of PAHs, petroleum substances and metals (Cd, Cr, Cu, Hg, Ni, Pb, Zn) are also presented. The article includes information about the changes in the infiltration characteristics of the monitored infiltration and retention facilities in the period 2008 – 2014. The release of the number of pollutants that can affect the elements of the environment and the human health is caused due to car traffic (Hvited-Jacobson & Yousef, 1991; Sansalone, 1999). The origin of particular pollutants in the surface run-off from roads

DE GRUYTER OPEN

and parking areas is summarized in detail by Lee and Touray (1998) and Bäckström et al. (2004). A part of the harmful substances dissolved in water flows away with the rain water and another part of noxious substances is bound to suspended particles (Norrström & Jacks, 1998). In the period 2005 – 2009 the monitoring of the surface run-off at the control network of the profiles of motorways and expressways was carried out within two subsequent research projects for the Ministry of Transport (Beránková et al., 2008; 2009 & 2010). In the first years the work focused on the quantity and quality of the effluent water. An identification of substances that are present in the effluent water in measurable concentrations was performed, and the tables of characteristic concentrations of the selected PAHs and metals were compiled. Not only were the monitoring and assessment of the occurrence of polycyclic aromatic hydrocarbons and toxic metals in run-off performed but also their toxic effect on the aquatic environment was investigated. In addition, the possibilities of remedial measures were monitored, e.g. their capture in filtration strips during the infiltration. In the period of 2008 - 2009, the selected components of the transport infrastructure – facilities for surface run-off retention and infiltration as a part of one of the mentioned research projects were monitored (Beránková et al., 2010). The results were used as materials for designing new monitoring of built objects and for preparing of design parameters of newly developed objects in the research project TA03030400, which aims to design, implement and by the three-stage pilot plant facility verify a complex treatment technology for stormwater run-off coming from the transport infrastructure and impervious surfaces of the industrial areas. The monitoring was focused on a set of different stormwater management facilities, including retention ponds, sedimentation tanks, infiltration furrows, etc.

The use of the filtration environment of artificially constructed wetlands in combination with a sedimentation area is described, e.g. by Bulc and Sajn Slak (2003). The Directive DWA-A 138 (2005) and the publication Hlavínek et al. (2007) report additional equipment design principles for retention and infiltration of rainwater and surface run-off. The study Aryal et al. (2006) summarizes the results of a longitudinal twenty-year-long monitoring of the cleaning effect of retention and infiltration facilities where the cleaning of surface run-off from roads in the filtration environment of the defined filter cartridge was carried out. The significance of organic matter to enhance the effectiveness of elimination of metals from surface run-off is stated by Aryal et al. (2006) and Seelsaen et al. (2006). The authors identified the best physical-chemical properties for the sorption of metal ions (Cu, Zn, Pb) for compost by the authors. However, the release of higher concentrations of dissolved organic carbon (DOC) was also found at the same time. The combination of sand, compost or even zeolite led to the reduction of DOC leaching and to maintaining the high efficiency of metal retention (75–96% efficiency for zinc; 90–93% efficiency for copper), while in the case of clean sand the efficiency of zinc removal was found out to be 16% and copper removal 29%.

The use of chemical substances for maintenance of roads, car parks and parking areas (for salting) has also an Impact on the change of hydraulic characteristics of filtration environment and mobility of metals. The detailed pieces of information are stated by Novotny et al. (1998) and Bäckström et al. (2004). As a consequence of salting, but also due to the dust run-off, there are changes in granularity, porosity and thus the hydraulic conductivity of the filtration area. Thus, the phenomenon of colmatage (clogging) occurs (Dierkes et al., 2006).

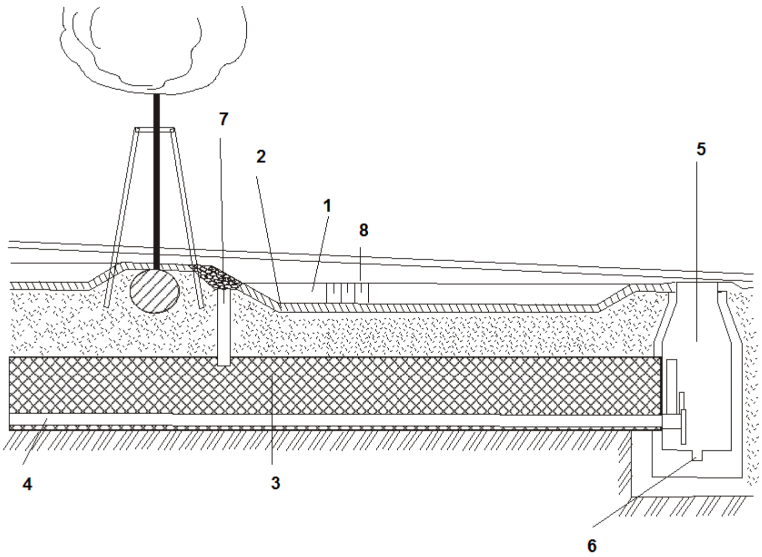
2 METHODS

A car park at the Masaryk University campus in Brno-Bohunice was selected as the first pilot locality of the Brno city area to assess the cleaning effect of the infiltration facilities of polluted stormwater. The car park is drained by the system of the infiltration open ditches (depressed areas) with retention trenches (Figure 1). The system is used for delaying torrential rainfall outflow and for pre-treatment of rainwater fallen in the car park. The more detailed description of the design of the drainage and retention system is introduced in the report of Beránková et al. (2010) and in the project documentation of dJV Project VH (2006). Based on the in-situ reconnaissance, two furrow areas were selected for monitoring. The first furrow is located in the upper, in 2008 and 2009 less used, part of the car park (the profile Bohunice 1). The second furrow is in the lower part of the car park, which was gradually more and more used in connection with the ongoing completion of the campus premises and the shopping centre (the profile Bohunice 2) in 2008. Both parts of the car park were fully used for parking during the period 2013 – 2014. The furrow "Bohunice 1" surface area was 121 m^2 by in-situ measurement and the corresponding area of the car park theoretically drained by this furrow was 592 m^2. The surface area of the other furrow "Bohunice 2 is 195 m^2 and the corresponding area of the car park theoretically drained by this furrow is 1,040 m^2. In the drainage shafts, into which piping drains of the particular furrows flow, collecting sampling containers made of polypropylene were placed, where the seepage water was trapped. Polypropylene sampling containers developed in the T. G. M. Water Research Institute, p.r.i. were put into the top soil. The intensity of collecting mixed water samples for analyses was based on the current weather conditions. The starting period of the car park operation was monitored in 2008 – 2009. The full use of the car park was monitored in 2013 – 2014. In addition the samples of rainwater and snow samples were collected, in order to determine the background levels of the concentrations of the monitored pollutants.

The other monitored facility, located in the city of Brno, is a retention basin intended for trapping, retention and treatment of surface run-off from the paved areas, car parks and roof structures of a shopping centre. The volume capacity is approx. 500 m^3, the depth between 1 and 3 m, drained area approx. 55 000 m^2. The banks and the bottom of the basin are reinforced with concrete perforated panels. The bottom was covered with a layer of sediment during both monitoring periods (0 – 30 cm thick) and a there were few places (approx. area of 0.25 m^2) with macrophyta vegetation (mainly Typha sp.) Samples from the inflow piping and outflow structure were taken, on the basis of the current weather conditions, after rain or snow melting periods.

These physical-chemical indicators of the water quality were measured in-situ in the water samples: water temperature, pH, electrical conductivity. The concentrations of the following water quality parameters: chloride, pollutants from the group of PAHs, petroleum substances (expressed as C_{10}–C_{40}), heavy metals (Cd, Cr, Cu, Hg, Ni, Pb, Zn) were determined with the use of accredited methods in laboratory. The selection of the indicators was based on the research of literature (Hvited-Jacobson & Yousef, 1991; Bayerisches Landesamt für Umwelt, 2008 etc.) and author's own findings from monitoring of surface run-off from highways and expressways (Beránková et al., 2008; Beránková et al., 2009). The assessment of the degree of the contamination of rainfall, snow samples, and samples of surface run-off and seepage water was performed with the use of the classification of water quality according to ČSN 75 7221 (1998) and in accordance with the pollution standards of the Government Regulation No. 23/2011 Coll.

As mentioned in the introductory part of the article, the cleaning effect depends on the composition of the seepage (filtration) layer substrate of infiltration furrows and changes in the hydraulic properties of the material. In addition, the use of chemical substances for maintenance of roads, car parks and parking areas (for salting) has an impact on the change in hydraulic characteristics of the filtration environment and mobility of metals. For this reason, the part of the research also dealt with the determination of characteristics of the filter medium (localization of cross profiles of infiltration furrows, determination of fundamental physical properties of filtration medium and transition filters, determination of the characteristics of dependence of filtration velocity on time, or the intensity of filtration depending on time respectively, determination of hydraulic conductivity, granular composition of the material, etc.) of the monitored furrows, after one year of the operation and in the year 2013. The determination of the intensity of filtration was carried out on the spot with the use of two classic infiltrometers. The infiltration capacity of soil was expressed as the amount of water soaked for a time interval or as the percolation rate of progress over time. The detailed description of the work methodology is given in the report Beránková et al. (2010).



1 – infiltration furrow, 2 – top humus soil, 3 – retention space filled by filtration material (loamy sand and fine gravel), 4 – drain piping, 5 – shaft with outflow control unit, 6 – outflow, 7 - emergency spillway, 8 – retention (up to 0.3 m)

Figure 1: Scheme of Infiltration Furrow.
(Source: JV Projekt VH, s.r.o., 2006; Beránková et al., 2010)

3 RESULTS AND DISCUSSION

In the samples of rainfall there were only very low (background) chloride concentrations in the order of mg/l (as well as in the samples of snow). The concentrations of monitored metals also ranged from I. to II. water quality class. The concentrations of petroleum substances and PAHs were always below the detection limit. The collected values are similar to the ones given for rainwater in the publication Hlavínek et al. (2007).

Snow samples were taken directly at the car park, namely in January 2009 (fresh snow) and in March 2009 (old, dense snow containing the remains of the inert material from gritting). Snow samples were not taken during the winter 2013 – 2014, because of warm winter weather conditions in the city of Brno. Warren and Zimmerman (1994) and Novotny et al. (1998) state that the snow contamination by the monitored pollutants increases with its age (time of deposition on roads and around). This statement was also confirmed by our results. In the samples of fresh snow, the contents of the monitored metals did not exceed values of the I. and the II. water quality class according to ČSN 75 7221 (1998), with the exception of zinc, which in one case exceeded the limit of the III. water quality class. The concentration of petroleum substances, expressed by the indicator C_{10}–C_{40}, was below the value 0.1 mg/l (pollution limit of the Government Regulation No. 23/2011 Coll.).

In contrast, regarding the samples of longer lying snow, the concentrations of petroleum substances (C_{10}–C_{40}) were close to 2 mg/l (i.e. an order of magnitude above the limit value), the concentration of metals reached from III. water quality class (Cd, Ni) to V. water quality class (Cu, Pb, Zn) of water quality. The concentrations of PAHs were similar in all samples (the sum of PAHs 20 to 90 ng/l, i.e. I. water quality class, pollution limit 200 ng/l).

Table 1 shows the range of values of particular indicators of water quality and the pollutants determined in the samples of the surface run-off and seepage water. Dierkes et al. (2006) published long-term concentrations of the following substances in surface run-off from car parks: Cd 1.2 µg/l; Cu 80 µg/l; Pb 137 µg/l; Zn 400 µg/l; PAH 3 500 ng/l. When performing a comparison of these values with the data in the Table 1, the concentrations detected on the surface run-off at the monitored location are lower for the both monitoring periods. The confrontation of furrows outflow concentrations of selected pollutants from the periods 2008 – 2009 and 2013 – 2014 showed that the range of values is practically similar.

Table 1: Range of values of selected pollutants in furrows outflows in periods 2008 – 2009 and 2013 – 2014.

Period of monitoring		2008-09	2013-14	2008-09	2013-14
Furrow		Bohunice 1	Bohunice 1	Bohunice 2	Bohunice 2
pH	–	7.3-8.4	8.2-8.5	6.4-8.7	8.2-8.4
EC	mS/m	36-70	43-76	24-891	58-91
Cl^-	mg/l	2-118	61-81	4-1570	65-241
C10 – C40	mg/l	< 0.02-0.58	< 0.1-0.14	< 0.02-0.23	< 0.1-0.16
Σ PAH	ng/l	< 100	< 100	< 100	< 100
Cd	µg/l	< 0.1-0.57	<0.1	< 0.1-1.04	<0.1
Cr	µg/l	8.7-39.5	5.1-10.6	4.7-24.9	8.1-9.6
Cu	µg/l	2.7-7.5	6.1-25.9	9.7-36.5	2.4-4.8
Hg	µg/l	< 0.05-0.22	< 0.1-0.24	< 0.05-0.74	0.1-0.14
Ni	µg/l	4.9-25.1	< 2-15.3	6.5-23.7	< 2
Pb	µg/l	0.9-4.9	< 0.5-1.4	0.5-6.7	< 0.5-0.6
Zn	µg/l	6-22	19-51	23-92	11-15

(Source: authors, T.G.M. WRI, p.r.i.)

Exceeded pollution standards for chlorides and the V. water quality class in the samples from the period January to May 2009 were associated with the winter maintenance (road salting) in the lower part of the car park where sample containers in the profile Bohunice 2 were placed. The upper part of the car park was only treated with inert material (very low occupancy of parking) in that period. A similar situation was observed during winter 2013 – 2014, but with lower maximum values. The values of electrical conductivity of water (correlation coefficient 0.9917) well correlated with the values of the concentrations of chlorides. Thus, in the three of the mentioned cases the values of electrical conductivity reached V. water quality class, otherwise they were on the levels of I and II. water quality classes.

High efficiency of the elimination (capture) of cadmium, copper, lead, zinc, petroleum products (indicator C_{10}-C_{40}) and pollutants from the group of PAHs was found in the filtration environment of the furrows. With regard to the redox conditions and the degree of saturation of the filter media, the release of metals into the aquatic environment was detected during the monitoring. This fact was recorded in the presence of low concentrations of metals in the surface run-off that corresponded to the I. and II. water quality classes (according to ČSN 75 7221). The similar results, when evaluating the efficiency of cleaning of filtration medium at very low concentrations of metals (mainly Cr, Cu, Pb, Zn), and in particular during the dry period are stated by Shutes et al. (2001). The authors report the capture efficiency of Cu, Cr, Ni and Zn 60 to 90% in the filtration environment of artificial wetlands with higher concentrations. Bulc and Sajn Slak (2003) state the efficiency of retention of the selected metals from surface run-off from roads in the gravel filtration media of artificially constructed wetlands. These long-term average values of efficiency: 69% of suspended solid substances, 97% of settleable substances, 90 or more percent metals (Cd, Cu, Ni, Pb a Zn) were reached on the monitored facilities. The authors also proved the binding of metals to suspended solid substances and they determined sedimentation and filtration as the predominant cleaning mechanisms. There are also results available for the comparison of monitoring of the wastewater treatment plants with the biological phase represented by the soil (ground) and gravel filters. A similar ability of the elimination of the monitored pollutants in the filtration media was confirmed for these devices, also usable for cleaning of the surface run-off (as claimed by e.g. Kadlec and Wallace (2009)). For exmple, Kröpfelová et al. (2009) reports the long-term average values of efficiency of 78% (Zn), 67% (Cu), 63% (Pb), 55% (Cr) and 25–50% for Hg, Cd and Ni (found in the Czech Republic).

The results of the retention basin monitoring are summarized in Table 2. In the both monitoring periods, the concentration of metals and PAH has a similar range of values in the basin outflow. The concentrations of zinc and mercury were out of the I. and II. water quality class ranges. The concentration of chlorides in the water samples was different due to different courses of winters. The basin shows a high elimination of petroleum substances (parameter C10-C40), with one exception of the collected samples. In that sample, the C10-C40 value was two orders of magnitude higher than in the other samples. Based on the course of sampling and further testing, the source of such a high amount of petroleum substances in the sample could be assigned to a surface film of oil after the release of oil from the sediment.

Table 2: Range of values of selected pollutants in retention basin outflow.

Parameter	pH	EC	Cl^-	Cd	Cr	Cu	Hg	Ni	Pb	Zn	Σ PAH	C10-C40
Period	-	mS/m	mg/l	μg/l	μg/l	μg/l	μg/l	μg/l	μg/l	μg/l	ng/l	mg/l
2008-09	7.6	174	372	<0.1	1.6	8.2	<0.1	3.4	<0.5	58	<30	<0.1
	8.2	430	1,280	<0.1	7.3	9.3	0.11	6.7	<0.5	283	<30	<0.1
2013-14	7.0	19	27	<0.1	<1	4.4	<0.1	<2	<0.5	21	<30	<0.1
	8.4	83	396	0.31	8	30.9	0.13	12.5	5	291	0.18	41.1

(Source: authors, T.G.M. WRI, p.r.i.)

The absorption capacity of soil is determined as the amount of water soaked for a time interval or as a course of absorption velocity in time. The absorption ability was therefore investigated on the surface of soil with the use of two concentric cylinders that are slightly recessed directly towards the surface of the infiltration strip of the Campus car park. h was evaluated according to the equations by Kosťjakov, Mezencev and Philip. The relationship between the rate of infiltration v_i on time t_i and the relationship of the cumulative value of the cumulative infiltration i_i on time t_i was determined from the field measurements. The simplest way is to express these dependencies by using empirical equations of Kosťjakov and Mezencev. The evaluation according to Philip is computationally more complicated, the detailed process is stated by Kutílek et al. (2000).

The values found for the two selected furrows representing both parts of the car park were similar (again the average values from the calculation by the three methods) in 2009:

K3 – infiltration rate v_t [mm/min] – beginning of the experiment 4; end of the experiment 3 / cumul. inf. i_t [mm] – beginning 15; end 353
K6 – infiltration rate v_t [mm/min] – beginning 3; end 3 / cumul. inf. i_t [mm] – beginning 15; end 334

During the research two samples were collected twice (from the lower and upper car park) for the determination of hydraulic conductivity of the filter material. The obtained values were compared with the requirements for the design of the infiltration furrows (e.g. Hlavínek et al., 2007; JV Project VH, 2006; DWA-A 138, 2005) when the hydraulic conductivity of materials is recommended in the range of 1.10^{-3} to 1.10^{-6} m/s (60 to 0.06 mm/min), while at values close to 1.10^{-6} m/s (0.06 mm/min) and lower, the infiltration with the accumulation of water (controlled retention) is recommended. Hydraulic conductivity of 1.10^{-5} m/s (0.6 mm/min) was assumed for the monitored facilities. The results of the tests performed with the material of the infiltration furrow from the car park after a one-year operation (in detail Beránková et al., 2010) show that the permeability is adequate only at the beginning of the experiment until the entire material is thoroughly saturated with water. The process of saturation occurs within 4-7 hours. We can assume that in operational conditions, e.g. persistent raining, the saturation of the entire filtration media of infiltration furrows will occur (full water saturation capacity when all pores are filled with water). For these reasons, but also because of the fact that the furrows are not designed to an absolute protection, the design and implementation of similar facilities need to allow the construction of emergency spillways as was done on the monitored furrows. Despite these facts, long-term possibilities of using similar equipment for the retention of and cleaning of surface run-off have been proven abroad, as stated by Aryal et al. (2006), and others.

The following values of infiltration velocity were calculated for both furrows in 2013: Bohunice-1 – 6.6 – 10.8 mm/min based on the existing moisture of filtration medium. Bohunice-2 – 9.6 – 15.6 mm/min based on the existing moisture of filtration medium.

The infiltration capacity of the furrows has still been sufficient for several years of operation, and the values measured in 2013 were similar to the values measured in 2009.

4 CONCLUSION

Our findings show that the surface run-off at the monitored area currently contains less pollution, especially metals. As already mentioned, at the time of the monitoring, the car park was increasingly affected as the other buildings in the area were put into service. The amount of monitored pollutants was higher in the surface run-off in transport infrastructure samples than in the rainwater samples, which presents a certain impact of traffic on the run-off water quality (Bulc & Sajn Slak, 2003; Bayerisches Landesamt für Umwelt, 2008; Beránková et al., 2008; etc.). The contamination of outflows from the monitored retention facilities has been in the same range of values since 2008. The retention facilities has been showing high elimination of monitored pollutants, but as was shown in the case of C10-C40 substances, an appropriate management is necessary (e.g. sediment disposal) to prevent secondary contamination of outflow water. Regarding the facts from longer monitored similar facilities abroad (Bayerisches Landesamt für Umwelt, 2008), it is possible to expect the increase in effects by the assessed pollutants. It has been confirmed that pollutants are bound and accumulated in insoluble substances which leads to their deposition in retention and drainage facilities. The infiltration characteristics of both furrows were similar between 2008 and 2014. In further development of the use of infiltration furrow technology with the retention area with regard to the treatment of water from roads and car parks, it is essential to focus on the issue of their operation and maintenance in winter, when more snow comes. The infiltration furrows will undoubtedly be used to store snow from the car park. It will be necessary to monitor the function of infiltration furrows during melting and to prevent flooding of the car park. It is also vital to pay attention to maintenance of the surface of retention areas and infiltration furrows, so that there are suitable filtration media properties (grain size, hydraulic conductivity and infiltration rate) provided.

ACKNOWLEDGEMENT

The study was supported by the project of the Technology Agency of the Czech Republic TA03030400 “Development of technologies for road and other paved areas stormwater runoff cleaning“.

REFERENCES

Aryal, R. K., Muramaki, M., Furumai, H., Nakajima, F., Jinadasa, H.K.P.K., 2006. Prolonged deposition of heavy metals in infiltration facilities and its possible threat to groundwater contamination. *Wat. Sci. Tech.*, 54 (6-7), pp. 295-212.

Bayerisches Landesamt für Umwelt, 2008. Bodenkundliche Untersuchungen im Rahmen des Entwicklungsvorhabens „Versickerung des Niederschlagwassers von befestigten Verkehrsflächen“ [on-line]. Augsburg: Bayerisches Landesamt für Umwelt, 2008 [cited 2014-09-12]. Retrieved from: http://www.lfu.bayern.de/boden/boden_daten/veroeffentlichungen/index.htm

Bäckström, M., Karlsson, S., Bäckman, L., Folkeson, L., Lind, B., 2004. Mobilisation of heavy metals by deicing salts in a roadside environment. *Wat. Research,* 38, pp. 720-732.

Beránková, D., Brtníková, H., Kupec, J., Huzlík, J., Prax, P., 2008. Pollution of the highways runoff. *Transactions on Transport Sciences*, 1 (2), pp. 31-38. ISSN 1802-971X.

Beránková, D., Brtníková, H., Kupec, J., Mlejnková, H., Huzlík, J., Prax, P., 2009. Parametry jakosti a množství povrchového splachu z dálnic. *VTEI*, příloha *Vodního hospodářství,* 51 (6), pp. 8-11. ISSN 0322-8916. (in Czech)

Beránková, D., Rozkošný, M., Vítek, J., Huzlík, J., Kupec., J., Kriška, M., Šálek, J., Mlejnková, H., Brtníková, H., 2010. *Kontrola jakosti dálničních splachů a hodnocení účinnosti jejich dočišťování při decentralizovaném systému odvodnění* (závěrečná zpráva projektu VaV 1F84C/031/910 za obd. 2008-2009). Brno: VÚV TGM, 72 p. (in Czech)

Bulc, T., Sajn Slak, A., 2003. Performance of constructed wetland for highway runoff treatment. *Wat. Sci. Tech.*, 48 (2), pp. 315-322.

ČSN 75 7221, 1998. Jakost vod - Klasifikace jakosti povrchových vod. (in Czech)

Dierkes, C., Göbel, P., Lohmann, M., Coldewey, W.G., 2006. Development and investigation of a pollution control pit for treatment of stormwater from metal roofs and traffic areas. *Water Science & Technology*, 54 (6-7), pp 291–298.

DWA-A 138, 2005. Planung, Bau und Betrieb von Anlagen zur Versickerung von Niederschlagswasser. Hennef: DWA, Arbeitsblatt - A138, 2005. ISBN 3-937758-66-6.

Hlavínek, P. et al., 2007. *Hospodaření s dešťovými vodami v urbanizovaném území*. Brno: ARDEC. ISBN 80-86020-55-X. (in Czech)

Hvited-Jacobson, T., Yousef, Y. A., 1991. Highway Runoff Quality, Environmental Impacts and Control. In Hamilton, R.S., Harrison, R.M. (eds.). *Highway Pollution*. Amsterdam: Elsevier, pp. 165-208.

JV Projekt VH, s.r.o., 2006. MU v Brně, Univerzitní Kampus Bohunice - AVVA, AVVA - infrastruktura, SO IV-322.2 parkoviště II – odvodnění, SO IV-325.4 parkoviště III - odvodnění, 051 (technická zpráva; arch. č. 05 065, 03/2006). (in Czech)

Kadlec, R.H., Wallace, S., 2009. *Treatment wetlands* (2nd ed.). Boca Raton (USA): CRC Press.

Kröpfelová, L., Vymazal, J., Švehla, J., Štíchová, J., 2009. Removal of trace elements in three horizontal sub-surface flow constructed wetlands in the Czech Republic. *Environmental Pollution*, 157, pp. 1186-1194.

Kutílek, M., Kuráž, V., Císlerová, M., 2000. *Hydropedologie*. Praha: ČVUT. 149 p. (in Czech)

Lee, P. K., Touray, J. C., 1998. Characteristics of a polluted artificial soil located along a motorway and effects of acidification on the leaching behavior of heavy metals (Pb, Zn, Cd). *Wat. Res*., 32 (11), pp. 3425-3435.

Nařízení vlády č. 23/2011 Sb. Praha: MŽP. [Government Regulation No. 23/2011 Coll., Ministry of the Environment of the Czech Republic] (in Czech)

Norrström, A. C., Jacks, G., 1998. Concentration and fractionation of heavy metals in roadside soils receiving de-icing salts. *Sci. Tot. Env.,* 218, pp. 161-174.

Novotny, V. et al., 1998. Cyanide and metal pollution by urban snowmelt: impact of deicing compounds. *Wat. Sci. Tech*., 38 (10), pp. 223-230.

Rozkošný, M., Kriška, M., Hudcová, T., Novotný, R., Beránková, D. Vývoj a změny charakteristik vsakovacích a retenčních objektů pro čištění smyvů z dopravní infrastruktury a zpevněných ploch [The development and changes in the characteristics of the infiltration and retention for transport infrastructure and paved areas surface run-off treatment]. In Jandová, V., Mikulová, I., Ličbinský, R. (eds.). *VI Czech and Slovak Conference "Transport, Health and the Environment"*, Brno (Czech Republic), November 10-11, 2014. Brno: Transport Research Centre, pp. 63-71. ISBN 978-80-86502-85-4. (in Czech)

Sansalone, J. J., 1999. Adsorptive infiltration of metals in urban drainage - media characteristics. *Sci. Tot. Env*., 235, pp. 179-188.

Seelsaen, N., McLaughlan, R., Moore, S., Ball, J. E., Stuetz, R. M., 2006. Pollutant removal efficiency of alternative filtration media in stormwater treatment. *Wat. Sci. Technol*., 54, (6-7), pp. 299-305.

Shutes, R.B.E., Revitt, D.M., Scholes, L.N.L., Forshaw, M., Winter, B., 2001. An experimental constructed wetland system for the treatment of highway runoff in the UK. *Wat. Sci. Tech*., 44 (11-12), pp. 571–578.

Warren, L.A., Zimmermann, P., 1994. The influence of temperature and NaCl on cadmium, copper and zinc partitioning among suspended particulate and dissolved phases in an urban river. *Wat. Res*., 28 (9), pp. 1921-1931.

NOTICE: The article was taken over from the proceedings of VI Czech and Slovak Conference "Transport, Health and the Environment" held on 10 – 11 November 2014 in Brno (Czech Republic), upon the decision of the proceedings publisher Transport Research Centre and with the consent of the authors of the article.

With the consent of the authors, the article was adapted on the basis of editing instructions of Transactions on Transport Sciences journal and translated into English language.