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Stormwater Infiltration Facilities-Philosophy, Design

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Abstract: Present approach to the integrated stormwater control consists in the accumulation and infiltration of rainwater at the place of its origin. For a design of the volume of the rainfall infiltration facility, the coefficient of infiltration is determined by an infiltration test. The design is subject to numerous uncertainties, arising from different conditions in carrying out the infiltration test and in operating a real infiltration facility. In this study the review of the most used facilities for infiltration is presented. An analysis of factors influencing the process of infiltration is carried out,relevant uncertainties influencing the design of the storage volume of the infiltration facility are discussed. The values of correction factors related to individual uncertainties arerecommended.

Key words: Storm water・Infiltration facility・Coefficient of infiltration・Uncertainty

INTRODUCTION

The management with rainwater aturbanized territories is traditionally carried out using a system of urban drainage. This method leads to overdimensioning and temporary overloading of sewers. Moreover this traditional approach leads to significant reducing of natural infiltration of storm water and thus reducing of groundwater(GW) replenishment. This effect is more stressing in arid areas with the lack of natural groundwater resources.

An alternative approach to the integrated control of rainwater prefers the accumulation and infiltration of rainwater at the place of its origin [1, 2]. At the present time, this approach is applied using directives and regulations. In the Czech Republic [CR], the requirements for rainwater infiltration are listed in the Building Code [3] and in the Water Act [4]. In the last decades, guidelines and standards have been developed abroad for the design of infiltration facilities [5-8]. In the Czech Republic, these are the Czech technical standards ÈSN 75 9010 [9] and TNV 75 9011 [10].

The standard ÈSN 75 9010 describes geological and hydrogeological surveys, the result of which is the determination of the coefficient of infiltration. The standard also gives a procedure for designing the volume of infiltration facilities.

The issue of infiltration and flow of water in the unsaturated zone was elaborated in a number of studies which were a basis for compiling relevant software products. The problems of seepagein the saturated and unsaturated zones and their modelling were elaborated for example in the studies [11-13]. For the use of numerical models, it is necessary to obtain the required geological and hydrogeological information about the structure of the groundwater(GW) body, the properties of porous materials in the zone of infiltration, their deposition and the regime of GWat the site. In case of a design for smaller or less important facilities, the extent of the geological survey is usually limited; the use of GW flow models is practically excluded for the reason of a lack of financial resources.

The design for the volume of infiltrated water and an infiltration facility is carried out using variables characterizing the infiltration capacity of soil - the coefficient of infiltration [9], hydraulic conductivity [6] or infiltration rate [5]. The parameters of infiltration are generally determined on the basis of the results of infiltration tests. It is also considered that such determined parameters sufficiently represent the conditions at a site, i.e. the permeability of a groundwater body, the homogeneity and anisotropy of materials, the moisture content of soil, the state of groundwater table and the depth to the impermeable basement. Practical

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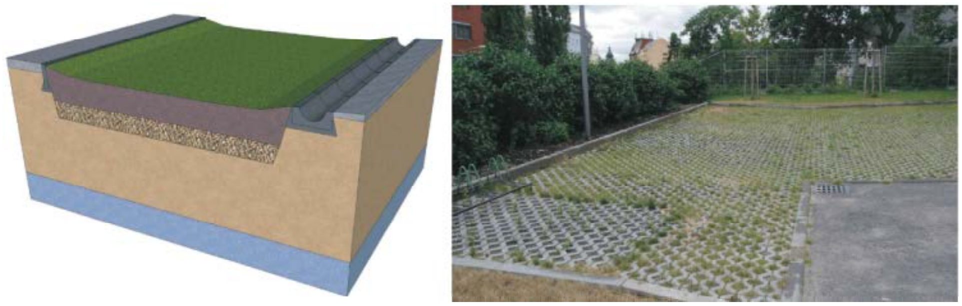

Fig. 1: Surface infiltration –left scheme [14], right Brno University of Technology, CR

Fig. 2: Swale infiltration –left scheme [14], right Kohoutovice, Brno, CR

experience shows that the designed is subject to numerous uncertainties which may lead to the underestimation of the volume of the designed infiltration facility when not taken into account.

In the paper the present approach to storm water management at urban areas is introduced. The design of infiltration facility volume is described, the factors influencing the reliability of the design are discussed together with the uncertainties of the individual parameters entering the calculation.

Types of Infiltration Facilities: Infiltration facilities can be divided based onspatial and structural arrangement:

- Surface infiltration.
- Swale infiltration.
- Swale trench infiltration.
- Shaft infiltration.
- Basin infiltration.
- Underground infiltration blocks.
- Shaft and pipe infiltration trench.

Surface Infiltration: Storm water is supplied to the designated infiltration area. Surfaces of such areas are adapted for infiltration. The surface may be equipped with grass, permeable concrete tiles, permeable soils (e.g. gravel) or combination of mentioned materials (Fig. 1).

Swale Infiltration: This type isused in areas without enough permeable surfaces. The swalehas infiltration function and only limited retention effect. For the swale infiltration shallow terrain depressions with the depth of approximately 0.3 meters with grass surface or another permeable material are used (Fig. 2). Below the sufficiently permeable surface subsoil should be embedded.

Trench Furrow Infiltration: This type of infiltration facility is typically linear(Fig. 3). It combines retention volume and infiltration intothe subsoil. Surface material should be naturally permeable (e.g. grass.) or artificial material.The facility is constructed along roads, sidewalks, railways for both drainage and infiltration.

Infiltration Shaft: Infiltration is local in facilities like wells or shafts (Fig. 4). The facility has permeable bottom and/or the walls. In front of the shaft the device for capturing contaminants must be placed that should also preventcloggingandsub-soil pollution. Groundwater table must be deep enough bellow the bottom of shaft. The shafts are used where there is not enough space for infiltration and if permeable subsoil underlies less permeable soil layer. It can be also used in combination with other infiltration facilities like infiltration pipes.

Fig. 3: Trench furrow infiltrationin Germany [15]

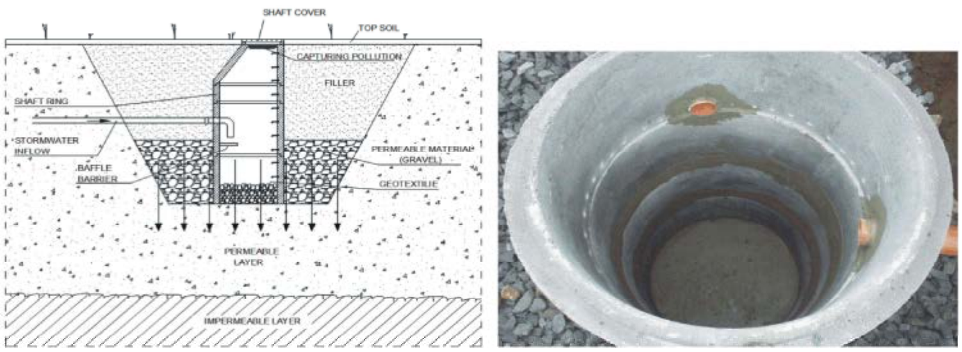

Fig. 4: Infiltration shaft in permeable layer –left scheme, right shaft with permeable bottom [16]

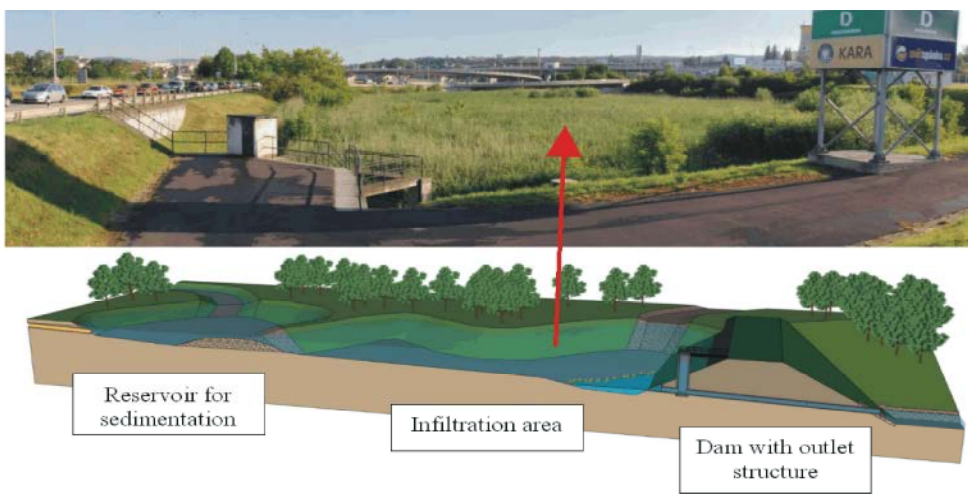

Fig. 5: Infiltration basin with reservoir for sedimentation – Královo pole, Brno, CR [14]

Infiltration Basin: The infiltration basinsserve as accumulation and infiltration devices. These are mostly artificial reservoirs whose bottomsare filled with permeable layers (Figs. 5, 6). Before the infiltration basin sand trap and sedimentation device (e.g. reservoir) should be located for settling of contaminants and fine particles which can cause clogging of permeable reservoir bottom. Another type of basin is reservoir where infiltration is realized in permeable areas along the slopes of the reservoir or at areas around the reservoir (Fig. 6). Such type of basin has only limited retention due to the constant water volume and dominant infiltration function. An inflow of storm water to the basin can be arranged by surface channels or subsurface pipes.

Subsurface Infiltration Blocks: Subsurface infiltration facility (Fig. 7) is made below the land surface as blocks made of permeable materials (gravel, rock) or of plastic

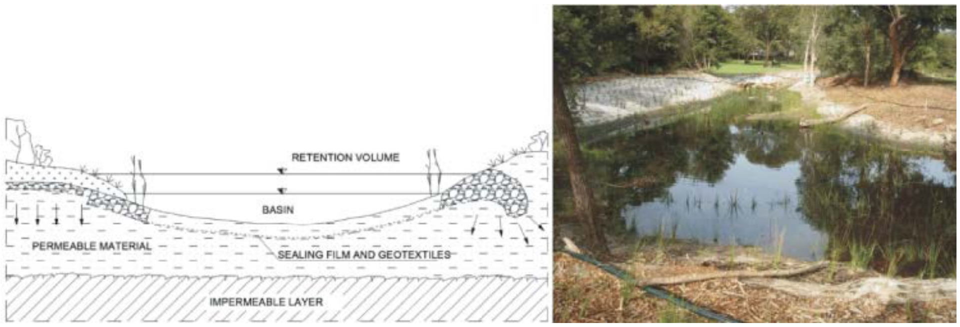

Fig. 6: The basin with permeable slopes [17]

Fig. 7: Underground infiltration blocks – scheme [14],CR [18]

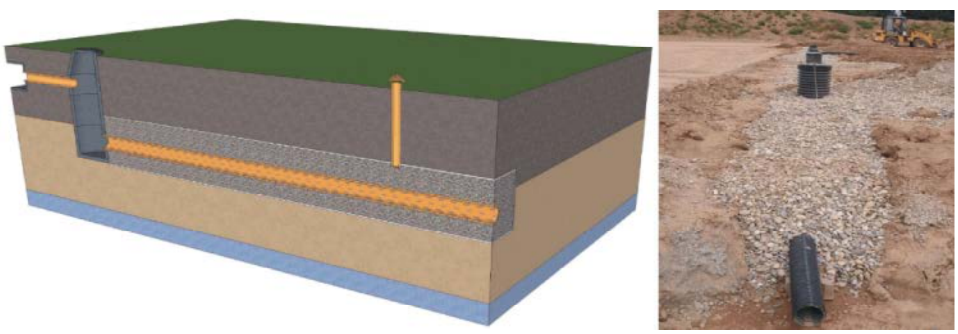

Fig. 8: Pipe infiltration trench [14, 19]

blocks. The latter can be filled with permeable soil, which is flexible for mounting and enable creating blocks of various size and capacity. The shafts for the sedimentation of contaminants and suspended solids are recommended to precede infiltration blocks. The protection of the blocks is assured by placing geotextile.

Shaft and Pipe Infiltration Trench: Storm water is supplied through the shaft which serves for sedimentation. The shaft is connected to the perforated pipe laid in the filter material capable of accumulation (gravel). Storm water from shaft goes to perforated pipe and infiltrate in subsoil (Fig. 8).

Design of the Infiltration Facility Volume

Design of the Facility Volume: The storage volume V_{VZ} of an infiltration facility may be determined asfollows:

$$V_{VZ} \geq \max_{t_c=0,t_{c,\max}} (V_S - V_{IN} \quad (1)$$

where V_S is the volume of precipitation fallen during the time t_c, V_{INF} is the infiltrated volume per time t_c and t_{max} is the maximum duration time of constant intensity design storm. The relation (1) may be rewrittenwith consideration of uncertainties in individual volumes as:

$$f_{VZ} \cdot V_{VZ} \geq \max_{t_c=0,t_{c,\max}} (f_S \cdot V_S - f_{INF} \cdot V_{IN} \quad (2)$$

where f_{VZ} is correction factor for the storage volume of infiltration facility, f_S is correction factor for the volume of precipitation, f_{INF} is correction factor for infiltrated volume. The correction factors express uncertainties related to the determination of individual volumes. Equation (2) may be refined by expressing individual volumes as follows:

$$f_{VZ} \cdot V_{VZ} \geq \max_{t_c=0,t_{c,\max}} \left(f_S \cdot \frac{h_d}{1000} \cdot (A_{red} + A_{VZ}) - f_{INF} \cdot k_v \cdot A_{INF} \cdot t_c \cdot \epsilon\right) \quad (3)$$

where V_{VZ} is the storage volume of the infiltration facility (m^3), h_d is the total design precipitation (mm) with the duration t_c (min) and frequency, A_{red} is the plan view of the drained area (m^2), $A_{VZ}$is the area of the infiltration facility (m^2),k_v is the coefficient of infiltration (m/s),A_{INF} is the infiltration area (m^2).

The coefficient of infiltration $k_v$describesthe ability of a test device to infiltrate water in testing location and is determined by an infiltration test with recommended duration of at least 24 hours. Other requirements for infiltration tests are specified e.g. in [9].The determination of the coefficient $k_v$requires more detailed discussion. The coefficient is determined on the basis of an infiltration test and is defined as follows:

$$k_v = \frac{Q}{A} \quad (4)$$

where Q_{ZK} is the volume of infiltrated water during the trial infiltration test or the inflow of water into atest object and A_{ZK} is the infiltration area in a test object.Practical experience shows that the test duration of 24 hours is seldom achieved; the common duration of infiltration tests is from 6 to 8 hours. In cases of shorter test duration (t< 24 hours) it is recommended to consider uncertainties described below.

Design Of The Infiltration Facility Volume Considering Uncertainties: Coming from Eq. (3) following"principal" uncertainties should be taken into account:

- Uncertainties in the geometry and the volume of storage volume V_{VZ} of an infiltration facility;
- Uncertaintyin theprecipitation water volumeV_S;
- Uncertainty in the volume of infiltrated waterV_{INF}.

Moreover the importance of the facility is usually taken into account by increasing the storage volume of infiltration facility. In the next text above mentioned uncertaintiesare discussed.

Uncertainty In Storage Volume Of The Infiltration Facility: During the construction and operation of the infiltration facility the storage volume may decrease. The reasons can be inaccurate calculation, e.g. in infiltration contour furrows or ponds,imperfect construction or silting.Larger deviations in the storage volume due to inaccurate calculation practically do not appear in technical structures such as rectangular reservoirs, wells or boreholes. A certain error may occur in topographically more complicated areas such as infiltration belts, contour furrows or reservoirs. In case of subsurfacefacilities,it is necessary to subtract the volume of fillings such as plastic elements or a coarse-grained soil fill.

The design volume can also be decreased by imperfect construction or by using different filling material at the site. Storage volume should be decreased according the method of construction and the possibility of technological deficiencies such as bulging of formwork, partial filling of storage volume by the material of the slopes, etc.

A significant reduction of the volume can result from silting. It is necessary to assess the amount of arriving sediment load, the efficiency of a cleaning device in front of the facility and the possibility of the periodical removal of deposits from the device.

In well-designed and periodically maintained objects constructed with high qualitythe correction factorin the volume is usually f_{VZ} = 0.9.

Uncertainty In The Volume Of Storm Water: The volume of storm water is identified according to [20-22] using procedures of the sewer systems hydrology. The corresponding particular uncertainties are connected withdetermining the drained area and determining the runoff coefficients which significantly depend on the history of precipitation and the saturation of the surface by water at the beginning of the rainfall event. Certain inaccuracy is also connected with design precipitation totals or rainfall intensities with given duration provided by hydrological services.

For practical designs the volume of storm water should be increased by 20%(f_s = 1.20) for smaller areas with precipitation-gauge stations and by40% (f_s = 1.40)for larger more rugged areas.

Uncertainty In The Volume Of Infiltrated Water: The most significant uncertainties are related to the determination of the volume of infiltrated water, namely to the determination of coefficient of infiltration. To express theseuncertainties following factorsshould betaken into account:

- The duration time of the infiltration test f_t;
- The position of the impermeable sub-base and instantGW table f_{GW};
- The instantaneous degree of soil saturation f_{DS};

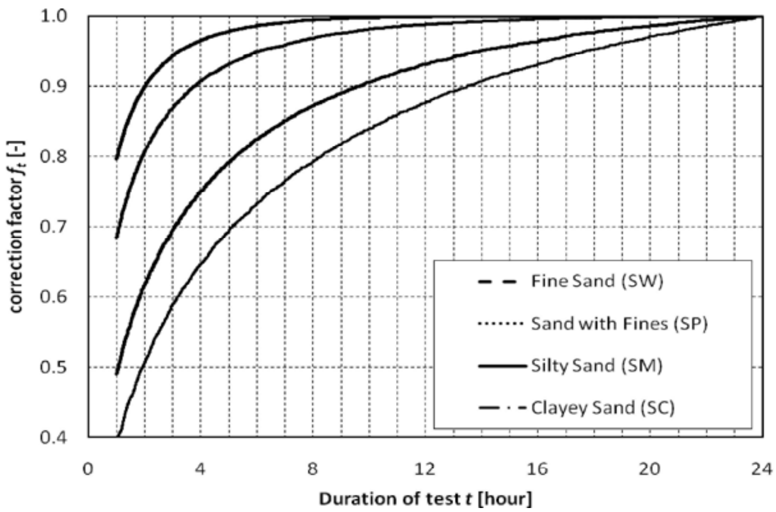

Fig. 9: Dependence of f_t on the duration of infiltration test

- The size and shape of the infiltration facility - infiltration surface f_Z;
- The ageing of the facility (clogging, degradation) f_c;
- the characteristics of the GW body (anisotropy, inhomogeneity) f_a.

Then thecorrection factor f_{INF}can expressed as:

$$f_{INF} = f_t \cdot f_{GW} \cdot f_{DS} \cdot f_Z \cdot f_c \cdot \quad (5)$$

Most of the uncertainties can be quantified by numerical simulations (e.g. by the HYDRUS-2D software [13]) and their comparison with field experiments, laboratory tests.

The Duration Time of The Infiltration Test: The recommended length of the infiltration test is at least 24 hours. Based on numerical simulations [23] the correction factor$f_t$was determined.The value of this factormay be determined for individual soil types using the diagram in Fig. 9 which shows that the corresponding value of k_v decreases with the duration of the test.It can be seen that for less permeable materials the coefficient of infiltration obtained from a shorter infiltration test should be significantly reduced; in opposite at sandy materials sufficient test duration is about 8 hours after which the infiltration becomes almost steady.

The Effect of Impermeable Sub-baseand Groundwater Table Depth: Different depth of the GW table and of the impermeable base below the infiltration facility bed influences the volume of infiltrated water and also the coefficient of infiltration. For different materials and different combinations of the depth of the impermeable base and depth to GW table corresponding correction factorwas numerically determined by [23]. Values of thecorrection factors range from f_{GW} = 0.2 (GW table is close to the bed of infiltration facility) tof_{GW} = 1.0, where GW table doesn't influence the process of infiltration.

The Effect of The Degree of Saturation (Moisture Content) of Soil: Instantaneous initial degree of saturation of soil plays relatively minor role. The uncertainty was quantified numerically in [23] for different materials and initial degree of saturation.The values of corresponding correction factor are close tof_{DS} = 0.85 in cases when the material at the beginning of infiltration is almost saturated, to f_{DS} = 1.0, where the material at the beginning of infiltration is completely dry (dry periods). Partially saturated and dry materials haveonly minor impact during longer infiltration process.

The Effect of The Shape And Size Of The Infiltration Facility: For the infiltration test following devices may be used:

- Trial pit;
- Double ring infiltrometer;
- Single ring infiltrometer;
- Borehole.

The deviations in the shape and dimensions between the designed infiltration facility and equipment for the infiltration test can cause a difference in the velocity and volume of infiltrated water.

Based on [23, 24] the values of the corresponding correction factorrange from f_Z = 0.5 to f_Z = 1.0. The coefficient of infiltration describes the ability of test device to infiltrate water in the testing location. If different device is used for infiltration test, then for design of infiltration facility the correction factor f_Z = 0.5is recommended.

The Effect of Ageing of The Facility: The ageing of the infiltration facility is governed by cloggingof surrounding soil. Its course was studied e.g. by Kovács [25]. His measurements show that clogging takes place especially in the layer about 0.50 m thick beneath the surface of infiltration; permeability decreases with time towards the surface of the infiltration facility, in which hydraulic conductivity can drop by up to several orders of magnitude after about 7 days. The reduction of coefficient of infiltration $k_v$should be determined with regard to the efficiency of water pre-treatment in front of the entrance to the infiltration facility and/or to the possibilities of its regeneration. It is recommended to use correction factorat leastf_c = 0.80in cases of high quality pre-treatment, in case of impossible regeneration and unreliable pre-treatmentf_c = 0.20.

The Effect of Anisotropy And Inhomogeneity: When conducting the infiltration test, it is assumed that the determined coefficient of infiltration already implies the effect of anisotropy of the permeable sub-base. Inhomogeneity could be expected in the form of alternation of more permeable layers with less permeable ones beneath the infiltration facility in different depth beneath the bottom of the infiltration facility. Here the reduction coefficient may vary from f_a = 0.30 in case of significant inhomogeneity, on contrary f_a = 1.0 in case where homogeneous strata is proved by geological survey.

DISCUSSION AND CONCLUSIONS

Actual trend in storm water management is to store and infiltrate precipitation water just at the place of its origin. For this purpose, various infiltration facilities may be used according the land surface and morphology and also in dependence on rain water volume. The analysis shows that practically all variablesentering the design of the volume of infiltration facility are subject to uncertainties arising from the design parameters of the infiltration facility, from the limited reliability of hydrological data and particularly from the limited extent and reliability of geological survey.In the paper the basic mass balance equation is supplemented by “correction factors” whose values are related to the uncertainties entering the design. The correction factors are analogic to the reliability factors used in structural and geotechnical engineering. In engineering practice their value is often determined by expert estimate and judgement. In this context the values of correction factors recommended in the paper may be a useful guidance on the design of an infiltration facility. When properly chosen the probability of underdimensioning the storage volume is significantly reduced. On contrary the designed volume of the facility increase results in raising capital expenditures on the infiltration facility.

REFERENCES

1. Grischek, T., *et al*., 1996. Urban groundwater in Dresden. Hydrogeology J., 4(1): 8-63.
2. Watkins, D.C., 1997. International practice for the disposal of urban runoff using infiltration drainage system. In: Groundwater in The Urban Environment, Vol. 1: Problems, Processes and Management: Proceedings of the XXVII IAH Congress on Groundwater in Urban Environment. Nottingham. Rotterdam: Balkena, 205-210.
3. Building Code, 2006. Act 183/2006 Coll., on town and country planning and building code (as last amended). Available at: http:// www.zakonyprolidi.cz/cs/2006-183.
4. WATER ACT, 2001. Act No. 254/2001 Coll. Water Act and certain acts as amended (as last amended). Available at: http://www.zakonyprolidi.cz/cs/2001-254.
5. Bloomberg, M.R. and C.H. Strickland, 2012. Guidelines for the Design and Construction of Stormwater Management Systems. NY City Department of Environmental Protection and Department of Buildings.
6. DWA 2005. Planning, construction and operation of facilities and infiltration of precipitation water. Arbeitsblat DWA-A 138. Hennef, Deutschland: DWA.
7. DWA 2007. Recommendations for dealing with rainwater. Recommendations for dealing with rainwater. Merkblatt DWA-M 153. Hennef, Deutschland: DWA.
8. PWD. 2014. Stormwater Management Guidance Manual Version 2.1. SMGM 2.1. Philadelphia Water Department. USA, Philadelphia: PWD.

9. ÈSN 75 9010. 2012. Stormwater soakaways. Institut for standardization and testing, Prague.
10. TNV 75 9011. 2013. Sustainable stormwater management. Ministry of Agriculture in Czech Republic, Prague
11. Bear, J. and A. Verujiit, 1992. Modeling Groundwater Flow and Pollution. Holland: D. Reidel Publishing Comp.
12. Lu, N. and W.J. Likos, 2004. Unsaturated Soil Mechanics. New Jersey: John Wiley & Sons.
13. Šejna, M. and J. Šimùnek, 2007. HYDRUS (2D/3D): Graphical User Interface for the HYDRUS Software Package Simulating Two- and Three-Dimensional Movement of Water, Heat and Multiple Solutes in Variably-Saturated Media. (Online). Prague. Available at: http://www.pc-progress.com.
14. M_P 2014. Nature friendly management of storm water in urban areas. Ministry of Environment in Czech Republic. Prague.
15. BLU, 2011. Stormwater – Desig of roads and area. The Bavarian State Office for the Environment
16. www.domovni-pripojky.eu
17. www.wsud.org
18. voda.tzb-info.cz
19. www.glynwed.cz
20. Bareš, V., I. Kabelková and D. Stránský, 2013. TNV 75 9011 Precipitation water management, Part 3: Dimensioning of Objects and Facilities. Water management, 11/2013: 383-386.
21. Peters, R.W., 2012. Hydrology and floodplain analysis, 5th edition. Environ. Prog. Sustainable Energy, 31: 332-334. doi:10.1002/ep.11677.
22. USDA. 1986. Urban Hydrology for Small Watersheds. TR-55. United States Department of Agriculture.
23. Duchan, D. and J. Říha, 2015. Considering Uncertainties in Design of Stormwater Infiltration Facility. In 14th International Symposium Water Management and Hydraulic Engineering 2015 (WMHE). Brno, CZ: Litera Brno. s. 356-378. ISBN: 978-80-214-5230- 5. ISSN: 2410- 5910.
24. Dušek, J., M. Dohnal and T. Vogel, 2009. Numerical Analysis of Ponded Infiltration Experiment under Different Experimental Conditions. Soil & Water Res., 4(Special Issue 2): 22-27.
25. Kovács, G., 1981. Seepage hydraulics. Budapest: Akadémiai Kiadó.
00. ÈSN 730002, 2004. Eurocode: Principles for Structural Design. ÈSN EN 1990 (73 0002). Institute for standardization and testing, Prague.