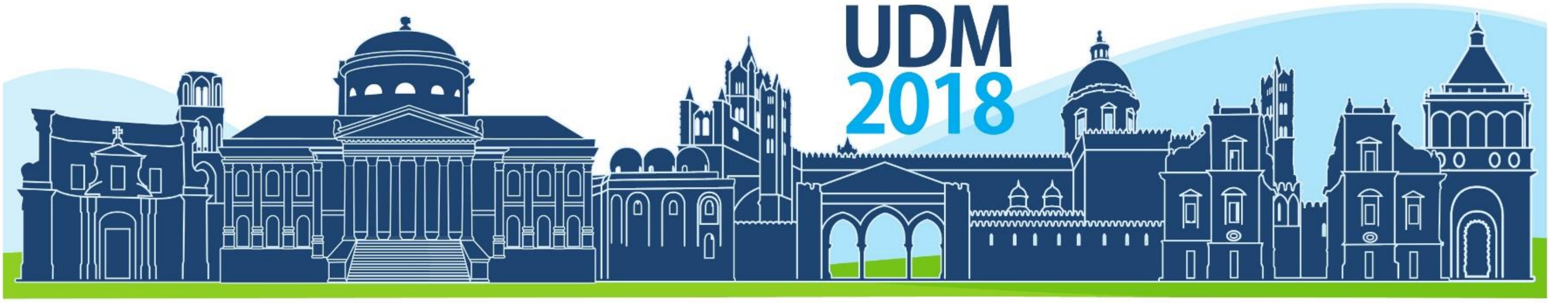

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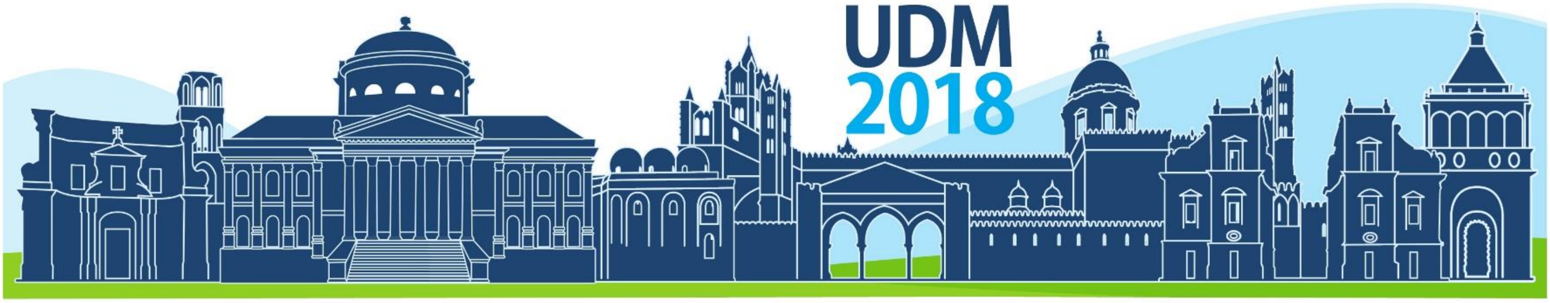

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Long term efficiency analysis of infiltration trenches subjected to clogging

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Abstract: In recent years, limitations linked to traditional urban drainage schemes have been pointed out and new approaches were developed introducing more natural methods for retaining and/or disposing of stormwater. Such practices include infiltration and storage tanks in order to reduce the peak flow and retain part of the polluting components. The impact of such practices on stormwater quantity and quality is not easily assessable because of the complexity of physical and chemical processes involved. In such cases, integrated urban drainage models may play a relevant role providing tools for long term analysis. In this study, the effect of the clogging phenomenon has been assessed by means of a simplified conceptual modelling approach developed in previous studies has been employed and different soils as well as different design criteria have been considered. On the basis of a long-term simulation of 6 years rain data, the performance as well as the effectiveness of an infiltration trench measure are assessed. The study confirmed the important role played by the clogging phenomenon on such infiltration structures.

Keywords: Best Management Practices, water quality, drainage system, infiltration, integrated urban drainage management

1. INTRODUCTION

The introduction of EU Water Framework Directive 60/2000 pushed the application of new sustainable technologies for disposing of stormwater like distributed infiltration structures and local storage (Chave, 2001). Such techniques are often considered as more 'natural' measures for managing stormwater in urban areas because they mainly try to revert the impact of urbanisation on the natural water cycle. Small infiltration and storage structures are often used to achieve control of stormwater quality and quantity in small catchment such as a parking lot or residential areas (Guo, 1998; Freni et al., 2004). Guo (1998) considered trench infiltration basins to be used as a means of storm water control and presented analytical expressions based on two-dimensional flow. However, in his study, it seems that the physics of flow is inadequately described. Youngs et al. (1996) investigated the unsteady groundwater paths below an irrigation ditch using a hydraulic sand tank model and Hele-Shaw analogue. Finite difference or finite element methods have not been used extensively for solution of these types of problems, due to the difficulty arising from the dynamic position of the water table and the need to solve the problem iteratively for the entire solution domain; at the opposite, simplified methods based on one-dimensional approximation of the infiltration process are preferred for their simple and inexpensive application (Demetracopoulos and Hadjitheodorou, 1996). Apart their easiness of use, simplified models may be constrained to highly restrictive hypotheses leading to excessive safety factors when used for design or unreliable results when used for efficiency analysis. The considerations discussed above suggest the improvement of infiltration structure mathematical models following two directions: the improvement of processes interpretation obtaining more detailed models for the single structure and the integration of such models in urban drainage integrated ones, i.e. models analysing the sewer system, the wastewater treatment plant and the receiving water body as a whole (Rauch et al, 2002; Mannina et al., 2018). The latter approach took the development of simplified conceptual models characterised by low computational requirements and able to be replicated several time in the integrated approach in order to simulate a large number of stormwater management facilities spread over the catchment. Two main assumptions are usually adopted in such models: a constant infiltration rate, assuming saturated soil conditions (Schlüter et al., 2007); dynamic infiltration rates assuming that they depend on soil saturation (Barraud et al., 2002; Browne et al., 2008). Another process that affects infiltration over time is clogging. Clogging is due to the presence of sediments in the runoff entering in the infiltration structure; sediments accumulate in the pores of the filler material or along the bottom and the sides of the infiltration structure and therefore reduce its infiltration capacity and its effective storage volume. A number of studies indicate that the performance of infiltration systems will decrease with time due to clogging effects from fine particles that enter the system via the stormwater inflow (see for instance Revitt et al., 2003). Due to the clogging a reduction of the infiltration rate occurs and this leads to more overflows from the trenches to the sewer system and prevents the system from functioning as intended (Bergman et al., 2010). The present study is aimed at studying the effect of soil type on the clogging phenomenon on infiltration structure by means of long term analysis. The study was carried out by long term simulations of different trench specific volumes and different soil types, trying to track both the effective structure volume and its infiltration capacity. The analysis has been performed considering hypothetical trenches located in the experimental catchment of Parco d’Orlèans (Palermo, Italy).

2. MATERIALS AND METHODS

2.1 The proposed model

In the present study, in order to simulate the dynamic processes of an infiltration trench, a previously developed model was employed (Freni et al., 2009). Specifically, the model is characterised by one input from the urban drainage model (simulating the runoff produced on the catchment) and by two outputs: the overflows to the drainage system simulated by a weir function and the infiltration discharge to the soil simulated by a non-linear function. A_{eff} is defined in the model as “effective infiltration area”, i.e. the horizontal area below the structure bottom where the infiltration paths start to be vertical parallel. In synthesis, A_{eff} becomes the fundamental model parameter to be calibrated both when the infiltration structure is clean and when clogging takes part. Freni et al. (2009) proposed two correlation relationships to link A_{eff} to the infiltration structure bottom area $A_{eff,0}$ and to the sediment level h_{sed}. The clogging processes is simulated by the mass balance for suspended solids at rainfall event scale. The height of sediments h_{sed} is computed by dividing the intercepted mass by sediment bulk density, infiltration structure void ratio and bottom area. The computation is made assuming that the distribution of sediments in the infiltration structure is uniform and that the solid accumulation on the walls of the structure may be negligible. The model takes into account the particle size of the sediments that can be accumulated and washed off over the catchment (Chebbo et al., 1990; Deletic et al., 1997). In the present study, two particle classes (equally proportioned in mass) are adopted in order to properly simulate different types of sediment transport: the fine ones (d_{50} = 50 μm, bulk density equal to 1600 kg/m^3) are transported as suspended load while the coarse ones (d_{50} = 500 μm, bulk density equal to 2000 kg/m^3) are mainly transported as bed load. More details about the model may be found in Mannina and Viviani (2010). The following infiltration structure characteristics were considered in the present study: trench specific volume equal to 20 m^3 per hectare of connected impervious area; filling material void ratio equal to 0.5, trench cross-sectional area equal to 2 m X 2 m; trench length was computed accordingly to the connected impervious area and to the design specific volume. The effect of infiltration facilities and the impact of clogging was analysed at rainfall event scale by computing two efficiency criteria: the stormwater volume reduction efficiency and the solid mass interception efficiency η_{TSS}, were estimated as in the following:

$$\eta_Q = \frac{V_{in} - V_{out}}{V_{in}} \qquad \eta_{TSS} = \frac{M_{sed,in} - M_{sed,out}}{M_{sed,in}} \tag{1,2}$$

where V_{in} is the input water volume from the catchment, V_{out} is the output water volume to the sewer, $M_{sed,in}$ and $M_{sed,out}$ represent, respectively, the mass inflow from the catchment and mass outflow by the weir to the sewer (the mass outflow by infiltration is considered null). The continuous simulations were run for four different soil classes, reported in table 1, and two commonly adopted design specific volumes: (20 and 40 m^3/ha_{imp}).

Table 1. Soil characteristics and parameters.

		TYPE OF SOIL				
	PARAMETER	Sandy-Loam	Loamy-Sand	Sand	Gravel	Unit
Soil characteristics	q_s	0.45	0.43	0.44	0.55	-
	q_0	0.05	0.04	0.02	0.01	-
	ψ	0.11	0.10	0.09	0.08	m
	k_s	2.18	6.12	23.41	36	cm/h

2.2 The case study

In order to evaluate the long term infiltration structure efficiency, an application has been carried out in the experimental catchment Parco d’Orlèans (Palermo – Italy). The Parco d’Orlèans experimental urban catchment is located in the University Campus. Its total drainage surface is 12.8 ha with 68% of impervious area, and the drainage system is separated and the stormwater system is made of concrete circular and egg-shaped pipes. Rainfall data have been collected since 1994 with a tipping bucket raingauge and data logger at maximum time resolution of 1 second. Discharge data have been collected since the same year with an ultrasonic flow meter installed at the basin outlet. A 6-year long continuous rainfall series was extracted by this database and used for the simulations. Starting from the database outlined above, a long term simulation has been carried out considering different soil types in order to assess their effect on the clogging phenomena. Further, the effect of the infiltration trench dimension has been quantified as well.

3. RESULTS

The current analysis was based on long term simulations carried out by means of a calibrated mathematical model. Different soil types were considered in order to obtain the different infiltration trench behaviour that may be expected for the analysed catchment. Different values of specific volume for the hypothetic trench were considered in order to assess the impact of design criteria on the infiltration structure efficiency both in the short term (when the structure is new and clean) and in the long term (after some years of operations and developing clogging). Infiltration structure efficiency dependency on its specific volume and type of soil is showed in Figure 1 and Figure 2 for an example structure having effective volume equal to 20 m^3/ha_{imp}. In the figures, storm events are not presented in their chronological order but in descending order according to the obtained efficiency. Each point in the graphs represents the storm events showing efficiencies higher than the one presented by each curve (either in terms of number of events or in terms of cumulated volume or in terms of cumulated TSS mass). In details, figure 1 shows efficiencies regarding the runoff volume versus the number of rainfall events (figure 1a) and the overall rainfall volume for the entire simulated period (figure 1b). Figure 2 shows the same graphs regarding suspended solids interception efficiency.

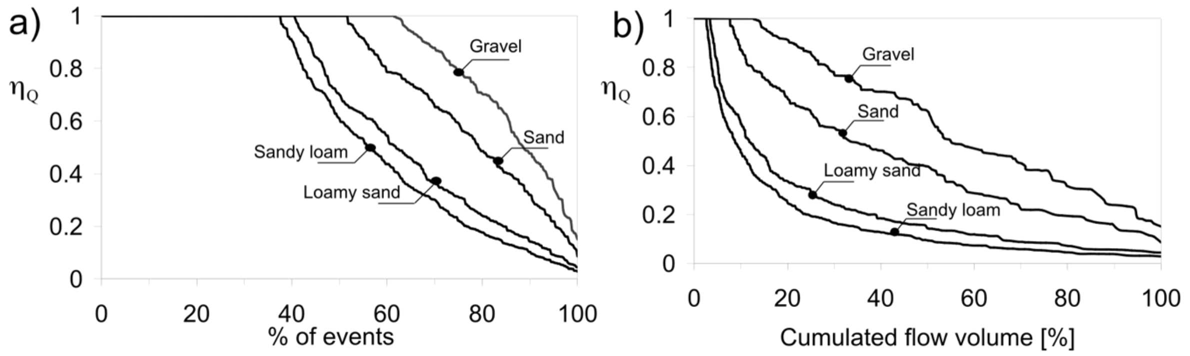

Figure 1. Infiltration structure water efficiency in terms (a) of number of rainfall events and (b) in terms of cumulated flow volume, for a design specific volume of 20 m^3/ha.

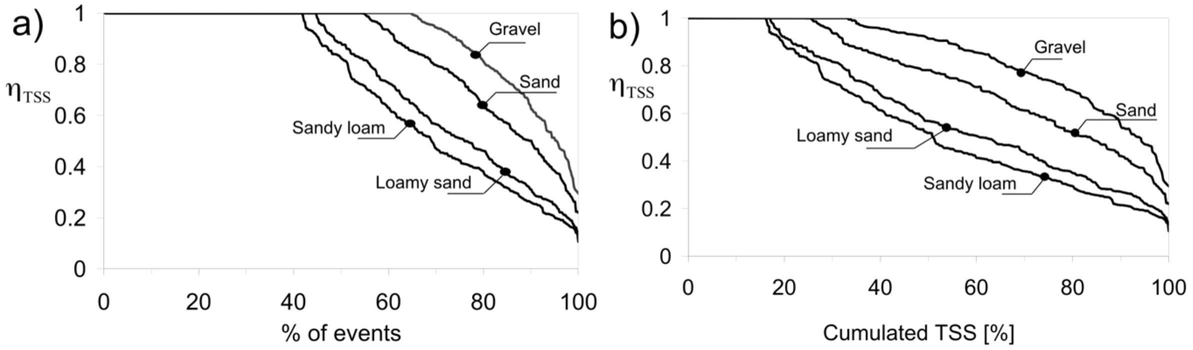

Figure 2. Infiltration structure TSS efficiency in terms (a) of number of rainfall events and (b) in terms of cumulated TSS for a design specific volume of 20 m^3/ha.

The results allow for some interesting considerations:

- figure 1 confirms that, in Mediterranean climate characterised by short and intense rainfall events, infiltration facilities can totally intercept only a small percentage of the total rainfall events (less then 40% in sandy loam soils) corresponding to an even smaller percentage of rainfall volume (less than 5% of the total runoff volume);

- runoff reduction efficiency decreases rapidly considering longer and more intense events (right side of the graphs in figure 1) highlighting that infiltration measures have marginal efficiency in peak flow control. Average runoff volume reduction in the analyzed period is lower than 20% for sandy-loam and loamy-sand, lower than 45% for sand and around 60% for gravel;
- TSS mass reduction efficiency is much higher showing that this kind of structure is suitable to stormwater quality mitigation. The lower design specific volume considered allows for average event mitigation efficiencies in terms of overall sediment mass between 40% and 80% depending on the soil type.

4. CONCLUSIONS

A simplified infiltration trench model was applied in order to evaluate the long term efficiency of infiltration trenches in different soil conditions and considering two different design criteria. The results showed that the infiltration devices are more effective for the quality than for the quantity control. Runoff reduction efficiency decreases rapidly considering longer and more intense events highlighting that infiltration measures have marginal efficiency in peak flow control. TSS mass reduction efficiency is much higher showing that this kind of structure is suitable to stormwater quality mitigation. The efficiencies rise when considering higher specific design volumes but the amount of events that are totally intercepted remains low because of the climatic characteristics of the area. The effect of climate is also displayed by the short difference between the two considered infiltration device specific volumes confirming that, in the Mediterranean area, large volume increments are needed for slightly increasing mitigation efficiencies: even in the most favourable soil conditions, the structure having 40 m3/haimp generated overflows in almost the 20% of the simulated events meaning by this a spill frequency of 9-10 events per year. Infiltration structures maintain a good performance for a short period after their installation because of the clogging phenomena and the absence of any pre-treatment structure. The performed analysis suggests to generally over-design the structure volume in order to allocate space for the collected sediments and in order to avoid the rapid reduction of structure performance in time. At the same time, the Mediterranean characteristics of adopted rainfall data showed that infiltration device efficiency is lower than the results presented in literature.

References

Barraud, S., Gibert, J., Winiarski, T., and Bertrand Krajewski, J. L. (2002). “Impact of a storm infiltration drainage system on soil and groundwater—Presentation of the OTHU project.” Water Sci. Technol., 45(3), 203–210.

Browne, D., Deletic A., Mudd G. M., Fletcher T. D. (2008). A new saturated/unsaturated model for stormwater infiltration systems. Hydrological Processes, 22, 4838-4849.

Chave, P. (2001). “The EU Water Framework Directive: an introduction.” IWA Publishing, London.

Chebbo, G., Musquere, P., Bachoc, A. (1990). “Solids transferred into sewers.” Proc., 5th Int. Conf. on Urban Storm Drainage, 23.-27.7.1990 Osaka (Japan), 325 - 332

Deletic, A., Maksimovic, C., Ivetic, M., (1997). “Modelling of storm wash-off of suspended solids from impervious surfaces.” J. Hydr. Res., 35(1), 99-118.

Demetracopoulos, A. C., and Hadjitheodorou, C. (1996). Seepage from surface canals by boundary element method. J. Irrig. Drain. Eng., 122(1), 40–48.

Duchene, M., McBean, E.A. and Thomson N.R. (1994) “Modelling of Infiltration from Trenches for Storm-Water Control” J. Water Resour. Plng. and Mgmt. 120(3), 276-293.

Freni, G., Oliveri, E., Viviani, G. (2004). “Infiltration facilities design: comparison between simplified approaches and detailed physically based modelling” 5th International Conference on sustainable techniques and strategies in urban water management – NOVATECH. Michel Desbordes et Bernard Chocat, Editors, 6-10 June 2004, Lyon France, Vol II, 1105-1112.

Freni G., Mannina G. Viviani G. (2009). Stormwater infiltration trenches: a conceptual modelling approach. Water Science and Technology, vol. 60 (1) pp. 185-199.

Green, W. H., and Ampt, G. A. (1911). ‘‘Studies on soil physics. I. The flow of air and water through soil.’’ J. Agric. Sci., 9, 1–24.

Guo, J. C. Y. (1998). Surface-Subsurface Model for Trench Infiltration Basins.Journal of Water Resources Planning and Management, 124(5), 280-284.

Mannina and Viviani (2010). An urban drainage stormwater quality model: model development and uncertainty quantification. Journal of Hydrology, Vol 381(3-4), 248-265.

Mannina, G., Butler, D., Benedetti, L., Deletic, A., Fowdar, H., Fu, G., Kleidorfer, McCarthy, D., Mikkelsen, P.S., Rauch, Sweetapple C., Vezzaro, L., Yuan, Z., Willems, P. 2018. Greenhouse gas emissions from integrated urban drainage systems: Where do we stand?, Journal of Hydrology, Volume 559, Pages 307-314.

Rauch W., Bertrand-Krajewski J. L., Krebs P., Mark O., Schilling, W., Schutze, M., Vanrolleghem, P. A. (2002). Deterministic modelling of integrated urban drainage system. Wat. Sci. Tech., 45,(3), 81-93.

Revitt, M., Ellis, B. and Scholes, L., (2003). Report 5.1 Review of the use of stormwater BMPs in Europe. Project under EU RTD 5th Framework Programme. WP5 / T5.1 / D5.1. Middlesex University.

Schlüter, W., Jefferies, C. and Zhang, X. X. (2007). Modelling of flow through gravel-filled trenches,Urban Water Journal,4:4,241 — 251.

Youngs, E. G., Spoor, G., and Goodall, G. R. (1996). Infiltration from surface ponds into soils overlying a very permeable substratum. J. Hydrol., 186, 327–334.