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Representation of infiltration and exfiltration processes in two types of infiltration drainage devices using the SWMM model

Utilisation du modèle SWMM pour représenter les mécanismes d'infiltration et d'exfiltration par temps de pluie dans deux cas de tranchées drainantes

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RESUME

Dans cet article, les auteurs suggèrent des modifications pour un algorithme mathématique simplifié disponible dans la littérature pour représenter le comportement de tranchées d'infiltration qui utilisent le modèle SWMM 5.0 ©. La méthodologie a été appliquée à des données qui correspondent à deux tranchées de la ville de Porto Alegre, au Brésil, et à trois tranchées de la ville de Montréal, au Canada. L'algorithme suggéré a démontré une bonne capacité de représentation des caractéristiques générales de tranchées de régulation totale et partielle dans les régions urbaines. Ce travail a représenté une étape initiale dans l'analyse de la simulation mathématique de ce type d'appareils. Pour atteindre un plus grand niveau de confiance, il est nécessaire d'avoir des données qui correspondent à un plus grand nombre d'événements.

ABSTRACT

In this paper the authors suggest modifications to a simplified mathematical algorithm available in the literature to represent the process of infiltration trenches using the model SWMM 5.0 ©. The methodology was applied to the data of two trenches of the city of Porto Alegre, Brazil, and three trenches in the city of Montreal, Canada. The suggested algorithm demonstrated a good capacity to represent the general characteristics of trenches of total and partial regulation in urban areas. This work represented an initial stage in the analysis of the mathematical simulation of this type of devices. To reach a higher degree of trust it is necessary to have data corresponding to a larger number of events.

KEYWORDS

Drainage control, infiltration devices, infiltration/ exfiltration modelling, SWMM model

1 INTRODUCTION

Latin America is characterized by an important number of big cities, most of them in quick growth, where the management of urban drainage shows an important backward state in relation to the developed countries. The current panorama is reflected by the exclusive validity of the traditional hygienist concept, the lack of hydrological data and the neglect to the problems of the quality of drained water. In spite of this, in the last years some actions that have to do with more modern concepts of drainage are observed. An example of this is the analysis of the behavior of control devices for the pluvial glide, as the retention and/or infiltration device.

In this paper, the authors show the tasks carried out with the purpose of simulating, by means of a mathematical model, the hydrological behavior of infiltration trenches dedicated to the control of the glide in urban areas. Information coming from two infiltration trenches developed by the Institute of Hydraulic Investigations (IPH) of Porto Alegre, Brazil, and a trench developed in the city of Montreal, Canada was used. The model used was the SWMM 5.0 ©, of free distribution. The study is framed within a project that begun in the Metropolitan Area of San Salvador (AMSS), El Salvador, for the study and implementation of these kind of devices. In this area, natural conditions of the volcanic soil are good for the infiltration process. The lack of hydrological data supported the making of the adjustment tests and verification of the behavior of the mathematical pattern based on available information of the above mentioned cities.

2 ASPECTS ASSOCIATED TO DEVICES OF INFILTRATION

The infiltration systems have been used in different cities of the world. Urbonas and Stahre (1993) presented the advantages and disadvantages of this type of devices. Among the first ones, they highlighted the generation of recharge conditions near to the natural conditions, the reduction of the contamination transported toward the rivers, the reduction of the maximum flows and the reduction of the occupation in surface in relation to another devices. Among the disadvantages, they mentioned that some soils could become waterproof with the time and the reduction of their infiltration capacity if in the drainage here are fine materials.

Blaszczyk et al. (1992) summarized the investigation and development studies that were carried out in Poland during the period 1986-1991, including a review of the design principles for systems of infiltration of pluvial surpluses in urban areas. Watanabe (1995) presented two infiltration systems used in the city of Yokohama (Japan) that reduced the peaks of the drainage system between 15 and 20%. Nowakowska-Blaszczyk et al. (1995) present the design of two different infiltration systems for two urban neighborhoods in the city of Warsaw (Poland). Warnaars et al. (1998) explained their experiences in two infiltration trenches located in an area of high density construction in Copenhagen (Denmark), which produced good results. Goldenfum et al. (2001) analyzed an experimental system of infiltration trenches, installed in Porto Alegre (Brazil), which has been checked since 1999. Matuzic et al. (2001) presented the results of investigations carried out in 14 infiltration devices in the peninsula Woy Woy (Australia), on sandy soils. Barnaud et al. (2004) characterized the infiltration soil associated to devices of infiltration of urban drainage in 4 experimental basins in the vicinity of the city of Lyons, France.

The operational time life of infiltration devices, depends on the reduction of the infiltration capacity throughout time. This process is associated to the fill effect. Observing some devices in Japan, Hasegawa et al. (1999), found out that the infiltration capacity decreases with time in an exponential way. Throughout 10 years of observation, the infiltration conduits had a reduction in the capacity of infiltration of

20%, the trenches of infiltration of 50% and the pavements of porous asphalt had a reduction of 15% in 3 years. However, according to the authors, the initial capacity of the infiltration conduits can be reestablished by means of maintenance work. Other authors, as Fujita (1996), suggested that the operation life of the infiltration devices can overcome 10 years. Borges of Souza (2002) summarized the maintenance tasks that should be considered in the maintenance of infiltration trenches.

In order to carry out the project of the infiltration devices there are different hydraulic methods. Some authors recommend the adoption of simplified methodologies focused on manual calculations. Among these, the ones used by Building Research Establishment, UK, (Pratt et al., 1992), the "rain-envelope-method", (Jonasson, 1984, and Urbonas and Stahre, 1993) and the model of Bouwer (1969) originally foreseen for channels or reservoir of phreatic feedback, stand out. Gautier (1998) to represent the quantitative operation of infiltration reservoirs in France, obtaining good results, used this model. Another alternative calculation is the use of algorithms of mathematical simulation associated to hydrological/hydraulic models, as the one presented by Rivard et al. (2001).

3 MATHEMATICAL SIMULATION OF INFILTRATION TRENCHES

The methodology applied to this work was inspired by the development presented by Rivard et al. (2001), using in this case the model SWMM version 5.0 © hydrodynamics. Some modifications were introduced in order to obtain a better representation of the involved processes. The basic structure of the rehearsed infiltration consisted on a permeable trench endowed in its interior with a perforated conduit from which the infiltration / percolation (flow of exit of the conduit toward the non saturated / saturated trench) processes and exfiltration (entrance flow from the trench toward the conduit) take place. As suggested by the MOE (1994, according to Rivard et al., 2001) the rate of infiltration of the conduit follows a similar behavior to that of the flow through a hole:

$$Q = C \cdot A \cdot \sqrt{2 \cdot g \cdot \Delta H} \quad (1)$$

where:

- Q : is the infiltration (m³/s) flow;
- C : is the hole (adopted similar to 0.63) coefficient;
- A : is the area of the hole, and
- H : is the hydraulic load on the center of the hole.

In this case, the analogy corresponding to each level (or height) of holes of the perforated conduit consisted on: supposing a similar hole which area is the addition of all the areas corresponding to the holes of the conduit of such level. On the other hand the hydraulic load ΔH , is the difference of water levels between the interior of the conduit and inside of the trench (Figure 1). A positive value of H corresponds to the infiltration process. On the other hand, a negative value of ΔH corresponds to the exfiltration process from the trench toward the conduit. This last phenomenon takes place during events of long duration, in those in which the infiltration/percolation process has previously taken place; this means the high state of humidity of the trench.

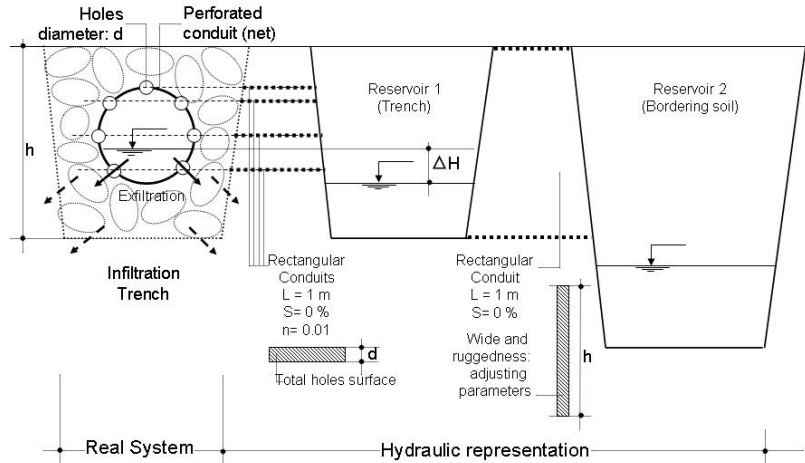


Figure 1. Hydraulic analogy employed in the simulation of infiltration trenches.

Rivard (2004) intended to represent the holes of the perforated conduit by means of fictitious conduits of rectangular section with height similar to that of the holes, and area similar to the amount of all the areas of the holes corresponding to a given level or height. These fictitious conduits drain toward a first reservoir that represents the available volume in the trench. A second reservoir, which has as an only hydraulic link, a connection to the first one, represents the available volume in the natural surrounding soil to the trench. According to the author (personal communication, 2005) the connection between both reservoirs was carried out by means of a circular conduit of 100 mm and slope similar to 0,05%. In all the cases, the fictitious conduits had a longitude of 20 m. The slope of the rectangular fictitious conduits was adopted as parameter of adjustment of the pattern.

The simulation carried out in this study sustained the idea of equivalent rectangular conduits proposed by Rivard et al. (2001) whose operation is similar to that of an hole as recommended by the MOE (1994, according to Rivard et al., 2001). However, in this case, all the fictitious conduits were supposed horizontal, of minimum longitude (adopted similar to 1 m because of the outline of mathematical simulation of the hydraulic pattern) and with relatively low ruggedness (0.01). Due to the impositions of the model SWMM ©, the fictitious conduits were simulated starting from the node of water under each conduit of the net.

The first fictitious reservoir, corresponding to the analogy with the trench, maintained the curve height-area of such analogy. The connection between this reservoir and the second was simulated by means of a rectangular horizontal conduit of 1 m of longitude, adapting its height to that of the trench. This way of simulating the water flow in the interface trench-soil implies the indirect consideration of the biggest difficulties that generally take place at the bottom of the devices. The width of this conduit and the coefficient of ruggedness of Manning were adopted as parameters of adjustment of the pattern.

4 USED DATA

Borges de Sousa (2004) presented the data corresponding to the two trenches of the city of Porto Alegre. Both devices did not include the perforated conduit in their interior, allowing the total control of the glide for the project conditions ($T_r = 5$ years). The soil of both devices was of loamy type, with saturated (K_o) hydraulic conductivity equal to 10 mm/h for trench I and of 30 mm/h for trench II. Trench I consists of an excavation of 10 m long, 0.80 m wide and 1,0 m deep, and it is monitored by two observation wells. It was installed in an area of 600 m² that drained water from a street paved by means of parallelepipeds. In its construction, geo textile filters, Bidim® type, were used, with material filler with porosity similar to 47%. The observation wells were carried out with PCV perforated tubes of 150 mm. Trench II received the contribution of an area of 450 m², corresponding to a parking lot paved with parallelepipeds. With the purpose of varying the dimensions of the trench and power to simulate different conditions, the same one was projected and built in 3 separate modules. This way, the experimental installation allowed the simulation of an only trench of 9 m or any combination among each module of 3 m. According to the contribution of solid material observed in trench I, the use as pre-filter of a strip of lateral grass of 1 m. was chosen. Filler material presented a porosity of 38%. For the simulation, the authors of this paper had four events (two for each trench). The available information is summarized in Table 1.

Characteristic	Unit	Trench I		Trench II	
		Event 03/25/01	Event 09/21/00	Event 10/01/01	Event 10/02/01
Precipitation	mm	25,7	47	19,5	24,8
Inflow	l/s	5,56	4,93	2,0	1,0
Volume	m ³	6,88	24,4	7,5	24,4
Maximum level	m	0,49	0,78	0,96	0,97
Use in		Adjust	Verification	Adjust	Verification

Table 1 Information of the events in the city of Porto Alegre, Brazil.

Rivard et al. (2001) presented three infiltration devices, which were built in Montreal (Canada) with similar technical characteristics. They consisted on permeable trenches filled with broken stone wrapped in a geo textile, endowed in their interior with a perforated conduit. Two of these devices were located under a park while the third was located under a boulevard. The volume of broken stone of these devices oscillated between 1000 and 2360 m³ of material. In this article, the simulation carried out on the system located under the boulevard G. Boucher is shown. The device consisted on two perforated conduits of 0,45 m of diameter and a longitude of 130 m with slope of 1,5%, surrounded by broken stone with porosity similar to 40%. The holes of the conduits were of 15 mm of diameter, distributed by lineal meter of conduit in 7 lines of 12 holes each one. In this case the authors counted on information about the three events kindly given by Rivard (personal communication) as summarized in table 2.

Characteristic	Unit	Event 08/11/98	Event 10/01/98	Event 10/28/98
Precipitation	Mm	20	9	17
inflow	l/s	1,10	0,11	0,14
outflow	l/s	0,36	0,12	0,12
Entered volume	m ³	2718,2	1262,6	1479,2
Left volume	m ³	1740,3	635,0	1258,4
Use in		Adjust	Verification	Verification

Table 1 Information of the events in the city of Montreal, Canada.

5 RESULTS THAT WERE OBTAINED

The objective pursued in the adjustment of the pattern was the reproduction of the observed levels inside the devices. The parameters of the pattern were constant for both trenches in the city of Porto Alegre. The adopted values were: number of Manning=0.01; height of the conduit to the reservoir n° 2=0,01 m; it base of the conduit = longitude of the trench. Figure 2 presents the observed levels versus the calculated ones corresponding to the events respectively registered (adjust and verification) in trenches I and II. A good performance of the model is observed. The difference between observed and calculated maximum levels was of 6%. The difference between the observed and calculated volumes was slightly inferior.

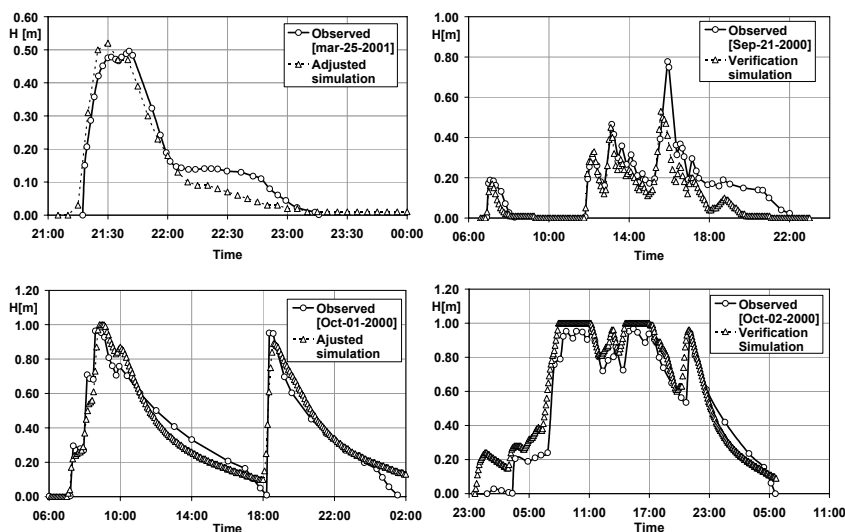


Figure 2. Adjust and calibration events in trenches I and II respectively (Porto Alegre, Brazil).

In Figure 3 the inflow and outflow hydrogram of the device are observed. The reduction of the flow peak for the events of trench I was respectively of 23% and 34%. For the case of trench II, this reduction was respectively of 82% and 63%. These values, added to the difference, indicate the potentiality of these devices to muffle and to regulate pluvial surpluses.

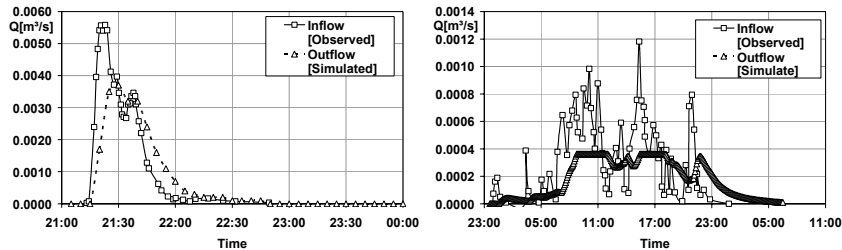
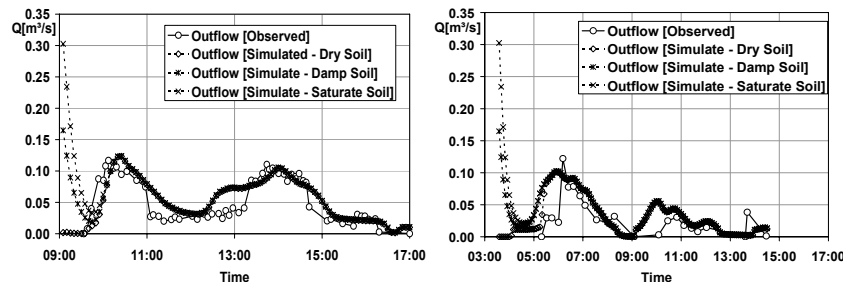


Figure 3. Input and output hydrographs in the trenches I and II respectively (Porto Alegre, Brazil).

As regards the simulation of the trench in the city of Montreal, the simulations were carried out based on the following values of the parameters of the pattern: n of Manning=0,2; height of the conduit to the reservoir n° 2=1,0 m; basis of the conduit=0,0065 m. These parameters reflected more restrictive conditions for the flow to and from the soil in connection with the trenches in Porto Alegre. Figure 4 presents the observed and simulated hydrograms corresponding to the verification events. Due to the lack of information's corresponding to the previous state of humidity of the soil in the verification events, the authors made different simulations which reflected the influence of this variable of the process. The initial decrease of the calculated hydrogram is due to the fact that both reservoirs of the pattern are supposed to be filled (in other words, a state of saturation of the device and of the surrounding soil). In general terms, the authors concluded that also in this case the operation of the pattern was adequate to the required objectives.



Figures 4. Observed and simulated hydrograms corresponding to Montreal city.

6 CONCLUSIONS

In this work, a simplified mathematical algorithm to represent the behavior of infiltration trenches using the model SWMM 5.0 © of free distribution, was suggested. The algorithm represents the infiltration and exfiltration processes through connected reservoir to the trench and allows simulation of trenches that have (or not) perforated conduits in its interior. The algorithm, based on the literature, introduces slight modifications that contribute to a better operation in relation to the original version. The suggested methodology showed a good capacity to represent the general characteristics of trenches of total and partial regulation in urban areas. The reduced number of parameters coincides with the shortage of hydrological data, this being a typical situation in urban basins.

Data corresponding to two trenches in the city of Porto Alegre, Brazil, and three trenches in the city of Montreal, Canada, was simulated with the model SWMM. The use of these data was justified due to its availability during the period of the research.

The values of the parameters do not keep a direct relationship with the physical characteristics of the feigned environment. This work represents the starting point to the analysis of the mathematical simulation of this type of devices. To reach a greater degree of confidence it is necessary to have data corresponding to a larger number of events.

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