UDM 2018

PROCEEDINGS

11th International Conference on Urban Drainage Modelling (UDM)

Sep. 23–26, 2018

Palermo, Italy

UDM 2018

11th International Conference on Urban Drainage Modelling

23-26 Sep | Palermo - Italy

PROCEEDINGS
11th International Conference on Urban Drainage Modelling (UDM)

Sep. 23–26, 2018

Palermo, Italy

Edited by Giorgio Mannina

Proceedings of 11th International Conference on Urban Drainage Modelling
Sep. 23-26, 2018, Palermo, ITALY.

How to cite the full proceedings:
Mannina, G., 2018. Proceedings of 11th International Conference on Urban Drainage Modelling
Sep. 23-26, 2018, Palermo, ITALY.

How to cite an individual paper:
Author, A., Author, B., Author, C…, 2018. This is the title of your paper. In: Mannina, G., 2018. Proceedings of 11th International Conference on Urban Drainage Modelling
Sep. 23-26, 2018, Palermo, ITALY.

Peer Review:
Each paper has been peer reviewed by at least three independent reviewers with possible outcomes of reject, revise, and accept.

UDM 2018
11th International Conference on Urban Drainage Modelling
23-26 Sep | Palermo - Italy

Rainwater reuse in urban areas: a mathematical model and a long-term modelling approach

Gabriele Freni[1], Giorgio Mannina[2], Michele Torregrossa[2] and Gaspare Viviani[2]

[1] Facoltà di Ingegneria ed Architettura, Università "Kore" di Enna, Cittadella Universitaria, 94100 Enna (IT), Italy
[2] Dipartimento di Ingegneria Civile, Ambientale, Aerospaziale, dei Materiali, Università di Palermo, Viale delle Scienze, Ed. 8, Palermo (IT), Italy

Abstract: Natural water resources are becoming increasingly limited due to global-scale climate change and water availability issues have become so severe that they must be addressed. Given these issues, reuse of wastewater and rainwater provides a promising way to cope with water shortages. This paper describes an investigation into the efficiency of rainwater usage systems. A conceptual model was built to assess the behaviour of rainwater tanks and their effectiveness in coping with water shortages. The study is based on a long-term simulation (12 years) of different rainwater reuse tank schemes. The associated reductions in residential freshwater demand (water reuse efficiency) and wet-weather runoff delivered to the sewer system (sewer discharge efficiency) were surveyed. The results clearly show that rainwater usage systems can significantly reduce drinking water consumption. The specific volumes required for the reuse of rainwater are high; however, for local scale application, the specific volumes necessary are comparable to the reservoir volumes already used to store freshwater resources during potable water shortage.

Keywords: Rainwater reuse; water saving measures; mathematical models; long-term efficiency analysis

1. INTRODUCTION

Rainwater reclamation has historically been used in Mediterranean countries for domestic applications (e.g. use of stormwater roof runoff for in-house non-potable purposes). Recent regulations in European countries (e.g. the EU Water Framework Directive in 2000 and the German DWA-A 138 in 2005). Environmental concerns about rainwater quality are primarily focused on the accumulation and subsequent wash-out of pollutants (Khare et al., 2004; Hu et al., 2003). Runoff from traffic areas can also vary in pollutant concentration depending on traffic density and vehicle types (Drapper et al. 2000). Other impervious surfaces (e.g., commercial and industrial areas) can degrade rainwater runoff quality to the point that runoff reuse is either not recommended or not economic due to extensive treatment requirements. Previous work has paid particular attention to water quality in the first flush, which is generally the most polluted due to the wash-off of accumulated pollutants (Deletic et al., 1997; Vaes and Berlamont, 2001).

Once the most polluted runoff (the first flush) has been excluded, currently available rainwater treatment technologies can obtain high reduction efficiencies. Simple mechanical technologies, such as filtration, have been shown to reduce heavy metals by 95% and hydrocarbons by 99% (Dierkes et al., 2005) while simultaneously removing suspended solids, bacteria, trash and debris. As a result, a large quantity of water can be reclaimed at considerably reduced cost relative to conventional treatment plants, thus making these solutions accessible to both developed and developing countries (Ghisi and Mengotti de

Oliveira, 2007). Including first flush diversion in the treatment process can reduce the amount of biological and mechanical treatment necessary, facilitating small, household-scale application of rainwater reuse. There are many residential uses for non-potable water, so fresh potable water can be saved by implementing affordable treatment systems that provide reused, non-potable rainwater. An inevitable trade-off exists between the volume of fresh water that can be saved and the installation complexity and dimensions of rainwater reuse systems (Dixon et al. 1999). The volume of fresh water than can be saved is commonly assessed during the design of rainwater collection systems, and several models have been described that evaluate this quantity as a function of rainfall amounts, catchment characteristics and users' water demand (Kim and Yoo, 2009; Mitchell et al., 2009; Liu et al., 2010).

The present study will address both issues in an integrated analysis. The main objective is to assess the effects of rainwater reuse on urban drainage systems using a modelling-based approach. The study is focused on local stormwater reuse facilities because they require lower investment costs and treatment costs. A long-term simulation is conducted using 12 years of rain data and a range of storage volumes, roof areas and water consumption rates. The resulting impacts on system efficiency and the frequency and severity of overflow events are discussed.

2. MATERIALS AND METHODS

2.1 The proposed model

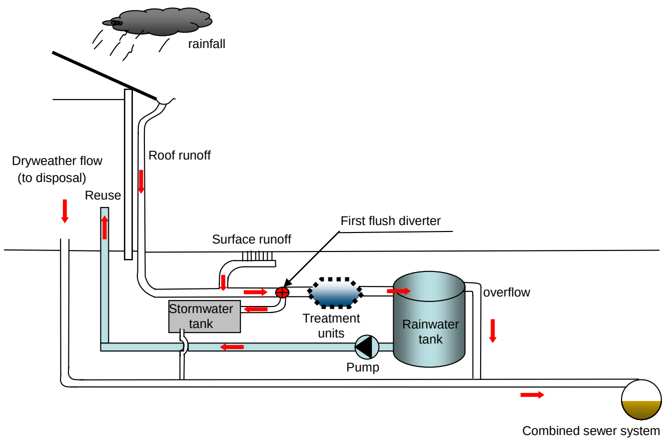
A simplified conceptual model was developed to evaluate the performance of rainwater reuse systems. A schematic of the modelled rainwater system is shown in Figure 1. The system consists of a rainwater tank equipped with an overflow weir and an inflow pipe. This pipe re-directs the roof runoff after mechanical treatment designed to remove some of the pollutants washed off by rainfall. As was previously described, pollutants accumulate on catchment surfaces during periods of dry weather. The first stage of a rain event, known as the first flush, is generally the most polluted, so a first flush tank can be added to the system to store and subsequently dispose of this extremely polluted initial runoff. The system is simulated using a linear reservoir modelling approach. After starting from the total rainfall and subtracting hydrologic losses, the effective rainfall runoff (Qrain) is evaluated.

2.2 The case study

To test the model and evaluate the effectiveness of rainwater reuse, the model described in the previous section was applied to a specific case study. Rainwater reuse efficiency depends on a combination of factors:

- meteorological conditions, which control rainfall volumes, intensities and frequencies;
- population density, which controls potential rainfall water production by indirectly determining the impervious area per capita; and
- water demand, i.e. the amount of rainwater that is needed.

(a)



(b)

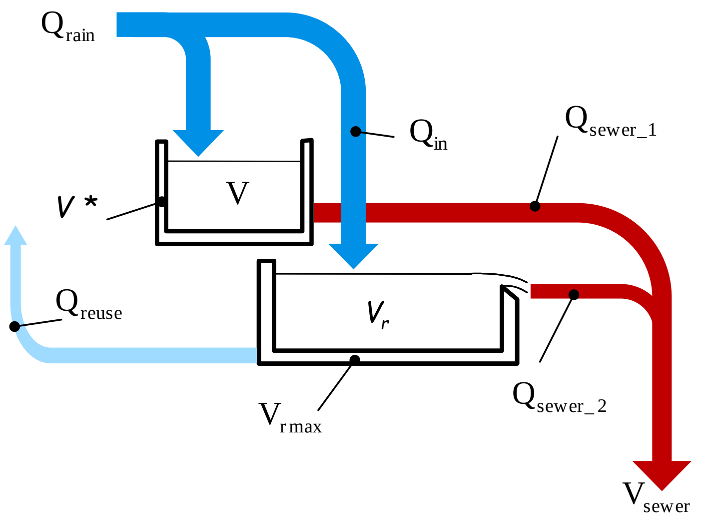


Figure 1. (a) Overview of a rainwater storage system. (b) A schematisation of the rainwater storage system model.

Rainfall data were collected in the Palermo urban area using a Parco d'Orleans rain gauge. The data have been collected continuously using a tipping bucket rain gauge with a volume equivalent to 0.2 mm and a data logger with the highest possible time resolution of 1 sec. For this study, 12 years between 1993 and 2004 were selected. Meteorological conditions at Palermo are typically Mediterranean with a warm, dry summer and a rainy winter season that extends from October to April. Average yearly rainfall is around 600 mm, so the local climate is not arid. Nonetheless, the longest yearly dry period is 64 days on average.

For the other two parameters (population density and water demand), representative values for the area were chosen. The population density in Palermo ranges from less than 100 inhabitants/ha to more than 1400 inhabitants/ha in the city. High population densities were not considered in the study because the ratio of rainwater production to demand is too low for practical application. Water demand depends on the uses that can be accommodated by reclaimed rainfall and it is the main parameter of this study. As previously mentioned, rainwater can be used for applications that do not require potability such as WC cleaning and gardening.

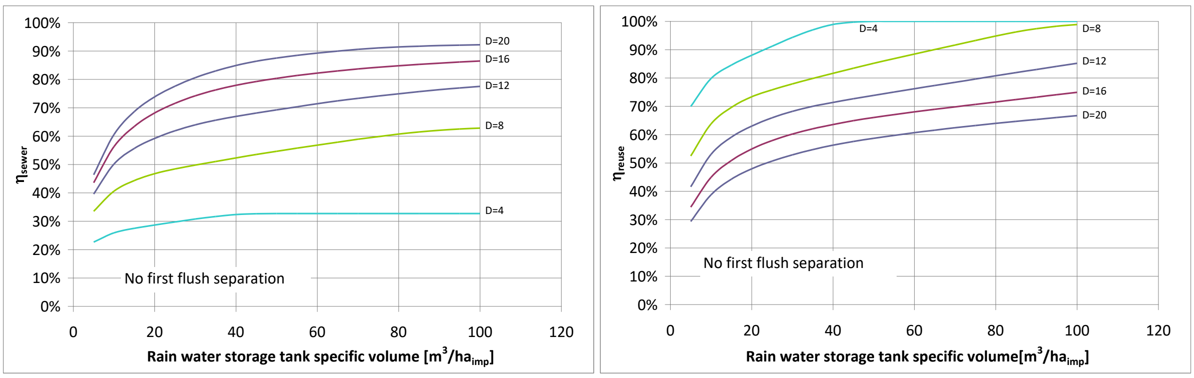
The total local water demand (D) is obtained by multiplying the per capita rainwater demand by the population density. This quantity was the main independent parameter used in this study and will appear in the graphs shown in the next section.

3. RESULTS

In this study, different rainwater reuse applications were compared in terms of their required rainwater tank dimensions and their need for a first flush separation tank. Different configurations were compared using two measures of system efficiency:

- The water reuse efficiency η_{reuse}, defined as the ratio of the rainwater demanded by the user to the rainwater provided by the reuse system.
- The sewer discharge efficiency sewer η_{sewer}, defined as the ratio of the volume of rainwater supplied for reuse to the runoff volume.

The water reuse efficiency is useful for evaluating the potential water savings of the reuse system, while the sewer discharge efficiency is useful for assessing the environmental impact of reuse in terms of the reduction of in sewer discharge during wet weather. The efficiency of several model reuse configurations was analysed using long-term simulations initialised from rainfall data (described in the previous section) and assuming constant rainwater demand over the entire period of the analysis. The first configuration was designed to maximise rainwater reuse efficiency by not including a first flush separation device. Figure 2 shows the average efficiencies for this system over the 12-year period of the analysis.



[a] [b]

Figure 2. Rainwater reuse efficiencies for a system without a first flush separation device, plotted for different values of total local rainwater demand D [$m^3/(ha*d)$]. The graphs show [a] sewer efficiency and [b] reuse efficiency.

4. CONCLUSIONS

This paper presents an analysis of a model designed to evaluate the potential benefits of reusing rainwater to satisfy residential water needs. The results show beneficial outcomes of rainwater reuse measures, including both reduced residential fresh water demand (high water reuse efficiency) and reduced wet weather runoff to sewers (high sewer discharge efficiency). Rainwater reuse leads to environmental benefits, including both fresh water savings and less frequent sewer overflows. The conclusions of the study can be summarised with the following points:

- Rainwater reuse efficiency is highly dependent on the ratio of available impervious surfaces to rainwater demand and population density. When this ratio is unbalanced by excessive demand or reduced runoff availability, excessively large rainwater harvesting tanks are needed.
- First flush tanks can reduce the amount of treatment needed before water can be reused. However, in the climate analysed here, the inclusion of first flush tanks reduces the rainwater reuse efficiency and thus may decrease interest in adopting these water saving measures.
- Rainwater reuse measures can provide environmental benefits because they can greatly reduce the frequency and severity of stormwater discharge events during wet weather, thus reducing sewer overflows from the drainage system.

References

Barton, A. B., and Argue, J. R. (2009). Integrated urban water management for residential areas: a reuse model. Water science and technology, 813-823.

Deletic, A. (1998) The first flush load of urban surface runoff. Water Research, Volume 32(8), 2462-2470.

Deutsche Vereinigung fur Wasserwirtschaft, Abwasser und Abfall – DWA-A (2005). Planning, Construction and Operation of Facilities for the Percolation of Precipitation Water. April, ISBN 978-3-937758-74-9

Dixon, A., Butler, D., and Fewkes, A. (1999). Water saving potential of domestic water reuse systems using greywater and rainwater in combination. Water science and technology, 25-32.

Drapper, D., Tomlinson, R. & Williams, P. (2000): Pollutant Concentrations in Road Runoff: Southeast Queensland Case Study. Journal of Environmental Engineering April: 313 – 320.

Evans, C.A., Coombes, P.J., Dunstan, R.H., Harrison, T. (2009) Extensive bacterial diversity indicates the potential operation of a dynamic micro-ecology within domestic rainwater storage systems. Science of The Total Environment, Volume 407, Issue 19, 5206-5215

Ghisi, E., Mengotti de Oliveira, S. (2007). Potential for potable water savings by combining the use of rainwater and greywater in houses in southern Brazil. Building and Environment vol. 42 (4) pp. 1731-1742

Khare, P., Goel, A., Patel, D., & Behari, J. (2004). Chemical characterization of rainwater at a developing urban habitat of Northern India. Atmospheric Research, 69, 135–145.

Kim, K., and Yoo, C. (2009). "Hydrological Modeling and Evaluation of Rainwater Harvesting Facilities: Case Study on Several Rainwater Harvesting Facilities in Korea." J Hydrol Eng, 14(6), 545-561.

Liu, S., Butler, D., Memon, F. A., Makropoulos, C., Avery, L., and Jefferson, B. (2010). "Impacts of residence time during storage on potential of water saving for grey water recycling system." Water Res, 44(1), 267-277.

Mitchell, V. G, McCarthy, D. T, Deletic, A, Fletcher, T. D. (2008) Urban stormwater harvesting - sensitivity of a storage behaviour model Environmental Modelling & Software vol. 23 (6) pp. 782-793

Vaes, G., Berlamont, J. (2001) The effect of rainwater storage on design storms. Urban water Vol 3(4), 303-307.