*European Water* 58: 497-503, 2017.


# The role of domestic rainwater harvesting systems in storm water runoff mitigation

I. Gnecco*, A. Palla and P. La Barbera
*Department of Civil, Chemical and Environmental Engineering, University of Genova, Genoa, Italy*
* *e-mail: ilaria.gnecco@unige.it*

**Abstract:** The role of Domestic Rainwater Harvesting (DRWH) systems in storm water runoff mitigation is investigated at the urban block scale by implementing a hydrologic-hydraulic model able to predict the outflow hydrographs together with the hydraulic behaviour of the DRWH at high time resolution. The hydrologic behaviour of an urban block equipped with DRWH systems has been continuously simulated over 26 years of rainfall records. The modelling is undertaken using EPA SWMM; the DRWH is implemented in the model by using a storage unit linked to the building water supply system and to the drainage network. In order to quantify the impact of DRWH systems on improving the hydrologic performance of the urban block, the peak and volume reduction are evaluated with respect the "do nothing" scenario. Although the reduction ratios are limited for exceedance rainfall events (high-intensity and short-duration), the installation of DRWH systems at the urban catchment scale contributes to satisfactory increase the hydrologic performance of the storm water drainage network. At the same time, the modelling results point out that the widespread implementation of rainwater harvesting systems at the urban catchment scale noticeably affects the quali-quantity aspects of urban water management; indeed these storage tanks contribute to reduce the use of potable water and to limit overflow discharges and drainage system failures.

**Key words:** rainwater harvesting; storage tank, storm water control; SWMM

## 1. INTRODUCTION

Rainwater Harvesting (RWH) systems are recognized as a widely accepted solution to save water in buildings. The installation of rainwater harvesting systems, as well as the use of water saving devices, are supported by the European legislation (EU, 2009). Domestic RWH (DRWH) consists of the small-scale concentration, collection, storage and use of rainwater coming from rooftops and other impervious surfaces. Rainwater can be used to replace drinking water for many uses in the house such as the flushing of toilets and the garden watering (USEPA, 2004).

RWH systems may also play an important role in mitigating the impact of urban storm water due to the increase of imperviousness in urban areas (Burns et al., 2015): according to the Low Impact Development (LID) principles and applications aimed at promoting storage, infiltration and evapotranspiration (Palla and Gnecco, 2015), RWH may contribute to increase at-source retention and detention of storm water. Then, catchment scale implementation of rainwater tanks may help to reduce frequency, volume and peaks of storm water runoff in urban drainage systems (see e.g. Palla et al., 2017).

In this framework, the main objective of this paper is to investigate the role of DRWH systems in storm water runoff mitigation at the urban block scale by implementing a hydrologic-hydraulic model able to predict the outflow hydrographs together with the hydraulic behaviour of the DRWH at high time resolution.

## 2. METHODS

### *2.1 The test description*

The test site is located in the neighbourhood of Albaro (Genoa, Italy) in the eastern part of the town centre. The test site corresponds to an urban block limited on the four sides by the small road network leading into the internal lots and two/three-storey buildings. The block area is about 0.6 ha and was urbanized in the sixties with 4 buildings and a private green area. The analysis of land use data reveals that 57% of the urban block is covered with impervious surfaces and that rooftops account for 33% of the total areas.

The precipitation regime of the study area is analysed based on rain data collected at the raingauge station of Villa Cambiaso (44.3986N; 8.9633E) located in the vicinity. Rainfall data are available since 1990 with 1-minute resolution. The statistics of the annual rainfall depth as well as the rainfall-event characteristics are typical of the Mediterranean area: the average and standard deviation values of the annual rainfall depth are respectively 1340 mm and 372 mm, the rainfall-event depth and Antecedent Dry Weather Period (ADWP) are higher than 14 mm and 1.5 days, on average.

The management of storm water is separated from the sewer system and addressed according to the traditional approach; in particular the separate sewer system consists of three pipes located below the street network without any LID source control solutions (such as green roofs, permeable pavements, rainwater harvesting systems) installed in the area.

The installation of a DRWH system for each building of the urban block is here assumed as hypothetic scenario for planning and design purposes according to an integrated storm water mitigation strategy.

In each DRWH system, the roof runoff is collected in the corresponding storage tank and pumped directly to the point of use while the overflow is directly conveyed to the downstream drainage network. The water demand to be supplied by rainwater is limited to the toilet flushing and is assumed to occur at a constant daily rate. The toilet flushing demand per person is assumed of 40 l/d (UNI/TS 11445, 2012).

In the present test site, the tanks are designed according to the simplified method as indicated in the Italian guideline UNI/TS 11445 (2012). This method is based on the evaluation of two terms: the annual inflow, $Q$, and the annual rain water demand, $D$. In particular, the annual inflow is evaluated by multiplying the collected area with the annual runoff depth and the latter is determined by multiplying the annual rainfall depth with the discharge coefficient of the corresponding collected area equal to 0.8 for a pitched roof. The storage volume of the tank is then assumed as the 6% of the minimum value between the inflow and the water demand on annual basis.

In order to define the water demand conditions in the selected urban block, and consequently to design the proposed DRWH systems a survey was carried out in May 2016 to investigate the actual number inhabitants for each building. Based on the survey, the four buildings are classified as 4-flat house (2 units), 6-flat house (1 unit) and condominium (1 unit) characterized, respectively, by the following numbers of inhabitants of 16, 24 and 32.

In Table 1, the main characteristics of each building in terms of roof area and number of inhabitants are reported together with the main characteristics of each DRWH system including the annual rain water demand, the demand fraction ($D/Q$), the tank capacity ($S$) and the storage fraction ($S/Q$). Note that the demand and storage fractions are dimensionless indexes that allow comparing the performance of different RWH systems (Palla et al., 2011).

### *2.2 The DRWHS modelling and performance indexes*

The hydrologic-hydraulic modelling is undertaken using EPA SWMM 5.1.007 (Rossman, 2010). In the present study, the DRWH systems are simulated in SWMM as hydraulic nodes using the *storage unit* objects. The inflow of the storage unit is the subcatchment outflow connected to the DRWH system. The storage outflows consist in the rainwater supply and the overflow that are implemented respectively as a pump linked to the building water supply and a weir section linked to the drainage network. Note that the building water supply system is schematized by an outfall section. In order to reproduce the daily rainwater-demand pattern, specific control rules (clock time rules) are defined to activate the pumps.

*Table 1. Main characteristics of the building (number of inhabitants, roof area) and DRWH system (annual water demand, demand fraction, tank capacity, storage fraction) for the three typologies of residential units*

| | Inhabitant number (-) | Roof area ($m^2$) | Annual water demand ($m^3$/y) | Demand fraction (-) | Tank capacity ($m^3$) | Storage fraction (-) |
|---|---|---|---|---|---|---|
| 4-flat house | 16 | 420 | 234 | 0.51 | 14 | 0.03 |
| 6-flat house | 24 | 420 | 350 | 0.77 | 21 | 0.05 |
| Condominium | 32 | 680 | 467 | 0.64 | 28 | 0.04 |

The study area in the current configuration ("do nothing scenario") is implemented in the model by means of 12 subcatchments, 6 junctions, 6 conduits and 1 outfall. The subcatchments are characterized by single land use type and homogenous properties according to the required high-spatial discretization. Compared to the current condition, the DRWH scenario includes 4 storage units (1 for each building), 4 weirs (1 for each tank), 8 pumps (2 for each DRWH), and 4 outfalls representing the water-supply system in the buildings. The geometry of each tank is designed according with the available surface area in the vicinity of the building and by considering an effective water depth in the tank of 2 m. Further details on the model configuration are provided elsewhere (Palla et al., 2017).

Finally, the modelling scenarios (relating to the "do nothing" and DRWH configurations) concern continuous simulation performed over 26 years at 1-minute time interval; as for the initial condition of the DRWH systems, the tanks are assumed initially empty as is generally recommended (Mitchell, 2007).

In order to assess the role of DRWH systems in storm water runoff mitigation two hydrologic performance indexes are defined: the peak and volume reduction rates, namely *PR* and *VR*, respectively. The hydrologic performance indexes are evaluated at the event scale. For each rainfall event, the peak reduction is calculated as the relative percentage difference between the outflow peaks of the "do nothing" and DRWH scenarios; the volume reduction is similarly evaluated.

## 3. RESULTS

### *3.1 The system performance*

The system performance is evaluated with respect to the entire simulation period by means of two dimensionless indexes commonly used in the literature (e.g. Palla et al., 2011): the water saving efficiency and the rainwater overflow ratio.

Figure 1 reports the water saving efficiency and overflow ratio for the three typologies of residential buildings. Results highlights excellent performance in terms of water saving efficiency whose value is almost equal to 0.8 in all cases. Further, it can be noticed that the water saving efficiency value slightly decreases with the increasing of the corresponding *D/Q* (or *S/Q*), since in the present study case *S/Q* corresponds to the 6% of the *D/Q* according to the simplified method of the Italian guidelines. The same behaviour is observed for the overflow ratio values that decrease from 0.66 to 0.59.

### *3.2 The hydrologic performance*

Results of the continuous simulation (26-year long) provide a fully characterization of the hydrologic-hydraulic behaviour of the investigated catchment together with each DRWH system (i.e. the water depth in the tank, the supplied rainwater discharge, the inflow and the overflow rates) at 1-minute time resolution. Based on the simulation results, it emerges that the mean values of peak (*PR*) and volume (*VR*) reduction rates, evaluated for the 2125 rainfall events, are respectively equal to 0.33 and 0.26, while the maximum values are 0.65 for peak and 0.51 for volume.

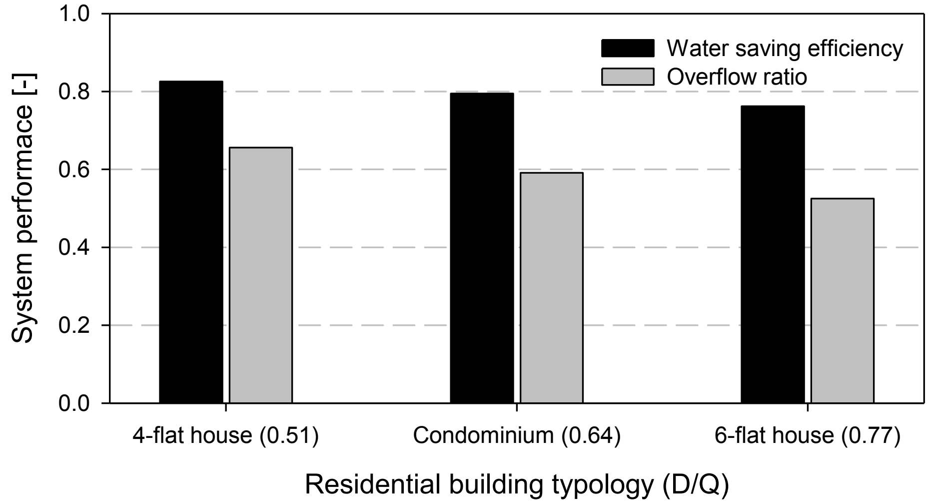


*Figure 1. The water saving efficiency and overflow ratio for the three typologies residential buildings.*

As an example, Figure 2 illustrates the hydrologic response of the urban block simulated for three rainfall events: the 20 September 2002, the 6 December 2006 and the 4 November 2011 events, respectively. In detail, each graph reports the hyetograph and the corresponding hydrographs simulated for the reference and the DRWH scenarios. The selected rainfall events differ in terms of rainfall event features thus resulting in different hydrologic performance at the catchment scales, in order to provide a picture of the impact of DRWH systems on the urban block hydrologic response. The 20 September 2002 rainfall event (see Figure 2) is characterized by a total rainfall depth and duration respectively of 52.6 mm and 1 h (2-year return period event) while the maximum rainfall intensity over 10 minutes is 146 mm/h (5-year return period event) and the ADWP is 18 hours. Being classified among the medium-to-high-frequency event, the DRWH systems contribute significantly to improve the hydrologic performance of the urban block thus resulting in $VR$ of 0.205 and $PR$ of 0.341. The 6 December 2006 rainfall event (see Figure 2) is characterized by a total rainfall depth and duration respectively of 60.6 mm and 3.2 h (less than 2-year return period event) while the maximum rainfall intensity over 10 minutes is 104 mm/h (2-year return period event) and the ADWP is less than 2 hours. Due to the limited ADWP the volume reduction is limited ($VR$ = 0.011), on the contrary, the storage tanks are effective on the peak reduction ($PR$ = 0.092). Finally, the 4 November 2011 rainfall event (see Figure 2) is characterized by a total rainfall depth and duration respectively of 301 mm and 8.4 h (300-year return period event) while the maximum rainfall intensity over 10 minutes is 191 mm/h (15-year return period event). Such event is included among the flash flood events occurring in Genoa (Italy), thus it is expected that any source control system such as DRWH tank, is ineffective in mitigate the catchment hydrologic response ($VR$ = 0.002 and $PR$ = 0.009).

Aiming at pointing out the influence of precipitation regime, the 2125 rainfall events are classified based on the following characteristics on event basis: the rainfall depth, the maximum rainfall intensity over 10 minutes (corresponding to the time of concentration of the urban block) and the ADWP. In particular, five classes characterised by a constant frequency of about 0.2 are defined.

Figure 3 shows the non-parametric distribution of the volume (hatched box) and peak (grey box) reduction rates for each class of the investigated rainfall event characteristics: ADWP (a); depth (a); maximum intensity over 10 minutes. Looking at data reported in Figure 3, it clearly emerges that high values of the ADWP (greater than 42 hours) reveal the highest performance both in terms of peak and volume reduction rate respectively equal to 0.5 and 0.4, on average. Indeed in such cases, the status of the DRWH tanks (only partially full) contributes to enhance the storm water runoff mitigation. Results confirm that for rainfall events with total depth exceeding 20 mm, the hydrologic performance decreases below 0.2 (in terms of both the median and mean values). Focusing on rainfall intensity, events characterized by the maximum rainfall intensity under 25 mm/h show that the hydrologic performance ranges between 0.25 and 0.35 while it slightly decreases for high-intensity event.

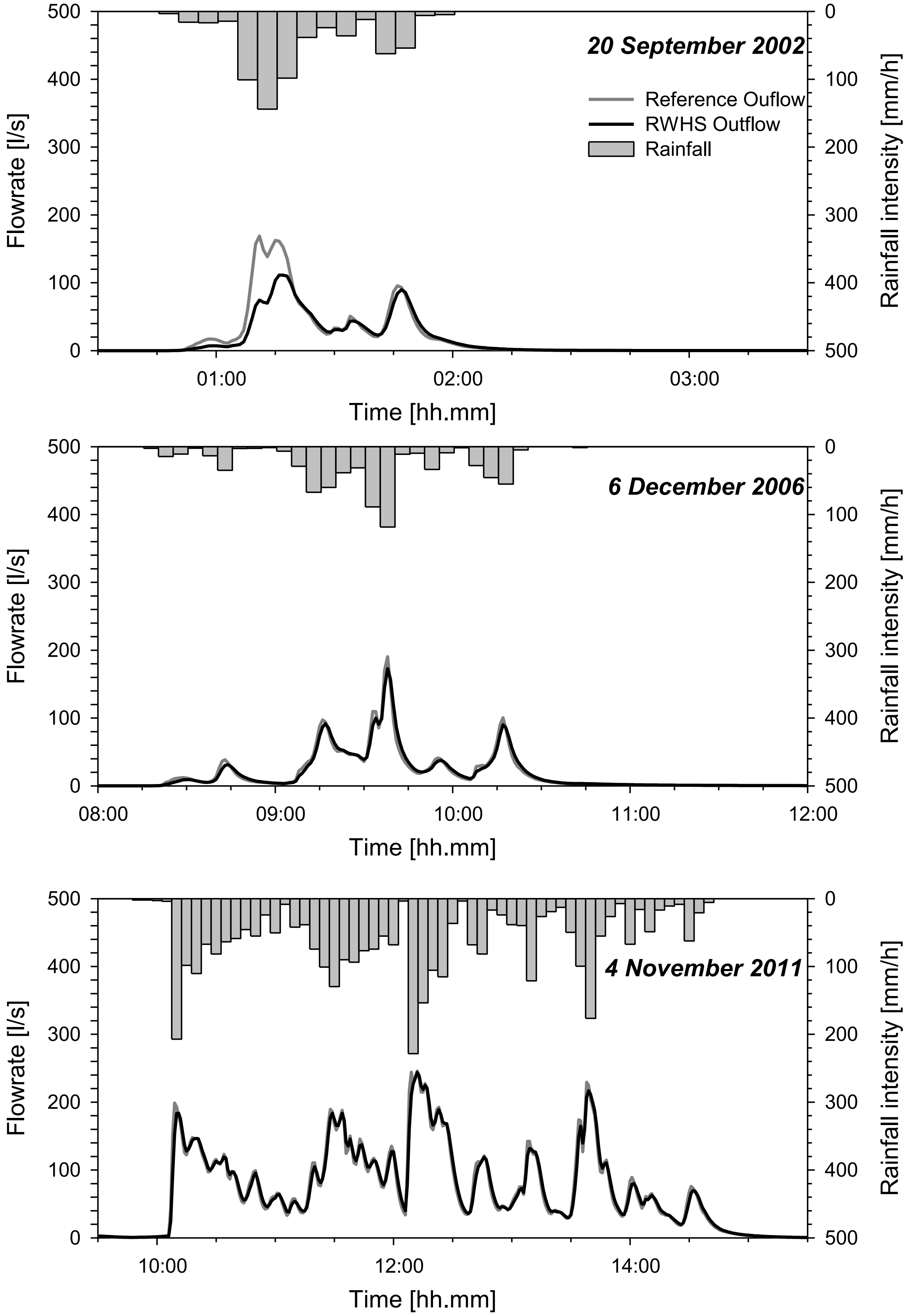


*Figure 2. The hyetograph, the corresponding hydrographs simulated for the reference and the DRWH scenarios are plotted for three rainfall events (the 20 September 2002,the 6 December 2006, and the 4 November 2011 events).*

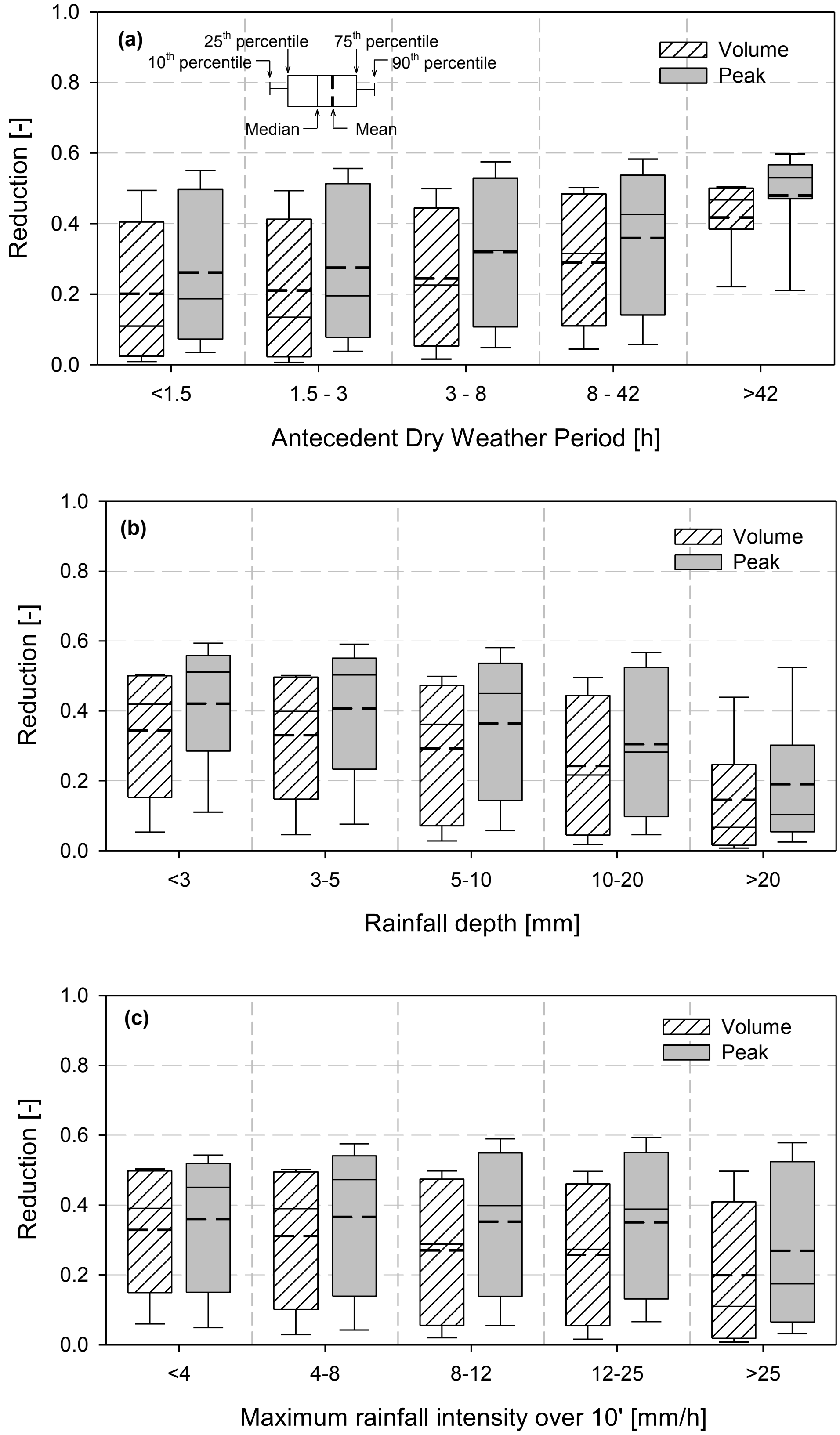


*Figure 3. Box-plots of the volume (hatched box) and peak (grey box) reduction rate with respect to the following rainfall event characteristics: antecedent dry weather period (a); depth (a); maximum intensity over 10 minutes.*

## 4. CONCLUSIONS

The hydrologic behaviour of the investigated urban block equipped with DRWH systems has been continuously simulated over 26 years of rainfall records using the EPA SWMM model. In order to quantify the impact of the DRWH systems on improving the hydrologic performance of the urban block, the peak and volume reduction are evaluated on event-basis with respect the "do nothing" scenario. Simulation results point out that the peak and volume reduction rate evaluated for the 2125 rainfall events are respectively equal to 0.33 and 0.26, on average. With reference to the influence of precipitation regime, ADWP greater than 42 hours are associated to the highest hydrologic performance (on average) while the rainfall depth seems to limit the hydrologic performance at least when the total depth exceeds 20 mm.

The present results point out that the widespread implementation of rainwater harvesting systems at the urban catchment scale noticeably affects the quali-quantity aspects of urban water management. In detail, the DRWH systems operate as source control solutions thus contributing to limit overflow discharges and drainage system failures; reducing the amount of runoff volume that need to be treated before discharging into the receiving water bodies and finally diminishing the use of potable water.

## REFERENCES

Burns, M.J., Fletcher, T.D., Duncan, H.P., Hatt, B.E., Ladson, A.R., Walsh, C.J. 2015. The performance of rainwater tanks for stormwater retention and water supply at the household scale: an empirical study. Hydrol. Process. 29: 152–160.

Campisano, A., Gnecco, I., Modica, C., Palla, A. 2013. Designing domestic rainwater harvesting systems under different climatic regimes in Italy. Water Sci. Technol. 67: 2511-2518.

European Commision. 2009. Study on water performance of buildings. Reference report 070307/2008/520703/ETU/D2.

Mitchell, V.G. 2007. How important is the selection of computational analysis method to the accuracy of rainwater tank behaviour modelling? Hydrol. Process. 21: 2850-2861.

Palla, A., Gnecco, I., La Barbera, P. 2017. The impact of domestic rainwater harvesting systems in storm water runoff mitigation at the urban block scale. J. Environ. Manage. 191: 297-305.

Palla, A., Gnecco, I. 2015. Hydrologic modeling of Low Impact Development systems at the urban catchment scale. J. Hydrol. 528: 361-368.

Palla, A., Gnecco, I., Lanza, L.G. 2011. Non-dimensional design parameters and performance assessment of rainwater harvesting systems. J. Hydrol. 401: 65-76.

UNI/TS 11445. 2012. Rainwater harvesting systems for non-potable uses. Design, installation and maintenance, UNI Ente Italiano di Unificazione (in Italian).

USEPA 2004. Guidelines for Water Reuse, EPA Report 625-R-04-108, US Environmental Protection Agency, Washington, DC, USA.