# SIZING METHOD FOR STORMWATER HARVESTING TANKS USING DAILY RESOLUTION RAINFALL AND WATER DEMAND DATA SETS

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## Abstract

This work presents a simplified method for rainwater harvesting (RWH) tank sizing using long day-resolution rainfall time series. This method considers heterogeneous contributing catchments and water demand flow rates. For the tank sizing, we proposed to take into account the probability to supply the water demand, as well as the most needed probable time step and their respective variabilities. The method was applied to a specific case study (Pontificia Universidad Javeriana, RHW project), with 73 years of daily-resolution rainfall information (between 1936-2010). For the analysis we used different time periods from data-set and the results were: (i) for the whole data-set 76 years: 395 $m^3$ (28 days, probability: 78%); (ii) for the last ten years: 494 $m^3$ (35 days, probability: 89%); (iii) for the last five years: 346 $m^3$ (25 days, probability: 84%); (iv) for the last year: 155-198 $m^3$ (11-14 days, probability: 89-90%). These results seem to be influenced by an evolution of rainfall depth in different selected periods, which will be studied in further researches.

Key words: rainwater harvesting system (RWH); time series; rainwater tank sizing; urban water management; water demand.

# MÉTODO DE DIMENSIONAMIENTO PARA TANQUES DE CAPTACIÓN DE AGUA LLUVIA UTILIZANDO SERIES DE RESOLUCIÓN DIARIA DE LLUVIA Y DE DEMANDA DE AGUA

## Resumen

Este trabajo presenta un método simplificado para el dimensionamiento de tanques de aprovechamiento de aguas lluvias (AAL). Este método considera cuencas tributarias heterogéneas y caudales de demanda de agua. Se propone tener en cuenta la probabilidad para suministrar la demanda de agua, así como el paso de tiempo necesario de recolección más probable y sus respectivas variabilidades. El método se aplicó a un estudio específico de caso (Pontificia Universidad Javeriana, proyecto AAL), con 73 años de información de precipitación a resolución diaria (entre 1936-2010). Para el análisis se utilizaron diferentes períodos de tiempo, los volúmenes del tanque con el tiempo de recolección fueron los siguientes: (i) para el conjunto entero de datos 76 años: 395 $m^3$ (28 días, probabilidad: 78%); (ii) para los últimos diez años: 494 $m^3$ (35 días, probabilidad: 89%); (iii) para los últimos cinco años: 346 $m^3$ (25 días, probabilidad: 84%); (iv) para el último año: 155 a 198 $m^3$ (11 a 14 días, probabilidad: 89-90%). Estos resultados parecen estar influenciados por una evolución de la altura de lluvia en los diferentes períodos seleccionados, lo cual será estudiado en investigaciones posteriores.

**Palabras clave**: sistemas de aprovechamiento de aguas lluvias; series de tiempo; dimensionamiento de tanques para aprovechamiento de aguas lluvias; gestión de agua urbana; demanda de agua.

## INTRODUCTION

Nowadays it exists an increasing attention on the rainwater harvesting (RWH) as an alternative source of water (Hatt, Deletic, & Fletcher, 2006) for non-potable uses (Appan, 2000; Coombes, Argue, & Kuczera, 2000; Coombes & Mitchell, 2006; EPA, 2004; Fewkes, 1999; Ghisi, Tavares, & Rocha, 2009; Handia, Tembo, & Mwiindwa, 2003; Hatt et al., 2006; Herrmann & Schmida, 2000; X.-Y. Li & Gong, 2002; Marinoski, Ghisi, & Gómez, 2004; Wong, 2007) which is additionally recognized as one of the specific adaptation strategies that the water sector should implement to deal with climate changes (Aladenola & Adeboye, 2009; Boelee et al., 2012; Mukheibir, 2007; Muller, 2007; Mwenge Kahinda, Taigbenu, & Boroto, 2010; Pandey, Gupta, & Anderson, 2003; Rozos, Makropoulos, & Butler, 2010). This technique have been successfully implemented as alternative water source in some countries such as China (F. Li, Cook, Geballe, & Burch Jr, 2000), South Korea (Song, Han, & Kim, n.d.), Malaysia (Lariyah, Mohd Nor, Mohamed Roseli, Zulkefli, & Amirah Hanim, 2011), Australia (Duan, Attwater, & Min, 2008) and Brazil (Ghisi et al., 2009). Typically, today's questions which have to be answered through research and engineering studies about the use of RWH are (Mitchell, McCarthy, Deletic, & Fletcher, 2008): “How much stormwater can be harvested? How reliable is this supply source? (Farreny, Gabarrell, & Rieradevall, 2011) And how large a storage is required?”

One of the most widely studied options for saving the rainwater harvested is the use of rainwater tanks. Typically, the studies about rainwater tanks focus on the design optimization (Campisano & Modica, 2012; Imteaz, Rahman, & Ahsan, 2012; Imteaz, Shanableh, Rahman, & Ahsan, 2011; Seo, Choi, & Park, 2012) and the performance of rainwater tanks considering the annual rainfall at a specific geographic location, homogeneous catchment area (only one type of surface – e.g. roofs – are considered) and water demand patterns (Fewkes, 1999; Jenkins, 2007; Khastagir & Jayasuriya, 2010; Walsh, Pomeroy, & Burian, 2014). Other studies focus on the effect that produces the use of rainwater tanks on the sewer system design (Vaes & Berlamont, 2001). More recently, (Youn, Chung, Kang, & Sung, 2012) developed a methodology that establishes a probabilistic relationship between the storage capacity and the deficit rate of a rainwater harvesting system considering climate change.

In Colombia some researches about RWH have been developed for potable (Sanchez & Caicedo, 2003) and non-potable uses (Ballén, Galarza, & Ortiz, 2006; Lara Borrero et al., 2007; Palacio Castañeda, 2010; Ramírez, 2009; Torres, Méndez-Fajardo, et al., 2011). (Ballén et al.,

2006) concluded that the feasibility of RWH depends on five variables: Precipitation of the area, house cover's area, water availability to supply, price per cubic meter of water and investment needed for the systems' construction and maintenance. On the other hand, in Colombia some sizing methodologies based on maximum intensities, and hence more adapted to flooding control, have been developed and implemented (Galarza & Garzón, 2005; Mora, Alvarado, & Torres, 2011; Navarro & Saldarriaga, 2008; Torres et al., 2012; Vélez et al., 2004). This paper presents a tank sizing simplified methodology specifically for RWH purposes and adapted to developing countries (low and medium hydrological data resolution) for non-potable uses of rainwater runoff from heterogeneous catchments.

## MATERIALS

The study case is the Pontificia Universidad Javeriana Bogotá (PUJB) RWH project. The PUJB campus includes 18.4 ha and almost 200000 $m^2$ of constructions where academic, administrative, parking areas, chapels, banks, meeting and other service buildings, as well as sport fields and green zones can be found. Every day, approximately 30000 people enter the campus, whose some buildings are up to 70 years old, but mostly around 40 years and several are recent constructions. It is located at the north-east of Bogota's center (Torres, Estupiñán Perdomo, & Zapata García, 2011).

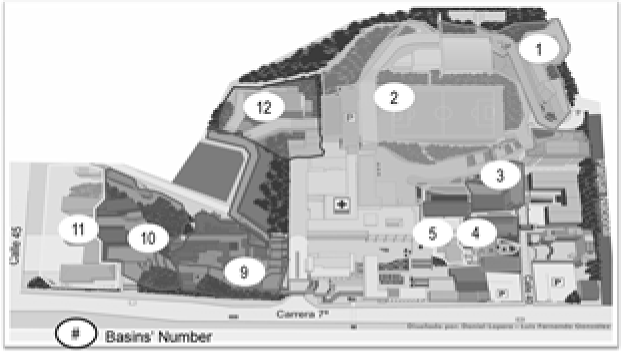
The RWH project in the PUJB was born within the framework of the PUJB Environmental Management Plan. A first project was proposed with the objective of assess economic and technical feasibilities of RWH as an alternative for irrigation and washing hard areas and buildings' facades. This project was leaded by the Research Group ***Ciencia e Ingeniería del Agua y el Ambiente*** (from the same university) in order to determine the amount of water potentially usable. Results show the possibility of using rainwater for some uses, from the standpoint of the amount of water (Lara Borrero ***et al***., 2007). As a result, measurement campaigns were conducted to know the quality of the stormwater on campus and to identify potential uses (Torres, Lara-Borrero, Torres, Estupiñan, & Méndez-Fajardo, 2011). Taking into account these results, Torres et al. (2011) undertook a study to identify the infrastructure requirements for the sustainable use of rainwater on the university campus. They concluded that rainwater could supply a maximum demand of 14%, requiring large investments and a change in the cultural model of water use.

Subsequently, a MCA (Multi Criteria Analysis) tool (called CRIDE: multiCRIteriaDEcision support tool – it's a Celtic word that means heart (Davis, 2002)) for supporting the process of decision making for RWH in PUJB campus was developed (Galarza-Molina, Torres, Moura, & Lara-Borrero, 2015). Six scenarios were proposed for RWH and, by applying CRIDE, the University's Physical Resources Division (PRD) chose the scenario number five. This scenario consists of the runoff collection on nine basins (Figure 1) (basins number 1, 2, 3, 4, 5, 9, 10, 11 and 12) for non-potables uses quality (floor cleaning, sanitary discharge and landscape irrigation) (as recommended by (Torres et al., 2011) using SUDS (Sustainable Urban Drainage

Systems) as basins, bioretention gardens, permeable paving and constructed wetlands (CIRIA, 2000) for collection and treatment of the rainwater (Galarza-Molina et al., 2015).

**Figure 1.** PUJ Campus. Basins defined for the scenario number five.

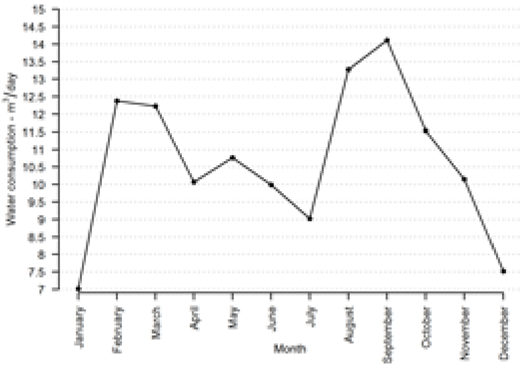
Source: figure given by PRD



The design and construction of the scenario number five will begin with the RWH of one of the nine basins (basin number 2), using a constructed-wetland / reservoir-tank system. Basin number 2 represents 15% (2.73 ha) of the total campus area, with a contributing catchment of 2.2 ha and with a weighted runoff coefficient of 0.51.

The inventory of water uses was taken from Torres et al. (Torres et al., 2011). Scenario number five considers the use of non-potable water uses. These monthly water uses range between 7.02 $m^3$/day and 14.11 $m^3$/day (Figure 2).

**Figure 2.** PUJ Monthly water uses in m3/day for floor cleaning, sanitary discharge and landscape irrigation in PUJB. Source: The authors



## METHODOLOGY

A script based on Rational Method was developed in R (R Development Core Team, 2012) considering daily rainfall, contributing catchment and water uses. We chose this method because of the size of the catchment (less than 80 ha) and its simplicity. The input data were the 73 years of inter-monthly precipitation information between 1936 and 2010 (without years 1969 and 1988 with no data) (Figure 3) and the water uses (demand). The rainfall data-set was collected from a daily rain gauge near the university campus (San Luis - type: Pluviograph station; latitude: 4°38'; longitude: 74°02'; elevation: 3000 m). The water demand was calculated from water bills (October 2003 - March 2010) delivered by PRD. The contributing catchment has a surface of 22026m$^2$, composed by a sport centre, a parking structure, a sport field and green zones and roads, with a weighted runoff coefficient of 0.51.

**Figure 3.** Evolution of total rain depth per year for 73 years

from San Luis station. Source: The authors.

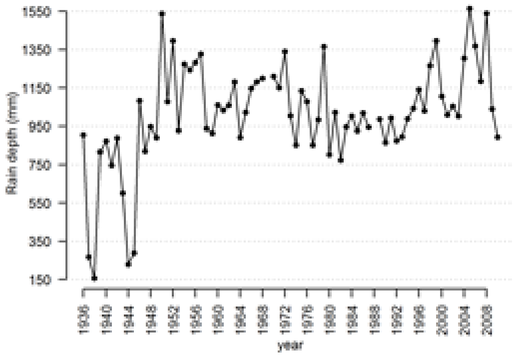


Figure 4 shows the process proposed for estimating the time needed to obtain de demand volume. This process is divided in five steps. The first one is the determination of the maximum value of storage ***Hmax*** needed to supply the water demand. ***Hmaxis***calculated using the amount of water needed per month, the contributing catchment characteristics (area and runoff coefficient) and the estimated time between events (***tej***). In order to begin the iterative procedure explained below, we used a time seed (***ts***) (the script is executed for ***ts*** from 1 day to 100 days) for the first ***tej***. The second step is the screening the data-set from the first (***i***=1) to the last day (***i***=n) for consecutive starting days ***i***. Then the cumulative daily depth height (***Hi***) is computed until Hi is greater than***Hmax***. The third step is undertaken when ***Hi***>***Hmax***, the number days between starting and ending days (time in days needed to supply ***Hmax***) is recorded as ∆***ti***, and the procedure is undertaken again with the next consecutive starting day (***i+1***) (see Figure 5). The result of this step is a list of days needed to supply ***Hmax***: ∆***ti***, ∆***ti+1***, ∆***ti+2***, …,∆***tn***, where i denotes the starting day. By using a frequency analysis (fourth step), the most probable time ∆***ti*** to obtain the demand volume is calculated (∆***tmp(j)***), and is compared with ***tej***. If they are equal (fifth step), ∆***tmp(j)*** is taken as the time needed to obtain the demand volume; otherwise the process will begin again with ∆tmp(j) as ***tej+1***until there is no difference between ***tej+k*** and ∆***tmp(j+k).***

**Figure 4.** Procedure proposed to estimate the time needed to obtain de demand volume Source: The authors.

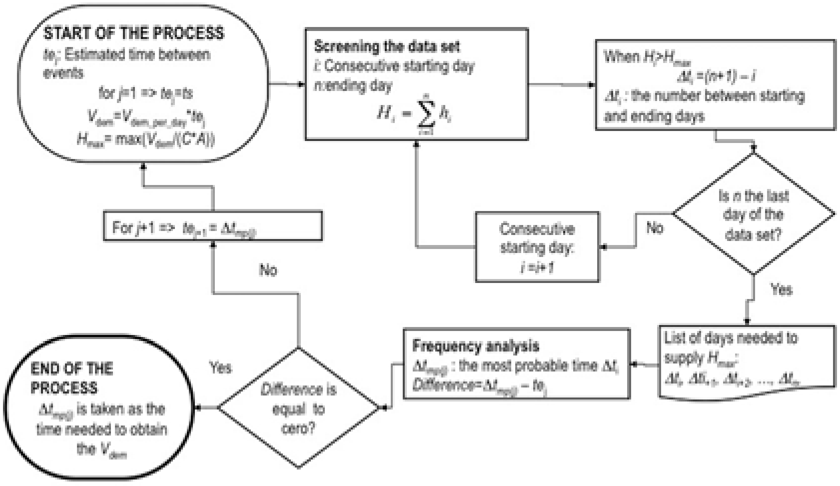
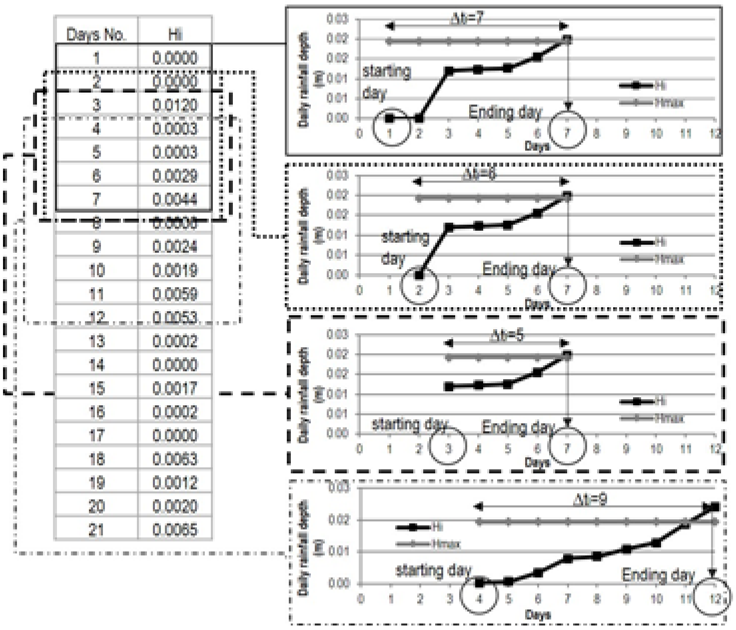


**Figure 5.** Procedure Rainfall data-set, the cumulative daily rainfall depth (Hi) is computed until $H_i$ is greater than $H_{max}$, for which the corresponding time is called "ending day". Source: The authors.



| Days No. | Hi |
|---|---|
| 1 | 0.0000 |
| 2 | 0.0000 |
| 3 | 0.0120 |
| 4 | 0.0003 |
| 5 | 0.0003 |
| 6 | 0.0029 |
| 7 | 0.0044 |
| 8 | 0.0000 |
| 9 | 0.0024 |
| 10 | 0.0019 |
| 11 | 0.0059 |
| 12 | 0.0053 |
| 13 | 0.0002 |
| 14 | 0.0000 |
| 15 | 0.0017 |
| 16 | 0.0002 |
| 17 | 0.0000 |
| 18 | 0.0063 |
| 19 | 0.0012 |
| 20 | 0.0020 |
| 21 | 0.0065 |

The script was executed four times using different parts of the data-set: with all the data, with the last ten years, with the last five years and the last year. For the analysis of these results it was constructed a confidence interval graph with equations 1 and 2, using the first (Q1) and the third quartiles (Q3) to define the confidence intervals bound.

Upper_bound=Q_3+1.5*(Q_3-Q_1) (1)
Lower_bound=Q_1-1.5*(Q_3-Q_1) (2)

To support the selection of ***Δtmp*** (the most probable time to obtain the demand volume) two variability indexes (VIi) are calculated using equation 3 and 4: the relation between the minimum ***Δtmpi*** and maximum ***Δtmpi***; and the relation between the minimum (min P(***Δtmpi***)) and maximum (max P***(Δtmpi***)) probability which each ***Δtmp*** would have.

〖VI〗_iΔtmp=min⁡(Δt_mpi )/max(Δt_mpi ) (3)
〖VI〗_iProbability=min⁡P(Δt_mpi )/maxP(Δt_mpi ) (4)

***Δtmp*** is chosen taking into account three criteria: higher values of ***VliΔtmp*** and***VliProbability*** (difference between upper and lower bounds), lower values of ***Δtmp*** to avoid oversized tank and high retention times (number of days are proportional to the amount of stored water) and higher values of probability of ***Δtmp***.

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## RESULTS AND DISCUSSION

With the script described above, the rainfall data-set, the water uses (demand) and time seed (ts) from 1 to 100 days, the results were extracted from four executions:

With all the rainfall data-set
With the last ten years of the rainfall data-set
With the last five years of the rainfall data-set
With the last year of the rainfall data-set

Taking into account the methodology for the selection of the ***Δtmp***, the variability indexes (***VliΔtmp*** and ***VliProbability***) were calculated. Figure 5 shows ***VliΔtmp*** for each probability and the most probable times (***Δtmp***) needed to obtain the demand volume in days.

For the first execution, (upper part of Figure 6), with all the rainfall data-set (solid line type), ***Δtmp*** varies between 1 day and 641 days. Significant differences between the probabilities' intervals of 73% – 86% and 97% – 99% can be observed, for the ***Δtmp***confidence bounds. For the last ten years of the rainfall data-set (dashed line type) ***Δtmp***varies between 1 day and 125 days. Significant differences between the probability's interval of 83% and 94% can be observed for the confidence bounds of ***Δtmp***. In the case of the execution of the last five years of the rainfall data-set (dotted line type), ***Δtmp***varies between 1 day and 144 days. Highest differences between the confidence bounds of ***Δtmp*** were found in the probability's interval of 80% and 89%. Finally, for the execution with the last year of the rainfall data-set (dot-lined type), ***Δtmp*** varies between 1 day and 53 days. In this case significant differences for median values and confidence bounds of***Δtmp*** were found in the probability's interval of 93% and 99%.

On the other hand, taking into account the first criterion (high values of VI) it was chosen a high value of ***VI*Δ*tmp*** = 85% (lower part of Figure 6). The results for each execution are shown in Table 1: the tank volume is calculated with the maximum demand value (14.11 m$^3$/day, Figure 2) and the corresponding Δ***tmp*** value.

**Figure 6.** Variability index ($VI_{\Delta tmp}$) for each probability. The upper part of Figure shows the most probable time ($\Delta t_{mp}$) needed to obtain the demand volume in days, extracted from the four executions. (____) All data lower and upper bound, (__ __) Last ten years lower and upper bound, (--) Last five years lower and upper bound and (._.) Last year lower and upper bound. Source: The authors.

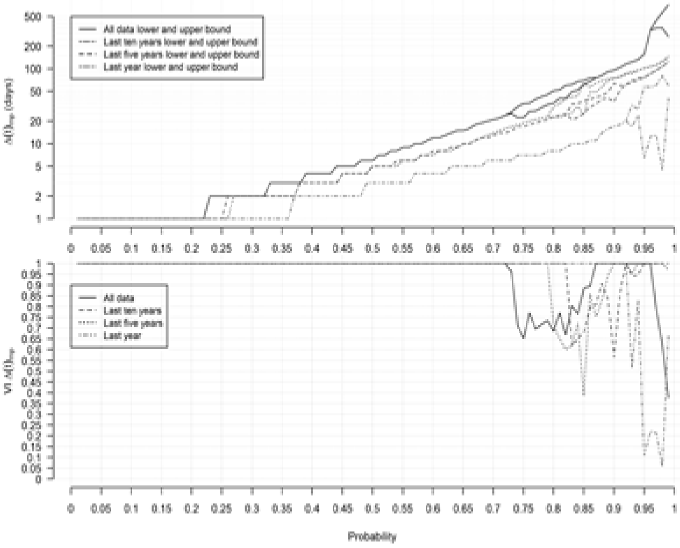
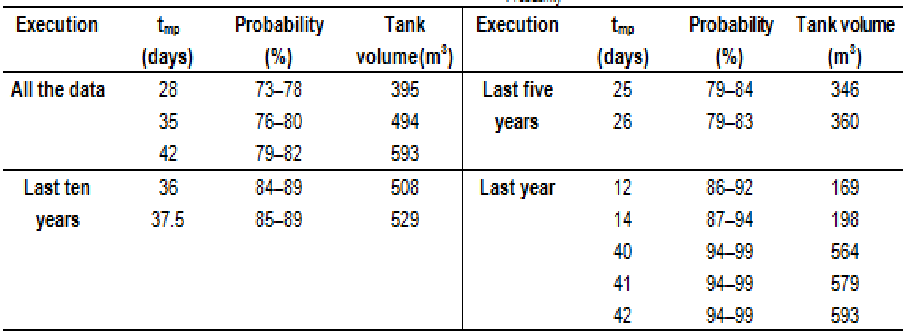


**Table 1.** Tank volumes of each execution for a $VI_{\Delta tmp}$= 85 %. Source: The authors.

| Execution | Probability (%) | Δtmp (days) | Tank volume (m$^3$) |
|---|---|---|---|
| **All the data** | 73 | 25–27 | 353 – 381 |
| | 85 | 60–70 | 847 – 988 |
| | 97.5 | 350–425 | 4939 – 5997 |
| **Last ten years** | 82.5 | 23–28 | 324 – 395 |
| | 87.5 | 35–43 | 494 – 607 |
| | 88.3 | 40–48 | 677 – 734 |
| | 91 | 52–60 | 734 – 847 |
| **Last five years** | 79.5 | 22.5–25 | 318 – 353 |
| | 86 | 49–57 | 691 – 804 |
| | 88.5 | 60–70 | 847 – 988 |
| **Last year** | 95.2 | 19–24 | 268 – 339 |

The Figure 7 shows the Δ***tmp*** versus ***VIProbability***. First it was chosen a high value of***VIProbability*** = 95%. The results for each execution are shown in Table 2, the tank volume is calculated with the maximum demand value (14.11 m$^3$/day, Figure 2) andΔ***tmp*** values.

Table 2.Tank volumes of each execution for a $VI_{Probability}$= 95 %. Source: The authors.

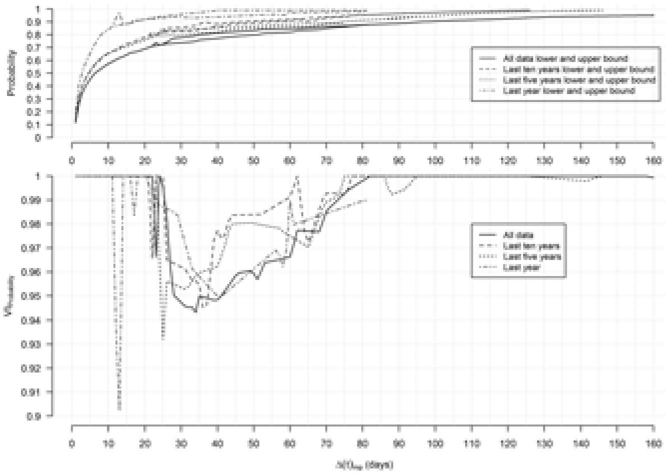


| Execution | $t_{mp}$ (days) | Probability (%) | Tank volume($m^3$) | Execution | $t_{mp}$ (days) | Probability (%) | Tank volume ($m^3$) |
|---|---|---|---|---|---|---|---|
| All the data | 28 | 73–78 | 395 | Last five years | 25 | 79–84 | 346 |
| | 35 | 76–80 | 494 | | 26 | 79–83 | 360 |
| | 42 | 79–82 | 593 | | | | |
| Last ten years | 36 | 84–89 | 508 | Last year | 12 | 86–92 | 169 |
| | 37.5 | 85–89 | 529 | | 14 | 87–94 | 198 |
| | | | | | 40 | 94–99 | 564 |
| | | | | | 41 | 94–99 | 579 |
| | | | | | 42 | 94–99 | 593 |

In accordance with the second criteria (lower values of ***Δtmp*** to avoid oversized tank and high retention times) it was chosen ***Δtmp*** between 20 and 30 days (282 and 423 m3). For this time step the minimum ***VIΔtmp*** is 0.735 (from the all data execution, see Figure 6) and ***VIProbability*** is 0.93 (from last five years execution, see Figure 7). The corresponding probabilities range between 69% and 93% for ***VIΔtmp*** (Figure 6) and between 69% and 98% for ***VIProbability*** (considering all the executions, see Figure 7). If we chose another time step ***Δtmp*** lower than 30 days, for example between 15 and 20 days (212 and 282 m3), the minimum ***VIΔtmp*** is 1 (from the all data execution, see figure 6) and ***VIProbability*** is 0.985 (from the last five years execution, see Figure 7) with a probability between 64% and 94.5% for ***VIΔtmp*** (Figure 6) and between 65% and 90% for***VIProbability*** (considering all the executions, see Figure 7).

On the other hand, in accordance with the third criteria (higher values of probability of***Δtmp***) if we chose probability values upper than 60%, it can be obtained ***Δtmp*** values higher than 12 days (169 $m^3$) (see figure 5 and 6). It seems important to study in detail the ***Δtmp*** intervals 14 to 16 (198 and 226 $m^3$) days and 18 to 20 days (254 and 282 $m^3$) (Figure 7): in these intervals ***VIProbability*** values for all the executions are the highest, with a minimum value of 0.985. The time step probability for the intervals 14 to 16 days and 18 to 20 days are between 63% and 89% and between 67% and 92%, respectively. Hence, it can be chosen any ***Δtmp*** within these intervals – 14-16 or 18-20 days – (e.g. for ***Δtmp*** = 20 days with VI = 1 and a probability between 70% and 90%, with a tank capacity of 282 $m^3$).

**Figure 7.** Zoom of the $\Delta t_{mp}$ interval 1 – 160 days, which shows huge changes of the variability index (min/max). The upper part of the Figure represents the maximum probability of each $\Delta t_{mp}$. (___) All data, (__ __) Last ten years, (--) Last five years and (._.) Last year. Source: The authors



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## CONCLUSIONS

This paper proposes a simplified method to sizing rainwater tanks using long day-resolution rainfall time series for heterogeneous catchment areas. This is a specific method based on the probability that has the daily rainfall to supply the water demand, as well as the most probable time step needed and their respective variabilities.

After applying this method to a specific case study (PUJ campus rainwater harvesting tank sizing) we found that the results differ depending on the selected period and the variability indexes: (i) whole data series - 76 years: 395 to 593 $m^3$ (***VIProbability***= 95%: 28 to 42 days, probability range: 73-82 ) and 353 to 5997 $m^3$ (***VI∆tmp***= 85%: 25 to 425 days, probability range: 73-97.5%); (ii) last ten years: 508 and 529 $m^3$ (***VIProbability***= 95%: 36 and 37.5 days, probability range: 84-89%) and 324 to 847 $m^3$ (***VI∆tmp***= 85%: 23 to 60 days, probability range: 82.5% – 91%); (iii) last five years: 346 and 360 $m^3$(***VIProbability***= 95%: 25 and 26 days, probability range: 79-84%) and 318 to 988 (***VI∆tmp***= 85%: 22.5 to 70 days, probability range: 79.5-88.5%); (iv) last year: 169 to 593 $m^3$ (***VIProbability***= 95%: 12 to 42 days, probability range: 86-99%) and 268 and 339 (***VI∆tmp***= 85%: 19 and 24 days, probability: 95.2%). The above results seem to be influenced by an evolution of rainfall depth in different selected periods, which will be studied in further researches by considering a possible climate change.

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## REFERENCES

- Aladenola, O. O., & Adeboye, O. B. (2009). Assessing the Potential for Rainwater Harvesting. ***Water Resources Management***, 24(10), 2129–2137. http://doi.org/10.1007/s11269-009-9542-y
- Appan, A. (2000). A dual-mode system for harnessing roofwater for non-potable uses.***Urban Water***, 1(4), 317–321. http://doi.org/10.1016/S1462-0758(00)00025-X
- Ballén, J. A., Galarza, M. Á., & Ortiz, R. O. (2006). ***Sistemas de aprovechamiento de agua lluvia para vivienda urbana***. Presented at the VI SEREA - Seminario iberoamericano sobre sistemas de abastecimiento urbano de agua, João Pessoa, Brazil, 5- 7, June, 2006
- Boelee, E., Yohannes, M., Poda, J.-N., McCartney, M., Cecchi, P., Kibret, S., … Laamrani, H. (2012). Options for water storage and rainwater harvesting to improve health and resilience against climate change in Africa. ***Regional Environmental Change***, 13(3), 509–519. http://doi.org/10.1007/s10113-012-0287-4
- Campisano, A., & Modica, C. (2012). Optimal sizing of storage tanks for domestic rainwater harvesting in Sicily. ***Resources, Conservation and Recycling***, 63, 9–16. http://doi.org/10.1016/j.resconrec.2012.03.007
- CIRIA. (2000). Sustainable Urban Drainage Systems: Design Manual for Scotland and Northern Ireland. Construction Industry Research and Information Association. London. ISBN 0 86017 521 9
- Coombes, P. J., Argue, J. R., & Kuczera, G. (2000). Figtree Place: a case study in water sensitive urban development (WSUD). ***Urban Water***, 1(4), 335–343. http://doi.org/10.1016/S1462-0758(00)00027-3
- Coombes, P. J., & Mitchell, V. G. (2006). Roofwater, storm water, and wastewater reuse. In T. H. F. Wong (Ed.), ***Australian runoff quality***. Sydney, Australia: The Institution of Engineers Australia.
- Davis, D. R. (2002). ***The Development of Celtic Linguistics 1850-1900***. New York: Routlegde Taylor and Francis Group.
- Duan, C., Attwater, R., & Min, L. (2008). Introduction to rainwater management in Australia and suggestions for China’s water problems. ***Journal of Chongqing University (English Edition)***, 7(1).
- EPA. (2004). Guidelines for Water Reuse. EPA/625/R-04/108, September 2004, US Enviromental Protection Agency, Washington, DC.

- Farreny, R., Gabarrell, X., & Rieradevall, J. (2011). Cost-efficiency of rainwater harvesting strategies in dense Mediterranean neighbourhoods. ***Resources, Conservation and Recycling***, 55(7), 686–694. http://doi.org/10.1016/j.resconrec.2011.01.008
- Fewkes, A. (1999). The use of rainwater for WC flushing: the field testing of a collection system. ***Building and Environment***, 34(6), 765–772. http://doi.org/10.1016/S0360-1323(98)00063-8
- Galarza-Molina, S., Torres, A., Moura, P., & Lara-Borrero, J. (2015). CRIDE: A Case Study in Multi-Criteria Analysis for Decision-Making Support in Rainwater Harvesting.***International Journal of Information Technology & Decision Making***, 14(01), 43–67. http://doi.org/10.1142/S0219622014500862
- Galarza, S., & Garzón, F. (2005). Estudio de viabilidad técnica de los sistemas urbanos de drenaje sostenible para las condiciones tropicales de Colombia.***Epiciclos***, 4(1), 59–70.
- Ghisi, E., Tavares, D. da F., & Rocha, V. L. (2009). Rainwater harvesting in petrol stations in Brasília: Potential for potable water savings and investment feasibility analysis. ***Resources, Conservation and Recycling***, 54(2), 79–85. http://doi.org/10.1016/j.resconrec.2009.06.010
- Handia, L., Tembo, J. M., & Mwiindwa, C. (2003). Potential of rainwater harvesting in urban Zambia. ***Physics and Chemistry of the Earth, Parts A/B/C***, 28(20–27), 893–896. http://doi.org/10.1016/j.pce.2003.08.016
- Hatt, B. E., Deletic, A., & Fletcher, T. D. (2006). Integrated treatment and recycling of stormwater: a review of Australian practice. ***Journal of Environmental Management***, 79(1), 102–113. http://doi.org/10.1016/j.jenvman.2005.06.003
- Herrmann, T., & Schmida, U. (2000). Rainwater utilisation in Germany: efficiency, dimensioning, hydraulic and environmental aspects. ***Urban Water***, 1(4), 307–316. http://doi.org/10.1016/S1462-0758(00)00024-8
- Imteaz, M. A., Rahman, A., & Ahsan, A. (2012). Reliability analysis of rainwater tanks: A comparison between South-East and Central Melbourne. ***Resources, Conservation and Recycling***, 66, 1–7. http://doi.org/10.1016/j.resconrec.2012.05.009
- Imteaz, M. A., Shanableh, A., Rahman, A., & Ahsan, A. (2011). Optimisation of rainwater tank design from large roofs: A case study in Melbourne, Australia.***Resources, Conservation and Recycling***, 55(11), 1022–1029. http://doi.org/10.1016/j.resconrec.2011.05.013
- Jenkins, G. A. (2007). Use of continuous simulation for the selection of an appropriate urban rainwater tank. Retrieved from Link

- Khastagir, A., & Jayasuriya, N. (2010). Optimal sizing of rain water tanks for domestic water conservation. ***Journal of Hydrology***, 381(3–4), 181–188. http://doi.org/10.1016/j.jhydrol.2009.11.040
- Lara Borrero, J. A., Torres, A., Campos Pinilla, M. C., Duarte Castro, L., Echeverri Robayo, J. I., & Villegas González, P. A. (2007). Aprovechamiento del agua lluvia para riego y para el lavado de zonas duras y fachadas en el campus de la Pontificia Universidad Javeriana (Bogotá). ***Ingenieria y Universidad***, 11(2). http://doi.org/10.1144/929
- Lariyah, M. S., Mohd Nor, M. D., Mohamed Roseli, Z. A., Zulkefli, M., & Amirah Hanim, M. . (2011). ***Application of Water Sensitive Urban Design at Local Scale in Kuala Lumpur***. Presented at the 12nd International Conference on Urban Drainage, Porto Alegre, Brazil. Retrieved from Link
- Li, F., Cook, S., Geballe, G. T., & Burch Jr, W. R. (2000). Rainwater Harvesting Agriculture: An Integrated System for Water Management on Rainfed Land in China's Semiarid Areas. ***AMBIO: A Journal of the Human Environment***, 29(8), 477–483. http://doi.org/10.1579/0044-7447-29.8.477
- Li, X.-Y., & Gong, J.-D. (2002). Compacted microcatchments with local earth materials for rainwater harvesting in the semiarid region of China. ***Journal of Hydrology***, 257(1–4), 134–144. http://doi.org/10.1016/S0022-1694(01)00550-9
- Marinoski, D. L., Ghisi, E., & Gómez, L. A. (2004). ***Aproveitamento de água pluvial e dimensionamento de reservatório para fins não potáveis: estudo de caso em um conjunto residencial localizado em Florianópolis***. Presented at the Conferência Latino-Americana de Construção Sustentável, Encontro Nacional De Tecnologia do Ambiente Construído, Sao Pablo, Brazil, 18-21 julho 2004.
- Mitchell, V. G., McCarthy, D. T., Deletic, A., & Fletcher, T. D. (2008). Urban stormwater harvesting – sensitivity of a storage behaviour model. ***Environmental Modelling & Software***, 23(6), 782–793. http://doi.org/10.1016/j.envsoft.2007.09.006
- Mora, O., Alvarado, D., & Torres, A. (2011). ***Economic Analysis of the application of porous pavements on Bogota roads***. Presented at the 12nd International Conference on Urban Drainage, Porto Alegre, Brazil, September 11 to 16, 2011
- Mukheibir, P. (2007). Water Resources Management Strategies for Adaptation to Climate-Induced Impacts in South Africa. ***Water Resources Management***, 22(9), 1259–1276. http://doi.org/10.1007/s11269-007-9224-6

- Muller, M. (2007). Adapting to climate change water management for urban resilience.***Environment and Urbanization***, 19(1), 99–113. http://doi.org/10.1177/0956247807076726
- Mwenge Kahinda, J., Taigbenu, A. E., & Boroto, R. J. (2010). Domestic rainwater harvesting as an adaptation measure to climate change in South Africa. ***Physics and Chemistry of the Earth, Parts A/B/C***, 35(13–14), 742–751. http://doi.org/10.1016/j.pce.2010.07.004
- Navarro, I., & Saldarriaga, J. (2008). Determinación de la viabilidad técnica y económica de un sistema de almacenamiento temporal de aguas de drenaje urbano para la ciudad de Bogotá. Universidad de los Andes, Bogotá. Retrieved from Link
- Palacio Castañeda, N. (2010). Propuesta de un sistema de aprovechamiento de agua lluvia como alternativa para el ahorro de agua potable, en la institución educativa María Auxiliadora de Caldas, Antioquia. ***Revista Gestión y Ambiente***, 13(2), 25–40.
- Pandey, D. N., Gupta, A. K., & Anderson, D. M. (2003). Rainwater harvesting as an adaptation to climate change. ***CURRENT SCIENCE***, 85(1), 46–59.
- Ramírez, J. (2009, March). Construcción verde en concreto. ***Noticreto***, 93, 20–27.
- R Development Core Team. (2012). Vienna, Austria: R: A language and environment for statistical computing. Retrieved from http://www.R-project.org/
- Rozos, E., Makropoulos, C., & Butler, D. (2010). Design Robustness of Local Water-Recycling Schemes. ***Journal of Water Resources Planning and Management***, 136(5), 531–538. http://doi.org/10.1061/(ASCE)WR.1943-5452.0000067
- Sanchez, L. S., & Caicedo, E. (2003). Uso del Agua Lluvia en la Bocana- Buenaventura (pp. 1–9). Presented at the AGUA 2003 Internacional: Usos Múltiples del Agua Para la Vida y el Desarrollo Sostenible, Cartagena, Colombia: Cinara.
- Seo, Y., Choi, N.-J., & Park, D. (2012). Effect of connecting rain barrels on the storage size reduction. ***Hydrological Processes***, 26(23), 3538–3551. http://doi.org/10.1002/hyp.8430
- Song, M. Y., Han, M. Y., & Kim, S. R. (n.d.). Considerations on the rainwater harvesting regulations. ***Journal of Korean Society of Water and Wastewater***, 17(6), 729–740.
- Torres, A., Estupiñán Perdomo, J.L., & Zapata García, H.O. (2011). ***Proposal and assessment of rainwater harvesting scenarios on the Javeriana University campus, Bogota***. Presented at the 12 nd International Conference on Urban Drainage, Porto Alegre, Brazil. Retrieved from Link
- Torres, A., Lara-Borrero, J., Torres, O., Estupiñan, J., & Méndez-Fajardo, S. (2011). Aprovechamiento de aguas lluvias en el campus de la Pontificia Universidad Javeriana, Sede Bogotá (PUJB). In L. D. Sánchez Torres, A. Galvis Castaño, I. Restrepo Tarquino, & M. R. Peña

Varón (Eds.), ***Gestión integrada del Recurso Hídrico Frente al Cambio Climático*** (pp. 325–336). Cali, Colombia: Programa Editorial Universidad Del Valle.

- Torres, A., Méndez-Fajardo, S., Lara-Borrero, J. A., Estupiñán Perdomo, J. L., Zapata García, H. O., & Torres Murillo, Ó. M. (2012). Hacia equipamientos urbanos sostenibles:aprovechamiento de aguas lluvias en el campus de la Pontificia Universidad Javeriana en Bogotá. ***Cuadernos de Vivienda y Urbanismo***, 5(9). http://doi.org/10.11144/5398
- Torres, A., Méndez-Fajardo, S., López-Kleine, L., Marín, V., González, J. A., Suárez, J. C., … Ruiz, A. (2011). PRELIMINARY ASSESSMENT OF ROOF RUNOFF RAIN WATER QUALITY FOR POTENTIAL HARVESTING IN BOGOTA'S PERI-URBAN AREAS. ***Revista U.D.C.A Actualidad &amp; Divulgación Científica***, 14(1), 127–135.
- Vaes, G., & Berlamont, J. (2001). The effect of rainwater storage tanks on design storms. ***Urban Water***, 3(4), 303–307. http://doi.org/10.1016/S1462-0758(01)00044-9
- Vélez, J. I., Guzmán, J. V., Poveda, G., Ramírez, C. J., Moreno, H. A., Roldán, P. A., & Arango, J. E. (2004). ***Evaluación de la cantidad de lluvia y su almacenamiento para abastecimiento de agua potable, aplicación en el centro de Antioquia***. Presented at the Seminario Internacional sobre Eventos Extremos Mínimos en Regímenes de Caudales: Diagnóstico, Modelamiento y Análisis, Medellín, Colombia, 23-25 de junio.
- Walsh, T., Pomeroy, C. A., & Burian, S. J. (2014). Hydrologic modeling analysis of a passive, residential rainwater harvesting program in an urbanized, semi-arid watershed.***Journal of Hydrology***, 508, 240–253. http://doi.org/10.1016/j.jhydrol.2013.10.038
- Wong, T. H. F. (2007). Water Sensitive Urban Design - the Journey Thus Far.***Australian Journal of Water Resources***, 10(3). Retrieved from Link
- Youn, S., Chung, E.-S., Kang, W. G., & Sung, J. H. (2012). Probabilistic estimation of the storage capacity of a rainwater harvesting system considering climate change.***Resources, Conservation and Recycling***, 65, 136–144. http://doi.org/10.1016/j.resconrec.2012.05.005

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