Usable rainwater volume; results of a hydrological study conducted at the Universidad de Santander, Bucaramanga, Colombia

L C Tiria1, L M Duran1, and D F Ardila1
1 Grupo de Desarrollo Experimental y Tecnológico GEDETEC, Universidad de Santander, Bucaramanga, Colombia

E-mail: lu.tiria@mail.udes.edu.co

Abstract. This study was carried out at the “Universidad de Santander”, in Bucaramanga, Colombia, to calculate the volume of rainwater capturable from the roofs of five campus buildings, as the blueprints for these surfaces were available to obtain their areas. Roof areas were first obtained for the Guane, Motilón, Arhuaco, Chibcha and Yariguíes buildings, from which rainwater can be captured. Intensity, duration, and frequency curves from the “Instituto de Hidrología, Meteorología y Estudios Ambientales” were then used to calculate a design flow, yielding the diameter of the pipe necessary to evacuate the water captured. In addition, data from the “Universidad de Santander” meteorological station was evaluated to obtain monthly rainfall figures. The highest-yielding structure was the Motilón building, with approximately 80 m³ in the months of May and November, 2018, as this structure has the largest roof area, and the area experienced its greatest quantity of rain during these months. The total accumulation predicted by the study was 1837.96 m³ annually, sufficient to suggest the possibility of its use in restrooms, gardens, and floor washing at the “Universidad de Santander”, Bucaramanga, Colombia. The volume of water calculated is variable on a yearly basis, and was estimated by means of one year of rainfall readings from the university’s meteorological station. Hydraulic structures designed for the purpose of capturing this water would require a specific study, taking into account the records of other nearby meteorological stations, and making necessary provision for the storage of water in excess of expected volumes.

1. Introduction
Fresh water demand and wastewater generation worldwide is comprised of 70% for agricultural irrigation and drainage, 11% for municipal consumption and sanitation, and 19% for industrial use [1]. Agricultural use includes the irrigation of green areas during dry periods. For example, when rainfall is low, the Universidad de Santander uses approximately 30 cubic meters of drinkable water monthly for the irrigation of its soccer field, alone - enough to supply three average Bucaramanga homes, Colombia [2].

Global climate change triggered by air pollution and greenhouse gas-induced warming has altered rainfall patterns across the country and surrounding region. Added to the misuse and waste of available drinking water, these changes spell concern for the future of our most vital resource. It is within this context that the present study undertook to determine the annual volume of water catchable from university campus buildings and usable for irrigation, washing floors, and supplying toilets [3,4].
To achieve this goal, data was collected from all the pluviometric stations within the Bucaramanga metropolitan area, Colombia, with a data history of at least 5 years, and recorded in “Instituto de Hidrología, Meteorología y Estudios Ambientales (IDEAM)” databases. rooftops with a potential for water capture were qualified according to their topographic and architectural characteristics [5]. To carry out the hydrological study, historical rainfall data was downloaded from the measuring stations, and the relevant calculations and models were created based upon geographical location, data age, and the accuracy of the measuring equipment in use [6,7]. With all the information processed, the volume of annual rainwater catchable at the cacique lakes campus was determined. The water in question would be suitable for irrigation of gardens, washing of external floors, and use in sanitary facilities. This project was developed in compliance with the green environmental policy of the Universidad de Santander, and with a view towards strengthening the university’s green metric international ranking [8]. The study was carried out with the aid of a wireless meteorological station, which allows for later studies to implement an artificial intelligence-based system for the recording and analysis of data. By this means, students at the “Universidad de Santander” and the larger scientific community benefit from the existence of the technological tools needed to make efficient use of water resources.

2. Methodology
To determine the annual volume of catchable water that could be used for activities such as watering gardens, washing floors, and flushing toilets, a hydrological study was carried out of the area surrounding the university, identifying possible points of collection and storage, and taking into account the necessary infrastructure that would be required [9].

The investigation began at the IDEAM, with data from local rainfall and runoff measurement stations. The data depends on the location of the station, therefore, the closest and most representative for the university was chosen, from which the required IDF curves were derived. In this analysis, \( I = \text{rain intensity}, D = \text{rain duration}, \) and \( F = \text{rain frequency}. \) According to the Ras 2000, hydrological studies [10], before designing water systems, one should take into account the "hydrographic characteristics of the basin, data, information, or estimates of the maximum and minimum water levels of the source in the place where the catchment will be built, if possible, using the most probable values", in order to obtain results closest to reality. The same publication recommends using sources with at least 20 years of historical data [10]. Nevertheless, in the current study, the scarcity of information available from the area of the university necessitated using data sources with at least 5 years of continuity [9,11].

With the preliminary data thus obtained, the university’s afferent area was then analyzed by means of the equation \( Q = C^*I^*A, \) where \( C = \text{runoff coefficient}, I = \text{intensity}, A = \text{afferent area or basin}. \) Equivalently, the basins can be modelled using programs such as Hec-Ras, EpacSwim, qual2k, or Arcgis [12,13].

The final data analysis estimates the amount of water catchable over a year, based on the array of possible methods and models, and takes into account the winter and summer seasons, the amount of water that can be reused, and the potential savings of currently-used drinking water [14,15].

3. Analysis and discussion of results
The current study calculated the areas of the building roofs from which water could be captured, as set out in Table 1.

| Building | Area (m²) |
|----------|-----------|
| Guane    | 474.70    |
| Motilón  | 628.01    |
| Arhuaco  | 403.19    |
| Chibcha  | 590.04    |
| Yariguíes| 227.88    |
| Total    | 2323.82   |
In the absence of specific values for the “Universidad de Santander” campus, this study employed the intensity, duration and frequency curves of the nearby “Universidad Industrial de Santander”, as shown in Figure 1. According to local roofing codes and climate conditions for the campus, the Ras 2000 [10] establishes a return period of 10 years with a duration of 30 minutes for the flow.

![Figure 1](image-url)  
**Figure 1.** IDF curves of the Universidad Industrial de Santander meteorological station. Adapted from [16].

With the intensity obtained using the duration and return period, the collection rate was calculated based on the runoff coefficient of the capture surface (see Equation (1)) [10].

$$Q_{\text{cap}} = C \times I \times \left( \frac{A_o}{10000} \right)$$  \hspace{1cm} (1)

Where: $Q_{\text{cap}}$ = collection rate ($\text{m}^3/\text{s}$), $C$ = Runoff coefficient, $I$ = intensity ($\text{L/s}$), and $A_o$ = area ($\text{m}^2$), of the roofs of the campus buildings.

Table 2 sets out the flows calculated based on the intensity, duration and frequency curves (Figure 1) provided by the IDEAM. Flow rates were calculated for a variety of return periods, in order to ensure a sufficiently broad design range for possible future plumbing connections from the campus roofs to storage sites – a goal for future studies. It can be noted that during the highest return period, significantly increased flows are obtained, thus, hydraulic designs will require larger diameter tubing for water capture. Between the 2 and the 100-year return periods, the flow rates approximately double, and the design will also depend upon the specifications outlined by the relevant construction codes [10].

| Period return (Years) | Runoff coefficient (Dimensionless) | Intensity (mm/hr) | Afferent area (hectare) | Flow (Lt/sec) | Flow (m$^3$/sec) | Maximum flow (m$^3$/sec) |
|-----------------------|-----------------------------------|------------------|--------------------------|--------------|----------------|-------------------------|
| 2                     | 0.9                               | 64.40            | 2323.82                  | 374434.33    | 374.43         | 449.32                  |
| 3                     | 0.9                               | 70.90            | 2323.82                  | 412226.61    | 412.23         | 494.67                  |
| 5                     | 0.9                               | 78.20            | 2323.82                  | 454670.26    | 454.67         | 545.60                  |
| 10                    | 0.9                               | 87.30            | 2323.82                  | 507579.45    | 507.58         | 609.10                  |
| 25                    | 0.9                               | 98.90            | 2323.82                  | 575024.15    | 575.02         | 690.03                  |
| 50                    | 0.9                               | 107.40           | 2323.82                  | 624444.83    | 624.44         | 749.33                  |
| 100                   | 0.9                               | 115.90           | 2323.82                  | 673865.51    | 673.87         | 808.64                  |
The annual volume of catchable rainwater was calculated according to the data obtained from the “Universidad de Santander” meteorological station (see Equation (2)).

\[ V_{\text{cap}} = C \times P \times \left( \frac{A_o}{10000} \right) \]  

(2)

Where: \( V_{\text{cap}} \) = collection volume (m\(^3\)), \( C \) = Runoff coefficient, \( P \) = daily precipitation (mm), \( A_o \) = area (m\(^2\)) of the roofs, and Runoff coefficient = 0.9.

Figure 2 shows the monthly volume of water that could be obtained from each of the buildings analyzed at the “Universidad de Santander”. Variation between buildings occurs due to the different cover area of each building; under the same rain intensity conditions greater cover area will yield more water. Rainfall was greatest during the months of May and November, 2018; with lower capture during the months of December and January. Additional studies will be required to establish monthly requirements for water usage, in order to take best advantage of the rainy season.

Figure 3 indicates the monthly and accumulated rainwater volumes for the five buildings analyzed over the course of one year. Taken altogether, the total accumulated annual volume is estimated at 1837.96 m\(^3\). The quantity calculated would be increased by adding the roof area of the buildings not yet studied. Including these structures would allow for water storage connections to be designed which would improve the availability of hydro resources in the university.
4. Conclusions
Based on the meteorological conditions of the study area, the current paper calculates the volume of rainwater which could be captured and stored within tanks on the university campus. Further design work will be required to optimize this storage space on a basis of monthly capture rates, as well as to take into account the consumption of each building in terms of washing floors, irrigation in gardens, and use in toilets.

For example, in November, the largest single contribution (approximately 80 m³) was the Motilón building, with its covered area of 628.01 m²; however, even the Yariguíes building would collect a volume of nearly 30 m³ in the same month, with its covered area of 227.88 m².

The total volume captured by the five buildings analyzed was calculated to be 1837.96 m³ at the end of the year. In future work, the model could be adjusted each year using monthly rainfall figures, acquiring greater reliability with more historical data.

References
[1] Organización de las Naciones Unidas para la Educación, la Ciencia y la Cultura (UNESCO) 2017 Informe mundial de las Naciones Unidas sobre el desarrollo de los recursos hídricos 2017 (Francia: Organización de las Naciones Unidas para la Educación, la Ciencia y la Cultura)
[2] Van de Wouw P M F, Ros E J M and Brouwers H J H 2017 Precipitation collection and evapo(transpi)ration of living wall systems: A comparative study between a panel system and a planter box system Building and Environment 126 221
[3] Wu F, Cui X and Zhang D-L 2018 A lightning-based nowcast-warning approach for short-duration rainfall events: Development and testing over Beijing during the warm seasons of 2006–2007 Atmospheric Research 205 2
[4] Huang W, Chang S-Q, Xie C-L and Zhang Z-P 2017 Moisture sources of extreme summer precipitation events in North Xinjiang and their relationship with atmospheric circulation Advances in Climate Change Research 8 12
[5] Rahimpour Golroudinary V, Zeng Y, Mannaerts C M and Su Z B 2017 Detecting the effect of urban land use on extreme precipitation in the Netherlands Weather and Climate Extremes 17 36
[6] Moses O and Ramonoto S 2018 Assessing forecasting models on prediction of the tropical cyclone Dineo and the associated rainfall over Botswana Weather and Climate Extremes 21 102
[7] Huang W-R, Chang Y-H and Liu P-Y 2018 Assessment of IMERG precipitation over Taiwan at multiple timescales Atmospheric Research 214 239
[8] Gong C and Hu C 2017 The research of gray space design of architecture based on green stormwater infrastructure application Energy Procedia 115 219
[9] Lewis E, Quinn N, Blenkinsop S, Fowler H J, Freer J, Tanguy M, Hitt O, Coxon G, Bates P and Woods R 2018 A rule based quality control method for hourly rainfall data and a 1 km resolution gridded hourly rainfall dataset for Great Britain: CEH-GEAR1 hr Journal of Hydrology 564 930
[10] Ministerio de Desarrollo Económico 2000 Reglamento técnico del sector de agua potable y saneamiento básico, RAS 2000 (Colombia: Ministerio de Desarrollo Económico)
[11] Iwashita H and Kobayashi F 2019 Transition of meteorological variables while downburst occurrence by a high density ground surface observation network Journal of Wind Engineering and Industrial Aerodynamics 184 153
[12] Rodriguez H A and Matamoros H 2017 Rehabilitación de sistemas de alcantarillado (Colombia: Editorial Escuela Colombiana de Ingeniería)
[13] Rodriguez H A 2013 Drenaje urbano elementos de diseño drenaje no convencional (Colombia: Editorial Escuela Colombiana de Ingeniería)
[14] Dhib S, Mannaerts C M, Bargaoui Z and Retzios V 2017 Maathuis, B.H.P. Evaluating the MSG satellite Multi-Sensor Precipitation Estimate for extreme rainfall monitoring over northern Tunisia Weather and Climate Extremes 16 14
[15] Pérez R 2013 Diseño y construcción de alcantarillados sanitario, pluvial y drenaje en carreteras (Colombia: Ecope Ediciones)
[16] Instituto de Hidrología, Meteorología y Estudios Ambientales (IDEAM) 2019 Curvas de intensidad, duración y frecuencia (Colombia: Instituto de Hidrología, Meteorología y Estudios Ambientales)