Design of Individual and Community-Scale Rainwater Harvesting Systems for Domestic Water Use in Austin, Texas

Gary Gold
GIS in Water Resources, Fall 2013
Department of Civil, Architectural, and Environmental Engineering
The University of Texas at Austin

Table of Contents

Introduction

Diminishing water supplies across the United States has led policymakers to look toward rainwater harvesting (RWH) as a viable water-conservation strategy. Currently, twelve states have enacted legislation such as tax incentives and building mandates to encourage rainwater capture. The Texas Water Development Board (TWDB 2006), in particular, sees vast potential in RWH "to generate additional water supply in urban and suburban settings (TWDB 2006)" and passed a mandate requiring all government buildings with roof area greater than 50,000 square feet to incorporate RWH into designs (NCSL 2013).

The costs associated with installment, operation, and maintenance of RWH systems are often financially prohibitive. Economic analyses indicate that the water-saving benefits do not justify the investment for private developers (Hicks 2008). One solution to alleviate the cost burden is a communal approach to RWH, which allows users to share the financial investment (Cook et al. 2013). In a community-scale RWH system, rainwater is collected at individual houses and moved to a shared storage facility where it can be redistributed for use by the participating houses in the neighborhood. The communal approach to RWH offers a mechanism to distribute the costs associated with water storage and treatment amongst multiple users.

The goal of this project is to investigate the potential of both the typical, independent RWH approach and the communal RWH system to supply domestic water for residences in Austin, Texas. The eleven-house neighborhood along 13th Street between Comal and Angelina, shown in Figure 1, was used as a case study for this RWH investigation. The questions to be answered in this evaluation of RWH feasibility are 1) what size storage tank is required for each individual house to meet household water needs through independent RWH and 2) what size storage tank is required for a communal system in the neighborhood. Through the use of ArcGIS and a Microsoft Excel model, these RWH design questions will be explored.

Figure 1: Case study neighborhood

One of the objectives in this project is to evaluate RWH from a new perspective and to explore aspects of RWH not investigated in previous RWH studies in the Austin area. The communal RWH system designed in this project offers a unique approach to rainwater collection for Austin. Another distinctive feature of this study is the use of a daily water balance in calculating expected storage. A majority of existing RWH studies for Central Texas conduct a water balance using monthly water-use as system output and mean or median monthly precipitation as the system input. Due the daily variability of precipitation, average monthly values may not be a valid indicator of rainwater collection potential. Rainfall variability is more accurately accounted for by taking daily rainfall values. This project aims to offer a more accurate approach to RWH investigation by conducting a daily water balance in design and analysis. By adopting a daily approach and investigating the communal design, this project aims to offer a new perspective on RWH for the Austin area.

Another central goal in this study is to demonstrate how Geographic Information Systems (GIS) can be used as a tool to collect, process, and communicate the information required for RWH system design. ArcGIS will be used in this investigation to acquire and organize information on the neighborhood, determine catchment areas, and to display results on a series of maps. By exploring GIS tools that aid in computation and communication, this project aims to show how ArcGIS can be utilized effectively for the design of RWH systems.

Methodology

Data Acquisition and Model Assumptions

Rainfall Data

The precipitation data used for this project is daily rainfall totals over a twenty-year period, from 1978 to 1997, collected at the Austin Bergstrom Airport gaging station operated by NOAA.

Water Usage

The RWH systems evaluated in this study will be designed for sole-source domestic use. This criteria means that rainwater is used for all household purposes in a self-sufficient system that does not require outside water supply on a regular basis. On the irregular occasion that rainwater storage drops below demand requirements, it is assumed that water will be trucked-in to refill the existing storage cisterns.

In designing systems for sole-source domestic use, TWDB recommends RWH cisterns to be sized for water usage rates between 25-50 gal/day for each occupant (TWDB 2005). The assumed water usage rate in this study is 45 gal/day for each occupant, a relatively high assumption based on the TWDB recommendation. The higher usage rate and will allow for a conservative design of rainwater storage tanks.

Rainfall Collection Efficiency

In projecting rainfall collection based on roof area, TWDB provides an estimate that 0.62 gallons of rainwater is collected per square inch of roof area. Additionally, the recommended efficiency of rainwater collection is 85% (TWDB 2005). These factors are both incorporated in the model described below.

Determining Catchment Area and Community-Scale Layout

In addition to providing tools to communicate results, ArcGIS was a valuable tool in organizing information into feature classes, estimating catchment areas, and designing the community-scale RWH layout. Using an ArcGIS basemap, the eleven houses in the case-study neighborhood were identified. A feature class titled “Catchment” was created to store information about the roof of each house. These roofs were outlined with the “editor” tool and added to the Catchment feature class as vectors. The Catchment feature class automatically calculates the area of each of the outlined roofs, a necessary parameter used to estimate potential rainwater collection in the model. As a check of the accuracy of the roof areas calculated in the feature class table, the areas were measured using the ArcGIS measure tool and using tools in Google Maps. All of these methods yielded similar values for roof area, and ultimately the area reported in the Catchment feature class table was used as the model input.

ArcGIS was also valuable in locating and designing the site for the community-scale storage cistern. Once the community-scale storage requirement was evaluated, it was necessary to find a viable location of the water storage tank and design the dimensions. An empty lot in the northeast corner of the neighborhood was located and the area was measured in ArcGIS. Ultimately, it was determined the lot was of adequate size, and the design storage tank was sized based the lot dimensions and added as a new feature on the ArcGIS map. The measuring and mapping tools in ArcGIS aided in determining model parameters, organizing information into feature classes, and designing the layout for the communal RWH design.

Model Calculations

Daily Water Balance

Using the data, assumptions, and measurements described above, daily rainfall collection is calculated by the model from Equation 1:

$$V_{in} = 0.85 * 0.62 * P * A \quad \text{(Equation 1)}$$

where V_{in} is the daily rainfall input to the cistern in gallons, P is the daily precipitation, and A is the roof area is square feet.

The daily volume leaving the storage cistern is calculated from Equation 2:

$$V_{out} = 45 \frac{gal}{day} * number\ of\ occupants \quad \text{(Equation 2)}$$

The net tank storage is then calculated by subtracting V_{out} and adding V_{in} to the storage of the previous day as follows:

$$S_{i+1} = S_i + V_{in} - V_{out} \quad \text{(Equation 3)}$$

where S_{i+1} represents the amount of water stored in the tank at the end of any given day. It is assumed that additional water supply would be trucked-in by a local provider and used to refill the existing tanks when storage drops below the "alarm level." The alarm level was set at 1.5 times the daily use for the given house. Additionally, if storage reaches capacity, the model assumes that any extra rainwater is discharged as overflow.

Using Equation 3 and potential design sizes for the two scenarios discussed in the following section, daily water storage was calculated for each day of the 20 years on record. The number of required tank refills during this period was counted and used as the parameter to determine the design storage requirement.

Design Cases

For cistern sizing, two different cases were analyzed. Case 1 assumes that the user refills the storage cistern an average of one time per year while Case 2 assumes the user refills the cistern an average of two times per year. Hence, the maximum number of refills during the 20-year period was 20 for Case 1 and 40 for Case 2. Using the water balance model, cistern sizes were tested in increments of 5000 gallons. The daily water storage and the number of refills over the 20-year period were evaluated for both Case 1 and Case 2 scenarios. Based on the daily water balance, the design storage tank was set to the minimum size that would allow the given household to maintain a refill count at or below the design criteria.

Using this methodology, the required cistern size was first estimated individually for each of the eleven houses using both the Case 1 and Case 2 criteria. These design sizes represent the required storage tank at each house to enable a RWH system to provide sole-source water supply if RWH is operated independently at each residence. Following the independent storage analysis, the communal storage requirement was calculated by adding the design storages for all of the eleven houses in the neighborhood.

In addition to determining the required volume for communal storage, dimensions for the shared storage tank were designed based on the required capacity. These possible storage designs are shown on the following maps and placed on the vacant lot in the northeast corner of the neighborhood. The following results section displays a few potential designs for communal storage cisterns for both the Case 1 and Case 2 criteria in addition to the individual storage requirements for each of the eleven houses

Results

Figure 2: Annual Average Rainwater Collection

The map in Figure 1 displays the average annual rainwater collection calculated by the model for each of the residences. Rainwater collection varies depending on roof area and this map offers an indication of the additional water supply that can be generated through RWH for houses in the neighborhood.

Figure 3: Storage Cistern Design for Case 1

The map in Figure 2 displays the design storage cistern sizes for Case 1 criteria of approximately one outside-source refill per year. It was determined that 8 out of the 11 design sizes are reasonable, between 10,000 and 15,000 gallons. The high occupancy residences required cistern sizes greater than 20,000 gallons, which are excessively large for individual houses. For the 8 residences with design sizes of 10,000 or 15,000 gallons, it is concluded that rainwater collection is a feasible mechanism to meet domestic water demand in this design case.

Figure 4: Storage Cistern Design for Case 2

For Case 2 design, approximately two refills per year, the cistern size requirements are slightly smaller, as shown in Figure 3. The design sizes of 5,000, 10,000, and 15,000 gallons are reasonable for individual residences. Based on this criteria, it is determined that 9 of the 11 houses in the study can meet domestic water needs by rainwater collection.

Figure 5: Community-Scale Design for Case 1

The tank in Figure 5 offers a design for communal rainwater storage for the neighborhood based on Case 1 criteria. The tank capacity meets the storage requirement of the neighborhood, enabling all of the houses to meet domestic water demand with rainwater storage at a shared facility. However, this single storage tank excessively large and may not be a reasonable approach.

Figure 6: Community-Scale Design for Case 1

The concurrent tanks shown in Figure 6 offer a more reasonable design of communal rainwater storage for the yearly refill scenario. However, due to the large storage requirement of the Case 1 criteria, it was concluded that a Case 2 design for communal rainwater storage is a more suitable approach for the neighborhood.

Figure 7: Community-Scale Design for Case 2

The shared storage tank shown in Figure 7 offers a practical approach to communal RWH for the neighborhood. The required storage for this design case is approximately 130,000 gallons. Incorporating a safety factor of 1.5, the design tank above offers a mechanism of rainwater storage to meet the domestic water needs of the entire neighborhood.

Discussion

This section analyzes the results presented above and provides comments on the feasibility of each of the RWH system designs considered for the neighborhood.

For the investigation of communal rainwater storage, the design shown in Figure 7 offers the most practical approach to a shared storage facility amongst the configurations offered in this study. This design is based on the storage estimation for the Case 2 semiannual refill criteria, which requires approximately 130,000 gallons of rainwater storage for the neighborhood. The storage tank shown in Figure 7 supplies over 200,000 gallons in storage capacity and incorporates a safety of approximately 1.5 into the design, meaning additional water can be collected during wet seasons. Fitting comfortably in the vacant lot, this tank would enable the community to meet indoor water demands with rainwater in a relatively sustainable system, with additional water being supplied approximately twice per year. The community storage design shown in Figure 7 offers an effective and practical option for communal rainwater harvesting in the case study neighborhood.

The configurations shown in Figures 5 and 6 offer possible design for Case 1 criteria of additional water being supplied approximately once per year. These designs, however, require excessive quantities of rainwater storage and may be impractical from an economic and land-use standpoint. For this design scenario, a total storage of 260,000 gallons is required to meet the estimated water demand for the neighborhood. In this analysis, two different tank designs are presented; the first is a single storage tank displayed in Figure 4 and the second is two cistern design displayed in Figure 5. Both of these storage configurations offer the required collection capacity, however, may not be practical from a design standpoint due to their excessive sizes. It is therefore concluded that the design suggested in Figure 7 requiring semiannual refills may be more appropriate for a communal rainwater-storage facility in the neighborhood.

The rainwater systems in this investigation are designed for “sole source” domestic use, meaning they are planned such that no outside water supply should be required on a regular basis to meet household needs. A valid question that arises is how many times is reasonable to refill a “sole-source” RWH system with supplementary water? A nearby rainwater harvester who was consulted for this project reports having additional water trucked-in approximately every five to six months for his current system, which has been operating for twelve years (Smith 2012). In modeling a system that operates similar to that of this user, the Case 2 criteria of semiannual refills is reasonable in that it requires additional water supply approximately twice per year. Therefore, it is concluded that the communal RWH design displayed in Figure 7 is reasonable based on the expected capability of the system to meet the domestic water demand of the neighborhood.

In addition to the communal rainwater storage design for the neighborhood, potential for rainwater collection as well as the independent storage requirements were investigated for each house. Figure 1 displays results for annual rainwater collection potential. These values were calculated by averaging the yearly totals for 20 years on record and offer an estimation of the additional water supply that can be generated through RWH at each residence. Estimates for the houses vary based on roof area: yearly rainwater collection ranges from 15,000 gallons for small roofs to close to 70,000 gallons for houses with large roof area. This evaluation of collection potential is in the range of estimates provided by a rainwater harvester in nearby Dripping Strings, Texas consulted during this study, who reports yearly collection of 30,000-40,000 gallons per year. When the site specifications from this existing system were input into the model, the yearly collection calculation was approximately 36,000 gallons, indicating the expected collection estimated in the model is reasonable. The collection potential computed by the model suggest that RWH can generate significant quantities of additional water to meet domestic demand for the neighborhood.

The Case 1 analysis for an average of one refill per year indicates that independent RWH is feasible at most, but not all locations in the neighborhood based on the required cistern size. Results for required cistern sizes for Case 1 independent-storage are displayed in Figure 3. The residences of 1401, 1403, and 1404 E. 13th street require storage cisterns greater than 20,000, which are prohibitively large for a single residence. The main reason that these houses required unreasonably large storage tanks is the high occupancy at these sites. Currently, there are five occupants at 1401, seven occupants at 1403, and four occupants at 1404. The high occupancy drives up cistern size requirements significantly in the model used for this analysis.

For eight of the eleven houses in the neighborhood, meeting domestic needs through RWH is concluded to be feasible if an average of one tank refill per year is anticipated. As displayed in Figure 3, eight residences required cistern sizes of 10,000 or 15,000 gallons in order to store adequate rainwater to meet domestic demand. These design sizes are reasonable tank requirements for a RWH system and it is therefore concluded that RWH is a viable option for these sites based on the annual refill criteria.

In the independent-storage design for Case 2, an average of two refills per year, it is determined that RWH is feasible for nine of the eleven residences. As displayed in Figure 4, a majority of the houses required tank sizes of 5,000, 10,000, or 15,000 gallons, which are practical requirements for rainwater storage at individual residences. Thus, RWH with independent storage is concluded to be feasible at nine of the eleven houses based on the design for approximately two refills annually.

Based on the analysis performed in this project, domestic water needs can be supplied by rainwater collection in this Austin neighborhood with either a system of independent units or a communal storage facility. The design requirement for independent storage at each house suggests that RWH is possible at most residences, with the exception of high-occupancy households. Another viable option is a communal storage system, which would enable all the residents of this neighborhood to utilize rainwater for domestic use with storage in a shared facility. This shared storage tank would allocate the costs of installation, operation, and maintenance of RWH amongst the residents of neighborhood, easing the economic costs RWH for individual users. This investigation into independent and communal RWH indicates vast potential for efficient use of rainwater to provide domestic water supply for this case-study neighborhood in Austin.

Conclusions and Future Work

Rainwater collection presents an exciting opportunity for individual households as well as entire neighborhoods to live off of self-sufficient water distribution systems. In particular, a communal storage facility offers a mechanism for residential users to sustainably meet domestic water needs while simultaneously sharing the financial burden associated with rainwater collection units. The economic costs of RWH, a significant deterrent for domestic users, can be reduced by implementation of a community-scale system. The analysis conducted in this project suggests that individual and communal

RWH can be practical and effective options to provide domestic water supplies and help alleviate the strain on municipal water resources.

In addition to investigating the feasibility of RWH in Austin, this project demonstrates the application of GIS tools for rainwater storage design. The mapping and analysis tools provided in ArcGIS are valuable in acquiring and organizing geographic information of the neighborhood, measuring catchment area, and communicating results on informative maps. These tools and other GIS capabilities will be used in future work with the hope of integrating spatial, temporal, and economic factors of RWH into a single model. Potentially, this model can provide estimations of the overall implications of RWH with respect to water supply, energy requirements, and economic tradeoffs. If economic barriers can be overcome, meeting domestic water demand through rainwater collection will be a foreseeable option for Austin communities.

References

Cook, Steven; Sharma Ashok; Chong, Meng. “Perfomance Analysis of a Communal Residential Rainwater System for Potable Supply: A Case Study in Brisbane, Australia.” *Water Resource Management.* 11 September 2013.

Hicks, Bill. “A Cost-Benefit Analysis of Rainwater Harvesting at Commercial Facilities in Arlington County, Virginia.” Duke University. 2008.

National Conference of State Legislatures (NCSL). “State Rainwater Harvesting Statutes, Programs, and Legislation.” Web 15 November 2013. <http://www.ncsl.org/issues-research/env-res/rainwater-harvesting.aspx>.

Smith, Keenan. “Rainwater Collection: The Villa Caliche.” *Rainwater Revival 2012.* PowerPoint presentation. 20 October 2012.

Texas Water Development Board (TWDB). “Rainwater Harvesting Potential and Guidelines for Texas.” *Report to the 80th Legislature.* November 2006.

Texas Water Development Board (TWDB). “The Texas Manual on Rainwater Harvesting: Third Edition.” Austin, Texas. 2005.