EVALUATION OF RAINWATER HARVESTING WITH CLOUD-BASED INFRASTRUCTURE AS A STORMWATER CONTROL MEASURE

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ABSTRACT

Although rainwater harvesting systems are designed to capture and use stormwater, use of this practice as a stormwater control measure (SCM) in Colorado is rarely seen as a viable alternative. First, the practice does not typically provide the volume required to capture the water quality capture volume (WQCV) when it rains because the cistern may already be full. Second, western water law dictates that diverting and using rainwater for beneficial use is illegal without a water right.

This study pairs rainwater harvesting with cloud-based infrastructure in an effort to increase available volume in the cistern when there is a forecast for precipitation. This type of automated system can be used to address stormwater treatment using a smaller footprint than would be required for conventional methods because it better utilizes the volume of SCMs in series. Additionally, communities with combined sewer overflows (CSOs) can use this type of system to “beat the peak” and reduce the volume of untreated wastewater entering the receiving water. UDFCD is using this data to determine if this type of configuration, utilizing automated controls at the outlet, is an effective tool in managing stormwater, and if this in combination with rainwater harvesting provides a more effective control measure than rainwater harvesting alone. Three years of data have been collected and analyzed.

INTRODUCTION

Conventional rainwater harvesting systems provide stormwater runoff volume reduction while also enabling use of stormwater for other water demands on site. However, they cannot be relied on for consistent stormwater treatment. The practice does not typically provide the volume required to capture the WQCV when it rains because the cistern may already be full. This practice is further complicated in Colorado where western water law dictates that diverting and using rainwater for beneficial use is illegal without a water right.

In 2012, Urban Drainage and Flood Control District (UDFCD) applied for a temporary permit from the State allowing for the construction of an above ground rainwater harvesting system on a new school building owned by Denver Public Schools (DPS). Per water law in Colorado, this system requires detailed accounting and augmentation.

The project is part of a Water Environment Research Foundation (WERF) study on high-performance SCMs that utilize cloud-based infrastructure. At this site, an 11.3 cubic meter (3,000-gallon) cistern collects rainwater from the roof of a school building and uses it for irrigation of the adjacent landscape areas. When available, the cistern will capture a rainfall depth of approximately 18 mm (0.7 inches), slightly larger than the water quality rainfall event in the Denver area. What makes this design unique and specifically designed for treatment of stormwater is that the system has a real-time connection to NOAA weather forecasting and will drain prior to an event, commensurate with the forecast, so that the volume is available for stormwater capture. The controls for this system are fully automated and can also be controlled remotely. The equipment assembly used to release and measure water evacuated from the system, as well as the software utilized for this purpose, was developed by Geosyntec Consultants.

OptiRTC software, developed by Geosyntec Consultants, was used to provide data monitoring and automated control for the rainwater harvesting system. OptiRTC aggregates data from a number of components at the site and provides a cloud-based platform and real-time data for analysis and visualization on a web dashboard. At this site, it also provides an adaptable system based on algorithms programed by Geosyntec Consultants. The system monitors NOAA weather forecasting and will purge the cistern in advance of a rain event of a user-specified probability. For this site, determining the appropriate probability required close monitoring of storm events. Following initial monitoring of the system, Geosyntec recommended and set the probability to 60 percent. When the chance of a rainfall event is 60% or greater, the system will evaluate the volume available in the cistern and if necessary will purge the cistern to ensure that that volume is available. For example, if NOAA forecasting predicts a 13 mm of rain with a 60 percent probability and the cistern is full, a valve will automatically open and drain the cistern commensurate with the rooftop tributary area multiplied by 13 mm multiplied by a user-defined runoff coefficient.

The primary goals for this study were to evaluate how using automated controls at the outlet of a SCM could improve efficiency and to evaluate how effective rainwater harvesting in a semi-arid climate could be for stormwater management and irrigation supply water. This project is a partnership consisting of UDFCD, WERF, and DPS. The project is also made possible by an Urban Watershed Research Institute research grant, Denver Water's augmentation of rainwater used for irrigation, and the Denver Green School, where the system is located.

Figure 1 shows the configuration of the rainwater harvesting system.

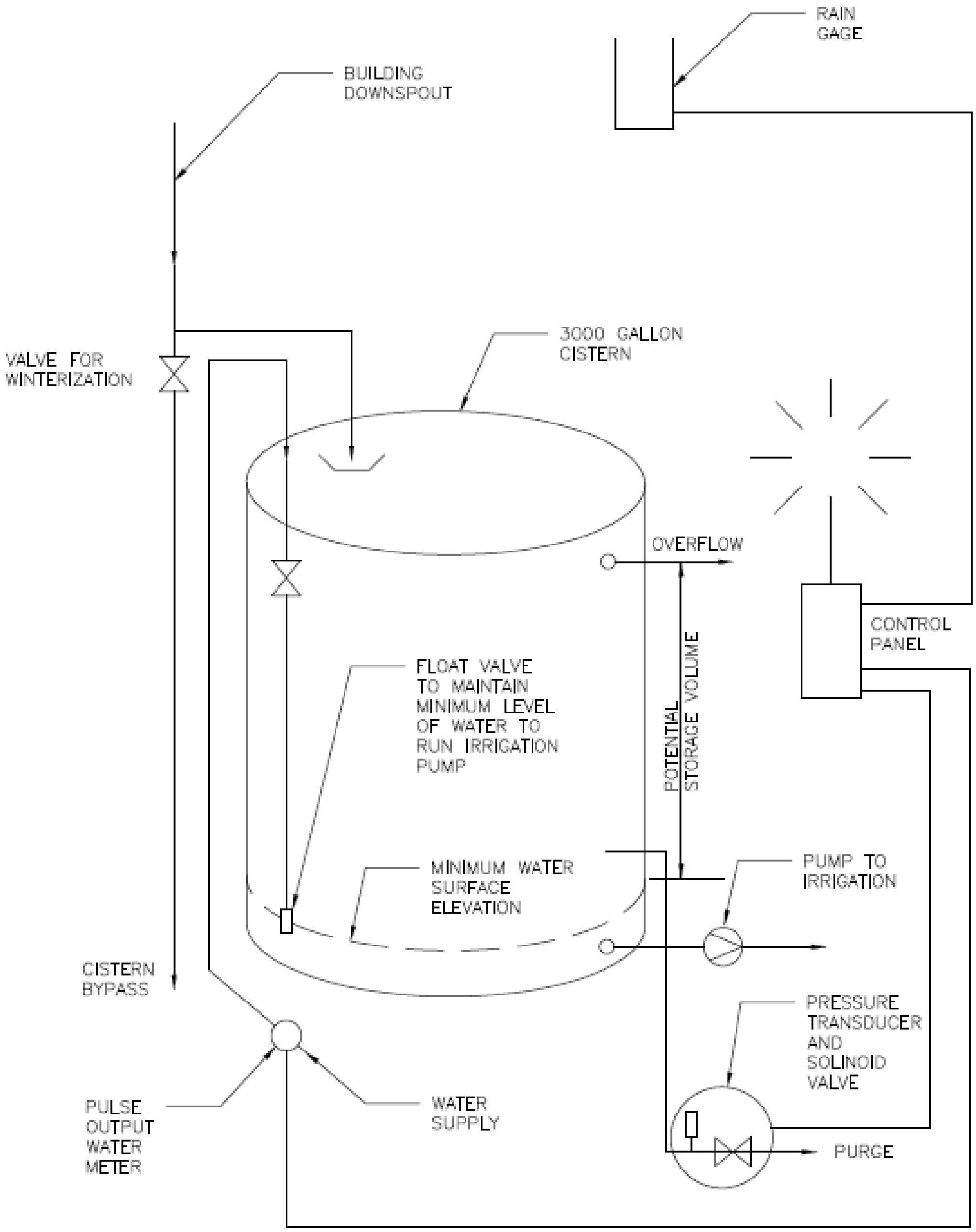

Figure 1. DGS rainwater harvesting schematic.

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This area of Colorado receives approximately 380 mm (15 inches) of precipitation per year. The system was designed to provide irrigation water for surrounding landscape areas from mid-April through September. Approximately two-thirds of the total annual precipitation is anticipated during this timeframe. Historically, May is the wettest month, receiving over 51 mm (2 inches) on average and September is the driest month receiving less than 25 mm (1 inch).

WQ-COSM, a continuous simulation model was used to assist in sizing the cistern. This is a statistical model used for optimizing water quality capture volume. Thirty years of rainfall data for the Denver area were used to run the model. It was assumed for the purpose of this evaluation that all stored runoff would be used over a period of 72 hours. Based on the output of the model an 11.3 cubic-meter (3,000-gallon) cistern was selected. Based on the assumptions used in running the model, this size cistern should capture approximately 85 percent of the total precipitation during the period from April through September. Considering dead storage and the elevation of overflow for the constructed cistern, less than 85% should be anticipated. The area of the roof draining to the cistern is approximately 678 square-meters (7,300 square-feet). For this watershed, a 11.3 cubic-meter (3,000-gallon) cistern corresponds to a capture volume that is associated with approximately 18 mm (0.7 inches) of rainfall. The water quality capture volume in this area is the runoff volume associated with 15 mm (0.6 inches) of rainfall which corresponds to the 80^{th} percentile event.

The size of the landscaped area to be irrigated with this water was not a consideration in designing the cistern. However, water use is relevant to the study and irrigation data are included in this paper. The area of irrigation can be described as follows: in 2012, when the project began, three irrigation zones were established and planted with drought tolerance species. Two areas contain perennials and one area was seeded with grasses. The total area to be irrigated was approximately 186 square-meters (2,000 square-feet). In 2013, additional perennials were planted and the irrigation schedule for establishment of new plants continued in all three zones. At the end of 2013, several plants in zone one and two were lost due to school kids trampling the area. Zone one also had clay soils and very high sun exposure that did not support the perennials. In May 2014, the school decided to stop irrigation in zone one and created different use for this area. The school received a donation at the same time for new perennials in zone two and three. For these reasons, irrigation demand has been relatively consistent because every year it has been scheduled to help establish new plantings. However, it should be noted that the area of irrigation was reduced from approximately 186 square-meters (2,000 square-feet) to approximately 111 square-meters 1,200 square-feet beginning in 2014.

DATA AND ANALYSIS

Volume reduction and irrigation supply. This paper includes all data collected from September 25, 2012 through September 11, 2014. On average for all data collected, the system reduced stormwater runoff on a per event basis by 88 percent and provided 76 percent of the irrigation demand.

In 2012, the Probability of Precipitation (PoP) was set at 70 percent. This means that when the rain forecast shows a 70 percent or greater chance of precipitation, the solenoid valve will enable, allowing the release of water commensurate with the volume needed to capture the forecasted precipitation. In September 2012, the cistern overtopped twice. At no time during the two months of monitoring in 2012 was the solenoid valve enabled. A total of six rain events totaling 23 mm (0.9 inches) occurred during September and October 2012 and the system reduced stormwater runoff by 77 percent on a per event basis. It should be noted that stormwater purged from the cistern was considered reduced in calculating volume reduction. One hundred percent of the irrigation used in the surrounding landscape areas came from rainwater in 2012.

The cistern overtopped twice in July of 2013. The solenoid valve enabled on August 5th and again on August 6th allowing for 59 percent capture of a rain events totaling 18 mm (0.7 inches) on August 7th and 8th. In September 2013, the Denver area received widespread flooding. The rain gage at this site recorded 132 mm (5.2 inches) over three days, a value in excess of the one percent probability rainfall event. Eleven percent of this storm was captured. The solenoid valve was enabled twice in late September 2013 allowing for additional capture of subsequent storms although, more precipitation occurred then was forecasted. In mid-September 2013, the PoP was reduced to 60 percent. A total of 23 rain events totaling 274 mm (10.8 inches) occurred in June through September of 2013. On average, the system reduced stormwater runoff by 83 percent on a per event basis. Fifty-four percent of the irrigation used in the surrounding landscape areas came from rainwater in 2013.

In 2014, Denver experienced a particularly wet year with 43 rain events spaced relatively evenly throughout the season. The longest period of no precipitation was 19 days. The cistern overtopped twice in 2014. On July 14 the cistern overtopped during a rain event totaling 6 mm (0.25 inches), capturing 90 percent of this storm. On July 29th it overtopped again after capturing 26 percent of a 51 mm (2.0-inch rain event). The solenoid valve was enabled 16 times. This allowed for 100 percent capture of nine storms that followed purging of the cistern. It should be noted that on four occasions the solenoid valve was enabled twice prior to a single storm event. A total of 43 rain events totaling 196 mm (7.7 inches) occurred May through September 11^{th} of 2014. On average, the system reduced stormwater runoff by 92 percent on a per event basis in 2014. Ninety-one percent of the irrigation used in the surrounding landscape areas came from rainwater in 2014.

Water quality. In 2013, three samples were collected from the discharge pipe of the cistern or an irrigation head. Samples were tested for E. coli and other constituents. E. coli in all samples was below detection limits. Other constituents including nutrients and metals were below concentrations found in typical stormwater runoff in the Denver area. Detection of E. coli was not anticipated at this site as the roof of the structure has no tree cover and therefore, no apparent source for pathogens (i.e., birds).

PROJECT COSTS

The cost of the cistern, pump, and downspout totaled $4702. The cost of the OptiRTC was $15,000. This project received partial funding of the OptiRTC from WERF. Funding provided by WERF for the OptiRTC has not been included in the costs provided. All costs are based on actual cost paid in 2012. Denver Water provided augmentation of diverted rainwater at the cost of $100 per year.

CONCLUSIONS

Effectiveness of cloud-based infrastructure for stormwater management. Substantial volume reduction can be achieved by a pairing cloud-based infrastructure with on-site SCMs. Data from all years combined show an 88 percent volume reduction in the average storm event. This exceeds volume reduction reported by the International BMP Database for normally-dry vegetated BMPs (SCMs), which were found to be more effective than other BMPs in the database. Bioretention with underdrains was found to be most effective for volume reduction with over 50 percent reduction. (International BMP Database, 2011) This value of reduction can only be realize if the evacuated water from the cistern is discharged to a location where it can be used, infiltrated, or otherwise reduced. At this site, a second SCM could not be constructed for this purpose. However, given the slow rate of release from the cistern when the solenoid valve is enabled, it may be possible to achieve this on site with a minimal footprint. This type of system would also be effective in a community with a combined sewer overflow (CSO), where enabling the valve and releasing water from the cistern in advance of the storm event would allow a greater volume of water to be treated before the storm and a reduction in untreated wastewater entering the receiving water.

Effectiveness of rainwater harvesting for supplemental irrigation water in the Denver area. Rainwater harvesting can provide significant reduction in irrigation demand for sites with a large rooftop to irrigated landscape area ratio (e.g., 3:1). Other water saving techniques such as the use of rain sensors and native plants and grasses will improve the effectiveness of rainwater harvesting for supplemental irrigation water. Although the current cost of water is relatively inexpensive, (approximately three dollars per thousand gallons for residential use), the cost of a water tap can be a significant consideration (e.g., A 19 mm (three-quarter inch) water tap in the Denver area cost over $8000 and a 25 mm (1-inch) tap is in excess of $19,000). When a planned rainwater harvesting system is used to reduce the size of the required water tap, the cost savings could be in excess of the harvesting system infrastructure cost.

REFERENCES

International Stormwater Best Management Practices (BMP) Database. (January 2011). Technical Summary: Volume Reduction. Geosyntec Consultants and Wright Water Engineers, Inc.

Urban Drainage and Flood Control District (UDFCD) (2010). "Urban Storm Drainage Criteria Manual, Volume 3 – best management practices." UDFCD, Denver, CO; URL: http://www.udfcd.org/downloads/pdf/critmanual/Volume%203%20PDFs/USDCM%20Volume%203.pdf