Water Quality and Conservation Benefits Achieved via Real Time Control Retrofit of Stormwater Management Facilities near Austin, Texas

Brandon Klenzendorf[1], Michael Barrett[2], Marty Christman[3], Marcus Quigley[4]

[1] Geosyntec Consultants, 8217 Shoal Creek Blvd, Suite 200, Austin, TX 78757, work: (512) 451-4003, bklenzendorf@geosyntec.com
[2] Center for Research in Water Resources, The University of Texas at Austin, PRC Building 119, MC R8000, Austin, TX 78712, work: (512) 471-0935, mbarrett@mail.utexas.edu
[3] Geosyntec Consultants, 8217 Shoal Creek Blvd, Suite 200, Austin, TX 78757, work: (512) 451-4003, mchristman@geosyntec.com
[4] OptiRTC, 356 Boylston Street, 2nd Floor, Boston, MA 02116, work: (844) 678-4782, mquigley@optirtc.com

ABSTRACT

Real time control (RTC) systems can be used to retrofit existing stormwater management facilities in order to automate active control and operation of stormwater facilities. Using an internet-based control platform, RTC systems connect real time on-site data with forecasted precipitation events to make advanced decisions on how to operate the facility. Active operation of the facility can lead to benefits like enhanced extended detention for improved water quality and potable water conservation functions when compared to traditional passive operation of the facility.

Two case studies of real time control system retrofit installations near Austin, Texas will be presented with an overview of project-specific objectives, retrofit installation activities, control system setup and logic, and data collection and analyses. Monitoring data and forecasted weather information will be presented to show the effects of real time control systems on water quality and water conservation benefits. The first case study is a rainwater harvesting cistern that is actively managed to maximize beneficial water reuse, reduce wet weather flows, and improve water quality. System optimization has allowed for use of the harvested rainwater for nearby landscaping, or discharge to a rain garden when a rainfall event is forecasted. The second case study is an existing detention basin that is actively managed for reducing nonpoint source pollution by improving water quality during wet weather flows through enhanced extended detention of stormwater runoff. Water quality was monitored in the retrofitted pond and a nearby unmodified pond in order to assess the effectiveness of extended detention.

In today's digital age where tasks are increasingly managed through "smart" technology, real time control systems have the potential to be useful tools for municipalities, neighborhoods, or owners of commercial and industrial facilities. As urban populations continue to rise, water supplies will be further strained, resulting in increases to potable water costs. Real time control systems can be used to address critical water resource allocation problems without jeopardizing the stormwater control facility's ability to capture the required design volume. Real time control systems can also be used to address more stringent permit requirements with respect to water quality and environmental flows through enhanced extended detention and treatment of nonpoint source pollutants in stormwater runoff.

INTRODUCTION

Cities in the United States and elsewhere face on-going challenges effectively managing stormwater runoff from growing urban areas. Despite cities' efforts to manage runoff, combined sewer overflows

(CSOs) remain a major polluter of American waterways. Efforts to control CSOs have often focused on traditional, high-cost grey infrastructure; from 1970 to 2000, the Federal government spent $122 billion on wastewater infrastructure (Quigley and Brown, 2014). The City of New York has estimated that every gallon of untreated wastewater that reaches local waterways costs $1 to $2 to remediate. Many cities have implemented green infrastructure to reduce CSOs, using distributed low impact development best management practices (BMPs) to encourage the infiltration and detention of rainwater where it falls.

This paper examines the potential for stormwater managers to optimize the performance of existing green infrastructure via distributed real time control (RTC) technologies. Automated or semi-automated RTCs can optimize BMPs by connecting their operations with forecasted precipitation events and other key real time data. Retrofitting existing stormwater control infrastructure with RTCs can potentially help conserve potable water and improve water quality by increasing runoff detention time. This paper examines two RTC system retrofits near Austin, Texas. Project objectives, installation activities, control system setup and logic, and data acquired are discussed and analyzed. The projects are: 1) a rainwater harvesting cistern actively managed to respond to predicted rainfall and irrigation demands, and 2) a detention facility actively managed to increase detention times and improve water quality.

Previous modeling work by Quigley and Brown (2014) indicates that RTCs may substantially improve green infrastructure performance, significantly decreasing the volume of stormwater discharged to combined sewers during rainfall events. During the simulation period, a dynamically controlled system reduced discharge to a combined sewer by 98.9% compared to a passive system. Retrofitting existing green infrastructure with RTCs may allow that infrastructure to serve larger populations than initially anticipated, and may allow municipalities to increase stormwater management capacity without constructing expensive new infrastructure projects. And retrofitting green infrastructure with smart controls may significantly expand the stormwater capacity of existing infrastructure at a cost an order of magnitude lower than that of constructing new green or grey infrastructure.

CASE STUDY: TWIN OAKS LIBRARY RAINWATER HARVESTING RETROFIT

Project Background

The Twin Oaks Library in Austin, Texas is the site of a pilot study of an internet-enabled real time control retrofit on an existing rainwater harvesting (RWH) system. The library and RWH system were constructed in 2010 and comprises two interconnected 334 ft^3 (2,500-gallon) above-ground cisterns that collect rainwater from 6,500 ft^2 of roof area and condensate from the library's HVAC system (see Figure 1). Harvested water was designed to discharge either to an irrigation system or overflow to a drain line when the cisterns are full. However, it was discovered that the existing drain line was clogged due to poor workmanship during the original installation by others. This prevented efficient active release of water. The drain line was designed to discharge to the City storm sewer line.

The RWH system was originally intended to conserve potable water for irrigation demands and educate the public about the importance of water conservation. The retrofit project is a collaboration between the City of Austin, the Water Environment Research Foundation (WERF), and Geosyntec Consultants, and aimed to demonstrate real time control technology as an innovative and improved green infrastructure management approach. The retrofit was intended to improve the performance of the RWH system, increase the amount of rainwater used for landscape irrigation on the project site, reduce outflows to the storm sewer during rain events, and encourage infiltration of rainwater through a rain garden constructed as a part of the project scope of work (see Figure 1).

Figure 1 – Twin Oaks Library (A) Rain Garden and (B) Cisterns

In November 2012, the original scope of work was executed to install the real time controller, install a water level sensor, design and install a controlled release valve system, and program the RTC controller and logic. In May 2013, an additional scope of work was executed to correct the existing drain line issues and reroute flows to a new 400 ft^2 rain garden. The new rain garden allows rainwater to infiltrate into the subsurface and provides the library with an attractive amenity. In addition, the existing irrigation pump on the site was rehabilitated into the active control system, and is actively controlled to irrigate 45 tree bubblers on-site.

The control system incorporates customized algorithms to integrate the RWH system controls with real time weather forecasts. Data has been collected at the library from January 2013 to present. Full wet weather rainwater capture logic and basic dry weather irrigation logic was installed by July 2013. During dry weather periods, when the cisterns are greater than half full, the system will irrigate 800 gallons of water once every two weeks. When the cisterns are less than half full, the system will automatically reduce the volume of water for irrigation to 400 gallons once every two weeks. The system also responds dynamically to weather forecasts in a way that increases its ability to retain stormwater and reduce outflows to municipal storm sewers: when forecasts predict rainfall with a probability of greater than 70 percent, the cisterns automatically drain the volume needed to capture the forecasted runoff. Current weather forecasts, irrigation controller states, and the system's current storage volumes can be monitored and controlled via the internet using a dashboard shown in Figure 2. The Twin Oaks Library RTC RWH system's underlying logic is pictured in Figure 3.

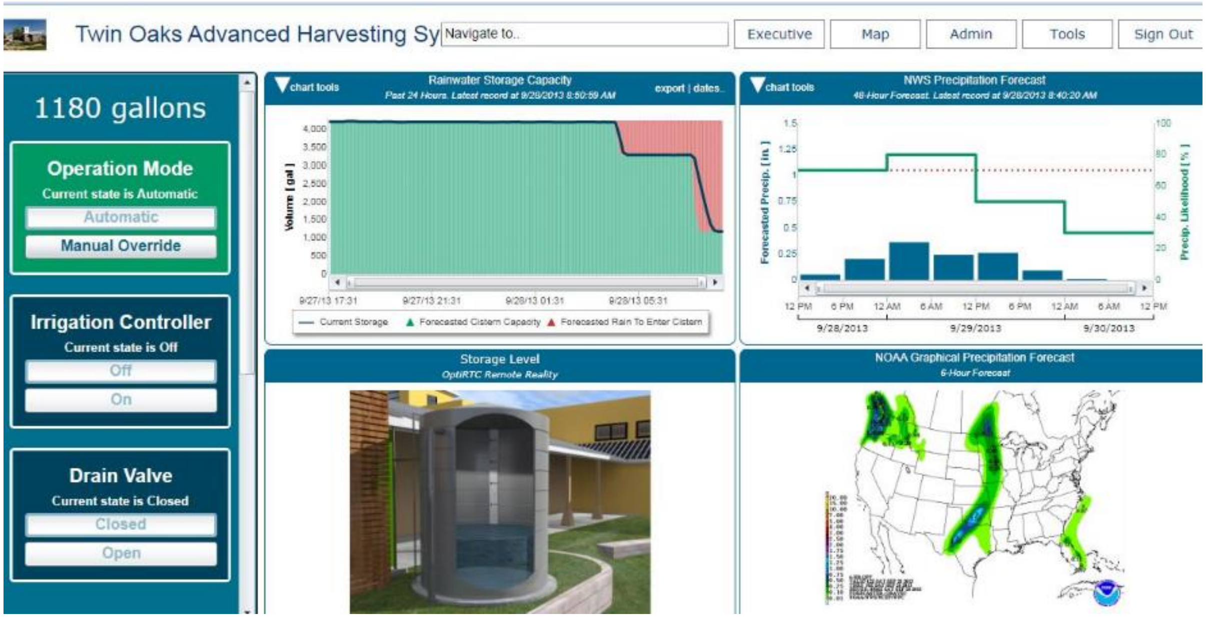

Figure 2 – Internet-based Dashboard Allows for Real Time Monitoring and Control of the Twin Oaks Library RHW System

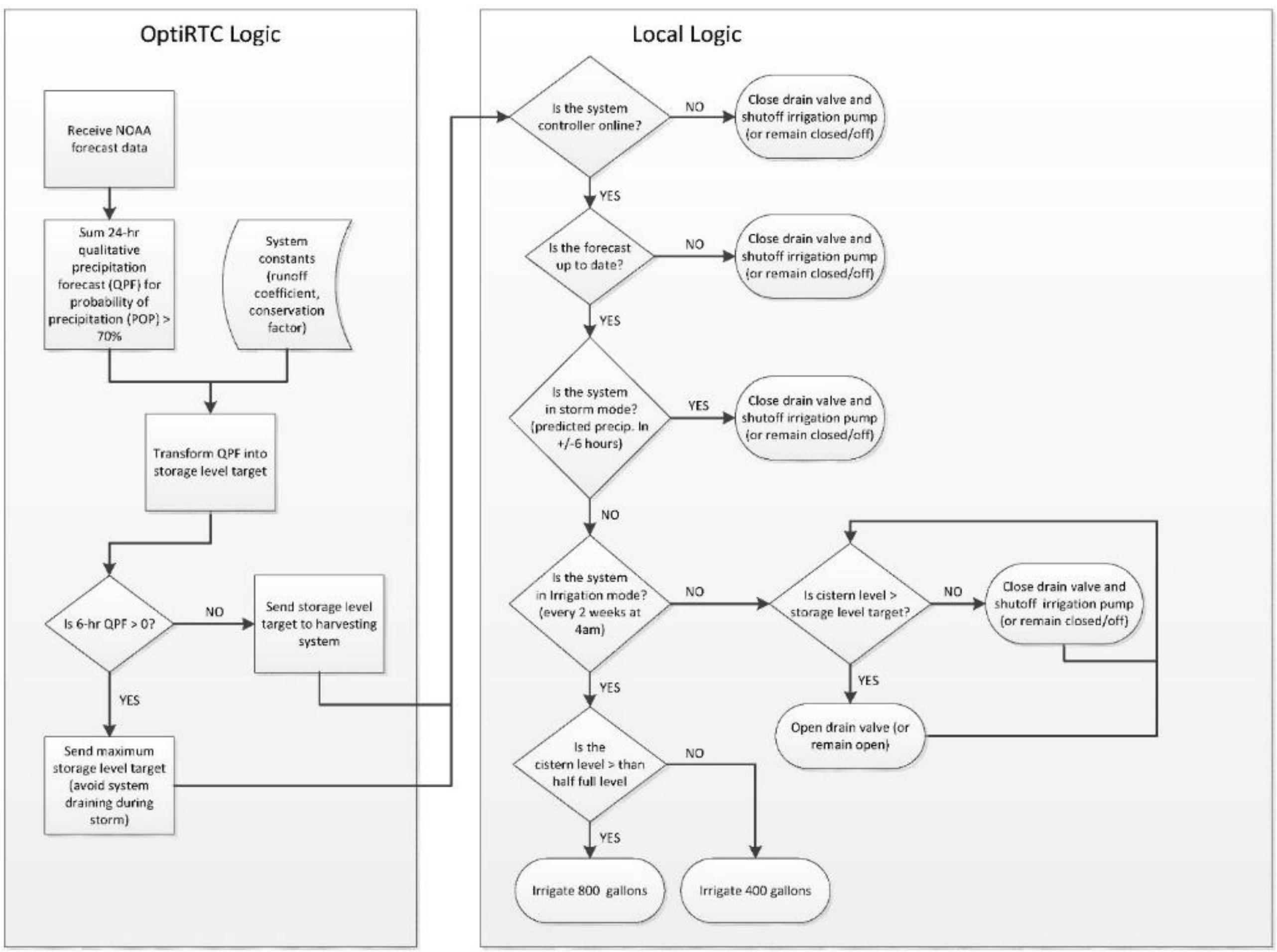

Figure 3 – Logic Used for Automatic Control of the Twin Oaks RWH System

Data and Analysis

Data was evaluated from 10 storm events starting on May 3, 2013. These events totaled 7.52 inches and equated to about 3,676 ft^3 (27,500 gallons) of runoff. During this initial monitoring period over 869 ft^3 (6,500 gallons) of stormwater were used for irrigation.

In addition to evaluating the data collected at the site, modeling scenarios were conducted that investigate two cistern management scenarios: 1) irrigate approximately 110 ft^3 (820 gallons) once every two weeks (referred to as the “2-week” management scenario), and 2) release all the captured runoff from a rainfall event within 48-hours from the end of the event (“48-hour” management scenario). The 2-week management scenario represents a simplification of the irrigation algorithm used by the control system but does not consider the “smart” portion of the controller that drains the cistern prior to rainfall events. The 48-hour management scenario is a simplification of the City of Austin Environmental Criteria Manual for managing cisterns, which requires the cistern to be empty within 48 hours of a rain event. The 48-hour management scenario does not allow for use of the harvested rainwater during dry periods since the cistern will be empty following a rainfall event.

Table 1 compares the two modeling scenarios together with the collected data from the RTC management scenario for the 2014 calendar year. Rainfall data used in the model was collected at a station six miles north of the Twin Oaks Library; therefore, minor differences in modeled rainfall versus on-site data are expected.

Table 1 – Management Scenario Model Results for 2014 Calendar Year

	2-week Management	48-hour Management	Data from RTC Management
Irrigation release (CF)	5,197	8,951	3,878
Overflow (CF)	12,310	8,541	N/A
Average volume (CF)	484.7	117.3	556.7

The 2-week management scenario modeling results suggest that 5,197 ft^3 (38,870 gallons) would have been used for irrigation during dry weather and 12,310 ft^3 (92,080 gallons) of rainfall overflowed from the cistern in 2014. The average annual volume in the cisterns was 484.7 ft^3 (3,626 gallons). Although the 48-hour management scenario has a larger irrigation volume, this is not representative of water conservation benefits. This management scenario results in an empty cistern during dry periods when irrigation is needed the most. This is expressed in the average annual volume in the cisterns of 117 ft^3 (875 gallons). The 48-hour management scenario represents the extreme case where the maximum volume captured is achieved, but no water is available for dry weather irrigation. It also shows that even with empty cisterns, there is still expected to be 8,541 ft^3 (63,890 gallons) of rainwater that overflows the cisterns during rainfall events.

The actual data collected at the site is comparable to the model results; however, rainfall is not measured at the library and overflow volumes are not monitored. Therefore, only the average volume in the cisterns and the measured irrigation releases can be analyzed. The data suggest that more volume is available in the cisterns (556.7 ft^3 on average) compared to the 2-week management scenario. In addition, of the 3,878 ft^3 (29,006 gallons) of water that was drained, approximately 2,949 ft^3 (22,058 gallons) was used for irrigation purposes during dry periods and 929 ft^3 (6,948 gallons) was drained to the on-site rain garden in advance of forecasted rainfall events. Additional volume was lost from the cistern due to a slow leak in the irrigation pump; the online dashboard was useful in identifying the leak. This volume was drained on-site but is not accounted for in the reported volumes. The RTC management scenario is more conservative regarding irrigation uses during dry periods and will restrict irrigation immediately after rainfall events or when less than half the cistern volume is available.

Although this management scenario appears to provide less water for irrigation than the 2-week management scenario, the RTC management further optimizes when irrigation water is needed and conserves captured rainwater when the capacity is reduced. Furthermore, the algorithms can be modified to allow for further optimization or management strategies.

Figure 4 investigates one rainfall event in May 2014 that completely filled the cisterns. All three management scenarios resulted in wet weather overtopping due to the magnitude of the rainfall event (2.25 inches). The 48-hour management scenario (red line) captured the largest runoff volume because the cisterns were empty prior to the rain event. The 2-week management scenario (blue line) captured the smallest amount of runoff. The RTC management scenario (green line) drained 256 ft^3 (1,915 gallons) of water prior to the event to gain additional capacity. The actual rainfall event was greater than the forecasted rainfall which resulted in the cisterns overtopping during the event.

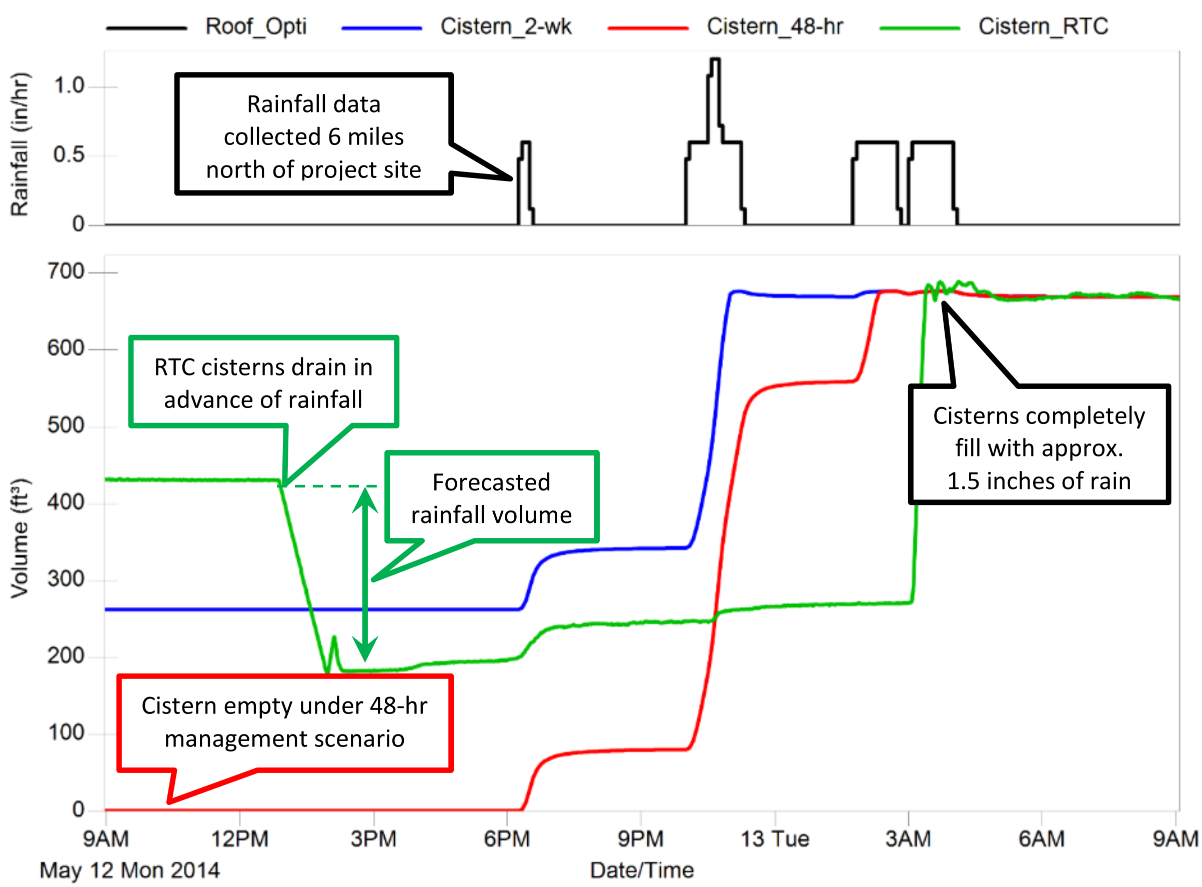

Figure 4 – Model Results and Collected Data

Figure 5 shows the annual volume-duration curves for each of the three management scenarios. This shows that the RTC management scenario retains captured water for a longer duration than each of the passive management scenarios. This allows for additional water conservation benefits during dry periods, but the "smart" technology allows for needed capacity prior to rainfall events in order to maintain the required wet weather capture volume.

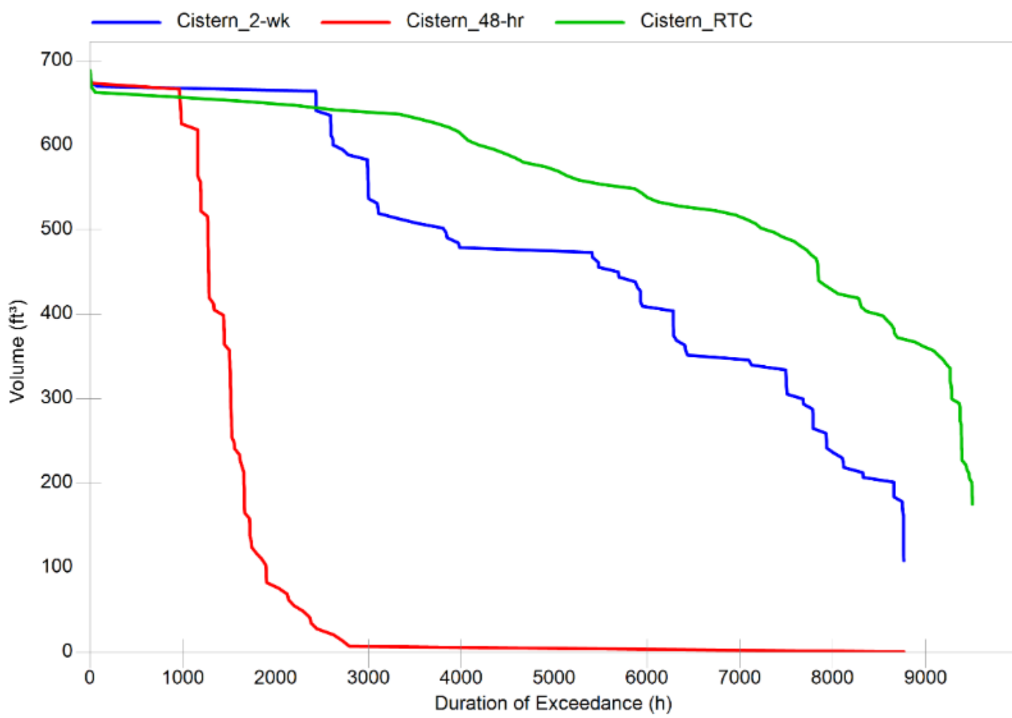

Figure 5 – Volume-Duration Results for Each Management Scenario

The Texas Water Development Board (TWDB) recently awarded the Twin Oaks Library the 2014 Texas Rain Catcher Award for excellence in the application of rainwater harvesting in Texas. Twin Oaks Library was recognized in the community category for its innovative efforts to improve the library's existing rainwater harvesting system.

CASE STUDY: GILLELAND CREEK TMDL PROJECT

The Gilleland Creek watershed is located in Travis County, Texas and is undergoing transition from primarily agricultural to heavily urbanized land use. This urbanization is believed to contribute to elevated bacteria levels. The Texas Commission on Environmental Quality (TCEQ) identified Gilleland Creek on the 303(d) list as an impaired water body for elevated bacteria levels, and developed a total maximum daily load (TMDL) program to restore water quality in the creek. As a part of the TMDL effort, researchers at The University of Texas at Austin Center for Research in Water Resources (CRWR) together with the TCEQ, City of Pflugerville, Springbrook Meadows homeowner's association, and Geosyntec Consultants developed a retrofit and sampling plan to use advanced controls to manage discharge from an existing retention basin located in a subdivision housing development area.

This project aimed to improve the quality of water entering Gilleland Creek from an existing flood control retention basin (the Pon Court basin) by retrofitting the basin with an automated valve (see Figure 6) that could be remotely opened after a storm event. Previous research by Middleton and Barrett (2008) showed that retrofitting stormwater basins with smart controls that increased detention times improved the basins' removal of a range of common stormwater pollutants; it was hypothesized that increasing stormwater's detention time in a basin could encourage the removal of bacteria through sedimentation and exposure to sunlight. The Pon Court basin serves an urban residential area of roughly 24 acres; the retrofit allowed the basin to begin releasing stormwater after a specified detention interval, rather than beginning to release water immediately following a storm event. The pollutant removal performance of the retrofit basin was compared to the pollutant removal performance of a second unmodified basin serving a residential area of a similar size.

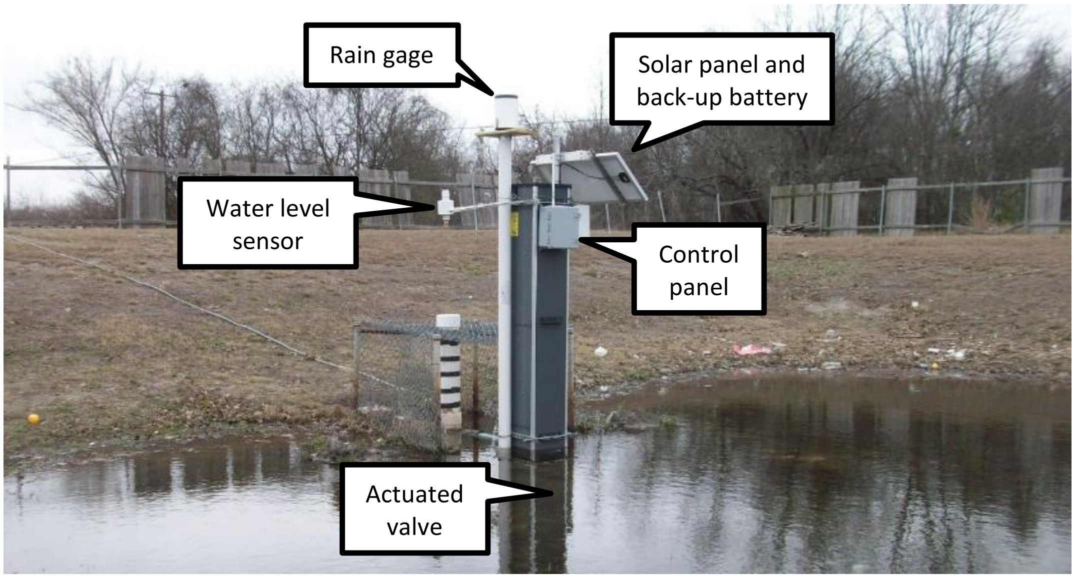

Figure 6 – Control System Installed at Pon Court Basin

Figure 7 shows the water level as reported on the online dashboard during the arrival of a rainfall event. The Pon Court basin was empty and the controlled actuated valve was closed prior to the rainfall event. The dashboard can be used to open and close the valve prior to a rainfall event and after a specified hydraulic residence time is achieved. For this research project, the valve was opened when personnel were on-site to collect a grab sample of effluent discharge for water quality analysis.

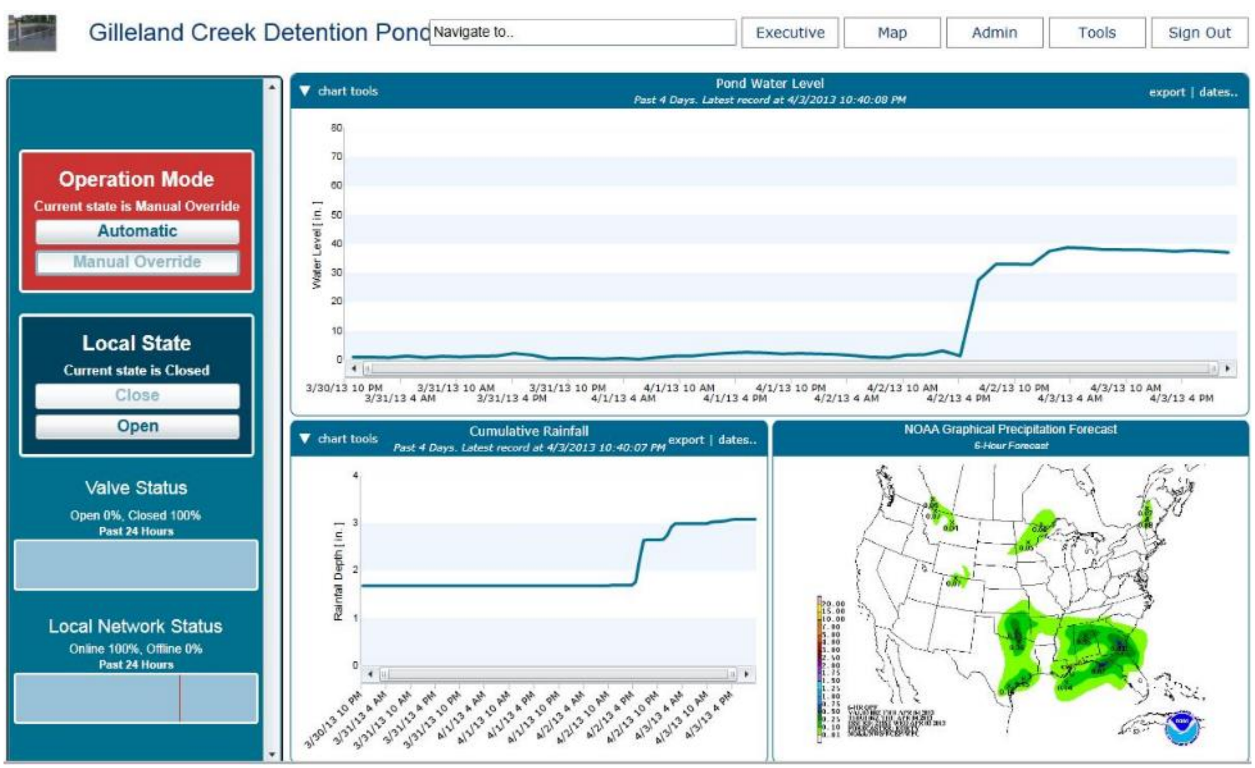

Figure 7 – Internet-based Dashboard Allows for Real Time Monitoring and Control of the Pon Court Basin System

The Pon Court and unmodified basins were monitored from March 2013 to March 2014. Only five storm events were sampled and analyzed during the study duration due to a combination of drought, holding time limitations, and equipment damage due to a flood in October 2013. Despite limitations of the sample size, the study found that the retrofitted Pon Court basin was effective at removing concentrations of Total Kjeldahl Nitrogen (TKN), nitrate/nitrite, and total suspended solids (TSS), although the basin did not achieve a significant reduction in *E. Coli* or total or dissolved phosphorous concentrations. Influent and effluent pollutant concentrations in the Pon Court basin are shown in Table 2. Pollutant removal rates are also shown for those pollutants that exhibited statistically significant concentration reductions.

Table 2 – Average Influent and Effluent Pollutant Concentrations at Pon Court Basin

	Influent Concentration	Effluent Concentration	Percent Reduction
E. Coli (MPN/100mL)	4,578	2,281	N/A
TKN (mg/L)	1.25	0.95	24%
Nitrate+Nitrite (mg/L)	0.40	0.11	73%
Total P (mg/L)	0.21	0.16	N/A
Dissolved P (mg/L)	0.09	0.10	N/A
TSS (mg/L)	85.6	5.2	94%

Effluent concentrations were also compared between the Pon Court basin, the unmodified basin, and typical detention basins. The typical detention basin concentrations are based on performance data collected by the International Stormwater Best Management Practices Database (Wright Water Engineers, Inc.; Geosyntec Consultants, 2010). Table 3 presents the effluent pollutant concentrations for each of the three basins.

Table 3 – Average Effluent Concentrations at the Pon Court Basin, Unmodified Basin, and Typical Detention Basin

	Pon Court Basin	Unmodified Basin	Typical Detention Basin
E. Coli (MPN/100mL)	2,281	6,472	429
TKN (mg/L)	0.95	1.13	1.61
Nitrate+Nitrite (mg/L)	0.11	0.66	0.36
Total P (mg/L)	0.16	0.17	0.22
Dissolved P (mg/L)	0.10	0.12	0.11
TSS (mg/L)	5.2	12.9	24.2

The typical detention basin outperforms the studied basins with respect to effluent *E. coli* concentrations, while the studied basins perform generally as expected with regard to TKN, nitrate+nitrite, total phosphorus, and dissolved phosphorus. The primary reason that the typical detention basins appear to perform better for *E. coli* removal is that the typical detention basins had much lower influent concentrations (1300 MPN/100mL) than the two monitored basins (about 4,800 and 29,000 MPN/100mL). In addition, testing of the typical detention basins found that the reduction in *E. coli* was not statistically significant. Pon Court basin and the unmodified basin are more effective at treating TSS than the typical detention basin.

CONCLUSIONS

The Twin Oaks Library RWH system was retrofit with real time controls that allow for increased retention of harvested water for water conservation benefits. The system is controlled automatically in order to optimize water use during dry periods.

The Gilleland Creek Pon Court basin was retrofit with real time controls that allow for increased residence time of stormwater runoff for water quality benefits. Retrofitting existing flood control facilities with smart controls has improved those facilities' pollutant removal of nitrogen and total suspended solids and could potentially provide other water quality benefits in a cost-effective manner.

The application of real time controls to green stormwater infrastructure is attractive because it combines the known benefits of green infrastructure such as rainwater reuse, increased infiltration, peak flow shaving, and water quality benefits with the benefits of advanced decision making, automated controls, and real time monitoring, thus optimizing the known advantages. In addition, dynamically controlled green infrastructure is entirely scalable and adaptable. Most importantly, cities facing a high cost of expanding stormwater infrastructure with grey or green strategies can achieve the same benefits with a much lower cost by retrofitting existing systems with real time monitoring and controls.

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