Final Report:

Demonstration & Monitoring of Rainwater Harvesting/ Cistern Technology in North Carolina

A 319(h) project sponsored by NC DENR – Division of Water Quality

FY 08 – NC DENR Project # EW08020

Contract Period: 9/01/07 – 5/31/10
Total Project: $181,425
Requested 319 (h) funds: $108,921

Principal Investigators:
William F. Hunt, III
Associate Professor and Extension Specialist, NCSU Biological & Agricultural Engineering
And
Kathy M. DeBusk
Extension Associate, NCSU Biological & Agricultural Engineering

Report Submission Date: July 9, 2010

Acknowledgements

This project was funded under an EPA Section 319(h) grant administered by the North Carolina Department of the Environment and Natural Resources' Division of Water Quality. Several entities provided tremendous support during this project included the Town of Boone (Eric Gustavson), the Craven County, Fayetteville Technical Community College (Sanford Cain), and Guilford County. Additionally, several extension agents facilitated this project including Wendy Patoprsty, Charlie Humphrey, George Autry, and Karen Neill. Without their cooperation none of this project would have been possible. Lastly, several NCSU BAE staff and faculty were instrumental in this project including Jason D. Wright (now with TetraTech), Matthew P. Jones (now with Hazen and Sawyer), and Shawn G. Kennedy. NCSU has enjoyed the collaboration with NC DENR's Stormwater Permitting Unit, especially that of Robert Patterson and Boyd Devane who adjusted NCDENR's design manual for water harvesting systems to reflect the findings from this project.

Table of Contents

	Page #
Executive Summary	2
Project Deliverables	3
Retrofit Descriptions	3
Greenbriar Wet Pond Conversion	3
Craven County Agricultural Center Rainwater Harvesting	6
Outcomes & Conclusions	8
Budget	9
Appendices	10
Sign installed at Greenbriar Wet Pond	10
Plan sheets: Greenbriar Wet Pond (not included digitally)	
Plan sheet: Craven County Agricultural Center Rainwater Harvesting Design (not included digitally)	

Executive Summary

The purpose of this project was to demonstrate and evaluate rainwater harvesting systems in the four main physiographic regions of North Carolina. Cisterns and their allied products were installed at the Craven County Animal Shelter, Fayetteville Technical Community College's horticultural campus, the Guilford County Agricultural Center, and the Town of Boone's Public Works compound. Two of the four sites evaluated water harvesting systems coupled with irrigation demand, while the other two had water used for washing animal cages (Craven County), mixing with salt to create a brine solution (Watauga County), and as a dust suppressant in street sweepers (Watauga County).

The water harvesting systems that did not rely on irrigation used the most water per square foot of contributing drainage area, and used water most regularly. Having a consistent, reliable demand for water clearly translates to the highest use of harvested water. This, in turn, leads to available space in the cistern so that stormwater events can be fully captured. Of all uses examined, washing the animal cages at the Craven County Animal Shelter seemed best and most reliable.

The town of Boone's use for the water to melt snow was very novel and provided an "outdoor" means for disposing water during the winter. It had been shown in this and other studies, that when water harvesting systems are restricted to "outdoor" demands were either not used or were severely underused during cooler, non-irrigating, months. While not every community in North Carolina can take full advantage of using rainwater to later melt ice, this does seem to be a perfect use for rainwater systems in the NC mountains.

Both Cumberland County and Guilford County irrigation applications had periods of high use, but when irrigation needs slowed or stopped, so did the benefit of rainwater harvesting systems associated with stormwater treatment. Irrigation is a logical use for captured rainwater, but this use must be supplemented by others, if rainwater harvesting systems are to be efficient stormwater treatment tools.

This project allowed for the first field testing of NCSU's Rainwater Harvester™ model. This model is part of NC DENR's rainwater harvesting design guidance, but had never been field verified. Results from this study show that Rainwater Harvester™ is a reliable model for predicting runoff capture, overflow producing events, and dry cistern frequency. Looking at long term field data and comparing that to model outputs showed that the dry cistern frequency for the four systems studied were always within 4% of each other. The predicted annual runoff captured versus that which was measured was typically within 10%. The model is clearly a more reliable tool when the usage demands of the system are regular, consistent, and year-round. The study supports the continued use of Rainwater Harvester™ by NCDENR, designers and communities.

A small water quality study conducted at the Guilford site indicates that cistern tanks do capture TN and TSS. Eventually those pollutants will require clean out from the bottom of the tanks, which is something that was not addressed during this study. Rooftop pollution tended to be relatively clean, except during pollen season when influent concentrations (particularly for nitrogen) were very high. The cistern's most noticeable improvement to water quality was during that time.

Results of this project were communicated in a variety of ways. Two extension publications were produced. The first focused on guiding homeowners through the cistern (not rain barrel) selection and design process. The second factsheet answered questions about the quality of rooftop runoff. Was it suitable for consumption and using it to irrigate edibles?

The Rainwater Harvester™ model was revised during this project. Both the revised model and the two publications were placed on the NCSU stormwater home website: www.bae.ncsu.edu/stormwater and the rainwater harvesting-specific website: www.bae.ncsu.edu/topic/waterharvesting. Rainwater Harvester™ and the first extension publication produced served as the basis for NC DENR's design guidance in the Rooftop Runoff chapter of the Stormwater BMP manual.

Finally, six different workshops were held in five cities across the state. Nearly 150 designers, regulators, and interested citizens attended. The tools produced for this project were utilized in those workshops.

The expected benefit of this study is the education of potential water harvesting designers and users. Due to more (and trusted) tools being available and the state's comfort with those tools, the use of well-designed rainwater harvesting systems is expected to increase.

Project Deliverables

The project was comprised of seven deliverables. All deliverables are listed below. Additionally, a brief description of how each was accomplished is given.

1. Pre-fabricated cisterns will be installed in three counties across North Carolina (Craven, Guilford, and Watauga).
   Two 3,000 gallon tanks were hydraulically connected at the Craven County Animal Shelter to supply water for washing animal cages. The two tanks treated a rooftop area of slightly less than 3,900 ft^2. Three tanks totaling approximately 4,500 gallons were installed to supply water for garden plot irrigation at the Guilford County Animal Shelter. Nearly 3,600 ft^2 of rooftop flowed to the cistern system. One 5,000 gallon cistern was installed at the town of Boone's public works facility for myriad uses, including mixing with salt to create a brine solution, using as part of street sweeping machines, and watering town maintained green area. Approximately 2800 ft^2 of rooftop was treated.

2. A small pond constructed for water harvesting will be installed in Cumberland County.
   Due to site issues at Fayetteville Technical Community College's horticulture campus, a pond was not constructed in Cumberland County. In its place, a 15,000 gallon underground cistern comprised of plastic milk crate-like structures was placed downslope of 7,500ft^2 of rooftop and 6,450ft^2 of lawn area. The cistern water was primarily used to irrigation container plants grown adjacent to the cistern.

3. 4 workshops/ field tours will be held at 4 locations across the state of North Carolina.
   Many workshops and associated field tours were held across the state of North Carolina. A brief listing of each follows:

- November 12, 2008. Hickory, NC at the Hickory Convention Center. 30 attendees. Workshop focused on using the Rainwater Harvester ™ model.
- December 2, 2008. Raleigh, NC at the JC Raulston Arboretum. 17 attendees. Workshop focused on using the Rainwater Harvest ™ model.
- June 30, 2009. Greensboro, NC at the Guilford County Extension Center. 25 attendees. Field tour of cisterns located on the Extension Center property.
- September 8, 2009. Asheville, NC at the NC Arboretum. 21 attendees. Field tour of cisterns located on the NC Arboretum campus.
- March 29, 2010. Raleigh, NC at the Wake County Commons. 25 attendees. Field Tour visited cisterns at the Raleigh Convention Center and a local firehouse.
- April 23, 2010. Wrightsville Beach, NC, at the Shell Island Resort. 43 attendees. This workshop was a combination of both filter strips and water harvesting systems and focused on above ground installations for seasonally high water tables.

4. Water Harvesting Website will be updated and maintained.
   The NCSU water harvesting website was updated and maintained through 2009. The website is located at www.bae.ncsu.edu/topic/waterharvesting. The model and new factsheet were placed on-line and some additional links were added.

5. A water harvesting model will be updated and made available to the general public.
   The model was updated to include supplemental water inputs, new precipitation inputs, to show the results of previous runs, and a schematic and active "how full is the tank" diagram. The model was field tested using these data and shown to be a reasonably accurate tool for predicting overflow, usage, and nutrient capture when inputs are known.

6. A factsheet will be produced and made available on the water harvesting website.
   Two factsheets were produced. Both were placed on the water harvesting website and www.bae.ncsu.edu/stormwater. Both are included as Appendices. The first factsheet from 2008 is entitled "Rainwater Harvesting: Guidance for Homeowners" and is direct linked here: http://www.bae.ncsu.edu/stormwater/PublicationFiles/WaterHarvestHome2008.pdf.
   The second document was produced in 2009, per frequent questions asked during the initial round of workshops mentioned previously regarding rooftop water quality. That document is found here: http://www.bae.ncsu.edu/stormwater/PublicationFiles/RooftopRunoff2009.pdf.

7. Various uses for water harvesting systems will be evaluated for efficient use of collected stormwater. Uses include vehicle/equipment washing, irrigation, and toilet flushing.
   Various uses were examined including washing of animal cages at Craven County, irrigation at both Guilford County and Cumberland County, and a myriad of public works uses in Watauga County, including mixing with salt to create brine solutions to melt snow, for use as a dust suppressant in street sweepers, and "spot" irrigation of Town of Boone maintained landscapes. The most reliable use from an annual water usage standpoint was the washing of animal cages. Irrigation was a good use of water during the spring and summer only, but had long periods of no use, leading to many events filling the tanks and producing overflow or bypass.

8. Results from evaluation coupled with revised water harvesting model will be used to predict runoff reduction and long term nutrient removal benefits that can be reflected in the State of North Carolina's Stormwater BMP Manual (Rooftop Runoff Chapter).
   The Rooftop Runoff chapter was significantly overhauled in 2008 and 2009, in part due to the findings associated with NC State's research. The first factsheet produced for this report formed the basis for much of the sizing guidance presented in the Rooftop Runoff chapter. The chapter also requires the use of Rainwater Harvester ™ or an equivalent model. NC DWQ chapter writers allowed NCSU to review the manual and provide suggested improvements. Nearly all of which were accepted.

Project Synopsis (KDB – This is where the report goes)

Outcomes and Conclusions

Data collected from this study provided valuable insight regarding the uses and benefits of water harvesting systems. The four systems included in this study indicate that the designated water use of a system determines the efficiency and overall benefits of the system. Water harvesting systems that are used solely for irrigation purposes (like Fayetteville Technical Community College and Guilford County Cooperative Extension Center) are often neglected during the non-growing season, and offer no water quantity or quality benefits during a large portion of the year. Water uses that require consistent, year-round extractions from the tank are most efficient in terms of providing stormwater quantity and quality benefits. Furthermore, small, frequent water demands increase the efficiency of a system (as with the animal shelter), as the likelihood of there being room for runoff storage for the next rain event is much higher than if the system stays full for extended periods of time and is then emptied all at once (as with the Town of Boone).

Overall, the Model does a good job at predicting system performance, and accuracy increases with more consistent and predictable water demands. For 3 of the 4 systems studied, the Rainwater Harvester Model® overpredicted the overflow frequencies, overpredicted the dry cistern frequency for 2 of the 4 systems and underpredicted the annual water usage for 2 of the 4 systems. The discrepancies between the observed data and the predicted data may be due to the data collection interval (usually 10-15 minutes) or the misrepresentation of water demands in the Model. Consistent, predictable water demands are easier to represent in the Model, thereby allowing more accurate predictions regarding system performance. This is apparent in the similarities between the predicted and observed performance variable for the Craven County animal shelter.

Water quality data collected during this study indicate that water harvesting systems can provide substantial water quality improvements, especially during times of vegetative pollination. While the reduction of runoff volumes by means of capturing and using roof runoff alone provides substantial water quality benefits via load reductions, peak flow reductions and runoff volume reductions, these documented improvements in nutrient and sediment concentrations potentially place water harvesting systems in the realm of stormwater management practices. Additional research should be conducted to confirm these predictions and quantify the concentration reduction capabilities of these systems.

Perhaps most importantly, this study highlighted certain aspects of water harvesting systems that are problematic for proper and efficient system performance. These issues, as well as recommendations for addressing them, are outlined below.

- Estimates of water usage are usually much higher than actual usage, resulting in oversized water harvesting systems. To appropriately size systems, a meter should be used to document frequency and volume of actual water usage before the system is designed and installed. This will reduce unnecessary cost and storage volume associated with an oversized system.
- The automation of water harvesting system substantially increased the efficiency and benefits, as this relinquishes humans of the responsibility to remember to turn the system on, or remember to use it, or remember to switch back to the system if they had to switch to a potable water supply. While automated systems require minimal attention and consideration on the part of the users, this can be problematic in the event of a system failure. Users tend to forget the system is in operation if it does not require their attention, and in the event of a part of the system malfunctioning, it may be weeks or months before the user realizes there is a problem. Perhaps systems should start incorporating a method of alerting users in the event of a system failure, or including some type of device that indicates the system is functioning properly. Additionally, periodic inspections should be mandated.
- Systems that are used solely for irrigation have two main problems: (1) the systems remain full and overflow during the entire non-growing season, thus providing no water quantity or quality benefit and (2) the times that plants need the water the most are during periods without much rainfall. The overall efficiency of these systems could be increased by finding a use for the water during the non-growing season. This ‘use’ could be an actual water demand, or could be an automatic slow-release of stored water, in which case the system behaves like a detention facility for roof runoff. As for the timing of rainfall versus irrigation needs, incorporating a backup water supply can eliminate the hassle of switching between water sources when the water harvesting system runs dry and reduce the chance of the users forgetting to switch back to the rainwater source.
- Smaller, more frequent water demands leave more storage volume available for small rain events and decreases the number of overflow events. If no such demand exists (as with the Town of Boone), water can be passively released from the system at a slow rate, thus increasing the detention capacity of the system. This type of system should be studied further, as this allows water harvesting system to serve as a stormwater management practice as well as a water conservation practice.

Budget

Actual Budget – Please note this project came in under budget by $993.

Item		**319 (h) Funds Requested***	**Non-federal Match**	**Total**
Salary/fringe		$44,623	$51,510	$96,133
Travel		$3,317		$3,317
Supplies and Materials		$33,484		$33,484
Contracted Services		$17,217		$17,217
Construction				
Other – Laboratory Fees		$378		$378
Direct charges		$99,019	$51,510	$150,529
Indirect charges (10%)		$9,902	$5,151	$15053
Under recovered indirect (16%)			$15,843	$15,843
Total		$108,921	$72,504	$181,425

Appendices

Appendix A: **Rainwater Harvesting: Guidance for Homeowners**
http://www.bae.ncsu.edu/stormwater/PublicationFiles/WaterHarvestHome2008.pdf

Appendix B: **Water Quality of Rooftop Runoff:** *Implications for Residential Water Harvesting Systems*
http://www.bae.ncsu.edu/stormwater/PublicationFiles/RooftopRunoff2009.pdf