RESEARCH

CAN GREENWALLS CONTRIBUTE TO STORMWATER MANAGEMENT? A STUDY OF CISTERN STORAGE GREENWALL FIRST FLUSH CAPTURE

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ABSTRACT
The authors set out to study the stormwater management viability of greenwalls in a simulated retention of roof runoff, using a cistern for simulated runoff to irrigate the greenwalls. By experimenting with two greenwalls of different exposures (one southeast and one northwest), this study demonstrated that the southeast facing greenwall and the northwest facing greenwall retained comparably favorable amounts to greenroof stormwater retention systems. With more and more competition for limited horizontal surface area in urbanized and urbanizing areas, the use of vertical surfaces for stormwater mitigation and evapotranspiration has attractive potential. This article presents the background, project, methods, findings, and conclusions of the study.

KEYWORDS
greenwalls, stormwater runoff, cistern, retention

INTRODUCTION
On-site stormwater management has become a major issue in early 21st century land development, with increasingly stringent regulations (Carter/Fowler 2008)to prevent not only downstream flooding but also non-point source pollution and combined sewer overflows. Today's environmentally responsive designers increasingly favor green infrastructure solutions over grey, mitigating stormwater quantity and quality in landscapes that perform multiple services (Oberndorfer et al 2007), from filtration to infiltration (Wanielista/Hardin 2006), rather than in pipes that make the stormwater disappear. But green infrastructure strategies are particularly challenging in our rapidly developing urban areas: at the same time that the city has huge amounts of impervious surface with runoff to be managed, the dense development of expensive land makes it challenging to find room for useful green infrastructure.

Creative thinkers have transformed one of the city's largest impervious areas—roof tops—into proven stormwater management systems (Dietz 2007) through the design of greenroofs (Getter/rowe 2006). But what about stormwater management on walls, via vertical

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planting systems? Particularly in the urban environment, wall area far exceeds roof area; might useful stormwater management be effectively accomplished through greenwalls?

Greenwalls were constructed to test their ability to retain first flush stormwater. Each of these greenwall systems was irrigated using a 300 gallon cistern to simulate rainfall during a growing season. This project was designed to compare the water retention capacity of greenwalls to that of conventional greenroofs to determine if the greenwall system can retain typical first flush runoff volume in typical rainfall event. By comparing a vertical wall system (greenwall) with a horizontal system (greenroof), this test can begin to recognize the potential to utilize vertical surface area for stormwater retention.

BACKGROUND

Stormwater management regulations in states across the country are broadening to encompass everything from combined sewer overflows (CSO) to non-point source pollution. Over the past 20 years, a predominant stormwater management objective in the United States has become controlling the first flush: retaining the most polluted initial ½″ to 1″ of runoff through retention, infiltration, biofiltration, or bioretention; removing pollutants from the water; and either permanently retaining the water for other use, or temporarily detaining it from the downstream discharge. While runoff from major storm events may bypass first flush systems, this strategy is commonly understood to retain around 60–90% of all rainfall events (See figure 7, an example from MPCA 2013). As of this writing, most states in the U.S. consequently—and quite logically—require first flush control (USEPA 2011); and an increasing number of municipalities, developers, and individuals accomplish this first flush control using green infrastructure systems: landscapes that retain and likely cleanse stormwater.

In the urban context, first flush management using green infrastructure is particularly challenging: simply put, cities have huge amounts of impervious surface with resulting huge amounts of runoff to be managed—in fact, the USEPA suggests that a typical city block generates 500% more runoff than the same size wooded lot (USEPA 2003). At the same time, dense development and expensive land make it more challenging to find room for useful green infrastructure. In 2008 the National Research Council (NRC) highlighted in a report to the USEPA a need for significant changes in the way stormwater is managed (NRC 2009). This report noted that rapid conversion of land to urban and suburban use is profoundly altering water flows; the report further called for an entirely new permitting structure with some additional actions, such as conserving natural areas, reducing hard surface cover (imperviousness), and *retrofitting urban areas with features that hold and treat stormwater* (authors' emphasis).

Some years ago, creative thinkers realized that the roofs making up a large portion of that imperviousness could, in fact, be retrofitted to become a useful urban location for green infrastructure through the creation of greenroofs (VanWoert et al. 2005). With this approach, an advantageous mitigation strategy emerges: the more buildings, the more opportunities for green infrastructure using green roofs. Stormwater management using greenroofs has been tested and found to significantly reduce the frequency of urban runoff flows into combined sewer systems (Bliss et al. 2008). Greenroofs additionally have been found effective in the management of both runoff quantity and quality (Berndtsson 2010). Greenroof stormwater retention has been tested on small scales and found to retain on average 34% of runoff and 57% of peak flow runoff, suggesting that greenroofs can be a viable alternative to conventional stormwater retention systems (Stovin 2009). Empirical models of greenroof systems reported in 18 publications allowed Jeroen Mentens to calculate that, on average, the greening of just 10% of buildings would reduce Brussels region's runoff by 2.7% and building runoff by 54% of (Mentens et al. 2005). With 40-50% of cities' impervious surfaces comprised of roofs, greenroof systems have the potential to make a large impact on mitigating urban stormwater. Urbanization has also reduced evapotranspiration locally and globally (Liu et al. 2013) and (Owen et al. 1998) and (Oke 1979), causing higher surface temperatures leading to urban heat island effects. The use of vegetated roofs for rainwater harvesting and evaporation/evapotranspiration can help to mitigate surface temperature. With all of these recognized greenroof benefits, the transdisciplinary community of ecosystem services this past decade has seen the greenroof industry rapidly expand through international greenroof conferences, articles and journals, demonstration sites, case studies, and scientific research, which in turn has generated North American greenroof policies at the federal, municipal, and community levels (Costanza and Kubiszewski 2012).

Do greenwalls hold the same potential for stormwater management? The prospect is appealing, particularly in the urban environment, since wall area far exceeds roof area; might first flush stormwater management be accomplished through greenwalls in the city? With more and more competition for limited horizontal surface area in urbanized and urbanizing areas, the use of vertical surfaces for stormwater mitigation and evapotranspiration has attractive potential. Consequently, research on the use of greenwalls for stormwater management makes sense to provide useful information for a potential new wave of green infrastructure.

Greenwalls, living walls, plant walls or vertical gardens are terms used to describe various technologies that utilize plant media attached to interior or exterior building walls (Weinmaster 2009). In "Are Green Walls as 'Green' as they Look? An Introduction to the Various Technologies and Ecological Benefits of Green Walls," author Mike Weinmaster suggested that nature provides us with answers to many battles of urbanization. While greenroofs have been studied and written about for their environmental and economic value—including water conservation, stormwater runoff and water quality management, local and regional cooling, aesthetic value, electricity savings, habitat provision for wildlife and carbon absorption (see Garrison and Hobbs 2006; Center for Neighborhood Technology 2010; Odefey et al. 2012; and Doshi and Peck 2013, to name a few)—there is very limited actual research on the potential for greenwalls to address stormwater management. This paper is intended to contribute to the discourse on using greenwalls for stormwater management, particularly in comparison to green roof management of first flush runoff.

THE PROJECT

With funding from Penn State's Raymond A. Bowers Program for Excellence in Design and Construction of the Built Environment and the Stuckeman School of Architecture and Landscape Architecture, the researchers constructed eight greenwall systems in the service yard of Penn State's Stuckeman School in State College, Pennsylvania.

Planter boxes

Each greenwall system used 16 modular chloroplast boxes with each box measuring approximately 12″w × 15″h × 5″d. Each planter box was fabricated from chloroplast material using a computer controlled router. Each planter box has 10 planting cells, each measuring approximately 6″w × 3″h × 5″d as shown in figure 2.

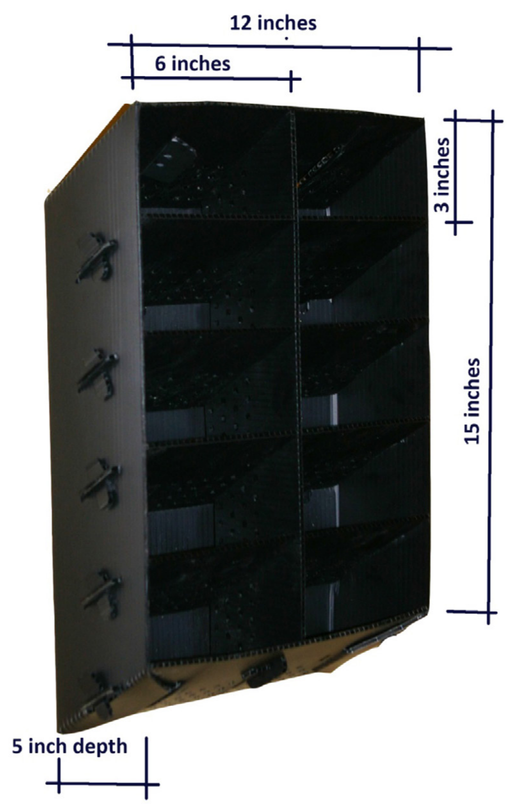
FIGURE 1. Four southeast facing greenwall systems.

Each of these planter boxes was filled with approximately 36 cubic inches of commercially available planting soil mixed with polymer granules to help absorb and hold water. Each cell was planted with either one or two plugs of 4 plant types: sedum angelina, sedum ternatum, sempervivum tectorum, and ajuga reptans (see figure 3). The four types of vegetation used within each of the greenwall systems were chosen in part because of their general resiliency in wet/dry and sun/shade conditions, but also because their slight variations in water and solar needs might prove informative.

Greenwall systems

16 individual planter boxes were combined to form one of eight separate greenwall systems, each system approximately 48″ across and 75″ tall. Each group of 16 planter boxes, or "system," had its own cistern, timed drip irrigation system, and drainage capture system. This allowed each greenwall system to operate and be tested independently of the other greenwall systems. The planter boxes were mounted on a framing system

FIGURE 2. Dimensions of typical chloroplast greenwall planter box.



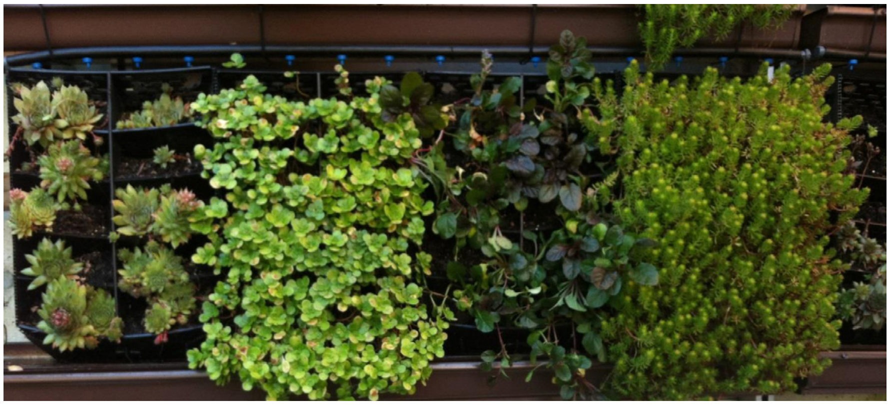


FIGURE 3. Typical plantings within planter box. Notice drip irrigation along top of boxes.

and attached to the existing concrete walls in the yard. The planter boxes in each greenwall system were arranged in four columns of different plant types, each column being four planter boxes tall (40 planted cells). Eight greenwall systems were built on two existing courtyard walls—one courtyard wall held four greenwall systems facing northeast and the other held four greenwall systems facing southwest—to provide an opportunity to observe any solar orientation influence on plant mortality or water retention (see figure 4).

FIGURE 4. Complete greenwall system on the right with start of second system to left.

Watering system

Stormwater collection from a roof was simulated using local rainfall data and 300 gallon cisterns based on 39.76″ of rain a year averaging 3.31″ a month. These cisterns were much larger than needed, but allowed flexibility as we continue to build and test greenwall systems. Water from the cisterns was used to irrigate the greenwall systems every day during the growing season. The advantage of using a large cistern to collect water and irrigate the greenwalls is that the watering system is not dependent on consistent rainfall frequency.

Daily watering was accomplished with drip irrigation. We used drip irrigation for three reasons: 1) slow release to minimize soil disturbance; 2) even and controlled water distribution throughout the greenwall; and 3) the materials are cost effective and readily available with installation needing only minor hardware and tools. A drip irrigation system using 0.5 Gallons per Hour (GPH) emitters was created for each greenwall system using basic plumbing hardware. This amount of release is comparable to the volume of rainwater captured over a three-day period in the State College area. Using NOAA data, the State College area receives rainfall between 110 and 115 days per year, so on average over the course of the year it rains every three days in State College (NOAA National Weather Service 2011). Drip emitters were evenly spaced across the top row of planter cells for each planter box, with 2 emitters directed toward each of the two top cells in each planter box as shown in figure 5. Each planter cell was perforated to allow water to irrigate lower cells not directly watered by the strip of drip emitters. The system consisted of ½″ plastic pipe and pipe fittings with emitters punched into the ½″ plastic pipes.

These irrigation systems were connected to the cisterns with a ⅓ hp sump pump providing pressure for drip irrigation emitters. Automatic timers were used to schedule watering

FIGURE 5. Drip irrigation system is used to simulate rainfall. The gutter system catches runoff from plants and is captured in buckets to measure runoff. Buckets can be seen below green wall in the image to the left.

twice a day, 7 days a week, during the growing season. This system allowed the irrigation volume to be altered if needed. Gutters were located below each row of planter boxes to collect any runoff (visible above the planter boxes in figure 5). Drainage from each greenwall system was then collected using this gutter conveyance and piped to a separate water collection and measurement container for each greenwall system. The collection and measurement system allowed drainage from each greenwall system to be accurately measured and subtracted from the irrigation volume to determine how much water was retained by each greenwall system.

THE METHODS

This project was designed to compare the water retention capacity of greenwalls to that of greenroofs.

The research questions were:

1. Can a greenwall retain typical first flush runoff volume (½″ to 1″ rainfall depth)?
2. Can greenwall water retention capacity compare favorably to the water retention capacity of a greenroof?

The amount of water used to irrigate the greenwall systems was controlled using timers and the 0.5 GPH flow rate of the irrigation emitters. For example—given that each greenwall system has 64 irrigation emitters (four per planter box, with 16 planter boxes on each greenwall system), if the watering timers are set for 10 minutes per day, the total irrigation water volume for each greenwall system would be 5.3 gallons per day (0.5 gallons per hour × 64 emitters × ⅙ hour per day = 5.3). Therefore the total irrigation water volume could be controlled and varied by simply changing the number of minutes of watering each day. Altering the irrigation timing was useful to better understand how antecedent soil moisture may affect the soil's water retention capacity; it was also useful to better understand how much water was really needed to keep different plant types alive. The greenwall systems were irrigated twice a day, during the early morning and late evening, to minimize leaf burn and evaporation loss during hot summer days. To better understand how much water the walls could retain and to observe any effect of overwatering, the irrigation time was varied between two minutes twice a day and 8 minutes twice a day.

Monitoring of the irrigation and collection systems began immediately upon installation, with data recorded daily to a logbook. Data collected for each wall system included: 1) length of time irrigated; 2) time of day irrigated; 3) amount of water pumped; 4) amount of water drained from each greenwall system; and 5) the amount of water retained by each greenwall system. Typical seven day water data sampling and averages for two of the eight greenwall systems are shown in figure 6.

Although we were only interested in the averages for all eight greenwall systems for this study, individual weekly data also provided some interesting results. For example, the intent of varying the irrigation volume (example shown in Figure 7) was to observe differences in the effect of soil moisture from the previous day on soil water retention capacity. Not unexpectedly we found that higher soil moisture would reduce the water retention capacity—that is, as the irrigation volume of water increased (water in)—the capacity of retention (capture) would reach a saturation limit and then any additional irrigation water would run off (water out). Figure 7 shows that the % capture would typically decrease when large volumes of water were used to irrigate the walls or soon after large amounts of water were used to irrigate the walls.

FIGURE 6. Typical seven day water data sampling and averages in gallons.

Gallons Southeast Green Wall System #1							Gallons Northwest Green Wall System #5			
water in		water out	capture	% capture		water in		water out	capture	% capture
5.30		2.24	3.06	58%		5.30		2.63	2.67	50%
4.27		1.69	2.58	60%		4.27		2.58	1.69	40%
2.13		0.74	1.39	65%		2.13		1.11	1.02	48%
2.13		0.94	1.19	56%		2.13		0.95	1.18	55%
3.20		0.40	2.80	88%		3.20		1.26	1.94	61%
3.20		0.32	2.88	90%		3.20		1.19	2.01	63%
5.33		2.00	3.33	62%		5.33		2.66	2.67	50%
3.65		**1.19**	**2.46**	**68%**		**3.65**		**1.77**	**1.88**	**52%**

While this study was not trying to determine retention capacity of the greenwall, we were able to observe the relationship of retention to volume of irrigation. We also found that the greenwall with some direct sun (southeast-facing) had greater water retention variation and greater average water retention than the greenwall without direct sun (northwest-facing). We have not compared solar radiation, temperature, humidity or wind factors because we expect that these factors, while very significant on a daily level, would have less impact on the average long-term water retention capacity, especially given the reliability and flexibility of using a large cistern to collect stormwater runoff and water the greenwalls as needed.

All irrigation, drainage and retention data was measured in gallons; however, for purposes of this discussion, gallons have been converted to cubic feet and then to rainfall depth in inches, because most stormwater management regulations require the first flush to be retained—and this volume is codified in stormwater regulations as rainfall depth in inches. Conversion of gallons to inches is a simple mathematical process; first, cubic feet of water retained can be calculated as the volume of gallons retained multiplied by 0.13368 to give us

FIGURE 7. Example of varying the irrigation volume to observe capture rate.

VariedAverage Gallons of the 4 Southeast Green Wall Systems						
water in		water out		capture		% capture
Mon. 2.13		0.74		1.39		61%
Tues. 2.13		0.86		1.27		38%
Wed. 6.40		2.89		3.51		50%
Thurs. 6.40		2.94		3.46		54%
Fri. 3.20		0.40		2.80		84%
Sat. 3.20		0.32		2.88		88%
Sun. 5.33		1.90		3.43		62%
Mon. 5.33		1.96		3.37		61%
Tues. 8.53		5.00		3.53		38%
Wed. 3.20		2.05		1.15		43%
Thurs. 3.20		0.81		2.39		70%
Fri. 3.20		1.68		1.52		48%
Sat. 4.27		2.34		1.93		42%
Sun. 4.27		1.34		2.93		67%

volume retained in cubic feet (1 gallon = 0.13368 ft^3). Therefore, for example, 2.5 gallons is equal to 0.3342 cubic feet (2.5 gallons × 0.13368 ft^3). Next: if we want to establish a direct comparison of greenwalls to greenroofs, then we can determine rainfall depth by assuming the same roof drainage area for greenwall (draining the roof area runoff into a cistern) and for greenroof. We can then calculate the rainfall depth in feet as water volume in cubic feet divided by square feet of the drainage area. Let's assume we're measuring rainfall depth of 2.5 gallons on 25 ft^2 of roof; 0.3342 ft^3 / 25 ft^2 = .013368 feet of rainfall depth. We can then convert this to inches simply by multiplying feet of rainfall depth by 12. Therefore, .013368 feet of rainfall depth multiplied by 12 is equal to .16 inches of rainfall depth. If we want to determine a reasonable estimate of first-flush volume in cubic feet we simply work the last calculations backwards: .5 inches of rainfall depth (common first-flush) is divided by 12 and multiplied by the 25 ft^2 of drainage area. For example, if first-flush is .5″ rainfall depth, then (.5″/12) x 25 ft^2 is equal to 1.04 ft^3 of water.

In this study we wanted to compare greenwalls to greenroofs for their first-flush retention potential. That is to say can one square foot of greenwall retain the same volume of rainfall as one square foot of greenroof? The greenwall systems are approximately 48″ across by 75″ tall or 25 square feet. Therefore, to compare these systems to greenroofs we used the same 25 square foot drainage area to determine the volume of first-flush to be retained and used for daily watering.

One variable we took into account is the fact that it does not rain every day in central Pennsylvania. In fact, in the non-desert continental United States, in the State College area, the majority of rainfall events are less than 1″ in depth, with 60% ½″ or less. The average monthly rainfall amounts during May, June, July, Aug, and Sept are 3.88 inches, with a range from 3.13 inches in Aug to 4.63 inches in July. The National Oceanic and Atmospheric Association website shows that precipitation equal to or above 0.01 inches occurs about 115 to 120 days of the year or about one in three days (NOAA National Weather Service 2011). We therefore used three days as our standard for watering the greenwalls with the first-flush volume retained from a 25 square foot roof drainage area, which is easily compared to greenroofs of the same size (and is the size used earlier in our example conversion of gallons to inches of rainfall depth). This equates to about .48 inches of rainfall depth (3 days × .16″ of rainfall depth per day, as shown earlier). So our target water retention for the greenwall systems was .48 inches rainfall depth over three days. Running the same equations backward this is equal to about 7.5 gallons every three days or 2.5 gallons a day for each of the eight greenwall systems. This study does not address the storm events that occur throughout the year; however, such events can be used to recharge the cistern to be used to irrigate during low periods of rain.

THE RESULTS

This study focuses on the ability of greenwalls to retain stormwater runoff. Results of this study suggest that greenwalls can retain a significant amount of stormwater. On average, over the course of five months (May 15 to Oct 3) the greenwall systems retained about 2.75 gallons of water a day: the southeast-facing greenwall systems retained an average of 2.96 gallons of water a day, while the northwest-facing greenwall systems retained an average of 2.51 gallons of water a day.

FIGURE 8. Comparison between average gallons of water irrigated and captured.

Average Gallons Comparison Southeast and Northwest Systems							
water in		water out		capture		% capture	
SE Wall 4.42		1.46		2.96		67%	
NW Wall 4.42		1.91		2.51		57%	

Question 1: Can a greenwall retain typical first flush runoff volume (1/2″ to 1″ rainfall depth)?

Since first flush management systems seek to mitigate the first ½″ to 1″ of stormwater, the answer to our first research question is yes: a greenwall can retain the first flush stormwater during the growing season. The 25 square foot greenwall systems retained on average 2.5 gallons of water a day, equivalent to ½″ of first flush runoff. But it is important to understand that the amount of water retained in a greenwall is related both to the way it is watered and to the way it drains. Unlike a greenroof, which can be flat and therefore may drain slowly, greenwalls are vertical and often drain rather quickly. This is one of the main reasons we watered the greenwall systems each day. Retaining the ½″ first flush would not have been possible using this design without spreading out the watering over three days. This also means that the irrigation strategy used in this project requires using a cistern to store the runoff/irrigation water.

Question 2: Can greenwall water retention capacity compare favorably to the water retention capacity of a greenroof?

As to the second research question, the answer is also yes: the water retention was about 7.5 gallons every three days for 25 ft^2 of greenwall, or about ½″, which is comparable to the retention of an extensive greenroof. Although rainfall retention depth for greenroofs can vary widely during different seasons, the results of this study were comparable to rainfall retention using extensive greenroof stormwater systems. According to a study conducted at Penn State's Center for Greenroof Research in 2009:

> Greenroofs in the study retained an average of 50% of the total precipitation during the study period. During summer months nearly all of the precipitation was retained. During the winter months retention was smaller (<20%). Seasonal effects appear to be a result of snow or freezing conditions, otherwise **greenroofs effectively retained up to 0.4 in.** (10 mm) regardless of season. (Berghage et al. 2009, 3-14)

There are, however, many differences in how greenwalls and greenroofs retain and manage rainfall. To begin with, greenroofs capture rainfall directly and do not require cisterns or irrigation systems. This can be an obvious and significant advantage because of the simplicity of the design. Likewise, greenroofs can retain rainfall year-round because freezing temperatures have little impact on direct capture: frozen precipitation simply collects on a greenroof and waters the vegetation as it slowly melts. "During winter storms the media in a green roof may freeze and slowly release moisture over an extended period. Snow may also accumulate and melt over an extended period." (Berghage et al. 2009, 3-9)

Greenwalls, however, do not directly collect significant amounts of frozen precipitation. In fact, greenwalls do not directly collect significant amounts of precipitation at all. We found that in our study rainfall had little or no impact on the greenwall systems. Because of the vertical configuration of these greenwall systems and the location of these walls placed on large retaining wall systems, unless the rain was blowing, most of the rainfall was blocked by the gutters integrated into the greenwall system .

OTHER RESULTS

Use of greenwalls for stormwater management is best accomplished with cisterns; and they don't need to be huge . . .

This study simulated rainwater being collected in a cistern and then pumped up to irrigate the greenwalls. Such a water harvesting system, we conclude, is the most effective way to establish the desired symbiotic relationship between greenwall and runoff. First, a large amount of rain can be collected in the cistern; and, as long as the cistern has enough free space to add more water, the water can collect over a series of rain events, large or small. A second advantage of this collection/irrigation strategy is that irrigation of the greenwall is completely independent of rain event timing—in other words, as long as the rainwater is collected then pumped, dry periods vs. wet periods of weather have no impact on the viability of the greenwall plants.

. . . but big cisterns make a big difference

The greenwall systems in this study had some advantages over typical greenroofs because of the water cisterns. The 300-gallon cisterns allowed the greenwall systems to capture much more water than a typical greenroof because they were greatly oversized for the 25 ft^2 greenwalls. These oversized cisterns harvested and held runoff volumes far greater than first flush; in contrast, a greenroof system saturated by first flush rainfall would pipe excess runoff into a grey infrastructure system. This rainwater detention strategy via large cistern creates three significant opportunities. The biggest opportunity is that the cisterns could remove concerns about extended drought conditions because the 300-gallon cisterns can collect far more water than needed. In fact, for greenwalls of this size we found that 55-gallon water barrels would likely be sufficient for a 25 ft^2 wall area. If there is concern about a lack of water, the barrels could always be topped-off with city water. Second, the cisterns could collect water during winter thaws; just as frozen precipitation is collected on a greenroof, then thaws during warmer winter weather. The irrigation system would still not function during the winter because of potential damage to the system from freezing; but rainwater could drain from roofs into the cisterns depending on temperatures. Third, the cisterns can act as a publicly visible indicator of the stormwater that is collected and then used to water the greenwalls.

The large cisterns also raise a question about the ability of greenwalls to manage stormwater because it is basically the cistern that is doing most of the work. That is to say, it is the cistern that actually captures the first-flush of rainfall and the greenwalls are actually used to "dispose" of the collected water. We could get the same stormwater management benefits in terms of combined sewer overflow reduction if we simply used the cisterns as extended detention systems. While this would not reduce nonpoint pollution of the first-flush, it must be acknowledged that the level of pollution coming from roof runoff is very low compared to parking lots and roads.

For a thoroughly "green" system, solar power can be used to pump the irrigating rainwater

In this study, both regular AC power and solar power were used to pump the water. Undertaking this stormwater management strategy "off the grid" would be quite viable. For example, the power to pump water for each of our 25 ft^2 greenwall systems was easily provided by a simple 3 × 3 foot photovoltaic panel with one 12-volt battery. In fact, one 3 × 3 foot photovoltaic panel could easily power the four greenwall systems we mounted on a single wall, and possibly all eight greenwall systems. This is because the amount of time that each pump had to run was generally only four minutes, twice a day, to deliver the equivalent of .16″ of rain (.48″ over 3 days).

Small rainfall events can easily be retained as needed

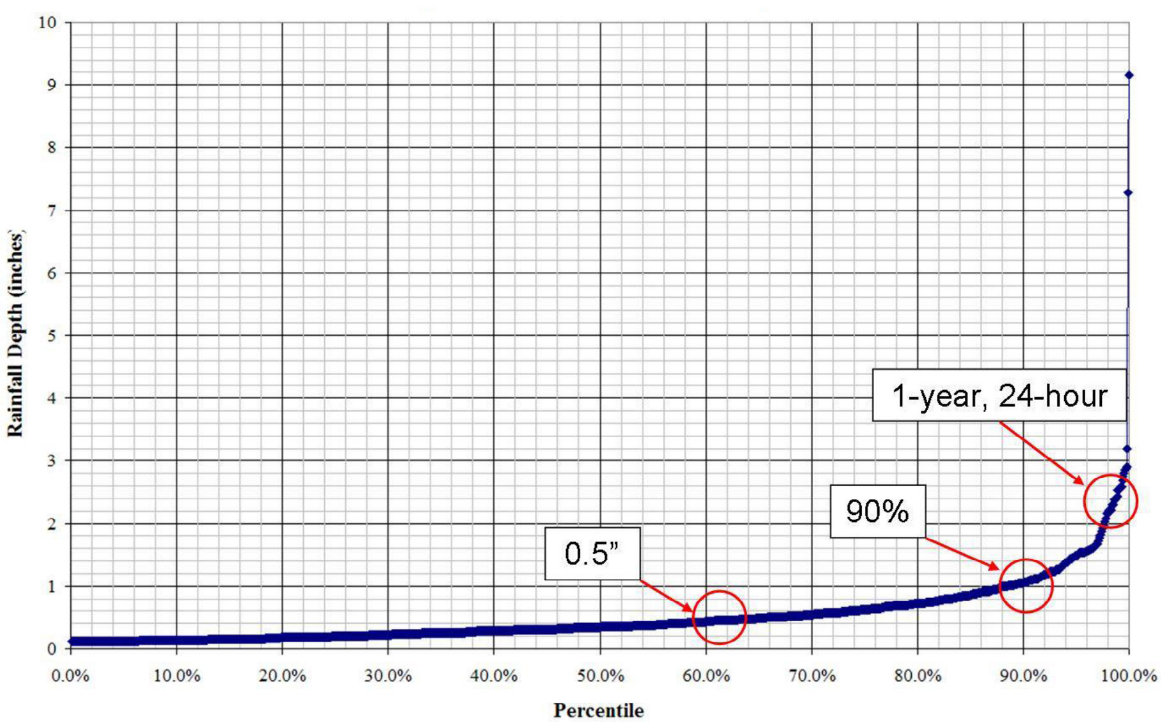
The big nonpoint-source pollution advantage of retaining the first-flush is the reduction of nuisance flooding and combined sewer overflows. Greenwall systems can easily retain ½″ of rainfall, which equates to about 60%–70% of rainfall events annually in many parts of the country, an example of which—from Minnesota— is shown in figure 9.

With this relatively small rainwater capture, greenwalls can significantly contribute to mitigation of urban nuisance flooding and combined sewer overflows.

Winter is a problem

Because freezing temperatures make it impractical to use irrigation, keeping a greenwall watered during the winter is a problem. During winter months, solar radiation or brief warm periods can cause some snowmelt that helps keep greenroofs moist; but greenwalls do not collect much if any snow, so solar radiation or brief melting periods cannot help keep them moist. Likewise, because cold air can circulate behind most greenwall designs (since there is typically air space between the greenwall system and the building façade), and there is little

FIGURE 9. Example Rainfall Depth Compared to Rainfall Frequency (MPCA 2013).



if any warmth derived from building heating, greenwall are very susceptible to harsh winter temperatures. Finally, the entire greenwall irrigation system, including the cisterns, needs to be drained to prevent freeze damage. These issues all combine to make winter care and survival challenging for many greenwall systems. We hope that continued research will help address many of these issues.

CONCLUSIONS

The most obvious conclusion of this study is that greenwalls linked to a cistern can, indeed, manage a significant amount of first flush stormwater comparable to greenroofs, thus holding the potential to contribute to stormwater management strategies especially in urban contexts. The amount of vertical surface area, especially in an urban setting, exceeds available roof area—meaning that there is literally more area for stormwater management on walls than on roofs; therefore, this study suggests that serious consideration of greenwalls for stormwater management may make good sense.

It should also be noted that increased depth of soil medium in the greenwall systems would be expected to increase the runoff retention capacity of the system. The greenwall systems used in this study had a soil depth of approximately 5″; if the cells were deeper, we surmise that the runoff retention capacity would grow, at the same time benefitting plant vigor. Of course, this prompts the question: how important are the plants themselves to runoff retention accomplished by greenwalls? Could a system of soil-filled cells accomplish the same degree of stormwater mitigation? Further research is warranted on the degree of runoff absorption and evapotranspiration accomplished by the plants themselves.

A final limitation is that, due to problems with using a drip irrigation system when temperatures drop below freezing, this study recorded stormwater retention only during the growing season of May–October. What is the runoff-holding capacity of a greenwall during the rest of the year? Year-round testing is warranted to support or refute the findings of this study.

Finally: while the study definitely suggests that greenwalls offer a useful alternative (or complement) to greenroofs for stormwater management, it is important to acknowledge that greenwalls are generally more expensive to install than greenroofs, and often seem to require more management to ensure robust plant growth; consequently, economically prudent designers must determine whether the added cost and effort are justifiable. One argument for greenwalls, especially in the city, may be grounded in the research conducted on the cooling value, property value, and public appreciation for greenwalls, and even the therapeutic value, both physical and mental, of views of greenery from windows. Overall this study suggests that greenwalls may prove viable for urban stormwater management, and that further research is definitely warranted on this subject.

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