Stormwater Reuse Opportunities and Effects on Urban Infrastructure Management; Review of Practices and Proposal of WinSLAMM Modeling

Leila Talebi[1], Robert Pitt[2] and Shirley Clark[3]

[1]Graduate student, Dept. of Civil, Construction, and Environmental Engineering, Univ. of Alabama, P.O. Box 870205, Tuscaloosa, AL 35487; e-mail: ltalebi@crimson.ua.edu

[2]Cudworth Professor, Urban Water Systems, Dept. of Civil, Construction, and Environmental Engineering, Univ. of Alabama, P.O. Box 870205, Tuscaloosa, AL 35487; e-mail: rpitt@eng.ua.edu

[3] Associate/Assistant Professor of Environmental Engineering, Penn State Harrisburg; e-mail: sec16@psu.edu

Abstract

This presentation summarizes a Water Environment Research Foundation (WERF)/EPA funded project which aims to show how currently available models and other tools can be interactively used to calculate the benefits of stormwater beneficial uses. This project summarizes the lessons learned, including successes, from a wide variety of international stormwater beneficial use projects. Our goal was to identify features that can be applied to U.S. conditions. The report includes summaries of case studies from developing countries in both arid and wet climates, case studies from developed countries in areas where future water conservation is necessary to support continued growth, and from developed countries where sustainable use of natural resources is of high priority. Also reviewed are typical water quality conditions from different stormwater sources in urban areas and desirable (or regulated) water quality requirements for the use of this water for different applications. Water quality degradation associated with different storage options is also examined along with different water treatment options to meet the needed "finished" water quality before use. Guidance is provided on how to determine the amount of supplemental landscape irrigation needed from stored stormwater, and how to calculate needed tankage volumes for many locations in the U.S.

The project calculates the beneficial use opportunities of stormwater, especially landscaping irrigation, in different areas of the country, using continuous stormwater models for the development of production functions for tankage volume alternatives. The project presents a method to evaluate or size water tanks needed to optimize the beneficial uses of stormwater. Irrigation of land on the homeowner's property was considered the beneficial use of most interest. Irrigation calculations rely on good evapotranspiration (ET) data, which is rare for urban settings. Guidance on plants that withstand a wide range of moisture conditions is also provided in order to maximize the use of the runoff water. Extensive appendices present monthly ET values for several hundred locations near urban areas in the U.S.

Keywords: Stormwater management, sustainable urban water design, beneficial uses of stormwater, rainfall harvesting, WinSLAMM.

Introduction

This paper is mostly excerpted from: R. Pitt, L. Talebi. R. Bean, and S. Clark, *Stormwater Non-Potable Beneficial Uses and Effects on Urban Infrastructure,* prepared for the Water Environment Research Foundation, scheduled to be published in September 2012.

Several important issues were evident from the case studies. As expected, the heavily urbanized developing countries in water stressed areas (such as in China and India) are most concerned with harvesting as much runoff as possible, with minimal concern related to water quality. Not only is roof runoff harvested (the likely cleanest water available), but also runoff from all urban areas. Usually, all paved areas are used to harvest runoff water, as maximum volumes are needed to augment the poor quality and poorly available local sources. The water is stored in large ponds, and sometimes injected to shallow aquifers. These efforts improve the water quality to some extent, greatly depending on the storage conditions.

In developing countries with large rural populations in water stressed areas (such as in Africa), most of the runoff harvesting schemes focus on collecting roof runoff for storage in tanks near the homes. The water is used for all domestic purposes and for irrigation of food subsistence crops during dry weather. The storage tanks are therefore relatively large to provide seasonal storage.

In developed countries with large urban population centers in water scarce regions (such as Australia), runoff harvesting has long been used to augment the water supplies. In most cases, the runoff is collected from roofs and stored in large tanks adjacent to homes where the water is used for non-potable uses. In some rural cases, the water is used for all domestic water uses. At large development water harvesting projects (such as at large apartment buildings in urban city centers), runoff is collected from all areas and undergoes some pretreatment before storage in large (usually underground) storage tanks. The water usually undergoes very sophisticated water treatment before use. In many cases, this highly treated harvested runoff is still restricted to non-potable uses.

Examples of runoff harvesting in developed countries that currently are not under-going water shortages (such as Germany) are similar to the processes used in Australia. The purposes are to develop "sustainable" urban environments, where water conservation is a key factor. In the U.S., many of the recent stormwater harvesting projects are either part of a LEED® certified project, and/or are used to help reduce stormwater discharges to combined sewer systems. The collected water is not used for potable uses, but mostly for irrigation uses, and sometimes for toilet flushing or for fire suppression.

Water Quality

Water reuse regulations or guidelines vary with the type of application, the regional context, and the overall risk perception. Few water reuse regulations address stormwater source water and were mostly initially developed for the reuse of treated sanitary wastewaters. The regulations therefore usually apply to all water sources that are deemed to be "wastewaters," including stormwater. Most of the general reuse guidelines have limits on quality objectives based on suspended solids, organic content (usually expressed as BOD_5), bacteria indicator organisms and some pathogens (total or fecal coliforms, *E. coli*, helminth eggs, enteroviruses), nutrient levels (nitrogen and phosphorus) and, in some cases, chlorine residual, while the stormwater beneficial use regulations mostly focus on *E. coli*, chlorine, pH, and turbidity.

This research also compared stormwater quality with the regulations and criteria for beneficial uses. Constituents where the typical stormwater average values likely exceed the available criteria include: BOD_5, COD, TSS, turbidity, total coliforms, fecal coliforms, and *E. coli*. Additional constituents may periodically exceed the criteria, as some of the reported maximum stormwater values can be high, including: pH, ammonia, nitrate plus nitrite, arsenic, cadmium, chromium, copper, iron, selenium, and zinc. The most potentially problematic constituents (where the exceedences are the greatest and likely most frequent), include the bacteria, followed by the solids and turbidity values. The metals having the potentially greatest exceedences include cadmium and zinc. As expected, roof runoff and landscaped areas have better water quality, but all stormwater source areas can exceed the numeric criteria for BOD_5, COD, TSS, and fecal coliforms. Stormwater runoff at outfalls exceeded the bacteria objectives by the greatest amount, followed by TSS. The BOD_5 and COD exceedences were not as great, but almost all samples from all land use areas exceeded these criteria Therefore, none of the stormwater or source waters would likely be able to meet the numeric criteria for stormwater beneficial uses without treatment, with the bacteria being the most problematic, and the solids and turbidity values also being an issue. Roof runoff is the preferred source water for beneficial stormwater uses, but treatment, especially for bacteria, will still be necessary in order to meet existing criteria.

Different materials are used in the collection and storage components of stormwater beneficial use systems. Some materials can degrade runoff water even with very short contact times, and would be a problem even if used for the collection surface. Other materials, however, require extended exposure periods to degrade the water, such as would be evident in storage tanks. The most significant potential problems are associated with galvanized metal roofs or gutters and tanks, plus copper pipes or other plumbing fixtures used in the systems. These materials can elevate the zinc and copper concentrations to problematic concentrations during rain events, while extended contact, such as with storage tanks, can cause very high concentrations of these metals.

Treatment of stormwater may therefore be needed to meet non-potable beneficial use criteria. For simple irrigation use, bacteria reductions would be necessary, along with the prevention of excessive metal concentrations through careful selection of materials. Extended cistern and water tank storage can reduce most bacteria levels to close to the regulation's numeric values, although some additional treatment may be needed. Roof runoff can have excessive bacteria levels, especially during the non-winter months and if trees are over the roofs, which provide inviting habitat for birds and squirrels (shown to cause very large bacteria levels in roof runoff). Depending on the water quality of the source stormwater and the intended beneficial use, different water quality treatment options can be used. There are a number of commercial treatment units available designed for treating wastewater for reuse that can also reduce stormwater solids, bacteria, and heavy metals to acceptable levels.

Typical wastewater reuse regulations were originally written to pertain to reuse of sanitary wastewaters and do not address stormwater as a source water. There are some regulations, however, that were specifically prepared to regulate the beneficial uses of stormwater, with some shown in Table 1. This table summarizes a few regulations identified that specifically addressed stormwater beneficial uses (New South Wales, Australia; Berkeley, CA; Texas; and the United Kingdom). Bacteria standards are common, with *E. coli* limits ranging from 1 count per 100 mL for non-potable uses with public access to 1,000 counts per 100 mL for controlled access. Chlorine residuals imply chlorination as a disinfectant, usually with a concurrent turbidity limit to allow more efficient disinfection. All of these focus on public health issues and contain restrictive levels of bacteria, with lower allowable limits where the public access is not well controlled, and with higher allowable limits for water non-contact situations and where access can be well controlled. Irrigation criteria may affect stormwater use for certain plants, especially if galvanized metals or copper is in contact with either the collection, storage, or distribution areas of the rain water harvesting systems. Situations where groundwater recharge is direct with injection wells, or other methods providing little treatment, may also result in adverse water quality. Also, water laws in certain (mainly arid) states severely restrict the beneficial uses of stormwater, even on the property owner's own land.

Table 1. Regulations Restricting Stormwater Beneficial Uses.

		Coliform	Chlorine	pH	Turbidity	Ammonia	Aluminum	Nitrate/Nitrite
WHO[1]	Roof water harvesting	*E. coli.* <10cfu/100 mL	>0.2–0.5 and <5 mg/L	6.5–8.5	Not relevant	<1.5 mg/L	Not relevant	Not relevant
	Surface Runoff	*E. coli*.<10cfu/100 mL	>0.2–0.5 and <5 mg/L	6.5–8.5	<15 NTU	<1.5 mg/L	<0.2 mg /L	<50 mg/L and <3 mg/L
	Sand dams	*E. coli*.<10cfu/100 mL	>0.2–0.5 and <5 mg/L	6.5–8.5	<5 NTU	<1.5 mg/L	<0.2 mg /L	<50 mg/L and <3 mg/L
NSW Australia	Level 1[2]	<1 cfu/100 mL	1 mg/L Cl_2 residual after 30 minutes or equivalent level of pathogen reduction	6.5–8.5	≤ 2 NTU			
	Level 2[3]	<10 cfu/100 mL	1 mg/L Cl_2 residual after 30 minutes or equivalent level of pathogen reduction	6.5–8.5	≤ 2 NTU			
	Level 3	<1000 cfu/100 mL		6.5–8.5	--------			
Berkeley[4] California	Non-potable indoor/outdoor uses	Total coliforms <500 cfu per 100 mL Fecal coliforms <100 cfu per 100 mL						
Texas[5]	Non-potable indoor uses	Total coliforms <500 cfu per 100mL Fecal coliforms <100 cfu per 100mL						
UK[6]	Non-potable indoor uses	Total coliforms 10/100 mL	<2 mg/L	6–8	≤ 10 NTU			
Virginia[7]	Non-potable indoor uses	Total coliforms < 500 cfu per 100 mL Fecal coliforms <100 cfu per 100 mL						

1- RAIN Water Quality Guidelines, 2008
2- Non-potable residential uses (e.g. garden watering, toilet flushing, car washing)
3- Public access public uses: -Spray or drip irrigation of open spaces, parks and sports grounds (no access controls), -Industrial uses – dust suppression, construction site use (human exposure possible), -Ornamental waterbodies (no access controls), -Fire-fighting
4- Guidelines for Rainwater Harvesting, Planning and Development Department Energy and Sustainable Development & Building and Safety Division, 2010
5- Rainwater Harvesting Potential and Guidelines for Texas, 2006
6- Draft British Standard on Rainwater Harvesting, 2008
7- Virginia Rainwater Harvesting Manual, Second Edition. 2009.

Water Harvesting Potential

The water harvesting potential for water tank use was calculated based on supplemental irrigation requirements for the basic landscaped areas. The irrigation needs were determined to be the amount of water needed to satisfy the evapotranspiration needs of typical turf grasses, after the normal rainfall (a conservative calculation, as only a portion of the rainfall contributes to soil moisture).

Rain gardens rain barrel/tanks, and disconnection of roof runoff are controls that can be used in residential areas. They are located on private property and receive the runoff from directly connected roofs. Their maximum benefit is dependent on the amount of runoff that is contributed from the source areas where they would be located. In these analyses of rainbarrels and storage tanks, irrigation of typical turf grass landscaping around the homes in the study area is the use being examined. This irrigation requirement is the additional water needed to supplement the long-term monthly average rainfall in order to match the evapotranspiration requirements for the area. Small rain barrels provide limited direct benefits, so larger water tanks were also considered. Also, in order to be most beneficial, these calculations assume that the irrigation rates are controlled by soil moisture conditions in order to match the ET requirements closely. This level of control is usually most effectively achieved with a single large storage tank connected to an automatic irrigation system and soil moisture sensors. Numerous smaller rain barrels are more difficult to control optimally.

Figure 1 is an input screens used for stormwater beneficial use with rain barrel or cistern water storage in WinSLAMM version 10. The only discharge is the monthly water use requirements (the irrigation demands).

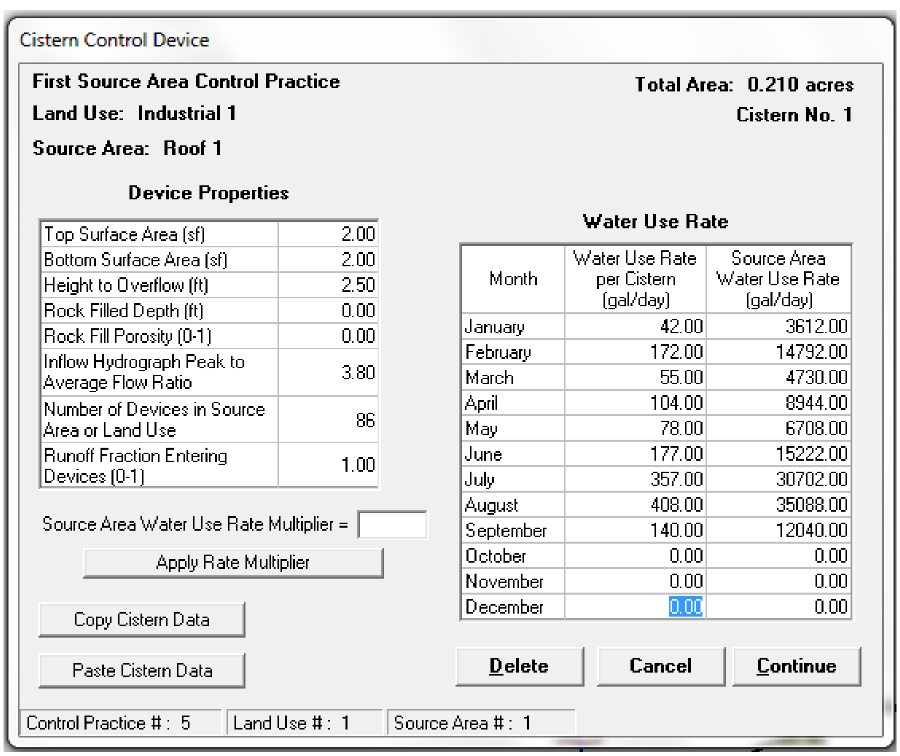

Figure 1. Cistern/Water Tank WinSLAMM Input Screen.

The calculations were performed for typical medium density residential areas in all six of the major U.S. rain zones. Table 2 shows the calculations for the Great Lakes region, based on Madison, WI, rain data and regional evapotranspiration (ET) values. The monthly infiltration amounts in the landscaped areas, assuming silty soils, were calculated using the continuous WinSLAMM simulations. Those values were subtracted from the monthly ET values to obtain the monthly deficits per month, and the daily deficits per house per day.

Table 2. Calculations for Medium Density Area Irrigation Demands for Great Lakes Region.

Great Lakes		Silty				
	total rainfall (in/month)	ET (in/day)	ET (in/month)	total infiltration (in/month)	irrigation deficit (in/month)	irrigation deficit (gal/day/house)
Jan	1.49	0.00	0.00	1.43	n/a	0
Feb	0.83	0.00	0.00	0.79	n/a	0
Mar	1.81	0.00	0.00	1.73	n/a	0
Apr	3.46	0.11	3.30	2.42	0.88	114
May	3.13	0.15	4.65	3.03	1.62	204
Jun	4.55	0.16	4.80	3.81	0.99	129
Jul	4.07	0.16	4.96	3.95	1.01	127
Aug	3.74	0.13	4.03	3.69	0.34	43
Sep	1.78	0.11	3.30	1.75	1.55	202
Oct	2.60	0.08	2.48	2.54	n/a	0
Nov	1.32	0.04	1.20	1.25	n/a	0
Dec	0.61	0.00	0.00	0.57	n/a	0
	29.39		28.72	26.96	6.40	

1 in = 25.4 mm = 2.54 cm, 1 gallon = 3.785 Liter

Table 3 shows the results of the continuous simulations for different water tank volumes, and shows corresponding percentage roof runoff reductions. Figure 2 is a plot of the roof runoff reductions vs. roof runoff storage tank volumes for Great Lakes area and for silty soil conditions.

Table 3. Calculated Benefits for Different Water Tank Volumes for Great Lakes Medium Density Residential Areas.

runoff water tank storage per house (ft^3)	rain barrel storage per house (ft^3) per roof area (ft^2, or ft depth over the roof)	total annual roof runoff per house (ft^3)	Rv for roof area	% reduction in roof runoff
0	0.0000	3683	0.91	
5	0.0007	3247	0.80	11.8
47	0.0072	2547	0.63	30.9
94	0.0144	2260	0.56	38.6
188	0.0288	1909	0.47	48.2
470	0.0719	1540	0.38	58.2
940	0.1439	1253	0.31	66.0
1880	0.2877	1195	0.30	67.6
2820	0.4316	1043	0.26	71.7
3760	0.5755	1043	0.26	71.7

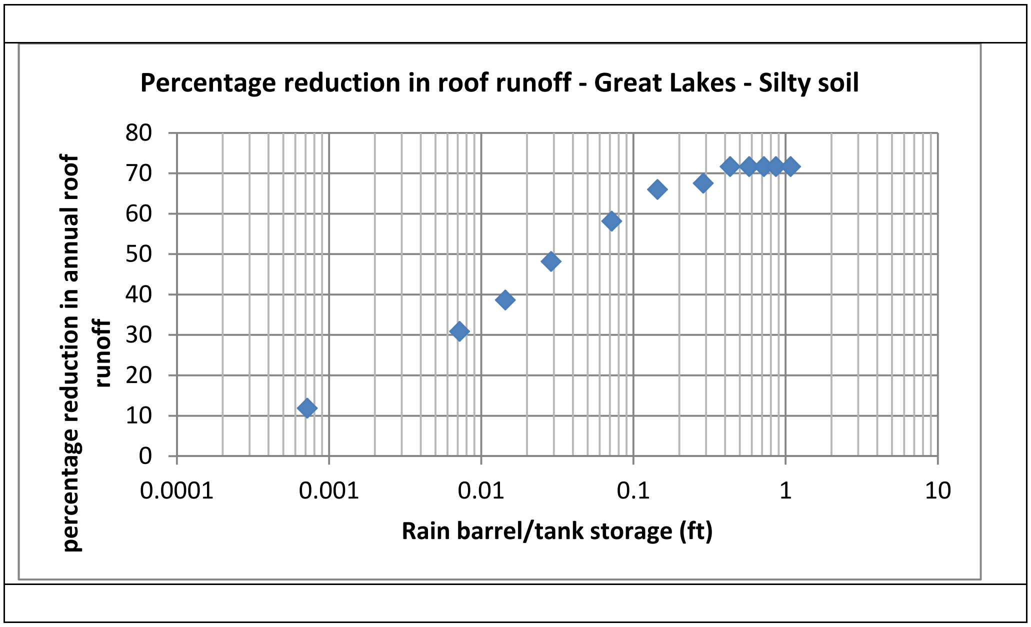

Figure 2. Roof Runoff and Water Tank Storage Production Function for Medium Density Residential Areas in the Great Lakes Area of the U.S. (1 ft = 30.5 cm)

Results

Table 4 summarizes calculations indicating the effects of different sized storage tanks for residential areas for irrigation use of roof runoff. The irrigation demands on this table are only to meet the evapotranspiration (ET) requirements, after infiltration of the typical rainfall. The continuous model used a five year rain series and does not consider any "over" irrigation or other uses. It is quite likely that excessive irrigation would be suitable as a stormwater disposal option. As an example, the use of roof runoff rain gardens usually do not only consider the minimum irrigation requirements, but supply an excess of water based on the infiltration capabilities of the soils. These values are therefore the minimum quantities of roof runoff harvesting available. The Central U.S. area has the highest level of potential stormwater beneficial use because the ET demands best match the rainfall distributions throughout the year. The Great Lakes area also has a high level of stormwater beneficial use potential. The East Coast, Southeast, and Southwest regions all had moderate levels of stormwater beneficial use potential due to poorer matches of the ET and rainfall patterns, or greater amounts of rainfall compared to the available irrigation demand (or both). The Northwest region has the poorest likely potential use of stormwater beneficial use due to the small ET-infiltration deficits (larger tanks have little additional benefit; the irrigation area would have to be greatly expanded to utilize any extra stored stormwater, or excessive irrigation applications would be needed).

Table 4. Maximum Roof Runoff Harvesting Benefits for Regional Conditions (Medium Density Residential Land Uses, silty soil conditions)

Region	total roof area (% of total resid. area for region)	landscaped area (% or total resid. area for region)	representative city	study period annual rain fall (inches per year) (1995 to 2000)	roof runoff control (%) for 0.025 ft^3 storage/ft^2 roof area (about 5 rain barrels per 1,000 ft^2 roof)	roof runoff control (%) for 0.25 ft^3 storage/ft^2 roof area (3 ft high by 6 ft diameter tank per 1,000 ft^2 roof)	roof runoff control (%) for 1.0 ft^3 storage/ft^2 roof area (two 6 ft high by 10 ft diameter tanks per 1,000 ft^2 roof)
Central	18.1	62.5	Kansas City, MO	33.5	40%	78%	90%
East Coast	15.9	54.5	Newark, NJ	53.0	24%	33%	42%
Southeast	8.8	81.1	Birmingham, AL	49.8	34%	41%	42%
Southwest	15.4	61.2	Los Angeles, CA	16.7	35%	44%	48%
Northwest	15.4	61.2	Seattle, WA	41.7	16%	16%	19%
Great Lakes	15.0	57.5	Madison, WI	28.7	46%	68%	72%

Example Alternative Irrigation Water Use Calculations

Tables 5 and 6 and Figures 3 and 4 are calculated supplemental irrigation requirements for residential areas in Millburn, NJ (Pitt, *et al.* 2012). These areas have roofs that are about 325 m^2 in area (3,500 ft^2) corresponding to about 13.5% of the land use, and landscaped areas about 1,440 m^2 (15,500 ft^2) corresponding to about 61% of the land use, with a relatively large roof to landscaped area ratio of about 0.23 (large homes and small lots).

Table 5 and Figure 3 summarize the irrigation needs that can be considered the minimum amount by barely meeting the landscaped area evapotranspiration requirements (assuming all of the rainfall contributes to soil moisture, which is true for rains less than about 25 mm (1 inch) in depth, but some of the rain flows to the storm drainage system for larger rains. The monthly rainfall compared to the monthly ET is shown in Figure 3 and illustrates how supplemental irrigation would be needed in the summer months, as expected. Table 5 shows these calculations, including the monthly irrigation needs in gallons per day per house. This rate would be used for barely meeting the ET needs with excessive irrigation. Excessive irrigation water would result in runoff (if applied at a rate greater than the infiltration rate of the surface soils), and recharge of the shallow groundwater. For a water conservation program, this irrigation amount is usually the target. However, for a stormwater management goal, maximum utilization of the roof runoff may be desired.

Table 5. Irrigation Needs to Satisfy Evapotranspiration Requirements for Essex County, NJ

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total Annual
Average monthly rain (in./mo)	3.42	3.11	4.16	3.71	3.99	2.88	4.21	4.04	3.61	3.06	3.70	3.47	43.37
Average monthly ET (in./mo)	0.47	0.85	3.26	3.90	4.81	4.65	4.81	4.19	3.60	3.57	3.00	1.40	38.47
deficit for ET needs (in./mo)	0.00	0.00	0.00	0.19	0.81	1.77	0.60	0.15	0.00	0.51	0.00	0.00	4.03
Deficit ET needed (gal/day/house) 0.36 acres	0	0	0	63	256	577	188	47	0	160	0	0	39,200 gal/year

(1 in./mo = 25 mm/mo)

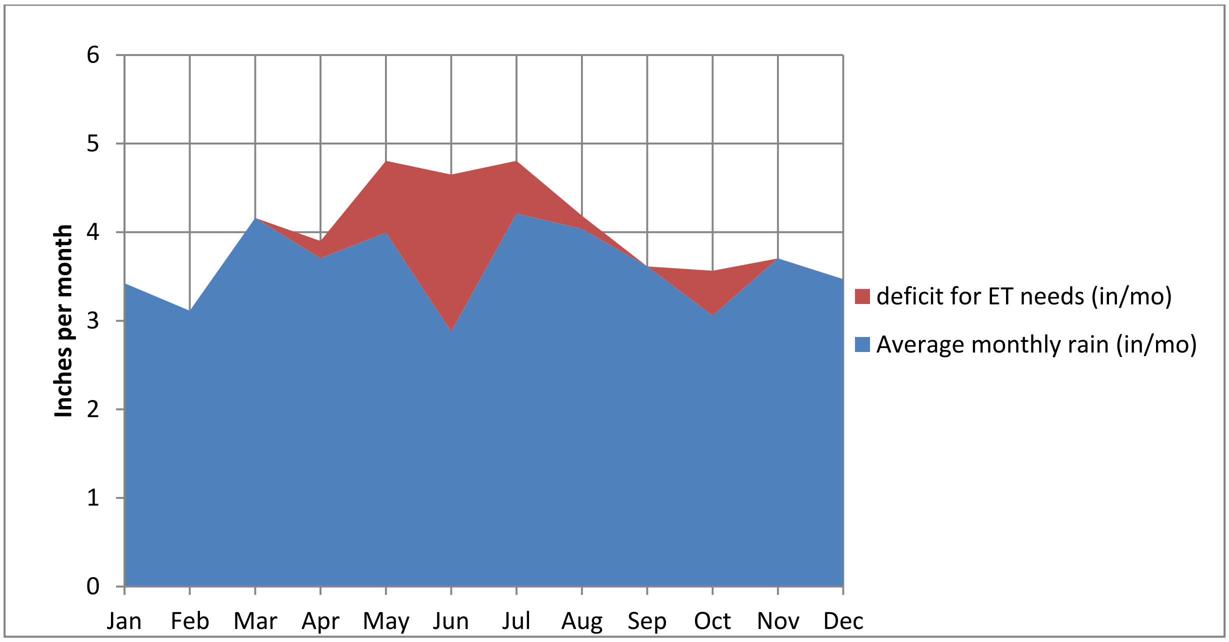

Figure 3. Plot of supplemental irrigation needs to match evapotranspiration deficit for Essex County, NJ. (1 in./mo = 25 mm/mo)

For maximum use of the roof runoff to decrease runoff volumes, it is desirable to irrigate at the highest rate possible, without causing harm to the plants. Therefore, Table 6 and Figure 4 show an alternative corresponding to a possible maximum use of the roof runoff. For a "healthy" lawn, total water applied (including rain) is generally about 25 mm (1inch) of water per week, or 100 mm (4 inches) per month. Excessive watering is harmful to plants, so indiscriminate over-watering is to be avoided. Some plants can accommodate additional water. As an example, Kentucky Bluegrass, the most common lawn plant in the US, needs about 64 mm/week (2.5 in./week), or more, during the heat of the summer, and should receive some moisture during the winter. Table 6 therefore calculates supplemental irrigation for 12 mm (0.5 inches) per week in the dormant season and up to 64 mm/week (2.5 inches/week) in the hot months. Natural rains are expected to meet the cold season moisture requirements. The total irrigation needs for this moisture series is about 1,200 m^3 (318,000 gallons) per year per home. This is about eight times the amount needed to barely satisfy the ET requirements noted above. However, the roofs in the Millburn study area are only expected to produce about 90,000 gallons (340 m^3) of roof runoff per year, or less than a third of the Bluegrass needs but more than twice the needs for the ET deficit. Therefore, it may be possible to use runoff from other areas, besides the roofs, for supplemental irrigation.

Table 6. Irrigation Needs to Satisfy Heavily Irrigated Lawn for Essex County, NJ

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total Annual
Average monthly rain (in./mo)	3.42	3.11	4.16	3.71	3.99	2.88	4.21	4.04	3.61	3.06	3.70	3.47	43.37
Lawn moisture needs (in./mo)	2.00	2.00	4.00	4.00	8.00	8.00	10.00	10.00	10.00	8.00	4.00	2.00	72.00
Deficit irrigation need (in./mo)	0.00	0.00	0.00	0.29	4.01	5.12	5.79	5.96	6.39	4.94	0.30	0.00	32.80
Deficit irrigation needed (gallons/day/house) 0.36 acres	0	0	0	96	1263	1669	1826	1880	2081	1558	96	0	318,000 gal/year

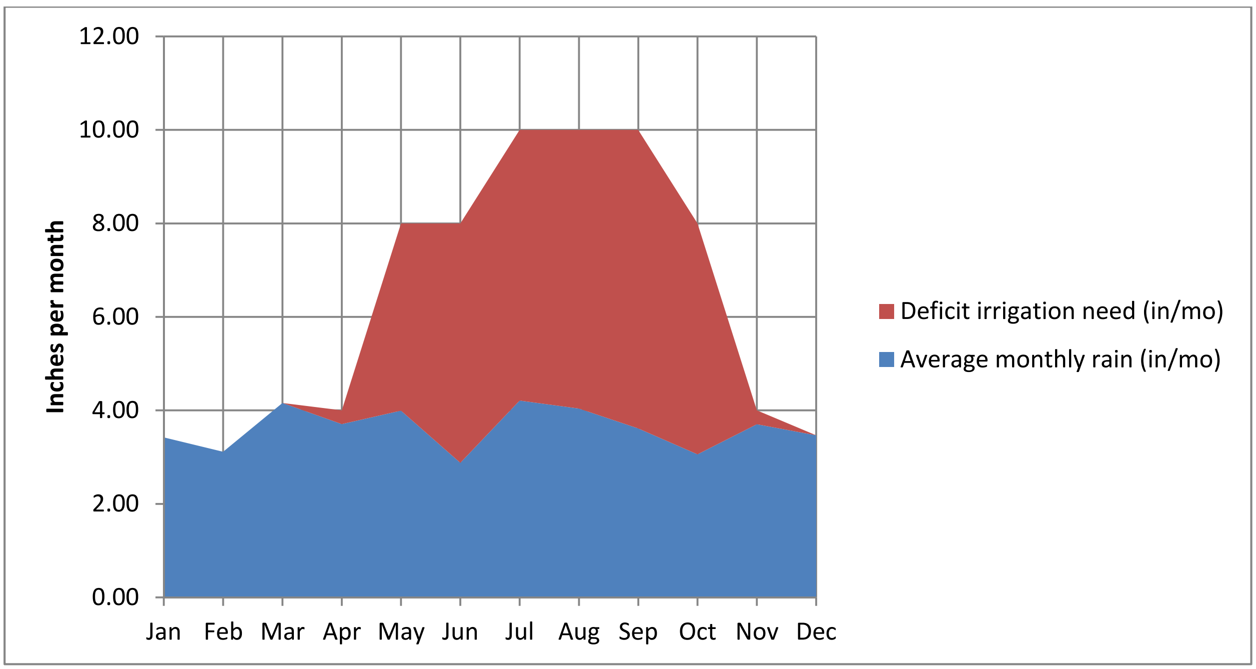

Figure 4. Plot of supplemental irrigation needs to match heavily watered lawn (0.5 to 2.5 inches/week) deficit for Essex County, NJ. (1 in./mo = 25 mm/mo)

Conclusion

The harvesting of urban stormwater to supplement non-potable water demands is emerging as a viable option, amongst others, as a means to augment increasingly stressed urban water supply systems and to reduce stormwater discharges. The beneficial use of stormwater for irrigation reduces domestic water use, and decreases the discharges of stormwater during storms to either separate or combined sewer systems. Existing water reuse regulations were also reviewed in this study. Current regulations addressing stormwater beneficial uses are typically based on more stringent precautions pertaining to reuse of sanitary wastewaters. Treatment of stormwater before beneficial use can be accomplished through storage in large water tanks and supplemented by relatively simple UV or other disinfection methods, as needed. This project showed how to consider site specific conditions and objectives in the sizing of rainwater harvesting systems. Most systems being constructed are not supported by basic engineering calculations and are likely too small for the benefits desired.

References

- Draft British Standard on Rainwater Harvesting, 2008. Available at: http://www.harvesth2o.com/adobe_files/UK_BSI.pdf
- Guidelines for Rainwater Harvesting, Planning and Development Department Energy and Sustainable Development & Building and Safety Division, 2010. Available at: http://www.ci.berkeley.ca.us/uploadedFiles/Planning_and_Development/Level_3_-_Energy_and_Sustainable_Development/rainwater.pdf
- Pitt, R., Talebi, L., Bean, R., and S. Clark, *Stormwater Non-Potable Beneficial Uses And Effects On Urban Infrastructure,* Water Environment Research Foundation, September 2012
- RAIN Water Quality Guidelines, 2008
- Rainwater Harvesting Potential and Guidelines for Texas, 2006. Available at: http://www.twdb.state.tx.us/innovativewater/rainwater/doc/RainwaterCommitteeFinalReport.pdf
- Virginia Rainwater Harvesting Manual, Second Edition. 2009. Available at: http://dcr.virginia.gov/documents/stmrainharv.pdf