Roof Runoff Harvesting Benefits for Regional Conditions in Low Density and Medium Density Residential Areas

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ABATRACT

Rain barrels are a very simple method for collecting roof runoff for beneficial uses. In these analyses as a part of a WERF/EPA supported project, irrigation of typical turf grass landscaping around homes is being examined for typical low density and medium density residential areas in six U.S. rain zone areas. The study areas include Great Lakes (Madison, WI), East Coast (Newark, NJ), Central (Kansas City, MO), Northwest (Seattle, WA), Southeast (Birmingham, AL), and Southwest (Los Angeles, CA). The monthly rainfall infiltration amounts in the landscaped areas in these six regions were calculated using continuous WinSLAMM simulations. Also, roof runoff and water tank storage production functions were calculated for each condition. The result shows that the Central U.S. area has the highest potential level of roof runoff control using beneficial irrigation because the period of the evapotranspiration (ET) demands best match the rain distribution pattern. The Great Lakes area also had a high level of control. The East Coast, Southeast, and Southwest regions all had moderate levels of maximum control due to poorer matches of ET and rainfall, or greater amounts of rainfall. The Northwest region has the poorest maximum level of control, and large storage tanks are not likely to be very effective due to small ET-infiltration deficits. The ratios of roof areas to landscaped areas for the medium density land uses range from 0.11 to 0.29 (average of 0.25); the ratios for low density land uses range from 0.05 to 0.23 (most at 0.11); while the ratios for strip commercial areas range from 1.8 to 4.0 (most at 2.3). Low density residential area irrigation uses would therefore have a greater maximum benefit compared to the medium density areas, while the strip commercial areas would have much worse maximum benefits due to the lack of landscaped areas to irrigate and the relatively large roof areas.

The analysis approach described above would be typical for areas most concerned with water conservation and minimum use of irrigation water. However, for stormwater management, the goal is to divert as much of the roof runoff from the drainage system as possible. This is limited, not by ET deficits, but maximum irrigation use that can be applied before harm occurs to the plants. As an example, Kentucky Bluegrass, the most common lawn plant in the US, requires substantial irrigation in most areas. Excess irrigation beyond ET and the plants needs would result in surface runoff (may be acceptable if the timing of the discharge does not harm the receiving waters) or discharge to shallow groundwaters (a common receiver of stormwater during infiltration to rain gardens or other infiltration stormwater practices. An example shows that these increased irrigation application rates results in substantially greater controls of roof runoff.

INTRODUCTION

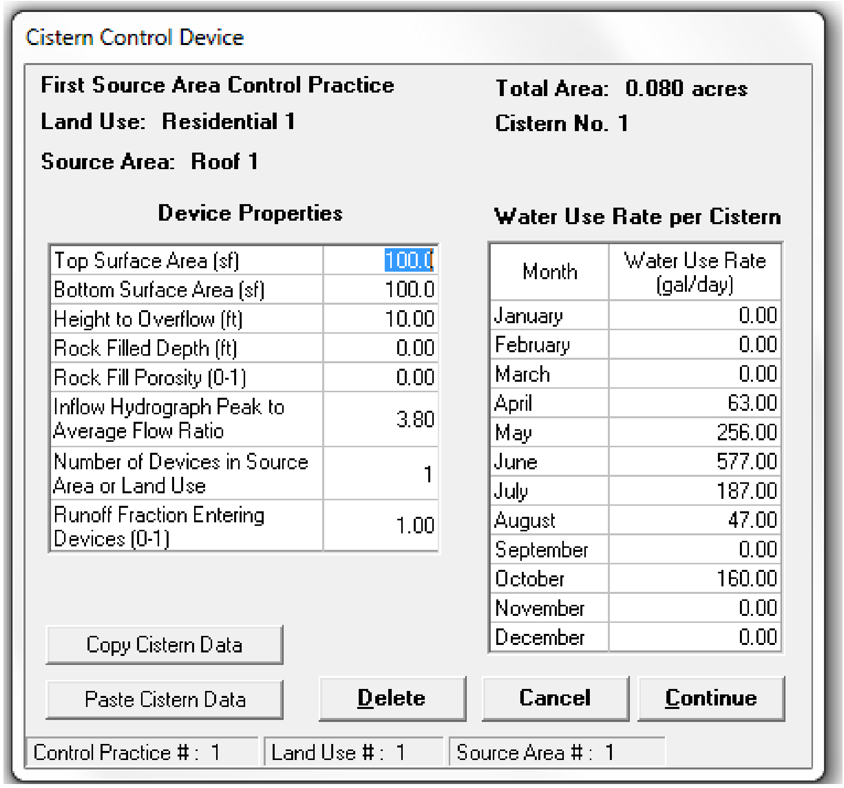
Water is one of the most important natural resources. Global consumption of water increases every year, therefore many predict that freshwater resources will become widely unavailable in the close future. The fast increase in population and subsequent urbanization of land has caused a significant strain on waterways including loss of natural water bodies in order to provide more space (Furumai 2008). On the other hand, the increases in urbanization also increase the amount of runoff caused by the impervious surfaces. Rainwater harvesting from the impervious surfaces is a strategy that can considerably address issues associated with urbanization as well as urban stream degradation and flooding (Fletcher et al., 2008; van Roon, 2007; Zhu et al., 2004).

This study presented a method to evaluate or size water storage 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. Production function curves were prepared for several locations in the U.S. showing the relationship between water tank sizes and roof runoff beneficial uses. Traditional irrigation calculations rely on good evapotranspiration (ET) data, which is rare for urban settings, along with continuous long-term rainfall records, in addition to information concerning site development characteristics. Benefits associated with stormwater used for irrigation and other on-site uses can be calculated based on this site specific information. Specifically, source area characteristics describing where the flows will originate and how the water will be used, are needed. In the most direct case, this information is used in conjunction with the local rainfall information and storage tank sizes to determine how much of the irrigation needs can be satisfied with the stormwater, and how the stormwater discharges can be reduced. The following section describes how WinSLAMM, the Source Loading and Management Model (Pitt 1997), was used to calculate production functions that can be used to size storage water tanks to maximize irrigation use for residential locations throughout the U.S.

WinSLAMM was developed to evaluate stormwater runoff volume and pollutant loadings in urban areas using continuous small storm hydrology calculations, in contrast to single event hydrology methods that have been traditionally used for much larger single drainage design storms. WinSLAMM determines the runoff based on local rain records and calculates runoff volumes and pollutant loadings from each individual source area within each land use category for each rain. Examples of source areas include: roofs, streets, small landscaped areas, large landscaped areas, sidewalks, and parking lots.

METHODS and MATERIALS

Rain gardens, rain barrel/tanks, and disconnection of roof runoff are controls being used in the residential areas in different regions of the U.S. In these analyses as a part of a WERF/EPA supported project, irrigation of typical turf grass landscaping around the homes was examined for typical low density and medium density residential areas in six U.S. rain zone areas (including Great Lakes: Madison, WI; East Coast: Newark, NJ; Central: Kansas City, MO; Northwest: Seattle, WA; Southeast: Birmingham, AL; and Southwest: Los Angeles, CA.) The model can use any length of rainfall record as determined by the user, from single rainfall events to several decades of rains. In this study, rain data from 1995 to 1999 was used. Figure 1 is an input screen used for water storage tanks/cisterns in WinSLAMM version 10.



First Source Area Control Practice

Land Use: Residential 1

Source Area: Roof 1

Total Area: 0.080 acres

Cistern No. 1

Device Properties

Top Surface Area (sf)	100.0
Bottom Surface Area (sf)	100.0
Height to Overflow (ft)	10.00
Rock Filled Depth (ft)	0.00
Rock Fill Porosity (0-1)	0.00
Inflow Hydrograph Peak to Average Flow Ratio	3.80
Number of Devices in Source Area or Land Use	1
Runoff Fraction Entering Devices (0-1)	1.00

Water Use Rate per Cistern

Month	Water Use Rate (gal/day)
January	0.00
February	0.00
March	0.00
April	63.00
May	256.00
June	577.00
July	187.00
August	47.00
September	0.00
October	160.00
November	0.00
December	0.00

Control Practice # : 1
Land Use # : 1
Source Area # : 1

Figure 1. Cistern/Water Tank WinSLAMM Input Screen

The monthly infiltration amounts in the landscaped areas in all of 6 regions, assuming silty, sandy and clayey soils, were calculated using the continuous WinSLAMM simulations. Those values were subtracted from the monthly ET requirements (adjusted for urban turf grasses) to obtain the monthly deficits per month, and the daily deficits per house per day. Also, roof runoff and water tank storage production functions were calculated for each condition. Table 1 and Figure 1 show the calculations and results for the East Coast region, based on Newark, NJ (Essex County) rain data and regional evapotranspiration (ET) values.

Table 1. Irrigation Needs to Satisfy Evapotranspiration Requirements for Essex County, NJ

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
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
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
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
Deficit for ET needs (gal/day/house) 0.36 acres	0	0	0	63	256	577	188	47	0	160	0	0

The total annual rainfall for this site is about 43inches while the total annual ET requirements are about 38 inches, and the annual total household supplemental irrigation requirements are about 39,000 gallons per year (0.36 acres of turf grass per home). Most of the deficits are in the months of May through July, as shown below on Figure 1. Many of the months do not require additional irrigation to meet the ET requirements for turf grass.

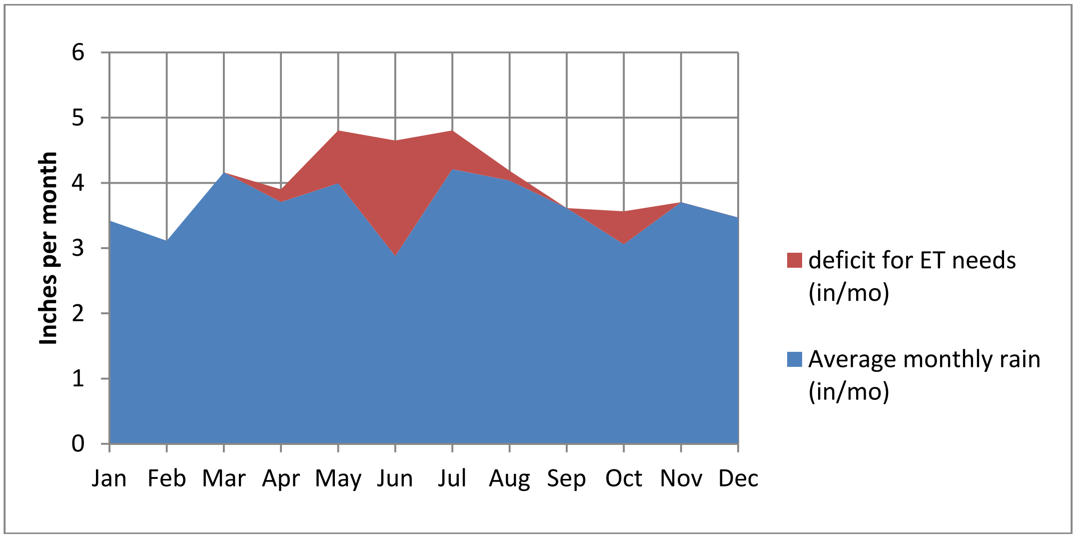


Figure 1. Plot of supplemental irrigation needs to match evapotranspiration deficit for Essex County, NJ.

For maximum use of the roof runoff, it is desired to irrigate at the highest rate possible, without causing harm to the plants. Therefore, Table 2 and Figure 2 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 1" of water per week, or 4" per month. Excessive watering is harmful to plants, so indiscriminate over-watering is to be avoided. Some plants can accommodate (and require) additional water. As an example, Kentucky Bluegrass, the most common lawn grass in the US, needs about 2.5 in/week, or more, during the heat of the summer, and should also receive some moisture during the winter. Table 2 therefore calculates supplemental irrigation to provide 0.5 inches per week in the dormant season and 2.5

inches per week in the hot months. Natural rains are expected to meet the cold season moisture requirements.

Table 2. Irrigation Needs to Satisfy Heavily Irrigated Lawn for Essex County, NJ

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
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
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
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
Deficit irrigation needed (gallons/day/house) 0.36 acres	0	0	0	96	1263	1669	1826	1880	2081	1558	96	0

The total irrigation needs for this moisture series is about 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 study area are only expected to produce about 90,000 gallons 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.

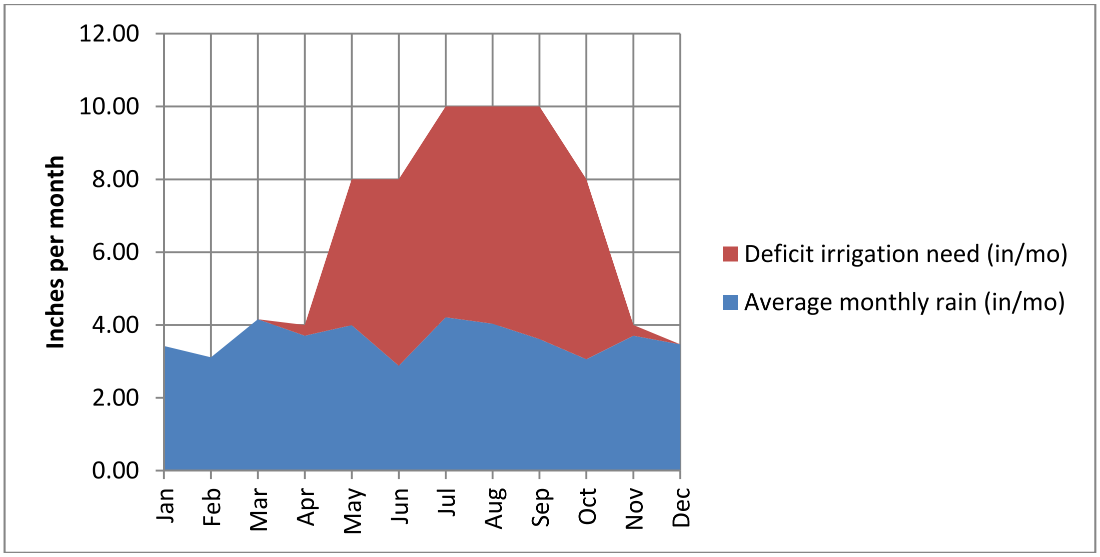


Figure 2. Plot of supplemental irrigation needs to match heavily watered lawn (0.5 to 2.5 inches/week) deficit for Essex County, NJ.

RESULTS and CONCLUSION

Figure 3 contains plots of the roof runoff reductions vs. roof runoff storage tank volumes for the Newark rain conditions and for silty soil conditions, the most common surface soil found in the Millburn, NJ study area, for storage tank sizes ranging from very small 0.003 to very large 3 ft of storage. The volume is expressed as the depth over the roof area (3500 ft^2); a 1 ft storage volume corresponds to about 3,500 ft^3 of storage for this example, or two large tanks about 10 ft deep and 15 ft in diameter. The 0.005 ft storage volume corresponds to a total tank storage volume of about 130 gallons, or about four typical 35 gallon rain barrels. For this example area, the outfall runoff reduction benefits are about one-third of the direct roof runoff reductions.

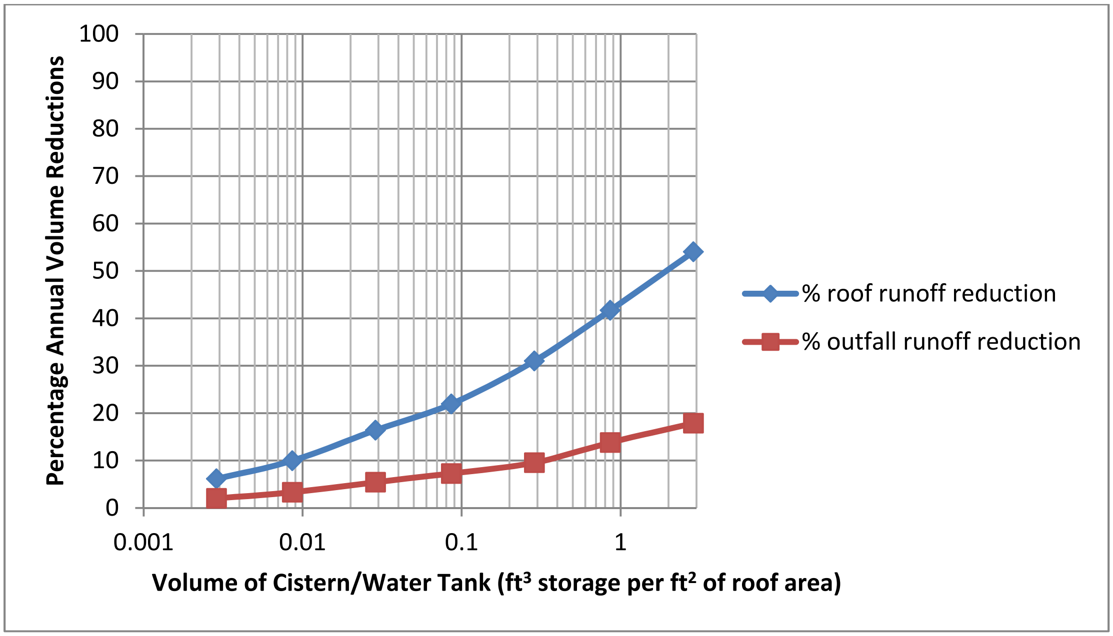


Figure 3. Roof runoff and water tank storage production function for Millburn Township residential areas (typical silty soil conditions).

Similar analyses for sandy soil areas resulted in lower levels of performance (about 50% for 2 ft of storage) compared to the clayey and silty soils (about 60% for 2 ft of storage) because more of the rainfall falling directly on the sandy landscaped areas contributed to soil moisture, resulting in less of an irrigation demand to match the ET deficits. Table 2 summarizes the results of these calculations for silty soil conditions for different areas of the US (Pitt and Talebi 2011). The Central and Great Lakes areas have the highest potential level of control because the ET demands best match the rain distributions. The East Coast, Southeast, and Southwest regions all had moderate levels of control due to poorer matches of ET and rainfall, or greater amounts of rainfall. The Northwest region has the poorest level of potential control, and large storage tanks are not likely to be very effective due to small ET-infiltration deficits.

Table 3. Roof Runoff Harvesting Benefits for Regional Conditions (Medium Density Residential Land Uses, silty soil conditions) (Pitt and Talebi 2011)

Region	total roof area (% of total residential area)	landscaped area (% or total residential area)	representative city for rain fall and ET values	study period annual rain fall (average 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%

Figure 4 is a similar plot, but shows the irrigation needs to meet the maximum moisture requirements of a heavily watered Kentucky Bluegrass lawn. The runoff reductions are much greater and reach 100% of the roof runoff (and 33% of the whole area runoff), but only for very large storage volumes. A storage volume of 0.25 ft (6,500 gallons or a storage tank about 10 ft high and 10 ft in diameter) would result in a roof runoff reduction ranging from 30 to 60%, depending on the irrigation rate actually used (from the minimum ET needs to the heavily irrigated lawn needs).

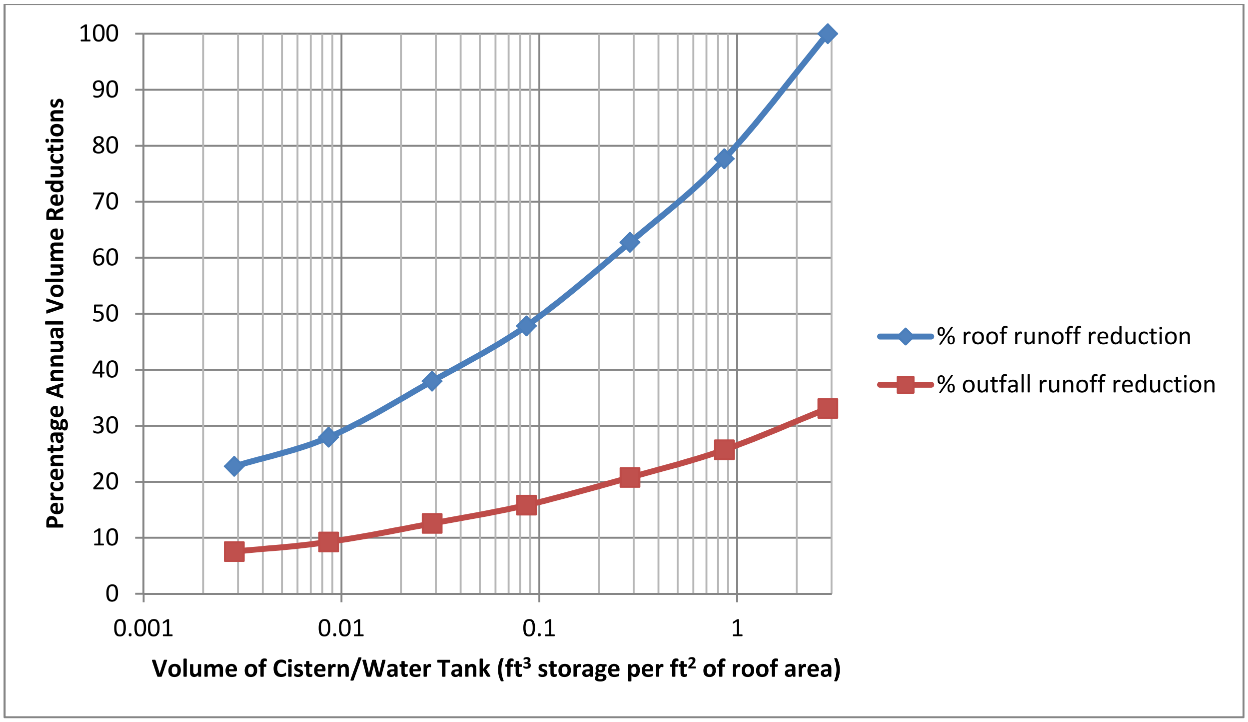


Figure 4. Water storage tank benefits for supplemental irrigation to meet heavily irrigated lawn deficits (Millburn, NJ).

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