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

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

[1]PhD Candidate, Department of Civil, Construction, and Environmental Engineering, University of Alabama, P.O. Box 870205, Tuscaloosa, AL 35487
[2]Cudworth Professor, Urban Water Systems, Department of Civil, Construction, and Environmental Engineering, University of Alabama, P.O. Box 870205, Tuscaloosa, AL 35487
[3] Associate/Assistant Professor of Environmental Engineering, Penn State Harrisburg

1

Outlines

- Objectives
- Review of Case Studies of Beneficial uses of Stormwater
  - Asia
  - Africa
  - Europe
  - Australia
  - North America
- Regulations Restricting Beneficial uses of Stormwater
- Water Harvesting Potential
- Modeling

2

Objectives

- Study U.S.A and international practices of recycling of urban stormwater;
- Identify each component's key design parameters, performance, current knowledge gaps, and obstacles to their implementation;
- Review possible uses of the harvested runoff: The research focused primarily on non-potable water use (e.g. irrigation and non-potable in-house use).
- Present a method to evaluate or size water storage tanks needed to optimize the beneficial uses of stormwater.

3

Background

- This presentation summarizes a recent project supported by the Water Environment Research Foundation and the Wet Weather Flow Research Program of the US EPA.
- One part of the project compared increased beneficial uses of runoff vs. increased infiltration into shallow groundwaters by bioretention facilities.
- The major element of the project examined how much of the household irrigation needs can be satisfied with stormwater and how this beneficial use results in reduced stormwater discharges.

4

Representative Case Studies of Stormwater Beneficial Use Examined

- Asia (Singapore, Japan, Thailand, Indonesia, Philippines, Bangladesh, China, South Korea, and India)
- Africa (South Africa, Kenya, and Tanzania)
- Europe (Germany and Ireland)
- Australia (South Australia, Queensland, Victoria, and New South Wales)
- North America (US Virgin Islands, Florida, Hawaii, Washington, New York, Maryland, California, Missouri, Oregon, Washington, D.C., and North Carolina)

5

Place	Project name	Study area (catchment)	Reuse Purpose			
			Irrigation.	Toilet flushing	Fire fighting	Air conditioning
Singapore	Residential area	7,420,000 m^2	✓	✓		
Singapore	Changi Airport			✓	✓	
Japan		8,400 m^2		✓		✓
South Korea	Star City (Seoul)	6.25 ha (62,500 m^2)	✓	✓		
India	Delhi	113,000 m^2	✓			
Tanzania	Makanya		✓			
Germany	Berlin; Belss-Luedecke-Strasse building	7,000 m^2 of roofs & 4,200 m^2 of streets	✓	✓		
Germany	Berlin-Lankwitz	12,000 m^2	✓	✓		
Germany	Frankfurt Airport	26,800 m^2	✓	✓		✓
Ireland	Queens University in Belfast	3,000 m^2		✓		
South Australia	Salisbury; Parafield	1,600 ha	✓			
NSW	Black Beach Foreshore Park	100 ha	✓			

6

Place	Project name	Study area (catchment)	Reuse Purpose				
			Irrigation	Toilet flushing	Fire fighting	Air conditioning	other
Florida	West Palm Beach; Renaissance						✓
Hawaii	U.S. National Volcano Park	2.4 ha		✓			✓
Washington	Seattle, King Street Center	30,380 m^2	✓	✓			
New York	Battery Park City; Solaire		✓	✓		✓	
Maryland	Annapolis; Philip Merrill Building		✓	✓	✓		
California	Santa Monica; SMURFF		✓				✓
California	Santa Monica; Robert Redford Building		✓	✓			
Missouri	Overland, Alberici Corporate Headquarters	3,920 m^2		✓		✓	

7

Heavily Urbanized Developing Countries In Water Stressed Areas

- Most concerned with harvesting as much runoff as possible, with minimal concern related to water quality.
- Not only is roof runoff harvested, but also runoff from all urban areas. Usually, all paved areas are used to harvest runoff, as maximum volumes are needed to augment the poor quality and poorly available local sources.
- The water is stored in large ponds, or injected into shallow aquifers. These improve the water quality to some extent, greatly depending on the storage conditions.

8

Developing Countries With Large Rural Populations

- Most of the runoff harvesting schemes focus on collecting roof runoff for storage in tanks near 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.

9

Developed Countries With Large Urban Populations in Water Stressed Areas

- 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 buildings where the water is used for non-potable uses.
- In some rural cases, the water is used for all domestic water uses. In large development water harvesting projects, runoff is collected from all areas and undergoes some pretreatment before storage in large (usually underground) storage tanks.
- The water then undergoes very sophisticated water treatment before use. In many cases, this highly treated harvested runoff is still restricted to non-potable uses.

10

The U.S.

- Many of the U.S. stormwater harvesting projects are either part of a LEED® certified project, and/or 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.

11

Selected Regulations Restricting Stormwater Beneficial Uses

		Coliform Bacteria	Chlorine	pH	Turbidity
WHO	Roof water harvesting	*E. coli.* <10 cfu/100 mL	>0.2–0.5 and <5 mg/L	6.5–8.5	Not relevant
	Surface Runoff	*E. coli.*<10 cfu/100 mL	>0.2–0.5 and <5 mg/L	6.5–8.5	<15 NTU
	Sand dams	*E. coli.*<10 cfu/100 mL	>0.2–0.5 and <5 mg/L	6.5–8.5	<5 NTU
New South Wales (Australia)	Level 1	<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	<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, CA	Non-potable indoor/outdoor uses	Total coliforms <500 cfu per 100 mL Fecal coliforms <100 cfu per 100 mL			

12

Selected Regulations Restricting Stormwater Beneficial Uses

		Coliform Bacteria	Chlorine	pH	Turbidity
Texas (2006)	Non-potable indoor uses	Total coliforms <500 cfu per 100 mL Fecal coliforms <100 cfu per 100 mL			
UK (2008)	Non-potable indoor uses	Total coliforms 10/100 mL	<2 mg/L	6–8	≤ 10 NTU
Virginia (2009)	Non-potable indoor uses	Total coliforms < 500 cfu per 100 mL Fecal coliforms <100 cfu per 100 mL			

13

Modeling

WinSLAMM was developed to evaluate stormwater runoff volumes and pollutant loadings in urban areas using continuous 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.

14

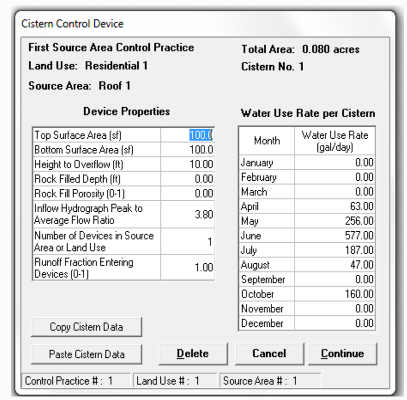
Methods and Materials

- Irrigation of typical turf grass landscaping around homes was examined for typical low and medium density residential areas in six different U.S. rain zone areas:
  - Great Lakes: Madison, WI
  - East Coast: Newark, NJ
  - Central: Kansas City, MO
  - Northwest: Seattle, WA
  - Southeast: Birmingham, AL
  - Southwest: Los Angeles, CA

15

Methods and Materials

- WinSLAMM 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.



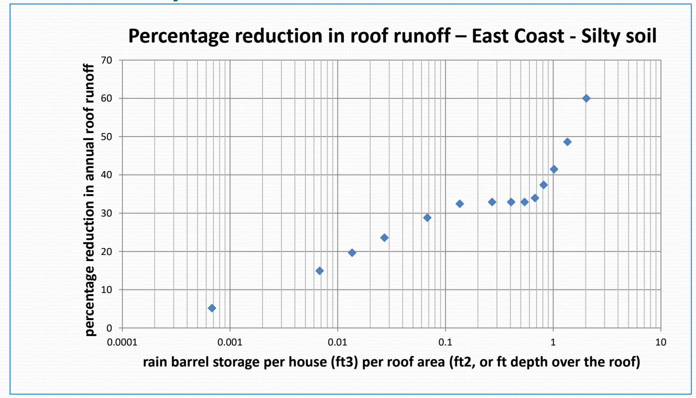
16

Methods and Materials

- The monthly rainfall infiltration amounts in the landscaped areas in the six study areas were calculated using continuous WinSLAMM simulations, for silty, sandy and clayey soils.
- These soil moisture contributing values were subtracted from the monthly ET requirements (adjusted for urban turf grasses) to obtain the moisture deficits per month, and the daily deficits per house per day.
- Roof runoff and water tank storage production functions were calculated for each condition.

17

Roof runoff and water tank storage production functions for medium density residential areas for the East Coast site



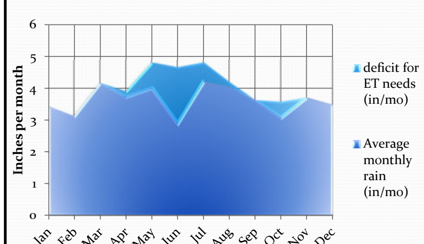
total roof area (%)	15.9
Landscaped area (%)	54.5
Average annual study period rain fall (in) (5-year period, 1995 to 2000)	53.01

18

Calculations

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 associated soil moisture (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/month/house) 0.36 acres	0	0	0	63	256	577	188	47	0	160	0	0



Total annual rainfall: 53 in. (43 in. will infiltrate and add to soil moisture) Total annual ET requirements: 38 in. The annual total household supplemental irrigation requirements are about 39,000 gallons per year (0.36 acres of turf grass per home).

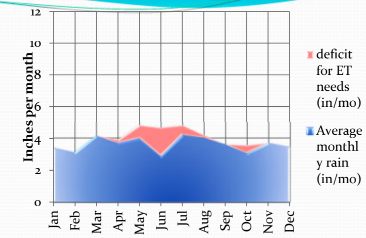
19

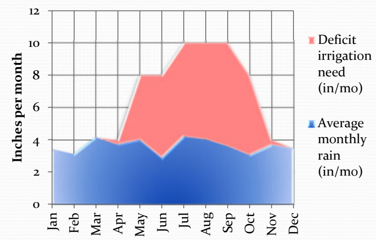
Calculations

- For maximum use of the roof runoff, it is desired to irrigate at the highest rate possible (beyond the minimum ET requirements), without causing harm to the plants. Any excess water not used by the plants would infiltrate and contribute to the shallow groundwater.
- For a "healthy" lawn, total water applied (including rain) is generally about 1" of water per week, or 4" per month.
- 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

20

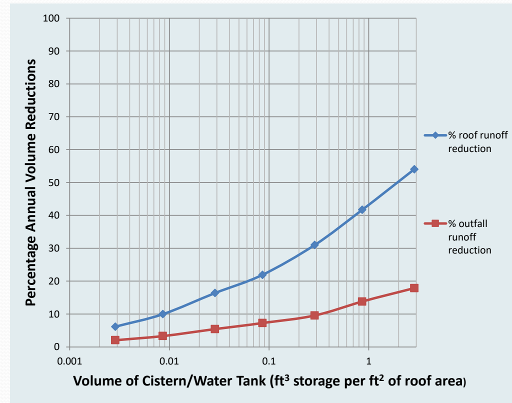
- The total irrigation needs for the second scenario (moisture series) is about **318,000 gallons** per year per home. This is about **eight times** the amount needed to "barely" satisfy the ET requirements (39,000 gallons).
- The roofs in the study area are only expected to produce about 90,000 gallons 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.





21

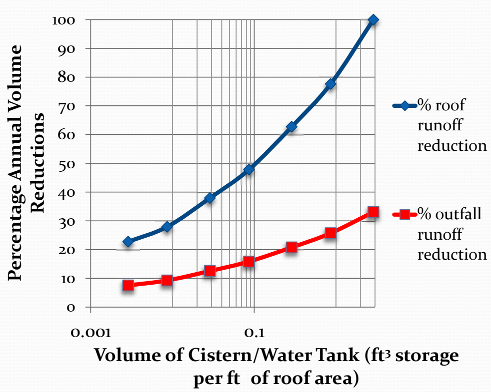
Roof runoff reductions vs. roof runoff storage tank volumes for the Newark rain conditions and for silty soil conditions.



- The volume is expressed as the depth over the roof area (very large homes having 3,500 ft^2 roof areas); 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. (54% annual roof runoff control)
- 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. (8% annual roof runoff control)

22

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 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 85%, depending on the irrigation rate actually used (from the minimum ET needs to the heavily irrigated lawn needs)

23

Results and Conclusion

Roof Runoff Harvesting Benefits for Regional Conditions to Barely Meet ET Requirements (Medium Density Residential Land Uses, silty soil conditions) (Pitt and Talebi, 2012)

Region	total roof area (% of total residential area)	landscaped area (% of total residential area)	representative city for rainfall 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 (9 ft high by 6 ft diameter tank per 1,000 ft^2 roof)
Central	18.1	62.5	Kansas City, MO	33.5	40%	78%
East Coast	15.9	54.5	Newark, NJ	53.0	24%	33%
Southeast	8.8	81.1	Birmingham, AL	49.8	34%	41%
Southwest	15.4	61.2	Los Angeles, CA	16.7	35%	44%
Northwest	15.4	61.2	Seattle, WA	41.7	16%	16%
Great Lakes	15.0	57.5	Madison, WI	28.7	46%	68%

24

Acknowledgements

- The information reported in this paper was partially funded by the Water Environment Research Foundation, Alexandria, VA, 22314 as part of the project: *Stormwater Non-Potable Beneficial Uses and Effects on Urban Infrastructure (INFR3SG09)*, and by the Urban Watershed Management Branch, U.S. Environmental Protection Agency, Edison, NJ, 08837, as part of the project: *Evaluation and Demonstration of Stormwater Dry Wells and Cisterns in Milburn Township, New Jersey* (EP-C-08-016).

- The University of Alabama

Selected References

- Furumai, H. 2008. Rainwater and reclaimed wastewater for sustainable urban water use, Physics and Chemistry of the Earth, Parts A/B/C Volume 33, Issue 5, *Integrated Water Resources Management in a Changing World*, Pages 340-346.

- Fletcher, T.D., Deletic, A., Mitchell, V.G., Hatt, B.E., 2008. Reuse of urban runoff in Australia: a review of recent advances and remaining challenges. *Journal of Environmental Quality* 37, S116-S127.

- Pitt, R. 1997. "Unique Features of the Source Loading and Management Model (SLAMM)." In: *Advances in Modeling the Management of Stormwater Impacts, Volume 6*. (Edited by W. James). Computational Hydraulics International, Guelph, Ontario and Lewis Publishers/CRC Press. pp. 13 – 37.

- Pitt, R. and Talebi, L. 2011. *Evaluation and Demonstration of Stormwater Dry Wells and Cisterns in Millburn Township, New Jersey*. EPA Contract: EP-C-08-016, Urban Watershed Management Branch, U.S. Environmental Protection Agency, Edison, NJ 08837, Office of Research and Development, Cincinnati, OH 45268. April 2012. 347 pgs.

- van Roon, M., 2007. Water localisation and reclamation: steps towards low impact urban design and development. *Journal of Environmental Management* 83, 437-447.

- Zhu, K., Zhang, L., Hart, W., Liu, M., Chen, H., 2004. Quality issues in harvested rainwater in arid and semi-arid Loess Plateau of northern China. *Journal of Arid Environments* 57, 487-505.