Beyond Green LID Zero Runoff Strategies for Our Cities

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Abstract

The technology of green stormwater strategies has advanced rapidly in the last twenty years so that we can now design or retrofit cities to achieve zero runoff for large storm events. A detailed examination of projects that have achieved zero runoff, full groundwater recharge, or advanced treatment prior to attenuated discharge to surface waters, provides insight into the LID options for our cities. Beyond green critical thinking, true multi-disciplinary problem solving, and rethinking regulations has led to these new concepts. Yes stormwater systems can be beautiful, function to a high degree, achieve beyond green results, and help create dynamic green livable cities.

Introduction

The earliest large stormwater infiltration systems were deep unsightly infiltration basins that hold water for extended periods of time (Ferguson, 1994). This paper focuses on a new type of large infiltration systems that began in the early 1990's (Kays, 2000), are designed to be both function and beautiful and are used in urban parks, major league baseball, football, and soccer sports fields, as well as, special use venues. Most of these new systems have been very successful, but some have not due to the fact that the critical design factors are not well understood (Kays, 2006).

Seven projects were examined to better understand the factors that are important in the design of large infiltration and filtration systems. The projects were evaluated to study the system size, soil depth, drained porosity, sand gradation, organic matter, hydraulic conductivity, volume of soil storage, rainstorm capacity, and rainstorm frequency. One of the systems had failed, later was rebuilt, and offers insight into the critical factors affecting success. Three small systems projects that have recirculating filtration prior to discharge were also studied.

Review of Large Bioretention Projects Studied

High rate infiltration bioretention systems typically use a uniformly graded sand based structural soil for the proper functioning of both the landscape plantings and the stormwater system. Seven large bioretention zero runoff projects were reviewed and they are as follows:

1. The Great Lawn in Central Park, New York, NY – a 0.762-meter deep uniformly graded sand based structural soil was installed in the Great Lawn (**Figure 1**) to capture rainfall events over a 9.72-hectare site, as well as, providing a compaction resistant surface for sports, concerts and other special venue events. The

project was completed by the Central Park Conservancy, Inc. Rainfall events are both detained and filtered through the sand, silt, and organic media before draining into the storm sewer system and treatment at the East River WWTP. The project design started in 1992 and construction was completed in 1997. In 1998 the conservancy was awarded a Design Honor Award by American Society of Landscape Architects and the Best Site Design of 1998 by New York Construction News. The project has functioned in an excellent manner and does not appear to have lost any hydraulic capacity over the last 17 years. Irrigation is provided and is especially needed in the summer months.

Figure 1 – Great Lawn in Central Park, New York, NY

2. Nelson Rockefeller Hudson River Park I, New York, NY – a 1.067-meter deep well graded sandy loam soil was installed on 0.972-hectare meadow lawns along the Hudson River Promenade by the Battery Park City Authority (**Figure 2**). The soil materials did not meet the design specifications, had insufficient sand, was not uniformly graded sand, became highly compacted, and would only conduct water extremely slowly. After the opening of the park, rainfall events caused water to pond on the surface of the meadows and remained ponded for prolonged periods of time. This is the largest know failure of sand based structural soil and the meadows had to be excavated and rebuilt.

3. Nelson Rockefeller Hudson River Park II, New York, NY – a new 1.067-meter uniformly graded deep sand based structural soil was installed on 0.972-hectare meadow lawns along the Hudson River Promenade by the Battery Park City Authority. The soil material meets the design specifications, had sufficient s uniformly graded sand, and properly conduct water when compacted. The soil has now been in place for over 12 years and has function to adequately drain and treated all of the stormwater for the park.

4. Longwood Gardens Main Fountain Garden, Kennett Square, PA – a 1.067-meter deep uniformly graded sand based structural soil 0.972-hectare in size will be

installed in 2015 on the 3.645-hectare Main Fountain Garden at Longwood Gardens, as part of its modernization of the famous fountain garden. Thousands of people attend the daily light and fountain shows at this venue. Therefore, it was critical for the lawns to rapidly drain immediately after a rainfall so that the events would not need to be cancelled. The sand based structural soil for the lawn, shrubs and trees provides a bioretention system for stormwater.

<u>Figure 2</u> – Nelson Rockefeller Hudson River Park left of the Solaire Building, Lower Manhattan, New York, NY

5. <u>National Capital Mall, Washington, DC</u> – a 0.381-meter deep well graded sand based structural soil was installed in 2012 on a 2.633-hectare portion of the National Capital Mall by the National Park Service. This is the first section of the mall to be rebuilt. The soil's primary function is to be a structural system that is resistant to compaction of pedestrians. In addition, the soil serves to minimize runoff from rainwater falling onto the lawn. This approach will be utilized as other sections of the National Capital Mall are subsequently rebuilt.

6. <u>Dwight D. Eisenhower Memorial, Washington, DC</u> – a 1.372-meter deep uniformly graded sand based structural soil is proposed on the 1.215-hectare Dwight D. Eisenhower Memorial for the Eisenhower Memorial Commission, along a section of Maryland and Independence Avenues. The soil is unusually deep to accommodate the large trees that will be planted. The soil serves as structural soil that is resistant to compaction and as a stormwater treatment system for the new park.

7. <u>Northern Guilford Middle & High School Campus, Greensboro, NC</u> – a 1.829-meter deep loamy sand structural soil was installed in 2007 in three sports fields on the campus by the Guilford County School System (**Figure 3**). One of the fields is dripped irrigated with treated wastewater effluent from the two schools. The other two fields provide sports fields and stormwater retention. All three of the fields are built to provide a structural soil that is resistant to compaction and playing surfaces that can be used immediately after a large rainstorm event. The clayey

subsoils on the fields were excavated down to friable saprolite that contains less than 10% clay. The excavations extended down to as much as 3-meters but average 1.829-meters and was filled with friable saprolite that was mined elsewhere on the site. Thus the loamy sand saprolite extends from the surface down to the water table which is more than 12-meters below the ground. A 0.23-meter coarse sand cap was installed for rapid surface detention in the soil. In 2008 the project received the Beyond Green Award from the Sustainable Building Industry Council as the best school project in the US.

Figure 3 – Sports field at Northern Guilford Middle & High School Campus, Greensboro, NC

Review of Stormwater Biofiltration Projects

Recirculating Biofiltration is a method that uses a uniformly graded sand/organic media or sand media to effectively treatment the stormwater prior to discharge into storm sewers or streams. The stormwater is recirculated using solar pumps to pass the stormwater through the filter multiple times to enhance treatment and denitrification. Below are three projects that illustrate this LID application (**Table 2**):

8. Creative Arts Building Campus, Haywood Community College, Clyde, NC – a 0.61-meter deep uniformly graded sandy media recirculating biofiltration system with 25% organic matter was installed in 2011 to treat the stormwater prior to stream discharge. Stormwater first flows through a single pass biofilter and cascades down four waterfalls before flowing into the stormwater pond. Next the water flows from the stormwater pond into the top of a 0.002-hectare biofilter and then flows into a storage tank. A solar pumping system is used for recirculation of the water back to the top of the waterfalls and subsequently into the biofilter for additional treatment. Once the tank becomes full it begins to discharge to the stream.

9. Isaac Dickson Elementary School, Asheville, NC – a 0.91-meter deep uniformly graded sandy media recirculating sand filtration system with 25% organic matter in the 0.016-hectare biofilter will be installed in 2015 to treat the stormwater prior to stream discharge. Stormwater will flow first into the biofilter, then into a storage tank, then it will be pumped to a shallow stormwater wetland pond, and the

outflow of the pond will flow back into the biofilter. Once the tank becomes full it will discharge to stream.

10. Turman Hall, Emory University, Atlanta, GA – a 0.61-meter deep uniformly graded sandy media recirculating biofiltration system with 4 percent organic matter was installed in 2010 to apply the roof rainwater harvesting and condensate water by irrigation of the sandy media. The sandy soil was installed on top of a parking deck and serves as an outdoor student plaza and garden for Turman Hall residents. The biofilter covers 0.061-hectare area on the parking deck. The excess water drain into a storage tank which is used to spray irrigated and filters the storm-water again. Once the tank becomes full it begins to discharge into the storm sewer.

Figure 4 – Turman Hall sand media filter system plaza over a parking garage at Emory University, Atlanta, GA

Discussion of Design Factors

Many of the basic design factors dealing with soils, porosity, pore size distribution; compaction, water movement, and layering of soils are explained in a recent publication (Kays, 2013). These systems are described as “bioretention”, but they are different from bioretention systems included in best management practice stormwater manuals. Design standards for small bioretention system cannot simply be scaled up to large systems.

Bioretention Systems with Under Drainage - The hydraulic conductivity of the five bioretention systems with under drainage ranged from 9.515 to 14.480 cm/hr (**Table 1**), had a mean conductivity of 12.07 cm/hr, mean percent sand of 86.2, mean percent of coarse + medium sand of 71.0, mean percent of organic matter of 7.8, mean soil depth of 0.93 meters, and mean size of 3.64-hectare.

No.	Project	Type of System	Sand	Co+M Sand	Sand Diameter	Organic Matter	Soil Depth	Sat. Hydraulic Conductivity, K	System Size
			% wt.	% wt.	mm	% Vol.	m	cm/hour	ha
1	Central Park	Bioret./Under Drainage	92.0	82.0	0.25 to 1.00	10	0.762	14.480	9.720
2	Hudson River Park 1	Bioret./GW Recharge	60.0	18.1	0.50 to 1.00	5	1.067	0.025	0.972
3	Hudson River Park 2	Bioret./Under Drainage	90.0	76.5	0.25 to 1.00	10	1.067	12.700	0.972
4	Longwood Gardens	Bioret./Under Drainage	86.9	73.6	0.25 to 1.00	4	1.067	12.700	3.645
5	National Capital Mall	Bioretention	79.1	49.2	0.005 to 2.00	5	0.381	10.920	2.633
6	Eisenhower Memorial	Bioret./Under Drainage	83.0	73.6	0.25 to 1.00	10	1.372	9.525	1.215
7	Northern Guilford Schools	Bioret./GW Recharge	72.3	36.0	0.05 to 2.00	0	1.829	2.515	2.475
Mean			86.2	71.0		7.8	0.930	12.065	3.64

Table 1 – Comparison of Sand Based Structural Soil Infiltration Projects

No.	Project	Type of System	Sand	Co+M Sand	Sand Diameter	Organic Matter	Soil Depth	Sat. Hydraulic Conductivity, K	System Size
			% wt.	% wt.	mm	% Vol.	m	cm/hour	ha
8	Haywood Community Coll.	Recirculating Biofilter	90.0	85.4	0.25 to 1.00	25	0.61	12.700	0.002
9	Isaac Dickson Elem. Sch.	Recirculating Biofilter	90.0	86.7	0.25 to 1.00	25	0.91	12.700	0.016
10	Turman Hall, Emory Univ.	Recirculating Biofilter	90.6	84.0	0.25 to 1.00	4	0.61	12.700	0.061
Mean			90.2	85.4		18.0	0.711	12.70	0.026

Table 2 – Comparison of Sand Organic Media Biofiltration Projects

Bioretention Systems with Groundwater Recharge – Two of the projects were designed for groundwater recharge (**Table 1**). Project #2 hydrologically failed to function and was rebuilt. Project #7 was the only successful groundwater recharge system and it was constructed in saprolite that existed on the site. The hydraulic conductivity was 2.515 cm hr^{-1}, percent sand was 72.3, percent coarse + medium sand was 36.0, percent organic matter was 0.0, soil depth was 1.820 meters, and its size was 2.475-hectares.

The hydraulic conductivity of the seven systems is proportional to the percent sand in the bioretention soil (**Figure 5**). The lowest data point on the graph represents the failed system #2. The second lowest data point on the graph represents the loamy sand textured saprolite.

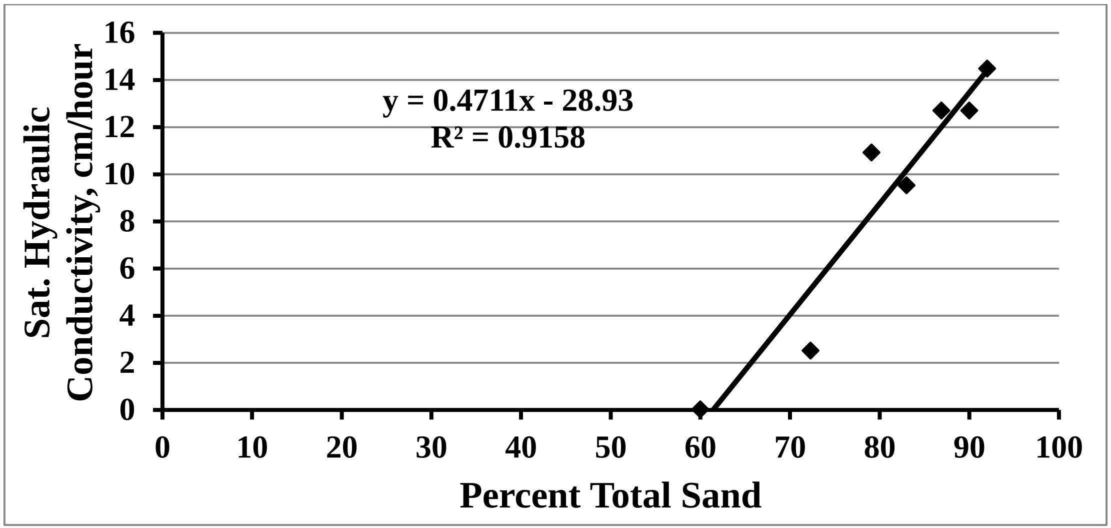

Figure 5 – Effect of Percent Sand on the Conductivity of Bioretention Systems

The hydraulic conductivity is also proportional to the percent of coarse + medium sand (**Figure 6**). The systems clustered in the top right corner of the graph all consist of uniformly graded sands, while the three lowest percentages are systems using well graded sands. After the total percent of sand, the second most important factor is the percent of uniformly graded coarse and medium sand.

Recirculating Biofiltration Systems – The three systems had hydraulic conductivities of 12.70 cm hr^{-1} (**Table 2**), mean percent sand of 90.2, mean percent of coarse + medium sand of 85.4, mean percent of organic matter of 18.0, mean soil depth of 0.71 meters, and mean size of 0.026-hectares.

The detention storage capacity of bioretention systems was calculated for the systems based upon the estimated drained porosity at 0.1 bars of soil moisture tension, depth of soil, and size of the system (**Table 3**). The rainfall capacity for 24-hour rainstorms ranged from 2.134 to 45.720 cm, and the frequency of the rainfalls ranged from 0.25

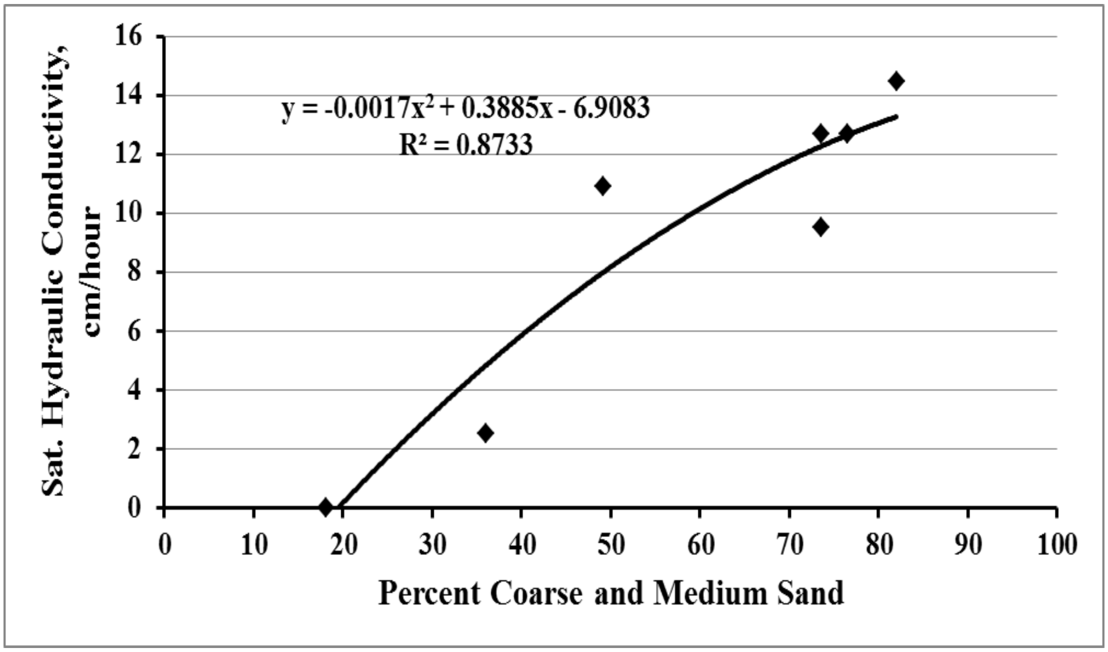

Figure 6 – **Effect of Percent Coarse + Medium Sand on the Conductivity**

to 1000 year events. It is interesting that the rainfall capacity of the bioretention system is so proportional to the rainstorm frequency over a rather large geographic area (**Figure 7**).

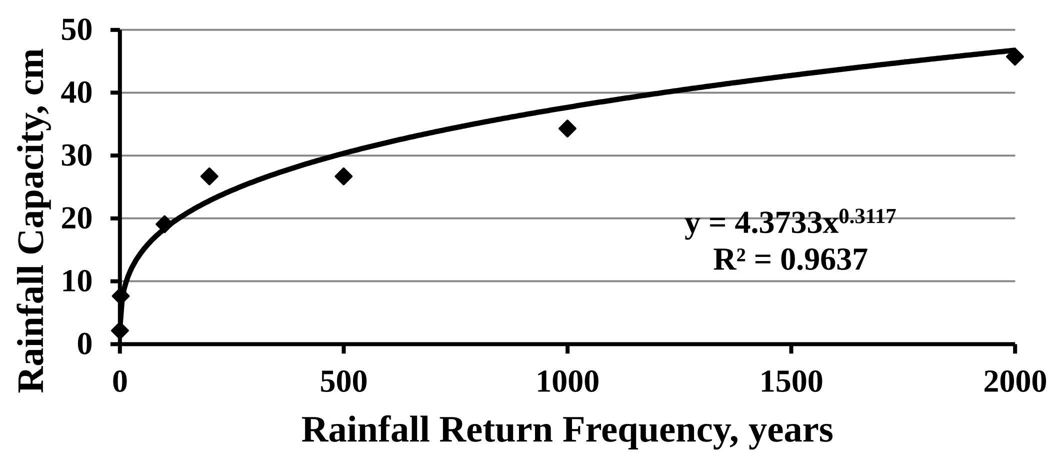

Figure 7 – **Rainfall Capacity of Bioretention System are Proportional to Rainstorm Frequency over a Large Geographic Area of New England, Mid-Atlantic, and Southeast Regions of United States**

The maximum rainfall events for recirculating filtration systems was calculated based upon the hydraulic conductivity and system size (**Table 4**). Projects #8 and #9 are typical filtration systems that are sized to handle numerous small storm events ranging from 1.306 to 1.582 cm rainfalls. Project #10 has a maximum rainfall capacity of 32.657 cm, although it typically operates only when the landscape needs to be irrigated.

No.	Project	Type of System	Ksat[1]	Drained Porosity[2]	Soil Depth[3]	System Size	Soil Storage	24-Hr Rainfall Capacity in Soil Detention Storage	
								Rainfall	Frequency
			cm/hour	%	m	ha	m^3	cm	years
1	Central Park	Bioret./Under Drainage	14.480	25%	0.762	9.720	18,516.60	19.050	100
2	Hudson River Park 1	Bioret./GW Recharge	0.025	2.0%	1.067	0.972	207.39	2.134	0.25
3	Hudson River Park 2	Bioret./Under Drainage	12.700	25%	1.067	0.972	2,592.32	26.670	200
4	Longwood Gardens	Bioret./Under Drainage	12.700	25%	1.067	3.645	9,721.22	26.670	500
5	National Capital Mall	Bioretention	10.920	20%	0.381	2.633	2,005.97	7.620	2
6	Eisenhower Memorial	Bioret./Under Drainage	9.525	25%	1.372	1.215	4,166.24	34.290	1000
7	Northern Guilford Schools	Bioret./GW Recharge	2.515	25%	1.829	2.475	11,313.87	45.720	2000
Mean			8.981	0.210	1.078	3.090	6931.942	23.165	543

Footnotes: 1-Saturated hydraulic conductivity, 2-Difference in soil moisture between saturation and 100 cm pressure, 3-Soil depth includes depth of planting soil and chocker layer

Table 3 – **Comparison of Hydraulic Capacity of Sand Based Infiltration Projects**

No.	Project	Type of System	Ksat[1]	System Size	Max. Rate Filtration	Storage Tank	Drainage Area	24-Hr Rainfall Capacity	
								Rainfall	Frequency
			m/day	m^2	m^3/day	m^3	m^2	cm	years
8	Haywood Community Coll.	Recirculating Biofilter	3.048	24.300	74.066	30.267	5,670.00	1.306	0.1
9	Isaac Dickson Elem. Sch.	Recirculating Biofilter	3.048	166.050	506.120	56.751	31,995.00	1.582	0.25
10	Turman Hall, Emory Univ.	Recirculating Biofilter	3.048	303.750	925.830	37.834	2,835.00	32.657	1000
Mean			3.048	164.700	502.006	41.617	13500.000	11.848	333.450

Footnotes: 1-Saturated hydraulic conductivity

Table 4 – **Comparison of Hydraulic Capacity of Sand Organic Media Biofiltration Projects**

Summary

The sand based bioretention systems provide an excellent LID stormwater system for highly density urban sites. However, it is essential that the system are constructed with 80 or more percent sand, and that at least 70 percent or more of the sand be uniformly graded medium to coarse sand. Large bioretention systems have been used for parks, sports fields, and other urban special use venues that need a compaction resistant surface for large numbers of pedestrians. All of the bioretention systems reviewed do not look like stormwater systems, because they are designed to blend into the landscape and also serve other purposes in our cities. When there is not sufficient space for a large landscape bioretention stormwater system, recirculation biofiltration provides an excellent treatment system.

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