GREENROOF PERFORMANCE STUDY: PUGET SOUND REGION

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1 ABSTRACT

Green roof infrastructure is rapidly becoming a hallmark of sustainable building strategies in the U.S. and globally. Well known as a community that supports urban sustainability issues, the city of Seattle is increasingly promoting green roof infrastructure through regulatory and incentive based development strategies. The University of Washington Green Roof Performance study was initiated to assess the hydrological performance of extensive green roof infrastructure for the Seattle metropolitan region. The study evaluates continuous hydrologic data from five (5) experimental panels (600ft^{2}each) to determine the capacity of extensive greenroof design strategies to alter the quantity and timing of runoff during storm events. Through one year (March 2011 through February 2012) of data collection, the panels retained 30 – 56% of all precipitation. During the regionally dry months (July and August) the panels retained 95 – 99% of all precipitation. However during the wet season performance dropped considerably with retention rates ranging from 28 – 55%. As expected, peak volumes and delay were strongly correlated to soil moisture conditions; however, during the most common storm events (0.01" – 0.25") peak volumes were reduced 66 – 87% and median peak delays ranged from 2 to nearly 4 hours.

1.1 Keywords

green roof, performance monitoring, stormwater, retention, environmental benefits

2 INTRODUCTION

Green roof (also known as eco roof and vegetated roof) infrastructure is rapidly becoming a hallmark of sustainable building strategies in the U.S. and across the globe. While this design strategy is not new, it is only in the past two decades that green roof technology has emerged as a mainstream roofing option in North America and the U.S. Pacific Northwest. Each year since 2004, the industry has realized a significant increase in new projects (GRHC, 2012). A recent review of an industry leading green roof database (greenroofs.com, accessed August 21, 2012) contained more than 1,300 projects from 39 states and 25 countries, a total area of nearly 10 square miles.

Commonly categorized as extensive (2-6" soil depth) or intensive (>6" soil depth) there is wide variation in the strategies and characteristics of green roof design. Intensive green roofs, with a greater soil depth, support a wide variety of garden and planting options including planter boxes and trees. Often accessible to visitors and residents, this roof type generally requires a relatively high level of maintenance and is structurally engineered to accommodate increased load requirements. In comparison, extensive green roofs generally cover a significant portion of roof area with vegetation, are relatively light-weight, and, depending on the vegetation used, have low maintenance requirements.

The ecosystem services of green roof infrastructure have been widely disseminated in the infrastructure and environmental performance literature (see Oberdorfer et al., 2007 for a full review). In particular, extensive green roof types have been found to extend the life span of roofing materials (Saiz et al., 2004), decrease ambient temperatures and building energy consumption (Wong et al., 2003; Niachou et al., 2001), and provide habitat for insect and avian species increasing biodiversity in urban areas (Lundholm, 2006; Gedge, 2004).

Arguably, the primary benefit of green roof infrastructure is its capability to mitigate the impact of stormwater on drainage infrastructure and receiving bodies of water (Oberdorfer et al., 2007; Mentens et al., 2005). Rapid runoff from roof and other impervious surfaces in urban and urbanizing areas can exacerbate issues of flooding and degrade the water quality of urban waterways. Like other low impact development strategies, green roof infrastructure has the capacity to retain precipitation, and delay the release of excess water (Lundholm and Peck, 2008; Moran et al., 2003). Much of the hydrological performance research conducted on this infrastructure type reveals that overall; runoff reduction varies widely by region and design. However, roof performance consistently reveals a net gain in rainfall retention, a reduction in peak runoff volumes, and a delay in runoff timing during storm events (Mentens et al., 2005). Each is important for mitigating the impacts of stormwater runoff for urban drainage infrastructure. However, regionally-specific data examining green roof performance is necessary to influence local development policy (Getter and Rowe, 2006; VanWoert, 2005).

The University of Washington Green Roof Performance study (GRP) was initiated to assess the hydrological performance of green roof infrastructure for the Seattle metropolitan area. Well known as an urban region that supports environmental health and sustainability issues, the city of Seattle and the jurisdictions that comprise its greater metropolitan area are increasingly supporting green roof infrastructure through regulatory and incentive-based development strategies, and over the past decade have generated an impressive resume of green roof projects. In 2010 the Seattle area was in the top 10 U.S. metropolitan regions constructing green roofs by area (GRHC, 2012). A recent survey of green roofs in the city of Seattle identified 62 buildings have existing green roofs (extensive and intensive combined), with a total area of nearly 360,000 ft^2 more than 6 American football fields (McIntosh, 2010).

While the number of green roofs in the area continues to expand, few regional studies have been implemented to assess their hydrological performance. One recent study examined the percent runoff and peak flow reduction of three green roof structures in Seattle over a three year period. Their findings reveal a high degree of seasonal variation in runoff depending upon moisture conditions in the soil. When wet, some samples had negligible retention results with runoff nearing 100%; however, in dry soil conditions the study plots retained 70% or more of the total precipitation and reduced peak runoff by up to 53% (Cardno TEC, 2012). Another study examined the performance of five green roofs in the city ranging from 2 -8" substrate depth over an 18-month period. Cumulative runoff mitigation for these roofs ranged from 65% to 94% well above the common percentages found with volume reduction from extensive green roofs (Ganges, 2007).

This paper presents the data collected for runoff retention, detention, and flow timing for five (5) extensive green roof design strategies in the Puget Sound Lowland region. The data is presented as a cumulative response for a 12-month period (Section 5.1) and more specifically is analyzed for seasonal variations (Section 5.2), and in terms of individual storm events (Section 5.3) taking wet/dry soil conditions, and performance based on the intensity of storm events measured by volume of precipitation into account.

3 MATERIALS AND METHODS

Located in the Northwest corner of the continental United States on the shores of Puget Sound, the climate of the Seattle Metropolitan region is temperate marine with mild, wet winters and warm, dry summers. Nicknamed the Emerald City due to the native coniferous forests that dominate the surrounding region, the area is known for its cloudy and wet weather. While the region does record more than 300 days of cloudy or partly cloudy weather annually, the total precipitation each year is approximately 38”, less than other metropolitan areas in the U.S. such as New York (49.9”) and Atlanta (50.2”). While the total amount may be relatively low, the pattern and intensity of daily and seasonal precipitation is important. There are on average more than 150 days annually with significant (>0.01 in) precipitation, yet on average only 1.8”, is received in the summer (July/August). Thus, 95% of the annual precipitation is received during the other 10 months of the year (Mass, 2008).

The test site is located in Maltby, Washington, approximately 16 miles to the northeast of downtown Seattle. Constructed on top of an equipment shelter (100’ x 30’) [2% northfacing slope] the roof is divided into five panels, each with an area of 600 ft^2. Each panel drains to an individual roof drain system and flow monitoring station.

Each test panel contains a distinct green roof system design – single-layer, multi-layer, and tray – with a slight variation in soil depth and plant palette (Figure 1). Four of the five panels (A, C, D, and E) are proprietary green roof systems developed by green infrastructure and roofing companies working in the region. In contrast, Panel B was designed and installed as a single-layer system to provide a design alternative to the multi-course and tray systems. Each of the test panels contains similar soil compositions. While proprietary mixtures were used on four of the five panels all contain less than 15% organic matter by volume. The plant composition on three of the panels (A, D, E) is composed entirely of sedum species with 100% coverage across the entire area. Panel C contains a mixture of sedum species and grasses (Carex spp.). During the testing period the panel increased from 85% to 95% coverage. Panel B was originally planted sparsely with native grasses and groundcovers and was further vegetated by volunteer species during the testing period.

3.1 Equipment and Research Design

A automated weather station is installed on the site to record meteorological parameters including ambient air temperature, relative humidity, and wind intensity and direction. A HOBO data logging rain gauge (Model RG3) is used to collect precipitation. Soil moisture probes (OnSet EcH20) were installed in 4 of the 5 test plots and calibrated twice over the study period. The precipitation tipping bucket, soil moisture probes, and weather station data is collected at 5 minute intervals.

Runoff data is collected using calibrated tipping buckets (Hydrological Services America TB1L) set to record total tip counts at 15-minute intervals. The tipping buckets are linked to the data logger with OnSet pulse adaptors. Data is stored on a HOBO mini-data logger system and manually downloaded at 2 to 4 week intervals. A control panel, also 600 ft^2, is located on top an adjacent building with a single-ply thermoplastic polyolefin (TPO) roof system. Stormwater runoff is collected from the control using an identical collection and logging system as the test panels.

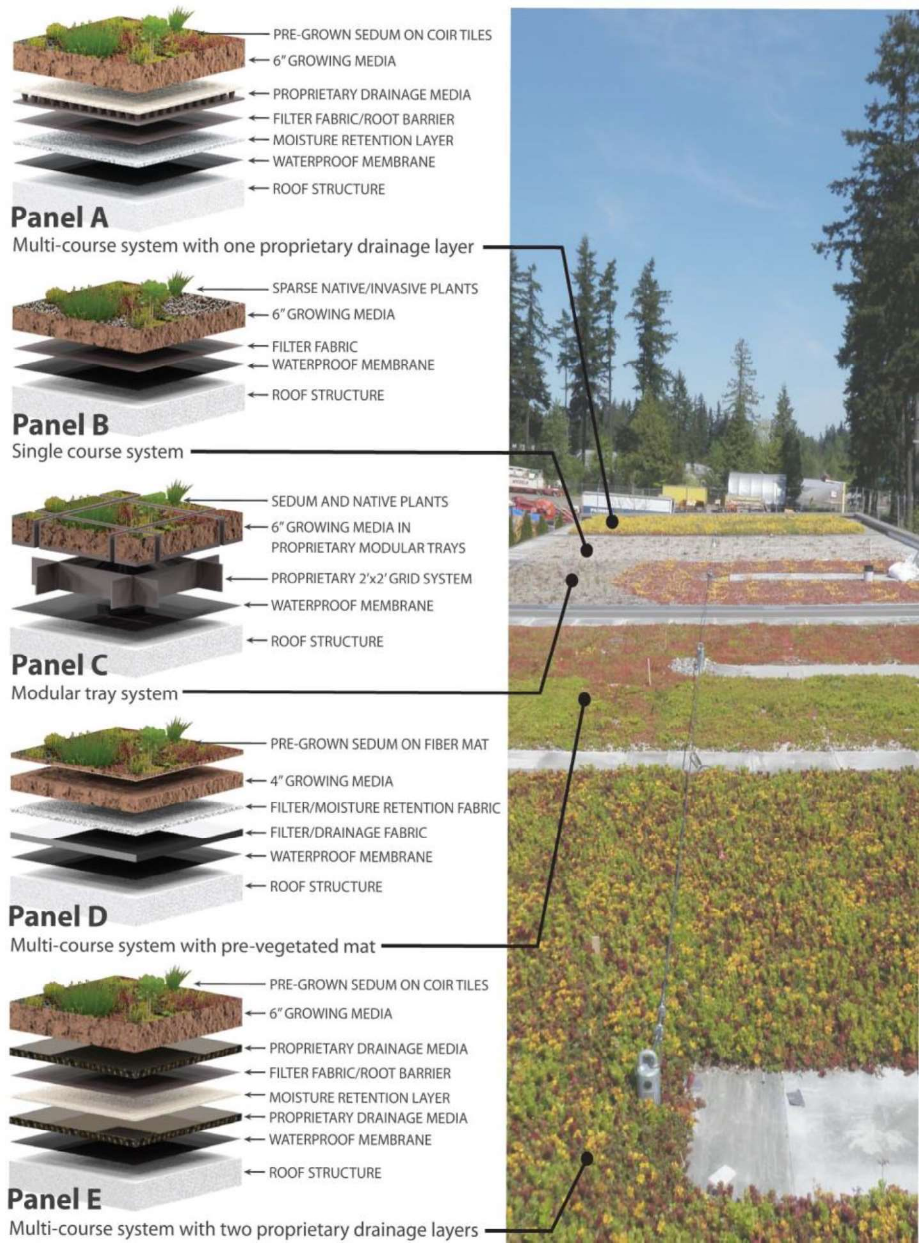

Figure 1. Test panel description and structure

Use of the tipping buckets for measurement of stormwater discharge has been reliable, although a unit did crack and data for one panel (C) for the period between the crack and installation of a replacement were discarded. Further the pulse adaptor for the control failed and was replaced. Runoff quantity and rate during the failure and replacement period for the control was determined by data collected during the rest of the collection period. We make the assumption that the rate and percent-runoff for each event does not vary significantly as the available data was consistent.

Continuous monitoring of the green roof test panels was initiated in December 2010 and for the control in February 2011. For the purpose of this study, we have selected a 12-month timeframe from March 2011 to February 2012. Over the period of study 129 independent rain events were recorded. Independent rain events are defined as periods of precipitation separated by 12 or more hours.

Soil moisture probes (OnSet EcH2O) were calibrated and inserted into four of the five test panels. The probes are used to determine soil conditions at the outset of a storm for classification (±0.00 mV) as a "wet" or "dry" rain event. Nearly 85% of the cumulative sample of events is classified as wet. Of the 44 analyzed events 66% (29) are wet events. Each of the selected events is also analyzed for peak volume and delay. Peak volume is simply determined by the greatest number of tips per 15-minute interval for each storm event. Delay is determined by comparing the difference between time-to-peak for the control panel and each of the test panels.

4 ANALYSIS AND DISCUSSION

The analysis is structured into three categories – annual, seasonal, and individual storm events. Annual represents the entire period of collection, seasonal evaluates the performance characteristics in seasonally wet and dry periods, and individual assesses the capacity of these roof designs to provide stormwater retention for regionally common (<0.25"), substantial (0.25 – 1.25") and more intensive (>1.25") storm events. The data for each of these categories is analyzed by percent-retention and peak reduction and peak delay is analyzed for the individual sampling of events.

4.1 Annual

Over the 12-month span of continual testing, 43.7" (111.01 cm) of precipitation (rain) was collected in 129 individual storm events. Nearly 65% (82) of those events recorded less than 0.25" of precipitation. Only 5 (3%) of the recorded events was greater than 1.25", the greatest of which being 2.96" over a 28 hour period in November 2011. There was a wide variation in the rainfall retention capacity of the individual test panels, ranging from roughly 30 to 56% (Table 1). By volume, the multi-course (panels A and E) and modular (panel C) systems retained more rainfall over the 12-month period while the single-course (panel B) and shallow system (panel D) retained less, 32% and 30% respectively. The disparity was expected as the single-course system was not constructed with a layer of moisture retention fabric and panel D contains less soil media by volume.

Table 1. Monthly and cumulative retention (%) for test panels

	Year	Month	Rainfall (cm)	Retention (%)				
				Panel A	Panel B	Panel C	Panel D	Panel E
	2011	March	17.48	34.24	36.38	15.99	8.50	21.92
	2011	April	11.46	23.42	18.05	22.53	17.23	78.20
	2011	May	10.67	37.63	32.05	65.45	31.54	57.91
	2011	June	5.89	81.19	70.97	78.77	65.42	83.05
Dry Season	2011	July	2.59	98.60	95.37	96.10	98.42	98.38
	2011	August	0.63	99.66	96.45	88.99	100.00	99.09
	2011	September	3.76	90.88	76.73	86.90	88.80	96.68
	2011	October	9.91*	46.52	54.18	54.17	39.88	74.32
	2011	November	15.16	22.51	3.09	42.81	4.66	70.51
	2011	December	4.27	14.10	3.82	79.34	18.85	11.49
	2012	January	18.49*	22.94	19.79	80.04	32.56	33.76
	2012	February	10.99	29.72	33.24	77.91	41.16	61.28
	TOTAL		**111.01**	**35.96**	**31.56**	**55.56**	**29.66**	**55.77**
	Seasonal							
	Dry		2.95	98.73	95.50	95.24	98.61	98.47
	Wet		108.07	34.25	29.82	54.48	27.78	54.61

*Average rainfall calculated using NOAA Online Weather Data

The annual retention rates of the extensive green roof panels fall within the range of long term (>6 months) retention for similar studies, as reported in the literature (Table 2). Of the examined studies there is a wide variation in annual retention performance (15 – 87%), eventhough all of the studies examined utilized an extensive roof structure, similar planting palettes, and predominantely inorganic soil composition.

Table 2. Comparison of average annual runoff retention for extensive greenroof infrastructure (Adapted from Spolek 2008)

Average annual retention (%)	Test Site	Location	Reference
30 - 56	**Test Panels**	**Maltby, WA**	**This Study**
15	Education Center	Seattle, WA	Cardno Tec 2012
29	Fire Station	Seattle, WA	Cardno Tec 2012
53	Offices	Seattle, WA	Cardno Tec 2012
29	Dormitory	Portland, OR	Spolek 2008
18	Offices	Portland, OR	Spolek 2008
57	Community Center	Toronto, Canada	Liu and Minor 2005
57 - 87	Offices	Raliegh, NC	Moran et al. 2005

4.2 Seasonal

Seasonally, the retention response for the test panels was distinct (Table 1). During the dry season for the region (July / August) only 11 rain events were recorded; totaling less than 1.2" of precipitation. Only two of the events generated more than 0.25" of precipitation. Retention performance was high for all of the test panels, ranging from 95 – 99%. The month of August contained the least amount of rainfall (0.24"), and during this time, the shallow, 4" panel (D) retained 100% of precipitation. The high retention rates are to be expected as the dryer soils during these months have a greater capacity for retaining precipitation (Berghage et al., 2009).

Nearly 97% of the precipitation for the test period occurred during the wet season (September – June), and the individual test panel responses in the wet season are closely aligned with the annual retention rate. Yet when examined on a monthly basis performance across the panels varied greatly, ranging from 3% to 91%. The lowest monthly average percent retained for all the panels occurred in December, following a very wet November (6.0") which concluded with a series of back-to-back storms. Such retention performance variability has been identified in similar studies without specific conclusions as to the its causes (Cardno Tec, 2012; Moran et al., 2005). While likely attributable to weather conditions including air temperature and the frequency of rain events, more detailed study needs to be conducted.

4.3 Individual Storm Events

Individual storm events are categorized as light (<0.25"), moderate (0.25 – 1.25"), and heavy (>1.25"). Of the total (129) events during the sampling period, 34% (44) representing each of the intensity categories were examined for cumulative retention rates, peak reduction, and peak delay during events with wet (29) and dry (15) soil conditions. See Figure 2 for an example of the data analyzed.

As reported in Section 5.2, all of the test panels performed well in dry soil conditions, retaining more than 96% of the precipitation generated for each storm event and significantly decreasing the volume and delaying the peak runoff as compared to the control panel (Table 3). In general, performance decreased as the intensity of the storm increased. Samples for only light and moderate storm events were assessed as a heavy event with dry soil conditions was not recorded during the sampling period. Though all panel designs performed well, the multi-layer panels (A and E) were the most efficient, retaining 100% of the precipitation in light storm events, and in moderate events delaying peak runoff for multiple hours.

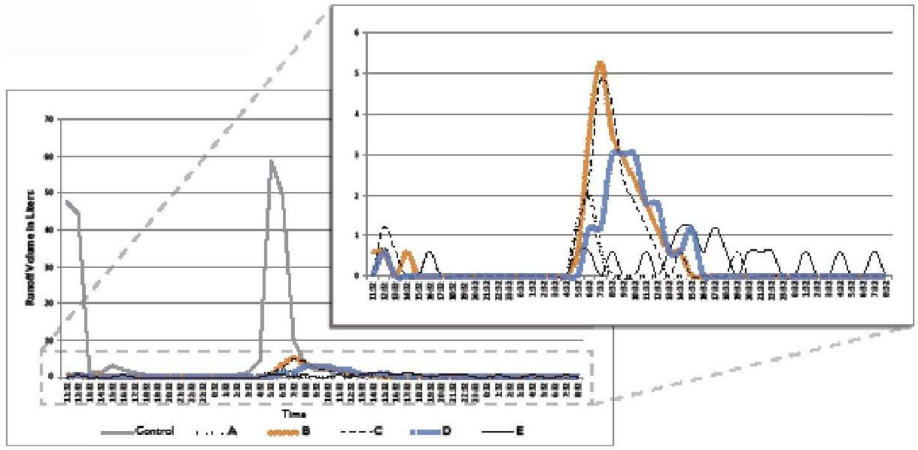

Figure 2. Test panel response to typical rain event with dry soil conditions (0.27”, 07/25/11)

For the sampled wet events, performance for the light storm events did not drop off significantly from that found with the dry events, and peak delay commonly remained at multiple hours. During moderate and heavy storm events however, performance dropped off considerably with all tested variables. For all of the panels, except for the multi-layer panel E, the variable with the most prominent decrease in performance was peak retention. Though all of the panels continued to delay peak flows and decrease total runoff, the relative measure of peak runoff decreased substantially. As expected, during heavy storm events the panels functioned less effectively across all measures, yet in general the multi-layer systems with 6” of soil media and moisture retention fabric (A, D and E) were the most effective across all measures for mitigating runoff.

Table 3. Total Retention, Peak Reduction, and Peak Delay for Individual Storm Events

			Panel A			Panel B			Panel C			Panel D			Panel E		
	Event Intensity	Selected Events (n)	Total Retention (%)	Peak Reduction (%)	Peak Delay (hrs)	Total Retention (%)	Peak Reduction (%)	Peak Delay (hrs)	Total Retention (%)	Peak Reduction (%)	Peak Delay (hrs)	Total Retention (%)	Peak Reduction (%)	Peak Delay (hrs)	Total Retention (%)	Peak Reduction (%)	Peak Delay (hrs)
Wet	< 0.25"	10	91	83	3.8	89	57	2.3	89	55	2	89	66	2	94	83	2.5
	0.25 - 1.25"	15	73	50	2	73	37	0.7	80	65	0.8	73	36	1.2	87	80	1.5
	> 1.25"	4	47	45	1	35	36	0.5	40	60	0.8	17	6	0.5	46	52	1
Dry	< 0.25"	10	100	98	1.2	98	69	2.6	99	88	2	99	91	2.4	100	97	6.9
	0.25 - 1.25"	5	99	82	1.2	97	58	1	98	65	1.4	99	74	1	100	97	3.7

5 CONCLUSIONS

The findings from this study, support previous research indicating that regardless of type and structure, green roof infrastructure can significantly decrease runoff and locally mitigate the impacts of stormwater on transfer infrastructure and receiving water bodies.

1. **All types and structures of green roof infrastructure tested show the potential for making a significant contribution in managing stormwater in the Puget Lowlands.**

- Over a 12-month period, the panels retained 30-56% of all precipitation.
- During seasonally dry periods the panels retained nearly 100% of all precipitation.
- With individual storm events, panel performance decreased with an increase in storm intensity with an average retention of 94% for one panel (E) during light events and as low as 17% for another panel (D) during heavy events. Peak delay also decreased with storm intensity, but the average delay for all panels and storm intensities with dry and wet soil conditions was nearly two hours.

2. **Monitoring performance is necessary to assess the effectiveness of green infrastructure strategies.**
   - The monitoring protocols used in this study worked well, despite some functionality issues with equipment.
   - Continued monitoring efforts in the Seattle metropolitan area will build a regionally significant foundation for making design and policy decisions regarding the most responsive and effective use of green infrastructure strategies in development.

6 REFERENCES

Berghage, R. D., Beattie, D., Jarrett, A.R., Thuring, C., Razaei, F., & O'Connor, T.P. (2009). Green roofs for stormwater runoff control. Report for the Environmental Protection Agency, EPA/600/R-09/026.

Gagnes, D. A. (2007). Seattle green roof evaluation project. Final Report. City of Seattle. Retrieved from: http://www.seattle.gov/dpd/cms/groups/pan/@pan/@sustainableblding/documents/web_informational/dpdp_019828.pdf.

Gedge, D., & Kadas, G. (2004). Bugs, bees, and spiders: Green roof design for rare invertebrates. Paper presented at the Second Annual Greening Rooftops for Sustainable Communities Conference, Awards and Trade Show; 2–4 June 2004, Portland, Oregon.

Getter K. L., & Rowe, D.B. (2006). The role of extensive green roofs in sustainable development. *HortScience*, 41, 1276–1285.

Green Roofs for Healthy Cities. (2012). Annual green roof industry survey for 2011. 10th Annual Green Roof & Wall Conference, Chicago, Illinois: October17-20, 2012 Retrieved from: www.greenroofs.org.

Liu, K., & Minor, J. (2005). Performance evaluation of an extensive green roof. In *Greening rooftops for sustainable communities*. Washington, DC, 1–11.

Lundholm J. T. (2006). Green roofs and facades: A habitat template approach. *Urban Habitats*, 4, 87–101.

Lundholm J. T., & Peck, S.W. (2008). Frontiers of green roof ecology. *Urban Ecosystems,* 11, 335-337.

Mentens J., Raes, D., & Hermy, M. (2005). Green roofs as a tool for solving the rainwater runoff problem in the urbanized 21st century. *Landscape and Urban Planning,* 77 (33), 217–226.

Mass, C. (2008). *The weather of the Pacific Northwest*. Seattle: University of Washington Press.

McIntosh, A. (2010). Green roofs in Seattle: A survey of green roofs and rooftop gardens" (Report). Seattle Public Utilities (August 2010). Retrieved from: http://www.seattle.gov/dpd/cms/groups/pan/@pan/@sustainableblding/documents/web_informational/dpdp020213.pdf.

Moran, A., Hunt, B., & Smith, J. (2005). Hydrologic and water quality performance from greenroofs in Goldsboro and Raleigh, North Carolina." In Proceedings of 3rd North American Green Roof Conference: Greening Rooftops for Sustainable Communities, Washington, D.C. Cardinal Group, Toronto.

Niachou, A., Papakonstantinou, K., Santamouris, M., Tsangrassoulis, A., & Mihalakakou, G. (2001). Analysis of the green roof thermal properties and investigation of its energy performance. *Energy Build,* 33 (7), 719–729.

Oberdorfer, E., Lundholm, J., Bass, B., Coffman, R.R., Doshi, H., Dunnett, N., Gaffin, S., Kohler, M., Liu, K. K., & Rowe, B. (2007). Green roofs as urban ecosystems: Ecological structures, functions, and services. *BioScience*, 57 (10), 823-833.

Saiz, S., Kennedy, C., Bass, B., & Pressnail, K. (2006). Comparative life cycle assessment of standard and green roofs. *Environmental Science and Technology,* 40, 4312–4316.

Spolek, G. (2008). Performance monitoring of three ecoroofs in Portland, Oregon. *Urban Ecosystems*, 11, 349-359.

VanWoert, N. D., Rowe, D. B., Andersen, J. A., Rugh, C. L., Fernandez, R. T., & Xiao, L. (2005). Green roof stormwater retention: Effects of roof surface, slope, and media depth. *Journal of Environmental Quality*, 34, 1034–1044.

Wong N. H., Chen, Y., Ong, C. L., & Sia, A. (2003). Investigation of thermal benefits of rooftop garden in the tropical environment. *Building and Environment,* 38, 261–270.