Studying water budget of paved urban sites using weighable lysimeter

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Abstract
Permeably paved surfaces make up a considerable percentage of total area in urban areas, especially in older cities. In urban hydrology one important task is keeping rain water in the unsaturated soil zone as long as possible in order to avoid floods and supply street trees with water. Our lysimeter study addresses a precise analysis of the water balance of two permeably paved surfaces. One surface is covered with concrete pavers and the second one with a so called “Bernburg mosaic of cobble stones”. Both are typical for the sidewalks of Berlin. Using this instrumentation, actual evaporation, runoff and drainage can be studied with a high temporal resolution for various climate conditions. A typical runoff coefficient could be gained for a span of typical rainfall intensities. They are essential for developing new urban water management strategies. Furthermore, impact scenarios of expected climate change on urban heat stress and urban hydrology can be predicted.

Key Words
Permeable pavements, lysimetery, evaporation, run-off coefficients, water budget.

Introduction
Adaptation to climate change and mitigation of the urban heat island should include the development of sustainable management of water and especially rainwater in urban areas. Surface runoff should be avoided whenever possible. Infiltration is not possible everywhere (Goebel *et al.* 2007). Instead, water should be stored and evaporated, contributing to the reintegration of water and energy cycles and providing benefits from evaporation cooling. In this sense, paved soils play a key role as they cover great portions of urban areas. For instance in Berlin, 60% of the city centre is sealed (Senstadt-Berlin 2001), and 30% accounts for streets and sidewalks which are permeably paved. Here water can infiltrate through seams between single pavestones (Borgwardt 1993). Although it is reduced, permeable pavements generate run off. The proportion of run-off from rainfall (RC) varies with pavement design, infiltration capacity of the seams and of the ground (static RC) and with the rainfall intensity (dynamic RC) (Mansell and Rollet 2006; Rim 2009). Process based models for runoff and evaporation from paved soils are needed in order to describe (i) the conditions in existing urban areas and (ii) to assess the impact of climate change scenarios and adaptation strategies using simulations. Little is known on processes that influence the dynamic RC of pavements, especially on evaporation from paved urban soils. Weighable lysimeters are the method of choice to conduct process studies on water cycles. We introduce a study on paved lysimeters and present first results on dynamic RCs and evaporation.

Methods
The permeable surfaces take a considerable percentage in the whole urban area of Berlin. The joint space with seam material makes up the real path of infiltration and interception of the rainwater. It is exposed immediately to the environmental pollution. To achieve the reasonable boundary condition old joint materials from the different inner city sidewalks were obtained and used as seam material and bed for the lysimeter pavement. Each lysimeter had a surface in size of 1 m^2; and a slope of about 2%. The lysimeter bodies stood in a 1.5 m deep cave on a scale with a 100g/sec resolution. The lysimeters were filled with construction sand to a depth of 1.3 m; there was a 0.2 m deep gravel layer on the ground. This served as a capillary blocking layer in the lower lysimeter boundary. The geotextile (polypropylene 1a white 500g) was placed around the gravel layer, serving as the leading capillary layer that captured the seepage water with four suction plates. The drainage could be measured with a resolution of 0.005g/sec. To measure the run-off separately, special gutters were set up directly along the surface edge that allowed the run-off to be immediately shunted to a separate discharge pipe where the run-off was measured in temporally high-resolution of 0.0005 mm/sec; no water was lost with this procedure.
The lysimeter wall and drain gutter are made of high-grade stainless steel. In the soil of lysimeter the water content and the soil temperatures will be measured by TDR sensors. The suction plates are set to a

subpressure of about -6.3 kPa. The paving coefficient of the cobble stone lysimeter is 45% and that of concrete paver is 7% (Rim 2009). Figure 1 illustrates the whole lysimeter construction which is found in Berlin Marienfelde, in the south of Berlin. Figure 2 and Figure 3 illustrate the individual aspects of the weighable lysimeter with Berlin's typical paving materials.

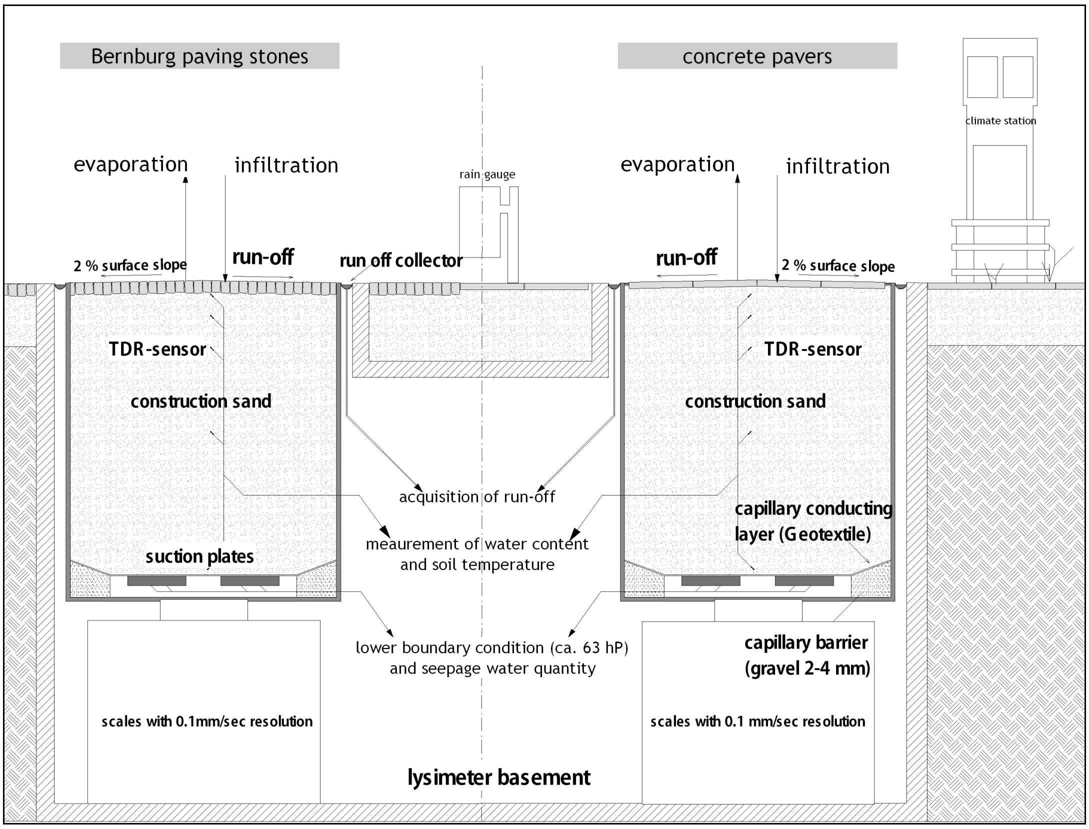

Figure 1. Construction of a weighable lysimeter system for studying the urban water budget.

Figure 2. Collection and measurement of run-off and groundwater recharge.

Figure 3. Views of lysimeter with cobble stones and concrete plates.

Results

Figure 4 shows the results of an irrigation experiment. It demonstrates how precisely rainfall could be measured using the weighable lysimeter. Results show a comparison to a Hellman rain gauge. Differences are < 1 %.

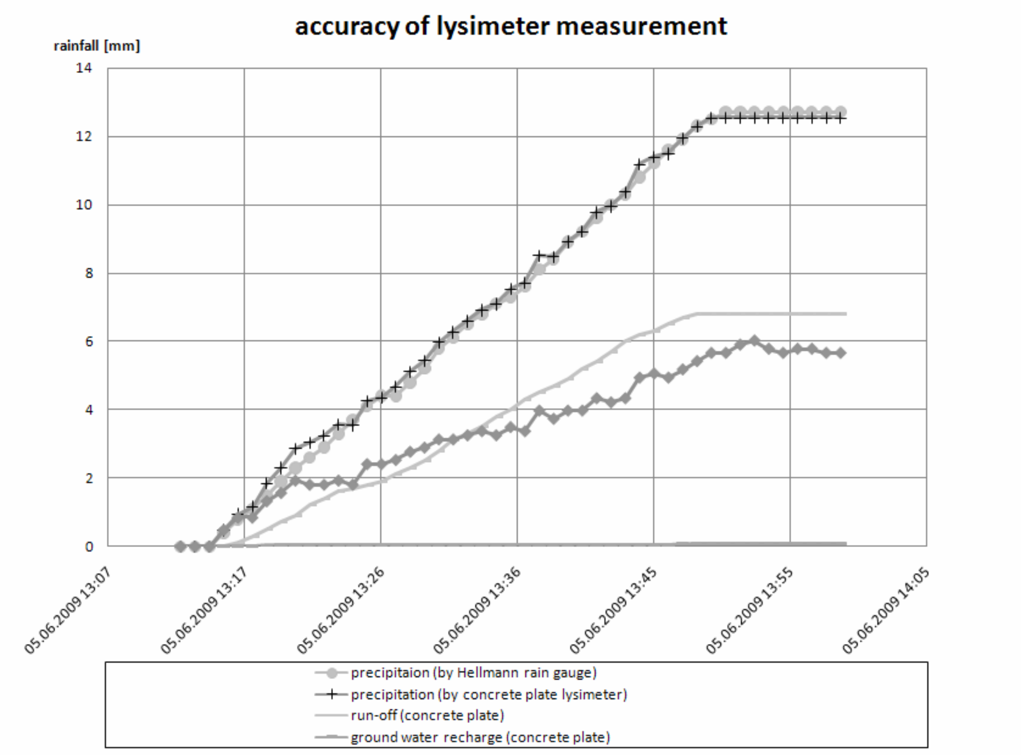

Figure 4. Accuracy of lysimeter measurement compared to data from rain gauge.

Run-off coefficients were dependent on the total rainfall, duration and intensity. Therefore, at first the whole precipitation continuum was separated into individual events of various intensities. The continuous rain data was grouped into individual distinctive events, each causing an individual distinctive run-off event. In most cases, the run-off process took longer than the rain event itself (dt in Figure 5), thus none of run-off event could be arbitrarily separated from the following rain event. The time span dt was set as the separation criterion. Figure 5 illustrates that a suitable separation coefficient of 10 min could be used to get individual run-off coefficients.

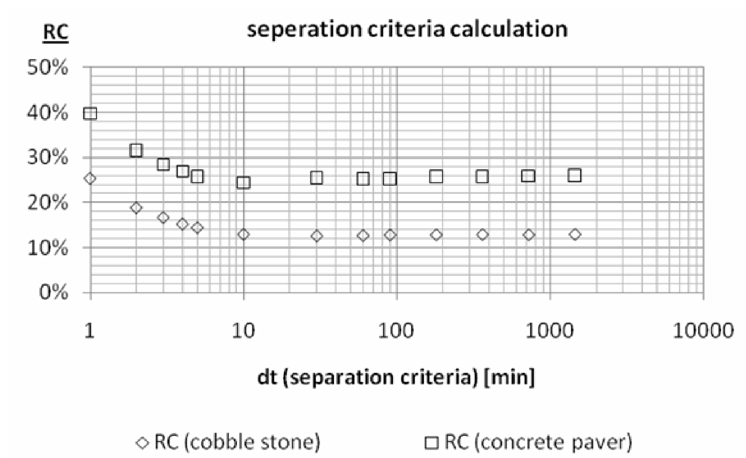

Figure 5. Criteria used for the separation of precipitation events.

About 160 rain events were separated and analyzed from April to September 2009. Rainfall events with intensities >0.04 mm/min could produce runoff from cobble stone surface, while rainfall events with intensities >0.02 mm/min could cause runoff from the concrete plate surface (Figure 5). After a rainfall intensity >0.2 mm/min up to 0.5 mm/min, RCs for the concrete paver surfaces increased at a significantly

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slower rate. RCs of cobble stone surface differed from concrete paver surfaces, continuing to increase even after intensities of >0.4 mm/min. These results lead to the conclusion that RCs are not dependent on the paving coefficient during strong precipitation events. These RC were typical for the rainfall characteristics of Berlin, Germany and should not be used for other climate regions without first adapting control variables.

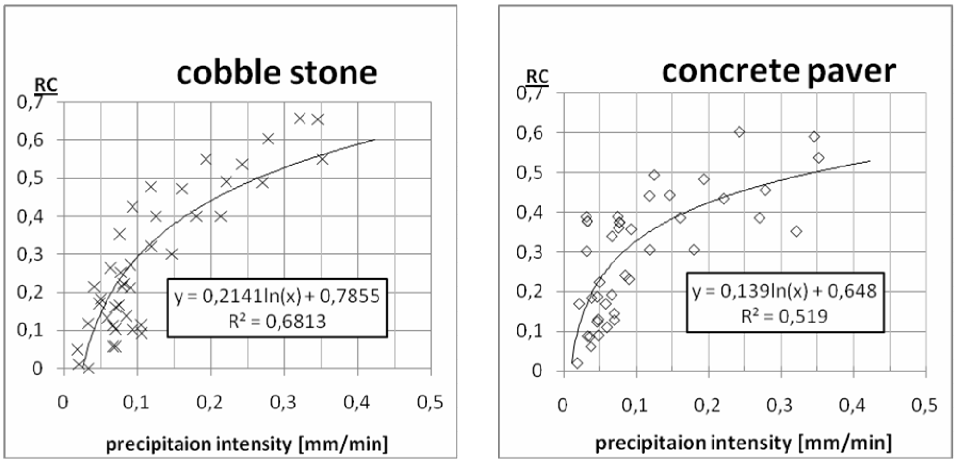

Figure 6. Runoff coefficient for cobble stone pavement (left) and concrete pavement (right)

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