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Water Resources Research

Supporting Information for

Is it worthwhile to invest in learning? A stormwater management case study with green infrastructure using Bayesian-based optimization

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Introduction

We present the design parameters of the stormwater management practices (SMPs) modeled in this paper in Text S1 and the description of the precipitation data in Text S2. Table S1 shows the assumptions about the key uncertain design parameters of the SMPs, and Table S2 lists the data source we retrieved for the case study. Finally, Figure S1 shows the annual rainfall trend in Philadelphia, PA, USA, as well as the storm duration and intensity histograms.

Text S1. SMP Design Parameter Assumptions

The five distinct types of SMPs evaluated in this paper include the following. *Rain gardens* (RGs) are vegetated SMPs that detain stormwater to infiltrate and recharge groundwater. *Infiltration trenches* (ITs) and *permeable pavement* (PP) are both non-vegetated infiltration SMPs. We consider three parameters to be uncertain: storage, seepage, and drainage area ratio (area treated/surface area), representing the uncertainty from design, natural soil, and installation, respectively. Other parameters are assumed to be known and fixed. Storage is the sum of the storage above ground, in the soil, and the bottom storage layer. The bottom storage layer is often made up of pebbles and rocks which can provide extra storage under the soil layer. Thus, our porosity assumptions are such that 1/2 of the volume in the soil and 1/3 of the volume in the storage layer can provide temporary water storage. The seepage is the rate at which water seeps into the natural soil. The drainage area ratio is the ratio of the area in which runoff is routed through an SMP to the surface area of the SMP itself. The mean values of the sizing parameters are chosen based on publicly available design guides (Hinman, 2005; PWD, 2015; Schueler & Claytor, 2009). Table 2 shows the parameter distributions assumed for the five SMPs.

Table S1

Distributions of Design Parameters of the Synthetic SMPs

SMP	Distribution of the SMP Design Parameters		
	Storage (cm)	Seepage (cm/hr)	Drainage Area Ratio
Rain Garden (RG)	*U(27.5,32.5)*	*N(1,0.3)*	*N(24,4)*
Infil. Trench (IT)	*U(33,43)*	*N(1,0.3)*	*N(30,5)*
Permeable Pavement (PP)	*7.5*	*N(1,0.3)*	*U(1,2)*
Rain Barrel (RB)	*91*	--	*N(108,18)*
Green Roof (GR)	*U(8.8,16.3)*	--	*1*

Note. *U(min, max)* denotes a uniform distribution in the range between *min* and *max*; $N(\mu,\sigma)$ denotes a normal distribution with mean μ and standard deviation σ.

The expected values of the drainage area ratio distributions are chosen based on the assumptions of the design storms treated by the SMPs. The assumptions are that RG and IT are for treating 12.5-mm (0.5-in) storms, RB is for treating 8.5-cm (0.3-in) storms, GR is for stormwater directly falling on the surface, and PP is designed to infiltrate runoff for an area up to two times its surface area. We assume that storage uncertainty mainly comes from installation due to site conditions and installation quality. PP and RB are simple and easy to install so we assume no uncertainty in their design storage, whereas the more complex SMPs (i.e., RG, IT, and GR), their storage depths are assumed varying (uniformly) in different ranges. Due to our limited understanding of the natural soil property, the seepage rate is assumed varying normally centered at 1 cm/hr (sandy loam) with a standard deviation of 0.3 cm/hr. However, this assumption does not have a significant effect on SMPs' performance as most storms can be treated by SMPs' storage. For the drainage area ratio, we assume that PP is uniformly distributed between 1 and 2, GR is deterministic (1), and the others are normally distributed with means calculated from the targeted storms and average storage volume and standard deviations equal to 1/6 of their means.

We do not assume optimal designs of the SMPs nor suggest that these SMPs fully represent the range of possible technologies. We limit the evaluation to these five SMPs to demonstrate the proposed analytical framework that allows stormwater managers to evaluate SMPs in their GI investment planning. Analysis of the optimal sizing and siting could be incorporated into this framework by adding decision variables to the optimization for other SMP designs, but that would be beyond the scope of this paper.

Text S2. Precipitation Data

The hourly precipitation data applied to this study were recorded at the weather station in Philadelphia International Airport (20 km south-west of the Wingohocking sewershed) downloaded from the NOAA Climatic Data Center (www.ncdc.noaa.gov/cdo-web/), which cover continuous data from 1980 to 2013. Two storms are separated if the dry period is longer than 4 hours, and the minimum rainfall is larger than 2.5 mm. In the absence of rainfall distribution data, we assume that the rainfall amounts are the same in all three subcatchments.

The annual rainfall volume ranges from 800 mm to 1,600 mm with an average of 1,060 mm (Figure 3a). Among the 3,674 storms in the 34- years period, 11% of the storms have rainfall depths exceeding 25 mm, and only 5% have a rainfall depth higher than 40 mm/hr, while 60% of the storms last 3 hours or less and only 10% can last longer than 10 hours (Figure 3b and 3c).

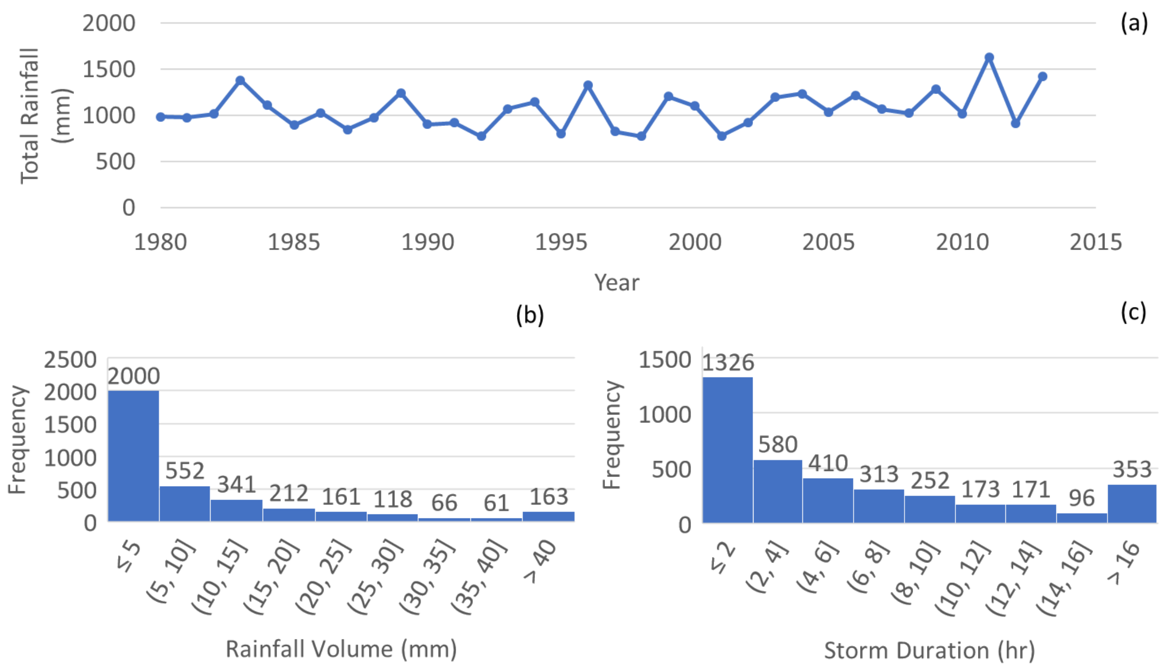

Figure S1. (a) Annual rainfall volumes from 1980 to 2013, (b) Histogram of rainfall depth, and (c) Histogram of storm duration (n = 3,674 storms)