WSUD using Continuous Simulation to Meet Design Storm Criteria

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Highlights

- WSUD using continuous simulation to meet design storm based regulatory standards.
- Coupling rainfall patterns to infiltration and evapotranspiration reduces raingarden footprint.
- Flow duration curves demonstrate geomorphologic protection.

Introduction

In the United States, most Water Sensitive Urban Design (WSUD) or Stormwater Control Measures (SCM) regulations are based on a central-peaking synthetic design storm developed from extreme event hydrology statistics. In Pennsylvania, stormwater designers are required to manage the net change in volume and quality of the pre- vs. post-development runoff volume from storms up to an including the 2-year/24-hour event. Due to geomorphologic concerns, this net change in the 2-year/24-hour storm is typically higher than water quality volume standards in other US states, which typically range from 7.6 mm to 38 mm (USEPA, 2016).

The term "2-year/24-hour storm" is featured throughout the regulations, leading to analysis using design storm-based methodologies. Currently, infiltration is the primarily recognized volume removal mechanism used by SCMs, such as rain gardens or porous pavements (PADEP, 2006). Unfortunately, the design storm artificially concentrates most of the rainfall volume over a small time interval at the centre of the storm, making it difficult for SCMs that rely on time dependent infiltration and evapotranspiration processes to meet requirements. A more dynamic approach that considers climate pattern, SCM configuration, vegetation, and the underlying soil properties has the potential to provide a much more resilient and appropriate SCM design (Traver and Ebrahim, 2017).

Design storms were developed with the best available data at the time, however with the development of computing power and availability of long-term rainfall records (i.e. 15-30 years), it is possible to design SCM through continuous simulation. Only one other US state, Washington, is known to have implemented continuous simulation as part of a methodology to meet regulations (Washington State Department of Ecology, 2012), though their approach is limited to protect geomorphology of the receiving rivers. The authors have proposed to move the statistical basis of the 2-year/24-hour storm from rainfall to runoff. This enables the use of continuous simulation as a design tool, eliminating the need for the central-peaking rainfall pattern. Furthermore, as the Pennsylvania stormwater runoff quality management is tied to the volumes of runoff and water quality up to and including the 2-year/24-hour event, this promotes consideration of a wide range of events in the design. With a continuous simulation approach, the design can consider climate, and both infiltration and evapotranspiration, and better represent the volume infiltrated and more appropriately target water quality. These processes require time to be credited, which is not available in the design storm approach

Methodology

Continuous Simulation Proof of Concept

To satisfy the design storm regulatory requirements, an example site was developed, then modelled using thirty years of hourly rainfall data to establish the SCM rain garden design. Using the runoff values from the model runs, the 2-year/24-hour runoff volume was developed for the natural, developed, and controlled condition and compared to results from the design storm approach. The 0.405-hectare site with a preconstruction condition of meadow and postconstruction condition of impervious with a rain garden (61-

cm deep sandy loam media with 45.7 cm of ponding) SCM was selected to compare design storm and continuous simulation approaches. Thirty years of hourly precipitation and daily temperature records from 1984 to 2014 from the Philadelphia International Airport station were obtained through the National Oceanic and Atmospheric Administration (NOAA) website, which hosts over 300 records of 15-year-long hourly or finer rainfall datasets in Pennsylvania. The USEPA SWMM was used to model the site and the footprint of the rain garden was adjusted to provide adequate volume control for the 2-year/24-hour storm. Since infiltration rates vary greatly across PA, the rain garden was modelled in different scenarios with various underlying infiltration rates (Table 1).

Table 1. Preconstruction and postconstruction watershed characteristics for continuous simulation scenarios.

HSG	Range (NEH 2007, Table 7-2)	Scenario Name	Selected Saturated Hydraulic Conductivity Rate (cm/d)	Selected Soil Suction (cm of water)
A	Greater than 86.6 cm/d	A	91.4	133
B	Between 86.6 and 34.8 cm/d	B	36.6	246
C	Between 34.8 and 3.7 cm/d	C1	18.3	351
		C2	12.2	351
		C3	6.1	422
D	Less than 3.7 cm/d	D	1.8	562

Water quality

The use of percent removal as a water quality strategy was not recommended due to concerns that its use was problematic and concerns that percent removal poorly describes water quality benefits (Jones et al., 2008). It is proposed instead to use runoff volumes tied to the event median concentrations for land use and outflow concentrations for SCMs to better represent water quality management. The best available data sources used include the National Stormwater Quality Database for land use median concentrations and the ASCE International Best Management Practice Database for SCM outflow concentrations for Total Suspended Soils (TSS), Total Phosphorus (TP), and Total Nitrogen (TN; ASCE, 2019; Clary et al. 2016; Pitt et al., 2004).

Results and discussion

Volume Requirement

As PA's volume requirement is based in the 2-year/24-hour storm event, the annual 50% exceedance probability is used to meet volume requirements using continuous simulation; the largest daily storm volume every year is ranked in order from least to greatest (Figure 1a). The SCM is designed so that the postconstruction runoff volume is less than the preconstruction volume at 50% exceedance to meet regulatory requirements. The SCM footprint sized by continuous simulation compared to those designed by a single storm-based method are generally smaller (Figure 1b).

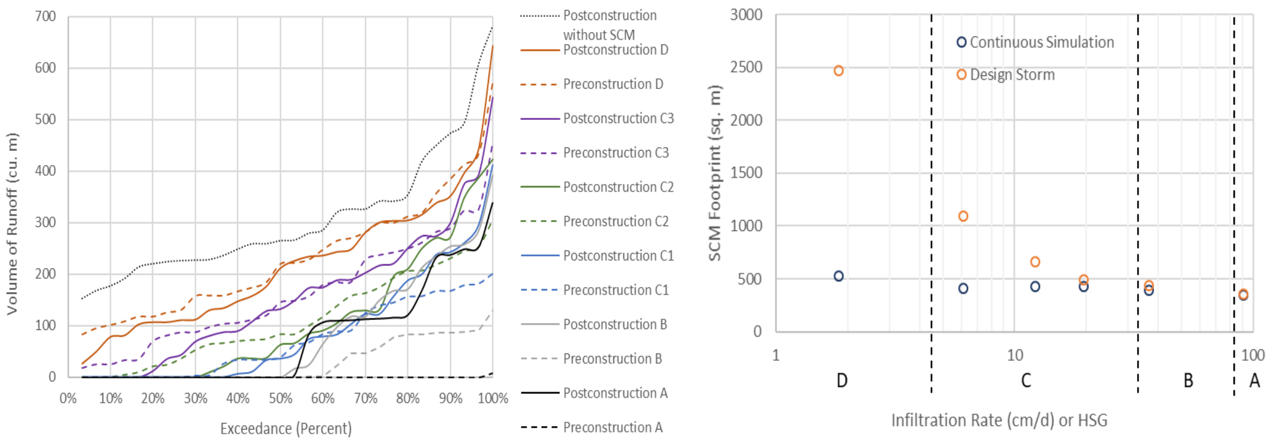

Figure 1a. 2-year/24-hour storm volume analysis for the six continuous simulation scenarios. **1b.** Comparison of SCM footprint size designed via continuous simulation and design storm.

Flow duration curves – geomorphologic concerns

Beside volume and peak flow associated with the 2-year/24-hour storm, one geomorphologic benefit to the continuous simulation approach is the ability to develop flow duration curves. The flow duration curves for these examples show that in all cases, the receiving stream has reduced duration exposure to erosive flows associated with the 2-year/24-hour storm and below (Figure 2).

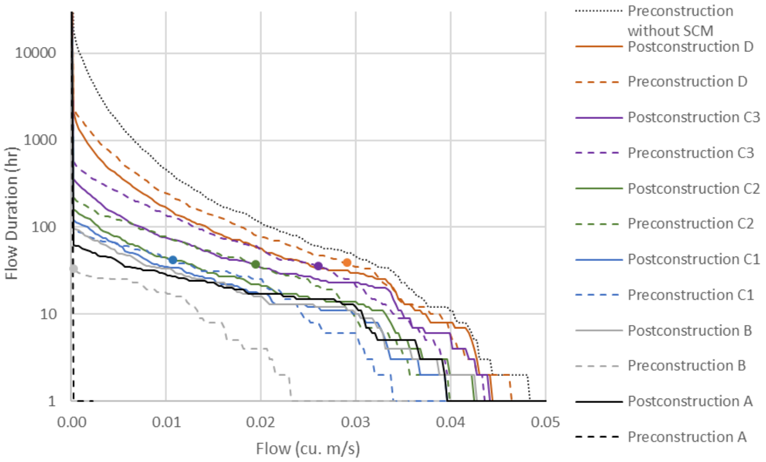

Figure 2. Flow duration curves for the six continuous simulation scenarios.

Water quality

The water quality volume treatment for storms up to an including the 2-year/24-hour storm can be fully represented using continuous simulation and it was found that surface water quality standards for TSS, TN and TP are most often easily satisfied using this approach.

Conclusions and future work

Continuous simulations using the EPA SWMM tool can model the interaction of the long-term rainfall patterns, climate, and soil physic processes to produce a more efficient and resilient tailored SCM design. Results demonstrate the advantages of the continuous simulation approach, and its applicability to function within regulatory requirements.

Ongoing future work includes adding climate change factors to the precipitation and temperature record and connecting the continuous modelling results to field research.

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