Design Storm and Continuous Simulation methods for Resilient SCM Design

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Highlights

- Continuous simulation can be used to meet design storm based regulatory standards.
- Simple methods can be used to incorporate climate change considerations to SCM design for both continuous simulation and design storm approaches.
- Coupling rainfall patterns to infiltration and evapotranspiration reduces raingarden footprint.

Introduction

In the United States, most 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. 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 short 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. With a continuous simulation approach that is suitable for wide-spread application, the SCM design can consider climate, infiltration, evapotranspiration and how these are affected by potential future climate conditions.

It is important to take into consideration the effect of climate change in SCM design, specifically due to changes to the rainfall volumes, patterns, and intensities that SCMs will be subject to in the future. Different parts of the U.S. have seen different amounts of change (e.g., some regions have less precipitation, and some regions have more precipitation) and different kinds of change (e.g., some regions a have the same volume of precipitation but distributed differently over the events and seasons) over time. In the northeast, a significant trend of the changing climate is an increase in annual precipitation; there has been an 8% increase in annual rainfall compared to the average between the years 1901 and 1960 (Walsh et al., 2014). For several municipalities in the Philadelphia region, it is estimated that in the near term (by 2035) a 10% increase in rainfall depth (i.e., 10% greater than the average depths often used for design) is expected. Design storm rainfall depths are predicted to increase up to 18% by 2100 (Maimone, et al., 2019). Both New York City and Philadelphia project that the number of 1 to 2-inch depth rainfall events are increasing and that these events have been increasing since the 1990s (Rosenzweig and Solecki, 2019; and Mayor's Office of Sustainability and ICF International, 2015).

Climate change predictions are very complex and have a large amount of uncertainty is associated with these predictions, however, the research herein focuses on attainable ways to consider climate change in both continuous simulation (via the SWMM CAT) and design storm approach (using the upper 90% confidence interval depth) to SCM design that are suitable for use throughout Pennsylvania. SWMM-CAT projections result in a rainfall increase of about 6% between 2020 and 2050 for the 24-hour design storm depths, an increase comparable to increase between NOAA's average 2-year/24-hour storm and the upper 90% confidence interval. Understanding of local climate change with respect to global climate change models is still at the forefront of current research. At the time of this writing, there has been one long-term data set developed for Philadelphia using best-known methods at the time established by Philadelphia Water Department (PWD) for planning purposes (Maimone et al., 2019). However, at this time global climate change models do not simulate extreme precipitation well, and there is concern whether the future intensities are underestimated. Until precipitation data sets are developed that incorporate climate change projections, SWMM-CAT is recommended.

Methodology

Continuous Simulation Proof of Concept

To satisfy the design storm regulatory requirements, an example site was developed, then modelled using a 15-year record to establish the SCM rain garden design for various underlying soil conditions. The 1-acre developed site is compared preconstruction condition of meadow using the runoff values statistically equivalent to 2-year/24-hour or 50% exceedance. The postconstruction condition is impervious with a rain garden (2-ft deep sandy loam media with an 18-in ponding depth) SCM.

The 15 years of hourly precipitation and daily temperature records from 2005 to 2020 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. These records were adjusted for climate change using the EPA SWMM CAT for near term, warm moist conditions, which outputs monthly temperature, evaporation, and rainfall adjustments (Table 1; conductivity adjustments are multiplication factors determined based on dynamic viscosity changes for average monthly temperature).

Table 1. Monthly climate and saturated hydraulic conductivity adjustments for Philadelphia.

Month	Temperature	Evaporation	Rainfall	Conductivity
January	2.952	0.006	1.133	0.593
February	2.250	0.006	1.054	0.627
March	2.196	0.008	1.061	0.716
April	2.070	0.007	1.053	0.850
May	2.358	0.009	1.044	0.986
June	2.286	0.008	0.938	1.122
July	1.908	0.007	1.076	1.188
August	2.196	0.007	1.021	1.166
September	2.016	0.005	1.165	1.057

October	2.394	0.006	1.053	0.897
November	2.178	0.006	1.084	0.766
December	2.394	0.005	1.023	0.644

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 (in/hr)	Selected Soil Suction (psi)
B	Between 1.42 and 0.57 in/hr	B	0.6	3.5
C	Between 0.57 and 0.06 in/hr	C1	0.32	5
		C2	0.2	5
		C3	0.1	6
D	Less than 0.06 in/hr	D	0.03	8

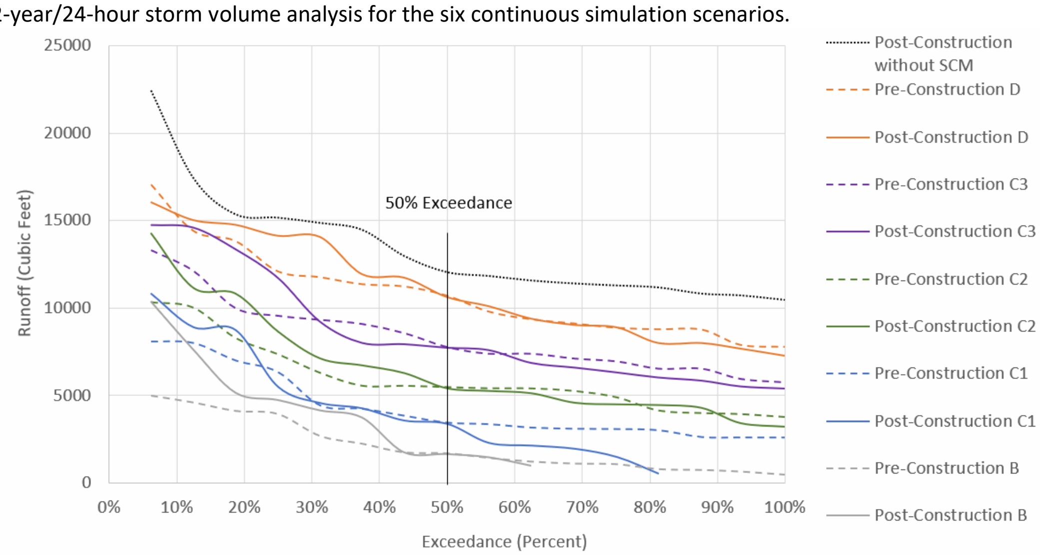
Results from the continuous simulation are compared against the new PA DEP method of a semi-dynamic design storm (where the mechanisms of infiltration during and after the event as well as ET for 6 days between events are considered) and the common static storage design.

Results and discussion

Volume Requirement

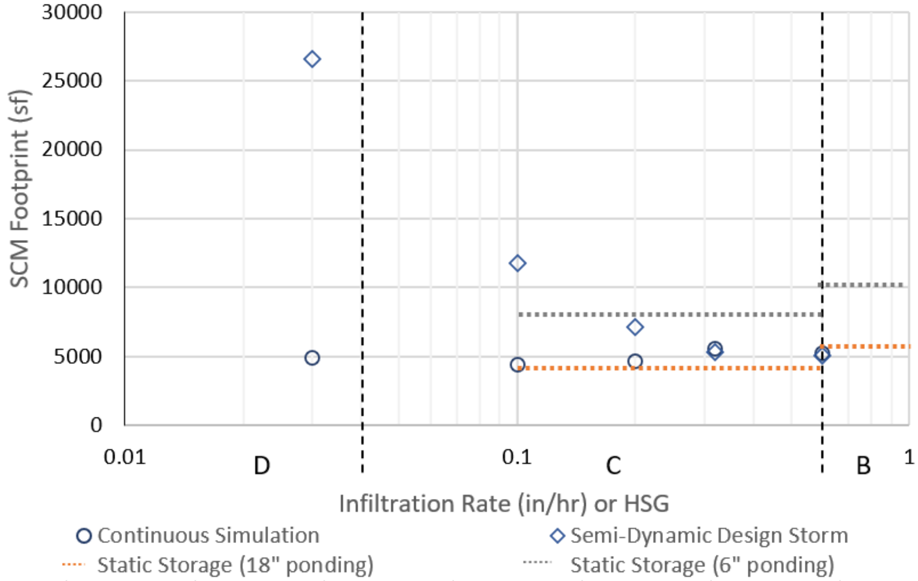
As PA's volume requirement is based in the 2-year/24-hour storm event, the annual 50% exceedance probability is used to meet volume requirements using continuous simulation; the SWMM statistics function is used for to obtain the precent exceedance and daily runoff volumes is ranked (Figure 2). The SCM is designed so that the postconstruction runoff volume is less than the preconstruction volume at 50% exceedance to meet regulatory requirements.

Figure 2. 2-year/24-hour storm volume analysis for the six continuous simulation scenarios.



The SCM footprint sized by continuous simulation compared to those designed by a semi-dynamic single storm-based methods (using the 90% upper confidence internal depth) are generally the same or smaller (Figure 3). Statically designed SCMs (for both a 6-inch and 18-inch ponding depths) are included but their comparison is limited based on recommendations in the 2006 PA BMP manual. The 18-inch provides a better comparison to the dynamic designed cases but the 2006 PA BMP manual limited ponding to a 6-inch depth and soil infiltration rate is typically limited to greater than 0.1 in/hr. For lower infiltration rates (around 0.1 in/hr) the static storage design is not less conservative than the dynamic-based designs and for higher infiltration rates (around 0.6 in/hr and greater) and is too conservative.

Figure 3. Comparison of SCM footprint size designed via continuous simulation and design storm.



Conclusions and future work

Continuous simulations using the EPA SWMM tool can model the interaction of the long-term rainfall patterns, climate, climate change, and soil physic processes to produce a more efficient and resilient tailored SCM design. Some way of incorporating dynamic processes and climate change is needed to ensure appropriately sized SCMs for the conditions in which they are expected to function. Results demonstrate the advantages of the continuous simulation approach, and its applicability to function within regulatory requirements. Methods presented include easy to use methods to incorporate climate change in both design storm and continuous simulation methods.

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