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SWMM through GIUH and OMS3: the design of stormwater drainage systems leveraging NET3.

Daniele Dalla Torre
University of Trento, dallatorre.daniele@gmail.com

Francesco Serafin
University of Trento

Olaf David
Colorado State University - Fort Collins

Riccardo Rigon
University of Trento

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SWMM through GIUH and OMS3: the design of stormwater drainage systems leveraging NET3.

Dalla Torre D. [1A] **, Serafin F.** [2A] **, David O.** [3B] **, Rigon R.** [4A]
[1] *d.dallatorre@studenti.unitn.it*, [2] *francesco.serafin@unitn.it*,
[3] *odavid@colostate.edu*, [4] *riccardo.rigon@unitn.it*
[A] *Department of Civil and Environmental Engineering, University of Trento, Trento, Italy*
[B] *Department of Civil and Environmental Engineering, Colorado State University, CO, USA*

Abstract: The EPA Storm Water Management Model (SWMM) is a robust software, widely used in urban catchments. However, it lacks two important aspects: a module for Storm Water Drainage System (SWDS) design and a flexible model structure. JSWMM, a new SWMM-based Java software, is developed to overcome these constraints. The SWMM data structure is refactored following the object oriented paradigm, while the computational core is split and redesigned as OMS3-compliant components. This approach allows for easily modifying and extending available modules by adding new functionalities, e.g. infiltration as part of runoff computation, different equation to evaluate evapotranspiration, etc. Input and output of JSWMM are maintained fully compatible with those of SWMM with which it remains, therefore, interoperable. The SWDS design module is based on the Geomorphological Instantaneous Unit Hydrograph theory by Rodríguez-Iturbe et al. (1979) and by Rigon et al. (2016). It automates the process of pipe dimensioning which requires the analysis of the maximum discharge in each section of the drainage system. Since this is a computationally expensive procedure, JSWMM is developed using NET3, a recently enhanced OMS3 functionality. NET3 schematizes any network with a directed acyclic graph data structure whose topology commands the execution of the models. Among the characteristics explained in the text, NET3 enables an additional layer of implicit parallelization of task located in independent vertices. JSWMM is developed as free software and made available on GitHub (https://github.com/geoframecomponents/jswmm).

Keywords: EPA SWMM; Object Modeling System; NET3; GIUH; stormwater systems design.

1 INTRODUCTION

The EPA Storm Water Management Model (SWMM) is a model that allows to combine different hydrologic and hydraulic conditions. The early development of SWMM started in 1971. Since then it has been continuously upgraded and extended to cover new environmental problems or to improve numerical solutions as shown by Metcalf (1971a, 1971b, 1971c, 1971d), Latham et al. (2016), Rossman et al. (2016) and Rossman (2017). It allows different approaches to evaluate the same physical process. However, enhancing its capabilities by adding innovative theories is not straightforward and rather complicated since it lacks of a flexible software design. The software is easy to setup and use for estimating runoff in urban settling, but it lacks also a module for design. SWDS design requires the estimation of the maximum discharge under specified IDF rainfall curves in any junction. SWMM does not provide it automatically. To accomplish this task the GIUH (Geomorphological Instantaneous Unit Hydrograph) theory has been shown to be a rational choice since it provides semi-analytical solution (e.g. Rigon et al., 2011).

2 METHODS

SWDS design is an iterative process since the designed dimension of a pipe depends on flow discharge rate under design rainfall intensities which depend upon the critical rainfall duration. The critical rainfall duration which maximizes the discharge is not known apriori. To find this maximum discharge, the actual SWMM implementation requires the user to repeatedly run simulations and manually adjust model parameters on each link of the network, until the solution is found. This is a feasible workflow for modelling small and simple networks. It is unfeasible and error prone as network complexity grows.

JSWMM implements the GIUH concept coupled to practical engineering rules to automate the design process upon the theory developed by Rigon et al. (2011). In this theory the critical rainfall time is found analytically for external pipes (those that do not have pipes uphill), and with a search algorithm for internal pipes (those that receive water from pipes uphill). Remarkably, the critical time depends upon on position and so the search must be repeated for any pipe.

JWMM tests the network with different rainfall duration defined a priori, evaluating the maximum discharge for each of them. The results are inputs in the following nodes, so the evaluation of maximum discharge is not position dependent.

Original SWMM is a fast and lightweight object based software written in C. Its design allows for an easy software maintenance, but increasing the already large variety of modeling equations is not effortless.

Viceversa, JSWMM is a Java software developed as OMS3-compliant components. OMS3 is a non-invasive modeling framework as shown by David et al. (2013) and Lloyd et al. (2011). The framework manages component connections, temporal stepping and enables implicit parallel computation of unrelated components. This design strategy allows for encapsulating physical process implementation into single responsibility components that are subsequently joined at runtime to obtain a specific modelling solution.

JSWMM also leverages a new OMS3 functionality: NET3. NET3 represents processes acting on a network as nodes in an acyclic graph data structure. In each vertex (node) of the graph resides a different OMS3 simulation. According to arrows joining the nodes, data produced at nodes are exchanged and can be used as inputs of ``downstream" OMS components, until at the outlet the total response is collected. Every vertex is run in parallel according to a schedule that is driven by the network topology. A more comprehensive description of NET3 is given in Serafin et al. (2018).

3 HYDROLOGY

To properly design the network, rainfall data are given by an Intensity Duration Frequency (IDF) curve described by equation (1).

$$I(t) = a(Tr) * t^{(n-1)}, \quad (1)$$

which accounts for rainfall intensity (I) based upon duration (t) of the precipitation event and its return period (Tr). Duration is fixed in a single simulation and the rainfall intensity resulting is time constant in each single simulation. The theory by Rigon et al (2011) shown that the maximum discharge flowing out of a catchment depends on the catchment size and geometry and to find the critical time that produces the maximum discharge many run of the rainfall-runoff model must be performed. Subsequently, infiltration is thought to be proportional to rainfall, according to a runoff coefficient, Φ, which is chosen according to the types of urban soil present in the area. Finally the runoff is produced by the convolution of a Clark type unit hydrograph (e.g. Beven et al. 2001) with the effective rainfall (Φ*I(t)) for any of the subareas partitioning the watershed.

4 IMPLEMENTATION

Before designing the software, the actual SWMM source code was analyzed in-depth. Subsequently, the core parts of rainfall-runoff model were extracted. The code was translated in Java, and turned into two independent OMS-compliant components. Inputs and outputs format produced by the components remain the same of the original code for preserving the user experience in the setup of simulations.

NET3 allows for mapping the stormwater network into a directed acyclic graph. Each node of the graph (A, B, and C in Figure 1) models a single drainage area and its related discharge pipe. A node is an OMS simulation file indeed and it is composed by three modules: the runoff module (red in Figure 1), the routing/dimensioning module (green in Figure 1) and the flow dispatcher (yellow in Figure 1).

Rainfall data and soil parameters per drainage area are inputs of the runoff simulation module. The runoff estimates for a variety of rainfall durations (and related intensities) the discharge curves for each drainage area, which become inputs of the routing/dimensioning module. The flow dispatcher module sums incoming discharges from upstream nodes. Then a pre-processing of dimensioning module evaluates the maximum discharge including local drainage area contribution. Both runoff and routing modules use uniform flow formulas to obtain the desired result.

The maximum discharge, along with user defined parameters of the pipe (e.g Manning-Gauckler Strickler coefficient or maximum fill level) becomes input to the dimensioning component, that returns the dimension of the pipe.

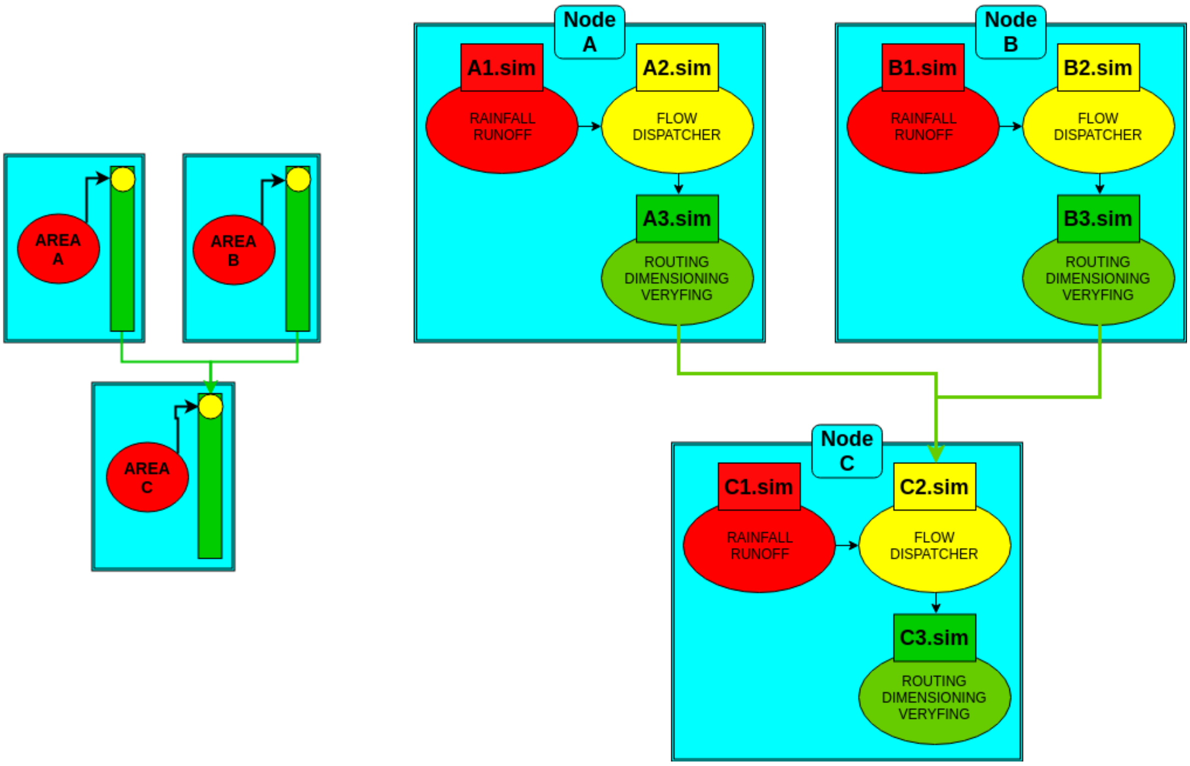

Figure 1. Example scheme of a three node physical problem (on the left) and its correspondent implementation in JSWMM (on the right)

JSWMM has a single data structure shared between vertices which contains all the input data values and results evaluated. An accurate design allows for proper concurrent access of multiple threads.

4 CONCLUSIONS

This contribution aims to create a lightweight stormwater network design tool. JSWMM implements a simplified yet sound physics with respect to SWMM which can be dedicated to the automatic design of

the pipes' network SWMM can seamlessly use the outputs of JSWMM to further verify the design with more complex runoff and infiltration modules and the two softwares can work cooperatively.
The JSWMM source code is distributed at https://github.com/geoframecomponents/jswmm under the GPL3 license.

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