Prediction of the Catchment-Scale Efficiency of Stormwater Control Measures in an Urban Watershed using a Process-Based Modelling Approach

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Highlights

- An integrated model of an urban watershed considering surfacewater-groundwater interactions has been constructed and calibrated.
- Various scenarios of implementation of stormwater control measures (SCMs) have been implemented in the model.
- The effect of different SCM design and coverage on measures of peak flow and volume has been studies.

Introduction

Stormwater control measures (SCM)s are practices aiming at reducing the volume and peak of surface runoff and pollutant loads through increased infiltration, evaporation, filtration or delayed release to the traditional sewer systems or receiving surface waters. To evaluate the effectiveness of SCMs, it is important to consider their effects on surface runoff as a result of not only their direct effect on capturing overland flow but also through their impacts on infiltration, inter-flow, groundwater recharge and base-flow into the streams. In this study, the application of a process-based model to predict the long-term impacts of SCMs on the hydrologic response of a highly urbanized watershed in the suburbs of Washington DC, is demonstrated. For this purpose a model representing pre-retrofit conditions of the watershed is constructed and calibrated based on observed flow data in the main stream. The watershed system is represented using a compartment-based model where each compartment represents one of overland flow, unsaturated soil, groundwater or segments of the stream network or different components of the SCMs. The model allows incorporating groundwater-surface water interaction which plays an important role on the baseflow in the stream.

After model calibration several scenarios of SCM implementation has been added to the model and the long-term impact of the SCMs on the changes of the some hydrographs' long aggregate characteristics, specifically the stream-flow rates corresponding to given exceedance probabilities have been evaluated. The SCMs studied include simple stormwater ponds and SCMs with storage or engineered soil layers with and without underdrain pipes. The results help quantifying the long-term impacts of various level of SCM coverage on the base and peak flow in the main stream. It was found that a high coverage implementation of SCMs (50%-90%) can substantially reduce the peak stream flows as measured by the corresponding streams flows to 1% and 0.1% exceedance probabilities. It was also found that presence of underdrain systems decreases the peak flows substantially. It was also found that the spatial distribution of the SCMs over the watershed area can have a significant effect on their effectiveness in reducing the peakflow.

Methodology

Study Site

TThe highly urbanized Sligo Creek watershed in the state of Maryland in the suburbs of Washing-96ton DC was considered for the study. Sligo Creek is a tributary to the Anacostia River. It discharges into the north east branch of the Anacostia River. The watershed is covered by a separate sewer system (MS4 permit) and the storm runoff ultimately discharges to the Sligo Creek. Several tributaries of Sligo Creek suffer from a wide range of problems including eroding stream banks,exposed sewer lines, a large amount of untreated impervious area, and land-uses associated with fertilizer and pesticide use. Consequently, the stream experiences frequent high flow rates during storms that continue to erode the stream channel resulting in high amounts of sediment (Cummins et al., 1998, Stribling et al., 2002).

Subheading 2 - tables and figures

The program GIFMod was used to create the conceptual model representing pre- and post-retrofit conditions of catchment processes in Sligo creek. GIFMod is a flexible tool that allows one to represent a watershed system as a network of blocks representing various components including overland flow, soil, groundwater, stream network, and various components of stormwater control measures (Massoudieh, et al., 2017). A model of water system can be constructed as a combination of nodes representing different media and links representing the interfaces between different media components (Figure 1).

Water and chemical mass balance is performed in the blocks while connectors represent the interfaces between the blocks where water and mass exchange can take place. Physically-based governing equations are used to compute the flow and transport between the nodes through the links. The blocks can represent various media types including catchment, stream segment, pond, unsaturated or saturated soil, aggregate storage, plants or other user-defined features of a water system.

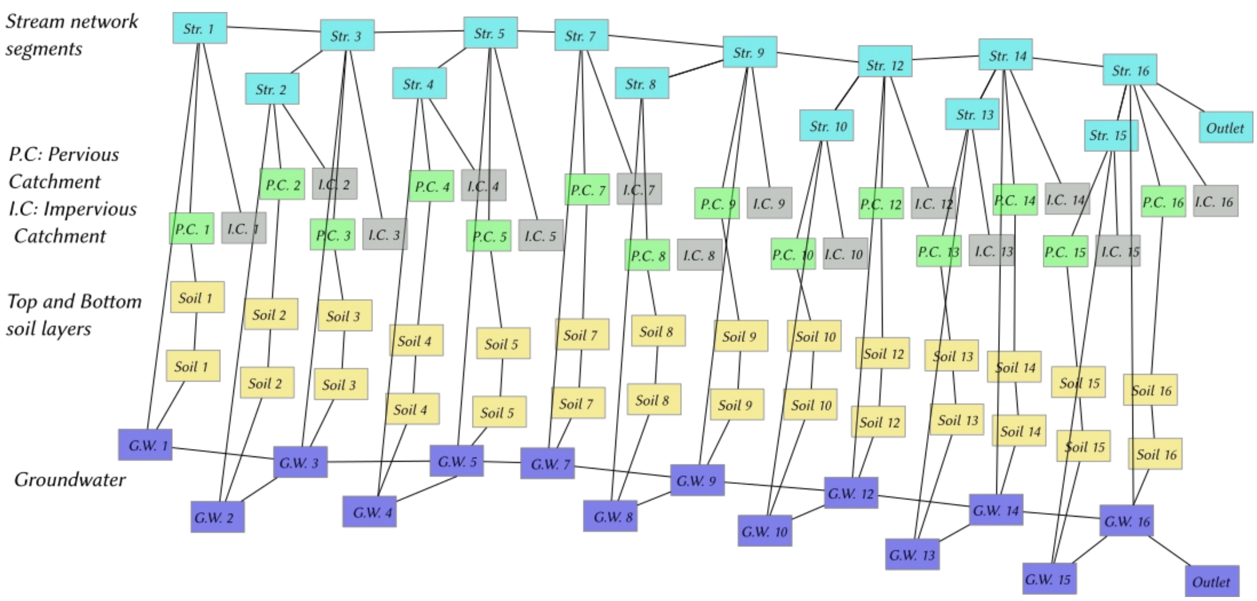

Figure 1. This is an example of a figure. Centre-aligned. Please ensure all text inside figures is legible; equivalent font 9 size is required. Note this figure occurs directly after the paragraph that first cited it.

The model allows considering surface water-groundwater interaction by connecting the groundwater component to the adjacent stream with each sub-catchment. Evapotranspiration is modeled using Penman model and it is assumed that evapotranspiration can withdraw water from surface water bodies as well as the top and bottom layers of soil, however correction factors have been applied to evapotranspiration rates from soil to account for the effects of shading, the limiting effects of moisture availability and the rate limiting effects of moisture transfer from soil to the surface through soil or plant roots.

After the model is calibrated and validated several scenarios of SCM implementation has been created. The scenarios include various coverage areas (%10, %50, %90) and various design configuration (stormwater pond, and infiltration-based approaches with and without underdrain). The three design scenarios include 1) stormwater pond with overflow and no underdrain (scenario 1), 2) infiltration-based SCM with engineered soil and no underdrain (scenario 2), and 3) infiltration-based SCM with underdrain discharging into the stream (scenario 3).

Results and discussion

Figure 2 shows the flow rates corresponding to the exceedance probabilities of 1% and 0.1% respectively for the baseline condition and for each SCM implementation scenarios and coverage level. A simulation has also been done to determine the corresponding exceedance flow rates for the pre-development conditions.

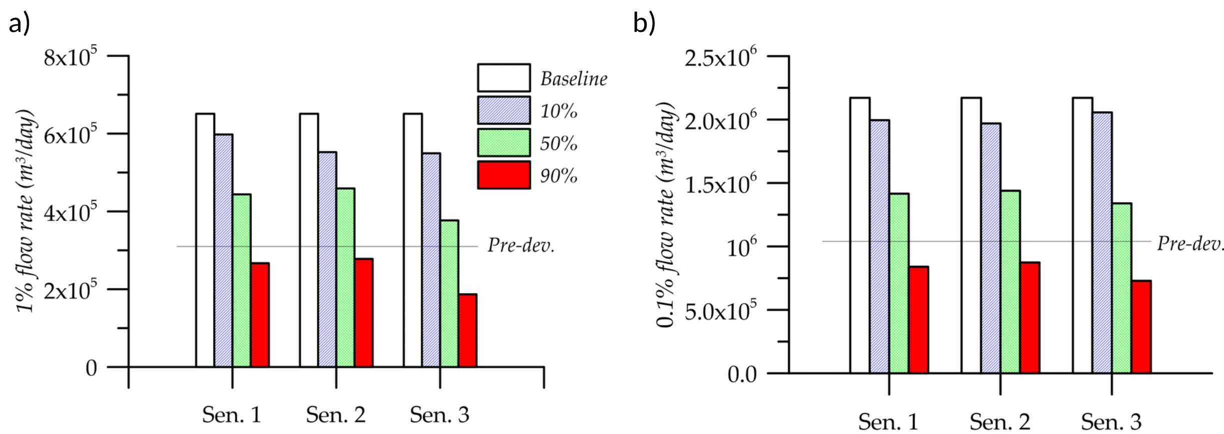

Figure 2. Flow rates corresponding to exceedance probabilities of a) 1% and b) 0.1% for all coverage and SCM scenarios considered.

It can be seen that the with 90% SCM implementation all design scenarios reduce the exceedance flows to less than the pre-development conditions while a 50% implementation level does not reduce the exceedance flows to the level of pre-developed condition. Also it can be seen that the infiltration-based design with under-drain outperforms the other designs for all coverage levels while the pond and infiltration-based design without under-drain perform quite similar to each other.

References

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