Assessing the Cost of Adapting Stormwater Control Measures to Climate Change

Évaluation du coût de l'adaptation des mesures de contrôle des eaux pluviales au changement climatique

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RÉSUMÉ

Les mesures de contrôle des eaux pluviales (SCM) sont souvent utilisées pour atténuer les effets de l'urbanisation. Les modèles de bassins hydrographiques comme le Modèle de gestion des eaux pluviales (SWMM) peuvent aider à sélectionner, à localiser, à calibrer et à évaluer les SCM en vue d'atteindre les objectifs de qualité de l'eau. Le changement climatique (CC) est susceptible de réduire l'efficacité des SCM. Par le passé, le SWMM a permis d'élaborer et d'appliquer une méthode de projection des impacts du CC sur la quantité et la qualité de l'eau du bassin versant urbain Difficult Run du comté de Fairfax en Virginie. Le bassin versant est un affluent de la baie de Chesapeake, qui est soumise à des réductions de charge en nutriments (azote et phosphore) et en sédiments, comme le spécifie la charge quotidienne maximale totale (TMDL). En automatisant l'exécution du SWMM, on a pu déterminer la combinaison la plus rentable de SCM dans un bassin versant pour un ensemble donné de conditions. RSMMM-Cost a été mis au point à cette fin et a été appliqué à un sous-bassin amont de Difficult Run dans les conditions actuelles. Nous poursuivrons dans la même direction en effectuant la même analyse dans plusieurs scénarios de CC. Ainsi, nous allons générer des courbes coût-efficacité pour les conditions existantes et les conditions modifiées par le CC. Le coût différentiel de l'adaptation au CC pourra ensuite être évalué en analysant les deux courbes.

ABSTRACT

Stormwater control measures (SCMs) are often used to mitigate the effects of urbanization. Watershed models such as the Storm Water Management Model (SWMM) can help select, site, size, and evaluate SCMs for meeting water quality goals. Climate change (CC) is expected to reduce SCM effectiveness. Previously, a method for projecting CC impacts on water quantity and water quality from an urban watershed using SWMM was developed and applied to the Difficult Run watershed of Fairfax County, Virginia. The watershed is tributary to the Chesapeake Bay, which is subject to load reductions of nutrients (nitrogen and phosphorus) and sediment as stipulated by the total maximum daily load (TMDL). Identifying the most cost-effective combination of SCMs in a watershed for a given set of conditions was accomplished by automating the execution of SWMM. RSMMM-Cost was developed for this purpose; and was applied to a headwater subcatchment of Difficult Run for current conditions. We will extend the previous effort by performing the same analysis for several CC scenarios. Thus, we will generate cost-effectiveness curves for existing and CC-altered conditions. The incremental cost of adapting to CC which can then be assessed by analysis of the two curves.

KEYWORDS

Climate Change, Cost-effectiveness curves, optimization, Stormwater Control Measures water quality

1 INTRODUCTION

The overall objective of the proposed research is to identify watershed restoration projects that are most cost-effective for improving runoff quality, and assess the costs of coping with changes in climate. The Chesapeake Bay estuary is experiencing eutrophication due to excessive loading of sediment and nutrients (nitrogen, N, and phosphorus, P), and as a result, the (U.S. Environmental Protection Agency, 2010) issued a Total Maximum Daily Load (TMDL), limiting N, P, and sediment discharges to its tributaries. Significant efforts are now being made by local governments to comply with the TMDL. Urbanization increases runoff and pollutant transport; these effects are amplified by climate change (CC) (Lee and Jetz, 2008). CC also reduces the efficiency of Stormwater Control Measures (SCMs) which are the main tools used in urban areas to achieve restoration goals (Hathaway *et al.*, 2014). Reductions in SCM effectiveness will likely need to be made up, adding cost and, diverting resources from other urban needs. Robust methods to predict the effects of CC on water quantity and quality and the cost-effectiveness of watershed restoration projects are needed to develop resilient strategies that meet water quality goals and minimize costs.

Stormwater Control Measures (SCMs) are the main tools in urban areas to mitigate the negative effects of urbanization. SCMs are typically designed based on the assumption of stationarity of historical climate data (Simonovic and Peck, 2009). However, with Climate Change (CC), it has been argued that this fundamental guiding principle may be erroneous and lead to nonconservative designs (Milly *et al.*, 2008). The efficiency of stormwater management systems in runoff reduction and pollutant removal will likely decrease due to the CC impacts (Shongwe *et al.*, 2011; Trenberth, 2011). Since SCMs are typically the lowest feature in a watershed to intercept runoff, and are the most susceptible component of stormwater infrastructure to CC-induced changes in rainfall.

CC may increase the effects of urbanization by increasing runoff, transport of sediment, nitrogen (N), phosphorus (P), and other pollutants. As excess nutrients accumulate in water bodies, eutrophication ensues, as previously described. SCMs have water quality treatment and runoff or mass reduction capabilities and thus can reduce downstream loadings of sediment, N and P. A variety of SCMs are available, with different capabilities, costs, and limitations; each selected SCM must be then appropriately sized. Generalized costs are nonlinear functions of SCM size and type. Increased rainfall intensities and longer dry weather periods from CC likely reduce the efficiency of SCMs by increasing buildup and wash off of pollutants from land surfaces, thereby increasing pollutant loading (Sharma *et al.*, 2016), and increasing bypass of untreated flows due to exceedance in design capacities. These effects should be considered in order to identify the most resilient and reliable SCMs for projected CC conditions. The objectives of this research are to advance the ability to identify the most resilient and cost-effectiveness set of SCMs in an urban watershed that achieve our water quality goals, and identify the incremental cost of adapting to CC.

2 METHODS

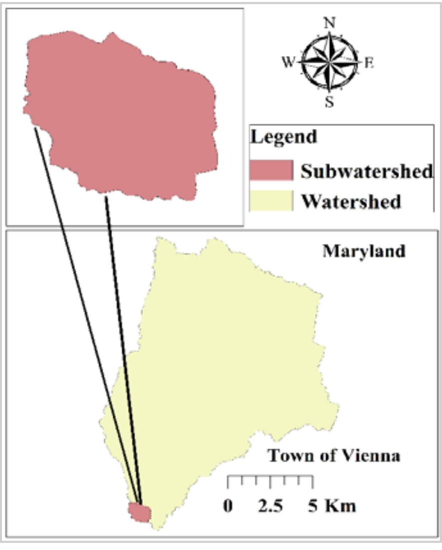

Figure 1. Water shed and subwatershed map.

In previous research, we developed and calibrated a Stormwater Management Model (SWMM) of Difficult Run, a 150 km^2 watershed, the largest watershed in Fairfax County, a suburb of Washington, DC. Difficult Run flows to the Potomac River which is tributary to the Chesapeake Bay. We have selected a 123.4 ha headwater watershed as an application test case for this study (Figure 1). We developed a SWMM model of the entire Difficult Run watershed, details are available in SWMM simulates runoff quantity and quality overland and through SCMs. Methods for downscaling and bias correction of global climate models (GCMs) and regional climate models (RCMs) were developed (Alamdari *et al.*, 2017).

Projections for precipitation, and temperature for the watershed from the North American Regional CC assessment program (NARCCAP) were used in the calibrated and verified SWMM model to predict streamflow; and TSS, TN and TP concentrations for historical and projected CC conditions. Two time periods, 1971-1998 and 2041-2068 using two Representative Concentration Pathways (RCP 4.5 and 8.5, which are a medium and intensive greenhouse gas emission scenario, respectively) were used (Alamdari *et al.*, 2017).

To facilitate running SWMM, RSWMM-Cost was developed to automate the execution and auto calibration of SWMM models. Cost estimation of SCMs and an optimization module were recently added using generalized relationships to calculate life cycle costs to identify least-cost groups of SCMs that meet water quality requirements of the TMDL (Alamdari and Sample, 2019). This analysis will be extended to include several CC scenarios. Thus, we will generate cost-effectiveness curves for existing and CC-altered conditions. The incremental cost of adapting to CC which can then be assessed by analysis of the two curves.

3 RESULTS

In RSWMM-Cost, many runs will be executed to adjust SCM, type, size and configuration to achieve the equivalent target load reduction for similar levels of performance when evaluating historical and projected climate conditions. A cost-effectiveness curve (Figure 2) will be generated for projected climate and historical conditions to assist in separation of solutions. Those solutions that are on or close to the line are known as the Pareto frontier, and are the most cost effective.

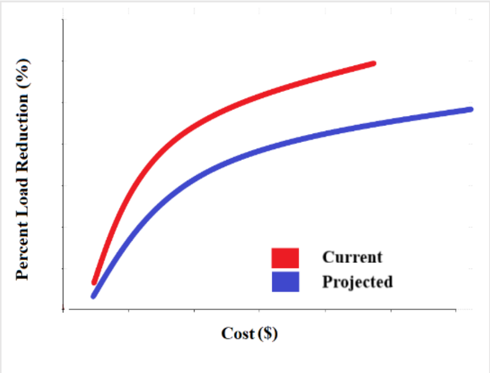

Figure 2. Example cost-effectiveness curves for current and projected climate conditions.

Expected results include the reduction in efficiency of SCMs and the increase in the associated costs, given an anticipated increase in overall precipitation in the watershed, as these measures are typically designed for historical conditions with no consideration of CC. Additional storage and routing structures will likely be needed to provide the same level of performance, the difference in costs between these represents the cost of adapting to CC.

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