Managing Stormwater with Low Impact Development in Highly Urbanized Areas

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ABSTRACT

Low impact development (LID) implements small-scale hydrologic controls throughout a catchment to replicate the pre-development hydrologic regimes or in other terms control stormwater as close to the source as possible. Examples of such controls include green roofs, bioretention swales, rain gardens, porous pavements. This project evaluates the effectiveness of large-scale LID implementation in Singapore and Hong Kong. We examine the hydrologic impacts, namely peak discharge mitigation and baseflow restoration, under different land uses, rainfall conditions and LID strategies. For further comparison, we adopt an integrated distributed hydrological model for Singapore and a lumped hydraulic model for Hong Kong. Studies of both Singapore and Hong Kong suggest that LID is effective if there is substantial level of infrastructures (e.g., covering 5 to 10% of catchment area). LID is more efficient in reducing/delaying peak discharge and restoring baseflow on an average long term basis. However, its performance, particularly in peak discharge mitigation, diminishes during design storms (e.g., ARI of 5 years). In terms of modeling techniques, integrated distributed hydrologic models require extensive parameterization but can accurately simulate some important processes (e.g., increase of infiltration and restoration of baseflow) that are simplified in lumped hydraulic models. Overall, large-scale LID potentially provides more sustainable stormwater management but its success depends on factors such as design objectives, existing land uses and drainage networks. We should therefore further research to increase the feasibility of large-scale LID in highly urbanized areas such as Singapore and Hong Kong.

1. INTRODUCTION

Urbanization significantly alters the hydrological cycle, resulting in less infiltration and groundwater recharge, as well as more surface runoff and river discharge. To mitigate the increased flooding associated with urbanization, engineers traditionally construct pervasive networks of drains to divert stormwater away from developed areas. However, the efficient drainage network further exacerbates the problems of reduced baseflow and increased peak discharge, etc. In recent decades, there have been rising interest worldwide in implementing small hydrologic controls throughout the urban areas to reduce the hydrologic impact of urbanization. This newer and more sustainable approach in stormwater management is referred to as low impact development (LID). Those hydrologic controls mimic natural or pre-development conditions, retaining and slowly releasing stormwater into the drainage system over a prolonged period of time. Examples of such controls include bioretention systems, green roofs and porous pavements (Figure 1).

A number of previous studies have examined the effectiveness of those controls, particularly as individual elements. For example, green roofs retain 40 – 80 % of rainfall [1-3] and reduce 60 – 80 % of peak discharge [4-6]. Bio-retention systems not only retain stormwater [7] but also enhance infiltration [8, 9] and thus groundwater recharge and baseflow. However, to effectively evaluate and implement LID, it is insufficient to examine their hydrologic performance at individual levels. This study evaluates the effectiveness of large-scale LID implementation in two urbanized catchments, one in Singapore and the other in Hong Kong. We examine the hydrologic impacts, namely peak discharge mitigation and baseflow restoration, under different land uses, rainfall conditions and LID strategies.

Figure 1: Examples of low impact development elements. Bioretention system (top) and green roof (bottom).

2. METHODS

We adopt numerical modelling to simulate the hydrologic conditions of various scenarios. We consider different level of urbanizations, from pre-urbanised to urbanized, as well as different LID implementation strategies. We perform simulations over a longer period (e.g., 1 year or more) to examine the average performance of the LID. We also subject the model to different design storms (3 month, 2 year, 5 year or higher ARI). The Singapore catchment is Marina Catchment with an area of around 161 km^2, while the Hong Kong catchment is that of Ma Wat River with an area of around 8 km^2 (Figure 2). For the Singapore catchment, we use Mike SHE (System Hydrologique European) which is an integrated physically based, distributed modelling system.

For the Hong Kong catchment, we use SWMM which is a lumped hydraulic model developed by U.S. Environmental Protection Agency. MIKESHE allows more accurate depiction of groundwater surface-water interactions (e.g., increase of infiltration, restoration of baseflow). However, SWMM can perform rigorous river routing with relatively less parameters.

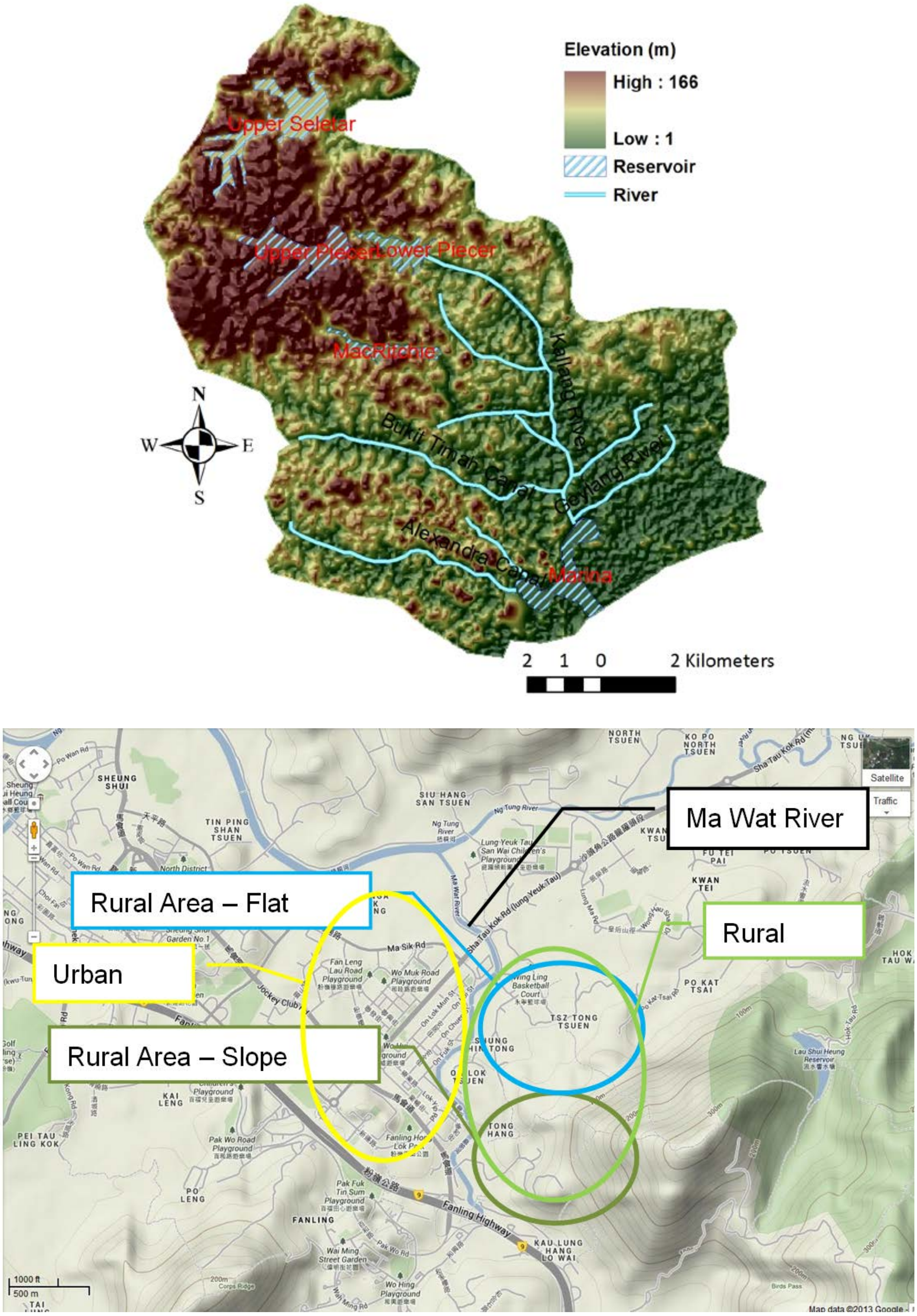

Figure 2: Study areas. Marina Catchment, Singapore (top) and Ma Wat River, Hong Kong (bottom)

3. RESULTS

In the Singapore case study, urbanization significantly increases the peak discharges of the storm events (Figure 3). Either green roofs or bioretention systems are effective in mitigating the peak discharges. They, however, require extensive retrofits, either converting 5% of the catchment area into bioretention systems, or converting the roofs of all the buildings which account for 14% of the catchment area. Furthermore, LID is particularly effective in the Singapore catchment on an average long term basis in reducing/delaying peak flow and restoring baseflow. However, its effectiveness in mitigating peak discharge decreases with the intensity of the storm. This is better illustrated in Figure 4 which shows the peak discharge reductions in the Hong Kong case study. The peak reduction decreases (i.e., LID not as effective) as the storm return period increases (i.e., larger storms). LID, unfortunately, is not effective in that particular Hong Kong catchment, mostly because there is a large undeveloped hillslope which accounts for 77% of the catchment area. LID is only implemented in the urban area, thus only reducing the urban area runoff which is however small compared to the total system runoff (Figure 5). Another reason is because only very limited space is available in the urban area for bioretention systems which are in general more effective than green roofs in retaining stormwater.

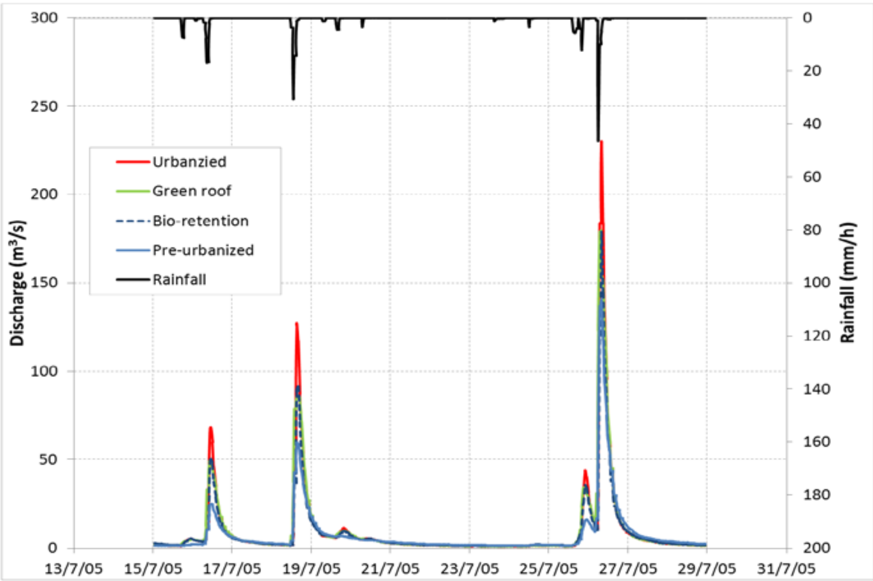

Figure 3: Catchment discharges of different scenarios of Marina Catchment

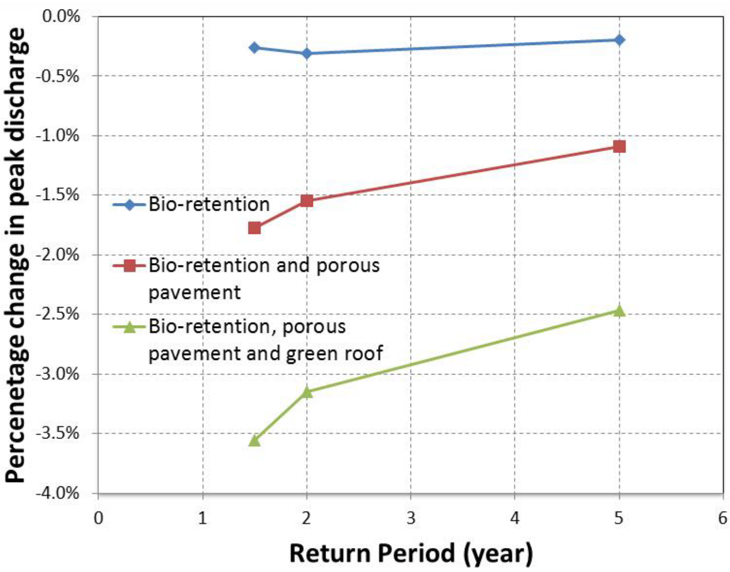

Figure 4: Peak discharge reduction of various scenarios and rainfall conditions

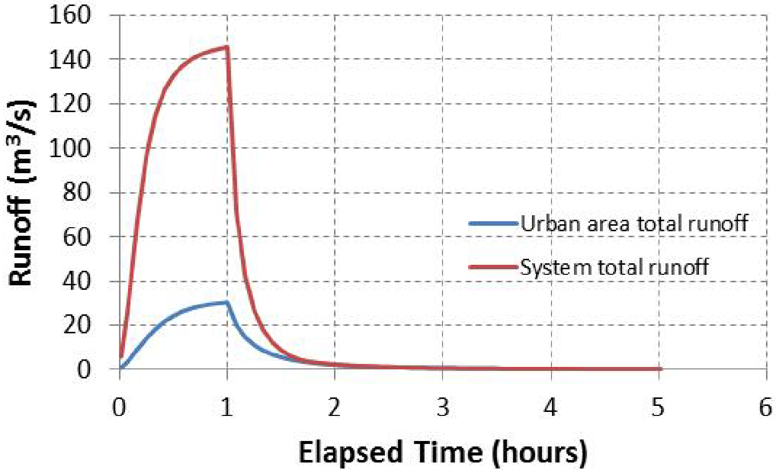

Figure 5: Runoff in Ma Wat Catchment during 2 year ARI

5. CONCLUSION

Only a catchment level of implementation is effective to mitigate peak discharge and restore baseflow. Such large-scale retrofits (e.g., covering 5 to 10% of catchment area) are challenging for urbanized areas due to existing constraints and infrastructures, and are more likely to be feasible in newly developing areas. Numerical modelling, both distributed and lumped hydrological models, facilitates the design of LID. The choice of modelling code depends on data availability and processes of interests (e.g., river routing for peak discharge mitigation, infiltration and groundwater recharge simulation for baseflow restoration). Overall, large-scale LID potentially provides more sustainable stormwater management but its success depends on factors such as design objectives, existing land uses and drainage networks. We should therefore further research to increase the feasibility of large-scale LID in highly urbanized areas such as Singapore and Hong Kong.

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