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Optimizing Bio-Retention Locations For Stormwater Management Using Genetic Algorithm

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OPTIMIZING BIO-RETENTION SYSTEM LOCATIONS FOR STORMWATER MANAGEMENT USING GENETIC ALGORITHM

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As part of stormwater best management practices, bio-retention systems have been applied in a number of developed countries to minimize the change of hydrological regime due to urbanization. Optimization techniques have also been applied to determine the locations that give the most hydrological benefits. However, optimization tools are commonly built in together with specific hydrological models, usually restricting the choices and components of hydrological models. Furthermore, it is redundant to build another hydrological model that has a built-in optimization tool if a hydrological model, and possibly more comprehensive one, has already been developed for the study area. The objective of this study is to develop a genetic algorithm (GA) that is independent from and can therefore be coupled with any existing integrated distributed hydrological model to optimize the locations of bio-retention systems. The GA is written in Visual Basic considering factors such as topography, distance from a river and groundwater table depth. The alternative combinations of bio-retention locations suggested by the GA are used as inputs of an integrated distributed hydrological model. The combination that gives the lowest outlet discharge is then regarded as the best solution. We demonstrate the approach by taking Marina catchment in Singapore as a case study and feeding the GA with results from MIKESHE. Overall, the GA developed is not only transferable to other study area but also can also be coupled with any hydrological model that is the most suitable for that particular case study.

INTRODUCTION

To minimize the change of hydrological regime due to urbanization, a number of developed countries have enforced stormwater best management practices in the past few decades. One approach is to implement small-scale hydrologic controls, such as bio-retention systems, throughout a catchment. However, the effectiveness of a bio-retention system, e.g., amount of rainfall collected, depends on its location in the catchment. Optimization techniques have been applied to determine the locations that give the most hydrological benefits. One of the optimization techniques is genetic algorithm (GA). During the last two decades, there has been a dramatic increase in the development and application of GA in water resources planning and management (Nicklow et al., 2009). It is proven to be flexible and powerful in solving an array of complex water resources problems such as reservoir operation (van Rooyen & van Vuuren, 2004), setting of water quality goals (Kaini et al., 2012), water quality monitoring network design (Park et al., 2006), and qualitative and quantitative control of urban runoff (Zare et al., 2012). However, optimization tools are commonly built in together with specific hydrological models. Thus, the choices and components of hydrological models are usually restricted. Furthermore, it is redundant to build another hydrological model that has a built-in optimization tool if a hydrological model, and possibly more comprehensive one, has already been developed for the study area. The objective of this study is to develop a GA that is independent from and can therefore be coupled with any existing integrated distributed hydrological model to optimize the locations of bio-retention systems. The GA is able to utilize results of any hydrological model, allowing users to simulate processes that are most relevant to their studies.

METHODOLOGY

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The optimization of this model has two parts: an integrated distributed hydrological model, Mike SHE, and a genetic algorithm (GA) written in Visual Basic. These two parts connect with each other by dynamic coupling. Figure 1 is the flow chart of the optimization model. In the beginning, the GA randomly generates one possible arrangement of bio-retention systems in the catchment. Two Mike SHE input files, affecting the soil and detention conditions of the catchment, are changed to incorporate the bio-retention system arrangement. These input files are then fed into Mike SHE for simulating a storm event. At the end of the simulation, the outlet peak discharge is extracted as the fitness function for the GA to create a new arrangement of bio-retention systems via GA operators such as Encoding and Decoding, Reproduction, Crossover, and Mutation, considering factors such as topography, distance from a river and groundwater table depth

The integrated distributed hydrological model is adapted from Trinh and Chui (2013). Bio-retention systems are implemented to mitigate the hydrological impacts of urbanization. The bio-retention accounts for 5% of the total catchment area. The bio-retention systems are modelled as soils with a higher hydraulic conductivity of 10^{-5} m/s, extending one meter below the ground. The systems are also equipped with 20 cm of detention ponding. Model is run for two days (from 7 – 9/12/2005) including a storm event on 8/12/2005 that has a rainfall depth of 60mm/h. The bio-retention system locations are optimized to minimize catchment peak outlet discharge.

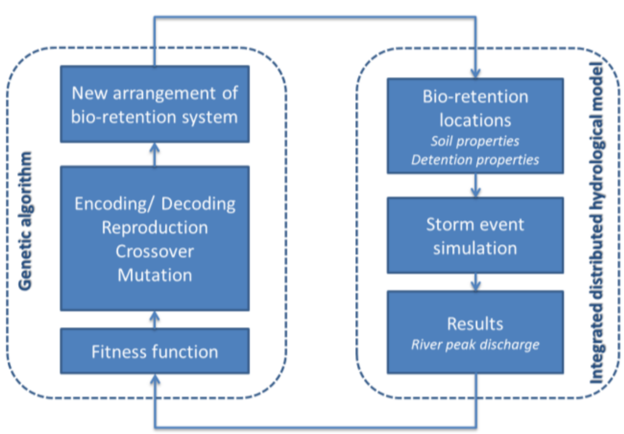

Figure 1 Flow chart of optimization model

RESULTS

Figure 2 shows two bio-retention arrangements from the optimization model. The arrangement on the left represents the "best" one while that on the right represents the random arrangement. When compared to the condition without the bio-retention systems (peak discharge of 444m^3/s), the case with random arrangement reduces the outlet peak discharge by 15%. The best arrangement reduces the peak discharge by 83 m^3/s (~20%) when compared to the one without bio-retention systems, and 13 m^3/s (~5%) when compared to the random arrangement. In both cases, bio-retention systems are not located in the nature reserve in the upper part of the catchment as they should not interfer non-urbanized areas. Compared to the random arrangement, bio-retention systems in the "best" arrangement are more concentrated along the river, especially Kallang River as demonstrated within the yellow circles in Figure 2. In addition, bio-retention systems within circle 1 suggests that the random bio-retention locations tend to be closer to each other and there are a numbers of bio-retention systems situated side-by-side; while they are more scattered in the "best" arrangement. Therefore, bio-retention systems might have better performances if they are well-distributed along a river. However, further study is needed to confirm this speculation. For bio-retention systems distributed along the Bukit Timah, Stamford and Alexanda canals, the arrangement are very similar in both cases.

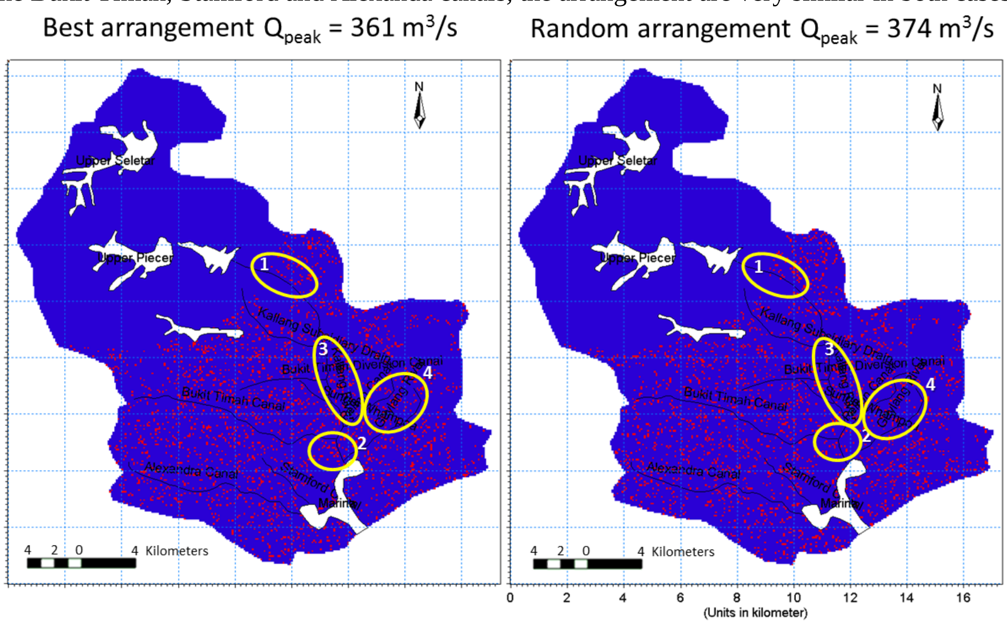

Figure 2 Bio-retention system arrangements (Red dots are the bio-retention systems)

CONCLUSION

This study proposed an optimization model to determine the best locations of bio-retention systems for stormwater management. The optimization model couples an integrated distributed hydrological model with a genetic algorithm model. Taking Marina catchment in Singapore as a case study, the results show that the "best" arrangement gives a peak discharge lower than that of a random arrangement. Overall, the GA developed is not only transferable to other study areas but also can be coupled with any hydrological model that is the most suitable for that particular case study.

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