Modelling and optimization of land use/land cover change in a developing urban catchment
Ping Xu, Fei Gao, Junchao He, Xinxin Ren and Weijin Xi

ABSTRACT

The impacts of land use/cover change (LUCC) on hydrological processes and water resources are mainly reflected in changes in runoff and pollutant variations. Low impact development (LID) technology is utilized as an effective strategy to control urban stormwater runoff and pollution in the urban catchment. In this study, the impact of LUCC on runoff and pollutants in an urbanizing catchment of Guang-Ming New District in Shenzhen, China, were quantified using a dynamic rainfall-runoff model with the EPA Storm Water Management Model (SWMM). Based on the simulations and observations, the main objectives of this study were: (1) to evaluate the catchment runoff and pollutant variations with LUCC, (2) to select and optimize the appropriate layout of LID in a planning scenario for reducing the growth of runoff and pollutants under LUCC, (3) to assess the optimal planning schemes for land use/cover. The results showed that compared to 2013, the runoff volume, peak flow and pollution load of suspended solids (SS), and chemical oxygen demand increased by 35.1%, 33.6% and 248.5%, and 54.5% respectively in a traditional planning scenario. The assessment result of optimal planning of land use showed that annual rainfall control of land use for an optimal planning scenario with LID technology was 65%, and SS pollutant load reduction efficiency 65.6%.

Key words | evaluation, LID, LUCC, optimization, SWMM

INTRODUCTION

With the rapid development of urbanization, impervious surface area has increased greatly, which leads to dramatic land use/cover change (LUC) and vegetation damage. Compared to the pre-development state, the main hydrological impacts were the increase in runoff volumes and peak flows and the decrease in rainwater infiltration and base flow (Shuster et al. 2005; Dietz & Clausen 2008; Du et al. 2012). This also increased associated pollutants, including the initial suspended solids (SS) and chemical oxygen demand (COD) pollutant load, resulting in severe water quality degradation. Low impact development (LID) practices have been mentioned as a promising strategy for urban stormwater runoff control, and pollution prevention under LUCC. For example, Sang-Soo Baek proposed optimization of the sizes of different types of LID to minimize the mass first flush by conducting intensive stormwater monitoring and numerical modeling on a commercial site in Korea (Baek et al. 2015). A combination of LID with the Storm Water Management Model (SWMM) was used to produce simulations for evaluating the hydrological impacts of LID and possibilities to restore the layout of land use via LID control in urban catchments (Alfredo et al. 2009; Jia et al. 2012). However, optimal planning research and comprehensive assessments of LID control under LUCC are particularly needed. Moreover, the simulation results for runoff and pollutant variations under LUCC will contribute to achieving optimal land use in urban planning.

In recent decades, hydrologic models have become increasingly important tools for the management of water resources (Sarkar & Kumar 2012; Shirke et al. 2012; Suliman et al. 2015). Most of the related studies have been carried out to evaluate urban runoff and pollutant variations and optimize management of LID facilities of future scenarios under LUCC (Deng et al. 2015; Guan et al. 2015; Yulianto et al. 2016). The SUSTAIN model was used to compare and analyze the two LID planning schemes, and the result showed that the optimization scheme was cost effective (Jia et al. 2014). Based on the NSGA-II algorithm, the multi-objective optimization method is proposed and simulated to test the optimal LID facilities design. The optimal scopes of LID facilities were defined with the simulation of the model (Zaremba et al. 2015). However, there are still
several limitations in these studies such as the complex randomness of NSGA-II, the uncertainty of the relevant parameter, and the limitations of models.

EPA SWMM is a dynamic rainfall-runoff simulation model used for single event or long-term (continuous) simulation of runoff quantity and quality from primarily urban areas. SWMM can provide the highest level of accuracy as detailed design tools. Compared with other models, the parameter calibration and model verification results of SWMM model are relatively mature. Therefore, to assess and optimize planning of LUCC, the SWMM model was tested and applied to produce a number of real and potential scenarios with the aid of the Matlab tool in this study. Based on the simulations and observations, the main objectives of this study were: (1) to evaluate the catchment runoff and pollutant variations with LUCC, (2) to select and optimize the appropriate layout of LID in a planning scenario for reducing the growth of runoff and pollutants under LUCC, (3) to assess the optimal planning schemes of land use/cover. The findings can be further utilized in the development of appropriate urban runoff management schemes for LUCC.

MATERIALS AND METHODS

Study site

Shenzhen is located in the south of China, lying in the southeast of Zhu Jiang Delta. The terrain character appears an overall trend of high in southeast and low in northwest. The city has a mild, subtropical maritime monsoon climate, the annual mean temperature is 23°C. The average annual precipitation is 1,935.8 mm, in which 86% of the precipitation falls from April to September. The average typhoon frequency is 4.8 times per year, which is usually accompanied with heavy storms or extraordinary rainstorm during the typhoon season.

Guang-Ming New District is located in the northwest of Shenzhen. In this study, the study area is the catchment area near Guang-Ming high-speed rail station of Guang-Ming New District, and has an area of approximately 1.8 km². Most of the present lands are in the undeveloped condition, the impervious area accounts for about 40%.

Data collection

Rainfall measurements

Three consecutive years’ rainfall events were measured (1-minute interval of rainfall) as the based rainfall data for the analysis of the SWMM model. The monitoring data were from JL-21 automatic recording rainfall gauge of the study area. The annual total precipitations were respectively 1,723 mm in 2012, 2,048 mm in 2013, and 1,795 mm in 2014, and the values could represent the typical rainfall situation of Shenzhen in recent years. Three consecutive years’ rainfall events are shown in Figure 1.

Initial SS and COD pollutant load measurements

The sampling point was at the outfall of the drainage system as shown in Figure 2. The samples were collected manually using polyethylene bottles, beginning at the initiation of a rain event and ending when the rainfall runoff had stopped or tended to become stable. Sampling intervals were 5 min in the first 30 min and 10 min in the period of 30 to 60 min and then 30 min afterwards. All samples were manually collected by researchers, complying with the instructions of

![Figure 1](https://iwaponline.com/wst/article-pdf/75/11/2527/453129/wst075112527.pdf)
Water Quality Sampling Technology Acquisition Methods (CEPA 2009). Samples of road runoff were collected at a rain grate by a Hach9000 pipe flow meter. After collection, the samples were immediately sent to the workstation laboratory, kept under 4°C, and the test completed within 24 hours. Collected samples were analyzed for SS (weight method), COD (rapid digestion and spectrophotometric method).

Design scenarios

On the basis of Guang-Ming New District of Shenzhen, the SWMM model was used to study different development scenarios for optimization of land use in the developing urban catchment.

(1) Land use of partially developed scenario (2013)

Under partially developed scenario (2013), most of the present land is in the undeveloped condition, mainly including bare land and green space. The developed areas are the high-speed rail station and square, high-tech industrial park and part of the municipal roads. LID facilities were set in two municipal roads, and the imperious area accounted for 40.6%. The LID facilities were located on the 36th road and 38th road near the high-speed rail station, with a total area of LID facilities of 6.36 ha. The LID facilities comprised open graded friction course (OGFC) road (motor vehicle and bicycle tracks), Porous Pavement (sidewalk) and Bioretention (green vegetation zones), the area accounted for 65%, 15% and 20% respectively.

(2) Land use in the traditional planning scenario

The land use will be complex after urban planning. The new planning area accounts for 77%, mainly including commercial, residential, industrial park, transport facilities, park, administrative office land, and education land. The impermeable area reached 62.3% in the traditional planning scenario. The schematic diagram of 2013 and urban planning land use are shown in Figure 2. (3) Land use in the optimal planning scenario

The optimization objectives were to achieve an annual mean runoff control effect of over 60% and reduction of the SS pollution load of over 40% compared to the traditional planning scenario. Based on the traditional planning scenario, the optimal planning scenario was optimized by selecting and applying different LID facilities in the study catchment.

Assessment and optimization approach

Target decomposition approach

To achieve the multiple objective requirements of the optimal planning scenario, the goals need to be decomposed into each type of construction project in the catchment. In the new areas, the planning LID facilities were combined with site development according to the comparative analysis of the traditional and target runoff coefficient and control methods (Wang et al. 2015). The specific control process is shown in Figure 3. In the built areas, reasonable layout of the LID combination facilities is achieved according to the practical engineering requirements for separate residential, commercial and industrial uses and/or the percentage mix of these uses.

The global optimal algorithm based on Matlab

To achieve the optimal index proportion values, this study listed the corresponding conditional equation and objective
function of the multi-objective linear function with the help of Matlab 8.0 (Matlab Inc., USA).

Reduction efficiency for runoff and pollutants

According to the following formula of reduction efficiency, the reduction efficiency for runoff and pollutants can be determined.

\[
\text{Reduction efficiency} \% \left( \frac{R_{\text{traditional scenario}}}{R_{\text{LID scenario}}} \times 100\% \right)
\]

Stormwater management model

The US EPA Stormwater Management Model (SWMM5.1008) (Lewis 2010) was selected to simulate and evaluate the urban hydrological impact of land use in the study catchment. In the hydrologic module of SWMM, the infiltration model employed the Horton model, whereas surface runoff was computed by Manning’s equation. This study selected the build-up and wash-off mechanism as the main model for water quality simulation. The simulated and measured runoff and pollutant variation trends are basically the same, and the simulated and measured peaks appear at the same time. The value of ENS was mostly above 0.77 and the value of \( R^2 \) was between 0.65–0.99, which means a high simulation accuracy for this model. The specific calibration results for the SWMM model parameters in this catchment were reported in a previous study (Ping et al. 2016), and the external input parameters and data sources are shown in Table 1.

The selection of LID facilities

Common LID facilities include Porous Pavements, grassed depressions, rain gardens, green roofs, vegetative swales and gravel systems etc. In order to intuitively reflect the runoff and pollutant control effectiveness of LID facilities, the planning scenarios model selected six kinds of LID facilities for new areas based on the control mechanism, control efficiency, the construction conditions and costs. By analyzing the performance efficiency of all types of facilities, they were applied according to the following conditions:

1. In order to guarantee the basic objective conditions during the simulation, the area and the location of grassed depressions and rain gardens, vegetative swales and gravel systems should be the same.
2. The coverage area of green roofs, porous pavements, grassed depressions and rain gardens should be designed according to region types (construction area, road and square, green) in the optimal scenario, whereas vegetative swales and gravel systems were applied according to the empirical values (10% of the total area).
3. Grassed depressions and rain gardens were simulated with the assumption that the rainwater from an impervious roof flowed into the nearest grassed depression and rain garden. The impervious roof was shown by the control ratios of runoff pollution in SWMM. Vegetative swales beside the roads and gravel systems in parking areas were shown in the same way.

RESULTS AND DISCUSSION

Runoff and pollutant variations of LUCC

To evaluate the runoff and pollutant variation in different development scenarios, the simulation result for rainfall-runoff variation of the partially developed scenario (2013) and traditional planning scenario are presented in Table 2.

According to Table 2, under the condition of annual mean precipitation of 1,855.2 mm and rainfall duration of 125 days, compared with the partially developed scenario (2013) and traditional planning scenario, the impervious area increased by 21.7% under LUCC, leading to annual mean runoff increasing by 529.6 mm, and the evaporation rate increasing by 62.0%, and the infiltration rate decreasing...
by 39.1%. The results showed that the corresponding rainfall runoff increased because of strong evapotranspiration and soil infiltration losses under the increased impervious area of LUCC. Under the conditions in the traditional planning scenario, the runoff-precipitation R–P ratio was raised by 45.0% in comparison to that in 2013, which clearly implied that annual mean runoff control effectiveness decreased with the increase in the impervious area under LUCC.

Compared with 2013 and the traditional planning scenario, the runoff volume, peak flow and total pollution load of SS, and COD increased by 35.1%, 33.6% and 248.5%, and 54.5% respectively. This is clearly explained by the low degree of urbanization development in 2013, whereby the rainwater under light rainfall was absorbed and purified by nearly 61% of the undeveloped land as bare land and grassed depressions through retention, infiltration and storage. Moreover, it was also observed that pollutant variations had a quicker response to hydrology in an urbanized catchment under LUCC.

The ‘flow–frequency’ curves (Fennessey et al. 2001) were calculated from long-term simulations of annual rainfall periods during 2012–2014, which visualized the changes in flow regimes both for extreme events and low flows, as shown in Figure 4.

According to Figure 4, from 2013 to the traditional planning scenario, it could be seen that the impervious area increased from 40.6% to 60.6%, which resulted in increasing runoff volumes, and the low-frequency high flow and the high-frequency low flow were increased. This revealed that the urban development results in a flashy effect on the flow–frequency curve. Compared with 2013, the low frequency high flow of the traditional planning scenario increased considerably, whereas the high-frequency low flow increased weakly. It was suggested that the changes in the low-frequency high flow are mainly affected by the impervious area, which also explained that LUCC can be the main influencing factor for hydrology changes in a developing urban catchment.

### Optimization of the layout of land use/cover

#### Target decomposition of land use/cover

According to planning requirements, the catchment was divided into 18 land use types, including new and existing areas. The total building density and total rate of green space were 13.8% and 37.0% respectively. According to the control index of target decomposition, the goal was decomposed to every type of land use in the form of the R–P ratios, and LID technology was applied to the site facilities for the goal of land use types. Combined with site

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**Table 1** External input parameters and data sources of SWMM model

<table>
<thead>
<tr>
<th>External data input</th>
<th>Data description</th>
<th>Data source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Map of land use type</td>
<td>Roof, pavement, greenbelt etc.</td>
<td>Map of Google Earth, satellite imaging, CAD map of plane layout</td>
</tr>
<tr>
<td>Information explanation of land use type</td>
<td>Table of attribute data (parcel area, rate of impervious area etc.)</td>
<td>Basic data of specific planning</td>
</tr>
<tr>
<td>Map of digital topographic</td>
<td>DEM (elevation and slope of plots)</td>
<td>Information extraction of CAD map, GIS management</td>
</tr>
<tr>
<td>Data of soil type</td>
<td>Soil properties, penetration rate etc.</td>
<td>Field test</td>
</tr>
<tr>
<td>Division map of catchment area</td>
<td>Dividing catchment area by using plot elevation and flow direction</td>
<td>Satellite imaging, CAD map of rainwater drainage system</td>
</tr>
<tr>
<td>Layout map of storm sewer system</td>
<td>Length, slope, diameter of pipeline and elevation, placing depth of inspection well etc.</td>
<td>CAD map of rainwater drainage system</td>
</tr>
</tbody>
</table>

**Table 2** Results contrast of system simulation in partially developed scenario (2013) and traditional planning scenario

<table>
<thead>
<tr>
<th>Simulation results</th>
<th>Observed_2013</th>
<th>Traditional planning scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual mean precipitation (mm)</td>
<td>1,855.2</td>
<td>1,855.2</td>
</tr>
<tr>
<td>Annual mean rainfall duration (d)</td>
<td>125</td>
<td>125</td>
</tr>
<tr>
<td>Annual mean runoff (mm)</td>
<td>751.0</td>
<td>1,080.6</td>
</tr>
<tr>
<td>Annual mean evaporation (mm)</td>
<td>100.9</td>
<td>163.5</td>
</tr>
<tr>
<td>Annual mean infiltration (%)</td>
<td>1,005.3</td>
<td>611.1</td>
</tr>
<tr>
<td>Runoff–precipitation ratio (R–P ratio)</td>
<td>0.4</td>
<td>0.58</td>
</tr>
<tr>
<td>Peak flow (m³/s)</td>
<td>49.3</td>
<td>66.6</td>
</tr>
<tr>
<td>Annual mean runoff volume (10³m³)</td>
<td>1,295.8</td>
<td>1,949.8</td>
</tr>
<tr>
<td>Annual mean SS pollutant load (t)</td>
<td>148.9</td>
<td>519.4</td>
</tr>
<tr>
<td>Annual mean COD pollutant load (t)</td>
<td>35.4</td>
<td>54.7</td>
</tr>
</tbody>
</table>
development, LID facilities of planning control were simulated by controlling the proportions of grassed depressions, green roofs, permeable pavements and runoff pollution from impervious areas. The analysis results of target decomposition in this catchment are presented in Figure 5.

In order to intuitively reflect the runoff and pollutant control effectiveness of LID facilities, the runoff volume, peak flow, SS and COD pollutants load of porous pavements, grassed depressions, rain gardens, green roofs, vegetative swales and gravel systems were simulated according to the various conditions of the facilities’ layout. Simulation results are shown in Table 3.

According to Table 3, under the same layout conditions of LID facilities, the control effectiveness of rain gardens was significantly higher than grassed depressions. The reduction effectiveness of rain gardens on the peak flow and total runoff volume was 1.9 times and 1.2 times the reduction effectiveness of grassed depressions, respectively, yet the reduction effectiveness of both on SS and COD pollutant loads was similar. As auxiliary facilities, the reduction effectiveness of vegetative swales and gravel systems on the peak flow and total runoff volume were similar, while both had the effect of peak clipping and conveying runoff. For curtailing SS and COD, vegetative swales were obviously superior to gravel systems. Through comparative analysis of all kinds of facilities' reduction efficiency per unit area, the degree of control efficiency in the widely used facilities was rain garden > grassed depression > permeable pavement > green roof. Of the auxiliary facilities, vegetative swales were superior to gravel systems. Therefore, for the new land use of the planning catchment, combined with the feature of space, the main facilities selected were rain gardens, grassed depressions, permeable pavements and green roofs. Vegetative swales were selected as the auxiliary facility for traditional road runoff.

Optimization of planning land use/cover

Optimization of new land use

To achieve the control index of target decomposition of land use, over 40% reduction of the SS pollution load of the

![Figure 4](https://iwaponline.com/wst/article-pdf/75/11/2527/453129/wst075112527.pdf)

**Figure 4** Flow frequency curve for the partially developed scenario 2013 and traditional planning scenario in long-term simulations of annual rainfall. (a) 2012, (b) 2013, (c) 2014.

![Figure 5](https://iwaponline.com/wst/article-pdf/75/11/2527/453129/wst075112527.pdf)

**Figure 5** Target decomposition of land use/cover for the optimal planning catchment by the R-P ratios of traditional and optimal planning scenarios. (a) Traditional planning scenario, (b) optimal planning scenario.
traditional scenario in the planning catchment, and maximizing the reduction rate of the peak flow and COD pollution load, while minimizing total cost requirements, the global optimal algorithm was used to solve the multi-objective linear function for the optimal value of the corresponding index, with the aid of the Matlab tool.

Function variables: green roof area was \( x(1) \), permeable pavement area was \( x(2) \), grassed depression was \( x(3) \), rain garden area was \( x(4) \), Vegetative Swale area was \( x(5) \); peak flow reduction per unit was \( a_{11}, a_{12}, a_{13}, a_{14} \) and \( a_{15} \) respectively; runoff volume reduction per unit area was \( a_{21}, a_{22}, a_{23}, a_{24} \) and \( a_{25} \) respectively; SS pollutant load per unit area was \( a_{31}, a_{32}, a_{33}, a_{34} \) and \( a_{35} \) respectively; COD pollutant load per unit area was \( a_{41}, a_{42}, a_{43}, a_{44} \) and \( a_{45} \) respectively; and cost price per unit area was \( a_{51}, a_{52}, a_{53}, a_{54} \) and \( a_{55} \) respectively. According to the practical engineering survey, the cost price per unit area of LID facilities was 150, 50, 400, 200 and 100 Yuan/m² respectively.

The multi-objective linear function of the corresponding objective function value, condition equation and the independent variable scope are shown as follows:

(1) Objective function equation

Peak flow reduction equation:
\[
Maxf(x) = a_{11}x(1) + a_{12}x(2) + a_{13}x(3) + a_{14}x(4) + a_{15}x(5)
\]

COD pollutant load reduction function:
\[
Maxf(x) = a_{41}x(1) + a_{42}x(2) + a_{43}x(3) + a_{44}x(4) + a_{45}x(5)
\]

Cost function:
\[
Minf(x) = a_{51}x(1) + a_{52}x(2) + a_{53}x(3) + a_{54}x(4) + a_{55}x(5)
\]

(2) Condition equation

Total runoff volume reduction equation:
\[
a_{21}x(1) + a_{22}x(2) + a_{23}x(3) + a_{24}x(4) + a_{25}x(5)
\]

(3) Independent variable scope

With the aid of the Matlab tool, the independent variable scope, condition equation and objective function were transformed into Matlab programming data. The global optimal algorithm was used to solve multi-objective linear function optimal solutions, and the optimal proportions of the following index are shown in Table 4.

Optimization of existing land use

Due to the limitations of construction, existing land use of the urban area can be used for water storage facilities and grassed space facilities to reduce the cost as much as possible.

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Table 3 | Results contrast for runoff and pollutant control effectiveness of LID facilities in planning catchment

<table>
<thead>
<tr>
<th>Comparison parameters</th>
<th>Porous pavement</th>
<th>Grassed depression</th>
<th>Rain garden</th>
<th>Green roof</th>
<th>Vegetative swale</th>
<th>Gravel system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precipitation (mm)</td>
<td>5,565.7</td>
<td>5,565.7</td>
<td>5,565.7</td>
<td>5,565.7</td>
<td>5,565.7</td>
<td>5,565.7</td>
</tr>
<tr>
<td>Peak reduction per unit area ( (10^{-5} \text{m}^3/\text{s/m}^2) )</td>
<td>0.5</td>
<td>4.0</td>
<td>7.5</td>
<td>4.7</td>
<td>8.0</td>
<td>7.8</td>
</tr>
<tr>
<td>Runoff reduction per unit area ( (\text{m}^3/\text{m}^2) )</td>
<td>3.5</td>
<td>4.5</td>
<td>5.6</td>
<td>1.6</td>
<td>0.1</td>
<td>0.6</td>
</tr>
<tr>
<td>SS pollutant load per unit area ( (\text{kg/m}^2) )</td>
<td>1.7</td>
<td>2.0</td>
<td>2.1</td>
<td>1.6</td>
<td>4.2</td>
<td>3.6</td>
</tr>
<tr>
<td>COD pollutant load per unit area ( (\text{kg/m}^2) )</td>
<td>0.12</td>
<td>0.17</td>
<td>0.19</td>
<td>0.15</td>
<td>0.26</td>
<td>0.08</td>
</tr>
</tbody>
</table>

\[ \geq \text{total precipitation} \times \text{total area} \times \left( \text{(traditional} - \text{target)} \right) R - P \]
(1) Existing industrial land

Due to the limitations of construction, combination facilities of grassed depressions, rain gardens and storage modules were applied in the established industrial zone. Subsidence ratios of grassed depressions were selected according to the ratio values of the new industrial land use. For 1,000 m² of impervious roof, the corresponding layout was of 30 m³ of storage module (Zhai et al. 2014), storage module was applied for impervious roofs.

(2) Existing high-speed station

Because of the large impervious area of the high-speed station, infiltration facility, rain garden and storage module were used in processing the rainwater of the land station.

Optimization of municipal planning roads

According to the optimized LID combination facilities, OGFC, Porous Pavement and Bioretention were applied in the municipal planning roads.

Form the optimal planning of land use/cover. Through the optimization study of the new and existing area, the optimal planning scheme for the study area is presented in Figure 6.

The statistics showed that the area of LID facilities was 66.5 ha, accounting for 36.9% of the total area of the study catchment. Among them, the area of municipal planning roads was 16.6 ha, accounting for 36.9% of the total area; squares, parking for new areas and park roads were planned to use permeable pavement, which covered an area of 24 ha, accounting for 13.3%. Considering vehicle traffic, traditional impermeable pavement was applied in the main roads in the new areas, and 1.6 m wide vegetative swales were applied to both sides of the street, covering an area of 2.85 ha, and accounting for 1.6%. For rainwater collection, retention and transport, grassed depressions and rain gardens were applied in 25% of public green space, which covered 9.8 ha and 6.8 ha respectively, accounting for 9.2%. And 3.6% of the total area was planned for green roofs. The storage module was applied to a volume of 1,300 m³ of impervious roof and high-speed square, which can collect rainwater recycling to the fullest.

Assessment of optimal planning scheme of land use/cover

To assess the impact of runoff and pollutants in the optimal planning catchment, comparing simulation results of the traditional planning scenario, the assessment results for optimal planning scenario are presented in Table 5.

According to Table 5, the annual mean runoff control effect of the optimal planning scenario was 65%, which met the requirements of the planning target and increased by 23% compared with the traditional scenario. Compared with the traditional scenario in the study catchment, the reduction efficiency of peak flow, runoff volume, SS pollutant load and COD pollutant load of the optimal planning scenario were 34.1%, 39.4%, 65.6% and 55.3% respectively. Moreover, the degree of reduction effectiveness of LID facilities for optimal planning catchment was SS pollutant load > COD pollutant load > runoff volume > peak flow. In addition, the annual mean total SS reduction could satisfy the requirements of the planning target for over 40%. It is also observed that the optimal planning scheme was in accordance with the best effects and costs for the planning objectives, which could provide a reference for the planning of Guang-Ming New District of Shenzhen city.

<table>
<thead>
<tr>
<th>Control indicators</th>
<th>Types of facilities</th>
<th>Residence</th>
<th>Commerce</th>
<th>Mixed residence and commerce</th>
<th>Industry</th>
<th>Public buildings</th>
<th>Square, parking</th>
<th>Park</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subsidence ratio of green land (%)</td>
<td>Grassed depression</td>
<td>50</td>
<td>30</td>
<td>20</td>
<td>30</td>
<td>25</td>
<td>15</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Rain garden</td>
<td>0</td>
<td>20</td>
<td>25</td>
<td>20</td>
<td>25</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Vegetative swale</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Covering ratio of green roof (%)</td>
<td>Green roof</td>
<td>–</td>
<td>30</td>
<td>25</td>
<td>20</td>
<td>25</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Ratio of porous pavement (%)</td>
<td>Porous pavement</td>
<td>70</td>
<td>90</td>
<td>70</td>
<td>65</td>
<td>70</td>
<td>50</td>
<td>60</td>
</tr>
<tr>
<td>Surface runoff control proportion of impervious underlying (%)</td>
<td></td>
<td>60</td>
<td>40</td>
<td>40</td>
<td>50</td>
<td>40</td>
<td>80</td>
<td>100</td>
</tr>
</tbody>
</table>

Table 4 | Optimal values of control indicators of LID facilities in new areas of the planning catchment
To assess the effectiveness of each LID facility in the optimal planning catchment, simulation contrasts of runoff control effectiveness are presented in Table 6 and Figure 7.

According to Table 6 and Figure 7, the order of per unit area of runoff control effect of LID facilities in planning lands in the study area was rain garden > grassed depression > bioretention > permeable pavement > green roof > water module > vegetative swale > OGFC. Among them, surface facilities such as rain gardens and permeable pavements performed better in runoff control due to the layer structure of the facility itself for retention, accumulation and infiltration. Surface facilities only relied on their own storage function, which was not better than the surface facilities above. Vegetative swales and OGFC (culvert emissions) were similar to the linear facilities, which had larger transmission characteristics. However, the retention and accumulation abilities of the facilities were weak, mainly using surface infiltration for runoff control. It is observed that the effects of similar types of facilities were quite different, such as the control effects of rain gardens and bioretention systems influenced

<p>| Table 5 | Simulation results of optimal planning scenario |</p>
<table>
<thead>
<tr>
<th>Simulation results</th>
<th>Optimal planning scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precipitation (mm)</td>
<td>5,565.7</td>
</tr>
<tr>
<td>Annual mean runoff control effect (%)</td>
<td>65</td>
</tr>
<tr>
<td>Peak flow reduction efficiency (%)</td>
<td>34.1</td>
</tr>
<tr>
<td>Runoff volume reduction efficiency (%)</td>
<td>39.4</td>
</tr>
<tr>
<td>SS pollutant load reduction efficiency (%)</td>
<td>65.6</td>
</tr>
<tr>
<td>COD pollutant load reduction efficiency (%)</td>
<td>55.3</td>
</tr>
</tbody>
</table>

<p>| Table 6 | Results contrast of runoff control simulation of each LID facility in planning catchment |</p>
<table>
<thead>
<tr>
<th>LID facilities</th>
<th>Annual mean runoff control (m³)</th>
<th>Area (m²)</th>
<th>Runoff control per unit area (m³/m²/y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green roof</td>
<td>48,502</td>
<td>64,179</td>
<td>0.756</td>
</tr>
<tr>
<td>Porous pavement</td>
<td>446,176</td>
<td>264,619</td>
<td>1.686</td>
</tr>
<tr>
<td>OGFC</td>
<td>25,856</td>
<td>99,913</td>
<td>0.259</td>
</tr>
<tr>
<td>Bioretention</td>
<td>92,213</td>
<td>41,631</td>
<td>2.215</td>
</tr>
<tr>
<td>Grassed depression</td>
<td>243,907</td>
<td>97,921</td>
<td>2.491</td>
</tr>
<tr>
<td>Rain garden</td>
<td>286,625</td>
<td>68,014</td>
<td>4.214</td>
</tr>
<tr>
<td>Vegetative swale</td>
<td>14,254</td>
<td>28,500</td>
<td>0.500</td>
</tr>
<tr>
<td>Storage module</td>
<td>433</td>
<td>650</td>
<td>0.666</td>
</tr>
</tbody>
</table>
by the site characteristics and confluence situation (Hsieh & Davis 2005; Brown & Hunt 2011).

Among planning LID facilities, permeable pavements were the largest contributor to the amount of annual runoff control, accounting for 38.53%, followed by rain gardens and grassed depressions, at 24.75% and 21.06%, respectively. It is suggested that characteristics of land use should be considered to choose different collocation function facilities for the optimal scheme.

CONCLUSIONS

Runoff and pollutant variations of LUCC were simulated using the SWMM model in this study. Three consecutive years of rainfall events (1-minute interval of rainfall) were measured as the base rainfall data for the analysis of the SWMM model. Results indicated that runoff control effectiveness decreased with an increase in impervious area, and water quality change has a quicker response to hydrology in an urbanized catchment under LUCC. LUCC was the main influencing factor for hydrology and water quality changes in a developing catchment.

For optimizing the layout of land use/cover with LID control in the planning catchment, the global optimal algorithm was used to solve a multi-objective linear function for the optimal value of the corresponding index, with the aid of the Matlab tool. It is concluded that for a planning scheme with LID facilities, the main layout of the new area was green roofs, permeable pavements, grassed depressions and rain gardens, the auxiliary of vegetative swales was applied to the main road. The result of assessment of the optimal planning of land use shows that annual rainfall control of land use for optimal planning scenarios with LID technology was 65%, and SS pollutant load reduction efficiency was 65.6%, which could meet the requirements for target decomposition. It is suggested that the characteristics of land use should be considered in choosing different collocation function facilities for the optimal scheme.

The modelling result of LUCC in this study enables decision makers and natural resource managers to forecast the effects of potential changes in the developing urban catchment. The outputs of optimization can be further utilized in achieving improved LUCC for local urban planning. Nevertheless, the model has a number of limitations. For example, the study spatial scale was only 1.8 km². Thus, in the future, research can be suggested and recommended to study different spatial scales so that future land use/cover types will be reflected more realistically.

REFERENCES


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