Design of Rainwater Management System for Eco-Housing Complex

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Abstract

Recently, rainwater management is considered as an essential means for recovering natural hydrological cycles in urban area. However, a lack of technical knowledge on the design of rainwater management system has been identified as a major hurdle preventing widespread application of rainwater management. This study focused on the application of design methods for rainwater management system. A model was developed and used to estimate the changes in runoff under various scenarios of rainwater management. The simulation results indicate that the surface runoff increases three times after the construction of the housing complex without rainwater management. It is also demonstrated that rainwater management with capacity of storage and infiltration could recover the distorted water cycle due to urban construction. A process for rainwater treatment consisting of first flush treatment and metal membrane/cartridge filter was suggested for use in the housing complex.

Keywords: Rainwater management, Urban water cycle, Design, Software, Simulation

Introduction

Rainwater management, which is regarded as one of the best available ways for sustainable urban development, is effective to recover natural hydrological cycles in urban area (Kim, Lee et al. 2003). Rainwater management not only allows an effective control of stormwater runoff by storing and infiltrating rainwater (Fewkes 1999) but also aids the control of non-point source pollution in urban areas. Moreover, rainwater management systems provide a source of ongoing water supply and reduce reliance on other water sources (Bambrah 1993; Herrmann and Hasse 1998).

However, a lack of technical knowledge on the design of rainwater management system has been identified as one of the primary factors preventing widespread adoption of rainwater management in urban area (Kim, Lee et al. 2004). Since the effectiveness of rainwater management system high depends on various factors including climate conditions, geographic information, water usage patterns, urban structure, and the major purpose of rainwater management, it is generally difficult to design rainwater management system with high efficiency and low cost. Moreover, different models may be required depending on the types of rainwater management.

This study focused on the application of design methods for rainwater management system. A model specially developed for rainwater management was used to estimate the water balance in a region where a housing complex is being constructed. The impact of housing complex construction and the effectiveness of rainwater management were theoretically examined using the model.

Materials and Methods

We developed a model for the design of rainwater management facilities in buildings and housing complex. This software calculates of water balance before and after the construction of buildings and roads based on daily input and out of water in the region. As shown in Figure 1, the water balance for a region of interest is:
\[ Q_R + Q_T = Q_E + Q_I + Q_S \]  \hspace{1cm} (1)

where \( Q_R \) is the daily flow rate of input water by rainfall; \( Q_T \) is the daily supply of tap water; \( Q_E \) is the rate of evaporation; \( Q_I \) is the rate of infiltration; and \( Q_S \) is the rate of surface runoff. \( Q_R \) was calculated using the measurement data for rainfall. The water cycle index (WCI), which implies the soundness of water cycle, is defined as:

\[ WCI = \frac{Q_E + Q_I}{Q_R} \]  \hspace{1cm} (2)

The model allows considering the impact of rainwater management equipments (storage tank, infiltration device, utilization systems) on the water balance in a region.

![Water balance diagram](image)

**Figure 1** Water balance in buildings and housing complex.

Our design method based on the software was applied to a region where a housing complex was planned to be constructed. The study area was located at Jukgok, Daegu in Korea. The total area was 65,214 m² and the area for buildings and apartments was 9,953 m². The estimated number of person who would live in this region was approximately 4,000. Table 1 summarizes the specifications for the housing complex in this study.

**Table 1** Summary of Daegu Jukgok housing complex

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total area (m²)</td>
<td>65,214</td>
</tr>
<tr>
<td>Area for buildings (m²)</td>
<td>9,953</td>
</tr>
<tr>
<td>Ratio of buildings to total area (%)</td>
<td>15.3</td>
</tr>
<tr>
<td>Facilities</td>
<td>Apartments and supporting facilities</td>
</tr>
<tr>
<td>Estimated residents</td>
<td>Approximately 4,000</td>
</tr>
</tbody>
</table>
Results and discussion

Calculation of water cycle before and after building rainwater management facility

The basic objective of rainwater management is to recover water cycle after urban development. Thus, the changes in water cycle before and after the construction of urban infrastructures were estimated as a measure to quantify the deviation from natural status. Moreover, the effect of rainwater management on water cycle was also estimated. Figure 2 compares the water cycles before the construction of the housing complex and after the construction without/with rainwater management.

![Flow rate comparison](chart.png)

**Figure 2** Calculation of water cycle before development, after development, and after building rainwater management facility (a) Before construction (b) After construction (c) With rainwater management (storage tank = 180 m³; infiltration = 2.7 m³/hr) (d) With rainwater management (storage tank = 180 m³; infiltration = 3.2 m³/hr)
As shown in Figure 2, the average of surface runoff before developing the housing complex is 62.72 m$^3$/day, which corresponds to 20% of total water inflow. After the development, the average surface runoff increases up to 188.27 m$^3$/day, which is approximately 3 times larger than the original value. Moreover, the amounts of infiltration and evaporation decrease from 225.8 m$^3$/day to 108.5 m$^3$/day and from 25.1 m$^3$/day to 16.8 m$^3$/day, respectively. Increased surface runoff may increase the possibility of urban flood whereas reduced infiltration may cause harmful effect on underground environment.

Introducing the rainwater management facilities helps to solve these problems. In Figure 2(a), the water cycle after building a storage tank (180 m$^3$) and infiltration system (2.7 m$^3$/hr) was presented as an example. The average surface runoff with rainwater management is 97.38 m$^3$/day, which is approximately a half of the runoff without rainwater management. Tap water supply is reduced by 65 % and infiltration increases by 92 %. Moreover, an increase in infiltration capacity cuts off the surface runoff to the level of original condition (before development), as shown in Figure 2(b). These results suggest that the size and capacity of rainwater management equipments should be determined by considering their impact on water cycle.

**Calculation of water cycle before and after building rainwater management facility**

Table 2 compares surface runoff and $WCI$ before constructing the housing complex and after constructing the housing complex without/with rainwater management. The surface runoff increased up to 200 % after constructing the housing complex without rainwater management. This may be reduced to the original level by introducing a rainwater management facility having a 180 m$^3$ of storage tank and an infiltration device with a capacity of 3.2 m$^3$/hr. $WCI$ before the construction of the housing complex is estimated to be 0.8 and decreased to 0.4 after the construction. Rainwater management increased $WCI$ to 0.6 ~ 0.7, which approaches its original value. In addition, the tap water saving after rainwater management is about 26 %, which corresponds to 65% saving.

**Table 2** Comparison of surface runoff, water cycle index, and tap water saving for different cases

<table>
<thead>
<tr>
<th></th>
<th>Before construction</th>
<th>After construction</th>
<th>With rainwater management (storage = 180 m$^3$; infiltration = 2.7 m$^3$/hr)</th>
<th>With rainwater management (storage = 180 m$^3$; infiltration = 3.2 m$^3$/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increase in surface runoff (m$^3$/day)</td>
<td>-</td>
<td>125.5 (+200%)</td>
<td>34.7 (+55%)</td>
<td>0 (0%)</td>
</tr>
<tr>
<td>Water cycle index ($WCI$)</td>
<td>0.8</td>
<td>0.40</td>
<td>0.61</td>
<td>0.72</td>
</tr>
<tr>
<td>Tap water Saving (m$^3$/day)</td>
<td>-</td>
<td>0 (0%)</td>
<td>25.9 (64.9%)</td>
<td>25.9 (64.9%)</td>
</tr>
</tbody>
</table>

**Process Configuration for Rainwater Management**

For rainwater management, not only water cycle but also water quality should be considered (Kim, Lee et al. 2004). Thus, different options of rainwater treatment were
compared in terms of treated water quality and operation/maintenance cost. Figure 3 shows the suggested process configuration for rainwater management. Treatment of first flush rainwater is found to be essential to prevent contamination of stored rainwater. Metal membrane and cartridge filter are applied to meet the target water quality for toilet flushing and cleaning. Novel materials such as surface-modified fiber filter media and foamed plastic particles are considered to remove trace pollutants such as heavy metals and toxic organics.

**Figure 3** Process configuration for rainwater management in Jukgok housing complex.

**Conclusions**

In this work, new methods and techniques for designing rainwater management system based on a simulation model were demonstrated for a region where a large-scale housing complex was planned to be constructed. The model allowed calculating water cycle before and after the construction and was found to be useful for optimum design of rainwater management systems.

**Acknowledgements**

This research was supported in part by a research grant entitled “Basic research projects: Development of Eco-materials to Improve Environmental Properties of Paved Surface” and in part by a grant entitled “Practical application of rainwater storage and utilization” from Sustainable Water Resources Research Center (SWRRC) of 21st century frontier R&D program.
References


