Improvement of urban flood damage estimation using a high-resolution digital terrain

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Abstract
Because urban flooding occurs frequently, it is important to calculate the areal extent of flooding based on flood volumes and water levels, and thus, the extent of expected damage can be effectively estimated. In this study, urban inundation from heavy rainfall and the contribution of topographic scales to urban river drainage basins in Seoul, Korea are simulated. A light detection and ranging (LiDAR)-based 1 × 1 m digital elevation model (DEM) and a 1:5,000 digital map-based 10 × 10 m DEM are used in this study for the storm water management model (SWMM). Using a multi-dimensional flood damage analysis to estimate economic damage, the asset value of each building type is analyzed in connection with the construction cost of buildings, household ratio, and building area, and then, the building damage is calculated at each flood level based on the percentage of building damage. Based on the analysis, 119.6 and 55.8 M USD in damages are expected to occur according to the 1 and 10 m DEMs, respectively. The results of this study can be used to evaluate alternatives for urban flooding mitigation and an optimal mitigation measure can be suggested among the alternatives because the methods used for predicting floods are examined and the associated damages are accurately estimated using digital terrain data at precise scales.

KEYWORDS
basin, disaster management, drainage, flood damage

1 | INTRODUCTION

Actual flood damages vary according to regional characteristics. The difference between urban and rural areas leads to different types of flooding, and it is extremely difficult to predict flood damage in a city with high densities of people and buildings. In Korea, many floods occur in cities, and various cases of flood damage caused by heavy rainfall are reported in major urban areas. In cities, forests and grasslands, slowing runoff and increasing infiltration are converted into houses and roads. Therefore, the impervious area increases, the peak runoff rises, and the runoff time shortens, which increases the risk of flood damage from a short period of heavy rainfall. When urban areas are flooded, the extent of damages depends on both the rainfall and installed inner basin drainage facilities. In this context, flood control projects that reflect regional characteristics should be prioritized to protect human lives and properties. An analysis of the damage reduction and economic effectiveness of installing flood control facilities serves as an important reference for evaluating the efficiency and feasibility of a project.

The accurate prediction of floods in urban areas is required to estimate the amount of damage that will arise. A runoff analysis should consider all topographic features,
including drainage basin slope, surface topography, and buildings. In particular, a runoff analysis that precisely considers topographic scales is required for urban areas where the population is densely concentrated, and the building and road networks are very complex. When a heavy downpour occurs in an urban area, the rainwater flows along roads and flooding also moves along the road slope. A runoff analysis that does not consider such detailed topographic features could under or overestimate the predicted flood area, leading to results that do not properly reflect the flood level. If such an error is made in urban areas, where roads and buildings are densely located, a flood could occur in an unexpected area, resulting in human life and damage to property. Accordingly, a runoff analysis using more detailed and accurate topographic data is needed for urban areas where buildings are densely located, and road networks are complex. However, the use of detailed topographic features dramatically increases the workload and cost of calculation, which reduces the benefit gained from the higher accuracy.

A flood analysis of an urban basin area should consider an overflow simulation based on the sewer discharge capacity, along with a two-dimensional analysis that considers the surface runoff according to topographic features, such as road shape and slope. Using XP-SWMM, which is a model combining the storm water management model (SWMM) and two-dimensional unsteady FLOW (TUFLOW)-based modeling, Phillips, Yu, and Thompson (2005) compared one-dimensional (1D), 1D/two-dimensional (2D), and 2D results and conducted a 2D analysis of an urban area. Another flood analysis has also considered the runoff characteristics in Korea. Lee, Han, et al. (2006), developed a dual-drainage sewer line simulation model and simulated the exclusion of the surface runoff. Regarding the analysis methods used in the flood analysis, Baek (2006) considered the re-inflow of overflow and flood runoff into the drainage system in a SWMM- and digital elevation model (DEM)-based 2D analysis and compared and analyzed the flooded areas depending on changes in the size of the calculation grid. Using XP-SWMM, Lee and Yeon (2008) analyzed the effect of buildings on urban flooding, whereas Ha, Han, and Cho (2010) produced DEMs with various resolutions using light detection and ranging (LiDAR) data, and the researchers analyzed the effect of topographic data resolution on the flood analysis. To predict the flooded area of roads in urban areas, Son, Kim, and Han (2015) studied floods using different grids and considering different roads and topographic features.

As a method for the economic analysis of flood control measures in urban areas of Korea, Lee, Han, et al. (2006), developed the multi-dimensional flood damage analysis (MD-FDA), which consists of a procedure that analyzes the economic effectiveness of flood control measures after the following steps are conducted: a flow and geography survey of the area, property survey of the flooded area, calculation of estimated damages, calculation of expected reduced damages, calculation of flood control measure costs, and an economic analysis.

Among studies that have calculated flood damage using the multi-dimensional flood damage analysis, Lee, Han, et al. (2006), researched the damage percentage of tangible fixed assets and public facilities in industrial areas by considering the inner basin drainage of urban areas. By using the hydraulic analysis model and DEM data together with a geographic information system (GIS), Yi, Choi, Shim, and Kim (2006) calculated flood levels and flood damage.

For the accurate prediction of flood inundation extent in urban areas, surface elevation data are crucial, particularly digital terrain data. In this regard, the differences in inundation prediction results depending on the accuracy of surface topographic data and subsequent differences in the amount of estimated flood damage are examined in this study. Therefore, the importance of topographic scale in modeling drainage in urban areas for establishing a flood prevention plan is demonstrated in this study.

2 | URBAN FLOOD MODELING AND ECONOMIC ANALYSIS

2.1 | SWMM and TUFLOW

The XP-SWMM, which is a commercially available model combining SWMM and TUFLOW, was developed to integrate the SWMM 1D distribution network analysis and the TUFLOW 2D surface runoff flow analysis. This model can simulate dynamic surface flow by considering only digital terrain model (DTM) data. By employing surface runoff analysis data and considering the distribution of permeable and impermeable areas in addition to a 1D flow analysis of storm drains and sewer lines, the XP-SWMM uses a DTM to simulate urban runoff and perform a surface flood analysis for an overflowing manhole scenario. In addition, this model can perform a dual-drainage analysis, in which some of the surface runoff flow can re-flow into the nonoverflowing inlets during the surface flood analysis. In considering the re-inflow of the surface runoff caused by flooding, the model calculates the volume of re-inflow water and redirects the flow into the distribution system (Huber & Dickinson, 1988).

2.2 | Multi-dimensional flood damage assessment (MD-FDA)

The key goal of this paper is to evaluate the impact of the computed inundation area, which varies with the DEM
scales, on estimated losses. In particular, the importance of geomorphological data with a higher resolution in urban flood analysis is quantitatively presented in this paper. To estimate the direct benefits of flood prevention facilities, the MD-FDA, which is a standard methodology used in Korea for flood damage assessment, divides the benefits into reduced damage to residential areas, agricultural areas, industrial areas, and public facilities. Except for public facilities, the assets in each of these areas are calculated as benefits based on statistics and are multiplied by the damage rate, which is based on the flood level and inundated inclusion ratio. By considering the inundated inclusion ratio at each flood level, the MD-FDA can more accurately calculate the amount of damage. A categorized asset survey is one of the most important factors in the MD-FDA, and the results can vary depending on the accuracy of the survey. To calculate flood damage in urban areas in this study, administrative district statistics were used, asset data was specified and investigated, and the flood damage was calculated based on the residential value. Table 1 shows the asset survey items in the MD-FDA.

The residential area survey factors include buildings and building contents. Calculation of the latter is based on the value of residential household goods, which is dependent on the type of building. The asset value of the building contents in an area can be calculated from the number of households, the building type, and the average value of the contents for that building type. Damages to the building are calculated by multiplying the asset value of the building in the affected area by the inundated inclusion ratio, which is based on the estimated flood level and flood damage rate. Under the assumption that the asset damage rate is the same regardless of the type of residence, the rate is calculated on the basis of a building damage rate table (Ministry of Land, Infrastructure and Transport (MOLIT), 2004). Table 2 and Table 3 show the building damage rate and building contents rate at each flood level, respectively. The underground space and apartment are considered parking lots and facilities. In addition, a row-house is considered underground housing ratios.

### Table 1: Research items of the MD-FDA (MOLIT, 2004)

| Local characteristics | Target assets                                                                 |
|-----------------------|-------------------------------------------------------------------------------|
| Living area           | - Building: Residential building                                               |
|                       | - Building contents: Residential household goods                               |
| Rural area            | - Agricultural land: Farmland, fields and paddies                              |
|                       | - Crops: Representative crop                                                   |
| Industrial area       | - Tangible inventories of assets in businesses: Production facilities or inventories of assets |

3 | DIGITAL TERRAIN DATA FOR FLOOD ANALYSIS

The digital terrain data used in a flood analysis are divided into a digital map, which includes elevation values and topographic items such as buildings and roads, and a DEM, which uses only elevation values. The digital terrain data currently used in flood analyses of urban areas include a 1:5,000 digital map, a 1:1,000 digital map, and a LiDAR-based 1 m DEM. This study used LiDAR data provided by the National Geographic Information Institute (NGII) and a 10 m DEM based on the 1:5,000 digital map. In general, the 1:5,000 digital map itself is not applied as digital terrain data for flood analysis. Instead, the map is converted into a DEM and then applied. The density and accuracy of the DEM for each of the topographic data vary depending on how the DEM is established. The following sections describe this process in greater detail.

3.1 | 1:5,000 digital map

To examine the applicability of the 1:5,000 digital map to urban flooding analysis in this study, a 10 m DEM based on the 1:5,000 digital map is used, which was provided by NGII. This map was developed based on an aerial survey; thus, the 10 m DEM established and published by NGII is also the result of an aerial survey. Accordingly, many studies use a 10 m DEM as digital terrain data for flood analysis; however, the validity of this DEM has not been verified to a sufficient standard. The 10 m DEM cannot exceed the elevation accuracy level of the 1:5,000 digital map upon which it is based. Table 4 shows the margin of error for the 1:5,000 digital map and the 10 m DEM in accordance with survey requirements, and Figure 1 (Telecommunications Technology Association (TTA), 2009) describes the procedure for producing the numerical elevation data using the digital map.

Table 5 lists the margin of error for each digital map. In this study, a 10 m DEM created using the 1:5,000 digital map is applied, and Table 6 describes the requirements for the grid intervals of the elevation data in each digital map. The acquired point density per square meter in accordance with numerical elevation data requirements is described in Table 7.

3.2 | LiDAR 1 m DEM

LiDAR, which is a method of acquiring elevation data, obtains high-density and high-precision elevation data based on the timing of the return interval of laser light. The final product, which is acquired after processing the raw data, is in the form of a coordinate system composed of points on the x, y, and z-axes. Ground data is acquired by removing structures such as trees and buildings. The resolution of the LiDAR DEM data currently provided by the NGII is 1 × 1 m.
and the DEMs accuracy is 25 cm. For establishment of a DEM using LiDAR, raw data acquired by LiDAR are converted into coordinates and point data (Kwon & Kim, 2006). Elevation data are extracted after the data are converted into point data, and then, the final DEM is generated.

### 4 ASSESSMENT OF A FLOODING SIMULATION WITH TERRAIN RESOLUTION

#### 4.1 Study area

The area examined in this study is Dorim Stream, which sustained flood damage in 2010 and 2011. Dorim Stream is the primary tributary of Anyang Stream, which itself is the primary tributary of the Han River. In addition, Daebang Stream and Bongcheon Stream flow into Dorim Stream as tributaries. The total basin area is 41.93 km², length is 14.20 km, average basin width is 2.95 km, and the stream consists of 17 drainage basins in total. Mt. Gwanak is the source of Dorim Stream, which flows through the administrative districts of Yeongdeungpo-gu, Guro-gu, Dongjak-gu, and Gwanak-gu into Anyang Stream. The tributaries Daebang Stream and Bongcheon Stream are mostly covered with concrete and are used as roads. This study examines a total of 17 drainage basins near Dorim Stream. Among the basins, the Daerim and Sinrim drainage basins are located in the middle of the mainstem of Dorim Stream (Figure 2). The Daerim drainage basin has an area of 1.25 km² and the Sin rim 3 and 4 drainage basin areas are 1.36 and 2.55 km², respectively, which makes a total area of 5.16 km². Samseongsan Mountain is located south of the Sinrim 3 drainage basin and has a maximum altitude of 194.8 m. The Sinrim 3 drainage basin flows into the Sinrim 4 drainage basin through a valley surrounded by mountains to

### TABLE 2 Building damage rate by flood depth (MOLIT, 2004)

| Structure type | 0.0–0.5 m | 0.5–1.0 m | 1.0–2.0 m | 2.0–3.0 m | > 3.0 m |
|----------------|-----------|-----------|-----------|-----------|--------|
| Detached       | 14.5%     | 32.6%     | 50.8%     | 92.8%     | 100%   |
| Apartment      | 14.5/n1 + α% | 32.6/n1 + α% | 50.8/n1 + α% | 92.8/n1 + α% | 100/n1 + α% |
| Row-house      | 14.5/n2 + 100*β% | 32.6/n2 + 100*β% | 50.8/n2 + 100*β% | 92.8/n2 + 100*β% | 100/n2 + 100*β% |

Note: The n1 is the # of apartment floors, n2 is the # of row-house floors, α is the damage rate of the apartment facilities, and β is the underground housing ratio of the row-house.

### TABLE 3 Building contents damage rate by flood depth (MOLIT, 2004)

| Damage rate | 0.0–0.5 m | 0.5–1.0 m | 1.0–2.0 m | 2.0–3.0 m | 3.0– |
|-------------|-----------|-----------|-----------|-----------|------|
| Detached    | 14.50%    | 32.60%    | 50.80%    | 92.80%    | 100.00% |
| Apartment   | 14.5/n1 + α% | 32.6/n1 + α% | 50.8/n1 + α% | 92.8/n1 + α% | 100/n1 + α% |
| Row-house   | 14.5/n2 + 100*β% | 32.6/n2 + 100*β% | 50.8/n2 + 100*β% | 92.8/n2 + 100*β% | 100/n2 + 100*β% |

### TABLE 4 1:5,000 digital map and 10 m DEM errors (National Geographic Information Institute (NGII), 2012)

| Scale          | 1/5,000 | 5 m/10 m DEM |
|----------------|---------|-------------|
| Standard deviation (m) | 0.72    | 1.0/2.0     |
| Maximum value (m)     | 1.44    | 1.5/3.0     |

### FIGURE 1 Digital elevation data production process using a digital map

and the DEMs accuracy is 25 cm. For establishment of a DEM using LiDAR, raw data acquired by LiDAR are converted into coordinates and point data (Kwon & Kim, 2006). Elevation data are extracted after the data are converted into point data, and then, the final DEM is generated.

### TABLE 5 Digital map errors (National Geographic Information Institute (NGII), 2012)

| Scale          | Standard deviation (m) | Maximum value (m) |
|----------------|------------------------|-------------------|
| 1/500–1/600    | 0.14                   | 0.28              |
| 1/1,000–1/1,200| 0.20                   | 0.40              |
| 1/2,500–1/3,000| 0.36                   | 0.72              |
| 1/5,000        | 0.72                   | 1.44              |
| 1/10,000       | 0.90                   | 1.80              |
| 1/25,000       | 1.00                   | 2.00              |

### TABLE 6 Digital map based on the elevation data grid scale (National Geographic Information Institute (NGII), 1999)

| Scale  | Grid scale |
|--------|------------|
| 1/1,000| 5 × 5 m    |
| 1/5,000| 10 × 10 m  |
| 1/25,000| 50 × 50 m |
| 1/50,000| 100 × 100 m |
the left and right. As the surface runoff flows into the low-altitude Sinrim 4 drainage basin, the flow is expected to be concentrated within the basin. The Sinrim 4 and Daerim drainage basins have drainage areas to the left of Dorim Stream; The Sinrim 4 and Daerim rainwater pumping stations are located in those areas. According to the automatic weather station (AWS) of the Korea Meteorological Administration, 266 mm of rain fell in 1 day from 24:00 local time on July 26, 2011 to 24:00 on July 27, 2011. The highest precipitation rate per hour was 113 mm. This intensity of rainfall was expected at an 80-year frequency, and 3,327 households in total sustained flood damage. The flood in the Sinrim 4 and Daerim drainage basins had various contributing factors including the effects of the water level outside the stream, poor drainage, concentration of runoff into the low-lying areas, and poor inner basin drainage of the pumping station. All these factors contributed to flooding in the low-lying area downstream of Dorim Stream.

4.2 | Model installation

4.2.1 | Urban runoff model

For the runoff analysis of urban areas, storm sewer drainage systems should be mapped in areas containing storm sewers. In the area examined in this study, 13,644 m of box culverts, 59,463 m of branch sewers (Ø150–Ø600), and 46,479 m of trunk line sewers (Ø150–Ø600) were installed underground. Seoul GIS sewer network data were used to obtain detailed information of the sewer shapes, depths, and manholes. Figure 3 shows the sewer network in the study area. According to Chow, Maidment, and Mays (1988) with regard to Manning’s roughness coefficients for trunk line and branch sewers, the coefficient for the concrete Hume pipe should be 0.012 (Table 8). However, in this study, a value of 0.014 was used after considering the maintenance conditions of the sewers.
The time-area method of flood volume calculation was chosen to determine the amount of runoff. As a boundary condition of the urban drainage calculation in the study area, a high water level in the Dorim River, which is referred to as the River Improvement Master Plan of Dorim River, was selected (Table 9).

4.2.2 | Rainfall data

The Dorim River, which is the area examined in this study, sustained flood damage caused by heavy storms in 2010 and 2011. To identify the effects of the digital terrain data on the flood damage simulation, in this study, a flood damage simulation was performed using data of heavy rainfall that occurred for 24 hr from 00:00 to 24:00 local time on July 27, 2011. Figure 5 shows a 10-min interval hyetograph provided by the AWS of the Korea Meteorological Administration. The total amount of rainfall was 266.5 mm, and the highest precipitation rate per hour was 113 mm.

4.3 | Flood simulation with digital terrain resolution

4.3.1 | Urban runoff model results

By using the SWMM model in this study, a runoff analysis was performed on the Daerim and Sinrim 3 and 4 drainage basins based on heavy rainfall occurring on July 272011 and 297 manholes were found to have overflowed. The total overflow volume was 1,898,480 m³, and the volume for each manhole ranged from 0 m³ to 202,964 m³. Of these overflows, the largest occurred in the Daerim drainage basin. Figure 6 depicts the locations of the overflowed manholes. The analysis revealed that manholes located in the northern part of the downstream Dorim River overflowed (Figure 6). This may be attributable to the effect of drainage from the Dorim River and the lack of water storage capacity in the complex sewer network buried under the flat terrain. The overflowed manholes were mostly consistent with the flooded areas, as illustrated in the inundation map in Figure 3. If the urban drainage facilities and sewer network's capacity are not secured, the overflowed storm water will remain for a long time on a flat surface. Figure 7 shows the terrain analysis results using a 1 and 10 m DEM in a flood prone area, respectively.

4.3.2 | Results of the flood simulation with terrain resolution

The flood inundation area and depth were calculated based on the results of the XP-SWMM simulation for the flood

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**TABLE 8** Manning roughness coefficients (Chow et al., 1988)

| Material                              | Typical manning roughness coefficient |
|---------------------------------------|---------------------------------------|
| Concrete                              | 0.012                                 |
| Gravel bottom with sides              |                                       |
| Concrete                              | 0.020                                 |
| Mortared stone                        | 0.023                                 |
| Riprap                                | 0.033                                 |
| Natural stream channels               |                                       |
| Clean, straight stream                | 0.030                                 |
| Clean, winding stream                 | 0.040                                 |
| Winding with weeds and pools          | 0.050                                 |
| With heavy brush and timber           | 0.100                                 |

**TABLE 9** High water level in the Dorim River (Ministry of Land, Transport and Maritime Affairs (MLTM), 2002)

| River | Station (no.) | 30 years | 50 years | 200 years |
|-------|---------------|----------|----------|-----------|
| Dorim | 40            | 14.43    | 14.76    | 17.96     |
event that occurred on July 27, 2011. The flooded areas, which were dependent on the digital terrain data types shown in Figure 8 and Tables 10 and 11, were 905,205 m$^2$ of LiDAR 1 m DEM and 804,743 m$^2$ of 10 m DEM, respectively. There was little difference found in the total flooded area between the two topographic models. On the other hand, areas with an inundation of 1 m or more, which can cause massive life and property losses, were nearly nonexistent when the 10 m DEM was used. More notably, the DEM also failed to represent the high-risk areas in the Daerim drainage basin.

The damage calculation of the inundation depth in the flood area was estimated based on land use information. The respective flooded areas from the LiDAR 1 m DEM and the 10 m DEM for each flood level were 470,074 and 791,251 m$^2$ at flood levels of 0–0.5 m, 286,369 and 12,476 m$^2$ for those of 0.5–1 m, 83,634 and 944 m$^2$ for those of 1–2 m, and 43,586 and 73 m$^2$ for those of 2–3 m. At flood levels of 3 m or more, the flooded area based on the LiDAR 1 m DEM was 21,542 m$^2$.

The results of the flood simulation showed that the 10 m DEM did not represent the 1 m or more flooding area in the Daerim drainage basin, and the flooded area was very small in the Sinrim 4 drainage basin. The reason appears to be the 2.0 m error margin in the 10 m DEM case, which did not adequately portray the terrain. The digital terrain data that better represented the flooded area on the northern side, where a large flooded area was identified, was the LiDAR 1 m DEM. However, when the 10 m DEM was used, its margin of error for the terrain did not allow the model to represent flood levels of 1 m or deeper in the Daerim area.

5 | FLOOD DAMAGE ASSESSMENT FOR EACH DIGITAL TERRAIN DATASET

5.1 | Asset survey of the flooded area

The Daerim and Sinrim 3 and 4 drainage basins examined in this study belong administratively to Gwanak-gu and Geumcheon-gu. Gwanak-gu includes the following five regions: Jowon-dong, Sinsa-dong, Miseong-dong, Nangok-dong, and Nanhyang-dong. Doksan-dong in Geumcheon-gu was excluded because this area has not experienced flooding in the past. By using the statistics from Gwanak-gu in this study, the asset criteria for the five aforementioned regions were examined. Table 12 shows the basic data for each administrative district. The asset value of each building type was calculated based on the construction cost for the building type, the building's household rate among the total number of households, and the building area. Tables 13 and 14 show the construction cost for the building type in the administrative districts and its average pyeong, which is a Korean unit used to measure area.

Because the Dorim Stream basin is located in an urban area of Seoul, in this study, reinforced steel concrete was assumed as the building type. Table 15 shows the asset value of the buildings in each region based on the area and construction cost.

In addition, when a building is flooded, its contents such as household goods are also damaged. The asset value of the building contents in administrative districts can be calculated using the average assessed value of household goods per household and the consumer price index. Table 16 shows the asset value of building contents in each administrative district.
FIGURE 7  Digital elevation model (DEM) terrain analysis details (Tak et al., 2016)

FIGURE 8  Results of the flood simulation at terrain resolution (Tak et al., 2016)

TABLE 10  Flooded area of the basin using LiDAR 1 m DEM (Tak et al., 2016)

| Flooded depth | Darim Basin | Sinrim 3 basin | Sinrim 4 basin | Total   |
|---------------|-------------|----------------|----------------|---------|
| Total         | 222,188 m²  | 12,272 m²      | 670,745 m²     | 905,205 m² |
| ~0.5 m        | 77,219 m²   | 12,272 m²      | 380,583 m²     | 470,074 m² |
| 0.5–1 m       | 52,269 m²   | 0 m²           | 234,100 m²     | 286,369 m² |
| 1–2 m         | 73,536 m²   | 0 m²           | 10,098 m²      | 83,634 m²  |
| 2–3 m         | 16,141 m²   | 0 m²           | 27,445 m²      | 43,586 m²  |
| 3 m~          | 3,023 m²    | 0 m²           | 18,519 m²      | 21,542 m²  |
### Table 11 Flooded area of the basin using 10 m DEM (Tak et al., 2016)

| Flood depth | Darim basin | Sinrim 3 basin | Sinrim 4 basin | Total |
|-------------|-------------|----------------|----------------|-------|
| Total       | 264,817 m²  | 15,275 m²      | 524,651 m²     | 804,743 m² |
| ~0.5 m      | 264,114 m²  | 15,219 m²      | 511,918 m²     | 791,251 m² |
| 0.5–1 m     | 703 m²      | 56 m²          | 11,717 m²      | 12,476 m² |
| 1–2 m       | 0 m²        | 0 m²           | 944 m²         | 944 m²  |
| 2–3 m       | 0 m²        | 0 m²           | 72 m²          | 72 m²   |
| 3 m~        | 0 m²        | 0 m²           | 0 m²           | 0 m²    |

### Table 12 Local residential data

| Index      | Unit | Sin-sa dong | Mi-sung dong | Nan-gok dong | Nan-Hyang dong | Jo-won dong |
|------------|------|-------------|--------------|--------------|----------------|-------------|
| Area       | ha   | 64.0        | 140.0        | 90.0         | 82.0           | 67.0        |
| Household  |      | 6,532       | 9,083        | 8,273        | 4,858          | 4,310       |
| Living area| ha   | 64.0        | 70.0         | 63.0         | 41.0           | 67.0        |

### Table 13 Building unit price (unit: 1,000 USD)

| Type                   | Detached | Apartment | Row-house | Multiplex-house | Nonresidential |
|------------------------|----------|-----------|-----------|-----------------|----------------|
| Reinforce concrete     | 665.95   | 521.47    | 521.47    | 665.95          | 495.29         |
| Iron frame             | -        | -         | -         | -               | 445.13         |
| Kite stone             | 629.38   | 450.79    | 450.79    | 629.38          | 414.60         |
| Wood wall              | 472.27   | -         | -         | 472.27          | 397.94         |
| Crushed mortar         | 349.15   | -         | -         | 349.15          | 175.69         |
| Soil wall              | 349.15   | -         | -         | 349.15          | 175.69         |
| Block                  | 468.42   | -         | -         | 468.42          | 376.99         |
| Simple mortar          | 349.15   | -         | -         | 349.15          | 175.69         |

### 5.2 Comparison of flood damage assessments between the 1 and 10 m DEM

The amount of flood damage to buildings was calculated by multiplying the building asset value of the affected area using the inundated inclusion ratio and flood damage rate based on the estimated flood level. The damage to the building contents was calculated using the building contents damage rate at each flood level. Under the assumption that the asset damage rate is the same regardless of the residence type, the value was calculated on the basis of a building damage rate table (MOLIT, 2004, Tables 2 and 3).

This study categorized the Daerim and Sinrim 4 drainage basins as one area, including Jowon-dong, Sinsa-dong, and Miseong-dong, where flooded areas were found to be large. The Sinrim 3 drainage basin, including Nangok-dong and Nanhyang-dong, was categorized as another area. To estimate the flood damage to buildings depending on the digital terrain data in this study, the results of the flooded area simulation for each flood level were used and the flood damage rate was calculated depending on the flood level.

The results of the flood simulation for each digital terrain dataset were used to calculate the inundated inclusion ratio depending on the flood level. By using the asset value of each building type, the building damage was estimated depending on the digital terrain data. In addition, the building contents damage was estimated using the building contents damage rate.

Table 17 and Figure 9 show the calculated building damage depending on the topographic data. The amount of building damage was estimated at 99.7 M USD using the LiDAR 1 m DEM and 46.8 M USD using the 10 m DEM. The amount of damage to the building contents was estimated at 20.0 M USD using the LiDAR 1 m DEM and 9.0 M USD using the 10 m DEM. The total damage costs were 119.7 and 55.9 M USD, respectively. Therefore, the total damage cost using the 10 m DEM was calculated as 53.33% less than that using LiDAR (Table 18). Difference in the flooded area between the two topographic models appear to be reflected in the flood simulation results. Similar to those results, damages for flood levels of 1 m or more were estimated as minimal when the 10 m DEM was used. Because the flood level in the
Daerim drainage basin was not represented properly, the estimated damage cost using the 10 m DEM was lower.

Table 19 shows the number of damaged buildings and the cost of damage in Gwanak-gu and Geumcheon-gu, referring to the 2011 Disaster Statistical Yearbook (MOIS, 2012), which is the official government document published by the Korean Ministry of Interior and Safety and summarizes the national annual damages by disaster category. These statistics are believed to simply calculate the damage caused by flooding together among other types of damage to the flooded buildings in Seoul. These damage figures, which are calculated from a total of 3,504 flooded building complexes in Gwanak-gu and Geumcheon-gu, do not consider the value of each building type, the building contents asset value, the inundated inclusion ratio, or the damage rate and show some discrepancy when compared with the actual damage. More importantly, damage to buildings can vary depending on the flood level because buildings are densely located, and various residence types are located in urban areas where road networks are designed in a very complex layout. When flooding is prolonged in a low-lying area or storm water-concentrated area, the damage rate and degree of damage may differ. Therefore, a more sophisticated method of damage calculation should be considered.

### Table 14 Average building area (MOLIT, 2004)

| Structure type         | Area m² |
|------------------------|---------|
| Detached               | 132     |
| Apartment              | 73      |
| Row-house              | 73      |
| Multiplex-house        | 63      |
| Nonresidential         | 106     |

### Table 15 Value of building type (unit: 1,000 USD)

| Structure type | Sin-sa dong | Mi-sung dong | Nan-gok dong | Nan-Hyang dong | Jo-won dong |
|----------------|-------------|--------------|--------------|----------------|-------------|
| Detached       | 200,445.00  | 464,391.01   | 378,084.58   | 303,380.32     | 232,507.83  |
| Apartment      | 41,796.57   | 96,834.35    | 78,853.88    | 63,273.45      | 48,501.01   |
| Row-house      | 8,535.10    | 19,736.50    | 16,065.97    | 12,891.10      | 9,900.50    |
| Multiplex-house| 20,034.09   | 46,416.07    | 37,782.38    | 30,290.22      | 23,218.17   |
| Nonresidential | 10,445.92   | 24,253.73    | 19,699.65    | 15,842.09      | 12,117.19   |
| Total          | 281,256.68  | 651,631.66   | 530,486.46   | 425,677.17     | 326,244.70  |

### Table 16 Value of building contents (unit: 1,000 USD)

| Building contents property | Sin-sa dong | Mi-sung dong | Nan-gok dong | Nan-Hyang dong | Jo-won dong |
|----------------------------|-------------|--------------|--------------|----------------|-------------|
| Building contents property | 66,723.79   | 92,782.38    | 84,508.02    | 49,624.10      | 44,026.17   |

### Table 17 Building damage based on topographic data (unit: 1,000 USD)

| Basins         | Flood depth (m) | LiDAR 1 m DEM | LiDAR 10 m DEM |
|----------------|-----------------|---------------|---------------|
|                | Building Contents | Building Contents | |
| Darim, Sinrim 4| 0.5–0.5         | 25,931.12 4,985.52 | 43,956.52 8,451.07 |
|                | 0.5–1.0         | 32,676.82 7,011.45 | 1,620.32 347.67 |
|                | 1.0–2.0         | 18,589.86 3,190.88 | 209.83 36.01 |
|                | 2.0–3.0         | 14,255.44 3,037.80 | 23.55 5.02 |
|                | 3.0–             | 7,409.72 1,617.89 | - - |
| Sinrim 3       | 0.5–0.5         | 831.68 138.77 | 1,031.40 172.09 |
|                | 0.5–1.0         | - - | 0.83 1.43 |
|                | 1.0–2.0         | - - | - - |
|                | 2.0–3.0         | - - | - - |
|                | 3.0–             | - - | - - |
| Total          |                 | 99,694.65 19,982.31 | 46,842.45 9,013.29 |
6 | CONCLUSIONS

The extent and type of flood damage differs among urban and rural areas. In urban areas, where impermeable ground accounts for most of the area and buildings are situated in a complicated layout, both the surface runoff flow and drainage capacity of the sewer network are important factors. Because residential and commercial zones are densely packed in urban areas, even a heavy downpour within a short period can result in extensive damage. The loss of both life and property are expected to be high in such cases because urban areas often utilize underground spaces to a considerable extent. In this regard, it is necessary to predict the flood-risk zones in urban areas using accurate topographic data. The digital terrain data used in flood prediction have different levels of accuracy depending on their specifications, and these margins of error can lead to differences in the predicted flooded area. By using the LiDAR-based 1 and 10 m DEM in this study, a flood simulation was performed to confirm the importance of accurate flood damage prediction. The damages were calculated based on the flood simulation using each of these topographic models.

In this study, a model for urban runoff analysis was established for the Daerim and Sinrim 3 and 4 drainage basins in Dorim Stream, which sustained flood damage in 2010 and 2011 and this model included a sewer network analysis. According to the results of the sewer network analysis, we performed the flood analysis using the LiDAR-based 1 m DEM and 1:5,000 digital map-based 10 m DEM.

The results of the 1:5,000 digital map-based 10 m DEM showed almost no areas with a flood level of 1 m or more, unlike those revealed using the LiDAR-based 1 m DEM and did not represent the high-risk area in the Daerim drainage basin. This demonstrates that the 10 m DEM has limitations in representing low-lying urban areas in terms of accuracy and density of the elevation data. By using flooded area prediction results based on those two topographic models in this study, the cost of flood damage to buildings was estimated. When the 1 and 10 m DEM were used, the costs were estimated at 119.7 and 55.9 M USD, respectively. Flood damage costs were calculated using the asset value of each building type in the area, the flood damage rate, and the inundated inclusion ratio depending on the flood level. The 10 m DEM did not properly calculate damages in the area with high flood damage rates because the DEM did not represent the high-risk area with flood levels of 1 m or higher. Therefore, careful model selection is necessary when establishing facility plans for flood prevention and postflood measures when predicting flood damage.

Because flood damage in urban areas is increasingly occurring, the accurate prediction of flooding is necessary to prevent damage to lives and property and to establish remedial measures. More specifically, when performing a flood
analysis that considers the topographic characteristics, it is necessary to use precise digital terrain data and a DEM of appropriate size. The extent of the flood damage in affected regions appeared to differ depending on the flood level and flooded area. Therefore, predicting floods based on accurate digital terrain data is necessary to accurately estimate the damage extent. In addition, a more accurate method for estimating damage is needed.

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