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Performance Analysis of Storm Sewer Network Simplify and Grid Resolution by Basin Scale

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Abstract

Frequent urban inundations from changing rainfall patterns highlight the need for reliable, timely flood forecasting. This study evaluates inundation prediction under varying storm sewer network simplification and surface grid resolutions using InfoWorks ICM, which supports 1D–2D coupled simulations. Five storm sewer configurations, determined by cumulative watershed area, and five grid resolutions yielded 25 scenarios. Results show that the number of two-dimensional mesh elements influences simulation time more than the number of storm sewer pipes. Coarser grids significantly reduce computation but may oversimplify topographic variability, reducing inundation depths and overestimating inundation extents. Conversely, increasing network detail raises inundation area and depth as well as computation time. For small- and medium-scale basins (e.g., Sinlim4, Daelim), a simplification threshold of 2.25 ha was optimal, while for large basins, 1 ha was best. These thresholds strike a balance between modeling accuracy and simulation speed. A sensitivity analysis was performed to examine changes in inundation depth and area for each simplification level, revealing high sensitivity in topographically complex areas. Additionally, the need for historical flood event validation—including the August 2022 flood in Dorim-river—is outlined for future work. The findings offer practical guidelines for real-time urban flood forecasting system design.

Highlights

- Simplifying the grid resolution and storm sewer network
- Analysis of changes according to the level of simplification by basin scale
- Identifying the appropriate level considering accuracy and rapidity for urban flood prediction

Introduction

Climate change has changed rainfall patterns significantly, causing frequent inundation in urban areas. On August 8, 2022, extreme heavy rainfall of 141.5 mm/hr occurred in Seoul, Korea, causing multiple casualties and property damage. Damage from heavy rainfall is gradually increasing due to changed rainfall patterns.

The government has been making efforts to establish various forecast systems to prevent repeated large-scale inundation damage in urban areas. The Ministry of Environment has enacted the Flood Damage Prevention Act for Urban River Basins. Its goal is to establish a streamlined urban flood response system for specific urban river basins (where flood damage has occurred or is a concern). It is going to implement an urban flood forecasting system that provides river and sewer water levels and the estimated flood range by replacing the existing flood forecasting system, which mostly covers river flooding. As these measures indicate, the importance of urban inundation forecasting is gradually increasing, and the prediction models for forecasting should be speedy to accurately analyze inundation and secure the golden hour.

Numerical analysis models for urban inundation analysis include Road Research Laboratory method (RRL), Illinois Urban Drainage Area Simulation (ILLUDAS), Storm Water Management Mode (SWMM), and Infoworks Integrated Catchment Model (Infoworks ICM), etc. In Korea, the SWMM model and Infoworks ICM are most commonly used. Since the urban inundation model must represent the phenomenon of manhole overflow accumulating on the surface, it is significantly influenced by the precision of storm sewere and the resolution of the surface grid. However, for urban areas that consist of complex topographical structures, the complexity of storm sewerage and a high-resolution surface grid significantly increase the analysis time. For this reason, it is necessary to derive an appropriate level of storm sewage simplification and surface grid resolution to secure the golden hour for urban inundation forecasting.

In order to reduce the calculation time required for urban inundation analysis, Son analyzed the numerical analysis results per square grid size and simulation time interval when applying the SWMM model to derive an appropriate grid resolution for the numerical analysis (Son et al., 2014). Tak evaluated the effect of surface grid resolution on flood analysis using the XP-SWMM model (Tak et al., 2016). Han used the overflow of the SWMM model as input data for the DEM-based 2D surface water analysis model, and compared the effect of flood analysis in each grid size (Han et al., 2006). Meanwhile, in a study that attempted to reduce simulation time through the simplification of storm sewerage, Lee used the SWMM model and XP-SWMM model to simplify the storm sewer network based on the basin area, and also to evaluate inundation analysis capability for each simplification level to reduce simulation time when studying urban flood forecasting (Lee et al., 2019). Park presented a comparison of results and appropriate levels according to the density of the storm sewer network configuration when analyzing inundation in high-density and low-density areas of storm sewer networks (Park et al., 2017). Choi used EPA-NET for large-scale water pipe networks (Choi et al., 2016). The equivalent pipe formula was applied to evaluate the analysis performance for each level of storm sewer network configuration. Lee applied the river dendritic classification method to the storm sewer network and classified it into secondary and tertiary dendritic structures (Lee et al., 2018). The structures were then applied to the Grid based Inundation Analysis Model (GIAM) (Lee et al., 2017), to present a standard for storm sewer network simplification. Outside of Korea, Cao used grid-based distributed Urban Hydrological Model (gUHM) to simulate various rainfall conditions for each level of storm sewer network simplification, and confirmed that urban inundation forecasts are more likely to be underestimated if the level of simplification is larger (Cao et al., 2019). Farina used EPA-SWMM to estimate watershed parameters from topographic information to build Simplified Models (SMs) and compared them with Detailed Models (DMs) for a study on improving prediction efficiency (Farina et al., 2023). These prior studies have mainly focused on storm sewer network simplification using various simplification methods, and analysis of the effects of rainfall-runoff models at each surface grid resolution. However, there has been no performance review that considers both conditions simultaneously. Therefore, in this study, urban inundation prediction performance was reviewed according to surface grid resolution and storm sewer network simplification using Infoworks ICM, which supports 1D-2D linkage simulation. In addition, to predict urban inundation, inundation depth and area change were analyzed according to the level of surface grid resolution and storm sewer network simplification, and its performance was reviewed.

Methodology

Numerical analysis model

In this study, Innovyze's Infoworks ICM, which supports 1D-2D linked hydraulic and hydrological modeling, was used to review the performance of each level of surface grid resolution and storm sewer network simplification. Infoworks ICM supports an irregular grid system, and its model construction is simple. The hydraulic formula for 2D surface flow (ground surface flow) is based on the nonlinear shallow water equation, which is as follows:

Continuity equation:

$$\frac{\vartheta \mathrm{h}}{\vartheta \mathrm{t}} + \frac{\vartheta(\mathrm{hu})}{\vartheta \mathrm{x}} + \frac{\vartheta(\mathrm{hv})}{\vartheta \mathrm{x}} = q_{1D} \qquad (1)$$

Momentum equation:

$$\frac{\vartheta(\mathrm{hu})}{\vartheta \mathrm{t}} + \frac{\vartheta}{\vartheta \mathrm{x}}\left(hu^2 + \frac{\mathrm{g}h^2}{2}\right) + \frac{\vartheta(\mathrm{huv})}{\vartheta \mathrm{y}} = -\mathrm{gh}\left(S_{o,x} - S_{f,x}\right) + q_{1D}u_{1D} \qquad (2)$$

$$\frac{\vartheta(\mathrm{hv})}{\vartheta \mathrm{t}} + \frac{\vartheta}{\vartheta \mathrm{y}}\left(hv^2 + \frac{\mathrm{g}h^2}{2}\right) + \frac{\vartheta(\mathrm{huv})}{\vartheta \mathrm{x}} = -\mathrm{gh}\left(S_{o,y} - S_{f,y}\right) + q_{1D}v_{1D} \qquad (3)$$

In equations (1) to (3), h is the water level, u and v are the velocities in the x-axis and y-axis directions, respectively, g is the gravitational acceleration, and $S_{o,x}$ and $S_{o,y}$ are the ground slope, while $S_{f,x}$ and $S_{f,y}$ are the friction slope, in the x-axis and y-axis directions, respectively. q_{1D} is the flow rate per unit area, and u_{1D} and v_{1D} are the flow rate and flow velocity components in the x-axis and y-axis directions, respectively. Equations (1) to (3) can be solved using the finite volume method (Mulet, 2005) with the Riemann formula. Turbulence effect is included in the energy loss due to bottom resistance (Innovyze, 2021).

Surface grid resolution and simplification of storm sewer network

The level of surface grid resolution and storm sewer network simplification was determined by referring to prior research. The level of surface grid resolution is divided into irregular grid sizes (1m^2, 25m^2, 100 m^2, 225m^2, 625m^2) using the Triangle Mesh generator (Shewchuk, 1996). The storm sewer network is simplified to user-defined areas (1ha, 2ha, 2.25ha, 6.25ha) by cumulative catchment area flowing into the manhole in the flow direction from the initial pipe to the discharge pipe. The simulation was performed for a total of 25 cases by combining the simplified sewer networks for each grid resolution level to check changes in simulation time, inundation depth and area for each simplification level (Figure 1).

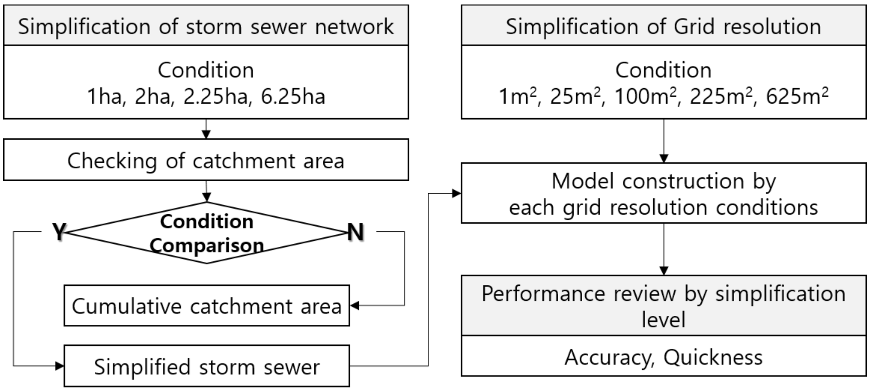
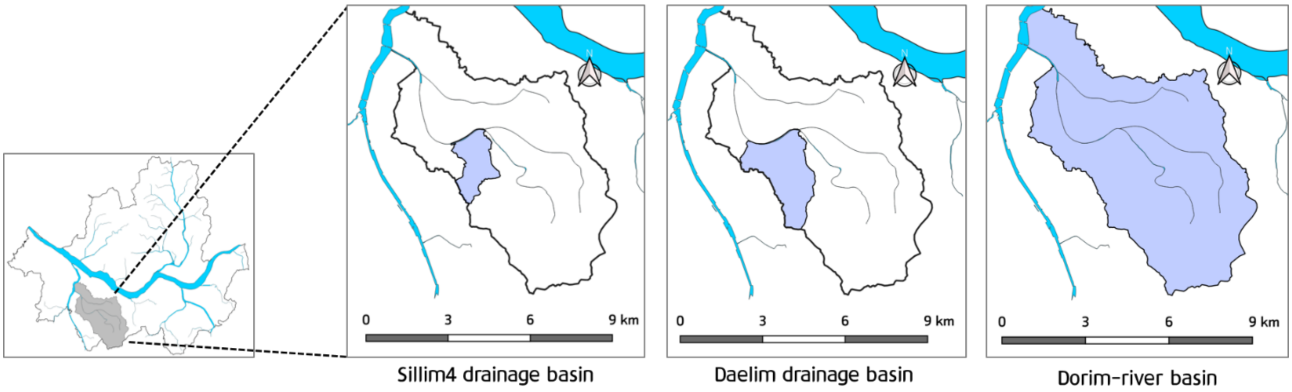


Figure 1. Grid Resolution and Storm Sewer Network Simplification Method

Target area selection and model construction

In order to analyze the two-dimensional Inundation pattern according to the level of simplification by basin scale, an initial model was constructed by using the Infoworks ICM model. The study area is the highly urbanized Dorim-river watershed, where flooding occurred due to river overflow in 2022. An initial model was constructed by dividing the Dorim-river basin into three areas: Sillim4 drainage basin, Daelim drainage basin, and the entire Dorim-river basin area. The number of sewer network elements in each basin(Sillim4 drainage basin, Daelim drainage basin, and Dorim-river basin) was 2,026, 3,761, and 30,588, respectively, and the watershed areas were 2.55km^2, 5.16km^2, and 44.25km^2. Figure 2 below shows the points by watershed size in the study target area, and Table 1 shows the current status and grid of simplified pipe networks for each watershed.



Sillim4 drainage basin Daelim drainage basin Dorim-river basin

Figure 2. Target area selection (Scale of the watershed)

Table 1. Construction of sewer networks and grid resolution for each target area

Basin Case	Sewer Simplify			Grid Resolution	
	Case	**Mangole**	**Pipe**	**Case**	**Mesh Elements**
Sillim4 drainage basin (2.55km^2)	Base	2,026	2,022	1m x 1m	221,025
	1ha	726	770	5m x 5m	45,682
	2ha	573	583	10m x 10m	17,473
	2.25ha	555	583	15m x 15m	10,908
	6.25ha	375	392	25m x 25m	8,525
Daelim drainage basin (5.16km^2)	Base	3,761	4,041	1m x 1m	384,757
	1ha	3,525	3,944	5m x 5m	86,398
	2ha	2,968	3,315	10m x 10m	30,096
	2.25ha	1,853	1,965	15m x 15m	13,052
	6.25ha	1,374	1,449	25m x 25m	11,282
Dorim - river basin (44.25km^2)	Base	30,588	32,443	1m x 1m	2,722,462
	1ha	25,630	27,482	5m x 5m	680,859
	2ha	24,261	26,787	10m x 10m	286,522
	2.25ha	23,656	24,331	15m x 15m	108,699
	6.25ha	21,516	22,115	25m x 25m	40,157

Results and discussion

For urban inundation forecasting, accurate inundation analysis and rapidity to secure golden time are required. In this study, we built a model for each target basin by simplifying the number of stormwater pipes and surface grid resolution, which affect accuracy and speed, and analyzed the inundation depth, inundation area, and simulation time by simplification level. The inundation analysis was performed for 25 cases with 5 cases of simplified stormwater pipes and 5 cases of grid resolution, and the inundation characteristics were analyzed by simplification level.

1) The simulation results of the simplified storm sewer network based on the cumulative watershed area for each grid resolution condition showed that the simulation time decreased proportionally as

the number of pipes and the number of grids decreased. It was analyzed that the number of mesh elements has a greater impact on the simulation time than the number of stormwater pipes, and it is judged that the number of mesh elements is relatively large compared to the initial number of storm sewer pipes, which greatly affects the computation speed.

2) As the storm sewer network simplification increased, the inundation area and depth tended to decrease. As the grid resolution increased, the inundation area increased and the inundation depth decreased. As the grid size increased, elevation changes were not reflected and average elevation values were used, so the grid was formed to be lower and wider than the actual grid. Therefore, an appropriate level should be selected considering the inundation pattern and model simulation time when simplifying the grid resolution and storm sewer network.

3) Two-dimensional inundation analysis of storm sewer network simplification and grid resolution by basin scale shows that simplification to 2.25 ha for small and medium-sized basin (Sinlim4 drainage basin, Daelim drainage basin) and 1 ha for large basin is most appropriate.

Conclusions and future work

For complex urban areas such as Dorim-river basin, it is necessary to select an appropriate grid resolution for accurate and speedy flood prediction. This study conducted sensitivity analysis to quantify how model outputs—particularly inundation depth—respond to different levels of sewer network simplification and grid resolution. We found that mesh resolution in particular dominates computation time, while both factors affect flood extent and depth. In future research, it is expected that an appropriate level of surface grid resolution will be identified and unnecessary storm sewer networks will be removed or combined, so the prediction performance of the model will be improved, enabling more efficient analysis and interpretation. Additionally, the model results will be validated using observed flood event data from the August 8, 2022 event in Seoul, to improve model credibility. The results of this study can guide practical model configuration for the Korean Urban Flood Forecasting System under the Flood Damage Prevention Act.

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