water

MDPI

Article

Application of Flood Nomograph for Flood Forecasting in Urban Areas

Eui Hoon Lee [1], Joong Hoon Kim [2], Yeon Moon Choo [3] and Deok Jun Jo [4,*]

1 Research Center for Disaster Prevention Science and Technology, Korea University, Seoul 02841, Korea; hydrohydro@naver.com
2 School of Civil, Environmental and Architectural Engineering, Korea University, Seoul 02841, Korea; jaykim@korea.ac.kr
3 Department of Civil, Environmental and Architectural Engineering, Korea University, Seoul 02841, Korea; chooyean@naver.com
4 Department of Civil Engineering, Dongseo University, Busan 47011, Korea
* Correspondence: water21c@gmail.com; Tel.: +82-051-320-1831

Received: 28 November 2017; Accepted: 8 January 2018; Published: 10 January 2018

Abstract: Imperviousness has increased due to urbanization, as has the frequency of extreme rainfall events by climate change. Various countermeasures, such as structural and nonstructural measures, are required to prepare for these effects. Flood forecasting is a representative nonstructural measure. Flood forecasting techniques have been developed for the prevention of repetitive flood damage in urban areas. It is difficult to apply some flood forecasting techniques using training processes because training needs to be applied at every usage. The other flood forecasting techniques that use rainfall data predicted by radar are not appropriate for small areas, such as single drainage basins. In this study, a new flood forecasting technique is suggested to reduce flood damage in urban areas. The flood nomograph consists of the first flooding nodes in rainfall runoff simulations with synthetic rainfall data at each duration. When selecting the first flooding node, the initial amount of synthetic rainfall is 1 mm, which increases in 1 mm increments until flooding occurs. The advantage of this flood forecasting technique is its simple application using real-time rainfall data. This technique can be used to prepare a preemptive response in the process of urban flood management.

Keywords: flood volume; flood forecasting; flood nomograph; rainfall runoff simulation

1. Introduction

Climate change has had various effects, including an increase in the frequency of extreme rainfall events. The area of imperviousness has also sharply increased with the increase in the ratio of urban to rural area. Therefore, urban floods have increased due to extreme rainfall events and urbanization. Various countermeasures, such as structural and nonstructural measures, have been developed to reduce urban flooding.

Flood forecasting has been studied as a nonstructural measure for preventing flood damage as follows. A flood forecasting model over a period of one year has been suggested for three catchments in the UK, and this model was based on rainfall and evaporation data [1]. Digital elevation models have been applied to a distributed model for real-time flood forecasting with a distributed basin simulator [2]. Short-term rainfall prediction models with the techniques of auto-regressive moving-average and artificial neural networks have been suggested for real-time flood forecasting [3]. Advanced flood forecasting using a grid-based hydrological catchment model with grid cells between 2 and 14 km has been proposed using a distributed hydrological model based on coupling meteorological observations [4]. Advances in real-time flood forecasting with an adaptive version of the stochastic Kalman filter algorithm have been suggested [5]. Soil moisture updating by ensemble Kalman filtering in real-time flood forecasting has been conducted for the 622 km^2 Kamp catchment in Austria [6]. These methods are difficult to use with small watersheds because the time interval of rainfall data in previous studies has been long. The time interval of rainfall data in a single urban drainage area is at least an hour, and the time of concentration in a single urban drainage area is less than that.

A neural network combined with various methods has been used for flood forecasting in previous studies. A neural network using the notion of basic ingredients was applied to flash flood forecasting, including ingredients-based forecasting [7]. A river flooding forecasting technique including flash flooding forecasting technique using a neural network has been suggested with 5 h prediction. [8]. Quantitative flood forecasting via neural networks using multisensory data in the watersheds ranging from 750 to 8700 km^2 has also been suggested [9]. A neural network and M5 model tree machine learning technique have been combined to perform flood forecasting with the process of training for the Huai River in China [10]. Flood forecasting has also been conducted using a neural network based on a genetic algorithm and adaptive network based fuzzy inference system in Yangtze River, China [11]. Additionally, the limitation of flash flood forecasting has been considered for the improvement of flash flood forecasting [12]. Flood forecasting techniques using a neural network require training and are time-consuming, and the application process is complex.

In these previous studies, the applied range in flood forecasting using the long interval rainfall data is not appropriate for a single urban drainage area requiring a short interval of time. Additionally, the applied flood forecasting process is complex because training and optimization techniques are required. Flood forecasting techniques in previous studies have been suggested for rivers, i.e., large, watershed applications, and the application processes of such techniques are complex. They are not suitable for small urban drainage areas, since the time of concentration is less than one hour. In this study, a new flood forecasting technique is proposed for predicting urban floods easily and quickly via a flood nomograph application. The flood nomograph was generated from the results of rainfall runoff simulations using synthetic rainfall data. A historical rainfall event was applied to the flood nomograph, and the results of this application were analyzed.

2. Methodologies

2.1. Overview

A flood nomograph means the threshold for flooding in the target watershed by rainfall events. A flood nomograph is made by applying synthetic rainfall events of various frequencies and durations. Synthetic rainfall is used as input data for rainfall runoff simulations, and it is essential for the generation of a flood nomograph. The initial amount of rainfall is 1 mm, which increases in 1 mm increments until flooding occurs. The amount and duration of each rainfall event are recorded when flooding occurs, and the first flooding rainfall amounts are converted to the first flooding rainfall intensities for each event. The first flooding rainfall intensities are checked in a graph, and a regression equation is generated. The threshold by the regression equation is the flood nomograph, which is used for flood forecasting. This study consists of several steps, from the generation of rainfall data to the discussion of flood forecasting.

1. Synthetic rainfall data were generated to obtain the first flooding node and amount for each duration via rainfall runoff simulations.
2. The initial rainfall runoff simulation with 1 mm of rainfall was initiated.
3. Rainfall runoff simulations were conducted continuously for 1 mm increments of rainfall until flooding occurred.
4. The first flooding rainfall amounts for various rainfall durations were checked.
5. The first flooding rainfall amounts were converted to the first flooding rainfall intensities.
6. The first flooding rainfall intensities were expressed in a graph.
7. A regression curve was generated from the regression equation of the first flooding rainfall intensities.

8. The regression curve is the threshold of the flood nomograph.
9. A historical rainfall event in the target watershed was applied to the flood nomograph.
10. The results of applied historical rainfall event in the flood nomograph were discussed.

2.2. Generation of Synthetic Rainfall Data

Synthetic rainfall data is required for obtaining flood nomographs using rainfall runoff simulations. The design of drainage facilities in Korea is based on the synthetic rainfall data per Huff distribution [13]. A Huff distribution consists of four quartiles according to the location of peak values. The third quartile of the Huff distribution is appropriate for the design of drainage facilities in Korea [14]. The regression equations for the first, second, third, and fourth quartiles of the Huff distribution are shown in Equations (1)–(4), respectively [15]:

$$P_r = 46.650{T_r}^6 - 149.92{T_r}^5 + 183.11{T_r}^4 - 104.670{T_r}^3 + 26.397{T_r}^2 - 0.5686T_r - 0.0019 \quad (1)$$

$$P_r = -41.103{T_r}^6 + 127.68{T_r}^5 - 144.14{T_r}^4 + 67.994{T_r}^3 - 10.324{T_r}^2 + 0.8843T_r - 0.0004 \quad (2)$$

$$P_r = 34.763{T_r}^6 - 97.703{T_r}^5 + 97.085{T_r}^4 - 41.707{T_r}^3 + 8.9582{T_r}^2 - 0.3974T_r + 0.0008 \quad (3)$$

$$P_r = -16.552{P_r}^6 + 40.907{P_r}^5 - 37.454{P_r}^4 + 16.415{P_r}^3 - 2.6978{P_r}^2 + 0.3827P_r - 0.0008 \quad (4)$$

where P_r is the cumulative rainfall ratio, and T_r is the cumulative time ratio. The generation of synthetic rainfall data consists of three steps. First, the cumulative distribution per Huff distribution is generated according to the regression equations. Second, the cumulative distribution is converted to the dispersed distribution. Third, the amount of rainfall is applied to the dispersed distribution, and the synthetic rainfall event is obtained [16–20]. The type of regression equations for the Huff distribution is cumulative distribution. Figure 1 shows the generating process of synthetic rainfall data using the Huff distribution.

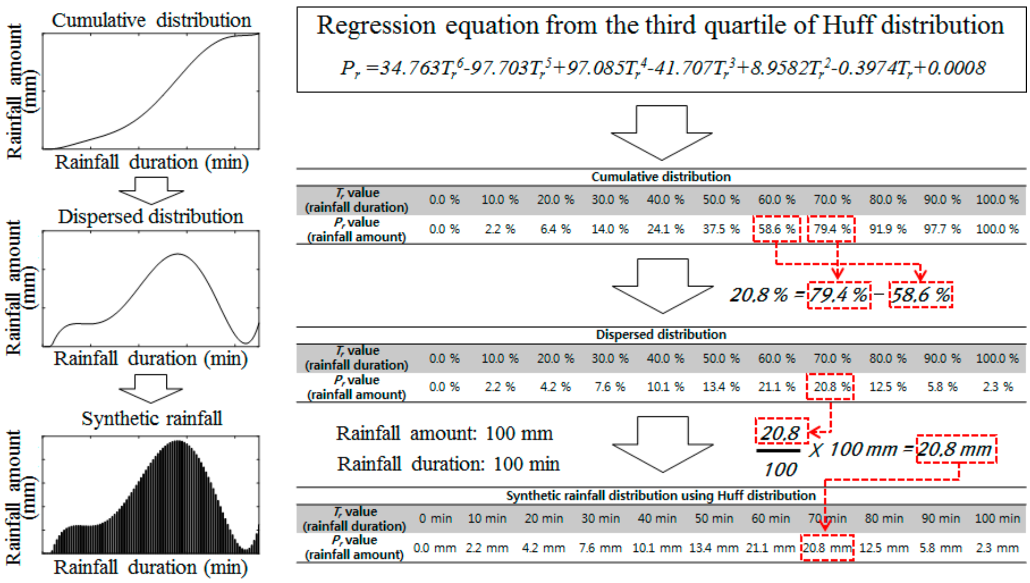


Figure 1. Generating process of synthetic rainfall data using the Huff distribution.

The rainfall runoff simulations using synthetic rainfall data generated via Huff distribution are conducted for the selection of the first flooding node. The selection of synthetic rainfall distribution for the selection of the first flooding node is based on the synthetic rainfall distribution used in the design of the urban drainage system in the target watershed. If a specific rainfall distribution is used in the design of the urban drainage system in the target watershed, a specific rainfall distribution should be chosen for the selection of the first flooding node. This means that the design and flood forecasting of urban drainage systems should be conducted using the same rainfall distribution.

The total amount of synthetic rainfall data in this section is distributed from 1 mm to the first flooding amount at each duration. The third quartile of the Huff distribution is used if the design of the target watershed is based on the third quartile of the Huff distribution though the distribution of real rainfall data can be different from it of synthetic rainfall data used in this method. The rainfall used in the flood forecasting by the flood nomograph was matched to the rainfall used in the design of the drainage network because it is difficult to consider all types of rainfall data in the flood forecasting as well as in the design.

2.3. Selection of the First Flooding Node for the Flood Nomograph

Selection of the first flooding node in urban drainage systems was used to select the monitoring node for the operation of drainage facilities, such as centralized and decentralized reservoirs in previous studies [16–18,20]. The decentralized reservoir upstream of the drainage network reserves the inflow from the drainage network if the water level of the monitoring node is high, and discharges inflow if the water level of the monitoring node is low. In the case of the centralized reservoir downstream of the drainage network, drainage pumps in the centralized reservoir are operated early if the water level of the monitoring node is high, and are normally operated if the water level of the monitoring node is low.

The initial amount of synthetic rainfall data in rainfall runoff simulations for the search of the first flooding node is 1 mm, which increases in 1 mm increments until flooding occurs. The first flooding node is selected, and its amount is checked when flooding occurs. The node where there is flooding is called the first flooding node when the flooding firstly occurs. The rainfall amounts of many first flooding nodes selected through this process are converted to rainfall intensities. The rainfall intensities constitute the flood nomograph, which is the threshold for flood forecasting. A flow chart for making a flood nomograph with the first flooding nodes is shown in Figure 2.

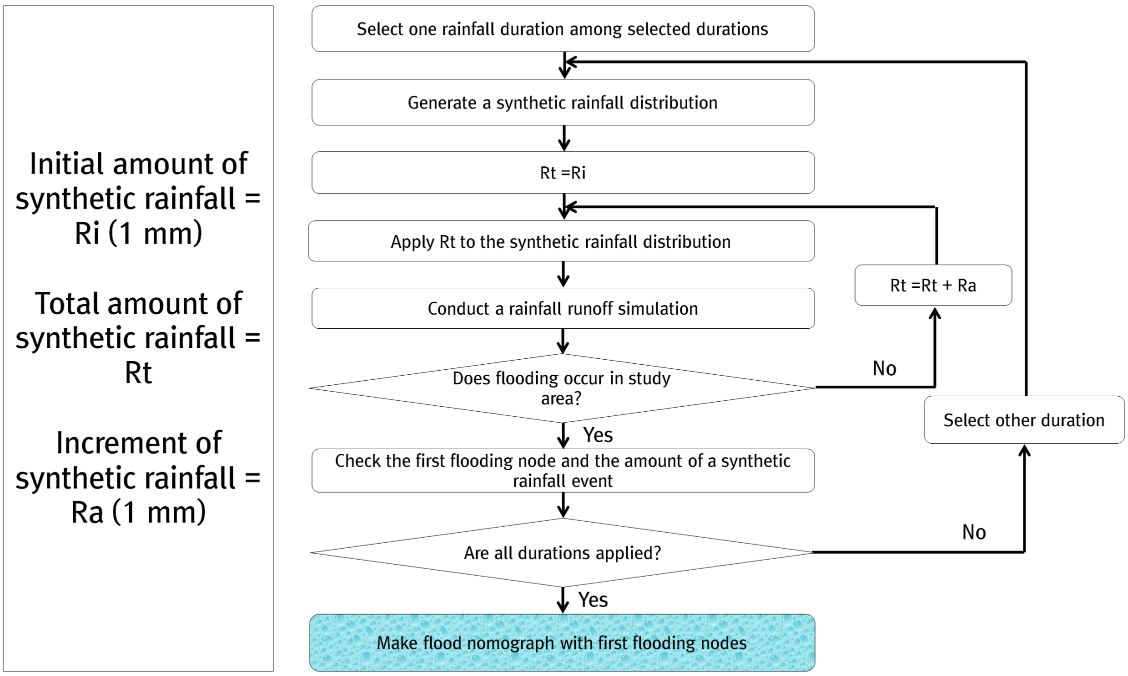


Figure 2. Flow chart for making a flood nomograph with the first flooding nodes.

The first thing to be assumed is that the flood nomograph should be generated by the synthetic rainfall used on the design of the drainage network. The selection of the first flooding nodes consists of several steps. One duration among various rainfall durations is chosen for the selection of the first flooding node. A synthetic rainfall distribution including the selected quartile for the Huff distribution is generated, and appropriate additional information is required if the rainfall distribution is different. The total amount of the synthetic rainfall is the initial amount of the synthetic rainfall (1 mm). The total amount of the synthetic rainfall is applied to the synthetic rainfall distribution. Flooding occurrence (whether flooding occurs or not) is examined via a rainfall runoff simulation. If flooding occurs, the first flooding node and the total amount of rainfall are checked. If flooding does not occur, the total amount of synthetic rainfall increases in 1 mm increments. This process is repeated until flooding occurs. Another duration is selected, and the same process is performed after the first flooding node and the total amount of rainfall are checked.

For making flood nomographs, the rainfall amounts of the first flooding nodes should be converted to rainfall intensities. The rainfall runoff model used for flood nomographs should be able to show the flooding volume in all nodes. The results for the first flooding nodes at various durations increase the accuracy of the flood nomograph for flood forecasting. It is appropriate to apply the quartile used in the design of drainage facilities, though various quartiles of the Huff distribution can be used for the generation of flood nomographs.

2.4. Concept of Flood Nomographs

The concept of flood nomographs is based on the flood forecasting using the same rainfall distribution used in the design of urban drainage systems including centralized and decentralized reservoirs. The target watershed is inundated if the intensity of the applied rainfall is higher than the rainfall intensity of the first flooding node. Using predicted rainfall data requires that the units of the predicted and real rainfall data should be identical. The inter-event time should be defined for the application of real rainfall events because real rainfall events continuously start and stop during rainy seasons. The inter-event time means the time interval between rainfall events. The inter-event time in a flood nomograph can be set to the time of concentration in the target watershed. For example, the latter rainfall event is newly applied to the flood nomograph if the time interval between two real rainfall events is longer than 30 min when the time of concentration in the target watershed is 30 min. In contrast, the present rainfall is continuously applied to the flood nomograph if the time interval between two real rainfall events is shorter than 30 min. Figure 3 shows a schematic of flood forecasting via flood nomographs.

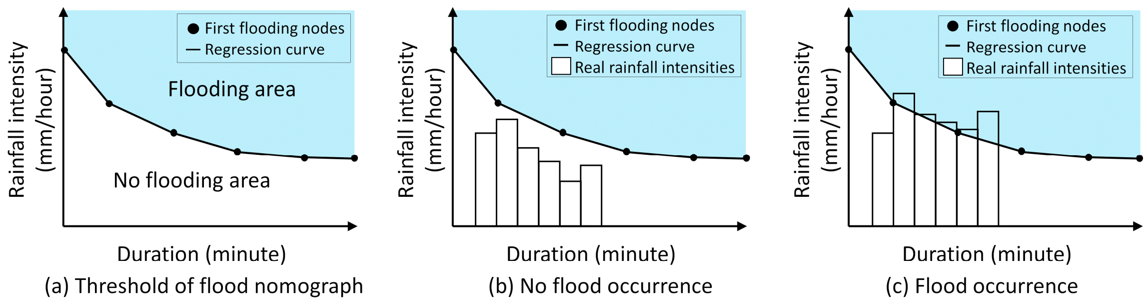


Figure 3. Schematic of flood forecasting via flood nomographs.

In Figure 3a, the rainfall amounts of the first flooding nodes are converted to rainfall intensities. Rainfall intensities are elements of the threshold in a flood nomograph. The threshold of a flood nomograph, as shown in Figure 3a, is generated from the regression curve of first flooding rainfall intensities. In Figure 3b, the rainfall intensities of the real rainfall event are lower than the threshold of the flood nomograph. This means that the real rainfall event is not extreme enough to cause floods in the target watershed. In Figure 3c, the rainfall intensities of the real rainfall event are higher than the threshold of the flood nomograph, which means that floods can be caused by the real rainfall event.

3. Applications and Results

3.1. Study Area

Korea has several metropolitan cities, such as Seoul, Busan, Incheon, Daegu, Ulsan, and Gwangju. Among these, Busan is the largest port city in Korea and has experienced several historical flood events. The Suyeong River flows through the center of Busan. This river has several tributaries, one of which is Oncheon Stream. Oncheon Stream also has tributaries, such as Geoje Stream and Sangmi Stream. Drainage areas adjacent to Geoje and Sangmi Streams were inundated in 2009. The upstream and midstream reaches of Geoje and Sangmi Streams are channels covered by roads. Downstream, the two streams join and flow into Oncheon Stream. Figure 4 presents geographical information regarding the target area.

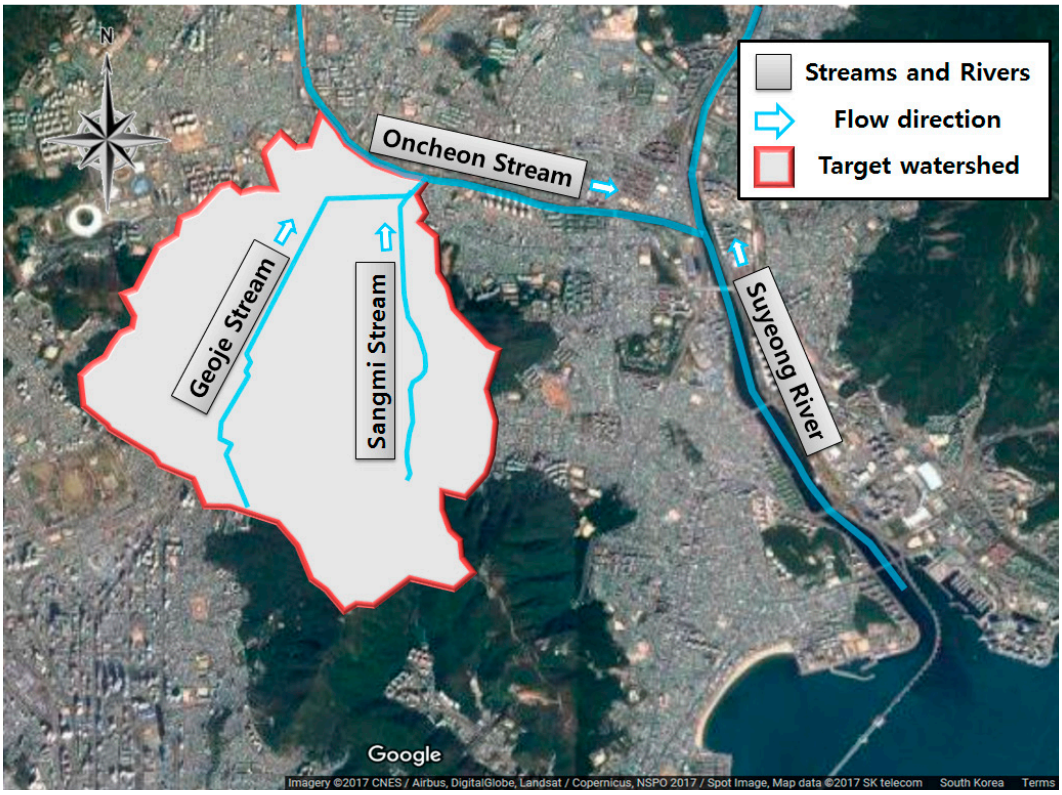


Figure 4. Geographical information of the target area (Imagery © 2017 Centre National d'Etudes Spatiales/Airbus, DigitalGlobe, Landsat/Copernicus, NSPO 2017/Spot Image, Map data © SK telecom).

Geoje and Sangmi Streams were located in the target watershed. The lengths of Geoje and Sangmi Streams are 4.26 and 2.87 km, respectively. The area of the target watershed is 9.65 km^2. The Storm Water Management Model (SWMM) 5.0 was selected for the rainfall runoff simulations and applied to the target watershed [21]. Information on the drainage network in the target watershed is based on the geographic information system (GIS) data for Busan provided by the Busan Metropolitan Government. The drainage system in the target watershed has 195 subcatchments, 195 nodes, and 195 links. Figure 5 shows the drainage network of the target watershed.

The outlet of the drainage network in the target watershed is located in the north of the target drainage area. Figure 5 includes additional information of the node elevations and link diameters. The slope in the target watershed is steep, so the time of concentration is short because the difference between the lowest and highest elevations is over 100 m. In the target watershed, the main conduits are rectangular and the branch conduits are circular. Figure 6 shows the validation of the drainage network matching the flooding area in the target watershed [22].

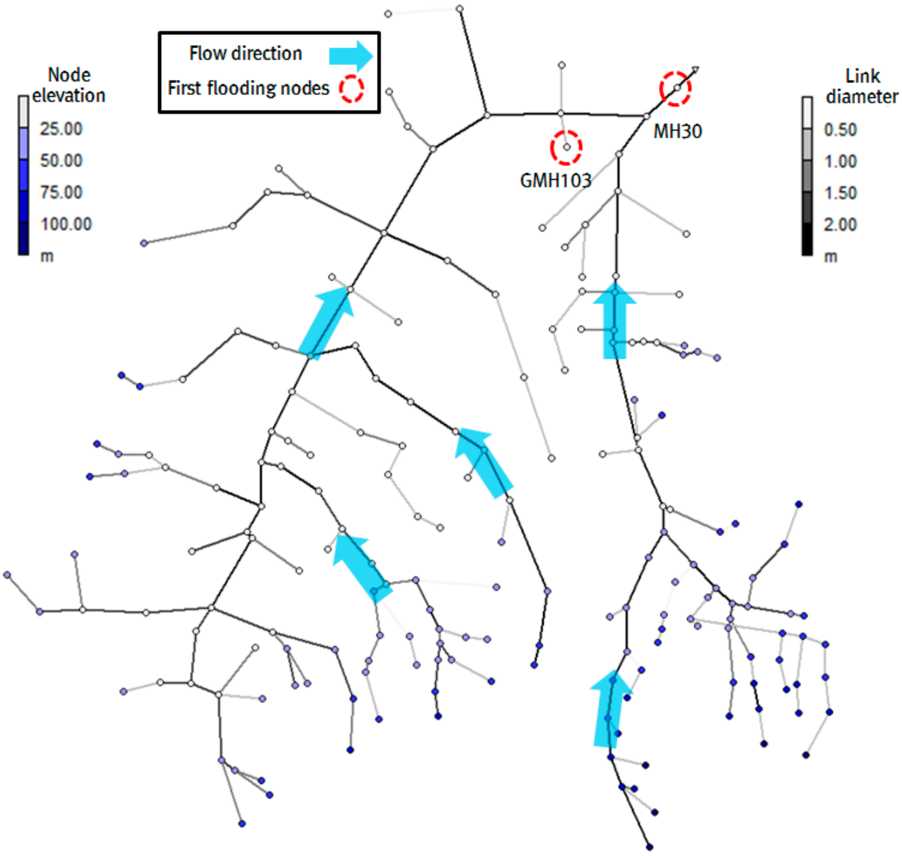
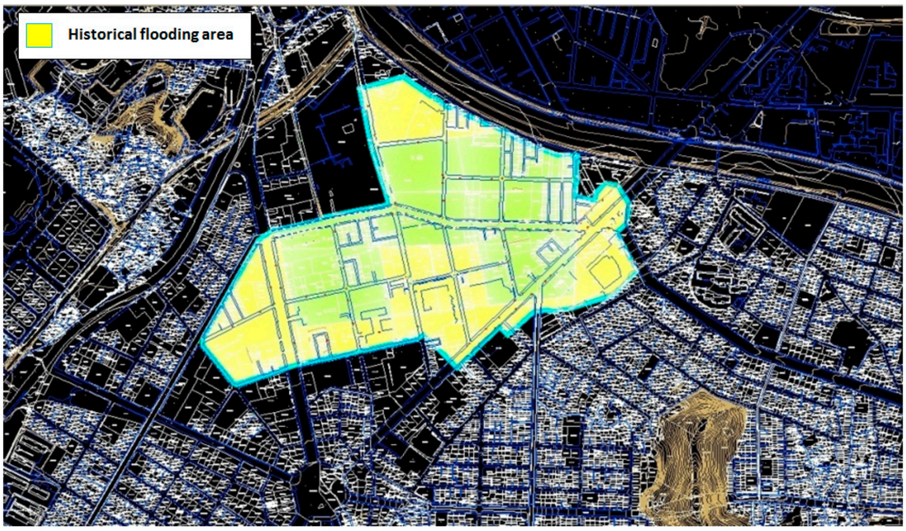
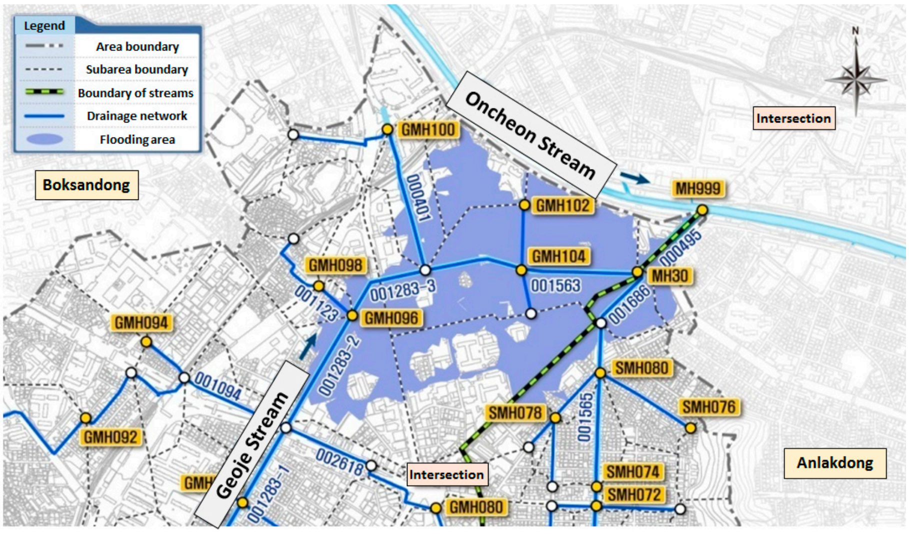


Figure 5. Drainage network of the target watershed.



(a) Historical flooding area in target watershed

Figure 6. *Cont.*



(b) Simulated flooding area in target watershed

Figure 6. Validation of the drainage network matching the flooding area in the target watershed.

3.2. Selection of the First Flooding Nodes

The distribution of synthetic rainfall data is based on the design of the drainage network in the target watershed. In this study, the design of the drainage network is conducted via the third quartile of the Huff distribution. The selection of the first flooding nodes are also based on rainfall runoff simulations using the third quartile of the Huff distribution as input. The rainfall data for obtaining the first flooding nodes has the same distribution and different amount in the selection of the first flooding nodes.

The generation of the flood nomograph was based on the selection of the first flooding nodes in the target watershed. Synthetic rainfall durations were distributed from 10 to 1440 min, which were applied to rainfall runoff simulations for obtaining the results of the first flooding nodes. As mentioned above, the initial amount of rainfall was 1 mm, which increased in 1 mm increments until flooding occurred. The results of the first flooding nodes, including rainfall amounts and intensities, are shown in Table 1.

Table 1. Results of the first flooding nodes.

Duration (Minutes)	**10**	**30**	**60**	**120**
Node (rainfall amount) Node (rainfall intensity)	GMH103 (30 mm) GMH103 (180 mm/h)	GMH103 (46 mm) GMH103 (92 mm/h)	GMH103 (86 mm) GMH103 (86 mm/h)	GMH103 (130 mm) GMH103 (65 mm/h)
Duration (Minutes)	**180**	**360**	**720**	**1440**
Node (rainfall amount) Node (rainfall intensity)	MH30 (130 mm) MH30 (43.3 mm/h)	MH30 (130 mm) MH30 (21.7 mm/h)	MH30 (130 mm) MH30 (10.8 mm/h)	MH30 (130 mm) MH30 (5.4 mm/h)

As shown in Table 1, Node GMH103 is the first flooding node until 120 min, and Node MH30 is the first flooding node after 120 min. These two nodes are located downstream of the drainage network in the target watershed. For durations shorter than 120 min, Node GMH103 was used as the threshold, and for durations longer than 120 min, Node MH30 was used as the threshold. The total rainfall amounts after 120 min remained constant. This means that the maximum allowable volume of the drainage network in the target watershed was approximately 130 mm.

In previous studies, the first flooding node for the operation of drainage facilities was selected in the main conduits [16–20]. All drainage conduits in Korea are classified as main or branch conduits according to the product (CA) of runoff coefficient (C) and the drainage area (A) [16]. If the value of CA is larger than 0.12 km^2, a conduit is classified as a main conduit. If the value of CA is smaller than 0.12 km^2, a conduit is classified as a branch conduit. In this study, the first flooding for flood forecasting was selected for all conduits, i.e., the main and branch conduits.

3.3. Generation of the Flood Nomograph

Generation of the flood nomograph required the regression curve from the first flooding rainfall intensities. The first flooding rainfall intensities were expressed in a graph, and the regression equation of the first flooding rainfall intensities was generated. The regression curve from the regression equation is the threshold for determining the flood forecast. The type of the regression equation is not limited, but the form of a power function can be recommended for easy application. Figure 7 shows the process of generating the flood nomograph.

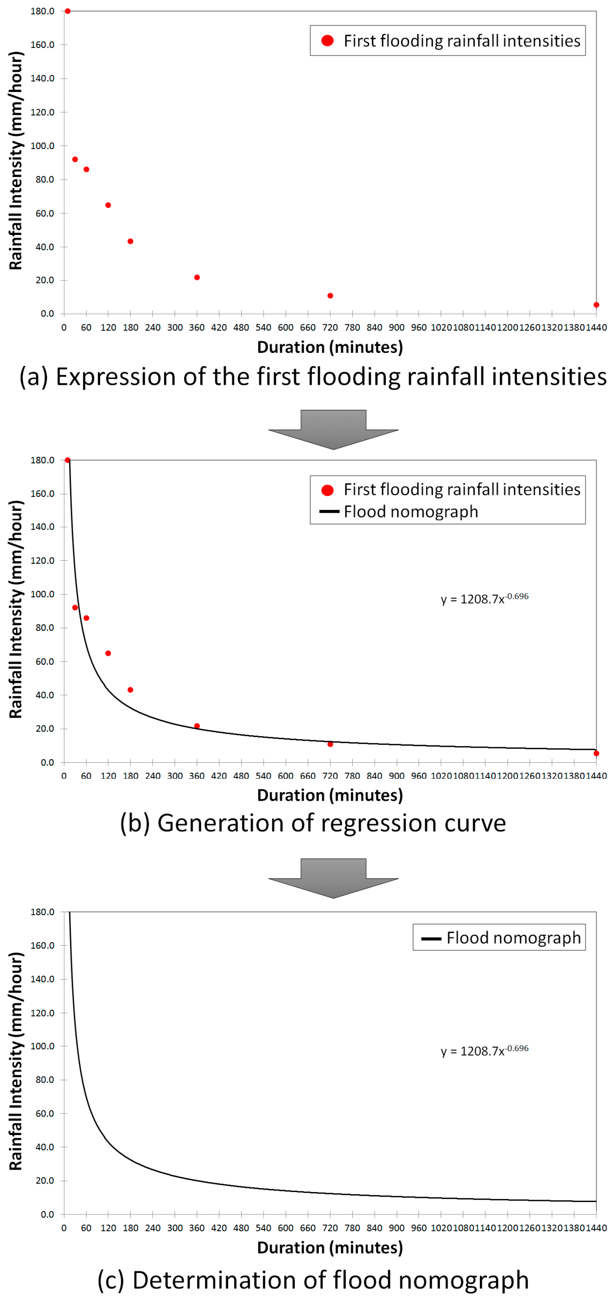


Figure 7. Process for generating the flood nomograph.

In Figure 7a, the first flooding intensities converted by the first flooding volumes are expressed in a graph. The regression curve from the first flooding intensities was generated (Figure 7b). As shown in Figure 7c, the threshold of the flood nomograph was produced for flood forecasting. It is possible to use a threshold connecting the first flooding intensities if it is difficult to use a regression equation.

3.4. Application of Rainfall Data to Flood Nomograph

The historical rainfall data for 7 July 2009 was selected for application of rainfall data to the flood nomograph. The Korea Meteorological Administration provides a 3 h predicted rainfall to the public [23]. It is hard to show the details of all application processes because it is too long. If the applied rainfall data are for 1 or 5 min increments, precise flood forecasting is possible, though the process becomes long. Figure 8 shows the application of the flood nomograph.

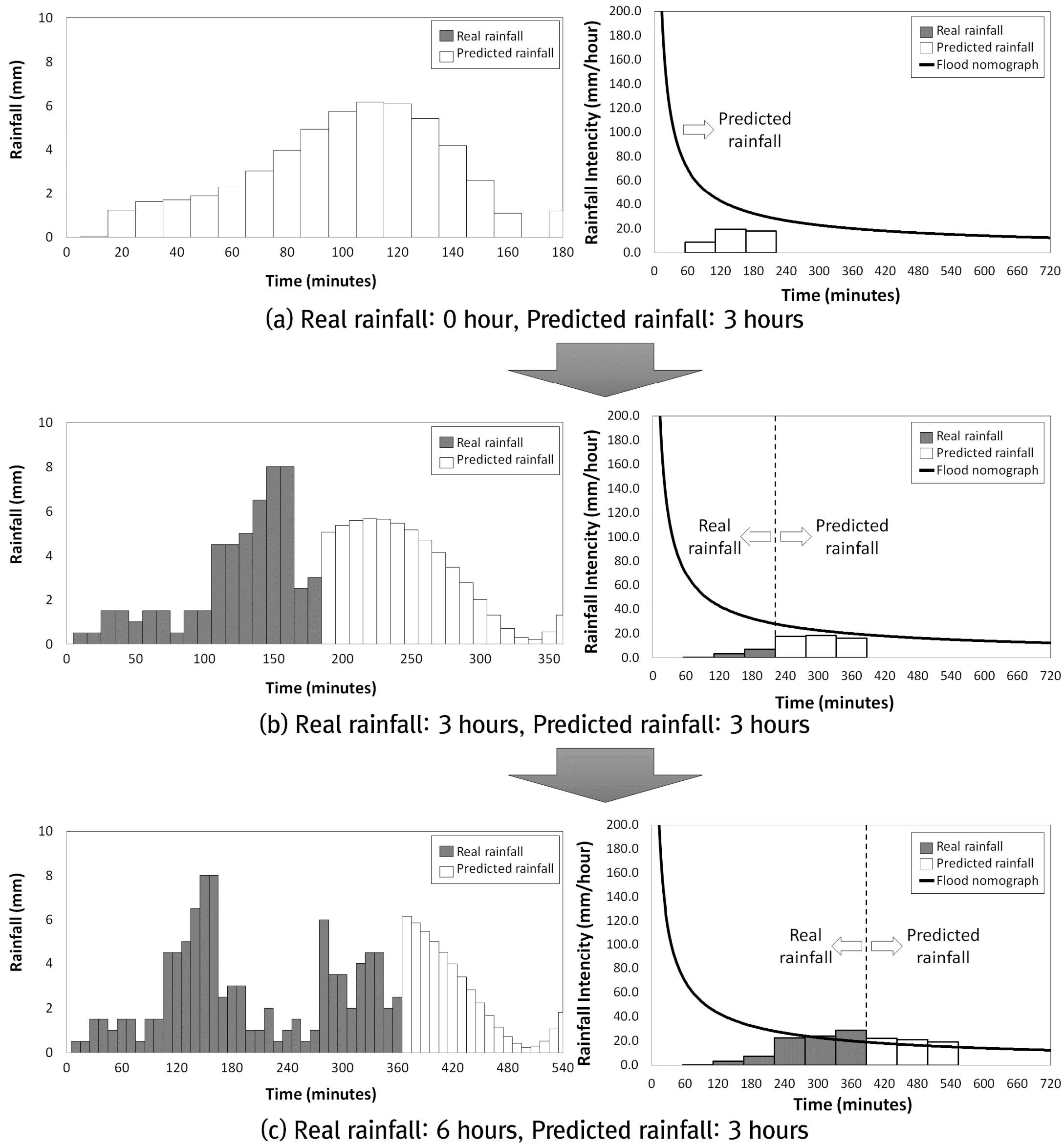


Figure 8. *Cont.*

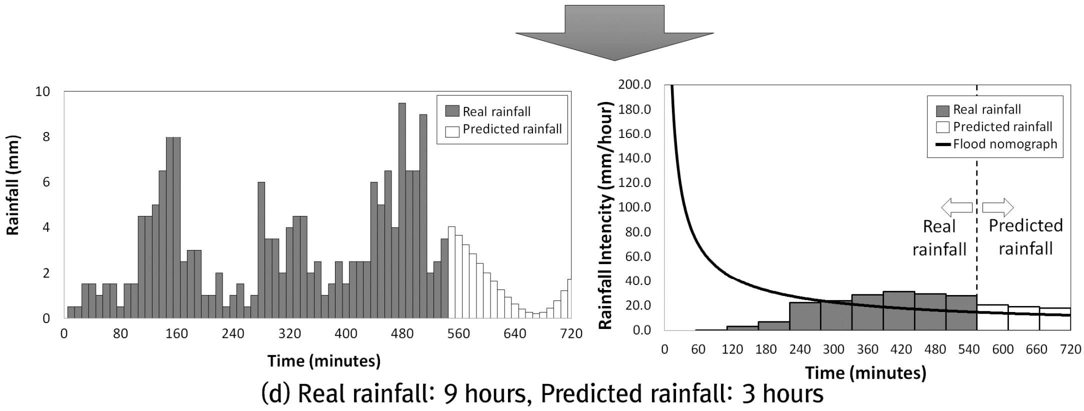


Figure 8. Application of rainfall to the flood nomograph.

In Figure 8a, the predicted rainfall (3 h duration) is applied to the flood nomograph, and it shows the initial status of the application of the flood nomograph for flood forecasting. The predicted rainfall intensity shown in Figure 8a is lower than the threshold of the flood nomograph. In Figure 8b, the real rainfall (3 h duration) and predicted rainfall (3 h duration) are applied to the flood nomograph. The real and predicted rainfall intensities shown in Figure 8b are lower than the threshold of the flood nomograph. In Figure 8c, the real rainfall (6 h duration) and predicted rainfall (3 h duration) are applied to the flood nomograph. The real and predicted rainfall intensities shown in Figure 8c are higher than the threshold of the flood nomograph. This means that flooding is occurring and is predicted to continue. The results shown in Figure 8d are similar to the results shown in Figure 8c because the real (9 h duration) and predicted rainfall (3 h duration) intensities are higher than the threshold of the flood nomograph.

3.5. Comparison of Flood Forecasting Techniques

Flood forecasting in Korea is based on water level of rivers/streams and Korea Government announces the locations for flood forecasting. The process of flood forecasting in Korea consists of four steps such as collecting hydrological data, flood/water level analysis, flood/water level control, and flood forecasting. Hydrological data includes rainfall data and water level data of rivers/streams. There are runoff and water level analysis in flood/water level analysis. Flood/water level control means the determination of anticipative discharging storage in dams. In the last step, flood forecasting is announced in all adjacent areas.

Flood forecasting in urban areas has several requirements compared with other flood forecasting because there are concentrations of population, increases in pavement area, small drainage areas, and short times of concentration in urban areas. Table 2 displays the requirements of the flood nomograph and other flood forecasting techniques.

Table 2. Requirements of the flood nomograph and other flood forecasting techniques.

Classification	Other Flood Forecasting Techniques	Flood Nomograph
Target watershed	Large drainage area	Small drainage area
	Small impervious area	Large impervious area
	Long time of concentration	Short time of concentration
Rainfall data	Gauged by radar or telemeter	Measured by simple rainfall gauge
	Gauged time interval over 1 h	Gauged time interval from 1 min
Drainage system	Flood forecasting by hydrological flood routing	Flood forecasting combined with urban drainage system
	System built around stream and river	Reflection of operation in pump stations and reservoirs

4. Conclusions

Flood forecasting is a non-structural measure because it requires no time or cost. In previous studies, various flood forecasting techniques have been developed and suggested. This simple new flood forecasting technique was needed because training time is essential for applying current flood forecasting techniques. The purpose of flood forecasting is to prevent damage to life and property. The new flood forecasting technique proposed in this study is based on the selection of the first flooding node in the drainage network of a target watershed. The first flooding nodes in each duration are obtained from rainfall runoff simulations using the synthetic rainfall data per Huff distribution. A Huff distribution consists of four quartiles according to the location of peak values. The design of drainage facilities in Korea is generally based on the third quartile of the Huff distribution. The initial rainfall amount as input data for rainfall runoff simulations is 1 mm, which increases in 1 mm increments until flooding occurs. If flooding occurs, the flooding node and the rainfall amount are checked. The results of the first flooding nodes are converted to the first flooding rainfall intensities, and the threshold per the regression equation based on the results of the first flooding rainfall intensities is the flood nomograph. The characteristics of flood nomograph is the following strong and weak points.

- The rainfall data is only required in the application of a flood nomograph.
- The flood nomograph can be applied to a single drainage area with a small watershed.
- Rainfall data with various time intervals are applicable to the flood nomograph.
- A new flood nomograph should be created when the target watershed is changed.
- Many flood nomographs are required when the flood nomograph is applied to a large watershed.

The results of the flood nomograph can be different from the results of flood damage because the flood nomograph is based on flood volume. The drainage area including Geoje and Sangmi Streams in Busan was selected as the target watershed for our flood nomograph application. The historical rainfall data for 7 July 2009 and predicted rainfall data from the Korea Meteorological Administration were applied to the flood nomograph in the target watershed. The interval of the applied rainfall data, including the historical and predicted rainfall data, was 10 min. If the intervals of the applied rainfall data are small, flood forecasting is more precise. The flood forecasting technique via flood nomograph can be easily applied to all drainage areas because it only requires rainfall data. Additionally, the flood nomograph in this study can be improved considering the status of the drainage network. In future studies, flood damage instead of flood volume will be used to generate the flood nomograph. The operation of drainage facilities in urban areas can be combined with flood forecasting using the flood nomograph.

Acknowledgments: This research was supported by a grant (17AWMP-B066744-05) from the Advanced Water Management Research Program funded by the Ministry of Land, Infrastructure, and Transport of the Korean government.

Author Contributions: Eui Hoon Lee and Deok Jun Jo carried out the survey of previous studies. Eui Hoon Lee wrote the manuscript. Eui Hoon Lee conducted all rainfall runoff simulations. Eui Hoon Lee, Joong Hoon Kim, Yeon Moon Choo, and Deok Jun Jo conceived the original idea of the proposed method.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Beven, K.J.; Kirkby, M.J.; Schofield, N.; Tagg, A.F. Testing a physically-based flood forecasting model (TOPMODEL) for three UK catchments. *J. Hydrol.* **1984**, *69*, 119–143. [CrossRef]
2. Garrote, L.; Bras, R.L. A distributed model for real-time flood forecasting using digital elevation models. *J. Hydrol.* **1995**, *167*, 279–306. [CrossRef]
3. Toth, E.; Brath, A.; Montanari, A. Comparison of short-term rainfall prediction models for real-time flood forecasting. *J. Hydrol.* **2000**, *239*, 132–147. [CrossRef]
4. Jasper, K.; Gurtz, J.; Lang, H. Advanced flood forecasting in Alpine watersheds by coupling meteorological observations and forecasts with a distributed hydrological model. *J. Hydrol.* **2002**, *267*, 40–52. [CrossRef]

5. Young, P.C. Advances in real–time flood forecasting. *Math. Phys. Eng. Sci.* **2002**, *360*, 1433–1450. [CrossRef] [PubMed]
6. Komma, J.; Blöschl, G.; Reszler, C. Soil moisture updating by Ensemble Kalman Filtering in real-time flood forecasting. *J. Hydrol.* **2008**, *357*, 228–242. [CrossRef]
7. Doswell, C.A., III; Brooks, H.E.; Maddox, R.A. Flash flood forecasting: An ingredients-based methodology. *Weather Forecast.* **1996**, *11*, 560–581. [CrossRef]
8. Campolo, M.; Andreussi, P.; Soldati, A. River flood forecasting with a neural network model. *Water Resour. Res.* **1999**, *35*, 1191–1197. [CrossRef]
9. Kim, G.; Barros, A.P. Quantitative flood forecasting using multisensor data and neural networks. *J. Hydrol.* **2001**, *246*, 45–62. [CrossRef]
10. Solomatine, D.P.; Xue, Y. M5 model trees and neural networks: Application to flood forecasting in the upper reach of the Huai River in China. *J. Hydrol. Eng.* **2004**, *9*, 491–501. [CrossRef]
11. Chau, K.W.; Wu, C.L.; Li, Y.S. Comparison of several flood forecasting models in Yangtze River. *J. Hydrol. Eng.* **2005**, *10*, 485–491. [CrossRef]
12. Collier, C.G. Flash flood forecasting: What are the limits of predictability? *Q. J. Royal Meteorol. Soc.* **2007**, *133*, 3–23. [CrossRef]
13. Huff, F.A. Time distribution of rainfall in heavy storms. *Water Resour. Res.* **1967**, *3*, 1007–1019. [CrossRef]
14. Yoon, Y.N.; Jung, J.H.; Ryu, J.H. Introduction of design flood estimation. *J. Korea Water Resour. Assoc.* **2013**, *46*, 55–68.
15. Korea Precipitation Frequency Data Server. Available online: www.k-idf.re.kr (accessed on 27 July 2017).
16. Lee, E.H.; Lee, Y.S.; Joo, J.G.; Jung, D.; Kim, J.H. Flood Reduction in Urban Drainage Systems: Cooperative Operation of Centralized and Decentralized Reservoirs. *Water* **2016**, *8*, 469. [CrossRef]
17. Lee, E.H.; Lee, Y.S.; Joo, J.G.; Jung, D.; Kim, J.H. Investigating the Impact of Proactive Pump Operation and Capacity Expansion on Urban Drainage System Resilience. *J. Water Resour. Plan. Manag.* **2017**, *143*, 04017024. [CrossRef]
18. Lee, E.H.; Kim, J.H. Design and Operation of Decentralized Reservoirs in Urban Drainage Systems. *Water* **2017**, *9*, 246. [CrossRef]
19. Lee, E.H.; Kim, J.H. Development of Resilience Index Based on Flooding Damage in Urban Areas. *Water* **2017**, *9*, 428. [CrossRef]
20. Lee, E.H.; Kim, J.H. Convertible Operation Techniques for Pump Stations Sharing Centralized Reservoirs for Improving Resilience in Urban Drainage Systems. *Water* **2017**, *9*, 843. [CrossRef]
21. United States Environmental Protection Agency. *Storm Water Management Model User's Manual Version 5.0*; EPA: Washington, DC, USA, 2010.
22. Busan Metropolitan Government. *Report on Design of Natural Disaster Maintenance in Geoje*; Busan Metropolitan Government: Busan, Korea, 2012.
23. Korea Meteorological Administration. Available online: www.kma.go.kr (accessed on 30 July 2017).

© 2018 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (http://creativecommons.org/licenses/by/4.0/).