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Web-based assessment for flood forecasting and warning systems

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ABSTRACT

The web-based assessment for flood forecasting system (WAFFS) was developed to evaluate the flood forecasting and warning system and to revise the existing management overview for flood forecasting system (MOFFS) Ver.3 suggested by the World Meteorological Organization (WMO) in early 1990s. The WAFFS is an evaluation system that represents the results of the forecasting and warning system performance for classified flood forecast sites and the flood events of each flood forecast system with a concisely organized evaluation template. Using the developed WAFFS, the flood forecast systems of the four major Korean Rivers including the Han River, the Nakdong River, the Geum River, and the Yeongsan River were evaluated. The data necessary for WAFFS evaluation are provided by the web service, and the evaluation results for the member countries were managed by each country, region, and storm event. Through the web-based system, the more convenient data collection and evaluation system was established and it will lead more efficient decision making for diagnose and improve the current flood defense system.

Keywords: MOFFS; Flood forecast system; Decision support program; Planning and operating system

1. Introduction

The management overview for flood forecasting system (MOFFS) Ver.3 was developed in early 1990s as a standard to evaluate the operation performance of the various flood defense systems over the worlds by flood events and flood warning sites. This system had a simplified type of system evaluation methodology granting points based on the operating results for each item within the three main categories of the flood forecast and warning system [1]. The fundamental purpose of the MOFFS was to serve as a diagnosis tool to complement the system by grasping and presenting the most vulnerable part within each component that connects the whole system. The existing MOFFS needs improvement by including the new evaluation components e.g. the current obser vation and data transmission system such as meteorological radar and satellite devices, and the physically-based rainfall-runoff model, etc. When the MOFFS Ver.3 was applied for the current flood forecasting system in the Geum River basin, it showed that there were barely any disparities with the minimum requirement points

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(the minimum required (MR) specification of the system) because the most evaluation items achieved high performance points. Except for some items, the most items acquired the points that were associated with the MR points. The result was possible because the missing data rates had been significantly decreased by approximately 98%. High collecting rates of the field hydrological data can be obtained mainly due to the advancement of monitoring and data transmission equipment system technology. The main objective for developing the new web-based assessment for flood forecasting system (WAFFS) is to include the current advanced monitoring devices and analysis methodologies in flood forecasting and provide warnings in vulnerable areas.

In this research the existing evaluation items of the MOFFS Ver.3 were mostly revised by considering the recent technological advances. Moreover new additional items were suggested if necessary. The research included evaluation of the disaster prevention facilities, originally having three evaluation factors, namely, flood storage capacity, channel restructuring ratio, and facility operation and maintenance management. A fourth evaluation criterion was also created by including the flood control facility criteria within the disaster prevention facility evaluation. Moreover, by enhancing the existing point scoring method, the "Optimality Points (OP)" item was added in order to discover the weak components of the currently operating flood forecasting system in contrast to the optimum condition. The developed evaluation system was referred to as the WAFFS which resolved the deficiencies found by participants of the evaluation process, therefore helping the system adopt in different countries Typhoon Committee. The WAFFS revised the contradictory or irrational procedures drastically during the points granting process of the MOFFS. Furthermore, WAFFS also divided the whole evaluation framework into the system operation module and the system planning module in order to have features for the decision-making support program that can enhance the existing flood management system.

2. Background

The composition of MOFFS have been experiencing fundamental changes in forecasting rainfall compared to the past due to the use of the numerical weather prediction (NWP), hydrological radar, and artificial satellite [2, 3]. This change has been referred to as an "integrated hydrometeorologic service." The research for the "integrated hydrometeorologic service" including the "multi-objective" methods, ability in establishing the flood control alternative plan has also been intensively conducted in the United States—since the "great flood" in 1993 [4]. Though the warning system and emergency action plan for the flood protection cannot be perfect, and their standards should be differentiated according to each country's own circumstance, the fact that the United States operates advanced monitoring equipment and operating technologies is a very noticeable example. The current main issues and research examples for each component of the flood forecasting and warning system are presented in Table 1. Among these, the utilization of the quantitative precipitation forecast (QPF) and hydrologic radar are still evoking arguments in terms of accuracy, but they have been improved according to the developments in NWP, as well as the hydrologic radar's level of mechanical reliability, monitoring density, and quality control method. The utilization of the distributed rainfall-runoff model is still an issue comparing with the existing lumped rainfall-runoff model. However, it has been known that the physical process of the distributed rainfall-runoff model itself compared to the lumped rainfall-runoff model has advantages in simulating the hydrodynamic characteristics during the runoff process since the errors intrinsic to the hydrograph simulation results are mainly affected by the errors included in the physical or mathematical methodologies of the model itself and the input data [5].

On the other hand, in Europe, as a part of the EU's European Program on Climatology and Natural Hazard (EPOCH) program, the EURO Flood Research Task was executed from March 1992 to January 1994. As the result of the task, the flood forecasting, warning and response system (FFWRS) is currently in operation. This system had been evaluated in many countries, including Netherlands, The Great Britain (including Scotland, Northern Island, England, and Wales), Germany, France, and Portugal.

3. The evaluation structure of WAFFS

3.1. The evaluation components of the WAFFS

The flood forecasting system is a disaster prevention measure that has an appropriate plan that can protect human lives and properties from flood risks. In narrow scope, it refers to the non-structural system that forecasts floods and issues appropriate public warnings. However, in broader scope, this system includes facilities, such as the levees, storage facilities, and multipurpose dams as part of flood protection structures. Among these facilities, the main purpose of the flood forecasting system is to forecast the size of the flood and a certain time that this flood may occur with tolerable accuracy so that people could prepare appropriate responses to the flood within lead time in order to minimize human lives and property damages.

Table 1
Main issues and research cases for each component of the flood forecasting and warning system.

Flood forecast and warning items		Main issues	Research cases
General flood forecast	River flux model	Real-time correction of state variables using the extended Kalman filter	Georgakakos and Smith [6]
		Real-time parameter correction of the global optimization method	Sorooshian et al. [7]
General flood forecast	QPF	Hydrologic utilization of QPF	Stewart et al. [8], Hughes [9], Eiben and Philips [10], Eiben and Yess [11]
		QPF guidance	Krzysztofowicz and Drake [3], Junker [12], Glan et al. [13]
	Probabilistic QPF	Necessity of probabilistic QPF	Murphy [14]
		Quantitativeness of forecast uncertainty	Krzysztofowicz et al. [2]
Unpredicted flood forecast	Rainfall-runoff model	Rainfall monitoring density and monitoring cycle	Krejewski et al. [15]
		Necessity of the "Nowcasting" method	Michaud and Sorooshian [16]
	Radar rainfall monitoring	Necessity of hydrologic radar in flood forecast	James et al. [17], Amburn and Fortin [18], Vieux and Vieux [5]
		Hyper short time rainfall forecast using Doppler weather radar	Chen and Kavvas [19] Smith and Austin [20]
		Rainfall radar utilization in lumped rainfall-runoff model	Georgakakos and Krajewski [21]
		Rainfall radar utilization in distributed rainfall-runoff model	Vieux and Vieux [5]
	Rainfall forecast from multi sensing	Two-component model (physically based model + statistical autoregressive model)	Seo and Smith [22]
		Motion equation model	French and Krajewski [23]
Flood warning System	Multiobjective method	Annual flood damage estimation method	Haimes et al. [24]
		Weight value setting in dynamic programming	Li et al. [25]
	Bayesian method	Optimum decision rule considering economic benefit	Krzysztofowicz et al. [3]

The flood forecast system is a system composed of various components. When each component is connected as a network, the superiority and integrity of a flood forecasting system can be determined by the weakest components within the system just like any system's whole intensity is determined by the most vulnerable part of the network.

Based on the existing MOFFS, the WAFFS was developed (1) to be used as a diagnosis program to evaluate the weakness of the flood protection system for the specific basin, (2) to establish a flood control plan in order to enhance flood protection system's integrity level, and (3) to determine the order of priority. Therefore, while the MOFFS had limited its role to evaluating the flood forecasting and warning system itself, the WAFFS covers its role of evaluation from non-structural to structural flood protection facilities. The major evaluation components of the structural flood protection facility are composed of flood defense capability and operation system for an independent flood event. In other words, the structural flood protection evaluates the defects (the status of deficit from the MR condition) in the process of the flood forecasting system operation during the flood period. Evaluation systems like the WAFFS and existing MOFFS are based commonly on the point-based STIRIF [26] that had been efficiently applied to the water supply and drainage system management. The comparison of the scoring systems, which had been utilized among the STIRIF, MOFFS, and WAFFS is presented in Table 2. In particular, unlike the existing MOFFS, the WAFFS composed the detailed evaluation components under the upper frame of flood control infrastructure and flood control operation. The WAFFS would evaluate the following six items that belongs to the flood forecasting system. Table 3 presents the six evaluation categories of the flood forecasting system and the detailed evaluation components associated with the categories.

3.2. The scoring system

3.2.1. The maximum points (Max)

The maximum points (Max) refer to the points that are relevant to the circumstance in which the system was ideally composed and operated. Within the WAFFS, it assigned 30–55 points as the maximum points for each main evaluation item. Out of the total points of 250 for the six main evaluations, 110 points were

Table 2
The points granted items among the STIRIF, MOFFS, and WAFFS.

Sewage treatment works (STIRIF)	Flood forecasting systems (MOFFS Ver.3)	Flood forecasting systems (WAFFS)	
Site factors	Hydrometric facilities	Flood defense infra	Hydrometric facilities
Electrical/mechanical equipment	Data processing		Flood defense structures
Treatment processes	Issue of forecasts		Flood control office
Effluent compliance	–	Flood control operation	Data processing and treatment
Environmental aspects	–		Flood forecasting model
–	–		Issue of forecasting and warning

Table 3
The evaluation items for the WAFFS.

Section	Main evaluation items	Detailed evaluation items	Points
Flood defense infra	Using hydrologic monitoring facilities	Utilization of meteorologic forecasting data	50
		Satellite and radar data	
		Rainfall gauge network	
		Water level gauge network	
		Water level observatory standard	
	Flood protection infrastructure	Flood storage capacity	30
		Channel restructuring ratio	
		Facility operations and maintenances	
	Flood control office	Flood control facility	30
		Flood control office—number of operators	
		Flood control office—education programs	
		Sub total	110
Flood control operation	Data transmission and processing	Transmission system of meteorological forecasts	50
		Transmission system of satellite and radar data	
		Transmission of rainfall data	
		Transmission of water level data	
		Transmission of dam data	
	Flood forecasting model	Time needed to forecast flood	55
		Types of flood forecasting model	
		Reliability of forecasts	
		User interface environment	
Flood control operation	Issuing forecast and warning	Emergency action plan	35
		Dissemination to end user	
		Satisfaction level of forecast issuing for end user	
		Sub total	140
		TOTAL	250

specially granted for the flood protection facilities while 140 points were for the flood control operation. The Max was set for each detailed evaluation component which is associated with the six main evaluation categories. Among the detailed evaluation items, the biggest Max item was the "Reliability of Forecasts" item, in which 25 points were assigned, followed by the "Dissemination to End User" of forecast result and the information item, which had 15 points assigned. The Max for all the other detailed evaluation items were assigned as 10 points.

3.2.2. The minimum requirement points (MR)

In executing the flood forecasting tasks for all flood forecasting sites, there would be a MR demand for each technical item in order for the flood forecasting system to function efficiently. As the subjective points were judged by a operator in charge who had numerous experience with floods, the MR points refer to the points of the realistically optimum mixture for the facilities and operating systems that were built in relevant watersheds, while considering the watersheds' runoffs and rainfall characteristics, the importance of the watersheds (urban and/or natural watersheds), and the operating difficulties of the flood forecasting and warning system. As the discrepancy between the maximum points and the achievement points increase, the MR serves an important role as the core in determining the deficit points (D) and OP. If the MR is over-estimated, the OP of the system would be lower while the D would be higher. However, if the MR is under-estimated, D would be lower but OP would be higher. In this regard, it is critically important to set the optimum level of MR that can make both the deficit points (D) and the OP have the most realistic values.

3.2.3. The achievement points (A)

In executing the flood forecasting tasks for flood forecast sites, the points refer to the evaluation of the actually operating circumstances. For some detailed evaluation items, it is possible the achievement points (A) would be higher than the MR points. For example, in terms of monitoring the density, if there are more observatories that exist than the optimum monitoring density within a watershed, A would be higher than MR.

3.2.4. The deficit points (D)

The deficit points (D) are evaluated by calculating the absolute value of (A–MR) for each detailed evaluation item. If D is higher than MR, then D is considered to be zero (0). Zero (0) value of D indicates a flood forecasting system that has been operated under the minimum or better than MR condition. It is represented as a percentage of the sum D to MR, while it would be an indicator that shows how the system has been efficiently operated for each flood event.

3.2.5. The optimality points (OP)

The OP are evaluated for each flood event by calculating the value of (MR/Max × 100) for each detailed evaluation item. OP would be a criteria for evaluating the current objective flood forecasting system in order to see to what extent the flood forecasting system approaches the ideal flood forecasting system. In other words, if MR is equal to Max, the system manager aims at the most optimum and ideal status.

3.2.6. The evaluation process

A new user would go through the user registration process, while the previously registered user would see the evaluation results arranged for each basin and storm event. It is possible to make an evaluation report with the saved evaluation values from the previously executed evaluation by a user request. The overall evaluation process is shown in Fig. 1.

4. The case studies

4.1. The Han River

The Han River basin, which is located between the latitude and longitude of 36°30′ < 38°55N and 126°24′ < 129°02′E, is located in the central region of the Korean peninsular. As the longest river in South Korea, the river covers 23% of the nation with a basin size of 26,356 km^2 (including 8,455 km^2 in the northern region) and the length of 481.7 km (with the average being 55.80 km). There are a total of 153 rainfall stations within the basin with 96 water level stations installed with the 10 alarming sites (six at the Han River, two at the Imjin River and Anseong Creek) that can issue the flood forecast for the Han River region.

On July 12, 2006, at 16:30, a flood alert was issued at the Jeongok site. During the period, the river area had precipitation of 113.00 mm at the Kunnam Station, 145 mm at the Gomun Station, 192 mm at the Jookam Station, and 162.00 mm at the Bongam Station. When the alert was issued, the estimated water level measured by the flood control office was 7.00 m while the actual gauged water level was 7.06 m which shows good agreement between prediction and actual observation. From July 12, 2006 at 18:30, the rainfall started to decrease and the alert was withdrawn around 20:30.

4.2. The Nakdong River

The Nakdong River basin is located at the south-east region of the peninsular (127°29′–129°18′E, 35°03′–37°13′N).

It is the second largest river in Korea adjacent to the Han River basin to the north, the Geum River and Seomjin River basins to the west. The river basin forms 24.1% of the total country area with the basin size of 23,817 km^2 and length of 521.50 km. There are a total 202 rainfall stations and 140 water level stations. There are total of five multipurpose dams within the basin, namely the Andong Dam, Imha Dam, Hapcheon Dam, Namgang Dam, and Milyang Dam with 10 flood forecast alarming sites.

On July 17, 2006 at 16:00, a flood alert was issued at the Hyeonpoong site. As the forecast issued by the seasonal rain front impact, the rainfall had reached 139.00 mm for the Hyeonpoong region. During this period, the estimated water level of the Nakdong River Flood Control Office was 12.00 m while the actual

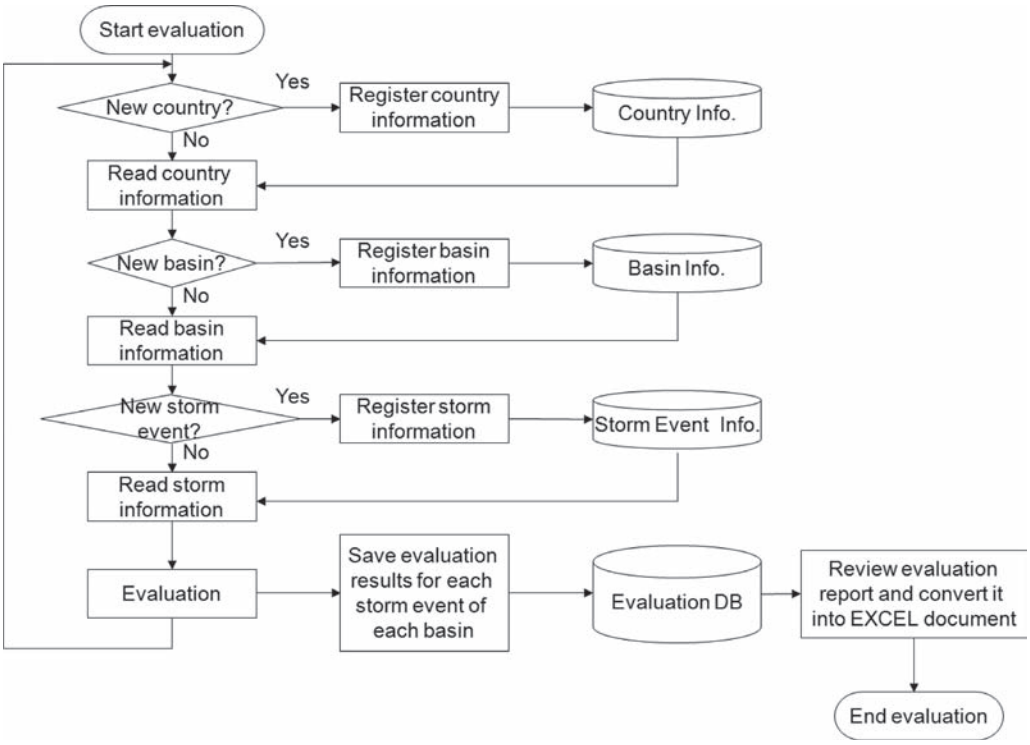

Fig. 1. Evaluation process and module structure in the WAFFS.

Table 4
The flood warning issuances in Han River basin in 2006.

Period	Section	Issued sites	Issued date	Remarks
July 12, 2006	Issuing flood alert	Jeonkok	July 12, 19:30	
	Withdrawing flood alert	Jeonkok	July 12, 20:30	

Table 5
The flood warning issuances in Nakdong River basin in 2006.

Period	Section	Issued sites	Issued date
July 17–19, 2006	Issuing flood alert	Hyeonpoong	July 17, 16:00
		Dongcheon	July 17, 16:00
	Withdrawing flood alert	Hyeonpoong	July 19, 21:00
		Dongcheon	July 17, 21:30

Table 6
The flood warning issuances in Geun River basin in 2004.

Period	Section	Issued sites	Issued date
June 19–23, 2004	Issuing flood alert	Seokwha	June 21, 05:00
	Withdrawing flood alert	Seokwha	June 21, 10:00

Table 7
The flood warning issuances in Yeongsan River basin in 2007.

Period	Section	Issued sites	Issued date
September 1–2, 2007	Issuing flood alert	Sintaein	September 1, 21:00
	Withdrawing flood alert	Sintaein	September 2, 02:00

gauged water level was 11.95 m so it could be regarded that the forecast was implemented properly.

4.3. The Geum River

The Geum River basin is located in the western region of the central part of the Korean peninsula (126°40′25″–128°03′53″E, 35°34′47″–37°03′03″N). As the third largest basin in the peninsula, it has the basin size of 9,911.83 km^2 and the length of 397.79 km. There are a total 99 rainfall stations within the basin and 102 water level stations. There are two multipurpose dams within the basin, namely the Yongdam dam and Daecheong dam, and total four flood forecasting alarming sites: Ganggyeong, Gyuam, Gongju, and Seokwha.

During the flood period of 2004, there had been several storm alerts, but the flood alert was issued just once on June 21. The storm occurred due to the monsoon (Jangma) frontal effects and the storm alert was issued at the North Choongcheong Province on June 19, at 04:00 and the drainage gate operation for the flood control of the Geum River estuary barrier had been carried out. At 23:00 on that day, the storm alert was replaced by the storm warning and the amount of rainfall on that day were ranged from 70.00 to 150.00 mm for the Geum River basin. At 06:00 on the next day, the flood warning was replaced with the storm alert. Then at 04:30 on June 21, the storm alert was back to storm warning again. The amount of rainfall on June 20 was about 100.00 mm, and the runoff volume was huge according to the amount of rainfall on June 19. Also, since the ground had already been totally saturated, the amount of rainfall on June 21 flowed rapidly out to the river. Therefore, the flood warning was issued due to the rapid water level rising from the Seokwha site in the Miho Creek, which is the first tributary of the Geum River rainfall system.

4.4. The Yeongsan River

One of the five important rivers in the Korean peninsula, the Yeongsan River is located in the North/South Jeonla Provinces in Korea (126°26′12″–127° 06′ 07″E, 34°40′ 16″–35° 29′ 01″N). The basin area of the Yeongsan River is 3,455 km^2 and its total length is 129.50 km. There are total 90 rainfall stations within the basin, and 100 water level stations have been installed. There are also total 10 flood forecast alarming sites.

On September 1, 2007 at 21:00, a flood alert was issued at the Sintaein site within the Dongsin River basin which is a tribunary of the Yeongsan River. During the period, the river area had precipitation of 127 mm for the Taein station, 118.00 mm for the Gobu station, 130.00 mm for the Sanoui station, 121.00 mm for the Bongam station, and 117.00 mm for the Gimjae station. When the alert was issued, the Yeongsan River Flood Control Office estimated the water level to be 5.00 m. The gauged water level was 5.14 m, so there was no significant gap between the estimated water level and the gauged water level.

5. The application results

In terms of the flood protection infrastructure category, there were some differences found among the four basins. The fact the low MR points showed a low "Optimality" for the Geum River reflect that the demand for infrastructures was not high enough since the Geum River basin was less damaged by flood. In fact, the infrastructures were actually being built in a relatively low level. On the other hand, the difference between the infrastructure demands and the Deficit points (*D*) of the actually built infrastructures of the Han River, Nakdong River, and Yeongsan River basins was not significant either. The application results of the WAFFS for the

Table 8
The WAFFS application results.

	Flood defense infra						Flood control operating system					
	Max	MR	A	D	D/MR (%)	OP (%)	Max	MR	A	D	D/MR (%)	OP (%)
Geum River	110	89	64	25	28.1	80.9	140	128	114	14	10.9	91.4
Han River		100	87	13	13.0	90.9		130	115	15	11.5	92.9
Nakdong River		102	85	17	16.7	92.7		130	113	17	13.1	92.9
Yeongsan River		100	86	14	14.0	90.9		128	112	16	12.5	91.4

D/MR: Deficit points with respect to minimum requirement points.

system operation category showed no significant differences (Table 8).

Compared to the Yeongsan River and the Nakdong River, the "satellite and radar data" item for the Han River basin was highly evaluated. For the Nakdong River, the "Flood storage capacity" item was highly evaluated compared to the Han River and the Yeongsan River. For the Yeongsan River, the "Flood control facility" item had a higher evaluation than those of the Han River and the Nakdong River. This is regarded as the result that is relevant to "when there is an updated manual within the recent 12 months" item, which is one of the evaluation items. The evaluation in this research for the flood forecasting models of the flood control offices in the Han River, Nakdong River, Yeongsan River, and the Geum River have shown a few differences in each evaluation components, However, the comprehensive analysis results do not indicate significant differences. If the data and information regarding the insufficient and well-performed parts among the flood control offices would be exchanged and developed later on, it would be possible to build a much more efficient flood forecasting model. In addition, if a high-tech flood forecasting system that uses the rainfall radar would be developed, the credible flood forecasting system that grasps the rapid rainfall volume (within 5 min) would be used and the local rainfall that goes through the region (which has no ground hydrometer among the existing target basins) would possibly be analyzed.

6. Results and discussions

The WAFFS is a system that presents the results of forecasting and warning system operations for classified flood forecast sites. The WAFFS also represents results of flood events of each flood forecasting system into a simplified concise evaluation template. In the 1980s the evaluations were primarily carried out on the printed data, such as graphic and numerical data, that had focused on the operating results of the flood forecasting and warning systems and the main countries for application were those enrolled in the World Meteorological Organization (WMO) Tropical Cyclone Program. However, that kind of evaluation methodology needed significant amount of time and effort and eventually failed to resolve complex problems, which led to the development of the MOFFS Ver.3. The MOFFS Ver.3 is a simple evaluation system that can evaluate the flood forecasting system quantitatively so that it could be vulnerable to an operator's standpoint. The methods that would make the system more objective were decided on and, in this regard, the web-based flood forecasting system was developed for the additional consideration of the evaluation items within the MOFFS Ver. 3. Using the developed WAFFS, the flood forecasting systems of the Han River, the Nakdong River, the Geum River, and the Yeongsan River in the Korea Peninsula were evaluated. The WAFFS data were provided by the web service, and the evaluation results of the member countries were managed as each country, region, and storm event. From now on, more evaluation and research should adopt the data (from different countries which are members of the Typhoon Committee) in order to compose technical guidelines. Through the web-based system, the more convenient data collection and evaluation system was established and it will lead more efficient decision making for diagnose and improve the current flood defense system.

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