

ESCAP/WMO Typhoon Committee

REPORT ON MOUNTAINOUS FLASH FLOOD FORECAST SYSTEM MANUAL

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REPORT ON MOUNTAINOUS FLASH FLOOD FORECAST SYSTEM MANUAL



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FOREWORD



ESCAP/ he WMOTyphoon Committee (TC) is an intergovernmental established body in 1968 under the auspices United Nations of Economic and Social Commission for Asia and the Pacific (ESCAP) and the World Meteorological Organization (WMO)

in order to promote and coordinate the planning and implementation of measures required for minimizing the loss of life and material damage caused by typhoons.

Despite being the most recent working group of the Committee, given that it was created in 2005, the Working Group on Disaster Risk Reduction (WGDRR) intends to work closely with the Working Group on Meteorology (WGM) and the Working Group on Hydrology (WGH), and contribute for an enhancedintegrationofallWMOobservingsystems through the establishment of a comprehensive, coordinated and sustainable structure ensuring the interoperability of its component observing systems, as it was recommended by the Fifteenth World Meteorological Congress (Geneva,7-25 May 2007).

It is hoped that this publication of the Working Group on Disaster Risk Reduction will contribute to greater participation of this working group in planning and implementing the new warning system for disaster risk reduction. The Flash Flood Forecast System (FFFS) has been pursuing the sharing of information in a timely and integrative way and should be managed in both top-down way via standardization and bottom-up way via implementation of each project under a specific purpose and target. The FFFS manual will be one of the best examples from the members of Typhoon Committee to allow for an integrated warning system of systems designed to improve the capability of Members to effectively provide a widening range of services and to better serve WGDRR research programme.

I am confident that this publication will be useful not

only for the members of Typhoon Committee but also for the other regional bodies of the Tropical Cyclone Programme of the World Meteorological Organization and for other members of WMO, in particular to their decision-makers, financial experts and emergency response managers, currently in the process of implementing and upgrading their respective observing systems, especially the end-to-end flash flood early warning systems, and educational institutions for training disaster awareness.

I congratulate the authors of this publication, expecting that the manual will be updated sooner or later following the improvement of FFFS. Meanwhile this manual will help the members of the TC to understand all the related information including data on flash flood, statistics and other information and knowledge. I would like to thank Dr. Jeong and other DRR experts for building the FFFS and giving all the basic material for this publication.

Samp Waon-Ho

(Chairman of Working Group on Disaster Risk Reduction) December 2010

EXECUTIVE SUMMARY

S udden violent storms and localized heavy rain frequently occur in Korea, especially recently, leading to serious disasters in mountain areas. These rainfall patterns are a direct cause of flash floods which leave large-scale damages in both urban and mountainous areas. Furthermore the impact of damages caused by flash floods show the magnitude of disasters has increased over time.

In urban areas, the number of casualties lost due to flash flooding is not as serious as that of rural areas, but property damage is high. Whereas flash floods that occur in mountainous regions have a huge impact on residents' lives. So the National Institute for Disaster Prevention (NIDP) established a plan to minimize damages and causalities in the valley of these regions by estimating flash floods in three hours and issuing an early warning within 20 to 40 minutes.

For this, the Flash Flood Forecasting System (FFFS) was established, with 4272 units in which 3 hours of rainfall are predicted using the McGill Algorithm for Precipitation nowcasting and Lagrangian Extrapolation (MAPLE). Among these, a total of 345 stations, including existing stations, were selected for the warning system. In the existing stations, rainfall is monitored and checked for warnings according to the Flash Flood Guidance Rainfall. New warning stations estimate rainfall by using AWS and MAPLE and then warn if the amount of rainfall has passed the limit line. Accuracy is determined by a separate expert system which predicts rainfall and compares it with measured data and the properties of the warning criteria are checking continuously.

This can be used for educational purposes of disaster risk reduction and international responses to climate changes and related flash flood events, as there are valuable examples and concrete figures of systems. Regardless of the competence of information technology and network environment, this FFPS with a proper manual will help each country understand the disaster behavior itself and the disaster mitigation strategy based on the statistics and reports.

I. INTRODUCTION

ecently, due to climate abnormality brought on by global climate change, severe, short-duration, sporadic and localized rainfalls occur frequently, resulting in considerable damage. In particular, flash floods in steep mountainous areas have caused fatalities and property damages. This is because 67% of the Korean peninsula is madeup of mountainous areas and because the country is affected by monsoon season. Also, the peninsula is located in the path of typhoons during the rainy season, resulting in heavy rainfalls frequently. Thus, flash flood occurrence will increase during the rainy season. For example, concentrated rainfall that took place between July 23 and 26, 2008 claimed eight lives and left about 0.3 billion USD of property damage in Bonghwa province, Kyungbook. Unfortunately, the Korean Meteorological Agency (KMA) and other government agencies were uninformed before this happened so they could not carry out any emergency procedures. Eventually, more damages occurred. Therefore, to minimize the damage by flash floods, there was the need to build a flash flood forecast system specifically for mountainous areas. To improve the accuracy of the flash flood prediction capability, the system should be integrated with the weather forecasting system operated by KMA. Based on those requirements, a flash flood forecast system for mountainous areas was developed.

II. THE COMPONENTS OF THE FLASH FLOOD FORECAST SYSTEM FOR MOUNTAINOUS AREAS

1. Archiving geographical data for flash flood risk areas

n this system, collected rainfall data which are used to explore the disaster mitigation information are then integrated with the geographical data to create the geographical data for high flash flood risk areas. The point rainfall data at the rainfall gage stations and the warning stations are collected from the reports which are made by the NIDP and the local governments. The locations of the rainfall gage stations are provided in the form of TM or Longitude and Latitude. Thus, the general information of the rainfall gage stations and the warning stations are arranged by the database standard. In accordance with the database standard, each station is assigned to a unique serial number and the data format associated with a station is modified to standardize the information. Also, the locations of the stations are converted into a GIS dataset. Finally, the serial numbers of the database and the GIS symbol codes are synchronized.

In general, a basin with mountainous flash flood risk should be a mountainous and steep area, resulting in a short travel time to the basin. In this system, using the standard basin map provided

by Water Management Information System (WAMIS), the following two criteria are applied to select target basins. First, to consider the fact that it should be a mountainous area, basins whose highest elevation is less than 500m are excluded. Among the basins whose highest elevation is higher than 500m, any basin whose average slope is less than 0.1 is also excluded because it is assumed that a basin of gentle slope may not be subject to flash flood. After these assumptions are applied, basins which are subject to flash flood are selected. Then, if a dam is located in the basin, the basin is divided into "upper basin" and "lower basin" from the dam. From this procedure, the 48 basins are selected to evaluate the flash flood risk. Table 1 shows the name of the selected mid-size basins.

To delineate a sub-basin in the selected midsize basins, which is the fundamental unit basin for the evaluation of flash flood risk, appropriate procedures are taken into account. First, "Flow Direction" and "Flow Accumulation" are performed on a selected mid-size basin and then channels are defined with the proper threshold size. The determination of the threshold size depends on the minimum area of a sub-basin. In this system, it is set to 1,000ha (10km²). The delineated subbasins are shown in the Figure 1.

| Tab | Table 1 The selected mid-size basins to evaluate the flash flood risk | | | | | | | | |
|-----|---|-----|---------------|-----|--------------|-----|---------------|--|--|
| No. | basins | No. | basins | No. | basins | No. | basins | | |
| 1 | ansengchen | 13 | gapshen | 25 | mankyunggang | 37 | sumjin | | |
| 2 | bochengchen | 14 | hapchendam | 26 | milyanggang | 38 | sumjingangdam | | |
| 3 | chengpengdam | 15 | hongcheongnag | 27 | mujunamdae | 39 | sumjinharue | | |
| 4 | chogang | 16 | hyungsangang | 28 | nakdong | 40 | suyeunggang | | |
| 5 | chunchendam | 17 | imjingang | 29 | nakdongang_1 | 41 | taewhagang | | |
| 6 | chungjudam | 18 | jejudo | 30 | namgangdam | 42 | uiamdam | | |
| 7 | daechen | 19 | juanmdam | 31 | namhangang_1 | 43 | wangpichen | | |
| 8 | daejongchen | 20 | junranamdo | 32 | sabkyochen | 44 | whoiyagang | | |
| 9 | dalchen | 21 | jurangetc | 33 | samchek | 45 | yangyangnam | | |
| 10 | dalcheon | 22 | kongjuetc | 34 | soyangdam | 46 | yongdamdam | | |
| 11 | dongjingang | 23 | kyunganchen | 35 | suachen | 47 | yongdamdam | | |
| 12 | gangreungnam | 24 | kyungbook | 36 | sumgang | 48 | yongduk | | |



In this system, channels including streams for the entire Korea Peninsula are defined and the characteristic velocity for a grid is estimated. Also, a grid's Curve Number (CN) of Soil Conservation Service (SCS) is determined based on the land use and soil map provided by WAMIS. To determine the Horton's Ratio for a channel, the channel order is analyzed for all channels. From these procedures, parameters can be estimated for a sub-basin to apply Geomorphic-Climatic Instantaneous Unit Hydrograph (GCIUH). Figure 2 shows the parameters for 76 sub-basins in the Anseong-cheun mid-size basin.

2. Development of a rainfall forecasting system based on the rainfall adjustment method

One of the difficulties involved in the flash flood forecast is to accurately forecast the amount and duration of rainfall in the area. However, to forecast

| 유역 🗊 | 최고차하천 💌 | 유역면적 🔻 | 최고차하천의길이 💌 | 하폭 ▼ | 유역경사 💌 | 면적비 💌 | 길이비 🔻 | 분기비 💌 | CN 👻 | 특성속도 💌 | 위락시설 💌 | 관광휴계시설 ▼ | 하도경사 |
|------|---------|------------|-------------|---------|---------|-------------|-------------|-------------|-----------|------------|--------|----------|--------|
| 1 | 3 | 2842.02 | 545.084193 | 9.6109 | 17.3675 | 1.394257368 | 1.588067608 | 1.664100589 | 73.094757 | 63.849742 | 5 | 0 | 0.4551 |
| 2 | 3 | 1019.88 | 732.3315333 | 5.1966 | 20.3696 | 1.450901144 | 1.442431066 | 1.354006401 | 74.053924 | 58.96207 | 1 | 0 | 0.3560 |
| 3 | 4 | 3813.93 | 469.8857121 | 11.466 | 5.3167 | 1.114600308 | 1.473393256 | 1.62598983 | 81.129165 | 173.347518 | 3 | 0 | 0.1521 |
| 4 | 4 | 2798.64 | 9.292090212 | 9.5227 | 8.9725 | 0.051092172 | 0.76811874 | 2.839276598 | 76.506614 | 92.954116 | 7 | 0 | 0.2075 |
| 5 | 4 | 2660.04 | 6.799114544 | 9.2368 | 13.0268 | 0.046973009 | 0.628141819 | 2.49218942 | 74.976257 | 106.084556 | 12 | 0 | 0.6480 |
| 6 | 4 | 4705.92 | 378.2400865 | 13.007 | 9.4127 | 1.088134914 | 1.347764912 | 1.56267737 | 79.799499 | 106.851753 | 24 | 2 | 0.2025 |
| 7 | 4 | 7520.76 | 925.1474861 | 17.2324 | 3.879 | 0.934598534 | 1.235751066 | 1.617290615 | 82.533653 | 190.041946 | 0 | 0 | 0.1748 |
| 8 | 4 | 7910.37 | 612.6444572 | 17.7627 | 4.5357 | 0.938225252 | 1.155491764 | 1.572666204 | 82.939849 | 109.902084 | 0 | 0 | 0.1371 |
| 9 | 4 | 1482.75 | 6.799114544 | 6.5047 | 26.6073 | 0.043972964 | 0.614368953 | 2.462288827 | 70.105148 | 59.450382 | 5 | 0 | 1.0013 |
| 10 | 4 | 2149.65 | 192.1653188 | 8.1285 | 29.7181 | 0.047905581 | 1.898094768 | 2.623829401 | 70.871231 | 66.839027 | 10 | 0 | 0.8836 |
| 11 | 4 | 8056.44 | 728.3423562 | 17.9587 | 15.2151 | 0.844725571 | 1.383721329 | 1.921180893 | 75.192817 | 162.555419 | 13 | 47 | 0.3331 |
| 12 | 3 | 1419.57 | 526.109199 | 6.337 | 18.188 | 0.812055993 | 1.235801731 | 1.258305739 | 72.493095 | 58.948005 | 0 | 0 | 0.5741 |
| 13 | 4 | 2057.22 | 498.4909168 | 7.917 | 13.3097 | 1.223935981 | 1.652015964 | 1.889059452 | 78.597274 | 73.62664 | 0 | 0 | 0.0704 |
| 14 | 5 | 18659.79 | 461.9991836 | 29.7258 | 9.1495 | 0.782276268 | 1.073299327 | 1.865525431 | 80.934272 | 216.672348 | 1 | 15 | 0.3380 |
| 15 | 4 | 6992.19 | 649.2269719 | 16.4952 | 20.1875 | 0.626785416 | 1.058826473 | 1.478384633 | 75.416252 | 127.125289 | 4 | 1 | 0.3211 |
| 16 | 3 | 1166.94 | 728.8696059 | 5.634 | 15.8345 | 1.217847921 | 1.69015469 | 1.61245155 | 74.436035 | 59.677639 | 0 | 0 | 0.6194 |
| 17 | 3 | 2280.69 | 655.6594362 | 8.4223 | 24.4781 | 0.634777701 | 1.208084698 | 1.341640786 | 73.494682 | 131.608566 | 0 | 0 | 0.2396 |
| 18 | 4 | 12357.18 | 1400.278905 | 23.2135 | 8.0985 | 0.818101787 | 1.086804745 | 1.532669325 | 83.331291 | 143.611511 | 0 | 0 | 0.5101 |
| 19 | 4 | 1963.98 | 30.47715932 | 7.6997 | 19.4582 | 0.048581708 | 0.971333317 | 2.466447908 | 75.93029 | 69.426475 | 7 | 1 | 1.0626 |
| 20 | 4 | 10332.9 | 955.3211399 | 20.8508 | 20.6988 | 0.61402656 | 1.001684061 | 1.51022255 | 77.43534 | 140.40097 | 3 | 0 | 0.2113 |
| 21 | 4 | 13785.3 | 1578.357016 | 24.7879 | 11.266 | 0.757442222 | 0.988793666 | 1.521472847 | 78.167655 | 146.049072 | 0 | 0 | 0.2516 |
| 22 | 4 | 1056.78 | 14.56133994 | 5.3086 | 25.3342 | 0.04973281 | 0.894201089 | 2.393628033 | 74.409217 | 49.658958 | 0 | 0 | 0.1702 |
| 23 | 4 | 17050.23 | 1876.138074 | 28.1597 | 14.9012 | 0.749651619 | 0.979913049 | 1.513711906 | 79.453689 | 159.061889 | 1 | 0 | 0.1168 |
| 24 | 3 | 1210.41 | 688.1091039 | 5.759 | 16.6095 | 1.019206962 | 1.501772009 | 1.511857892 | 76.129821 | 64.6651 | 0 | 0 | 0.8154 |
| 25 | 4 | 14647.14 | 1236.71917 | 25.7064 | 9.5302 | 0.819275196 | 1.265329206 | 1.714562764 | 81.960144 | 209.24208 | 0 | 0 | 0.0961 |
| 26 | 4 | 19632.33 | 2261.839434 | 30.6459 | 9.0325 | 0.752565899 | 0.971937195 | 1.483743397 | 81.25634 | 176.005828 | 0 | 0 | 0.3803 |
| 27 | 5 | 24730.65 | 932.3014291 | 35.1991 | 7.0162 | 0.791873321 | 1.06954263 | 1.706824137 | 82.069335 | 252.802444 | 0 | 0 | 0.0771 |
| 28 | 5 | 36844.11 | 425.5729481 | 44.7106 | 5.8072 | 0.7303518 | 0.964881086 | 2.148308815 | 82.291404 | 230.77893 | 0 | 0 | 0.0881 |
| 29 | 3 | 1356.93 | 619.8719811 | 6.1677 | 9.6666 | 0.648360345 | 1.431405891 | 1.527525232 | 79.196655 | 77.172065 | 0 | 0 | 0.1000 |
| 30 | 6 | 62029.89 | 726.1175658 | 61.1154 | 1.409 | 1.151032219 | 1.279780433 | 2.614450775 | 85.126068 | 260.083801 | 0 | 0 | 0.1000 |
| 31 | 4 | 7761.3296 | 388.5431423 | 17.5611 | 19.883 | 1.023862988 | 1.37072661 | 1.536314009 | 74.945365 | 166.832672 | 4 | 1 | 0.5281 |
| 32 | 4 | 2550.69 | 426.6368253 | 9.0071 | 12.5626 | 1.217712594 | 1.55882661 | 1.678917325 | 76.772415 | 119.466117 | 0 | 0 | 0.1811 |
| 33 | 3 | 1114.11 | 462.9113864 | 5.4796 | 18.0448 | 0.481606133 | 1.087764408 | 1.369306394 | 75.244392 | 54.50872 | 0 | 0 | 0.1227 |
| 34 | 5 | 11469.4196 | 459.5085329 | 22.198 | 12.6677 | 1.007611046 | 1.221985375 | 1.736708647 | 77.228454 | 186.291061 | 0 | 0 | 0.7279 |
| 35 | 6 | 64668.51 | 1339.473996 | 62.6622 | 3.1881 | 1.005047302 | 1.153151987 | 2.193871808 | 85.028015 | 278.842498 | 0 | 0 | 0.0403 |
| 36 | 3 | 3000.33 | 551.0674874 | 9.9287 | 9.0668 | 0.704961686 | 1.132374103 | 1.210076739 | 80.17649 | 123.076087 | 0 | 0 | 0.2138 |
| 37 | 3 | 2990.7 | 405.9576011 | 9.9095 | 19.9276 | 0.555356927 | 0.971497996 | 1.164964745 | 75.674468 | 97.594535 | 0 | 0 | 0.6014 |
| 38 | 4 | 5402.79 | 960.6998614 | 14.1306 | 11.6668 | 1.087492969 | 1.423522427 | 1.776675102 | 77.537239 | 88.554649 | 0 | 0 | 0.1000 |
| 39 | 6 | 69744.51 | 1715.043849 | 65.5686 | 3.217 | 0.981310238 | 1.088163958 | 2.037838781 | 83.907608 | 294.456024 | 0 | 0 | 0.2404 |

0

Figure 2 The estimated parameters for 76 sub-basins in the Anseong-cheun mid-size basin

Figure 1 The delineated sub-basins

the amount and duration of rainfall many tasks are required including the observation of meteorological data. Currently, the weather radar is widely used to observe temporal and spatial distribution of rainfall and yet, from a single observation, sufficient data may not be obtained to forecast the convective rainfall. Since localized flash floods have caused severe damages, the weather radar is used to try forecasting short term rainfall.

To accomplish the accurate forecast of rainfall, the McGill Algorithm for Precipitation nowcasting and Lagrangian Extrapolation (MAPLE) is used to develop the rainfall forecast system for this system. MAPLE was developed by the National Institute of Meteorological Research (NIMR) and McGill University, Canada and shows its capability to forecast rainfall characteristics in less than 3 hours. Although MAPLE may forecast the rainfall characteristics precisely in less than 3 hours, there is still need to adjust its forecast result using the data integration between MAPLE and Auto Weather System (AWS) as shown in Figure 3.



To carry out the real-time rainfall adjustment, MAPLE data are obtained from the FTP server of the NIMR and the AWS data are then converted into the required input data for the analysis through National Disaster Management System (NDMS). Meanwhile, data measured from the ground rainfall stations and obtained by the weather radar are shown in the system.

From the two data sets, MAPLE and the AWS connected in the system, the data measured by a ground rainfall station should fall into a grid of the weather radar. This process is necessary to determine the number and location of AWS which is used for the adjustment of data and rainfall information of a station located within the standard range (30km x 30km).



Figure 4 Grids for the rainfall adjustment in the system



Figure 5 Displaying AWSs located within an unit grid

Through this process, the number and locations of an AWS which is in the standard range can be changed depending on which AWS is selected as the central grid. To resolve this problem, as shown in Figure 4, the AWS information for each unit grid is pre-determined after the country is divided into 30km x 30km grids. Since the number of AWSs will vary depending on where the start location was set, the system is forced to determine the start location to make the 77 rainfall stations distributed as evenly as possible. Figure 5 shows the locations of AWSs within a unit grid.

Once a ground rainfall station is selected, a radar grid and its number where the ground rainfall

station is located, is identified and the average adjustment is carried out based on the ratio of ground-radar ratio (G/R; Figure 6). In case of the selected rainfall data which are estimated by each unit grid, it is possible that a couple of grids are located in the same district if it is a big district. It is also possible that more than two districts are located within a same grid. In this case, the system calculates the ratio of the area of each district within the grid and the ratio is then used to calculate the amount of rainfall for each district which will be displayed on the screen of the developed system.



Figure 6 Monitoring results at a high flash flood risk area before and after the adjustment

III. DEVELOPMENT OF A REAL-TIME WARNING DELIVERY SYSTEM

he development of a real-time flash flood warning delivery system for the country is explained in this chapter. Current flash flood risk areas and other areas where flash floods may occur within 3 hours are identified based on rainfall data collected in real-time. The flash flood warning messages are "Caution", "Warning", and "Evacuation", and the warning criterion for each message is pre-defined at each warning station. If the appearance of a flash flood risk area is noticed, a SMS message and Email are automatically sent to pre-designed persons working for National Emergency Management Agency (NEMA) and NIDP. As shown in Figure 7, a person who is designated by NEMA and NIDP should register his/her information such as name, affiliation, email address, and contact phone number in the system. Also, he/she should choose the warning cycle and type of message they wish to receive (SMS or email).

As mentioned before, if the appearance of a flash flood risk area is noticed or it is predicted that a flash flood is expected to occur within 3 hours, all registered persons in the system will be informed via SMS or email. Currently, the Email warning system shown in Figure 8 is working and the SMS warning system is being set up. Warning information delivered through SMS will be concise and include the warning time and current situation for each district. More detailed information will be sent via Email.

Through email, the following information will be included (i) Type of the warning: "Caution", "Warning", and "Evacuation"; (ii) Data of the area: Province, District, and Town; (iii) Trend of rainfall recorded in the previous analysis: rise, descent, or constant.

| 자료분석 설정 분단위 ▼ 20 ● E-Mail ● 3 *********************************** | Accession of the second s | 연락처 010-1235-1652 010-9190-4946 단당자 등록 | 강우모니터링 돌발홍수모니터링 환경: |
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| 분단위 💌 20 @ E-Mail @ 3 소속 방재연구소 | SMS E-Mail hong@nema.go.kr | 010-1235-1652 010-9190-4946 | |
| 방재연구소 | hong@nema.go.kr | 010-1235-1652 010-9190-4946 | |
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| 삭제 | | 담당자 등 이 를 ^{정재} 소 속 ^{방재} | • 록 학 연구소 boat @ nema.go,kr ↓ - 9190 - 4946 |
| | 삭제 | 삭 제 | 이 를 정재 소 속 방재 E-Mail blue 연락처 010 |

Figure 7 Screen capture of System Environment Setting window

| | 일 08시00분 현재 | 위험지역 > | | | | |
|--------------------|-------------------------------------|------------|----------------|------|------------------|----------------------|
| 경보종류 | 시도명 | 시군구명 | 읍면동명 | 경향 | 현재강우량 | 누적강우량 |
| 대피 | 전라남도 | 순천시 | 1000000 Bar Ba | ▲ | (mm/hr) 19.32 | (mm/hr) |
| 대피 | 전라남도 | 순천시 | | - | 14.31 | |
| 대피 대피 | 울산광역시 울산광역시 | 울주군 울주군 | | | - | 114.74 123.42 |
| | | | | | - | |
| 대피 | 울산광역시 | 울주군 | | | - | 84.19 |
| 대피 | 울산광역시 | 울주군 | | | - | 104.6 |
| 경보종류 | 시도명 | 시군구명 | 1 | i면동명 | 경향 | 3시간예측강우량 (mm/3hr) |
| 대피 | 울산광역시 | 울주군 | | | - | 114.74 |
| 대피 | 울산광역시 | 울주군 | | | - | 123.42 |
| 대피 | 울산광역시 | 울주군 | | | - | 84.19 |
| 대피 | 울산광역시 | 울주군 | | | - | 104.6 |
| 대피 | 울산광역시 | 울주군 | | | | 125.39 |
| 대피 | 부산광역시 | 기장군 | | | - | 187.07 |
| 월부파일 2개 — - | 모든 첨부파일 다운로드 현재위험지역 79K 보기 다운 | l.jpg | | | | |

Figure 8 Email warning system

For sub-basins where flash floods are expected within 3 hours, all information provided for the sub-basins where flash floods are about to occur is provided as well. In addition, forecasted rainfall data within 3 hours are provided for the sub-basins. Personnel in charge of dealing with flash floods in NEMA and NIDP are also provided with that information making it possible to integrate the control center and the decision support system of NEMA with the developed mountainous flash flood forecast system.

IV. FLASH FLOOD FORECAST SYSTEM

1. Main window of the Flash Flood Forecast System

n the main window of the Flash Flood Forecast System shown in Figure 9, the user can login the system. With his/her authorized ID, the user types the username (1) and the PW (2) and then clicks the login button 5) to start the system. To terminate the session, clicks the cancel button (6). Also, the user can save his/ her ID (click 3) and PW (4) to not retype the ID and PW for the next session.



Figure 9 Main window of the Flash Flood Forecast System

The initial window of the system is shown in Figure 10. The window consists of 5 sub-windows. The radar image window (3) shows the very short-term rainfall data and current flash flood areas which are determined by analyzing the current rainfall data that are then shown in window 4. The areas where the occurrence of flash floods is expected within 3 hours are shown in window 5. As mentioned before, these areas are determined by the forecast rainfall data using MAPLE.

- The radar image window: every 20 minutes, the very short-term forecast rainfall data is collected and shown in the window. The time and date of the collected data are displayed in the excel sheet (1).
- The flash flood risk area window: flash flood risk areas are determined by the short-term forecast rainfall data and the flash flood warning degree ("Caution", "Warning" and "Evacuation") for the area. After the areas are determined, an appropriate warning degree

will be issued. Measured rainfall data are displayed in the excel sheet of window 2.



Figure 10 The initial window of the system

Figure 11 shows 3-hour flash flood risk areas. Based on the forecast rainfall data obtained from the very short term rainfall data, the warning will be issued if a 20-minute duration rainfall is expected to pass the warning criteria within 3 hours. After analyzing the collected information and if any warning degree such as "Caution", "Warning" or "Evacuation" is to be expected, the regional information will be displayed in the excel sheet (1) for each type of information along with the warning degree.



Figure 11 The windows for 3-hour flash flood risk areas

When the flash flood risk area is identified, the warning message will be delivered to predesignated persons via SMS or Email as shown in Figure 12. Warning information delivered via SMS will be concise and include warning time and current situation of each district. More detailed information will be delivered via Email. Window 1 is for SMS delivery (being installed) and 2 is the Email delivery windows.



Figure 12 Delivering the warning degree via SMS or Email

Figure 13 is the rainfall station window. Data of the rainfall stations located in the flash flood area is shown in window 1. The user can add a new rainfall station by clicking the "add" button (2) or modify the data of a rainfall station by selecting from the excel sheet. Also, the user can remove a rainfall station by clicking the "remove" button (4) after selecting the station.

| 2* | 돌발 | 홍수예 | 측시 | 스ᄐ | 9 | | | | N | 국립방재연구소 전영대 전부분weter |
|-------|---------------------|-------------------|--------|-------|------------|----------|------------|-----------|---------------|-------------------------|
| - |)료관리 자료조 보조회 경보국 | 회 자료분석 정보조회 유의 | 리 정보조회 | 1 강우관 | 승지적 정보조회 | | | | 강우모니터링 돌발 | 홍수모니터링 환경설 |
| 0 187 | 구역으로 검색 | 시도영 | T N | 270 | | | | | | |
| | 2국명으로 검색 | NIZ 6 | • | 278 | | | | | | 조 회 다운로드 |
| | 북위 | 동경 | LSYSID | LRTUD | SLOCALNAME | LGROUPNO | SGROUPNAME | SAREANAME | 시설명 | 지구명 |
| 1 | 34" 59' 49' | 128" 06' 22" | 2 | 9 | 백천경보국2 | 0 | 와롱산지구 | 사천 | 백천2경보국 | 백천계곡 |
| 2 | 34" 39" 41" | 128" 05' 34" | 2 | 10 | 백천경보국1 | 0 | 와롱산지구 | 사천 | 백천1경보국 | 백천계곡 |
| 3 | 37 27 38 | 129" 01' 29" | 3 | 9 | 주차장경보 | 0 | 무롱지구 | 동해시 | 주차장 | 무륭계곡 |
| 4 | 35" 11" 29" | 127 22 40 | 5 | 9 | 압록유원지 | 0 | 압록지구 | 곡성군 | 예성교경보국 | 죽곡면압록윾 |
| 5 | 35" 07" 52" | 127" 18' 26" | 5 | 10 | 용바위낚시터 | 0 | 압록지구 | 곡성군 | 용바위경보국 | 죽곡면압록유 |
| 6 | 35" 07" 50" | 127 22 14" | 5 | 11 | 주차장1경보 | 1 | 태안사지구 | 곡성군 | 기념관경보국 | 태안사계: |
| 7 | 35' 07' 47' | 127 22 26- | 5 | 12 | 반야교2경보 | 1 | 태안사지구 | 곡성군 | 반야교경보국 | 태안사계 7 |
| 8 | 35" 07" 46" | 127 22 45 | 5 | 13 | 해탈교3경보 | 1 | 태안사지구 | 곡성군 | 해탈교경보국 | 태안사계; |
| 9 | 35" 13" 42" | 127 22 27 | 5 | 14 | 청소년야영장 | 0 | 압록지구 | 곡성군 | 야영장경보국 | 가정 |
| 10 | 35" 39" 32" | 128" 03" 20" | 8 | 9 | 오동산1경보 | 0 | 오도산지구 | 합천 | 오도1경보국 | 오도산휴일 |
| 11 | 35" 39" 59" | 128" 03" 27" | 8 | 10 | 오도산2경보 | 0 | 오도산지구 | 합천 | 오도2경보국 | 오도산휴일 |
| 12 | 35" 40" 20" | 128" 03" 42" | 8 | 11 | 오도산3경보 | 0 | 오도산지구 | 합천 | 오도3경보국 | 오도산휴일 |
| 13 | 35" 30" 44" | 127" 58' 32" | 8 | 12 | 하금경보 | 1 | 하금계곡지구 | 합천 | 하금1경보국 | 하금계곡 |
| 14 | 35' 15' 48' | 127" 51" 39" | 11 | 16 | 유원지경보 | 0 | 대원사지구 | 산청 | 제1경보 | 덕천강 |
| 15 | 35' 17' 36' | 127" 49" 03" | 11 | 17 | 내원1경보 | 1 | 산형내원사지구 | 산청 | 제1경보 | 내원사 |
| 16 | 35' 17' 41' | 127" 48" 48" | 11 | 18 | 내원2경보 | 0 | 산청내원사지구 | 산청 | 제2경보 | 내원사 |
| 17 | 35" 16" 51" | 127" 46" 13" | 11 | 19 | 야영장경보 | 0 | 대원사지구 | 산청 | 중산교(야영장)경보국 | 중산리 |
| 18 | 35' 19' 54' | 127" 50" 21" | 11 | 20 | 석남경보 | 0 | 대원사지구 | 산형 | 제2경보 | 덕천강 |
| 19 | 35" 17' 39" | 127" 49" 10" | 11 | 25 | 낙포대(04신) | 1 | 산형내원사지구 | 산청 | 낙포대경보국 | 내원사 |
| 20 | 35" 22" 15" | 127" 46" 11" | 11 | 32 | 새재(04국) | 0 | 대원사지구 | 산형 | 새재 우량국 | 대원사 |
| 21 | 35" 15' 36" | 127 47 10 | 12 | 9 | 중산1경보 | 0 | 중산리지구 | 산청 | 중산1경보국 | 중산리 |
| 22 | 35" 15" 34" | 127 47 24" | 12 | 10 | 중산2경보 | 0 | 중산리지구 | 산청 | 중산2경보국 | 중산리 |

(a) Data management of rainfall stations

| 😒 우량국 등록 | |
|------------|--------------|
| 우량국 | 등록 |
| TM_X | 301624,5633 |
| TM_Y | 441235, 1652 |
| LSYSID | 6 |
| LRTUID | 1 |
| SLOCALNAME | 00우량국 |
| LGROUPNO | 1 |
| SGROUPNAME | 00지구 |
| SAREANAME | 00시 |
| 시설명 | 00우량국 |
| 지구명 | 00지구 |
| 주소 | 00도 00시 00군 |
| | 등록 취소 |

(b) Add a new rainfall station

| 😒 우량국 수정 | | |
|------------|--------------|-------|
| 우량국 | 수정 | |
| TM_X | 261751,5935 | |
| TM_Y | 251076, 3956 | |
| LSYSID | 33 | |
| LRTUID | 4 | |
| SLOCALNAME | 영각우량 | |
| LGROUPNO | 0 | |
| SGROUPNAME | 부전지구 | |
| SAREANAME | 함양 | |
| 시설명 | 서상1우량(영각) | |
| 지구명 | 부전지구(1차설치) | |
| 주소 | 서상면상남리 산9-1 | |
| | | 수정 취소 |

(c) Remove a rainfall station

Figure 13 Management of the data associated with rainfall stations located in the flash flood risk area

Figure 14 is the warning station window. Data of the warning stations located in the flash flood area are shown in window 1. The user can add a new warning station by clicking the "add" button (2) or modify the data of a warning station by selecting from the excel sheet. Also can remove a warning station by clicking the "remove" button (4) after selecting the station.

| 3 | 도바 | | | | | | | | | |
|------------------------|-------------|--------------|--------|------------|------------|----------|------------|-----------|-------------|-------------|
| | 5 5 | 홍수예 | 측시 | 스ᄐ | 4 | | | | - | 지민가 국립방재연구: |
| | | | | | | | | | | |
| | | 회 자료분석 | | 1.00.00.00 | | | | | 상수보디터링 물 | 발발홍수모니터링 환경 |
| 14 8 | 보조회 경보국 | SXX8 23 | 역 성보소회 | 1 강우관 | 측지점 정보조회 | | | | | |
| 현장 | 경구역으로 검색 | 시도명 | ▼ A | 군구명 | | | | | | |
| 0 31 | 보국명으로 검색 | | | | | | | | | 조 회 다운로 |
| | 북위 | 83 | LSYSID | LRTUID | SLOCALNAME | LGROUPNO | SGROUPNAME | SAREANAME | 시설명 | 지구명 |
| 1 | 34" 59' 49' | 128" 06" 22" | 2 | 9 | 백천경보국2 | 0 | 와롱산지구 | 사천 | 백천2경보국 | 백친계 |
| 2 | 34" 39" 41" | 128" 05' 34" | 2 | 10 | 백천경보국1 | 0 | 와롱산지구 | 사원 | 백천1경보국 | 백친계 |
| 3 | 37" 27" 38" | 129" 01' 29" | 3 | 9 | 주차장경보 | 0 | 무릎지구 | 동해시 | 주차장 | 무릎계 |
| 4 | 35" 11" 29" | 127" 22" 40" | 5 | 9 | 압록유원지 | 0 | 압록지구 | 곡성군 | 예성교경보국 | 죽곡면압록 |
| 5 | 35" 07" 52" | 127" 18" 26" | 5 | 10 | 용바위낚시터 | 0 | 압록지구 | 곡성군 | 용바위경보국 | 죽곡면압록 |
| 6 | 35" 07" 50" | 127 22 14 | 5 | 11 | 주차장1경보 | 1 | 태안사지구 | 곡성군 | 기념관경보국 | 태안사기 |
| 7 | 35' 07' 47' | 127" 22" 26" | 5 | 12 | 반야교2광보 | 1 | 태안사지구 | 곡성군 | 반야교경보국 | 태안사기 |
| 8 | 35" 07" 46" | 127' 22' 45' | 5 | 13 | 해탈교3경보 | 1 | 태안사지구 | 곡성군 | 해탈교경보국 | 태안사기 |
| 9 | 35' 13' 42" | 127" 22" 27" | 5 | 14 | 청소년야영장 | 0 | 압록지구 | 곡성군 | 마영장경보국 | 가정 |
| 10 | 35" 39" 32" | 128° 03' 20' | 8 | 9 | 오동산1경보 | 0 | 오도산지구 | 합천 | 오도1경보국 | 오도산휴 |
| 11 | 35" 39' 59" | 128° 03' 27' | 8 | 10 | 오도산2경보 | 0 | 오도산지구 | 합천 | 오도2경보국 | 오도산휴 |
| 12 | 35" 40' 20" | 128° 03' 42" | 8 | 11 | 오도산3경보 | 0 | 오도산지구 | 합천 | 오도3경보국 | 오도산휴 |
| 13 | 35" 30' 44" | 127" 58' 32" | 8 | 12 | 하금경보 | 1 | 하금계곡지구 | 합천 | 하금1경보국 | 하금계 |
| 14 | 35" 15' 48" | 127° 511 391 | 11 | 16 | 유원지경보 | 0 | 대원사지구 | 산청 | 제1경보 | 덕천3 |
| 15 | 35" 17' 36" | 127" 49" 03" | 11 | 17 | 내원1경보 | 1 | 산형내원사지구 | 산청 | 제1경보 | 내원/ |
| 16 | 35" 17' 41" | 127" 48" 48" | 11 | 18 | 내원2경보 | 0 | 산형내원사지구 | 산청 | 제2경보 | 내원/ |
| 17 | 35" 16' 51" | 127" 46" 13" | 11 | 19 | 야영장경보 | 0 | 대원사지구 | 산청 | 중산교(야영장)경보국 | 중산리 |
| 18 | 35" 19' 54" | 127" 50" 21" | 11 | 20 | 석남경보 | 0 | 대원사지구 | 산청 | 제2경보 | 덕천3 |
| 19 | 35" 17' 39" | 127" 49" 10" | 11 | 25 | 낙포대(04신) | 1 | 산형내원사지구 | 산청 | 낙포대경보국 | 내원/ |
| 20 | 35" 22" 15" | 127" 46" 11" | 11 | 32 | 새재(04국) | 0 | 대원사지구 | 산청 | 새재 우량국 | 대원/ |
| 21 | 35" 15' 36" | 127" 47" 10" | 12 | 9 | 중산1경보 | 0 | 중산리지구 | 산청 | 중산1경보국 | 중산리 |
| 22 | 35" 15' 34" | 127" 47" 24" | 12 | 10 | 중산2경보 | 0 | 중산리지구 | 산성 | 중산2경보국 | 중산2 |

(a) Data management of the warning stations

| 😒 경보국 정보 | |
|------------|-----------------|
| 경보국 | 등록 |
| 북위 | 34' 25' 56'' |
| 동경 | 128' 05' 51'' |
| LSYSID | 5 |
| LRTUID | 2 |
| SLOCALNAME | 00경보국 |
| LGROUPNO | 1 |
| SGROUPNAME | 00지구 |
| SAREANAME | 00시 |
| 시설명 | 00경보국 |
| 지구명 | 00⊼ 구 |
| 주소 | 00도 00시 00군 00읍 |
| | 등록 취소 |

(b) Add a new warning station

| 🔮 경보국 수정 | □ .× |
|------------|--------------------|
| 경보국 | 수정 |
| 북위 | 35° 15′ 34″ |
| 동경 | 127° 47′ 24″ |
| LSYSID | 12 |
| LRTUID | 10 |
| SLOCALNAME | 중산2경보 |
| LGROUPNO | 0 |
| SGROUPNAME | 중산리지구 |
| SAREANAME | 산청 |
| 시설명 | 중산2경보국 |
| 지구명 | 중산리 |
| 주소 | 산청군 시천면 중산리 산114-7 |
| | <u>주정</u> 취소 |

(c) Remove a warning station

Figure 14 Management of the data associated with warning stations located in the flash flood risk area

Figure 15 is the attribute window for rainfall stations located in the flash flood risk area. The user can find the attribute associated with a rainfall station located in the flash flood risk area and it is possible to obtain information of the accumulated rainfall every hour during the period assigned by the user as shown in Figure 16. All the information associated with a rainfall station located in the flash flood risk area is displayed in the excel sheet (1). Once a rainfall station for which the user wants to know the rainfall data, click the "rainfall data reference" button (2) which then opens the "hourly and accumulated rainfall" window.

| Y | 돌 | 발홍수 | 예측시 | 스템 | | | | | | NC: 국립방재연구소 Netional institute for Disaster Prevention |
|----------------|--------------------------|--------------|----------|------------|--------|--------|--------|--------|-------------|--|
| 일 | 자료관리 지 | 료조회 자료 | 분석 | | | | | | 강우모니티 | 내 <mark>리 돌발홍수모니터리</mark> 환경실 |
| ¥ Z | 정보조회 경험 | 보국 정보조회 | 유역 정보조회 | 이 강우관측지 | 점 정보조회 | | | | | |
| | | | | | | | | | | 다운로드 |
| | 考원 ◊ 🎝 | 동경 👌 🏹 | LSYSID 0 | r lrtuid 👌 | SLOCA | LGRO O | SGROUP | NAME O | 시설명 🔷 🛛 | 7 지구명 《 꼬 |
| 28 | 260912,3140 | 196885,9387 | 21 | 3 | 단천 | 0 | 화계지구 | 하동 | 단천우량 | 지리산 화개지구 (2차설치) |
| 29 | 260178,8166 | 193151,7713 | 21 | 4 | 불일야영장 | 0 | 화계지구 | 하동 | 불일야영장우량 | 지리산 화개지구 (2차설치) |
| 30 | 261501,7465 | 199417,2115 | 21 | 5 | 작은세제골 | 0 | 화계지구 | 하동 | 작은세재골우량국 | 화개지구(하동) |
| 81 | 265424,9488 | 191523, 7949 | 22 | 1 | 청암1우량 | 0 | 청암지구 | 하동 | 학동다리우량 | 청암지구 (1차설치) |
| 12 | 266174,8883 | 192731,2405 | 22 | 2 | 청암2우량 | 0 | 청암지구 | 하동 | 묵계치우량 | 청암지구 (1차설치) |
| 33 | 266862,8639 | 192027,4113 | 22 | 3 | 청암3우량 | 0 | 청암지구 | 하동 | 묵계우량 | 지리산 청암지구 (2차설치) |
| 14 | 266336, 9994 | 198218,5319 | 23 | 1 | 도장골 | 0 | 덕천강지구 | 하동 | 도장골우량 | ·청군지역 (우량국보강)(2차설치 |
| 5 | 268307, 3259 | 194996,9810 | 23 | 2 | 순두류 | 0 | 덕천강지구 | 하동 | 순두류우량 | ·청군지역 (우량국보강)(2차설치 |
| 6 | 271541,4176 | 201648,5378 | 23 | 3 | 안내원 | 0 | 덕천강지구 | 하동 | 안내원우량 | ·청군지역 (우량국보강)(2차설치 |
| 17 | 269788,8088 | 206134,7723 | 23 | 4 | 노루목 | 0 | 덕천강지구 | 하동 | 노루목우량 | ·청군지역 (우량국보강)(2차설치 |
| 8 | 202866, 5474 | 428572,4600 | 26 | 1 | 곡현우량 | 0 | 고기동지구 | 용인시 | 곡현우량국 | 고기리계곡 |
| 9 | 268677, 5201 | 245640,6028 | 31 | 1 | 상사평우량 | 0 | 용추지구 | 함양 | 안의우량1(상사평) | 용추지구(1차설치) |
| 10 | 268105,9371 | 244773, 1623 | 31 | 2 | 휴양림우량 | 0 | 용추지구 | 함양 | 안의우량2(휴양림) | 용추지구(1차설치) |
| 1 | 258360, 3086 | 239495,0273 | 33 | 1 | 덕운봉우량 | 0 | 부전지구 | 함양 | 서상우량1(덕운봉) | 부전지구(1차설치) |
| 12 | 262623,8650 | 237767,0237 | 33 | 2 | 통정골우량 | 0 | 부전지구 | 함양 | 서상우량2(통정골) | 부전지구(1차설치) |
| 3 | 262767, 3688 | 249542, 3490 | 33 | 3 | 버석농장 | 0 | 부전지구 | 함양 | 서상2우량(버섯농장) | 부전지구(1차설치) |
| 4 | 261751,5935 | 251076, 3956 | 33 | 4 | 영각우량 | 0 | 부전지구 | 함양 | 서상1우량(영각) | 부전지구(1차설치) |
| 5 | 276190, 4326 | 352268, 9480 | 61 | 1 | 관평 | 0 | 화양동지구 | 괴산군 | 관평우량국 | 화양지구(159,8375) |
| 6 | 279249, 3514 | 349121,1864 | 61 | 2 | 이평 | 0 | 화양동지구 | 괴산군 | 이평우량국 | 화양지구(159,8375) |
| 7 | 269667, 3809 | 348144,2790 | 62 | 3 | 진들 | 0 | 청천지구 | 괴산군 | 진들우량 | 청천지구(159,8875) |
| 8 | 283601,9404 | 363929,9136 | 63 | 4 | 교동 | 0 | 달천지구 | 괴산군 | 교동우량 | 달천지구(159,8125) |
| 9 | 282065, 4982 | 358612,2884 | 64 | 2 | 쌍곡폭포 | 0 | 쌍곡지구 | 괴산군 | 폭포우량국 | 쌍곡지구(154,85) |
| 0 | 281892,2682 | 355959, 2690 | 64 | 3 | 제수리 | 0 | 쌍곡지구 | 괴산군 | 제수리우량국 | 쌍곡지구(154,85) |
| 1 | 283644.3711 | 414124.0271 | 73 | 1 | 덕동우량 | 0 | 덕동지구 | 제천시 | 우량덕동 | 백운면덕동지구(154.8125) |
| Ú. | a contra e contra contra | | 1000 | | | | | | 230 332 | → |

Figure 15 Attribute window for rainfall stations located in the flash flood risk area



Figure 16 The hourly and accumulated rainfall window

Figure 17 is the attribute window for warning stations located in the flash flood risk area. The user can find the attribute associated with a warning station located in the flash flood risk area and all the information associated with a warning station located in the flash flood risk area will be saved in the excel sheet (1).

| - | 돌발 | 홍수예 | 측시 | 스퉈 | 4 | | | | N | 국립방재연구소 Millioni Infilmenton |
|--------|---------------------|--------------------|--------|--------|------------|----------|------------|-----------|-------------|---------------------------------|
| | 자료관리 자료: 보조회 경보국 | 5회 자료분석 정보조회 유약 | 격 정보조호 | 1 강우관 | 속지점 정보조회 | | | | 강우모니터링 돌발 | §수모니터링 환경설 |
| 8 88 5 | 친구역으로 검색 | 시도역 | | 군구명 | | | | | | |
| | 보국명으로 검색 | 1128 | | 210 | | | | | | 조 회 다운로드 |
| - 1 | 북위 | 동경 | LSYSID | LRTUID | SLOCALNAME | LGROUPNO | SGROUPNAME | SAREANAME | 시설명 | 지구명 |
| 1 | 34" 59' 49" | 128" 06' 22" | 2 | 9 | 백천경보국2 | 0 | 와롱산지구 | 사천 | 백천2경보국 | 백천계국 |
| 2 | 34" 39" 41" | 128" 05' 34' | 2 | 10 | 백천경보국1 | 0 | 와롱산지구 | 사천 | 백천1경보국 | 백천계3 |
| 3 | 37" 27' 38" | 129" 01' 29" | 3 | 9 | 주차장경보 | 0 | 무롱지구 | 唇胡 人 | 주차장 | 무롱계곡 |
| 4 | 35" 11' 29" | 127" 22" 40" | 5 | 9 | 압록유원지 | 0 | 압록지구 | 곡성군 | 예성교경보국 | 즉곡면압록위 |
| 5 | 35" 07' 52" | 127" 18' 26" | 5 | 10 | 용바위낚시터 | 0 | 압록지구 | 곡성군 | 용바위경보국 | 즉곡면압록위 |
| 6 | 35" 07' 50" | 127 22 14 | 5 | 11 | 주차장1경보 | 1 | 태안사지구 | 곡성군 | 기념관경보국 | 태안사계 |
| 7 | 35" 07' 47" | 127 22 26 | 5 | 12 | 반야쿄2경보 | 1 | 태안사지구 | 곡성군 | 반야교경보국 | 태안사계 |
| 8 | 35" 07" 46" | 127 22 45 | 5 | 13 | 해탈교3경보 | 1 | 태안사지구 | 곡성군 | 移탈교경보국 | 태안사계 |
| 9 | 35" 13" 42" | 127 22 27 | 5 | 14 | 청소년야영장 | 0 | 압록지구 | 곡성군 | 0:영장경보국 | 가정 |
| 10 | 35" 39" 32" | 128" 03" 20" | 8 | 9 | 오동산1경보 | 0 | 오도산지구 | 합천 | 오도1경보국 | 오도산휴9 |
| 11 | 35" 39" 59" | 128" 03" 27" | 8 | 10 | 오도산2경보 | 0 | 오도산지구 | 합천 | 오도2경보국 | 오도산휴9 |
| 12 | 35" 40" 20" | 128" 03" 42" | 8 | 11 | 오도산3경보 | 0 | 오도산지구 | 합천 | 오도3경보국 | 오도산휴8 |
| 13 | 35" 30" 44" | 127 58 32 | 8 | 12 | 하금경보 | 1 | 하금계곡지구 | 합천 | 하금1경보국 | 하금계; |
| 14 | 35" 15" 48" | 127" 51" 39" | 11 | 16 | 유원지경보 | 0 | 대원사지구 | 산청 | 제1경보 | 덕천강 |
| 15 | 35" 17' 36" | 127" 49" 03" | 11 | 17 | 내원1경보 | 1 | 산형내원사지구 | 산청 | 제1경보 | 내원사 |
| 16 | 35' 17' 41' | 127" 48" 48" | 11 | 18 | 내원2경보 | 0 | 산청내원사지구 | 산청 | 제2경보 | 내원사 |
| 17 | 35" 16" 51" | 127" 46" 13" | 11 | 19 | 야영장경보 | 0 | 대원사지구 | 산청 | 중산교(야영장)경보국 | 중산리 |
| 18 | 35' 19' 54' | 127" 50" 21" | 11 | 20 | 석남경보 | 0 | 대원사지구 | 산형 | 제2경보 | 덕천강 |
| 19 | 35" 17' 39" | 127" 49" 10" | 11 | 25 | 낙포대(04신) | 1 | 산형내원사지구 | 산청 | 낙포대경보국 | 내원사 |
| 20 | 35" 22" 15" | 127" 46" 11" | 11 | 32 | 세재(04국) | 0 | 대원사지구 | 산형 | 새재 우량국 | 대원사 |
| 21 | 35" 15' 36" | 127" 47" 10" | 12 | 9 | 중산1경보 | 0 | 중산리지구 | 산청 | 중산1경보국 | 중산리 |
| 22 | 35' 15' 34' | 127" 47" 24" | 12 | 10 | 중산2경보 | 0 | 증산리지구 | 산청 | 중산2경보국 | 중산리 |
| 4 | | | _ | _ | | _ | _ | | | |

Figure 17 Attribute window for warning stations located in the flash flood risk area

Figure 18 is the attribute window for rainfall observation areas located in the flash flood risk area. The user can find the attribute associated with a rainfall observation area located in the flash flood risk area and it is possible to obtain hourly and accumulated rainfall information during the period assigned by the user as shown in Fig. 19. All the information associated with a rainfall observation areas located in the flash flood risk area is displayed in the excel sheet (1). Once a rainfall observation location for which the user wants to know the rainfall data, click the "rainfall data reference" button (2) which then opens the "hourly and accumulated rainfall" window (Figure 19).

| 2 | 돌 | 발흥· | 수예측시 | - 스템 | | | | | | | NC 국립방재연구 전문대학자원국 |
|------|---------|--------|-----------|-------------|--------------|----|----|----|----|-----|----------------------|
| | 자료관리 ; | 다료조회 기 | 다료분석 | | | | | | | 강우도 | 니터링 돌발홍수모니터링 환 |
| 국장 | 영보조회 경 | 보국 정보조 | 회 유역 정보조 | 회 강우관측지점 ? | 경보조회 | | | | | | |
| · 현3 | 청구역 | AI: | 도명 🔹 🕽 | ₩군구명 💌 | | | | | | | |
|) 관(| 촉지점정보 | V | 기상청(관서용) | [] 기상왕(AWS) | 8면동강우계 | | | | | | 조 회 다운: |
| 1 | 지점변호 | 지점명 | 지점명(영문) | 위도 | 경도 | 정보 | 정보 | 정보 | 정보 | 정보 | |
| 1 | 2002445 | 영양 | Yeongyang | 388303,262 | 352285,095 | 0 | 0 | 0 | 0 | 0 | |
| 2 | 1007420 | 여주 | Yeoju | 257383,3321 | 421675,8881 | 0 | 0 | 0 | 0 | 0 | |
| 3 | 2024410 | 상북 | Sangbuk | 388353,256 | 214588,258 | 0 | 0 | 0 | 0 | 0 | |
| 4 | 1017445 | 안양 | Anyang | 191375,583 | 433628, 343 | 0 | 0 | 0 | 0 | 0 | |
| 5 | 1101404 | 안성 | Ansung | 224745,6102 | 389636, 5048 | 0 | 0 | 0 | 0 | 0 | |
| 6 | 1101410 | 82 | Yanggam | 195050,5370 | 397657,0110 | 0 | 0 | 0 | 0 | 0 | |
| 7 | 2008410 | 상주(견) | Sangju | 303903,179 | 326062,276 | 0 | 0 | 0 | 0 | 0 | |
| 8 | 2010416 | 산성 | Sansung | 352689,965 | 293238,811 | 0 | 0 | 0 | 0 | 0 | |
| 9 | 2019430 | 봉수 | Bongsu | 312139,631 | 220587,109 | 0 | 0 | 0 | 0 | 0 | |
| 10 | 1202420 | 반월2 | Banwol2 | 189358,579 | 427677,5379 | 0 | 0 | 0 | 0 | 0 | |
| 11 | 1202410 | 반월1 | Banwol1 | 187932,2263 | 423381,9003 | 0 | 0 | 0 | 0 | 0 | |
| 12 | 2013430 | CH 7ł | Daega | 307221,286 | 266608,251 | 0 | 0 | 0 | 0 | 0 | |
| 13 | 1017420 | 남면 | Nammyeon | 194804,8708 | 427286,8743 | 0 | 0 | 0 | 0 | 0 | |
| 14 | 1017415 | 낙생 | Naksaeng | 204401,2731 | 432345, 3089 | 0 | 0 | 0 | 0 | 0 | |
| 15 | 2024440 | 김해 | Kimhae | 370621,643 | 193853,956 | 0 | 0 | 0 | 0 | 0 | |
| 16 | 1018410 | 김포 | Kimpo | 174885,0837 | 457050, 1688 | 0 | 0 | 0 | 0 | 0 | |
| 17 | 2012410 | 김천 | Kimcheon | 299864,973 | 291489,728 | 0 | 0 | 0 | 0 | 0 | |
| 18 | 9000067 | 금약 | Keumak | 281507,9605 | 521563,4022 | 0 | 0 | 0 | 0 | 0 | |
| 19 | 9000146 | 군남 | Kunnam | 201342,9051 | 505904,8012 | 0 | 0 | 0 | 0 | 0 | |
| 20 | 2016410 | 고령 | Goryeong | 315386,256 | 248277, 701 | 0 | 0 | 0 | 0 | 0 | |
| 21 | 2201440 | 경주2 | Kyeongju | 398830,769 | 261936,852 | 0 | 0 | 0 | 0 | 0 | |
| 22 | 1015440 | 경안 | Kyeongan | 223226,9229 | 433846,7197 | 0 | 0 | 0 | 0 | 0 | |
| 4 | | | | | | | _ | _ | | | |
| | 유자료 조희 | _ | | | | | | | | | |

Figure 18 Rainfall observation areas located in the flash flood risk area



Figure 19. The hourly and accumulated rainfall window

Figure 20 is the data analysis window. The user can select the combo box assigned as the observed rainfall event and click "Analysis" button (4). Then all of the warning records in accordance with subbasins' names and the warning degrees during the selected period will be displayed.

| 2 | 말 왕 수 해 속 시 스템 돌발 홍 : | 수예측시스템 | | ◆ 문 NIC: 국립방지연구소 Million: The set |
|----|--------------------------|----------------------------------|--------------|---|
| 말 | 자료관리 자료조회 : | 자료분석 | | 강우모니터밍 돌말홍수모니터밍 환경승 |
| | 조회분류 | | | |
| | ○ 자동경보강우 ④ | ⑦관측장 ○ 3시간예측장 | | |
| | 조회기간 2009년 7월 | # 11일 • 0 • 시 0 • 분 ~ 2009년 7월 2 | 10 호시 이 호분 | 분석 |
| | 시간 | 주의 | 37 | CH III |
| 1 | 2009-07-11 03:50 | | | 남창지구, 내변산지 |
| 2 | 2009-07-12 03:50 | 작전리지구, 작전리지구 | 청천지구 | 남창지구, 달친지구, 달친지 |
| 3 | 2009-07-12 04:00 | 응유지구, 작전리지구, 작전리지구, 청천지구 | | 남창지구, 달친지구, 달친지 |
| 4 | 2009-07-12 04:30 | | 달친지구, 명호지구 | 덕동지구 |
| 5 | 2009-07-12 04:40 | 반성현지구, 용유지구, 작전리지구, 작전리지구, 청현지두 | 명호지구 | 상지구, 달친지구, 달친지구, 덕동지 |
| 6 | 2009-07-12 05:00 | | 달천지구, 영호지구 | 덕동지구, 청천지 |
| 7 | 2009-07-12 05:10 | 달친지구, 덕동지구, 청천지구 | | 명호지구, 청천지 |
| 8 | 2009-07-12 05:20 | 달천지구, 덕동지구, 명호지구, 청천지구 | | 청천지구 |
| 9 | 2009-07-12 05:30 | 달쳔지구, 덕동지구, 청천지구 | | 명호지구, 형천지 |
| 10 | 2009-07-16 05:50 | 대운산지구, 배내골지구 | | 내변산지구, 석남지구, 석남지구 |
| 11 | 2009-07-16 06:00 | 석남지구, 옥동천지구 | | 석남지구, 오봉계곡, |
| 12 | 2009-07-16 06:10 | 대운산지구, 배내골지구, 석남지구 | 옥동천지구 | 내변산지구, 석남지구, 오봉계곡 |
| 13 | 2009-07-16 06:20 | 대운산지구, 배내골지구, 석남지구 | 옥동쳔지구, 옥동천지구 | 내변산지구, 석남지구, 오 |
| 14 | 2009-07-16 06:30 | 구, 배내골지구, 석남지구, 안성천지구, 육동천지구, 육[| 남창지구 | 내변산지구, 석당지구, 오! |
| 15 | 2009-07-16 06:40 | 운산지구, 배내골지구, 석남지구, 옥동천지구, 옥동천지- | | 창지구, 내변산지구, 석납지구, 안성 |
| 16 | 2009-07-16 06:50 | 운산지구, 배내골지구, 석남지구, 육동천지구, 육동천지- | | 창지구, 내변산지구, 석남지구, 안성 |
| 17 | 2009-07-16 07:00 | 배내골지구, 석납지구, 옥동천지구, 옥동천지구 | | 산지구, 대운산지구, 석납지구, 안성 |
| 18 | 2009-07-16 07:10 | 배내글지구, 석남지구, 육동천지구, 육동천지구 | | 운산지구, 동곡지구, 석남지구, 안성 |
| 19 | 2009-07-16 07:20 | 태안사지구 | 대운산지구 | 남창지구, 동곡지구, 안성천지 |
| 20 | 2009-07-16 07:30 | 대운산지구, 안성현지구, 육동천지구 | | 남창지구, 동곡지구, 압록지구, 어? |
| 4 | | | | |

Figure 20. Data analysis window

Once the user clicks on a row of the excel sheet to select a period and clicks the "Display chart" button (2), the window shown in Figure 21 opens. The line charts in the window show the number of the warning degree of the flash flood warnings during the selected period.



Figure 21 The number of the warning degree of the flash flood warnings during the selected period

Figure 22 shows the region where the flash flood warnings are issued during the selected period. The region is shown in different colors depending on the warning degree namely "Caution", "Warning" or "Evacuation".



Figure 22. Displaying regions in accordance with the warning degree issued

The window in Fig. 23 is the system environment setting. In the window, all of the designated persons information can be found in the excel sheet (1) and their information can be managed with "add" (2), "modify" (3), and "remove" (4). If "reception" is set to "Y" in the information of the designated person, he/she will receive the warning message via Email. In the window to register a designated person (5), new information is added to the system. With this window, the following information can be set and managed.

- The types of the very short-term rainfall data (CAPPI10, CAPPI20, CMAX20, CMERGE10, CMERGE20)
- Warning period
- Warning device (SMS or Email)

With the "initial setting" button (6) the warning period is set to the initial value which is of 20 minutes.

| 자료관리 | TOTAL T | | | | |
|-------------|-------------------|--------------|---------------------------|----------------------|----------------------|
| | 사태조의 ^ 우예측자료 설 | | | | 강우모니터링 돌말홍수모니터링 환경설을 |
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| • 경보담당 | 당 자 | | | | |
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| ✓ 수신여부 Y | 담당자 홍길동 | 소속 방제연구소 | E-Mail hong@nema.go.kr | 연락처 010-1235-1652 | 3 |
| Y | 송열종 점재학 | 방재연구소 | blueboat@nema.go.kr | 010-9190-4946 | |
| | | | | | |
| | | | | | |
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2. Messenger client

The messenger client is developed to quickly spread the current regional conditions which are collected and expected by the developed flash flood forecast system to all authorized persons to handle the situation properly. Figure 24 is the login window for the messenger client. It is automatically connected to the mountainous flash flood server and performs the initial and idle tasks to receive the circumstance report message from the server. "File" (1) includes the type of program and log-out functions and "See" (2) shows all the information related to the previous warnings. "Environmental setting" (3) allows us to set the environmental setting of the messenger client. The name of the server in 4 refers to which server is connected to the messenger client and 5 indicates the communication condition. 6 lets the user make choose whether he/she wants to use the device notification or not. 7 is the log-in and log-out button and is used to connect and disconnect from the server.



Figure 24 Flash flood warning messenger client

Figure 25 is the circumstance reporting window that pops up after messenger client is activated. It shows an expected circumstance which is required to issue a flash flood warning based on the 3-hour forecast rainfall. The warning degree is set to "Caution", "Warning", and "Evacuation" depending on the severity. In the window, 1 is used to hide the window and the color of the window (2) will automatically change to inform a warning was issued. "Regional Information" (3) shows the information of the region where the warning was issued. If the user clicks this button, as shown in Figure 26, the user obtains "Full extent" (1) for the region, "Contact" (2), "Address and photos of the region" (3). 4 shows the warning messages which were issued earlier and saved in the system. 5 displays the time of the warning message issued and with 6 the user can obtain the warning degree, the name of the region, the amount of rainfall, 3-hour forecast rainfall and more. "Suspension of warning" (7) button is used to stop the device notification and the number of the warning messages which have been issued till now can be found by clicking 8.



Figure 25. Circumstance reporting pop-up window



Figure 26. Regional Information where a flash flood warning has been issued

When an immediate flash flood incident is expected, the following procedures should be performed as shown in Figure 27.

- Flash flood warning issued after the circumstance has been analyzed
- Check-out the regional information and perform according emergency actions
- Notify the circumstance to the region and identify critical factors
- Identification of critical factors, performing emergency actions and reporting to on-duty employees in the region

side of the window

- Toolbar (2) and Menubar (3) on the upperright of the window
- Map (4) and Legend (5) on the lower-right of the window

In the rainfall data collection window, rainfall data analyzed by the user is displayed after the searched data in "C:\Compress". Once the user can select any rainfall data from the list (1), the observed rainfall phase and other 36 phases of the forecasted rainfall are displayed on the map (4) and from the legend (5), the user can find the rainfall intensity. Using the period button in



Figure 27. Flow chart of performing emergency procedures

3. Flash flood forecast system for professionals

Figure 28 is the initial window of the flash flood forecast system for professionals. This window consists of

• Rainfall data collection window (1) on the left

the toolbar (2), the relevant information of both the observed and forecasted rainfall phases corresponding to the selected period will be displayed on the map (4). By clicking the "System End" button (6), the system is completed.



Figure 28 The initial window of the flash flood forecast system for professionals

Figure 29 is the screen for the analysis of the areal rainfall. First, select very short-term rainfall data in the list window (1) and click "Analyze the areal rainfall" (3). A message window (2) will then pop up explaining the functions of the analysis of the areal rainfall. Clicking the "Yes" button performs the analysis of the areal rainfall. If "No" button is

clicked, the task is finished. After the user selects a target range on the map by dragging a mouse, he/she double-clicks to open the window showing the rainfall analysis results 4). The min, max, and average rainfall, and standard deviation, and the total amount of rainfall are obtained.



Figure 29 The screen for the analysis of the areal rainfall

The rainfall movement speed can be estimated by clicking the "Rainfall trace analysis" button of the toolbar as shown in Figure 30. If the user sets the start time and location to analyze the rainfall movement velocity in the combo box (1), the radar image corresponding to the time the user set is displayed in the map on the left (7). The user clicks "Start location set" button (3) and clicks again on the location to be analyzed on the map. To set the end time and location for the analysis, repeat the same procedures but using the "End location set" button (4) instead of the "Start location set" button.

"Redraw" button (5) allows the user to restart the analysis. After clicking the "Movement velocity analysis" button (6), the user finds results on the upper-right corner of the window (8). The speed in the window is calculated by using the distance which is set by the user. The analyzed distance is shown on the map and by clicking the "Download" button (9), the screen containing the information related to the analyzed distance can be saved. "End" button (10) finishes the analysis.



Figure 30 The window for the analysis of the rainfall movement velocity



Figure 31 Analysis of the rainfall movement velocity (1)



Figure 31 (cont') Analysis of the rainfall movement velocity (2)

By clicking the "Rainfall movement trace analysis" button of the toolbar, the window of the rainfall movement trace analysis opens as shown in Figure 32. Once the user selects the time that he/she wants to analyze in the combo box (1), the radar image corresponding to the time the user set is displayed in the map bellow (7). After clicking the "Display the rainfall movement trace" button (3), the user clicks again on the location to be analyzed on the map to perform the analysis. The time information for the analysis is displayed in the combo box of the rainfall movement trace (2). The rainfall movement trace for other time periods can be performed by following the same procedure.

"Redraw" button (5) allows the user to restart the analysis.

The analyzed rainfall movement trace is shown on the map and by clicking the "Download" button (7), the screen containing the information related to the analyzed rainfall movement trace can be saved. "End" button (9) finishes the analysis.



Figure 32. Analysis of the rainfall movement trace (1)



Figure 32 (cont'). Analysis of the rainfall movement trace (2)

By clicking the "Accumulated rainfall" button in the toolbar, the window for the analysis of accumulated rainfall opens. Once the user selects the time of rainfall to be analyzed on the "Set the analyzed data" (1), the list of observed rainfall phases will be displayed in the combo box and the analyzed accumulated rainfall data corresponding to the observed rainfall selected will be displayed on the map. From the legend 5), the rainfall intensity data will be identified. At the same time, if the "Analyze the areal rainfall" button (3) is clicked, it will perform the same analysis as the analysis of the areal rainfall. The user can save the analysis results shown in the window by clicking "Download" (5). "End" button (6) finishes the analysis.

V. CONCLUSION

n this system the flash flood forecast system based on GIS is developed to predict flash flooding from occurring in mountainous areas. With the system, basin data can be obtained and sub-basins are delineated from the Korea Peninsula to identify which are the mountainous flash floods risk areas. The data associated with each sub-basin such as the characteristics of velocity, length of channel, area slope, and channel slope are estimated. These data are needed to obtain the hydrographs. Also, the rainfall adjustment method is built to improve the reliability of forecasted rainfall. To issue a flash flood warning promptly, an emailing system has been developed and an SMS service system is being developed. To obtain the flash flood warning time, a very short-term rainfall forecast model is selected and a methodology to adjust forecasted results from the model is developed.

Since Republic of Korea, where this forecast system is being applied, is vulnerable to flash floods due to its geographical characteristics as well as climate change, it will be a constant concern to keep the country safer from mountainous flash flood. For this purpose, IT and hydrological methodologies are integrated to develop the scientific disaster mitigation technology and to advance the current system based on this technology. With the developed technology and the system, it is possible to obtain the pre-disaster mitigation capability which is a sociological and academic demand for this era. This is the main reason that led us to carry out this system.

REFERENCES

- Anagnostou, E.N., Krajewski, W.F., Seo, D.J., and Johnson, E.R. (1998). Mean-field rainfall bias studies for WSR-88D, Journal of Hydrologic Engineering, Vol. 3, No. 3, pp. 149-159.
- Andrieu, H., Creutin, J.D., Delrieu, G., and Faure, D. (1997). Use of a weather radar for the hydrology of a mountainous area. Part I: radar measurement interpretation, Journal of Hydrology, Vol. 193, pp. 1-25.
- Austin, P.M. (1987). Relation between measured radar reflectivity and surface rainfall, Monthly Weather Review, Vol. 115, pp. 1053-1070.
- Barnston A.G. (1990). An empirical method of estimating raingage and radar rainfall measurement bias and resolution, Journal of Applied Meteorology, Vol. 30, pp. 282-296.
- Brandes, E.A. (1975). Optimizing rainfall estimates with the aid of radar, Journal of Applied Meteorology, Vol. 14, pp. 1339-1345.
- Bratseth, A.M. (1986). Statistical interpolation by means of successive corrections, Tellus, 38A, pp. 439-447
- Brilly, M., Rusjan, S., and Vidmar, A. (2006). Monitoring the impact of urbanisation on the Glinscica stream, Physics and Chemistry of the Earth, Vol. 31, pp. 1089-1096.
- Caya, A., Sum, J., and Snyder, C. (2005). A comparison between the 4DVAR and the ensemble Kalman filter techniques for radar data assimilation, Monthly Weather Review, Vol. 133, pp. 3081-3094.
- Collier, C.G. (1983). Accuracy of rainfall estimates by radar, Part I: Calibration by telemetering raingauges, Journal of Hydrology, Vol. 83, pp. 207-223.
- Collier, C.G., Larke, P.R., and May, B.R. (1986). A weather radar correction procedure for real time estimation of surface rainfall, The Quarterly Journal of the Royal Meteorological

Society, Vol. 109, pp. 589-608.

- Creutin, J.D., Delrieu, G., and Lebel, T. (1988). Rain measurement by raingaugeradar combination: A geostatistical approach, Journal of Atmospheric and Oceanic Technology, Vol. 5, pp. 102-115.
- Errico, R., Ohring, G., Derber, J., and Joiner, J. (2000). NOAA-NASA-DoD workshop on assimilation of satellite data, Bulletin of the American Meteorological Society, Vol. 81, pp. 2457-2462.
- Gebremichael, M. and Krajewski, W.F. (2005), Modeling the distribution of temporal sampling errors in area-time-averaged rainfall estimates, Atmospheric Research, Vol. 73, pp. 243–259.
- Grecu, M. and Krajewski, W.F. (2001). Rainfall forecasting using variational assimilation of radar data in numerical cloud model, Advanced in Water Resources, Vol. 24, pp. 213-224.
- Gupta, V.K., E. Waymire and C.T. Wang (1980). A representation of the instantaneous unit hydrograph from geomorphology, Water Resources Research, Vol. 16, No. 5, pp.855-862.
- Hoke, J.E. and Anthes, R.A. (1976). The initialization of numerical models by a dynamic-initialization technique." Monthly Weather Review, Vol. 104, pp. 1551-1556.
- Jensen, N.E. and L. Pedersen (2005). Spatial variability of rainfall: Variations within a single radar pixel, Atmospheric Research, Vol. 77, pp. 269–277.
- Jordan, P., Seed, A., and Austin, G. (2000). Sampling errors in radar estimates of rainfall, Journal of Geophysical Research, Vol. 105(D5), pp. 2247–2257.
- Journel, A.G., and Huijbregts, C.J. (1978).
 Mining geostatistics, Academic Press, San Diego.

- Kalnay, E. (2003). Atmospherical modeling data assimilation and predictability, Cambridge University Press, Cambridge.
- Krajewski W.F., and Smith, J.A. (2002). Radar hydrology: rainfall estimation, Advances in Water Resources, Vol. 25, pp. 1387-1394.
- Krajewski, W.F. (1987). Cokriging of radarrainfall and rain gage data, Journal of Geophysical Research, Vol. 92, pp. 9571-9580.
- Kuo, Y.H., Guo, Y.R., and Westwater, E.R. (1993). Assimilation of precipitable water measurement into a mesoscale numerical model, Monthly Weather Review, Vol. 121, pp. 1215-1238.
- McLaughlin, D. (2002). An integrated approach to hydrologic data assimilation: interpolation, smoothing, and filtering, Advances in Water Resources, Vol. 25, pp. 1275-1286.
- Peters, N.E. (2009). Effects of urbanization on stream water quality in the city of Atlanta, Georgia, USA, Hydrological Processes, Vol. 23, pp. 2860-2878.
- Rodriguez-Iturbe, I. and Gonzalez-Sanabria, M. (1982). A Geomorphoclimatic Theory of the Instantaneous Unit Hydrograph, Water Resources Research, Vol. 18, pp.977-886.
- Rodriguez-Iturbe, I. and Valdes, J. (1979). The Geomorphologic Structure of Hydrologic Response, Water Resources Research, Vol. 15, No. 6, pp.1409-1420.
- Rosenfeld, D., Wolff, B.D., and Atlas, D. (1993). General probability-matched relations between radar reflectivity and rain rate, Journal of Applied Meteorology, Vol. 32, pp. 50-72.
- Seo, D.J., Breidenbach, J.P., and Johnson, E.R. (1999). Real-time estimation of mean field bias in radar rainfall data, Journal of Hydrology, Vol. 223, pp. 131–147.

- Seo, D.J., Krajewski, W.F., and Bowles, D.S. (1990a). Stochastic interpolation of rainfall data from rain gages and radar using cokriging: 1. Design of experiments, Water Resources Research, Vol. 26, pp. 469-477.
- Seo, D.J., Krajewski, W.F., Azimi-Zonooz, A., and Bowles, D.S. (1990b). Stochastic interpolation of rainfall data from rain gages and radar using cokriging: 2. Results, Water Resources Research, Vol. 26, pp. 915-924.
- Sinclair, S., and Pegram, G. (2005). Combining radar and rain gauge rainfall estimates using conditional merging, Atmospheric Science Letters, Vol. 6, pp. 19-22.
- Smith, J.A., and Krajewski, W.F. (1991). Estimation of the mean field bias of radar rainfall estimates, Journal of applied meteorology, Vol. 30, pp. 397-412.
- Takasao, T., Shiba, M., and Nakakita, E. (1994). A real-time estimation of the accuracy of short-term rainfall prediction using radar, Stochastic and Statistical Methods in Hydrology and Environmental Engineering, Vol. 10, pp. 339-351.
- Todini, E. (2001). A Bayesian technique for conditioning radar precipitation estimates to rain-gauge measurements, Hydrology and Earth System Sience, Vol. 5, pp. 187-199.

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