# REVIEW OF THE FLASH FLOOD GUIDANCE SYSTEM (FFGS) WITH GLOBAL COVERAGE PROJECT

## Final Report

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**Independent Reviewers**

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## Acknowledgements

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## Executive Summary

Following the catastrophic flash flooding in Central America from Hurricane Mitch in 1998, the Flash Flood Guidance System (FFGS) was developed as a tool to help prevent such huge losses from killer flash floods in the future. Since then, the WMO began a Global program to implement the FFGS that has expanded rapidly to over 60 countries world-wide. Since the inception of this program, there have been many countries that have adopted and used the system but there has been no evaluation of the value or effectiveness of this program which has been a significant investment. Recognizing the need for an assessment of the system and the program, the WMO established a team to conduct an assessment of the program. The assessment of the strengths, weaknesses and effectiveness of the Flash Flood Guidance System with global coverage project (GFFG) and the program of implementation utilized the OECD DAC principles of Evaluation of Development Assistance. The WMO appointed team designed a questionnaire which was distributed to over 90 developers, program managers, National Meteorological and Hydrological Services (NMHSs) forecasters, end users and key individuals involved with development and implementation of the system. The team conducted many interviews and visited two regional centers as well as selected national centers. Key findings of the team reveal that the GFFG system has introduced a very important and effective capability to NMHSs to issue flash flood warnings where these warnings did not exist in the majority of participating countries before the implementation of the program. Before the FFGS implementation, most national weather services and response agencies were not trained to anticipate and plan effective response actions to these disasters due to their short time scales of occurrence and due to their infrequent nature for many particular locations. The FFGS implementation and operation allowed forecasters, for the first time, to predict a phenomenon that is very difficult to predict. From this standpoint, the FFGS contributed significantly to NMHSs capacity to monitor and issue early warnings of flash floods hence it had a highly positive impact on NMHSs and NDMAs and, most importantly, on the affected people who are the ultimate beneficiaries of the project to help save lives and reduce adverse impacts. Although there are many successful use of the FFGS, participants indicated that the system needs to be updated to improve flexibility and functionality of including the system structure, products and program management, and execution.

Therefore, establishment of a Configuration Management Control Committee is recommended as a mechanism to prioritize correcting bugs and features which exist as well as setting priorities for enhancements to future versions. Some of the major required improvements identified include the need to: improve skill and accuracy of satellite estimated rainfall (use is made of the NOAA Hydroestimator due to its low latency in observations), increase the willingness to collect and share real time observed rainfall data to bias correct satellite data, improve the training program, and structuring a more flexible system (open up the system) for NMHSs to better utilize and adapt the system to meet their needs. Human and monetary resources are another issue limiting the development and implementation of the system. However, the biggest concern is with the sustainability of the GFFG program. The current partnership of WMO, USAID, HRC and NOAA needs to expand to include an infusion of more donors, development partners and organizations to produce a stronger partnership that will ensure not only the delivery of warning services in the future but innovative and community practices to improve the quality and effectiveness of the end to end system down to the last kilometer. We also believe that the GFFG is part of a multi-hazard early warning system (MHEWS) that through collaboration with programs such as CIFDP and SWFDP could strengthen this system further by leveraging resources and standardizing the E2E process.

## Background

Following the catastrophic flooding of Hurricane Mitch in 1998 in Central America, the United States Agency for International Development (USAID) Office of Foreign Disaster Assistance (OFDA) initiated a project in 2000 (known as the Central America Mitigation Initiative, CAMI) to have NOAA coordinate the development of an early warning system for flash floods in the region. The Central America Flash Flood Guidance (CAFFG) system became operational in 2003 to seven NMHSs in Central America. A verification study of CAFFG was done a year later and it showed, in general, that the first regional FFG System was indeed performing well and reported flash flooding was occurring were CAFFG was predicting flooding. This set the pace for expansion of this system.

Recognizing the disastrous impact on lives and properties of affected populations by flash floods, the Fifteenth World Meteorological Congress approved the implementation of a Flash Flood Guidance System (FFGS) project with global coverage that had been developed by the WMO Commission for Hydrology (CHy) jointly with the WMO Commission for Basic Systems (CBS) and in collaboration with the US National Weather Service (US NWS), the US Hydrologic Research Center (HRC) and USAID/OFDA.

The implementation of the Flash Flood Guidance System with global coverage project (GFFG) has expanded through a Memorandum of Understanding (MoU) for establishing a cooperative initiative among WMO, USAID/OFDA, NWS and HRC. This MoU came into effect on 25 February 2009, and was extended by mutual agreement for an additional five-year period, and expired on 31 December

2017. Efforts are underway to develop a new MoU among the organizations to further enhance early warning capabilities for flash flooding.

There are six regional FFGS systems that have been established: Black Sea and Middle East, Central America, Central Asia Region, Mekong River Commission, Southern Africa Region and South East Europe and have become fully operational, covering 41 countries. Four systems located in Haiti and Dominican Republic, South Asia, Southeast Asia and Southeastern Asia-Oceania are under implementation, covering an additional 17 countries. As this assessment is occurring, another two FFGSs are being designed. One is a stand-alone system for an individual country, while another is for Northwest South America (emanating from the Zarumilla River Basin pilot application), which includes three countries. The system has also been successfully implemented at a subnational scale. The systems are shown in Figure 1.

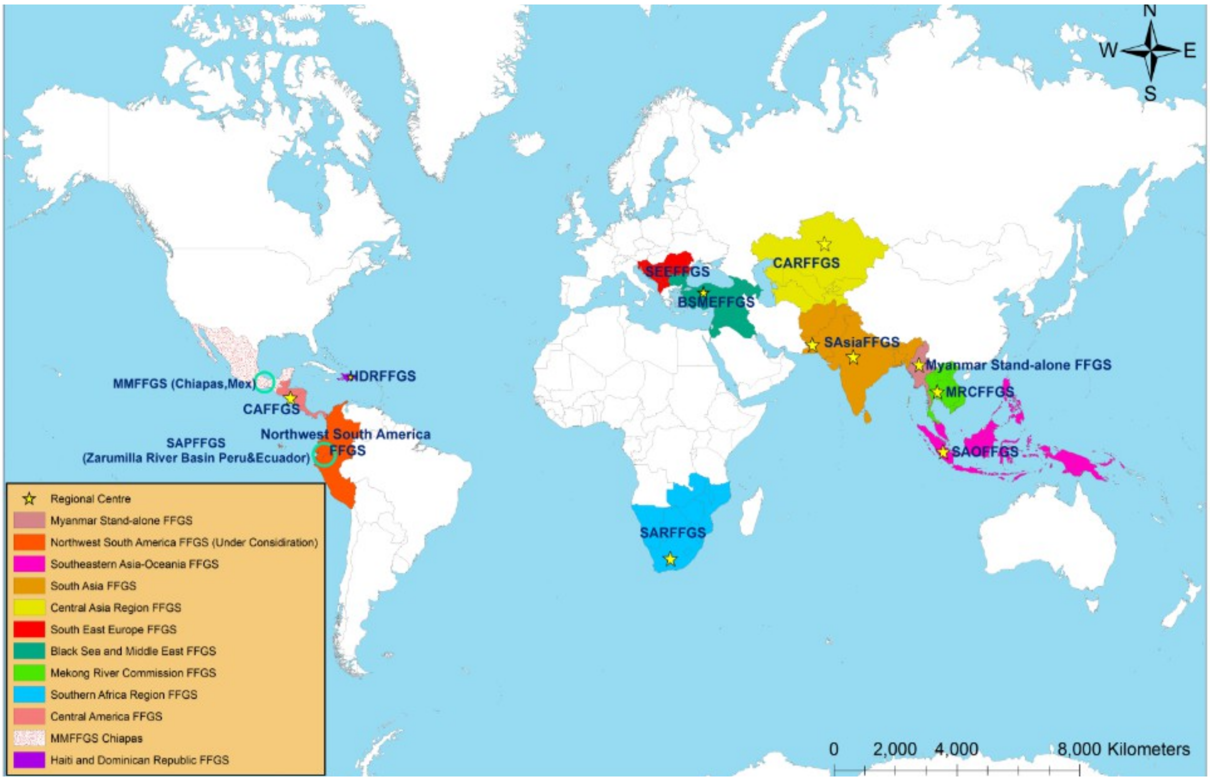


Figure 1.Regional FFGS systems

## Overview, purpose and approach of the assessment

Since 2003, the Flash Flood Guidance System has been expanding into many regions of the world. The number of countries for which the system has been implemented will be over 60 countries this year. Since its inception, there has been no evaluation or assessment of the program to implement GFFG, the FFG System itself, and the effectiveness and sustainability, which are major questions given the size of the investment and the expectations of the performance.

## *Mission and purpose of Assessment*



In August of 2018, WMO established a team to conduct an assessment of the GFFG Program. The team consisted of Dr. Yuri Simonov, Hydrometeorological Research Centre of the Russian Federation, Mr. Marcelo Uriburu Quirno, National Commission of Space Activities of Argentina and Mr. Curtis Barrett, Hydrometeorological Advisor, USAID OFDA, to conduct a review of the FFGS current status and progress in the implementation of the FFGS with global coverage project. In addition, the assessment team was asked to review performance of completed activities and those under development based on available reports, interviews, and discussions with selected target group representatives, including evaluation of benefits and costs of the various projects undertaken. The review is to be conducted following OECD DAC principles of Evaluation of Development Assistance which will be further described below.

The TOR for this study specifies the review of the overall FFGS with global coverage project concept and its regional projects will be conducted with regards to efficiency and effectiveness, evaluating strengths and weaknesses, and proposing improved efficiency and effectiveness for future projects. Recommendations will include future governance options and resource requirements for carrying out further development efforts and on-going operations in a sustainable manner. It will provide an assessment of the benefits and examine the need for establishing different approaches (if needed) that could be applied to advance the use of early warning systems for flash flooding. The results of this review are scheduled to be presented to the CHy Advisory Working Group and CBS Management Group, as a formal report and a power point presentation. The results of this review are then scheduled to be delivered to the President of CHy on behalf of the president of CBS, to the World Meteorological Congress-18 in 2019.

The team was originally assigned a timeline of 3 months (July 1 through September 30, 2018) to complete the assessment but due to a late start of the team and problems encountered scheduling the visits and interviews, an extension of one month was agreed upon by WMO. Thus the submission of the first draft originally scheduled for September 30, 2018 was delayed until November 2, 2018.

## *Description of the approach taken to assess the Program*

The GFFG Assessment Team decided to use a very similar approach that was used for the WMO APFM Assessment. That approach consisted of sending out questionnaires to stakeholders and contacts in the program, conducting telephone interviews to key program and project individuals, making a few selected visits, and reviewing all reports, documents and information available. The team decided to conduct selected visits to existing FFGS countries (Dominican Republic in the Caribbean, Kazakhstan and Kyrgzystan of the Central Asia FFG System, the Slovenian Republic, of the South East Europe FFG System, and Turkey. The Turkish State Meteorological Service (TSMS) is a regional center for two Regions: the Black Sea and Middle East FFGS and the South East Europe FFGS. In addition to the selected visits, the team constructed a questionnaire that was sent to FFGS focal points of operational system and those under development, WMO personnel involved with the GFFG program, partners of the GFFG Agreement (NOAA, HRC and USAID/OFDA), scientists and program managers of projects involved in flash flood forecasting such as EFAS and SCHAPI and a few selected users such as National Disaster Management Agencies. The Table of contact persons is in Appendix 1 while the Questionnaire distributed to Developers and Operational personnel is in Appendix 2. We encountered difficulty reaching out to the ultimate users of FFGS produced warning products such as Disaster Managers. In most cases National Disaster Management Agencies (NDMAs) do not receive FFGS products directly but rather alerts and warnings which are derived from FFGS products. We did however directly interview selected Disaster Management Officials during our visits.

There were 28 Questionnaires received, 19 telephone interviews conducted, 5 countries were visited, and 6 NMHS forecasters were interviewed. There were many reports and documents reviewed about the system design, system implementation, system operation, project briefs, implementation requirements, project implementation plans, forecaster guides, meeting reports, case studies, and presentations.

### *Assessment approach based on OECD DAC Principles for Evaluation of Development Assistance*

Although FFGS with global coverage project is intended to advance early warnings of flash floods in all countries, this review was conducted following the OECD DAC Principles for Evaluation of Development Assistance, focusing on relevance, efficiency, effectiveness, impact and sustainability:

Relevance: The extent to which the FFGS with global coverage project is suited to the priorities and policies of the target group. For example Is it serving the needs of its communities?, the recipients and donors? To what extent are the objectives of the FFGS with global coverage project still valid? Are the activities and outputs of the FFGS project consistent with the overall goal and the attainment of its objectives? And are the activities and outputs of the FFGS consistent with the intended impacts and effects?

Effectiveness: A measure of the extent to which the FFGS with global coverage project attains its objectives should consider to what extent were the objectives of the initial MoU achieved / are likely to be achieved in its new formulation and what were the major factors influencing the achievement or non-achievement of the objectives?

Efficiency: Efficiency measures the outputs -- qualitative and quantitative -- in relation to the inputs. The Assessment team is to compare alternative approaches to achieving the same outputs, to verify efficiency in approach. Questions such was the work programme implementation carried out in a cost-efficient manner, was the work programme an efficient way of translating the strategy operationally compared to alternative approaches and is there a more efficient approach that can be recommended?

Impact: What has happened as a direct or indirect consequence of the implementation of the FFGS with global coverage project? What tangible change has the implementation of the activities of the FFGS with global coverage project made?

Sustainability: Are benefits of the activities likely to continue? What were the major factors which influenced the achievement or non-achievement of sustainability of the programme or its specific projects, such as, for example, the creation and active participation of a growing number of early warning systems for flash floods? The second is concerned with the future sustainability of the initiative regarding how it should be reshaped and the need for human and financial resources for it to succeed (e.g., governance structure, system upgrades and maintenance, on-going training).



This review was required to produce conclusions and recommendations with respect to the future directions of the FFGS with global coverage project, need for establishing new, modified, or complementary approaches that could be taken in advancing the concept of early warning systems for flash flooding. Also suggestions for means of ensuring the efficient relationship of the FFGS with global coverage project with other relevant initiatives including the Severe Weather Forecast Demonstration Project (SWFDP) and the Coastal Inundation Forecast Demonstration Project (CIFDP) and other related international programmes to ensure delivery of efficient and effective sustainable services. The complete TORs can be found in Appendix 5.

The GFFG Assessment team designed a questionnaire to address the 5 criteria for OECD evaluation. The questionnaire was designed recognizing that the collective organizations involved in the development and implementation of GFFG (HRC, WMO, NOAA and USAID/OFDA) had an entirely different role in the FFG System of Global Coverage than the operational users involved in the Operation, Maintenance and Use of the system such as NMHSs and the end users. The end users primarily consisted of the National Disaster Management Agencies but also the media and other users working on Disaster Risk Reduction such as NGOs (Red Cross) and the private sector. There are two sections of the questionnaire: Part A- Design, Development and Implementation, and Part B- Operation, Maintenance and Use. The Questionnaire is included in Appendix 2. The team then constructed Part A and B tables that summarizes the major responses of the questionnaires which appears in Appendix 3.

As the Severe Weather Forecast Development Program (SWFDP) provides products of importance to the FFGS and its new riverine flood forecasting is integral to accomplishing the Coastal Inundation Forecasting Demonstration Project (CIFDP) objectives, the FFGS assessment team interviewed the SWFDP and CIFDP Program Managers and WMO staff to understand how FFGS inter-relates with these other two programs.

### *Inception report and strategy development*

The Assessment Team TORs also included the requirement to develop an Inception report within the initial startup period to provide an overview of how the review will be carried out. The Inception report was provided to the Chief, Hydrologic Forecasting and Water Resources Division (C/HFWR) on July 27, 2018. The Inception report is in Appendix 4.

The assessment involved surveying all the partners involved in the two categories 1) project development and implementation, and 2) FFGS operation and maintenance. The strategy followed was to assess the various organizations and partners involved in implementation of the program. Various FFGS program documents were reviewed by the team such as Implementation plans, strategy documents, Steering committee reports, training sessions, HRC Work Plans, Project briefs, Workshop reports, the FFG System Implementation plan, summary reports, and the GFFG Program Sustainability Action Plan.

Surveys and interviews have been conducted from key personnel involved with HRC, WMO, USAID/OFDA, and the NOAA National Weather Service. The Presidents and Vice Presidents of the WMO Commissions CHy and CBS have been interviewed as well as key personnel involved in the operational program in the WMO Secretariat. Recognizing there are many Regional Centers and countries involved with operating FFGS, the Assessment team chose 5 NMHSs located in 3 Regions which comprised operational centers that are strong and in need of further support. Starting with the first FFGS in Central America (CAFFG), the El Salvador NMHS and Costa Rica Regional Centers were polled as well as the SARFFGS Regional Center, which is hosted by the South Africa Weather Service (SAWS). The Turkish State Meteorological Service (TSMS) was also visited as was the NMHS of Kazakstan that is hosting the Central Asia FFGS Regional Center and the NMHS of Kyrgyzstan. At the various NMHSs, both hydrologists and meteorologists were interviewed. In addition in these designated regions, we attempted to learn how or if FFGS products are being used by users such as NDMAs and tourism, but this level of effort did not have much success except during the planned visits.

## Description of the Flash Flood Guidance System

### *Overview of FFG System and its components*

The FFGS is used to calculate diagnostic indices known as flash flood guidance that are used to evaluate the potential for flash flooding. Flash flood guidance is defined as the amount of rainfall of a given duration over a small basin needed to create minor flooding (bankfull) conditions at the outlet of the basin. When used with meteorological forecasts and nowcasts of same-duration rainfall over these basins, flash flood guidance leads to the estimation of flash flood threat (the amount of rainfall of a given duration in excess of the corresponding flash flood guidance value) for these small basins. The FFG System indicates the likelihood of flooding of small streams over large regions by using bias-corrected remotely-sensed precipitation estimates and real time soil moisture estimates to produce flash flood guidance and flash flood threat. Flash floods are a hydrometeorological phenomenon that requires (a) integration of meteorology and hydrology in real time and (b) ingestion of local

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information and expertise for developing reliable warnings. The FFGS system design is based on providing both of these functions. The system serves as a catalyst to develop protocols in line with regional and country norms pertaining to other event warnings. The system allows that even within a region, different countries will develop their own manner of system use adapted to local requirements and based on expert knowledge as a tool for developing flash flood warnings and watches together with other local timely information.

The operational functions of the global network of regional systems are as follows (Figure 2):

- Data, Communications, and Data Analyses Centers (Global Data and Knowledge) – global data ingest, data quality control, data communications, global meteorological information, system integration, system product generation, hydrometeorological-related discussions

- Regional Centers (Regional Data and Knowledge) – regional hydrometeorological analyses, analyses communications, regional product modifications, regional threat identification, feedback to Data, Communications, and Data Analyses Centers, hydrometeorological-related discussions

- Countries (Local Data and Knowledge) – country hydrometeorological analyses, country product modifications, local warnings, feedback to regional centers

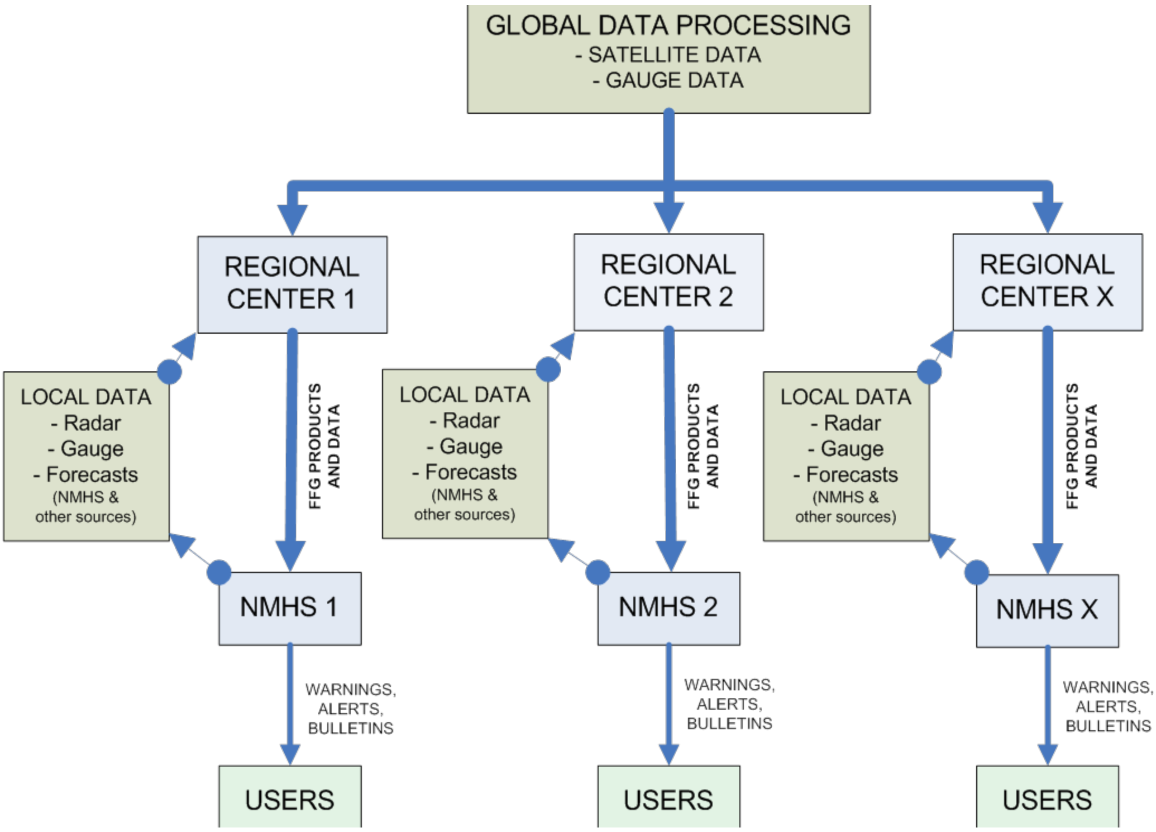


Figure 2- Schematic showing Global-Regional-National structure of the GFFG

The Regional Centers are placed at selected NMHSs throughout the world and are critical to successful operations (Figure 2). These centers perform the operational functions noted above and also focus on regional training programs. In addition to the primary concern for telecommunications and regional administration at the Regional Centers, the configuration of these centers also takes into consideration regional homogeneity in hydrometeorological and geomorphological characteristics to the extent possible. Regions are identified collaboratively by the GFFG partners. Locations of the Data, Communications, and Data Analyses Center(s) are sources of global real time data (satellite and in-situ) and process system guidance computations. The regional centers receive data and disseminate it to individual countries together with additional regional guidance on severe storms over particularly vulnerable regions. The regional centers are also the source of system validation and training. National Hydrological and Meteorological Services (NMHSs) receive the guidance and have the capability to modify the hydrology and meteorology involved on the basis of local information to produce local watches and warnings. Important technical elements of the Flash Flood Guidance and Warning System are the development and use of a bias-corrected satellite precipitation estimate field, high-resolution numerical weather prediction model outputs (where available), and physically-based hydrological modelling to determine flash flood guidance and flash flood threat. Real-time estimates of high resolution precipitation data from satellite are now routinely available globally (and can be further enhanced with locally available radar estimates of precipitation). Global digital terrain elevation databases and geographic information systems are used to delineate small basins and their stream network topology anywhere in the world. In addition, there are global soil and land cover spatial databases available to support the development of physically-based soil moisture accounting models (see flow chart in Figure 3). The real-time satellite precipitation estimates needed to drive the regional systems on a global scale (using global data provided by NOAA) are computed, analyzed, and provided as products as well as input to the hydrologic model. The system allows the NMHSs to use local nowcast/short-term-forecast methods they wish to use to issue the warnings, including (and strongly recommended) local forecaster adjustments. The system design allows this coupling with the existing or developing NMHS approaches on a national or even local scale.

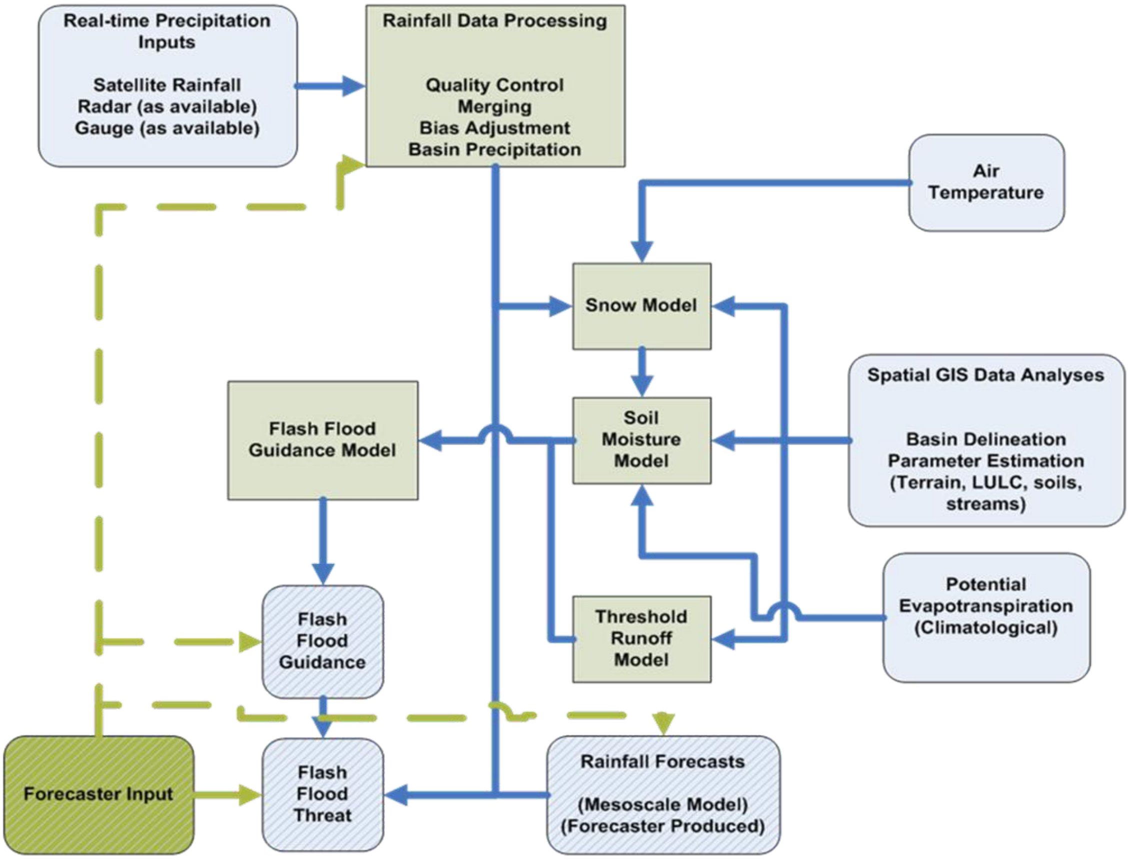


Figure 3 - FFG System Schematic

## Description of the current Flash Flood Guidance System Program

### *Introduction*

The information provided in this section describing the current Flash Flood Guidance Program was principally taken from three sources: WMO and the Hydrologic Research Center (HRC) web sites, and “Konstantine P. Georgakakos, Overview of the Global Flash Flood Guidance System and its Application Worldwide, Bulletin Vol. 67 (1) – 2018, Special Issue on Water, WMO”.

This section is included for the sake of completeness and is intended to provide context to the assessment, although it is acknowledged that the target reader of this report is well aware of the program characteristics and status.

Important technical elements have been covered in the previous section of this report.

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## ***Program structure and partners***

Coordinated by the World Meteorological Organization, the project partners are the Hydrologic Research Center (HRC), the National Oceanic and Atmospheric Administration (NOAA) / National Weather Service (NWS), and the U.S. Agency for International Development/The Office of U.S. Foreign Disaster Assistance (USAID/OFDA). This project is ongoing, with a funding of about ten million US dollars, with the donor being the USAID/OFDA.

The partners have signed a quad-parte Memorandum of Understanding (MoU) for the "Flash Flood Guidance System with Global Coverage Project" establishing a cooperative initiative for its implementation. This MoU came into effect on 25 February 2009, and was extended by mutual agreement for an additional five year period, and it expired on 31 December 2017.

The four partners, jointly with National Meteorological and Hydrological Services (NMHSs) in host countries, undertook the implementation of the system, in order to assist countries in developing flash flood warning systems. The system was designed for interactive use by meteorological and hydrological forecasters throughout the world to provide real-time monitoring of flash flood risk.

Systems have been implemented or underway for the following regions: Central America, Southern Africa, Black Sea/Middle East, Southeast Asia, Haiti/Dominican Republic, Southeast Europe, Central Asia, South Asia, Pakistan/Afghanistan, South Eastern Asia Oceania, North West South America (Colombia, Ecuador, and Peru), and the following individual countries: Myanmar, Romania, Mexico, Oman, Viet Nam, and the Republic of South Africa.

The countries included in the regions for the implementation are: Afghanistan, Albania, Armenia, Azerbaijan, Bangladesh, Belize, Bhutan, Bosnia and Herzegovina, Botswana, Brunei Darussalam, Bulgaria, Cambodia, Costa Rica, Croatia, Dominican Republic, Ecuador, El Salvador, Georgia, Guatemala, Haiti, Honduras, India, Indonesia, Iraq, Israel, Jordan, Kazakhstan, Kyrgyzstan, Lao People's Democratic Republic, Lebanon, Lesotho, Malawi, Malaysia, Montenegro, Mozambique, Myanmar, Namibia, Nepal, Nicaragua, Pakistan, Palestinian Authority, Panama, Papua New Guinea, Peru, Philippines, Republic of Moldova, Romania, Serbia, Slovenia, South Africa, Sri Lanka, Syria, Eswatini, Tajikistan, Thailand, The former Yugoslav Republic of Macedonia, Timor-Leste, Turkey, Turkmenistan, Uzbekistan, Viet Nam, Zambia, and Zimbabwe (funding obtained by WMO).

The system is implemented on regional and country scales and uses flash flood guidance as the basis for trained forecasters at National Meteorological and Hydrologic Services to use operationally to develop flash flood watches and warnings.

## ***Program objectives***

The program objectives can be summarized as follows:

- enhance the capacity of National Meteorological and Hydrological Services (NMHSs) to issue effective flash flood warnings and alerts

- enhance collaboration between NMHSs and Emergency Management Agencies
- foster regional development and collaboration
- generate flash flood early warning products by using state-of-the-art hydrometeorological forecasting models
- provide extensive training, including on line training, to hydrometeorological forecasters
- support the WMO Flood Forecasting Initiative

### *Alignment with the international agenda*

The development of the Flash Flood Guidance Program for global implementation of the FFG System is in concert with the WMO Flood Forecasting Initiative managed by the Hydrology and Water Resources Branch of the Climate and Water Department of WMO. This program is also well framed within two of the seven priorities of the WMO Strategic Plan 2016-2019: Disaster Risk Reduction, and Capacity Development, although it is more or less indirectly related with the rest of them.

In regards to the International agenda, flash floods, and in general all water-related risks, play an important role in the Sendai Framework for Disaster Risk Reduction 2015-2030 and its predecessor Hyogo Framework for Action. The four Sendai Framework priority areas are: (1) Understanding disaster risk, (2) Strengthening disaster risk governance to manage disaster risk, (3) Investing in disaster risk reduction for resilience and (4) Enhancing disaster preparedness for effective response and to “Build Back Better” in recovery, rehabilitation and reconstruction. The Flash Flood Guidance Program is inherently compliant with Priority 2 but also has strong linkages to Priority 1.

The 2030 Agenda for Sustainable Development, adopted by all United Nations Member States in 2015, provides a shared blueprint for peace and prosperity for people and the planet, now and into the future. Seventeen Sustainable Development Goals (SDGs) were established which are an urgent call for action by all countries, developed and developing, in a global partnership. The Flash Flood Guidance Program is well aligned with some of the goals, especially with: No poverty, Good health and well-being, Sustainable cities and communities, and Life on land.

The Paris Agreement on Climate Change (December 2015) brings all nations into a common cause to undertake ambitious efforts to combat climate change and adapt to its effects, with enhanced support to assist developing countries to do so. With climate change it is expected an increased risk of higher magnitude and frequency of flash floods and, therefore, an increased urgency for NMHSs capacity to operate the FFGS in order to develop flash flood forecasts and warnings. At the same time, the relevance and impact of the Flash Flood Guidance SystemProgram will keep growing steadily, while it would provide increased benefits to all societal and economic stakeholders of each country.

### *Training program*

Education and training in product interpretation and communication with disaster management agencies are a fundamental and challenging component of the program, especially because of diverse forecaster backgrounds, the necessary interdisciplinary and multidisciplinary nature of the assessment process that leads to the generation of warnings, and the cultural and socioeconomic diversity in the perceived value of and response to warnings by forecasters, disaster managers and the public.

In addition to research and technical development and implementation of systems, the project includes extensive technical training programs on flash flood prediction for country meteorological/hydrological service personnel. An extensive training program, designed to allow forecasters to adjust system products in real time based on local experience and local up-to-the-minute information, complements the system. Both extensive online courses and hands-on training sessions conducted in the regions and at HRC enable country forecasters to use the system products effectively. They can also develop skills for making real-time adjustments as necessary.

The training programme, structured in five steps (in pedagogical order), is intended to build capacity for flash flood hydrometeorologists in the regions where FFGS has been implemented. Forecasters that attain the required level of performance earn WMO certification to become FFGS trainers in their countries or abroad. Steps 4 and 5 involve such trained and certified in-region trainers.

### *Recent advances in system functionality*

Current advances of the basic FFG System capability include: (a) the ability to produce real-time forecasts of landslide occurrence based on precomputed high-resolution susceptibility maps and real-time estimated thresholds of the FFGS-produced precipitation and soil water, (b) the capability of riverine routing and reservoir simulation, in order to provide simulated and forecast hydrographs for pre-specified locations on large regulated rivers of a region, useful for riverine flood warnings, (c) the ability to use input from several mesoscale numerical weather prediction models to develop threat indices for each model for forecaster review, and (d) the capacity of producing seasonal ensemble forecasting of snow water equivalent, and combined runoff from snowmelt and rainfall with 6-hourly temporal resolution, (e) the extension of the system to include urban area flash flood early warnings, and (f) the development of a simulator, an online interactive training program that will allow simulating a lot of scenarios, based on a collection of flash flood case studies from around the globe.

### *How GFFG Projects are established and managed*

The signed Memorandum of Understanding between USAID/OFDA, WMO, NOAA and HRC, is the instrument that governs how GFFG projects are established, managed and completed.

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Countries that are in need of the GFFG capability must obtain funds, sign an agreement with WMO and commit to the process of implementation. USAID/OFDA has in the past been the primary donor in this process but now other donors and financial institutions are starting to fund country systems or extend existing system's functionality. We hope this trend continues. The process of selecting regions to be implemented seems to have worked well. Countries express interest in knowing more about the FFG System. An informational workshop is then funded and technical representatives from country NMHSs are briefed on how the system works, what responsibilities and commitments are involved followed by a formal Agreement with WMO to implement the system. A multi-year schedule of implementation is then followed involving primarily HRC and WMO and the funding donor. Projects are established with HRC mandated to implement the system and WMO manages the project including achieving the technical project objectives and management of funds. This procedure works in that in most instances projects are completed in a reasonable amount of time and the use of funds seems to be effective based on review of project documents, questionnaires and interviews. However there is a large resource expended by WMO to make this happen. The GFFG Project Manager (PM) must spend the majority of his time in meeting project management responsibilities. The combination of the Manager's time and the technical/administrative support by a full time project coordinator is still not enough to conduct the essential project management functions such as monitoring and evaluating the project implementer (HRC) effort. Also countries need more technical support from WMO which right now is not possible because of the resource limitation. There is concern as to who will replace the current project manager this northern summer when he retires. Other than the resource limitation issue, the current structure for implementing and managing projects seems to be working well and needs to continue.

## Relationship with the Severe Weather Forecast Demonstration Project (SWFDP) and the Coastal Inundation Forecast Demonstration Project (CIFDP)

Established by WMO in 2003, the Flood Forecasting Initiative (FFI) has an objective to improve the capacity of meteorological and hydrological services to jointly deliver timely and more accurate products and services required in flood forecasting and warning and in collaborating with disaster managers, active in flood emergency preparedness and response. In 2011, the World Meteorological Congress (Cg) passed Resolution 15 (Cg-XVI) establishing the WMO Flood Forecasting Initiative - Advisory Group (FFI-AG) with the objective to provide guidance and advice on the hydrological forecasting elements of a number of flood-related initiatives and programs in progress under WMO programs, including GFFG, Coastal Inundation Demonstration Project (CIFDP), and Severe Weather Forecast Demonstration Project (SWFDP). More information about FFI could be taken from FFI web page (http://www.wmo.int/pages/prog/hwrp/FFI-index.php). Since its creation FFI-AG has been involved in the advising on how to better implement these three important initiatives, and build more tight relationships between them, so that each of them better serves its initial need - improving warning capabilities of NMHSs for weather-related disasters.



### *Relationship with SWFDP*

WMO Severe Weather Forecast Demonstration Project (SWFDP) is intended to strengthening capacity of NMHSs in developing countries in issuing weather forecasts and warning, including its severe high-impact events such as heavy precipitation, and strong winds. The project in its operation uses a "cascading" principle - from global forecasts to regional and then national weather forecasting. The SWFDP started in 2006 from 5 countries in South Africa. However, its successful implementation and operation lead to its continuous growth - covering now large areas from Eastern Caribbean to Central Asia, and Southeast Asia (Figure 4).

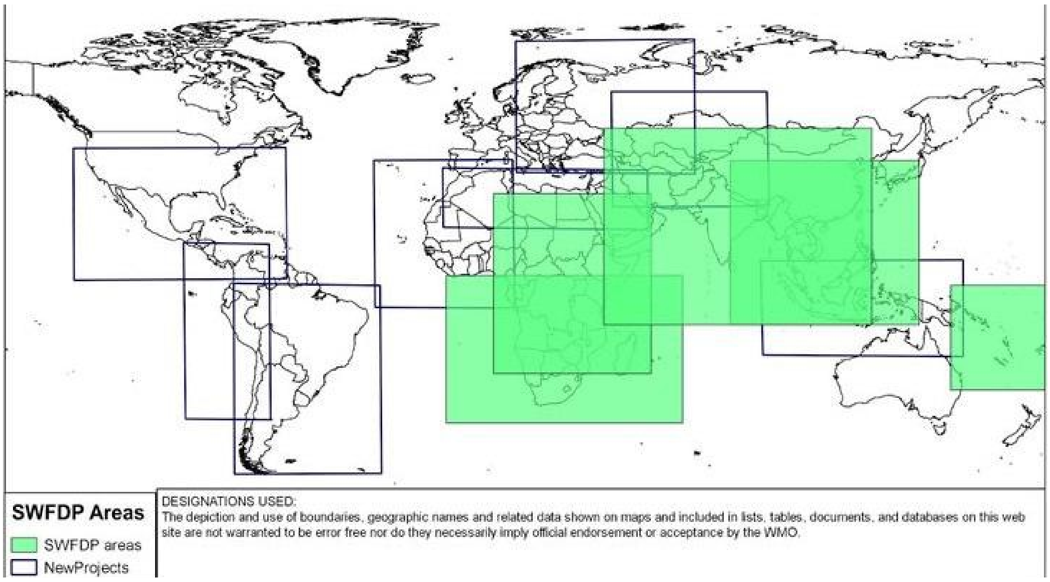


Figure 4. - Areas where SWFDP is implemented/planned to be implemented in nearest time (source: https://www.wmo.int/pages/prog/www/swfdp/)

More information about SWFDP could be achieved at the project's web page (https://www.wmo.int/pages/prog/www/swfdp/).

Features of SWFDP implementation is of significant importance to GFFG, as numerical forecasts of major meteorological parameters, used for flash flood process modeling and forecasting (e.g. precipitation and air temperature) are vital input parameters to GFFG, defining its important products as forecasted flash flood threat (FFFT). In many developing countries, where GFFG has been implemented, SWFDP's output was the best solution in terms of weather forecasts products available for an area. This defines strong linkage between GFFG and SWFDP: features of SWFDP setup (which differs from region to region) highly influence flash flood modeling and forecasting capabilities in the area. The following aspects of NWP model setup, which are implemented within SWFDP, can significantly affect FFGS operations:

- NWP modeling domain(s): depending on the geomorphologic features of an area there could be one single domain, or two domains - one main domain and a subdomain with thinner resolution:
  - one (single) domain in case of mountain relief in the area of interest;
  - two domains in case of different relief features of an area - one domain for plain area, another for mountainous part of the domain;
- spatial resolution: depending on a domain feature and watershed size (area), requirements for resolution may be different - a simple rule is to set a thinner resolution for mountainous areas where catchments tend to be smaller in size, and meteorological features are unevenly distributed (preferable a resolution would be 2 by 2 km or thinner);
- temporal resolution: as FFGS products are being issued every 1 hour for the next 1, 3, 6 hours (and 24 hours) requirements in terms of temporal resolution of NWP output should not be coarser than 1 hour;
- output format: digital format (not JPEG, PNG, other raster format) is obligatory.

These and others linkages between GFFG and SWFDP were recognized by the WMO Flood Forecasting Initiative - Advisory Group (FFI-AG) during its second meeting (December 2015). It was noted that in a number of SWFDP regional implementations, it was necessary to communicate with each SWFDP implementation team in order to explain GFFG requirements in terms of NWP output. It was also noted that development of unified NWP requirements from GFFG side and sharing such requirements with SWF Project Steering Group would be beneficial for GFFG implementation in the future.

### *Twinning of FFGS and SWFDP*

In the past three years, the WMO, USAID/OFDA, HRC and NOAA have successfully implemented a project to integrate both the Flash Flood Guidance System and the Severe Weather Forecasting Demonstration Project. This Southern Africa Region Twinning Project took steps to Integrate hardware, software and data in both of the Southern Africa Region Flash Flood Guidance System and the Severe Weather Forecasting Demonstration Project. The Twinning Project goal was to improve forecast operations at the Regional Specialized Centre - Pretoria (hosted by SAWS) and the nine Southern African countries that have both systems, to build capacity of the hydrological and meteorological operations of each national center and the SAWS Regional Center and finally improve delivery of service to the National and Regional Disaster Management Operations and DRR users, through improved warning dissemination and enhancement of severe weather disaster awareness, preparedness and response. Eight of the nine countries involved in the SARFFGS participated in this project and are now utilizing the integrated system operationally. This process is ongoing with goals to implement such activities to other regions that have both of these systems operational. This is another step in creating the needed MHEWS environment needed by developing country NMHSs.

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### ***Relationship with CIFDP***

The WMO Coastal Inundation Forecasting Demonstration Project (CIFDP) is a joint initiative of Joint WMO-IOC Technical Commission for Oceanography and Marine Meteorology (JCOMM) and WMO Commission for Hydrology (CHy). The aim of this initiative is building improved operational forecasting and warning capability for coastal inundation, combining extreme waves, surges and river flooding events that can be sustained by the responsible national agencies. There are three ongoing subprojects in Indonesia, Dominican Republic, and Fiji; and one completed - in Bangladesh. More information about the project, including documents, presentations, and brochures can be found in the project's web page (https://jcomm.info/cifdp).

The inundation forecast modeling system has the following structure (Figure 5): forecast of sea level characteristics (surge, tide, waves, tsunamis) and riverine flood forecasting, with the necessity of linking these two blocks to achieve an integrated structure. This is a common structure for the modeling and forecasting system, where in reality different subprojects of the CIFDP have used atmospheric, wave and surge models while generally avoiding the use of rainfall-runoff and river models. From the hydrological side, the selection of possible hydrological models to be implemented and used highly depends on data availability in or near the basin and the organization's institutional capacity (to run a model in a sustainable way). Thus from hydrological perspective (covering "Rainfall Runoff model" and "River model" blocks in Figure 5), the first is dealing with weather generated runoff models in upstream catchments, connected to a potentially sophisticated hydrodynamic model of the main river, which flows into the ocean. Use of a hydrodynamic model can reflect changing hydraulic conveyance due to varying downstream water levels (surge, tides). Or a rather simplified empirical (or possibly regression-based) approach could be used that uses observed and forecasted precipitation and observed upstream water levels to then generate water levels near the mouth of a river, that inflows into the ocean.

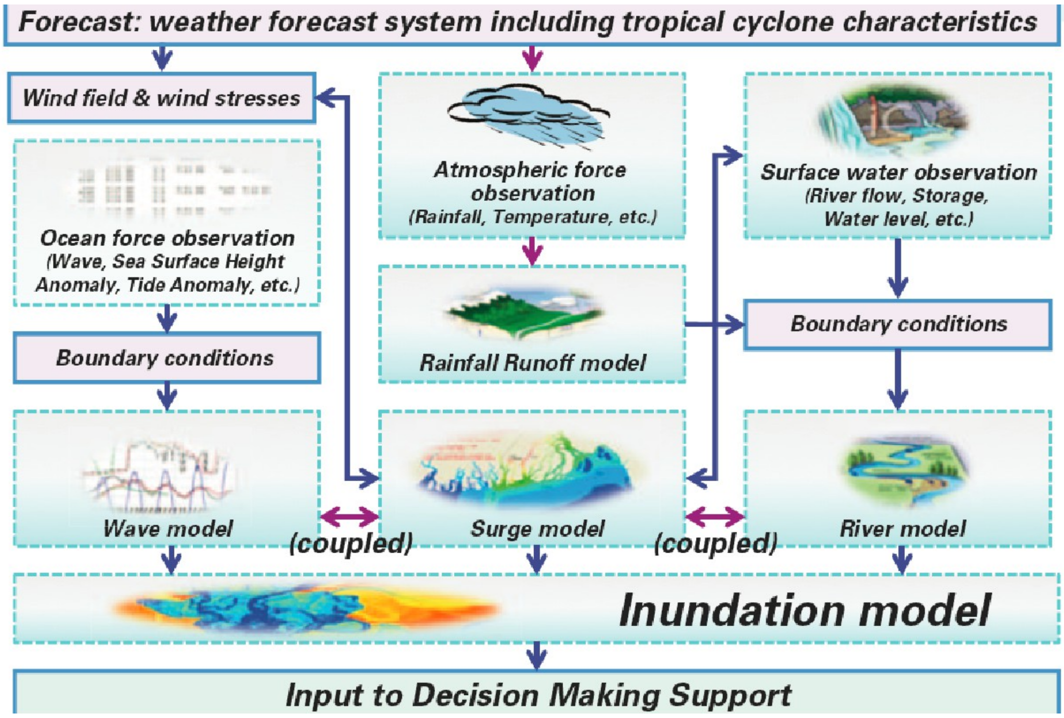


Figure 5. - The CIFDP modeling system layout with (source: https://jcomm.info/cifdp)

In both options, FFGS products can be of great help:

- in a complex hydrological modeling environment, FFGS can provide QPE/QPF products as input to the rainfall-runoff generation models, used in upstream river catchments;

- in a simplified modeling option, FFGS can provide both QPE/QPF and also some of its final products (e.g. FFG, PFFT, FFFT), so that it can be incorporated within an empirical model as one of the predictors, influencing the resultant water level near the river mouth.

It should be also noted that the recent advances in FFGS functionality pertaining to riverine flood forecasting (see above) includes rainfall-runoff modelling (so that streamflow is quantitatively calculated in catchment outlets and then provided as output), and river routing. This recent advent may be of significant interest to CIFDP.

## Review-team findings of the Flash Flood Guidance System with global coverage project

### *Relevance*

- All countries which have already implemented or are currently implementing FFGS are affected by flash floods; many of them are affected country-wide. The FFG System is fully relevant in what refers to the validity of its objectives.

- Irrespective of the various areas deserving improvements, according to our findings, the activities and outputs of the FFGS with global coverage project are consistent with the overall goal and the attainment of its objectives.
- The extent to which the FFGS with global coverage project is serving the needs of its users is addressed in other sections of this report. However, we consider the program to be fully relevant in terms of the understanding of the urgent local requirements of flash flood forecasting and warning of most countries and the subsequent system development and implementation.
- A few countries already served by the FFG System are not using it, meeting the flash flood forecasting needs with alternative systems, basically their own. In some cases, the FFG System did not meet either their high expectations or unique requirements, or it did not perform better than what was already in place. Since we do not know the circumstances for decision making by these few countries to use or not use FFG as a diagnostic tool, we consider that these few instances have no effect on the relevance of the program. They are less than 5% of all the served countries.

### *Effectiveness*

- In El Salvador, the system as a whole (including the FFGS) achieved a decrease in casualties caused by intense storms from more than 300 people between 2004 and 2009, to around 12 between 2009 and 2018. The CAFFGS, the oldest in operation, went through a process of updating of versions and improvements that is reflected in these figures that prove the achievement of the objectives.
- A few countries have indicated a significant rate of flash floods false alarms.
- No matter how good the system is, some flash floods will always be missed and false alarms will always be issued. The lack of verification studies and not communicating the product uncertainty (or doing it in a way that cannot be effectively included in the decision-making process) impairs the perception of the system reliability among end users and beneficiaries.
- Based on many respondents from the NMHSs, we consider that significant value was added to their flash floods warning procedures when FFGS became operational. It is also a fact, however, that a few more highly developed NMHSs are not using FFGS intensively or not using it at all, satisfying their flash flood forecasting needs with alternative systems, sometimes developed by them. We do not know what criteria were used in these decisions but it must be recognized that FFG is a diagnostic tool amongst other tools forecasters use as guidance to produce flash flood warnings. In addition, it is not known whether data inputs were identical to both systems, and what the basis of the analysis was, for these few countries, that determined their system was better.
- After the FFGS was implemented and became operational, some NMHSs improved their interaction with NDMAs, which is always positive.

### *Efficiency*

According to interviews, responses from questionnaires and visits, the GFFG was generally considered efficient. The program and projects were considered efficient in their establishment and execution of projects although there were inefficiencies noted because of resource constraints at WMO and in the signing of agreements. There were issues of some countries in providing the data and information needed, such as historical hydrometeorological data and geomorphological data for calibration and modeling and to verify river basin delineations. These are the responsibilities of the countries, which at times are slow in so doing. WMO's role is to remind countries of the importance of undertaking these activities in a timely way. There were a few instances of very slow responses in providing Letters of Commitment to the project. There is no question that limited human resources in the WMO Program office limited efficiencies (hampered timeliness) in project implementation and in assisting countries in fulfilling their requirements. Feedback from both forecasters and WMO indicated that training was perhaps the least efficient and cost effective because of the training costs associated with HRC's location and not in more actively engaging national or regional experts/trainers to provide the training.

The success and durability of the program depends on the flexibility provided to allow dealing with very diverse countries and regional centers. The implementation of the project is interactive between developers and countries/regional-centers.

The program was generally cost effective, according to the majority of respondents. The regional nature of the approach has been an important reason for this.

### *Impact*

- Before the FFGS implementation, most national weather services and response agencies were not trained to anticipate and plan effective response actions to these disasters due to their short time scales of occurrence and due to their infrequent nature for many particular locations, as reported by HRC. The FFGS implementation and operation allowed forecasters, for the first time, to predict a phenomenon that is very difficult to predict. From this standpoint, the FFGS had a highly positive impact on NMHSs and NDMAs and, most importantly, on the affected people who are the ultimate beneficiaries of the project.
- Several interviewees from the NMHSs agreed on the fact that, beyond the threat products, intermediate products as the catchment-average soil moisture, the snow water equivalent, the QPE and QPF, and long term archived data are per se extremely useful for the general service operations, and supporting a variety of productive activities such as hydropower generation, irrigation and agriculture in general (decisions on seeding dates, and fertilizer, pesticide and other agrochemical dosage), transportation (damage to roads and rail lines), and water resources management. In this regard, the FFGS also had a tangible impact on productive activities and general NMHS operations.

- Some sectors could benefit from the FFGS intermediate outcomes or by-products. However, we have not been specifically informed of their effective use for these purposes. Examples of these include: health (infectious disease monitoring, environmental stress), and drought prediction (with long term archived data).
- The case of El Salvador mentioned in the previous section (a decrease in casualties caused by intense storms from more than 300 people between 2004 and 2009, to around 12 between 2009 and 2018) is a good example of the impact of the system implementation and entry into operation, in terms of the tangible change in the number of casualties.



### *Sustainability*

- The greatest uncertainty of the programme is sustainability, mostly because the system itself is not sustainable as it is today without continuous donor infusion of funds. The principal concern of the team is how the various region and country FGG systems will continue to operate in the future. These concerns focus on the Operation and Maintenance (O&M) of these systems at the national, regional and global levels. O&M involves replacing servers, updating software, IT support services and continuous training of new meteorologists and hydrologists. A number of countries in the past have required donor infusion of funds to replace existing regional servers and retraining efforts. This requires a commitment of the partners and participants (NMHSs) to continue supporting this system.
- Program sustainability should be seriously addressed as the program moves on to the next phase.
  - Some factors threaten the continuity of the program, such as lack of sufficient funding from donors in relation to the increasing needs for the devised system advances, new functionalities and capabilities, and reduction in qualified and experienced human resources (both in the MoU parties and in the NMHSs) due to retirement or staff turnover.
  - Although the amount of funding required for operation is relatively low, continued funding is a challenge for many National entities which raises concerns about sustainability of the program in the long term as updates are required.
  - WMO is short on resources yet most respondents indicated that WMO needs to increase its involvement with the GFFG. This is a dilemma.
  - Monitoring and Evaluation is required, in part, in order to understand and help developing countries and to ensure proper development, implementation and use of the system. Sustainability strongly depends on that. However, more funds and more human resources are required for this.
  - Limited resources of NMHSs continue to be a challenge for participation in regional training even with external financial support due to staff constraints.
  - Some factors, of a more technical nature, may put at risk the system sustainability. One is the fact that today, in many areas, there is only one remotely sensed global precipitation product with sufficiently low latency to deal with flash floods (the

NESDIS Global Hydroestimator, GHE). Indeed, there are FFG systems that use radar (which provides better rainfall estimation accuracy) and some use automated rain gauges. However, a few countries have no rain gauges and depend totally on the GHE.

- A critical issue is that NESDIS needs more funding to properly re-calibrate new satellite data, take advantage and make available higher resolution data from the new generation of satellites, and to adjust for satellites going off-line. Its funding is from US taxpayers and, therefore, it supports US benefits.
- Not having an open system, where only one organization can make any changes to the system on data or recalibration, or modifying basin delineations, etc. limits the application and flexibility by regions and countries to continuously operate, adjust and maintain the system.

## Consideration of alternative approaches

### *Overview*

One of the efficiency aspects that deserves close attention is the potential development and implementation of alternative approaches that would allow operational use in a more efficient and effective manner than through the FFGS with global coverage project. Sustainability is also involved in the consideration of alternative approaches, since the current system can only be updated for all country applications by one organization.

We acknowledge that deeply understanding how other systems work and perform, and how their OECD measures of success compare to GFFG would take a considerable amount of time, in the order of months, and we consider this is beyond the scope of the assessment here reported, according to the mandated TORs.

In order to overcome some of the reported inefficiencies of the current system, potential alternative approaches should comply as much as possible with the CHy principles stated under the Community of Practice approach of the E2E EWS for Flood Forecasting. These principles enunciate that the adopted system (platforms and models) must be operationally used, be freely available, have low hardware requirements, be available in one of the official UN languages, have available training material, be sustainable and be institutionally supported. It is also emphasized that the system should also be open source and easy to use.

If any available system were to be considered as an alternative to GFFG, we believe, a significant infusion of funds would be required for its adaptation and global implementation. Our limited research of “other approaches” that might be considered as candidates in the future are briefly described in the following subsections.

### *Global Flood Awareness System (GloFAS) and European Flood Awareness System (EFAS)*



The Global Flood Awareness System GloFAS: the global flood service of the European Commission Copernicus Emergency Management Service is an operational system monitoring and forecasting floods across the world. The aim of GloFAS is to complement relevant national and regional authorities and services, and to support international organisations in decision making and preparatory measures before major flood events (particularly in large trans-national river basins). However, GloFAS only focuses on rivers, and does not provide real-time forecast information on flash flood risk or coastal flooding, nor on inundated areas (http://www.globalfloods.eu/general-information/about-glofas/).

The GloFAS is conceptually based on the EFAS, that is, European Flood Awareness System. EFAS is the first operational European system monitoring and forecasting floods across Europe under the umbrella of the Copernicus emergency management service and is fully operational since October 2012. Unlike GloFAS, EFAS does have a Flash Flood Indicator (Alfieri et al., 2012, Raynaud et al., 2014), though restricted to a European domain which is even smaller than the regular EFAS hydrologic forecasting system (https://www.efas.eu/efas-videos.html). The system computes the ERIC index. Similarly to FFGS, ERIC is based on modeled soil moisture in top-soil layer (with the distributed LISFLOOD model instead of the Sacramento) and on forecasted rainfall ensembles from COSMO-LEPS (the Consortium for Small-scale Modeling - Limited-Area Ensemble Prediction System, at 7-km grid size). The modelled soil moisture is converted to a dimensionless degree of saturation value used to compute a runoff coefficient which is then multiplied by the forecasted rainfall (for the following 6, 12 and 24 hours) in order to obtain a forecasted runoff (interpolated at 1km cells). ERIC is the ratio of this runoff to a climatologic maximum runoff. ERIC is computed for each one of the 16 COSMO-LEPS ensemble members. EFAS Flash Flood Notifications are issued when the 20-year return period ERIC threshold is exceeded by more than 35% of the ensemble members, and the lead time less than three days. Quantiles of ERIC have been previously computed based on the records of ERIC for the 20-year modelled period from 1990 through 2009.

Additional EFAS products: maps of the probability of exceeding 50 mm (and 150 mm) of rainfall according to COSMO-LEPS, and a landslide product based on a European landslide susceptibility map.

### *NWS National Water Model and NWS Flooded Locations and Simulated Hydrographs (FLASH) system*

In the United States, two real-time, continental-scale hydrologic modeling applications have evolved for use in the NWS: the National Water Model and the Flooded Locations and Simulated Hydrographs (FLASH) system (Gourley and Clark III, 2018). The National Water Model is based upon the Weather Research and Forecasting (WRF) Hydro framework, and models land surface states using the Noah-Multiparameterization (NOAH-MP) land surface model (Gochis, Yu, & Yates, 2015).

Once there is ponded water on the surface, it is routed downstream using a diffusive wave solution to the Saint Venant equations and continues downstream in the channels using Muskingum-Cunge channel routing. The National Water Model runs under different configurations to provide short-, medium-, and long-term forecasts of hydrologic conditions at 2.67 million river reaches across the United States. The short- and medium term forecasts are forced by deterministic QPFs from the High Resolution Rapid Refresh (HRRR) and Global Forecast System (GFS) models, respectively.
Short-term forecasts of streamflow and streamflow anomaly are provided out to 15 hours and are updated hourly with a data latency of almost 2 hours. All forecasts utilize a nudging scheme (data assimilation) to adjust forecast streamflow values to those that have been observed at USGS stream gauging sites.
The FLASH system encompasses a suite of rainfall and hydrologic products that have been designed to provide NWS forecasters with information regarding impending flash floods (Gourley et al., 2017). This system is driven by rainfall estimates from the MultiRadar MultiSensor (MRMS) system. MRMS provides a suite of radar products across the United States in real time on a grid with horizontal spacing of 1 km. The radar-only QPE products are used in FLASH and have an update frequency of 2 min. There are three basic categories of products contained within FLASH: (a) rainfall return periods, (b) comparison of rainfall to FFG values, and (c) direct simulations of discharge from the Ensemble Framework For Flash Flood Forecasting (EF5) system. The rainfall-based products in the first two categories are produced at the same frequency and on the same grid as the MRMS rainfall estimates (i.e., every 2 min on a 1-km grid) across the CONUS (Gourley and Clark III, 2018).

### *VIGICRUES (SCHAPI / DREAL)*

The SCHAPI (Central Service of Hydrometeorology and Support to Flood Forecasting) is a new service of the Ministry of Ecology and Sustainable Development within the Water Department in France. It provides support for flood forecasting services with 24-hour monitoring for flash floods. It also provides information to services and the public as well as scientific and technical coordination in the field of flood forecasting. In particular, Vigicrues Flash is a free warning service offered by the VIGICRUES network (SCHAPI / DREAL) of the French Ministry of the Environment. Some recent dramatic flood events on small catchments not covered by the flood surveillance system highlighted the need of a new warning system to anticipate violent flash floods, an automatic system specifically dedicated to local crisis managers.
The Vigicrues flash flood service is based on a rainfall-runoff semi-distributed hydrological model (called AIGA) fed by rainfall measured by the weather radar network provided by Meteo-France (De Saint-Aubin, et al., 2016). The model has been calibrated for gauged catchments and is being progressively regionalized across the French territory in order to cover ungauged catchments as well. Resulting hydrographs are then compared with predetermined high or very high flood thresholds in order to determine which rivers are prone to flash floods. In fact, the peak discharge forecasts are compared to reference peak flow quantiles that are computed offline based on a regionalized stochastic rainfall generator that yields the rainfall and flood frequency analyses. The same

hydrologic model is used in the generation of the offline flood frequency analysis, and so there is an inherent bias correction when comparing flood peak forecasts to historic distributions to estimate flood quantiles. Flash flood alerts are determined based on the resulting return periods in the following categories: 2-10 years (yellow), 10-50 years (orange), and more than 50 years (red) (Gourley and Clark III, 2018). When the system identifies a significant flash flood risk on a stream of a given municipality for the next few hours, a message indicating a high or very high flood risk is automatically issued. The flood risk estimate is updated every 15 minutes. Previous subscription to the system is required for the municipalities. In 2018, the Vigicrues flash flood service is delivered to over 10,000 municipalities in France.

### *FLARE – Flash Flood Advisory Resource*

The national Flash Flood Advisory Resource (FLARE) of Australia is an authoritative resource created to assist agencies with flash flood warning responsibilities, such as councils and emergency services, to design, implement and manage fit-for-purpose flash flood warning systems. This helps agencies and the community to increase their resilience to flash floods. As indicated in its web site (www.bom.gov.au/australia/flood/flashfloodadvisoryresource/) FLARE is not an operational service; rather it provides access to a wealth of information that supports local organisations to develop flash flood warning systems.

Co-ordinated by the Bureau of Meteorology, FLARE includes a website and advisory service for registered users. The FLARE website will support a community of best practice, providing an invaluable repository of information including: step-by-step guidance, standards and guidelines, case studies, resources and discussion forums. FLARE is available to employees of agencies with responsibility for developing and operating flash flood warning systems including Local government, State government agencies, Emergency services.

The FLARE advisory service provides phone and email access to Bureau staff with knowledge of resources available, and the standards and guidelines necessary for developing local flash flood warning systems. The advisory service is not an operational service and cannot provide guidance or access to operational data and information during a flash flood event.

### *Integrated Nowcasting through Comprehensive Analysis (INCA)*

The Integrated Nowcasting through Comprehensive Analysis (INCA) is a nowcasting system developed by the Austrian NMS (ZAMG) and used also in Environmental Agency of the Republic of Slovenia. INCA combines different sources of data to obtain best possible analysis of the current state of the atmosphere and to derive nowcasting fields. As a first guess for the state of the atmosphere INCA uses NWP fields from the ALADIN model. Then, adding real-time data from different sources (synop and AMP stations, radar, satellite, radisounding, AMDAR, etc.) and taking into account the laws of physics, it provides the high resolution analyses with spatial resolution of 1 km. Analysis fields of temperature, moisture, wind, precipitation and cloudiness are obtained. Such analyses are the base for nowcasting up to 12h, where in the first 2 hours more weight is put to the measurements and then gradually more and more weight is put to the NWP fields.

### *Catalonian FF-EWS*



In Catalonia, a flash flood early warning system (FF-EWS) has been designed on radar based estimates and forecasts of rainfall (Versini, Berenguer, Corral, & Sempere-Torres, 2014). The system begins with radar QPE on a 1 x 1–km grid produced every 5–10 min. The radar rainfall fields are extrapolated forward in time up to 3 hours to provide added lead time. The rainfall amounts are aggregated in time, and also in space based on the upstream precipitation, as in EPIC, and then compared to available IDFs. There is an assumption that the computed return periods of rainfall are linked to those with streamflow. In other words, flash floods at the high return periods become rainfall-driven so that the soil moisture states and other geomorphologic characteristics that dictate dominant runoff processes can be neglected (Gourley and Clark III, 2018).

### *Machine Learning Approaches*

In their comprehensive study of available real-time flash flood prediction systems, Gourley and Clark III (2018) present an overview of Machine Learning Approaches, focused on the Random Forest method. Machine learning is a subset of artificial intelligence, in which algorithms learn and evolve over time by iterating through vast amounts of data thousands, millions, or hundreds of millions of times. The value in these approaches as applied to weather forecasting lies in their ability to identify patterns that might elude traditional methods like model output statistics, training/experience, empirical indexes, or rules of thumb. Supervised machine learning is a specific type of learning in which a label, or dependent attribute, is provided to the algorithm such that the algorithm is told what to predict. Random forests, a type of machine learning algorithm, have been used to predict flash flooding impacts from GFS NWP forecasts. Because global NWP models are available in data-sparse regions, these methods may enable reliable probabilistic forecasts of flash floods even in areas that lack weather radar, dense in situ rainfall measurements, and high-resolution, distributed hydrologic models.

### *Concluding remarks*

We have briefly reviewed some existing systems for flash flood prediction, potentially alternatives to the GFFG. Some of them are at their initial stages, some are well developed systems. We did not undertake the detailed research to understand how sophisticated/complex these systems are, how operational “friendly” they are, how they perform in terms of accuracy and lead time as well as what success in predicting flash floods and resultant decision making and benefits that have occurred. We have not reached a deep understanding of how their OECD measures of success compare to those of the GFFG. Finally, we have not assessed the degree of compliance of those systems with the CHy principles stated under the Community of Practice approach of the E2E EWS for Flood Forecasting, and mentioned in the Overview above.

This section is simply a preview of upcoming systems that may have promise in the future but none of these existing systems have developed the degree of integration, training, capacity building and performance history of the GFFG. As a conclusion, we consider that for any available system aspiring to become an alternative to GFFG, a deep analysis of the mentioned approaches in order to assess their compliance with all the identified requirements has to be carried out. And we firmly believe that even for those systems that present a high degree of compliance, a significant amount of funds will be required for their adaptation and global implementation.



## Governance model for the FFGS with global coverage project

Many definitions of program governance are available in the thematic literature. They can be summarized as the set of processes and management structures (including definition of roles and responsibilities) that allow key decisions to be made during the program lifecycle to ensure that its benefits and outcomes are achievable and its objectives are met. Governance is necessary to ensure coordination among process initiatives by different functional units or partners.

As mentioned in a previous section, in support of the FFGS program, a MoU was signed by the four partners to work together under a cooperative initiative to implement the FFGS worldwide. In the MoU, the roles and responsibilities of the parties are explicitly stated. The FFGS program is a public benefit effort on behalf of the four partners. It is important to note that a public benefit activity is an activity that provides a significant benefit to society, especially if it is directed towards charitable activities, protection of civil and human rights, development of civil society, education, science, culture and promotion of health and disease prophylaxis, support for environmental protection, flood and drought risk prevention, provision of assistance in cases of catastrophes and extraordinary situations, especially for low-income and socially disadvantaged person groups.

The MOU is not a binding agreement and does not create any enforceable rights or duties. Hence, a structured governance is a real challenge in the GFFGS. Being a multi-partner project, the partners are organizations with different foundational objectives, visions and missions, governmental, international and non-governmental, located in different geographies (in two continents), whose interlocutors (i.e. “the clients”), the NMHSs of the served countries, are distributed virtually around the whole world. The MoU clearly states the roles and responsibilities of the four partners. Although, partners participate in annual steering committee meetings and there are regional steering committee meetings, these meetings could be organized better to feed into one governance structure and needs to have clear action to address gaps and challenges.

This being said, the review-team members have to recognize that the project has been alive and healthy for almost a decade despite to lack of structured governance since 2009 (and for an additional period since the first implementation of the system in Central America that predated the

MoU), with highly positive results, and a large number of countries being able to deliver flash flood forecasts and warnings for the first time ever. This success, which occurred without a formalized governance structure (that we are aware of), may be ascribed to the high standard and vast experience in large-project management of the organizations involved in the endeavor, according to the opinion of the review team. However, we consider that the continuation of the GFFG under a new MoU for carrying out further development efforts and on-going operations in a sustainable manner, and given the few identified project weaknesses and areas needing improvement, requires the formalization of a sound governance model. Its structure should reflect and be able to deal with the sustainability of the overall project and should take into account the following recommendations given by the review team.

- As a new MoU is being developed and signed, it should not only state the roles and responsibilities of the parties clearly, but also include a formal governance structure. Should the timing for this not allow its inclusion in the new MoU, a formal (higher level) governance structure with a Terms of Reference should be agreed upon and adopted by the parties.
- The higher level governance structure to be adopted should build on existing non-formalized governance brought by the Project Steering Committees or Groups, but should be taken advantage of to improve coordination among parties, and with NMHSs, NDMAs, donors and stakeholders.
- It is important to recognize that the current approach has in general been successful as it has been adaptive to meet diverse countries and region needs and capacities. However, it was also clear from responses to our questionnaires, visits and interviews that a new governance structure is needed to be more responsive to end users’ needs.
- In what refers to human resources, some key positions have to be covered financially to ensure the program’s sustainability, especially in WMO (as found in various interviews we conducted).
- Some specific requirements are currently met by outsourcing professional services of interpretation and translation, travel agency. However, changes to internal administrative procedures that make organizing a meeting and arranging travel in a timely fashion less difficult are recommended. There needs to be simplification and streamlining of procedures to make coordination less bureaucratic and more responsive to the project needs.
- The role of Regional Project Steering Committees (PSCs) should be intensified. Country focal points and their alternates (one meteorologist, one hydrologist) need to have a louder voice as the connoisseurs of local realities, with all their political, institutional, technical and human-resource related particularities.
- Monitoring and Evaluation of the project is seriously needed, in order to ensure proper development, implementation and use of the system, to better understand which countries are using the system and how it is used, or the reasons why it is not used, if applicable, and its performance. This role has to be formally assigned within the structure and should reside with the WMO Secretariat.

# The Way Forward - Recommendations for the future implementation of GFFG

## *The modeling system components*

It will be beneficial if recently developed functionalities of FFGS (e.g. multiple QPF ingestion; riverine, urban flooding, and landslides modules) are installed within existing systems where most required, if budget sources are defined and available.

In some regions in East Europe and other areas, there are karstic catchments whose hydrological response is not fully represented by the current modelling system. It is recommended to assess to what extent the effort of adapting / replacing the underlying models is worthwhile, by surveying the countries. However, development of this module will require definition of Karst subsurface flow pathway data (inexistent or with reduced availability) if this approach is to be applied in the future.

We consider that surveying countries to determine their other modeling needs beyond flash floods is necessary and that WMO should conduct the survey.

It is recommended to explore the possibility and feasibility of implementing updating schemes in order to correct model states by assimilating quasi-real-time remotely sensed data as soil moisture estimates or other data, with due consideration to their latency, spatial resolution and low penetration depth (in relation to the model upper soil depth). We have been informed that HRC has completed a few studies, which were funded by NASA and the European Space Agency (ESA). HRC's findings indicate that the most promising index from satellites pertains to inundation that is the result of backwater effects in large rivers.  This changes the local soil water content substantially and satellite data is the only way to quantify spatial coverage. Additional studies by HRC showed a negligible impact on modelled soil water content by the assimilation of satellite estimates.

## *Expanding modeling capabilities*

Users should have the ability to recalibrate models used within the system. This would allow changing environmental conditions (e.g. land-use change) and additional data availability to be better addressed. Users should also have the ability to alter basin delineations or implement new functionalities themselves.

## *Satellites as input*

There continues to be many recommendations that satellite rainfall estimates should be improved. Currently, there are satellites that are producing rainfall information. Almost all satellites have large latencies in obtaining rainfall estimation. Because of the need to have real time satellite rainfall estimation for the flash flood guidance model, the NOAA NESDIS Hydroestimator is used to obtain the needed real time hourly rainfall estimation at a 4 km spatial resolution. The estimates may be too high for cold cloud tops and too low for warm cloud tops. In an interview with the NESDIS, we have been informed that increased accuracy is expected in the future through implementation of the GOES 17 Precipitation estimator which has yielded much improved accuracy above the present GHE.

It is noted that, since 2012, FFGS uses a multi-spectral estimate (microwave, MW, and IR) of precipitation that uses the MW/IR based CMORPH product to adjust the GHE. Now the MWGH and the GHE are available in real time with very low latency. HRC indicates that in most studies and away from the coast, the MWGHE has superior performance than the GHE.

As satellites come and go, NESDIS adjusts new satellites for the rainfall estimator. NESDIS is operating on a "Continuity of Operations of Global Estimation". The importance of NESDIS Operations to provide this high level of real time satellite based rainfall estimates that will likely improve in the future deserves major recognition and is the foundation of the GFFG Program. We strongly recommend WMO and participating countries in the GFFG continue to recognize the importance of NOAA's contribution and recognize the value of this worldwide contribution.

### *Verification assessments*

It is very important to insist on the usefulness for the NMHSs of conducting verification assessments. NDMAs should make an effort to document the effective occurrence of flash floods in a more systematic way, including determinations of the exact location, date and hour, duration, severity, local impact, and any other feature that may help to increase the understanding of the observed flash flood. A standardized survey form could be designed to include at least this information. A photographic bank of local flash floods can be maintained to improve the interpretation of the surveyed information. Some country NMHSs reported they do not receive information of observed flash floods from NDMAs. Efforts should be made in order to correct this situation and to involve NDMAs in system validation programs. A deeper understanding of the importance of performing verification studies will increase the likelihood of success of this change of habits and NDMAs involvement.

### *User interface*

We understand that the Web server functionality is now part of the standard FFG system deployed by HRC. This is a significant improvement voiced by many NMHS's surveyed. This feature should be implemented to countries that received older versions that did not contain the Web Server. Additional informational layers (which can be turned on/off by a user) should be added into the interface: boundaries (national/regional), water structures, cities, etc. It will be beneficial to add observational data layers as well if resources allow doing so.

### *Aspects of operations*

Increased confidence in the system could be reached if FFGS operated on a national level, using national computing resources (and nationally installed and used QPF). Developing a strategy when there could be a possibility to implement the system on a national level, if a country both requests and has capacity to maintain this system capability.

It is noted that there are currently countries which have supported national implementations and they maintain the systems implemented. Typically, these systems are associated with specialized input data for the country (such as radar data) or higher-resolution output products that are not part of the regional system.

We acknowledge, however, that most countries likely cannot afford to support this option (not enough financial or technical personnel resources to maintain the system).



### *Map Server*

Many questionnaires, interviews and visits emphasized the need for a system that visualizes the topography of the areas covered analyzing the FFGS outputs and better identifying which basins might be prone to flash floods (e.g. because of orographic precipitations, or being downstream to flash flood prone basins). The current Map Server module accomplishes this requirement but has not been installed in many FFGS country servers yet. This module should be routinely installed with all current FFG System implementations and added to existing FFG Systems that do not have it. We have been informed by HRC that completed installation is expected by the end of this year (2018). It is noted that, currently, only HRC can add layers to a country's Map Server.

### *Advancement and sustainability of the system*

There are many recommendations for advancing the FFG System. Improvements in visualization is probably the leading improvement followed by opening the System up so that countries can improve their operations through recalibration, addition of other models or applications that follows a Community of Practice (COP) concept. We strongly recommend that the system be opened up so that countries with capacity can improve the system and adapt the models and inputs to optimize their needs. Also additional technical expertise is needed to ensure the system can be operated and maintained in the future without burdening the HRC with this growing responsibility. Some countries have chosen not to use this system because of the "black box" structure not allowing them to include models and algorithms that are needed and work well in their country. We are aware that there will be monetary costs involved in this process to create a more open system and that will be a factor in the decision to significantly alter the current system architecture. Currently COPs are being used in dissemination of FFGS Alerts in India, Malawi and other countries with WhatsApp to share technical data such as maps, pictures of flooding and even alerts that help neighboring countries and communities.

We recommend a Configuration Management Control Committee be established to address the various aspects of making the system more flexible but understanding both technical and financial costs involved in achieving various possible flexibilities. This Committee should be composed of HRC, selected NMHS experts, WMO and possibly an OFDA technical representative. This Committee could also address the various improvements needed and serve as a prioritization mechanism for future versions of FFG.



Also, it is recommended to make efforts in the future in order to communicate product uncertainty, and to make it in a way that it can be effectively included in the structure of probabilistic forecasts that facilitate the decision-making process. The system is today ready to include it, as reported by HRC. Based on NWP ensembles, likelihood can be provided along with the climatology for comparison.

Other suggestions include: allowing use of other QPF models; improving satellite based rainfall estimation from another technique or using newer satellite capabilities; adaptation of model products to other uses such as rainfall estimation for water management, soil moisture for agriculture and fire danger applications; use of the system to advance seasonal and sub seasonal streamflow applications; and producing hydrographs for each of the small river basins. Since there are costs associated with each of these enhancements, there needs to be a process where user needs are collected and priorities are determined that will have the biggest return on investment for users (NMHS & end users). Efforts would also be needed to attract funding sufficient to address the top priorities.

### *National Disaster Management Agencies*

In most of the countries where FFGS is implemented, NDMAs are receiving the information about the possible flash flood events, not FFGS products. However, participation of NDMAs in developing products to factor in their decision making processing for action as well as in verification of forecasts will improve the use of FFGS products. As we move in implementation of impact-based forecasting, some of the understanding of FFGS products and how they can best be used will improve.

The twining of FFGS and SWFDP has helped in pilot countries to further increase collaboration between NDMAs and other agencies.

## The Way Forward - Recommendations on programmatic aspects

### *Maintaining and operating the system*

The operation and maintenance of the FFGS software, files and system is totally dependent on the Hydrologic Research Center. Although the O&M has clearly been accomplished in the past, this situation could be considered a risk to the sustainability of the system in the future since an NGO is fulfilling what normally is provided by governments: the O&M of a system used to save lives and property in 60 countries. The annual cost of maintaining this function according to HRC is USD8500/year/country. The nucleus of this operational system is fully dependent on HRC. This risk is too high for this situation to continue in the long term. As such we recommend the GFFG Partners look at a more reliable, sustainable system structure to assure full reliable operability and functioning of the system. A comprehensive discussion should be held in order to conclude whether or not a pathway to achieve this more sustainable system is to adopt an open system approach (suggested by some of our interviewees as an improvement). We consider that the right meaning and, mostly, the implications of an "open system" should also be seriously discussed and evaluated. The concept of "open system" may imply different things to different people. It can be interpreted in several ways, each approach with increasing versatility and development and implementation costs, from simply having full access to model parameter files and user accessibility to intermediate model results, on the simplest end, to the possibility for the users of incorporating their own model algorithms, to finally having an open-source system in which models, model parameterizations, inputs, input sources, and outputs can be freely adjusted, adapted and tailor-made according to user's needs, on the most sophisticated end. Whatever the option, comparisons with the current operational system should be conducted before becoming operational for flash flood prediction.

The option of developing a cloud based system with direct country access should also be carefully evaluated, including the establishment of one or two global support centers to maintain and sustain this cloud implementation or other solutions. These options can be worked on by both the GFFG Management Committee and by establishing the Configuration Management Control Committee.

### *Inclusion into WMO Global Data-Processing and Forecasting System (GDPFS)*

WMO is developing enhanced integrated and seamless Data-processing and Forecasting System that will integrate with the WMO Weather Information System (WIS) and the WMO Integrated Global Observing System (WIGOS). GDPFS is addressing the trend toward Earth system modelling to provide products at all timescales and to all sectors and applications that require such information. It is also being developed to leverage improvements in computing power and the accuracy and forecast lead-time of numerical prediction across a wide range of time and space scales such as GFFG. It is strongly recommended that GFFG be included in the GDPFS. Since the GDPFS will be a flexible and adaptable ecosystem of independent centres that will expand and strengthen prediction of the environment, making impact-based forecasts and risk-based warnings accessible, it is important to include the FFG System.

### *Formalizing a governance structure*

The Flash Flood Guidance System with Global Coverage Project has been implemented without a formalized governance structure. As mentioned in the corresponding section of this report, the review team considers that the continuation of the GFFG under a new MoU would greatly benefit from the formalization of the existing governance model. This would assist the partnership in carrying out further development efforts and on-going operations in a sustainable manner, and may be able to better address the concerns of technical and financial sustainability.

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### *Resource Mobilization*

Efforts should be made to increase donors and funding institutions willing to bear the cost of the future system implementation and further developments. A fundraising plan/effort should be developed in order to identify, contact and engage funding organisations (philanthropic donors or financial institutions) whose funding priorities are compatible with the FFGS objectives and goals, in addition to USAID. As an advantage, it is noted that, at present, the FFGS has much more visibility than it had in the past (when the MoU was first signed), as a consequence of the implementation and operation throughout the world in more than sixty countries.

### *Human resources*

Some key positions have to be covered to ensure the GFFG program sustainability, especially in WMO. Development of more simplified internal procedures (as presented in Governance section, for meetings and travel would help).

### *Global conference and web based community*

To maintain high level of communication between all FFGS stakeholders, including developers, donors, and users, it is strongly recommended to organize a global conference (forum) right now and to consider (funding available) having future meetings on routine basis either globally or at least regionally. This ongoing and direct communication between users and system developers, and users' interaction between themselves (sharing experience, solving technical problems, sharing innovative approaches and lesson learned practices) is important for maintaining system operational capability. Such conferences (forums) will highlight important needs of local flood forecasters, so that system developers are aware of latest requirements of operational applications of FFGS. It would also allow the Configuration Management Control Committee better perspective on what important system problems need to be fixed as well as priority improvements needed by NMHS's. The conference should consider establishing a network of users and experts (such as an Association) that can communicate and help support each other for training, technical support, maintenance and sharing successes that the domain of users could benefit from.

In addition to an offline conference it would be beneficial to set up a web based community of practice for the FFGS, where all relevant materials, resources, user forum, developers' help-desk and other features can be placed.

### *Training*

In order to build confidence of the trainees it is necessary to organize training as hands on sessions with a number of case studies (preferably from the region, where trainees are based). It may help to build confidence in the system operations.

The number of trainers from Regional centers and country NMHSs has to be increased. Two persons (one hydrologist and one meteorologist) are not sufficient as they could leave the service, and the meteorologist could be involved in totally different operational tasks. Those trainers certified by WMO (after successfully completing Step 4 level), in addition to the more theoretical training received in Step 3 from HRC, can also pass on to future trainees their vast operational experience (during Step 5 workshops, and possibly other instances). It should be noted that more than one of the criticisms found in this assessment is that HRC has no flash flood forecasting operational experience. Having experienced operational forecasters providing the training would improve communicating how the science, theory and model performance can be applied to the forecasters' environment.

Step 3 training (held in HRC premises in San Diego) is more expensive than training off site such as in countries with lower hotel and per diem expenses. A 4-week training course in San Diego can cost around USD 7500/8000 per person for just their travel and local living expenses. Only those with the highest grades in Step 2 training would be invited to the Step 3 training. Training costs must be reduced that would allow an increase in experts trained. Efforts should be made to organize Step 3 training in regional centers making maximum use of certified WMO FFGS trainers to give the training. There has been a successful experience in Turkey, where the travel-related costs were reduced to around USD 3000 per person (around 40% of the San Diego option). In this way, more potential candidate trainers per country would be able to attend, which is highly desirable for the mentioned reasons.

Trainers who were previously certified were certified for what they know of the FFGS and not for their knowledge on how to train people on the use of FFGS. They received zero hours on how to be an effective communicator or lecturer. This should be overcome by devoting some supplemental training hours to develop training abilities and communication skills.

Additional feedback we received from forecasters indicates the existing approach to training needs to be re-assessed and modified to benefit from past student recommendations. Training platform and methods are old fashioned and unfriendly for users, and training must be more operationally based. Findings noted by developers (Appendix 3) suggest a number of specific actions (based on lessons learned) that need to be taken to improve the training program. The review team recommends that efforts be made in order to improve the training program.

There is a great interest among users in the simulator (i.e. the online interactive training program) that is being built. It will allow simulating a lot of scenarios, and to answer What-if questions, based on a collection of flash flood case studies from around the globe, developed using FFGS software and archives from implemented flash flood guidance systems. Given the identified high interest among users and the high potential benefits derived from use of the tool, it is recommended to make the necessary efforts to have it developed and operative in the near future.

## Conclusions



We have been requested by WMO to conduct a review of the Flash Flood Guidance System (FFGS) with Global Coverage Project, following the detailed terms of reference (TOR) provided for this purpose. The TOR specifies the review of the overall GFFG project concept and its regional projects, following the OECD DAC principles of Evaluation of Development Assistance.

The assessment team was asked to review performance of completed activities and those under development based on available reports, interviews, and discussions with selected target group representatives, including evaluation of benefits and costs of the various projects undertaken.

During the 4-month period assigned to the review, we have: (a) distributed a questionnaire among numerous project stakeholders, including system developers and implementers, and NMHSs forecasters and end users, with specific questions to both groups, requesting them to further distribute it among persons with opinions worth being taken into consideration, at their own judgment, (b) conducted numerous remote interviews to selected target group representatives, (c) conducted several face-to-face interviews to NMHSs and NDMAs personnel involved in the operation or verification of the system from five different countries in three project regions, (d) read and analyzed a plethora of documents about the system design, system implementation, system operation, project briefs, implementation requirements, project implementation plans, forecaster guides, meeting reports, case studies, and presentations.

We have reported on our interpretation and findings of the questionnaire answers from 28 respondents (it is noted that confidentiality of the respondent answers has been guaranteed), as well as discussions during visits with around fifteen forecasters, on our findings of the program and the system, in terms of the OECD DAC principles, and on our recommendations and the way forward, based on our findings. Out of 28 respondents, 20 were personnel from NMHSs. The questionnaire was sent to more than ninety recipients, and all of them have been asked to distribute it among key personnel, at their own judgement, totalizing more than one hundred recipients. These conclusions are partially based on the answers of a sample of relatively reduced size, resulting in caution being exercised in their interpretation.

We also provided a brief description of the system and the program, and the relationship between the FFGS with Global Coverage project with the Severe Weather Forecast Demonstration Project (SWDP) and the Coastal Inundation Forecast Demonstration Project (CIFDP), in terms of how to build tighter relationships between them, so that each of them better serves its initial need: improving warning capabilities of NMHSs for weather-related disasters.

Based on all the above, we arrived at the conclusion that the program is highly relevant since it is suited to the priorities and policies of the countries where the system was implemented, and the project objectives are still valid, it had a positive impact on the countries, in the sense that for most of the countries served, the operational implementation of the FFGS allowed forecasters for the first time ever to predict flash floods, it is effective in the sense that it attained its main objectives. Efficiency of the system can certainly be improved. The success and durability of the program is based on the flexibility provided to allow dealing with very diverse countries and regional centers. The implementation of the project is interactive between developers and countries/regional-centers. Delays in response from the countries require a real-time adaptive development environment.



However, the key issue and largest challenge is ensuring the program is sustainable. The program is not sustainable given the likelihood of funding limitations and uncertainties in the future, and we strongly recommend that great efforts have to be made in this direction given the importance of this system in saving lives and reducing property loss for so many countries and people.

We provided several recommendations for consideration. We emphasized that big efforts should be made in order to engage donors willing to bear the cost of the future system implementation and further developments. A fundraising (marketing) plan needs to be developed in order to increase the likelihood of engaging donors. The program sustainability greatly depends on the success of a fundraising plan.

This report has also presented a possible governance option. Recommendations included adopting it, with the purpose of improving administration issues, adding clarity to the parties' roles and responsibilities, and intensifying the liaisons with Regional Centres (through the Steering Committees) and country NMHSs.

Flash floods are among the world's deadliest natural disasters, and have significant social, economic and environmental impacts. The primary purpose of the Flash Flood Guidance System with global coverage project (GFFG) is to provide real-time guidance products to forecasters worldwide and a means to adjust and integrate the products to develop assessments and warnings pertaining to flash-flood occurrence, with the aim to reduce loss of life and human suffering from the devastation caused by flash floods. As a review team, we advocate such an endeavor and vote for the continuation of the program (under a new MoU) for a global implementation, but with due consideration to the recommendations provided, and by strengthening the relationship with the NMHSs which are, at the end of the day, the link with the real beneficiaries, the vulnerable peoples in flash-flood prone areas of the world. We also believe this program should be better coordinated as appropriate with CIFPD and SWFDP to address the need for countries to operationally implement E2E multi-hazard early warning systems.

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## Appendix 1. Table of Interviews and list of POCs

Table1. Interviews and list of POCs

| № | Entity | Individual to interview | Position / contact information | Interviewer | Means of interview |
|---|---|---|---|---|---|
| 1 | WMO Commission for Hydrology (CHy) | President CHy (H. Lins) | chy.president@gmail.com | Y. Simonov, M. UriburuQuirno , CBB (*) | call |
| | | CHy expert 1 nominated by President CHy (optional) | | | |
| | | CHy expert 2 nominated by President CHy (optional) | | | |
| 2 | WMO Commission for Basic Systems (CBS) | President CBS (M. Jean) | Michel Jean<br>michel.jean2@canada.ca | YS<br>MUQ (*)<br>CBB | |
| | | CBS expert 1 nominated by President CBS (optional) | | | |
| | | CHy expert 2 nominated by President CBS (optional) | | | |
| 3 | NMHSs and Regional Centers of the FFGS<br>- to be defined | NMHS 1 – Turkish HMHS – TSMS as Regional Centre for SEEFFGS and BSMEFFGS | MrBahattin Aydın (Director of Hydrometeorology Division) bahattinaydin@mgm.gov.tr<br>MrEnverErbas (Director of External Relations, to be kept in copy to facilitate discussions) eerbas@mgm.gov.tr | Y. Simonov (*), MUQ | call, or face-to-face meeting |

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| | | | | | |
|---|---|---|---|---|---|
| | | | Suggested to contact also<br>MsAzraBabic (Bosnia) azra.babic@fhmzbih.gov.ba as a critical voice from the user point of view | | |
| | | NMHS 2 – Costa Rica NMHS – El Salvador CAFFG-Central America | Mr. Naranjo Díaz (met) jnaranjo@imn.ac.cr , Mr. R Cerón (hyd) rceron@marn.gob.sv | M. UriburuQuirno (*), CBB | Call |

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<td>NMHS 3 – Kazakhstan NMHS – Kazhydromet as Regional Centre for CARFFGS</td>
<td>
<table>
<tr><th>Country</th><th>Focal Points</th></tr>
<tr><td>Kirhgizistan</td><td>MsOmorova Elvira<br>omorova@meteo.kg<br>+996 777 900 401</td></tr>
<tr><td>Tajikistan</td><td>MsDzhamilaBaydulloeva<br>734025, Tajikistan, Dushanbe, Shevchenko str. 47<br>+992935018405<br>hydrometcenter@gmail.com</td></tr>
<tr><td>Turkmenistan</td><td>MrNazarovBayramov<br>Turkmenistan, Ashgabat c. Magtygulyave, 95<br>Tel. (99312)935453<br>bayramovnazar@gmail.com<br>meteo@online.tm</td></tr>
<tr><td>Kazakhstan</td><td>Ms LidiyaNikiforova<br>Astana, Orynbor 11/1<br>Tel. +77051076207<br>Email: lidagidro@rambler.ru</td></tr>
<tr><td></td><td></td></tr>
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</td>
<td>Y. Simonov (*), CBB</td>
<td>call, or face-to-face meeting</td>
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| | | | | | |
|---|---|---|---|---|---|
| | | NMHS 4 – South Africa NMHS as Regional Centre for SARFFGS | Ezekiel Sebego<br>Eugene.Poolman@weathersa.co.za<br>ezekiel.sebego@weathersa.co.za<br>Christina ThaeleChristina.thaele@weathersa.co.za | CBB (*), MUQ | |
| | | NMHS 5 – Dominican Republic. HDRFFGS | Mr. CampusanoLasose, Deputy Director (Technical) DR. acampunsano@gmail.comlasose2002@yahoo.com<br>Mr Luis Osoria Lara Emergency Management Agency (COE)<br>osoriar10@hotmail.com<br>Haiti<br>Focal Point: BRUNO Edmond b.edmond2001@gmail.com<br>Alternate: Nicole Francois CELHOMME<br>fran_coly@yahoo.fr<br>Participants to the 2nd Steering Committee:<br>- Ms Marie CarmelleValcount Unité Hydrométéorologique vmellecar@gmail.com<br>- Ms Nicole François : fran_coly@yahoo.fr<br>- MrWilner Polydor<br>wpolydor86@gmail.com | MUQ,<br>CBB | Call |
| | | NMHS 6 – Romania. SEEFFGS | Mr. M. Matreata (hyd) | MUQ, CBB (*) | Call |
| | | NMHS N – … | | | |
| 4 | NDMAs | DREP, Cooper (?) | | | |

| | | | | | |
|---|---|---|---|---|---|
| | - to be defined | SA | To be asked to the two focal points above | | |
| | | TURKEY | To be asked to the TSMS focal point above | | |
| | | ,NOAA, knows DManagers of CA | | | |
| | | Ask hyd/met from NMHS to provide contact names of NDMAs | | | |
| 5 | WMO Secretariat | P. Pilon | ppilon@wmo.int | YS, MUQ, CBB | call, and/or face-to-face meeting (will be in Geneva in August 22-24).<br>Paul, to coordinate the meetings |
| | | P. Mutic | pmutic@wmo.int | | |
| | | C. Caponi | ccaponi@wmo.int | | |
| | | J. Cullmann | jcullmann@wmo.int | | |
| | | A. Harou | aharou@wmo.int | | |
| | | A. Hussain | ahussain@wmo.int | | |
| | | S. Grimes | sgrimes@wmo.int | | |
| 6 | Hydrologic Research Center (HRC) | K. Georgakakos | kgeorgakakos@hrcwater.org | YS, MUQ | call |
| | | R. Jubach | rjubach@hrcwater.org | | |
| | | T. Modric | | | |
| | | | | | |
| 7 | US National Weather | Dan Beardsley | Project Manager | CBB (*), | |

| | | | | | |
|---|---|---|---|---|---|
| | Service | | | | |
| 8 | USAID/OFDA | S. Tokar | stokar@usaid.gov | YS, MUQ (*) | |
| 9 | EFAS/GLOFAS | Christina Ecklund (former director) can provide names | cristina.alionte.eklund@smhi.se | MUQ (*) | |
| 10 | SCHAPI | Etienne Le Pape | etienne.lepape@developpement-durable.gouv.fr | YS (*) | |
| 11 | German FF system (?) | Google it (?) Hydrological Advisor from Germany can provide hints. J. Cullman? | Siegfried Demuth, HA of Germany<br>Demuth@bafg.de | YS (*) ? | |
| 12 | Coupled Hydrology Atmospheric Modeling and Prediction and Seamless Forecasting (CHAMP) | V. Fortin | vincent.fortin@canada.ca<br>Scientific researcher – Hydrological Forecasting Environment Canada | MUQ (*), YS | |
| 13 | NOAA / NWS | Dan Beardsley to provide names on | | CBB | |

| | | | | | |
|---|---|---|---|---|---|
| | Coupled model (?) | their approach | | | |

## Appendix 2. Questionnaire

# FLASH FLOOD GUIDANCE SYSTEM (FFGS) WITH GLOBAL COVERAGE PROJECT

# QUESTIONNAIRE

**Introduction**

The Seventieth Session of WMO Executive Council (EC-70) met in June 2018 and endorsed the recommendation of the WMO Flood Forecasting Initiative – Advisory Group that the Commission for Hydrology (CHy) and the Commission for Basic Systems (CBS) be engaged to undertake an independent review of the Flash Flood Guidance System (FFGS) with global coverage project.

The objective of the review is to assess the effectiveness, efficiency, impact, relevance and sustainability of the FFGS with global coverage project, considering its achievements through the current regional and national projects. This includes provide findings, conclusions and recommendations to the WMO Secretariat in order to assist in setting the future overall design for the implementation of flash flood forecasting and warning systems.

The implementation plan of the Flash Flood Guidance System with global coverage project has been formulated through a Memorandum of Understanding (MoU) signed in 2009 by four organizations: WMO, the Hydrologic Research Center (HRC), US National Oceanic and Atmospheric Administration (NOAA) National Weather Service (NWS), and United States Agency for International Development (USAID) Office of Foreign Disaster Assistance. This MoU expired on 31 December 2017. Efforts are underway to develop a new MoU among the organizations to further enhance early warning capabilities for flash flooding, and to include additional regions.

The external review is being carried out by a team of the following three independent professionals:

- Curtis B. Barrett, USA, Hydrometeorological Advisor, USAID OFDA
- Marcelo UriburuQuirno, Argentina, National Commission of Space Activities of Argentina
- Yuri Simonov, Russian Federation, Hydrometeorological Research Centre of the Russian Federation

As part of this independent review, a questionnaire has been prepared. The questions set out in the questionnaire aim to collect your views on the Flash Flood Guidance System (FFGS), from a variety of perspectives.

You received this questionnaire because your opinion is deemed highly significant and relevant to the review team and will be a valuable input to the FFGS external review.

You are kindly requested to fill out the form with respondent’s information, answer the questions to the best of your knowledge, and submit the document to the following e-mail addresses: <cubarrett@usaid.gov>, <muriburu@conae.gov.ar>, <yuri.simonov@mail.ru>. Please note that your response will be confidential. We realize there are a lot questions and we very much appreciate you taking time to answer as many of these questions as you can.

You are also requested to submit your answers at your earliest convenience, but not later than 10 September 2018. The cumulative analysis and result of your responses will be included in the Assessment report which will be produced by mid-October 2018.

**Respondent Information**

Please, fill out the following form.

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|---|---|
| FULL NAME | |
| ORGANISATION | |
| POSITION | |
| HIGHEST EDUCATIONAL LEVEL DEGREE | |
| NUMBER OF YEARS INVOLVED WITH FFGS | |
| YOUR CURRENT RESPONSIBILITY AND ROLE WITHIN THE FFGS (mark with an X) | **(A) DESIGN, DEVELOPMENT, IMPLEMENTATION AND SUPPORT** (HRC, NWS, WMO, USAID/OFDA, CHY, CBS)<br>- designer<br>- developer<br>- implementer<br>**(B) OPERATION, MAINTENANCE AND USE** (National Meteorological and Hydrological Services (NMHSs), National Disaster Management Agencies (NDMAs), other users)<br>- operator / forecaster<br>- IT technician<br>- maintenance technician<br>- DB administrator |

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| | - disaster manager / civil protection agent<br><br>- other (specify): |



**Overview and Structure of the Questionnaire**

The questionnaire is divided into two different sections (A and B). You are only requested to answer one of the sections, depending on your current responsibility and role within the FFGS (as marked in the Respondent's Information table, above). Please, answer Section (A) if you put an X in any of the categories under the title "Design, Development, Implementation and Support", and answer Section (B) if you put an X in any of the categories under the title "Operation, Maintenance and Use".

In order to give your answers, simply position the cursor below each question and use as many paragraphs as necessary.

# (A) DESIGN, DEVELOPMENT AND IMPLEMENTATION

(1) Is the Flash Flood Guidance System (FFGS) providing adequate guidance and information to allow issuing credible flash flood alerts and warnings to users? If not, what are the issues?

(2) Do you think that National Disaster Management Agencies (NDMAs) of the countries with implemented FFGS are fully satisfied with its products? If not, please describe why, and what do you think could be done to overcome such dissatisfaction?

(3) What additional activities/outputs can make the FFGS more consistent with its objectives? If any, please explain what you would like to see as such additional activities/outputs. To what extent does the FFGS achieve its objectives? If there are any issues - please describe.

*Note: The main objectives of the Flash Flood Guidance System with global coverage are to:*

- *enhance National Meteorological and Hydrological Services (NMHSs) capacity to issue flash flood alerts and warnings to help mitigate the adverse impacts of hydrometeorological hazards;*
- *enhance collaborations between NMHSs and National Disaster Management Agencies;*
- *generate flash flood early warning products by using state-of-the-art hydrometerological forecasting models;*
- *provide extensive training including on-line training to the hydrometeorological forecasters; and*
- *foster regional developments and collaborations.*

(4) Do you agree with the statement that the implementation of the work programme was carried-out in a cost effective manner? Do you think there could be any improvements with respect to cost effectiveness of implementation, such as in the areas of development and on-going operational support? Please briefly explain.

(5) Is there another approach rather than one used in FFGS (both implementation process and how it is applied operationally) that could be applied to improve the operational flash flood early warning system? If yes, please explain.

(6) How would you improve the work processes of FFGS: data management, modelling approach, final products (incl. format and dissemination), implementation process, operational run, and training program? Or, do you think the present approach is adequate? Please explain briefly each point, if you think that it could be more efficient or effective.

(7) What are main impacts and benefits for a country that has implemented the FFGS? What aspects of NMHSs service have improved since implementation?

(8) What potential improvements to the FFGS are needed (taking into account new potential functionalities and products of FFGS such as landslide and urban forecasting). Are there other functionalities needed that are not available or being currently developed?)

(9) What do you see as some major limitations under the current FFGS and its available functionalities?

(10) Please, explain briefly your views on the robustness of the FFGS. For example: how does the system operate with less data than the system was designed for (in some cases no operational rainfall data are available)? How stable is the software? Is the system reliable, that is little down time? Is the system helpful in providing information during extreme events such as the 100-year flood or more severe events?

(11) Is the operational performance monitoring of FFGS (i.e. using skill scores) helpful and useful for damage centre locations and lead times? If not, please explain.

(12) Is there a need to modify or adjust the forecasting model (such as recalibration of parameters) to improve flash flood forecasting performance, or any other chain of forecasting process? Is yes, please explain how it is done or how it should be done.

(13) What long-term budget allocations are needed to support the operational use of FFGS by the NMHSs (e.g. supporting sufficient levels of staff training, system maintenance)? Please explain.

(14) How does the forecaster use the FFGS system to construct flash flood warning products? Please explain.

(15) Would you please describe the level and type of training or education required of decision-makers and mass-media to understand the uncertainties of flash flood warning products, their limitations and benefits? Is this a problem?

(16) A number of NMHS professionals expressed some concerns on the limitations of the FFGS because it's viewed as a black-box system. Can you mention advantages or disadvantages of implementing an open source or modular FFGS, providing flexibility to locally made adaptations to the System?

# (B) OPERATION, MAINTENANCE AND USE

The questionnaire section B is structured in the following topics:

- Relevance & Effectiveness
- Product Usability
- Impact
- Sustainability
- System Performance Evaluation
- Lessons Learned
- Level of Satisfaction & Areas of Improvement
- Additional Information

Within each topic, a maximum of six questions were included. At the end of the questionnaire (under Additional Information) you will have the opportunity to add further comments and views on aspects not fully reflected in the questions or not covered in your previous answers, keeping in mind that your opinions should help the reviewers to make a more thorough assessment of the overall System characteristics.

There are many questions and not all of them may be applicable to your role within the FFGS. We very much appreciate you taking the necessary time to answer as many of the applicable questions as you can. We also kindly ask you to be as straightforward and concise as possible in your answers.

## 1 Relevance & Effectiveness

Relevance is understood as the extent to which the FFGS is an appropriate approach to mitigate flash flood losses in your country or region, and is adequately serving the needs of communities at risk.

Effectiveness is a measure of the extent to which the FFGS in your country and region attains its objectives, keeping in mind that the FFGS is a tool necessary to provide operational forecasters and disaster management agencies with real-time informational guidance products pertaining to the threat of small-scale flash flooding. In your opinion:

(i) Are flash floods really an issue in your country / region? Please explain briefly.

(ii) To what extent have the FFGS objectives been achieved so far in your country / region?

*Note: The main objectives of the Flash Flood Guidance System with global coverage are to:*

*- enhance National Meteorological and Hydrological Services (NMHSs) capacity to issue flash flood alerts and warnings to help mitigate the adverse impacts of hydrometeorological hazards;*

*- enhance collaborations between NMHSs and National Disaster Management Agencies;*

*- generate flash flood early warning products by using state-of-the-art hydrometerological forecasting models;*

*- provide extensive training including on-line training to the hydrometeorological forecasters; and*

*- foster regional developments and collaborations.*

(iii) How effective are the products and information of the FFGS in reducing the impact and effects of flash flooding? Can you provide a specific example?



## 2 Product Usability

This section deals with the usability of FFGS products in terms of their ability to form the basis for making decisions. In your opinion:

(i) How easily are FFGS products correctly interpreted by users? Please explain.

(ii) How "user friendly" is the FFGS web site (product console, dashboard, etc.)? Please explain.

(iii) The FFGS is designed to allow product adjustments based on the forecaster's experience with local conditions, incorporation of last minute local observations (e.g. non-traditional rain gauge data), or local observer reports. To what extent are these possibilities being effectively used? Please explain.

(iv) Do you use the FFGS to generate information on alerting on potential flooding over the next 24/48 hours? If so, how do you use it?

(v) How adequate are decisions concerning issuing alerts or warnings derived from FFGS products in your country / region?

## 3 Impact

Impact refers to the changes produced by the FFGS in your country / region, directly or indirectly, intended or unintended. In your opinion:

(i) What were the main impacts of the FFGS in your country / region, directly or indirectly, intended or unintended?

(ii) Has there been an observable reduction of flash flood losses after the implementation of the FFGS in your country / region? Is there a specific example you can give?

(iii) Are the uncertainties embedded in flash flood warning products properly considered in the decision making process, and sufficiently understood by mass media? Please explain.

## 4 Sustainability

Sustainability is the ability of the FFG System to be maintained in the future at least at the current level of functionality.

(i) In your opinion, are the benefits of the FFGS in your country / region likely to continue? If not, what are the weak links in keeping the system operating and maintained in the future?

(ii) Is the need for human and financial resources a cause of concern in your country / region? If so, is there any strategy in place to deal with this problem?

(iii) Training programs are a fundamental part of sustainable systems. Have the training courses for FFGS been adequate for forecasters to operate the system and use the system to its potential? Would staff require further training? Please explain.

(iv) What long-term budget allocations or factors are needed to support the operational use of FFGS by the NMHS in your country or region (e.g. supporting sufficient levels of staff training, system maintenance)? Please explain.

## 5 System Performance Evaluation

As you know Flash-Flood Guidance is an index of the volume of rainfall of a given duration over a small catchment that is just enough to cause minor flooding at the outlet. It is used with estimated or forecasted precipitation over the catchment to arrive at a flash flood threat index that forms the basis of decisions regarding the dissemination of warnings. The dominant source of uncertainty in these decisions is precipitation. Performance evaluation is sometimes, though not exclusively, conducted through the computation of skill scores such as probability of detection and false alarm ratio.

(i) Have performance evaluations been conducted on a regular basis in your country / region? If yes, would you briefly comment on the main findings, to the best of your knowledge? Could you share your results?

(ii) If there are no quantitative studies of performance verification, what is your qualitative technical opinion on the accuracy, reliability and functioning of the system when it is needed?

(iii) If there are no quantitative studies of performance verification, would you please explain why this is the case?

(iv) To the best of your knowledge, how well does the system perform? Consider impacts and benefits for your country, and major limitations of FFGS available functionalities. Please, justify your answer.

## 6 Lessons Learned

Lessons learned refer to the knowledge or understanding gained by experience. This section deals with the information that reflects both the positive and negative experiences, gained by yourself and others, after some years of FFGS operation in your country / region.

(i) Please provide the main lessons learned (at least two) in the years of operation of the FFGS in your country / region, in relation with the role you have within the system. Please explain.



## 7 Level of Satisfaction and Areas of Improvement

In this section, the level of satisfaction with the FFGS in your country and region is surveyed, and there is also the opportunity to include potential areas needing improvement and suggestions on increasing the benefits of the system.

(i) In your opinion, what is the general level of satisfaction with the FFGS in your country / region? Choose from very low through very high, and justify your answer.

(II) Do you know how users use the warnings or products? Can you provide illustrations of how users make decisions or take actions based on products?

(iiI) Do you think that NDMAs in your country are fully satisfied with FFGS products? If not, please describe why and what you think could be done to overcome such deficiencies.

(iv) In your opinion, what are the main areas with the FFGS in need of improvement of for your country / region? Consider: data management, modelling approach, operational use, final product format, dissemination, awareness and education of users, and training program, and any other aspect you deem important.

(v) Feel free to add suggestions on how to increase the benefits of the system.

(vi) Are you aware of alternate operational flash flood early warning systems that, in your opinion, could perform better in your country or region than the FFGS?

## 8 Additional Information

This section is intended to allow you to add further information on the FFGS or on the provision of flash flood forecasting and warning in your country and region, regarding aspects not covered in the previous sections that, in your opinion, may serve to make a more thorough assessment of the overall FFGS or alternate forecast systems.

(i) Please add additional information.

# Appendix 3. Tables summarizing questionnaire key responses

## *Main findings from Section A*

The following table summarizes the main findings from the responses of Section A of the Questionnaire, received from developers. There were 8 developers out of 28 questionnaire responses. Developers included major partners in developing and implementing the GFFG including HRC, USAID/OFDA, WMO, NOAA and NMHS's who had a development role such as Turkey and South Africa.

Table 2. Main findings from Section A

| Question | Findings |
|---|---|
| (1) Is the Flash Flood Guidance System (FFGS) providing adequate guidance and information to warnings to users? If not, what are the issues? | ● The majority of respondents indicated that the Flash Flood guidance system provides adequate guidance and formation to users but there is a need to continue to improve it.<br>● For a small number of respondents, FFGS provides guidance and information that flooding has occurred but not useful in establishing credible ALERTS<br>● Most respondents indicated data is a very limiting factor.<br>● FFGS might benefit from an improved GUI (graphical user interface) to allow quicker download and interpretation of data. Several countries where FFGS system is in operation are using FFGS in monitoring and detecting flash flood events. In some countries, participating NMHSs employ FFGS continuously to issue warnings to other agencies and public.<br>● In some NMHS's FFGS is not used to full extent due to staff turn-over, lack of resources to maintain the system, lack of official designation to issue warning, lack of support from ministerial level, long approval processes of forecasts, among others.<br>● Most respondents describe FFGS as a system that is designed to allow forecasters to add their experience with local conditions and incorporate other data and information such as numerical weather prediction products and any last minute local observations from |

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| | stations to assess the threat of a flash flood. |
| (2) National Disaster Management Agencies (NDMAs) of the countries with implemented FFGS are fully satisfied with its products? If not, please describe why, and what do you think could be done to overcome such dissatisfaction? | ● Many NDMA Officials are enthusiastic about potential timely and accurate information that could be received during training sessions. In some documented cases FFGS has improved delivery of service (In Dominican Republic and Pakistan, NDMA was very supportive of NMHS to receive resources to implement FFGS. Turkish State Meteorological Service continues to communicate and work with emergency managers at provincial and local governments in advance of flash floods to enable them to take early action to reduce loss of lives after the implementation of the system.<br>● Participation of NDMAs in developing products to factor in their decision making processing for action as well as in verification of forecasts will improve the use of FFGS products<br>● Many Alerts to NDMA issued by other means than FFG(3)<br>● FFG not designed for NDMA officials, it is designed for NMHS forecasters<br>● FFG could be useful to NDMAS to target high risk areas such as shopping centers, rivers crossings roads etc.- Higher resolution is needed.<br>● It was noted that as we move in implementation of impact-based forecasting, some of the understanding of FFGS products will improve.<br>■ Need to review inputs to model to see if better results can be obtained.<br>■ In most of the countries where FFGS is implemented, NDMAs are receiving the information about the possible flash flood events, not FFGS products<br>■ Most of the countries implementing FFGS have not developed additional models and systems for flash flood prediction |
| (3) What additional activities/outputs can make the FFGS more consistent with its objectives? Please explain what you would like to see as such additional activities/outputs.To what extent does the FFGS | ● One NMS indicated the need to Decrease range of rainfall display scale<br>● In almost every questionnaire the forecasters and developers indicated the need to Add Map server.<br>● Many NMS's need the Urban FFG, riverine and Landslide modules (3)<br>● Increasing use and experience in Using the WHATSUP APP has led to increased interaction with users and |

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| achieve its objectives? If there are any issues - please describe. | improved service delivery.<br>■ FFG needs to indicate areas of potential flash floods at least 3 to 6 hours lead time in advance<br>● Improvement in the Global Hydro Estimator is needed.<br>● Step 5 training is led by certified forecasters yet there is neither guideline agenda nor assistance to conduct these needed training sessions. *This statement is not entirely correct. In fact, Step 5 training material is available and all Step- 5 trainings are scheduled for the Phase III of the project.*<br>● Need to make the process of adding certified trainees easier- If you miss the regional training session there's no structured way to get trained.<br>● Step 3 training has a high number of repetitions between the presentations delivered by the WMO Certified Trainer (WCT) and the ones delivered through teleconference by HRC.<br>● A gap exists between the concepts explained in the step 2 training and the meteorological knowledge required at the beginning of the step 3<br>● Some respondents indicated that training was not sufficient to have an understanding of the FFGS system<br>● There was concern that there was too much over protection of files, copyright that was a barrier to a user friendly system.<br>● The overall user friendliness of the FFGS dashboard and products might be greatly improved by adopting simple user-interface solutions<br>● An important missing element in the FFGS to some NMS's is the possibility to visualize geography in the basins. This is because they did not have the Map Server version.<br>● The whole training curriculum should be revised and improved, considering the necessity to move towards a replication of Step 3 trainings outside of HRC headquarters (the costs related to this option, combined with the difficulty or impossibility of access to the USA for some trainees, makes it not sustainable in the long term)<br>● Although the FFGs program increases communications and the relationship between NMHS and the NDMA, the objective of enhancing collaboration between |

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| | NMHSs and NDMA still needs to be improved. Twining FFGS and SWFDP will helped in pilot countries to further collaboration between NDMAs and they can prove valuable for impact-based forecasting undertaken as "Weather Ready Nations" initiatives in some of the countries<br>● Many respondents recommended that NDMAs should be more involved in the FFGS Training Programme (from the beginning and in all five steps of the training programme). |
| (4) Do you agree with the statement that the implementation of the work programme was carried-out in a cost effective manner? Do you think there could be any improvements with respect to cost effectiveness of implementation, such as in the areas of development and on-going operational support? Please briefly explain. | ● Many respondents indicated that the Work program was cost effective however many more indicated a cost effective CoP approach would be more cost effective.<br>● In some regions, long term technical support, capacity building and updates of the system continue to require outside funding.<br>● Local (national) NMHS units need to express their needs to Regional Centers. In general, this is not being done.<br>● A few respondents said that additional costs should be negotiated with work program and national institutions. |
| (5) Is there another approach rather than one used in FFGS (both implementation process and how it is applied operationally) that could be applied to improve the operational flash flood early warning system? If yes, please explain. | ● Many responders acknowledged the need for more automated data, the use of radar and establishing community local EWS.<br>● Develop mobile phone APP of FFGS was recommended.<br>● France has developed a flash flood guidance in the framework of their Vigicrues, and Italy might have some flash flood guidance integrated in the DEWETRA platform. This is currently being explored through TT E2 of the CHy.<br>● Some of the flash flood systems have accuracy of forecasting flash floods but they are extremely sophisticated and require variety of equipment and sensor thus significant funding and capacity.<br>● Highly sophisticated systems have many challenges for developing countries and are very difficult to operate, maintain and repair with limited budget and staff.<br>● FFGS Output needs to be analysed and compared to other model results. Developers need to cooperate with |

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| | local users.<br>● WMO should have more communication with the RCs in training and this kind of collaboration and feedback should be on-going for sustainability of the regional projects.<br>● Establishment of FFGS WhatsApp groups for regional Systems. This is already occurring is some regions and very successfully.<br>● There are similar systems in Australia and the Czech Republic: Flash Flood Advisory Resource (FLARE) and Australia uses the rainfall guidance of choice is the Bureau's RAINFIELDS/STEPS – Short Term Ensemble Prediction System<br>● In the Czech-Republic, A GIS based flash flood guidance procedure. It is based on HEC-HMS and in general it computes the CN value at each grid point based on soil characteristics, slope and soil saturation. |
| (6) How would you improve the work processes of FFGS: data management, modelling approach, final products (incl. format and dissemination), implementation process, operational run, and training program? Is the present approach is adequate? | ● A few respondents indicated the existing approach is adequate<br>● Increase training in flash floods, hydrology, routing flow, riverine model is needed<br>● Include display of hydrographs and water level elevations<br>● A few respondents indicated that Models should be changeable when necessary, and end products modified to meet user's needs<br>● WMO should work more closely with the countries and make sure that all available data is provided in advance to HRC<br>● Many respondents wanted to be able to include more NWPs if they are operationally available in the region.<br>● Some respondents indicated that lack of calibrated radars is an issue for rainfall estimation.<br>● The FFGS modules of landslides, urban Flash Flood component and Riverine are needed in countries.<br>● Countries should be more involved during all phases of the implementation process, especially development phase. Also, during the Initial Planning Meetings it should be mentioned that Regional Centres need to sign the licensee agreement.<br>● Operational model update time should be one, instead of six hours. |

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| (7) What are main impacts and benefits for a country that has implemented the FFGS? What aspects of NMHSs service have improved since implementation? | ● Many respondents indicated that improved warnings to Emergency Management are occurring and much better coordination between agencies is occurring.<br>● Many respondents said benefits are the Detection, forecast and warning of Flash Floods.<br>● For us very effective for training and for case studies to determine where flash flooding occurred, when rainfall persistent, FFGS is useful; also knowledge of areas prone to flash floods has increased.<br>● Implementing FFGS also improves quantity and quality of data.<br>● Turkish Met Services documented various events that FFGS enabled them to issue warnings and helped them communicate with local emergency managers to take action.<br>● The FFGS is enhancing collaboration between hydrologists and meteorologists, collaboration between NMHSs and NDMAs, regional collaboration, capacity building.<br>● Some NMHS are Using soil water products as advisories to agricultural agencies.<br>● Using the quality controlled remotely sensed precipitation data to support other than flash flood activities (e.g., in the Mekong use it to force the large river models). |
| (8) What potential improvements to the FFGS are needed (taking into account new potential functionalities and products of FFGS such as landslide and urban forecasting). Are there other functionalities needed that are not available or being currently developed? | ● Inundation maps from satellite and model simulations.<br>● Adding nowcasting products.<br>● Displaying and assimilating stream flow records.<br>● Lightning data sets.<br>● New functionalities of FFGS contribute significantly on areas usually not covered in many NMHS such as landslide risk and improve understanding of hazards such as urban flooding.<br>● FFGS has developed UFFEWS, urban flash flood forecasting model. UFFEWS can be further improved. It is beneficial to adapt the landslide prediction model to the UFFEWS prediction model.<br>● The operational use of the Map Server Interface System is much more effective and easier for forecasters. Forecaster has the ability to zoom into the potential warning area, look at the plots, and add layers (e.g. roads, evacuation routes, houses, schools, etc.), satellite |

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| | images, digital elevation model, and maps.<br>● Multi Model QPF- up to 5 QPF from operational NWP could be ingested into FFGS and made available to forecasters.<br>● Seasonal and sub seasonal flow prediction.<br>● Avalanche forecasting.<br>● Addition of ensemble prediction products that indicate uncertainty would improve services. |
| (9) What do you see as some major limitations under the current FFGS and its available functionalities? | ● In many countries, Rainfall predictions only updated twice a day and it takes too long time to receive QPF forecasts. *In fact, it is four times per day.*<br>● Maintaining and replacing servers at regional centers.<br>● Maintaining access to data such as satellite rainfall estimates, NWP data and gage data.<br>● Training program too limited.<br>● Routine monitoring and feedback operations.<br>● Urban flash flooding needs to improve.<br>● Improving browsing speed of FFGS products.<br>● Adapt FFGS to cell phone Apps.<br>● In densely equipped catchments with plenty of measurements and information other models might work better than the FFGS system. However, the reality is that most catchments and most countries are lacking basic data.<br>● Training did not include information on model and how it compares to other models used for FF forecasting. Model treated as a black box.<br>● No discussion in training on validation of the model. *This statement is not correct: validation is included in Step 4 and Step 5 trainings.*<br>● FFGS radar precipitation data should be examined for adjusted data use in prediction. Results that do not match the actual values can be obtained. It should be known that the consistency of other precipitation prediction models deviate greatly.<br>● Difficult to change input data without incurring additional costs.<br>● Sustainability of the only remotely sensed global precipitation product (the NESDIS Global Hydroestimator) is the weakest point, and it has a low latency of a few minutes. |
| (10) Please, explain briefly your | ● Remarkably, even with deficient rainfall data, system |

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| views on the robustness of the FFGS. For example: how does the system operate with less data than the system was designed for(in some cases no operational rainfall data are available)?How stable is the software? Is the system reliable, that is little down time? Is the system helpful in providing information during extreme events such as the 100-year flood or more severe events? | has validated well with case studies.<br>● Many respondents indicated the Software is stable.<br>● Downtime issues due to data feed interrupts not FFGS software.<br>● System works well with persistent rainfall so does well for 100 year floods.<br>● System designed to provide information if local data absent but motivates local NMHS to increase local data input.<br>● System provides adequate performance for low data availability situation as long as forecaster is experienced.<br>● A few respondents said it is too early to make an early decision on the robustness of the FFGS system. it is necessary to use it operationally and to determine its requirements. A more robust system can be designed for these requirements.<br>● The main effort expended was in making this robust and requiring very little maintenance. This has been achieved and unless hardware fails the system will work well even with little data using the many default options. |
| (11) Is the operational performance monitoring of FFGS (i.e. using skill scores) helpful and useful for damage centre locations and lead times? If not, please explain. | ● Many respondents indicated the system operational performance monitoring is adequate.<br>● A few respondents indicated Verification was important tool and there is a strong need to include verification as operational requirement.<br>● The Verification process is difficult—Need to get data from the field and understand quality of data and information.<br>● Useful for damage center locations but not useful for lead times.<br>● More attention is needed on how to best evaluate forecasts as a tool to support forecaster.<br>● Unfortunately the developers get little feedback from the regional center or the countries on this. |
| (12) Is there a need to modify or adjust the forecasting model (such as recalibration of parameters) to improve flash flood forecasting performance, or | ● Predicted products only updated twice a day. *This statement is not factual. Updating generally takes place 4 times per day and once per hour in South Asia.*<br>● Very important to recalibrate model parameters-should be based on verification results. |

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| any other chain of forecasting process? Is yes, please explain how it is done or how it should be done. | ● Updating systems such as recalibration is a sustainability issue not addressed.<br>● Most basins in urban areas probably need recalibration.<br>● FFGS should make adjustments in the model outputs in line with the needs of local users. These may include rainfall corrections, etc.<br>● Catchment delineation, geomorphological relations need to be checked by country, also validate bias adjustments.<br>● The system allows for new parametric files to be inserted after installation and after operations begun. |
| (13) What long-term budget allocations are needed to support the operational use of FFGS by the NMHSs (e.g. supporting sufficient levels of staff training, system maintenance)? Please explain. | ● The number one response was the need for training and more training.<br>● Second most frequent response was budget for Maintenance and updating system hardware & software for Regional centres.<br>● Costs of obtaining data, disseminating products to users, support FF operations, communications, historical archive of information, support regional training and routine support of IT should be the Regional NMHS responsibility. Not all regional centers can handle this cost. *This bullet is not strictly correct: data are freely available, and WMO is supporting regional trainings.*<br>● Cost for System enhancement.<br>● Maintenance Cost is $8000/yr/country according to HRC but since it's still a black box, NMHSs remain too dependent on HRC.<br>● There should be at least one trained hydrometeorologist in charge of the use of the FFGS at NMHSs that receive products for real time forecasting of flash floods. Periodic training of other forecasters is also necessary as flash floods are hydrometeorological events needing both hydrology and meteorology. |
| 14) How does the forecaster use the FFGS system to construct flash flood warning products? Please explain. | ● Forecaster consults the 3 product consoles to evaluate spatial and temporal risk distribution. *In fact, this is valid for all products (this was covered in every training).*<br>● Forecasters use it to monitor for flash floods but other approaches used to help in decision making so alerts can be sent out quickly. |

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| | ● Number one response, forecaster using local information should be able to modify both FFG values and forecast values and generate modified forecast FFT values. |
| 15) Would you please describe the level and type of training or education required of decision-makers and mass-media to understand the uncertainties of flash flood warning products, their limitations and benefits? Is this a problem? | ● Trainings, based on workshops, talks and introduction in plain language, to both emergency managers and the media.<br>● Should be part of Outreach & Education of NMHS for all severe weather threats. Mandatory part of high impact forecast training.<br>● Basic hydrologic training for forecasters.<br>● Basic public training to differentiate flash foods from river floods.<br>● Decision makers and media should not be users of FFGS products directly. Forecasters should generate warning and target specific risk locations.<br>● Minimum bachelor or university degree, use of browser and computer and Internet exploration, clear concepts on risk management, minimally capable of completing online courses on basic concepts of hydrology and geographic information system, as well as processes of flash floods and basic meteorology.<br>● Forecasters issue warnings not FFG. The training to decision makers should be based on warning product information not FFG.<br>● The problem is that the model outputs that need to be suspected are not able to fully meet the needs of the decision makers. This problem can be solved with cooperation. The same is true of mass media.<br>● Besides the FFGS Initial Planning Meeting, special trainings for the mass-media (including NDMAs and NMHSs) should be organized. |
| (16) A number of NMHS professionals expressed some concerns on the limitations of the FFGS because it's viewed as a black-box system. Can you mention advantages or disadvantages of implementing an open source or modular FFGS, | ● Many Respondents indicated this is important.<br>● And the system needs to be opened up for improvements and adjustments.<br>● HRC has developed an analysis version of FFGS that allows model parameter adjustment but this requires extensive training and knowledge on how to use it. Although it is not yet generalized across regions, it shows it is possible.<br>● The challenge of improving the product with new |

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| providing flexibility to locally made adaptations to the System? | techniques and new products, sharing the possibility of making improvements with software programming for hydrologists that is a trend. Local ability supported by the developer and by the WMO so that the users of the FFGS can expand their potential and develop skills that make the hydrological forecast better and reduce the impact of flood events.<br>● As proved in other open source or modular systems (e.g. the MCH database), an open-source approach can lead to the development of CoP that self-sustain the system, providing troubleshooting and upgrades to the wider community.<br>● Open source or modular FFGS might help improvement of FFGS implementation given it is done by experts who understand the system with careful verification as well as potential sustainability of FFGS<br>● We believe that flexible local implementation of the FFGS system is beneficial. Because the needs change as the conditions change. In line with these needs, FFGS must make the necessary additions and adjustments quickly.<br>● A black box System is not appropriate for any form of sensitivity analysis. The advantage of this kind of System is that System cannot "crash" (it is under control) which is extremely important in the operational flash flood forecasting, it is easy to optimise and can run very rapidly and it does not require a great deal of computing power<br>● Currently it is very difficult for us to make any changes to the system and often when issues arise it takes a long time to make the necessary changes. By allowing more flexibility in this regard it may result in necessary changes being implemented earlier, thus improving the system and perhaps allowing the confidence of the forecasters using it to grow. |

### *Main findings from Section B*

The following table summarizes the main findings from the responses of Section B of the Questionnaire, received from forecasters and NMHSs personnel, representing 20 out of 28 questionnaire responses.



Table 3. Main findings from Section B

| **1. Relevance & Effectiveness** | |
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| Main findings | ● FFGS system is of high relevance. All countries which have implemented FFGS (or which are now in the process of implementation) are affected by flash floods. The majority of countries are affected by flash floods country-wide.<br>● Many NMHS's felt significant value added to their flash floods warning procedures when FFGS became operational. Some countries are waiting for FFGS to become operational. However a few (highly developed) NMHS did not feel using FFGS added significant inputs to their flash flood warning procedures.<br>● The NMHSs which are using FFGS products in their operational flash flood warning procedures (majority of users) and felt improvement with NDMA's interaction when FFGS became operational.<br>● Most countries estimated FFGS training program as significantly beneficial. Several users feel that there could be improvements in terms of online course as it is regarded as more theoretical than practical. A few users interviewed described the training structure as the old way of doing lectures, and that HRC does not fully share information.<br>● Another criticism is that HRC does not have operational experience yet they are training operational forecasters on an operational system.<br>● Quality and quantity of rainfall input is the greatest limitation to effectiveness in flash flood guidance product |

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| | value. In some countries, observations are not processed into the system, and in some countries rainfall rates occur in very short temporal scales with no observed rain gage data available.<br>● In some regions/countries, the Hydroestimator rainfall estimation is not acceptable. Example is cirrus cloud contamination causing overestimation of rainfall. This restricts quantitative application of the satellite based rainfall product but even with these errors, in many environments, this is all the rainfall information that is available.<br>● Countries that do not have weather radar based rainfall estimation input to FFGS need it.<br>● Some countries consider that since FFGS implementation there has been an increase interaction/cooperation between NMHS and users on a regional level. Conversely, some other countries consider there is little communication between regional and national centres.<br>● In general users recognize FFGS products as effective. In the same time it was noted by many, that effectiveness highly depends on effectiveness of FFGS estimation of current weather situation and its nowcasts (as stated by users - satellite rainfall products are more accurate in case of stratiform and less so for orographic precipitation). Some users noted that there is significant rate of flash floods false alarms.  Meanwhile users from developed NMHSs (e.g. Slovenian NMHS, Israel NMHS, S. Africa) did not feel, that FFGS products are effective compared to existing techniques used nationally, one reason for this from their point of view that the system was not completely adjusted to their conditions (input data, calibration of model, etc).<br>● In El Salvador, the system as a whole (including the FFGS) achieved a decrease in casualties caused by intense storms |

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| | from more than 300 people between 2004 and 2009, to around 12 between 2009 and 2018. |
| **2. Product Usability** | |
| Main findings | ● FFGS products could be easily interpreted by a user assuming that FFGS training has been received; it is much preferable for a user to have both meteorological and hydrological experience for successful FFGS products' interpretation.<br>● A number of users replied more improvements are needed in the flash flood early warning products generation process within FFGS. Different areas needing improvement were indicated, particularly user friendliness of the interface.<br>● In many if not most NMHSs, Forecasters have gained confidence in the system and are modifying their Standard Operating Procedure -CONOPS to reflect using FFG. In Dominican Republic need assistance in developing their SOP.<br>● Users in general recognize FFGS web site to be user friendly. However it was noted that the interface could be improved (e.g. in terms of map navigation).<br>● Not so many users use dynamic adjustment within FFGS for a number of reasons: some users say that it is necessary to use QGIS which takes time, others - that it either requires very well trained personnel, or it is not well implemented within FFGS system.<br>● Regarding FFGS application for 24/48 hours flood warnings - a number of users use this option for issuing flood watch, others have other models and platforms for longer term forecasts. It was noted that some users use FFGS derived QPE/QPF as input to their own modeling and forecasting systems. Kazakhstan NMHS uses FFGS derived soil/snow products in their long-term spring flood forecasting technique, and also for agrometeorological |

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| | forecasting.<br>● Adequacy of decisions concerning issuing alerts or warnings derived from FFGS products is case dependent - if QPE/QPF derived by FFGS are adequate then flash flood warnings are adequate in most cases (and vice versa). However it was noted that for the majority of users, that FFGS information is not used alone to issue alerts and/or warnings - is always used together with other sources in flash flood warning issuance process. |
| **3. Impact** | |
| Main findings | Main impacts of FFGS were seen as:<br>– improved ability to issue flash flood warnings;<br>– It raises awareness of users and administrators for flash floods;<br>– Validation of the occurrence of flash floods<br>– strengthened community of hydro/meteorological forecasters in the region;<br>– Increases coordination and communication between hydrologists, meteorologists and disaster managers<br>– stimulated efforts towards redefinition of the hydrological warning process at NMHS<br>– reduction of flash flood losses (following the replies of those NMHSs who obtain loss statistics)<br>– increased understanding of flash flood warning uncertainty by forecasters and in some cases mass media (developed countries) |
| **4. Sustainability** | |
| Main findings | ● Many respondents said that the system needs to move away from a black box and that a community of practice should be established.<br>● WMO is short on resources yet most respondents indicated needs to increase its involvement with GFFG. |

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| | • The greatest weakness of the programme is sustainability.<br>• The system is not sustainable as it is today.<br>• Monitoring and Evaluation is required in order to understand and help weaker countries. Sustainability strongly depends on that.<br>• Although amounts of funding required for operation is fairly low, continued funding is a challenge for National entities which raises concerns about sustainability of the program. *This statement likely refers for the additional staff time needed to use the FFGS and issue warnings. It is noted that, in addition to paying for Internet, there should not be special local computer requirements (system runs on a PC) nor IT issues that require continued resources.*<br>• Staff turnover is high, thus constituting a challenge to sustainability.<br>• Local entities have significant challenges with equipment and capacity building and updates of the system when they inquire new equipment.<br>• Trained forecasters not training their colleagues for continuous feed of forecaster to the system.<br>• Limited resources of NMHSs continue to be a challenge for participation of regional training without external support.<br>• Difficulties in communication among regional centres and focal points in the countries were also seen as a threat to the system sustainability.<br>• Another sustainability issue is linked to that of the only remotely sensed global precipitation product, i.e. the NESDIS Global Hydroestimator, which has a low latency of a few minutes and is the only one available in many regions to detect the potential occurrence of flash flooding. |
| **5. System Performance Evaluation** | |
| Main findings | • In a number of countries, no system performance evaluation has been conducted. The main reasons given |

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| | were: (a) scarcity of personnel, (b) the system is not yet operational, (c) only recently the system has become operational.<br>● Some verification studies are made with scarce data or with a reduced proportion of actual events. In some countries, the civil protection rarely informs back to the NHS on the effective occurrence of the flash flood, their exact location, the impact, etc. Some verification studies depended strongly on newspaper or broadcast information on the effective occurrence of flash flood events.<br>● Some interviewees reported that the system performance is low. The main reasons given were: (a) the system was not designed / calibrated according to the local data and information (not proper catchment delineation, no local soil type and land use information, and no river cross section data), (b) karstic or permafrost catchments are not properly modelled by the Sacramento model, (c) reduced number of in situ rain gauges used in the system versus what is nationally available. *Regarding (a), it is noted that local data were to be provided by the countries. We've been informed of cases where a large effort was made in order to provide local data that were not finally used. It is not clear for the reviewers if these data were provided in a timely manner, and how many countries indeed provide their local data or improved initial basin delineations.*<br>● Some interviewees reported that the system performance is moderate. The main reasons given were:(a) the hydro-estimator can greatly over or underestimate the rainfall or shift the storm location for convective systems, (b) heavy thunderstorms (convective storms) are less well represented by the NWP models, thus impacting on the FFGS performance. For instance, NWP model do not represent well the events during summer and spring in |

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| | Turkey, thus impacting on the FFGS performance. However, the behaviour of the system in the case of frontal precipitation events is higher.<br>● Even in countries where system performance has not been conducted or where results are poor, some interviewees expressed their satisfaction with the system, or their feeling that the system will be useful and perform well, or their opinion on the system high potential. A respondent considered the system to work very well most of the times, and, even though there is room for improvements, the system allows disaster managers and people to react to forecasts and to have anappropriate response time to protect lives and property. |
| **6. Lessons Learned** | |
| List of the reported lessons learned | Answers have been focused in different ways. Some emphasized what they had learnt after they started using the FFGS, while some others described situations where the FFGS was used both successfully and unsuccessfully. The lessons learned can be summarized as follows:<br>● FFG provides learning and numerical validation of flooding. It helps them pay attention to where the flood threat is relative to the population at risk.<br>● Deeper and more comprehensive knowledge gained about the flash flood generation process, but mainly through FFGS trainings, not operation.<br>● Many things have been learned after training and use of the FFGS: hydrology, meteorology and floods, and also GIS software, and programming languages as R.<br>● The implementation of the FFGS increased the understanding of the importance of flash flood prevention, as a good forecast can save lives and property.<br>● There were cases of flash floods in site that were not detected by the FFGS and no warning was issued (misses). FFGS is useful as an additional tool, although there is the |

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| | need of weather radar for real time prediction.<br>● It is easy to support FFGS system. It is a reliable system. Most of their concern is physical machine, in case of power shortage, etc. Another primary concern is the provision of observational data from meteo-stations, and from numerical weather prediction.<br>● It is imperative to evaluate the system inputs (hydro-estimator and MAP product) before using the outputs (ASM, FFG and Threat products).<br>● Even if the system is not performing well, the system may still guide a forecaster: the information is there, it just may need to be adapted even if this is done mentally with local knowledge and experience.<br>● One country reported that their system does not do well with short-life intense systems or systems that contain clouds with warm cloud top temperatures or significant amounts of cirrus clouds.<br>● Training approach needs to be hands on, case study based. This has been the only way to get the forecasters to build confidence in using the system.<br>● A country reported that when developing a flood forecasting system it is very important to involve the local experts from the operational agencies, and that this was not done there. The system was not updated with local data and the NHS was not involved in the process, resulting in an inefficient tool.<br>● Before starting the project, it is better to find out what products are already in use in each country. Sometimes local agencies have already developed and are using other tools. *In fact, at the Initial Planning Meeting countries are asked to provide a presentation that provides these details as well as the main causes of flooding. It is not known by the reviewers if in all cases that presentation has been given or to what extent it has been taken into account.* |

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| | *However, considering all special cases is not feasible when a global system is being developed and implemented.*<br>● Every country is in different level of development regarding flood forecasting. The approach in this project was wrong because it did not consider this fact.<br>● The system has the ability to define clear and distinct responsibilities for the meteorological and the hydrological services.<br>● The FFGS presence in the region has contributed towards the redefinition of the hydrological warning process at some NHSs.<br>● An improved regional cooperation among hydrometeorological services has been observed.<br>● In one country where the system has been in use for a short time, it was experienced the importance of having real-time in situ data to incorporate to the products. In that particular case, weather stations have a delay of approximately 2 hours. On one occasion, there was significant rainfall in a sector where the threat products did not show high values. People who were in the place reported a rise in the levels of various rivers, after which an alert was issued. When the system finally received the precipitation data, the threat maps were updated, now showing much larger values.<br>● Based on a case in September 2017, of an extreme event at the Adriatic coast, where the FFGS predicted very precisely the location of possible flash floods, but the NWP model severely underestimated precipitation (ALADIN gave 40 mm/ 6h, and more than 100 mm fell were observed over a 1 hour period), the following lessons have been learned: (a) NWP models drive flood predictions, (b) the short lead time is the biggest constraint to issuing flash flood warnings, and c) NWP QPF should be post processed and adjusted by local expert knowledge when using the |

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| | FFGS. |
| **7. Level of Satisfaction & Areas of Improvement** | |
| Q7i. Average mark (0 to 4) of level of satisfaction with the FFGS, and number of answers | Moderate level of satisfaction: 2.5 |
| Q7ii. Main findings | FFGS products (but not only) are used to generate flash flood warnings, which then are used by Emergency managers to take actions, or media, public. FFGS products are not sent to users directly. |
| Q7iii. Main findings | NDMA's don’t receive direct FFGS products, but rather flash flood warnings, which are issued based on different sources including FFGS. |
| List of main areas of improvement | ● Data/ data management: taking into account all local data provided (DEM, soil data - Slovenia example), ability to switch to different precipitation products (use local QPE/QPF products within the system).<br>● Modelling approach: longer lead time, urban area flood forecasting, calibration/recalibration every several years (change of basins' properties due to land use change), update time needs to be done more regularly - less than 6 hours (preferably 1 hour).<br>● Final products/display: the new Map server is preferable as it will make the system much more user friendly, store FFGS products at forecaster's workstation.<br>● Dissemination: secondary communication link has to be considered in case of internet collapse; web services development.<br>● Training program. |
| List of suggestions on how to increase the benefits of the | ● Decrease the lag of time for latest available data to be processed by the system. |

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| system | ● Include the function of dynamic user adjustment into the web interface.<br>● Make past historical data available to FFGS users.<br>● To allow operate FFGS system at the national level by every NMHS so to avoid the political difference (in particular in South and Central Asia).<br>● Better communication with the local agencies that are responsible for flood forecasting and see what they really need (as done by EFAS, for example). *It is noted that this is usually done from the onset in the Initial Planning Meeting for a potential new system deployment.*<br>● FFGS system should be offered to the regional expert users to have higher level of control over it.<br>● The users should be able to include relevant data to the FFGS and fine-tune it by themselves.<br>● Extend QPF to 72 hours.<br>● Reduce scale of precipitation /legend intervals. *It is noted that this is already doable at country request.*<br>● Would like to download files into workstation.<br>● Download GIF image with better resolution. The image resolution is sufficient. *It is noted that today there are two different resolutions to choose for download. It was not specified the required resolutions.*<br>● Add political boundaries to map server.<br>● Adjust FFT. |
| List of alternate FF early warning systems | ● ERIC, ERICHA (EFAS products)<br>● HBV implemented for small mountainous catchments<br>● the Hydro model<br>● self-developments (Slovenian NMHS) |
| **8. Additional Information** | |
| | Some interviewees used this section to express their further requirements: |

- Additions to the system, concerning a forecast adapted to urban and peri-urban areas, drought related features for farmers and also for fishing, in order to properly supervise fishermen.
- In depth training programmes for the new FFGS products such as landslides and urban forecasts and to see if we can benefit a lot more with the map server interface.
- To get the information on the discharges that can cause flash floods.
- Rainfall - runoff model to get the information of total amount of discharge that can cause flash floods. Sediment model to calculate the total sediments on the water flow.
- An additional rainy season would be needed to make a case study and for the forecaster to become familiar with the FFGS products. Performing a validation study is also needed.

Some interviewees used this section to express opinions or in other ways:

- The system has been a great help in issuing flash flood warnings and has been a great additional tool to use in our country (we do not have another tool to do the same thing). The concern at the end of the day is that there are a number of times the system has not helped forecasters and they have lost the confidence in using the system. We do try and emphasise that like any NWP model the system may have good days and bad days so it is important to evaluate the system and then to make the necessary adjustments. We are struggling to regain the confidence of the forecasters. The hope is that with the new display system/map server the FFGS will be much more user friendly and perhaps forecasters will be more willing to use it as they can provide the disaster management with a

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| | much more detailed forecast with more detailed information about local areas that will be affected (which is something we need with the introduction of impact based forecasting).<br>● Itis believed that WMO has good will in trying to improve national flood forecasting system but the way it was done in this project missed the target. It is always better to work with local stakeholders and not only with consultants like HRC, who decided for us which hydrological model to use (the old Sacramento model), who just asked for data from users, never involving them in the process, the calibration and the output of the system, in spite of several claims about it.<br>● To be allowed more time to evaluate their system. It has only been in operation for a few months.<br>● The short duration of high water usually does not leave enough time for flood protection (which can never be "regular" but only "extraordinary"). Unfortunately, in most cases, flash floods did not cause any active measure of defense, but rather the repair the consequences of flooding. In this case, the most important are preventive measures to protect flood prone areas: accurate and timely assessments of the quantity and location of rainfall dynamics. |

**Appendix 4. Inception Report**



# Inception report:

# proposed approach to review the Flash Flood Guidance System (FFGS) with Global Coverage Project

# July 27, 2018

by

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## Overview

The purpose of this report is to 1) Assess the effectiveness, efficiency, impact, relevance and sustainability of the FFGS with the global coverage project, considering its achievements through the current regional and national projects particularly since the inception of the MoU in February 2009 and 2) Provide findings, conclusions and recommendations to the WMO Secretariat in order to assist in setting the future overall design for the implementation of flash flood forecasting and warning systems, also taking into consideration the new MoU being developed by the FFGS partners to promulgate its implementation.

These activities are in line with the Terms of Reference (TOR), Part A- FFGS -Review of the Flash Flood Guidance System (FFGS) with Global Coverage Project written by Dr. Paul Pilon, Chief of the Hydrological Forecasting and Water Resources Division (C/HFWR) in June 2018.

Our approach and the review process will be divided into 3 parts:

1 review of major documents pertaining to the FFGS including Steering Committee reports, training session reports, technical reports etc , produced by WMO, HRC, NOAA, or associated partners,
2 Interviews at selected site visits and interviews with two operational Regional Centers of the FFGS, possibly those hosted by TSMS and SAWS (RSMC-Pretoria) and some participating countries' NMHSs, NDMAs and stakeholdersas well as relevant stakeholders in WMO, Geneva.
3 A draft report will be submitted for review on September 30, to the WMO Secretariat's C/HWR, who will review and distribute it to the Presidents of CHy and CBS for their review. A period of 2 weeks is envisioned for this review, from October 1 to 15, 2018.Comments and suggestions from the review of the draft report will be considered and where appropriate incorporated in the preparation of the final report. A period of 2 weeks is envisioned to finalize the report, with submission to the C/HWR for final approval by October 31 2018

### Compliance with OECD DAC Principles for Evaluation of Development Assistance

The performance of Organizations involved in the FFGS Program will be assessed using the methodology developed by OECD which is based on the following criteria:

- relevance to underline the adequacy between the needs of the target groups and FFGS results
- effectiveness to compare achievements to objectives
- efficiency to measure if funding was best suited
- impact to determine the benefits produced all along FFGS life
- sustainability to evaluate how the benefits of the program will continue

## Background

Flash floods occur throughout the world, and the time thresholds vary across regions from minutes to several hours depending on land surface, geomorphological, and hydroclimatological characteristics of the region. However, for the majority of these areas there exists no formal process for flash flood warnings, and there is a lack of general capacity to develop effective warnings for these quick response events.

Recognizing that flash floods have a particularly disastrous impact on lives and properties of affected populations, the Fifteenth World Meteorological Congress had approved the implementation of a Flash Flood Guidance System (FFGS) project with global coverage that had been developed by the WMO Commission for Hydrology (CHy) jointly with the WMO Commission for Basic Systems (CBS) and in collaboration with the US National Weather Service (US NWS), the US Hydrologic Research Center (HRC) and United States Agency for International Development/Office of U.S. Federal Disaster Assistance (USAID/OFDA).

The implementation of the Flash Flood Guidance System with global coverage project has been implemented through a Memorandum of Understanding (MoU) for establishing a cooperative initiative among four organizations, namely, WMO, the HRC, US NOAA NWS and USAID/OFDA. This MoU came into effect on 25 February 2009, and was extended by mutual agreement for an additional five year period, and expired on 31 December 2017. Efforts are underway to develop a new MoU among the organizations to further enhance early warning capabilities for flash flooding. The WMO Flood Forecasting Initiative-Advisory Group (FFI-AG), established by Resolution 15 (CG-XVI), decided at its 3rd meeting, held in December 2017 that it was timely to undertake an independent external review of the FFGS activities.

### Needs

The first FFG System was developed in 2003. The Central America Flash Flood Guidance System (CAFFGS) became operational in 6 countries and continues to operate today. Since then the FFG system has expanded throughout the world and is running in some 60 countries. The FFGS was designed to provide the necessary products to support the development of warnings for flash floods from rainfall and snowmelt events through the use of remotely sensed precipitation (e.g., radar and satellite-based rainfall estimates) and hydrological models. To assess the threat of a local flash flood, the FFGS is designed to allow product adjustments based on forecaster experience with local conditions, incorporation of other information (e.g., Numerical Weather Prediction Model output) and any last minute local observations (e.g., non-traditional rain gauge data) or local observer reports. Recognizing that the FFG system is a diagnostic tool to be used with other data and tools by NMHS’s to provide warnings of flash flooding there has been many experiences and lessons learned through the 15 years of operations and expansion. It is the purpose of this Assessment to review experiences gained, and lessons learned, and to uncover the successes and challenges that have occurred in order to evaluate the system performance and the need to improve operation and sustainability of the system in the future.

As stated previously, the implementation of the FFG system is the result of a partnership between USAID/OFDA, NOAA National Weather Service, the WMO and the Hydrologic Research Center (HRC). The WMO program has been steered by the Hydrology Commission (CHY) and the Commission for Basic Systems. The Hydrology Secretariat has been the project Manager, providing the necessary coordination of all the organizations involved in the implementation of the system as well as overall system improvement, development and capacity building. There are many regional centers, country NMHS's and users that are involved in the successful operation of this end to end forecast and warning system designed to save lives and reduce economic losses.

There are many components of the system that must function properly from the acquisition and collection of data to the dissemination and delivery of warnings to the population at risk. And even if the warning arrives with adequate time and accuracy, the users must understand the contents of the warning, activate a measured response and take the necessary actions to reduce loss of lives & property. Is the system designed properly to deliver the necessary warning products and information needed?

Is warning lead time provided for response actions adequate and is the accuracy acceptable? Do the NMHS's understand the system and use it? Do the Disaster Managers, media and other users utilize the products and services? Is operating the system understood? Is training available and adequate? Do NMHS's have the capacity to use the system? Is it sustainable?

It is the purpose of this assessment to determine the value of the FFGS system and program in delivering warning guidance for flash floods in order to reduce flooding impact and losses to communities at risk.

**Proposed approach**

Because of the size of this effort and the many partners and players involved, this assessment involves surveying all the partners involved in the two categories 1) project development and implementation, and 2) FFGS operation and maintenance. The strategy will be to assess the various organizations & partners involved in implementation of the program. Various FFGS program documentation will be reviewed by the team such as Implementation plans, strategy documents, Steering committee reports, training sessions, HRC Work Plans, Project briefs, Workshop reports, the FFG System Implementation plan, summary reports, and the GFFG Program Stainability Action Plan.

Surveys and interviews will be conducted from key personnel involved with HRC, WMO, USAID/OFDA, and the NOAA National Weather Service. The Presidents and Vice Presidents of the WMO Commissions CHy and CBS will be interviewed as well as key personnel involved in the operational program in the Secretariat. Recognizing there are many Regional Centers and countries involved with operating FFGSs, the Assessment team will sample Regions and NMHS's that are both strong and in need of further support. Starting with the first FFGS in Central America (CAFFG), the El Salvador NMHS and Costa Rica Centers will be polled as well as the South Africa Weather Service (SAWS) Regional Center and a visit to the Turkish Meteorological Service (TMS) and associated country NMHS's linked to the regional centers. Finally the Central Asia FFGS will be interviewed starting with Kazakhstan. At the various NMHS's, both hydrologists and meteorologists will be interviewed. In addition in these designated regions, efforts are planned to survey key disaster management personnel and users to learn how or if the FFG products are being used?

Because the FFGS program overlaps with and integrates with the Severe Weather Development Program (SWFDP) and the Coastal Inundation Forecasting Demonstration project (CIFDP), the FFGS assessment team will interview the SWFDP and CIFDP Program managers and WMO staff to understand how FFGS inter-relates with these other two programs.

A Table reflecting team schedule of participation in the various interviews is attached.

## Proposed schedule and workplan

The proposed workplan by the FFGS Assessment team is to review all relevant FFGS documents during the period from July 15-August 15th. During this period, the team will finalize the surveys to be sent out to key experts and responsible persons connected with every facet of the FGG Program activities. Based on the agreed upon assignments of field trips, teleconference interviews, and key individuals to be surveyed (see attached table) , the team will send out surveys in early August and will schedule interviews throughout the month of August and some in early September . The current schedule of interviews and travel is included as a separate document and is constantly being adjusted now. It is anticipated that there will be difficulty in scheduling interviews in August due to vacations, coordination of travel by WMO and travel schedules. Thus, interviews may run through mid-September if needed. Each Organization designated to be interviewed has a primary FFGS team member responsible to coordinate scheduling of the call and/or arranging for obtaining needed data and reports. Notes from each interview will be produced and compiled by team members participating. Travel to the Turkey Meteorological Service is tentatively scheduled for early September by team members Yuri Simonov and Marcelo UriburuQuirno. Turkey is the Regional center for both the Black Sea and Middle East region as well as the Southeastern Europe region. The team will not only visit the regional center in Ankara but one team member will go to Romania or a SE Europe NMHS and the other will visit JORDAN or a NMHS in the Black Sea and Middle East Region. In addition to the field trip to the NMHS's, the team will schedule a trip to WMO in August or September to interview a number of key personal involved in FFGS, CIDFP and SWFDP programs, and to collect information and opinions of key representatives. The second trip to Geneva will be in October to present findings and recommendations of this Assessment. This includes technical individuals as well as WMO Management.

By mid-September, the team must complete all interviews, meetings and review of documents. The last two weeks of September will be involved in writing the report. The Outline of the report will be established by the end July and sent to WMO and program partners for review. Program and regional project efficiency and effectiveness will be provided, noting strengths and weaknesses, and proposing improved efficiency and effectiveness of any future projects, including future governance options and resource requirements for carrying out further development efforts and on-going operations in a sustainable manner. It will also provide an assessment of the benefits/need for establishing new, modified, or complementary approaches that could be taken in advancing the use of early warning systems for flash flooding. As per the Terms of Reference, the draft report will be sent to WMO C/HWR by September 30, 2018 for comments and feedback. WMO will review the document for two weeks and send the FFGS team the marked up document for finalization by October 15. Also, sometime during the period of time (October 1-15), the Secretariat will establish a date for meeting to brief WMO personnel, CHy AWG-2, and the CBS Management Group on the Report's findings, and recommendations. The FFGS team will produce a final report by October 31, 2018.

| WEEK | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FIRST DAY OF WEEK (MONDAY) | 02-07 | 09-07 | 16-07 | 23-07 | 30-07 | 06-08 | 13-08 | 20-08 | 27-08 | 03-09 | 10-09 | 17-09 | 24-09 | 01-10 | 08-10 | 15-10 | 22-10 | 29-10 |
| **ACTIVITIES** | | | | | | | | | | | | | | | | | | |
| Review FFGS documents | | | | | | | | | | | | | | | | | | |
| Send out surveys | | | | | | | | | | | | | | | | | | |
| Interviews | | | | | | | | | | | | | | | | | | |
| Preparation of outline of the report | | | | | | | | | | | | | | | | | | |
| Visits to Geneva | | | | | | | | | | | | | | | | | | |
| Writing of the report | | | | | | | | | | | | | | | | | | |
| **MILESTONES** | | | | | | | | | | | | | | | | | | |
| Submission of inception report | | | | # | | | | | | | | | | | | | | |
| Submission of outline of the report | | | | | | | & | | | | | | | | | | | |
| Submission of draft report | | | | | | | | | | | | | * | | | | | |
| Reception of reviewed report | | | | | | | | | | | | | | | | + | | |
| Submission of final report | | | | | | | | | | | | | | | | | | x |

## Team scheduled events Noted:

Curtis Barrett to FFGS Meeting at San Diego August 6-10

Yuri Simonov to WMO JCOMM meeting at Geneva August 20-26; to CHY AWG meeting at Geneva October 8-14

Marcelo UriburuQuirno to CHY AWG meeting at Geneva October 8-14.

## Appendix 5.Terms of Reference for the GFFG Assessment team

**JOINT REVIEW OF THE JCOMM/CHy COASTAL INUNDATION FORECASTING DEMONSTRATION PROJECT (CIFDP), CHy FLASH FLOOD GUIDANCE SYSTEM (FFGS) AND CBS SEVERE WEATHER FORECASTING DEMONSTRATION PROJECT (SWFDP)**

**Introduction**

The WMO Executive Council Working Group on Disaster Risk Reduction (EC-DRR) met in March 2018, and recommended a joint independent review of the three WMO activities:

- **Severe Weather Forecasting Demonstration Project (SWFDP)** supported by the Commission for Basic Systems (CBS);
- **Flash Flood Guidance System (FFGS)** supported by the Commission for Hydrology (CHy) and CBS; and
- **Coastal Inundation Forecasting Demonstration Project (CIFDP)** supported by the WMO/IOC Joint Technical Commission for Marine Meteorology and Oceanography (JCOMM) and CHy.

The objective of the joint review would be to emphasise how these projects have made a difference in the life of communities they served and on their training needs and sustainability as well as the importance of a national voice for the dissemination of warning information.

The EC-DRR WG also recommended that, following the review, a consolidated approach be developed jointly by the Presidents of CBS, CHy and co-President of JCOMM (WMO) to ensure that the SWFDP, CIFDP and FFGS ensure efficient implementation at both Secretariat and national/regional levels for sustainable service delivery related to hazardous weather, water and climate, without duplication of efforts.

Each of the activities will need an independent review to determine the status of each, prior to the joint review. The Terms of Reference for the independent reviews of each are considered ‘Part A’, and the Terms of Reference for the joint review ‘Part B’.

**TERMS OF REFERENCE - PART A - FFGS**

**REVIEW OF THE FLASH FLOOD GUIDANCE SYSTEM (FFGS) WITH GLOBAL COVERAGE PROJECT**

**TERMS OF REFERENCE**

**Background**

Flash floods are among the world’s deadliest natural disasters with more than 5,000 lives lost annually and result in significant social, economic and environmental impacts. Accounting for approximately 85% of the flooding cases, flash floods also have the highest mortality rate (defined as the number of deaths per number of people affected) among different classes of flooding (e.g., riverine, coastal).



Recognizing that flash floods have a particularly disastrous impact on lives and properties of affected populations, the Fifteenth World Meteorological Congress had approved the implementation of a Flash Flood Guidance System (FFGS) project with global coverage that had been developed by the WMO Commission for Hydrology (CHy) jointly with the WMO Commission for Basic Systems (CBS) and in collaboration with the US National Weather Service (US NWS), the US Hydrologic Research Center (HRC) and United States Agency for International Development/Office of U.S. Federal Disaster Assistance (USAID/OFDA).

Flash floods occur throughout the world, and the time thresholds vary across regions from minutes to several hours depending on land surface, geomorphological, and hydroclimatological characteristics of the region. However, for the majority of these areas there exists no formal process for flash flood warnings, there is a lack of general capacity to develop effective warnings for these quick response events.

A system such as the FFGS is an important tool necessary to provide operational forecasters and disaster management agencies with real-time informational guidance products pertaining to the threat of flash flooding on small basins. The FFGS is designed to provide the necessary products to support the development of warnings for flash floods from rainfall and snowmelt events through the use of remote sensed precipitation (e.g., radar and satellite-based rainfall estimates) and hydrological models. To assess the threat of a local flash flood, the FFGS is designed to allow product adjustments based on forecaster experience with local conditions, incorporation of other information (e.g., Numerical Weather Prediction output) and any last minute local observations (e.g., non-traditional rain gauge data) or local observer reports.

The implementation of the Flash Flood Guidance System with global coverage project has been implemented through a Memorandum of Understanding (MoU) for establishing a cooperative initiative among four organizations, namely, WMO, the HRC, US NWS and USAID/OFDA. This MoU came into effect on 25 February 2009, and was extended by mutual agreement for an additional five year period, and expired on 31 December 2017. Efforts are underway to develop a new MoU among the organizations to further enhance early warning capabilities for flash flooding. The WMO Flood Forecasting Initiative-Advisory Group (FFI-AG), established by Resolution 15 (CG-XVI), decided at its 3rd meeting, held in December 2017 that it was timely to undertake an independent external review of the FFGS activities.

**Objectives of the review**

(i) Assess the effectiveness, efficiency, impact, relevance and sustainability of the FFGS with global coverage project, considering its achievements through the current regional and national projects particularly since the inception of the MoU in February 2009.

(ii) Provide findings, conclusions and recommendations to the WMO Secretariat in order to assist in setting the future overall design for the implementation of flash flood forecasting and warning systems, also taking into consideration the new MoU being developed by the FFGS partners to promulgate its implementation.

The Terms of Reference for the review of the FFGS with global coverage project are:

(1) To review and comment on the current status and progress in the implementation of the FFGS with global coverage project, fulfilment of its objectives and its effectiveness in so doing;

(2) To examine, review and comment on the performance of completed activities (projects) and those under development based on available reports and interviews and discussions with relevant target group representatives, including aspects of the benefits and costs of projects undertaken. Although FFGS with global coverage project is intended to advance early warnings of flash floods in all countries, the review is to be conducted following the OECD DAC Principles for Evaluation of Development Assistance, focusing on relevance, efficiency, effectiveness, impact and sustainability:

(a) *Relevance*: The extent to which the FFGS with global coverage project is suited to the priorities and policies of the target group (is it serving the needs of its communities), including recipients and donors, considering the following questions: (i) To what extent are the objectives of the FFGS with global coverage project still valid? (ii) Are the activities and outputs of the FFGS with global coverage project consistent with the overall goal and the attainment of its objectives? (iii) Are the activities and outputs of the FFGS with global coverage project consistent with the intended impacts and effects?

(b) *Effectiveness:* A measure of the extent to which the FFGS with global coverage project attains its objectives, considering the following questions: (i) To what extent were the objectives of the initial MoU achieved / are likely to be achieved in its new formulation? (ii) What were the major factors influencing the achievement or non-achievement of the objectives?

(c) *Efficiency:* Efficiency measures the outputs -- qualitative and quantitative -- in relation to the inputs. It is an economic term which signifies that the programme uses the least costly resources possible in order to achieve the desired results. This generally requires comparing alternative approaches to achieving the same outputs, to see whether the most effective and efficient process has been adopted. When evaluating the efficiency of the FFGS with global coverage project work programme during its period of implementation, consider the following questions: (i) Was the work programme implementation carried out in a cost-efficient manner? (ii) Was the work programme an efficient way of translating the strategy operationally compared to alternative approaches? (iii) Are there alternative mechanisms or approaches that would allow attainment of the development and implementation of flash flood early warning systems for operational use in a more efficient and effective manner than through the FFGS with global coverage project?

(d) *Impact:* The changes produced by the FFGS with global coverage project, directly or indirectly, intended or unintended, considering the following question: (i) What has happened as a direct or indirect consequence of the implementation of the FFGS with global coverage project? (ii) What tangible change has the implementation of the activities of the FFGS with global coverage project made? (iii) This should include examples of the impact the FFGS with global coverage project has made particularly since inception of the MoU in 2009, and what might reasonably materialize over the coming decade.

(e) *Sustainability:* Sustainability is concerned with two aspects. The first is concerned with measuring whether the benefits of the activities are likely to continue. What were the major factors which influenced the achievement or non-achievement of sustainability of the programme or its specific projects, such as, for example, the creation and active participation of a growing number of early warning systems for flash floods? The second is concerned with the future sustainability of the initiative regarding how it should be reshaped and the need for human and financial resources for it to succeed (e.g., governance structure, system upgrades and maintenance, on-going training).

(3) Within this overall structure, the review will also include:

(a) Conclusions and recommendations with respect to the future directions of the FFGS with global coverage project, identifying remedial actions to enhance its development (both in terms of functionality and geographic coverage) and sustainability, and on the benefits and need for establishing new, modified, or complementary approaches that could be taken in advancing the concept of early warning systems for flash flooding;

(b) Suggestions for means of ensuring the efficient relationship of the FFGS with global coverage project with other relevant initiatives including the Severe Weather Forecast Demonstration Project (SWFDP) and the Coastal Inundation Forecast Demonstration Project (CIFDP) and other related international programmes to ensure delivery of efficient and effective sustainable services related to hazardous weather, climate and water, especially in light of the Sendai Framework as adopted at the Third United Nations (UN) World Conference on Disaster Risk Reduction (WCDRR), the Paris Agreement (within the framework of the United Nations Framework Convention on Climate Change - UNFCCC), and the 2030 Agenda for Sustainable Development;

(c) Suggestions to enhance the active participation and outreach of National Meteorological and Hydrological Services (NMHSs) and National Disaster Management Agencies (NDMAs) to increase benefits from use of early warning systems for flash flooding;

(d) Recommendations on a proposed governance model for the FFGS with global coverage project for advancing early warning systems for flash flooding, its suggested Terms of Reference and Composition, including mechanisms to improve coordination with NMHSs, NDMAs, donors and stakeholders;

(e) A review and comment on raising of extra-budgetary resources and make recommendations on how best this should be approached; and

(f) Any other related issues.

**Expected Outcomes:**

A review of the overall FFGS with global coverage project concept and its regional projects, with regards to efficiency and effectiveness, noting strengths and weaknesses, and proposing improved efficiency and effectiveness of any future projects, including future governance options and resource requirements for carrying out further development efforts and on-going operations in a sustainable manner. It will also provide an assessment of the benefits/need for establishing new, modified, or complementary approaches that could be taken in advancing the use of early warning systems for flash flooding. The results of the review are expected to be presented to the CHy Advisory Working

Group and CBS Management Group, in the form of one formal review report and presentation. The outcomes of the review shall be reported by the President of CHy, on behalf of the President of CBS, to the World Meteorological Congress-18 in 2019.



**Review Mechanism**

The Lead Reviewers will:

(1) Devise relevant questions and overall approaches for the review;
(2) Draw on the various available WMO FFI, FFI-AG and FFGS-related reports;
(3) Hold consultative meetings using electronic means with experts, such as but not limited to the Presidents of the WMO Technical Commissions for Hydrology (CHy) and Basic Systems (CBS), select NDMAs, NMHSs and Regional Centers of the FFGS, a selection of experts from participating countries using the FFGS, the WMO Secretariat, Hydrologic Research Center, US National Weather Service and USAID/OFDA, as required;
(4) Undertake visits to the WMO Secretariat (WMO Headquarters in Geneva), as appropriate;
(5) Review the reports of the various FFGS Project Steering Committee meetings and training sessions;
(6) Conduct site visits and interviews with at least two operational Regional Centers of the FFGS, possibly those hosted by TSMS and SAWS (RSMC-Pretoria) and some participating countries' NMHSs, NDMAs and stakeholders;
(7) Provide presentations and briefings on their review to the CHy AWG-3 to be held October 8-12, 2018 in Geneva and the CBS Management Group.

**Implementation**

The envisaged phases required to complete the assignment are described below.

*Timeline*: The review will be carried out over a period of approximately 4 months, commencing 1 July 2018, to be completed with the delivery of the Final Report at the latest by 31 October 2018.

*Inception*: An initial period of approximately 1 week is suggested for the inception phase concluding with the submission of an "inception report" to the Chief, Hydrological Forecasting and Water Resources Division (C/HFWR). The inception report will include an overview of how the review will be carried out, including a description of the baseline assumptions and the detailed methodology that will be applied to achieve the review objectives.

*Report drafting*: Data collection will be carried out through both electronic means (telephone, skype, email, etc.) and in-person interviews, as noted above, in close collaboration with the WMO Secretariat. Approximately 11 weeks are foreseen for this step.

*Review of Draft report*: A draft report will be submitted for review on September 30, to the WMO Secretariat's C/HWR, who will review and distribute it to the Presidents of CHy and CBS for their review. A period of 2 weeks is envisioned for this review, from October 1 to 15, 2018.

*Briefing by the Consultants*: The reviewers will brief the WMO Secretariat and Presidents about the draft Report and hear feedback from them on completion of their review. Estimated date for completion of briefings is by 15 October 2018.

*Finalise report*: Comments and suggestions from the review of the draft report will be considered and where appropriate incorporated in the preparation of the final report. A period of 2 weeks is envisioned to finalise the report, with submission to the C/HWR for final approval by October 31 2018.



**Timeline (30 days maximum over 4 months per reviewer)**

| **Phase** | **Week** | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *1* | *2* | *3* | *4* | *5* | *6* | *7* | *8* | *9* | *10* | *11* | *12* | *13* | *14* | *15* | *16* | *17* |
| Inception | ⧫ | | | | | | | | | | | | | | | | |
| Report drafting | | | | | | | | | | | | ○ | ○ | | | | |
| WMO Sec and Presidents CHy and CBS (WMO) review draft report | | | | | | | | | | | | | | | | | |
| Consultants brief WMO and Presidents CHy and CBS (WMO) | | | | | | | | | | | | | | | | | |
| Finalise Report (including review comments) | | | | | | | | | | | | | | | | | |
| Submit Final report | | | | | | | | | | | | | | | | | ● |

Deliverables: ⧫ Inception report

○ Draft report

● Final Report

1 July to 30 September - overall review.

End September - submit to WMO Secretariat

1- 15 October - WMO Secretariat and Presidents (CHy and CBS) to review

15 October- Consultants to brief WMO Secretariat and Presidents (CHy and CBS)

15 to 31 October - Consultants to finalise report

October 31 - Consultants to submit Final FFGS Part A Report to WMO

**Required Expertise**

The three selected Reviewers will have professional qualifications in flood modelling and early warning system management and development. In addition, the Reviewers should have the following qualifications:

(a) Demonstrated experience in planning, overseeing or implementing efforts to forecast flooding and issue warnings, with particular advantage for those having experience in flash flood forecasting and warnings;
(b) Experience in assignments conducting evaluations possibly of a similar nature;
(c) Knowledge of international and national organizations working in early warnings of flooding; and
(d) People who can independently and without bias conduct the review.

**Estimated Time Allocation**

The Reviewers will be engaged over the full assessment period for part A of approximately 4 months. It is estimated that approximately 30 person-days will be required per Reviewer to complete the assignment.

The Reviewers will decide as a team on how best to most effectively and efficiently allocate their time and focus their expertise and skills to fulfil the Terms of Reference of Part A.