PROSPECTUS

IMPLEMENTATION OF A

FLASH FLOOD GUIDANCE SYSTEM

WITH GLOBAL COVERAGE

A JOINT PROPOSAL BY

WMO COMMISSION FOR HYDROLOGY
AND
WMO COMMISSION FOR BASIC SYSTEMS

IN COLLABORATION WITH

HYDROLOGIC RESEARCH CENTER
U.S. NATIONAL WEATHER SERVICE
U.S. AGENCY FOR INTERNATIONAL DEVELOPMENT/OFFICE OF FOREIGN DISASTER ASSISTANCE

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Program Overview

Introduction

Everyone is aware of devastation caused by flash floods. On the average, these events kill more people worldwide than any other natural disaster – in an average year, flash floods kill over 5,000 unsuspecting people and cause millions of dollars of property damage. Recent flash flood occurrences in Central and Southeast Asia have shown the impacts that can be caused by these events. For many countries, access to flash flood early warning technologies is not available because of human and financial resource limitations – often, these are the countries most at risk. However, the capability to implement an effective warning system throughout the world exists and, once implemented, will provide the tool for these countries to warn people at risk.

The Hydrologic Research Center (HRC), a non-profit public benefit corporation located in San Diego, California USA has developed a concept for the implementation of a Flash Flood Guidance System with Global Coverage (GFFG) that can be used as a diagnostic tool by National Meteorological and Hydrologic Services (NMHS) and disaster management agencies worldwide to develop warnings for flash floods. The purpose behind this initiative is to improve the world wide response by federal, state, and local governments, international organizations, non-governmental organizations, the private sector, and the public to the occurrence of flash floods. **This system is designed to be incorporated into NMHS operations and used along with other available data, systems, tools, and local knowledge to aid in determining the near-term risk of a flash flood in small streams and basins.** The system can be used in its real-time mode or in a forecast mode when outputs are used along with NWP precipitation forecasts.

This initiative is consistent with recent findings of the WMO where of the 139 countries responding to the WMO country-level disaster prevention and mitigation survey, 105 indicated that **flash floods** were among the top two most important hazards around the world and require special attention. This initiative will include the implementation of the technical tool as well as development and implementation of appropriate operational protocols and training.

The topic of world-wide flash flood guidance systems was raised at the *International Workshop on Flash Flood Forecasting* held in San Jose, Costa Rica from 13-17 March 2006. This workshop was organized by the World Meteorological Organization (WMO) and the U.S. National Oceanic and Atmospheric Administration/National Weather Service (NWS). During the workshop both the WMO and NWS indicated the strong need for global, remote sensing-based solutions to the flash flood problems throughout the world, especially for helping to resolve these issues in third world and developing countries. The implementation of this system addresses this need.

WMO has indicated that early warning systems must be supported by strong governance and organizational coordination mechanisms. This is necessary to ensure that warnings are developed and the messages are understandable and disseminated to those at risk and those that have the responsibility to take action in a timely fashion to ensure safety of lives, livelihoods and property. Under the crosscutting framework of the WMO Natural Disaster Prevention and Mitigation Programme (DPM), which spans all WMO structures including Programmes, technical commissions and the regional associations, the Executive Council Advisory Committee on DPM had recognized that there was need to demonstrate the benefits of multi-disciplinary approach and coordination among relevant WMO Programmes, as well as to work with other partners such as the civil protection agencies and disaster management authorities in the countries as well as regional and international agencies involved in disaster risk reduction. This program, through design and implementation of its technical applications and protocol development ensures that these WMO initiatives are addressed and met.

Background

HRC has implemented this flash flood guidance system on a regional scale in Central America through a project funded by the U.S. Agency for International Development/Office of Foreign Disaster Assistance (USAID/OFDA) and in collaboration with NWS. The system implemented in Central America is known as the Central America Flash Flood Guidance system or CAFFG. CAFFG is currently operational for each of the seven countries in the Central America region. The system is available to the meteorological and hydrologic services in the region to be used as a diagnostic tool to analyze weather-related events that can initiate flash floods (e.g., heavy rainfall, rainfall on saturated soils) and then to make a rapid evaluation of the potential for a flash flood at a location. The CAFFG system is designed to allow the forecaster to add his/her experience with local conditions, incorporate other data and information (e.g., NWP output) and any last minute local observations (e.g., non-traditional gauge data), to assess the threat of a local flash flood. Evaluations of the threat of flash flooding are done over hourly to six-hourly time scales for basins from 100-300 km^2 in size. Satellite precipitation estimates are used together with available regional in-situ precipitation gauge data to obtain bias-corrected estimates of current rainfall volume over the region. These precipitation data are also used to update soil moisture estimates.

Important technical elements of the flash flood guidance system is the development and use of a bias-corrected satellite precipitation estimate field and the use of physically-based hydrologic modeling to determine flash flood guidance and flash flood threat. These system elements can now be applied anywhere in the world. Real-time estimates of high resolution precipitation data from satellite are now routinely available globally. Global digital terrain elevation databases and geographic information systems may be used to delineate small basins and their stream network topology anywhere in the world. In addition, there are global soils and land cover spatial databases available to support the development of physically-based soil moisture accounting models. With these global data and information, the CAFFG system model can be implemented anywhere.

It is possible to establish one or more Data, Communications, and Data Analyses Centers that will process the existing historical and near real-time data and information to produce estimates of flash flood guidance and flash flood threat – parameters which can be used to develop flash flood warnings. These Centers can be linked to a network of Regional Centers throughout the world through global communications networks that can then disseminate the information to NMHSs in countries with no or poor local flash flood warning capability. These national services would then produce flash flood warnings using the data and information disseminated from the centers plus any other local data and information readily available to them.

The implementation will also be a mechanism for capacity building for NMHSs as well as national disaster management services. Through the development of the technical tool, development of protocols and implementation of centers, training and capacity building will be provided on use of the data and products for effective mitigation and response to flash flood threats world wide.

Need for a Global Implementation of a Flash Flood Guidance System

There is a strong need for the implementation of a flash flood guidance system globally. Very few local human-machine systems are available throughout the world to provide early warning against these devastating events and many such systems that are implemented provide no significant early warning for these disasters. Local monitoring uses on site sensors that are expensive to implement, require frequent maintenance, do not fully cover the areas that are flash flood prone (e.g., mountainous areas), and may have imposed data restrictions for regional use. Very few regional flash flood guidance systems are being deployed using remotely sensed data, surveying large areas (hundreds of thousands of kilometers) with very high resolution (order of one hundred square kilometers), and with good performance with respect to threat detection against false warnings.

Presently, vast flash flood prone areas remain without any surveillance with unmitigated threat for millions of people worldwide.

Benefits of a Global Implementation of a Flash Flood Guidance System

A key benefit of the flash flood guidance system is providing early awareness of impending local flash flood threats for all potentially vulnerable world communities. A true value of the system will be to provide rapid assessments of the potential of flash floods allowing world-wide improvement of the early warnings for the occurrence of a flash flood and therefore allowing for the more rapid mobilization of response agencies.

The system implementation also provides global capacity building and cooperation for effectively mitigating disasters from flash floods. Training and capacity building will be a strong component of the implementation of this program. There will be opportunities in cross-training of hydrologists and meteorologists from different countries and with different backgrounds and skills in the science of hydrometeorology, which forms the basis of flash flood detection and prediction. The availability of the system guidance products will emphasize the regional (cross-border) nature of many flooding events, encouraging international cooperation in preparing public awareness campaigns and response strategies.

The implementation will include the development of a global infrastructure allowing for the generation and dissemination of real time data and products. This infrastructure may also host other global products pertaining to disaster mitigation and response. Products will be developed useful for delineating high risk flood areas globally to effectively plan future development. Soil water information is also a by-product of the flash flood guidance system operation. This output may be a source of valuable information to complement other such products in the region for agricultural use.

Link with Disaster Risk Reduction

During the implementation of the flash flood guidance system program, partnerships will be sought with agencies such as the International Federation of Red Cross and Red Crescent Societies, and its regional offices, the United Nations Office for the Coordination of Humanitarian Affairs (UN/OCHA) and its regional offices, regional inter-governmental agencies with membership represented by disaster risk management authorities and ministries to develop a joint strategy and concrete action for implementation of the Flash Flood Guidance System in a particular region. Through these initiatives, the objective is to bring partners representing the technical aspects of the system implementation and operation together with agencies in disaster risk reduction to develop a detailed work plan that will enable operational engagement of technical and disaster risk reduction agencies for implementation of the system.

The work plan for disaster risk reduction will address activities such as joint training programs and public outreach and awareness programs. This effort will provide the opportunity for enhancement of regional and global collaboration of disaster risk management agencies and improvement of community awareness of flash flood disaster threat and mitigation. Training programs will be designed to include NMHSs and the disaster management agencies. All these agencies will be involved in system validation programs which will require determinations of where flooding did or did not occur. Responsible national agencies (NMHSs and disaster management) will be establishing criteria for issuing warnings based on flash-flood guidance and flash flood threat.

The flash flood system functions at one level as a disaster mitigation tool by mitigating loss of life and injuries, and by rapidly targeting disaster response agencies to potential problem areas. On another level it can be used to provide maps of flash flood probabilities. These maps can be used to provide guidance concerning the development of infrastructure – that is, as a guide to where special care should be taken in the design and siting of particular facilities or housing as the population expands to encroach flood prone areas.

Operations, Validation/Reliability and System Sustainability

Operations of the flash flood guidance system are an inherently governmental responsibility. It is imperative that, during implementation and operation of this program, strong collaborations between NMHSs and disaster management agencies be developed and maintained so that the system becomes a necessary tool in managing flash floods. The system will be designed to become an integral part of disaster management and risk reduction operations. This will help to ensure that that political will is obtained to maintain and sustain this system.

An appropriate concept for the operations of the system within the operations of the centers and countries will be developed during implementation. These operation concepts will be based on country–specific needs and requirements and will include requirements for system operations and evaluations of reliability. One key to sustainability is confidence in a reliable, accurate system. To accomplish this, reliability evaluations will be included in the concept of operations.

Training Approach

NMHS representatives and Regional Center staff require training to use, manage, and interpret output from the GFFG system, and to alert response agencies and the public of an impending or existing threat. The over-arching goal of the training is for NMHS representatives to interpret system output and warn response agencies and the public in a timely, organized manner that saves lives. This training will not be limited to the technology transfer portion of the GFFG implementation but will also encompass follow-up training during operations to ensure continued, appropriate use of the system in the operational environment.

The training philosophy incorporates cooperative development, authentic instruction, and other standard elements and methods of modern teaching theory in a learner centered strategy that is adapted to meet the needs of each country and its unique geography, communications infrastructure, and people. The training will simulate the operational environment where each trainee can experience a realistic representation of the system design, features, and controls. The training format will minimize reliance on lectures and manuals while maximizing active learning through web exercises, video-based group collaboration classrooms, and hands-on activities. Training will be organized around and focused on the regional center representatives who will become the educators. Initial trainees will ultimately conduct the training of NMHS representatives using the training techniques developed with the GFFG. Thus, the capacity to operate independently is built from within each region. Training programs will not be solely for the NMHSs but will include users as well such as disaster management organizations.

Funding

It is expected that government agencies and philanthropic donors will bear the cost of system development, implementation (including operational remotely sensed data availability and training) and operation. HRC will coordinate the funding efforts and evaluate the viability of various presentations and workshops organized in collaboration with partner agencies to allow enhanced visibility of the concept for potential donor foundations, organizations, and individuals.

Technical Overview

The following presents a more detailed technical overview of the proposed GFFG implementation addressing specific areas of the design and implementation.

System Concept

The GFFG 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.

This system has the capability to indicate 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** (Figure 1).

Catchment Flash Flood Guidance **Catchment Flash Flood Threat**

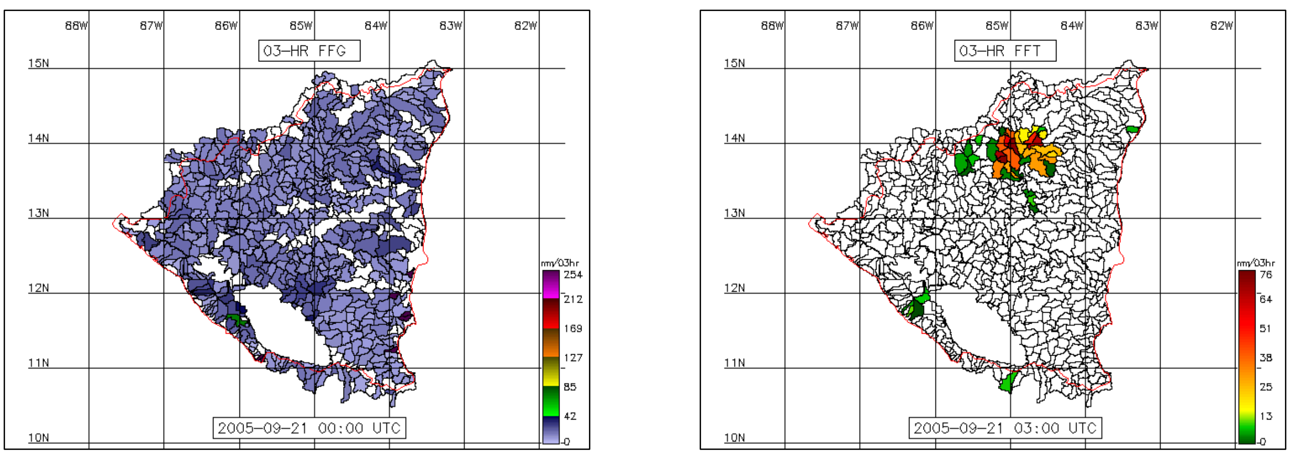

Figure 1: Sample graphical system output for Nicaragua from the CAFFG System.

The Central America Flash Flood Guidance System (CAFFG,a regional flash flood guidance system) has been in operation since 2004. It was designed by HRC in collaboration with NWS and USAID/OFDA along the same lines as the proposed global-coverage system. Two validation case studies have been made in association with CAFFG pertaining to the estimation of the probability of correct detection of flash floods versus the probability for false alarms. The first study involved the stream-gauged watershed of 400sq.km. Chagres River in Panama and it used only in-situ gauge information from four gauges in and near the basin. The aim of this study was to provide validation for the computational component associated with the hydrologic models used by CAFFG for a 6 hour operation. The result of runs that span more than 20 years gave an estimate of the probability of detection equal to 0.83 with a probability of false warning less than 0.1. The second study was performed in association with the NMHSs in the region and it involved the daily contact of local agencies (media, response agencies, etc.) for areas for which CAFFG indicated likelihood of flooding (performance conditional on having issued a warning). The warnings in this case included the local adjustments by hydrologists and meteorologists for El Salvador and Costa Rica and they pertain to a 3 hour lead time. The results for the entire Central America region (contain both locally-adjusted and unadjusted guidance) show a frequency of detection of 57%, a frequency of false alarm of 30% and a frequency of a miss of 13%. For Costa Rica, the results show a frequency of detection of 100% with 0% probability of false alarm and miss. For El Salvador, they show a frequency of detection of 63%, a frequency of false alarm of 21%, and a frequency of a miss of 16%. These results clearly indicate that local adjustments improve the performance of the warning service.

The system allows the NMHSs to use whatever local nowcast/short-term-forecast method they wish to use to issue the warnings, including (and recommended) local forecaster adjustments. System design allows this coupling with the existing or developing NMHS approaches on a national or even local scale. Flash flood warning protocols are not available for most of the world's countries (emphasis on flash flooding on small basins) and they are very different from other flood protocols or from protocols for severe events. This is a true hydrometeorological phenomenon that requires (a) integration of meteorology and hydrology in real time and (b) infusion of local information and expertise, for reliable warnings. System design aims to allow for both. This system will serve as a catalyst to develop protocols in line with regional and country norms pertaining to other event warnings. It may not be feasible to have a unified approach for all the regions (other than uniformity of interpretation of the system products ascertained by training). CAFFG showed that even within a region different countries will develop their own manner of system use as a tool for developing flash flood warnings and watches together with other local timely information. System flexibility and system capability to engage local forecasters should help greatly toward the development of regional/local protocols for integration within existing warning dissemination systems.

The system will provide evaluations for the threat of flash flooding over time scales of hourly to six hours and for basins 100-300 sq. km – as does the CAFFG system. Given the computational burden and depending on available computational resources, it is very likely that the most valuable lead times for system use will be 3 - 6 hours. This does not mean that the system will miss shorter term events necessarily, but it means that the forecaster will forecast potential flash flooding within the interval from 0 to the next 3 hours. Since updates of system status will happen continuously, no time interval will be missed. The average envisioned basin area covered for flash flood prone basins is 200 sq. km. with typical response times of greater than 3 hours.

System design is based on research and development over a period of more than 15 years (see section on documentation at the end of this document).

Proposed GFFG Program

Global Network

The operational functions of the global network of regional systems are as follows:

- **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

The Regional Centers, placed at selected NMHSs throughout the world, will be critical to successful operations. These centers will be performing the operational functions noted above and also be the focus of regional training programs. In addition to the primary concern for telecommunications and regional administration at the Regional Centers, the configuration of these centers will take into consideration regional homogeneity in hydrometeorological and geomorphological characteristics to the extent possible. Regions will be identified in collaboration with WMO.

Locations of the Data, Communications, and Data Analyses Center(s) will be based on the need to access and process global data and to be able to access global communication systems for the dissemination of system products and data. These centers would be the sources of global real time data (satellite and in-situ) and processing power for system guidance computations. The regional centers would receive such data and would disseminate it to individual countries together with additional regional guidance on severe storms or 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.

Data Communications Systems

The existence of the GTS and its most recent advancement, the WMO Information System (WIS), are of paramount importance for the GFFG as it is a natural and fitting choice for the acquisition of observations and for the transmission of flash flood related hydrometeorological information (GFFG data and products, etc.). The WIS network infrastructure will be critical in the ultimate location of the Data, Communications, and Data Analyses Center(s) and, to some degree the Regional Centers. To the extent possible, the WIS will be used to transmit information to the NMHSs through the existing WMO telecommunication networks.

WMO's approval of the incorporation of GFFG data and information within the WIS will minimize costs for development and maintenance. It is also envisioned that, in addition to the WIS, use of the internet will be made for less time and content sensitive information. This will be in line with the on-going world wide transition of the WMO telecommunications from a GTS-exclusive to a combination of GTS – Internet environment, and the use of Transmission Control Protocol/Internet Protocol (TCP/IP).

The system is designed to transmit minimal text information for use locally in a range of software from GIS to spreadsheets so that forecasters can make valuable adjustments as discussed earlier locally with minimal information transfer through the communication networks.

Implementation Approach

A phased implementation approach is planned, limiting each phase to a series of regional implementations. Phasing would involve development of capabilities of one or more Data, Communications, and Data Analyses Center(s) (or a surrogate) and then full implementations for the regions, perhaps as many as four at a time. The first phase implementations will be pilot programs designed to refine the implementation process for future regions. HRC will perform all implementations and will coordinate system testing and evaluation in collaboration with the Regional Centers. HRC will work with WMO in defining priority regions for implementation. Once the GFFG is completely operational, HRC expects to relinquish operations to government agencies as this is an inherently governmental responsibility.

Implementation of the GFFG is expected to occur under the auspices of the WMO in a manner consistent with the *WMO Flood Forecasting Initiative – Strategy and Action Plan for the Enhancement of*

Cooperation Between National Meteorological and Hydrological Services for Improved Flood Forecasting (8 January 2007).

Implementation components for each complete regional system include:

- **Implement a computational system for flash flood guidance and flash flood threat** (at the Data, Communications, and Data Analyses Centers) – Technical resources are required to maintain a computational system that supports a data base containing historical and static data, operates a model for estimating flash-flood thresholds, tracks soil moisture, displays data and information, ingests real time rainfall and other data, and disseminates products to the NMHSs.

- **Develop protocols for guidance dissemination** (at the Regional Centers and Countries) – Protocols for flash-flood guidance/threat dissemination will be developed.

- **Provide training** (at the Regional Centers and Countries) – Training and system documentation will be key elements of a sustainable system.

- **Provide hardware** (at all centers and countries) – Hardware needs at Regional Centers and countries are expected to be minimal, and will be provided as needed for developing nations.

Development and testing for the system computational component that generates the flash flood guidance information is global in nature. Development of the remaining operational regional and local components of the system, including training and assistance for operational protocol development for flash flood warnings using/modifying the guidance, is on a region-by-region basis. After development, HRC together with one or more regional centers would operate the computational component through an initial transition period of approximately two years to trouble shoot and test the computational component and its links to regional and national components. After that, HRC would transfer the computational component hardware and software to one or more of the Data, Communications, and Data Analyses Centers and would perform necessary training activities for data ingest and troubleshooting operations to transition the system computational component to full operational status (expect approximately one year for such a transition). Regional centers are expected to be populated by representatives from NMHSs in the region, possibly on a rotating basis as appropriate. The composition and population of the regional centers will be developed through collaboration of the individual NMHSs in the region, regional agencies and WMO. NMHSs will be assisted in developing flash flood warning protocols that are appropriate for their region and mode of operation, as well as by their particular links to within-country disaster management agencies. Responsibilities for global data ingest and computational component maintenance and operation lies with the Data, Communications, and Data Analyses Center(s). Responsibility for regional information (e.g., highlighting particularly vulnerable areas within the region), training and regional coordination of flash flood warning operations, as well as regional system validation lies with the regional centers. Responsibility for warnings and disaster preparedness as well as coordination with disaster management/response agencies lies with the country.

Once operational, system short term improvements are enacted at the regional/national level where, on the basis of two or more years of operation (when there is enough of a regional database for validation), local system biases are determined and are used by the local adjustment process (either of the meteorological nowcasts/short-term-forecasts or of the flash flood guidance estimates).

System design and implementation allows for these adjustments and initial action will be to simply implement simple bias correction rules based on the local ability for adjustments. A second validation after a few years should determine whether such forecaster adjustments indeed improve performance. If they do, then any biases on the computation of the flash flood guidance may be corrected by changes in the parametric files of the soil/channel models of the computational component of the system, enacted at the appropriate Data, Communications, and Data Analyses Center(s). Protocols for formal requests for changes and the process for enacting such changes at the site of the computational component will be defined during system implementation. It is noted that the system does not contain computational components for the nowcast or prediction of short term precipitation, other than a simple persistence computation, and, as such, any biases identified that are associated with meteorological nowcasts and short term forecasts would be fed back to the regional and local meteorological services for consideration in their efforts for improvement of their nowcasting and mesoscale forecasting ability.

The system requires the ingest of in-situ precipitation gauge data in order to adjust biases of the satellite-based precipitation estimates. Since the density of these gauge networks vary throughout the world, the system integrates data uncertainty as part of the computations for reliability. Thus the smaller the density of the data the higher the uncertainty in the estimated precipitation amounts and in the flash flood guidance values. So flash flood guidance values will have high uncertainty where the density is low and lower uncertainty when the density is high for true reliability. However, it is important to recall that the system operator/forecaster evaluates the likelihood of flash flood occurrence not any deterministic quantity. However, to keep bias differences to a minimum, the satellite-based precipitation approach uses modern methods of adaptive filtering that tracks changes of bias in real time.
