# FlaFloM – an early warning system for flash floods in Egypt

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## Abstract

The Flash Flood Manager project (acronym "FlaFloM, co-funded by the EU under the LIFE Third Countries Fund) is aimed at developing an early warning system for forecasting flash floods in the Wadi Watier catchment, located in the Sinai Peninsula (Egypt). The system consists of a number of components, which are automatically activated and linked: a rainfall forecasting model (Weather Research and Forecast model), a hydrological model (custom-built to reflect arid region conditions), a hydraulic model (InfoWorks-RS) and a warning module (FloodWorks). Forecasts have a lead time of up to 48 hours. The system is currently in an operational testing phase. This paper provides a brief overview of the early warning system and addresses a number of challenges related to the development and calibration of the hydraulic model, as well as the definition of threshold levels in the warning module.
*Keywords: flash floods, forecasting, early warning system, emergency system.*

## 1 Introduction

Flash floods frequently occur in the Sinai Peninsula (Egypt). They often result in damage to infrastructure, loss of life, erosion and pollution of the coastal environment. As recently as January 2010, significant flash floods occurred throughout the area, resulting in the death of at least 5 people.

The US National Weather Service Weather Forecast Office defines a flash flood as "A flood caused by heavy or excessive rainfall in a short period of time, generally less than 6 hours. Flash floods are usually characterized by raging

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torrents after heavy rains that rip through river beds, urban streets, or mountain canyons sweeping everything before them. They can occur within minutes or a few hours of excessive rainfall. They can also occur even if no rain has fallen, for instance after a levee or dam has failed, or after a sudden release of water by a debris or ice jam" [1]. This definition reveals why flash floods can be so lethal: the very short lead time between the rain that causes the flood and the flood itself, makes it very difficult to issue warnings or to take safety measures, once the rain has started. The safest option is to try and forecast the possibility of a flash flood long before it actually occurs, enabling precautionary measures (such as closing an area to traffic) to be taken well in advance.

The Flash Flood Manager project (acronym "FlaFloM) aimed at developing an early warning system for forecasting flash floods in the Wadi Watier catchment. To the best of the authors' knowledge, it is the first of its kind in the Arab world and the entire Nile basin.

## 2 Study area

The Wadi Watier catchment is located in the south-eastern part of the Sinai Peninsula, near the Gulf of Aqaba, as shown in figure 1.

The catchment occupies an area of 3580 km$^2$. It is characterized by steep hills (rising up to 1600 m above sea level), intersected by dry river beds, known as wadis. The hills mainly consist of impermeable rock, whereas the river beds are filled with a highly permeable mixture of gravel and sand. The climate is hyper-arid (UNEP aridity index < 0.05). The average annual rainfall ranges from

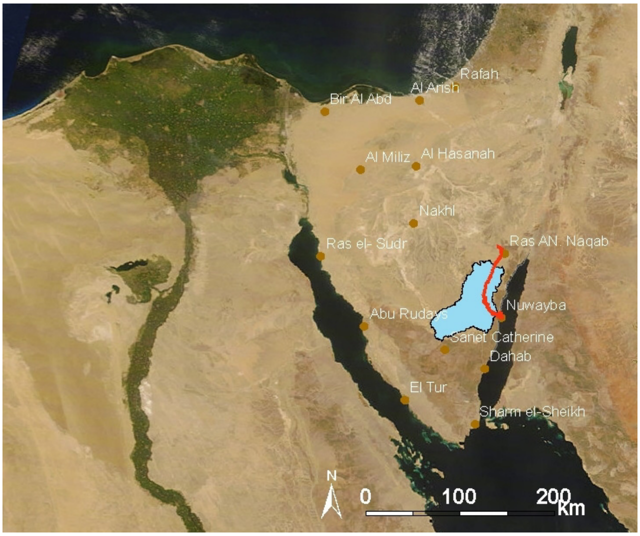


Figure 1: Location of the study area (light area) and the international road (dark line).

10 mm in the low coastal areas to 50 mm in the high inland areas. Severe storms, accompanied by flash floods, occur on the average every 2 to 3 years.

The main wadi (wadi Watier) runs from the north to the south and discharges into the Gulf of Aqaba near the city of Nuweiba. An international road, connecting Ras El-Naqb to Nuweiba, runs through this wadi. Two Bedouin villages are located along major wadis: Sheikh Atia in the north and Ain-Um-Ahmed in the south. At Nuweiba, flood diversion dikes have been constructed to protect the city from flooding. In the upstream parts of the catchment, five small dams (up to 11 m in height) have been constructed to create storage reservoirs.

## 3 Early warning system

The early warning system consists of a number of components, which are automatically activated and linked. These components are shown in figure 2.

A rainfall forecasting model is used to produce spatially distributed rainfall forecasts from meteorological data. The rainfall data are subsequently transformed into spatially averaged catchment rainfall for each subcatchment in the study area. The subcatchment rainfall serves as input for a hydrological model, which predicts subcatchment runoff. The runoff is used as input for a hydraulic model. The hydraulic model predicts the discharge in the main wadis and the water levels in the storage reservoirs. The warning system interprets all forecasts and issues a warning, whenever necessary.

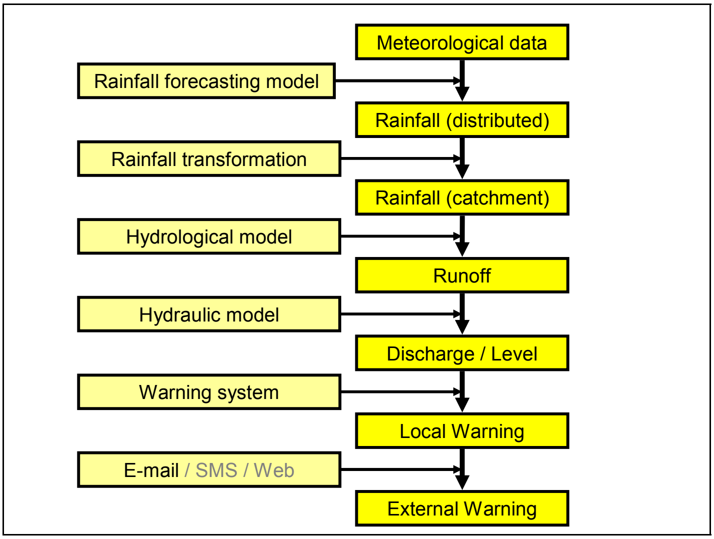


Figure 2: Early warning system components.

## 4 Rainfall forecasting

Rainfall forecasts are based on near real time meteorological data. These data are downloaded from the Research Data Archive, maintained by the Computational and Information Systems Laboratory at the National Center for Atmospheric Research (US). More specifically, the NECP final Operational Global Analysis data (contained in dataset 083.2) are used. The meteorological data are produced by the Global Forecast System, which is run four times a day in near real time. Every morning, the datasets spanning the last 24 hours are downloaded.

Rainfall forecasts are produced by means of the Weather Research and Forecasting model (WRF, Skamarock et al. [2]). Every day, a rainfall forecast for the next 48 hours is prepared.

The rainfall forecasts produced by the WRF model consist of a series of spatially distributed rainfall grids. An example of such a grid is shown in figure 3. A rainfall transformation program converts these grids into time series containing spatially averaged rainfall for all subcatchments in the study area.

For a full description of the rainfall forecasting and transformation process, the reader is referred to [3, 4].

## 5 Hydrological model

Arid zones exhibit distinct hydrological characteristics. An elaborate discussion of these characteristics and their implications for rainfall-runoff modelling can be found in Pilgrim et al. [5]. Because of these distinct features, many commercially

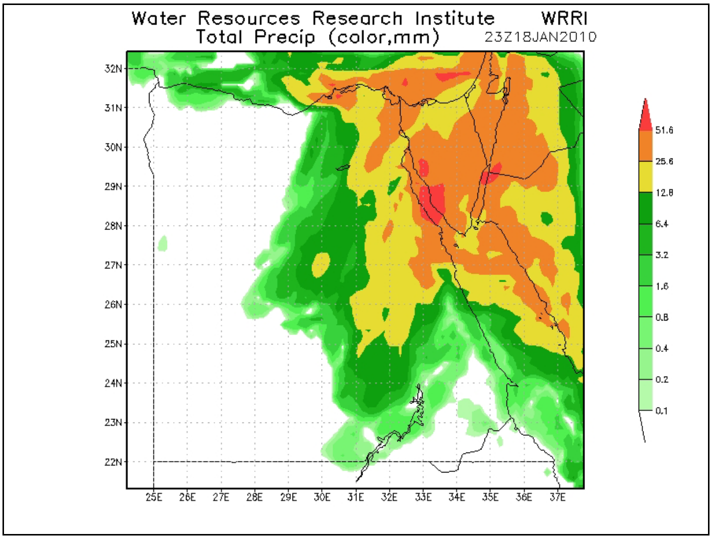


Figure 3: Rainfall forecast generated by the Weather Research and Forecast model.

available hydrological models are not suitable for use in arid zones. Therefore, a new hydrological model, reflecting arid zone conditions, was developed by means of the software packages “Matlab” and “Simulink”, distributed by The MathWorks [6]. The hydrological model is a lumped, discrete event model. It calculates excess rainfall, taking into account initial losses (interception and wetting), depression losses, evaporation losses, continuous losses and infiltration. Overland flow within a subcatchment is computed by means of a Nash cascade [7]. A detailed description of the hydrological model can be found in [8].

The study area was divided into 48 subcatchments, as shown in figure 4. The hydrological model is used to calculate runoff from each of these subcatchments.

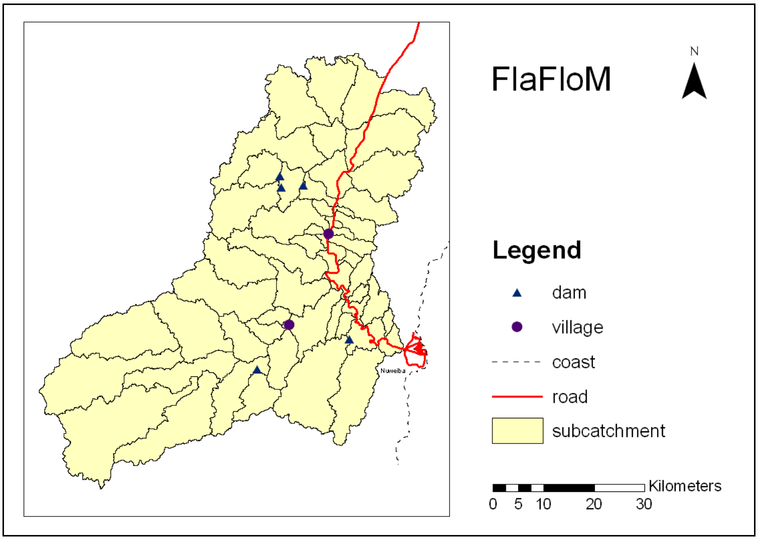


Figure 4: Hydrological subcatchments.

## 6 Hydraulic model

The major wadis are characterized by steep bed slopes, which range up to 2.5%. This implies that supercritical flows may occur in some areas and that backwater effects are not likely to be important. Because of the high permeability of the bed materials, infiltration losses can be significant. Five small dams have been constructed across upstream wadis. These dams and the reservoirs behind them also influence the flow in the downstream wadis.

The hydraulic model is used to predict the flows in the main wadis and the water levels in the storage reservoirs. This model can also produce flood maps for the downstream parts of the main wadis. It was constructed by means of the software package “InfoWorks-RS”, distributed by Wallingford Software [9]. The model extent is shown in figure 5.

The flows in the wadis are calculated by means of the Muskingum routing technique [7]. This technique was selected over full hydrodynamic solutions as it provides both fast computation and numerical stability, features which make it very suitable for use in a forecasting system. The main disadvantage associated with this technique is that it only provides discharges. In order to be able to use the model for flood mapping or flood damage mapping, flow depths and flow velocities are required too. These are estimated by means of flow-depth and flow-velocity relationships, obtained from the Manning equation [7]. The dams and reservoirs are accounted for by means of "spill units" (representing the dam crest) and "storage areas" (representing the reservoirs). Infiltration in the wadis and the reservoirs is taken into account by means of "abstraction units", which withdraw flows from the system. The infiltration rate is determined by a set of logical rules. A detailed description of the hydraulic model can be found in [10].

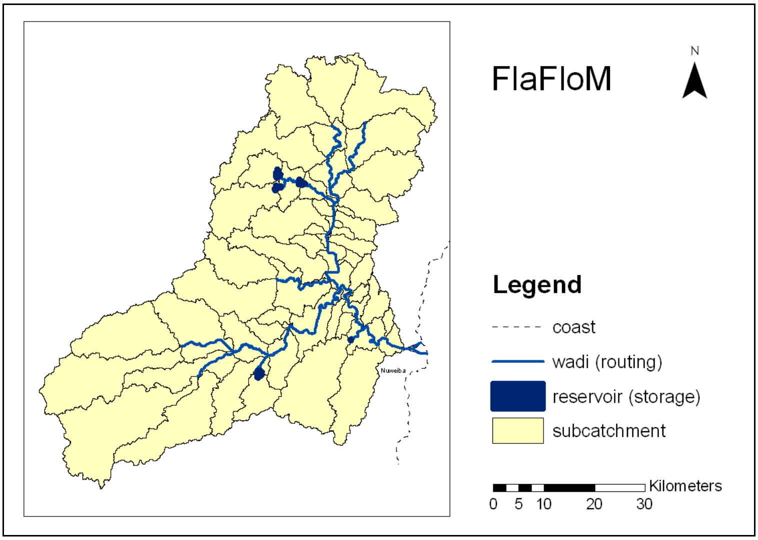


Figure 5: Hydraulic model.

## 7 Warning module

The warning module reads the output from the other system components and compares the numerical values to a number of pre-defined thresholds. Whenever one of these thresholds is exceeded, a visual warning or alert will be shown on the user interface. The warning module was constructed by means of the software package "FloodWorks", distributed by Wallingford Software [11].

The key aspect of the warning module is the selection of the thresholds for issuing warnings or alerts. The warning module is capable of evaluating four different state variables: rainfall, runoff, water level and discharge. For each of these, three different thresholds can be defined. The first threshold ("start") indicates the onset of rainfall, runoff and discharge or the presence of some water in the reservoirs. The second threshold ("warning") indicates the possibility of dangerous floods, whereas the third threshold ("alert") indicates a high likelihood of dangerous floods.

Rainfall thresholds are based on local experience with flash floods in the Sinai Peninsula. A warning is issued when the cumulative rainfall over a 6 hour period exceeds 10 mm. When the cumulative rainfall exceeds 15 mm, an alert is issued.

As the hydrological model has not been calibrated yet, no runoff thresholds have been defined in the current version of the early warning system. Once the hydrological model has been validated, runoff thresholds could be used to replace rainfall thresholds.

The water level thresholds apply to the water levels in the reservoirs and are based on the position of the water level in the reservoir relative to the dam crest level. When the reservoir level is less than one meter below the dam crest level, a warning is issued. When the reservoir level is at or above the dam crest level, overtopping will occur and an alert will be issued.

The hazard associated with a given discharge is very difficult to interpret directly. Usually flow depth, flow velocity or a combination of both are used instead. In addition, the hazard also depends on the nature of the threatened objects: houses, vehicles, adults, children, animals, etc. Flows in the wadis are considered dangerous as soon as they threaten the stability of people standing in them, as loss of stability may lead to injuries or even drowning. Jonkman et al. [12] summarize the results from experiments conducted by Abt et al. [13] and Karvonen et al. [14]. These results (shown in figure 6) indicate that loss of

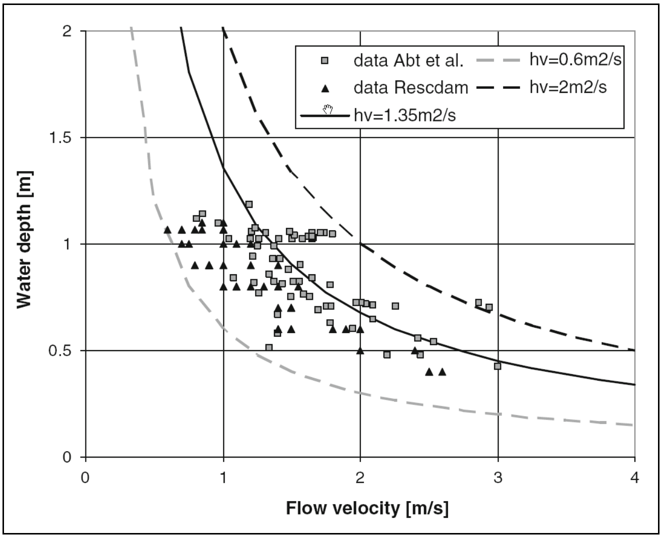


Figure 6: Loss of human stability in flowing water (from Jonkman et al. [12]).

stability may occur when the product of depth and velocity exceeds an average of 1.35 $m^2/s$, with a lower limit of 0.6 $m^2/s$ and an upper limit of 2.0 $m^2/s$. Based on these findings, the early warning system will issue a warning whenever the local product of depth and velocity exceeds 0.6 $m^2/s$ anywhere in a wadi. When the average product of depth and velocity for the entire wadi also exceeds 0.6 $m^2/s$, an alert will be issued.

Additional details on the warning module can be found in [15].

## 8 Real time integration and operation

The early warning system automatically activates and links all components in real time, whenever a new rainfall forecast is submitted. The results from the models and the warnings issued by the warning module can be viewed by means of a flexible and user-friendly graphical user interface (GUI). This GUI was constructed by means of the software package "FloodWorks" [11]. Figure 7 below shows the main GUI window.

The early warning system is an autonomous system, capable of gathering data, generating forecasts, displaying visual warnings or alerts on the GUI, sending e-mails to a pre-defined address list and generating reports. Future extensions will enable sending warnings via text messages (SMS) and publishing forecasts on a website.

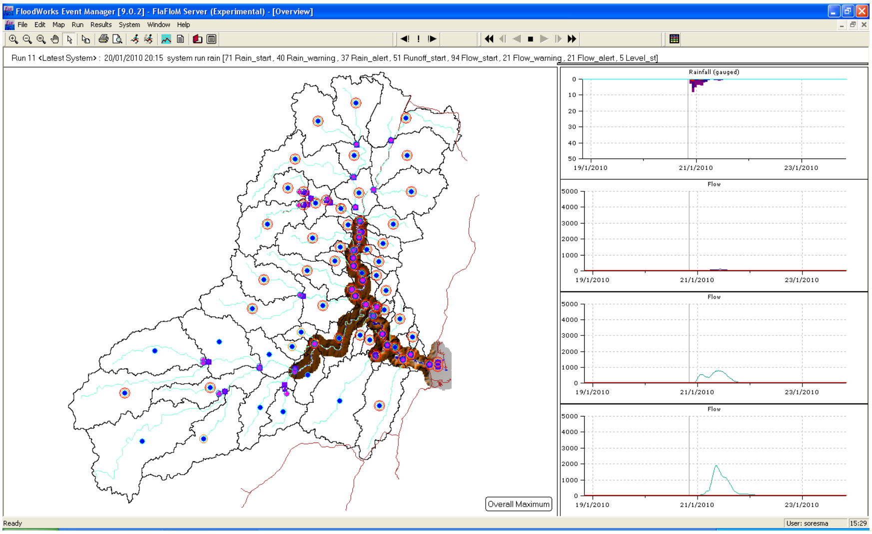


Figure 7: Graphical user interface, showing a number of visual warnings (concentric circles) for a fictitious event.

## 9 Calibration

The hydrological and hydraulic models contain a number of parameters that need to be estimated by calibration. This requires the availability of concurrent rainfall and streamflow data. At the start of the project, rainfall data were scarce and streamflow data were unavailable. Moreover, no clear correlation could be found between rainfall in the catchment (recorded by rain gauges or satellite images) and observed floods at the outlet. These apparent discrepancies can be attributed to the specific nature of the storms causing flash floods (limited areal extent and short duration), the low spatial resolution of the existing rain gauge network and the low temporal resolution of the historical satellite images. A more elaborate discussion of these issues can be found in Cools et al. [16]. For lack of calibration data, all model parameters were initially estimated from literature data and expert judgement. In the course of the project, additional rain gauges were installed throughout the catchment, a water level recorder was installed at the outlet and a satellite dish, capable of receiving images from meteorological satellites was installed at the Water Resources Research Institute in Cairo. All instruments were operational by the end of 2009 and are expected to provide the data needed for calibrating and validating the models.

## 10 Operational testing

The early warning system was installed at the Water Resources Research Institute (Cairo) in November 2009 and is now undergoing operational tests. As the models have not been calibrated yet, all forecasts need to be carefully evaluated. It is expected that this testing phase will last several years, depending on the number of flash floods. In spite of the present limitations, the first experiences are very encouraging. Only two months after installation, the early warning system already demonstrated its potential. The rainfall forecasting model successfully predicted the storms which struck the Sinai Peninsula in January 2010, 48 hours in advance. The data recorded during this storm, are also expected to provide the information required for calibrating the models and improving the thresholds in the warning module.

## 11 Conclusions and recommendations

An early warning system for forecasting flash floods in Wadi Watier (Sinai Peninsula, Egypt) has been developed. The system is currently undergoing operational tests and the first experiences are very encouraging.

During the testing phase, which is expected to take several years, all forecasts should be used for evaluation purposes only. After successful completion of this testing period, the validated system can be used for operational purposes too.

## Acknowledgement

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