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A FLASH-FLOOD PREDICTION SYSTEM

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1. INTRODUCTION

One of the most challenging problems facing meteorologists and hydrologists is the accurate forecast of flash floods. This is mainly because of the short-lived, local nature of the flash-flood phenomenon that demands: timely collection and processing of precipitation and streamflow data, and dissemination of warnings with adequate forecast lead time for the saving of lives and the reduction of damage to property.

The term flash flood commonly refers to a flood that follows the causative precipitation event within 6 hours time (WMO, 1981). On occasion, failure of a natural or man-made dam can create a flash flood downstream. In this work, however, we focus on the floods created by intense rainfall. Most of the flash floods observed are characterized by localized, intense rainfall on a catchment of highly sloping ground or on a catchment of impervious ground (urban flooding).

Damages resulting from flash flooding have been very high. In the United States, damages of $1 billion per year have been quoted (e.g., Peck, 1978), while flash flooding claims about 200 lives each year throughout the country. Other countries incur similar damages (e.g., Sharma and Vangani, 1982; Kinosita, 1974; WMO, 1981).

Because of the short response-time of the phenomenon, an observation-intensive, automated approach is imperative for accurate and timely forecasts. Furthermore, given the fact that any increase in the forecast lead time of accurate prediction results in damage reduction (e.g., Krzysztofowicz and Davis, 1984), a local, combined hydrological-meteorological approach is indicated. Consequently, models for quantitative precipitation forecasting, coupled in real time with hydrologic models for streamflow forecasting, running at the local site and relying on observations from automated censors, appear as the solution to the flash-flood forecasting problem (WMO, 1981).

This work reports on the preliminary configuration of prototype flash-flood prediction system that possesses many of the characteristics desired for a flash-flood forecasting system.

2. HYDROMETEOROLOGICAL MODEL

In a review paper, Georgakakos and Hudlow (1984) examine various approaches to quantitative precipitation forecasting that potentially can provide useful input information for hydrologic forecasting. Among the approaches examined, the work of Georgakakos and Bras (1982a), based on a coupled precipitation and catchment model with real-time updating capabilities, has several attractive characteristics for use in flash-flood forecasting.

A physically based, one-dimensional, precipitation model produces mean-areal precipitation forecasts over the catchment of interest. A conceptual, spatially lumped, soil-moisture accounting model distributes the forecast rain in the various soil zones and produces the channel inflow. Finally, a non-linear, hydrologic, storage routing model routes the channel inflow downstream and produces forecasts of the discharge (or stage) at the catchment outlet.

The hydrometeorological model is in the form of a set of first-order differential equations, coupled by the mass conservation law that applies at the boundaries between 1) the precipitation model and the soil-moisture accounting model; and 2) the soil-moisture accounting model and the channel routing model. The input data consist of surface meteorological data (temperature, pressure, and dewpoint temperature), discharge data at the catchment outlet, and estimates of mean areal precipitation from raingage data.

The model state variables are the volumes of water in storage in the clouds over the catchment of interest, in the various soil layers, and in the channel reaches.

The model is particularly suitable for real-time operation since it includes an automatic updating mechanism based on Kalman Filtering theory (Gelb, 1974). The updating mechanism compares in real-time the model forecasts of mean areal precipitation and catchment-outlet discharge with the corresponding observations and generates corrections to the model states so that at the next integration period (forecast step) more accurate initial conditions for the model states are used. Observations are utilized as soon as they become available in real time. It is this characteristic and the coupled nature of the model that makes it particularly appealing for the real-time forecasting of flash floods.

Georgakakos and Hudlow (1984) present a summary of the results of application of the model in the real-time forecasting of river flows in the 2344 km^2 Bird Creek basin near Sperry, Oklahoma.

Good results were obtained both for the 6-hour forecast lead time and for the longer forecast lead times for that basin. In more than 70 percent of the flood hydrographs in a 5-year period of 6-hourly data, the hydrometeorological model forecast: 1) the peak discharge on time or 6 hours earlier, and 2) the peak discharge magnitude within 20 percent of the observed one. For the tests, the Georgakakos and Bras (1984a,b) station precipitation model, the National Weather Service River Forecast System soil-moisture accounting model (Peck, 1976), and the Georgakakos and Bras (1982b) flood routing model were used.

Tests of the precipitation component are reported in Georgakakos and Bras (1984b), and Georgakakos (1982, 1984). The tests show that the precipitation model optimal parameters remain reasonably constant for various storm types, topographical locations, and parameter optimization criteria. This characteristic is particularly useful in the real-time forecasting of precipitation.

3. INTEGRATED HYDROMETEOROLOGICAL FORECAST SYSTEM (IHFS) FOR FLASH FLOODS

Based on the concepts of coupled precipitation and catchment models and of real-time updating, a prototype system for the real-time prediction of flash floods was designed.

In flash flooding, the infiltration abstraction is negligible during the time of the flood because of the high rain intensities that saturate the upper soil layers in a short time. Because of this fact and for the purpose of reducing the model run-time costs, a simple Antecedent Precipitation Index (API) procedure substituted for the soil-moisture accounting scheme in the hydrometeorological model described in the previous section. Also, a computationally efficient form of the updating mechanism was devised.

The above mentioned modifications resulted in an Integrated Hydro-meteorological Forecast System (IHFS) with 40-kilobyte computational requirements. IHFS is suitable for implementation in mini- and micro-computers at local sites.

IHFS requires precipitation and discharge data of short time increment (1 hour to 6 hours, depending on the catchment under study), together with 3-hourly surface meteorological data from a nearby Weather Service meteoro-logical observation site. The River Forecast Center that is responsible for the area that contains the site of flash flooding can provide the API parameters (usually once a day). When available, forecasts of surface meteorological variables, issued by the large-scale, numerical, weather prediction models, can be used as input to IHFS.

The system runs on an event basis. Links to Automation of Field Operations and Services (AFOS) are envisioned, with IHFS automatically accessing the meteorological data and the RFC input.

Crucial to system optimal performance is the availability of real time, short time-increment precipitation and discharge data from automated sensors. However, IHGS is designed to also run with only precipitation or only discharge data at a time.

IHFS is capable of producing real-time probabilities of flooding for the site of interest as a result of the updating procedure.

Tests of IHFS, simulating real-time conditions, using data from actual flash floods are very encouraging. Probabilities of flooding higher than 0.7 were produced for the times when flooding actually occurred.

4. CONCLUDING REMARKS

A flash-flood prediction system, called IHFS, was developed and it is undergoing tests simulating real-time conditions. The system couples a local, quantitative precipitation forecast model with an API procedure and a channel router. An updating mechanism corrects the model states in real time utilizing observed precipitation and discharge data.

The system is suitable for implementation at the local site on mini- or micro- computers.

Optimal system performance is attained when high frequency data are obtained from both precipitation and stage (or discharge) automated sensors in real time.

IHFS is expected to be particularly useful in tropical climates due to the capability of the precipitation component to better model convective storms. Also, with minor modifications, IHFS can be used the prediction of urban flooding.

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