1.6 PREDICTIVE UNCERTAINTY OF WATERSHED RAINFALL-RUNOFF MODELS USING WEATHER RADAR

Lynn E. Johnson*[1, 2], William F. Roberts, Brian E. Skahill[2], and Scott O'Donnell[1]
NOAA Research - Forecast Systems Laboratory
Boulder, Colorado
[1]*[In collaboration with the Cooperative Institute for Research in the Atmosphere (CIRA),*
Colorado State University, Fort Collins, Colorado]
[2]*Department of Civil Engineering, University of Colorado at Denver, Denver, Colorado*

1. INTRODUCTION

Remote sensing using meteorological radars provides rainfall intensity estimates at time intervals of a few minutes and space scales on the order of square kilometers. Numerical analysis and geographic information systems (GIS) techniques allow us to simulate incident rainfall, infiltration, flood runoff and channel routing at these microscopic time and space intervals. However, computational requirements of the discrete numerical procedures limit their utility for real-time flash flood warning operations at this time. For real-time operations, simplified and macroscopic procedures may be used to provide quick indicators of flash flood threats.

This paper describes activities for comparison of two hydrologic models – the AMBER and F2D models – for application to flash flood warning operations at National Weather Service (NWS) Weather Forecast Offices (WFOs). The models use radar-rainfall estimates as input and provide predictions of flash flood threats. The models were applied using rain gauge adjusted radar-rainfall estimates for a number of historical events in the Denver, Colorado metropolitan region. The watersheds exhibit varying degrees of urbanization expressed as percent impervious surfaces. Predictive uncertainties were examined using a Monte Carlo approach with a view toward providing guidance on the range of prediction to be expected. The research is relevant to forecasters who could use the models to provide early warning on flood threats in urbanized areas.

2. AMBER & F2D HYDROLOGIC MODELS

Two hydrologic models were used in association with radar-rainfall fields – AMBER (Areal Mean Basin Effective Rainfall) and F2D (Flood 2-Dimensional).

AMBER was developed by NWS forecasters (Davis, 1989) to provide a basic but effective means for preparing WFO flash flood warnings. It computes the average basin rainfall (ABR) for defined watersheds every 5-6 min in its area of responsibility. AMBER is applied to watershed databases with varying scales ranging from in excess of 300 sq km down to 5 sq km.

The likelihood of flooding is established by comparing the ABR with the Flash Flood Guidance (FFG), the ABR in inches for some duration (e.g., 1, 3, and 6 hr) needed to bring a stream to bankfull stage. THE FFG is provided periodically (e.g., 6 a.m. daily or more often) by the regional NWS River Forecast Center (RFC); its' spatial resolution is for counties or a nominal 4 sq km grid.

AMBER computes the rainfall rate for a basin, and time tracking of the rate provides an important forecasting cue. Rates that trend towards and exceed an "alert" rate of 1 in per hr (25 mm per hr) are considered noteworthy, since significant ABR rates generally occur prior to significant accumulations (Arthur, 2000).

F2D is an event-based, kinematic, infiltration-excess, distributed rainfall-runoff model developed to account for spatial variability of watershed rainfall, abstractions, and runoff processes (Skahill and Johnson, 2000a). The F2D rainfall-runoff model operates on a square grid of specified spatial resolution, typically 200m to 800 m. The main model outputs include a volume summary, discharge hydrographs for interior locations and for the main basin outlet, and raster maps of various variables, such as, cumulative infiltration and water depth throughout the basin.

F2D has been used to examine the uncertainty of several parameters relevant to storm surface runoff production and surface flow (Skahill and Johnson, 2000b). For the calibration and uncertainty estimates, we applied a variation of the Generalized Likely Uncertainty Estimation (GLUE) procedure (Beven and Binley, 1992).

3. RADAR-RAINFALL ESTIMATION

Radar-rainfall remote sensing imagery is the primary dynamic input to the AMBER and F2D models. Eight events were selected for study application on the Ralston Creek basin. The Mile High Radar (MHR) was the source for the rainfall estimates for the events from 1991; MHR is a NEXRAD prototype radar with 0.95° beam width and 225 m gate spacing. The temporal resolution of the radar reflectivity data was approximately 6 min. The *Z-R* power law relationship: $Z = 500R^{1.3}$; where *Z* and *R* represent the radar reflectivity (in mm^6/m^3) and rainfall rate (in mm per hr), respectively, was used to transform reflectivity into rainfall rate. This *Z-R* relation has been used with reasonable success for

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Corresponding author address: Dr. Lynn E. Johnson, Mail Code R/FS6, NOAA Forecast Systems Laboratory, 325 Broadway, Boulder, CO 80305-3328

the summertime climate of the Colorado Front Range (Smith and Lipschutz 1990). A reflectivity threshold of 53 dBZ was applied before converting to a rainfall rate (Fulton et al. 1998).

A bias correction factor was computed for each storm event based on the ratio of the precipitation measured by the rain gauges to the precipitation measured by the radar (Table 1). Rain gauge adjusted radar-rainfall estimates were subsequently determined by multiplying the original radar-rainfall estimates by the correction factor. Fulton (1999) used this approach in his study and found that 63% to 25% reductions were required with bias correction.

TABLE 1

Event	Date	Bias Factor
1	1 June 1991	0.46
2	21 June 1991	0.64
3	22 June 1991	0.64
4	26 May 1996	0.73
5	August 1996	0.65
6	18 Sept. 1996	0.49
7	30 July 1997	2.63
8	4 August 1997	0.92

4. AMBER & F2D MODEL APPLICATIONS

F2D was applied to simulate storm surface runoff from the Ralston Creek basin, an urbanizing watershed (est. 20% impervious) with a 225 km^2 drainage area and primarily silt loam soil type. Eight events were selected for F2D application on the Ralston Creek basin; four were used for calibration, the other four for validation. Six events were used for calibration and model sensitivity analysis on the Goldsmith Gulch basin. Figure 1 shows an observed runoff hydrograph over-plotted with 95% uncertainty bounds obtained from the F2D model for Ralston Creek.

The F2D model results are considered good once calibrated. While using rain gauge adjusted radar-rainfall estimates and operating at a coarse spatial scale, the model was very accurate in simulating time to peak and reasonably accurate in simulating runoff volume and peak discharge. Also, the 95% uncertainty bounds obtained from the model envelop almost all observed responses at the main basin outlets for the events considered, suggesting an acceptable model structure.

A F2D model sensitivity analysis was performed using the calibrated model and bias-corrected radar-rainfall data for Goldsmith Gulch. This analysis indicated that one can be 90% confident that the actual peak flow will be less than 133% of a given model prediction. This level of predictive uncertainty associated with the runoff process contrasts that of the radar-rainfall, which is on the order of 200%.

Application of the AMBER procedure to Ralston Creek obtained results of a similar character – the radar-rainfall data must be bias corrected to obtain useful model predictions.

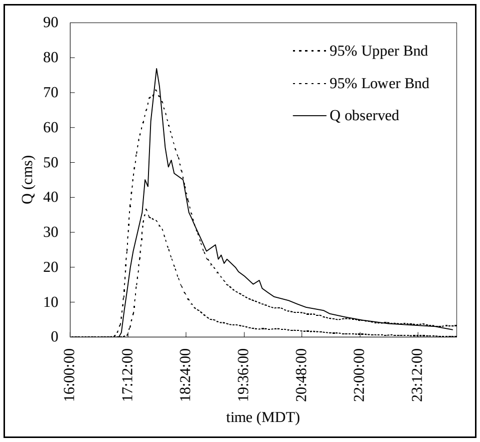

Figure 1. Ninety-five percent uncertainty bounds obtained from the F2D model for the 1 June 1991 storm on the Ralston Creek basin.

The AMBER model uses the FFG index to represent antecedent conditions and effective rainfall threshold. It is our opinion that the FFG has inherent inaccuracy at least of the same order as the F2D runoff response. Also, it has a coarse spatial resolution.

The AMBER ABR magnitude is compared to a threshold "alert" level of 70% of the FFG and a threshold "alarm" level of 90% FFG. Thus, the AMBER application provides the forecaster with some consideration of radar-rainfall estimation error.

A key factor in the AMBER application to Ralston Creek was the size of the subbasins on which the rainfall accounting was performed. Averaging of incident rainfall over basin areas larger than the overall storm resulted in underestimates of the flash flood threat. Subdivision of the lower portion of the Ralston Creek watershed into subbasins of 30 sq km or less resulted in better performance for the AMBER procedure; 30 sq km is the mean storm size of Colorado Front Range convective storms (Dixon and Johnson, 1998). The F2D model does not incur this averaging problem because is has a much smaller grid size than the AMBER subbasins.

The computed AMBER ABR rainfall rates provide important early warning cues on the flash flood threats. The ABR rate, expressed in in per h, is computed for every radar scan period (about 6 min) and the various basins are listed by ABR magnitude and rate. Time tracking of the ABR rate provides a basis for comparison to critical rates (e.g., 1 in per hr) as well as the ABR rate trend (i.e., increasing, level, decreasing). This rate trend can provide valuable lead time for forecasting purposes. In cases where the radar-derived precipitation estimates are too low or too high, the relative ABR rates still provide a cue usable by forecasters to assess flash flood threat prior to runoff occurring.

5. SUMMARY

This paper described the application and comparison of the AMBER and F2D hydrologic procedures for flash flood forecasting which use radar-rainfall estimates as input. A major concern with either model is the evident inaccuracy of the radar-rainfall estimates based only on a Z-R relation without bias correction. Given bias correction, the F2D model was shown to produce good estimates of runoff timing, volume, and peak. Application of a Monte Carlo simulation technique provided an envelop of possible F2D system response, information useful for forecasters in assessing the significance of F2D model predictions.

The AMBER model was limited as well by radar-rainfall estimation and FFG inaccuracies; ABR computations were only as accurate as the input rainfall and the FFG values may be too general for a specific small watershed. However, the AMBER ABR rate information was more indicative of flash flood potential than the ABR accumulations. The AMBER procedure must be applied to sub-basins similar in scale to the incident storms. Application of AMBER will require careful consideration of uncertainties of rainfall and land surface response, and spatial averaging. There will be required a balancing between a need to know and “false alerts” by the forecasters.

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