BRMS: MONITORING BASIN RAINFALL AND POTENTIAL FLOODING

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Abstract

The Basin Rainfall Monitoring System (BRMS) is a new development of the Forecast Systems Laboratory's Dissemination Project. Since 1992 the Dissemination Project has been conducting experiments to determine the use of advanced meteorological information by local government operations. Local emergency preparedness agencies (involving emergency preparedness, sheriff and police departments) can gain great benefit from appropriate information about weather hazards. The Dissemination Project, a pilot project, employs a workstation especially designed to focus on four weather hazards of particular importance to emergency preparedness: flash floods, fire danger, severe weather and disruptive winter storms. The BRMS complements the workstation in assisting emergency managers in evaluating flash flood situations. The system uses high-resolution weather datasets produced by analysis and prediction models, and the WSR-88D radar, which provides mesoscale detail about rainfall distribution that is not available from gauge networks. When in the surveillance mode, the BRMS alerts users if flood danger is high. Users are then able to request more detailed products on the workstation, and the system computes assertions, weather characteristics related to spatial (regions) and temporal (periods) objects such as river basins and storm evolution. Emergency managers can use the meteorological displays to analyze flooding conditions over several basins, which enables them to better forewarn the public of flash flood potential.

1. Introduction

Flash flooding usually occurs in narrow canyons or urban areas shortly after or during heavy rains, especially during summer convective storms [White 1975], and can cause deaths, severe property damage, and traffic disorders. To minimize loss of life and economic damage, emergency managers must be able to predict the flash flood event and take certain actions, some of which are expensive and may inconvenience many people, such as evacuation and traffic closure. The decisions they make are based on various sources of information: weather data and state of the community: holiday celebration, rush hour traffic, or rest time. Of course, physical factors such as soil moisture, surface characteristics and reservoir water levels are very important to the type of decisions made. The more accurate and timely the information, the better their decisions. Furthermore, the false alarm rate, which can cause people to not respond to a real emergency, will be lower. In addition to the accuracy of the information used by emergency managers, another factor that influences the quality of the decisions is the stress level of the decision-maker. Emergency managers work under pressure mostly because of severe time constraints. For example, the period between the initial rainfall and the consequent flooding is often less than an hour, a very short period to monitor the amount of rain fallen over the river basin and decide on appropriate actions.

The characteristics of flash flooding led us to design a system that supports emergency managers in evaluating flash flood situations using high-quality weather data. The BRMS uses gridded data fields from an analysis and prediction system, and presents the data at different levels, from summary information to a very detailed level, in various modes: images, maps, graphs, text, and tables. A summary product is provided as the first level of information; this allows users to quickly make a preliminary judgment of the situation, and, if warranted, they can further explore the situation by requesting more detailed products with a simple click of the mouse. The optional modes of presentation allow the system to prepare efficient displays that correspond to the type of information being presented (spatially or temporally distributed, summary or detailed).

BRMS is one of the experimental decision support systems developed within the Dissemination Project [Small 1993]. This project is intended to study the utility of advanced weather data sets to various users, such as emergency and traffic managers. NOAA and local emergency preparedness staff realize that the official method of disseminating local weather data through text bulletins can be significantly improved with graphics and other means of expression. The methodology adopted in the Dissemination Project is to develop experimental weather decision support systems, install these systems at various evaluation sites, get feedback from real users, and repeat the cycle again.

To illustrate the need to develop systems such as BRMS, we describe one of the most devastating flash floods in the nation, the Big Thompson Canyon flash flood, as well as the lessons we learned from it. Then the data sources used in BRMS are discussed, and we argue why the use of hydrological models is currently inappropriate. Next we introduce the features of FSL's approach to system design, the system architecture, and the user interface. Some implementation issues are addressed before the concluding remarks.

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2. The Big Thompson Canyon Flash Flood

One of the most severe cases of flash flooding occurred on 31 July 1976 in the Big Thompson Canyon, Colorado [Simons 1978]. During that evening, an intense thunderstorm stalled over a small portion of the canyon dropping over 10 inches of rain in a 3-hour period. Because the topography of the canyon is steep and mountainous, the rainfall quickly concentrated in the stream and formed a wall of water that swept away everything in its path. Trees, sediment, boulders, and even houses were swept downstream. The final toll of this flash flood event was staggering: 139 people dead, 4 missing, and property damage exceeding $41 million. The reason for the huge toll on life is twofold. First, the flood struck an area that was totally unprepared for such an event. Second, there was little effective warning with significant lead time for the 4000 people who were celebrating Colorado's Centennial Celebration in the canyon, and the many residents of the developments that had encroached onto the floodplain. The huge toll on property was mainly because of lax or nonexistent zoning restrictions for both commercial and residential development of flood hazard areas.

Boulder County, has a similar, if not a worse, scenario with Boulder Creek. Boulder Creek has a steep mountain topography and a short concentration time similar to the Big Thompson canyon, but is worse because it runs through the city of Boulder. More important, there is tremendous development and a high population density along the creek and its floodplain.

The after-effect of the Big Thompson flood reminded people of the substantial flood hazards in mountain canyons. Cooperation between the various public safety, flood control and emergency management agencies was excellent. The Urban Drainage and Flood Control District (UDFCD), Boulder County, and the City of Boulder worked together to develop and implement a flood detection and warning system to reduce the loss of life if a similar flood should occur in Boulder County. To better detect rainfall, rain and stream gauges were installed on the watershed and streams. Hydrological consultants and the Corps of Engineers analyzed the creeks and streams, and their analyses were used to formulate a flood detection and warning system. The hydrological analysis of the creeks showed that flood flows can develop in the canyon within 1 to 2 hours of peak rainfall, and the time for it to travel down to populated areas is considerably less, typically between 30 and 50 minutes. Thus, in a worse case scenario, flooding can occur in Boulder within three hours of the beginning of rainfall. The warning process requires a much longer lead time than the period from flood detection to flood arrival. It necessitated the detection system to be activated during storm development and warnings issued 30 to 50 minutes before upstream flooding is detected to provide adequate time for the public to respond. The warning process would use alert radios, sirens, public address systems on emergency vehicles, and the broadcast media where the emergency manager can tap into the network television stations and send out alerts to the public.

3. Data sources

Emergency managers use weather information as one of their key data sources for decision-making. Currently, accurate and comprehensive datasets about certain weather variables such as temperature, relative humidity, precipitation type and amount, and wind velocity are produced by different analysis and prediction models. Two models are being developed at FSL to analyze and predict the weather at different spatial and temporal scales: the Mesoscale Analysis and Prediction System (MAPS) [Benjamin et al. 1991] and the Local Analysis and Prediction System (LAPS) [McGinley et al. 1991]. They both produce gridded datasets from various sources: radar, automatic surface and upper-air measurement, and satellites. The grids have different spatial and temporal resolutions and domains: the MAPS grid has a 60 km spatial and 3-hour temporal resolution that covers the United States, and LAPS grids have a 10 km spatial and 1-hour temporal resolution that cover approximately an area as large as Colorado.

Another source of information is the newly installed WSR-88D (previously NEXRAD) radars that provide both reflectivity and velocity [Kelsch 1992]. From these radars, information of reflectivity and its derived products such as rainfall accumulation can be obtained with a resolution of 2 km every 6 minutes [Smith and Lipschutz 1990]. A second type of LAPS grids is planning to use this high spatial and temporal resolution in the future.

For the type of flash flooding analyzed here, high resolution precipitation amount is the most important weather variable. State variables such as stream levels that can be obtained from stream gauges and river basin soil moisture are other important variables. Although the estimation of rain rates from radar reflectivity is not very accurate, it is sufficient to start experiments, and there is the strong expectation that it will improve in the near future [Rasmussen and Smith 1989]. This rain-rate dataset with a spatial resolution of 2 km updated every 6 minutes can be viewed as having automatic raingauges at every 2 km which would be prohibitively expensive to install and maintain physically. However, currently, a limited number of raingauges are located sparsely over the river basin. Basin-wide rain averages are obtained using the Theissen polygon method, but it has a drawback of being unable to detect the small-scale convective storms that are located in between the raingauges. This can lead the decision-maker to make the erroneous and dangerous judgment of "no flood danger."

Emergency managers can benefit from other information such as the following basin characteristics: time to peak, shape, size, topography, soil type, and vegetation. Some of these parameters may not be used during an actual flooding event, but they can be used by decision-makers to familiarize themselves with the river basin under their responsibility. Such data can be produced by rainfall-runoff hydrological models such as the Precipitation-Runoff Modeling System (PRMS) and the Hydrologic Engineering Center's HEC-1 flood hydrograph model [Bedient and Huber 1988]. Although these models, provide the potential for very accurate predictions of flood danger for river basins, using the radar derived rain rates and the rain input, they have two fundamental drawbacks: they need parameters that are hard to obtain, and the model runs take too long to monitor many basins simultaneously. Therefore, we took another approach in designing a system that is simpler and could prove to be helpful to the decision-maker.

4. The FSL approach - a new system design

After considering the problems of emergency managers in a city and county office, we have designed a system that supports the decision-making process. Our design comprises the following features:

- A data source from the LAPS model and the nearest radar located in Denver, which provides rain-rate data at 2 km resolution.
- A Geographical Information System (GIS), called ARC/INFO, provides data for other variables such as soil type, basin area, and vegetation. Other basin characteristics such as time to peak were obtained from basin analyses by the UDFCD and the Corps of Engineers. Soil type and vegetation are used in a separate model that computes the field soil moisture, which in turn has direct effect on the level of flooding.
- The information is presented on multimodal displays using images, maps, tables, text, and charts. Each mode presenting different aspects of the information that are consistent with one another and build on each other.
- Original data are presented as well as summarized information.
- Some derived variables such as basin and subbasin flood danger mode are computed, in addition to pure weather variables.
- Simple action rules, obtained from the County Warning Plans associated with the corresponding flood danger mode, are suggested to make the presentation more familiar to users, and to remind them of certain important actions they must undertake.
- Hypermedia access to the information is provided, starting from a summary surveillance product and going into more detailed ones.

5. System Architecture

Since BRMS is supposed to work in a distributed environment (Section 8), we adopted a highly modular structure, each module fulfilling a separate, well-defined task and communicating with the other modules via standard types of messages. There are six processes that run in the system:

- **From grids to bitmap images**. Converts raw gridded data into Windows bitmaps. A lookup table (LUT) encodes each weather parameter value into a color. For example, the temperature parameter has a LUT that goes from light magenta for the lowest values to red for the highest values. Each grid point value is converted to a color using the LUT, and then a colored box representing the temperature of the grid point is drawn on the screen.
- **From grids to assertions**. Converts raw gridded data into assertions providing immediate answers to questions the user is likely to pose in a situation of flash flooding. The assertions are organized into coherent chunks of information so that the user can better perceive them and create a mental representation of the situation. As explained in greater detail in Section 6, the assertions are weather or other characteristics related to spatial and temporal objects known to the user. Territory and time models define the regions and periods used in assertions. The characteristics are values of certain variables organized in a parameter model.
- **From assertions to maps**. Presents a set of assertions about different regions into a map, in which each assertion is represented by an icon. To do this we designated a spot for each region where the icon should be placed. The color and the shape of the icon depend on the assertion parameter and value. Maps are used for presenting the flood danger for the different basins and subbasins (cf. Section 7).
- **From assertions to text**. Text is used when assertions represent heterogeneous information such as extreme and mean values of rain rate, non-weather characteristics such as time to peak, action rules (e.g., "Evacuate people from buildings along the creek.") and trends. The text generated by BRMS conforms with a template predefined by the designers of the system. This template specifies constant phrases with slots for assertion values and action rules.
- **From assertions to charts**. A chart is used for presenting the dependency of one variable from another, for example, the evolution of the rain rate over a particular region.
- **From assertions to tables**. Presents the same time series that is displayed as a bar chart above as a table. The table in BRMS contains the rain rates every 18 minutes of a 3-hour and 36-minute period.

The process "from grids to assertions" is carried out by the assertional subsystem; its functions are described in the next section. All other processes are carried out by a presentation subsystem, which also accepts the user's commands that are given by selecting from menus or by clicking on visual objects that are already displayed.

6. Assertion generation

Assertions are weather characteristics related to spatial and temporal objects. The spatial objects, called *regions*, are of particular importance and they are defined in a territory model. The territory model contains the following information for a region: *name* (e.g. Boulder), *type* (e.g., county, city, basin), *carrier* (the set of grid points that belong to the region), and the *superregion* link (a region *A* is a superregion of another region *B*, if *A* contains *B*). The temporal objects, called *periods*, are predefined and hard-coded in the current version of the system. The weather characteristics are computed by applying certain methods to the gridded data that relate to the assertion region and period. Some broadly used methods are mean value, accumulation, maximum value, minimum value, and predominant (mode) category. The weather variable and the method, taken together, represent the *parameter* of the assertion. As a result of the computation of a parameter for a region and period, a *value* is assigned to the assertion. A comprehensive description of the current state of the assertional system featuring complete territory, time, and parameter models can be found in [Kerpedjiev 1993].

The BRMS uses a territory model with four basins in the Denver metropolitan area. Each basin consists of several subbasins, which are subregions in the terminology of the territory model. The basins and some subbasins are shown in Figures 1 and 2, respectively. Assertions are generated for a period of 3 hours and 36 minutes, which is divided into twelve 18-minute subperiods. Two gridded variables at spatial resolution of 2 km are used as input to the assertional subsystem: rain rate and soil moisture. The following parameters are used:

- **Rain accumulation.** Provides information about the total amount of rain received by a region over a given period.
- **Predominant category of soil moisture.** Indicates the wetness of the soil. The wetter the soil, the smaller the proportion of rain absorbing into the soil and the greater the proportion of water contributing to the flood. Four categories of soil moisture are used: dry, moderately dry, moderately wet, and wet.
- **Storm frequency/recurrence interval.** Indicates the flood danger as a storm recurrence interval. It is obtained using the Frequency/Depth/Duration analysis for 2-hour convective storms by the UDFCD. A 100-year storm, for example, means that this size storm happens on average once every 100 years. Thus this storm has a 0.01 probability of occurring in any single year. A 100-year storm is an extreme storm event and probably requires evacuation.
- **Rain index.** Indicates the flood danger for a region by using the maximum 1-hour rain accumulation and the UDFCD Urban Flash Flood Guidance for short duration storms (less than 1 hour). The UDFCD obtained these values by analyzing the mountain streams in the Front Range area.

Assertions for several time-independent parameters are precomputed for all regions and stored with the territory model. Examples of such parameters are basin area and time to peak.

Individual assertions, organized into a time series, or assertions representing a regional description are submitted to the presentation module which generates the corresponding display: map, text, chart, or table.

7. User Interface

The BRMS can be in one of four modes: general surveillance, basin survey, subbasin, and color image display of weather data. General surveillance information is given as a map of the four basins (Figure 1). A frame of a certain color surrounds each basin. The color of the frame corresponds to the highest rain index detected in that basin. Figure 1 shows that the rain index is 2 (high) in three of the basins and it is 3 (very high) in the fourth basin. This display allows users to immediately detect if there is any flood danger in their area of responsibility.

By clicking anywhere within the frame surrounding a basin, the user gets into basin survey mode, which provides a detailed map representing the flood danger modes of all subbasins within that basin. The rain index for a subbasin is given as a box over the subbasin (Figure 2). The color of a box corresponds to the flood danger for the corresponding subbasin. Figure 2 shows that the subbasin with rain index 3 is closer to the mouth of the creek, which means that the flooding may occur sooner than the average time for this basin.

Clicking on the box of a subbasin gets the system into subbasin mode giving more detailed information about this particular subbasin in the form of text, chart, and table (the right hand part of Figure 2). The chart on this display is particularly informative because it shows when the heaviest rain occurred. The exact values of the rain accumulation can be found in the table next to the chart. The text on the top right corner provides diverse information about the current situation.

The user can also select a particular variable from a menu whereby the field of that variable is presented as an image (e.g., the rain rate field is shown in Figure 3). This high-resolution display allows users to monitor where and when the heavy rain occurred and to adjust their perception of the situation. Other fields such as radar reflectivity are also accessible from the menu and presented to the user as an image.

8. Implementation Issues

The current Dissemination Workstation consists of three parts: a central server which acts as a file server, the FSL VAX computer cluster which stores all FSL meteorological products, and the Visualization IBM Personal Computer (PC) which displays the meteorological and environmental information to the Emergency Manager. The Visualization PC is a generic, off-the-shelf DELL 486 IBM compatible PC; it uses MS-DOS 5.0 and Microsoft Windows Version 3.1 as its operating system. The PC is connected to the central server on the FSL VAX cluster via a 56 kbaud modem-router combination and uses the Digital Equipment Corp. (DEC) Pathworks communication utility.

The assertional system was written in FORTRAN, and the presentation system was written in Microsoft Visual Basic.

Currently the Dissemination Project deploys two PCs outside FSL. One is in use at the Boulder County Emergency Services Office and the other is located at the Denver Weather Service Forecast Office. The initial response from the officers using our system is positive.

9. Concluding Remarks

This paper describes BRMS, a system designed to help emergency managers create graphical interpretations of flash flood situations to help them react appropriately so that disasters like the Big Thompson flash flood can be mitigated. The system, which supports the mission of the Dissemination Project, provides four types of displays with different spatial scope and level of detail. In surveillance mode, it detects and shows the existence of any flooding conditions over several basins. In basin survey mode, it indicates in categorical terms the amount of rainfall over the subregions of a basin, allowing the user to infer how this rain will contribute to a possible flash flood. In subbasin mode, BRMS provides details about the temporal pattern of the rain, as well as various characteristics of both the basin and the rainfall. Additionally, BRMS provides for action rules, actions to be taken in response to certain events, which are based on the county flood warning plans. In rain rate mode, the system allows the user to view the spatial pattern of the rain with very high resolution. The images are directly generated from gridded data, whereas the other types of displays are created from assertions, which in turn are produced from gridded datasets.

We expect more feedback from the current users that would allow us to make a better judgment of the utility of BRMS. Currently, we are developing a technology for adapting BRMS to other regions, as well as expanding its scope to other types of weather hazards. As FSL is moving toward the world of Open Systems, we need to adjust our architecture to the new computing environment as well. Another area of research that is going on in the Dissemination Project and might influence BRMS is the development of a new assertional and presentation system supporting a wide variety of descriptions and modes of presentation.

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Figures

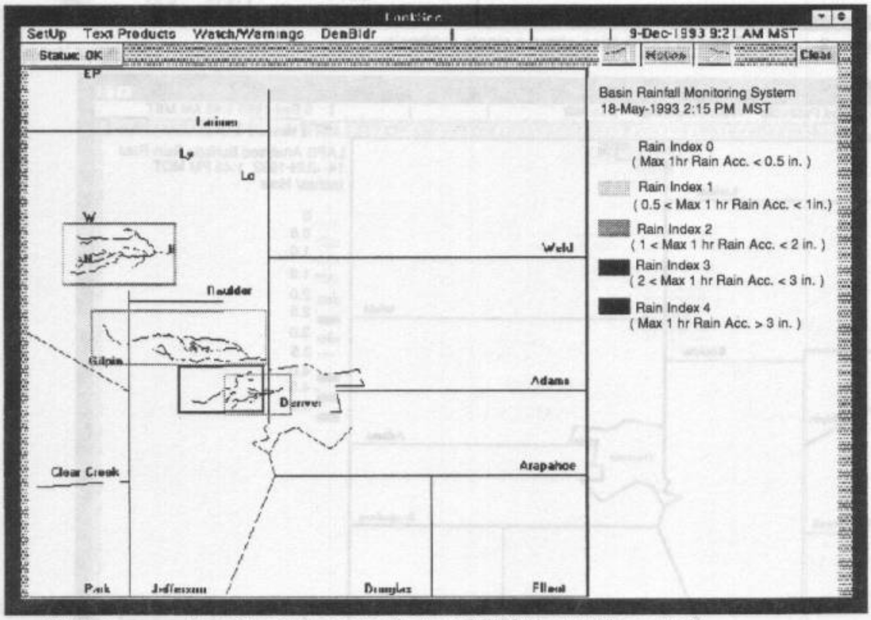

Figure 1. Basin Rainfall Monitoring System (BRMS) in surveillance mode.

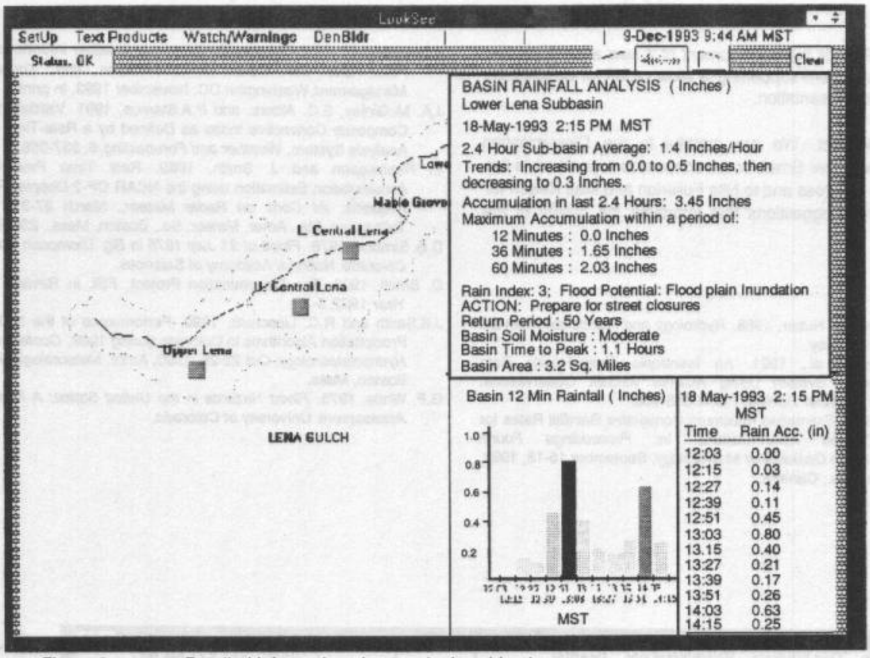

Figure 2. Detailed information about a single subbasin

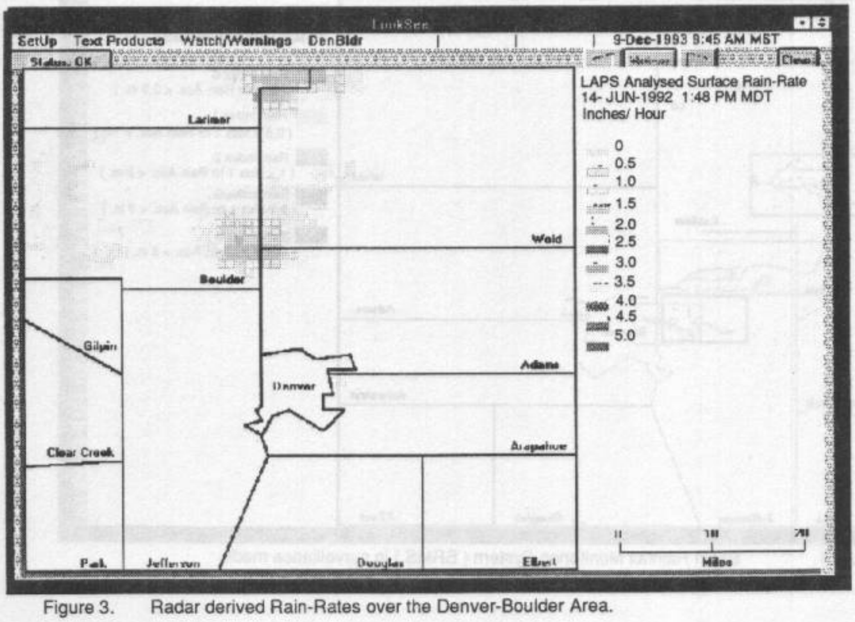

Figure 3. Radar derived Rain-Rates over the Denver-Boulder Area.