STORM-FEST HYDROMETEOROLOGY: AN OVERVIEW OF SOME EVOLVING WSR-88D DATA APPLICATIONS

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ABSTRACT: Between February 1 and March 15, 1992 a research project called the STormscale Operational Research and Meteorology - Fronts Experiment Systems Test (STORM-FEST) was conducted over the midwestern U.S. to investigate development and evolution of winter storms and to test and evaluate new observational systems being deployed as part of the National Weather Service (NWS) modernization. The hydrometeorologic component of STORM-FEST, called MESH (MESoscale Hydrology), focused on estimating precipitation in central Oklahoma using radar data from the new WSR-88D (NEXRAD) observing system. Additional objectives included evaluation of experimental precipitation forecasts, evaluation of experimental stage height river forecasts, and improving our understanding of basin hydrology. This paper summarizes the experimental design, presents examples of the data collected, and discusses some of the opportunities for improved water management that the new WSR-88D technology offers to the water resource community.
KEY TERMS: STORM-FEST, WSR-88D, mesoscale hydrology, hydrometeorology, precipitation algorithms, raingages

INTRODUCTION

The most accurate way to measure rainfall is with a rain gage. However, rain gages only measure rainfall at a point. For home gardeners, or farmers with small acreage, one or two gages provide sufficient information for crop watering needs. For most of society, there is greater interest in accurate spatial and temporal rainfall amounts over larger catchment areas. Extrapolating a few point measurements over vast areas introduces unacceptable errors. Alternatively, to have a sufficient number of gages to measure accurately the temporal and spatial variability of rainfall over large domains is prohibitively expensive.

Since the advent of the WSR-57 radars, scientists have been trying to improve our ability to estimate areal precipitation amounts using various remote sensing parameterizations. The accuracy of the radar-measured technique has shown considerable variability through the years from storm to storm, from season to season, and from one geographical location to another (Battan, 1973). Nevertheless, radar has the advantage of being able to survey very large areas and make millions of measurements in minutes.

To minimize the errors inherent in each of the above approaches, scientists have tried to take advantage of the best qualities of each by using rain gage-radar combinations to estimate the areal average rain. The objective is to combine sparse rain gage and dense radar rainfall data to produce a rainfall estimate with the point accuracy of gages and the spatial resolution and coverage of radar. This approach has yielded some improvement (see e.g., Wilson and Brandes, 1979), however, after many years of development of techniques, there is still no satisfactory method for accurately estimating the rainfall rate when high spatial and temporal resolution is required (Doviak and Zrnic, 1984).

With the deployment of the WSR-88D radars, a unique opportunity exists to use their higher resolution data and almost complete nationwide coverage (by 1996), to improve significantly our ability to measure precipitation remotely. Two of the first WSR-88D sites are in Oklahoma. The recent field project, STORM-

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FEST, provided a framework for the beginning of an ongoing collaboration to evaluate 88D precipitation algorithms in the Oklahoma area and to examine some of the potential benefits to the hydrology community from improved spatial and temporal rainfall data.

EXPERIMENTAL DESIGN

Between February 1 and March 15, 1992 a research project called the STormscale Operational Research and Meteorology - Fronts Experiment Systems Test (STORM-FEST) was conducted over the midwestern U.S. to investigate development and evolution of winter storms and to test and evaluate new observational systems being deployed as part of the National Weather Service modernization. STORM-FEST was a multi-agency experiment consisting of laboratory groups and principal investigators from 7 federal agencies and 15 universities (for a complete description, see the STORM-FEST Operations Plan). There were 21 intensive observing periods that collected enhanced data sets from both operational and research facilities on six major cyclonic storm events, as well as for frontal, boundary layer, and hydrologic studies.

Figure 1 shows the primary experimental domain (rectangular box) and also indicates supporting upper air sites both within and upstream of the domain. Over 3600 soundings were taken during the experiment from NWS, Canadian, military, and supplemental radiosonde and dropwindsonde sites. Other data collected included over 300 flight hours on five research aircraft, high frequency surface data from 80 new NWS sites, over 200 hours of rapid scan satellite data, and high frequency sounding data from 22 Wind Profiler sites.

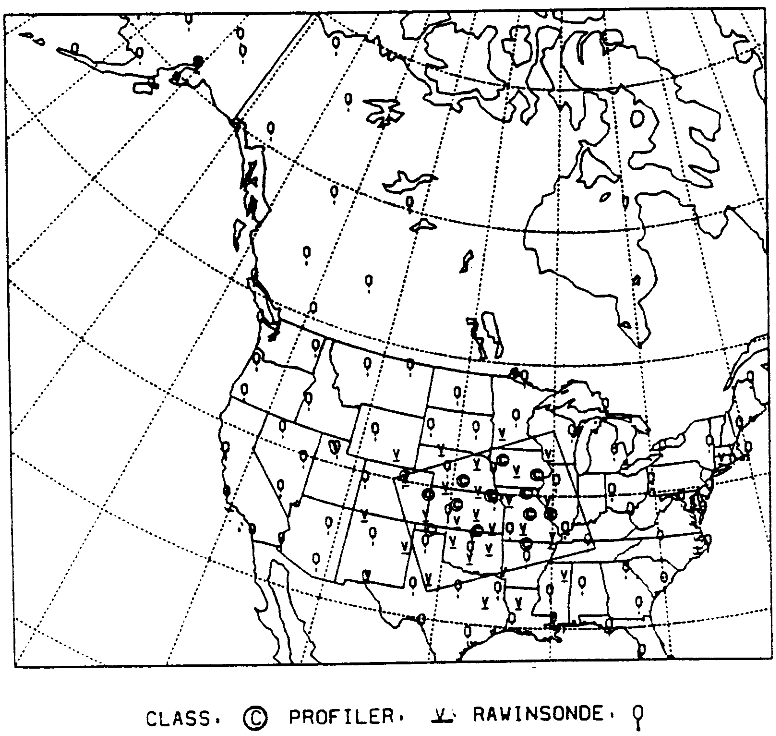

Figure 1. STORM-FEST Experimental Domain

Within the larger framework of STORM-FEST, a MESoscale Hydrology (MESH) project was designed and conducted in central Oklahoma. The KOKC and KFDR WSR-88D radars provided the centerpiece around which the hydrology experiments were planned. Also available was the KOUN prototype WSR-88D. The NWS Operational Support Facility (OSF) coordinated operations and data collections from the three radar sites. Located within the scanning range of all three radars is the U.S. Department of Agriculture/Agricultural Research Service (ARS) Little Washita raingage network. This 42 gage network, spaced over 590 km^2 comprising the Little Washita watershed, provided an opportunistic setting to begin to assess the accuracy of WSR-88D precipitation estimates on the mesoscale and their potential contribution to improving our understanding of basin hydrology.

Additional participants included the United States Geological Survey (USGS), who recorded streamflow measurements from two gaging stations along the Little Washita; the National Severe Storms Laboratory (NSSL), who collected dual-polarization data from their 10-cm research Doppler radar as well as raindrop size distributions from three drop disdrometers; the NWS Experimental Forecast Facility (EFF) who provided experimental quantitative precipitation forecasts (QPF) for the Little Washita watershed; and the NWS Arkansas-Red Basin River Forecast Center (ABRFC) who examined the impact of 88D precipitation data on simulated real time river forecasts. Table 1 summarizes the experimental framework.

TABLE 1. STORM-FEST MESH Experimental Framework

Radar Data:	KOKC WSR-88D KFDR WSR-88D KOUN WSR-88D NSSL 10 cm polarized Doppler
Precipitation Data:	ARS Raingage Network USGS Raingage Network Raindrop Disdrometers
Streamflow Data:	USGS gaging stations on Little Washita
Watershed Models:	ARS SWRRB ABRFC Sacramento
Thermodynamic Data:	Ft. Sill and OKC rawinsondes Purcell Profiler surface stations
Experimental Forecast Facilities:	Norman EFF ABRFC

Figure 2 shows the state of Oklahoma with the 230 km range circles of the three radars approximately indicated. Also shown is the location of the USGS statewide raingage network (dots) and the Little Washita watershed (hatched) wherein is deployed the ARS raingage network. The location of NSSL's Cimarron research radar (CIM) is indicated as well.

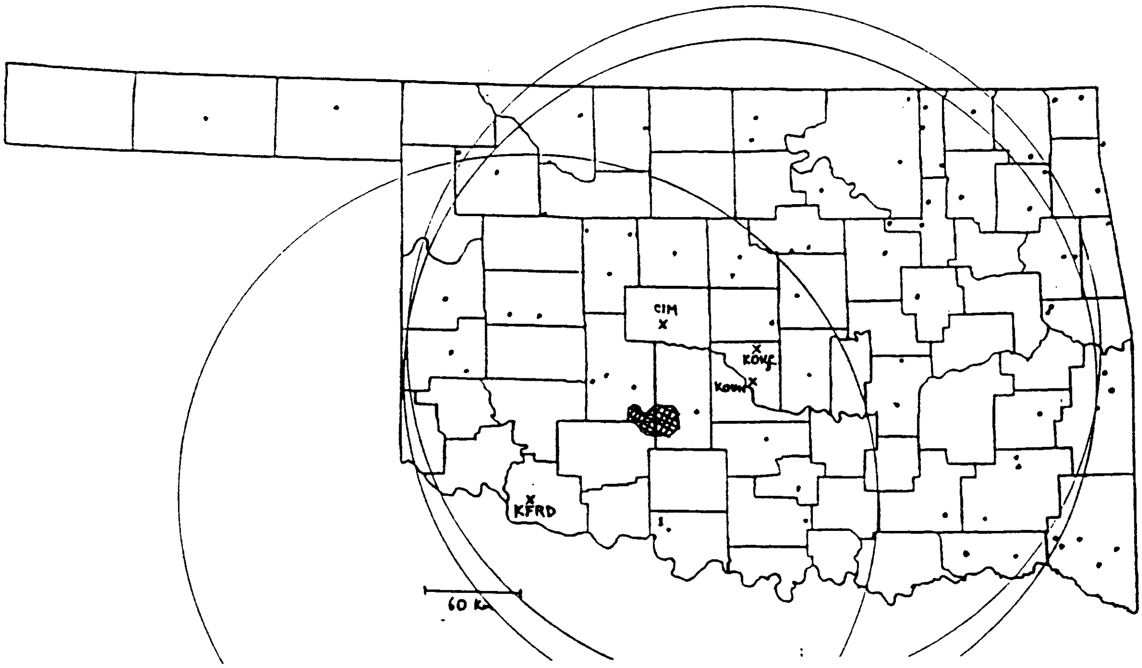

Figure 2. STORM-FEST MESH Experimental Domain

The primary **operational** objectives for STORM-FEST MESH were to:

* Begin to develop quantitative procedures for assessing the accuracy of radar estimates of precipitation.

* Begin to assess performance of the WSR-88D Precipitation Processing System for estimating precipitation during the winter season.

* Attempt to identify algorithm enhancements having high likelihood of improving WSR-88D precipitation estimates during the winter season.

* Evaluate experimental precipitation forecasts issued by the EFF in Norman, Oklahoma.

* Evaluate experimental streamflow forecasts issued by the NWS/ABRFC.

The primary **research** objectives for STORM-FEST MESH were to:

* Begin to identify the dominant physical processes that affect the capability to estimate stratiform rainfall rate from radar reflectivity observations.

* Begin to characterize the spatial and temporal variability of stratiform precipitation.

* Develop new methods to assimilate WSR-88D data in numerical models simulating basin hydrology.

* Examine the liquid/solid discriminating capabilities of polarized Doppler radar and implications for improved estimates of liquid and solid precipitation amounts.

Figure 3 shows a schematic activity summary encapsulating the participants, interactions, and general goals of STORM-FEST MESH.

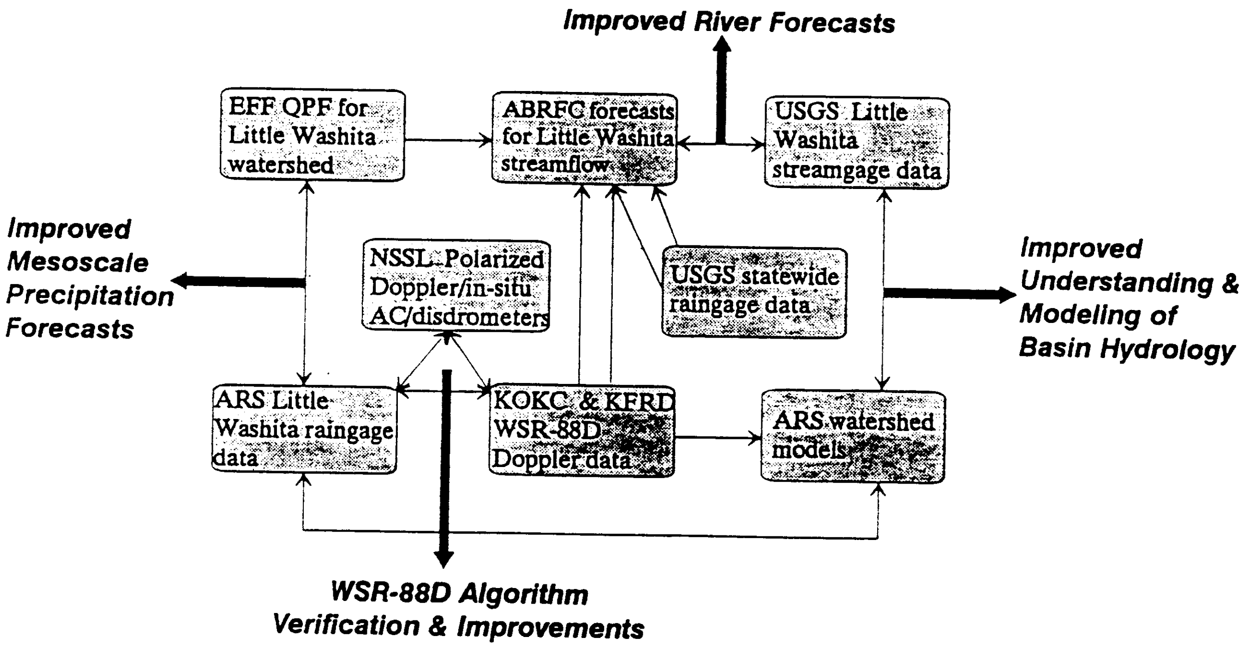

Figure 3. STORM-FEST MESH Activity Summary

EVENT SUMMARY

The first three weeks of the project were dominated by a high pressure ridge over the intermountain and west central Plains, leaving Oklahoma in weak northwesterly flow with little precipitation. The pattern became more zonal during the last three weeks of the project, producing three "significant" precipitation events over the Little Washita watershed. A summary of all precipitation events is compiled in Table 2 with convective events being designated by (C) and stratiform by (S).

TABLE 2. STORM-FEST MESH EVENT SUMMARY

FEB 12:	0 - Trace within the watershed (C)
FEB 22:	0 - 0.5" within the watershed (C)
FEB 24:	0.5 - 1.1" within the watershed (S)
MAR 3-4:	0.5 - 1.6" within the watershed (C)
MAR 8:	0 - 0.1" within the watershed (C)

DATA APPLICATIONS FOR WATER RESOURCE MANAGEMENT

To demonstrate some of the potential water resource management applications that data sets of this type will offer, the 3-4 March event is best suited for the purpose at this time.

Event summary - March 3-4, 1992: A low pressure system tracked across NE New Mexico and along the Kansas-Oklahoma border with an associated cold front progressing from west to east across Oklahoma. The warm sector ahead of the front was characterized by considerable low level moisture and moderate instabilities. The frontal push and several imbedded rotating short waves associated with an upper level low to the west initiated convection in SW Oklahoma on the evening of 3 March. Convective activity which formed ahead of the front moved across the watershed during the evening followed by a narrow squall line associated with the front. Precipitation ended over the watershed by 2 am on 4 March.

Rainfall amounts are of primary interest for managing water resources. The WSR-88D produces graphical products displaying 1 inch increments of precipitation amounts with a 2 X 2 km spatial resolution out to a range of 230 km. Three products are produced: storm total, three hour, and one hour precipitation amounts. An example is shown in Figure 4 which shows storm total precipitation for the 3-4 March event within the KOUN radar umbrella. The watershed is outlined and appears in the SW quadrant of the display. Precipitation estimated to have fallen in the watershed ranges from less than an inch in the SE two thirds to greater than an inch in the NW third, with one pixel indicating a greater than 2 inch amount.

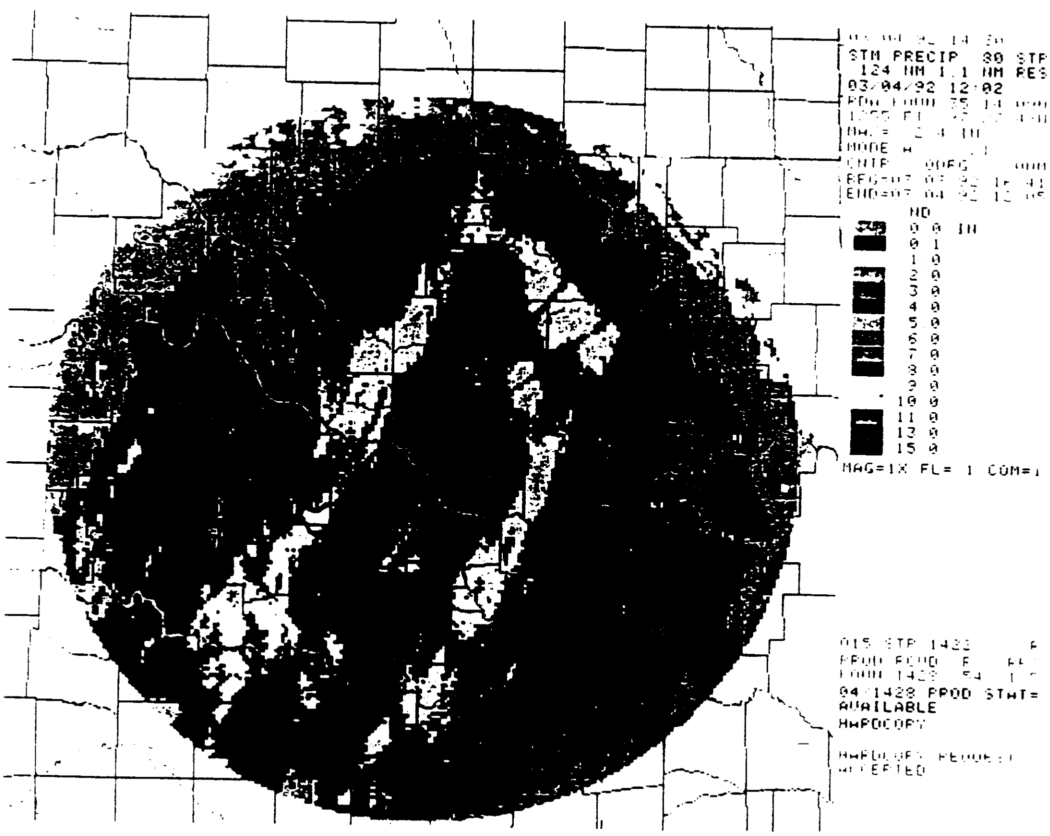

Figure 4. Storm total precipitation for the 3-4 March event as estimated from the KOUN WSR-88D

To get a better look at important features, various magnifications of the display are possible. Figure 5 shows storm total precipitation over the watershed and surrounding region (8X mag), as of 11:17 pm on 3 March, as estimated from the KOUN radar. The nature of the 2 X 2 km resolution shows up much more clearly at this magnification. At this time, precipitation amounts vary from 0 in the extreme east to greater than an inch in the middle western one third of the watershed. An 8X magnification from KOUN of storm total precipitation for the entire event was not readily available as of preprint deadline.

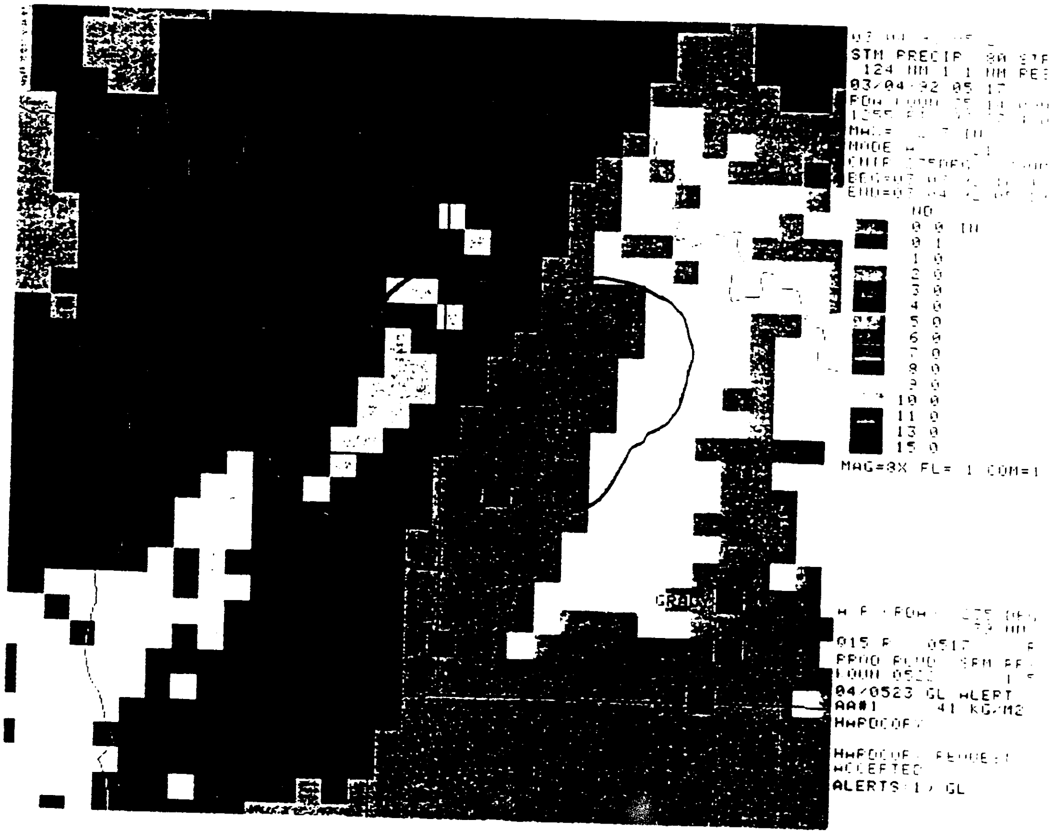

Figure 5. Storm total precipitation (8x mag) estimated from the KOUN WSR-88D for the Little Washita watershed, as of 11:17 PM on 3 March

It is expected that the nationwide deployment of WSR-88D systems will greatly improve our ability to estimate areal rainfall. However, although the existing algorithms have been formulated to the best that current knowledge allows, it is still not clear that optimal estimation of areal rainfall has been achieved. One of the purposes of the STORM-FEST MESH experiment was to collect mesoscale rainfall data to verify and, if possible, improve existing algorithms.

The workhorse for this task is the ARS raingage network in the Little Washita watershed. The raingage network consists of 42 gages spread over approximately 590 sq. km. This equates to a gage approximately every 5 km. The gages operate by means of a collecting bucket whose weight is continually weighed and recorded on chart paper covering a cylindrical drum rotating at a fixed rate. Once a week, the chart paper is changed and the drum is rewound. Information extractable from the record includes the weekly frequency of rainfall events, when these events occurred, how long they lasted, how rainfall intensity varied during the event and how much precipitation fell per event and in total. The raingages are accurate to 0.01 inches and about 2 minutes.

Figure 6 shows storm total precipitation as measured by the raingage network for the 3-4 March event. Gage sites are noted by dots and the precipitation measured at that site. Isopleths have been drawn with 0.2 inch increments. Note that the watershed received between 0.5 and 1.6 inches of rain with a maximum swath oriented SW/NE across the middle western 1/3 of the region. Precipitation amounts decrease to 1 inch toward the NW and to 0.5 inches in the SE. A comparison with Fig. 4 shows that the WSR-88D did a good job of capturing the essence of the precipitation event over the watershed, particularly with regard to spatial distribution. The 88D does suggest a small region of greater than two inches which was not captured in the raingage data. However, it is possible that 2 inch amounts fell between the gages. Also, no raingage data has been used to adjust the 88D precipitation field as will be the case under normal operating conditions in the near future.

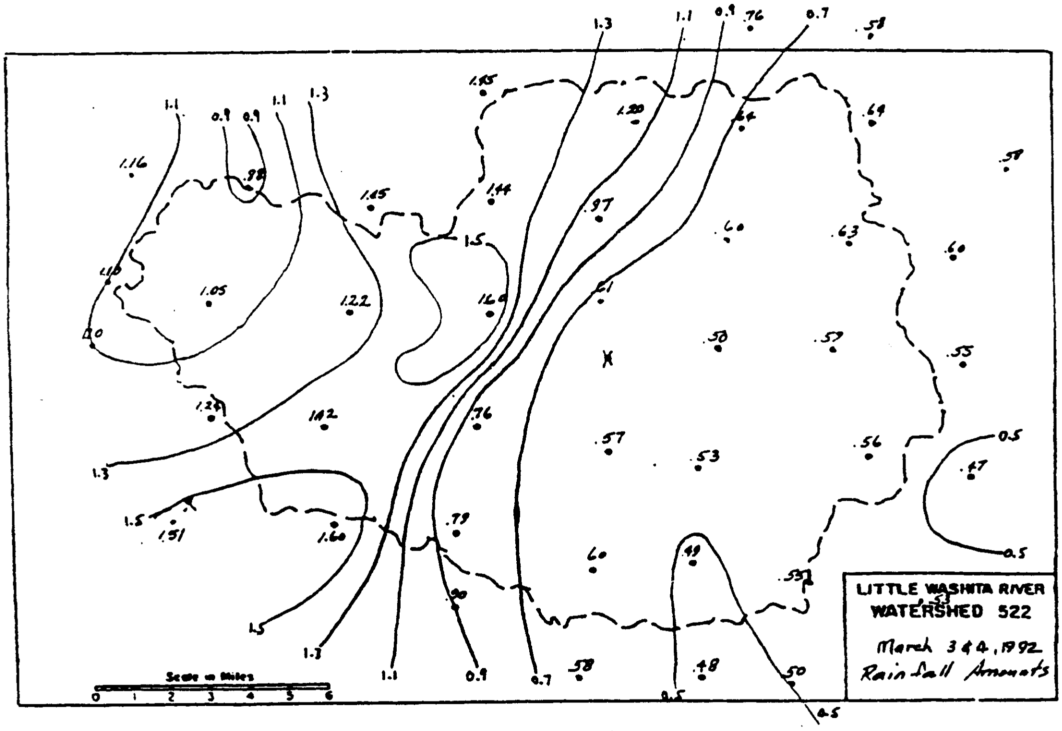

Figure 6. Storm total precipitation for the 3-4 March event as measured by the ARS raingage network in the Little Washita watershed.

It should be noted that the current scale of 1 inch rainfall increments which will be displayed in the WSFO's, while sufficient for real time flash flood considerations, is not very practical for more general water resource considerations. There is a big difference between 0.15 inches of rain and 0.95 inches of rain. More detailed precipitation information is available from the WSR-88D system in the form of a digital array product of the running hourly accumulations. The product, updated every volume scan, will be mapped onto a 4 X 4 km grid. Although the spatial scale is somewhat degraded, it will provide 6 minute temporal resolution and up to 100 rainfall increment categories. (Walton, et al., 1988). Through careful examination of the digital array products and comparisons with mesoscale raingage networks, researchers will make the verifications and observe the discrepancies which will eventually lead to optimization of the WSR-88D precipitation estimation procedures.

For many water resource applications, the amount of rainfall reaching the ground is only part of the answer. What happens to the water after it reaches the ground has profound implications for such things as flash flood occurrence; recharging of soil moisture, reservoirs and aquifers; quality of drinking water; soil erosion; nutrient exchange; and improved understanding of the earth's hydrologic cycle. STORM-FEST MESH included aspects aimed at addressing some of these issues as well.

The Little Washita watershed is well suited for these types of studies. During the past thirty years, the watershed has served as a major focal point for the collection of hydrologic data. This data collection process involved an intensive raingage network and a stream gaging station near the watershed outlet that provided data on continuous flow, suspended sediment transport, and, for a few years, water quality. Data on groundwater levels and channel geometry were also collected. In addition, the entire watershed has been characterized as to soil type, vegetation, underlying geology, as well as the location and type of farm ponds, flood control structures, irrigation channels, and other natural and manmade phenomena that might influence basin hydrology (Allen and Naney, 1991). It is probably the most studied and best characterized watershed of its size in the Nation.

As a result of its history and future potential, the watershed is becoming a site for enhanced scientific studies. As part of a long term effort to add and improve instrumentation within the watershed, but sparked by the conduction of STORM-FEST MESH, the USGS installed two automated gaging stations on the Little Washita. One was located at the outlet from the watershed and another at an upstream site at the outlet from an imbedded sub-shed. These gages provide hourly discharge and stage height measurements. Thus, not only do the data sets contain high resolution spatial and temporal rainfall data, but also the impact of the precipitation event on runoff from the watershed. This offers an exciting opportunity to improve our modeling and understanding of basin hydrology. ARS, among others, is pursuing this aspect.

In addition to the 88D and watershed data, STORM-FEST MESH also included data collection by NSSL's polarized Doppler radar. This research is part of a longer term effort to examine whether alternating vertically and horizontally polarized radar signals can improve our ability to distinguish and measure rain, snow, sleet and hail. NSSL also deployed three raindrop disdrometers which will be used to examine how variations in raindrop size spectra can affect 88D precipitation estimating algorithms.

The NWS/WSFO in Norman provided experimental precipitation forecasts for the Little Washita basin. Through comparisons with WSR-88D observations and case studies examining how the weather actually evolved to how it was forecast to evolve, it is expected that the 88D, in conjunction with other new NWS observing technologies, will lead to improved precipitation forecasts in the not too distant future. In addition, the NWS/ABRFC, who are using 88D data as part of their routine flash flood forecast mission, also has the capability to evaluate how accurately their real time forecast models using 88D precipitation input is simulating streamflow on the Little Washita. This will hopefully lead to improved real time flash flood forecasts.

SUMMARY

The STORM-FEST MESH project, described in this paper, provides numerous research opportunities which will lead to improved water resource management capabilities during the coming years. These are summarized in Table 3. In addition, the cooperation developed during the project (see Figure 3) continues as an ongoing activity as all of the important instrumentation remains in place and collecting data. Together, such efforts will lead to improved forecasts of the amount, timing, and spatial distribution of precipitation; more accurate measurements of the amount, timing, and spatial distribution of precipitation; improved forecasts of the location, amount and timing of stream and river runoff; and improved understanding of the hydrologic cycle. All of these advances will have direct positive consequences for managing our water resources.

TABLE 3. STORM-FEST MESH Research Opportunities

Evaluation of EFF QPF forecasts
- case studies of synoptic/mesoscale evolution
- 2 minute raingage measurements (5x5km) over the Little Washita watershed

Temporal and spatial evaluation of WSR-88D algorithm performance
- 6 minute precipitation estimates (4x4km) from WSR-88D
- 2 minute raingage measurements (5x5km) over the Little Washita watershed
- 0.5 - 2 minute disdrometer data

Temporal and spatial evaluation of basin hydrology models
- 1 hour stage height measurements
- 2 minute raingage measurements (5x5km) over the Little Washita watershed
- 6 minute precipitation estimates (4x4km) from WSR-88D
- 0.5 - 2 minute disdrometer data

Evaluation of ABRFC stage height forecasts
- 1 hour stage height measurements
- 6 minute precipitation estimates (4x4km) from WSR-88D

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