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"Preliminary Operational Results from Application of the Next Generation Weather Radar to Hydrologic Forecasting"

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ABSTRACT

After more than a decade of planning, development, and testing for the Next Generation Weather Radar (NEXRAD) in the United States, operational implementation is now underway. This new radar system (called the WSR-88D) is a modern, integrated Doppler system capable of making high quality measurements and includes the levels of numerical processing required to derive quantitative precipitation estimates. The software designs for obtaining precipitation estimates for input to hydrologic modeling and forecast applications are multistage in nature. Preliminary results are now forthcoming from all stages of processing and analyses, including the third stage which has as a component the compositing of information from multiple radars covering large river basins.

Hydrologic applications of WSR-88D based precipitation estimates include improved information for flood forecasting and control, drought assessment forecasting and a wide scope of water management decision-making. Preliminary results from actual storms observed by the first operational WSR-88D systems are presented. Finally, a framework is developed for future technical improvements to all of the multistages of processing.

1. INTRODUCTION

After many years of effort in the United States, the realization of applying radar-based rainfall estimates to real-time hydrologic forecasting problems is nearing fruition. Descriptions of the history of developments over the years and the evolution of the methodology for a multistage precipitation processing system can be traced by referring to Ahnert et al. (1983), Ahnert et al. (1984), Hudlow et al. (1983), Shedd et al. (1991), Hudlow et al. (1991), Hudlow (1990), and Shedd and Smith (1991).

Figure 1 illustrates the three stages of the multistage processing and analysis system. Stages I and II are fully automated software systems while Stage III is an interactive system which allows the hydrometeorological forecaster to interactively analyze mosaicked precipitation fields through the use of networked scientific workstations (Shedd and Smith, 1991).

Figure 2 illustrates those WSR-88D systems already delivered under the limited production phase of the NEXRAD contract. Figures 3 and 4 illustrate anticipated coverage by WSR-88D systems

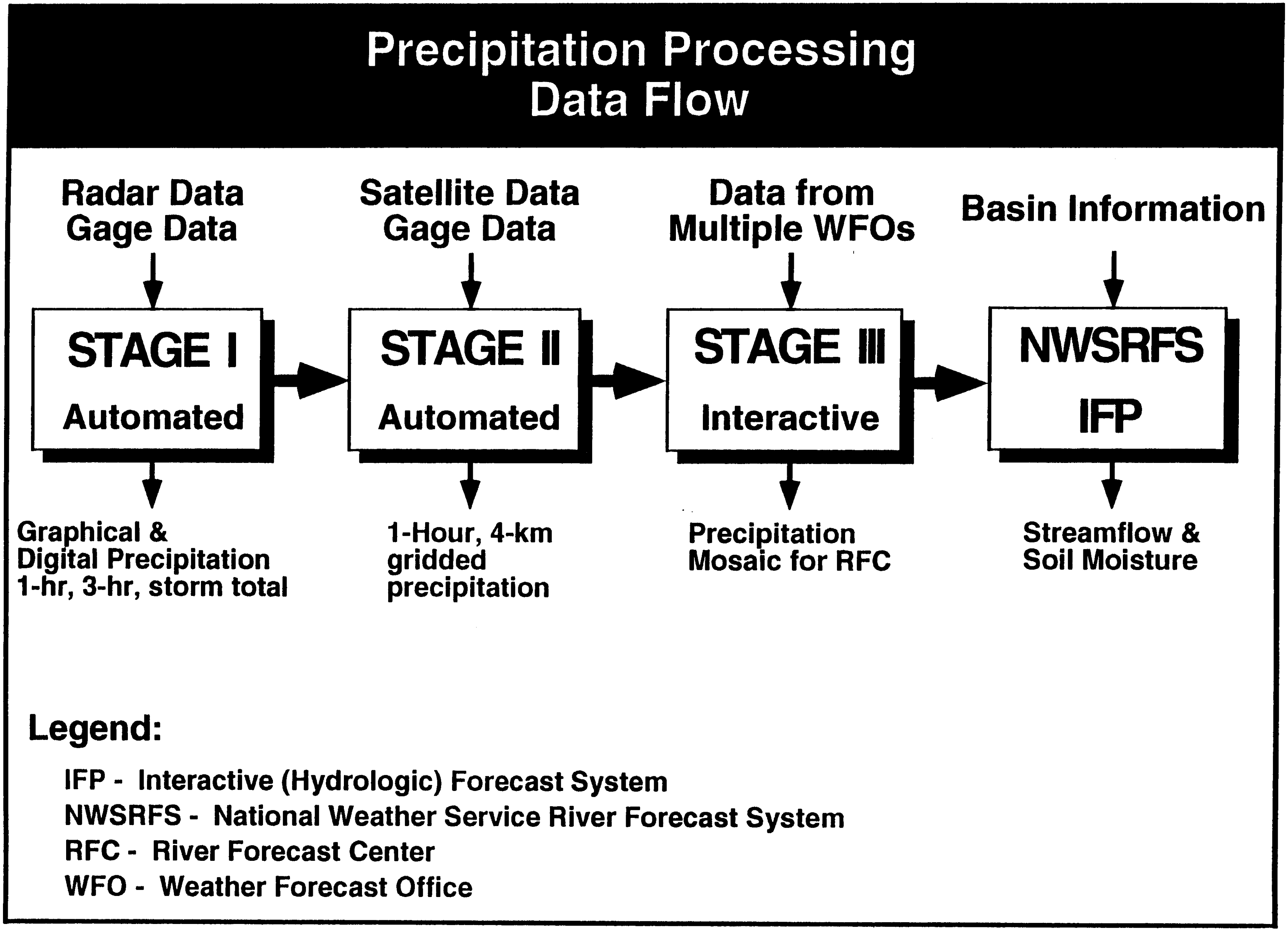


Figure 1: **Illustration of the processing stream associated with the multistages of processing employed to prepare the rainfall estimates for input to the NWSRFS.**

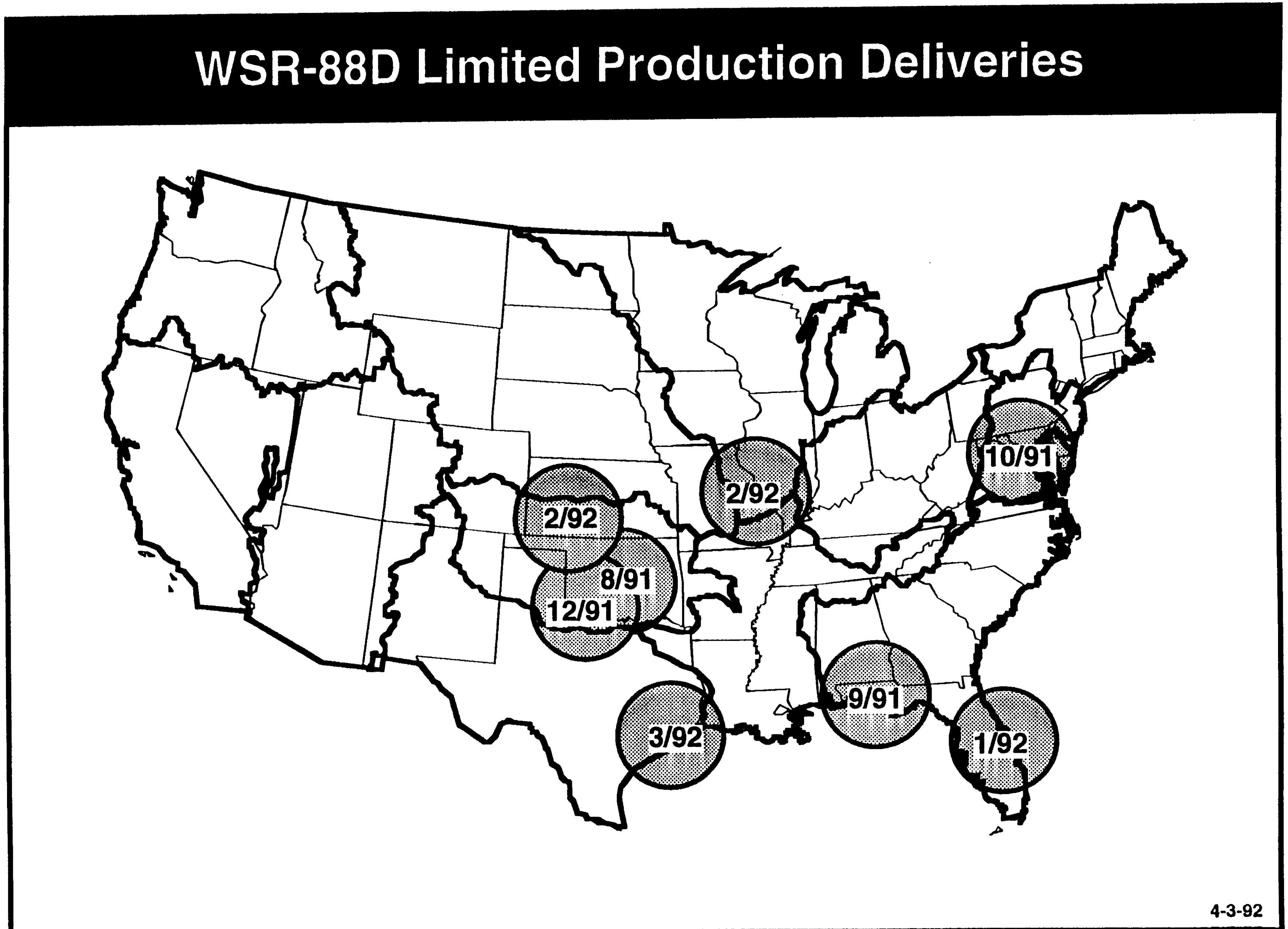


Figure 2: **WSR-88D Coverage with Limited Production Systems.**

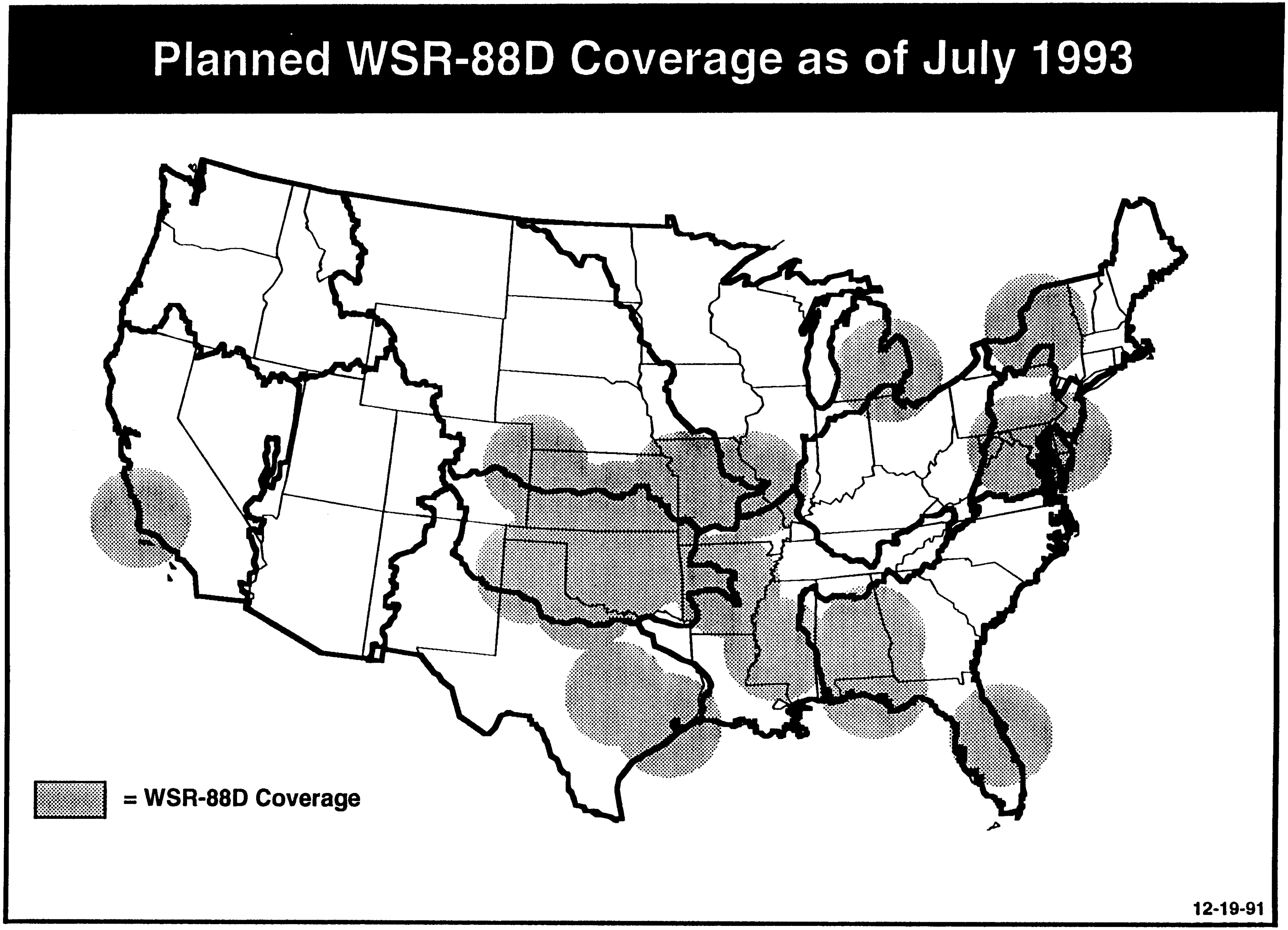


Figure 3: **Anticipated WSR-88D Coverage by July 1993.**

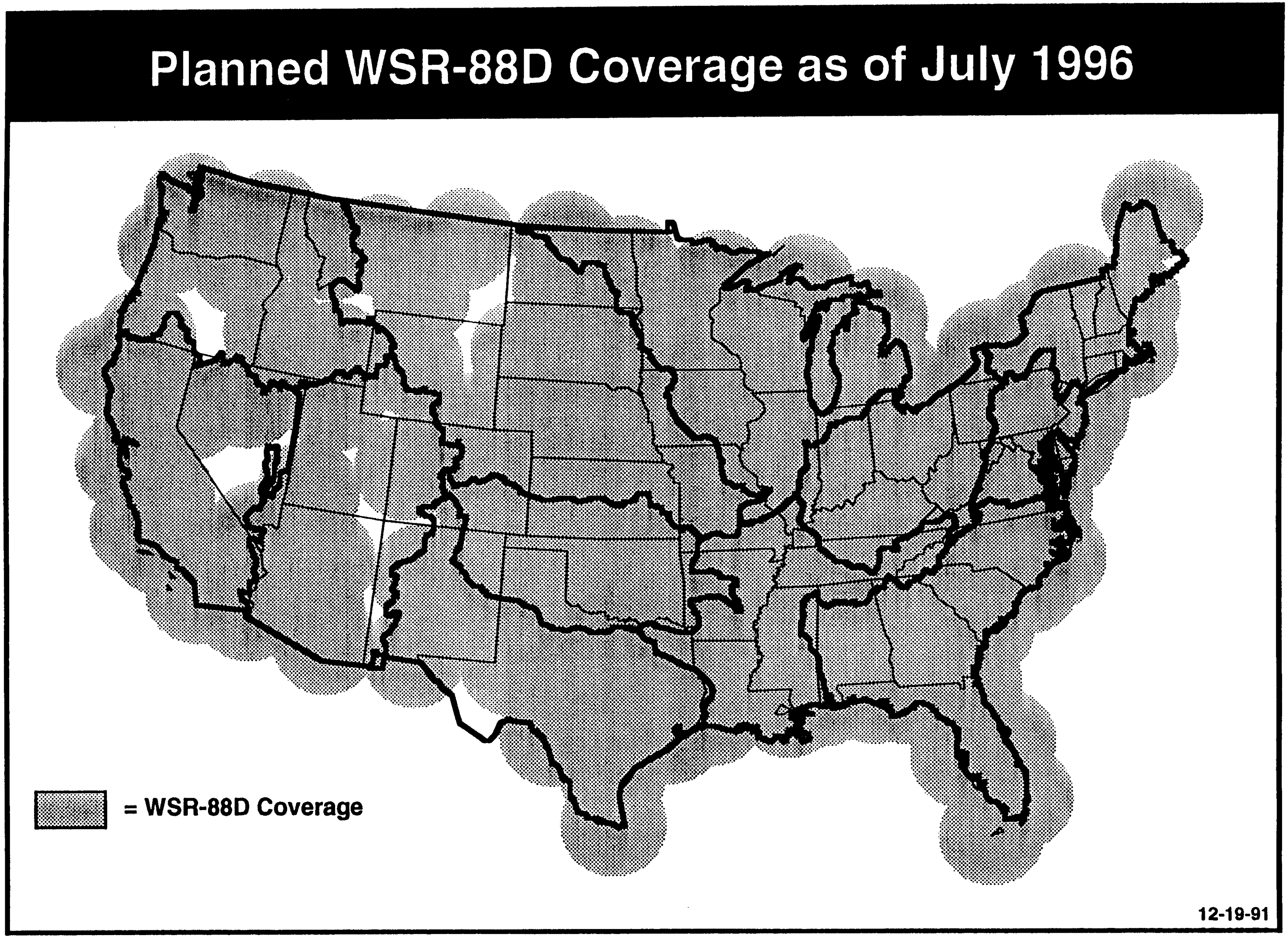


Figure 4: **Anticipated WSR-88D Coverage by July 1996.**

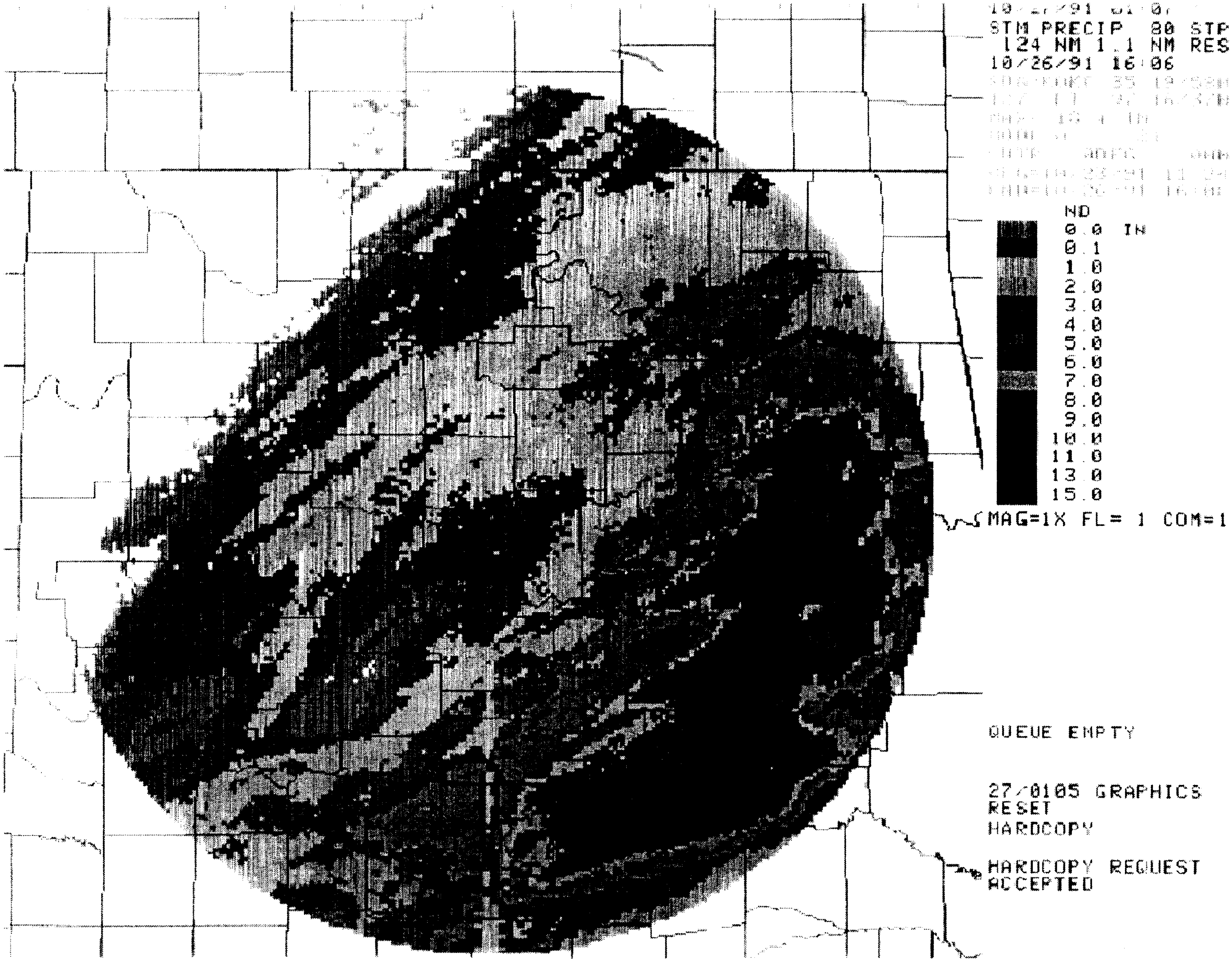
by July 1993 and July 1996, respectively. The latter date is the currently projected time at which all systems would have been installed in the 48 contiguous United States. The range of the circles in all cases is 230 km which is the maximum range that processing is carried out for precipitation estimation. The actual coverage in some of the mountainous western states will be somewhat less than the ideal as shown in Figure 4, although great effort has been taken in the processing to minimize the impact of blockages from terrain and manmade obstructions.

2. PRELIMINARY RESULTS

We are now beginning to see preliminary results from the Stage I processing, and to a lesser extent from Stages II and III, from the radars that have been installed under the Limited Production Phase of the NEXRAD contract (Fig. 2). Much of the developmental and testing effort is focused in the Arkansas-Red River Basin which comprises all of the State of Oklahoma and portions of Colorado, Kansas, New Mexico, Texas, Missouri, and Arkansas, (see Figure 6). This focus stems from the intent to concentrate resources and bring an initial River Forecast Center (RFC) to a full level of modernized operations as described in the document entitled "Hydrometeorological Service Operations for the 1990's" (Office of Hydrology, 1991). A parallel effort is underway to demonstrate modernized meteorological operations at the Weather Forecast Office (WFO) in Norman, Oklahoma. As illustrated in Figure 3, almost all of the area of responsibility of the Arkansas-Red Basin RFC (ABRFC) [located at Tulsa, Oklahoma] is scheduled to be covered by WSR-88D based precipitation estimates in July 1993. Part of the operational demonstration activities in Oklahoma include real-time interactions and exchange of information between the Norman WFO and the ABRFC, and they in turn with principal cooperating water agencies.

Figure 5 is an example of a storm accumulation map from the WSR-88D system located in Twin Lakes, Oklahoma (near Oklahoma City). This example was for a storm which produced some minor flooding in Southeast Oklahoma during late October, 1991. In this case, storm accumulations reached 15 inches and would have produced major flooding except for dry antecedent conditions. Although the Stage II and III processing systems were not fully operational at the ABRFC at the time, forecasters manually input estimates from the Stage I output into the NWS River Forecast System (NWSRFS) to produce operational forecasts. This was done because extremely limited gage data existed over the major area of concentrated rainfall and because the very few gages available compared favorably with WSR-88D estimates. The resulting river forecasts were verified and clearly produced results superior to those which would have been possible with the sparse rain gage network only. Similarly good results have been reported for other cases from the Twin Lakes radar and from WSR-88D radars located in Melbourne, Florida and Sterling, Virginia. One of the most surprising findings to date has been the superior performance of the WSR-88D at far ranges (the maximum range displayed in Figure 5 is 124 nautical miles or 230 km). Range effect corrections are employed in Stage I processing. Nevertheless, even taking into account these first order corrections, the WSR-88D is exceeding expectations, especially in light to moderate precipitation.

To support numerical hydrologic modeling, an RFC requires Stage II and Stage III precipitation



Figture 5: **Storm total accumulation map based on Stage I estimates from the WSR-88D radar located in Twin Lakes, Oklahoma.**

processing capabilities. The initial operational configuration of these systems is now undergoing testing at the ABRFC. Figure 6 illustrates a mosaicked map of hourly precipitation accumulations within the ABRFC. Many of the interactive features of the Stage III precipitation processing system (Shedd and Smith, 1991) are designed to aid the hydrometeorological forecaster in quality control of the final precipitation estimates before they are entered into the NWSRFS and to reiterate, if necessary, based on observed versus forecasted streamflows. Figure 7 illustrates just one of the many features of the Stage III interactive systems. This particular feature employs "X-windows" technology to provide side-by-side comparisons of multisensor derived rainfall fields and gage-only derived rainfall fields.

3. FUTURE DIRECTIONS

A number of considerations exist in setting future directions for continued improvements in the application of WSR-88D information to hydrologic/hydrometeorological applications. Clearly much of the effort must continue to be directed toward developing refinements and enhancements to the Stage I, Stage II, and Stage III precipitation processing systems. Furthermore, effort must be expanded to more effectively couple, allowing for reiteration, the Stage III interactive precipitation processing systems and the interactive NWSRFS (Figure 8). Specific application of the WSR-88D rainfall estimates to the improvement of flash-flood warnings is an area requiring considerable additional work, although much progress has been made (Walton et al. 1985; Walton et al., 1986; O'Bannon, 1988).

The remainder of this section of the paper will focus on the description of a framework to proceed with future refinements and enhancements of the Stage I, II, and III precipitation processing systems. Table 1 and Table 2 summarize this framework. Table 1 includes the following information: 1) the item from which errors can be introduced or the item which needs improving in order to reduce errors from various sources of contamination of the radar data, the gage data, or both; 2) the level of impact that the item can have on the quality of the precipitation estimates; 3) the current (now) level of capability existing within the three stages of processing to address the item; 4) the level of corrective action that may be possible in the future for the item for the three stages of processing; 5) the magnitude of resources required to achieve the possible level of corrective action for the item; and 6) a note which is keyed to Table 2.

For the three stages of processing, Table 2 contains a summary of : 1) the current status of techniques employed to address the items identified in Table 1 (and Table 2); 2) future work anticipated to more completely address the items; and 3) some appropriate references relevant to the individual items and corrective actions employed. Again, the "note" cross references Tables 1 and 2.

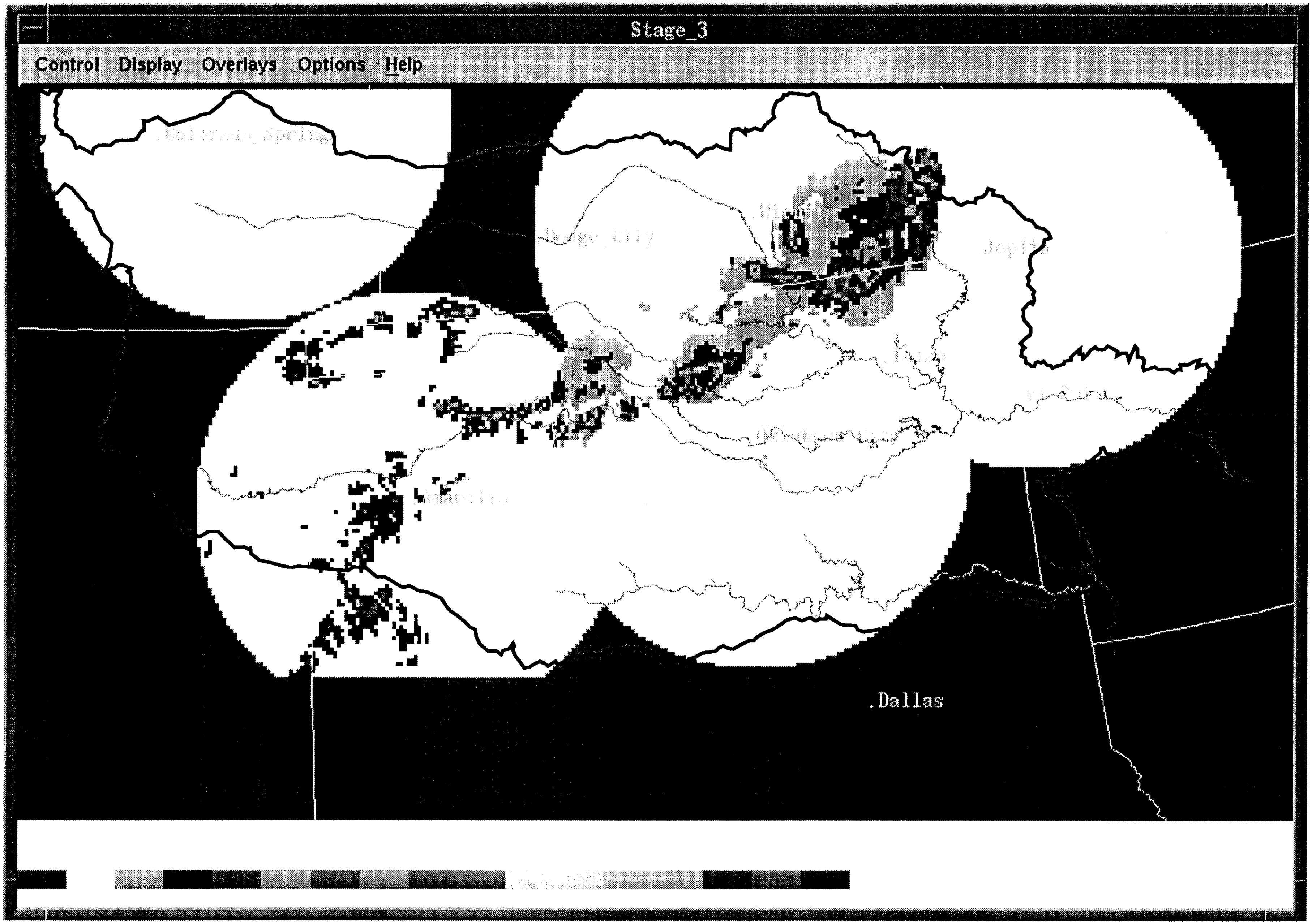


Figure 6: **Example display from the Stage III interactive system illustrating the mosaicking of the hourly rainfall accumulations within the Arkansas - Red River Basin.**

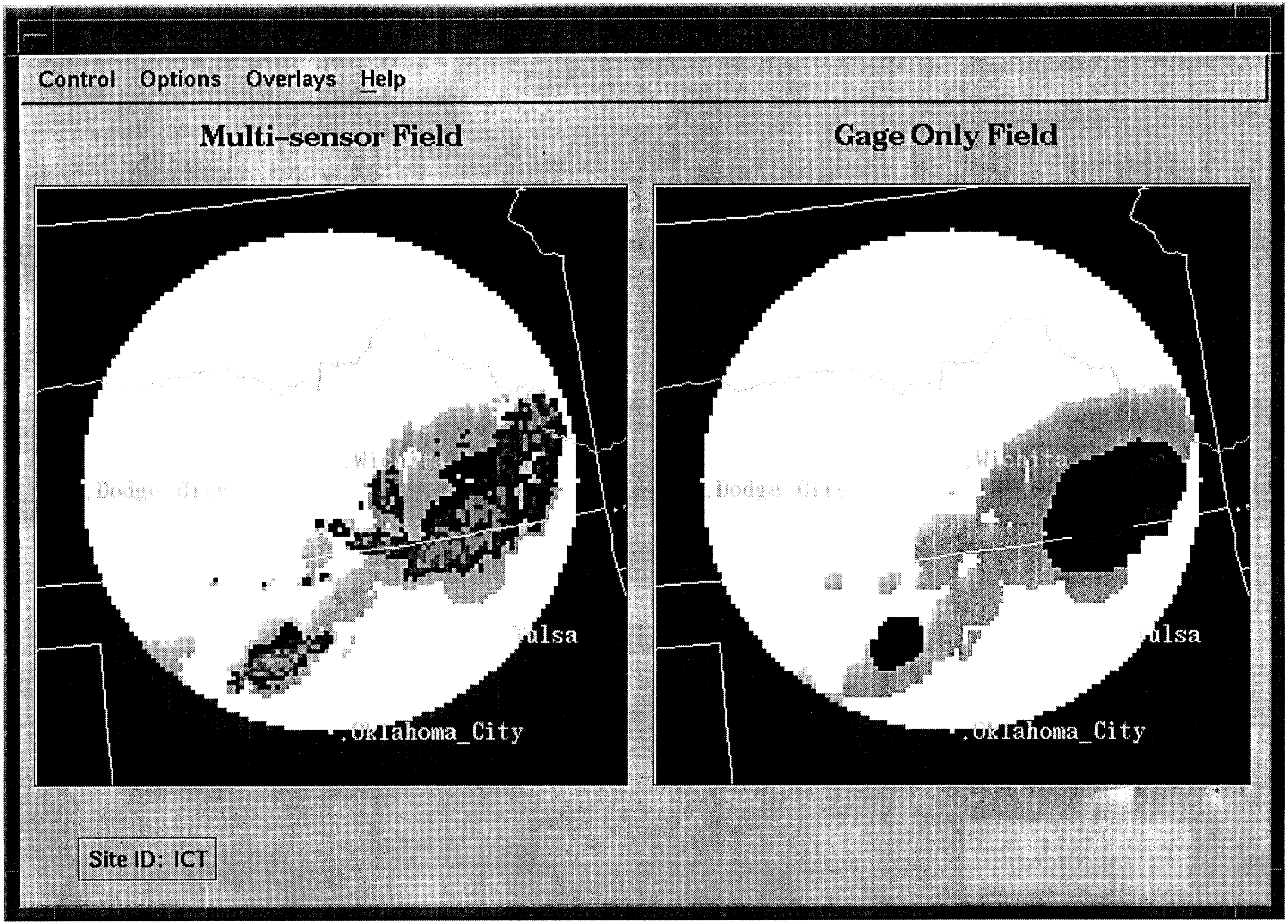


Figure 7: **Illustration of one of the interactive features provided by the Stage III precipitation processing system**

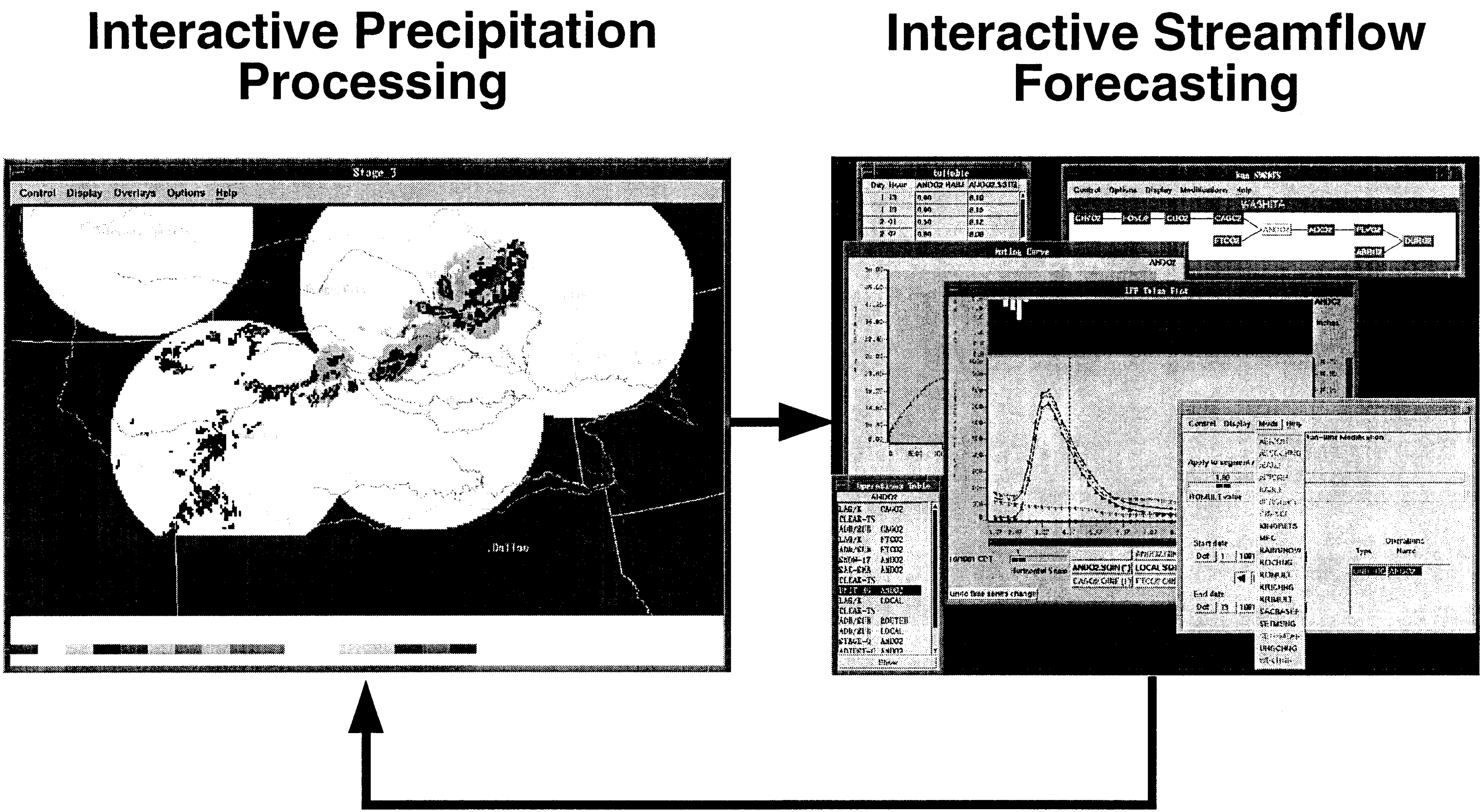


Figure 8: **Illustration of the coupled Stage III precipitation processing system and the interactive NWSRFS.**

4. CONCLUDING REMARKS

The next several years promise to be extremely exciting ones in the field of hydrometeorology. The science and technology has now reached a point that during this decade we should make revolutionary advances in precipitation estimation and hydrologic forecasting. The lives to be saved and economic benefits to be derived from these new capabilities are enormous. This paper has largely concentrated on development and the operational demonstration efforts underway in the United States. Similar progress is being made in other parts of the world as described by Romijn (1990) and Cluckie and Collier (1991).

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Table 1: Framework for future refinements and enhancements of precipitation processing software. Those items on the first page represent physically based impacts on the precipitation analysis. Those on the second are refinements to processing techniques. This table does not represent a comprehensive list of potential areas of investigation.

ITEM	Impact	STAGE I				STAGE II				STAGE III			
		Now	Level	Res.	Note	Now	Level	Res.	Note	Now	Level	Res	Note
Anomalous Propagation (AP)	A	2	3	a	1	2	3	a	2	2	1	a	3
Bright Band	B/A	3	2	b,d	4	3	2	d	5	2	2	c	6
Oxygen Absorption	C	1	1	a	7								
Range Effects	A	2	3		8	2	3		9	1	2	a	10
Snow	A	3	3	d,c	11								
Hail	B/A	2	2/3	d,c	12	3	2	d	13				
Beam blockage	A	2	3	a	14	2	3	b	15	2	2	d	16
Orographic Effects	B/A regional	3	3	d	17	2	2	d	18	3	2	c/d	19
Attenuation	C	2	2	a	20					2	3		30

ITEM	Impact	STAGE I				STAGE II				STAGE III			
		Now	Level	Res.	Note	Now	Level	Res.	Note	Now	Level	Res	Note
Interactive Features	B/A	3			31	3			32	2	2	b/c	33
Adaptation Parameters	B/A	2	2	a/c	21	2	2	a/c	22	2	2	b/c	23
Quality Control of Gages	B/A	2	2	a/c	24	2	2	a/c	25	2	2	b/c	26
Field Quality Control	B/A	2	2	a/c		2	2	a/c		2	2	b/c	
Numerical Analysis Techniques	B/A	2	2	c/d	27	2	2	c/d	28	2	2	c/d	29

Impact: A: Major impact on precipitation estimates
B: Minor to moderate impact, may have some visual impact
C: Little or no impact

Now: 1: Full level possible being met
2: Some correction being made
3: No correction currently attempted

Level: 1: Complete correction possible
2: Sufficient correction possible to reduce impact
3: Some correction possible, further required
4: Detection possible, but not correction

Res: a: No additional resources required
b: Minor to moderate level of resources required
c: Technology exists, significant resources required
d: Requires basic and/or applied research

Note: cross reference between tables

Table 2: Summary of current techniques and future work to address the items listed in table 1. The dark line separates the physically based from processing techniques. This list should not be considered comprehensive.

Note	Item	Stage	Current Status	Future Work	Reference
1	Anomalous Propagation (AP)	I	hybrid scan; bi-scan maximization; rate of change of volumetric water; comparison of data from low two tilts		Ahnert et al. (1983)
2	Anomalous Propagation (AP)	II	satellite IR check		Fiore et al. (1986)
3	Anomalous Propagation (AP)	III	interactive identification	further improvements in interactive techniques	Shedd & Smith (1991)
4	Bright Band	I	none explicit other than basic outlier checks	working on adaptation of British detection scheme; will allow detection; capability for correction to be determined; use of Dual polarization may also assist in detection in the distant future	Smith, C. (1986)
5	Bright Band	II	implicit adjustments in vicinity of gages	incorporate vertical sounding data to determine existence of bright band and height of melting layer	
6	Bright Band	III		interactive editing when bright annuli appear	
7	Oxygen Absorption	I	performed in signal processing prior to execution of scientific algorithms		
8	Range Effects	I	simple 3 parameter model exists adjusting rates as function of rate & range; requires a significant amount of archive data to optimally set parameters	carry out post analysis to optimize parameter values	Ahnert et al. (1983)
9	Range Effects	II	not explicitly addressed; localized adjustments with gages may reduce some impacts of range effect		Krajewski and Ahnert (1986)
10	Range Effects	III	mosaicking procedure will reduce range effects in areas of good overlapping coverage		

Note	Item	Stage	Current Status	Future Work	Reference
11	Snow	I		requires some basic research to improve methodology; as interim measure could develop modified Z-R to use for known snow cases	
12	Hail	I	this is currently being handled through use of outlier parameters	incorporate data from an improved WSR-88D hail algorithm; VAD from Doppler channel or use of dual polarized data may also in the distant future improve capabilities of adjusting for hail	
13	Hail	II	not explicitly addressed; localized adjustments with gages may reduce some impacts of hail contamination	use other data (VIL) to indicate presence of hail	
14	Beam Blockage	I	sectorized hybrid scan; occultation adjustments made in preprocessing by adjusting or averaging with surrounding reflectivity as appropriate		Ahnert et al. (1983)
15	Beam Blockage	II	areas of constant blockage are replaced with data from gage only field	incorporate satellite and/or lightning data in mountainous areas in west to fill in missing areas	
16	Beam Blockage	III	use of mosaicking with surrounding radars will fill in areas of missing radar information where overlap exists		Shedd and Smith(1991)
17	Orographic Effect	I	nothing explicit		
18	Orographic Effect	II	some weighing with climatological mean rainfall may reduce some effects	improved weighing with climatological mean rainfall may reduce some effects	
19	Orographic Effect	III		use of interactive procedures using other hydrometeorological and GIS information may allow forecaster to identify and modify rainfall accumulation anomalies	
20	Attenuation	I	attenuation should not be severe problem with S-band radar; however, adjustments are implicitly made through adjustment of the radar data with gage data		

Note	Item	Stage	Current Status	Future Work	Reference
21	Adaptation Parameters	I	initial default parameters established	use archive data to establish improved estimates	Smith et al. (1989)
22	Adaptation Parameters	II	initial default parameters established	use archive data to establish improved estimates	
23	Adaptation Parameters	III	initial default parameters established	use archive data to establish improved estimates	
24	Quality Control of Gages	I	check for excessive values		
25	Quality Control of Gages	II	check for excessive values; time distribution of multi-hour gages based on radar	incorporate more sophisticated gage quality checks including improved cross comparison between gages and other hydromet data	
26	Quality Control of Gages	III	interactive editing and comparison with radar	incorporate features to handle areas within field with no gage or radar data available	
27	Numerical Analysis Techniques	I	Kalman filter to determine mean field bias	refine Kalman filter parameters	Ahnert et al. (1986)
28	Numerical Analysis Techniques	II	Kalman filter to determine mean field bias; multivariate objective analysis to merge gage and radar fields	optimize approach for specifying weighing coefficients dependent on dynamic covariance function	Krajewski & Ahnert (1986)
29	Numerical Analysis Techniques	III	mosaicking of neighboring radars using average of non-zero accumulations	consider other mosaical approaches	Shedd & Smith (1991)
30	Interactive Features	III	viewing Stage II products; viewing gage data; geopolitical overlays; time loops; identification of bad data; selection of data fields to incorporate in mosaic	refine features based on operational experience as well as making use of associated data sets such as lightning, wind profilier, and satellite.	Shedd & Smith (1991)

Note	Item	Stage	Current Status	Future Work	Reference
31	Field Quality Control	I	as described in above features; and identification of outliers and isolated data points		
32	Field Quality Control	II	local adjustments based on gage and satellite data;	incorporate techniques sensitive to orographic effects and make use of additional data sets such as wind profilier, etc.	
33	Field Quality Control	III	selection of multi-sensor or gage-only fields	incorporate new mosaicking techniques and make additional data sets.	