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A PRELIMINARY EVALUATION OF A VERIFICATION SCHEME TO COMPARE MEAN AREAL PRECIPITATION TO LOCAL QUANTITATIVE PRECIPITATION FORECASTS DURING WIDESPREAD RAINFALL EVENTS

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1. Introduction

Improvements in hydrologic planning and water management over the next decade will depend greatly upon the ability of the National Weather Service (NWS) to provide timely and accurate river forecasts and flood warnings. To save lives and minimize economic losses, excessive precipitation events over specific river basins will have to be anticipated well in advance.

The use of Quantitative Precipitation Forecasts (QPFs) in hydrologic models will significantly impact River Forecast Centers' (RFCs) ability to forecast accurate river stages over a specific drainage basin. Utilizing QPFs can improve river forecast model output at peak flow, and has the potential to reduce the underforecasting of river stages, especially when precipitation is still occurring (Reed, *et al.* 1997). An accurate QPF can increase the RFCs ability to forecast more precise times and heights of the flood wave. It also can lead to a Flood/Flash Flood Watch or a Flood Potential Statement being issued prior to a warning. An example is when a flood forecast, based solely on QPF, is made twenty-four hours prior to the event. Conversely, an erroneous QPF can generate a simulated flood in the wrong basin, resulting in unnecessary economic losses to water resource agencies and landowners.

National Center for Environmental Prediction (NCEP) forecasters have been preparing routine operational QPFs since the 1960s (Olson *et al.* 1995). Improvements in numerical models, the modernization of the NWS, and the establishment of the Hydrometeorological Analysis and Support (HAS) Unit at each of the 13 national RFCs have made it possible to generate QPFs locally.

The implementation of the Windows QPF (WinQPF) software program at local Weather Forecast Offices (WFOs) allows forecasters to generate and disseminate gridded precipitation forecasts to RFCs twice daily (Fenbers 1995). These QPFs include four-six hour forecasts of areally averaged rainfall over river basins in the local Hydrologic Service Area (HSA). HAS Unit forecasters then composite these local QPFs for their area of responsibility as input into hydrologic models.

Precipitation forecasting remains one of the more challenging tasks for operational meteorologists. Mesoscale evolution of rainfall events, which is especially difficult to predict, is of primary importance. In order for forecasters to improve their QPF prediction, WFOs need verification schemes to compare RFC-calculated Mean Areal Precipitation (MAP) to WFO generated QPFs. This will aid in the identification of local precipitation forecast biases, and provide real time quality control of station generated QPFs.

This study will examine selected widespread precipitation events over the Fort Worth HSA. A locally developed QPF verification scheme is used to provide insight into the regional climatology of MAP, the identification of station wet and dry biases, and the accuracy of local QPF efforts to predict mean areal precipitation amounts.

2. Data

Widespread and prolonged rainfall events that affected over 100 river basins in the WFO, Fort Worth Hydrologic Service Area (HSA) between October 1996 and April 1998 were examined (Figure1). Local QPFs were generated by the National Weather Service Forecast Office (NWSFO) in Fort Worth. MAP estimates were determined by the West Gulf River Forecast Center (WGRFC).

Individual rainfall dates were selected based upon the following criteria: 1) a majority of river basins in the Fort Worth HSA observed rainfall; 2) twenty-four hour rainfall accumulations covered a spectrum of amounts ranging from zero to over one inch; and 3) the duration of rainfall in a majority of river basins included at least two six-hour time periods.

WinQPF computer software was used to draw isohyets of forecast precipitation and to perform automated isohyetal analysis calculations. This technique converted areal QPF estimates for a 24-hour time period from 12z Day 1 to 12z Day 2 using four six-hour time intervals (12z-18z, 18z-24z, 00z-06z, and 06z-12z). Individual 6, 12, and 24-hour MAPs were generated by the WGRFC. These areal averages were derived using the Stage III method of producing gridded precipitation fields by coupling Weather Surveillance Radar - 1988, Doppler (WSR-88D) precipitation estimates and hourly rain gauge reports (Briendenbach *et al*, 1998).

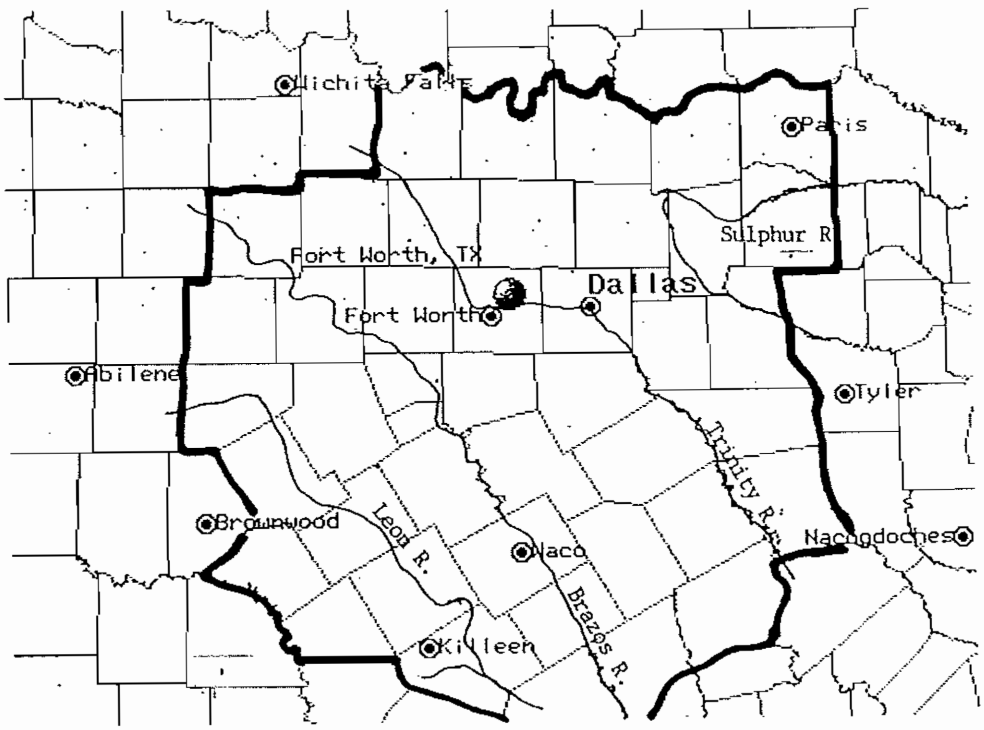


Figure 1. WFO Fort Worth Hydrologic Service Area.

3. Approach

Widespread rainfall events were investigated by individual time periods to establish the frequency distribution of mean areal precipitation by rainfall category and to determine the accuracy of local quantitative precipitation forecasts.

The Stage III analysis procedure described by Briendenbach, Seo, and Fulton (1998) was used to determine MAP (Figure 2). This method inputs hourly digital precipitation (HDP) computed by each radar and rain gauge reports within the RFCs area of responsibility. Differences between gauge and HDP grid values were combined to create a new multi-sensor precipitation estimate. These multi-sensor precipitation fields were then mosaiced into a total basin precipitation field.

In order to determine local precipitation forecasting bias, the percentage of accurate, wet, and dry-biased QPFs were calculated in the verification procedure. Precipitation amounts were subdivided into the seven rainfall categories (Table 1). **An *accurate* quantitative precipitation forecast is defined as one in which the local QPF fell within the same rainfall category as the observed MAP.** For example, a local QPF of 0.35 of an inch would be considered accurate only if the observed MAP value was measured between 0.25 and 0.49 of an inch. If the precipitation forecast was one or more categories too wet or dry, it was labeled as a ***wet-biased*** or ***dry-biased*** forecast, respectively. If in the example above, the observed MAP value was between 0.01 and 0.24 of an inch, then the QPF would be considered a one category wet bias. Contrarily, if the MAP value was between 1.00 and 1.49 of an inch, then the QPF would have a two category dry bias.

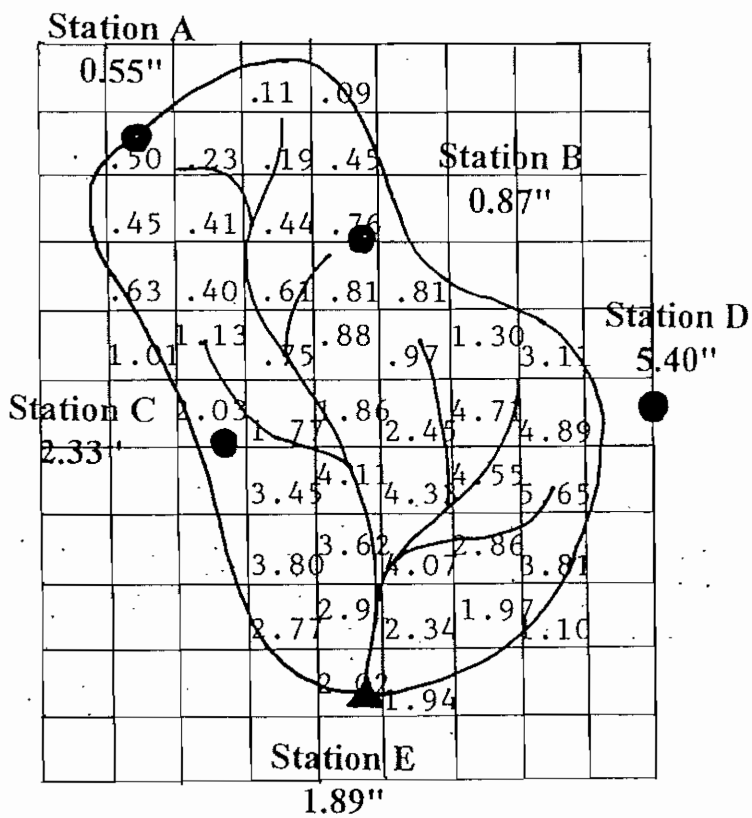
4. Process

A joint distributions-oriented scheme, similar to Brooks and Doswell (1996), was used to develop a MAP to QPF matrix for individual 6-, 12-, and 24-hour periods. A locally developed computer program compared computed MAP values with predicted QPFs for over 100 river basins in the Fort Worth HSA. Percentages were based upon an accumulative basin count that was determined by multiplying the number of river basins considered by the number of QPF issuances. For example, sixty-five QPF issuances for 100 basins would yield 6500 basins for interpretation.

In Table 1, the diagonal numbers in bold represent the number of basins where both the observed (MAP) and predicted (QPF) fell within the same range of the defined rainfall categories. Numbers to the right of the bold diagonal represent wet-biased forecasts while those to the left were dry-biased. For example, the number of basins in the first diagonal line just to the right of the bold numbers (246, 628, 285, 124, 50, 17) symbolize the number of basins with a one category wet bias for individual precipitation amounts.

The columns M and p(y) represent the number and percentage of times a basin **observed** a particular rainfall amount. The rows Q and p(x) indicate how often QPF forecasters **predicted** the occurrence of that rainfall amount. Rounding procedures precluded percentages from adding exactly in some cases. The column 0.01 to 0.24 implies that the local QPF predicted this rainfall amount on 36 percent of all forecasts

MAPX (WSR-88D Gridded Estimate) Computation of Mean Areal Precipitation For a River Basin



MAPX is computed using the average of the 4 km x 4 km WSR-88d radar 1-hourly gridded precipitation estimates for those grids located in a basin. Gridded estimates are from the Stage III processing as performed at the West Gulf River Forecast Center.

Figure 2. MAPX (WSR-88d Gridded Estimate) Computation of Mean Areal Areal Precipitation for a river basin (Arkansas Red Basin RFC).

{p(x)} or for a total of 2397 basins {Q}. Examination of row 0.01 to 0.24 implies that this rainfall category was observed on 35 percent of the forecasts {p(y)} or for a total of 2348 basins {M}.

Another routine of the program is to determine the number of basins and percent of QPFs that were accurate, wet or dry-biased. In Table 1, accurate forecasts are a total of the bold numbers in the matrix diagonal. All basins listed to the right of the bold diagonal were summed and labeled as wet while those to the left were dry. Table 2 summarizes these totals and further divides each bias by category. For example, the row {3 category bias} indicates that 520 or 8 percent of the basins had a QPF bias of 0.50 to 0.99 of an inch. This particular categorical bias was further subdivided to include 223 or 3 percent of the basins with a wet bias and 297 or 5 percent of the basins with a dry bias.

	QPF									
	Rainfall	**0.00**	**.01-.24**	**.25-.49**	**.50-.99**	**1.00-1.49**	**1.50-1.99**	**>=2.00**	**M**	**p(y)**
	0.00	**151**	246	83	48	4	2	0	534	8%
	0.01 - 0.24	126	**1084**	628	329	103	57	21	2348	35%
M	**0.25 - 0.49**	26	462	**444**	285	98	47	22	1384	21%
A	**0.50 - 0.99**	22	345	305	**302**	124	101	25	1224	18%
	1.00 - 1.49	6	169	127	153	**66**	50	18	589	8%
P	**1.50 - 1.99**	1	54	56	71	31	**18**	17	248	3%
	>= 2.00	1	37	45	50	37	29	**26**	225	3%
	Q	333	2397	1688	1238	463	304	129		
	p(x)	5%	36%	25%	18%	7%	4%	1%		

Table 1. MAP to QPF verification matrix for categorical rainfall events that occurred between September 1996 and April 1998 over the WFO, Fort Worth Hydrologic Service Area.

5. MAP Frequency Distribution

Frequency distributions for MAP amounts of zero, 0.01 to 0.24, 0.25 to 0.49, 0.50 to 0.99, 1.00 to 1.49, 1.50 to 1.99, and greater than or equal to 2.00 inches were investigated for 6-, 12-, and 24-hour time periods. Rainfall amounts were divided into three categories: 1) light (0.01 to 0.24 of an inch); 2) moderate (0.25 to 0.99 of an inch); and 3) heavy (1.00 inch or greater).

Individual MAP frequency patterns for each time period are relatively uniform. There is a considerable decline in the number of events from the predominant light rainfall category to heavier amounts. Thre quarters of all 24-hour basin MAP indicated amounts less than one inch. Approximately one third of these cases recorded a MAP value of 0.01 to 0.24 of an inch and it is slightly more common for these amounts to occur between 12z and 00z GMT (Figure 3).

The number of basins declines considerably for any amount of 1.00 inch or greater. Only three percent of the basins observed 24-hour amounts in the categories of 1.50 to 1.99 inches and greater than 2.00 inches. These statistics imply that the issuance of a QPF with heavy amounts should be conservative and that MAP amounts of 1.50 inches or greater are a rare occurrence.

Areal coverage of rainfall patterns imply that during any 6-hour time period only one half of the basins within the HSA observed a measurable MAP amount. Approximately one third of these cases recorded a MAP value of 0.01 to 0.24 of an inch. Only one to two percent of the basins observed rainfall amounts of 1.00 inch or greater (Figure 4).

Individual 6-hour time intervals suggest that rare heavy rainfall events prefer the evening and nighttime 00z to 06z time period. This preference for evening and nighttime maxima precipitation may be the result of processes such as the radiation budget near the tops of middle and high clouds, the diurnal cycle in the boundary layer wind speeds, and the evolution of mesoscale pressure systems generated by convective activity to produce a more favorable environment for the nocturnal development and organization of thunderstorm systems (Hoxit, et al. 1978).

QPF Verification								
	Basins	**Percent**	**Bias**	**Basins**	**Percent**	**Bias**	**Basins**	**Percent**
Accurate	**2091**	**31%**	**Wet**	**2308**	**35%**	**Dry**	**2153**	**34%**
1 category bias	**2456**	**38%**	**Wet**	**1350**	**21%**	**Dry**	**1106**	**17%**
2 category bias	**1235**	**19%**	**Wet**	**629**	**10%**	**Dry**	**606**	**9%**
3 category bias	**520**	**8%**	**Wet**	**223**	**3%**	**Dry**	**297**	**5%**
4 category bias	**188**	**3%**	**Wet**	**83**	**1%**	**Dry**	**105**	**2%**
5 category bias	**61**	**1%**	**Wet**	**23**	**0%**	**Dry**	**38**	**1%**
6 category bias	**1**	**0%**	**Wet**	**0**	**0%**	**Dry**	**1**	**0%**

Table 2. Comparison of accurate, wet, and dry-biased QPFs for the WFO, Fort Worth HSA for the period September 1996 through April 1998.

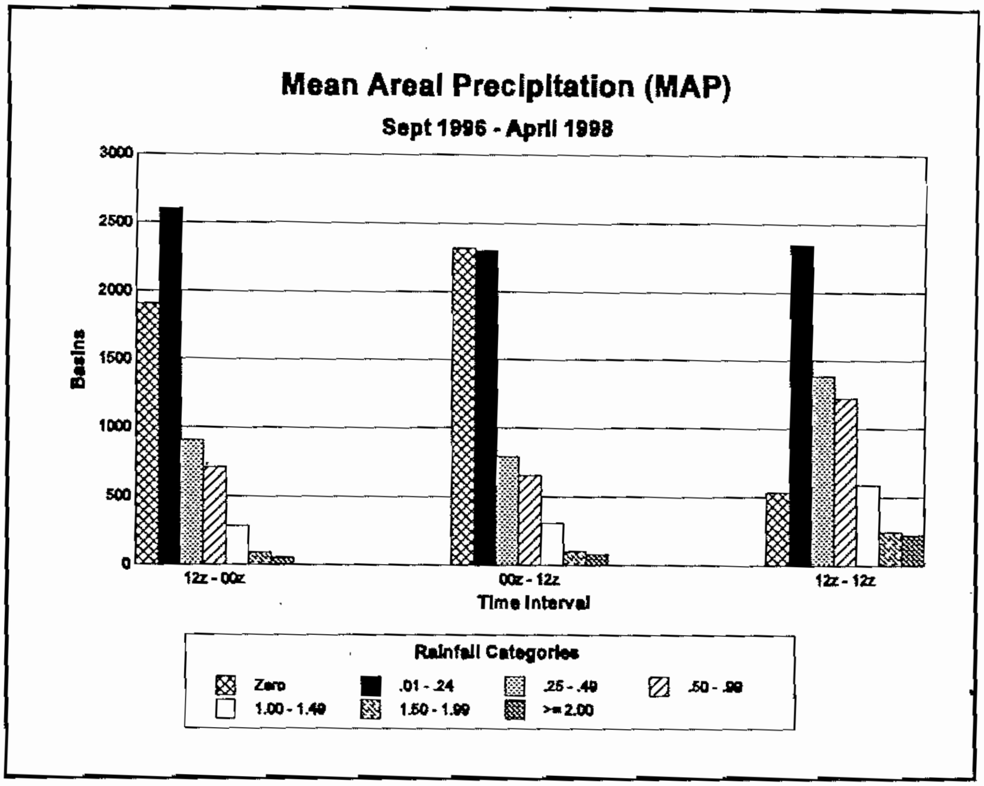


Figure 3. Twelve and 24-hour basin MAP frequency distribution.

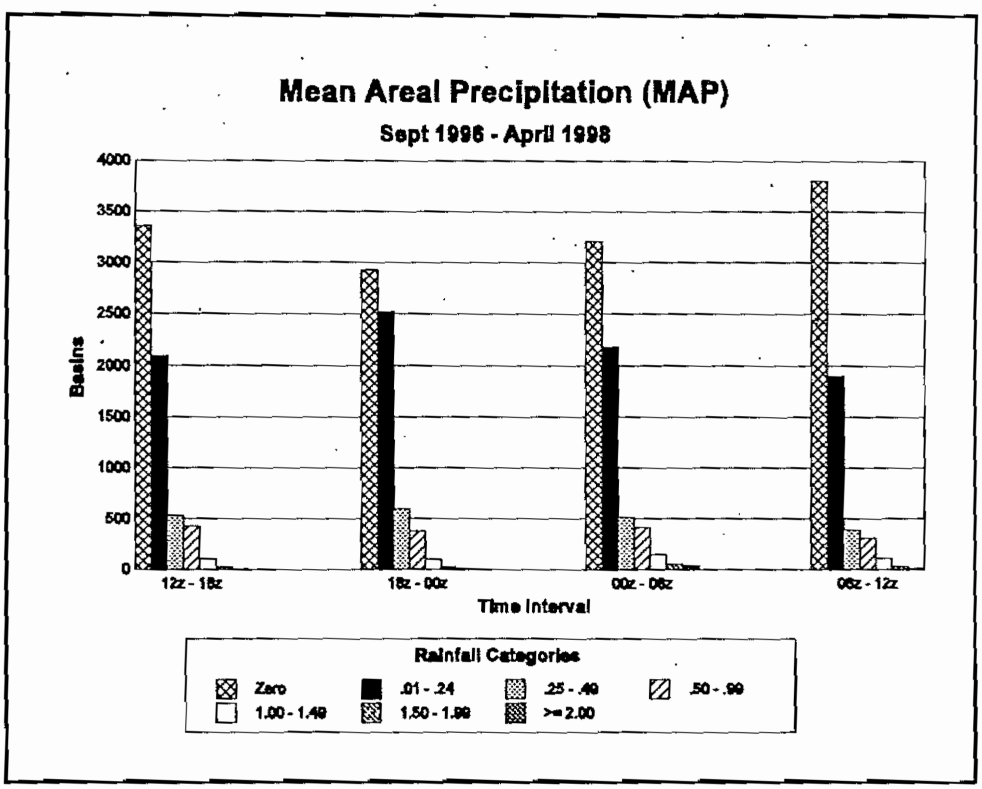


Figure 4. Six-hour basin MAP frequency distribution.

6. Spring and Winter MAP Frequency Distribution

The seasonal distribution of rainfall over Texas indicates that the convective spring season is wetter than the more stratiform winter months (Figures 5 and 6). This is likely attributed to the diurnal increase in convective storms associated with increased solar heating and more frequent intrusion of low-level gulf moisture.

In North Texas, spring 6-hour rainfall events of less than 1.00 inch occur more frequently during the 00z to 06z time period. During winter, when the intensity of solar radiation is greater earlier in the day, widespread light to moderate precipitation occurred more often between 18z and 00z (Figures 7 and 8). Substantial 6-hour rainfall amounts of 1.00 inch or greater rarely occur. Of the few cases investigated, these heavy rainfall amounts were more prevalent between 06z and 12z in the spring and between 00z and 06z in the winter.

7. Verification of Local QPFs

One of the challenges of local QPF forecasters is the determination of whether or not precipitation will develop. In this investigation, over 90 percent of the accumulative river basins in the North Texas HSA received a 24-hour mean areal precipitation amount. Local forecasters responded by issuing a measurable QPF for 95 percent of these rainfall events. A second demand of QPF forecasters is the ability to recognize both the synoptic and mesoscale processes that are conducive to heavy rainfall. This entails the ability to recognize whether or not a particular rainfall event will persist.

Figure 9 summarizes the QPF bias for individual time periods. Accurate precipitation forecasts near equaled the number of wet or dry-biased forecasts for the 24-hour period 12z Day 1 to 12z Day 2. During each 12-hour period, an increasing percent of accurate forecasts remained consistent. A wet-biased QPF was more prevalent in the initial 12 hour period while the percent of dry-biased QPFs increased slightly between 00z and 12z.

Individual six hour time intervals show that nearly half of all forecasts were accurate with highest percentages between 06z and 12z when wet biased QPFs were held to a minimum. The number of dry biased forecasts was consistently less and showed no preference for individual time periods.

Spring and winter were similar in the proportion of accurate, wet, and dry-biased 24-hour QPFs (Figures 10 and 11). In spring, the initial 12-hour QPF was too wet, while the 06z to 12z period showed the greatest accuracy. Although little difference is obvious in winter 12-hour QPFs, accurate forecasts were more pronounced in the 06z to 12z and 12z to 18z time periods when overrunning precipitation and light amounts were prevalent.

8. Analysis of Rainfall Categories

The extent that local QPFs overforecast or underforecast mean areal precipitation was first determined by examining categorical departures from accurate forecasts. A one categorical difference generally means

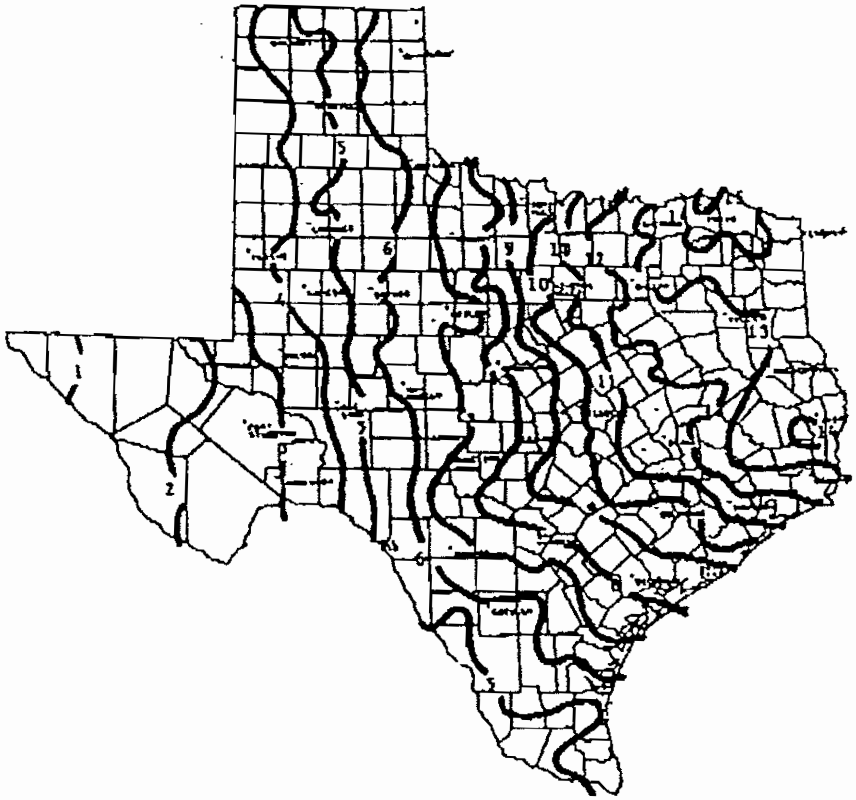


Figure 5. Average spring precipitation (inches) for the period 1961-1990 (Bomar, 1995).

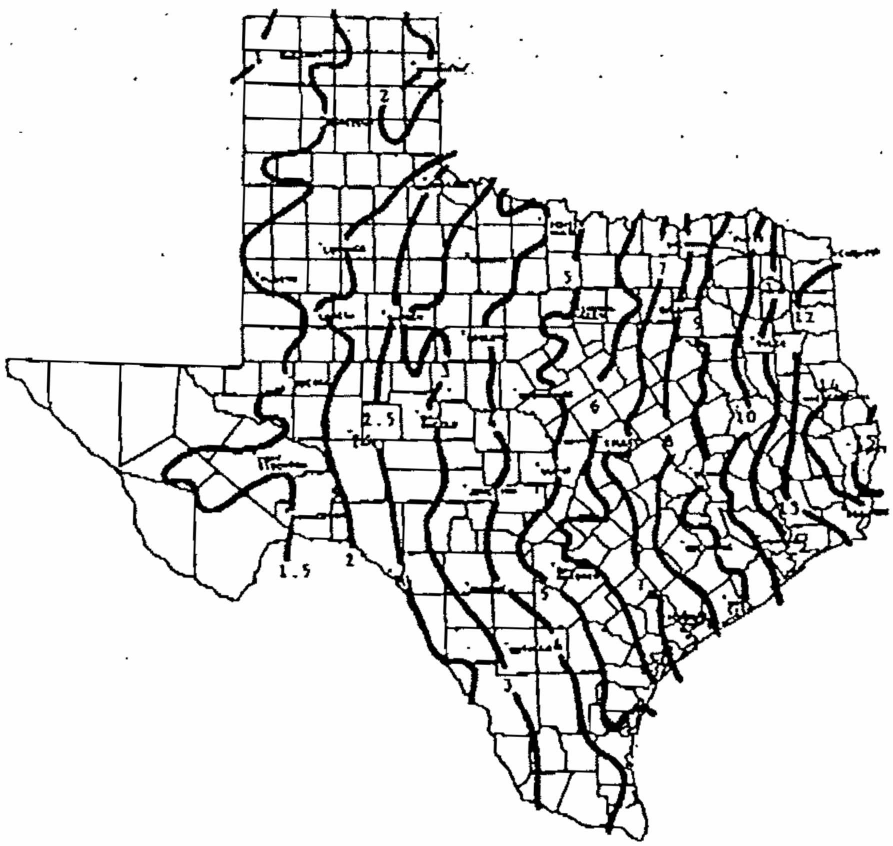


Figure 6. Average winter precipitation (inches) for the period 1961-1990 (Bomar, 1995).

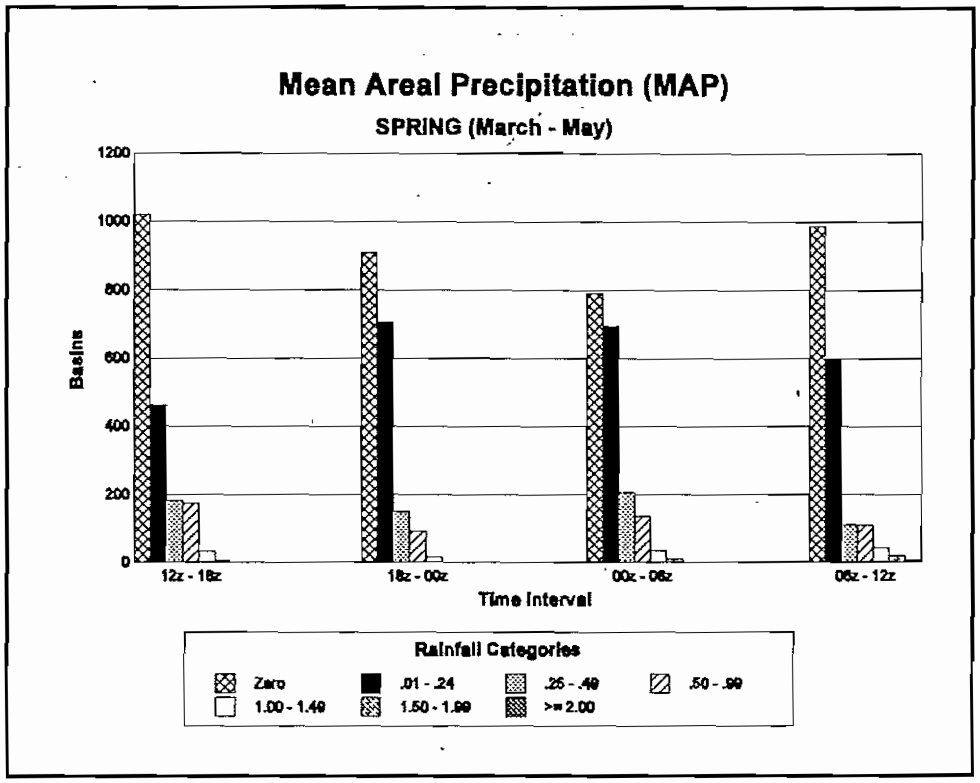


Figure 7. Spring 6-hour basin MAP frequency distribution.

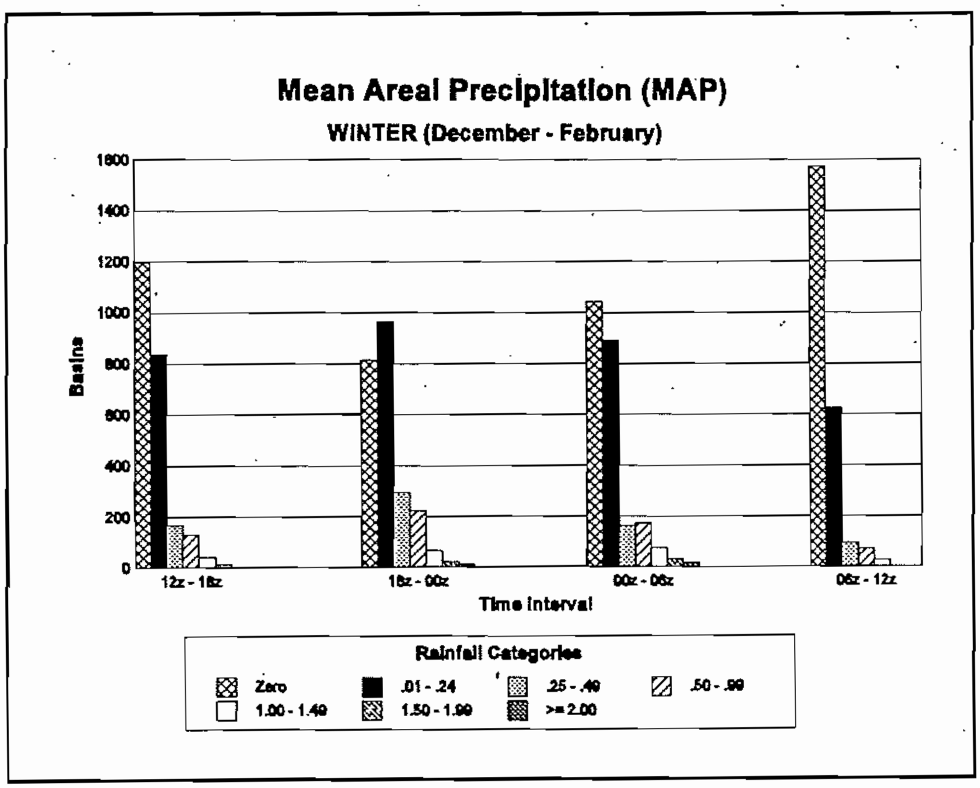


Figure 8. Winter 6-hour basin MAP frequency distribution.

that the QPF was approximately one quarter of an inch too wet or dry for light rainfall amounts and one half of an inch for moderate to heavy amounts. Each successive category would add an additional one quarter to one half inch error.

Twenty-four hour comparisons for all basins exhibit mainly a one category bias (Figure 12). Each succeeding category was reduced in half and exhibited an equal proportion of wet and dry bias. Both spring and winter events exhibited similar results (Figures 13 and 14). Higher categories of error showed a tendency for a dry bias in winter whereas the spring season tended to be wet.

Specific rainfall categories were also evaluated by comparing the percent of occurrence of the observed MAP with how often the category was predicted by the local QPF. This type of verification scheme displays not only the likelihood of a particular rainfall category but which categories local QPF forecasters have a inclination to either overforecast or underforecast.

Figure 15 indicates that in widespread rainfall events, 24-hour QPFs closely mirrored individual MAP rainfall categories regardless of the amount. Light to moderate amounts did represent a majority of these events and there was a very slight tendency of QPFs to overforecast amounts of one quarter to less than one half of an inch.

Similar results were achieved during each twelve-hour period (Figures 16 and 17). There was a trend to overforecast the occurrence of light to moderate rainfall amounts. There was also a small tendency to underforecast the occurrence of heavy rainfall events during the evening and nighttime 00z to 12z period. Since widespread rainfall events were selected for this study, QPFs seldom predicted a zero amount of precipitation.

During each 6-hour period, no rain was observed for approximately one half of the MAP events (Figures 18 through 21). The only period in which QPFs significantly inflated a forecast of no rain was in the latter 06z to 12z period. This correlated well with the increased MAP observance of no precipitation events. An overforecast of rainfall amounts of 0.01 to 0.24 of an inch is evident. However, QPFs accurately reflected both moderate and heavy rainfall categories.

The convective spring season 24-hour QPFs tended to underestimate light rainfall amounts and overestimate those in the moderate category (Figures 22 through 24). This mainly occurred in the first twelve hour period. There was also a minor underestimate of rainfall in the heavier 1.00 to 1.49 inch category. A reverse trend was noted during the winter months where 24-hour QPFs overestimated light amounts and underestimated moderate rainfall categories (Figures 25 through 27). In this season, a secondary overestimate of the 1.50 to less than 2.00 inch category is apparent.

Winter precipitation favored the 18z to 00z time period with a secondary peak between 00z and 06z. In spring, precipitation events slightly favored the 00z to 06z time interval. Light rainfall amounts in winter were overforecasted in each 6-hour period and during the 12z to 18z and 18z to 00z time periods in spring. The occurrence and prediction of both moderate and heavy rainfall events are reasonably correlated in both seasons (Figures 28 through 35).

9. Magnitude of QPF Bias

The magnitude of wet and dry bias was determined by comparing the categorical difference between the local QPF and the observed MAP. For 24-hour QPFs, forecasters generally had a one categorical wet bias for observed zero MAP events. This means that for no rainfall events, a majority of QPFs were for a value of 0.01 to 0.24 of an inch. Most of the remaining zero rainfall events had either an accurate QPF for a zero amount or a lesser number of two categorical wet bias QPFs within the range of 0.25 and 0.49 of an inch (Figure 36).

Forecasters exhibited their greatest QPF accuracy for MAP values of less than an inch. A majority of accurate forecasts were for amounts less than a quarter of an inch. In this category, a significant number of QPFs did exhibit a one to two categorical wet bias but were rarely drier than one category. Moderate rainfall events of a quarter of an inch to less than one inch were either accurate, had a one category wet bias, or had a one to two category dry bias. In the case of heavier MAP measurements, there are strong indications of an increasing dry bias or reluctance of forecasters to provide a wetter QPF.

Individual six-hour QPFs showed considerable skill in forecasting MAP values of zero to less than one quarter of an inch (Figures 37 through 40). Forecasters were quite proficient in determining which six-hour time periods these light precipitation events would occur. It is apparent that there is a one category wet bias for zero MAP events in every six-hour period. However, this wet bias was held to a minimum for MAP values of 0.24 of an inch or less. For MAP values of a quarter of an inch or greater, QPFs generally resulted in the addition of a categorical dry bias for each increasing MAP range. This trend suggests that forecasters are producing conservative six hour QPFs for moderate rainfall events. It is also apparent that QPF forecasters are reluctant to predict MAP values of 1.00 inch or greater since they rarely occur with a six-hour time interval.

In both winter and spring, over three quarters of the 24-hour precipitation events were for amounts less than one inch. This percentage increased to over ninety percent for each 12 hour period. Zero rainfall events for 6-, 12-, and 24-hour periods during both seasons showed either an accurate QPF or a one categorical wet bias (Figures 41 through 46). In addition, both seasons exhibited a peak number of accurate QPFs for light MAP amounts of less than one quarter of an inch. Moderate to heavy rainfall events during each 12- and 24-hour periods yielded a greater likelihood for dry-biased QPFs in both seasons. In general, the spring season had a more substantial increase in wet-biased QPFs.

10. Summary

Widespread rainfall events investigated in this study emphasize that a majority of cases will produce moderate 24-hour mean areal precipitation amounts of less than an inch. Individual 6-hour increments will likely receive less than a mere quarter of an inch. Rare heavy rainfall amounts generally prefer the evening and nighttime period while light rainfall is more evenly distributed through the 24-hour period.

The character and scale of precipitation events change with the seasons. Warm-season precipitation is dominated by small-scale convective processes. In the cool-season, synoptic-scale systems marked by pronounced low-level warm-advection predominate (Olson, *et al.* 1995). In North Texas, widespread precipitation occurs more frequently in the spring season with a nocturnal preference.

Verification of local QPFs in the Fort Worth HSA exhibited a proportionate number of accurate, wet, and dry-biased 24-hour forecasts regardless of the time of year. Nearly half of all 6-hour forecasts were accurate with the exception of spring when a wet bias dominated the12z to 00z time period. Doswell and Maddox (1986) state that the most difficult QPF problem is convective QPF, because knowledge of the relationship between synoptic weather systems and convection is limited and models are unlikely to perform consistently well when truly unusual convective events are happening.

One finding in this study is that it is uncommon for precipitation to spread over more than half of the entire Fort Worth HSA during a 6-hour period. In addition, when forecasts of moderate to heavy rainfall events were held to a minimum, they closely mirrored the number of times these events occurred. The fact that there was an overforecast of light rainfall events when no rain was observed emphasizes that isohyets must be correct in a very detailed sense for the QPF to be accurate. A more thorough delineation of the zero isohyet interval would greatly reduce the overprediction of rain events and likely curtail the overforecast of light and moderate amounts in spring.

11. Conclusions

This paper illustrates that local QPF verification statistics can be useful in determining average rainfall distribution patterns within a HSA and in identifying station biases and tendencies in forecasting widespread precipitation events. The technique implied in this study can aid in the identification of poorly predicted events and in examining specific forecasts when major floods occur, especially when combined with local rainfall climatology.

One of the difficulties in producing an accurate local QPF is that the meteorologist is being asked to provide a specific rainfall isohyet down to the scale of drainage basins. Improved displays of model output in both temporal and spatial resolution in the Advanced Weather Interactive Processing System (AWIPS) will enhance the recognition of large-scale systems. However, it is doubtful that in most mesoscale events, storm-scale evolution will be accurately forecasted with enough lead time to satisfy the hydrologist's requirements.

QPF forecasters should update their estimates of the onset, location, and magnitude of MAP especially during times of threatening heavy rainfall and potential flooding. HAS unit forecasters and RFC hydrologists should provide guidance to local WFOs as to what thresholds of precipitation may lead to a river flood. In many circumstances, this coordination might lead to the issuance of a River Flood Watch rather than a River Flood Warning for those events when the potential river flood is based upon the local QPF and is not forecast to occur until beyond the time for which a warning would be required.

Acknowledgments

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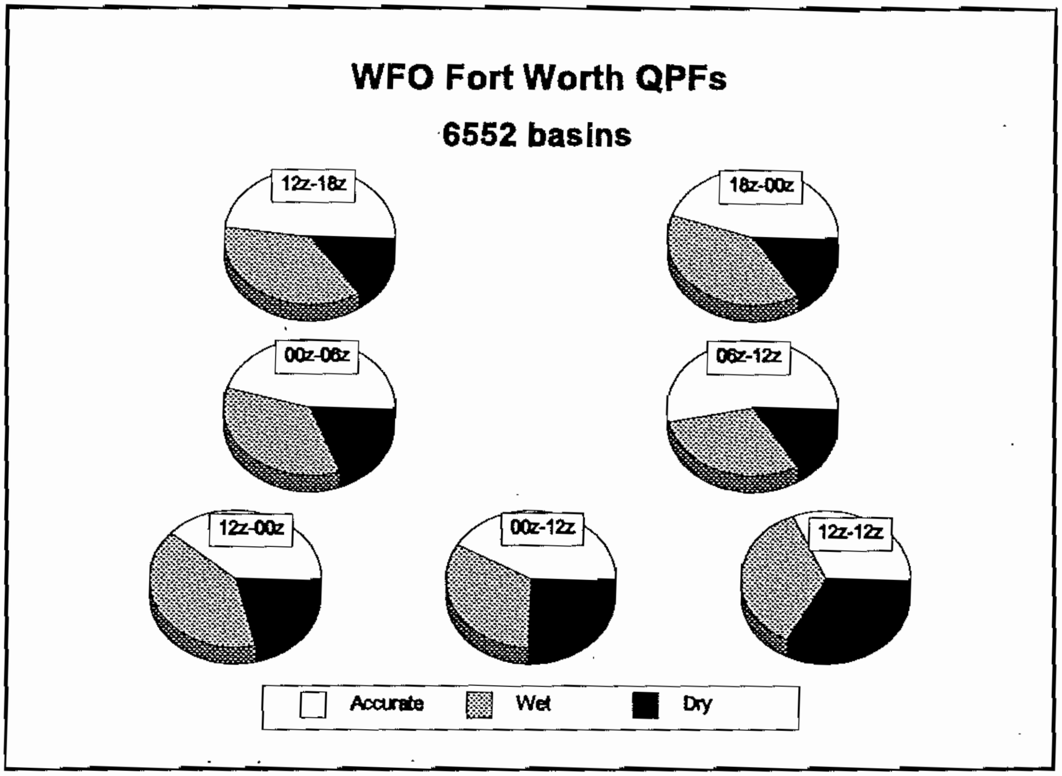

Figure 9. Proportion of accurate, wet, and dry-biased QPFs for September 1996 through April 1998.

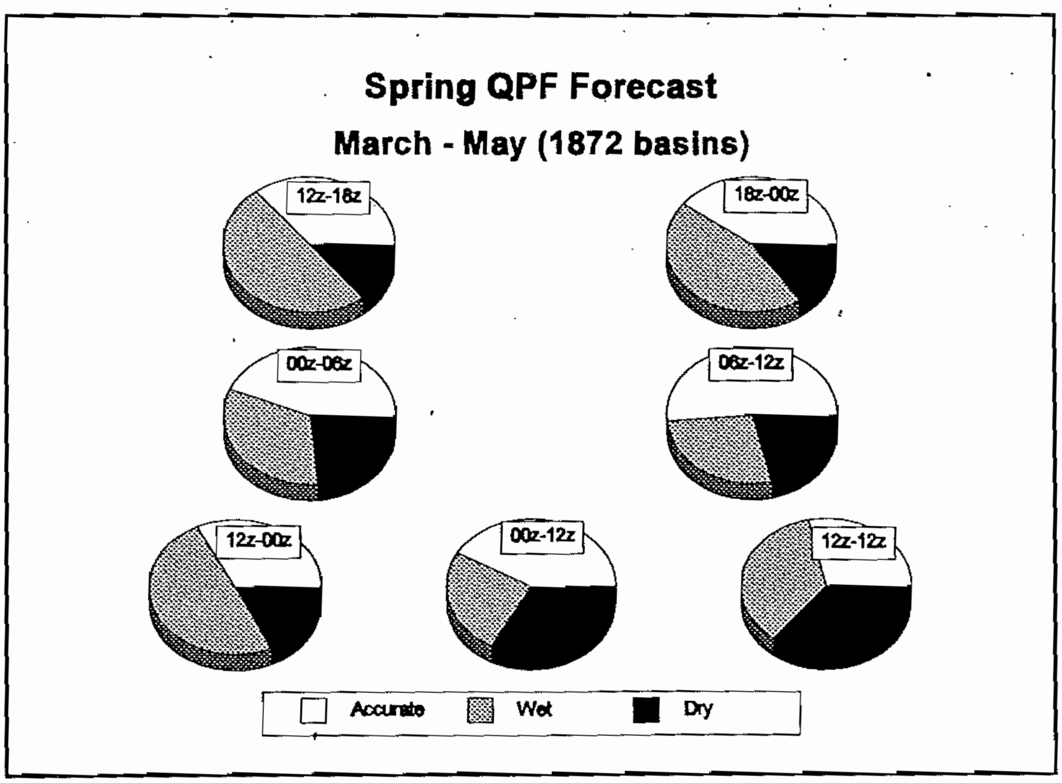

Figure 10. Proportion of accurate, wet, and dry-biased QPFs during spring.

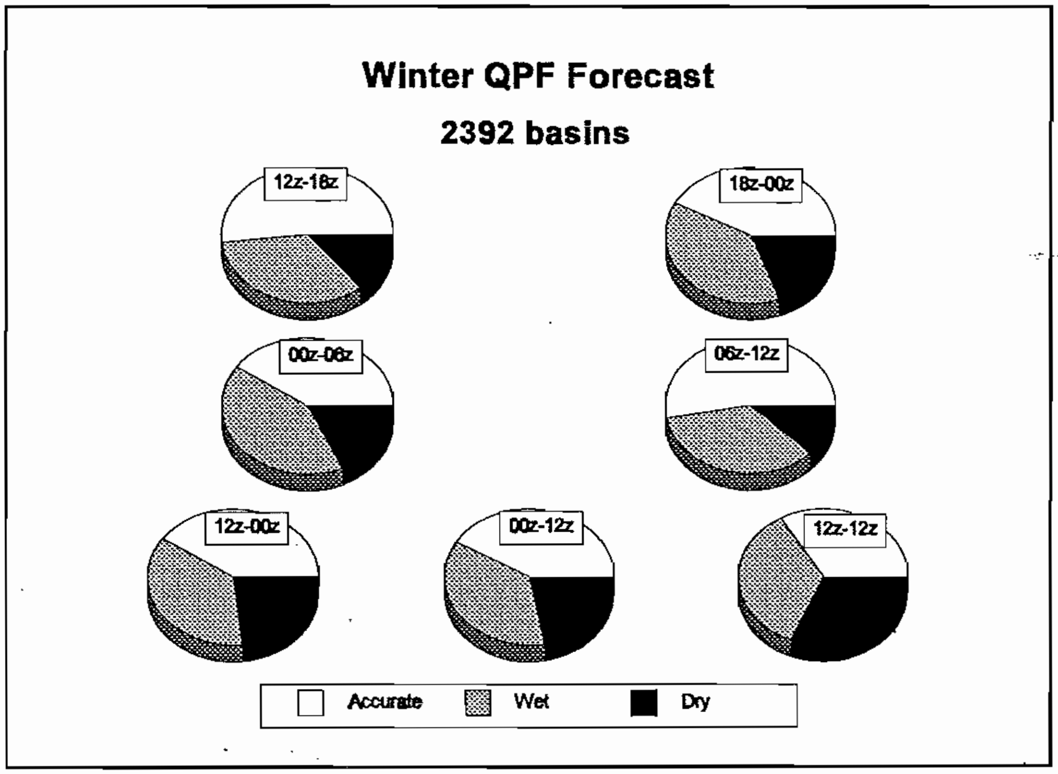

Figure 11. Proportion of accurate, wet, and dry-biased QPFs during winter.

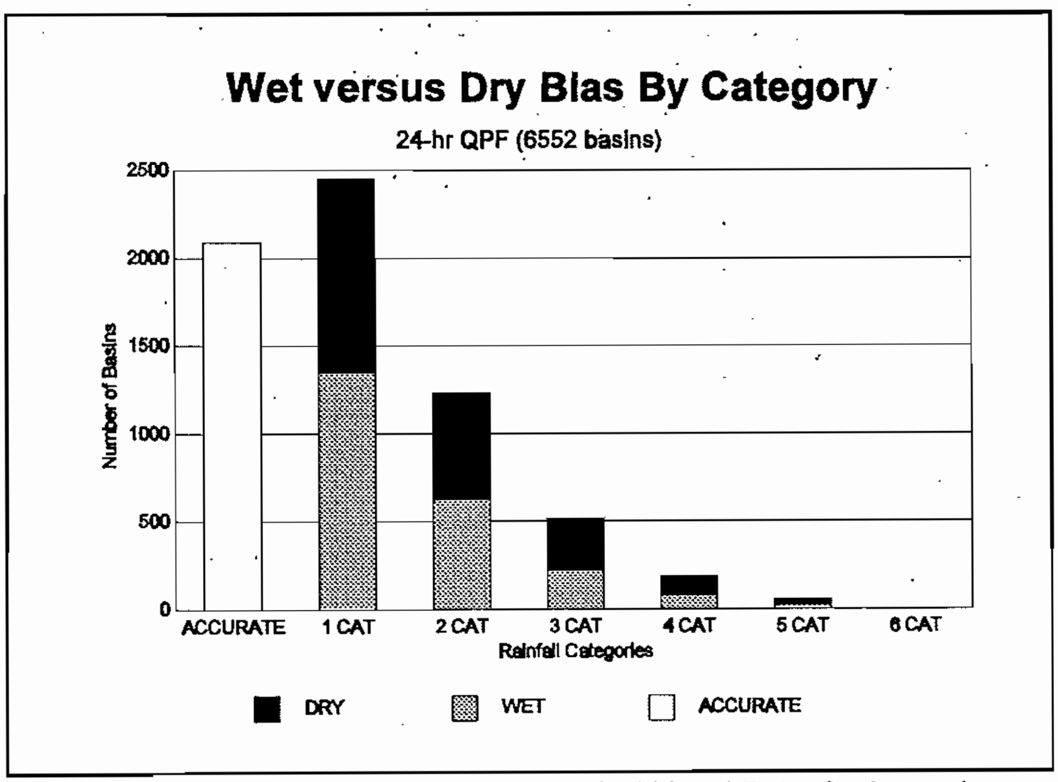

Figure 12. Comparison of accurate to categorical biased QPFs for September 1996 to April 1998.

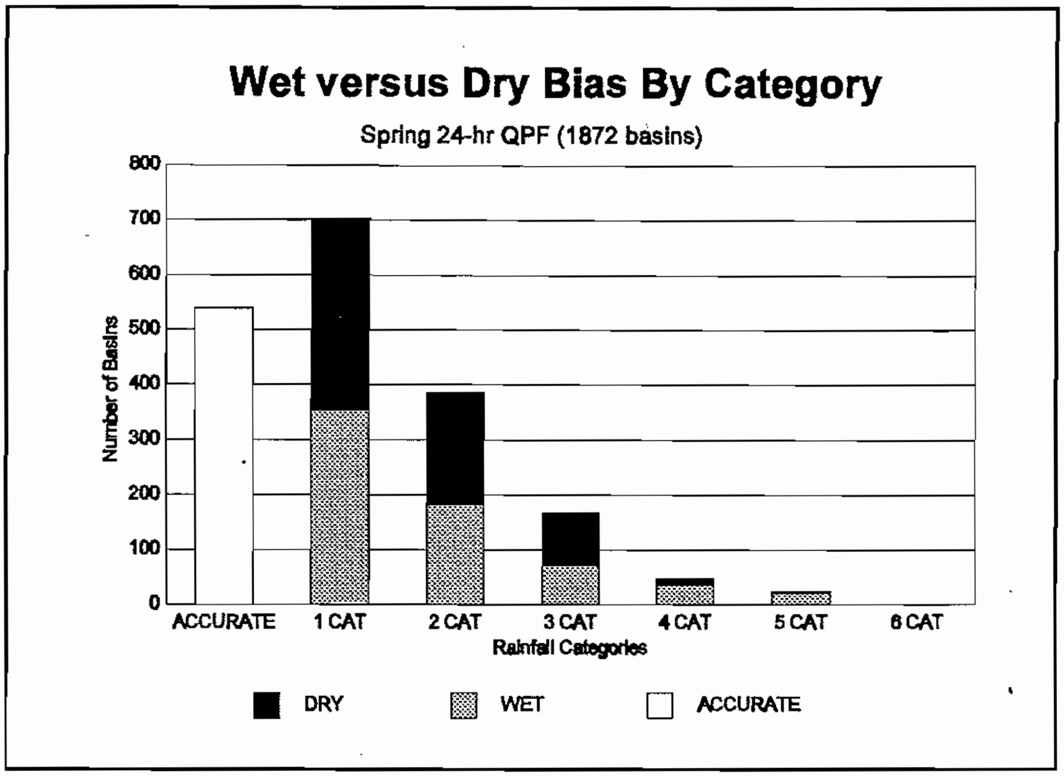

Figure 13. Comparison of accurate to categorical biased QPFs during spring.

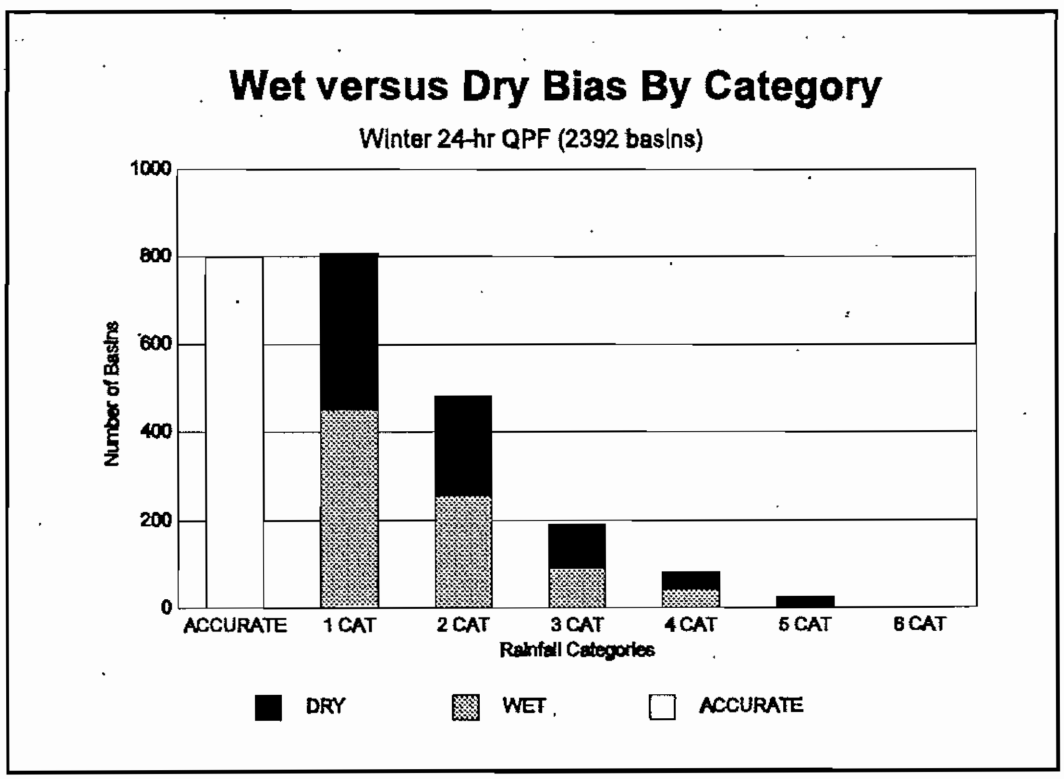

Figure 14. Comparison of accurate to categorical biased QPFs during winter.

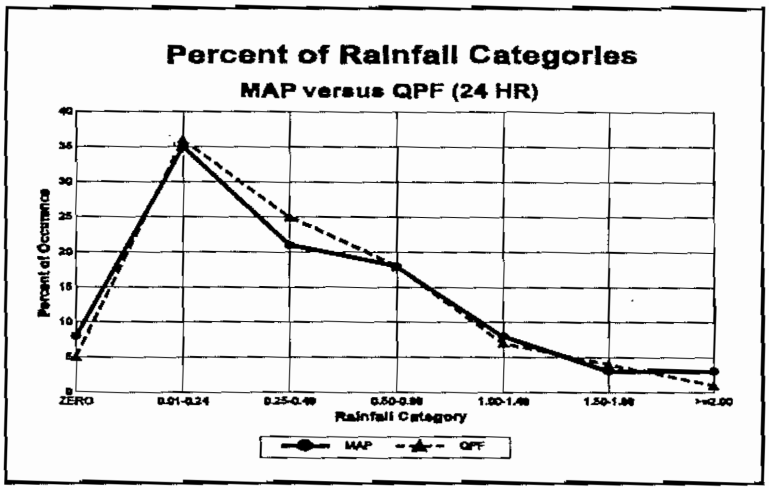

Figure 15. Twenty-four hour comparison of MAP and QPF for individual rainfall categories.

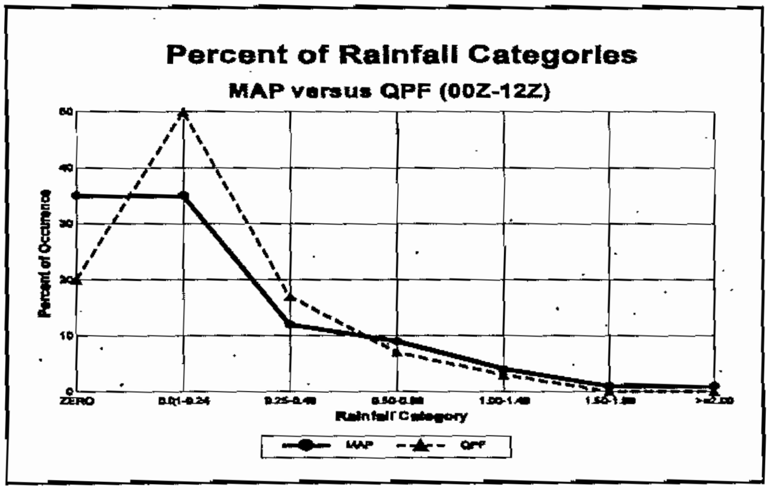

Figure 16. Twelve hour comparison of MAP and QPF for individual rainfall categories (00z-12z).

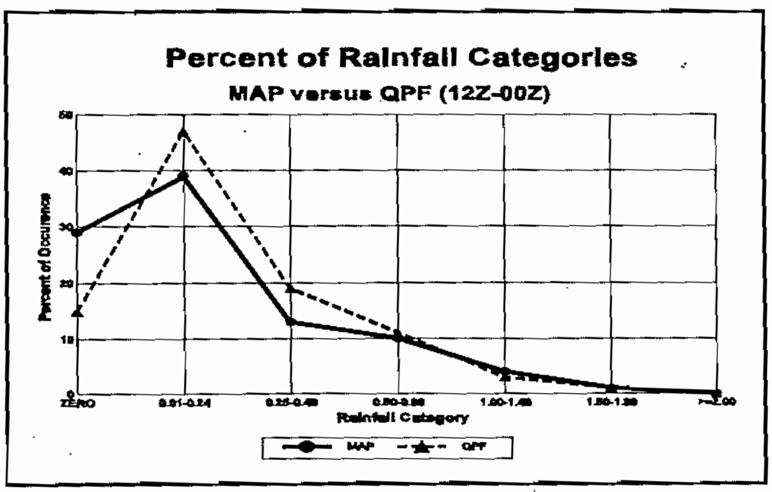

Figure 17. Twelve hour comparison of MAP and QPF for individual rainfall categories (12z-00z).

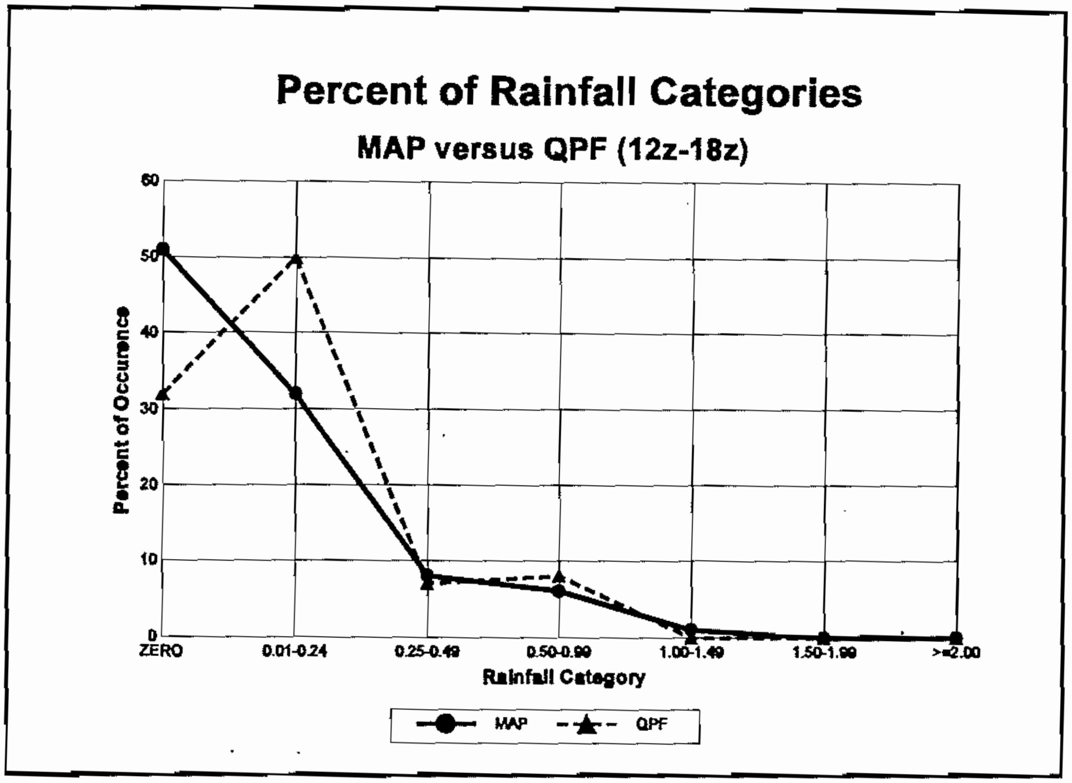

Figure 18. Six-hour comparison of MAP and QPF for individual rainfall categories (12z-18z).

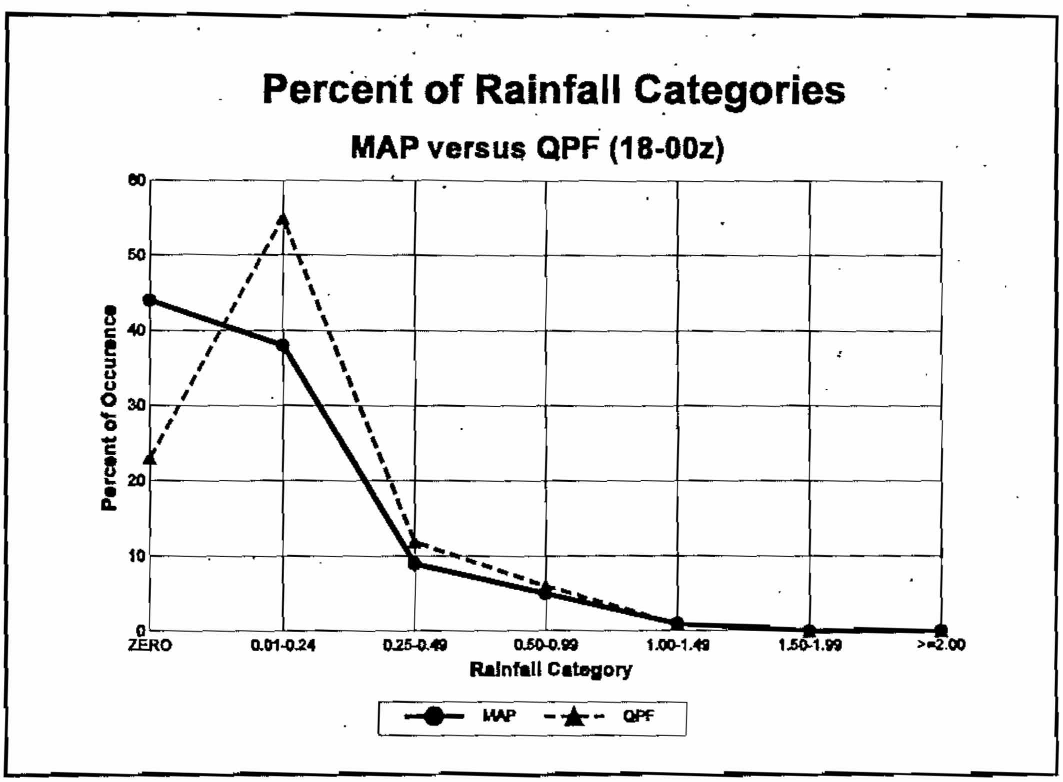

Figure 19. Six-hour comparison of MAP and QPF for individual rainfall categories (18z-00z).

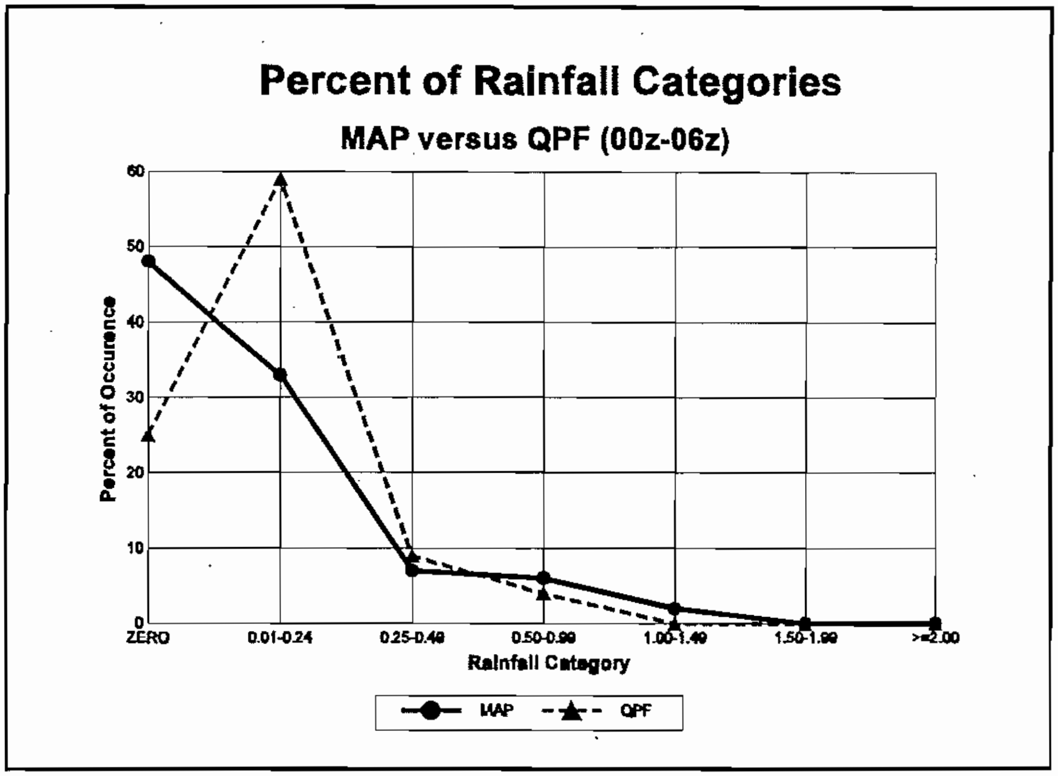

Figure 20. Six-hour comparison of MAP and QPF for individual rainfall categories (00z-06z).

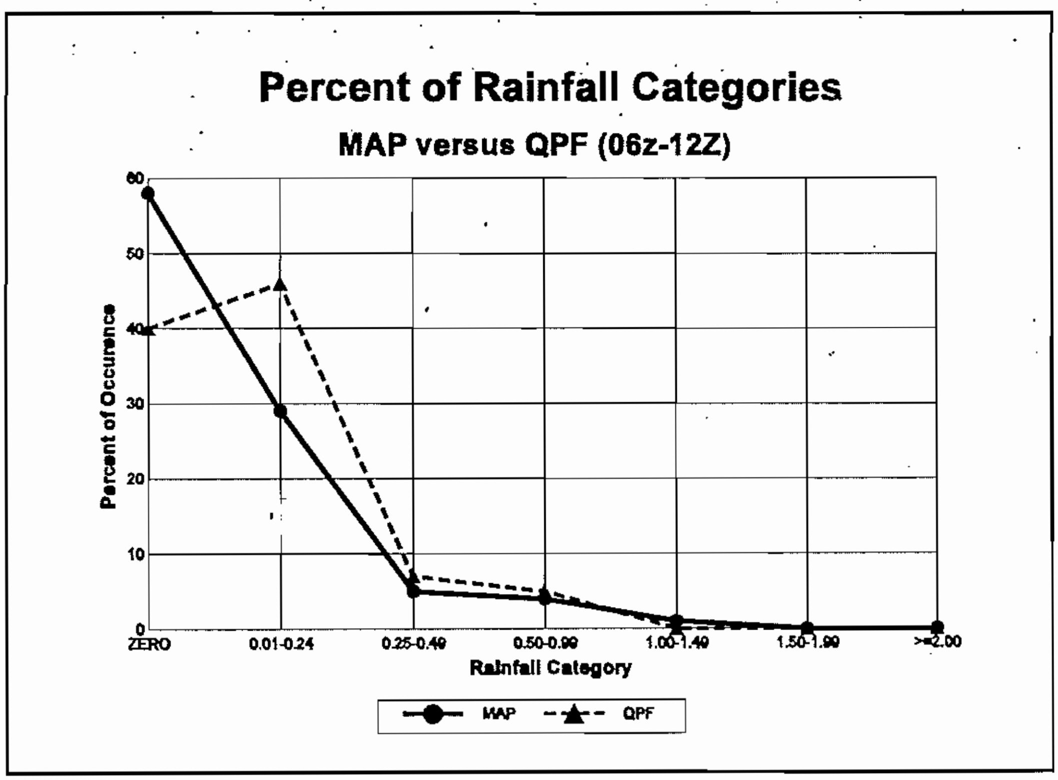

Figure 21. Six-hour comparison of MAP and QPF for individual rainfall categories (06z-12z).

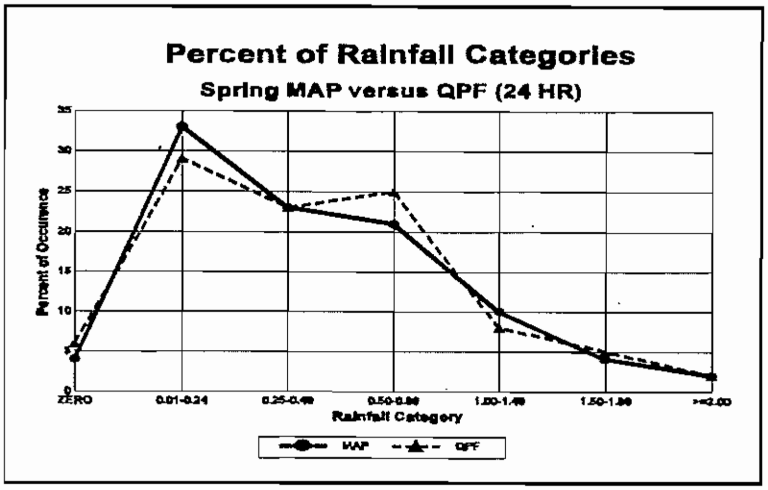

Figure 22. Twenty-four hour comparison of MAP and QPF for individual rainfall categories in spring.

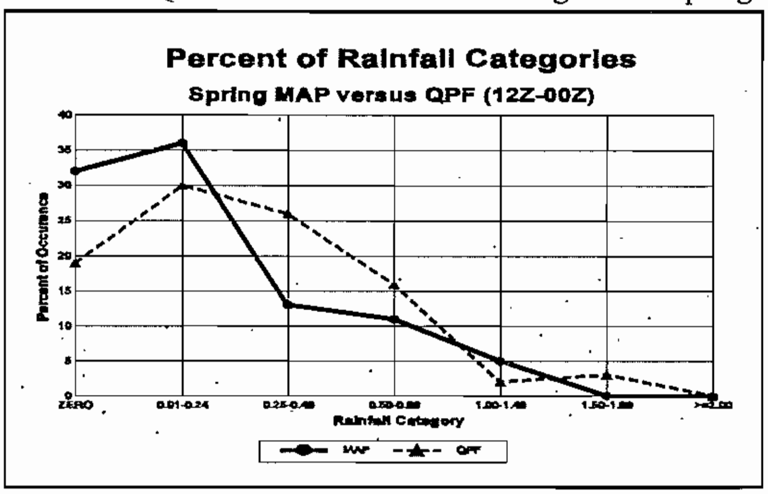

Figure 23. Twelve hour comparison of MAP and QPF for individual rainfall categories in spring.

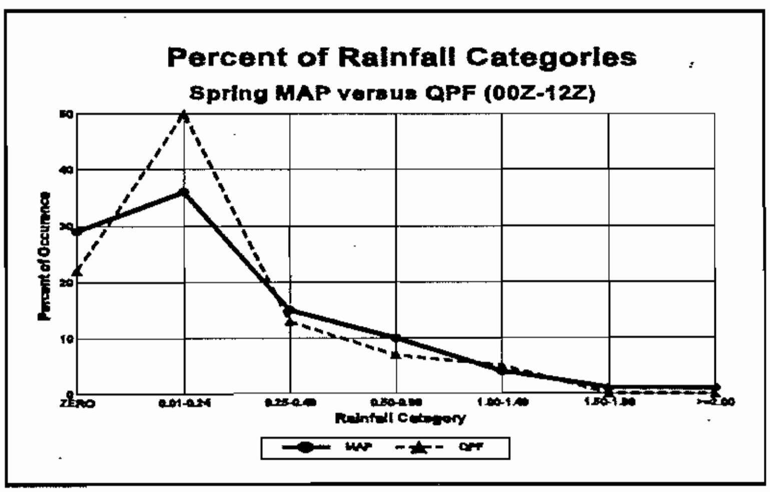

Figure 24. Twelve hour comparison of MAP and QPF for individual rainfall categories in spring.

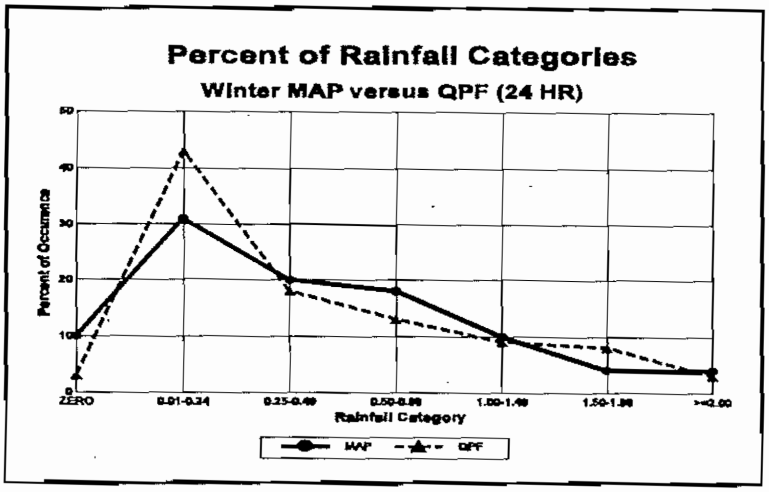

Figure 25. Twenty-four hour comparison of MAP and QPF for individual rainfall categories in winter.

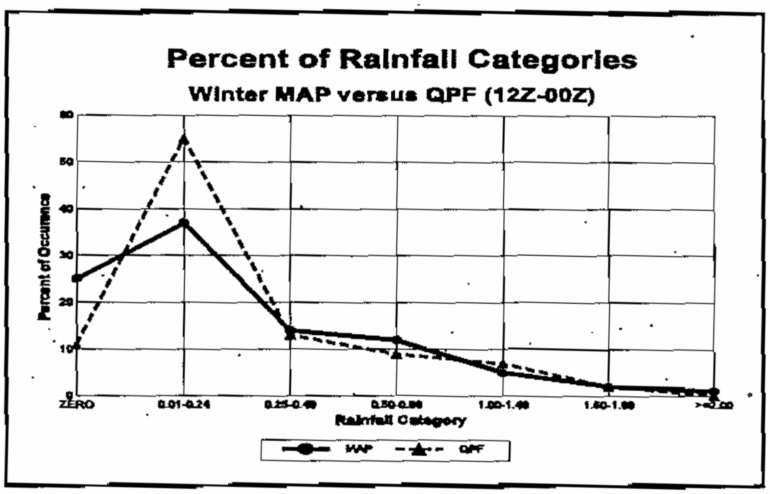

Figure 26. Twelve hour comparison of MAP and QPF for individual rainfall categories in winter.

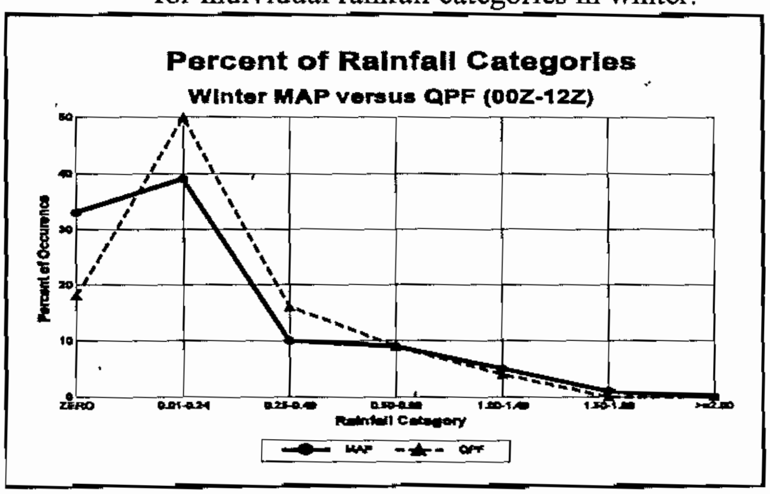

Figure 27. Twelve hour comparison of MAP and QPF for individual rainfall categories in winter.

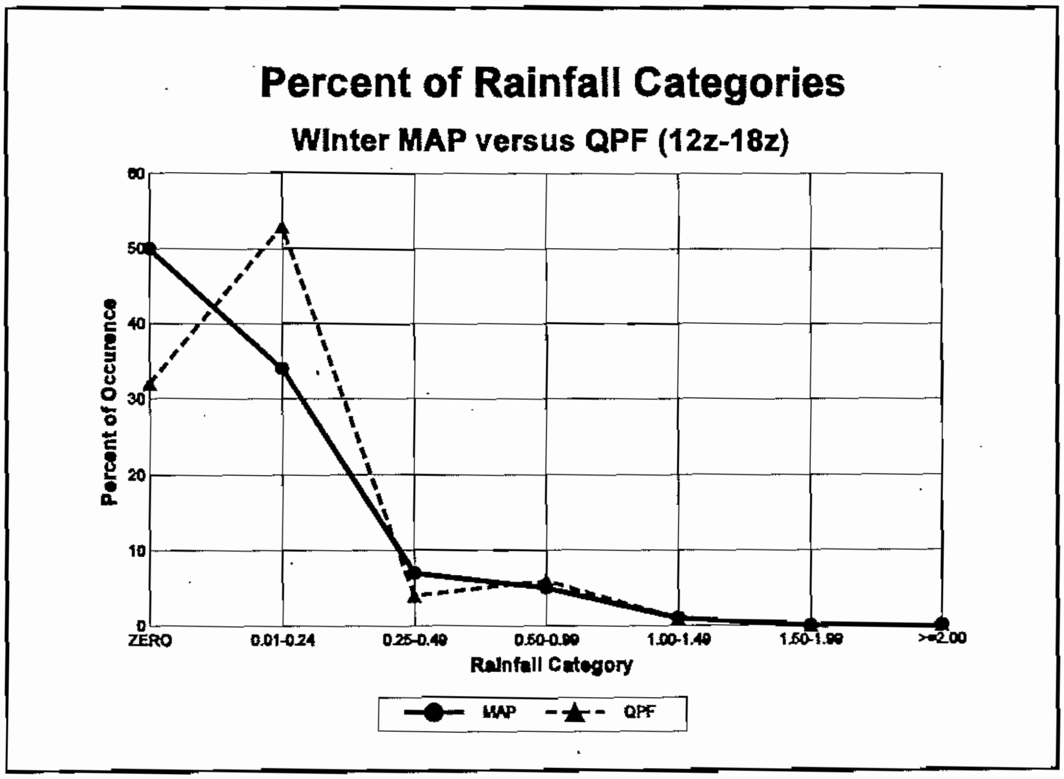

Figure 28. Six hour comparison of MAP and QPF for individual rainfall categories in winter (12z-18z).

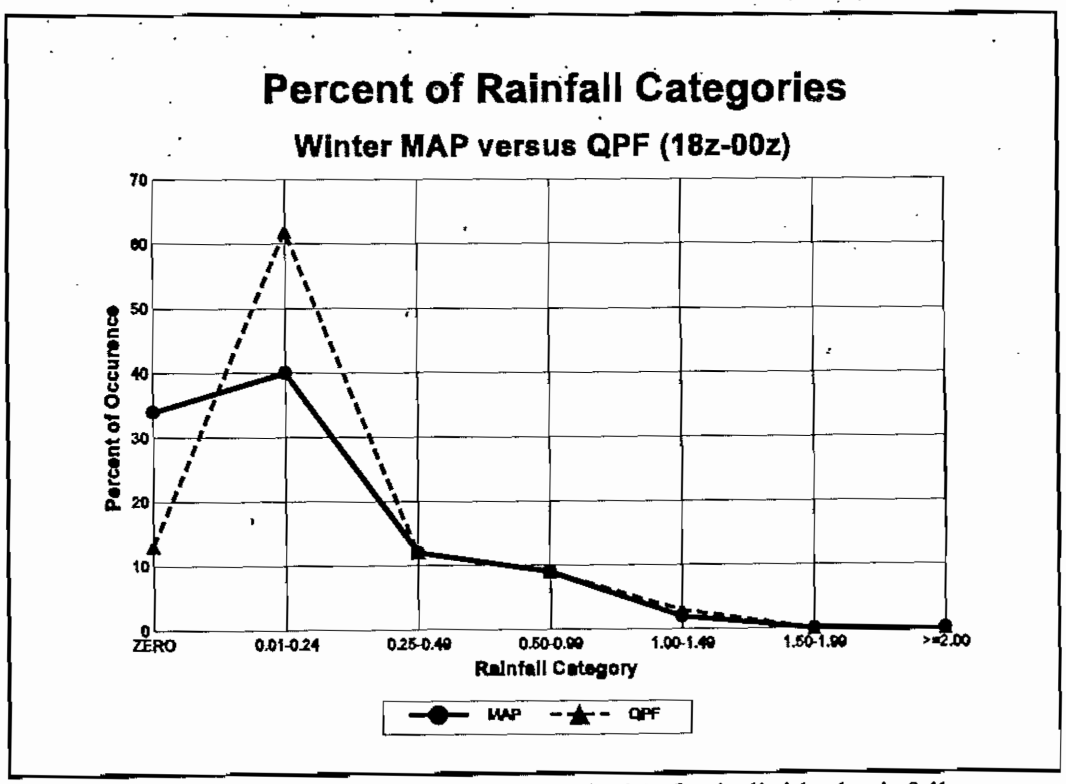

Figure 29. Six hour comparison of MAP and QPF for individual rainfall categories in winter (18z-00z).

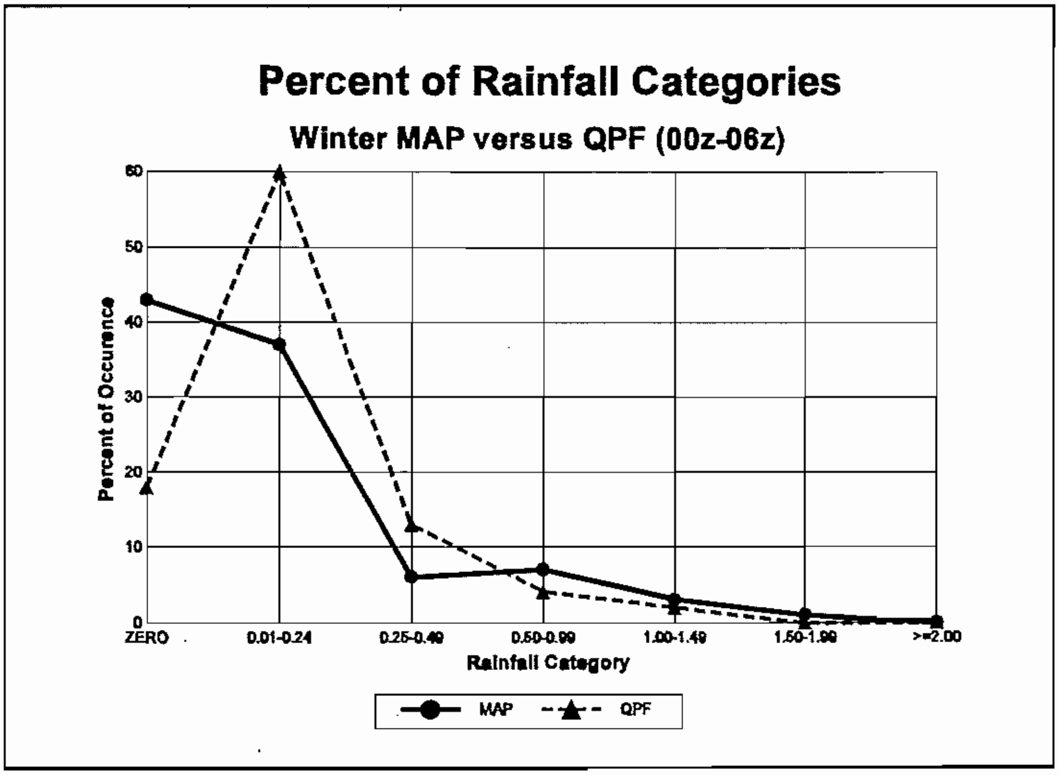

Figure 30. Six hour comparison of MAP and QPF for individual rainfall categories in winter (00z-06z).

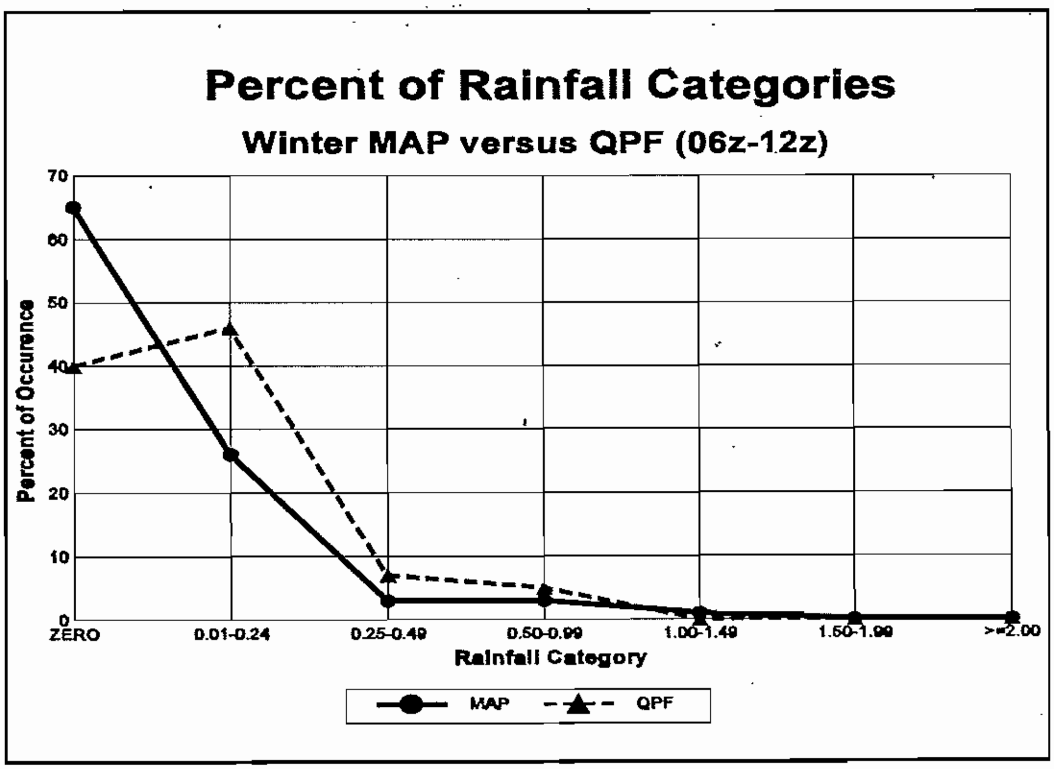

Figure 31. Six hour comparison of MAP and QPF for individual rainfall categories in winter (06z-12z).

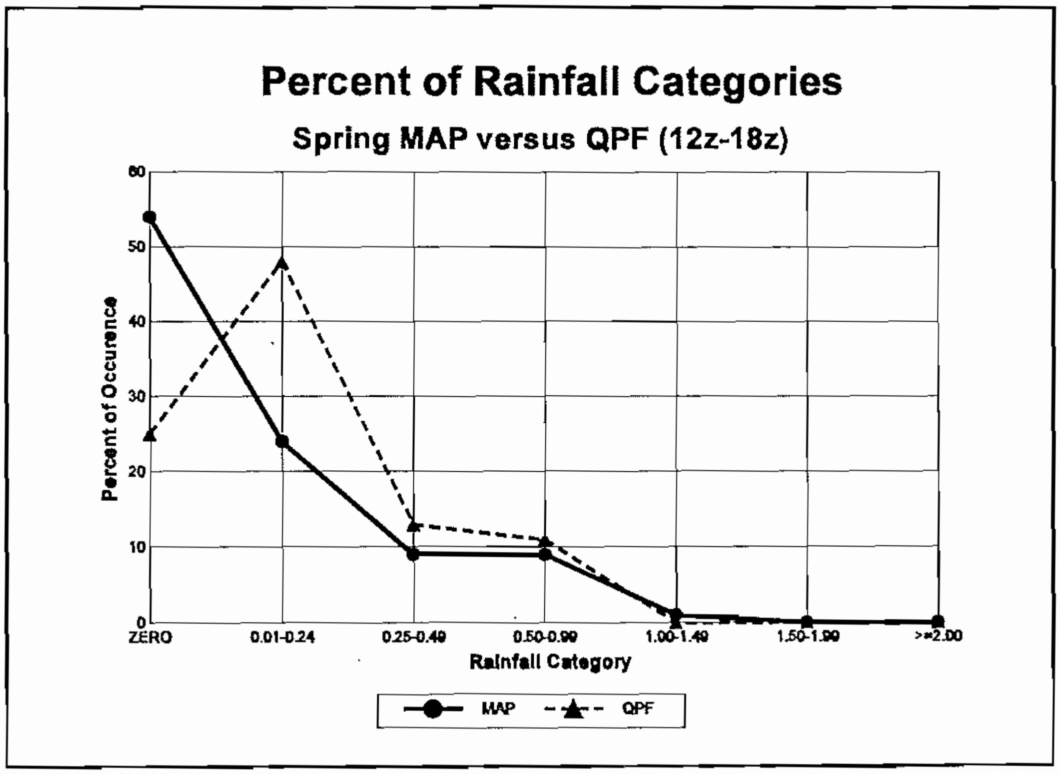

Figure 32. Six hour comparison of MAP and QPF for individual rainfall categories in spring (12z-18z).

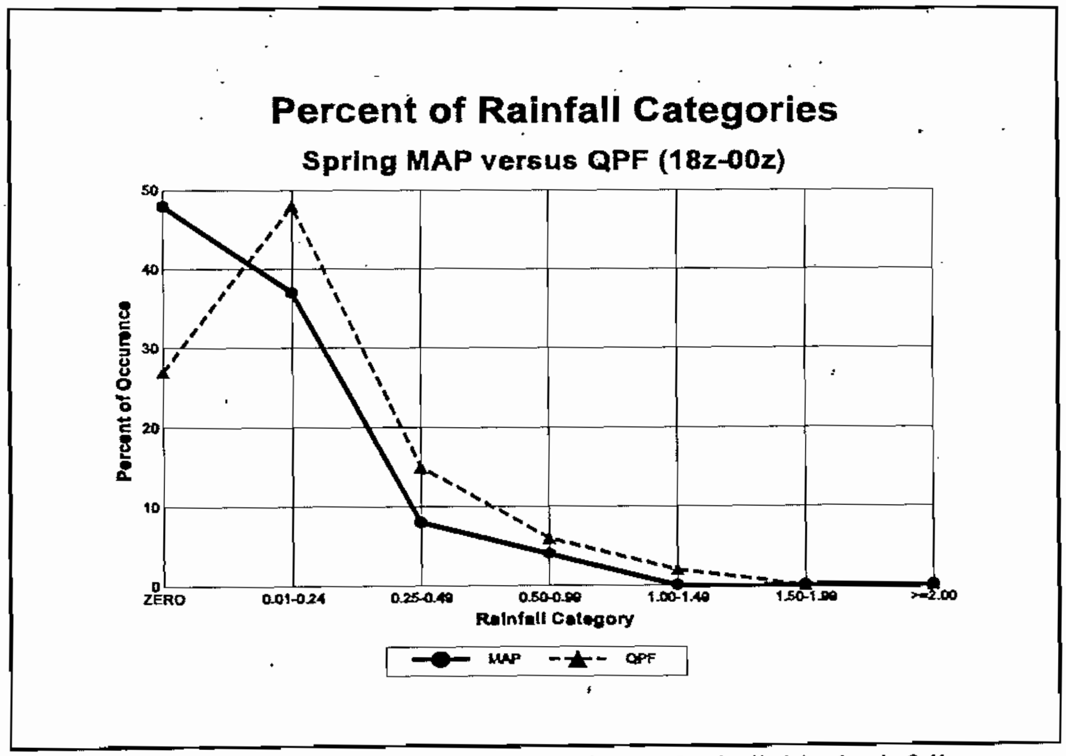

Figure 33. Six hour comparison of MAP and QPF for individual rainfall categories in spring (18z-00z).

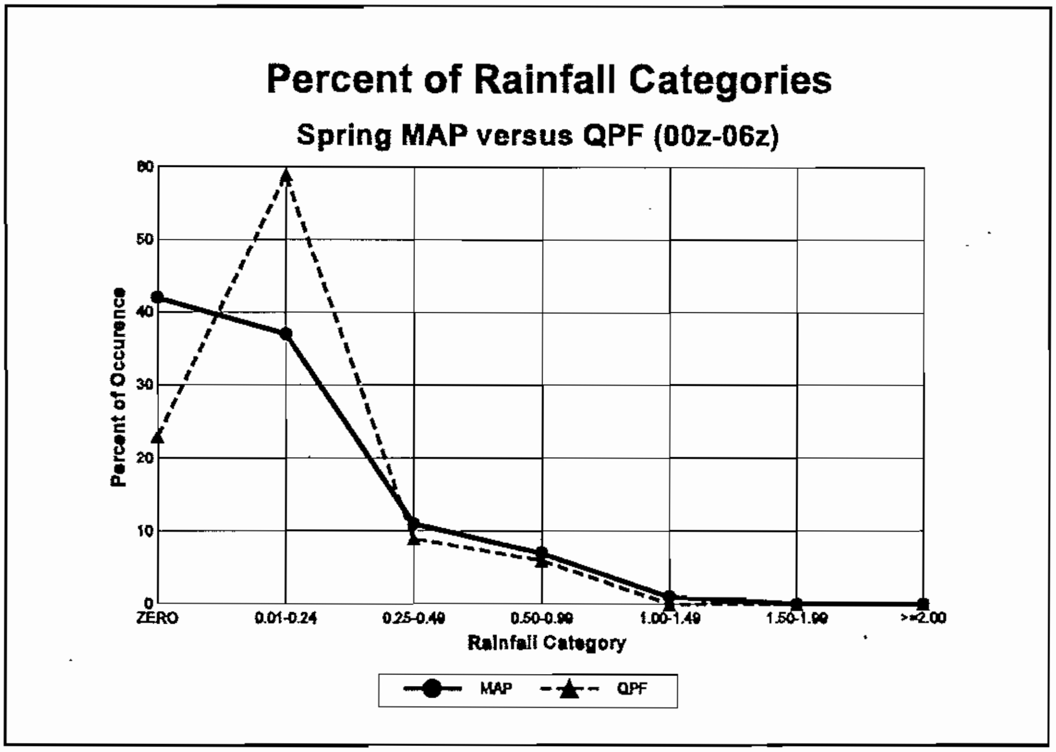

Figure 34. Six hour comparison of MAP and QPF for individual rainfall categories in spring (00z-06z).

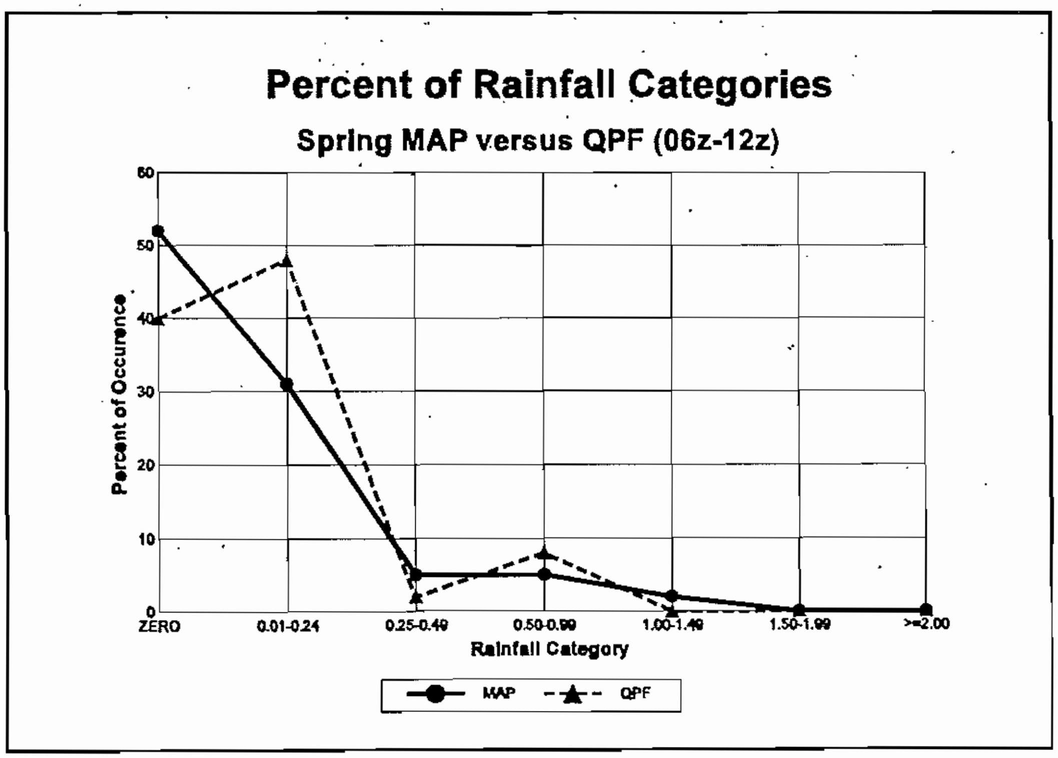

Figure 35. Six hour comparison of MAP and QPF for individual rainfall categories in spring (06z-12z).

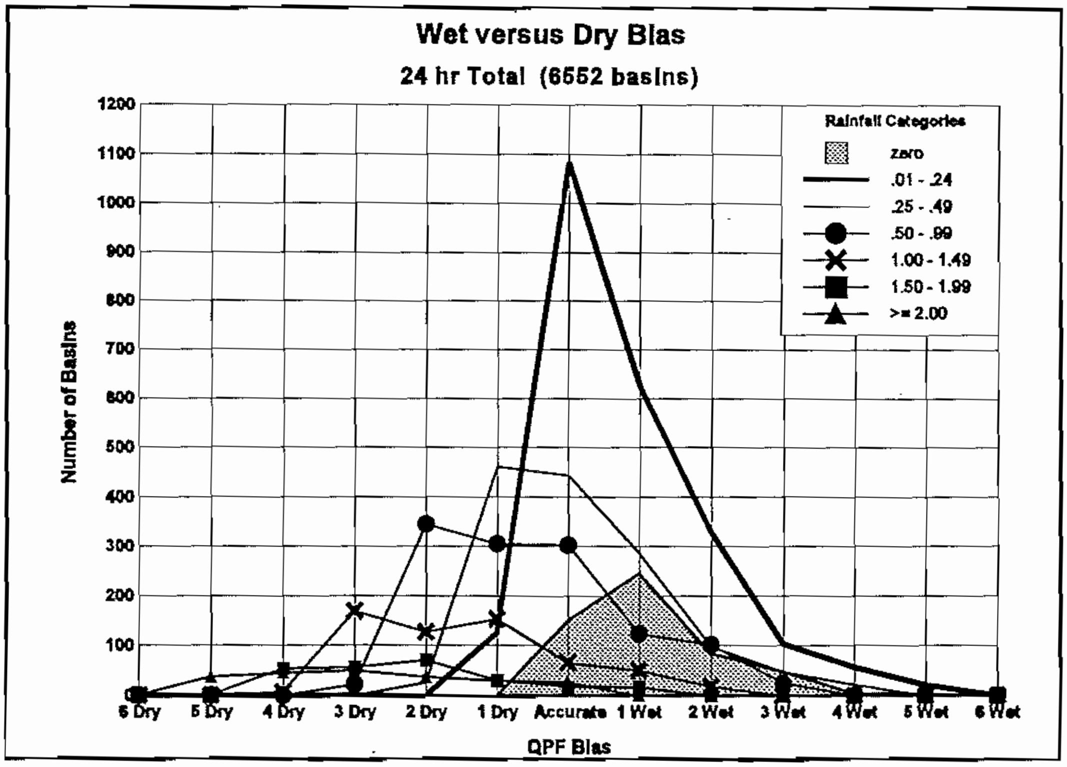

Figure 36. Magnitude of the QPF bias for the 24-hour period 12z Day 1 to 12z Day 2.

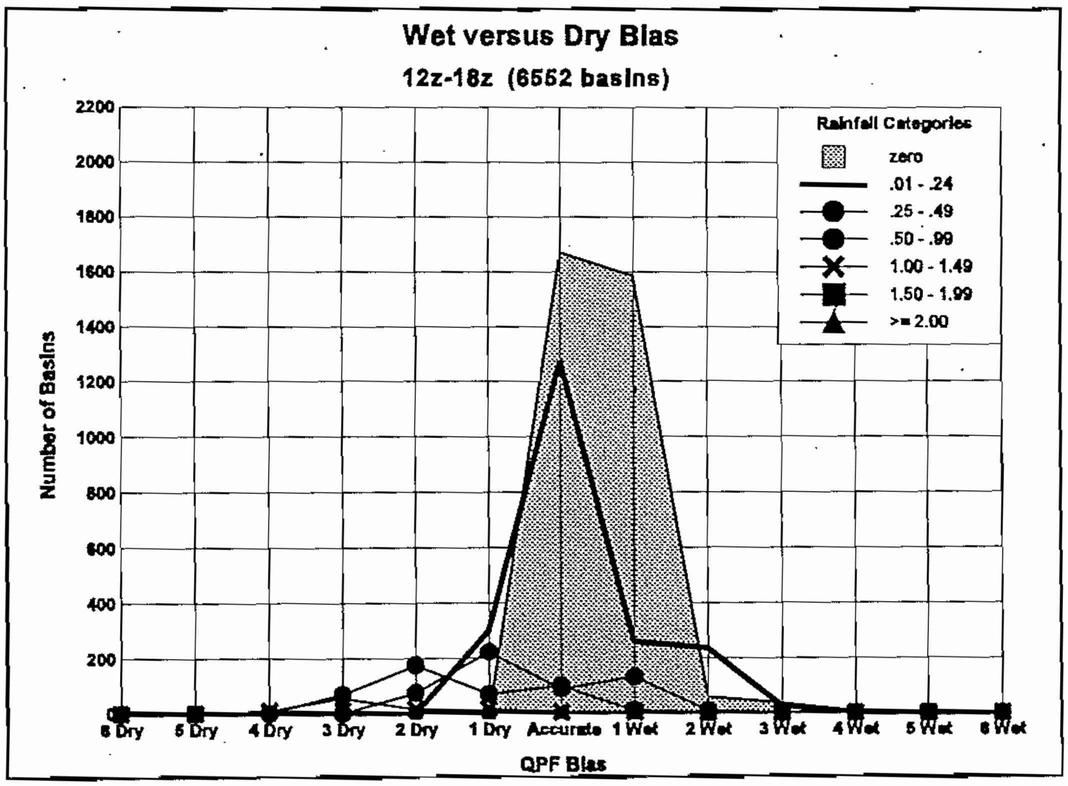

Figure 37. Magnitude of the QPF bias for the six hour period 12z-18z.

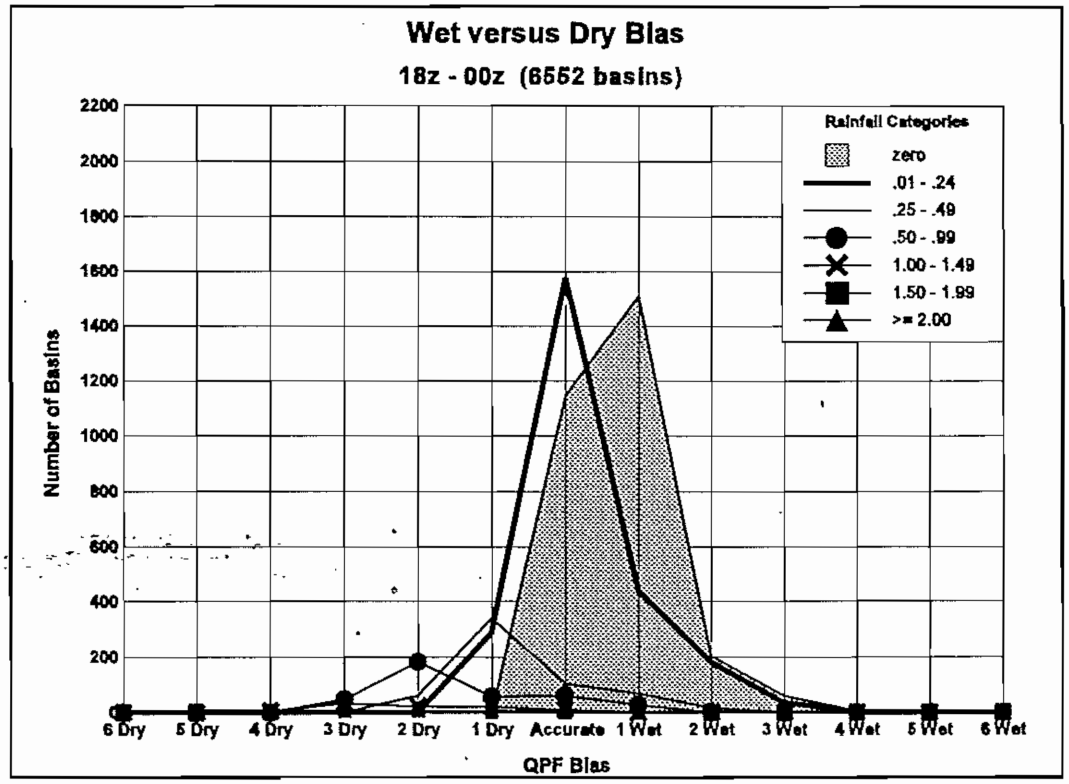

Figure 38. Magnitude of the QPF bias for the six hour period 18z-00z.

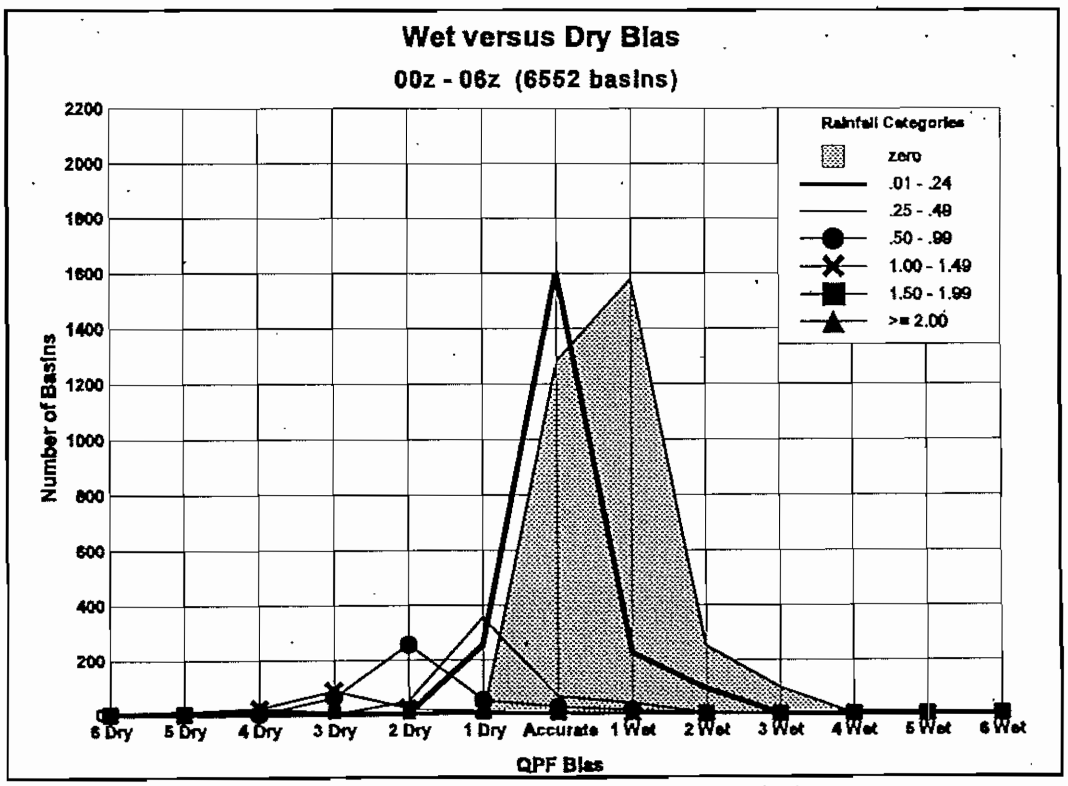

Figure 39. Magnitude of the QPF bias for the six hour period 00z-06z.

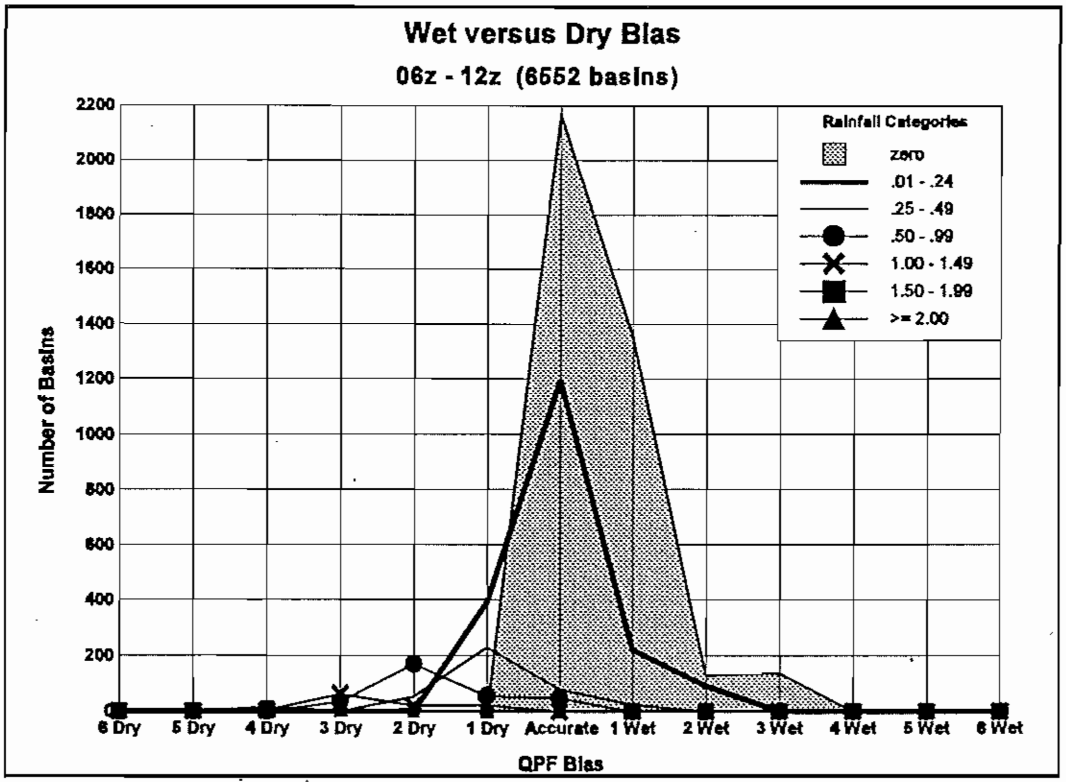

Figure 40. Magnitude of the QPF bias for the six hour period 06z-12z.

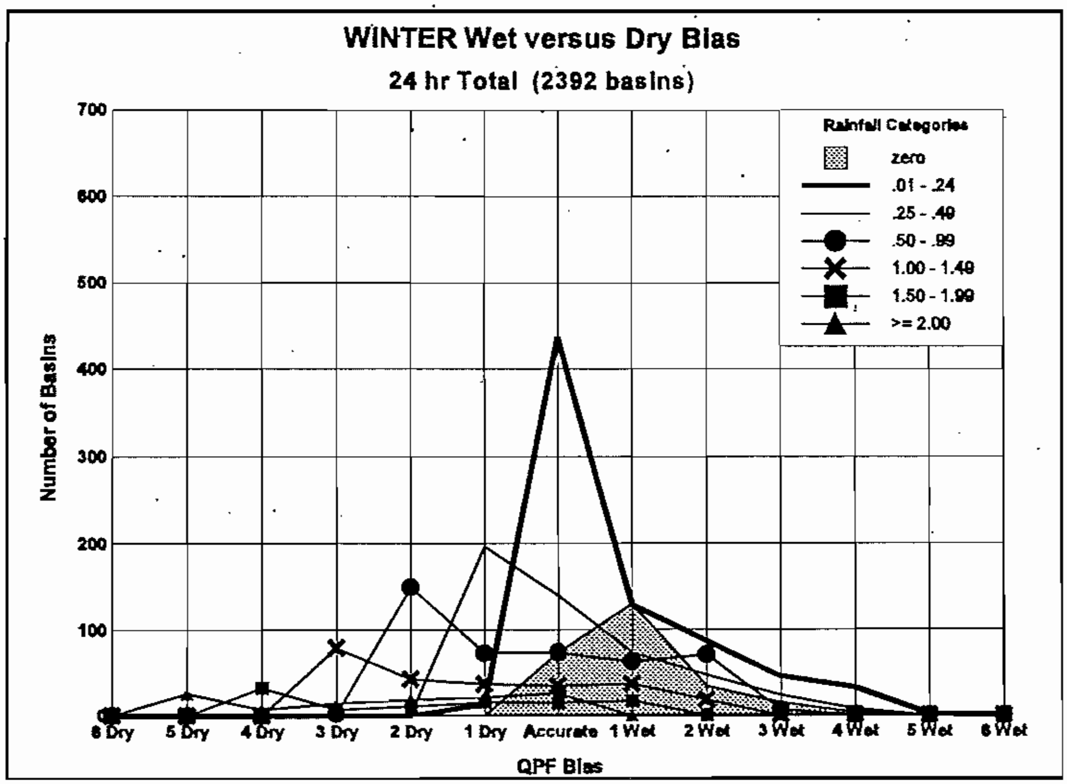

Figure 41. Magnitude of the QPF bias in winter for the 24-hour period 12z Day 1 to 12z Day 2.

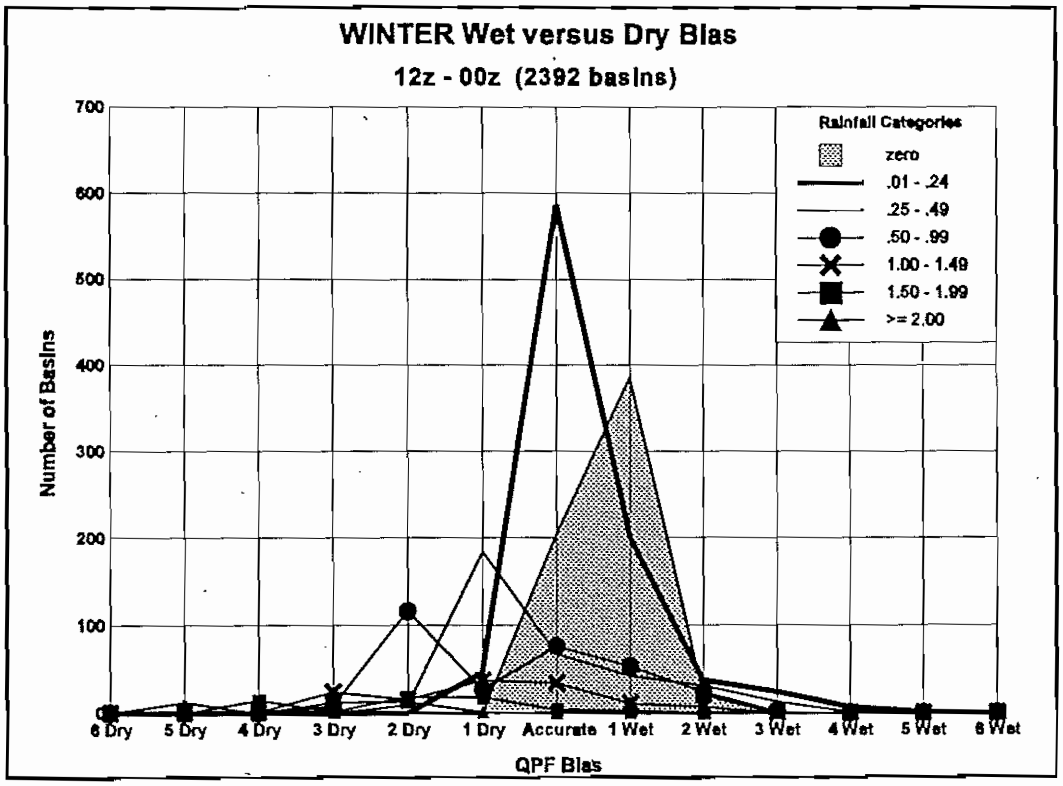

Figure 42. Magnitude of the QPF bias in winter for the twelve hour period 12z-00z.

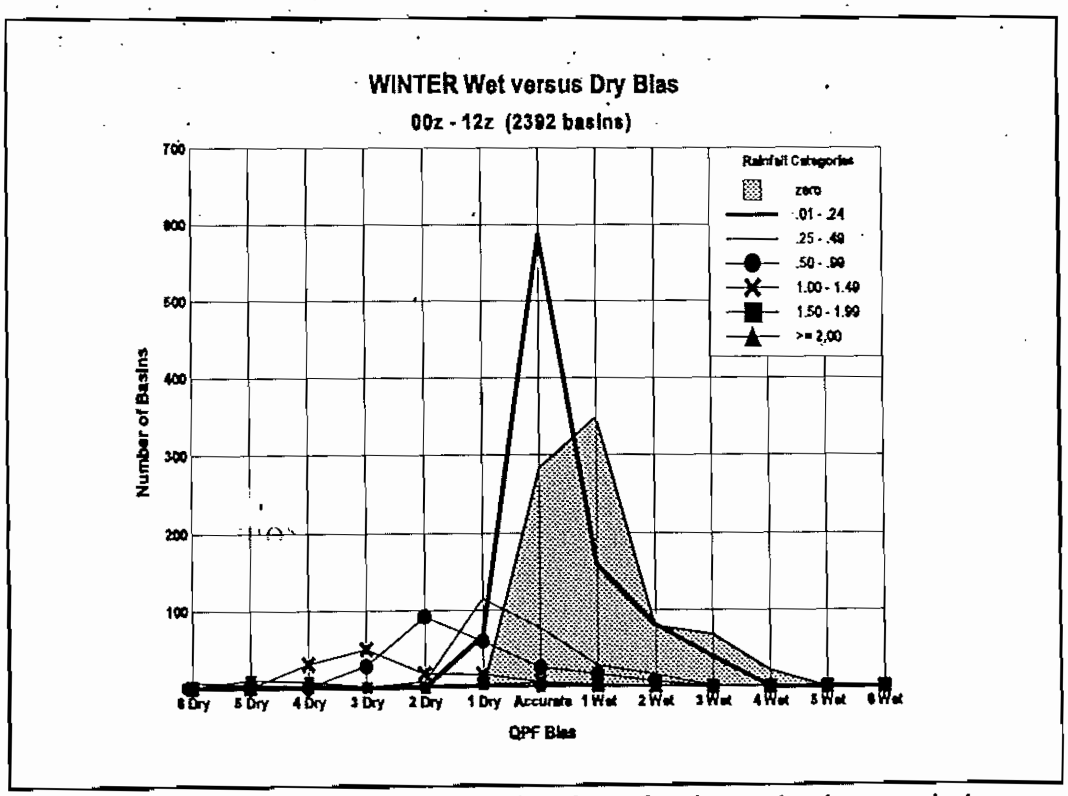

Figure 43. Magnitude of the QPF bias in winter for the twelve hour period 00z-12z.

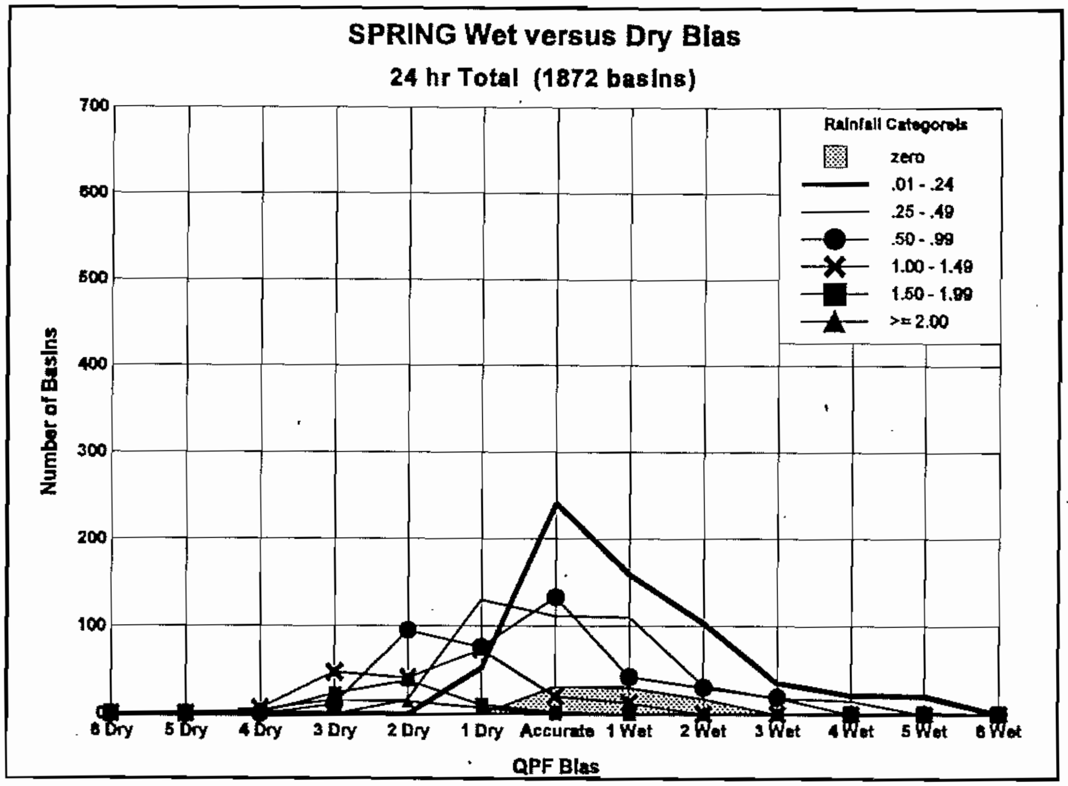

Figure 44. Magnitude of the QPF bias in spring for the 24 hour period 12z Day 1 to 12z Day 2.

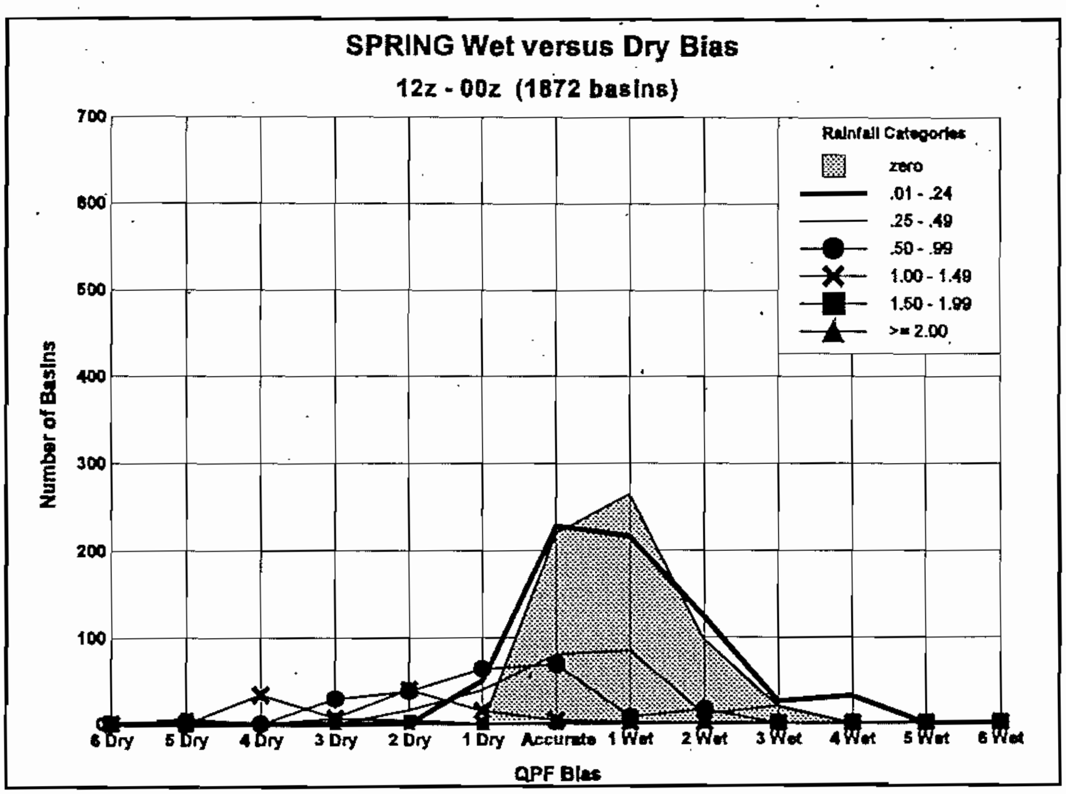

Figure 45. Magnitude of the QPF bias in spring for the twelve hour period 12z-00z.

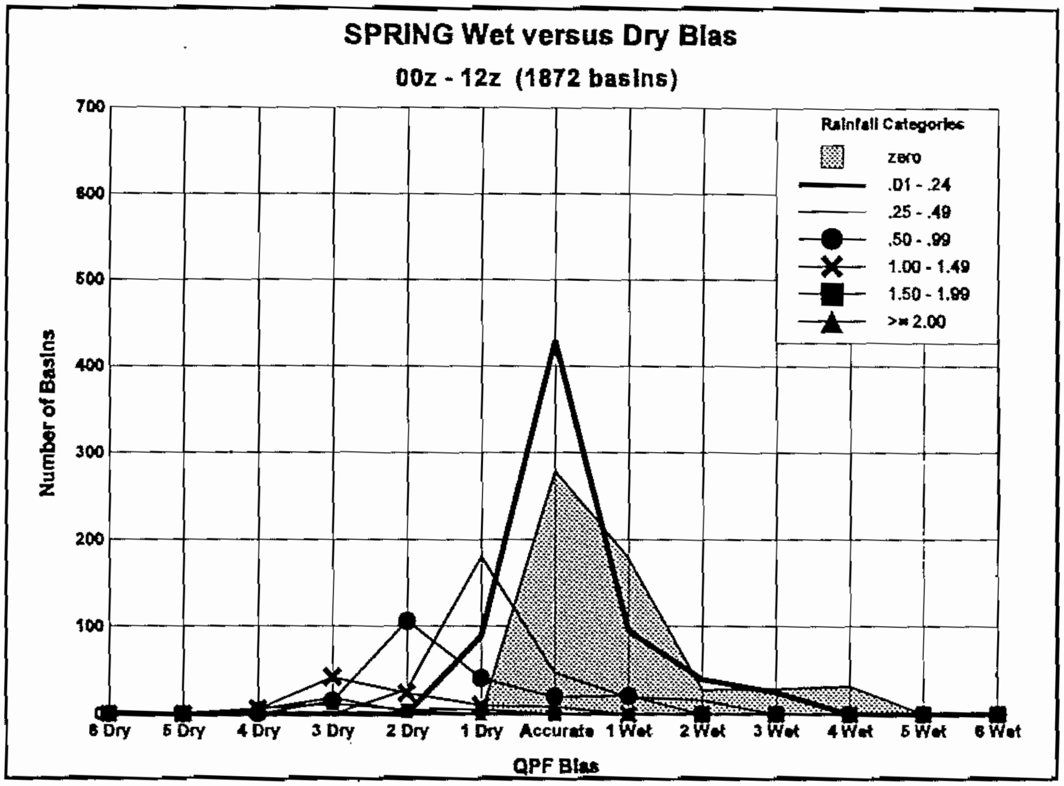

Figure 46. Magnitude of the QPF bias in spring for the twelve hour period 00z-12z.