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A FLASH FLOOD AID - THE LIMITED AREA QPF

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1. INTRODUCTION

Excessive rains in recent years have produced several disastrous flash floods in widespread sections of the United States, such as Big Thompson (Maddox et al., 1977), Johnstown (NOAA, 1977), and Rapid City (NOAA, 1972). While research has been done on the radar detection of flood producing rains, such as the Manually Digitized Radar Code (Moore et al., 1974), and the use of satellite data in estimating rainfall amounts (Scofield and Oliver, 1977), there have been only a few published studies in the field of Quantitative Precipitation Forecasting (Mogil and Groper, 1976).

The Quantitative Precipitation Forecast (QPF) is an extremely useful tool of both the meteorologist and hydrologist because it shows the areal distribution and the amount of rainfall expected to occur over a given period of time. The most important facet of the QPF is that it alerts the forecasters to the potential for excessive rains . The National Meteorological Center (NMC) has a Quantitative Precipitation Branch (QPB) that issues QPFs several times a day. However, due to limited staffing, the QPB concentrates on synoptic scale features, leaving mesoscale analysis and forecasting to the field forecasters.

The National Weather Service (NWS) is currently implementing the Critical Flood Support Office concept. This concept allows a specified office to modify a QPF over a limited area in support of their River Forecast Centers (RFC). However, for this to succeed, each forecaster must know the rainfall characteristics of his area and should have a systematic method for developing a QPF. This paper introduces the QPF program which has been developed at WSFO, Lubbock, Texas, for use in West Texas.

2. THE WSFO LUBBOCK QPF PROGRAM

Since June 1976, WSFO Lubbock has prepared QPFs for West Texas on a daily basis during the primary flash flood threat season, May through September. The program was initiated for several reasons, the main one being meteorological support of the NWS Flash Flood Program. However, the final product was used to brief the RFCs serving West Texas and the International Boundary and Water Commission (IB & WC) which has flood control responsibility for the Rio Grande watershed. Also, the QPF was used effectively in the station's public and agricultural forecast programs.

A limited area QPF is prepared twice daily by the public forecaster. Normally, a QPF is prepared by 10Z and is valid from 12Z to 12Z the next day using the 24-hour Limited Area Fine Mesh (LFM) forecast parameters from the 00Z data. The second QPF, prepared at 20Z, updates the first QPF. It uses the latest 12-hour LFM forecast parameters from the 12Z data and the latest upper air data. Intermediate updates can be made if the need arises, but this is a rather uncommon situation.

3. DEVELOPMENT OF THE QPF PROCEDURES

The WSFO Lubbock QPF procedures were developed primarily to indicate the maximum amount of precipitation expected within an area. Parameters investigated were climatology, certain 500 mb flow patterns, and five atmospheric variables which had been found to correlate well with episodes of heavy rain. These variables were lifted index, K-index, mean relative humidity (surface to 500 mb), tropopause temperatures, and precipitable water. Other variables, such as surface dew points and winds aloft, may be incorporated into the program in the future; but the program should be kept simple and relatively easy for the forecasters to use.

3.1 Climatology

The four climatological regions used in this study are outlined in Figure 1. These regions have different rainfall characteristics, mainly due to differences in topography (Orton, 1964). Each region is discussed below.

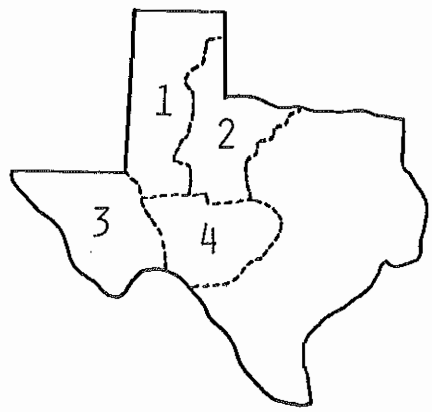


Figure 1. Climatic regions for which QPF's are developed and for which linear regression equations are available.
1. High Plains
2. Low Rolling Plains
3. Trans Pecos
4. Edwards Plateau

Trans Pecos - This region is characterized by terrain varying from rolling plains to rugged mountains. The soils are extremely rocky with little vegetation, which allows high runoff amounts. Annual rainfall amounts are generally less than 15 inches. However, extremely intense rains have occurred at times with amounts in excess of 20 inches falling over areas as large as 1 to 5 thousand square miles during a 48-hour period (Shipe and Riedel, 1976).

Edwards Plateau - This area is characterized by steep hills and deep valleys. Many streams originate in and across this area. Soils are very rocky with variable amounts of vegetation. Annual rainfall amounts vary from 15 inches in the western section to 25 inches in the eastern portion. Extreme rains of the same magnitude as in the Trans Pecos will occur from time to time.

High Plains - This area is almost all flat farmland with grassland in the Texas Panhandle. The area slopes from 4000 feet above mean sea level (MSL) along the border with New Mexico in the west to 3000 feet MSL along the "caprock" escarpment. Annual rainfall amounts vary from 14 inches in the western portion to 20 inches in the eastern portion. Historically, heavy rains have been confined to the area along the escarpment and in the Canadian River Valley.

Low Rolling Plains - This region is mainly relatively flat grasslands with several large rivers crossing the area in deep valleys. Annual rainfall amounts vary from 20 to 27 inches. Extreme rains have been relatively rare.

Although almost all areas in West Texas are subject to severe ponding or flash flooding, the greatest potential for a killer flood lies in the Edwards Plateau and Trans Pecos Regions. This is due to the rainfall and topographic characteristics of the regions and because both areas are popular with tourists.

3.2 General Flow Patterns

One of the primary steps in preparing a QPF in West Texas is identifying the 500 mb flow patterns which predominate in each climatic region. Local studies have shown that certain 500 mb flow patterns correlate better with excessive precipitation than others. During the summer months, the Bermuda Ridge becomes well established over the southern United States as the westerlies retreat northward. During this time of year there are four general 500 mb flow patterns over West Texas. In addition, two other flow patterns may occur in the area during the spring and fall. The flow patterns are discussed below and ranked in importance with respect to rainfall production. Refer to Figure 2 for a graphic illustration.

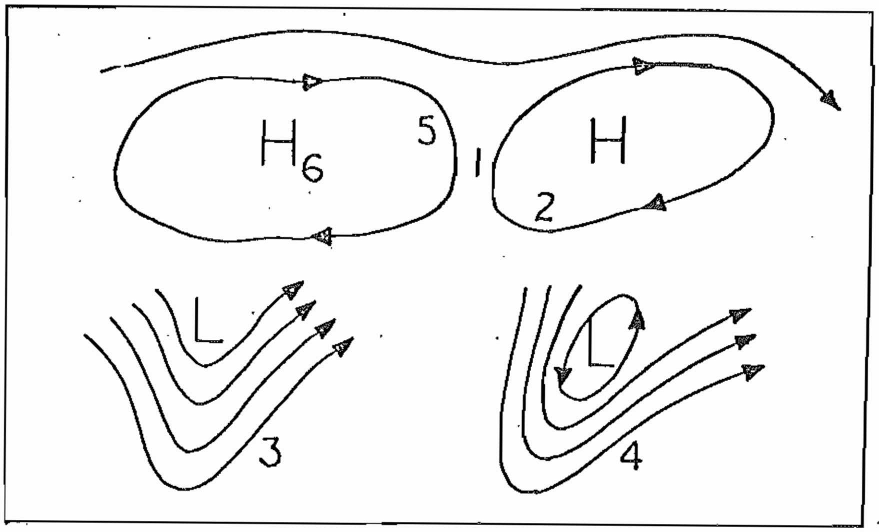


Figure 2. Basic flow patterns which were used in developing the QPF equations. Numbers indicate location of the flow pattern in relation to the forecast area.

1. Ridges of high pressure located east and west of the forecast area with a stationary trough over the forecast area. Weak short wave troughs may be embedded in the flow area between the highs.

2. Ridge aloft to the north of the forecast area with easterly or southeasterly flow over the forecast area. Inverted troughs may be embedded in the easterlies.

3. Advancing trough aloft west of the forecast area. This pattern usually has a frontal system assocated with it and is most common in the fall and spring.

4. Stationary trough aloft west of the forecast area with short waves embedded in the southwesterly flow over the forecast area. This pattern is most common in the fall and spring.

5. Ridge aloft west of the forecast area with northerly flow aloft over the forecast area. Weak short waves may be embedded in the northerly flow aloft.

6. Ridge aloft over the forecast area with rather weak flow at all levels.

3.3 Meteorological Variables

Observed values of each of the five meteorological variables discussed below have correlated well with rainfall amounts in previous studies and in this study also. It should be noted that other parameters could be used in a system such as this one; however, the ones used are those which worked best in West Texas.

1. Lifted Index (LI) - The lifted index is used as a measure of atmospheric stability and is essential for determining the likelihood of convective rainfall (Erickson et al., 1960). This variable can be obtained from the output of the LFM or calculated from radiosonde data.

2. Precipitable Water (Pw) - The precipitable water is the observed liquid water equivalent of water vapor in a column of the atmosphere. It has been noted that precipitable water amounts greater than 1.25 inches are present during most excessive rainfall episodes (Mogil and Groper, 1976). This variable can be calculated from radiosonde data or obtained from the 4-panel composite moisture chart twice daily from National Facsimile Circuit (NAFAX).

3. Tropopause Temperature (Tt) - The position of the cold thermal ridge of the tropopause level has been found to be significant when delineating areas of possible excessive rainfall (Johnson et al., 1974) and (Ropar, 1972). Also, local studies at WSFO Lubbock have shown that areas where tropopause temperatures are colder than normal will have a greater probability of excessive rainfall. This information can be obtained from the National Environmental Satellite Service (Heckman, 1976).

4. Mean Relative Humidity (surface to 500 mb) (RH) - This is by far the best predictor found in this study. In every case where heavy rainfall occurred, the mean relative humidity was in excess of 50 percent; it was greater than 70 percent the majority of the time. Also, this quantity is one of the variables forecast by the LFM model.

5. K-Index (K) - The K-Index is a measure of air mass thunderstorm potential and has proven useful in delineating the area over which precipitation can be expected (George, 1960). This predictor is obtained from the FOUS Trajectory Forecast (Reap, 1972).

4. DEVELOPMENT OF REGRESSION EQUATIONS FOR RAINFALL PREDICTION

Regression equations for estimating the maximum storm precipitation, percentage of the area covered by measurable precipitation (determined by the number of reporting stations receiving measureable rain), and average precipitation were developed using the five meteorological variables discussed in Section 3 for both rain and no-rain days. The variables were correlated with 24 hour rainfall totals.

Data for the equation development were obtained from several sources. The 500 mb flow patterns were taken from the NOAA Daily Weather Map Series and the rainfall data were taken from the monthly rainfall data published by the National Climatic Center (NCC). The meteorological parameters were taken from the following NAFAX facsimile charts: Composite Moisture Analysis, and Tropopause Pressure, Temperature and Wind.

There were a total of 72 equations developed for the four climatological areas and six general flow patterns. However, three equations were not used because less than 5 cases were available for the particular climatic region and pattern. Multiple correlation coefficients for the regression equations ranged from .35 to .93. The coefficients for all equations are shown in Table 1.

Table 1
Multiple Correlation Coefficients for the QPF Linear Regression Equations

		High Plains	Low Rolling Plains	Trans Pecos	Edwards Plateau
Flow Pattern #1	Avg. Precip.	.64	.61	.47	.66
	Max. Precip.	.64	.59	.51	.60
	Pct. Covg.	.66	.75	.69	.82
	# of cases	18	20	23	22
Flow Pattern #2	Avg. Precip.	.41	.63	.76	.83
	Max. Precip.	.49	.63	.78	.84
	Pct. Covg.	.80	.81	.78	.93
	# of cases	17	20	31	33
Flow Pattern #3	Avg. Precip.	.77	.58	.56	.58
	Max. Precip.	.71	.61	.55	.75
	Pct. Covg.	.62	.72	.75	.75
	# of cases	28	25	16	13
Flow Pattern #4	Avg. Precip.	.75	.70	.42	*
	Max. Precip.	.73	.67	.48	*
	Pct. Covg.	.61	.61	.61	*
	# of cases	12	8	17	3
Flow Pattern #5	Avg. Precip.	.49	.57	.93	.68
	Max. Precip.	.65	.55	.90	.64
	Pct. Covg.	.66	.52	.62	.88
	# of cases	22	20	7	10
Flow Pattern #6	Avg. Precip.	.38	.40	.62	.58
	Max. Precip.	.43	.46	.66	.49
	Pct. Covg.	.35	.39	.74	.58
	# of cases	7	19	22	45

* Indicates too few cases to correlate.

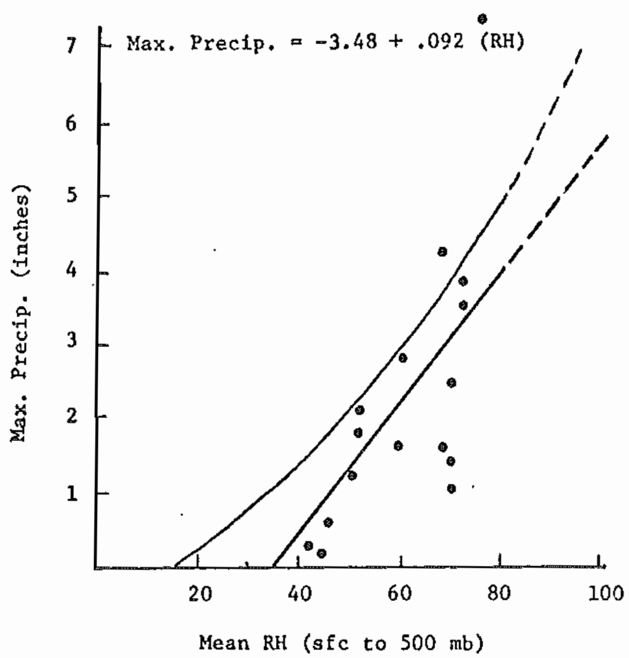
As indicated in Table 2, the variable chosen as a primary predictor most frequently was relative humidity, with none of the other four variables being a clear cut second choice.

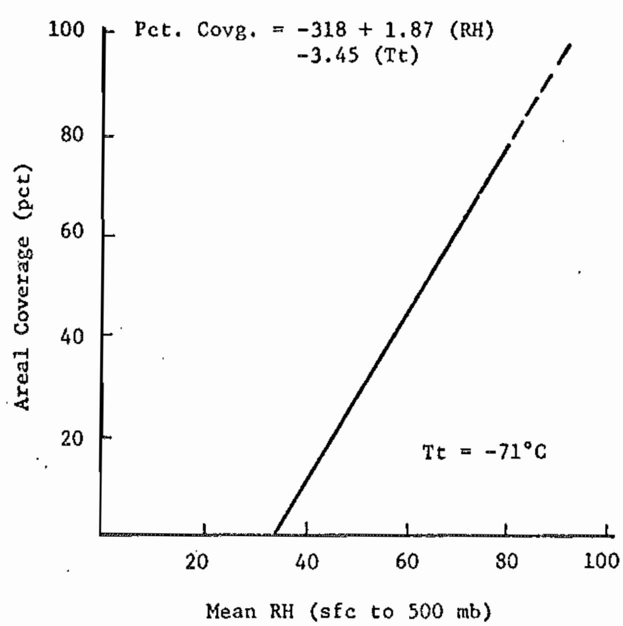
Table 2
The Percentage of Times that the Variables were Chosen as the Best Predictors in the Regression Equations

	Max. Pre.	Avg. Pre.	Percent Covg.
LI	16	17	23
RH	45	32	49
Pw	16	11	0
K	14	20	11
Tt	9	20	17

In order to simplify the equation portion of the QPF technique, graphs were plotted showing the mean relative humidity versus the forecast rainfall. Mean relative humidity was picked because it is a readily available forecast parameter and correlated well in almost every equation. This facilitates the preparation of a systematic QPF. However, the equations can be used in certain situations where abnormally cold tropopause temperatures or very high precipitable water amounts will give much higher rainfall estimates than what is indicated on the graphs. A small sample of graphs and equations are shown in Figure 3. Additional graphs and equations are available at WSFO Lubbock.

Figure 3. An example of the graphs and equations used in forecasting maximum precipitation and areal coverage. (Edwards Plateau for flow pattern No. 1) Thin hyperbolic line on maximum precipitation graph represents the 90 percent confidence level.





A 90 percent confidence line is depicted by the light hyperbolic line in Figure 3. Assuming a normal distribution of observations about the regression line, the probability that the next observation will be below the line is 90 percent (Draper, 1967). In other words, there is only a 10 percent chance that, for a given mean relative humidity, the maximum rainfall amount will lie above the line.

The 90 percent level is used primarily when most of the predictors strongly indicate heavy rains. By using this level, rainfall forecasts are more easily made for extreme cases. This is an excellent tool to use during a potential flash flood episode. However, as explained in the next section, the equations and graphs are only one step in developing a good QPF.

5. SEQUENTIAL STEPS IN DEVELOPING A QPF

The Lubbock QPF program is designed to be as simple and straightforward as possible. In preparing a QPF, the forecaster will look at much of the same data used in developing the zone forecasts. Therefore, little additional work is required for the QPF.

The QPF is developed by a four step process. All four steps must be done or a significant rainfall episode could be overlooked.

<u>Step A</u> - Plot and analyze the LI, Tt, Pw, RH, and K. The LI and RH are obtained from the LFM 4-panel, prognostic charts, using either the 12 or 24 hour forecast values, whichever is appropriate. The K is obtained from the FOUS 55 message and is a 24 hour forecast. The Tt and Pw are obtained from the latest upper air data.

<u>Step B</u> - The forecaster now determines where precipitation will occur within the forecast area. This is accomplished by identifying the following:

(1) Areas of Positive Vorticity Advection (PVA) as indicated on the numerical models. The Zero Relative Vorticity Line (Rosendal, 1976) is an excellent tool for determining the boundary of the rain area.

(2) Orographic lift caused by the mountains of Southwest Texas especially when strong east to southeasterly flow dominates the area.

(3) Areas of strong afternoon heating coupled with abundant low level moisture (i.e., dew points above 60°F).

(4) Areas of low-level convergence as indicated on plotted low-level winds or on the Sangster Chart (Sangster, 1967).

<u>Step C</u> - The forecaster must now calculate the extent to which precipitation will occur in the area where precipitation is forecast in Step B.

(1) Determine which of the flow patterns is present for each climatic region.

(2) Calculate the maximum precipitation, average precipitation and percent coverage from either the graphs or equations. If the precipitation covers two adjacent climatic regions, then the forecast must be adjusted for a smooth transition from one area to another since different equations in each area may give different forecast values.

Step D - In the last step, the forecaster looks for indications of possible excessive rains. The following meteorological situations have worked well for WSFO Lubbock, but other situations may be effective in other sections of the country.

(1) Areas of strong diffluence at the 200 mb or 300 mb levels.

(2) Large increase in Pw values to at least 50 percent above normal (Lott, 1976). (See Appendix)

(3) Tropopause temperatures equal to or exceeding 6 degrees colder than normal.

If any two or more of the parameters listed in Step D are present, the area should be considered as having the potential for very heavy rains and either the 90 percent confidence line or the regression equations should be used for the forecast, whichever gives the greater value.

6. QPF FORMAT

In order for the QPF to be useful, it must be set forth in an effective manner while staying within the limits of the program. All information must be presented in such a way that persons with limited time and no QPF expertise can readily use it. It should be noted at this time that since the Lubbock QPF program is designed mainly for support of the Flash Flood Program, forecasting small rainfall episodes, generally less than one inch, has been de-emphasized. Therefore, the format of the QPF is designed to show the upper limits of the expected rainfall.

Several different formats have been tried from time to time, but the following format has proven best for use in West Texas. See Figure 4 for an illustration.

The steps used in the analysis of the precipitation map are:

(1) The portion of the basic forecast area (FP) which has a 20 percent chance of rain or greater is outlined by a dashed line, providing the value obtained from the graphs for average precipitation is at least 0.25 inch. This lower limit was chosen because of the economics relating to agriculture.

(2) Draw the one inch isohyet around the area which has the greatest probability of precipitation, as determined from the LFM vorticity progs, if the maximum amount forecast is expected to be greater than one inch. Isohyets of greater than one inch can be drawn, but these are at the discretion of the forecaster and depend on the strength of the weather system and the inflation factors in Section 5, Step D. This usually cannot be done when flow patterns 5 and 6 are present because the activity will be widely scattered.

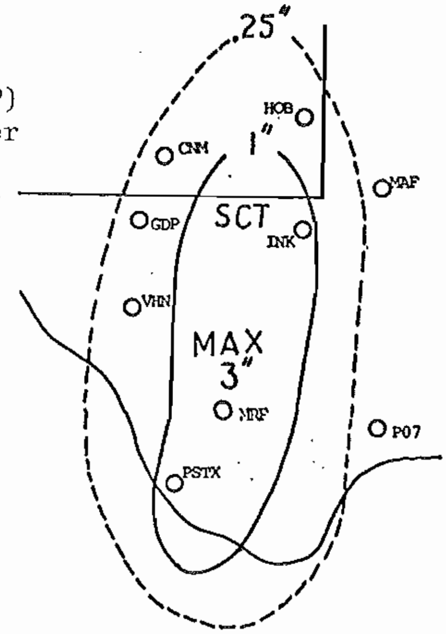


Figure 4. Example of the QPF format as used at WSFO Lubbock.

(3) Use a descriptive adjective within the one inch isohyet to describe the areal distribution of the showers and thunderstorms. The value is obtained from the graphs of percent coverage. However, the value may be altered depending on the confidence of the forecaster that precipitation will occur somewhere in a specific area.

Isolated (ISOLD)	- Less than 10% coverage
Widely Scattered (WSCT)	- 10 to 20% coverage
Scattered (SCT)	- 20 to 30% coverage
Numerous (NMRS)	- 30 to 50% coverage
Widespread (WDSPRD)	- 50% or greater coverage

(4) The final step is to enter the maximum point rainfall that is expected to occur in the precipitation area. This is designated by the term MAX.

In the final analysis, the Lubbock QPF should be able to answer the question, "What percent of the area will receive measurable precipitation averaging _____ inches with maximum amounts of _____ inches expected?"

7. VERIFICATION AND RESULTS

Verification was performed on each year separately because of the addition of the linear regression equations in 1977.

First, a determination had to be made as to what constituted a correct forecast. This was accomplished by comparing the forecast of areal coverage and the maximum precipitation to the reported observations within each area. Several forecasters were asked to judge the QPFs independently. Secondly, skill scores were calculated for both 1976 and 1977 using the 24 hour maximum precipitation forecast versus the maximum precipitation observed within the area during the 24 hour period where precipitation was forecast.

Results of the verification (see Table 3) indicate the QPFs issued by the forecasters at WSFO Lubbock were, for the most part, good. In 1976, 54 percent of the forecasts were judged to be correct. In 1977, 67 percent of the forecasts were correct. Skill scores showed the same improvement from 1976 to 1977. The improvement is probably due to several reasons. However, the two most significant are the addition of the linear regression equations to the forecast program and the greater experience of the forecasters.

The Lubbock verification was not compared to the NMC QPF verification. This was because the NMC method of verification (Olson, 1977) uses square degree inches rather than maximum precipitation for verifying the products.

Most of the incorrect forecasts were due to overforecasting precipitation amounts and areal coverage. This is illustrated in Table 3. The chief cause of the overforecasting was the forecaster not looking at the LFM close enough to see if it was exhibiting biases in the FOUS data or the vorticity tracks. The problem was primarily in the lifted index and relative humidity. This can be corrected by forecasters learning more about the limitations and biases of the model.

Table 3
Contingency Tables Showing the Verification of the Lubbock QPF for 1976 (Top) and 1977 (Bottom)

OBSERVED	Forecast 0-.50	.51-1.50	1.51-2.50	2.51-3.50	3.51-4.50	4.51-5.5	≥ 5.5
0 - .50	18	10	11	7	2	1	1
.51 - 1.50	1	12	3	3	0	0	2
1.51 - 2.50	0	3	5	2	3	2	1
2.51 - 3.50	0	2	5	4	1	2	3
3.51 - 4.50	0	2	0	1	3	0	1
4.51 - 5.50	0	0	0	0	0	0	1
> 5.50	0	0	0	0	0	2	0

Number of forecasts = 114
Number of correct = 61
Percentage correct = 54
Skill Score = .43

OBSERVED	Forecast 0-.50	.51-1.50	1.51-2.50	2.51-3.50	3.51-4.50	4.51-5.5	≥ 5.5
0 - .50	43	15	3	2	0	1	0
.51 - 1.50	3	19	11	1	0	0	0
1.51 - 2.50	0	9	10	3	0	0	0
2.51 - 3.50	0	3	2	1	1	0	0
3.51 - 4.50	1	1	0	1	1	1	0
4.51 - 5.50	0	0	0	0	0	1	0
> 5.50	0	0	0	0	0	0	0

Number of forecasts = 133
Number of correct = 89
Percentage correct = 67
Skill Score = .53

8. CONCLUSIONS AND RECOMMENDATIONS

This has proven to be an excellent program at WSFO Lubbock. The main asset is that a forecaster must systematically look at the parameters which signify a potentially heavy rain situation on a day-to-day basis. Therefore, the possibility of overlooking a situation that has flash flood potential is reduced. Also, when developing procedures for a program such as this, much is learned about the climatology of rainfall for an area. However, because a technique that works well in one part of the country may not work in another, we recommend that other WSFOs initiate similar studies.

The QPF program should improve yearly at WSFO Lubbock as more data and additional storms are studied. Also, improvements made in the LFM products should increase the accuracy of the forecasts.

9. ACKNOWLEDGMENTS

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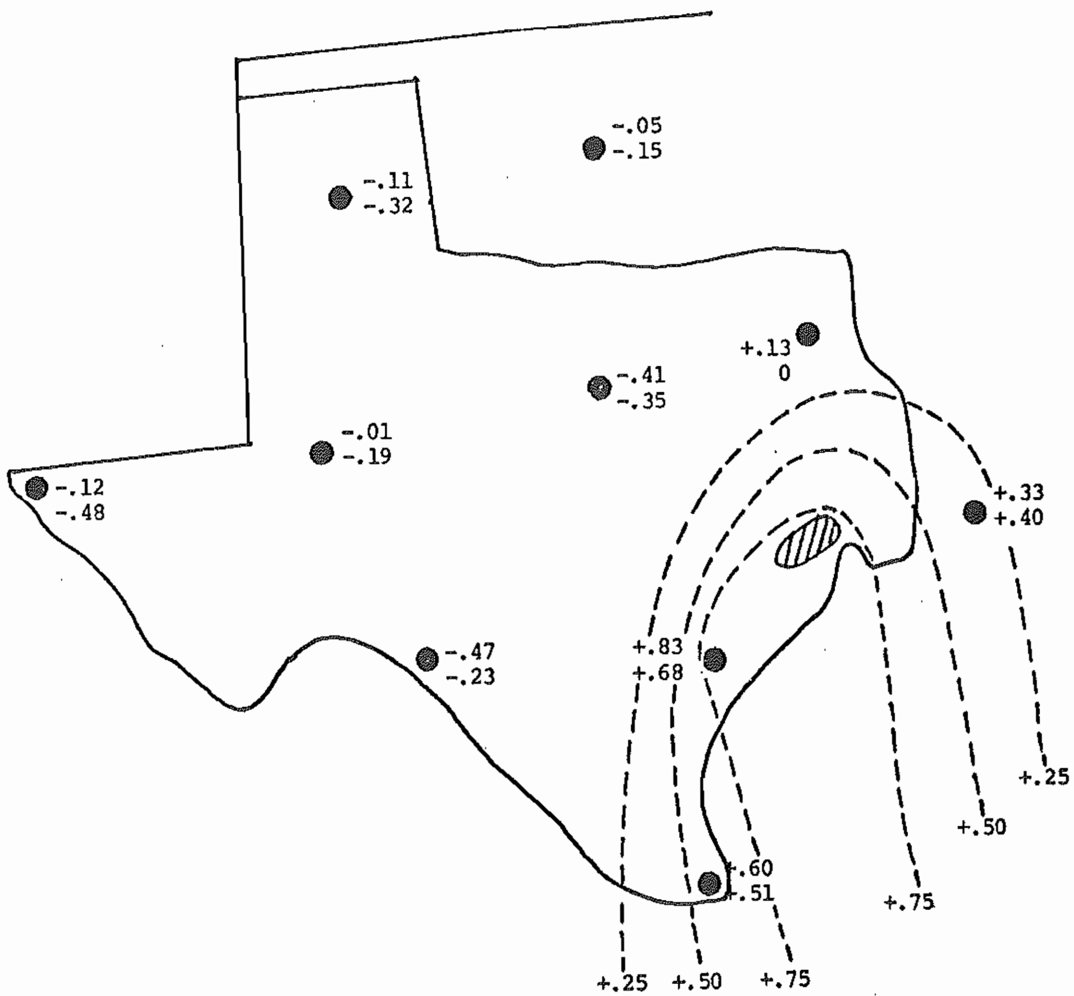
11. APPENDIX



Storm of June 15, 1976 related to the 12 hour (June 15, 00Z to 12Z) precipitable water change (upper number) and the deviation from climatological mean (lower number) of the 12Z values. Dashed lines show increase in precipitable water values. Hatched area is where maximum rainfall fell. The maximum reported rainfall was 13 inches.