A TECHNICAL MEMORANDUM NWS CR-110

THE EFFECT OF QUANTITATIVE PRECIPITATION FORECASTS ON RIVER FORECASTS

Noreen O. Schwein
National Weather Service Office
Central Region Headquarters
Regional Hydrology
Kansas City, Missouri

January 1996

U.S DEPARTMENT OF Commerce / National Oceanic and Atmospheric Administration / National Weather Service

NOAA TECHNICAL MEMORANDA
National Weather Service, Central Region Subseries

The National Weather Service Central Region (CR) subseries provides an informal medium for the documentation and quick dissemination of results not appropriate, or not yet ready, for formal publication. The series is used to report on work in progress, to describe technical procedures and practices, or to relate progress to a limited audience. These Technical Memoranda report on investigations devoted primarily to regional and local problems of interest mainly to regional personnel, and hence will not be widely distributed.

Papers 1 through 15 are in the former series, ESSA Technical Memoranda, Central Region Technical Memoranda (CRTM); Papers 16 through 36 are in the former series, ESSA Technical Memoranda, Weather Bureau Technical Memoranda (WBTM). Beginning with Paper 37, the papers are part of the series, NOAA Technical Memoranda NWS.

Papers that have a PB or COM number are available from the National Technical Information Service, U. S. Department of Commerce, 5285 Port Royal Road, Springfield, VA 22151. Order by accession number shown in parenthesis at the end of each entry. Prices vary for all paper copies. Microfiche are $4.50. All other papers are available from the National Weather Service Central Region, Scientific Services, Room 1836, 601 East 12th Street, Kansas City, MO 64106.

ESSA Technical Memoranda

CRTM 1 Precipitation Probability Forecast Verification Summary Nov. 1965 - Mar. 1966, SSD Staff, WBCRH, May 1966.
CRTM 2 A Study of Summer Showers Over the Colorado Mountains. William G. Sullivan, Jr., and James O. Severson, June 1966.
CRTM 3 Areal Shower Distribution - Mountain Versus Valley Coverage. William G. Sullivan, Jr., and James O. Severson, June 1966.
CRTM 4 Heavy Rains in Colorado June 16 and 17, 1965. SSD Staff, WBCRH, July 1966.
CRTM 5 The Plum Fire. William G. Sullivan, Jr., August 1966.
CRTM 6 Precipitation Probability Forecast Verification Summary Nov. 1965 - July 1966. SSD Staff, WBCRH, September 1966.
CRTM 7 Effect of Diurnal Weather Variations on Soybean Harvest Efficiency. Leonard F. Hand, October 1966.
CRTM 8 Climatic Frequency of Precipitation at Central Region Stations. SSD Staff, WBCRH, November 1966.
CRTM 9 Heavy Snow or Glazing. Harry W. Waldheuser, December 1966.
CRTM 10 Detection of a Weak Front by WSR-57 Radar. G. W. Polensky, December 1966.
CRTM 11 Public Probability Forecasts. SSD Staff, WBCRH, January 1967.
CRTM 12 Heavy Snow Forecasting in the Central United States (an Interim Report). SSD Staff, January 1967.
CRTM 13 Diurnal Surface Geostrophic Wind Variations Over the Great Plains. Wayne E. Sangster, March 1967.
CRTM 14 Forecasting Probability of Summertime Precipitation at Denver. Wm. G. Sullivan, Jr., and James O. Severson, March 1967.
CRTM 15 Improving Precipitation Probability Forecasts Using the Central Region Verification Printout. Lawrence A. Hughes, May 1967.
WBTM CR 16 Small-Scale Circulations Associated with Radiational Cooling. Jack R. Cooley, June 1967.
WBTM CR 17 Probability Verification Results (6-month and 18-month). Lawrence A. Hughes, June 1967.
WBTM CR 18 On the Use and Misuse of the Brier Verification Score. Lawrence A. Hughes, August 1967 (PB 175 771).
WBTM CR 19 Probability Verification Results (24 months). Lawrence A. Hughes, February 1968.
WBTM CR 20 Radar Prediction of the Topeka Tornado. Norman E. Prosser, April 1968.
WBTM CR 21 Wind Waves on the Great Lakes. Lawrence A. Hughes, May 1968.
WBTM CR 22 Seasonal Aspects of Probability Forecasts: 1. Summer. Lawrence A. Hughes, June 1968 (PB 185 733).
WBTM CR 23 Seasonal Aspects of Probability Forecasts: 2. Fall. Lawrence A. Hughes, September 1968 (PB 185 734).
WBTM CR 24 The Importance of Areal Coverage in Precipitation Probability Forecasting. John T. Curran and Lawrence A. Hughes, September 1968.
WBTM CR 25 Meteorological Conditions as Related to Air Pollution, Chicago, Illinois, April 12-13, 1963. Charles H. Swan, October 1968.
WBTM CR 26 Seasonal Aspects of Probability Forecasts: 3. Winter. Lawrence A. Hughes, December 1968 (PB 185 735).
WBTM CR 27 Seasonal Aspects of Probability Forecasts: 4. Spring. Lawrence A. Hughes, February 1969 (PB 185 736).
WBTM CR 28 Minimum Temperature Forecasting During Possible Frost Periods at Agricultural Weather Stations in Western Michigan. Marshall E. Soderberg, March 1969.
WBTM CR 29 An Aid for Tornado Warnings. Harry W. Waldheuser and Lawrence A. Hughes, April 1969.
WBTM CR 30 An Aid in Forecasting Significant Lake Snows. H. J. Rothrock, November 1969.
WBTM CR 31 A Forecast Aid for Boulder Winds. Wayne E. Sangster, February 1970.
WBTM CR 32 An Objective Method for Estimating the Probability of Severe Thunderstorms. Clarence L. David, February 1970.
WBTM CR 33 Kentucky Air-Soil Temperature Climatology. Clyde B. Lee, February 1970.
WBTM CR 34 Effective Use of Non-Structural Methods in Water Management. Verne Alexander, March 1970.
WBTM CR 35 A Note on the Categorical Verification of Probability Forecasts. Lawrence A. Hughes and Wayne E. Sangster, August 1970.
WBTM CR 36 A Comparison of Observed and Calculated Urban Mixing Depths. Donald E. Wuerch, August 1970.

NOAA Technical Memoranda NWS

NWS CR 37 Forecasting Maximum and Minimum Surface Temperatures at Topeka, Kansas, Using Guidance from the PE Numerical Prediction Model (FOUS). Morris S. Webb, Jr., November 1970 (COM 71 00118).
NWS CR 38 Snow Forecasting for Southeastern Wisconsin. Rheinhart W. Harms, November 1970 (COM 71-00019).
NWS CR 39 A Synoptic Climatology of Blizzards on the North-Central Plains of the United States. Robert E. Black, February 1971 (COM 71-00369).
NWS CR 40 Forecasting the Spring 1969 Midwest Snowmelt Floods. Herman F. Mondschein, February 1971 (COM 71-00489).
NWS CR 41 The Temperature Cycle of Lake Michigan 1. (Spring and Summer). Lawrence A. Hughes, April 1971 (COM 71-00545).
NWS CR 42 Dust Devil Meteorology. Jack R. Cooley, May 1971 (COM 71-00628).
NWS CR 43 Summer Shower Probability in Colorado as Related to Altitude. Alois G. Topil, May 1971 (COM 71-00712).
NWS CR 44 An Investigation of the Resultant Transport Wind Within the Urban Complex. Donald E. Wuerch, June 1971 (COM 71- 00766).
NWS CR 45 The Relationship of Some Cirrus Formations to Severe Local Storms. William E. Williams, July 1971 (COM 71- 00844).
NWS CR 46 The Temperature Cycle of Lake Michigan 2. (Fall and Winter). Lawrence A. Hughes, September 1971 (COM 71-01039).

(Continued on Back Cover)

NOAA TECHNICAL MEMORANDUM NWS CR-110

THE EFFECT OF QUANTITATIVE PRECIPITATION FORECASTS ON RIVER FORECASTS

Noreen O. Schwein
National Weather Service Office
Central Region Headquarters
Regional Hydrology

January 1996

UNITED STATES DEPARTMENT OF COMMERCE
Ronald H. Brown
Secretary

National Oceanic and Atmospheric Administration
D. James Baker
Under Secretary

National Weather Service
Elbert W. Friday, Jr.
Assistant Administrator

TABLE OF CONTENTS

THE EFFECT OF QUANTITATIVE PRECIPITATION FORECASTS ON RIVER FORECASTS

Noreen O. Schwein
National Weather Service
Central Region Headquarters
Regional Hydrology

1. INTRODUCTION

Quantitative Precipitation Forecasting (QPF), the forecasting of the amount of rain or water equivalent of frozen precipitation that will fall over a particular area over a given period, is of great interest to the National Weather Service in relation to river and flash flood prediction. A "good" QPF would be when the amount predicted would translate to a forecast of a river rise earlier than the river forecast without a QPF, and verifying. Therefore, a good QPF could provide better lead time, resulting in a flash flood warning being issued hours ahead of time, or a river flood warning being issued days ahead of time.

Successfully producing a good QPF is no simple task. Using meteorological models and national scale QPFs from the National Meteorological Center (NCEP) as guidance, considering local effects, and assessing such parameters as available moisture, instability and lifting mechanisms, the forecaster must attempt to learn where, when and how much precipitation will fall.

The NCEP Heavy Precipitation Branch has been producing QPF since 1960, and according to their verification statistics, has shown a marked improvement over time. To date, QPF operations at NCEP and in Weather Service Forecasts Offices (WSFO) in the U.S. vary a bit. However, verification statistics, although dissimilar, show a common trend that the QPFs improve as forecasters gain experience, and that forecasters seem to under forecast heavy rain events and over forecast light events. The reader should understand that the terms, heavy and light are subjective but generally, heavy can be considered an inch or more and light would be less than a half inch, over a 24-hour period. NCEP further defines excessive amounts as those that exceed flash flood guidance and/or are greater than five inches within 24 hours.

The purpose of this paper is to present an analysis of the impact, if any, QPF had on forecasts for six different locations over a period from June 15, 1993 to October 31, 1993, and attempt to determine whether that impact was beneficial or detrimental to the river forecast. A comparison will also be made to results of a 1992 QPF risk reduction exercise (described in Section 2).

2. BACKGROUND

During 1992 and 1993, QPF risk reduction exercises were conducted to detect the benefit, if any, QPF had on river forecasts. In 1992, the exercise went from April 1 through November 15 for several basins in Wisconsin, and resulting data was sparse due to a relatively dry period. Additionally, QPFs were only produced for amounts of at least half an inch in a 24-hour period, which was deemed to show a significant change to the river forecast, given normal conditions. This resulted not only in a small data base, but did not give WSFO forecasters the day-to-day experience helpful in gaining expertise. The 1992 study did not show that QPF improved the river forecast. It did show that the heavy events were under forecast, and that the first 12 hours of the 24-hour forecast period verified much better than the latter 12 hours. Therefore, the exercise in 1993 utilized only the first 12 hours of forecasted precipitation.

In 1993, the Great Midwest Flood occurred, affecting portions of the risk reduction area and supplying a larger database than in 1992. As discussed later in this text, although the two exercises were different, there *was* some compatibility in certain respects.

3. DESCRIPTION OF RIVER BASINS AND FORECAST POINTS

The six locations chosen for the 1993 exercise are described in Table 1 and displayed in Figure 1. The basins were chosen such that one drainage area did not affect another, and that river gage height readings and forecasts were received in six-hourly intervals. The National Weather Service River Forecast System (NWSRFS) models used were run twice, once without the addition of QPF and once with QPF. All other variables or modifications made for the river forecast were the same in both instances, allowing for QPF alone to affect a difference in the output forecasts.

The response time (time for river to crest after the onset of rainfall) varied for each basin. Some responded within 24 hours, others from three to five days. Therefore, the time of verification for individual basin statistics was taken at 1200 UTC for either the 1, 3 or 5 day forecast (Table 1).

4. METHODOLOGY

Meteorologists at WSFOs Minneapolis, Minnesota (MSP) and Milwaukee, Wisconsin (MKX), prepared a QPF around 1000 or 1100 UTC, valid from 1200 - 0000 UTC that day, and transmitted it to the North Central River Forecast Center (NCRFC) in Minneapolis (Figures 2a and 2b). The digital QPF product automatically was stored in a local database at NCRFC. The initial operational river forecast was prepared without QPF. The hydrologists, after assessing the

TABLE 1
DESCRIPTION OF STATION

Basin	Station Name/ River	Valid 12Z forecast	Local Drainage Area(mi^2)	Topography	Flood Stage
JDNM5	Jordan, MN/ Minnesota	3-day	1300	Flat	20 ft
NEWW3	New London, WI/ Wolf	5-day	1060	Rolling - to flat	9 ft
LNEM5	Lanesboro, MN/ N. Fork Root	1-day	615	Hilly	12 ft
RAYW3	Raymond, WI/ Root River Canal	1-day	57.2	Flat	8 ft
DARW3	Darlington, WI Pecatonica	1-day	273	Flat	11 ft
GRDM5	Garden City, MN Watonwan	3-day	812	Flat	not available

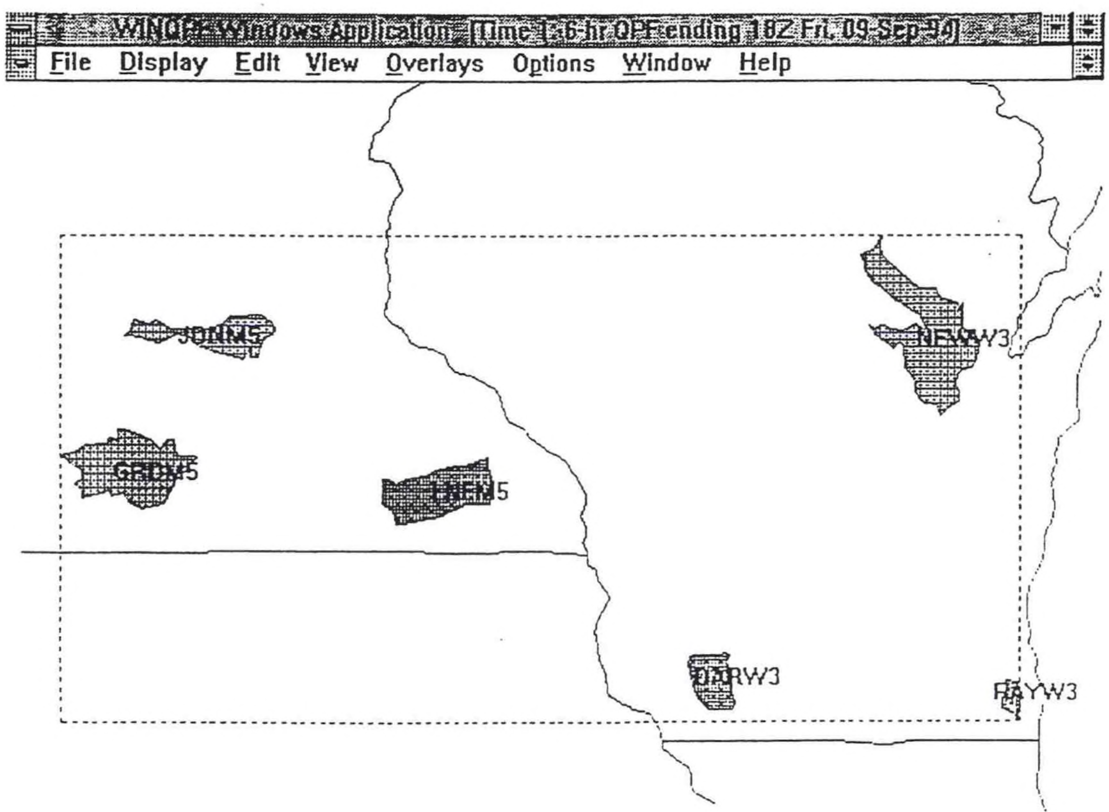

Figure 1. Basins used in 1993 Risk Reduction Exercise (southeast Minnesota, northern Iowa, and central Wisconsin are shown).

```
<ZCZC MKEQPSMKE
ETTAA00 KMKE 161208

ROUTINE QPF FOR WISCONSIN
NATIONAL WEATHER SERVICE MILWAUKEE/SULLIVAN WI
1204 UTC 06/16/93

.B MKE 930616 Z DH12 /DC9306161204
.B1 /DRH+06/PPQFZ  /DRH+12/PPQFZ  /DRH+18/PPQFZ
.B2 /DRH+24/PPQFZ  /PPXFZ
:
:       6-HR  6-HR  6-HR  6-HR  TOTAL
:       PCPN  PCPN  PCPN  PCPN  PCPN
:       ENDG  ENDG  ENDG  ENDG
:       18Z   00Z   06Z   12Z
:       06/16 06/17 06/17 06/17
:
WIB01   0.18/ 0.25/ 0.00/ 0.00/ 0.43/  :BASIN ONE
DARW3   0.43/ 0.25/ 0.00/ 0.00/ 0.68/  :DARLINGTON
RAYW3   0.01/ 0.01/ 0.00/ 0.00/ 0.02/  :RAYMOND
RACW3   0.01/ 0.01/ 0.00/ 0.00/ 0.02/  :RACINE
.END
```

Figure 2a. A reduced version of Milwaukee's QPF product.

```
<ZCZC MSPQPSMSP
ETTAA00 KMSP 161204

Routine QPF for Minnesota
National Weather Service Minneapolis/St. Paul Minnesota
1200 UTC 06/16/93

.B MSP 930616 Z DH12 /DC9306161200
.B1 /DRH+06/PPQFZ  /DRH+12/PPQFZ  /PPXFZ
:
:       6-HR  6-HR  TOTAL
:       PCPN  PCPN  PCPN
:       ENDG  ENDG
:       18Z   00Z
:       06/16 06/17
:
SPFM5   0.01/ 0.05/ 0.06/  :COTTONWOOD R  SPRINGFIELD  MN
JDNM5   0.04/ 0.05/ 0.09/  :MINN R JORDAN
APPM5   0.00/ 0.18/ 0.18/  :POMME DT APPLETON
HKHM5   0.18/ 0.00/ 0.18/  :ROOT R HOKAH MN
.END
```

Figure 2b. A reduced version of Minneapolis' QPF product.

hydrologic situation concerning such details as the location and movement of precipitation over the basin, and the intensity and duration of the precipitation, then made subjective changes to the model output river forecasts for the final non-QPF forecast product. The river forecasts were then rerun to include the QPF.

Both forecasts, with and without QPF, for the basins listed in Table 1, were stored in a database for verification, broken into 6-hourly increments according to the NWS RFS models. Each forecast covered a period of five days.

Mean Areal Precipitation (MAP) was computed daily by NCRFC through the NWS RFS as described by Larson (1975), for verification of the QPFs for each basin. This data was deemed quite important by the WSFOs as response to the meteorologists, but will not be addressed in depth in this study. We are mainly concerned with verification of the river forecasts with and without QPF, and not the verification of the QPF itself. However, examples of verified QPF will be used to illustrate the effects on the river forecasts.

Using PARADOX database software, verification statistics such as mean error, mean absolute error, standard deviation, and bias, was calculated for the individual basins and all basins combined. It was decided to forego using correlation coefficients since a large portion of the QPF and non-QPF forecasts were equal, leaving the remaining portion of those samples too small to show a true significant correlation. The verification time for the combined basins was chosen to be 1200 UTC Day 1 (a 24-hour forecast). The verification time for the individual basins was chosen as specified in Table 1.

5. RESULTS FOR ALL BASINS COMBINED

For a first look at the data, all basins combined were considered. The data were separated by months, as some months were abnormally wet. Figures 3 and 4 display results of positive and negative errors, for each month of the exercise. It can be easily seen that those forecasts with QPF tend to over forecast more than those without QPF, and that those forecasts without QPF tend to under forecast more than those with QPF. Additionally, the river forecast with QPF, monthly positive error, was quite high in July. This may be attributed to the scenario that when there were repeated heavy rain events over an area, the meteorologists either over forecasted the amount or did not forecast the proper location. Furthermore, the data showed 13% of the time, when rainfall was predicted (i.e., QPF > 0), it occurred in the 12-24 hour period (after 0000 UTC), instead of the forecast period targeted, the 1200-0000 UTC period.

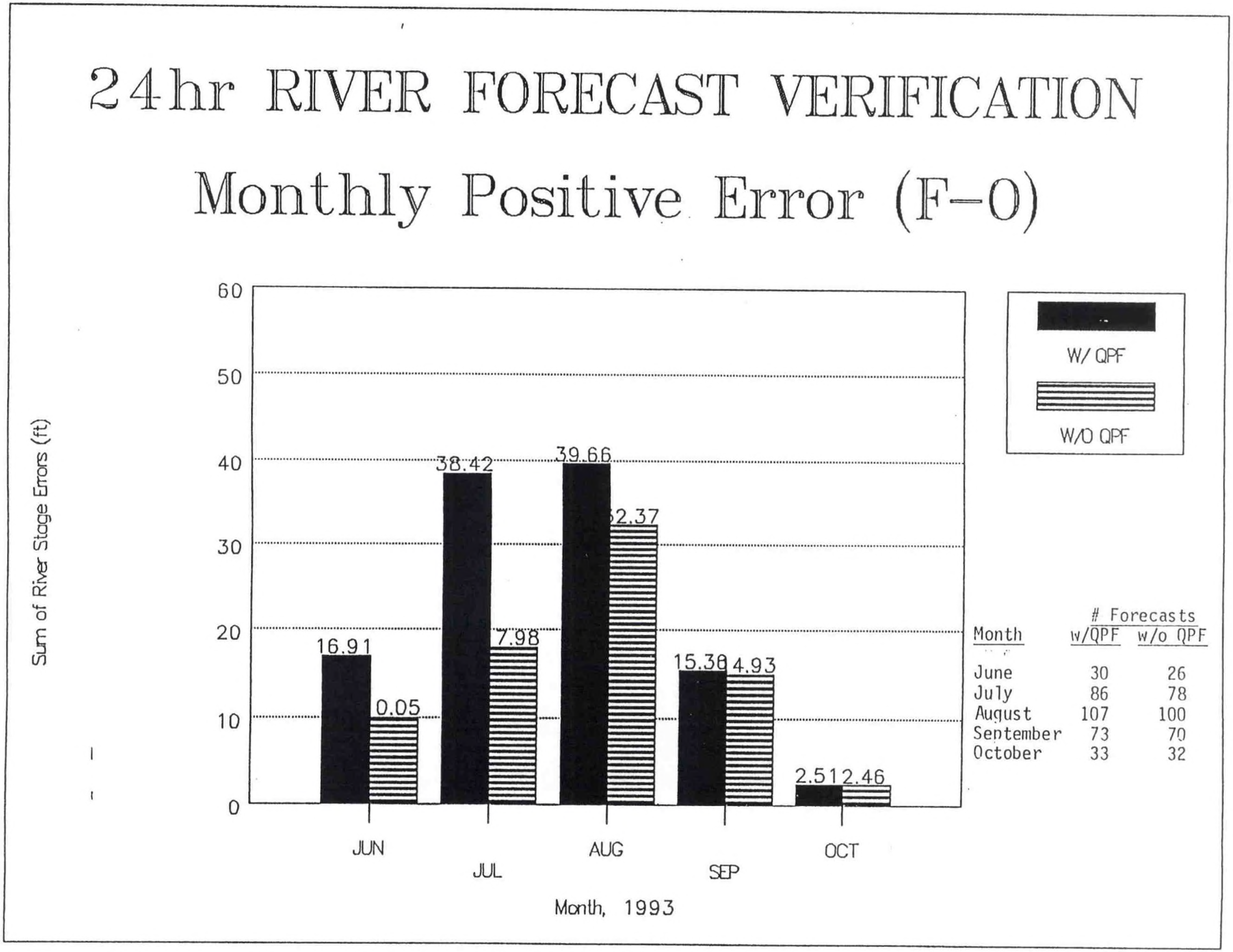

Figure 3. Positive Forecast Errors (all basins combined).

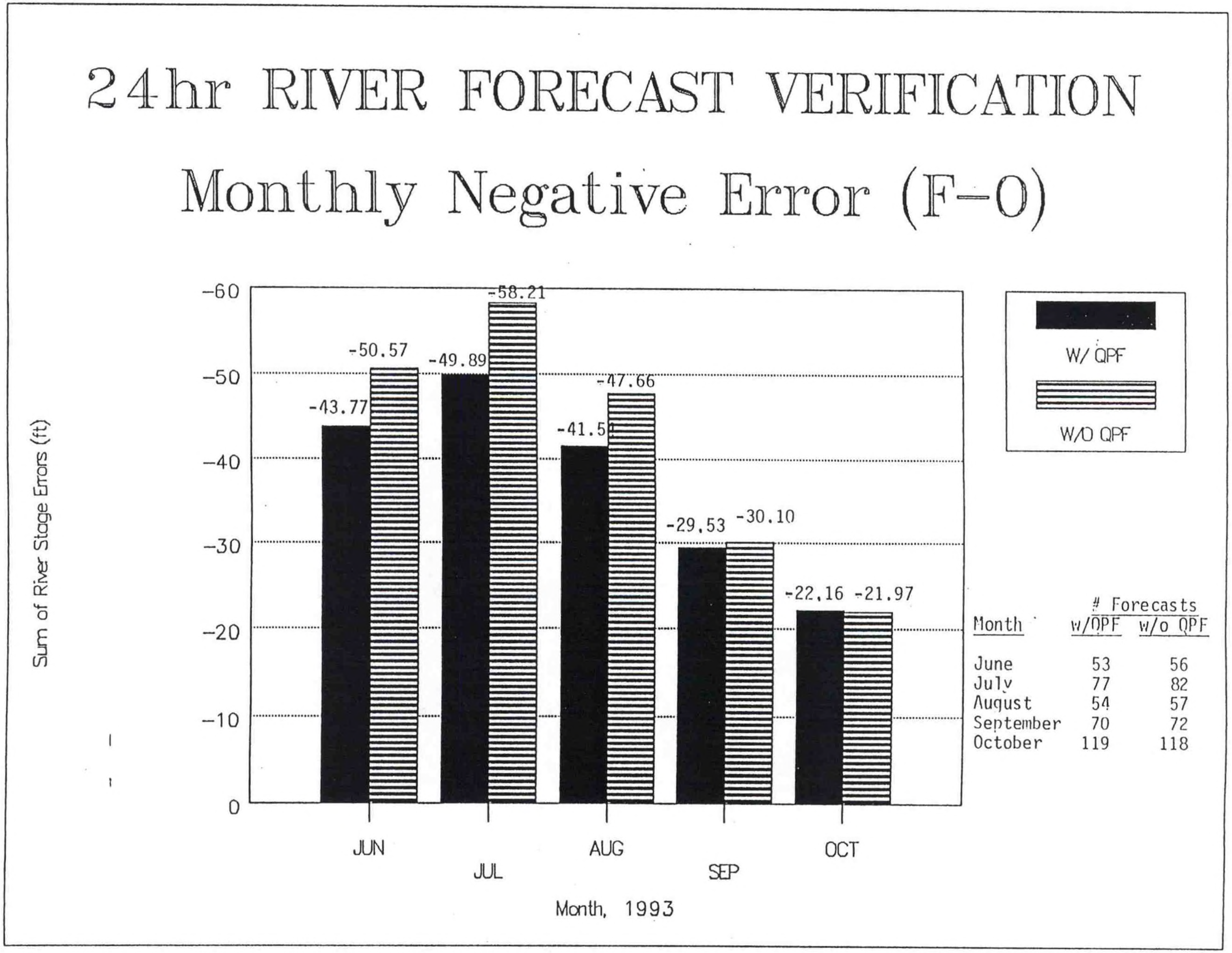

Figure 4. Negative Forecast Errors (all basins combined).

Looking also at Figure 5, which shows the actual 12-hour amounts of QPF versus MAP by month, some improvement can be seen in August. Both July and August were wet months with 22.31 inches and 14.10 inches of MAP, respectively. However, the percent of QPF that actually verified as MAP slightly increased from 65% in July to 68% in August. This may reflect the increased experience of the forecasters. September was even better with the 12.16 inches of MAP verifying as 99% of the forecasted precipitation.

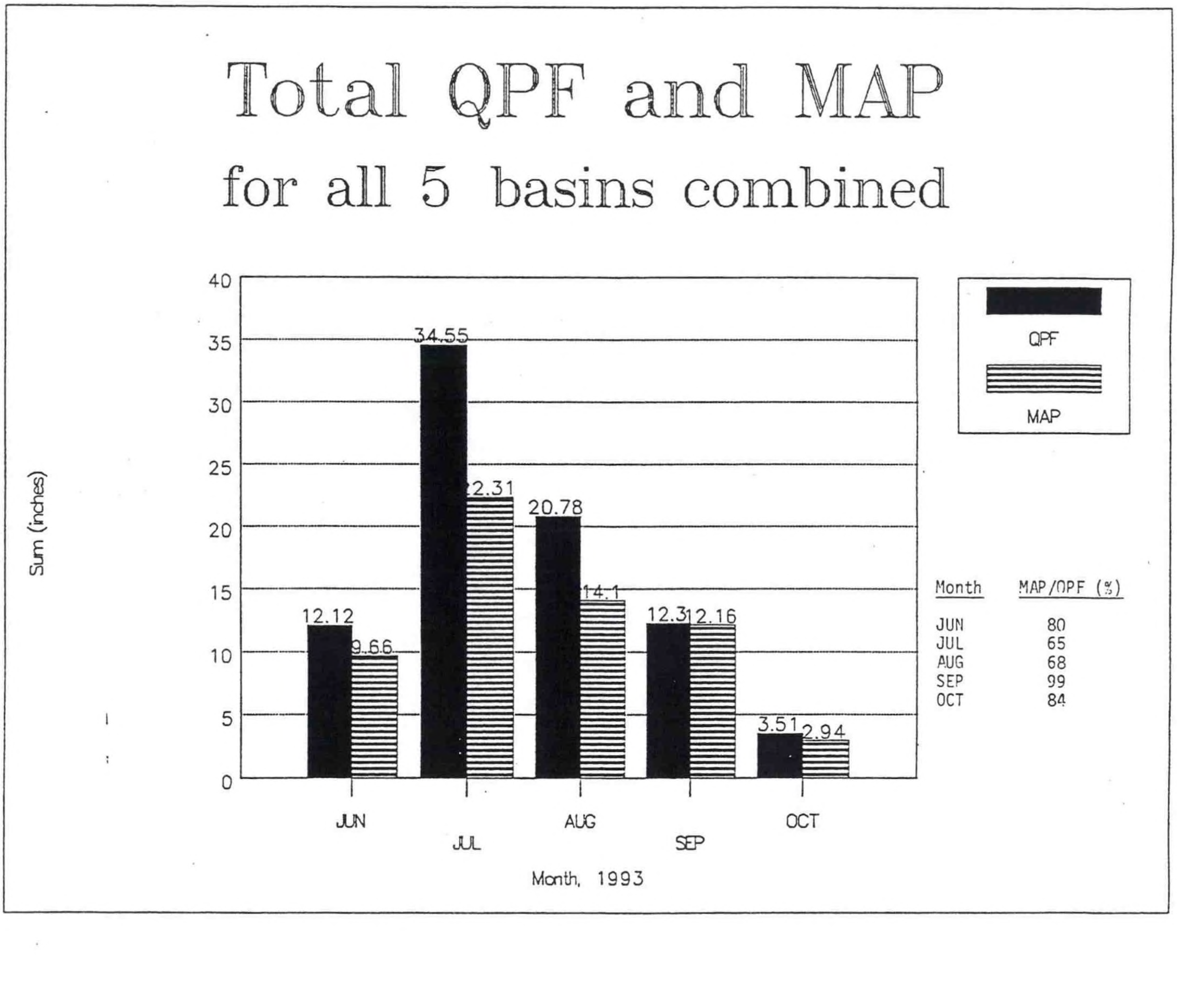

Figure 5. Monthly Summation of QPF and MAP for all basins June 15-October 31, 1993.

A further breakdown of 12-hour QPF versus 12-hour MAP can be seen in Table 2. A few items to note would be that about one third of the time a QPF was forecasted to be greater than zero, it did not verify, and about one fifth of the time where QPF equaled zero, precipitation did occur. Using a half inch of rainfall to be a significant amount as in the 1992 risk reduction, the table also shows a summary concerning QPF and MAP of ≥ 0.50 inch. Note, it is interesting that there were only six out of 47 episodes of forecasting a half inch or more where no precipitation occurred and two cases out of 40 where ≥ 0.50 inch of precipitation occurred but none was forecast. Also, there were 23 cases where a half inch or more was forecast and verified. These 23 cases were about half the total number of cases where QPF ≥ 0.50 inch.

TABLE 2
QPF AND MAP COMPARISONS

QPF & MAP (inches)	Number of Records	% of Occurrence[1]
All cases	828	100%
QPF = 0	497	60%
MAP = 0	545	66%
QPF = 0 & MAP = 0	439	53%
QPF > 0	331	40%
MAP > 0	283	34%
QPF > 0 & MAP = 0	106	32%[2]
QPF = 0 & MAP > 0	58	20%[3]
QPF ≥ 0.50	47	14%[2]
MAP ≥ 0.50	40	14%[3]
QPF ≥ 0.50 & MAP = 0	6	13%[4]
QPF ≥ 0.50, 0 < MAP < 0.50	18	38%[4]
QPF = 0 & MAP ≥ 0.50	2	5%
QPF ≥ 0.50 & MAP ≥ 0.50	23	49%[4], 56%5

1. for all records unless otherwise stated
2. for all records where QPF > 0
3. for all records where MAP > 0
4. for all records where QPF ≥ 0.50

The bar graphs in Figures 6a and 6b show the total absolute values of the positive and negative errors of the river forecasts for all six basins combined, and the total arithmetic error. The arithmetic error, or bias, is the sum of all errors, positive and negative. One can see that both QPF and non-QPF forecasts tend to under forecast more than over forecast. Also in Figure 6a, the total absolute error for 24-hour river forecasts with QPF was 5% greater than the error for non-QPF forecasts. For those graphs in 6b, where the errors were taken at the verification response times of 1, 3, or 5 days as shown in Table 1, the total absolute error for forecasts with QPF was slightly less but still 3% greater than the non-QPF forecast errors. With the 1-day responses being equal, this difference would lead to the conclusion that there was some improvement in the QPF versus non-QPF forecasts in the 3- and 5-day range. The range of error narrowed. Table 3 (which will be discussed in more detail later) shows how these forecasts compare to those that do not use QPF.

The total arithmetic error is shown as the last set of bars in Figures 6a and 6b. As stated earlier, it can be seen that these biases are definitely on the negative side (under forecasting) for both types of forecasts. The reason for this is obvious concerning the river stage forecasts without QPF as they only account for precipitation that has already occurred, and not future precipitation. The reason that river stage forecasts with QPF also tends to under forecast is probably due to the conservative nature of the meteorologist producing the QPF.

Note also that the biases are less for forecasts with QPF. This could be attributed to those river forecasts fluctuating more around the observed value, as opposed to the "stair-stepping" effect with the non-QPF forecasts. (This will be discussed further in the next section.) Additionally, the bias is less with the 24-hour forecast verifications in 6a as compared to 6b, because the slower responding streams show much less of a change over a 24-hour period.

TABLE 3
STATISTICAL SUMMARY OF RIVER FORECASTS - ALL CASES

Basin	w/ QPF[1] w/o QPF[2]	ABSERR[3]	RMSE[4]	MEAN[5]	STD DEV[6]	$H:\mu_1=\mu_2$[7]
JDNM5	136	0.65	±1.00	-0.28	±0.96	Y
	136	0.65	±0.99	-0.31	±0.94	Y
NEWW3	134	0.61	±0.78	-0.12	±0.77	Y
	134	0.62	±0.79	-0.15	±0.77	Y
LNEM5	137	0.32	±1.21	0.09	±1.19	Y
	138	0.19	±0.87	-0.19	±0.83	Y
RAYW3	138	0.27	±0.35	0.17	±0.30	Y
	138	0.27	±0.36	0.14	±0.33	Y
DARW3	138	0.84	±1.56	-0.67	±1.41	Y
	138	0.87	±1.65	-0.73	±1.48	Y
GRDM5	135	0.84	±1.68	-0.43	±1.63	Y
	134	0.83	±1.71	-0.55	±1.62	Y

1. Total number of river forecasts including QPF
7. Total number of river forecasts without QPF
2. Average Absolute Error (ft)
3. Root Mean Square Error (ft)
4. Arithmetic Mean Error (ft)
5. Standard Deviation of Errors(ft)
6. Null hypothesis that data sets the same, rejected (Y=Yes/N=No)
7. Total number of river forecasts without QPF

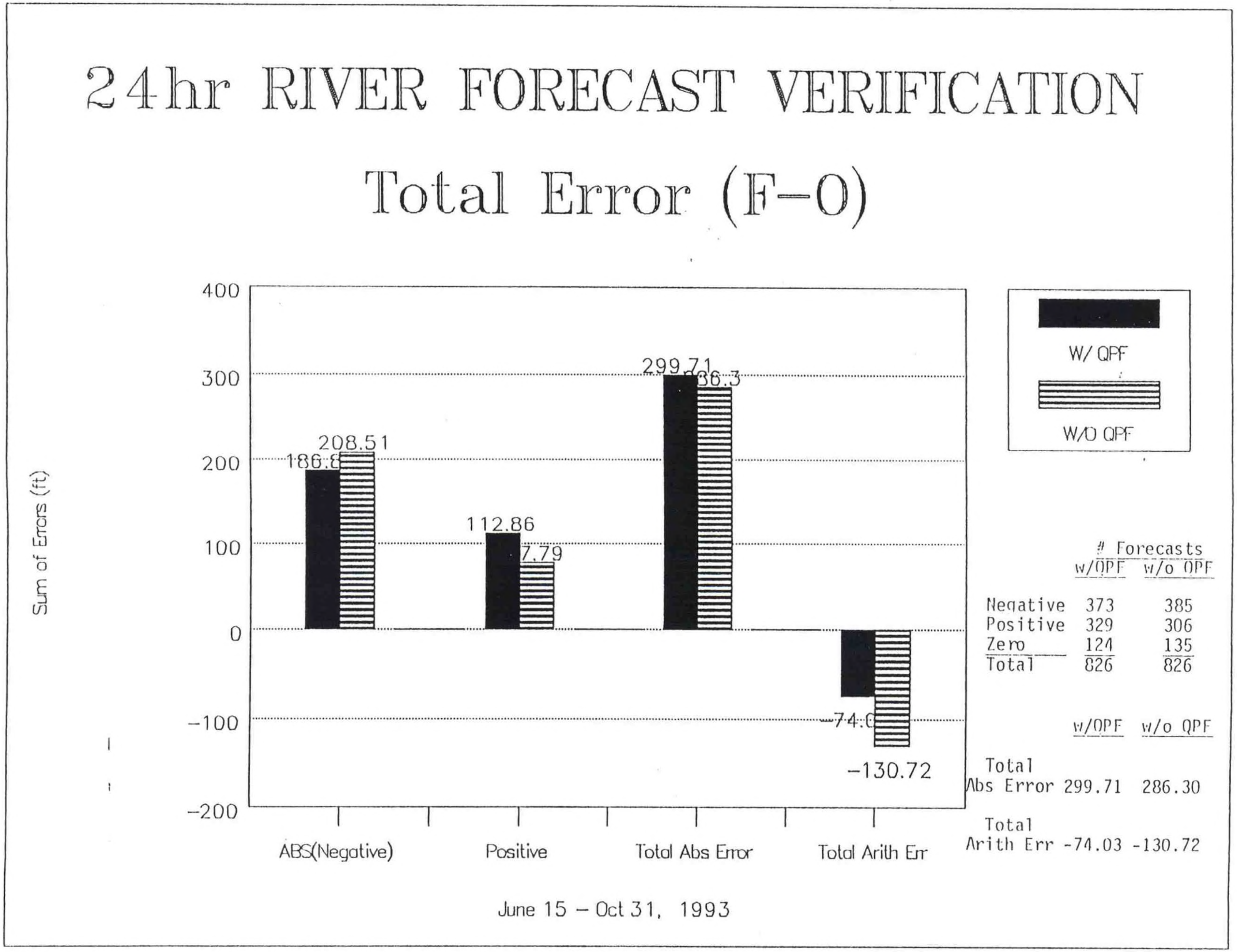

Figure 6a. Verification using 24-hour forecast times.

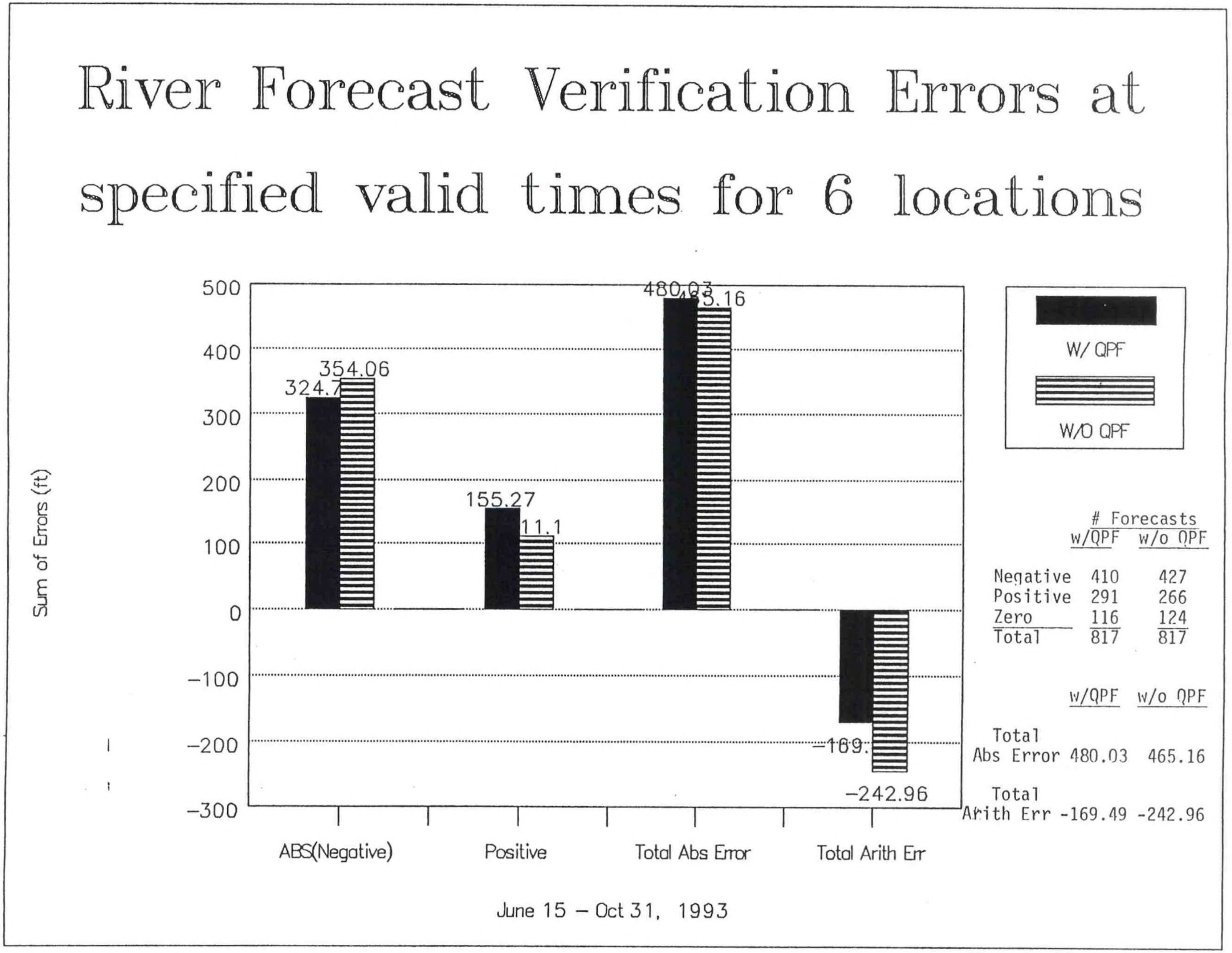

Figure 6b. Verification using response times from Table 1.

ERRATA

NOAA TECHNICAL MEMORANDUM
NWS CR-110

REPLACE:

Pages 13-14 and 19-20

CHANGES:

Equation (2) incorrectly written.

The explanation of equations (6) and (11) were incorrectly written.

6. FURTHER STATISTICAL ANALYSIS

Additional statistical analyses were conducted on the data to determine if the QPF had a significant impact on the river stage forecasts, and if so, did that impact show improved results (i.e., better lead time). To accomplish this, it was decided to look at each basin separately. This would provide the opportunity to verify the data at different times according to the individual basin response times, and to show the effect on 1, 3, and 5 day forecasts.

Again, looking at positive and negative errors (over and under forecasting, respectively), the average absolute error (ABSERR) and root mean square error (RMSE) can be defined as:

$$ABSERR = (\sum(PERR) + \sum(NERR))/N \qquad (1)$$

$$RMSE = \sqrt{((\sum(PERR)^2 + \sum(NERR)^2)/N)} \qquad (2)$$

where

PERR the positive error (forecast - observed) value
NERR the absolute value of the negative error value and
N the total number of cases.

Table 3 shows' the outcome of the analysis for each basin over the entire time period for all cases (including QPF = 0). For all basins but one, Lanesboro (LNEM5), the values of the ABSERRs and RMSEs were quite close for both types of forecasts, differing by less than 0.10 ft. At Lanesboro, the difference in the RMSEs was 0.34 feet. (This greater difference is largely due to a particular forecast and is discussed further in Section 7.) The question then arose, were these values significantly different? Were the results showing that there was no significant difference in the forecasts, with or without QPF?

To answer this question, a "Student's" t-test was conducted to test the null hypothesis (H) that had there been an infinite number of forecasts, the difference (D) would be zero (i.e., the mean of the hypothetical population of D's would equal zero). As suggested by Panofsky and Brier (1965), the limiting probability for this test was chosen to be 5% (i.e., $\alpha = 0.05$). In other words, if the t-test showed a probability of 5% or less that the two samples came from the same population, the hypothesis would be rejected. As specified by Ostle (1963), two normal populations would be assumed with means μ_1 and μ_2, and the null hypothesis would be expressed as:

$$H: \mu 1 - \mu 2 = 0 = \bar{D} \quad (3)$$

The value of t would be expressed as:

$$t = \bar{D}/s_{\bar{D}} \quad (4)$$

where

$$\bar{D} = \sum D/N \qquad D = F - Q$$

$$s_D = \sqrt{((\sum D^2 - (\sum D)^2/N)/(N-1))} \quad (5)$$

$$s_{\bar{D}} = \sqrt{((s_D)^2/N)} \quad (6)$$

and

$\bar{D}$	is the mean of differences, D
F	is the river stage forecast without QPF
Q	is the river stage forecast with QPF
s_D	is the standard deviation of the differences, D (for positive root of the variance, s_D^2)
$s_{\bar{D}}$	is the standard deviation of the mean difference
N	is the number of pairs of forecasts

For this two-tailed t-test, one would reject H for values of t where

$$-t_{(1-\alpha/2)(n-1)} \geq t \geq +t_{(1-\alpha/2)(n-1)} \quad (7)$$

and

$$(1 - \alpha/2) = 0.975$$

The resulting values of t for each basin showed less than a 5% chance that the two data sets were from the same population (i.e., the test of the hypothesis failed). The t values follow:

Basin ID	$-t_{(1-\alpha/2)(n-1)}$	t
LNEM5	-2.009	-2.70
RAYW3	-2.003	-2.43
DARW3	-1.999	-2.55
GRDM5	-2.006	-2.75
JDNM5	-2.007	-3.33
NEWW3	-2.005	-3.33

We decided to make further use of the "Student's" t-test as follows:

Test Hypothesis, H: QERR < FERR

where

FERR = Mean Forecast error without QPF
QERR = Mean Forecast error with QPF

This would require a one-tailed test assuming normal populations and $\alpha = 0.05$. H would be rejected for:

$$t \geq t_{(1-\alpha)(n_1+n_2-2)} \quad (10)$$

where

n_1 = number of QERRs
n_2 = number of FERRs

The value for t would be computed using

$$t = (\bar{x}_1 - \bar{x}_2) \,/\, (s^2/n_1 + s^2/n_2) \quad (11)$$

where

$\bar{x}_1$ = the arithmetic mean of QPF error
$\bar{x}_2$ = the arithmetic mean of non-QPF error

$$s^2 = ((n_1 - 1)s_1^2 + (n_2 - 1)s_2^2)/(n_1 + n_2 - 2) \quad (12)$$

s_1 = the standard deviation of the stage forecast with QPF and

s_2 = the standard deviation of the stage forecast without QPF

For all forecasts and for cases where QPF > 0, by basin, the statistical "Student's" t-test of the null hypothesis that the mean forecast error was significantly less for forecasts with QPF, was not rejected for JDNM5, NEWW3, DARW3, GRDM5 and RAYW3, but was rejected for LNEM5.

The test was not conducted for cases where all QPF and non-QPF forecasts were different since there was less than 30 cases to consider in all but one basin (the suggested minimum (30) acceptable sample for the t-test (Panofsky and Brier 1965)). The calculated t values follow:

For all cases

Basin ID	$t_{(1-\alpha)(n_1+n_2-2)}$	t
LNEM5	1.651	2.24
RAYW3	1.651	0.75
DARW3	1.651	0.35
GRDM5	1.651	0.60
JDNM5	1.651	0.25
NEWW3	1.651	0.33

For cases where QPF > 0

Basin ID	$t_{(1-\alpha)(n_1+n_2-2)}$	t
LNEM5	1.661	2.24
RAYW3	1.660	1.29
DARW3	1.659	0.47
GRDM5	1.661	0.58
JDNM5	1.661	0.32
NEWW3	1.660	0.40

7. EFFECT OF QPF ON INDIVIDUAL FORECASTS

Next to consider was the effect on the individual forecasts. What were some of the best and worst cases involving river forecasts with and without QPF? Did QPF add significant lead time? Figures 8-13 show some examples of forecasts from individual NWS RFS model runs for each forecast point, taken through their respective response times. The QPF that was forecast and the MAP that occurred is shown in the lower right-hand corner of the individual

6. FURTHER STATISTICAL ANALYSIS

Additional statistical analyses were conducted on the data to determine if the QPF had a significant impact on the river stage forecasts, and if so, did that impact show improved results (i.e., better lead time). To accomplish this, it was decided to look at each basin separately. This would provide the opportunity to verify the data at different times according to the individual basin response times, and to show the effect on 1, 3, and 5 day forecasts.

Again, looking at positive and negative errors (over and under forecasting, respectively), the average absolute error (ABSERR) and root mean square error (RMSE) can be defined as:

$$ABSERR=(\sum(PERR)+\sum(NERR))/N \tag{1}$$

$$RMSE=\sqrt{((\sum(PERR)2+\sum(NERR)2)/N)} \tag{2}$$

where

PERR the positive error (forecast - observed) value
NERR the absolute value of the negative error value and
N the total number of cases.

Table 3 shows' the outcome of the analysis for each basin over the entire time period for all cases (including QPF = 0). For all basins but one, Lanesboro (LNEM5), the values of the ABSERRs and RMSEs were quite close for both types of forecasts, differing by less than 0.10 ft. At Lanesboro, the difference in the RMSEs was 0.34 feet. (This greater difference is largely due to a particular forecast and is discussed further in Section 7.) The question then arose, were these values significantly different? Were the results showing that there was no significant difference in the forecasts, with or without QPF?

To answer this question, a "Student's" t-test was conducted to test the null hypothesis (H) that had there been an infinite number of forecasts, the difference (D) would be zero (i.e., the mean of the hypothetical population of D's would equal zero). As suggested by Panofsky and Brier (1965), the limiting probability for this test was chosen to be 5% (i.e., $\alpha = 0.05$). In other words, if the t-test showed a probability of 5% or less that the two samples came from the same population, the hypothesis would be rejected. As specified by Ostle (1963), two normal populations would be assumed with means μ_1 and μ_2, and the null hypothesis would be expressed as:

$$H: \mu 1 - \mu 2 = 0 = \bar{D} \tag{3}$$

The value of t would be expressed as:

$$t = \bar{D}/s_{\bar{D}} \tag{4}$$

where

$$\bar{D} = \sum D/N \qquad\qquad D = F - Q$$

$$s_D = \sqrt{((\sum D^2 - (\sum D)^2/N)/(N-1))} \tag{5}$$

$$s_{\bar{D}} = \sqrt{((s_D)^2/N)} \tag{6}$$

and

$\bar{D}$	is the mean of differences, D
F	is the river stage forecast without QPF
Q	is the river stage forecast with QPF
$s_{\bar{D}}$	is the standard deviation of the differences, D (for positive root of the variance, s_D^2)
s_D	is the standard deviation of the mean difference
N	is the number of pairs of forecasts

For this two-tailed t-test, one would reject H for values of t where

$$-t_{(1-\alpha/2)(n-1)} \geq t \geq + t_{(1-\alpha/2)(n-1)} \tag{7}$$

and

$$(1 - \alpha/2) = 0.975$$

The resulting values of t for each basin showed less than a 5% chance that the two data sets were from the same population (i.e., the test of the hypothesis failed). The t values follow:

Basin ID	$-t_{(1-\alpha/2)(n-1)}$	t
LNEM5	-1.980	-2.50
RAYW3	-1.980	-2.25
DARW3	-1.980	-2.40
GRDM5	-1.980	-2.39
JDNM5	-1.980	-3.38
NEWW3	-1.980	-3.33

We then considered the arithmetic means and standard deviations of those means as they could show some significance about "stair-stepping" versus "fluctuating" forecasts. A stair-stepping forecast is one that generally lags behind the rising trend of the river and is common with non-QPF river forecasts. This is due to the fact that observed precipitation is incorporated into the river forecasting model after it has fallen, sometimes as much as 24 hours later. For example, if 0.50 inches of rain fell in the past 24 hours ending at 1200 UTC, but continued for several hours totaling 1.00 inches for the event, the river stage forecast without QPF would only consider the 0.50 inch amount. The river forecast the following day at 1200 UTC would then utilize the additional 0.50 inch amount.

The result of this would be that the first forecast stage would be lower than the second forecast stage, and the upward trend from one forecast to the next would be one-step. If a similar rainfall episode happened again on the second day, you would have another step, and so on. If the river had a response time of less than 24 hours, then the second forecast would finally "catch up" to the observed value on the second day. This gradual rising of the river forecast to the eventual observed river stage is known as stair-stepping.

Fluctuating forecasts, more common with QPF input, are those that may have too high (low) a value with one forecast and too low (high) a value with the next due to the difference between the forecast amount of precipitation versus the amount that actually falls.

Figure 7 shows an example of stair-stepping and fluctuating forecasts. Notice how the forecast values without QPF on 6/19 and 6/20 are about one foot lower than what was observed. On 6/21, the non-QPF forecast "catches up" to the observed value. This demonstrates the stair-stepping effect. The fluctuating effect can be seen in the forecast values that utilized QPF where on 6/19, the forecast was about half a foot higher than observed and 6/20 the forecast was a few tenths of a foot lower than observed.

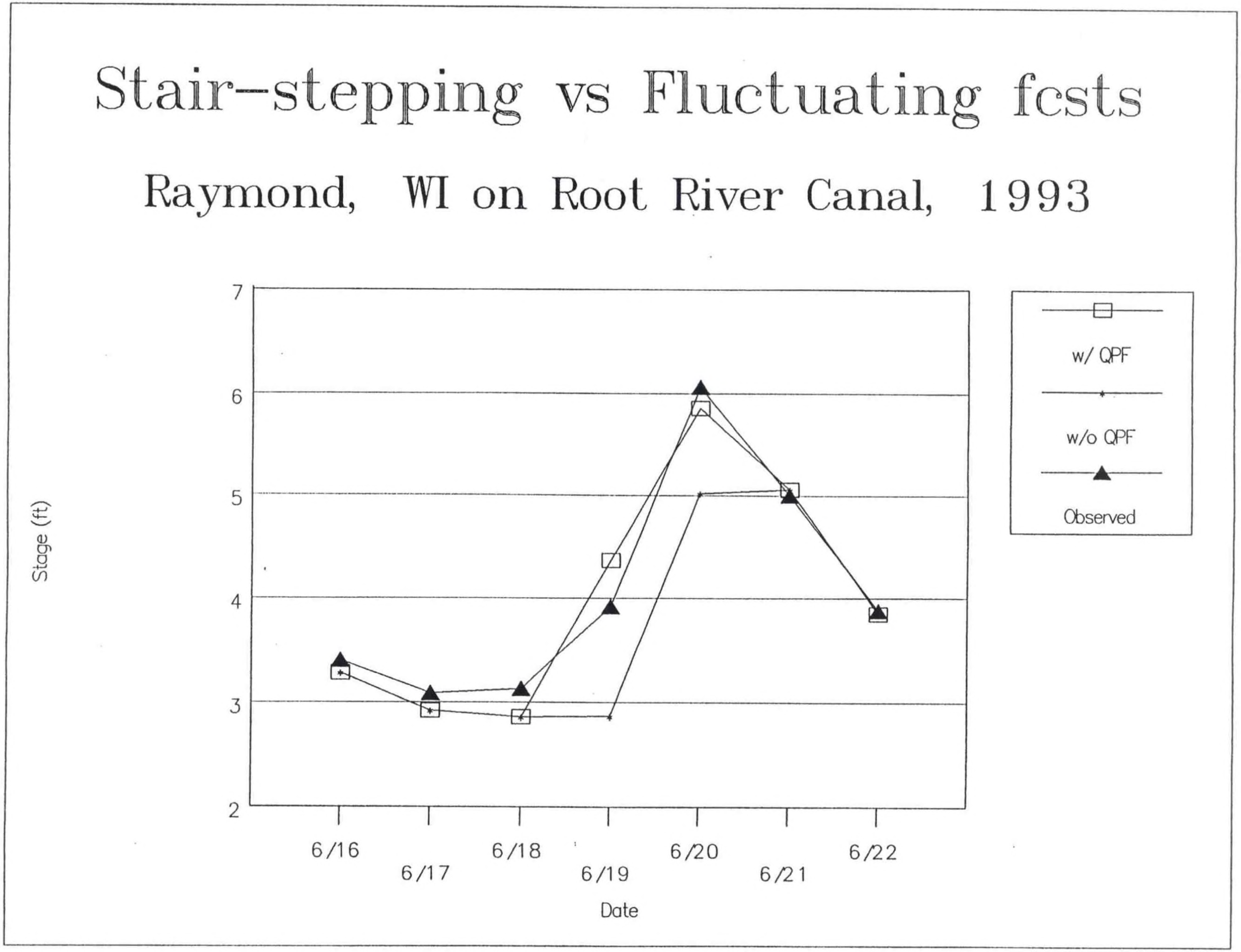

Figure 7. This is a graph of river forecasts vs. observed stages (forecasts initialized at 1200 UTC 16 June 1993). Forecast with QPF denote "fluctuating". Forecasts without QPF denote "stair-stepping".

The mean and standard deviation was computed according to Spiegel (1961), as follows:

$$\bar{x} = (\sum X/N) \tag{8}$$

and

$$s = \sqrt{(\sum (X - \bar{x})^2/N)} \tag{9}$$

where

X represents actual forecast errors (with or without QPF)
$\bar{x}$ the mean forecast error (with or without QPF)
N is the number of forecasts
s is the standard deviation

The standard deviations of the mean errors as shown in Table 3, proved to be slightly less in magnitude than the $RMSE_S$ of the absolute value errors. Still, the difference was only by a few hundredths except Lanesboro, which differed by 0.36 ft. One could conclude at this point that:

1) there was little difference in the forecast errors concerning stair-stepping or fluctuating forecasts, and

2) that the error deviated less around the arithmetic mean as opposed to the absolute mean.

At this point, we decided to delve a bit deeper and run similar analyses on a data set excluding values where QPF = 0 inches, and on an even smaller data set where QPF made a definite difference in *every* forecast. To further explain the latter sample, there were times when a small amount of QPF resulted in both QPF and non-QPF forecasts being equal. Therefore, the latter case only considers those forecasts which were different at the selected verification times referred to in Table 1.

Tables 4 and 5 show the results of these analyses. The errors become gradually larger as the data set becomes smaller. What is interesting is that the absolute errors are all quite close in every example, except Lanesboro, and the mean errors are less for forecasts with QPF in most cases *including* Lanesboro.

TABLE 4
STATISTICAL SUMMARY OF RIVER FORECASTS FOR QPF > 0

Basin	w/ QPF w/o QPF	ABSERR	RMSE	MEAN	STD DEV	$H:\mu_1=\mu_2$
JDNM5	52	0.76	±1.22	-0.38	±1.15	Y
	52	0.77	±1.20	-0.45	±1.11	Y
NEWW3	55	0.63	±0.79	-0.04	±0.79	Y
	55	0.64	±0.81	-0.10	±0.81	Y
LNEM5	50	0.84	±1.99	0.29	±1.97	Y
	50	0.47	±1.44	-0.47	±1.36	Y
RAYW3	57	0.34	±0.44	0.22	±0.38	Y
	57	0.34	±0.45	0.13	±0.43	Y
DARW3	62	1.16	±1.89	-0.96	±1.63	Y
	62	1.23	±2.06	-1.10	±1.74	Y
GRDM5	54	1.37	±2.37	-0.82	±2.23	Y
	54	1.36	±2.41	-1.07	±2.16	Y

TABLE 5
STATISTICAL SUMMARY OF RIVER FORECASTS
"where QPF effected a change" (N/A = Not applicable)

Basin	w/ QPF w/o QPF	ABSERR	RMSE	MEAN	STD DEV	$H:\mu_1=\mu_2$
JDNM5	45	0.70	±1.15	-2.09	±2.19	N/A
	45	0.69	±1.12	-2.93	±2.85	N/A
NEWW3	26	0.60	±0.78	-0.31	±0.72	N/A
	26	0.63	±0.83	-0.42	±0.72	N/A
LNEM5	20	1.97	±3.14	0.84	±3.02	N/A
	20	1.05	±2.25	-1.05	±1.99	N/A
RAYW3	19	0.42	±0.48	0.34	±0.33	N/A
	19	0.43	±0.52	0.08	±0.51	N/A
DARW3	18	2.00	±2.84	-1.47	±2.43	N/A
	18	2.24	±3.21	-1.95	±2.55	N/A
GRDM5	24	1.81	±2.91	-0.74	±2.82	N/A
	24	1.76	±2.99	-1.37	±2.66	N/A

The t-test was again used for samples where QPF > 0 as depicted in Table 4. From equation (7), the hypothesis that the two data sets came from the same population would be rejected for values of t. As before, the resulting t values showed that the two data sets were indeed from separate populations, and are listed below.

Basin ID	$-t_{(1-\alpha/2)(n-1)}$	t
LNEM5	-2.009	-2.70
RAYW3	-2.003	-2.43
DARW3	-1.999	-2.55
GRDM5	-2.006	-2.75
JDNM5	-2.007	-3.33
NEWW3	-2.005	-3.33

We decided to make further use of the "Student's" t-test as follows:

Test Hypothesis, H: QERR < FERR

where

FERR = Mean Forecast error without QPF
QERR = Mean Forecast error with QPF

This would require a one-tailed test assuming normal populations and $\alpha = 0.05$. H would be rejected for:

$$t \geq t_{(1-\alpha)(n_1+n_2-2)} \tag{10}$$

where

n_1 = number of QERRs
n_2 = number of FERRs

The value for t would be computed using

$$t = (\bar{x}_1 - \bar{x}_2) / (s^2/n_1 + s^2/n_2) \tag{11}$$

where

$_1$ = the arithmetic mean of QPF error
$_2$ = the arithmetic mean of non-QPF error

$$s^2 = ((n_1 - 1)s_1^2 + (n_2 - 1)s_2^2)/(n_1 + n_2 - 2) \tag{12}$$

s = the standard deviation of the stage forecast with QPF and

s = the standard deviation of the stage forecast without QPF

For all forecasts and for cases where QPF > 0, by basin, the statistical "Student's" t-test of the null hypothesis that the mean forecast error was significantly less for forecasts with QPF, was not rejected for JDNM5, NEWW3, DARW3, GRDM5 and RAYW3, but was rejected for LNEM5.

The test was not conducted for cases where all QPF and non-QPF forecasts were different since there was less than 30 cases to consider in all but one basin (the suggested minimum (30) acceptable sample for the t-test (Panofsky and Brier 1965)). The calculated t values follow:

For all cases

Basin ID	$t_{(1-\alpha)(n_1+n_2-2)}$	t
LNEM5	1.651	2.24
RAYW3	1.651	0.75
DARW3	1.651	0.35
GRDM5	1.651	0.60
JDNM5	1.651	0.25
NEWW3	1.651	0.33

For cases where QPF > 0

Basin ID	$t_{(1-\alpha)(n_1+n_2-2)}$	t
LNEM5	1.661	2.24
RAYW3	1.660	1.29
DARW3	1.659	0.47
GRDM5	1.661	0.58
JDNM5	1.661	0.32
NEWW3	1.660	0.40

7. EFFECT OF QPF ON INDIVIDUAL FORECASTS

Next to consider was the effect on the individual forecasts. What were some of the best and worst cases involving river forecasts with and without QPF? Did QPF add significant lead time? Figures 8-13 show some examples of forecasts from individual NWS RFS model runs for each forecast point, taken through their respective response times. The QPF that was forecast and the MAP that occurred is shown in the lower right-hand corner of the individual graphs, and the flood stage for the forecast point. All forecasts had an initial time at the first time step in the graph. No 1800 UTC observed data was available. Generally, the "a" figures show a positive effect of QPF, and the "b" figures a negative effect.

Figure 8a shows an opposite situation, where the observed stage is about 9 feet higher than the non-QPF forecast that was disseminated, but only 4 feet higher than the forecast that included QPF. The QPF forecast would not have prompted a flood warning, but would have given a 24-hour advanced notice of a significant rise in the river.

Figure 8b depicts the worst of all cases where a QPF of 3.34 inches resulted in over forecasting by nearly 11 feet. With a flood stage of 12 feet, this would have resulted in a false warning. This one case was a major contributor to the statistics and explains the problem with over forecasting precipitation.

In all the "a" figures, it can be seen that where QPF had a positive result (i.e., where the forecast was more accurate than that without QPF), the observed stage was still higher. This reemphasizes the tendency to under forecast.

Figure 10b shows an interesting case where the QPF and non-QPF forecasts were quite similar, but the observed stages were one-to-three feet lower. This may be attributed to the rainfall pattern over the basin not being uniform as the river forecasting models assume, or another problem such as erroneous rainfall data incorporated into the model that morning. Figure 12b is a similar example.

Figure 11b is another interesting case. QPF had the effect of over forecasting by half of a foot while the non-QPF forecast under forecast by nearly the same amount.

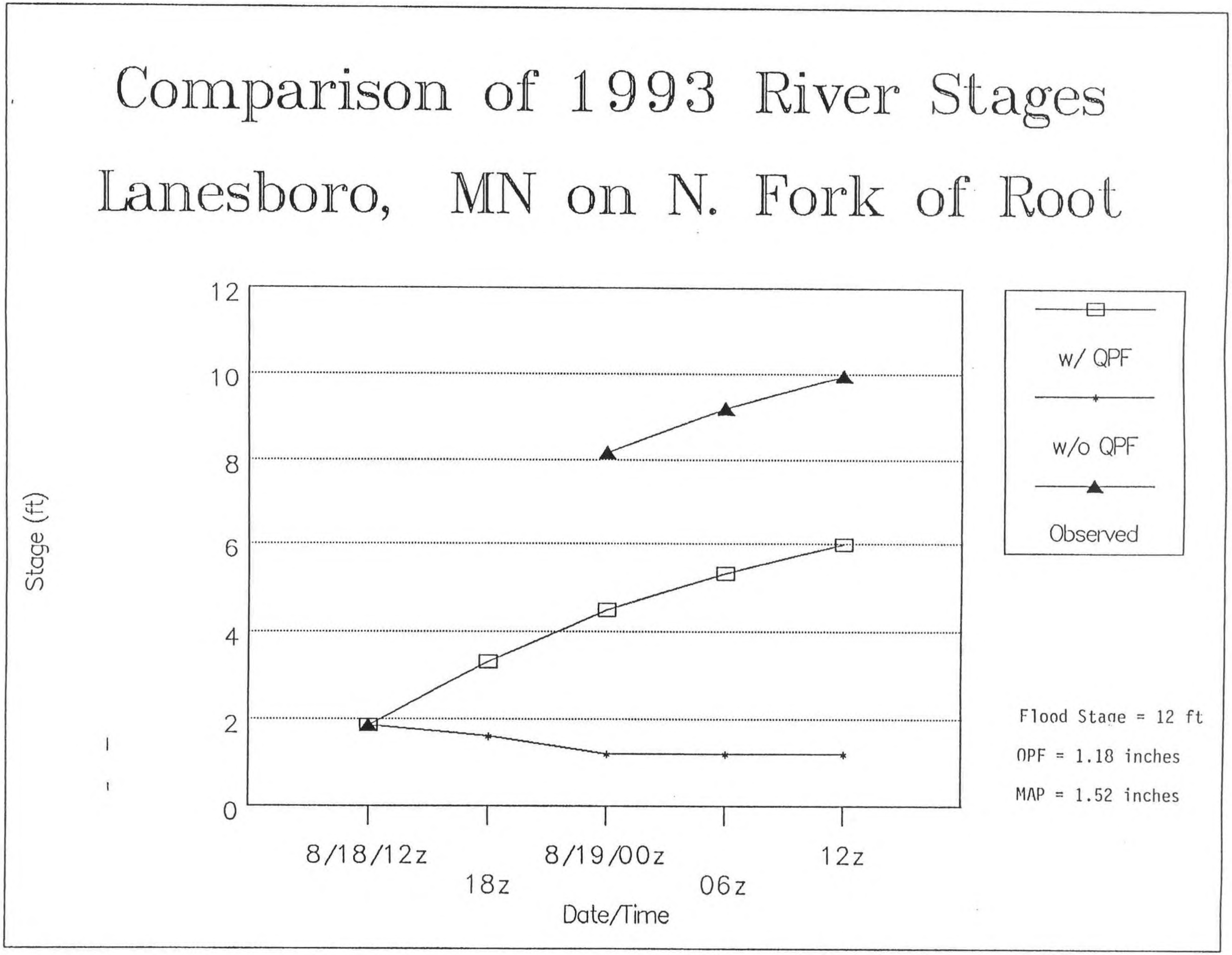

Figure 8a. Hydrograph for Lanesboro, Minnesota. Valid 1200 UTC August 18-1200 UTC August 19, 1993.

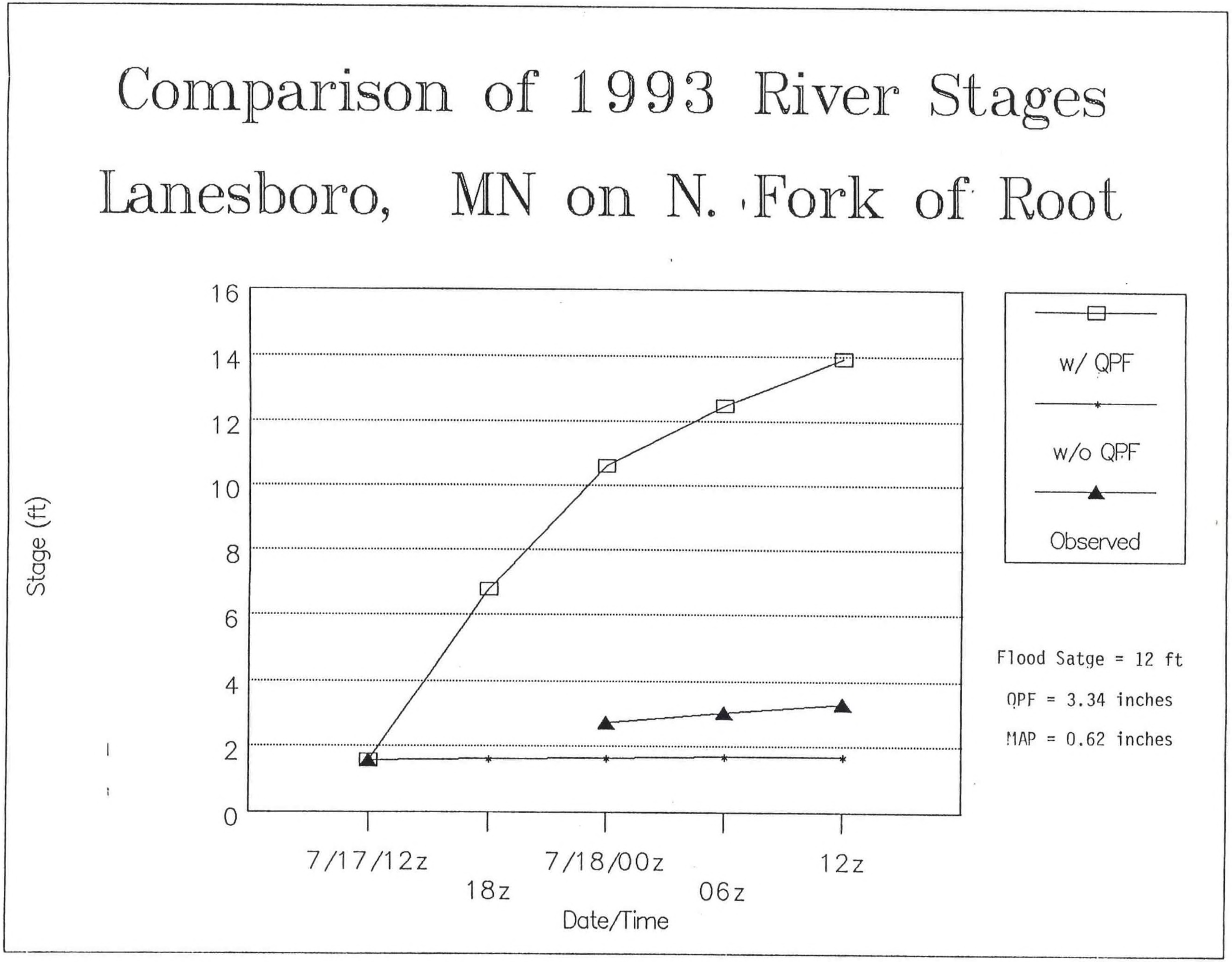

Figure 8b. Hydrograph for Lanesboro, Minnesota. Valid 1200 UTC July 17-1200 UTC July 22, 1993.

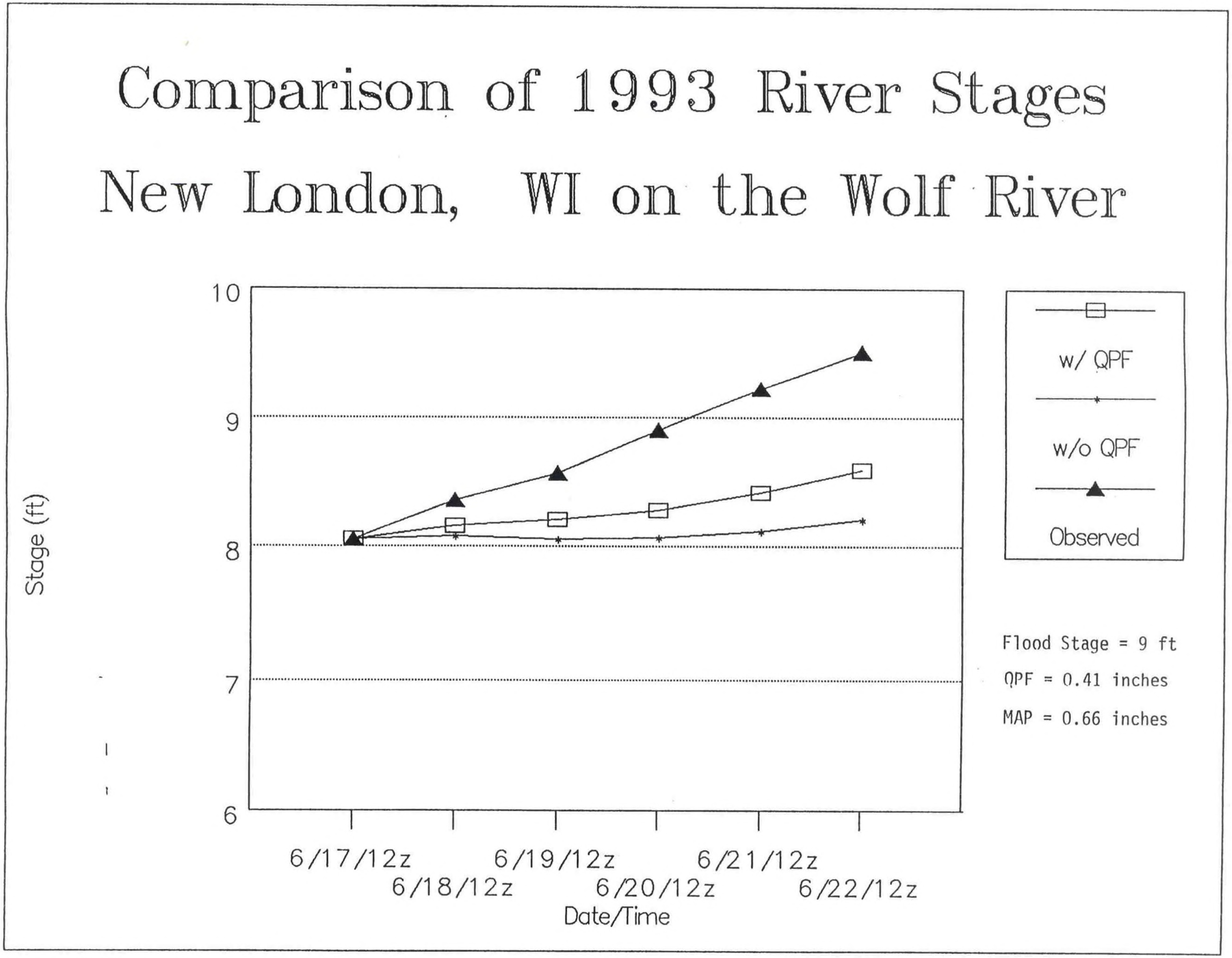

Figure 9a. Hydrograph for New London, Wisconsin. Valid 1200 UTC June 17 - 1200 UTC June 22, 1993.

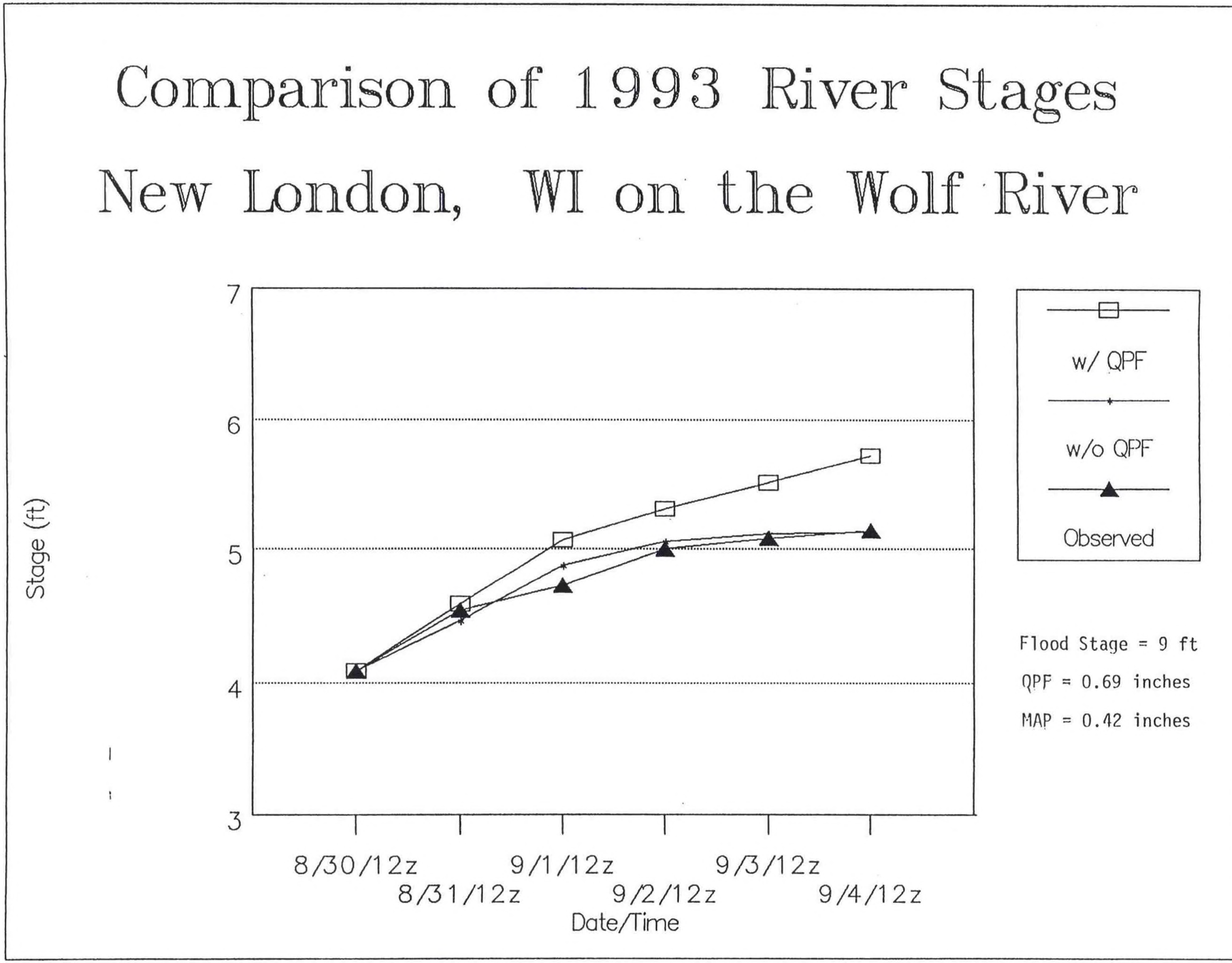

Figure 9b. Hydrograph for New London, Wisconsin. Valid 1200 UTC August 30 - 1200 UTC September 4, 1993.

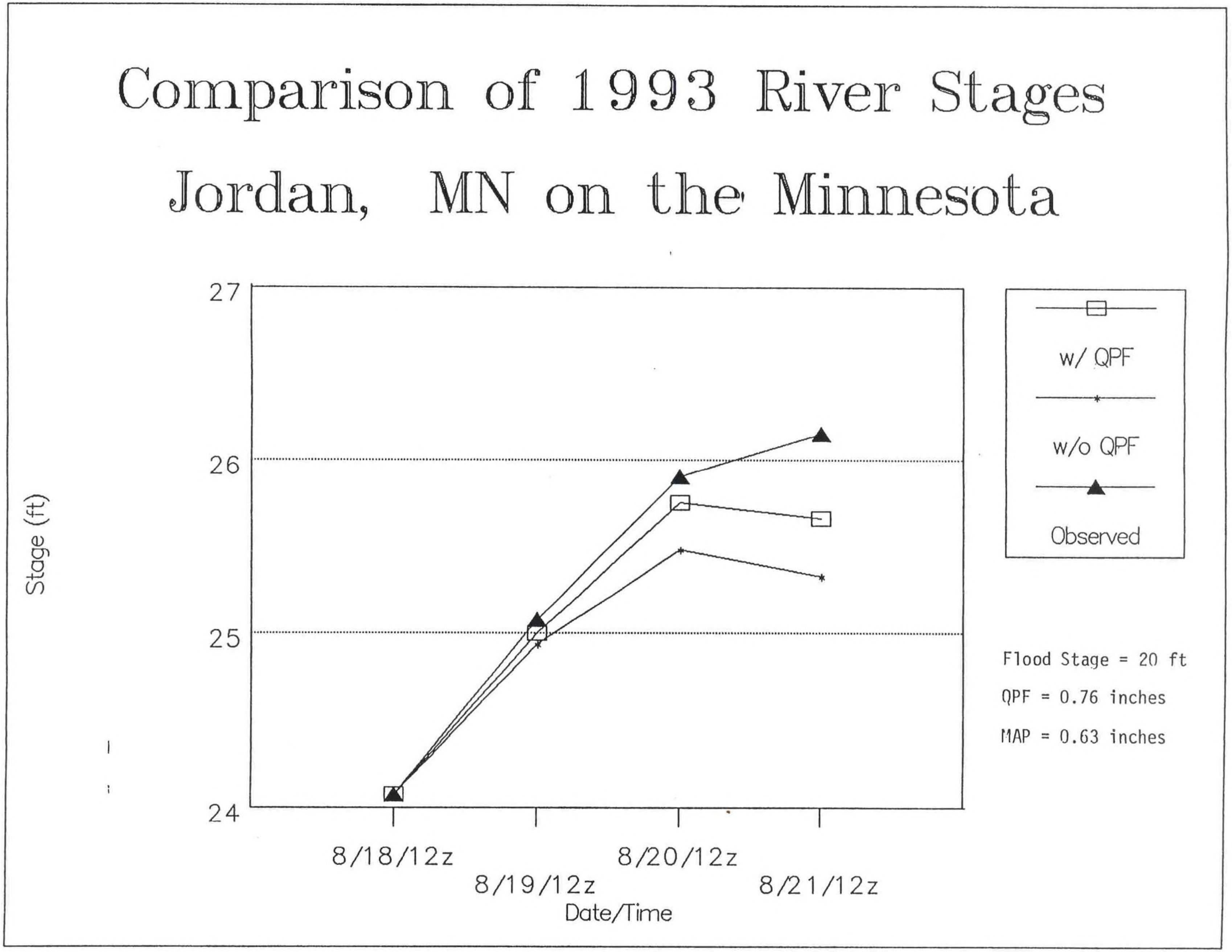

Figure 10a. Hydrograph for Jordan, Minnesota. Valid 1200 UTC August 18 - 1200 UTC August 21, 1993.

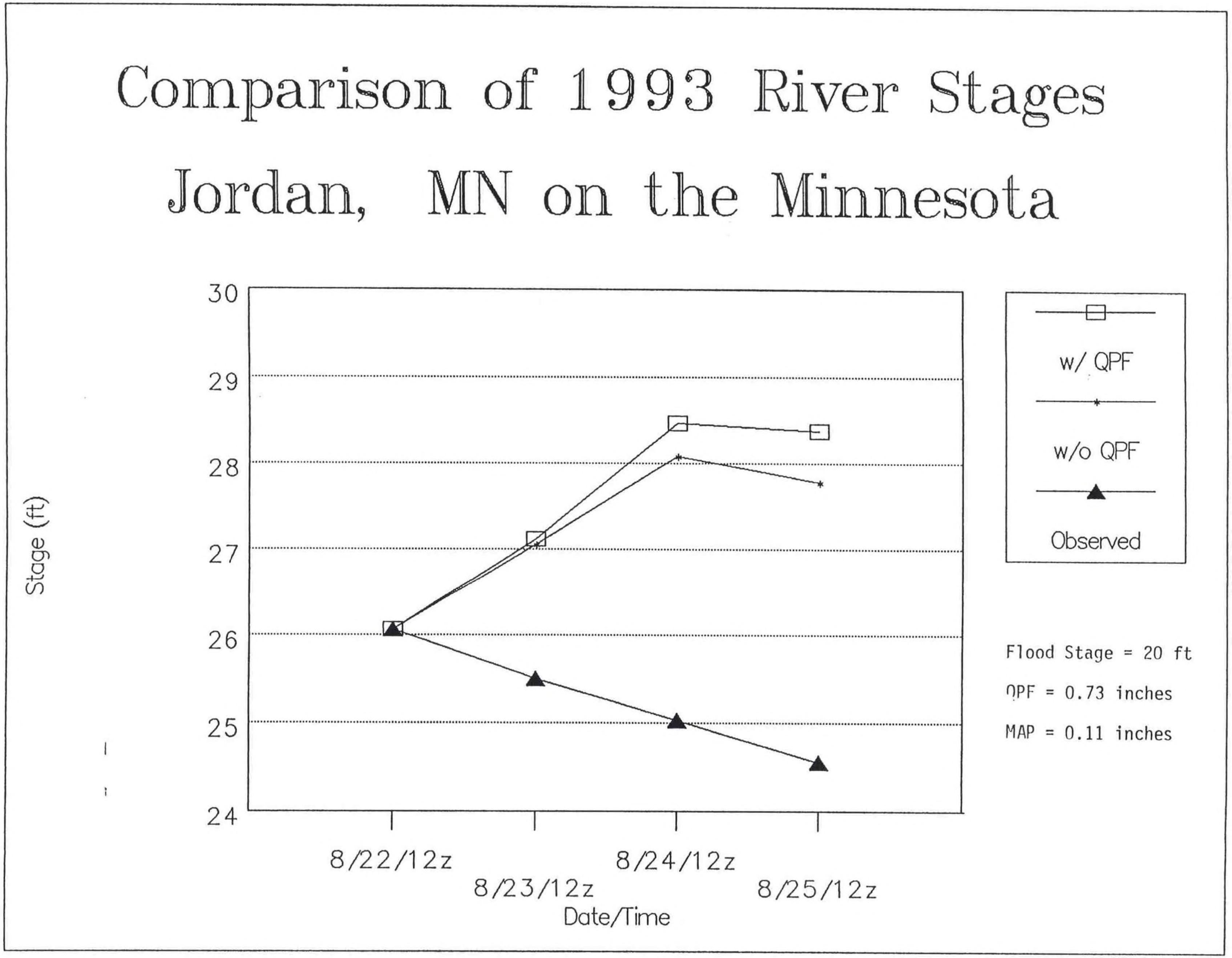

Figure 10b. Hydrograph for Jordan, Minnesota. Valid 1200 UTC August 22 - 1200 UTC August 25, 1993.

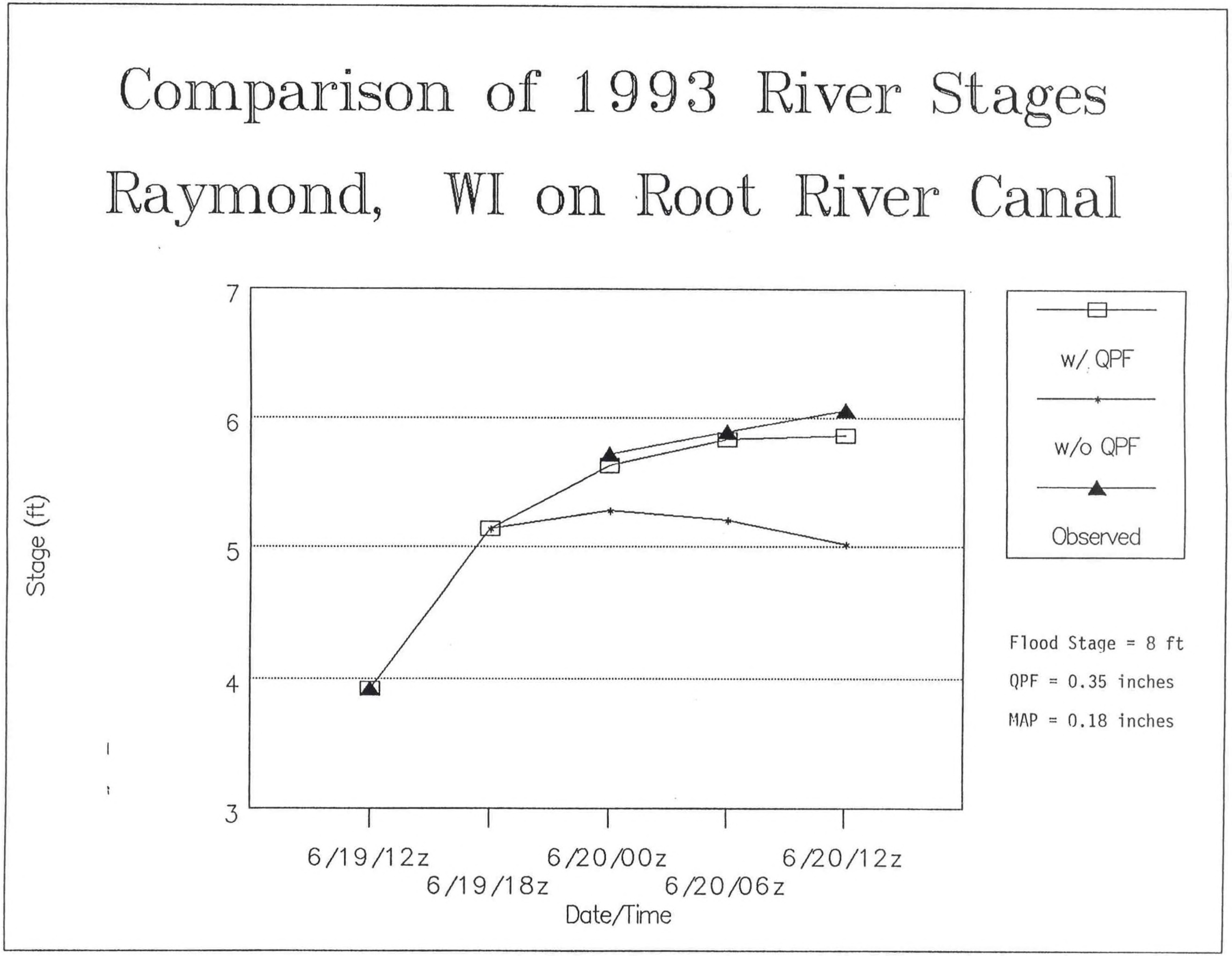

Figure 11a. Hydrograph for Raymond, Wisconsin. Valid 1200 UTC June 19 - 1200 UTC July 12, 1993.

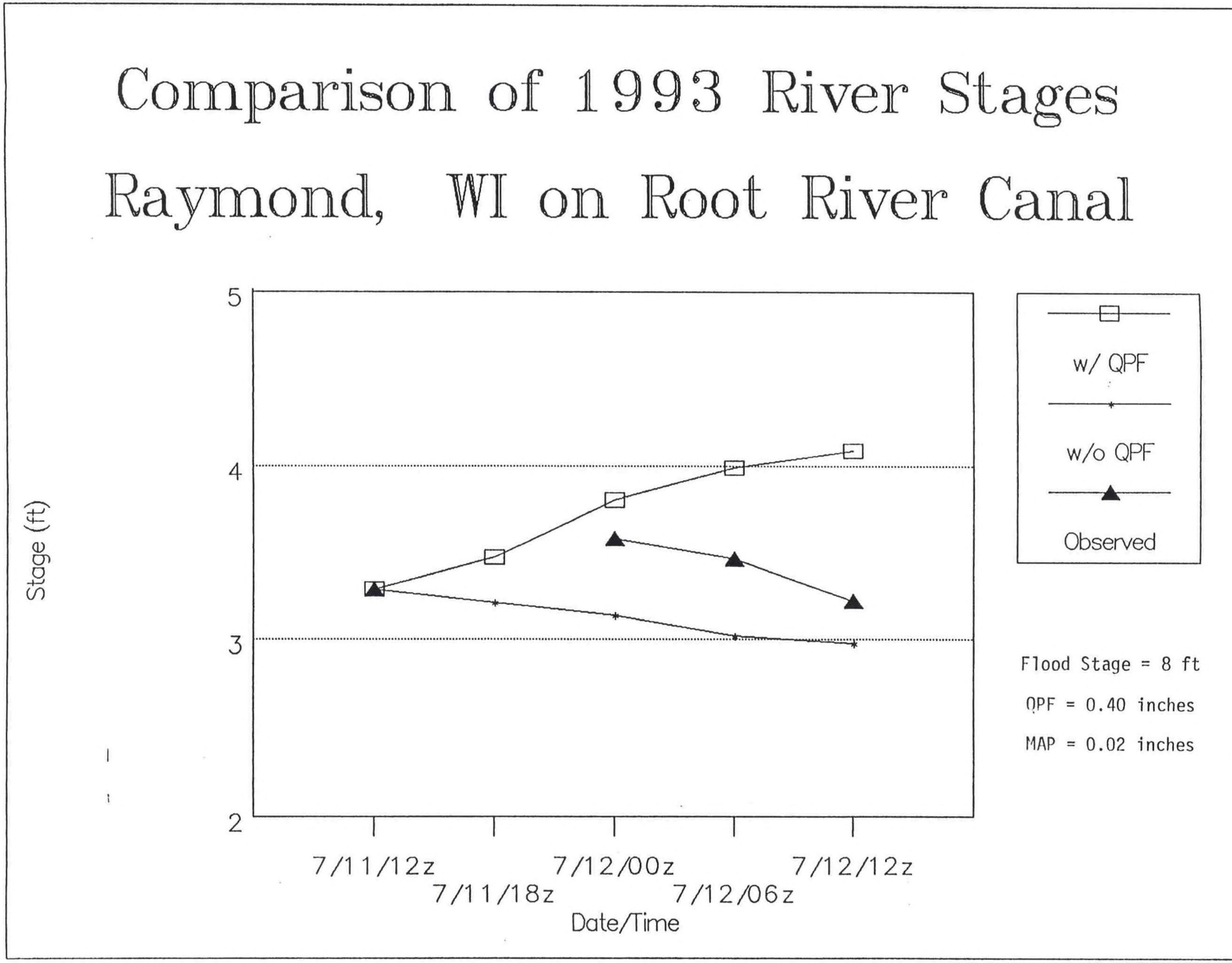

Figure 11b. Hydrograph for Raymond, Wisconsin. Valid 1200 UTC July 11 - 1200 UTC July 12, 1993.

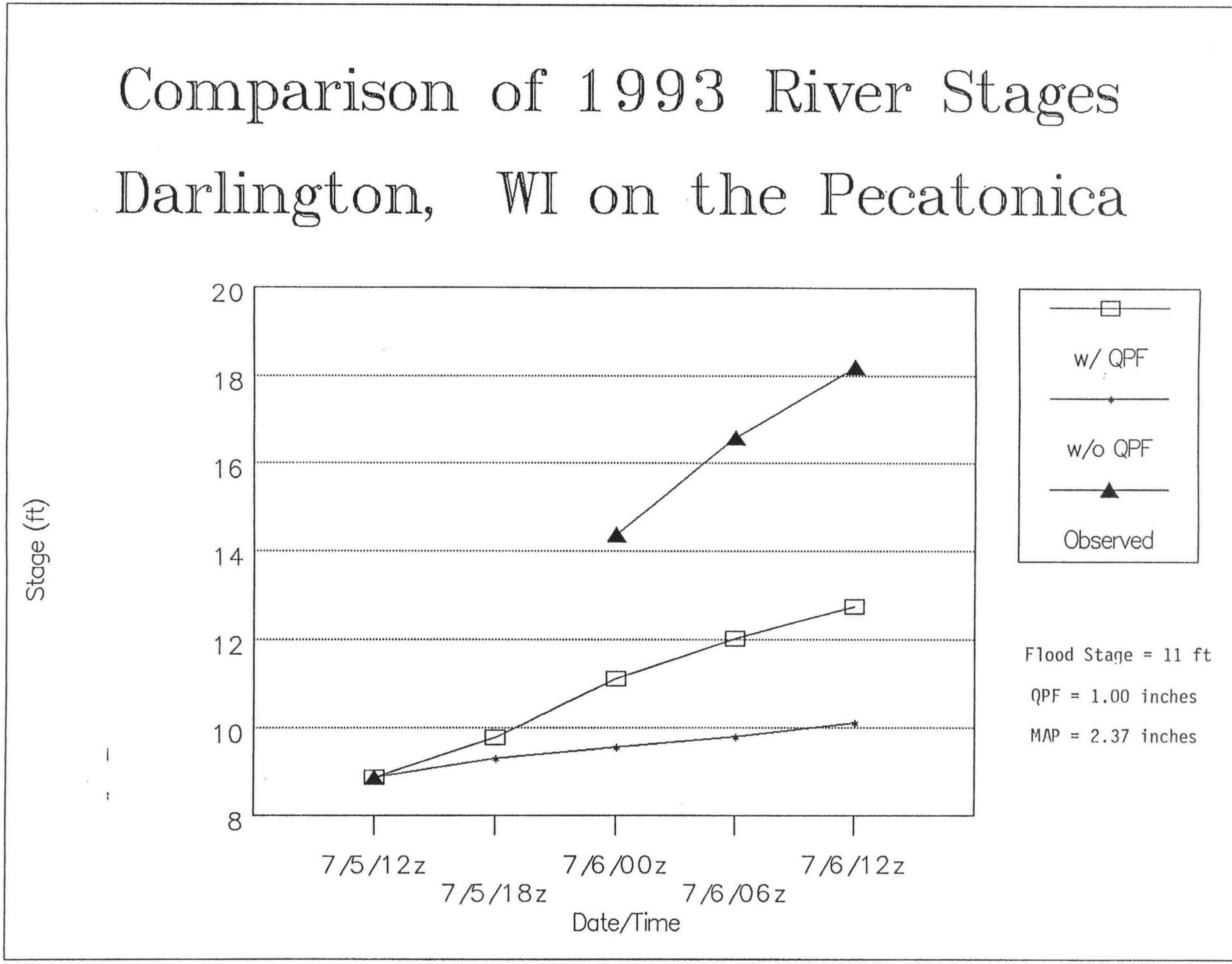

Figure 12a. Hydrograph for Darlington, Wisconsin. Valid 1200 UTC July 5 - 1200 UTC July 6, 1993.

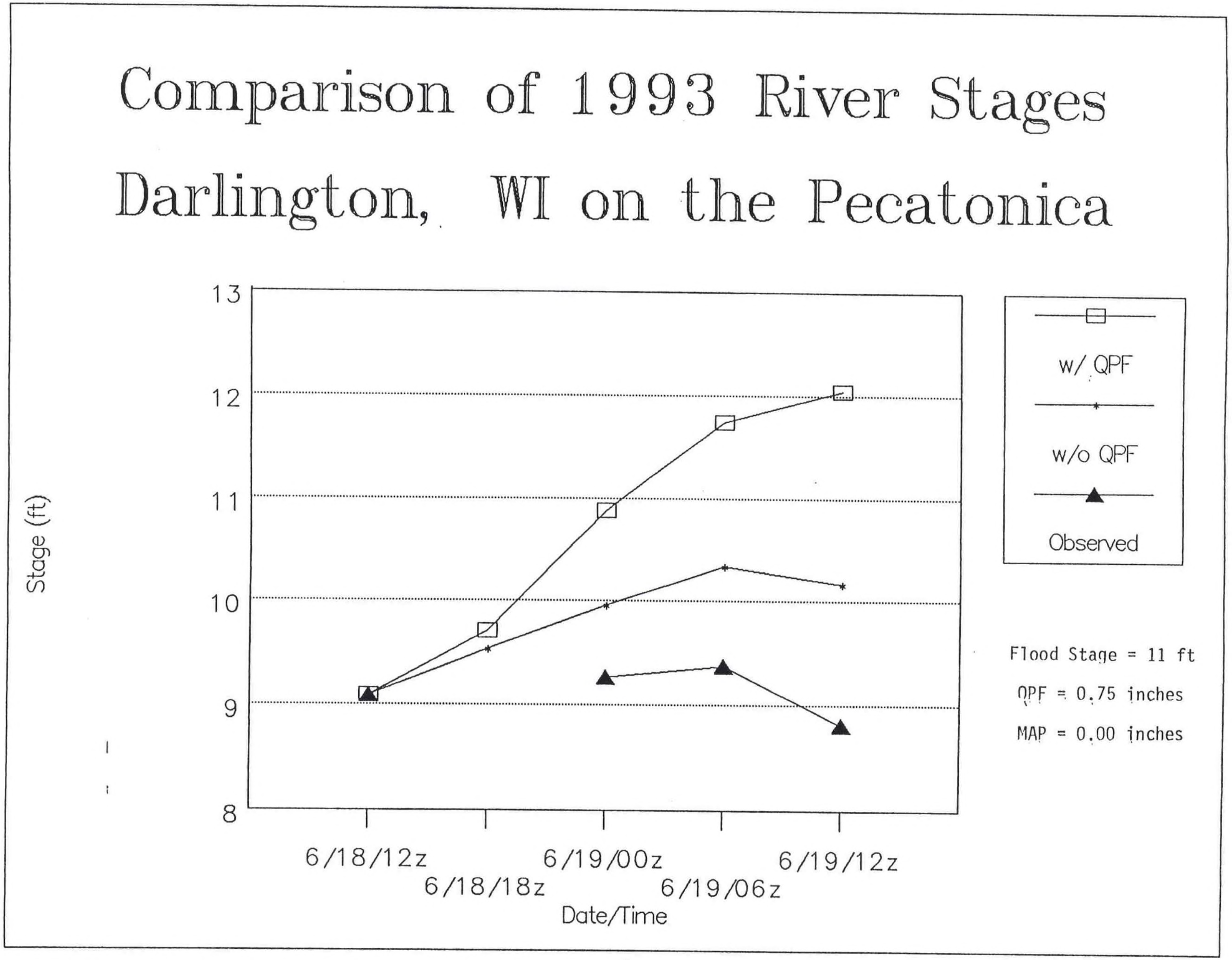

Figure 12b. Hydrograph for Darlington, Wisconsin. Valid 1200 UTC June 18 - 1200 UTC June 19, 1993.

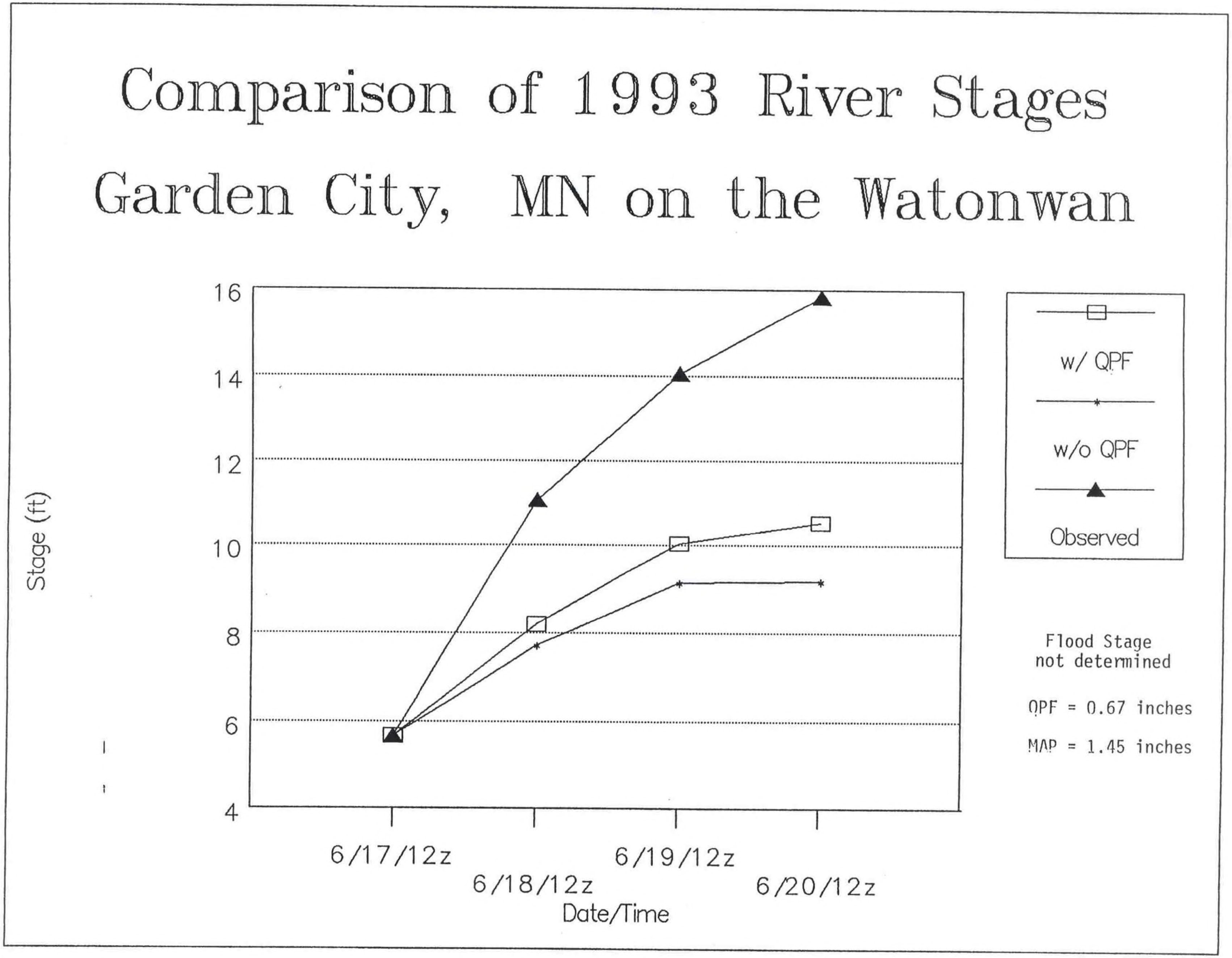

Figure 13a. Hydrograph for Garden City, Minnesota. Valid 1200 UTC June 17 - 1200 June 20, 1993.

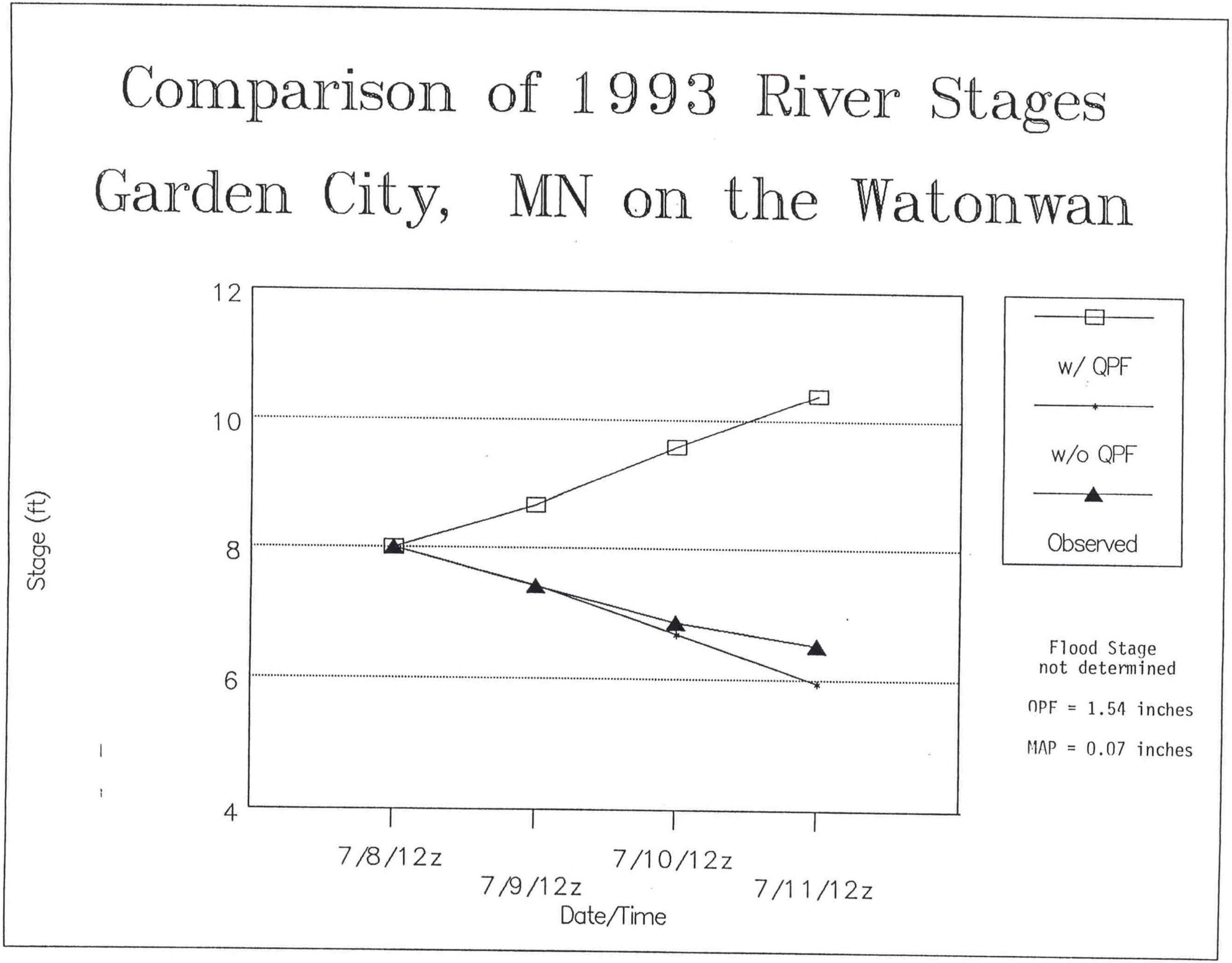

Figure 13b. Hydrograph for Garden City, Minnesota. Valid 1200 UTC July 8 - 1200 UTC July 11, 1993.

8. COMPARISON OF 1992 AND 1993 RISK REDUCTION EXERCISES

The final item we addressed was to compare results of the 1993 risk reduction with that of 1992 (Braatz 1992). As mentioned in Section 2, the two exercises were somewhat different as follows:

> In 1992, QPF was only produced if the expected 12 hour amount was ≥ 0.50 inch, as opposed to daily forecasts in 1993.
>
> Also, the 1992 study used all forecast points in Wisconsin, whereas the 1993 study dealt with three points in Minnesota and three points in Wisconsin.

Even with these differences, some results could be compared. They are depicted as forecast summaries in Tables 6-9.

Tables 6 and 7 show results for all forecasts for each project. It should be reiterated here that the data base used to produce Table 7 was much larger than that for Table 6. Table 7 shows the verification results in 1993 were not as good as those in 1992 (83% versus 96% for non-QPF forecasts and 84% versus 90% for QPF forecasts). This was most likely because the 1993 exercise was during a much wetter period.

Tables 8 and 9 show results for forecasts near or above flood stage. In this area, QPF forecasts did not fair well in 1992 with only 41% being verified, whereas in 1993, 82% were verified. For non-QPF forecasts, 89% were verified in 1992 compared to 80% in 1993. Again the changes are likely due to the wetter 1993 season, and increased experience of the meteorologists producing the QPF.

9. CONCLUSIONS

A. The two data sets (river forecasts with QPF and river forecasts without QPF) were shown to be statistically unique.

B. QPFs of a half inch or more, verify with measurable rainfall most of the time (41 out of 47 here or 87%).

C. QPFs of a half inch or more verify with MAP of a half inch or more, half of the time.

D. Both river forecasts with and without QPF tend to under forecast (showed a negative bias).

TABLE 6
1992 RISK REDUCTION FORECAST SUMMARY - ALL CASES

Month	Total Fcsts[1]	Number of QPF Fcsts Verified[2]	Number of Non-QPF Fcsts Verified
April	120	101	113
May	60	56	59
June	30	27	30
July	104	91	100
August	28	28	28
September	129	120	124
October	27	24	25
November	19	19	19
TOTAL	519	466[3]	498[4]

1. Fcsts = Forecasts throughout document
2. Verified meaning + or - 1 Foot
3. 90% of stage forecasts with QPF verified
4. 96% of stage forecasts without QPF verified

TABLE 7
1993 RISK REDUCTION FORECAST SUMMARY - ALL CASES

Month	Number of QPF Fcsts	Number of QPF Fcsts Verified[1]	Number of Non-QPF Fcsts	Number of Non-QPF Verified
June	81	54	81	50
July	186	157	186	157
August	186	151	186	151
September	180	154	180	152
October	184	171	184	171
TOTAL	817	687[2]	817	681[3]

1. Verified Meaning Within + or - 1 Foot
2. 84% of stage forecasts with QPF verified
3. 83% of stage forecasts without QPF verified

TABLE 8
1992 RISK REDUCTION FORECAST SUMMARY
(all forecasts near or above flood stage)

Month	Number of QPF Fcsts Near or Above FS[1]	Number of QPF Fcsts Above FS Verified[2]	Number of Non QPF Fcsts Near or Above FS	Number of Non QPF Fcsts Above FS Verified
April	18	7	7	6
May	0	--	0	--
June	1	0	0	--
July	0	--	0	--
August	0	--	0	--
September	3	2	2	2
October	0	--	0	--
November	0	--	0	--
TOTAL	22	9[3]	9	8[4]

1. FS = Flood Stage throughout document
2. Verified Meaning Within + or - 1 Foot
3. 41% of stage forecasts with QPF verified
4. 89% of stage forecasts without QPF verified

TABLE 9
1993 RISK REDUCTION FORECAST SUMMARY
(all forecasts near or above flood stage)

Month	Number of QPF Fcsts Near or Above FS	Number of QPF Fcsts Above FS Verified[1]	Number of Non-QPF Fcsts Near or Above	Number of Non-QPF Fcsts Above FS Verified
June	25	17	25	15
July	51	45	46	42
August	31	25	31	24
September	9	8	9	8
October	0	--	0	--
TOTAL	116	95[2]	111	89[3]

1. Verified Meaning Within + or - 1 Foot
2. 82% of stage forecasts with QPF verified
3. 80% of stage forecasts without QPF verified

E. The sum of the absolute errors showed a 3% greater total error in the river forecasts with QPF as compared to the forecasts without QPF. This implies too much fluctuation of the QPF-type forecasts.

F. There was a noted decrease in error of the QPF forecasts compared to the non-QPF forecasts, in the 3-5 day range.

G. The mean error was generally less for those river forecasts with QPF showing that those forecasts fluctuate closer to the actual observation than the non-QPF forecasts.

H. The river forecasts with QPF verified within one foot of the observed stage and flood stage, better than the non-QPF forecasts in 1993 but not in 1992. This is probably because the 1993 exercise occurred over a much wetter season than in 1992, and perhaps also to the increased forecaster experience and daily routine.

10. SUMMARY

The total effect of QPF on the river forecasts resulted in a slightly larger error, overall (higher total absolute error), as shown in Figure 6b. This was only a small difference, however (3%), and should improve as forecasters' experience continues. With that improvement, combined with the forecasts fluctuating closer to the eventual observed value (item six above), the river forecast should improve by utilizing QPF.

As was shown in some examples of Section 7, there is a problem with both over forecasting precipitation, and not forecasting it at all. The extreme event of over forecasting by nearly 11 feet, as shown in Figure 8b, could result in unnecessary preparedness actions which not only take time and effort, but could also be costly. On the other hand, the forecast with a good QPF could save lives and money, by providing earlier warnings.

The meteorologists who produced the QPF were generally conservative in their efforts as can be seen by the predominance of under forecasted river stages. For forecasters just beginning to do QPF, this is probably the tack to take to prevent too many false alarms, until more experience and confidence is gained. At least the forecast that uses QPF will most times show an upward trend that will alert the users earlier than the non-QPF forecast. It will be important however, to inform the users when QPF is part of the forecast, due to the change from stair-stepping to fluctuating river forecasts.

Using QPF in river forecasting will be increasing in the National Weather Service (NWS) over the next several years because of the NWS move toward modernization (Office of Hydrology 1991) and because of findings and recommendations of the National Oceanic and Atmospheric Administration Natural Disaster Survey Report of the Great Flood of 1993. In particular, Recommendation 6.4 states, "The NWS should support research, development, and operational testing to incorporate current QPF into river forecasting procedures".

The NWS modernization will be accompanied by new technologies such as Doppler radar providing rainfall estimates and improved satellite information that will give the forecaster a better view of hydrometeorological phenomena on a smaller scale. An understanding of these phenomena with a knowledge of the local area and climatology, will be a key in identifying areas of heavy precipitation to the finer resolution needed by river forecasting models. Local studies regarding forecasting quantitative precipitation will be another important enhancement, as will the future implementations of local mesoscale models.

This study has shown that adding QPF to the river forecast was generally not a detriment, due to the conservative nature of the meteorologist. The advanced notice of rising river conditions as depicted in Figure 8a shows the benefit of QPF. The question now does not seem to be "What harm did QPF do to the river forecast?", but "How can we continue to improve the expertise needed to produce QPF that will benefit the river forecast?"

11. ACKNOWLEDGMENTS

The author wishes to recognize the staff at NCRFC for their efforts in archiving the data used for this report, and to the staffs at the Minneapolis, Minnesota and Milwaukee, Wisconsin NWS Forecast offices for their contribution in producing the QPFs. The author would also like to thank Mark M. Ziemer, Patrick J. Neuman, and John W. Seemann of NCRFC for their technical support in the field of hydrology and the methodology of the 1992 Risk Reduction Exercise. Finally, a special thanks to Dr. Lee W. Larson and Thomas F. Schwein for their guidance through much of the statistical analysis of this project.

12. REFERENCES

Braatz, D., 1992: Final Report on QPF Enhanced River Forecasts in Wisconsin, 9 pp.

Larson, L.W., 1975: Precipitation Model, National Weather Service River Forecast System User's Manual Part II, Chapter 6, NWS Office of Hydrology, 1-16.

DOC, NOAA, 1994: The Great Flood of 1993. Natural Disaster Survey Report, 278pp.

___________, __________, NWS, Office of Hydrology, 1991: Hydrometeorological Service Operations for the 1990's, 1-2p.

Ostle, B., 1963: *Statistics in Research*, Second edition, The Iowa State University Press, 585pp.

Panofsky, H., and G. Brier, 1965: *Some Applications of Statistics to Meteorology*, The Pennsylvania State University, 224pp.

Spiegel, M., 1961: *Schaum's Outline of Theory and Problems of Statistics*, Schaum Publishing Company, 359pp.

NWS CR 47 Practical Application of a Graphical Method of Geostrophic Wind Determination. C.B. Johnson, November 1971 (COM 71-01084).

NWS CR 48 Manual of Great Lakes Ice Forecasting. C. Robert Snider, December 1971 (COM 72-10143).

NWS CR 49 A Preliminary Transport Wind and Mixing Height Climatology, St. Louis, Missouri. Donald E. Wuerch, Albert J. Courtois, Carl Ewald, Gary Ernst, June 1972 (COM 72-10859).

NWS CR 50 An Objective Forecast Technique for Colorado Downslope Winds. Wayne E. Sangster, December 1972 (COM 73-10280).

NWS CR 51 Effect on Temperature and Precipitation of Observation Site Change at Columbia, Missouri. Warren M. Wisner, March 1973 (COM 73-10734).

NWS CR 52 Cold Air Funnel Clouds. Jack R. Cooley and Marshall E. Soderberg, September 1973, (COM 73-11753/AS).

NWS CR 53 The Frequency of Potentially Unfavorable Temperature Conditions in St. Louis, Missouri. Warren M. Wisner,October 1973.

NWS CR 54 Objective Probabilities of Severe Thunderstorms Using Predictors from FOUS and Observed Surface Data. Clarence A. David, May 1974 (COM 74-11258/AS).

NWS CR 55 Detecting and Predicting Severe Thunderstorms Using Radar and Sferics. John V. Graff and Duane C. O'MalleyJune 1974 (COM 74-11335/AS).

NWS CR 56 The Prediction of Daily Drying Rates. Jerry D. Hill, November 1974 (COM 74-11806/AS).

NWS CR 57 Summer Radar Echo Distribution Around Limon, Colorado. Thomas D. Karr and Ronald L. Wooten, November 1974 (COM 75-10076/AS).

NWS CR 58 Guidelines for Flash Flood and Small Tributary Flood Prediction. Lawrence A. Hughes and Lawrence L. Longsdorf, October 1975 (PB247569/AS)

NWS CR 58 (Revised) March 1978 (PB281461/AS)

NWS CR 59 Hourly Cumulative Totals of Rainfall - Black Hills Flash Flood June 9-10, 1972. Don K. Halligan and Lawrence L. Longsdorf, April 1976 (PB256087).

NWS CR 60 Meteorological Effects on the Drift of Chemical Sprays. Jerry D. Hill, July 1976 (PB259593).

NWS CR 61 An Updated Objective Forecast Technique for Colorado Downslope Winds. Wayne E. Sangster, March 1977 (PB266966/AS).

NWS CR 62 Design Weather Conditions for Prescribed Burning. Ronald E. Haug, April 1977 (PB268034).

NWS CR 63 A Program of Chart Analysis (With Some Diagnostic and Forecast Implications). Lawrence A. Hughes, December 1977 (PB279866/AS).

NWS CR 64 Warm Season Nocturnal Quantitative Precipitation Forecasting for Eastern Kansas Using the Surface Geostrophic Wind Chart. Wayne E. Sangster, April 1979 (PB295982/AS).

NWS CR 65 The Utilization of Long Term Temperature Data in the Description of Forecast Temperatures. Arno Perlow,November 1981 (PB82 163064).

NWS CR 66 The Effect of Diurnal Heating on the Movement of Cold Fronts Through Eastern Colorado. James L. Wiesmueller, August 1982 (PB83 118463).

NWS CR 67 An Explanation of the Standard Hydrologic Exchange Format (SHEF) and Its Implementation in the Central Region. Geoffrey M. Bonnin and Robert S. Cox, April 1983 (PB83 193623).

NWS CR 68 The Posting of SHEF Data to the RFC Gateway Database. Geoffrey M. Bonnin, April 1983 (PB83 222554).

NWS CR 69 Some Basic Elements of Thunderstorm Forecasting. Richard P. McNulty, May 1983 (PB83 222604).

NWS CR 70 Automatic Distribution of AFOS Products Created at the NOAA Central Computer Facility via Hamlet (RJE) PunchStream. Billy G. Olsen and Dale G. Lillie, November 1983 (PB84 122605).

NWS CR 71 An Investigation of Summertime Convection Over the Upper Current River Valley of Southeast Missouri. Bartlett C. Hagemeyer, July 1984 (PB84 222389).

NWS CR 72 The Standard SHEF Decoder Version 1.1. Geoffrey M. Bonnin, August 1984 (PB85 106508).

NWS CR 73 The Blizzard of February 4-5, 1984 Over the Eastern Dakotas and Western Minnesota. Michael Weiland, October 1984 (PB85 120087).

NWS CR 74 On the Observation and Modeling of the Slope Winds of the Upper Current River Valley of Southeast Missouri and Their Relationship to Air-Mass Thunderstorm Formation. Bartlett C. Hagemeyer, June 1985 (PB85 226926/AS).

NWS CR 75 Complete Guide to Canadian Products in AFOS. Craig Sanders, July 1985 (PB85 228153/AS).

NWS CR 76 The Reliability of the Bow Echo as an Important Severe Weather Signature. Ron W. Przybylinski and William J. Gery, September 1985 (PB86 102340).

NWS CR 77 Observation of Bow Echoes with the Marseilles Radar System. John E. Wright, Jr., September 1985 (PB86 102340).

NWS CR 78 Statistical Analysis of SHEF Coding Errors. Robert S. Cox, Jr., January 1986 (PB86 145141).

NWS CR 79 On the Midwestern Diurnal Convergence Zone on the West Side of the Warm Season Bermuda High. Bartlett C. Hagemeyer, March 1986 (PB86 171378).

NWS CR 80 Some Characteristics of Northeast Kansas Severe Weather 1963-1984. Larry W. Schultz, March 1986 (PB86 173952/AS).

NWS CR 81 The Severe Thunderstorm Outbreak of July 6, 1983 in Southeast Idaho, Western Wyoming and Southwest Montana. Gary L. Cox, April 1986 (PB86 184322/AS).

NWS CR 82 Some Proposals for Modifying the Probability of Precipitation Program of the National Weather Service. Wayne E. Sangster and Michael D. Manker, July 1986 (PB86 226636/AS).

NWS CR 83 Deformation Zones and Heavy Precipitation. Henry Steigerwaldt, August 1986 (PB86 229085/AS).

NWS CR 84 An Overview of the June 7, 1984 Iowa Tornado Outbreak. Charles H. Myers, August 1987.

NWS CR 85 Operational Detection of Hail by Radar Using Heights of VIP-5 Reflectivity Echoes. Richard B. Wagenmaker, September 1987.

NWS CR 86 Fire Weather Verification: The Forecaster Does Make a Difference. Therese Z. Pierce and Scott A. Mentzer, December 1987 (PB88 140744).

NWS CR 87 Operational Use of Water Vapor Imagery. Samuel K. Beckman, December 1987 (PB88 140751).

NWS CR 88 Central Region Applied Research Papers 88-1 Through 88-7. NWS Central Region, Scientific Services Division, May 1988 (PB88-210836).

NWS CR 89 Compendiums of Information for the Missouri Basin River Forecast Center and the North Central River ForecastCenter. NWS Central Region, Scientific Services Division, June 1988 (PB88-226204).

NWS CR 90 Synoptic-Scale Regimes Most Conducive to Tornadoes in Eastern Wyoming — A Link Between the Northern Hemispheric Scale Circulation and Convective-Scale Dynamics. William T. Parker and Edward K. Berry, July 1988 (PB88-231337).

Continued on Back Cover.

NWS CR 91 Heavy Snowfall in Northwest Wyoming. Michael S. Weiland, September 1988 (PB89 109524).

NWS CR 92 On the Utility of a Geographic Information System in Modelling Climatic Suitability. Bartlett C. Hagemeyer, September 1988 (PB89 109516).

NWS CR 93 The Synoptic and Meso-Alpha Scale Meteorology of Wyoming Flash Floods. Joseph A. Rogash, October 1988 (PB89 117709)

NWS CR 94 The Removal of Stagnant Winter Air Masses From Wyomings Wind River Basin. Gary L. Cox and Jeffrey M. Graham, November 1988 (PB89 128664).

NWS CR 95 Floods Along Des Plaines and Fox Rivers: September-October 1986. Thomas L. Dietrich, February 1989 (PB89 152797/AS)

NWS CR 96 A Case Study Evaluation of Satellite-Derived Rainfall Estimates and Their Application to Numerical Model Precipitatio Forecast Verification. Glenn A. Field, May 1989 (PB89 194591).

NWS CR 97 Central Region Applied Research Papers 97-1 through 97-6. NWS Central Region, Scientific Services Division, July 198 (PB89 213375/AS).

NWS CR 98 The Record Rainfall of August 13-14, 1987 at Chicago, Illinois. Paul Merzlock, November 1989.

NWS CR 99 Central Region Applied Research Papers 99-1 through 99-7. NWS Central Region, Scientific Services Division, November 1989 (PB90 151325).

NWS CR 100 A Guide to Forecasters in Judging Weather Impact on Growth Environments and Farm Operations in the Midwest. John W. Kottke, December 1989 (PB90 141011).

NWS CR 101 Numerical Solutions to the Shallow Water Equations as Applied to a Local Meteorological Forecast Problem. Eric R. Thaler, March 1990 (PB90 191230).

NWS CR 102 Postprint Volume National Weather Service Aviation Workshop Kansas City, Missouri, December 10-13, 1991. NWS Central Region, Scientific Services Division, March 1992 (PB92-176148).

NWS CR 103 An Investigation of Two Microburst Producing Storms Using A Microburst Recognition Algorithm. David Eversole, January 1994 (PB94-156577).

NWS CR 104 Lincoln ASOS Temperature Test January 13-15, 1993, Gregory Grosshans and Phil Clark, March 1994 (PB94-159993).

NWS CR 105 Forecasting Snowfall Using Mixing Ratios on an Isentropic Surface "An Empirical Study", Crispin Garcia, Jr, May 1994 (PB94-188760).

NWS CR 106 The Use of Profiler Data for Analysis and Nowcasting of a Winter Season Extratropical Cyclone, Bradley S. Small, June 1994 (PB94-187804).

NWS CR 107 Flood Forecasting for the Lower Missouri River Basin: June - September, 1993, John F. Pescatore, September 1994 (PB95-123568).

NWS CR 108 Heterogeneous Nucleation and its Relationship to Precipitation Type, Gregory Smith, April 1995 (PB95-217170).

NWS CR 109 Synoptic, Mesoscale and Radar Aspects of the Northeast Kansas Supercell of September 21, 1993, Kenneth Labas and Bria Walawender, October 1995 (PB96-125075).

NOAA SCIENTIFIC AND TECHNICAL PUBLICATIONS

The National Oceanic and Atmospheric Administration was established f the Department of Commerce on October 3, 1970. The mission responsibilities of N e to assess the socioeconomic impact of natural and technological changes in the env t and to monitor and predict the state of tha solid Earth, the oceans and their living r , the atmosphere, and the space environment of the Earth.

The major components of NOAA regularly produce various types of scientific and technical information in the following kinds of publications:

PROFESSIONAL PAPERS--Important definitive research results, major techniques, and special investigations.

CONTRACT AND GRANT REPORTS--Reports prepared by contractors or grantees under NOAA sponsorship.

ATLAS--Presentation of analyzed data generally in the form of maps showing distribution of rainfall, chemical and physical conditions of oceans and atmosphere, distribution of fishes and marine mammals, ionospheric conditions,etc.

TECHNICAL SERVICE PUBLICATION--Reports containing data, observations, instructions, etc. A partial listing includes data serials; prediction and outlook periodicals; technical manuals, training papers, planning reports, and information serials; and miscellaneous technical publications.

TECHINCAL REPORTS--Journal quality with extensive details, mathematical developments, or data listings.

TECHNICAL MEMORANDUMS--Reports of preliminary, partial, or negative research or technology results, interim instructions, and the like.

Information on availability of NOAA publication can be obtained from:

NATIONAL TECHNICAL INFORMATIN SERVICE
U.S. DEPARTMENT OF COMMERCE
5285 PORT ROYAL ROAD
SPRINGFIELD, VA 22161