CRH SSD
FEBRUARY 1994

CENTRAL REGION TECHNICAL ATTACHMENT 94-05

MISSISSIPPI RIVER FLOODS - OUTLOOKS AND FORECASTS

Pat Neuman
National Weather Service
North Central River Forecast Center
Minneapolis, Minnesota

1. Introduction

The purpose of this paper is to provide information that can be helpful in the interpretation of the Spring Snowmelt Flood Outlooks, which are issued by the North Central River Forecast Center (NCRFC). The paper focuses on historical spring floods, but also includes an analysis of the 1993 summer flood. Verification of past snowmelt flood potential crest values is discussed. The paper concludes with an explanation of Spring Snowmelt Flood Outlook methodology, present and future. Please see Figure 1 which shows a map of the locations of rivers and gages that will be discussed in this paper.

Figure 1. Location of rivers and gages discussed in text.

The main factors that contribute to spring snowmelt flooding include:

1. Wet fall soil moisture
2. Significant frost in ground
3. Heavy snow cover water equivalent
4. rapid, continuous melt rate
5. Moderate to heavy rain during the period

In addition to the above factors, ice jams can greatly aggravate flooding in local areas, possibly producing major flooding with little or no advanced warning.

Snowmelt runoff can represent a substantial contribution to the upper Mississippi River spring flood crests above Grafton, Illinois. Below Grafton, the upper Mississippi River basin snowmelt runoff usually contributes to high base levels. Flows that enter the Mississippi River from the Missouri River during these high base periods can have an additional and substantial effect on the crests at St. Louis, Missouri.

Multiple spring snowmelt crests are common from Quincy, Illinois to St. Louis. An initial spring snowmelt crest may occur from March to mid-April, due to runoff from Iowa, Illinois, northeastern Missouri, and the Missouri River basin.

A second (final) snowmelt crest often occurs from the drainage area in Minnesota, and Wisconsin. For heavy snow cover years, the snowmelt crest at St. Paul usually occurs from early to mid-April. The tributaries that have the greatest effect on the final snowmelt crest (in addition to the runoff from the Mississippi River basin above Minneapolis) include: the Minnesota, St. Croix, Chippewa, and Wisconsin rivers. The spring crest flows at McGregor, Iowa, and Davenport, Iowa are largely determined by the flows that occur on the rivers identified above. However, locally heavy rains between McGregor and Davenport can have an influence on the magnitude and timing of the crests for those two gages. The final snowmelt crest usually reaches the Grafton and St. Louis area in late April or early May.

As the crest moves downstream from Davenport, the occurrence of moderate to heavy spring rains may result in additional crests, and can alter the timing of the final snowmelt crests. Additionally, the nature of the temperature patterns for any given year effect the timing of the crests.

2. Historical Floods

Table 1 shows crest stages for selected major floods that have occurred along portions of the Mississippi River during the 20th Century. The historical floods provide insight into the causes, and complexity of flooding.

TABLE 1: SELECTED CREST STAGES FOR THE MISSISSIPPI RIVER FLOODS

			1st crest	2nd crest		Spring		Summer
	year:	1952	1965	1965	1969	1973	1993	1993
	FS	4-14		4-16	4-14	3-19	4-5	7-11
Minneapolis	16	19.5	****	20.0	17.5	10.8	8.8	11.4
		4-16		4-16	4-15	3-20	4-8	6-26
St. Paul	14	22.0	****	26.0	24.5	11.2	12.5	19.2
		4-23		4-24	4-22	3-21	4-23	6-29
McGregor	16	21.0	****	25.4	21.6	20.2	17.3	21.9
		4-29		4-28	4-27	3-26	4-25	7-9
Davenport	15	18.6	****	22.5	19.3	18.8	18.6	22.6
		4-25	4-17	4-28	4-29	4-23	4-27	7-13
Quincy	17	21.9	24.3	24.8	20.2	28.9	23.9	32.2
		4-30	4-19	5-3	5-2	4-28	4-27	8-1
Grafton	18	24.6	23.8	23.5	22.7	33.1	28.2	38.2
		5-1	4-16	5-1	5-1	4-28	4-18	8-6
St. Louis	30	33.8	28.8	25.9	30.9	43.2	36.5	49.6

Note: The day and month of the crest is listed above each crest value.
**** There was only one crest in the spring of 1965 for these gage locations.

A. 1952 Spring Flood

The 1952 flood at St. Paul had four of the five factors that contribute to spring snowmelt flooding; wet fall, deep frost, heavy snow cover, and a rapid melt. The water equivalent of the snow cover varied from 3-6 inches. Rainfall during the melt period was less than 0.5 inches. The peak flow of the Minnesota River synchronized closely with the peak flow from the Mississippi River above Minneapolis, and resulted in a crest stage on the Mississippi River at St. Paul of 22.0 feet on April 14 (8 feet over flood stage). The contribution from the tributaries from below St. Paul to Davenport, Iowa during the following two weeks was generally minor. The crest at Davenport was 18.6 on April 29 (3.6 feet above flood stage). Heavy rains in Iowa, and Illinois April 22-23 produced significant rises in tributaries between Davenport and Grafton. As a result, the crest at Quincy, Illinois of 21.9 on April 25 (4.9 feet above flood stage) preceded the crest at Davenport by five days. The crest at Grafton was 24.6 on April 30 (6.6 feet above flood stage).

Below Grafton, the Missouri River experienced an up river flood, and its crest reached the Missouri-Mississippi junction about the same time as the upper Mississippi River crest. However, both crest were subjected to reduction by valley storage,and thus the combined flow produced only moderate flooding at St. Louis (crested 3.8 feet above flood stage on May 1) (Reichelderfer 1954).

B. 1965 Spring Flood

The 1965 flood of record for the upper Mississippi River above Davenport was influenced by all of the five factors that contribute to spring snowmelt flooding. Heavy precipitation, during August and September of 1964, resulted in high fall soil moisture in the basin. Deep frost was present in the soils. On April 5, the water equivalent of the snow cover over the drainage area above St. Paul averaged 4 to 8 inches. Heavy rain occurred during the melt period. Precipitation centers of 4 to 6 inches in southern Minnesota and northeast Iowa were over twice normal. Daily maximum temperatures during the wet periods ranged from the mid-30s into the high 40s, and were in the 50s and 60s during the warm spells. Dew point temperatures were generally in the 30s and 40s (Paulhus and Nelson 1967), which accelerated the melt. In addition, to the five factors, an ice sheet developed within the snowpack (Baker 1971), and a serious ice jam preceded the flood at Anoka, Minnesota (20 miles north of Minneapolis) (Johnson 1966). Heavy widespread April rain resulted in an initial crest from Quincy to St. Louis, (April 16-19) that was slightly higher then the final snowmelt crest (April 28-May 3) for that portion of the river.

It is interesting to note from this discussion that the record crest at St. Paul in 1965 (12 feet above flood stage), resulted in a below flood stage crest at St. Louis (Table 1). Thus, it may be concluded that heavy snow cover and major flooding over the Mississippi River basin above St. Paul does not necessarily mean that downstream flooding at St. Louis will occur. Fortunately, in 1965, the contribution of flow from the Missouri River was low, while the upper Mississippi River snowmelt crest was reaching St. Louis.

The crest-to-crest lag time for St. Paul to Grafton, Illinois for the second crest was 17 days. However, lag time can be effected by the magnitude of flows, weather conditions, and the flow characteristic of the intervening tributaries. Thus, lag time can differ from year to year.

C. 1969 Spring Flood

The 1969 upper Mississippi River flood had three of the five factors; wet fall, heavy snow cover, and moderate rains during the melt period. Precipitation during September and October of 1968 was above normal. Little or no frost was present at St. Paul (Baker 1971). The water equivalent of the snow cover on March 14 was 6-10 inches. Rain and a partial melt of the snow cover occurred in late March, followed by complete melt with above normal rainfall in April. April temperatures over the upper Midwest were well above normal, with daily highs from the mid-40s to low 70s (Paulhus 1971). Although the melt rate in April was rapid, the partial melt and runoff in March had the effect of lessening the flood potential by allowing some of the water to be released downstream in advance of the main April snowmelt flood. Flooding was substantial from St. Paul to Grafton, but the crests in 1969 were below the 1965 crests (Table 1). Minor flooding occurred at St. Louis (crested 0.9 feet above flood stage) due receding flows on the Missouri River at the time of the upper Mississippi River peak flows.

D. 1973 Spring Flood

The absence of a heavy snow cover and flooding at St. Paul does not mean that downstream flooding will not occur. This was evident in 1973. On March 6, the snow cover above St. Paul contained 1-3 inches of water equivalent. The crest stage at St. Paul remained below flood stage, the crest exceeded flood stage by 3.8 feet at Davenport, Iowa, and the crest reached a record level at St. Louis (13.2 feet above flood stage). This flood was caused mainly by heavy rains.

E. 1979 Spring Flood

Heavy snow cover alone is not necessarily enough to cause flooding. In 1979, a heavy snow cover of 5-6 inches existed on March 14. An additional 1-3 inches of precipitation occurred by the end of March. In late March, maximum temperatures in the 40s with minimums in the 30s eliminated the snow cover. A continuous snow cover beginning in mid-November insulated the soils from the very cold temperatures that occurred in January and February. The lack of frost, and near to below normal soil moisture, allowed the soils to absorb a large portion of the snowmelt and rain, above St. Paul.

April rainfall was heavy over portions of Iowa, Illinois, and Missouri. Crests exceeded flood stage from McGregor to St. Louis as shown below:

St. Paul:	0.1 feet below flood stage on April 26
McGregor:	0.3 feet above flood stage on May 3
Davenport:	1.3 feet above flood stage on April 3, and 0.8 feet above flood stage on May 3
Grafton:	11.4 feet above flood stage on April 14/15
Quincy:	4.6 feet above flood stage on April 1
St. Louis	7.8 feet above flood stage on April 14

F. 1984 Spring Runoff

Record seasonal snowfall alone does not guarantee a flood. Record seasonal snowfall (98.6 inches, versus normal seasonal snowfall, 49.9 inches) occurred at the Minneapolis/St. Paul station in 1983-84. A partial melt occurred in February. March precipitation was below normal, and the late March snowmelt period extended over a two week period. Snowmelt runoff was minor. The snowmelt crest at St. Paul in 1984 was 2.7 feet below flood stage, and downstream stations remained below flood stage.

G. 1987 Spring Runoff

Very wet fall soils, alone, do not mean that flooding for the following spring is imminent. Other factors including, heavy snow cover, and/or heavy spring rains are needed to produce significant flooding. Widespread rains and flooding occurred in September and October of 1986 (The crest at St. Louis was 9.1 feet above flood stage on October 9). Soil moisture going into the

1986-1987 winter period was high. Weather conditions during the winter period were mild, with below normal precipitation. Snow cover was light, and an early February melt occurred. Spring runoff was minor, with no main stem flooding on the Mississippi River.

H. 1993 Spring Flood.

The spring, 1993 flood included the five factors that contribute to flooding. Fall soil moisture was high, frozen soils were present, a snow cover containing 2-4 inches of water equivalent existed in late March, a rapid melt occurred, and precipitation was above normal during the runoff period in April. It is noted, however, that snow cover water equivalent was much higher over Minnesota, and Wisconsin in the big snowmelt flood years of: 1952 (3-6 inches), 1965 (4-8 inches), and 1969 (6-10 inches).

The 1993 spring crests on the Mississippi River varied from below flood stage at St. Paul, 1.3 feet above flood stage at McGregor, 3.6 feet above flood stage at Davenport, 10.2 feet above flood stage at Grafton, and 6.5 feet above flood stage at St. Louis (Table 1). April precipitation was 150 to 200 percent of normal over northeast Iowa, northwest Illinois, and southwest Wisconsin. The heavy April precipitation occurred as the crest from snowmelt was moving downstream, substantially increasing the crest stages from Davenport to St. Louis.

I. 1993 Summer Flood

May temperatures were below normal over the upper midwest. Precipitation for May was above normal over Minnesota, Wisconsin, Iowa, and Missouri. Four-to-eight inches of rain occurred over southern Minnesota in May, with severe flooding on the Redwood River at Marshall, Minnesota. By the end of May, the Mississippi River had fallen to near or below flood stage from St. Paul to St. Louis. However, saturated soil conditions existed across Minnesota, Wisconsin, Iowa, Illinois, and Missouri. Baseflows were well above seasonal normals.

Spring-like soil and vegetation conditions lingered into summer. The National Agricultural Summary for May 31 - June 6, 1993 indicated greater than 50 percent surplus soil moisture for Minnesota, and Wisconsin. Cold wet conditions delayed the planting of crops, and stunted vegetation. Evapotranspiration rates remained low. Heavy rains in mid-June occurred over southern Minnesota, western Wisconsin, and northern Iowa. Daily flood forecasts by river basin were being issued by the NCRFC, and updated during evening hours as needed. Upper Mississippi River basin flooding was becoming widespread, and severe.

In recognition of the developing severe nature of the flood, the NCRFC began providing a detailed daily Flood Summary and Outlook product on June 27, 1993. Daily flood fighting schedules were arranged around the issuance of the Flood Summary and Outlook product (Bruce 1993). The June 27 product contained the following statement for the Mississippi River basin. The river stage at St. Louis, Missouri was just 1.1 feet above flood stage, with a slow fall in progress.

> "WIDESPREAD SATURATED SOIL CONDITIONS EXIST ACROSS THE UPPER MIDWEST. RESERVOIRS AND RIVER BASIN STORAGE AREAS ARE NEAR CAPACITY. RIVER FLOWS WILL REMAIN WELL ABOVE NORMAL LEVELS THROUGH JULY. ADDITIONAL RAINFALL OVER THE NEXT SEVERAL WEEKS WOULD CAUSE GREAT CONCERN FOR PERSONS THAT ARE EFFECTED BY RIVER CONDITIONS WITHIN THE UPPER MIDWEST."

The summer flood on the Mississippi River resulted primarily from multiple periods of heavy, widespread rains over wet soils. The heavy rains predominated over Minnesota, and Wisconsin in June, and were followed by very heavy rains over Iowa, and the Missouri River basin in July. Timing of the heavy rains had the effect of increasing the crest as it moved downstream, as shown on Figure 2. The timing of the rains acted to delay the crests (which were also delayed due to the overtopping of upstream levees, and the filling of the valley storage areas behind the levees).

The summer rainfall, averaged over the basins was unmatched in historical records. These record rainfalls had return periods estimated at greater than 200 years (Kunkel 1994). July rainfall totals ranging from 200-600 percent of normal were common over the upper midwest. The flood would have been tremendous no matter when, in time, the storms which generated it occurred. (Dyhouse 1994). However; wet antecedent conditions likely increased the severity of the flooding, due to minimal available storage, and very low percolation rates.

The summer 1993 flood was much greater than the spring, 1993 flood (Table 1). Record crests occurred from Davenport to near the confluence of the Mississippi and Ohio rivers. Features that made this flood unique included: the record high levels, the large areal extent of the flood, the long duration of flooding, and the season of the year (National Weather Service 1993). An early report indicates that at 42 United States Geological Survey streamflow-gaging stations, the peak discharge was greater than the previous known discharge (for stations within the Mississippi River basin above the confluence with the Ohio River (Parrett, et al., 1993). Crest stages exceeded previous record stages for many rivers. Three of the largest rivers; Missouri, Iowa, and Des Moines, had numerous locations where new record high stages were established in the summer 1993 flood. The characteristics of this flood will be studied for many years.

3. Complexity of Hydrologic Forecasting

Modeling and forecasting river conditions in the upper midwest is a very difficult task. The glaciers left the upper midwest with very diverse soil characteristics. The extremely cold temperatures that occur over this area can allow for deep freezing of the soils, particularly when the snow cover is shallow. Determining the depth and nature of the frost and its effect on percolation and runoff is very complex.

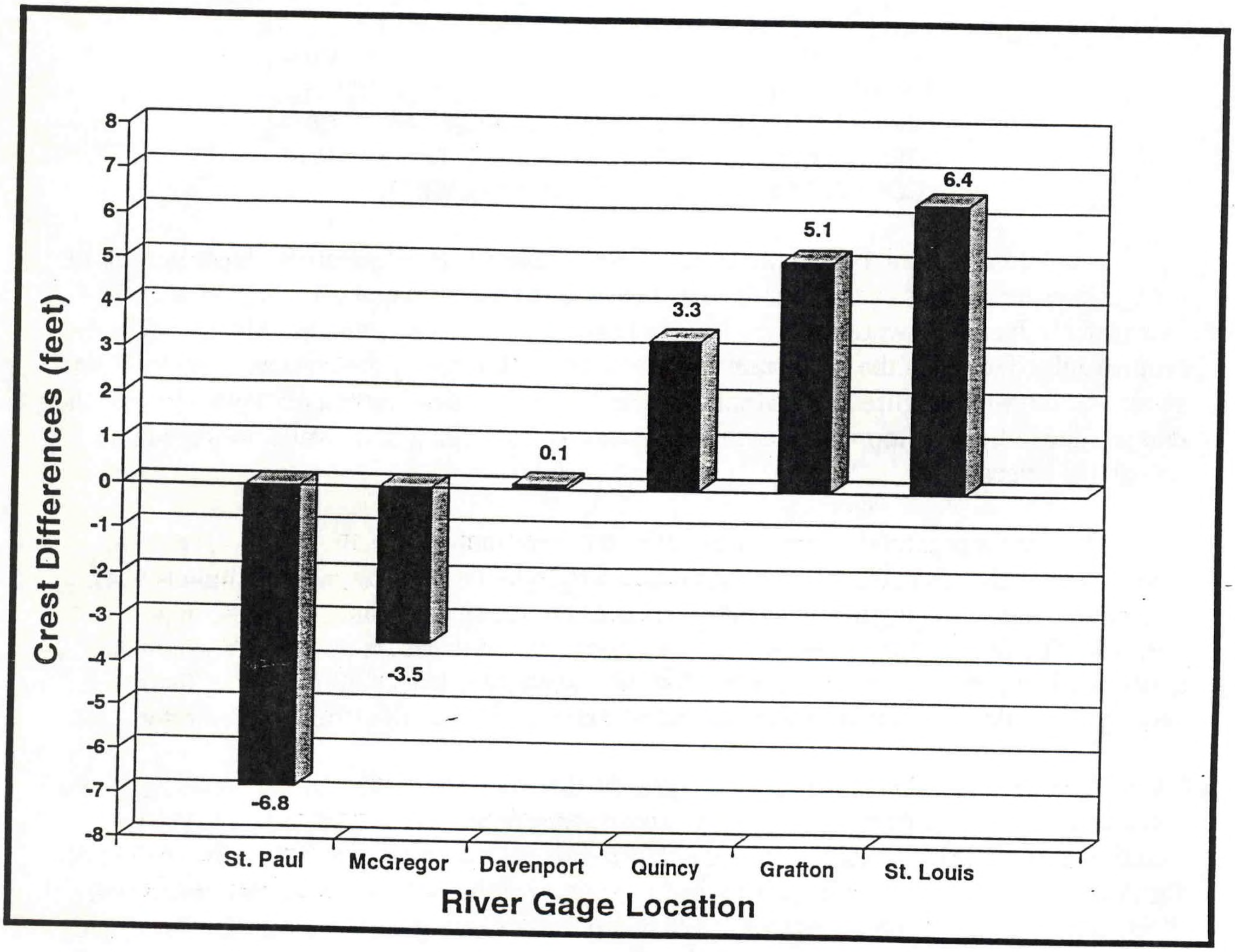

Figure 2.

CREST DIFFERENCES BETWEEN THE 1993 SUMMER CRESTS AND THE OLD RECORD CREST STAGES.

The old record stages for St. Paul and McGregor occurred in 1965 (and they were not exceeded in 1993). The old record date for Davenport was 1965 (and it was exceeded by 0.1 of a foot in 1993). The old record stages for Quincy, Grafton and St. Louis occurred in 1973 (and they were exceeded in 1993).

There are many other factors that make modeling, and forecasting river conditions difficult. Ice and snow can temporarily block snowmelt runoff in low areas, ditches, and small streams. Then, when the next warm spell or rain occurs, streams and rivers can rise quickly as the ice blockages give way due to warming and increased runoff. This condition was observed in March of 1982, during an areal snow survey over the Minnesota River basin (with less than 50 percent of the land still covered by snow and ice) (Neuman, 1982). This condition discussed above is especially prevalent in river basins with flat terrain, where runoff and small streams typically flow slowly due to less gradient.

Dangerous ice jams can develop, especially near river bends, at locations where river slopes decrease, near the mouths of tributaries, downstream of dams or power plants (that produce open water, where frazil ice can develop), and upstream of bridges or flow obstructions. Accurate modeling of the development, crest, and breakup of river ice jams is not possible. River forecasters monitor ice conditions and alert users to the dangers associated with ice, but actual crest predictions due to ice jams is very difficult to make with confidence.

Alternating periods of freezing and thawing, drifting snow, and many other factors make accurate modelling of snowmelt and runoff very challenging, but also frustrating at times.

Backwater effects, diversions (natural, and man-made), over-topping of levees, rating shifts; and limited, sometimes untimely, and sometimes unreliable data, all add to the forecast difficulty. In addition, future weather conditions cannot be predicted with great precision, and quantified; especially for the longer term.

A model has been developed to simulate the effects of the occasional freezing of soils on percolation and runoff (Anderson and Neuman 1984). The model is limited in that the effect of snow density on frost penetration is not directly modelled. Thus, the model would need updating based on observed frost data. This model for simulating frozen ground was tested using operational data from the fall of 1981 to the spring of 1982 period, for the Minnesota River basin (Neuman 1983). However, there was not much frost during that period due to an early snow cover. Frost data is available beginning in 1961 for Wisconsin (Spencer, et al., 1978), but the data is not in an easy to use quantifiable form for input to computers. The NCRFC is evaluating plans to calibrate all of the basins within the NCRFC area using this model. More testing of the model is needed.

4. Present Spring Snowmelt Flood Potential Methodology.

Outlooks are based on an accounting of the existing conditions (snow cover, soil conditions, and streamflow), along with assumptions or methods to handle future weather conditions. Present procedures assume normal additional precipitation and snowmelt rates for the future period. Outlooks are usually issued during late February and March. Weather conditions can change rapidly during this period of the year. An early melt can occur, which would act to reduce the flood potential. March is typically the heaviest snowfall month in the upper midwest. During years when the snow exists into late March, the flood potential increases. The increased flood potential is due to the greater likelihood of a rapid melt; with longer days, continuous warmth, and a greater possibility of heavy rain during the snowmelt runoff period.

The crest stage values that are provided in the outlooks are to be used as an indication of the potential for flooding, only; and are not specific predictions or crest forecasts. An increase in the potential should be expected if above normal precipitation and/or a rapid melt develops. Likewise, a decrease in the potential should be expected if below normal precipitation, and/or a gradual or intermittent melt occurs. With present procedures, potential crest values are only provided when there is a significant snow cover.

5. Verification of Present Spring Snowmelt Flood Potential Values

Verification is done on a year to year basis. In addition, a study was done using 1980-1987 data (Neuman 1988). The study showed an average absolute difference between potential crest values and observed crest values of 2.0 feet (Mississippi River), and 3.1 feet (Red River of the North).

6. Three-day Stage Forecasts and Crest Forecasts

As snowmelt runoff develops, specific 3-day stage forecasts will be issued as needed. Then, after enough information on observed snowmelt, rainfall, and river data becomes available, crest forecasts will be issued and updated on a daily basis. Until that time, users are asked to refer to the latest potential statement and potential crest values, for crest guidance. As in previous years, for the snowmelt period of 1994, 3-day stage and crest forecasts will not include any future precipitation. A short-term temperature forecast will be applied to generate at least 3-day forecast melt values for input to the daily operational model.

7. Future Spring Flood Outlook Procedures

Changing the methodology for issuing spring flood outlooks has been considered (Neuman and Braatz, 1985). Application of a statistical procedure to produce numerical spring crest guidance will take place over the next several years. The procedure is called the Extended Streamflow Prediction (ESP) program (Day and VanBlargan, 1983).

The NCRFC will create mean areal precipitation and temperature time series for nearly 750 sub-basins, using historical climatological data from the 1948-1988 period (which will need to be updated for recent flood years). These time series are then input to ESP along with the existing conditions (snow cover water equivalent, soil condition, and streamflows; from the NCRFCs daily operational model). Conditional streamflow traces will be generated for each forecast point. The traces will be analyzed statistically, resulting in probabilistic output. The output will then be used to provide the spring flood outlooks.

The products will be called Spring Flood Outlooks, rather than Spring Snowmelt Flood Outlooks; because it will not be possible to clearly separate snowmelt related crests from those due mainly to historical heavy rain conditions using the ESP methodology.

ESP does not automatically account for the effect of a widespread deep snow cover on future temperature expectations. Some years used in the computations would probably have to be thrown out of the analysis if those years were deemed inappropriate for use with the existing snow cover conditions.

8. Concluding Remarks

Neither methodology is designed to incorporate the National Weather Service's 30-day outlook for precipitation and temperatures. Finally, the increased stages that may occur due to ice effects are not incorporated in either methodology.

9. Terminology Used in this Report.

Snowmelt Flooding:	Flooding resulting from snowmelt and the rainfall that occurs during the snowmelt runoff period.
Crest:	The highest stage or level of a flood wave as it passes a point.
Upper Mississippi River:	Includes the portion of the River from the headwaters in Minnesota to the confluence of the Mississippi and Illinois rivers at Grafton, Illinois.
Evapotranspiration:	The total water loss from the soil, including that by direct evaporation and that by transpiration from plants.
Rating Shift:	A Change in the relationship between stage and flow for a particular gage location.
Frazil Ice:	Tiny crystals of ice formed in supercooled turbulent waters.

10. Acknowledgements

Figures 1 and 2 were prepared by Mike Anderson, Hydrologist, North Central River Forecast Center.

11. References

Anderson, E.A., and Neuman, P.J., 1984: Inclusion of frozen ground effects in a flood forecasting model. Proceedings of The Northern Research Basins Symposium, The role of snow and ice in northern basin hydrology, Vierumaki Finland, 14pp.

Baker, D.G., 1971: Snow cover and winter soil temperatures at St. Paul, Minnesota. Water Resources Research Center, University of Minnesota, Minneapolis, Minnesota. 24pp

Bruce, M.A., 1993: National Weather Service Central Region Memorandum dated September 5, 1993, Upper Mississippi River Valley Association Meeting.

Day, G.N. and VanBlargan, E.J., 1983: The use of hydrometeorological data in the NWS extended streamflow prediction program. Preprints, Fifth Conference on Hydrometeorology, AMS, 17-19 October, 1983, Tulsa, Oklahoma.

Dyhouse, G.R., 1994: Hydrologic Effects of the 1993 Flood--Myths and Misconceptions. Preprints, Symposium on The Great Flood of 1993, AMS, 23-28 January, Nashville, TN.

Johnson, P.E., 1966: Report on Mississippi and Rum River 1965 Record High Water Conditions in the City of Anoka Area and Information for Future Predictions, Action and Community Service. City of Anoka, Minnesota

Kunkel, S.A., 1994: Climatic Perspective on the 1993 Upper Mississippi River Basin Flood. Preprint, Symposium on The Great Flood of 1993, AMS, 23-28 January, Nashville, TN.

National Weather Service, 1993: The National Weather Service's Role During the 1993 Midwest Flooding. NOAA, National Weather Service, July 17, 1993. Hydrology 7/16/93.

Neuman, P.J.,and Braatz, D.T., 1985: Future Spring Flood Outlook Procedures. NOAA, National Weather Service, Central Region Technical Attachment 85-3. Kansas City, Missouri.

Neuman, P.J., 1983: The Use of the National Weather Service River Forecast System for Modeling Frozen Ground in the Minnesota Basin. Preprints, Fifth Conference on Hydrometeorology, AMS, 17-19 October, Tulsa, Oklahoma.

Neuman, P.J., 1982: NCRFC files: Aerial gamma flight over the Minnesota basin 3/1/82.

Neuman, P.J., 1988: Snowmelt Outlook Verification. NOAA, National Weather Service, Central Region Technical Attachment 88-40, Kansas City, Missouri.

Parrett, C., Melcher, N. B. and James, Jr., R. W., 1993: Flood discharges in the Upper Mississippi River Basin, 1993. U. S. Geological Survey Circular 1120-A. 14pp.

Paulhus, J.L.H., and Nelson, E.R., 1967: The March-May 1965 Floods in the Upper Mississippi, Missouri, and Red River of the North Basins. ESSA Technical Report WB-4, Weather Bureau, Office of Hydrology, Silver Spring, Maryland, 100pp.

Paulhus, J.H., 1971: The March-April 1969 Snowmelt Floods in the Red River of the North, Upper Mississippi, and Missouri Basins. NOAA Technical Report NWS 13, National Weather Service, Office of Hydrology, Silver Spring, Maryland, 92pp.

Reichelderfer, F.W., 1954: Floods of 1952 Upper Mississippi/Missouri-Red River of the North, Technical Paper No 23, Weather Bureau, Hydrologic Services Division, 93pp.

Spencer,C.D., Davies, J.R., and Heiser, M.R., 1978: Snow and Frost in Wisconsin 1961-1977. Wisconsin Agriculture Reporting Service, Madison, Wisconsin, 38pp.