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COMPENDIUMS OF INFORMATION FOR THE MISSOURI BASIN RIVER FORECAST CENTER AND THE NORTH CENTRAL RIVER FORECAST CENTER

National Weather Service Central Region
Scientific Services Division
Kansas City, Missouri

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FOREWORD

Contained herein are the combined compendiums of both Missouri Basin and North Central River Forecast Centers. Since each compendium was written independently, there may be some natural differences of writing style and content between each document. However, both compendiums should provide the reader with a fairly complete and accurate picture of the operational river forecast program in the Central Region.

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A COMPENDIUM OF INFORMATION
MISSOURI BASIN RIVER FORECAST CENTER

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1. INTRODUCTION

A. Background

The National Weather Service (NWS) has the hydrologic forecasting responsibility for the nation. The mission of the NWS Hydrologic Service Program is to save lives, reduce property damage, and contribute to the maximum use of the nation's water resources. The scope is large; current annual flood losses are estimated at approximately 200 deaths and $2 billion in property damage.

The NWS meets its hydrologic responsibilities through the efforts of the thirteen River Forecast Centers (RFC's) located throughout the United States. The River Forecast Center, a first echelon office in the hydrologic forecast organization analogous to the National Meteorological Center (NMC) with respect to weather forecasts, initiates and is responsible for all flash flood guidance and nearly all river forecasts, streamflow, and water supply volume forecasts. Each RFC provides hydrologic guidance and expertise to a network of both National Weather Service Forecast Offices (WSFO's) and National Weather Service Offices (WSO's) located within each RFC's area of hydrologic responsibility. Products generated by the RFC's include flood forecasts, general river forecasts uses for navigation, reservoir inflow forecasts, water supply outlooks, spring flood outlooks and various types of flash flood guidance.

In addition, RFC's provide a variety of other services; they develop forecast procedures as required and requested, develop and implement new forecast techniques, computer systems, data handling techniques, and hydrologic-related hardware. Also, the RFC's provide hydrologic expertise on a wide range of hydrologic activities such as dambreak analysis for NWS and other federal, state, and local agencies.

The NWS has a total field hydrologic staff of approximately 125 hydrologists. The hydrologists at the RFC's analyze and process a wide range of hydrologic data and prepare river, flood, and reservoir forecasts as well as hydrologic outlooks for public distribution. The forecast procedures are based on historical data and account for current hydrologic, hydraulic, and meteorologic factors. The RFC's generate hydrologic forecasts for approximately 1,600 forecast points nationwide and rely on data from a network of 1,800 river gages and approximately 10,000 rainfall stations which represent a large portion of the supporting ground data collection network.

River forecasting provides a good non-structural means of reducing flood damage and loss of life. Its advance warning of an approaching flood permits evacuation of people, livestock, and property. River and flood forecasts are primarily concerned with predicting the time and height of flood crests. Flood crests can be predicted because there is a natural time delay (or lag) between rainfall or snowmelt and the resulting rise of the river.

B. Office Description

The Missouri Basin River Forecast Center was established in October of 1946. MBRFC provides a variety of hydrologic services in an area which includes the entire Missouri River drainage and the Saint Mary Basin in Montana (which is an international treaty stream with Canada) encompassing a 530,000 square-mile area. Containing a population of over 9 million, the area has a critical high damage potential, and encompasses some or all of 10 states and parts of southern Canada.

Meteorological features of the region vary greatly, experiencing temperature regimes ranging from 121 degrees above to 66 degrees below zero, an average annual rainfall varying from 6 to 50 inches, and an average snowfall depth ranging from 20 to 200 inches. Streamflow characteristics also vary greatly, with the rapidly falling creeks and rivers of the mountains and Northern Plains in the upper reaches to the flat valley floors and sluggish streams in the lower reaches of the Missouri Basin.

Floods may occur at any time of the year, but are more frequent in the spring on most of the large rivers because of snowmelt, ice jams, high soil moisture and widespread rainstorms. On the smaller streams, the most severe floods, flash floods, generally result from summer thunderstorms of the cloudburst type. The MBRFC, through the public dissemination of flood warnings in the upper Midwest for a growing number of locations, currently enables protection of life and property providing dollar savings which total millions each year.

There are nine Weather Service Offices whose responsibility it is to issue forecasts from guidance received from the Missouri Basin River Forecast Center. The average annual forecast products issued by these offices number near 100,000. They collect an average of 350,000 rainfall, river, temperature, and snow reports annually from 1,280 rainfall and 560 river stations.

Presently, 745 runoff zones are used to forecast 440 river and reservoir locations. The total number of points requiring forecasts by hydrologic service area are:

Bismarck, North Dakota - WSFO	14
Cheyenne, Wyoming - WSFO	20
Denver, Colorado - WSFO	36
Des Moines, Iowa - WSFO	33
Great Falls, Montana - WSFO	59
Omaha, Nebraska - WSFO	102
St. Louis, Missouri - WSFO	69
Sioux Falls, South Dakota - WSFO	41
Topeka, Kansas - WSFO	102

This is a total of 476 points which includes 36 water supply forecasts. Sometimes special requests are made by the WSFO for locations that are not a regular forecast point. In addition to the NWS offices, the MBRFC coordinates and provides forecasts to government agencies. These agencies include the division and district offices of the U.S. Army Corps of Engineers, the Soil Conservation Service, the Bureau of Reclamation, and the U.S. Geological Survey.

Certain forecast deadlines must be met by MBRFC so that appropriate action might be taken by our own WSFO's, other government agencies and the news media. Timely and accurate forecasts save lives and property. Accuracy is important so that protective measures and evacuations may be taken. The return to normal operations after the flood water recedes is also an important phase of forecasting to recover the use of property at the earliest possible time. Even in non-flood periods, the efficient operation of water control structures, riverside interests, and navigation depends on timely and accurate forecasts.

2. OPERATIONS

A. Data

(1) Introduction

The history of weather observations in the Missouri Basin has been one of evolution beginning with reports of trappers and explorers, followed by systematic observations at sparsely located military outposts culminating in the present system.

The National Weather Service collects hydrologic data from many sources, the backbone of which is still the paid or cooperative observers, some of who may report daily and some on a criteria basis. Other sources include the U.S. Army Corps of Engineers, Bureau of Reclamation and U.S. Geological Survey as well as city, county, and state networks. More and more data are being collected by automated gages such as BDT's, telemarks, ASOS, ALERT, and satellite gages. The need for data around the clock and from remote areas requires more data to be automated.

(2) Data Collection

The majority of hydrologic data (river states, precipitation, temperature, snow depth, and water content) are collected by Weather Service Offices and Weather Service Forecast Offices. The data is collected and reviewed at the WSFO, which is also designated as Hydrologic Service Area (HSA), and transmitted to the River Forecast Center in Standard Hydrologic Exchange Format (SHEF).

(3) Airborne Gamma Radiation Snow Survey Program

Ground snow cover data are used by hydrologists at the MBRFC to access the impact of winter snow cover on spring flood potential. Ground snow cover data are difficult, time-consuming, and in some cases, hazardous to collect. Additionally, ground snow data may be significantly in error. Ice lenses within the snow pack and at the ground-snow interface can contribute substantial error to the measurement. Redistribution of snow cover into drifts and blown-clear areas makes the selection of a representative sampling site virtually impossible.

In an effort to provide more useful snow water equivalent data, the NWS Office of Hydrology began research and development in 1969 on a technique using natural terrestrial gamma radiation to measure mean areal snow water equivalent from a low-flying aircraft. The early research led to the implementation of an operational Airborne Gamma Radiation Snow Survey Program located in Minneapolis, Minnesota.

In wintertime, getting much needed snow depths and water equivalents for snowmelt forecasts is difficult at best. Airborne Gamma Radiation Snow Surveys supplement ground data collected by cooperative observers.

There are 203 flight lines in the MBRFC area of responsibility.

(4) Satellite Hydrology Program

Snow cover maps are derived from satellite imagery. These maps provide forecasters with information on snow pack location, elevation, and extent. Currently, snowmapping operations utilize real-time full resolution 1 km GOES data on the interactive Centralized Storm Information System (CSIS) at the National Severe Storms Forecast Center in Kansas City, Missouri. The CSIS digital snow cover mapping technique is based on the fact that snowcover increases the brightness of a land area.

There are 43 snowcover mapping basins in the MBRFC area of responsibility.

The incorporation of airborne snow cover measurements and snow cover maps into the continuous conceptual snow model provides the mechanism for continued improvements in the hydrologic forecasting services provided by the MBRFC to the public.

(5) Quantitative Precipitation Forecast and Contingency Forecasts

Quantitative Precipitation Forecasts (QPF) are currently produced by the National Meteorological Center (NMC) in Camp Springs, Maryland. The products cover the entire United States, but are limited in detail for RFC operations. The MBRFC disseminates stage forecasts derived from QPF and contingency river forecasts that are based on increments of potential precipitation. Contingency river forecasts will answer a HSA's or a RFC's "what if?" request if a storm is impending. Either the HSA or the RFC can make the initial call to request QPF data.

B. Flood Forecasting

(1) Introduction

The RFC decodes the data, reviews it for quality control, and proceeds to process the data to determine: runoff from rainfall from stage, and snowmelt from temperature to make a stage and/or flow forecast.

After the precipitation has been tabulated, the mean areal distribution is determined for all areas of concern. Manually, the average precipitation can be obtained by an arithmetical average, Theisen Polygon, and by drawing isohyetals. Although the process is always calculated by machine, occasionally, a manual manipulation is better because the precipitation occurred in a narrow band or was concentrated up or down stream within the basin.

At MBRFC, the API method of soil moisture accounting is used. Observed river stages and flows are used to adjust the initial API values. Having only one parameter makes it easy to adjust excessive rainfall runoff. Unit hydrographs are used to convert excessive rainfall runoff to flow and time. The unit hydrographs were developed empirically and synthetically. Synthetic unit hydrographs are generally developed using the Soil Conservation Service (SCS) method. The SCS method requires a minimum of data, namely, length of storm, slope, size of drainage area, and the desired duration of time. The flows generated from unit graphs are then routed downstream using one of two methods i.e., K and L or Tatum routings.

(2) Forecast Problems

The accuracy and timeliness of the river forecasts, especially for floods, are of the utmost importance to the safety of lives and property throughout this widespread Midwest region. Evacuation of people, livestock, and goods and protective measures for fixed installations, can be accomplished only if sufficient warning time is available. If accuracy is not maintained, warnings may not be given, or protective measures and evacuations may be taken when not required. Organized plans of action would then bog down because of lack of confidence in the forecasts. The decisions to issue flood warnings and stage forecasts actually prepared and disseminated under MBRFC responsibility are the initial or "trigger" actions that start numerous and costly operations to prevent loss of life and damage to property. The return to normal operations after the flood waters recede is also an important phase of forecasting calculated to ease suffering, reduce further loss of business and to recover use of property at the earliest possible time. Even in non-flood periods, efficient operation of water control structures, riverside industry, and navigation depends on the accurate and timely forecasts of changes in river stages, and thus has considerable economic impact.

Forecasting is complicated by wide variations in runoff characteristics among tributaries; by artificial controls from numerous locks and dams; by the rapid expansion of irrigation, transmountain diversions, improved land-use practices, shifting channels, flood control structures and releases for navigation, energy, municipal water supply and environmental pollution abatement.

Ice jams are a real problem to winter and spring forecasting. At the present, there is no quantitative means of forecasting the forming or breaking up of ice jams. "Rules-of-thumb," "seat-of-the-pants," and experience are the only tools for forecasting these jams and their movement.

Another major problem in the MBRFC area is in the ever-shifting ratings of many of the rivers. This is particularly true of the Missouri River from Sioux City to the mouth. Cold water is more viscous than warm, hence cold water has a tendency to dig and carry more solids than warm water. Therefore, the same flow may experience different stage readings depending on the stage-discharge relationship at that time.

(3) Forecast Products

Many and varied forecasts are issued by this office. The most common guidance is the crest forecasts; however, three-day forecasts are issued daily for the Missouri River mainstem. Seven-day forecasts are released daily for Kansas City and Hermann, Missouri. Long-range forecasts (30 days) are issued for the mainstem each Wednesday. Water supply forecasts are coordinated with the SCS, Portland, Oregon office and issued monthly January through May and/or June. Each February and March, Spring Snowmelt Outlooks are made for those areas with historical and potential snow problems. In addition to daily, monthly, and seasonal forecasts, MBRFC (upon request or due to certain criteria) makes reservoir inflow forecasts. Also, upon request, MBRFC will make contingency forecasts based upon forecasted rainfall. Lastly, this office issues zonal flash flood and headwater guidance daily for meteorological forecast zones. Flash flood and headwater guidance for specific locations is issued twice a week and more often if meteorological conditions dictate.

(4) Dissemination

All forecasts and guidance are issued to National Weather Service Offices in MBRFC area of responsibility, to other RFC's, certain Corps of Engineers Offices, Bureau of Reclamation and Soil Conservation Offices when applicable. This office has a policy not to deal with public or private parties.

C. Flash Flood

Local flash flood warning systems may be totally automated or manually operated. The automated systems are made up of remote automatic reporting rainfall, stream gages, and a computer which is located in a 24-hourly manned office. When rainfall or stream height reaches a predetermined value, a warning device sends a signal to commence activity. The manual alert systems require that a predetermined value of rainfall causes someone to take action based on a guidance value supplied by MBRFC. The difference being, in one system, the gages are event reporting while the other relies upon people to report a value after the event, usually at a set time of day. At best, the manual system may be initiated by a radar report or an observer who calls in a rainfall report.

The devastation that occurs as impounded reservoir water escapes through the breach of a failed dam and rushes downstream is quick and deadly. This potential for disastrous flash flooding poses a grave threat to many communities located downstream of dams. Indeed, a report by the U.S. Army (1975) indicates 20,000 dams in the United States are "so located that failure of the dam could result in loss of human life and appreciable property damage..." This report, as well as the tragic destruction resulting from the failures of the Buffalo Creek coal-waste dam, the Toccoa Dam, the Teton Dam, and the Laurel Run Dam, underscores the real need for accurate and prompt forecasting of dambreak flooding.

Advising the public of downstream flooding during a dam failure emergency is the responsibility of the National Weather Service (NWS).

There are currently 200 flash flood and headwater points in the MBRFC area of responsibility.

D. Spring Outlook

Early each spring, four spring outlooks are issued by this office. These outlooks discuss in qualitative and/or quantitative terms, the potential for spring snowmelt flooding. Ground snow data, flight line and satellite snow information as well as existing ground and river conditions are all taken into consideration.

Snowmelt outlooks are produced using two major scenarios: (1) melt based on future probable temperatures and "normal" future precipitation for the season; and (2) melt based on future probable temperatures and no additional precipitation (rain or snow).

In addition to these four statements, unscheduled advisories and/or forecasts are issued as hydro-meteorologic conditions warrant.

There are currently 305 potential spring outlook points in the MBRFC area of responsibility.

E. Water Supply

Presently, water supply forecasting is a multi-step process. This process should be completed during the first five working days of each month, year-round. The calendar year is split into two seasons, the forecast season (generally January through May) and the non-forecast season (generally June through December).

MBRFC provides water supply guidance for the Upper Missouri River Basin. Each month, a variety of products are issued by MBRFC. The end result of this effort is a joint monthly publication by the SCS and NWS entitled "Water Supply Outlook for the Western United States."

Water supply flow volume forecasts issued in terms of annual and seasonal runoff are used in the long range planning of water users for the operation of multi-purpose reservoirs to accomplish optimum flood control and to minimize wasting of valuable water resources. The initial water supply forecasts are issued in early January to permit an early outlook for planning the planting of irrigated crops, the possible rationing of a short water supply for both agricultural and municipal users, for establishing the length of the navigation season on the Missouri and for the early release of upstream reservoir water to gain increased capacities for the reduction of anticipated flood crests.

3. FORECAST MODELS

A. Forecast Tools

Techniques based on hydrologic and hydraulic principles and statistical methods used to develop objective procedures include:

(1) Rainfall-runoff relations involving the daily evaluation of the index of soil moisture conditions as influenced by the amount of antecedent precipitation, the time of occurrence of precipitation in relation to the present, the variable vegetative seasonal demands (or interception and transpiration), the deviation from normal of the climatological influence on the vegetative cycle, evaporation and basin geology.

(2) Snowmelt runoff relations involving the evaluation of basin-wide water content of snow from antecedent precipitation and/or snow survey data; evaluation of the rate of melting by applying the physics of snow and heat transfer to meteorological observations; and consideration of the modifying effect of forest cover.

(3) Application of the unit hydrograph principles to each unit sub-area of the drainage basin based on storm morphology and physiographic features of the sub-area.

(4) Flood routing based on principles of river hydraulics, advanced dynamic routing techniques for streamflow and backwater effects, sediment transport theory, and an understanding of engineering aspects of reservoir operations.

(5) Backwater relations involving consideration of the slope in the stream profile produced by valley storage, a downstream tributary, or a large river at the confluence.

(6) Low flow forecasting affected primarily by ground water geology and hydrology, but influenced by hydroelectric and navigation dam operations.

(7) Water supply forecasting based on double mass analysis and multiple correlation of precipitation and runoff regimes affected by climatic trends, sampling techniques and water utilization.

Much reliance is placed on familiarity with the current technical literature. A large amount of effort involves adaptation of general techniques, experimentation with known techniques and their modification to suit the peculiarities of a particular watershed. Techniques and ideas are frequently discussed with other River Forecast Centers and other engineers and scientists of the Hydrologic Research Laboratory (HRL) of the National Weather Service Office of Hydrology (OH).

B. Models

Three computer models simulate the hydrologic cycle for each runoff zone. At least once a day, these continuous models use precipitation, temperature, and river or reservoir elevations as input.

(1) The Snow Model

Primary input to the snow model is precipitation and temperature. The purpose of this model is to simulate the water content of the snow pack for each sub-basin. The model is calibrated using reported snow depth and water equivalent values from a network of individual observers (who take core samples for snow depth and melt them to determine water content).

In the model, air temperature data determines whether the reported precipitation is treated as rain or snow. As air temperatures change, the condition of the snow (ripeness) is simulated using heat storage equations. The model uses forecasted "future temperatures" to forecast melt and runoff from the snow pack.

(2) The Soil Moisture Model

Input for the soil moisture model is rain plus melt from the snow model. This model is continuous, as it simulates soil conditions on a daily basis. An accounting of precipitation and melt is kept by the model. Adjustments for evaporation and transpiration are made using seasonal indices and the percent of water "lost" to percolation is calculated using a recession coefficient tailored for the basin. Runoff simulated depends on the state of the soil, the season of the year, the storm's duration, and the amount of rainfall or snowmelt. Each runoff zone is fitted with a runoff-rainfall relationship which accounts for various soil types, vegetation, and climatic conditions. The model is flexible enough to make adjustments as physical response is determined.

(3) The Flow Model

Output from the soil moisture model is runoff, which becomes input for the flow model. Runoff is converted into a volume of flow in cubic feet per second. From this simulation, the result is a graphical display called a hydrograph. The hydrograph is a plot of patterns of flow due to runoff (volume increase and decrease in a period of time) at a given point along the river. The relationship between flow and stage (or elevation of the water surface) is called a rating and is normally a relatively constant one.

The flow model also routes the flow (or flood wave) downstream. This routed flow is combined with the local simulated hydrograph at a downstream point to determine the overall pattern of river stage through time, at that point.

(4) Water Supply Forecast Model

Water supply forecasts for each basin are generated through use of multiple regression equations. Each forecast point possesses a unique family of regression equations. Station weights, seasonal weights, and snow index weights are determined by statistical analysis of historical data.

Most of the forecasts are generated by computer programs which utilize observed precipitation, snow water equivalents, flow data, and SCS forecast flows as input. Missing data is estimated.

(5) Dambreak Model

To aid in forecasting the inundation resulting from dam failures, the numerical NWS Dam-Break Flood Forecasting Model (DAMBRK) was developed to model the outflow hydrograph produced by a time-dependent, partial dam breach, and route this hydrograph downstream using the complete one-dimensional unsteady flow equations while accounting for the effects of downstream dams, bridges, and off-channel storage.

Although MBRFC uses this program in advance of a dambreak, in some situations, the real-time use of the DAMBRK model may be precluded because warning-response time is extremely short or adequate computing facilities are not available. As a general rule, the crest produced by a dambreak will be one-half of the height of the dam immediately below the dam. The crest will attenuate by one-half for each additional ten miles downstream and the flood wave will travel at about three to four miles per hour.

4. PHYSICAL DESCRIPTION

A. Missouri River Basin

(1) Basic Geography

The Missouri River, from its beginning at the confluence of the Gallatin, Madison, and Jefferson Rivers in Montana, to its confluence with the Mississippi River above St. Louis, Missouri, drains all or parts of ten states, while flowing over a course 2,460 miles long (1941 adjustment). The total drainage area of the basin is 529,350 square miles, which is more than 42 percent of the total area drained by the Mississippi River and one-seventh of the total area of the United States. The Rocky Mountains, with elevations ranging to over 14,000 feet above sea level, form the western boundary of the Missouri Basin and ranges of these mountains extend into the basin for considerable distances. Except for the semi-mountainous Black Hills in South Dakota and the Ozark uplift in southern Missouri, all of the basin to the east of the Rocky Mountains may be regarded as plains country. For the most part, these high plains range from 2,000 feet above sea level at their eastern margin to 4,000-6,000 feet where they give way to the steep eastern slopes of the Rocky Mountains.

With a total fall of 3,630 feet, the slope of the Missouri River averages 1.5 feet per mile, ranging from 4.3 feet per mile for the reach from Three Forks (head of the river) to above the falls at Great Falls, 3.7 feet per mile from below the falls to Zortman (near the head of Fort Peck Reservoir), 1.1 feet per mile from Zortman to the Yellowstone River, and an average of 0.9 foot from the Yellowstone River to the mouth (with variations to as low as 0.2 foot per mile in local reaches). Outstanding among the tributaries are the Yellowstone River which drains an area of over 70,000 square miles and joins the Missouri River near the Montana-North Dakota boundary, the Platte River with a 90,000 square mile drainage area which enters the Missouri in eastern Nebraska, and the Kansas River which empties into the main stem in eastern Kansas and drains an area of about 60,000 square miles. The most prominent feature of the drainage pattern of the upper and middle portions of the Basin is that every major tributary, with the exception of the Milk River, is a right bank tributary flowing to the east or to the northeast. Only in the extreme lower basin, below the mouth of the Kansas River, is a fair balance reached between left and right bank tributaries. The direction of flow of the major tributaries is of particular importance from the standpoint of potential concentration of flows from storms that typically move in an easterly direction.

(2) Climate

Wide ranges in temperature and irregular annual and seasonal precipitation characterize the climate of the Missouri Basin. The extremes in temperature are caused by alternating cold air masses moving in from the northwest and warm air masses moving in from the Gulf of Mexico. All areas, except the mountains, have experienced temperatures over 100°F to below zero.

Wind directions tend to be from the south and southwest in summer and from the north and northwest during the winter. Maximum wind velocities range from 45 to 120 miles per hour. The Great Plains generally record the higher velocities. High winds with high temperatures increase evaporation, damage crops, and cause dust storms. The winter high winds and low temperatures cause blowing snow and blizzards.

The amount of annual precipitation, its form, and seasonal variation are related to the topography of the area. The highest amounts of precipitation fall over the Rocky Mountains and the Ozarks. Precipitation ranges from over 40 inches annually of measurable water equivalent. One hundred inches of snowfall is common throughout the Rockies. Average annual precipitation on the Great Plains varies from under 12 inches to slightly over 20 inches. Generally, the southeastern portions report the larger amounts with decreasing amounts occurring to the northwest.

The lowlands of eastern South Dakota, Nebraska, and Kansas, and western Iowa and Missouri generally receive 20 to 40 inches of precipitation annually. The yearly precipitation in the northern portion of this area is divided between summer rains and winter snow, while the southern portion's annual precipitation is almost entirely rainfall which occurs throughout the year.

Floods in the Rockies are generally flash floods occurring in the warm season, especially on the smaller streams. The larger streams flood mainly when rain falls on melting snow. Flood flows elsewhere are usually due to thunderstorms passing over the area. Ice jams play an important role in all but the extreme southeastern portion of the Missouri River Basin.

(3) Major Tributaries

The following table summarizes the major tributary rivers to the Missouri River having drainage areas larger than 6,000 square miles. Also included are the last river stations with elevation above which the drainage areas are computed.

Major Missouri River Tributaries With Drainage Areas Above 6,000 Square Miles at the Specified River Station

Tributary	River Station	Elevation Ft.m.s.l.	Drainage Area Sq. M.
1. Jefferson River	Sappington, MT	4,170	9,277
2. Milk River	Nashua, MT	2,028	22,332
3. Powder River	Locute, MT	2,385	13,194
4. Yellowstone River	Sidney, MT	1,881	69,103
5. Little Missouri River	Watford, ND	1,929	8,310
6. Cheyenne River	Eagle Butte, SD	1,440	24,500
7. James River	Scotland, SD	1,169	21,500
8. Missouri River	Sioux City, IA	1,057	314,600
9. Big Sioux River	Sioux City, IA	993	9,810
10. Niobrara River	Verdel, NE	1,308	12,600
11. North Platte River	Sutherland, NE	2,792	34,900
12. South Platte River	Paxton, NE	2,788	24,300
13. Loup River	Columbus, NE	1,428	15,200
14. Elkhorn River	Waterloo, NE	1,107	6,900
15. Platte River	Louisville, NE	1,007	85,800
16. Republican River	Clay Center, KS	1,159	24,542
17. Smoky Hill River	Enterprise, KS	1,103	19,261
18. Big Blue River	Manhattan, KS	992	9,640
19. Kansas River	Kansas City, KS	717	60,060
20. Missouri River	Kansas City, MO	716	489,200
21. Grand River	Brunswick, MO	616	7,883
22. Osage River	St. Thomas, MO	528	14,500
23. Missouri River	St. Charles, MO	414	529,190

B. St. Mary Basin

The St. Mary River, located in northern Montana, flows in a northerly direction towards Canada and is part of the Hudson Bay drainage. The St. Mary drainage area within the United States is approximately 465 square miles.

Climate and geography are similar to the headwaters of the Marias and Milk Rivers.

5. DAMS

There are 14,000 plus dams in the nine states that the Missouri River Basin encompasses, many of which are located outside the MBRFC area of responsibility. Of interest to this office are those dams which affect the forecast schemes. MBRFC's prime interest is flood control. However, navigation is equally important at certain times of the year. Generation of power and irrigation play a dominant role in certain locations and seasons. Of lesser importance most of the time, but highly important at other times, is the need to adjust flows to help prevent ice jams from becoming too troublesome, especially on the Missouri River.

Of the numerous dams in the MBRFC area of responsibility, approximately 70 dams are included in the forecast schemes. A partial list of dams would include:

Kansas River System

Bonny Reservoir, CO	South Fork Republican River
Swanson Reservoir, NE	Republican River
Hugh Butler Reservoir, NE	Red Willow Creek
Harry Strunk Reservoir, NE	Medicine Creek
Harlan County Reservoir, NE	Republican River
Cedar Bluff Reservoir, KS	Smoky Hill River
Kanopolis Reservoir, KS	Smoky Hill River
Wilson Reservoir, KS	Saline River
Kirwin Reservoir, KS	North Fork Solomon River
Webster Reservoir, KS	South Fork Solomon River
Glen Elder Reservoir, KS	Solomon River
Norton Reservoir, KS	Prairie Dog Creek
Lovewell Reservoir, KS	White Rock Creek
Milford Reservoir, KS	Republican River
Tuttle Creek Reservoir, KS	Big Blue River
Perry Reservoir, KS	Delaware River
Clinton Reservoir, KS	Wakarusa River
Enders Reservoir, NE	Frenchman Creek

Marais des Cygnes - Osage River System

Melvern Reservoir, KS	Marais des Cygnes River
Pomona Reservoir, KS	Hundred Ten Mile Creek
Hillsdale Reservoir, KS	Big Bull Creek
La Cygne Reservoir, KS	White Sugar Creek
Stockton Reservoir, MO	Sac River
Pomme De Terre Res., MO	Pomme De Terre River
Harry S. Truman Res., MO	Osage River
Bagnell Reservoir, MO	Osage River

Missouri Mainstem

Fort Peck Dam, MT	Missouri River
Garrison Dam, ND	Missouri River
Oahe Dam, SD	Missouri River
Big Bench Dam, SD	Missouri River
Fort Randall Dam, SD	Missouri River
Favins Point Dam, SD	Missouri River

Elkhorn-Platte River System

Cheesman Reservoir, CO	South Platte River
Chatfield Reservoir, CO	South Platte River
Bear Creek Reservoir, CO	Bear Creek
Cherry Creek Reservoir, CO	Cherry Creek
Wheatland Reservoir #2, WY	Laramie River
Grayrocks Reservoir, WY	Laramie River
Guernsey Reservoir, WY	North Platte River
Glendo Reservoir, WY	North Platte River
Kinsley Dam, NE	North Platte River
Keystone Dam, NE	North Platte River

James River System

Pipestem Dam, ND	Pipestem Creek
Jamestown Dam, ND	James River
Columbia Road Dam, SD	James River

Upper Missouri System

Tongue River Reservoir, MT	Tongue River
Ruby Dam, MT	Ruby River
Tiber Dam, MT	Marias River
Fresno Dam, MT	Milk River
Gibson Reservoir, MT	Sun River

Miscellaneous Tributaries to Missouri River

Heart Butte Dam, ND	Heart River
Dickinson Dam, ND	Heart River
Angostura Reservoir, SD	Cheyenne River
Cold Brook Reservoir, SD	Cold Brook Creek
Smithville Reservoir, MO	Little Platte River
Longview Reservoir, MO	Little Blue River
Rathburn Reservoir, IA	Chariton River
Long Branch Reservoir, MO	East Fork Little Chariton R.
Thomas Hill Reservoir, MO	Middle Fork Chariton River

Numerous other dams are potential flash flood points because of their threat to life and property.

6. DESCRIPTION OF FLOOD EVENTS

A. Introduction

This section of the compendium briefly highlights several major flood and flash flood events that have occurred in the Missouri Basin. More detailed discussions of these and other flood events can be found in various reports which can be found in MBRFC library.

B. Major Floods

(1) 1844

The flood of June 1844 is considered the greatest known in the lower Missouri Basin. A large area of the lower Missouri River Valley received heavy rainfalls during the months of May and June. Totals ranged from 18 inches at St. Louis, Missouri, to 27 inches at Ft. Scott, Kansas.

A report of the "Floods of 1903" describes this event:

> "The floods of 1785 and 1844 ran harmlessly over unbroken forests and bottom, tenanted only by the beasts of the field and the birds of the air, save along the Kaskaskia bottoms and the adjoining ones of the Mississippi, where were the little farms of the French colonists."

(2) 1903

The floods of May and June 1903 were caused by unusually heavy precipitation events during the latter half of May. This flood was considered the most devastating since the settlement of the Kansas and lower Missouri River Valleys.

The same report referred to above goes on to state:

> "The floods of 1903 descended upon broad, fertile, and highly cultivated fields, and upon rich valleys filled to overflowing with vast industries devoted with never ceasing energy to the fulfillment of the

insatiable demands of commerce... The number of human lives lost will never be accurately known, but the total reliable reported was exactly 100...

(3) 1951

The floods of June and July 1951 exceeded any others that had occurred in the lower Missouri River Valley since the historic flood of 1844. A two-month period of above-normal precipitation followed by unprecedented intense rains over a 72-hour period in early June caused the resulting floods. The area most seriously affected was the Kansas basin and Missouri drainage below Kansas City, Missouri.

The Weather Bureau technical paper of this event states:

> "Industrial districts and transportation centers of three metropolitan areas, Kansas City, Kansas, Kansas City and St. Louis, Missouri, were in the path. Two state capitals, Topeka, Kansas, and Jefferson City, Missouri, experienced the devastation. In addition, 150 flourishing communities and smaller cities suffered severe damage. Thirty thousand farms, consisting of three million acres, were affected by the flood waters. Tangible losses amounted to nearly a billion dollars. Twenty-eight lives were lost. This flood, occurring in an important agricultural and industrial area, constituted a major national catastrophe."

(4) 1952

The floods of 1952 were caused by rapid melt of an above-normal snow cover in eastern Montana, North Dakota, and South Dakota. Record and near record flooding occurred on the Milk River, several tributaries to the Missouri River in North and South Dakota, James River, Big Sioux River, and the Missouri Mainstem.

(5) 1984

Large areas of the Missouri River basin received intermittent heavy rainstorms during the months of May and June 1984. Above average precipitation also occurred during the preceding months. The prolonged wet spring culminated with flooding in June. The flooding was the worst since the disastrous flooding in 1952. Numerous towns and river front developments were flooded or threatened with flooding. Many roads and bridges were washed out or damaged. Millions of acres of land were flooded or damaged by soil erosion. Thousands of acres of cropland were not planted because of the magnitude and timing of the flooding, causing a severe financial hardship for farmers. Combined, the rainfall and flooding caused hundreds of millions of dollars' worth of damage.

The tributary river basins in which flooding or high flows occurred were the Beaverhead River and Ruby River basins in Montana; the Vermillion River, James River, and Big Sioux River basins in South Dakota; the Big Sioux River, Little Sioux River, and Nishnabotna River basins in Iowa; and the Salt Creek, Papillion Creek, Elkhorn River, and North Platte, and Platte River basins in Nebraska.

In addition to the major flooding that took place May-June 1984, three flash flood events occurred during June. The events occurred on June 9-10, 1984, along Indian Creek in Overland Park, Kansas, the Blue River in Kansas City, Missouri, and creeks in the St. Joseph, Missouri area. Another flash flood event occurred June 20, 1984, in the Belton, Missouri area taking one life.

C. Flash Floods

(1) The Black Hills Flood of June 9-10, 1972

On June 9, 1972, an almost stationary group of thunderstorms formed over the eastern Black Hills of South Dakota near Rapid City and produced record amounts of rainfall. Nearly 15 inches of rain fell in about six hours near Nemo, South Dakota, and more than ten inches of rain fell over a 60 square-mile area. The resulting floods were the highest ever recorded in South Dakota.

At least 237 people died in the Black Hills flood and another 3,057 people were injured, and total damage is estimated to have exceeded $160 million.

(2) The Big Thompson Canyon Flood of July 31-August 1, 1976

Big Thompson Canyon is one of many scenic spots in Colorado. It winds tortuously down through the Front Range of the Rocky Mountains. Estes Park marks the western end of the canyon and it ends near Loveland where the mountains meet the Great Plains. The small river (usually a clear, cold, rapidly flowing mountain stream one to two feet deep) descends some 2,500 feet through the 25-mile long canyon.

On the evening of July 31, 1976, in less than a six-hour period, very heavy rain fell over a 70 square-mile area. More than 12 inches fell over the slopes of the western third of the Big Thompson Canyon and more than four inches of rain fell over the entire canyon area from near Estes Park to Drake, Colorado. The resulting flooding was devastating; over 135 persons were killed.

(3) The Kansas City Area Floods of September 12-13, 1977

Outstanding floods occurred on streams in the Kansas City area as a result of two separate rainfall events within 24 hours. The first storm saturated the ground, which allowed a greater part of the second rainfall event to run off. As much as 16 inches of rainfall was reported in the Kansas City area.

Twenty-five persons lost their lives and an estimated $50 million in damages occurred. Although many homes and businesses suffered losses in the small stream basins, the major monetary damage occurred in the Brush Creek basin of Missouri and Kansas and within the lower Blue River basin of Missouri.

(4) The Cheyenne, Wyoming Flood of August 1-2, 1985

By late afternoon on August 1, 1985, a stationary thunderstorm developed over Cheyenne, Wyoming, producing record amounts of rainfall. In approximately a three-hour time span, six plus inches of rainfall occurred. The storm produced at least one tornado, heavy rains, and hail. In some parts of town, hail piled up to depths of four-six feet.

The severe flooding resulted in 12 deaths, 70 injuries, and total damages exceeding 61 million dollars.

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A COMPENDIUM OF INFORMATION
NORTH CENTRAL RIVER FORECAST CENTER

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1. INTRODUCTION

The objectives of the hydrologic service program of the National Weather Service are:

1. to mitigate loss of life and property damages caused by floods by providing the nation with timely issuance of river and flood forecasts and low water forecasts;

2. to conduct the necessary research to implement and improve forecasts and warnings; and

3. to provide hydrometeorological data for broad applications to water resource planning, flood plain management and operational programs.

There are two levels to the hydrologic service offered by the National Weather Service. The River Forecast Center (RFC) is an office staffed by professional hydrologists which issues river, reservoir, and flood forecasts using computer models for the predictions. The RFC issues forecasts to the Weather Service Forecast Offices (WSFO's) which, in turn, release warnings, forecasts, outlooks, and related hydrologic information to the public.

2. NCRFC OPERATIONS

The North Central River Forecast Center (NCRFC) is located in Minneapolis, Minnesota and has been in operation since 1979. The NCRFC's area of responsibility includes the Red River of the North to the Canadian border, including the Souris basin in North Dakota and Roseau River in Minnesota. The NCRFC's area also includes the Rainy River in Minnesota, and the Mississippi River drainage from the headwaters to Chester, Illinois, excluding the Missouri River basin. Also included are the mouth of the Big Muddy in Illinois, and the Great Lake tributaries in Michigan, Minnesota, Wisconsin, Illinois and Indiana, except the Maumee Basin (Figure 1).

A. Data Collection Network

The NCRFC has a precipitation data collection network of nearly 1,400 points. Eighty-nine of these points are first order observing points, such as National Weather Service, FAA, military contract and Canadian observations. The remaining points are either GOES satellite data collection platforms (DCP's),

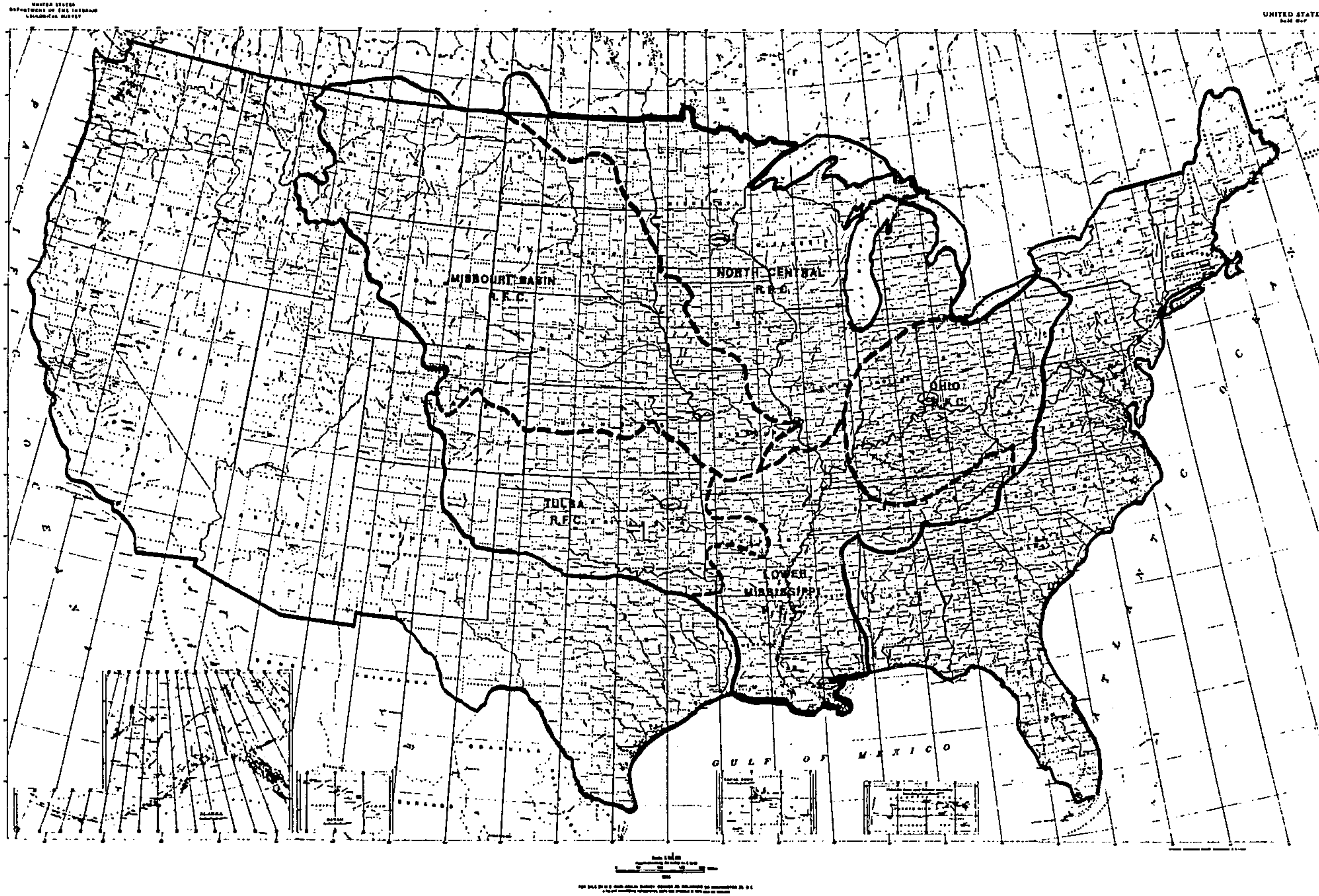

Figure 1. North Central RFC's area of responsibility as related to other RFC's.

private observers or organizations. River stage and reservoir data is collected from GOES data collection platforms, other automatic recording gages, or from cooperative and organizational observers.

B. Data Acquisition

Hydrologic data collection for the NCRFC's area is divided between nine WSFO's, designated as Hydrologic Service Area offices (HSA's). Data is also collected at designated Weather Service Offices (WSO's). All river, rainfall, snow, and temperature data, excluding GOES satellite data, is collected, reviewed, quality controlled, and transmitted by these offices to the NCRFC.

C. Forecasts

Precipitation and stage data, once received in the NCRFC, is entered into the computerized hydrologic forecast models using remote job entry in a batch mode. The models are executed on the NAS 9000 mainframe computer at the NOAA central computer facility in Suitland, Maryland. These results are analyzed by the RFC hydrologist. If necessary, model adjustments are made and the program is rerun. Forecasts are based on the hydrologic models, which takes into account basin characteristics, existing soil moisture conditions, routing of water downstream, and the forecaster's experience.

Several types of forecasts are issued at the NCRFC. At selected headwater points flash flood guidance is routinely issued twice a week, more frequently if needed. Daily state zonal flash flood guidance is also issued. Flash flood guidance is discussed in more detail later.

There are several points where three-day stage forecasts are issued daily. Forecasts at Alton, Illinois; St. Louis, Missouri; and Chester, Illinois on the Mississippi River are issued daily, year round. Three-day forecasts are also issued during the open water season for selected points on the Illinois and the Upper Mississippi Rivers. Daily forecast points are chosen based on the needs of the towing industry. Stage crest forecasts are issued for designated forecast points on rivers in the NCRFC's area when there is a flooding event showing rises above or near flood stage. Forecasts may also be issued showing moderate rises in the river to inform the WSFO that levels will increase without danger of flood damage. Forecasts continue daily or more frequently in a flood situation until the river falls below flood or another designated stage.

The total points requiring forecasts by hydrologic service area are:

Ann Arbor, Michigan WSFO	71
Bismarck, North Dakota WSFO	57
Chicago, Illinois WSFO	97
Des Moines, Iowa WSFO	68
Indianapolis, Indiana WSFO	7
Minneapolis, Minnesota WSFO - MN	56
Minneapolis, Minnesota WSFO - WI	37
St. Louis, Missouri WSFO	30

D. Extended Forecasts

Extended forecasts are issued once a week on the Mississippi River at Alton, Illinois, St. Louis, Missouri; and Chester, Illinois. Daily stages are issued for two weeks into the future while weekly stages are forecasted for the third and fourth week. This product ignores future rainfall providing users with a recession from existing flows.

E. Snowmelt Outlooks

A snowmelt outlook is issued during the spring for a guidance of expected flooding from snowmelt runoff. Data collected for the outlook preparation includes precipitation, snow depth and water content, soil moisture, ground frost, river stages and flows, and reservoir elevations. The RFC is aided in this data collection by the WSFO/WSO, Corps of Engineers, various state agencies, the Department of Agriculture and the NWS Airborne Gamma Radiation Snow Survey Program. Initially, the snow outlook is issued in mid-February as a narrative statement of winter conditions to that date. In early March a numerical outlook is issued and subsequent narrative and numerical outlooks are issued as conditions warrant. The numerical outlooks include two crests. The first crest is based on normal melt of existing snow cover. The second figure is based on normal melt of the snow cover plus normal precipitation up to and through the melt period. Reservoir inflow outlooks are also prepared upon request by project operators.

F. Low Flow Outlooks

Low flow outlooks are issued for municipalities which experience water supply shortages from streamflow during drought periods. These products are prepared upon request.

G. Flash Flood Guidance

Flash flood guidance is issued by NCRFC in two forms, SHEDS and ZONES. SHEDS is issued twice weekly or more frequently if needed. This guidance provides three- to six-hour rainfall amounts which will produce minor flooding at specific locations. These guidances are used internally by NWS field offices in the issuance of flash flood watches, warnings, and statements. Headwater advisory tables which utilize the SHEDS guidance are designed for particular headwater points. These guidance values enable the WSFO or WSO to make a rational crest forecast when time is of the essence. ZONES is a more general guide geared to state forecast zones. Issued daily, this product is designed as a statewide guide to the WSFO and WSO for small, ungaged streams to reach bankfull. The NCRFC issues about 100 ZONE guidance values each day and some 250 headwater advisory points are included in the SHEDS product.

H. Additional Flash Flood Programs

Local flash flood warning programs are programs in which a local community implements a flash flood detection and warning system. The NCRFC's flash flood hydrologist assists communities in the setting up of these programs.

The program includes a network of both precipitation and river gages which allow a community to detect, record, and warn of impending flooding. These programs can be either by networks of observers or automatic and self-contained.

Automated Local Evaluation in Real-Time Systems (ALERT) is a local, automatic, self-contained flood warning system. The ALERT system allows for rapid detection and analysis of flash flooding situations; on flashy streams there is a brief time period before heavy upstream rain generates large downstream flows. The basic components of an ALERT system are: automated processing equipment, manual hydrologic and meteorologic analysis techniques and warning distribution. Currently there is one ALERT system in operation in the NCRFC's area of responsibility.

I. Dambreak

On occasion when there is a need for a dambreak forecast, the NCRFC will provide crest and time to crest information to the appropriate WSFO.

J. Ice Statements

Ice statements are issued by the NCRFC for the navigable portion of the Illinois and Mississippi Rivers. The statements are issued once a week from mid-November until the ice has disappeared in the spring. The purpose of the ice statement is to summarize existing river ice conditions, discuss changes in the ice conditions since the last ice statement, and indicate future weather outlooks. The statement gives the latest extended temperature forecast and 30-day temperature outlook and identifies locations of significant ice jams and potential problems. Early in the season prior to ice formation water temperatures are provided.

K. Product Dissemination

Forecasts generated by the NCRFC are sent to WSFO's that have hydrologic service area responsibilities. These WSFO's are responsible for releasing the forecast and outlook information to the public in the form of statements and warnings.

L. Contingent Forecasts

Contingent forecasts are issued to WSFO's and cooperating agencies based on a given amount of future rainfall. This is especially useful for planning purposes if a river is showing a significant rise and more rainfall is expected. Operational models are run to determine how a river will respond inputting a predicted amount of rainfall.

M. Operational Forecast System

The operational forecast system consists of a runoff and flow model. The runoff model calculates the amount of basin runoff using observed precipitation (either snow or rain) existing soil moisture conditions, and temperature. The flow model simulates the flow of water in a river and includes runoff (from the runoff model), tributary flow, and existing baseflow. The flow model uses this input to compute a hydrograph which is a plot of stage or flow over time (Figure 2). The flow model keeps track of the flow of water in the river and routes the water downstream based on basin characteristics.

N. Airborne Gamma Radiation Snow Survey Program

The amount of expected runoff generated from snowmelt depends on an estimate of the snow and soil wetness. This is aided by the Airborne Gamma Radiation Snow Survey Program which is a program that measures the snow water equivalent and soil moisture using gamma radiation. Measurements are made at critical times during the hydrologic cycle over selected flight lines in North Dakota, South Dakota, Minnesota, Iowa, Wisconsin, Illinois, Indiana, and Michigan. This data aids in making an estimate of the amount of runoff to expect from the existing snow cover.

3. CLIMATE

The NCRFC's area of responsibility is located in the Midwestern section of the U.S. The climate of this area is affected not only by the interior continental location but also, in some areas, by their proximity to the Great Lakes. The states that, for the most part, have a continental climate include Iowa, Illinois, Minnesota, Missouri, Wisconsin, South Dakota, and North Dakota.

The continental climate is characterized by extremes of temperatures. In the summer the prevailing weather system comes north from the Gulf of Mexico. The air is very warm and moist and produces much of the rainfall. In the winter the prevailing weather system is the southerly flow of cold, dry Canadian air which can cause extremely cold temperatures. The extremes of cold and hot air will vary over the area with the coldest temperatures occurring in northern Minnesota and North Dakota and the warmest occurring in southern Iowa and Missouri. Annual precipitation ranges from 14 inches in North Dakota to 48 inches in Missouri (Table 1). Much of this precipitation occurs during the summer months.

The states of Michigan and northwestern Indiana have climates that are dominated by the presence of the Great Lakes. In Michigan the climate is quasi-marine in spite of the midcontinental location. The state averages about 31 inches of precipitation a year. Cold air passing over the warmer lake water induces precipitation in the lee of Lake Michigan in the fall and winter. Snowfall is the greatest next to the lakes and decreases further inland. Northwestern Indiana also is affected by its proximity to Lake Michigan. Precipitation is the greatest in the counties next to the lake through which the Kankakee River runs.

Temperatures in these states are moderated by the presence of the lakes. The extremes of hot and cold are not as great.

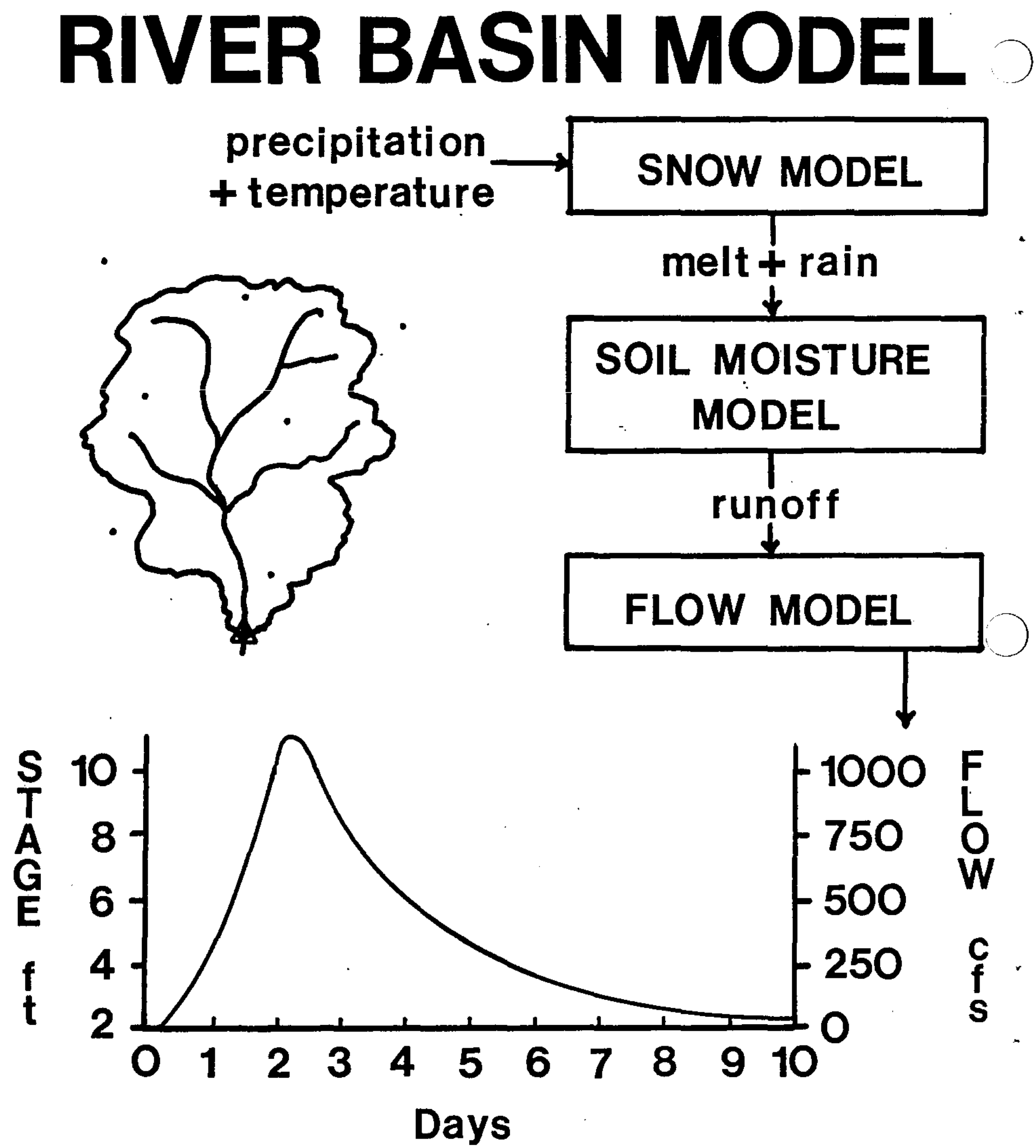

Figure 2. Operational Forecast Model used by the NCRFC

Table 1
Extremes of Temperature and Normal Precipitation

State	Temperature (°F) High	Temperature (°F) Low	Normal Precipitation (inches)
Illinois	106	-22	35 to 47
Indiana	104	-19	36 to 42
Iowa	111	-34	25 to 40
Michigan	105	-28	28 to 32
Minnesota	103	-46	20 to 32
Missouri	114	-25	35 to 48
North Dakota	121	-60	14 to 20
South Dakota	106	-39	15 to 25
Wisconsin	104	-37	27 to 30

4. TOPOGRAPHY

Most of the topography for the NCRFC's area of responsibility has been formed or affected by glacial activity. In North Dakota the flat Red River Valley has deep soils which were formed under a glacial lake. There is very little change in elevation in the eastern part of North Dakota and most of the land is in agriculture. Further west in North Dakota there is a gradual rise in elevation to the Young Drift Plains and the Great Plains. The portion of South Dakota which is in the NCRFC's area has a very flat topography and is just south of the glacial lakebed which the Red River of the North drains.

Minnesota is a state with varied topography. In the northwest, the Red River Valley is very flat and like the eastern part of North Dakota, was formed from glacial lake sediments, and is mostly agricultural land. The northeastern portion of Minnesota was formed by glaciation with shallow topsoil and the bedrock close to the surface. The higher elevations of the state are found in this area with forests and numerous lakes. Central Minnesota has a rolling topography formed from glacial moraines and outwash plains. The southwestern part of the state is flat to rolling with deep glacial till while the southeastern part of the state is more hilly with an unglaciated topography. There are more hills and valleys in the southeast and the soil are loess deposits from the glaciers to the north. Both the southwestern and southeastern parts of the state are largely agricultural now with original vegetation being tall grass prairie in the southwest and broadleaf forest in the southeast.

The topography of Iowa is rolling prairie and changes in elevation are small across the state varying from 1,675 feet in northwest Iowa to 477 feet in the southeast. The topography was formed mainly from outwash plains from the glaciers to the north and east. The northeastern part of the state has some rugged terrain. Much of the rolling terrain of Iowa is in agricultural land while the eastern portion has some forested areas.

The terrain of Illinois is generally flat except for a few hills in the south and a small unglaciated area in the northeast. Illinois has deep loess soils in the north which were originally tall-grass prairie and now support very high agricultural production. Forests were present in the extreme southern and northeastern part of the state but now have been cut down.

Missouri has three main terrain features; the rolling prairies north of the Missouri River, the Ozarks in the west-central counties, and the lowlands of the southeast. The northeastern part of the state slopes down to about 700 feet near the Mississippi River. The terrain varies from rugged areas bordering some of the larger streams, with deep valleys and steep hills, to broad, rolling uplands. Agricultural is common on the prairies of northern and west-central Missouri and in the rugged areas forestry is important.

Wisconsin's topography is varied across the state. The extreme northern part of the state was formed by glaciation so there are many lakes. This area is generally forested and has a high elevation and is the origin of most of the major streams of the state. A comparatively flat, crescent shaped lowland lies immediately south of the Northern Highlands. It is largely agricultural and includes nearly one-fourth of Wisconsin's area. The eastern ridges and lowlands to the southeast of the Central Plains are the most densely populated and have the highest concentration of industry and farms.

The NCRFC's area of responsibility includes only the extreme northwestern part of Indiana. This section of the state is the Great Lakes Plain. The Kankakee Valley is found in this part of the state and the valley slopes gently towards the west and drains what was formerly low marshlands, but is now muckland farms.

The State of Michigan is divided into the upper and lower peninsulas. The upper peninsula is largely undeveloped for forecasting by the NCRFC. The lower peninsula features range from quite level terrain in the southeast to gently rolling hills in the southwest, with elevations generally between 800 and 1,000 feet. A series of sand dunes along the Lake Michigan shoreline rise to heights of nearly 400 feet above lake level. These are the result of the prevailing westerly winds blowing across the lake. Tablelands cover the northern part of the lower peninsula and reach an elevation of 1,700 feet near Cadillac, Michigan.

5. GEOGRAPHY OF MAJOR BASINS

A. Canadian Drainage

(1) Red River of the North

The Red River of the North is formed by the confluence of the Otter Tail and Bois de Sioux Rivers below the cities of Wahpeton, North Dakota and Breckenridge, Minnesota. The river flows on a northerly course for about 400 miles before reaching the U.S.-Canadian international boundary where it continues north into Lake Winnipeg and Hudson Bay. The watershed of the Red River of the North includes the northern corner of South Dakota, much of eastern North Dakota, northwestern Minnesota and a small portion which drains from Manitoba through the United States. At the international boundary the river drains a total of 40,200 square miles. Of this area approximately 800 square miles are located in South Dakota, 21,000 square miles in North Dakota, 16,400 square miles in Minnesota and 2,000 in Canada. About 5,800 square miles are noncontributing in North Dakota.

Two distinct topographic types are encountered in the basin--the level plain adjoining the river on both sides, known as the Red River Valley, and the rougher upland areas east and west of the plain. Elevations (MSL) range from 2,300 feet in the highest upland area to 800 feet at the Canadian border. Toward the west, the plain slopes gently upward to almost the elevation of the upland area; but, toward the northwest, the gentle sloping valley terminates with an abrupt rise. To the northeast the topography varies from a level plain to extensive swamplands. As a result of the extremely flat land in much of the basin, a slight increase in stages on the Red River causes overbank flow to move overland for many miles.

The principle tributaries from the west include the Wild Rice, Sheyenne, Goose, Forest, Park, and Pembina Rivers. From the east major tributaries include the Otter Tail, Buffalo, Red Lake River, Two Rivers and Roseau River.

(2) Souris River

The Souris River basin encompasses 24,800 square miles in Canada and the United States. Of the total area, 15,480 square miles (62 percent) are in Canada and 9,320 square miles (38 percent) are within the United States. All of the Souris River basin in the U.S. lies in North Dakota. There are 10,600 square miles pertinent to the U.S. gage in Minot, North Dakota, of which 3,900 square miles (37 percent) contribute to normal flooding and 6,700 square miles (63 percent) are noncontributing.

Major tributaries of the Souris River in the United States are the Des Lacs, Wintering, Deep Rivers, and Willow Creek. Souris River basin topography is characterized by hilly to gently rolling glacial moraine in the west and central sections which gradually give way to a flat, featureless glacial lake bed in the eastern section. The floodplain is typically broad, flat-floored, and incised to a depth of 100 to 200 feet below the adjacent land surface, except in the glacial lake bed area.

Artificial lakes impounded by low, earth-filled dams cover much of the Souris River valley bottomlands. Only one is large enough to provide some flood flow regulation and it is found 30 miles upstream from Minot, North Dakota. The Souris River basin is a semiarid region with precipitation averaging less than 16 inches annually. The average annual snowfall of 33 inches comprises about 21 percent of the yearly precipitation. Floods usually result from rapid runoff of heavy winter and spring snowfalls augmented by spring rains.

B. Upper Mississippi River Basin

The Upper Mississippi River basin drains 189,000 square miles from a point approximately 70 miles south the the U.S.-Canadian border to the Ohio River at Cairo, Illinois. The NCRFC's area extends from the headwaters to

Chester, Illinois. The river starts by flowing north, then east, and then curves around to the southeasterly direction. The headwaters is a region of dense forests, swamps, and thousands of lakes.

The Mississippi River drops nearly 60 percent of its total fall from the headwaters to Dam 10 at Guttenburg, Iowa. Normally no major flood problems exist north of Minneapolis/St. Paul because of flatland slopes and the large storage capacity of the swamps, lakes and reservoirs. As the Mississippi flows south of St. Paul it drains fertile agricultural regions. Topography near the pools is generally characterized by high bluffs and rolling hills. Land use bordering the pools is primarily agricultural but there are many urban areas and some wildlife areas. Urban areas on the river are subject to flood in high flow events. The upper Mississippi River basin is characterized by hot summers and very cold winters. The weather conditions often change rapidly over short periods of time. A high percentage of the precipitation occurs during the summer growing season.

C. Great Lakes Drainage

The Great Lakes drainage includes most of the State of Michigan, the extreme northeastern part of Minnesota, and the northern and eastern part of Wisconsin. This area was scoured and formed by glaciation. The basins are characterized by numerous swamps and lakes, and covered by forests, particularly in the headwaters region. Elevations range from 1,980 feet above sea level in the headwaters section to 600 feet above sea level near Lake Superior. The tributaries and main stems in the northern part of the area follow rocky courses characterized by chutes, falls, and rapids. Mid-Michigan is characterized by undulating prairie, swamps, and hilly sections.

Much of the Great Lakes drainage in the upper peninsula and the northern part of the lower peninsula of Michigan, the northeastern part of Minnesota, and northern Wisconsin have not been developed for forecasting by the NCRFC.

6. SUMMARY OF MAJOR TRIBUTARIES

A. Canadian Drainage

Des Lacs River - tributary of the Souris River. The Des Lacs rises in Canada and flows 110 miles southeast to join the Souris.

Sheyenne River - has a drainage area of 7,140 square miles with a length of 500 miles and a vertical drop of 846 feet. The Sheyenne rises in east-central North Dakota, flows south and then loops north to join the Red River north of Fargo, North Dakota.

Devils Lake Subbasin - Subdivision of the Red River basin. Drainage area is 3,580 square miles with no flow to the Red River. The basin is located in north-central North Dakota and has flat topography with potholes.

Goose River - has a drainage area of 1,280 square miles. The river flows 186 miles in east-central North Dakota to its confluence with the Red River.

Forest River - has a drainage area of 1,030 square miles. The Forest rises in northeast North Dakota and flows southeast and east to the Red River.

Park River - has a drainage area of 1,010 square miles. The Park rises in northeast North Dakota and flows southeast to the Red River 36 miles south of the international boundary.

Pembina River - has a drainage area of 3,960 square miles with 1,960 square miles being in the U.S. The total length is 310 miles.

Roseau River - drains 2,057 square miles in southwest Manitoba and northwest Minnesota. Sixty percent of the drainage area is in Minnesota. The Roseau includes Roseau Lake and Big Swamp and flow northwesterly for 180 miles.

Two Rivers - drainage area of 1,112 square miles. Two Rivers rises in northwestern Minnesota and the drainage basin is flat with poorly drained topography.

Red Lake River - rises in northwestern Minnesota at the outlet of Red Lake. The river flows 196 miles to its confluence with the Red River at East Grand Forks, Minnesota. The drainage area is 5,700 square miles.

B. Upper Mississippi River Basin

Mississippi Headwaters - rises in north central Minnesota at Lake Itasca, flows north, east, and then curves around to the south to enter Minneapolis-St. Paul, Minnesota. The headwaters area is characterized by forested, rolling till plains with low hills and ridges with many lakes.

Minnesota River - rises at Big Stone Lake on the South Dakota, Minnesota border and flows southeast for 225 miles to Mankato, Minnesota. At Mankato it flows northeast for 109 miles to the Mississippi River at Minneapolis-St. Paul. Drainage area is 16,920 square miles. It has a slope of 0.84 feet per mile. Tributaries from the southwest are similar in character to the mainstem Minnesota with well developed drainage patterns, descending rapidly from higher ground having the potential to produce sudden high flood flows.

St. Croix River - rises about 25 miles south of Lake Superior with the first 40 miles of its length being in Wisconsin and for the remaining 135 miles it forms the Minnesota-Wisconsin boundary. The St. Croix drains upland, wooded areas with a drainage area of 7,650 square miles and joins the Mississippi River near Prescott, Wisconsin.

Chippewa and Black River Basins - Chippewa has as its origin a large number of lakes and swamps in the north-central part of Wisconsin and flows in a generally southwest direction to its confluence with the Mississippi River 75 miles downriver of St. Paul, Minnesota at Lake Pepin. Total length of the river is 200 miles with a difference in elevation of 650 feet. The principle tributaries to the Chippewa are the Flambeau and Red Cedar Rivers. The Black River rises at Black Lake in the west-central portion of Wisconsin and flows for 183 miles in a southwesterly direction and joins the Mississippi River a few mile north of La Crosse, Wisconsin.

Wisconsin River - originates in a network of interconnecting lakes and swamps in the northern highland section of Wisconsin. From its source, the river flows south to Portage, Wisconsin, then flows southwest to Prairie du Chien, Wisconsin. Total length is 428 miles and elevation difference is 1050 feet. The principle tributaries are Tomahawk, Prairie, Rib, Eau Claire, Big Eau Pleine, Plover, Yellow, Lemonweir, Baraboo, Pine and Kickapoo Rivers.

Rock River - is located in southern Wisconsin and northwestern Illinois. It rises near Waupon in southeastern Wisconsin and is 293 miles in length. It is joined by the Pecatonica River and enters the Mississippi River immediately below Rock Island, Illinois. The total drainage area of the Basin is 10,710 square miles with a difference in elevation of 370 feet. The upper basin exhibits a rolling topography while the lower and central part form a broad alluvial plain. Near the Mississippi River the terrain becomes rugged and the streams have steep slopes.

Illinois River - total area of drainage 29,010 square miles. Lies principally in the state of Illinois with segments of its drainage area extending into the southwestern portion of Wisconsin and northwestern part of Indiana. The river flows southwesterly and joins the Mississippi River at Grafton, Illinois. Major tributaries in the northern section of the Illinois include the Fox, Des Plaines, Kankakee and Sangamon Rivers. The Illinois River allows navigation from the Mississippi River to Lake Michigan, its entire length being controlled by locks and dams for navigation. The headwaters generally follow shallow, broad troughs between morained areas.

Kaskaskia River - length is 325 miles with a vertical drop of 390 feet. The river rises in south-central Illinois and flows southwesterly to its confluence with the Mississippi River eight miles north of Chester, Illinois. The drainage basin is hilly in the southwest and flat in the northeast.

Big Muddy River - 2,988 square miles drainage area, source in southern Illinois and flows 155 miles southwest to the Mississippi River. Topography varies from hilly with upland ridges to flat relief with wide valleys.

Meramec River - located in southeast Missouri in the northeastern part of the Ozark Highlands south of the Missouri River. The river drains 3,980 square miles and the terrain is classified from rugged to open plains.

Salt River - located in northeastern part of Missouri and originates 12 miles south of the Missouri-Iowa state line. The Salt flows southeasterly until its confluence with the Mississippi River near the town of Louisianna, Missouri. The total drainage is 2,920 square miles and falls over 400 feet in its 72 mile length. The topography ranges from steep hills and rolling country to level prairie and the flat Mississippi flood plain.

Fox, Wyaconda, and Fabius Rivers - rise in extreme southeastern part of Iowa and flow southeasterly through northeastern Missouri, to their confluence with the Mississippi River. The drainage area total is 2,530 square miles. The basins lie in the Dissected Till Plains consisting of the Mississippi flood plain and upland area.

Des Moines River - Total area drained is 14,540 square miles and originates in extreme southern Minnesota and flows southeasterly into Iowa. It joins the Mississippi River a few miles below Keokuk, Iowa. Major tributaries include the Raccoon River.

Skunk River - originates near center of the state of Iowa and flows southeasterly to it confluence with the Mississippi River. The river is 264 miles long and has a total drainage area of 4,355 square miles. The river valley varies from narrow and shallow to steep and narrow.

Iowa, Cedar Rivers - drains 12,640 square miles. The Cedar River rises in marshy depressions in southeastern Minnesota and flows southeasterly to join the Iowa River in southeast Iowa about 30 miles from the Mississippi River. The basins are gently rolling prairie land with surface elevations less than 150 feet above the streams.

Turkey, Maquoketa, Wapsipinicon, and Upper Iowa Rivers - total drainage area of 8,970 square miles. The Turkey rises in northeastern Iowa and flows southeast to the Mississippi River south of Guttenburg, Iowa. The Turkey falls 740 feet in 135 miles. The Maquoketa River is further south than the Turkey and its total length is 135 miles. The Wapsipinicon River is the longest and southernmost. It rises in southeast Minnesota and flows southeast 225 miles to confluence with Mississippi River below Clinton, Iowa.

C. Great Lakes Drainage

St. Joseph River - basin size is 4,600 square miles. The St. Joseph rises in southern Michigan, flows northwesterly then southwesterly, enters Indiana, and then turns northward and discharges into Lake Michigan at St. Joseph, Michigan. The slope of the river is gradual but constant, dropping 570 feet in 210 miles. The river is fed by springs and small lakes and is not subject to rapid and excessive rises, nor to extremely low stages.

Grand River - drainage area is 5,572 square miles. The Grand is 260 miles long and drops 460 feet. It rises in central Michigan and flows west into Lake Michigan. The Grand has a steep slope on over half its length, but flattens out as it approaches Lake Michigan. The flood plains of this river are very broad.

Saginaw River - drainage area is 6,260 square miles. The Saginaw rises in eastern Michigan and flows northeasterly to the Saginaw Bay of Lake Huron. The river flows through gently rolling uplands and low lying, swampy areas. Major tributaries of the Saginaw River include the Flint, Shiawassee, Cass and Tittabawassee Rivers.

Fox River - rises in east-central Wisconsin and flows easterly into Green Bay on Lake Michigan. The river flows into Lake Winnebago and the section from the headwaters to Lake Winnebago is 107 miles long with a 40 foot fall. The section of the river from Lake Winnebago to Green Bay is 37 miles long with a drop of 168 feet. The total area drained is 2,000 square miles. Much of the area of the upper Fox is marshy while the lower Fox has higher banks with the surrounding area being well-drained.

Wolf River - rises in small lakes 25 miles south of the Michigan boundary in eastern Wisconsin. The Wolf flows south to Stephensville, Wisconsin, then turns sharply west to beyond New London, Wisconsin and then turns south and southeast and flows through lakes Poygan and Winneconne before flowing into the Fox River. The upper half of the Wolf flows through a bed of crystalline rocks near the surface and descends 7.94 feet per mile. During flooding the river expands at various points to several miles in width.

7. MAJOR FLOODS

A. Souris River

The spring flood of 1976 was significant on the Souris River at Minot, North Dakota. A stage of 21.30 feet was measured with flood stage being 14.0 feet. Conditions which contributed to this flood included very high rainfall in the fall of 1975 and high water equivalents of snow on the ground in the spring. Other years of major flooding include 1882, the flood of record, spring 1975 with stage of 20.35 and the spring of 1970 with a stage of 17.02.

B. Red River of the North

A significant flood occurred the spring of 1979 on the Red River. At Grand Forks, North Dakota the peak stage was 48.63 feet where flood stage is 28.0. The months of November through April received precipitation amounts well above normal which accounted for this flood. Other significant flooding events occurred in the spring of 1897; the flood of record with a stage of 50.2 feet, the spring of 1882 with a stage of 48.0 feet, and the spring of 1978 with a stage of 45.73.

C. Mississippi River

The April 1965 flood was the flood of record for 300 miles on the Mississippi River from Ft. Ripley to Dam 10. Conditions that contributed to this flood included a wet fall, with a cold winter and heavy rains in February. A cold spell with large amounts of snow in March and a fast thaw also contributed to the flooding. St. Paul recorded a stage of 26.01 feet with a flood stage of 14.0 feet and La Crosse, Wisconsin recorded a stage of 17.9 feet; flood stage being 12.0 feet. Other years of major flooding occurred the spring of 1969 and the spring of 1952. Measured stages were 24.52 and 22.02 for the respective years at St. Paul and 16.5 and 15.3 respectively at La Crosse.

Further downstream at Burlington, Iowa and Hannibal, Missouri the spring of 1973 produced the flood of record. Burlington recorded a stage of 22.0 feet with flood stage of 15.0 feet and Hannibal recorded 28.59 with flood stage at 16.0. Conditions that contributed to this flood included high rainfall in the fall of 1972 and the spring of 1973. Other years of major flooding occurred in the spring of 1965 and the spring of 1979. Stages at Burlington were 21.4 and 18.5 feet respectively and at Hannibal, 24.59 and 22.69 feet respectively.

D. Great Lakes

Major floods in Grand Rapids, Michigan on the Grand River with a flood stage of 18.0 feet, occurred in 1904, 1907, 1948, 1947, and 1976 with stages of 23.2, 21.3, 21.2, 20.4, and 19.3 respectively.

8. NAVIGATION

The Mississippi River nine foot channel extends from above the Fall of St. Anthony in Minneapolis, Minnesota to below the mouth of the Missouri River near St. Louis, Missouri. The nine foot channel for this stretch of river was authorized in the 1930's and was achieved by the construction of a system of locks and dams, supplemented by dredging.

In order to minimize flooding to adjacent lands, the dams of the river are low structures, and for this reason have no flood control benefits.

The Lock and Dam projects were designed and are regulated for navigational purposes. The dams are utilized to maintain a minimum pool elevation in order to provide a nine-foot navigation channel (Table 2).

Table 2
Locks and Dams for Navigation on the Upper Mississippi River

Number	Location	Year in Operation	Normal Upper Pool Elevation (MSL 1912 datum)
Upper St. Anthony Falls	Minneapolis, MN	1964	799.2
Lower St. Anthony Falls	Minneapolis, MN	1958	750.0
1	Minneapolis, MN	1917	725.1
2	Hastings, MN	1931	687.2
3	Red Wing, MN	1938	675.0
4	Alma, WI	1935	667.0
5A	Winona, MN	1936	651.0
5	Minneiska, MN	1936	651.0
6	Trempealeau, WI	1936	645.5
7	La Crescent, MN	1937	639.0
8	Genoa, WI	1937	631.0
9	Lynxville, WI	1937	620.0
10	Guttenburg, IA	1937	611.0
11	Dubuque, IA	1937	603.0
12	Bellevue, IA	1939	592.0
13	Fulton, IL	1939	583.0
14	Le Claire, IA	1939	572.0
15	Quad Cities	1935	561.0
16	Muscatine, IA	1937	545.0
17	New Boston, IL	1939	536.0
18	Gladstone, IL	1937	528.0
19	Keokuk, IA	1913	518.2
20	Canton, MO	1936	480.0
21	Quincy, IL	1938	470.0
22	Saverton, MO	1938	459.5
24	Clarksville, MO	1940	449.0
25	Winfield, MO	1939	434.0
26	Alton, IL	1938	419.0
27	St. Louis, MO	1962	398.0

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