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AEC Research and Development Report

MISSOURI RIVER HYDROLOGY
(STREAMFLOW AND TEMPERATURE)--
SIOUX CITY, IOWA TO
RULO, NEBRASKA

OCTOBER 1972

BNWL-1692

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SIOUX CITY, IOWA

TO

RULO, NEBRASKA

by

David L. Schreiber

October 1972

BATTELLE
PACIFIC NORTHWEST LABORATORIES
RICHLAND, WASHINGTON 99352

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MISSOURI RIVER HYDROLOGY (STREAMFLOW AND TEMPERATURE)

SIOUX CITY, IOWA

TO

RULO, NEBRASKA

David L. Schreiber

INTRODUCTION

In any plan for the development of water and land resources, hydrology must be a basic consideration. Because of the Missouri River Basin's large size and the many associated variations in hydrologic characteristics, hydrology is of special significance.

The Missouri River drains an area of approximately 530,000 square miles, and it is the longest river in the United States (2,315 miles). The source of the Missouri River is the headwaters of the Red Rock River in Montana, and the mouth is at the Mississippi River near St. Louis, Missouri. Part or all of 10 states and 9,700 square miles in Canada are contained in the Missouri River Basin.

The basin's physiographic features and the resulting effects on the basin's hydrology are extremely varied, since the basin extends into three major physiographic divisions, the Rocky Mountain System, the Interior Plains, and the Interior Highlands. The Interior Plains Division contains by far the greatest part of the Missouri River Basin.

The Missouri River is characterized by wide variations in seasonal flow; lowest flows occur during the winter months. A complicating factor during the winter is ice, which may cover the river as far south as Kansas City, Missouri. When the ice cover breaks up, significant ice jams may form and cause resultant flooding. Discharges are significantly increased in the spring due to snowmelt, and low flows generally prevail during the late summer and early fall.

Missouri River streamflow characteristics are further complicated by six large storage reservoirs located on the main stem above Sioux City,

Iowa, and operated by the U.S. Army Corps of Engineers. The dams range from Gavins Point, located at river mile 811.1, to Fort Peck at river mile 1771.5. These reservoirs have a total flood storage capacity of almost 12 million acre-feet.

The Missouri River main stem reservoirs have been operated as a system for about 19 years, since Fort Randall and Garrison were first regulated in conjunction with Fort Peck. During this period, the remaining reservoirs were filled to normal operating levels, while providing some multipurpose water usage. Until the reservoirs were finally filled to normal operating levels in 1967, the actual operation was atypical and downstream flows were below normal.

The Missouri Basin Inter-Agency Committee's (MBIAC) recent Comprehensive Framework Study⁽¹⁾ evaluates the basin's current (1970) physical, economic, water, and land resources development and extends the development to the years 1980, 2000, and 2020. Effects of the framework plans on available water supply (quantity and quality) for those future years were also analyzed.

Developments in the framework plans will cause depletions that will considerably reduce hydroelectric power generation by the Missouri River main stem plants and that will require frequent curtailment or interruption of the navigation season. The reservoir system was, however, fully effective for flood control for all runoff conditions experienced during the 1898-1968 period of streamflow record, as adjusted to the particular level of basin development under consideration. In all of the levels of development, sufficient releases were maintained for irrigation.

For the study period of record, water quality control requirements were met for all development levels. However, hydroelectric power generating capability for 2020 on the main stem was only one-third of the existing and projected capacity.

Therefore, future development and resulting depletions of Missouri River water amount to additional constraints on the hydrology of the Missouri River Basin. Because construction of two nuclear power plants is

presently in progress and because several more such plants are in the planning stages for locations on the Missouri River below Gavins Point Dam, it is imperative that a better understanding of the hydrology of the river in these reaches be provided. This report attempts to further such an understanding of the streamflow and river temperature regime between Sioux City, Iowa (river mile 732.3), and Rulo, Nebraska (river mile 498.0).

SUMMARY AND CONCLUSIONS

Low-flow frequency curves are presented for four stations below the Missouri River main stem reservoir system. The annual, lowest average flows for seven consecutive summer (May through October) days, as determined from U.S. Geological Survey records for the calendar years 1967 through 1971 were plotted. These data were extrapolated to obtain the once-in-ten-years, lowest average flows for seven consecutive summer days under present water resources development. These flows are as follows:

<u>Station</u>	<u>Flow, cfs</u>
Sioux City, Iowa	23,700
Omaha, Nebraska	25,600
Nebraska City, Nebraska	30,900
Rulo, Nebraska	31,800

Similarly, the once-in-ten-years, lowest average flows for seven consecutive winter days, including icing conditions, are determined to be the following for present basin development:

<u>Station</u>	<u>Flow, cfs</u>
Sioux City, Iowa	5,000
Omaha, Nebraska	7,000
Nebraska City, Nebraska	8,000
Rulo, Nebraska	8,700

Future development of Missouri River water resources is expected to cause streamflow depletions that will considerably reduce hydroelectric power generation and will require frequent curtailment or interruption of the navigation season. However, flood control, water supply for irrigation, and water supply for water quality are expected to be available for all development within the next 50 years.

As an example of the effects of future developments, the 90% exceedance flow is 7,700 cfs during the winter season (December through March) at Omaha under current development; whereas, for 2020-level development, the 90% exceedance flow is 4,500 cfs. During the navigation season (April through November) at Omaha, the 90% exceedance flow is 27,800 cfs under current development, but will be only 5,500 cfs under 2020-level development.

At Sioux City during the winter season, the 90% exceedance flow is 8,400 cfs under current development, but will be only 4,500 cfs under 2020-level development. During the navigation season at Sioux City, the 90% exceedance flow is currently 26,400 cfs, but will be only 5,500 cfs in 2020.

The analyses and discussions presented later in this report yield estimates of the lowest average flows for seven consecutive days having return periods of 10 years at Sioux City and Omaha for 2020-level development. These flows in cfs are as follows:

<u>Sioux City</u>		<u>Omaha</u>	
<u>All Flows</u>	<u>Summer Flows</u>	<u>All Flows</u>	<u>Summer Flows</u>
2,700	4,900	4,100	5,100

Therefore, barring major changes in present Federal laws or policy, it appears that industrial uses of the Missouri River for cooling purposes will be severely limited by the year 2020 because of projected depletions for other water resources development.

Based upon temperature data obtained during four summers, 1967 through 1970, and after the normal operating levels of the Missouri River main stem reservoirs were attained, little change in monthly maximum and minimum river temperatures occurs within the 63-mile reach between the North Omaha Power Station (river mile 625.2) and Nebraska City (river mile 562.6). The greatest difference between the two stations for either maximum or minimum

temperatures was less than 4°F, but in general, maximum summer monthly temperatures at the two stations and minimum summer monthly temperatures at the two stations are within 1 to 2°F.

Monthly average diurnal temperature changes ranged from 0.9°F to 2.4°F during the months of June through September for the years 1967 through 1971 and including June through July 16, 1972, for the North Omaha Power Station. Based on data obtained from temperature recorders which were installed at the Metropolitan Utilities District water intake (river mile 626.3) and at the Fort Calhoun Nuclear Power Plant site (river mile 645.9) during the late spring of 1971, monthly average diurnal temperature changes vary by no more than 0.4°F along the 21-mile river reach between Fort Calhoun and the North Omaha Power Station.

Therefore, neither temperature changes between stations nor diurnal temperature changes at any one station appear to pose any additional constraints for industrial use of the Missouri River water in this reach for cooling purposes.

STREAMFLOWPresent Main Stem Reservoir Operations

Except as a means of transportation, the Missouri River was little used before 1865. After the Civil War, early settlers and homesteaders began filing for water-use permits to start irrigation and mining ventures. By 1898, 3 million acre-feet per year were being depleted. Depletions gradually grew to about 13 million acre-feet on an average annual basis by 1970.⁽¹⁾

To evaluate the development of the Missouri River Basin, the MBIAC chose year-1970 conditions as a common level for water resources development, water use, and streamflow depletion. To evaluate the effects of the filled main stem reservoir system during a long period of record, the 1970-level development study was based on the following conditions:

1. Historic monthly streamflow records;
2. 1970-level streamflow depletions;
3. June 1969-level reservoir storage loss to sedimentation;
4. Minimum releases to meet downstream water quality and supply requirements;
5. Highest navigation releases as practical with available supply;
6. Adequate storage space reserve to minimize downstream flooding, and
7. Maximum power generation consistent with other uses.

Because of the constantly changing level of water resources development in the 1898-1968 record period, the historical streamflows were adjusted to represent those that would have occurred under the 1970-level of development.⁽¹⁾

Based on present non-damaging downstream channel capacities, the following maximum permissible, mean daily, main stem reservoir releases were used in the MBIAC 1970-level study:

<u>Reservoir</u>	<u>Mean Daily Discharge, cfs</u>	
	<u>Open Water</u>	<u>Ice Cover</u>
Fort Peck	25,000	12,000
Garrison	75,000	30,000
Oahe	100,000	powerplant capacity
Big Bend	100,000	powerplant capacity
Fort Randall	100,000	15,000
Gavins Point	100,000	15,000 plus inflow beyond Fort Randall

On the basis of water intake and power peaking requirements, the minimum permissible, mean daily release rates were:

Fort Peak	3,000 cfs
Garrison	6,000 cfs
Oahe	6,000 cfs
Big Bend	6,000 cfs
Fort Randall	3,000 cfs
Gavins Point	3,000 cfs

Releases from Fort Randall in excess of 3,000 cfs were scheduled during the non-navigation season whenever necessary to maintain minimum water quality control requirements at Sioux City, Omaha, and Kansas City. During the period from December through February, requirements were 1,800 cfs, 4,500 cfs, and 5,400 cfs at the three stations, respectively. Requirements for November and March were 1,350 cfs, 3,375 cfs, and 4,050 cfs at the three stations, respectively.⁽¹⁾

To provide a full 8-month navigation season (April through November), navigation flows established by MBIAC for the 1970-level study were 25,000-31,000 cfs at Sioux City and Omaha, 27,000-37,000 cfs at Nebraska City, and 31,000-41,000 cfs at Kansas City. Flows selected were to depend on the status of storage in the main stem reservoirs. The total system storage at the end of March, April, May, and June was used as a basis for determining the length of the navigation season. If necessary,

the season could be shortened in quarter-month increments to close before December 1. Flow levels during shortened seasons were always held at the established minimums.⁽¹⁾

At the main stem reservoirs other than Fort Randall and Gavins Point, the generation of energy affected the release rates. Energy requirements could increase release rates at these reservoirs as a result of ice-cover flow restrictions.

Illustrated in Figure 1, are the highlights of the MBIAC 1970-level development study of the Missouri River. Annual volumes at Sioux City for 1949 unregulated river flows are compared to 1970 regulated flow conditions. The system storage curve indicates an essentially filled reservoir system, except for the severe drought of the 1930's and the moderate drought of the late 1950's and early 1960's. The cycle between navigation and non-navigation releases and the years when high releases were required to provide flood control storage are reflected in the system release curve (Gavins Point discharges). The navigation service curve shows that, except for five years during the 1930's drought, full service was provided. The reductions in energy generation and capability during the two drought periods are illustrated in the power service graph.⁽¹⁾

In conjunction with, but published later than the MBIAC study, the Missouri River division of the U.S. Army Corps of Engineers conducted a study of the Missouri River main stem reservoir operations for development levels anticipated in 1970, 1980, 2000, and 2020.⁽²⁾ These studies were conducted for the same conditions and objectives as the MBIAC study, but not all of the results were included in the MBIAC report. More detail concerning actual reservoir operations is given in the Corp's report. Information appropriate to the material contained herein is presented in Figure 2. This figure depicts the water supply downstream of the main stem reservoir system plotted at quarter-month intervals for the historical record adjusted for the 1970-level of water resources development.

FIGURE 1. Results of the Missouri River Main Stem Reservoir Operations for the 1970-Level of Development (1)

FIGURE 2. Water Supply Downstream of the Missouri River Main Stem Reservoir System for the 1970-Level of Development (2)

Present Summer Flows

Regulation of Missouri River streamflow below the main stem reservoir system is an important factor when considering the river for its capacity to dissipate thermal effluent heat for nuclear power plants. Water quality in the section of the Missouri River described in this report is managed according to State of Nebraska Water Quality Standards.⁽³⁾ This section of the Missouri River is classified as Class "A" water. Present river temperature criteria for ice-free conditions are stated as, "The temperature of the receiving water shall not be increased by a total of more than 5°F from May through October and not more than 10°F from November through April. Maximum rate of change limited to 2°F/hr."⁽³⁾ These criteria are applicable at flows equal to or exceeding the lowest average flow for seven consecutive days under conditions that can be expected to occur at a frequency of once every ten years.

In evaluating thermal emissions from nuclear power plants along the section of the Missouri River described herein, two separate flow conditions, winter and summer, must be considered for the once-in-ten-years, lowest average flow for seven consecutive days. During the summer period, May through October, thermal releases, under present standards, must not increase Missouri River water temperatures by more than 5°F. This period occurs during the navigation season, April through November, when river flows and temperatures are generally high. During the winter period, November through April, river flows and temperatures are generally low, and thermal releases to the river may increase the natural temperature by as much as 10°F.⁽³⁾

Since the Missouri River main stem reservoirs were not all filled to normal operating levels until 1967, streamflow records obtained prior to that time cannot be used without modification to obtain the lowest average flow for seven consecutive days that occurs once every ten years under present conditions. To obtain such a value for summer flow conditions, U.S. Geological Survey daily flow records for the calendar years 1967 through 1971 at the following stations were used: Sioux City, Iowa (river mile 732.3); Omaha, Nebraska (river mile 615.9); Nebraska City, Nebraska (river mile 562.6); and Rulo, Nebraska (River mile 498.0).

The annual lowest average flows for seven consecutive days during the summer at the four above-mentioned stations over the last five calendar years are presented in Table 1. In addition to the annual, lowest average, 7-day flows, Table 1 lists the minimum and maximum flows experienced during the 7-day period for each station and each year.

The annual, lowest average, 7-day, flow data from Table 1 were then used to estimate the once-in-ten-years, lowest average flow for seven consecutive days that would occur during the summer months (May through October) at each of the four stations.

It is possible to prepare a frequency curve of low flow, much in the same manner as a flood frequency curve is prepared. In this instance, the objective is to find the low-flow event that occurs with a frequency of once in ten years. Thus, the average 7-day flows for the years of record are plotted as a frequency curve, which is extrapolated to yield the average 7-day low flow having a recurrence interval of 10 years.

Several different statistical distributions have been suggested for extending streamflow records.⁽⁴⁾ One commonly used method is the distribution of extreme values (Gumbel method), which is based upon the argument that the distribution of floods (or droughts) is unlimited, because there is no physical limit to the maximum flood (or minimum drought). Linear-extreme value coordinate paper (Gumbel paper) exhibits recurrence interval (return period), t_r , in years versus flow rate. The extreme value scale is laid out such that the equation for the extreme value probability distribution plots as a straight line. Thus, to obtain the flow rate for an event having a greater recurrence interval than the period of record, the historical record is plotted as a frequency distribution on Gumbel paper; the best-fit line is then drawn through the data points and extended to the recurrence interval of interest.

Data from Table 1 were plotted as frequency distributions on Gumbel paper and are shown in Figure 3. Best-fit lines were drawn through the data

TABLE 1. Seven Consecutive Low Flow Days During Summer Months (May Through October) Since the Filling of the Missouri River Main Stem Reservoirs (a)

Station & River Mile Location	Calendar Year	Dates	Flow, cfs		
			Maximum	Minimum ^(b)	Average
Sioux City, Iowa (732.3)	1967	June 13-19	29,400	21,100	26,300
	1968	Oct. 25-31	31,100	30,400 ^(c)	30,700
	1969	June 30-July 6	37,600	32,000	35,500
	1970	May 2-8	31,300	29,800	30,700
	1971	May 1-7	37,000	36,100	36,500
Omaha, Nebraska (615.9)	1967	July 3-9	31,900	31,300 ^(d)	31,600
	1968	Oct. 25-31	31,800	30,100	31,000
	1969	June 16-22	38,700	37,000	38,000
	1970	May 1-7	31,400	30,100	30,900
	1971	May 1-7	37,700	36,200	36,600
Nebraska City, Nebraska (562.6)	1967	May 21-27	36,600	34,100	35,300
	1968	Sep. 9-15	33,600	32,800	33,300
	1969	June 5-11	45,800	40,600	43,100
	1970	May 4-10	39,400	36,600	37,600
	1971	May 1-7	48,900	43,600	44,800
Rulo, Nebraska (498.0)	1967	May 21-27	36,200	35,300	35,800
	1968	Sep. 9-15	34,300	33,600	34,000
	1969	June 5-11	46,300	43,200	44,700
	1970	May 5-11	38,900	37,400	38,300
	1971	May 1-8	49,500	44,200	45,200

(a) Data from U.S. Geological Survey records.

(b) Minimums listed are also daily minimums for the summer months, except as further noted.

(c) The summer minimum daily flow was 30,000 cfs on June 27.

(d) The summer minimum daily flow was 30,600 cfs on June 3.

FIGURE 3. Frequency Distributions for the Missouri River Below the Main Stem Reservoir System for Minimum Average, Seven Consecutive Day, Summer (May Through October) Flows--Data Period 1967 Through 1971

points for each station and extended to obtain the flows with return periods of 10 years. Thus, from Figure 3, the lowest average flows for seven consecutive summer-month days that occur with a frequency of one year in ten at each station are approximately:

<u>Station</u>	<u>Flow, cfs</u>
Sioux City, Iowa	23,700
Omaha, Nebraska	25,600
Nebraska City, Nebraska	30,900
Rulo, Nebraska	31,800

Present Winter Flows

As mentioned earlier in this report, lowest Missouri River flows generally occur during the winter months of December through February because of ice storage which may occur as far south as Kansas City, Missouri. To obtain a better understanding of Missouri River streamflow under winter and icing conditions, an analysis similar to the one used for summer flows was conducted. In the winter flow case, minimum average, seven consecutive day flows were obtained from U.S. Geological Survey daily flow records for each climatic year from April 1, 1966, through March 31, 1972.

The climatic year begins on April 1 and ends on the following March 31. Such a data year has been used in this analysis, because a general flow recession usually begins in the summer months and may persist through the winter months. If the water year ending September 30 or the calendar year ending December 31 were used, a single low flow period might be recorded as two separate events.

The annual lowest average flows for seven consecutive days at the four river stations under consideration for the past six climatic years are presented in Table 2. Note that the low flows at all four stations for climatic year 1966 occurred in early 1967 after the Missouri River main stem reservoir system had been filled to normal operating levels. Table 2 also lists for each station the minimum and maximum flows experienced during the annual 7-day low flow period.

TABLE 2. Seven Consecutive Low Flow Days Since the Filling of the Missouri River Main Stem Reservoirs (a)

Station & River Mile Location	Climatic Year (b)	Dates	Flow, cfs		
			Maximum	Minimum (c)	Average
Sioux City, Iowa (732.3)	1966	Feb. 16-22, 1967	8,500	6,270 (d)	7,410
	1967	Jan. 24-30, 1968	12,600	9,780	10,970
	1968	Dec. 10-16, 1968	15,800	6,240	10,200
	1969	Jan. 8-14, 1970	13,500	9,000	12,200
	1970	Jan. 14-20, 1971	14,500	13,500	13,900
	1971	Jan. 15-21, 1972	25,000	14,500	17,900
Omaha, Nebraska (615.9)	1966	Feb. 18-24, 1967	8,700	6,630 (e)	7,740
	1967	Jan. 26-Feb. 1, 1968	13,500	8,700	10,960
	1968	Dec. 11-17, 1968	15,100	6,000	11,200
	1969	Jan. 9-15, 1970	16,000	10,000	13,400
	1970	Jan. 6-12, 1971	14,000	9,000	11,400
	1971	Jan. 13-19, 1972	22,600	5,440	13,400
Nebraska City, Nebraska (562.6)	1966	Jan. 9-15, 1967	14,000	8,500	11,000
	1967	Jan. 3-9, 1968	11,000	8,500	9,570
	1968	Dec. 12-18, 1968	19,400	6,420	13,600
	1969	Jan. 9-15, 1970	17,000	10,500	14,100
	1970	Jan. 7-13, 1971	12,000	9,500	10,200
	1971	Jan. 13-19, 1972	25,000	10,000	16,200
Rulo, Nebraska (498.0)	1966	Jan. 9-15, 1967	14,000	9,000	11,100
	1967	Jan. 2-8, 1968	11,000	8,500	9,430
	1968	Jan. 1-7, 1969	17,500	11,000 (f)	14,600
	1969	Jan. 10-16, 1970	17,000	11,000	14,200
	1970	Jan. 8-14, 1971	11,000	10,000	10,100
	1971	Jan. 13-19, 1972	26,300	10,700	19,500

(a) Data as presented by the U. S. Geological Survey, including flows during icing conditions.

(b) Climatic year, April 1 through the following March 31, was used for low flow data, because a general flow recession usually begins in the summer months and may persist through the winter months.

(c) Minimums listed are also daily minimums for the year, except as further noted.

(d) The minimum daily flow for the climatic year was 5,000 cfs on 1/8/67.

(e) The minimum daily flow for the climatic year was 4,800 cfs on 1/10/67.

(f) The minimum daily flow for the climatic year was 9,050 cfs on 12/17/68.

The annual average 7-day low flow data from Table 2 were then plotted as frequency distributions on Gumbel paper and are shown in Figure 4. Best-fit lines were drawn through the data points for each station and extended to obtain the flows with return periods of 10 years. Thus, from Figure 4, the lowest average flows, including icing conditions, for seven consecutive days that can be expected to occur with a frequency of one year in ten at each station are approximately:

<u>Station</u>	<u>Flow, cfs</u>
Sioux City, Iowa	5,000
Omaha, Nebraska	7,000
Nebraska City, Nebraska	8,000
Rulo, Nebraska	8,700

Future Basin Development and Main Stem Reservoir Operations

As mentioned previously, the MBIAC's Comprehensive Framework Study⁽¹⁾ and the Corps of Engineers' Main Stem Reservoir Operation Studies⁽²⁾ extend the Missouri River Basin's current water and land resources development to the years 1980, 2000, 2020. These future developments will cause streamflow depletions that will considerably reduce hydroelectric power generation and will require frequent curtailment or interruption of the navigation season. Other multiple-purpose uses (flood control, irrigation, and water quality) were satisfied using the 1898-1968 period of streamflow records adjusted to the particular level (1980, 2000, or 2020) of development under consideration.

For the 2020-level of development, hydroelectric power generating capability was only one-third of the existing and projected capacity. To provide a full 8-month navigation season (April through November), average flows at Sioux City must be maintained between 25,000 to 30,000 cfs. For the 71-year period of record at the 1970-level development, full service to navigation was supplied for 66 years. The number of years with full

FIGURE 4. Frequency Distributions for the Missouri River Below the Main Stem Reservoir System for Minimum Average, Seven Consecutive Day Flows--Data Period April 1966 through March 1972 Including Icing Conditions.

length navigation seasons was reduced to 61 years for 1980-level development. Full-length navigation seasons were possible for only 43 years under 2000-level development, and by 2020 this number was further reduced to only 15 years.⁽¹⁾

Figures 5, 6, and 7 can be used to place in perspective the effect of future developments on Missouri River Streamflow. Highlights of the MBIAC 2020-level development study are illustrated in Figure 5.⁽¹⁾ Annual flow volumes at Sioux City for 1949 unregulated streamflows are compared to the anticipated 2020-regulated streamflow conditions. System storage curves are compared for current (1970) development and 2020-level development, and as noted, the reservoir system under latter development does not remain nearly as full for the historic period of record as it does under current development. The system release curve (Gavins Point discharge) reflects the cycle between navigation and non-navigation releases for both current and 2020-level development. As noted in both the system storage and system release curves, almost no releases for flood control purposes are necessary for 2020-level development. The navigation service level curve at Sioux City reflects the curtailment in navigation, and the power service curve illustrates the reduction in hydroelectric power generation that will be necessary under 2020-level development.

The Corps of Engineers has extended the MBIAC study to include available water supply downstream of the main stem reservoir system for the current (1970) and future (1980, 2000, and 2020) levels of basin development.⁽²⁾ The 1970-level downstream water supply was illustrated previously in Figure 2. Available downstream water supply for 2020-level development is shown in Figure 6 plotted at quarter-month intervals for the adjusted historical record.

Illustrated in Figure 7 are Missouri River streamflow duration probability curves for the unadjusted historic record and the various MBIAC development levels at Sioux City, Omaha, Kansas City, and Hermann.⁽¹⁾ These curves illustrate the drastic effects anticipated for downstream Missouri River flows upon completion of future developments. For example,

FIGURE 5. Results of the Missouri River Main Stem Reservoir Operations for the 2020-Level of Development (1)

FIGURE 6. Water Supply Downstream of the Missouri River Main Stem Reservoir System for the 2020-Level of Development (2)

SIoux CITY WINTER SEASON

1000 CUBIC FEET PER SECOND

PERCENT OF TIME EQUALED OR EXCEEDED

HISTORIC

1970

1980

2000

2020

SIoux CITY NAVIGATION SEASON

1000 CUBIC FEET PER SECOND

PERCENT OF TIME EQUALED OR EXCEEDED

HISTORIC

1970

1980

2000

2020

OMAHA WINTER SEASON

1000 CUBIC FEET PER SECOND

PERCENT OF TIME EQUALED OR EXCEEDED

HISTORIC

1970

1980

2000

2020

OMAHA NAVIGATION SEASON

1000 CUBIC FEET PER SECOND

PERCENT OF TIME EQUALED OR EXCEEDED

HISTORIC

1970

1980

2000

2020

KANSAS CITY WINTER SEASON

1000 CUBIC FEET PER SECOND

PERCENT OF TIME EQUALED OR EXCEEDED

HISTORIC

1970

1980

2000

2020

KANSAS CITY NAVIGATION SEASON

1000 CUBIC FEET PER SECOND

PERCENT OF TIME EQUALED OR EXCEEDED

HISTORIC

1970

1980

2000

2020

HERMANN WINTER SEASON

1000 CUBIC FEET PER SECOND

PERCENT OF TIME EQUALED OR EXCEEDED

HISTORIC

1970

1980

2000

2020

HERMANN NAVIGATION SEASON

1000 CUBIC FEET PER SECOND

PERCENT OF TIME EQUALED OR EXCEEDED

HISTORIC

1970

1980

2000

2020

FIGURE 7. Missouri River Steamflow Duration Probability Curves Illustrating Effects of Future Basin Development(1)

at Omaha during the winter season (December through March) under 1970-level development, the 90% exceedance flow is 7,700 cfs; whereas, for 2020-level development, the 90% exceedance flow is 4,500 cfs. During the navigation season (April through November) at Omaha, the 90% exceedance flow is 27,800 cfs under current development, but will be only 5,500 cfs under 2020-level development. At Sioux City during the winter season, the 90% exceedance flow is 8,400 cfs under current development, but will be only 4,500 cfs under 2020-level development. During the navigation season at Sioux City, the 90% exceedance flow is 26,400 cfs currently, but will be only 5,500 cfs in 2020.

Information presented previously in Figures 3 and 4 for Sioux City and Omaha can be compared in a somewhat limited degree to the information presented for these stations in Figure 7 for the 1970-level development. A low flow with a return period of 10 years has a probability of 0.1 of occurring in any one year, or in other words, it will be exceeded 90% of the time. From Figure 3, the lowest average flow at Sioux City for seven consecutive summer-month (May through October) days with a return period of 10 years is 23,700 cfs. The corresponding 90% exceedance value from Figure 7 during the navigation season (April through November) under 1970-level development is 26,400 cfs. In a similar manner, the summer-month, 10-year return period value for Omaha from Figure 3 was 25,600 cfs, which compares to the corresponding 90% exceedance value of 27,800 cfs from Figure 7. Similarly for winter month flows at Sioux City, 5000 cfs from Figure 4 compares to 8400 cfs from Figure 7, and at Omaha, 7000 cfs from Figure 4 compares to 7700 cfs from Figure 7. Since the comparisons between the two separate analyses presented in Figures 3 and 4 and in Figure 7 appear reasonable, the Gumbel Method is deemed satisfactory for obtaining the lowest average flow for seven consecutive days having a return period of 10 years.

Based upon the reasonable comparison between the Gumbel Method and the 1970-level analysis, estimates of 2020-level development, lowest average flows for seven consecutive days having a return period of 10 years can be obtained by the method of ratios. This results in the following:

Lowest Average Flow, cfs, for Seven Consecutive Days Having a Return
Period of 10 Years for 2020-Level Development of the Missouri River Basin

<u>Sioux City</u>		<u>Omaha</u>	
<u>Winter</u>	<u>Summer</u>	<u>Winter</u>	<u>Summer</u>
2,700	4,900	4,100	5,100

Therefore, barring major changes in present Federal laws or policy, it appears that industrial uses of this reach of the Missouri River for cooling purposes will be severely limited by the year 2020.

TEMPERATURE

In order to completely evaluate thermal releases to the Missouri River, the water temperature regime must be known, including diurnal temperature variations. To establish a data base for analyzing the water temperature regime, data were obtained from the U.S. Geological Survey and the Omaha Public Power District.^(5,6) Data were only considered for the period of time since the Missouri River Main Stem Reservoir System was filled to normal operating levels.

Summer monthly variations of maximum, minimum, and average temperatures at Nebraska City (river mile 562.6) are listed in Table 3. The maximum and minimum temperatures from this table can be compared to those in Table 4. The latter table presents the monthly temperature ranges, the monthly diurnal temperature ranges, and the monthly average diurnal temperature changes at three sites--North Omaha Power Station (river mile 625.2), Metropolitan Utilities District intake (river mile 626.3), and Fort Calhoun (river mile 645.9).

Based upon the temperature range data for four summers, 1967 through 1970, at Nebraska City and North Omaha Power station, little change in maximum and minimum river temperatures occurs in the 63-mile stretch between the stations. The greatest difference between the two stations for either maximum or minimum temperatures was less than 4°F, but in general, maximum and minimum summer monthly temperatures at the two stations are within a degree or two.

The diurnal temperature changes listed in Table 4 indicate that the highest observed monthly maximum diurnal temperature change was 5.2°F and it occurred during May 1972 at the Metropolitan Utilities District water intake. Two higher maximum daily temperature changes were noted, but these were not true diurnal changes, since a gradual drop in temperature occurred over a 24-hour or longer period. Average diurnal temperature changes ranged from 0.0°F to 2.4°F for the data reported in Table 4. Since the

summer of 1971 after recorders were installed at all three stations, monthly average diurnal temperature changes vary by no more than 0.4°F between stations along the 21-mile stretch of river.

Therefore, neither temperature changes between stations nor diurnal temperature changes at any one station appear to pose any additional constraints for industrial use of this reach of the Missouri River water for cooling purposes.

TABLE 3. Summer Temperature Variations in the Missouri River at Nebraska City, River Mile 562.6^(a)

<u>Year</u>	<u>Month</u>	<u>Temperature, °F</u>		
		<u>Max.</u>	<u>Min.</u>	<u>Avg.</u>
1967	May	69	45	57
	June	76	55	69
	July	81	71	76
	Aug.	81	71	75
	Sep.	71	60	66
	Oct.	66	45	55
1968	May	64	55	59
	June	75	64	72
	July	79	70	75
	Aug.	79	68	75
	Sep.	70	61	64
	Oct.	64	46	55
1969	May	72	50	61
	June	72	64	68
	July	82	72	77
	Aug.	79	73	75
	Sep.	75	63	68
	Oct.	65	44	53
1970	May	71	56	63
	June	79	67	74
	July	80	74	77
	Aug.	80	76	77
	Sep.	78	58	67

(a) Data used to derive table were obtained from the U.S. Geological Survey. Data only tabulated for the years since the filling of the Missouri River main stem reservoirs.

TABLE 4. Diurnal Temperature Changes in the Missouri River^(a)

Year	Month	Site ^(b)	Temperature Range, °F	Diurnal Temperature Change, °F		
				Max.	Min.	Avg.
1967	June	NOPS	55.8-76.5	6.1 ^(c)	0.7	2.4
	July		70.8-83.8	4.1	0.6	1.8
	Aug.		71.4-81.0	2.5	0.9	1.7
	Sept.		60.4-72.2	2.7	0.4	1.5
	Oct.		44.3-66.3	2.6	0.8	1.7
	Nov.		35.5-47.5	2.3	0.4	1.2
1968	June	NOPS	60.9-74.7	3.5	1.2	2.3
	July		67.8-79.0	2.9	0.3	1.7
	Aug.		67.7-79.3	2.7	0.8	1.8
	Sept.		60.2-70.6	2.6	0.3	1.6
1969	June	NOPS	64.0-73.0	3.6	0.4	1.6
	July		72.9-84.7	2.9	0.8	1.5
	Aug.		75.0-80.1	3.0	0.7	1.3
	Sept.		64.0-76.0	2.0	0.2	0.9
1970	June	NOPS	66.0-79.1	2.2	0.6	1.5
	July		74.0-81.5	2.7	0.5	1.5
	Aug.		73.7-82.2	2.7	0.4	1.3
	Sept.		60.0-77.3	3.5	0.4	1.4
	Sept.	MUD	60.0-76.0	3.0	0.0	1.4
	Oct.		48.4-65.1	6.5 ^(e)	0.0	1.5
	Nov.		32.0-48.0	4.5	0.0	1.1
	Dec.		33.0-39.0 ^(f)	2.0	0.0	0.3
1971	Jan.	MUD	33.0-33.5 ^(f)	0.5	0.0	0.0
	Feb.		33.0-34.0 ^(f)	1.0	0.0	0.2
	Mar.		32.2-43.9 ^(f)	3.9	0.0	1.5
	Apr.		38.5-50.0 ^(g)	2.9	0.0	1.6
	May	MUD FC	56.8-63.0 ^(h)	2.7	0.0	1.4
			55.0-64.0	4.0	0.0	1.8
	June	NOPS	63.6-78.4	2.4	0.5	1.3
		MUD	68.5-78.2 ⁽ⁱ⁾	2.0	0.2	1.0
		FC	63.0-78.0	3.0	0.5	1.4
	July	NOPS	70.8-79.0	2.9	0.5	1.2
		MUD	70.0-80.0	3.0	0.2	1.0
		FC	68.0-78.0	4.0	0.0	1.3

TABLE 4. Diurnal Temperature Changes in the Missouri River (Cont.)

<u>Year</u>	<u>Month</u>	<u>Site</u> ^(b)	<u>Temperature Range, °F</u>	<u>Diurnal Temperature Change, °F</u>		
				<u>Max.</u>	<u>Min.</u>	<u>Avg.</u>
1971	Aug.	NOPS	71.1-80.2	2.7	0.3	1.2
		MUD	70.0-79.0	1.9	0.2	1.0
		FC	69.5-80.0	2.5	0.0	1.2
	Sept.	NOPS	59.9-76.8	2.3	0.5	1.2
		MUD	59.0-75.3	2.9	0.4	1.2
		FC	59.0-76.5	3.0	0.0	1.2
	Oct.	MUD	49.0-66.5	4.0	0.0	1.2
		FC	48.0-66.5	3.0	0.0	1.4
	Nov.	MUD	37.7-49.0	3.7	0.0	1.2
		FC	36.5-50.0	2.5	0.0	1.3
	Dec.	MUD	32.2-38.6	2.8	0.0	0.7
		FC	32.0-38.0	3.0	0.0	0.9
1972	Jan.	MUD	32.4-34.0 (f)	1.5	0.0	0.2
	Feb.		32.2-36.0 (f)	2.0	0.0	0.5
	Mar.		32.5-44.0 (f)	3.2	0.0	1.3
	Apr.	MUD	39.0-55.0	3.8	0.0	1.6
		FC	48.0-52.0	4.0	0.0	2.0
	May	MUD	48.1-70.0	5.2	0.2	1.5
		FC	60.0-64.0	4.0	0.0	1.6
	June	NOPS	66.4-75.0	2.5	0.2	1.6
		MUD	65.2-74.0	4.0	0.1	1.4
		FC	67.0-77.0	4.0	0.0	1.5
	July	NOPS	72.0-80.0 (j)	2.8	0.3	1.5
		MUD	70.7-78.2 (j)	3.0	0.3	1.2

(a) Data supplied by Omaha Public Power District (OPPD).

(b) NOPS: Hourly data to nearest 0.1°F from OPPD recorder on Unit No. 4 at North Omaha Power Station, river mile 625.2.

MUD: Hourly data to nearest 0.1°F from OPPD recorder in the Metropolitan Utilities District water intake, river mile 626.3

FC: Six-hourly data (midnight, 6:00 a.m., noon, 6:00 p.m.) to nearest 0.5°F from 11-Agency recorder at Fort Calhoun site, river mile 645.9

TABLE 4. Diurnal Temperature Changes in the Missouri River (Cont.)

- (c) Gradual drop in temperature throughout day from 74.7°F to 68.6°F
- (d) Record started September 5, 1970.
- (e) Gradual drop in temperature from 62.9°F at 12:01 a.m. on October 8 to 50.0°F at 11:59 p.m. on October 9.
- (f) Infrared electric heaters used to prevent surface ice at intake may result in readings slightly higher than 32°F even though probe was more than 4 feet under water.
- (g) Valid record only from April 1 through April 12.
- (h) Valid record only from May 17 through May 27.
- (i) Valid record only from June 7 through June 30.
- (j) Record available only through July 16.

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