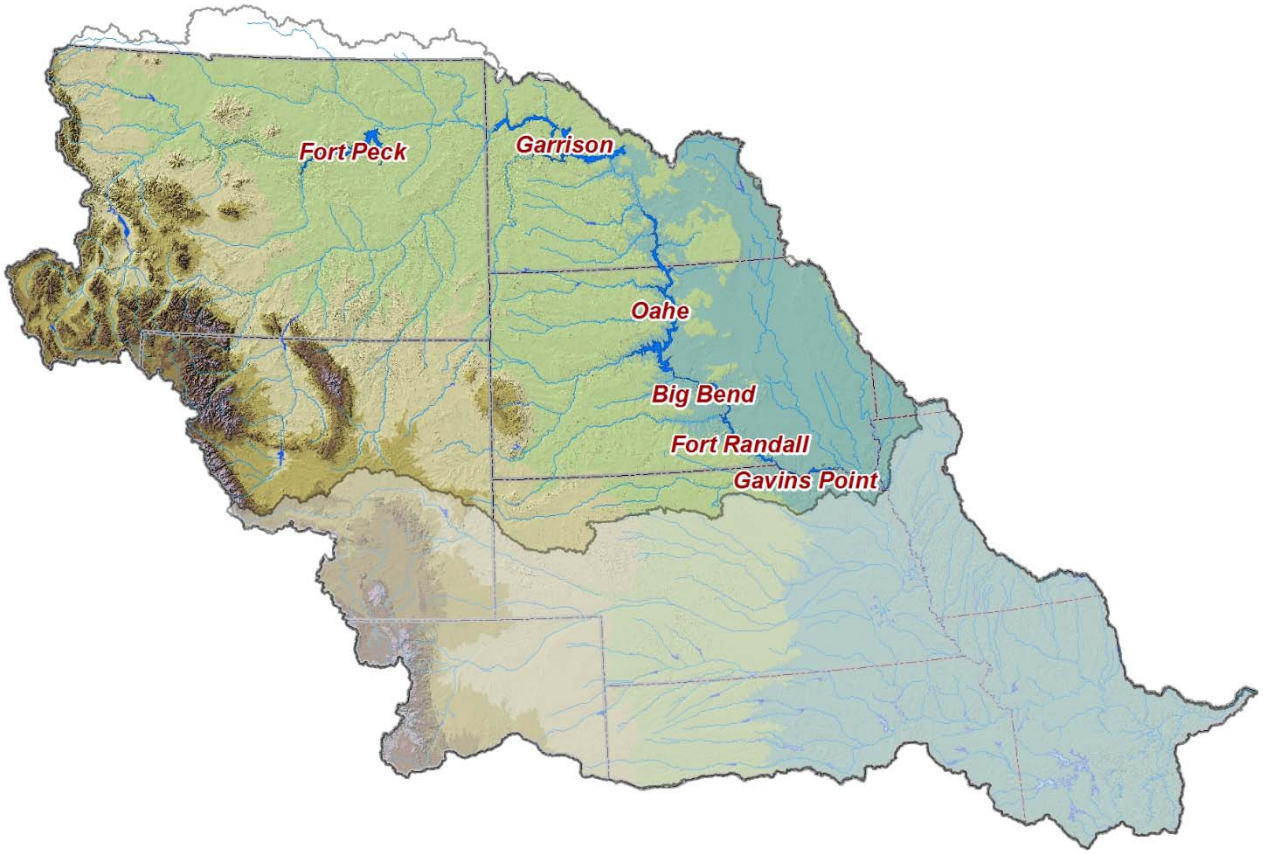
US Army Corps of Engineers ®
Northwestern Division

Long-Term Runoff Forecasting

Technical Report



Missouri River Basin Water Management Division
Omaha, Nebraska

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Missouri River Basin Water Management Division

Technical Report - Long-Term Runoff Forecasting

February 2017

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List of Abbreviations, Acronyms and Terms

AMJ	April-May-June
AOP	Annual Operating Plan
Avg	Average
CoCoRaHS	Community Collaborative Rain, Hail and Snow Network
COOP	NWS Cooperative Observer Program
CPC	NWS Climate Prediction Center
deg F	degrees Fahrenheit
ENSO	El Niño Southern Oscillation
kAF	thousand acre-feet
Master Manual	Master Water Control Manual
MA	March-April
MJJ	May-June-July
MRBWMD	Missouri River Basin Water Management Division
NCEI	NOAA National Center for Environmental Information
NOAA	National Oceanic and Atmospheric Administration
NOHRSC	NWS National Operational and Remote Hydrologic Sensing Center
NWS	NOAA National Weather Service
NRCS	USDA Natural Resources Conservation Service
SNOTEL	NRCS Snowpack Telemetry Network
NWD	U.S. Army Corps of Engineers, Northwestern Division
SWE	Snow water equivalent
System	Missouri River Mainstem Reservoir System
upper Basin	Missouri River Basin above Sioux City, Iowa
USACE	U.S. Army Corps of Engineers
USDA	U.S. Department of Agriculture

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Appendix A	Significant March-April Runoff Seasons of the Past Two Decades
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I. INTRODUCTION

A. Background

This report describes the data, assumptions, and methods used to make long-term runoff forecasts for the Missouri Basin above Sioux City, Iowa (upper Basin). The upper Basin is subdivided into six reaches at the location of each Missouri River Mainstem System (System) reservoir. The six System reaches, shown in **Figure 1**, include the headwater reach above Fort Peck Dam (Fort Peck), the incremental reach from Fort Peck Dam to Garrison Dam (Garrison), the incremental reach from Garrison Dam to Oahe Dam (Oahe), the incremental reach from Oahe Dam to Fort Randall Dam (Fort Randall), the incremental reach from Fort Randall Dam to Gavins Point Dam (Gavins Point), and the incremental reach from Gavins Point Dam to Sioux City, Iowa (Sioux City). Long-term runoff forecasts for the six System reaches are included in the Calendar Year Runoff Forecast for the upper Basin.

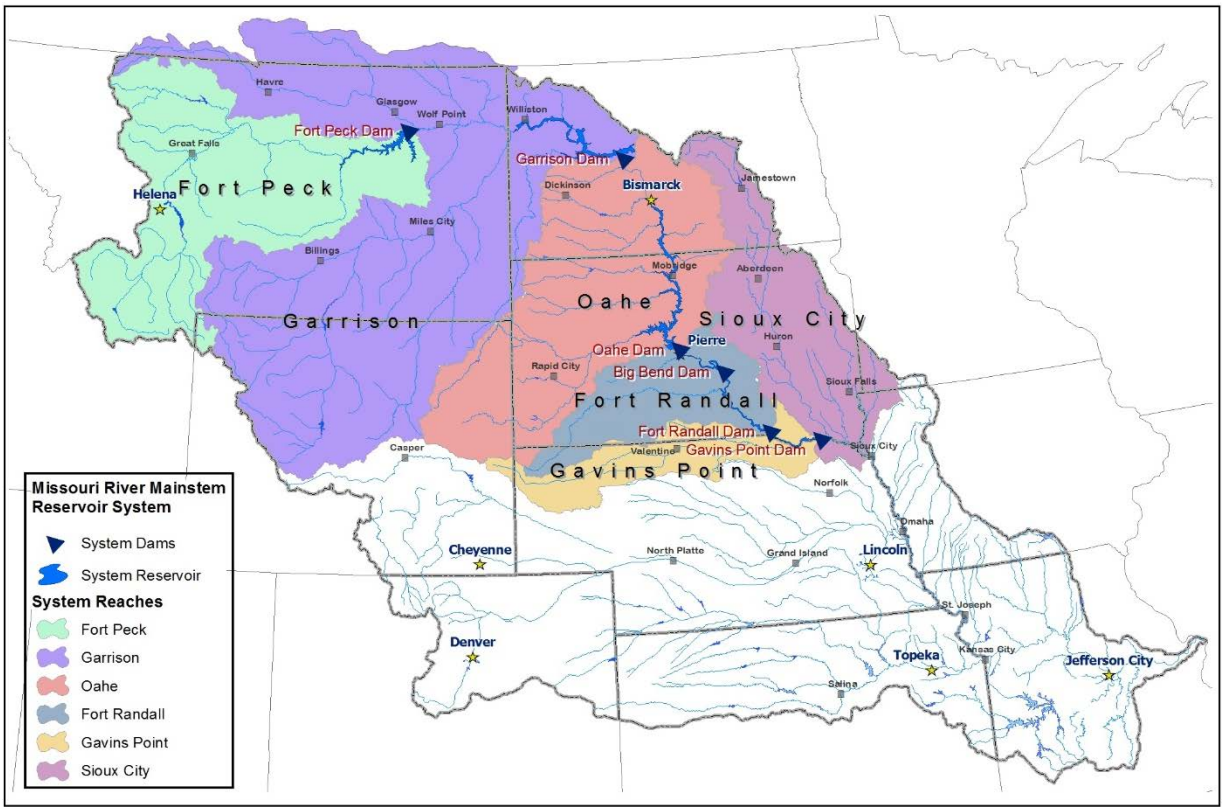

Figure 1. The upper Missouri River Basin and System reaches.

Upper Basin reach runoff is defined as the unregulated volume of water that would enter each of the System reservoirs. During the period of record, there has been substantial development of water-related resources in the upper Basin; therefore, it is necessary to adjust runoff to a common level of development for comparative purposes. The 1949 level of upper Basin development represents a base prior to the accelerated water resource development that occurred in the upper Basin during the 1950s. Records accumulated prior to and since 1949 have

been adjusted to the 1949 level of development. Additional discussion on basin development and depletions may be found in Missouri River Mainstem Reservoir System, System Description and Regulation (MRBWMD, 2007).

The average monthly runoff for each of the six System reaches based on the 1898-2014 period of record is provided in **Table 1**. The annual runoff summation is the sum of the monthly upper Basin runoff volumes that would enter all System reaches during a calendar year.

Table 1. Average monthly upper Basin runoff, period and annual runoff (kAF) for the System reaches based on the 1898-2014 period of record.

	Fort Peck	Garrison	Oahe	Fort Randall	Gavins Point	Sioux City	Summation[4]
January	312	263	13	28	100	51	768
February	360	355	96	55	132	101	1,099
March	597	1,002	587	214	211	325	2,936
April	640	1,080	508	144	180	384	2,936
May	1,082	1,265	321	147	185	322	3,321
June	1,640	2,720	445	160	185	325	5,474
July	832	1,822	189	58	138	246	3,285
August	361	614	77	42	116	149	1,359
September	331	453	112	38	110	109	1,151
October	380	529	73	5	119	89	1,195
November	380	391	68	4	118	81	1,043
December	328	251	3	12	100	58	753
March-April[1]	1,237	2,082	1,095	358	390	709	5,871
May-June-July[2]	3,553	5,807	955	365	508	892	12,080
August-February[3]	2,451	2,866	441	184	795	638	7,366
Annual[4]	7,242	10,745	2,491	907	1,693	2,240	25,317

[1] March-April average runoff is the average of the non-rounded March-April sum of each year.
[2] May-June-July average runoff is the average of the non-rounded May-June-July sum of each year.
[3] August-February average runoff is the average of the non-rounded August-September-October-November-December-January-February sum of each year.
[4] Annual average runoff and monthly summations are the average of all non-rounded monthly runoff volumes.

Runoff in the upper Basin occurs in three general runoff time periods characterized by their dominant runoff source: (1) the March-April (MA) plains snowmelt period, (2) the May-June-July (MJJ) mountain snowmelt period, and (3) the August-February rainfall-runoff and baseflow period. Approximately 71 percent of the annual upper Basin runoff occurs during the MA plains snowmelt and MJJ mountain snowmelt periods. Approximately 23 percent of the annual runoff occurs during the MA period in all six System reaches, due primarily to plains snowmelt and rainfall runoff. Approximately 48 percent of the average annual runoff occurs during the MJJ period. Approximately 37 percent of the annual runoff occurs during the MJJ period in the Fort Peck and Garrison reaches alone, caused primarily by mountain snowmelt runoff. **Figure 2** illustrates the importance of MA runoff from all reaches and MJJ runoff from the Fort Peck and Garrison reaches. **Figure 2** also illustrates the monthly distribution of average annual upper Basin runoff and the concentration of runoff during the March to July period. Fort Peck MJJ runoff and Garrison MJJ runoff are the dominant sources of upper Basin runoff during this time

period. Therefore, the MA and MJJ periods and reaches require more detailed analysis and forecast methods.

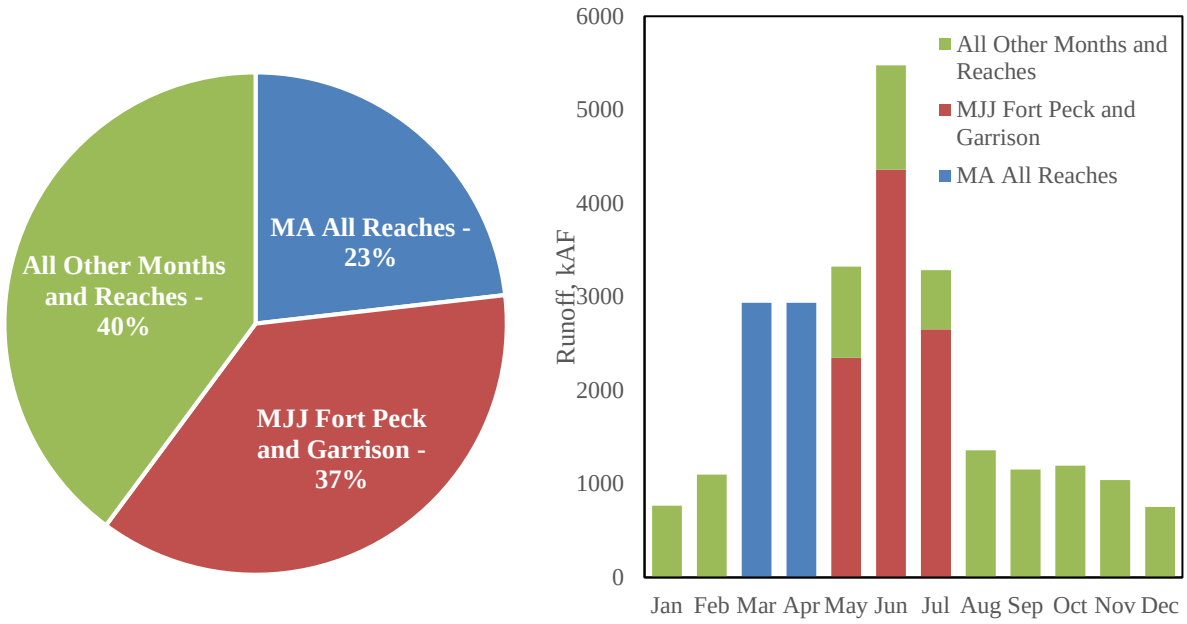

Figure 2. Percent of average annual upper Basin runoff by runoff period, and the monthly distribution of average annual upper Basin runoff (kAF) based on the 1898-2014 period.

B. Calendar Year Runoff Forecast

The Calendar Year Runoff Forecast, or Basic Forecast, presents monthly runoff during the calendar year from the six System reaches for all observed and forecast months. An example of the Calendar Year Runoff Forecast is shown in **Table 2**. The Calendar Year Runoff Forecast is used in the Monthly Study, a long-term System reservoir simulation. The Monthly Study model forecasts monthly System reservoir conditions through the remainder of the calendar year and January and February of the following calendar year. The Monthly Study forecasts how the System reservoirs will be regulated to serve the authorized purposes during this time period.

The Calendar Year Runoff Forecast is initially developed on January 1, when substantial information on hydrologic conditions is available to be able to make an initial runoff forecast. On January 1, monthly runoff is forecast for all six reaches and 12 months of the year. As the calendar year progresses, the forecast is updated on the first day of each month with observed runoff from past months and with updated runoff forecasts for future months. **Table 2** illustrates an example of a Calendar Year Runoff Forecast updated on March 1. Two months of observed runoff in January and February precede 10 months of forecast runoff from March through December in all six System reaches.

In order to provide a probable range of potential future runoff volumes that could occur if hydrologic conditions are wetter and drier than the Basic Forecast, the Upper Basic Forecast and

the Lower Basic Forecast are developed from the Basic Forecast, respectively. The methods for developing these forecasts are described in Determination and Analysis of Upper Basic and Lower Basic Forecasts (MRBWMD, 2015). The Upper Basic Forecast represents an approximate 10 percent exceedance (wetter-than-expected) runoff scenario, while the Lower Basic Forecast represents an approximate 90 percent exceedance (drier-than-expected) runoff scenario. All three forecasts are used in the Monthly Study model of future monthly System reservoir conditions to encompass approximately 80 percent of the potential future runoff volumes and reservoir conditions, given wetter and drier conditions.

Long-term runoff forecasts used in the Calendar Year Runoff Forecast rely on observed data including plains and mountain snowpack, and hydrologic conditions data to calculate estimates of future upper Basin runoff beginning on January 1. Forecasts developed on January 1 possess considerable runoff uncertainty because of uncertainty in future accumulations of plains and mountain snowpack, and uncertainty in future weather events in the upper Basin. Plains and mountain snowpack are the dominant runoff factors in the upper Basin, and forecasts developed after mountain snowpack has reached its peak accumulation possess potentially less runoff uncertainty. Furthermore, runoff uncertainty due to future weather events is high at lead times greater than one month, but uncertainty decreases as lead times decrease.

C. Previous Technical Reports

The original technical report describing runoff forecast methods was the Missouri River Division Reservoir Control Center Technical Report MH-73, Missouri River Reservoir System Long Range Runoff Forecasts (RCC, 1973). The subsequent technical report was the Missouri River Division Reservoir Control Center Technical Report D-79, Missouri River Mainstem Reservoir System Inflow Forecasting (RCC, 1979).

The most recent draft technical report on long-term runoff forecasts is Missouri River Basin Water Management Draft Technical Report D-96, Long-Term Runoff Forecasting (RCC, 1996). The D-96 report updated the methodology to use plains snow cover conditions to forecast MA runoff. It also incorporated longer-term mountain snowpack records, precipitation records, and temperature records to forecast MJJ runoff.

D. Purpose

The main purpose of this report is to describe two methods used to forecast MA runoff in the six reaches of the upper Basin and four variations of a method to forecast MJJ runoff in the Fort Peck and Garrison reaches. MA forecast methods use plains snowpack and hydrologic conditions data, while MJJ forecast methods use observed mountain snowpack and observed and forecast precipitation and temperature data. This report also describes methods to forecast monthly reservoir reach runoff during the remaining months of the year. Finally, guidance is provided on how to apply these methods together to develop a Calendar Year Runoff Forecast. Details regarding the data and analyses are incorporated into the appendices.

Table 2. Calendar Year Runoff Forecast

Upper Missouri River Basin

Calendar Year

Runoff Forecast (kAF)

March 1, 2010

	Incremental Runoff in Reaches								
	Fort Peck	Garrison	Oahe	Fort Randall	Gavins Point	Sioux City	Summation above Gavins Point	Summation above Sioux City	End-of-Month Accumulated Runoff above Sioux City
	(Observed)								
JAN 2010	343	340	87	210	176	238	1,156	1,394	1,394
AVERAGE	312	263	13	28	100	51	717	768	768
DEPARTURE	31	77	74	182	76	187	439	626	626
% OF AVG	110%	129%	658%	740%	175%	468%	161%	182%	182%
FEB 2010	330	313	48	144	158	176	993	1,169	2,563
AVERAGE	360	355	96	55	132	101	998	1,099	1,866
DEPARTURE	-30	-42	-48	89	26	75	-5	70	697
% OF AVG	92%	88%	50%	263%	119%	175%	99%	106%	137%
	(Forecast)								
MAR 2010	650	1,160	1,146	480	350	860	3,786	4,646	7,209
NORMAL	597	1,002	587	214	210	325	2,610	2,936	4,802
DEPARTURE	53	158	559	266	140	535	1,176	1,710	2,407
% OF NORM	109%	116%	195%	224%	166%	264%	145%	158%	150%
APR 2010	700	1,260	977	320	300	1,010	3,557	4,567	11,776
NORMAL	640	1,080	508	144	180	384	2,552	2,936	7,738
DEPARTURE	60	180	469	176	120	626	1,005	1,631	4,038
% OF NORM	109%	117%	192%	223%	167%	263%	139%	156%	152%
MAY 2010	630	730	526	160	289	676	2,336	3,011	14,787
NORMAL	1,082	1,265	321	147	185	322	3,000	3,321	11,059
DEPARTURE	-452	-535	205	14	104	354	-664	-310	3,728
% OF NORM	58%	58%	164%	109%	156%	210%	78%	91%	134%
JUN 2010	1,000	1,640	447	299	351	507	3,737	4,244	19,031
NORMAL	1,640	2,720	445	160	185	325	5,149	5,474	16,533
DEPARTURE	-640	-1,080	2	139	166	182	-1,412	-1,230	2,498
% OF NORM	61%	60%	100%	187%	190%	156%	73%	78%	115%
JUL 2010	550	1,115	189	58	138	246	2,050	2,296	21,327
NORMAL	831	1,822	189	58	138	246	3,039	3,285	19,818
DEPARTURE	-281	-707	0	0	0	0	-989	-988	1,510
% OF NORM	66%	61%	100%	100%	100%	100%	67%	70%	108%
AUG 2010	361	614	77	42	116	149	1,209	1,359	22,686
NORMAL	361	614	77	42	116	149	1,209	1,359	21,176
DEPARTURE	0	0	0	0	0	0	0	0	1,510
% OF NORM	100%	100%	100%	100%	100%	100%	100%	100%	107%
SEP 2010	330	453	112	37	110	109	1,042	1,151	23,837
NORMAL	330	453	112	37	110	109	1,042	1,151	22,327
DEPARTURE	0	0	0	0	0	0	0	0	1,510
% OF NORM	100%	100%	100%	100%	100%	100%	100%	100%	107%
OCT 2010	380	529	73	5	119	89	1,106	1,195	25,032
NORMAL	380	529	73	5	119	89	1,106	1,195	23,522
DEPARTURE	0	0	0	0	0	0	0	0	1,510
% OF NORM	100%	100%	100%	100%	100%	100%	100%	100%	106%
NOV 2010	380	391	68	4	118	81	962	1,043	26,074
NORMAL	380	391	68	4	118	81	962	1,043	24,565
DEPARTURE	0	0	0	0	0	0	0	0	1,510
% OF NORM	100%	100%	100%	100%	100%	100%	100%	100%	106%
DEC 2010	328	251	3	12	100	58	694	753	26,827
NORMAL	328	251	3	12	100	58	694	753	25,317
DEPARTURE	0	0	0	0	0	0	0	0	1,510
% OF NORM	100%	100%	100%	100%	100%	100%	100%	100%	106%
	Calendar Year Totals								
	5,982	8,796	4,095	1,773	2,324	4,200	22,627	26,827	
NORMAL	7,242	10,745	2,491	907	1,693	2,240	23,078	25,317	
DEPARTURE	-1,260	-1,949	1,604	866	631	1,960	-450	1,510	
% OF NORM	83%	82%	164%	195%	137%	188%	98%	106%	

II. MARCH-APRIL RUNOFF FORECASTS

The runoff season begins around March 1; therefore, the MA runoff period is a critical time of runoff for the upper Basin. MA runoff can exhibit substantial variability, ranging from very low runoff to very high runoff as seen in the **Figure 3** plot of MA upper Basin runoff for the 1898-2014 period. The average MA runoff volume is 5,872 kAF and the median runoff volume is 5,331 kAF. The minimum runoff volume was 2,184 kAF (37.2 percent of average) in 1931, while the maximum runoff volume was 15,871 kAF (270 percent of average) in 1952.

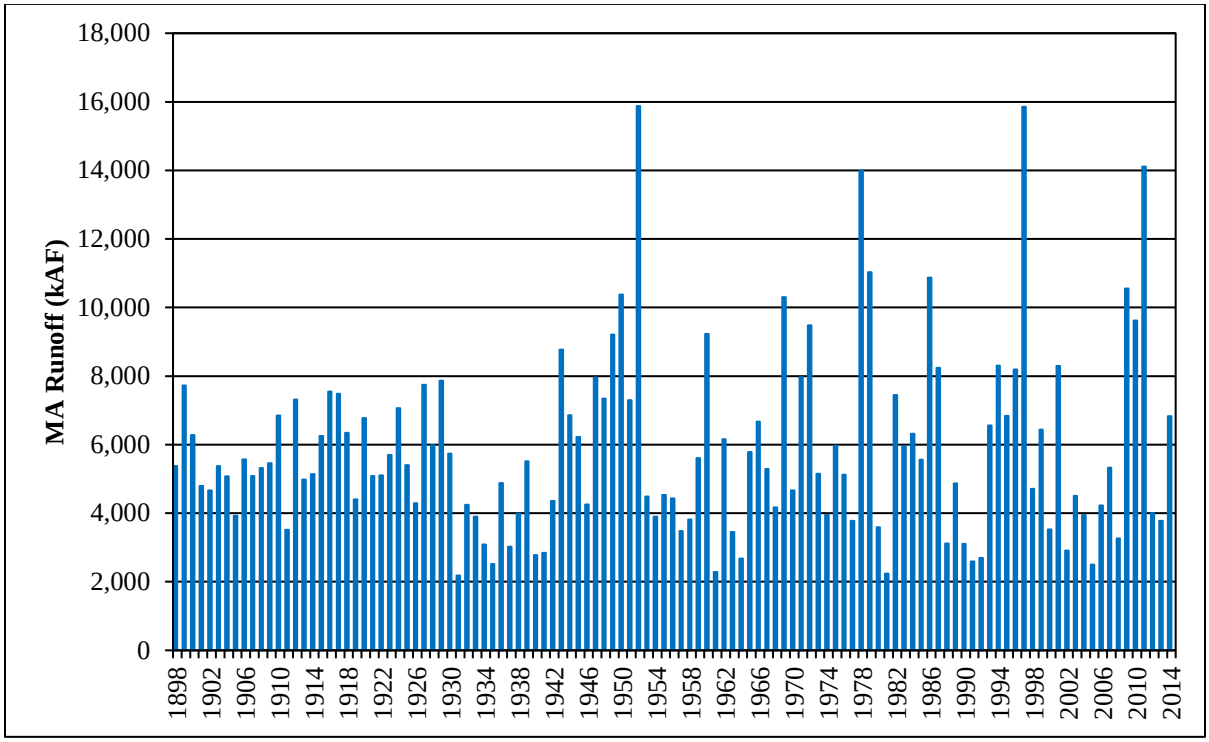

Figure 3. MA upper Basin runoff summation (kAF) for the 1898-2014 period.

MA runoff in the upper Basin is influenced by plains snowmelt and, to a lesser extent, rainfall. The magnitude of MA runoff is primarily a factor of plains snowpack coverage and the snow water equivalent (SWE), the depth of liquid water contained in the snowpack. Furthermore, the timing of snowmelt runoff can influence MA runoff variability. Early snowmelt, caused by unseasonably warm temperatures, may cause some of the snowmelt runoff to occur in January and February. Conversely, late snowmelt, caused by unseasonably cold temperatures, may cause all accumulated snowmelt runoff to occur during the latter part of the MA period. **Appendix A** describes significant plains snowmelt events that occurred during the past two decades.

The following two methods to forecast MA runoff are discussed in this report: 1) MA Method 1 – MA Runoff Forecast from Plains Snowpack and 2) MA Method 2 – MA Runoff Forecast from Hydrologic Conditions.

A. MA Method 1 – Runoff Forecast from Plains Snowpack

MA Method 1, MA Runoff Forecast from Plains Snowpack, uses the plains snowpack condition to forecast MA reach runoff. The plains snowpack condition is a qualitative and quantitative measure of the plains snowpack extent and magnitude by System reach during the plains snow accumulation season. The MA System reach runoff forecast using MA Method 1 includes four steps:

1) Determine plains SWE and depth by reservoir reach,
2) Determine the plains snowpack condition by reservoir reach,
3) Forecast MA System reach runoff based on an association of the plains snowpack condition to a MA runoff table, and
4) Divide the MA runoff forecast into March and April runoff forecast volumes.

1. Determination of Plains SWE and Snow Depth

The determination of plains SWE and depth may be accomplished by considering modeled plains snowpack assessments from the NWS National Operational Hydrologic Remote Sensing Center (NOHRSC), and snow depth and SWE measurements from various sources.

a) NOHRSC SWE and Snow Depth

One of the primary tools used by MRBWMD to assess plains SWE and snow depth in the upper Basin is the NOHRSC National Snow Analysis. An example NOHRSC snow analysis map showing inches of SWE is shown in **Figure 4**. NOHRSC maps are currently available at the NOHRSC website: http://www.nohrsc.noaa.gov/. NOHRSC provides comprehensive snow observations, analyses, datasets and map products for the United States. The NOHRSC maps allow the user to view current and past plains snow depth, SWE and other derivatives since 2005. MRBWMD forecasters evaluate current and historic plains information to determine the relative magnitude of the plains snowpack.

b) SWE and Snow Depth Measurements

Several useful plains SWE and snow depth measurement networks provide point snow measurements for the upper Basin. These point measurements are considered as independent data to assess plains snowpack, and also as verification to modeled plains snowpack assessments such as the NOHRSC national snow analysis. The sources of plains snow depth and SWE measurements used by MRBWMD are:

1) **North Dakota State Water Commission Atmospheric Resource Board Cooperative Observer Network**. The North Dakota volunteer network of over 500 observers collects daily snowfall and daily snowpack depth when snowfall occurs. Snowfall and snowpack data are currently available at the website: http://www.swc.nd.gov/arb/ndarbcon/.
2) **Community Collaborative Rain, Hail & Snow Network (CoCoRaHS)**. CoCoRaHS is a nationwide volunteer network that collects daily measurements of rain, hail and snowfall using low-cost measurement tools. Volunteers measure snowfall depth, cumulative snowpack depth, and to a limited degree, new SWE and cumulative SWE.

Snowfall and snowpack depth and SWE are currently available at the website: http://www.cocorahs.org/.

3) **National Weather Service Cooperative Observer Program (COOP)** and the **Automated Surface Station**. This network provides daily measurements of snowfall precipitation and SWE. The NWS performs cumulative snow depth and SWE measurements in the warning forecast office regions to periodically assess the state of plains snow. All measurements are currently available through the NWS website: http://www.weather.gov.

4) **USACE Cooperative Plains Snow Survey**. MRBWMD coordinates a volunteer group of plains SWE and snow depth observers. Cooperative observers are a collection of state and federal government observers including the NWS, USACE, the U.S. Geological Survey, as well as local government and private individual volunteers. The goal of this effort is to collect periodic plains SWE and depth measurements throughout the winter at predefined locations across the plains region of the upper Basin using snow survey equipment provided by USACE. Data from the measurements are used to assess the magnitude of plains snowpack as it evolves through the winter, and to help verify other plains snow assessment products. Information on how to make snow measurements, locations, and current measurement data are currently available through the USACE website: http://www.nwd-mr.usace.army.mil/rcc/snowsurvey/snowsurvey.html.

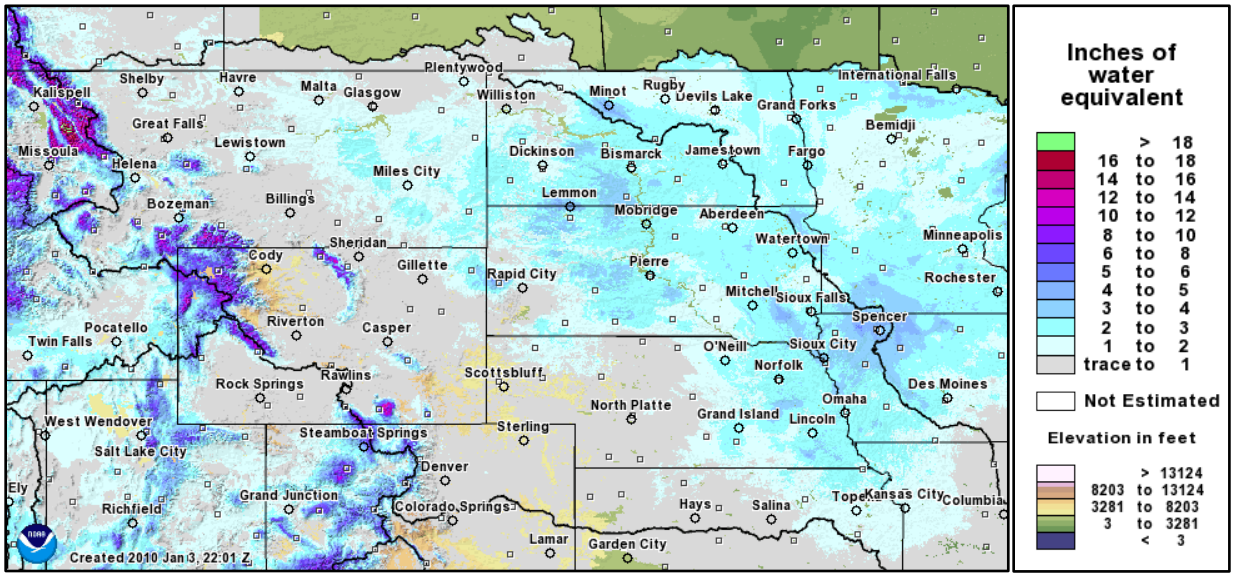

Figure 4. Example NOHRSC snow analysis map showing modeled SWE in the Missouri Basin.

2. Determination of the Plains Snowpack Condition

The determination of the plains snowpack condition can be performed by comparing current plains snowpack measurements and modeled depictions to historic measurements and depictions. This can be accomplished by comparing current SWE and snow depth measurements and maps to past SWE and snow depth records; however, plains snow assessments using modern tools, such as the NOHRSC national snow analysis, are available from 2005 to present.

In order to provide a quantitative method to determine the plains snowpack condition, MRBWMD developed numerical ranges of SWE, based on historic weather station snow data, for each plains snowpack condition. A detailed discussion about the development of the numerical ranges of SWE is provided in **Appendix B**. Plains snowpack conditions in **Table 3**, associated with numerical ranges of snowpack SWE for each System reach, include "light," "moderate," "heavy," and "very heavy" conditions. Plains snowpack and SWE depth can vary significantly within the System reservoir reaches due to differences in snowpack accumulation, wind movement and snowmelt. Since snowpack within a reservoir reach can vary substantially, the numerical ranges are used to characterize the average System reach snowpack condition. These ranges should be used as a guide, not an exact measure of SWE, to determine the plains snowpack condition. Snow depth and SWE measurements from the sources described in the previous section are considered when determining a plains snowpack condition.

Table 3. Numerical ranges of snowpack SWE (inches) associated with plains snowpack conditions, based on November through March snowfall accumulations.

System Reach	Plains Snowpack Conditions			
	"light"	"moderate"	"heavy"	"very heavy"
Fort Peck	1.5-2.5	2.5-3.5	3.5-4.5	4.5+
Garrison	1.5-2.5	2.5-3.5	3.5-4.5	4.5+
Oahe	1.0-2.0	2.0-3.0	3.0-4.0	4.0+
Fort Randall	1.0-2.0	2.0-3.0	3.0-3.5	3.5+
Gavins Point	1.0-2.0	2.0-3.0	3.0-3.5	3.5+
Sioux City	1.5-2.5	2.5-3.5	3.5-4.5	4.5+

One additional source of data to consider is an experimental, satellite-based plains snowpack assessment tool being developed for the Missouri Basin by the USACE Environmental Research and Development Center Cold Regions Research and Environmental Laboratory. A discussion on the development of the experimental satellite-based plains snowpack assessment tool is provided in **Appendix B**.

3. MA System Reach Runoff Forecasts

MA reach runoff forecast volumes are determined by associating plains snowpack conditions in **Table 3** with MA runoff volumes in **Table 4**. The MA runoff volumes in **Table 4** were developed from the 1898-2014 period runoff volumes. MA runoff in **Table 4** is divided into two general categories: 1) runoff that is forecast to occur during years when limited-to-no snow accumulates in the plains, and 2) runoff that is forecast to occur during years when snow accumulates in the plains and subsequently melts during March and April. Historic MA System reach runoff has been generally less than average during years with limited-to-no plains snowpack. Therefore, the No Snow Accumulation column of runoff volumes are the average of all historic MA runoff seasons, by individual System reach, when MA runoff was less than the historic MA average runoff. MA runoff volumes in **Table 4** should be used as a guide to forecast MA System reach runoff.

Table 4. MA runoff volumes (kAF) associated with the plains snowpack conditions.

System Reach	No Snow Accumulation[1]	MA Average Runoff	Plains Snowpack Condition Runoff Volumes[2]			
			25th percentile "light"	50th percentile "moderate"	75th percentile "heavy"	90th percentile "very heavy"
Fort Peck	960	1,240	1,350	1,510	1,860	2,270
Garrison	1,500	2,080	2,420	2,830	3,550	4,290
Oahe	560	1,100	1,320	1,640	2,460	3,990
Fort Randall	190	360	410	540	810	1,120
Gavins Point	300	390	480	580	690	820
Sioux City	330	710	870	1,080	1,800	2,390

[1] No Snow Accumulation volumes are based on 1898-2014 MA runoff seasons that were less than the 1898-2014 average MA volume.
[2] Plains snowpack condition runoff volumes are based on percentiles of 1898-2014 MA runoff seasons that were greater than the 1898-2014 average MA volume.

Plains snowpack condition runoff volumes for the four plains snowpack conditions are used when seasonal plains snowpack is present throughout the winter and melts beginning around early March. The plains snowpack condition runoff volume delineations are based on percentiles of MA runoff volumes from the MA record years in which the individual MA reach runoff volumes were greater than the historic MA average reach runoff. The runoff category percentiles associated with the plains snowpack conditions are: 1) 25th percentile "light," 2) 50th percentile "moderate," 3) 75th percentile "heavy," and 4) 90th percentile "very heavy." The runoff forecast volumes serve as a general guide to the forecaster and can be adjusted given considerations for soil moisture conditions, frost depths, streamflow conditions, temperatures and other pertinent factors that influence MA runoff.

4. March and April Runoff Volume Ratios to the Total MA Volume

The MA runoff forecast is divided into March and April runoff volumes using ratios of individual monthly runoff volumes to MA reach runoff volumes in **Table 5**, calculated for the 1898-2014 and 1985-2014 periods. The 1898-2014 period ratios provide a historical perspective of the ratio of monthly runoff to MA reach runoff, while the 1985-2014 period ratios provide a more recent perspective. It is important to note when comparing the two sets of ratios that the March ratio is higher and the April ratio is lower for the upper three reaches in the 1985-2014 period. For the lower three reaches, the 1985-2014 March ratios are lower than the 1898-2014 ratios, while the April ratios are higher.

Either set of ratios can be used as a general guide to determine March and April runoff in the Calendar Year Runoff Forecast. The 1985-2014 set of ratios is recommended as a starting point for the forecast, because they reflect the most recent 30 years of runoff. If seasonal observed temperatures and forecast temperatures are colder than the past 30 years of temperature climatology, or if plains snowmelt is anticipated to occur later in the season, the 1898-2014 ratios can be used to determine March and April runoff in the upper three reservoirs. The division of MA runoff between March and April could also consider a number of factors including observed temperature, forecast temperature, snowmelt timing and observed snowmelt runoff.

Table 5. Ratios of March and April runoff volumes to the MA runoff volumes based on the 1898-2014 and 1985-2014 period data.

Reservoir Reach	1898-2014		1985-2014	
	March	April	March	April
Fort Peck	0.48	0.52	0.53	0.47
Garrison	0.48	0.52	0.54	0.46
Oahe	0.54	0.46	0.58	0.42
Fort Randall	0.60	0.40	0.58	0.42
Gavins Point	0.54	0.46	0.53	0.47
Sioux City	0.46	0.54	0.40	0.60

5. Application

The steps to forecast MA reach runoff using MA Method 1 are as follows:

1) Determination of Plains SWE and Snow Depth. Use the NOHRSC national snow analysis maps in combination with field measurements provided by the listed sources of plains SWE and snow depth data to determine the range of SWE and average SWE within each System reach on the date of the current forecast.
2) Determination of Plains Snowpack Condition. Compare the current average reach SWE and range of SWE values to the numerical SWE ranges in **Table 3** with consideration for the time of year that plains SWE is being reported. Assign a plains snowpack condition based on the collective information.
3) Forecast MA System Reach Runoff. Using the reach plains snowpack conditions from **Table 3** and the MA runoff forecast volumes in **Table 4** as a guide, determine the MA runoff forecast volumes by reach.
4) Division of Forecast MA Reach Runoff Volumes. Using the ratios of March and April runoff to MA runoff in **Table 5** as a guide, determine the March and April runoff forecast volumes by reach. The March and April reach runoff forecast volumes can be further adjusted, based on factors discussed in **Section II.A.3** and **II.A.4**.
5) April 1 Plains Snowpack Condition Update (optional). On April 1, if additional plains snow accumulated during March, update the plains snowpack condition to the appropriate condition.
6) Forecast April System Reach Runoff. To forecast April reach runoff, subtract current observed March runoff from the forecast MA reach runoff volumes in step 3. If the plains snowpack condition increased to a higher condition, update the forecast MA runoff volumes. Subtract the current observed March reach runoff volumes from the updated MA reach runoff volumes to determine the forecast April reach runoff volumes. Adjust the forecast April reach runoff volumes, as needed, based on factors discussed in **Section II.A.3** and **II.A.4**.

The following discussion provides a brief example on how to use MA Method 1. On January 1, the NOHRSC SWE map for the Missouri Basin (**Figure 4**) indicated the Garrison to Oahe reservoir reach contained SWE amounts ranging from trace amounts near the Black Hills to 3.0 to 4.0 inches of SWE in the western tributaries of North Dakota and South Dakota. The average SWE based on this assessment was 2.0 to 3.0 inches. Cooperative snow survey measurements

for western North Dakota and South Dakota indicated point SWE measurements ranged from 1.5 to 2.5 inches. Based on SWE amounts from the NOHRSC snow map and snow survey measurements, a "moderate" plains snowpack condition (**Table 3**) was preliminarily assigned to the Oahe reach. However, the NWS future precipitation and temperature outlooks indicated a high likelihood for above normal snowfall and below normal temperatures during January and February; therefore, the snowpack condition was increased to "heavy". From **Table 4**, a MA runoff forecast volume of 2,460 kAF, corresponding to the "heavy" condition, was chosen for Oahe. Using the monthly ratios for the 1898-2014 period in **Table 5**, the March runoff forecast was 1,328 kAF and the April runoff forecast was 1,132 kAF.

On April 1, 1,378 kAF of observed March runoff was computed, which was very close to the March runoff forecast (1,328 kAF). Observed March runoff was subtracted from the MA runoff forecast volume to compute a new April runoff forecast volume of 1,082 kAF.

B. MA Method 2 - Runoff Forecast from Hydrologic Conditions

Although MA Method 1 is a good indicator of MA runoff potential based on observed plains snowpack, MA runoff varies substantially under variable snowpack and hydrologic conditions. Plains snowpack is challenging to assess due to variability in areal coverage, accumulation over time, and in measurement and reporting methods. An analysis of available hydrologic conditions data from the NOAA National Center for Environmental Information (NCEI) and the CPC indicated there is good correlation between MA runoff and hydrologic conditions data such as soil moisture, accumulated precipitation and seasonal temperatures. MA Method 2, MA Runoff Forecast from Hydrologic Conditions, utilizes multiple linear regression equations relating hydrologic conditions data to MA runoff.

1. Hydrologic Conditions Data

Hydrologic conditions data used in MA Method 2 includes soil moisture content, accumulated seasonal precipitation and average seasonal temperature. These three conditions were evaluated using monthly NCEI and CPC climate division data. Climate division data is an areal value of the hydrologic and meteorological parameters, derived from point measurements or modeled estimates of the parameter in a zone or area. In this analysis, hydrologic conditions data for the regressions was derived by computing average System reach values of soil moisture, precipitation, and temperature from monthly climate division data. Multi-month values of the hydrologic conditions are provided in **Appendix C**.

a) Soil Moisture

Soil moisture content describes the amount of water that a soil profile is holding as a percent or fraction of the soil profile capacity, or the amount of soil moisture contained in the profile expressed as a depth of moisture. Soil moisture is a very important parameter influencing the volume of runoff that could occur as a result of precipitation accumulation as rainfall or melted snow, precipitation infiltration into the soil, and precipitation runoff from the soil surface. NCEI climate division soil moisture data is computed by the CPC using the one-layer hydrologic model known as the Leaky Bucket Model (van den Dool, et al., 2003).

An analysis of soil moisture content at various dates versus MA runoff indicated that end-of-February soil moisture had the highest correlation to MA runoff. End-of-February soil moisture for each System reach was calculated by averaging the end-of-February soil moisture from the climate divisions that substantially overlap the System reaches. The resulting end-of-February average reach soil moisture in units of inches was used in the MA runoff regression analysis for the 1932-2014 period. For forecasting purposes, the current daily end-of-February soil moisture for each System reach is used to forecast the current season MA runoff. To forecast MA runoff on earlier dates, the current month-to-date soil moisture may be used. Historic end-of-February soil moisture for the reservoir reaches is provided in **Table C-2** and **Table C-3** in **Appendix C**.

b) Accumulated Precipitation

Precipitation as a source of runoff can occur as snow and rain during the winter season and during March and April. As it pertains to this analysis, accumulated precipitation during the snow accumulation season can be used as a substitute for accumulated plains SWE to predict MA runoff. NCEI climate division monthly precipitation totals were compiled for multi-month time periods, including three-month (December-January-February), four-month (November-December-January-February or December-January-February-March) and six-month (September-October-November-December-January-February or October-November-December-January-February-March) accumulation periods.

Accumulated multi-month precipitation for each System reach was calculated by determining the average multi-month precipitation from the climate divisions that substantially overlap the System reaches. The resulting reach multi-month accumulated precipitation in units of inches was used in the MA runoff regression analysis for the 1932-2014 period. For forecasting purposes, the average multi-month accumulated precipitation uses precipitation data from current observed months. If observed precipitation is not available because the current multi-month period ends on a future date, an estimate of forecast precipitation for each System reach may be developed from precipitation forecasts from sources such as NWS or CPC. Historic precipitation data for the reservoir reaches is provided in **Table C-2** and **Table C-3** in **Appendix C**.

c) Temperature

Temperature may affect MA runoff in several ways. Colder temperatures during the snow accumulation season maintain snowpack and delay the onset and rate of snowmelt. Increased snow accumulation and delayed snowmelt can increase MA runoff; and, decreased snow accumulation and early snowmelt decreases MA runoff. NCEI climate division average temperature was developed for each reach for multi-month periods including December-January-February and January-February-March.

Average multi-month temperature for each System reach was calculated by determining the average multi-month temperature from the climate divisions that substantially overlap the System reaches. The resulting reach multi-month average temperature in units of degrees Fahrenheit (deg F) was used in the MA runoff regression analysis for the 1932-2014 period. For forecasting purposes, the average multi-month temperature uses temperature data from current observed months. If observed temperature is not available because the current multi-month period ends on a future date, an estimate of forecast temperature for each System reach may be

developed from temperature forecasts from sources such as NWS or CPC. Historic temperature data for the reservoir reaches is provided in **Table C-2** and **Table C-3** in **Appendix C**.

2. Hydrologic Condition Regression Equations

MA Method 2 utilizes multiple linear regression equations to determine the MA runoff based on current antecedent hydrologic conditions data. The MA Method 2 equations were developed from historic data during the 1932-2014 period. The analysis to develop these equations determined which combinations had the strongest relationships to MA runoff. The hydrologic condition that produced the strongest multiple linear regression relationships, as indicated by the coefficient of determination (R^2) statistics, are provided in **Table 6**. R^2 is defined as the proportion of the variability in the dependent variable accounted for by the independent variable(s). The R^2 statistic has a range from 0 to 1.0, and a perfect relationship would result in an R^2 of 1.0. Climate divisions used in the regression analysis are also listed in **Table 6**.

Table 6. Best combinations of hydrologic conditions from NCEI climate division data used in the multiple linear regressions to forecast MA reach runoff volumes.

Reach	Climate Divisions[1]	Soil Moisture	Accumulated Precipitation	Average Temperature	R^2
Fort Peck	MT 2,3,4	February 28/29	Nov-Dec-Jan-Feb	Jan-Feb-Mar	0.738
Garrison	MT 3,5,6,7; ND 1,4,7	February 28/29	Nov-Dec-Jan-Feb	Jan-Feb-Mar	0.743
Oahe	ND 4,5,7,8; SD 1,2,4,5,6	February 28/29	Nov-Dec-Jan-Feb	Jan-Feb-Mar	0.753
Fort Randall	SD 5,6,8	February 28/29	Dec-Jan-Feb	Jan-Feb-Mar	0.428
Gavins Point	SD 9; NE 1,2	February 28/29	Oct-Nov-Dec-Jan-Feb-Mar	Jan-Feb-Mar	0.465
Sioux City	IA 1; MN 7; ND 5,9; SD 3,7,9	February 28/29	Oct-Nov-Dec-Jan-Feb-Mar	Jan-Feb-Mar	0.625

[1] State and climate divisions are shown in **Figure C-1** of **Appendix C**.

The multiple linear regression analysis used log-transformed data to develop a standard equation that uses the hydrologic conditions data combinations in **Table 6**. The standard form of the hydrologic conditions regression equation is:

$$Q = C * SM^{B1} * P^{B2} * T^{B3} \qquad \textit{(MA Method 2)}$$

where

Q = MA runoff forecast (kAF),

C = regression coefficient (**Table 7**),

SM = current year February 28/29 soil moisture (inches) ,

P = current year average accumulated reach precipitation (inches) based on observed and forecast division data for the multi-month period (**Table 6**),

T = current year average reach temperature (deg F) based on observed and forecast division data for the multi-month period (**Table 6**), and

B1, B2, B3 = regression exponents for SM, P and T (**Table 7**).

Table 7. Regression coefficients for the MA Method 2 equation.

	Reach					
	Fort Peck	**Garrison**	**Oahe**	**Fort Randall**	**Gavins Point**	**Sioux City**
Parameter						
C	215.2	641.8	141.5	563.7	102.1	0.304
B1	1.521	1.289	2.013	2.198	1.028	2.839
B2	0.339	0.572	1.221	0.706	0.387	1.348
B3	-0.572	-0.629	-1.042	-1.728	-0.447	-0.499

3. Application

In application, the MA forecast should consider both MA runoff forecast methods. At this time it is unknown which method is more accurate because a hindcasting analysis has not been performed. MA Method 1 can be used to make early forecasts based solely on snowpack, whereas MA Method 2 relies on current hydrologic conditions, which are not accurately known at the beginning of the calendar year. As the year progresses and hydrologic condition data becomes available, MA Method 2 can potentially become more accurate. Method 2 may be used with a combination of current observed and forecast hydrologic data, but it is most accurate when all hydrologic data is observed.

An example using MA Method 2 is illustrated in the following discussion for an Oahe forecast made on March 1, 2010. During the winter of 2009-2010 the plains received particularly heavy snowpack that persisted late into the winter. In addition, winter temperatures were well-below average and plains soil moisture was high at the beginning of winter. From **Table 6**, the hydrologic conditions data used for a MA runoff forecast at Oahe are February 28 soil moisture, accumulated November-December-January-February precipitation, and the average observed January-February-March temperature. Since March temperature is unknown on March 1, an estimate of March temperature must be made based on weather forecasts. One reliable source of precipitation and temperature forecasts is the CPC one-month and seasonal climate outlooks, based on numerical forecast models and expert assessments. CPC temperature outlooks indicate the probability that the average observed monthly or three-month temperature will be in the warmest, coldest, or average thirds of temperature climatology. Likewise, CPC precipitation outlooks indicate the probability that the average observed monthly or three-month precipitation will be in the wettest, driest, or average thirds of precipitation climatology. Forecast temperature and precipitation may also be based on recent weather trends.

The February 28, 2010 soil moisture, based on NCEI division data in the Oahe reach, was 10.0 inches. November-December-January-February precipitation, based on NCEI division data in the Oahe reach, was 2.2 inches (116 percent of the 1.9-inch long-term November-December-January-February average precipitation). The observed January-February Oahe reach temperature was 13.8 deg F (2.7 degrees below average). The CPC temperature outlook indicated there were equal chances that March temperatures would be in the warmest, coldest and average third of temperature climatology; therefore, March temperatures were expected to be average (29.1 deg F) in the Oahe reach. The average January-February-March temperature parameter computed from the observed January-February temperature and forecast March temperature was 18.9 deg F. Given the parameters estimated from observed and forecast

divisional data, the MA Method 2 equation using the Oahe coefficients in **Table 7** resulted in a MA runoff forecast of 1,786 kAF. March and April volumes for Oahe were divided using the 1898-2014 monthly ratios in **Table 5.** The MA Method 2 and the MA Method 1 runoff forecast volumes are provided in **Table 8**.

The MA Method 1 forecast agreed very well with the observed MA runoff, while the MA Method 2 under-forecast the MA runoff. The MA Method 1 forecast was 2.9 percent higher and MA Method 2 was 25.3 percent lower than the observed MA runoff. MA runoff in 2010 was influenced by March and April precipitation, and MA Method 2 does not account for March and April precipitation in the Oahe reach. The MA Method 1 runoff forecast assumed additional snowfall would occur later in the season, resulting in a higher plains snowpack condition.

Table 8. Comparison of the example March 1, 2010 MA runoff forecasts using MA Method 1 and MA Method 2 for the Oahe reach.

Period	Observed Runoff kAF	Method 1 Forecast kAF	Method 1 Difference		Method 2 Forecast kAF	Method 2 Difference	
			kAF	percent		kAF	percent
MA	2,391	2,460	69	2.9	1,786	-605	-25.3
March	1,378	1,328	-50	-3.6	964	-414	-30.0
April	1,013	1,132	119	11.7	822	-191	-18.9

III. MAY-JUNE-JULY RUNOFF FORECASTS FOR THE FORT PECK AND GARRISON REACHES

The MJJ runoff period is the most significant runoff period, accounting for approximately 48 percent of the annual runoff in the upper Basin. This forecast period is particularly important because it occurs at the peak of the runoff season. Runoff from the Fort Peck and Garrison reaches during the MJJ period account for 37 percent of the annual runoff in the upper Basin. The combined MJJ runoff in the Fort Peck and Garrison reaches for the 1898-2014 period is shown in **Figure 5**.

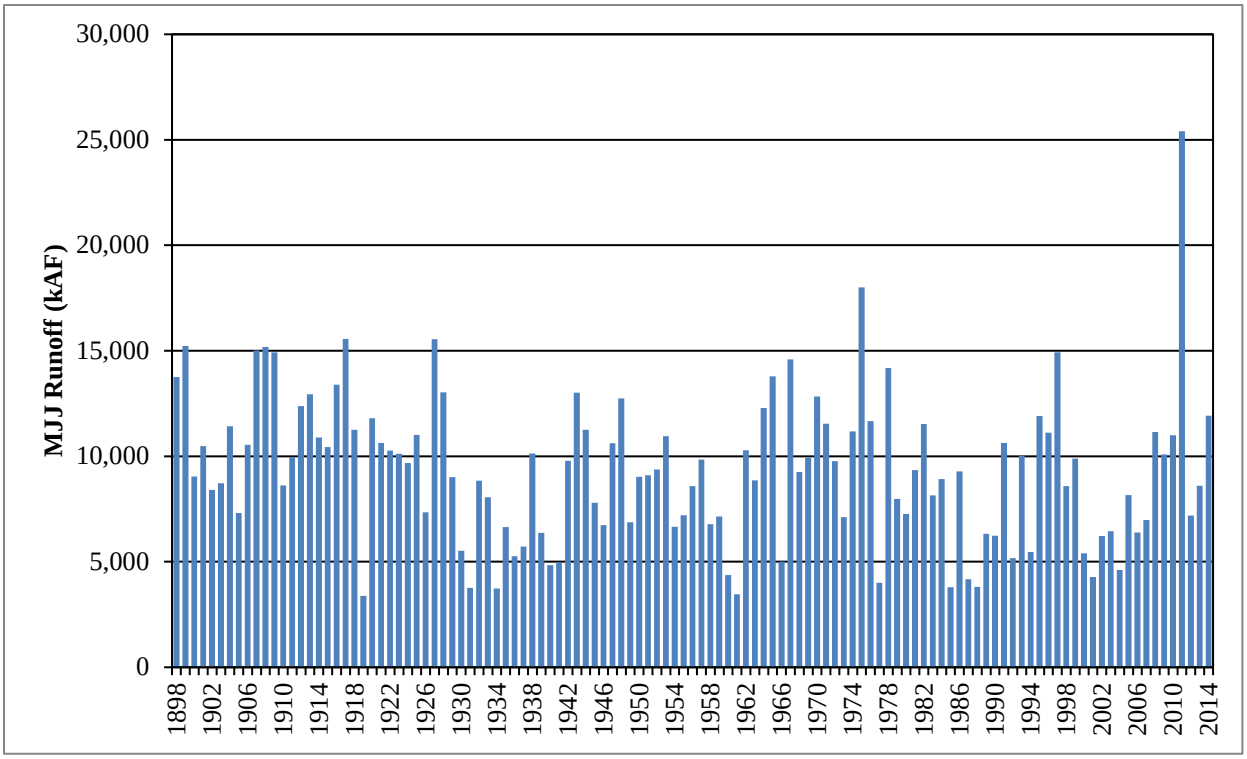

Figure 5. MJJ runoff (kAF) in the Fort Peck and Garrison reservoir reaches for the 1898-2014 period.

Seasonal mountain snowpack accumulation is the primary factor used to forecast MJJ runoff in the Fort Peck and Garrison reaches. Seasonal mountain snowpack accumulation, represented as the average Fort Peck and Garrison reach SWE, can have good correlations ($R^2 = 0.6$ at the peak SWE accumulation) with MJJ runoff. Since mountain snowpack typically accumulates from early October through mid-April, and then melts from mid-April through mid-July, monitored mountain snowpack enables forecasters to predict MJJ runoff. Other important factors used to forecast runoff during the MJJ period are average accumulated MJJ precipitation, average maximum April-May-June (AMJ) temperature, observed May runoff to forecast June-July runoff and observed May and June runoff to forecast July runoff.

The MJJ runoff forecast equations for the Fort Peck and Garrison reaches were developed in a simple and multiple linear regression analysis. Data used in the development of the forecast methods is provided in **Appendix D** and the forecast method development is described in **Appendix E**. The equations are used to forecast current year MJJ runoff from the runoff factors

of current year average reach SWE, current year average accumulated MJJ precipitation, current year average maximum AMJ temperature, observed May runoff and observed June runoff. There are four variations of the linear regression method equations that can be used depending on the availability of runoff factor data. The four variations of the MJJ runoff forecast method are as follows:

1) **MJJ Method 1 – SWE-Only**. This method utilizes average mountain reach SWE to forecast MJJ runoff. It is the only method to forecast runoff for the January 1, February 1, and March 1 forecast dates. It is also applicable to forecast MJJ runoff based on the April 1, peak and the May 1 average mountain reach SWE in the absence of other runoff factor data.
2) **MJJ Method 2 – SWE-Precipitation-Temperature**. This method utilizes average mountain reach SWE, observations of precipitation and temperature, and short lead-time precipitation and temperature forecasts (e.g. NOAA CPC three-month outlooks). It is the recommended method to forecast runoff for the April 1, May 1 and the peak SWE accumulation forecast dates when short lead-time forecasts of seasonal precipitation and temperature are available.
3) **MJJ Method 3 – SWE-Observed Runoff**. This method utilizes average mountain reach SWE and observed May or May-June runoff to forecast June-July and July runoff, respectively. It is one of two recommended methods to forecast June-July and July runoff for the June 1 and July 1 forecast dates.
4) **MJJ Method 4 – SWE-Precipitation-Observed Runoff**. This method utilizes average mountain reach SWE, observed May or May-June runoff and observed and forecast precipitation to forecast June-July and July runoff. It is one of two recommended methods to forecast June-July and July runoff for the June 1 and July 1 forecast dates.

Table 9 outlines the recommended use of the four variations of the MJJ runoff forecast methods, as they apply to the forecast date. Shading in the table indicates if the MJJ method is recommended (green), applicable (yellow) or inapplicable (light red). The recommended method changes as the year progresses because the strength of the correlations between MJJ runoff and the runoff factors increases or decreases.

Table 9. Recommended use of the four MJJ method variations by forecast date.

	MJJ Method			
Forecast Date	1	2	3	4
January 1	R	N/A	N/A	N/A
February 1	R	N/A	N/A	N/A
March 1	R	N/A	N/A	N/A
April 1	A	R	N/A	N/A
Peak Date	A	R	N/A	N/A
May 1	A	R	N/A	N/A
June 1	N/A	N/A	R	R
July 1	N/A	N/A	R	R

R – Recommended method
A – Applicable method
N/A – Inapplicable method

A. Runoff Factor Data

Current year mountain SWE, precipitation, temperature, and observed runoff are used in the MJJ forecast equations to forecast MJJ runoff. In order to forecast future MJJ runoff, runoff factor data must be prepared in a manner consistent with how it was analyzed when developing the forecast equations. The following sections describe the data sources and how the data should be prepared to develop runoff forecasts. Data from the 1961-2014 period was used in the development of the MJJ runoff forecast equations.

1. Mountain SWE

Mountain SWE data is monitored by the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) using the Snow Telemetry (SNOTEL) network of automated stations. The SNOTEL network of automated stations provides daily measurements of snow depth, SWE, and temperature. A map of station locations is shown in **Figure D-2** and a list of stations are included in **Table D-1** of **Appendix D**.

Average mountain reach SWE was analyzed as the main predictor in the regression analysis of MJJ runoff. The SNOTEL network came into existence during the middle to late 1960s, but it was not extensively expanded until the late 1970s and early 1980s. Since mountain SWE data is not consistently represented by the same number of stations in each System reach through the period of record, station records were adjusted using relationships between sets of stations to extend the record back to 1961, which is the year snow data was first used in previous MRBWMD forecasting reports. For analysis and forecasting purposes, average reach SWE is determined from 48 SNOTEL stations in the Fort Peck reach and 45 SNOTEL stations in the Garrison reach. The historic values of average reach SWE on the first day of each month from January through June and the date of peak accumulation are tabulated in **Table D-2** and **Table D-3** in **Appendix D** for the Fort Peck and Garrison reaches, respectively. MRBWMD computes current average daily reach SWE for monitoring purposes and on the aforementioned dates for forecasting purposes.

2. Precipitation

The average accumulated MJJ precipitation values from key NWS COOP weather stations within the Fort Peck and Garrison reaches are used to represent the precipitation runoff factor in the MJJ methods. In the Fort Peck reach, average accumulated MJJ precipitation was determined by computing the average of the accumulated MJJ precipitation from Montana weather stations in Bozeman, Cut Bank, Dillon, Helena, Great Falls, Glasgow, and Lewistown. In the Garrison reach, average accumulated MJJ precipitation was determined from Montana weather stations in Billings, Wolf Point, Glasgow, and Glendive, and from Wyoming weather stations in Lake Yellowstone, Lander, and Sheridan. The locations of these stations are shown in **Figure D-2** and listed in **Table D-4** in **Appendix D**. Data from Glasgow was used in the Fort Peck and Garrison reaches because it is geographically suitable for both reaches, and it correlated to MJJ runoff in both reaches. The historic values of average accumulated MJJ precipitation used in the regression analyses are tabulated in **Table D-5** of **Appendix D**.

For forecasting purposes, current year average accumulated MJJ precipitation is based on both observed and forecast MJJ precipitation. Observed precipitation is incorporated into the average accumulated MJJ precipitation factor as observations become available. Forecast MJJ precipitation can be estimated by adjusting the long-term average MJJ precipitation based on weather and CPC climate outlooks.

3. Temperature

Average maximum April-May-June (AMJ) temperature values from NWS COOP weather stations within the Fort Peck and Garrison reaches are used to represent the temperature runoff factor in the MJJ forecast methods. Temperature is an important factor in the accumulation and melt of mountain snowpack. Colder temperatures often yield greater snowpack accumulations, later peak accumulations, delayed snowmelt and greater runoff volumes. Warmer temperatures often yield lower snowpack accumulations, earlier peak accumulations, earlier snowmelt, and lower runoff volumes. In the analysis of temperature data, it was found that maximum daily temperature averaged during the AMJ period for selected weather stations had the greatest correlation to MJJ runoff. In the Fort Peck reach, average maximum AMJ temperature was computed from Montana weather stations in Cut Bank, Dillon, and Helena. In the Garrison reach, average maximum AMJ temperature was computed from weather stations in Billings, Montana; Sheridan, Wyoming and Lander, Wyoming. The locations of these stations are shown in **Figure D-2** and listed in **Table D-4** in **Appendix D**. The historic values of average maximum AMJ temperature for the Fort Peck and Garrison reaches are tabulated in **Table D-6**.

For forecasting purposes, current year average maximum AMJ temperature is based on both observed and forecast AMJ temperature. Observed maximum temperature is incorporated into the average maximum AMJ temperature factor as observations become available. Forecast AMJ temperature can be estimated by adjusting the long-term average maximum AMJ temperature based on weather forecasts and CPC climate outlooks.

4. Observed Runoff

Observed runoff has been incorporated as a regression parameter in order to improve the June-July runoff forecast and the July runoff forecast. Fort Peck and Garrison observed May runoff and observed May-June runoff are used to represent the observed runoff factor in the June-July and July forecast methods, respectively. Since current year observed runoff is first available on June 1, the MJJ forecast method that uses observed runoff as a runoff factor can only be used on June 1 to forecast June-July runoff and July 1 to forecast July runoff.

B. MJJ Method 1 - SWE-Only

The MJJ Method 1 – SWE-Only equations to forecast MJJ runoff are based on current forecast year mountain SWE on the date of forecast. The analysis indicated that a log-log equation provided the most accurate results for the January 1, February 1, March 1, April 1, and the date of peak SWE forecasts while the log-linear equation provided the most accurate results for the May 1 forecast.

The log-log form of the MJJ Method 1 equation is:

$$Q = B * SWE^{X} \qquad \textit{(MJJ Method 1 Log-Log)}$$

where

Q = MJJ runoff forecast (kAF),

SWE = average reach SWE (inches) on the date of forecast,

B = regression coefficient (**Table 10**), and

X = regression exponent (**Table 10**).

The log-linear form of the MJJ Method 1 equation for May 1 forecasts is:

$$Q = B * 10^{X*SWE} \qquad \textit{(MJJ Method 1 Log-Linear)}$$

Table 10. Regression coefficients for the MJJ Method 1 – SWE Only equation.

	Fort Peck			**Garrison**		
Log-Log Parameters	***B***	***X***	**R^2**	**B**	***X***	**R^2**
Forecast Date						
January 1	605.0	0.850	0.212	901.0	0.940	0.299
February 1	157.0	1.270	0.415	374.0	1.190	0.445
March 1	104.0	1.310	0.393	282.0	1.190	0.404
April 1	42.0	1.540	0.454	132.0	1.380	0.429
Peak SWE	19.0	1.770	0.591	56.0	1.640	0.613
Log-Linear Parameters	***B***	***X***	**R^2**	***B***	***X***	**R^2**
Forecast Date						
May 1	1,056.7	0.030	0.567	1586.4	0.040	0.635

C. MJJ Method 2 - SWE-Precipitation-Temperature

The MJJ Method 2 - SWE-Precipitation-Temperature equation is based on current forecast year mountain SWE on April 1, May 1, and the date of peak mountain SWE, current year average accumulated MJJ precipitation, and current year average maximum AMJ temperature. The precipitation and temperature parameters are based on observations and forecasts as discussed in **Section III.A**. The standard form of the MJJ Method 2 equation is:

$$Q = B * SWE^{X1} * P^{X2} * T^{X3} \qquad \textit{(MJJ Method 2)}$$

where

Q = MJJ runoff forecast (kAF),

SWE = average reach SWE (inches) on the date of forecast,

P = current year average accumulated MJJ precipitation (inches) based on observed and forecast precipitation,

T = current year average maximum AMJ temperature minus 32 (deg F) based on observed and forecast temperature,

B = regression coefficient (**Table 11**), and

X1, X2, X3 = regression exponents for *SWE, P, & T* (**Table 11**).

Table 11. Regression coefficients for the MJJ Method 2 – SWE-Precipitation-Temperature equation.

	Fort Peck			Garrison		
Forecast Date	**April 1**	**Peak**	**May 1**	**April 1**	**Peak**	**May 1**
Parameter						
B	460,255	42,618	381,722	60,150	1,190	15,300
X1	1.111	1.228	0.605	1.080	1.300	0.790
X2	0.522	0.507	0.492	0.590	0.610	0.520
X3	-2.617	-2.048	-2.116	-1.790	-0.900	-1.140
R^2	0.849	0.847	0.776	0.830	0.856	0.832

D. MJJ Method 3 - SWE-Observed Runoff

The MJJ Method 3 – SWE-Observed Runoff equation is based on June 1 mountain SWE for the current forecast year, and May or May-June observed reach runoff. The observed May runoff parameter is used for the June-July forecast, and the observed May-June runoff parameter is used for the July forecast. The standard form of the MJJ Method 3 equation is:

$$Q = B + C_1 * SWE + C_2 * Q_m \qquad \textit{(MJJ Method 3)}$$

where

Q = June-July or July runoff forecast (kAF),

SWE = average reach SWE (inches) on June 1,

Q_m = observed May runoff (kAF) for the June-July forecast or observed May-June runoff (kAF) for the July forecast,

B = regression intercept (**Table 12**), and

C_1, C_2 = regression slope coefficients for *SWE* & Q_m (**Table 12**).

Table 12. Regression coefficients for the MJJ Method 3 – SWE-Observed Runoff equation.

	Fort Peck		Garrison	
Forecast Date	**June 1**	**July 1**	**June 1**	**July 1**
Parameter				
B	217.0	71.0	943.0	-218.0
C_1	168.3	23.3	272.7	87.2
C_2	1.023	0.249	1.235	0.379
R^2	0.749	0.656	0.757	0.737

E. MJJ Method 4 - SWE-Precipitation–Observed Runoff

The MJJ Method 4 – SWE-Precipitation-Observed Runoff equation is based on current year June 1 mountain SWE, May or May-June observed reach runoff, and current year average accumulated MJJ precipitation from precipitation observations and forecasts. For the June-July runoff forecast, the average accumulated MJJ precipitation is based on observed May and forecast June-July precipitation, and observed May runoff is used. For the July runoff forecast, the average accumulated MJJ precipitation is based on observed May-June and forecast July precipitation, and observed May-June runoff is used. The standard form of the MJJ Method 4 equation is:

$$Q = B + C_1 * SWE + C_2 * P + C_3 * Q_m \qquad (\textit{MJJ Method 4})$$

where

Q = June-July or July runoff forecast (kAF),

SWE = average reach SWE (inches) on June 1,

P = current year average accumulated MJJ precipitation (inches), based on observed and forecast data,

Q_m = observed May runoff (kAF) for the June-July forecast or observed May-June runoff (kAF) for the July forecast,

B = regression intercept (**Table 13**), and

C_1, C_2, C_3, = regression slope coefficients for SWE, P & Q_m (**Table 13**).

Table 13. Regression coefficients for the MJJ Method 4 – SWE-Precipitation-Observed Runoff equation.

	Fort Peck		Garrison	
Forecast Date	**June 1**	**July 1**	**June 1**	**July 1**
Parameter				
B	-1,009	-457	-694	-925
C_1	165.9	38.5	264.8	107.0
C_2	241.8	111.2	375.0	196.6
C_3	0.753	0.142	0.765	0.214
R^2	0.842	0.771	0.839	0.807

F. Monthly Volume to the Total MJJ Volume Ratios

The MJJ runoff forecast volume can be divided into May, June, and July runoff forecast volumes using ratios of individual monthly runoff volumes to the total MJJ runoff volume. The ratios in **Table 14** were calculated from 1898-2014 and 1985-2015 historic MJJ runoff data. Either set of ratios can be used as a guide to determine the monthly runoff forecasts from the MJJ runoff forecast. The division of the MJJ runoff forecast into monthly forecasts can also consider situational factors that affect the timing of snowmelt such as the dates of the peak SWE accumulation, the starting dates of snowmelt, the rate of snowmelt, the amount of snowpack remaining in subsequent months, and forecasted temperatures. When observed monthly runoff

volumes have been computed at the time of the June 1 forecast, the June-July runoff forecast volume is divided into June and July volumes using the relative ratios of the June and July ratios in **Table 14**.

Table 14. Ratios of the monthly runoff volumes to the total MJJ runoff volumes based on 1898-2014 and 1985-2014 period data.

	1898-2014			1985-2014		
Month	**May**	**June**	**July**	**May**	**June**	**July**
Fort Peck	0.30	0.46	0.24	0.29	0.46	0.25
Garrison	0.22	0.47	0.31	0.21	0.47	0.32

G. Application

Table 15 illustrates an example of how the MJJ methods can be used to develop the MJJ runoff forecast for the Calendar Year Runoff Forecast. Using 2010 data for the Garrison reach, **Table 15** lists the MJJ forecast equation runoff factors of SWE, average accumulated MJJ precipitation, average maximum AMJ temperature, observed runoff, and the resulting MJJ, June-July, and July runoff forecast volumes. The observed runoff volumes are listed, and the difference between the forecast and observed runoff volumes are calculated. Additionally, the forecast results are shaded to correspond with the recommended methods (green shading) and applicable methods (yellow shading), as defined in **Table 9**.

During the 2010 winter, mountain SWE in the Garrison reach was below average. From January 1 to March 1, mountain SWE in the Garrison reach increased slowly, but fell further below the long-term average SWE on each forecast date. For MJJ Method 2, which uses MJJ precipitation and AMJ temperature, NOAA CPC three-month climate outlooks were used to estimate future precipitation and temperature in the absence of current year observed precipitation and temperature. Long-term average accumulated MJJ precipitation and average maximum AMJ temperature, provided in **Appendix D,** were adjusted using the CPC precipitation and temperature outlooks. At the time of the forecasts, CPC was indicating increased chances for above-normal precipitation, combined with increased chances for below-normal temperatures. In the May 1 forecast, average maximum AMJ temperature was computed from current year observed maximum April temperatures, based on COOP station data, and on forecast maximum May-June temperatures. Since current year observed precipitation was not available on May 1, accumulated MJJ precipitation was computed from forecast MJJ precipitation for the May 1 forecast. For the June 1 forecast, MJJ precipitation was computed using current year observed May precipitation, based on COOP station data, and on forecast June-July precipitation. For subsequent months, additional observed COOP data was available to compute precipitation and temperature. For simplicity in this example, all forecast dates used the same average accumulated MJJ precipitation (8.5 inches) and average maximum AMJ temperature (31.0 deg F) parameters. It is important to note that the accuracy of MJJ runoff forecasts is dependent on the accuracy and interpretation of forecast precipitation and temperature parameters, when current observed precipitation and temperature data is not available.

Method 1 was used for January 1, February 1 and March 1 forecasts. MJJ runoff forecasts were well below the 5,807 kAF long-term average runoff for the Garrison reach (**Table 15**). The April 1, May 1, and date of peak SWE forecasts were made using Methods 1 and 2. Method 1 used only the mountain SWE factor. Method 2 used mountain SWE, an estimate of average accumulated MJJ precipitation forecast, and an estimate of average maximum AMJ temperature forecast. Since the CPC forecasts indicated a significant probability for above-normal precipitation and below-normal temperatures, the Method 2 forecasts were favored over the Method 1 forecasts for April 1, May 1 and the peak date of SWE accumulation. Method 3 and Method 4 forecasts were used for June 1 and July 1 forecasts using June 1 mountain SWE, and observed May and observed May-June runoff to forecast June-July and July runoff, respectively. Method 4 forecasts use average accumulated MJJ precipitation to account for the effects of seasonal precipitation. The Method 4 June 1 forecast used observed May precipitation and a June-July precipitation forecast, combined into average accumulated MJJ precipitation. The Method 4 July 1 forecast used observed May-June precipitation and a July precipitation forecast combined into average accumulated MJJ precipitation. Since average accumulated MJJ precipitation was well-above average in this forecast, the Method 4 forecasts for June 1 and July 1, which account for the influence of above-average precipitation, are recommended over Method 3.

Table 15. Comparison of example MJJ forecast method results for the Garrison reach.

Method	Forecast Date	Parameters			Runoff (kAF)		Difference (kAF)	Difference (percent)
		SWE (inches)	n/a	n/a	Forecast MJJ	Observed MJJ		
1	**January 1**	5.43			4,420	6,872	-2,452	-35.7
	February 1	6.99			3,780		-3,082	-44.8
	March 1	8.26			3,480		-3,392	-49.4
	April 1	10.57			3,500		-3,372	-49.1
	May 1	11.15			4,430		-2,442	-35.2
	Peak	14.26			4,370		-2,502	-36.4
		SWE (inches)	**P (inches)**	**T (deg F – 32)**	**Forecast MJJ**	**Observed MJJ**	**Difference (kAF)**	**Difference (percent)**
2	**April 1**	10.57	8.5	31.0	5,810	6,872	-1,062	-15.5
	May 1	11.15	8.5	31.0	6,240		-632	-9.2
	Peak	14.26	8.5	31.0	6,320		-552	-8.0
		SWE (inches)	**n/a**	**Qm, (kAF)**	**Forecast June-July/July**	**Observed June-July/July**	**Difference (kAF)**	**Difference (percent)**
3	**June 1**	9.29		980	4,695	5,892	-1,197	-20.3
	July 1	9.29		4,345	2,245	2,527	-282	-11.2
		SWE (inches)	**P (inches)**	**Qm (kAF)**	**Forecast June-July/July**	**Observed June-July/July**	**Difference (kAF)**	**Difference (percent)**
4	**June 1**	9.29	8.5	980	5,710	5,892	-182	-3.1
	July 1	9.29	8.5	4,345	2,700	2,527	173	6.8

A comparison of the MJJ runoff forecast to the observed runoff for the recommended methods indicates that the January 1, February 1 and March 1 forecasts exhibited substantial forecast error. Method 1 forecast runoff was 35.7 to 49.4 percent below the observed MJJ runoff. For later forecast dates, better observations of Garrison reach SWE, and precipitation

and temperature forecasts could be incorporated into the Method 2 forecast. This led to better forecasts of MJJ runoff. When observed May runoff was incorporated with June 1 Garrison SWE and MJJ precipitation using Methods 3 and 4, respectively, the difference between the observed June-July runoff and the June-July runoff forecast became much smaller (-20.3 to -3.1 to percent). Finally, when observed May-June runoff was incorporated using Methods 3 and 4 to compute July runoff, the differences between observed runoff and the runoff forecast ranged from -11.2 to 6.8 percent.

IV. REMAINING MONTHLY REACH FORECASTS

Upper Basin runoff during the remaining months of the calendar year, August-February in all reaches and May-July in the Oahe to Sioux City reaches, depends on seasonal baseflow and seasonal precipitation. The upper Basin August-February runoff for the 1899-2014 period is shown in **Figure 6**. Data for the August 1897-February 1898 period is not included because there is no data for August-December 1897. The total Oahe, Fort Randall, Gavins Point, and Sioux City May-July runoff for the 1898-2014 period is shown in **Figure 7**.

Forecasts during the remaining months of the calendar year are made by:

a) Using average monthly reach runoff as a starting approximation,
b) Adjusting the monthly reach runoff based on soil moisture conditions,
c) Adjusting monthly reach runoff based on the following seasonal climate forecasts:
    1) the NOAA CPC monthly to seasonal temperature outlooks
    2) the NOAA CPC monthly to seasonal precipitation outlooks, and
d) Adjusting the monthly reach runoff estimates based on results from the Monthly Runoff Persistence Method, which assumes past monthly trends will persist.

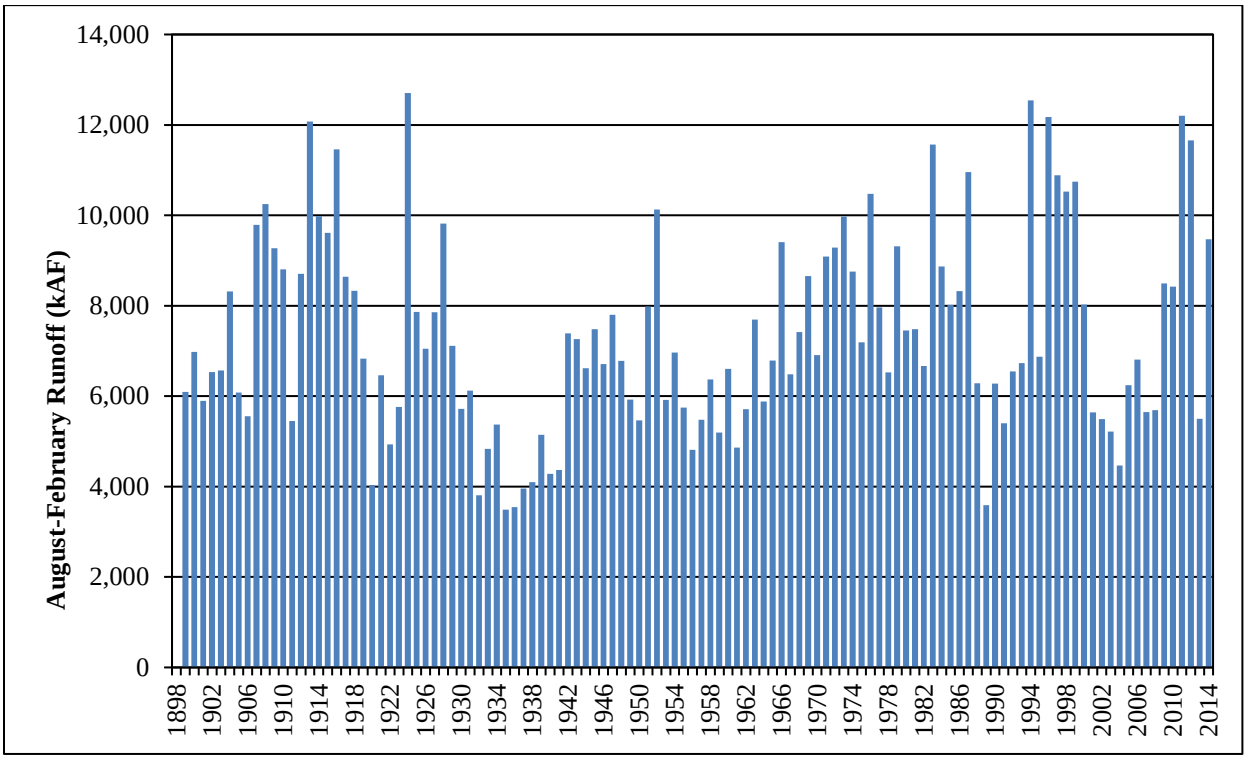

Figure 6. August-February upper Basin runoff summation (kAF) for the 1899-2014 period.

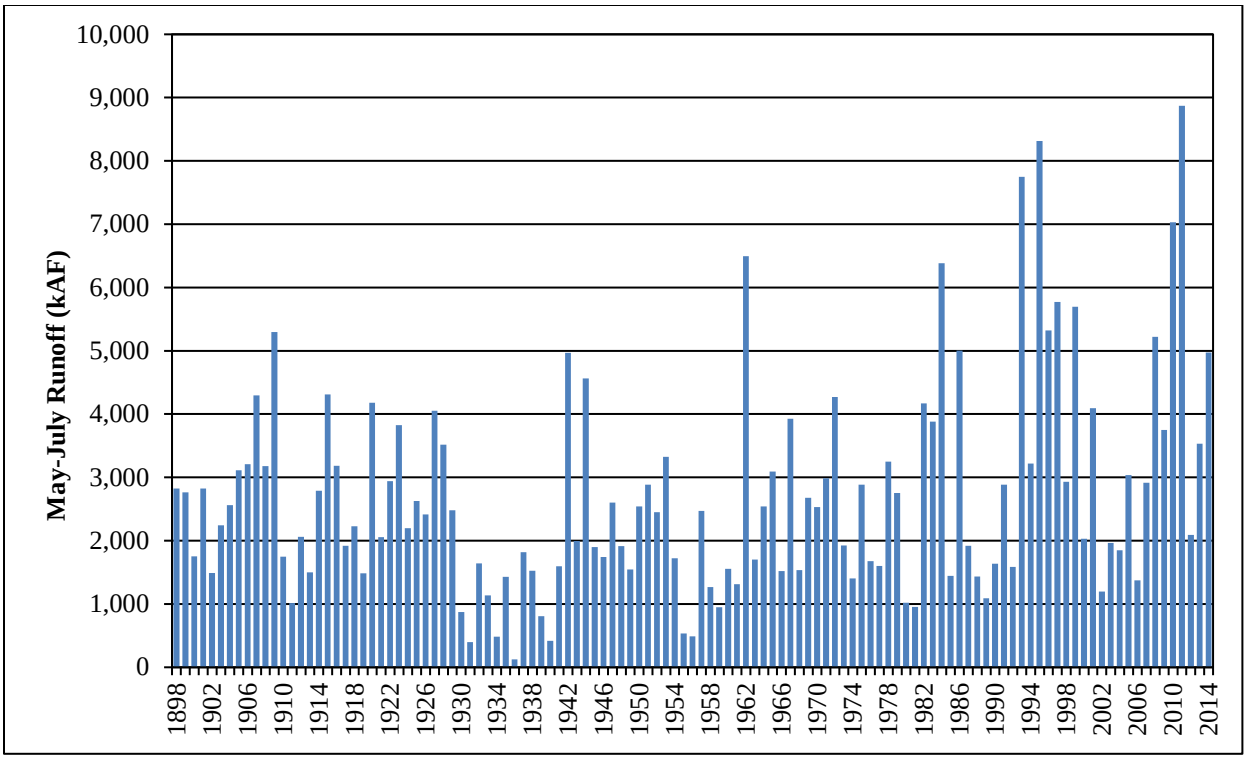

Figure 7. May-July Oahe, Fort Randall, Gavins Point, and Sioux City reach runoff (kAF) for the 1898-2014 period.

A. Average Monthly Runoff and Deciles

Average monthly runoff by System reach for the 1898-2014 period is provided in **Table 1**, and historic System reach runoff is provided in **Table F-1** through **Table F-6** in **Appendix F**. Average monthly runoff may be used as an aid to forecast future monthly reach runoff.

In addition to average monthly runoff, the monthly reach upper quartile and lower quartile runoff volumes and upper decile and lower decile runoff volumes can be used as an aid to forecast monthly reach runoff. The upper and lower quartiles and upper and lower deciles are provided in the MRBWMD Technical Report - Runoff Volumes for AOP Studies (MRBWMD, 2013).

B. Soil Moisture Conditions

Soil moisture content has a major influence on the volume of runoff that can occur during a runoff season. The influence of soil moisture content on MA runoff was discussed in Chapter II and in **Appendix C**. Under increasingly wet soil moisture conditions, runoff volumes tend to increase given constant precipitation and temperature, and vice versa. Therefore, runoff forecast volumes may be adjusted up or down from average runoff volumes in order to reflect wetter or drier soil moisture conditions at the time of the forecast. Two commonly used tools to evaluate soil moisture conditions are the CPC Soil Moisture Monitor, currently available at http://www.cpc.ncep.noaa.gov/products/Soilmst_Monitoring/US/Soilmst/Soilmst.shtml, and the National Land Data Assimilation System Soil Moisture Monitor, currently available at

http://www.emc.ncep.noaa.gov/mmb/nldas/drought/. Both assessments provide a U.S. map of modeled soil moisture in the active soil profile, the soil moisture anomaly, and the soil moisture percentile ranking. The soil moisture percentile ranking and soil moisture anomaly maps are very useful because they provide comparisons of the current soil moisture conditions to the normal soil moisture based on all other modeled years of soil moisture.

C. Seasonal Climate Forecasts

Monthly to seasonal outlooks of precipitation and temperature developed by the NOAA CPC are also considered in determining monthly runoff forecasts for the remaining months. Monthly and seasonal outlooks are currently available at http://www.cpc.ncep.noaa.gov/. These outlooks provide a forecast of the probability for precipitation and temperature to be below normal, normal, or above normal, relative to the 30-year climatological normal values. Monthly outlooks are updated at the end of the month, and on the third Thursday of each month for the following month. The three-month outlooks are updated for the subsequent three-month periods on a monthly basis with lead times up to one year in advance. Since outlook skill typically increases as the lead time decreases, forecaster confidence is typically lower for outlooks created more than one month in advance, unless climate indicators such as the El Niño Southern Oscillation (ENSO) are present. Although the outlooks do not convey an actual precipitation amount or temperature level, the outlook probabilities, which provide an indication of future precipitation and temperature conditions, are considered by the forecaster.

D. Monthly Runoff Persistence Method

In all System reaches, there is typically month-to-month correlation or persistence between monthly runoff. In other words, the runoff in a single reach during one month can be used as an indicator for runoff in a single reach during the subsequent month. For example, if runoff is high with respect to average monthly runoff, the subsequent month runoff is also likely to be high with respect to average monthly runoff.

The Monthly Runoff Persistence Method was developed by performing simple linear regressions between consecutive months of observed monthly runoff. For example, a simple linear regression was developed between the Fort Peck July runoff volume (observed) and the Fort Peck August runoff volume (to be forecast). Linear regressions were performed for all reaches to develop equations to predict the subsequent monthly reach runoff given monthly observed runoff. The standard form of the persistence equation is:

$$Q_f = B + C * Q_m \qquad \text{(\textit{Persistence Method})}$$

where

Q_f = monthly runoff forecast (kAF),

Q_m = observed previous month's runoff (kAF),

B = regression intercept (**Table 16**), and

C = regression coefficient (**Table 16**).

This method is intended to be used as one of several monthly runoff forecast tools. As a general guideline, the Persistence Method should be limited in use to August-February in all reaches and to May, June, and July in the Oahe, Fort Randall, Gavins Point, and Sioux City reaches. The results of the equations should be considered alongside current hydrologic conditions, and precipitation and temperature outlooks.

Table 16. Monthly Runoff Persistence Method coefficients.

Forecast Month	**Fort Peck Coefficients**			**Garrison Coefficients**		
	B	***C***	**R^2**	***B***	***C***	**R^2**
January	173.5	0.475	0.238	185.5	0.150	0.020
February	170.5	0.698	0.211	249.7	0.439	0.075
August	167.3	0.255	0.539	102.6	0.252	0.573
September	128.7	0.586	0.365	160.3	0.442	0.426
October	154.6	0.679	0.633	384.2	0.383	0.224
November	152.0	0.655	0.745	231.9	0.263	0.159
December	94.5	0.603	0.449	206.2	0.050	0.003
Forecast Month	**Oahe Coefficients**			**Fort Randall Coefficients**		
	B	***C***	**R^2**	***B***	***C***	**R^2**
January	30.4	-0.007	0.000	70.9	0.067	0.004
February	133.2	0.629	0.131	85.4	0.152	0.012
May	262.6	0.270	0.235	76.3	0.623	0.295
June	234.6	0.403	0.199	81.8	0.570	0.239
July	110.6	0.215	0.151	8.8	0.294	0.327
August	-8.2	0.532	0.544	20.5	0.464	0.408
September	35.7	0.316	0.309	-2.4	0.484	0.290
October	3.6	0.818	0.130	-29.5	0.611	0.267
November	56.2	0.187	0.172	-17.8	0.053	0.005
December	-20.9	0.429	0.173	53.3	-0.016	0.000
Forecast Month	**Gavins Point Coefficients**			**Sioux City Coefficients**		
	B	***C***	**R^2**	***B***	***C***	**R^2**
January	87.1	0.295	0.102	37.9	0.575	0.435
February	81.8	0.688	0.261	71.9	0.677	0.294
May	85.1	0.679	0.405	136.3	0.534	0.633
June	136.4	0.426	0.166	151.9	0.700	0.448
July	77.0	0.491	0.308	-7.1	0.741	0.530
August	67.5	0.463	0.386	44.7	0.445	0.731
September	8.1	0.852	0.632	30.4	0.590	0.747
October	28.5	0.771	0.753	2.8	0.920	0.808
November	47.8	0.652	0.599	50.0	0.526	0.568
December	75.3	0.310	0.094	20.0	0.673	0.567

V. SUMMARY

This report presented methods to develop long-term runoff forecasts for upper Basin runoff during the three general runoff periods during the calendar year: (1) the MA plains snowmelt period, (2) the MJJ mountain snowmelt period for the Fort Peck and Garrison reaches, and (3) the remaining months including the August-February rainfall-runoff and baseflow period.

The report described two methods to forecast runoff in all reaches during the MA runoff period: 1) MA Method 1 – MA Runoff Forecast from Plains Snowpack, and 2) MA Method 2 – MA Runoff Forecast from Hydrologic Conditions. Used individually or together, MA Methods 1 and 2 can forecast runoff in all six reaches during March and April. Shown as the green-shaded area in the Calendar Year Runoff Forecast in **Table 17**, MA methods forecast runoff for 12 of the 72 months that must be forecast on January 1. In an average runoff year, 23 percent of the average annual runoff in the upper Basin occurs during the MA period.

The report described four variations of the MJJ Method, used to forecast MJJ runoff in the Fort Peck and Garrison reaches. Shown as the blue-shaded area in the Calendar Year Runoff Forecast in **Table 17**, the four variations of the MJJ Method account for 6 of the 72 forecast months. About 48 percent of average annual runoff in the upper Basin occurs during the MJJ period in all reaches. About 37 percent of the average annual runoff occurs in the Fort Peck and Garrison reaches during the MJJ period.

Finally, the report described several methods used to forecast runoff during the remaining months for the August-February period in all reaches, and also during the MJJ period in the Oahe, Fort Randall, Gavins Point, and Sioux City reaches. Shown as the gray-shaded area in the Calendar Year Runoff Forecast in **Table 17**, these methods account for the remaining 54 forecast months in the Calendar Year Runoff Forecast, and approximately 40 percent of the average annual runoff in the upper Basin.

Table 17. Recommended methods for the Calendar Year Runoff Forecast

Key
MA Methods
MJJ Methods in Fort Peck and Garrison
Remaining Monthly Reach Forecasts

Missouri River Basin
Calendar Year
Runoff Forecast (kAF)

March 1, 2010

	Incremental Runoff in Reaches								
	Fort Peck	Garrison	Oahe	Fort Randall	Gavins Point	Sioux City	Summation above Gavins Point	Summation above Sioux City	End-of-Month Accumulated Runoff above Sioux City
	(Observed)								
JAN 2010	343	340	87	210	176	238	1,156	1,394	1,394
AVERAGE	312	263	13	28	100	51	717	768	768
DEPARTURE	31	77	74	182	76	187	439	626	626
% OF AVG	110%	129%	658%	740%	175%	468%	161%	182%	182%
FEB 2010	330	313	48	144	158	176	993	1,169	2,563
AVERAGE	360	355	96	55	132	101	998	1,099	1,866
DEPARTURE	-30	-42	-48	89	26	75	-5	70	697
% OF AVG	92%	88%	50%	263%	119%	175%	99%	106%	137%
	(Forecast)								
MAR 2010	650	1,160	1,146	480	350	860	3,786	4,646	7,209
NORMAL	597	1,002	587	214	210	325	2,610	2,936	4,802
DEPARTURE	53	158	559	266	140	535	1,176	1,710	2,407
% OF NORM	109%	116%	195%	224%	166%	264%	145%	158%	150%
APR 2010	700	1,260	977	320	300	1,010	3,557	4,567	11,776
NORMAL	640	1,080	508	144	180	384	2,552	2,936	7,738
DEPARTURE	60	180	469	176	120	626	1,005	1,631	4,038
% OF NORM	109%	117%	192%	223%	167%	263%	139%	156%	152%
MAY 2010	630	730	526	160	289	676	2,336	3,011	14,787
NORMAL	1,082	1,265	321	147	185	322	3,000	3,321	11,059
DEPARTURE	-452	-535	205	14	104	354	-664	-310	3,728
% OF NORM	58%	58%	164%	109%	156%	210%	78%	91%	134%
JUN 2010	1,000	1,640	447	299	351	507	3,737	4,244	19,031
NORMAL	1,640	2,720	445	160	185	325	5,149	5,474	16,533
DEPARTURE	-640	-1,080	2	139	166	182	-1,412	-1,230	2,498
% OF NORM	61%	60%	100%	187%	190%	156%	73%	78%	115%
JUL 2010	550	1,115	189	58	138	246	2,050	2,296	21,327
NORMAL	831	1,822	189	58	138	246	3,039	3,285	19,818
DEPARTURE	-281	-707	0	0	0	0	-989	-988	1,510
% OF NORM	66%	61%	100%	100%	100%	100%	67%	70%	108%
AUG 2010	361	614	77	42	116	149	1,209	1,359	22,686
NORMAL	361	614	77	42	116	149	1,209	1,359	21,176
DEPARTURE	0	0	0	0	0	0	0	0	1,510
% OF NORM	100%	100%	100%	100%	100%	100%	100%	100%	107%
SEP 2010	330	453	112	37	110	109	1,042	1,151	23,837
NORMAL	330	453	112	37	110	109	1,042	1,151	22,327
DEPARTURE	0	0	0	0	0	0	0	0	1,510
% OF NORM	100%	100%	100%	100%	100%	100%	100%	100%	107%
OCT 2010	380	529	73	5	119	89	1,106	1,195	25,032
NORMAL	380	529	73	5	119	89	1,106	1,195	23,522
DEPARTURE	0	0	0	0	0	0	0	0	1,510
% OF NORM	100%	100%	100%	100%	100%	100%	100%	100%	106%
NOV 2010	380	391	68	4	118	81	962	1,043	26,074
NORMAL	380	391	68	4	118	81	962	1,043	24,565
DEPARTURE	0	0	0	0	0	0	0	0	1,510
% OF NORM	100%	100%	100%	100%	100%	100%	100%	100%	106%
DEC 2010	328	251	3	12	100	58	694	753	26,827
NORMAL	328	251	3	12	100	58	694	753	25,317
DEPARTURE	0	0	0	0	0	0	0	0	1,510
% OF NORM	100%	100%	100%	100%	100%	100%	100%	100%	106%
	Calendar Year Totals								
	5,982	8,796	4,095	1,773	2,324	4,200	22,627	26,827	
NORMAL	7,242	10,745	2,491	907	1,693	2,240	23,078	25,317	
DEPARTURE	-1,260	-1,949	1,604	866	631	1,960	-450	1,510	
% OF NORM	83%	82%	164%	195%	137%	188%	98%	106%	

VI. REFERENCES

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APPENDIX A

SIGNIFICANT MARCH-APRIL RUNOFF SEASONS OF THE PAST TWO DECADES

Several significant plains snowmelt events have occurred during the past two decades including 1997, 2009, 2010 and 2011. In addition, several regionalized snowmelt events have impacted particular System reaches such as Gavins Point in 1998 and 1999, and the Sioux City reach in 2007. The major March-April (MA) events that were recorded in 1996, 1997, 2001, 2009, 2010 and 2011 are discussed in the following paragraphs. Major MA event runoff volumes are ranked with respect to the 1898 to 2014 runoff record.

1. 1996

The MA upper Basin annual runoff summation was 8,192 kAF, ranking 18th highest since 1898. Above Fort Peck, MA runoff was 1,942 kAF, ranking ninth highest since 1898. Runoff in the Garrison reach was 3,039 kAF, ranking 16th highest since 1898. Similarly, Oahe reach runoff was 1,702 kAF, ranking 18th highest.

2. 1997

The upper Basin annual runoff summation was 49.0 MAF, which was the second highest runoff in the 1898 to 2014 117-year period. The MA runoff summation was 15,860 kAF (15.9 MAF), ranking second highest of all MA periods, only behind 15,871 kAF (15.9 MAF) in 1952. In the Fort Peck reach, 1,348 kAF of runoff occurred, ranking 34th highest; however, in the Garrison reach 3,864 kAF of runoff occurred, ranking ninth highest. The Oahe reach contributed the greatest volume with 5,432 kAF, ranking as the highest Oahe MA runoff period. In the Fort Randall and Gavins Point reaches, 1,296 and 761 kAF of runoff occurred, respectively, while 3,159 kAF of runoff occurred in the Sioux City reach, ranking second highest in the MA period.

3. 2001

Significant plains snow accumulated in the upper Basin below Oahe Dam. In the Fort Randall reach, 917 kAF of runoff occurred, ranking eighth highest since 1898. The Gavins Point reach received 797 kAF, ranking sixth highest since 1898. The Sioux City reach received 2,496 kAF, primarily from the James and Big Sioux Rivers, ranking fourth highest since 1898.

4. 2009

The MA upper Basin runoff summation was 10,551 kAF (10.6 MAF), ranking seventh highest of all MA periods since 1898. The MA period runoff was highlighted by the 5,310 kAF of runoff that occurred in the Oahe reach, ranking as the second highest volume of runoff to occur in this reach, behind 1997. Heavy plains snowpack accumulated in this reach over very wet and frozen soil conditions. In late March the reach experienced a significant spring warm-up, followed by a very large winter storm that produced 1 to 2 inches of rain and SWE over the area. This coincided with river ice break up on several Missouri River tributaries including the Heart River at Mandan, causing a significant ice jam on the Missouri River on the south side of Bismarck, ND. Late March snowmelt and additional precipitation in April were other factors contributing to the high MA runoff totals in the Oahe reach.

5. 2010

The MA upper Basin annual runoff summation was 9,624 kAF (9.6 MAF), ranking tenth highest among all runoff years since 1898. Heavy plains snowpack accumulated in the reaches extending from Garrison Dam to Sioux City, IA. Snowpack was particularly heavy from Gavins Point to Sioux City, IA in the James, Vermillion and Big Sioux River basins, ranging from 4 to 6 inches of SWE. In the Sioux City reach, runoff was 2,886 kAF (2.9 MAF), third highest of record, while in the Fort Randall reach, runoff was 1,227 kAF (1.2 MAF), also third highest of record. In the Oahe reach, runoff was 2,391 kAF (2.4 MAF) and eleventh highest of MA runoff seasons from 1898 to 2014. The MA runoff into Fort Peck and Garrison were below their respective long-term averages.

6. 2011

The MA upper Basin annual runoff summation was 14,112 kAF (14.1 MAF), ranking third highest among all recorded MA runoff seasons. This high volume of runoff was caused by a basin-wide plains snow accumulation that extended from central Montana into eastern South Dakota. At the peak of the plains snow accumulation, SWE amounts in excess of 4 inches were present north and east of a line extending from Sioux Falls, SD to Glasgow, MT. Greater amounts ranging from 5 to 8 inches existed from northeast South Dakota into northeast Montana. Snowmelt occurred from March into early April over significantly wet soil conditions. The resultant MA runoff was 1,901 kAF above Fort Peck, 4,102 kAF of runoff in the Garrison reach, 3,327 kAF of runoff in the Oahe reach and 3,328 kAF of runoff in the Sioux City reach. MA runoff in the Sioux City reach ranked as the highest of all MA runoff periods from 1898 to 2014, MA runoff in the Garrison and Oahe reaches ranked as the sixth highest MA runoff periods, respectively, and MA runoff in the Fort Peck reach ranked as the eleventh highest MA runoff period.

APPENDIX B

DATA AND ANALYSIS FOR MA METHOD 1 – MARCH-APRIL RUNOFF FORECAST FROM PLAINS SNOWPACK

March-April (MA) runoff in the upper Basin is greatly influenced by plains snowmelt and rainfall runoff to a lesser extent. The wide variability in MA runoff is typically explained by the magnitude of plains snowpack coverage and SWE. MA runoff in the plains is generally high when heavy snow accumulates on the plains during the winter, while MA runoff is generally low when limited to no snow accumulates on the plains. Other factors that may influence the volume of MA runoff can include the timing of snowmelt runoff as affected by temperatures, the presence of soil frost that serves as an impervious surface, soil moisture content at the time of snowmelt and seasonal precipitation. Although these factors are not explicitly considered in the forecast of MA runoff using MA Method 1, they may be implicitly considered while adjusting the forecast runoff volumes determined through MA Method 1.

While plains snowpack is generally a good indicator of MA runoff, it is important to note that runoff due to heavy plains snowpack is highly variable. For example, the plains snowpack in 2009 and 2010 was considered "heavy" over most of the upper Basin, and in some areas "very heavy" in 2010 according to **Table 3** in Chapter II. The MA runoff in 2009 was 10,551 kAF, about 180 percent of average, and the MA runoff in 2010 was 9,624 kAF, about 160 percent of normal. Though slightly less snow cover existed in 2011 than in 2010, MA runoff in 2011 was 14,112 kAF, which is 243 percent of normal and the third highest MA runoff on record. The highest MA runoff volume of 15,871 kAF occurred in 1952, while the second highest MA runoff volume of 15,860 kAF occurred in 1997.

The sections in Appendix B explain the development of the tools created as part of MA Method 1 – March-April Runoff Forecasting from Plains Snowpack in Chapter II of the main report:

A. Numerical ranges of plains SWE that are associated with the Plains Snowpack Conditions,
B. MA runoff forecast volumes, and
C. Experimental satellite-based plains SWE detection and comparison tool.

A. Numerical Ranges of Plains SWE

A recommendation of the independent technical review panel that wrote the "Review of the Regulation of the Missouri River Mainstem Reservoir System During the Flood of 2011" was to develop classifications of plains SWE that correspond to the NWS NOHRSC national snow analysis maps. The panel recommended MRBWMD assign ranges of SWE amounts to the Plains Snowpack Conditions that are associated with forecasted MA runoff volumes in order to provide a more objective method for classifying plains SWE. When plains snow is present, the plains snow cover conditions with their associated range of plains SWE amounts are used to forecast MA reach runoff based on snow cover and SWE. The addition of numerical ranges of SWE to the existing method will improve the forecasting method.

APPENDIX B

Long-term records of accumulated plains SWE measurements throughout the plains region are lacking due to many challenges of consistently measuring plains SWE. Therefore, numerical ranges of System reach SWE were determined by analyzing winter season snowfall accumulations and snow depth records at snowfall monitoring locations with more than 50 years of record. Snowfall and snow depth data for 12 NWS COOP weather stations in the upper Basin was obtained from the NOAA NCEI, and the entire period of record for each monitoring location was used to develop percentile classes of cumulative snowfall that occurred during two periods: 1) December-February and 2) November-March. An important assumption made in the Long-Term Runoff Forecasting report is that snowfall and accumulation influenced MA runoff during winter seasons when the observed runoff volume exceeded the long-term average MA runoff volume. Therefore, snowfall accumulation percentile classes greater than the 50th percentile (median) snowfall accumulation during the December-February and November-March periods were developed. **Table B-1** and **Table B-2** present the average snowfall, 50th percentile, 75th percentile, 90th percentile and 95th percentile snowfall for these periods. The December-February percentile classes represent continuous snow accumulation that begin in December and melt at the end of February. The November-March percentile classes represent continuous snow accumulation that begin in November and melt at the end of March. These tables represent a range of snowfall accumulations that vary based on the length of season.

Table B-1. December-February snowfall percentiles based on station periods of record

Station	State	Average	50th Percentile	75th Percentile	90th Percentile	95th Percentile	Maximum
Billings Logan Intl Arpt	MT	25.9	24.3	30.5	40.3	47.2	79.1
Glendive	MT	13.4	11.9	18.1	25.2	27.6	40.6
Glasgow Intl Arpt	MT	18.4	15.5	23.6	32.4	36.5	80.1
Great Falls Intl Arpt	MT	26.0	25.9	32.2	42.1	48.8	63.3
Bismarck Municipal Arpt	ND	23.5	20.2	29.0	45.0	46.2	58.0
Williston Sloulin Intl Arpt	ND	22.4	18.6	28.4	41.9	52.3	61.7
Aberdeen Regional Arpt	SD	20.4	18.2	25.0	36.9	47.2	62.1
Mobridge 2 NNW	SD	16.8	15.3	22.0	30.2	35.7	55.1
Pierre Regional Arpt	SD	16.5	15.3	20.9	27.5	32.7	68.0
Sioux Falls Foss Fld Arpt	SD	22.4	20.5	26.7	40.2	49.5	89.2
Watertown Regional Arpt	SD	17.4	14.3	23.5	31.4	40.1	70.9
Sioux City Gateway Arpt	IA	20.4	17.3	27.0	37.2	39.5	57.5

Table B-2. November-March snowfall percentiles based on station periods of record.

Station	State	Average	50th Percentile	75th Percentile	90th Percentile	95th Percentile	Maximum
Billings Logan Intl Arpt	MT	41.9	40.7	50.0	61.1	66.5	95.7
Glendive	MT	20.6	21.3	27.2	32.4	38.9	72.0
Glasgow Intl Arpt	MT	27.0	24.4	36.1	42.8	51.2	104.1
Great Falls Intl Arpt	MT	42.5	43.3	50.0	61.2	67.4	86.9
Bismarck Municipal Arpt	ND	38.5	34.5	47.9	70.3	77.6	100.2
Williston Sloulin Intl Arpt	ND	34.3	32.3	45.2	60.5	65.0	90.5
Aberdeen Regional Arpt	SD	31.7	29.4	37.9	57.2	69.8	90.0
Mobridge 2 NNW	SD	26.8	25.9	35.6	45.4	50.5	72.2
Pierre Regional Arpt	SD	27.1	25.9	34.1	40.7	48.3	80.0
Sioux Falls Foss Fld Arpt	SD	36.5	34.8	48.3	56.5	64.8	94.0
Watertown Regional Arpt	SD	27.9	24.9	37.2	48.7	52.8	78.3
Sioux City Gateway Arpt	IA	30.9	27.1	39.6	51.0	58.2	64.8

Since plains SWE is the most important factor used to forecast MA runoff, the seasonal snowfall accumulations in **Table B-1** and **Table B-2**, must be converted to cumulative SWE for the same time periods. It was assumed that the average snowfall to SWE ratio was twelve to one based on conventional practices. SWE percentile classes were computed with the ratio for each station. The SWE percentile classes for the December-February and November-March time periods are presented in **Table B-3** and **Table B-4.** These tables indicate that in an average winter season, about 1-2 inches of SWE can occur during the December-February period (**Table B-3**) and about 2-3.5 inches of SWE can occur during the November-March period (**Table B-4**). These tables assume that all snowfall accumulates on the ground surface and does not melt. Actual cumulative SWE, based on measurements of SWE on the ground, could differ from the values presented in these tables; however, long-term SWE measurement records in the plains do not exist to verify or dispute these values. Further study of long-term cumulative plains SWE is recommended.

Table B-3. December-February cumulative estimated SWE percentiles based on station periods of record.

Station	State	Average	50th Percentile	75th Percentile	90th Percentile	95th Percentile	Maximum
Billings Logan Intl Arpt	MT	2.2	2.0	2.5	3.4	3.9	6.6
Glendive	MT	1.1	1.0	1.5	2.1	2.3	3.4
Glasgow Intl Arpt	MT	1.5	1.3	2.0	2.7	3.0	6.7
Great Falls Intl Arpt	MT	2.2	2.2	2.7	3.5	4.1	5.3
Bismarck Municipal Arpt	ND	2.0	1.7	2.4	3.8	3.9	4.8
Williston Sloulin Intl Arpt	ND	1.9	1.6	2.4	3.5	4.4	5.1
Aberdeen Regional Arpt	SD	1.7	1.5	2.1	3.1	3.9	5.2
Mobridge 2 NNW	SD	1.4	1.3	1.8	2.5	3.0	4.6
Pierre Regional Arpt	SD	1.4	1.3	1.7	2.3	2.7	5.7
Sioux Falls Foss Fld Arpt	SD	1.9	1.7	2.2	3.4	4.1	7.4
Watertown Regional Arpt	SD	1.5	1.2	2.0	2.6	3.3	5.9
Sioux City Gateway Arpt	IA	1.7	1.4	2.2	3.1	3.3	4.8

Table B-4. November-March cumulative estimated SWE percentiles based on station periods of record.

Station	State	Average	50th Percentile	75th Percentile	90th Percentile	95th Percentile	Maximum
Billings Logan Intl Arpt	MT	3.5	3.4	4.2	5.1	5.5	8.0
Glendive	MT	1.7	1.8	2.3	2.7	3.2	6.0
Glasgow Intl Arpt	MT	2.3	2.0	3.0	3.6	4.3	8.7
Great Falls Intl Arpt	MT	3.6	3.6	4.2	5.1	5.6	7.2
Bismarck Municipal Arpt	ND	3.2	2.9	4.0	5.9	6.5	8.4
Williston Sloulin Intl Arpt	ND	2.9	2.7	3.8	5.0	5.4	7.5
Aberdeen Regional Arpt	SD	2.6	2.4	3.2	4.8	5.8	7.5
Mobridge 2 NNW	SD	2.2	2.2	3.0	3.8	4.2	6.0
Pierre Regional Arpt	SD	2.3	2.2	2.8	3.4	4.0	6.7
Sioux Falls Foss Fld Arpt	SD	3.0	2.9	4.0	4.7	5.4	7.8
Watertown Regional Arpt	SD	2.3	2.1	3.1	4.1	4.4	6.5
Sioux City Gateway Arpt	IA	2.6	2.3	3.3	4.2	4.9	5.4

Numerical ranges of reach SWE were developed from the cumulative SWE percentile classes for the stations that were analyzed. Stations used to determine numerical ranges of reach SWE

are listed in **Table B-5**. Taking the values presented in **Table B-3** and **Table B-4** for the stations that correspond to each reach, cumulative estimated SWE percentiles by reach were computed and are shown in **Table B-6** and **Table B-7**.

Table B-5. NWS COOP weather stations used to develop numerical reach SWE ranges.

Reach	Stations
Fort Peck	Billings Logan International Airport, MT (COOP: 240807) Glasgow International Airport, MT (COOP: 243558) Great Falls International Airport, MT (COOP: 243751)
Garrison	Billings Logan International Airport, MT (COOP: 240807) Glasgow International Airport, MT (COOP: 243558) Glendive, MT (COOP: 243581) Williston Sloulin International Airport, ND (COOP: 329425)
Oahe	Bismarck Municipal Airport, ND (COOP: 321819) Aberdeen Regional Airport, SD (COOP: 390020) Mobridge 2 NNW, SD (COOP: 395691) Pierre Regional Airport, SD (COOP: 396597)
Fort Randall Gavins Point	Pierre Regional Airport, SD (COOP: 396597) Sioux City Gateway Airport, IA (COOP: 137708)
Sioux City	Bismarck Municipal Airport, ND (COOP: 321819) Aberdeen Regional Airport, SD (COOP: 390020) Sioux Falls Foss Field Airport, SD (COOP: 397667) Watertown Regional Airport, SD (COOP: 398932) Sioux City Gateway Airport, IA (COOP: 137708)

Table B-6. December-February cumulative estimated reach SWE percentiles.

Station	Average	50th Percentile	75th Percentile	90th Percentile	95th Percentile	Maximum
Fort Peck	2.0	1.8	2.4	3.2	3.7	6.2
Garrison	1.9	1.6	2.4	3.5	4.4	5.1
Oahe	1.5	1.4	1.9	2.6	3.2	5.1
Fort Randall	1.5	1.4	2.0	2.7	3.0	5.2
Gavins Point	1.5	1.4	2.0	2.7	3.0	5.2
Sioux City	1.7	1.5	2.2	3.2	3.7	5.6

Table B-7. November-March cumulative estimated reach SWE percentiles.

Station	Average	50th Percentile	75th Percentile	90th Percentile	95th Percentile	Maximum
Fort Peck	3.1	3.0	3.8	4.6	5.1	8.0
Garrison	2.9	2.7	3.8	5.0	5.4	7.5
Oahe	2.4	2.3	3.0	4.0	4.7	6.7
Fort Randall	2.4	2.2	3.1	3.8	4.4	6.0
Gavins Point	2.4	2.2	3.1	3.8	4.4	6.0
Sioux City	2.8	2.5	3.5	4.7	5.4	7.1

Numerical ranges of reach SWE were calculated as the range of reach SWE from **Table B-6** and **Table B-7** approximately rounded to the nearest 0.5 inches of SWE. The numerical ranges of reach SWE associated with the Plains Snowpack Condition are provided in **Table B-8**. The Plains Snowpack Conditions are “light”, “moderate”, “heavy” and “very heavy”. The numerical ranges of reach SWE are intended to describe the average SWE depth in the entire plains region of the System reach.

Table B-8. Numerical ranges of reach SWE (inches) associated with Plains Snowpack Conditions based on November through March snowfall accumulations.

Mainstem Reach	Plains Snowpack Condition			
	50th percentile "light"	75th percentile "moderate"	90th percentile "heavy"	95th percentile "very heavy"
Fort Peck	1.5-2.5	2.5-3.5	3.5-4.5	4.5+
Garrison	1.5-2.5	2.5-3.5	3.5-4.5	4.5+
Oahe	1.0-2.0	2.0-3.0	3.0-4.0	4.0+
Fort Randall	1.0-2.0	2.0-3.0	3.0-3.5	3.5+
Gavins Point	1.0-2.0	2.0-3.0	3.0-3.5	3.5+
Sioux City	1.5-2.5	2.5-3.5	3.5-4.5	4.5+

B. MA Runoff Forecast Volumes

Forecasting MA reach runoff is accomplished by associating Plains Snowpack Conditions described in **Table B-8** with MA runoff volumes presented in **Table B-9**. MA runoff volumes in **Table B-9** were developed from 1898-2014 period of record runoff data. **Table B-9** should be used as a guide to forecast MA System reach runoff. MA runoff in **Table B-9** is divided into two general categories: 1) runoff that is forecast to occur during years when limited to no snow accumulates in the plains, and 2) runoff that is forecast to occur during years when substantial snow accumulates in the plains and subsequently melts during March and April. Historic MA System reach runoff by individual reach has been generally less than the long-term average MA System reach runoff by individual reach when there is limited to no plains snowpack. Therefore, the No Snow Accumulation column of runoff volumes are the average of all MA runoff seasons by individual System reach when MA runoff was less than the long-term MA average runoff, also listed in **Table B-9**.

Table B-9. MA runoff forecast volumes (kAF) associated with the Plains Snowpack Conditions.

Mainstem Reach	No Snow Accumulation[1]	MA Average Runoff	Plains Snowpack Condition Runoff Volumes[2]			
			25th percentile "light"	50th percentile "moderate"	75th percentile "heavy"	90th percentile "very heavy"
Fort Peck	960	1,240	1,350	1,510	1,860	2,270
Garrison	1,500	2,080	2,420	2,830	3,550	4,290
Oahe	560	1,100	1,320	1,640	2,460	3,990
Fort Randall	190	360	410	540	810	1,120
Gavins Point	300	390	480	580	690	820
Sioux City	330	710	870	1,080	1,800	2,390

[1] No Snow Accumulation volumes are based on 1898-2014 MA runoff seasons that were less than the 1898-2014 average MA volume.

[2] Plains Snowpack Condition Runoff Volumes are based on percentiles of 1898-2014 MA runoff seasons that were greater than the 1898-2014 average MA volume.

Historic MA reach runoff volumes have been generally greater than long-term average MA reach runoff volumes when plains snowpack can be classified into one of the four Plains Snowpack Conditions. MA System reach runoff volumes associated with the four Plains Snowpack Conditions are listed to the right of the MA Average Runoff in **Table B-9**. The Plains Snowpack Condition runoff volume columns are based on percentiles of the population of MA reach runoff volumes in which the individual MA runoff volumes were greater than the long-

term MA average reach runoff. The runoff category percentiles associated with the Plains Snowpack Conditions are: 1) 25th percentile "light" Plains Snowpack Condition, 2) 50th percentile "moderate", 3) 75th percentile "heavy", and 4) 90th percentile "very heavy". The runoff forecast volumes serve as a general guide to the forecaster, and can be adjusted given considerations for soil moisture conditions, frost depths, streamflow conditions, antecedent temperatures and other pertinent factors that affect MA runoff.

C. Experimental Satellite-Based Plains Snowpack Assessment Tool

The USACE Cold Regions Research and Environmental Laboratory is developing an experimental web-based tool to process and display satellite-based estimates of SWE in the Missouri Basin. The web-based tool processes plains SWE determined by passive microwave satellite observations taken with the Special Sensor Microwave/Imager into a near real-time map (**Figure B-1**) of SWE in the Missouri Basin. The tool displays average basin SWE in the Missouri Basin at the US Geological Survey (USGS) Hydrologic Unit Code (HUC)-8 scale, and in the upper Basin on a Mainstem System reach scale. Since passive microwave data has been available since 1987, it can provide a sufficient historic record to compare the current snowpack to historic statistics, thus weekly SWE estimates for the period of satellite record since 1987 in the Missouri Basin have been developed in addition to the near real-time estimates. Furthermore, historic SWE statistics including maximum, 90th percentile, 75th percentile, 50th percentile (median), 25th percentile, 10th percentile, and minimum SWE have been computed for the 1987-2015 satellite-based snowpack record and can be displayed for each HUC-8 subbasin and System reach (**Figure B-2**).

The satellite-based plains snowpack assessment tool can be used by the forecaster to determine the magnitude of plains snowpack SWE by reach relative to historic plains SWE percentiles. The tool uses comparison plots of the current SWE versus the historic SWE percentiles by HUC-8 and System reach as shown in **Figure B-1**. After this tool is tested and verified, the ranking of current plains SWE by reach versus the historic percentiles could eventually be used to determine the Plains Snowpack Condition in **Table B-8** assuming the ranking of current SWE versus historic percentiles has significant correlation to the Plains Snowpack Conditions, which are also percentile based. The difference between this tool and the Plains Snowpack Condition classification is that MA reach runoff volumes associated with the Plains Snowpack Condition (**Table B-9**) are based on the MA reach runoff volume dataset that is greater than the average MA reach runoff.

The satellite-based plains snowpack assessment tool is in its final phase of development before it can be integrated into the array of plains snowpack assessment procedures. When it is complete, its intended use is to provide near real-time assessments of plains snowpack in the upper Basin and comparisons to historic conditions. Further implementation into MA runoff forecasting procedures will continue as results from this tool are evaluated.

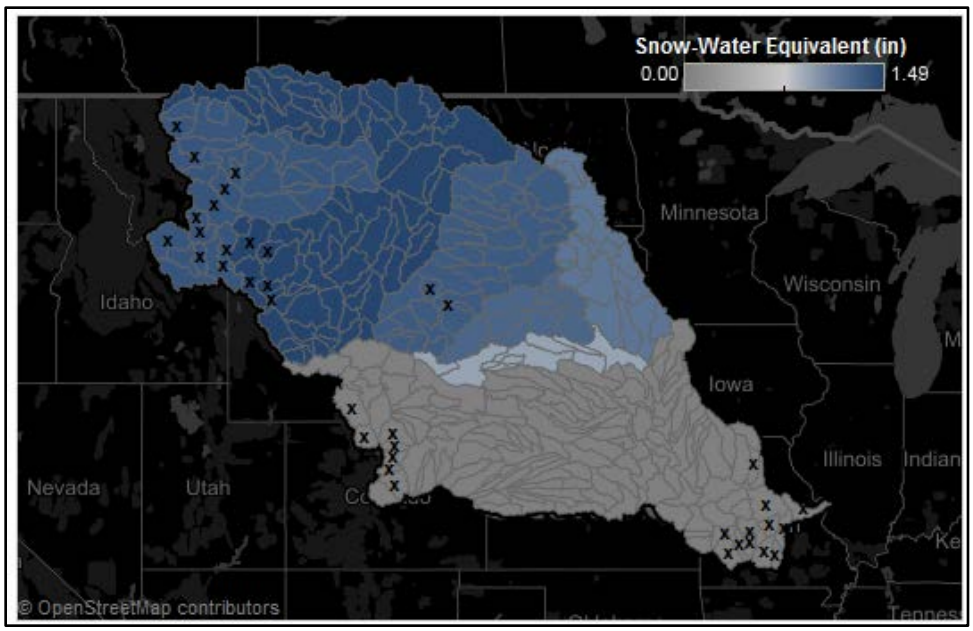

Figure B-1. Experimental satellite-based SWE assessment tool map showing the average System reach SWE.

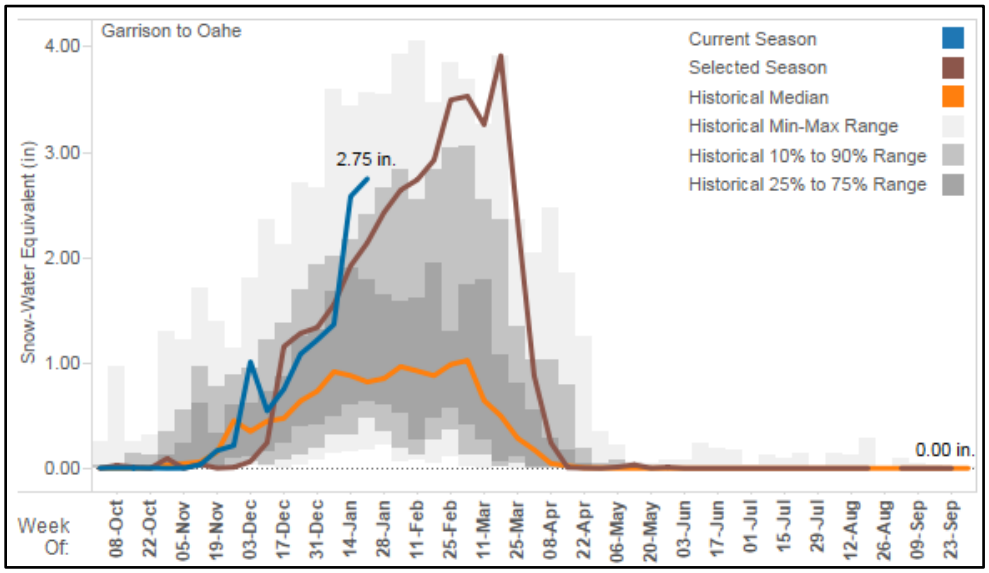

Figure B-2. Experimental satellite-based SWE assessment tool comparison of current season SWE versus a selected season and the historic percentile ranges for the Garrison to Oahe Reach.

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APPENDIX C

DATA AND ANALYSIS FOR MA METHOD 2 – MARCH-APRIL RUNOFF FORECAST FROM HYDROLOGIC CONDITIONS

As discussed in Section II.A, plains snowpack is one factor used to predict MA runoff. While it is generally considered that plains snowpack is a good qualitative indicator of MA runoff, results sometimes show otherwise. For example, runoff occurring during the MA period of 2009, 2010 and 2011 (**Table C-1**) varied greatly during plains snowpack years that were considered similar in magnitude and extent. Furthermore, the runoff forecast for each year was not accurate and exhibited tendencies to both over- and under-predict, suggesting other factors in addition to plains snowpack should be considered in forecasting MA runoff.

Table C-1. Comparison of forecast and actual MA runoff (kAF) above Sioux City and into Fort Peck, Garrison and Oahe.

Year	MA Runoff Upper Basin			MA Runoff Fort Peck, Garrison, Oahe		
	Forecast (kAF)	Actual (kAF)	% Error	Forecast (kAF)	Actual (kAF)	% Error
2009	5,020	10,551	-52.4	3,065	8,753	-65.0
2010	12,834	9,624	33.4	8,539	4,817	77.3
2011	8,012	14,112	-43.2	5,272	9,330	-43.5

The hydrologic conditions evaluated in this report include soil moisture content, accumulated precipitation as a proxy for accumulated plains snowpack and seasonal temperature. Precipitation is a driving factor in MA runoff, while soil moisture serves as a storage mechanism for precipitation inputs into the hydrologic system. Temperature influences MA runoff by changing the state of moisture in the hydrologic system such as soil moisture into frost, river ice formation, the occurrence of precipitation as snow, snow accumulation and snowmelt. These three conditions were evaluated using monthly NOAA NCEI and CPC climate division data. In this analysis, hydrologic conditions were derived from monthly climate division values of soil moisture, precipitation, and temperature over the upper Basin and each individual System reach.

A. Data

Climate divisional data is the historic long-term spatial dataset used in historic climate analyses for the contiguous United States. The dataset was originally created for monitoring drought, temperature, precipitation and heating/cooling degree-day values along climate division, statewide, regional and national boundaries. In each climate division, average monthly, accumulated, and end-of-month values have been determined from NWS COOP daily station data. For example, in the state of Montana, approximately 280 stations were used to compute average monthly precipitation and temperature for the entire state, which is separated into seven climate divisions.

There are 344 climate divisions (see **Figure C-1**) in the Continental United States with precipitation and temperature datasets extending back to the late 1800s and a simulated soil moisture dataset extending back to 1932. Climate divisions are delineated based on areas of similar climate, geographic boundaries and government boundaries. For example, Montana contains seven climate divisions drawn along both geographic and county lines.

APPENDIX C

Climate division parameters being considered in this analysis include monthly soil moisture, monthly precipitation and monthly temperature since 1932. Temperature and precipitation are computed from daily COOP station data; however, soil moisture is computed using a runoff model analysis performed by the NWS CPC. This analysis is discussed in the following section.

All data is utilized in its unit of measure for the period 1932-2014. System reach values were averaged over three-, four- and six-month periods with the exception of soil moisture. Soil moisture was represented as an end-of-month soil moisture value because it represents a hydrologic state at a point in time. All monthly periods ended in February and March.

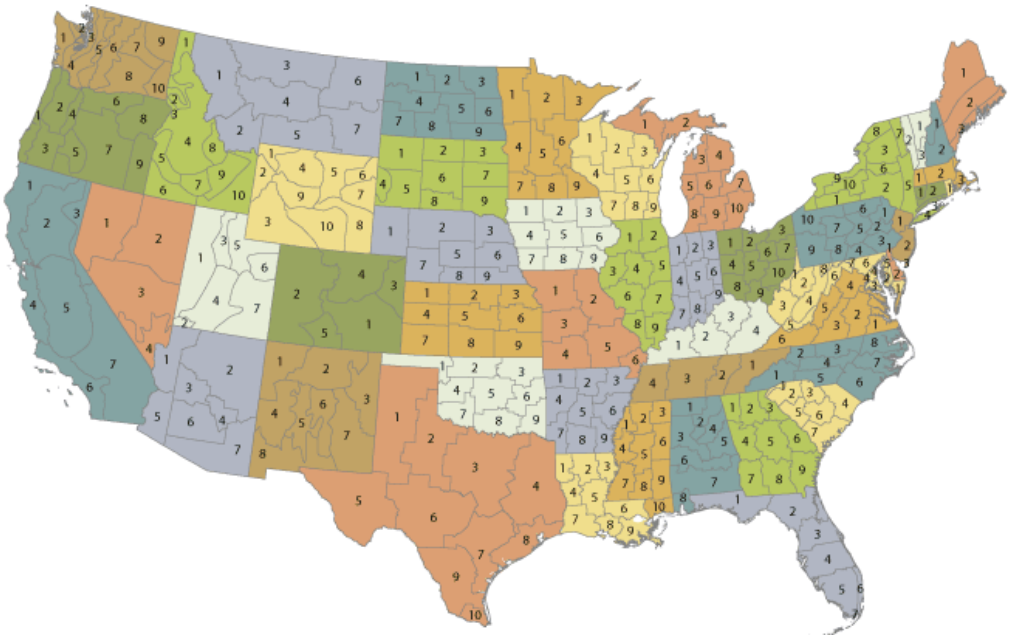

Figure C-1. Locations of U.S. climate divisions.

1. Soil Moisture

Soil moisture content describes the amount of water that a soil profile is holding as a percent or fraction of the soil profile capacity, or the amount of soil moisture contained in the profile expressed as a depth of moisture. Soil moisture is a very important factor influencing the amount of runoff that will occur as a result of precipitation accumulation as rainfall or melted snow, precipitation infiltration into the soil, and precipitation runoff from the soil surface. Thus, soil moisture content is a very good indicator of the capacity of a watershed to store precipitation in the profile and produce runoff throughout the calendar year.

The CPC calculates soil moisture by a one-layer hydrological model known as the Leaky Bucket Model (Huang et al., 1996, and van den Dool et al., 2003). The model integrates observed precipitation and temperature to calculate soil moisture, evaporation and runoff. The model is calibrated to observed streamflow. The model uses a standard 5.25-foot (1.6-meter) soil profile depth with a porosity of 0.47, resulting in a total soil moisture capacity of 29.9 inches (760 mm). Although this model does not represent the actual physical state of the soil, it serves

as a good estimate of soil moisture in relation to rainfall-runoff processes. Modeled CPC soil moisture data is currently available at the ftp site: ftp://ftp.cpc.ncep.noaa.gov/wd51yf/us.

An analysis of soil moisture content at various dates versus MA runoff indicated that end-of-February soil moisture had the highest correlation to MA runoff. End-of-February soil moisture for each System reach was calculated by averaging the climate division soil moisture for the divisions that substantially overlap the System reaches. The resulting end-of-February average reach soil moisture in units of inches was used in the MA runoff regression analysis for the 1932-2014 period. **Table C-2** and **Table C-3** list end-of-February soil moisture in inches by System reach. The tables list the state climate divisions used in each reach.

2. Accumulated Precipitation

As it pertains to this analysis, precipitation can occur as snow or rain during March and April. Accumulated precipitation as a proxy for plains snow accumulation can be used to predict runoff during March and April after the accumulation has occurred. Accumulated precipitation can be assumed to represent snowfall precipitation and snow accumulation if it occurs during the time period when snowfall normally occurs. Climate division precipitation data from NCEI is currently available at the website: http://www1.ncdc.noaa.gov/pub/data/cirs/climdiv/.

NCEI climate division monthly precipitation totals were compiled for multi-month time periods, including three months (December-February), four months (November-December-January-February or December-January-February-March) and six-month (September-October-November-December-January-February or October-November-December-January-February-March) accumulation periods. Accumulated multi-month precipitation for each System reach was calculated by averaging the multi-month precipitation for the climate divisions that substantially overlap the System reaches. The resulting reach multi-month accumulated precipitation in inches was used in the MA runoff regression analysis for the 1932-2014 period. **Table C-2** and **Table C-3** list the average reach accumulated multi-month precipitation in units of inches that was used in the final multiple-linear regression analysis.

3. Temperature

The third factor, temperature, may affect MA runoff in several ways. Colder temperatures leading up to March and April can increase the amount of snow accumulation during the winter, and also delay the onset of snowmelt until later in the snowmelt season. The combination of increased snow accumulation and delayed snowmelt can cause increased MA runoff. Climate division temperature data is currently available at the website: http://www1.ncdc.noaa.gov/pub/data/cirs/climdiv/.

Average multi-month temperature for each System reach was calculated by averaging the multi-month temperature for the climate divisions that substantially overlap the System reaches. The resulting reach multi-month average temperature in units of degrees Fahrenheit (deg F) was used in the MA runoff regression analysis for the 1932-2014 period. **Table C-2** and **Table C-3** list the average reach January-February-March temperatures that were used in the final multiple-linear regression analysis.

Table C-2. Fort Peck, Garrison and Oahe reach average climate division soil moisture (inches), precipitation (inches) and temperature (deg F) for use in MA Method 2. Soil moisture source is NOAA CPC. Precipitation and temperature source is NOAA NCEI.

	Fort Peck Divisions: MT 2,3,4			Garrison Divisions: MT 3,5,6,7; ND 1,4,7			Oahe Divisions: ND 4,5,7,8; SD 1,2,4,5,6		
Year	Feb 28/29 SM[1]	NDJF P[2]	JFM T[3]	Feb 28/29 SM[1]	NDJF P[2]	JFM T[3]	Feb 28/29 SM[1]	NDJF P[2]	JFM T[3]
1932	5.64	3.99	19.9	5.12	1.93	16.9	6.45	2.12	17.0
1933	7.28	4.28	22.0	7.17	2.07	20.1	7.12	1.24	21.3
1934	7.04	4.19	30.2	5.92	2.03	26.2	5.52	1.34	25.7
1935	6.01	2.95	22.9	4.11	1.45	20.9	4.83	1.17	24.1
1936	6.10	4.01	13.5	6.07	2.54	7.4	6.40	2.22	8.0
1937	5.88	3.92	13.4	4.42	1.93	10.8	4.22	1.83	11.9
1938	6.68	3.99	22.8	6.10	2.19	20.4	6.21	1.91	21.4
1939	7.89	3.57	23.0	6.92	2.19	18.7	6.50	2.01	19.2
1940	6.76	4.04	21.5	5.83	1.66	17.5	5.81	1.09	17.0
1941	6.57	2.89	26.1	6.26	1.49	22.2	6.10	1.38	21.0
1942	8.94	5.72	21.1	8.65	2.13	22.0	8.76	1.03	23.1
1943	8.18	5.82	17.9	8.00	2.71	14.6	8.93	1.84	16.1
1944	6.13	2.38	22.7	6.78	1.48	20.1	7.65	1.93	19.1
1945	6.64	3.29	25.1	7.62	2.35	23.0	9.19	3.21	23.8
1946	6.78	3.92	27.7	6.60	2.18	25.1	7.09	1.32	26.0
1947	8.25	4.93	21.7	7.90	2.22	18.1	9.49	1.51	19.5
1948	7.68	4.68	20.9	7.62	2.75	17.5	8.39	2.32	16.9
1949	7.73	5.72	14.2	7.33	3.37	11.0	8.53	2.95	12.5
1950	6.07	3.78	16.5	5.89	2.00	10.2	7.54	1.91	11.3
1951	7.38	4.68	17.1	7.38	2.48	13.0	7.78	1.79	15.4
1952	9.10	5.13	18.8	8.17	2.55	15.3	9.82	2.58	16.5
1953	6.40	4.53	28.8	5.32	1.74	25.0	6.21	1.76	24.3
1954	6.41	4.39	22.3	7.02	2.14	20.1	7.19	1.53	22.5
1955	6.61	2.54	18.2	6.95	1.33	16.6	7.32	1.37	18.0
1956	7.43	6.01	20.2	6.27	2.34	17.3	7.08	1.93	17.9
1957	6.39	3.85	18.2	6.08	2.15	16.3	7.50	2.24	17.8
1958	7.07	3.31	24.9	7.11	2.03	22.2	9.00	1.95	21.7
1959	7.91	6.41	21.5	6.75	3.45	17.2	6.70	2.12	18.2
1960	7.51	3.96	20.4	6.81	2.21	17.0	6.91	1.88	16.3
1961	5.14	2.70	30.1	5.05	1.75	27.1	6.19	1.55	26.0
1962	6.88	4.50	19.7	5.72	1.87	16.7	6.50	1.49	17.1
1963	7.66	4.62	24.7	7.34	2.15	21.4	8.23	1.44	21.4
1964	6.51	3.69	23.9	6.22	1.45	23.0	7.05	0.96	22.9
1965	8.16	6.30	19.8	7.44	3.03	13.5	7.30	1.83	14.5
1966	7.93	3.52	22.0	7.35	1.54	16.6	8.34	1.40	16.4
1967	6.88	5.03	24.9	6.87	2.64	20.8	8.23	1.97	21.9
1968	7.88	4.89	26.4	6.61	2.28	22.9	7.02	1.36	22.8
1969	9.19	6.19	14.6	8.42	3.24	11.4	8.84	2.93	14.1
1970	7.22	3.62	23.0	6.86	2.03	17.6	6.96	1.59	17.2
1971	8.18	5.33	22.4	7.98	3.07	17.7	8.25	2.92	17.3
1972	7.23	5.57	22.2	8.65	2.78	16.6	9.18	2.06	17.3
1973	6.53	2.74	25.2	7.32	1.52	25.7	7.88	1.55	26.0
1974	7.04	5.10	24.7	7.06	2.32	21.7	7.60	1.54	22.4
1975	7.04	4.45	19.2	6.74	1.98	17.7	6.33	1.59	18.2
1976	9.41	4.23	25.5	8.57	2.60	23.6	7.37	2.05	24.3
1977	6.82	2.54	25.3	6.16	1.77	22.2	6.02	1.56	21.8
1978	8.96	6.47	20.1	8.56	3.49	13.5	10.09	3.12	13.2
1979	9.09	5.36	16.3	9.17	3.35	10.9	8.38	2.56	11.4
1980	6.22	3.93	21.4	5.72	1.82	18.8	6.69	1.14	19.7
1981	7.16	3.23	29.9	6.52	1.60	28.5	7.32	1.09	28.1
1982	7.80	4.87	18.5	7.03	2.67	13.3	8.09	2.10	14.8

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Year	Fort Peck Divisions: MT 2,3,4			Garrison Divisions: MT 3,5,6,7; ND 1,4,7			Oahe Divisions: ND 4,5,7,8; SD 1,2,4,5,6		
	Feb 28/29 SM[1]	NDJF P[2]	JFM T[3]	Feb 28/29 SM[1]	NDJF P[2]	JFM T[3]	Feb 28/29 SM[1]	NDJF P[2]	JFM T[3]
1983	7.81	3.64	30.1	8.54	1.73	28.0	10.15	1.28	28.3
1984	8.00	4.28	28.4	6.44	2.09	26.8	7.80	1.86	25.8
1985	7.22	3.35	20.5	5.76	1.60	19.2	7.02	1.35	20.2
1986	8.79	4.64	29.5	7.90	2.82	27.0	8.55	3.04	26.1
1987	7.75	2.81	28.5	8.12	1.90	28.3	10.24	2.65	27.9
1988	6.43	3.03	25.1	6.29	1.39	22.1	6.94	1.27	21.2
1989	6.46	4.74	19.2	5.34	2.55	16.4	5.47	1.84	18.0
1990	7.98	4.44	27.0	6.18	2.29	26.9	6.62	1.56	28.1
1991	5.91	3.33	27.3	5.28	1.68	25.2	6.47	1.49	25.5
1992	6.74	3.20	32.6	6.72	1.29	31.5	7.47	1.48	31.2
1993	7.72	4.13	20.9	6.69	2.20	18.5	7.79	2.54	18.8
1994	9.65	3.41	24.7	9.09	2.59	18.3	10.28	2.88	17.5
1995	6.53	3.63	26.3	7.52	1.82	23.7	9.41	1.85	23.4
1996	8.86	5.21	19.9	7.88	2.61	16.1	9.64	2.04	17.1
1997	7.24	6.11	24.4	7.46	3.23	20.3	10.72	3.69	20.3
1998	7.33	3.15	25.9	7.28	2.07	23.6	8.90	1.99	24.2
1999	7.47	5.43	28.9	8.54	3.15	26.5	10.60	2.44	27.1
2000	6.31	3.77	27.8	7.08	1.92	26.4	9.07	1.58	27.9
2001	5.65	2.67	25.1	7.08	2.54	22.0	8.97	3.10	21.3
2002	5.15	3.17	22.4	5.63	1.43	21.4	7.11	1.02	23.1
2003	6.88	3.58	25.7	6.49	1.77	20.7	6.79	1.39	21.0
2004	5.94	4.16	26.7	6.48	2.43	22.3	6.97	1.95	23.4
2005	6.10	2.24	27.1	6.18	1.13	24.3	7.57	0.87	25.1
2006	7.74	4.75	27.7	7.53	2.30	27.2	7.92	1.93	27.6
2007	7.32	3.89	27.5	6.60	1.76	24.6	6.99	1.44	24.1
2008	6.68	3.95	24.6	5.87	1.33	21.7	7.26	1.05	21.5
2009	7.11	4.61	25.2	8.19	3.37	20.0	10.67	3.85	20.1
2010	6.92	2.97	26.7	7.54	1.96	21.4	9.98	2.20	20.6
2011	9.09	5.75	21.8	9.39	3.69	17.1	10.21	3.13	17.1
2012	8.29	3.44	29.1	7.42	1.69	29.6	8.39	1.57	31.0
2013	7.49	4.03	26.7	5.73	2.07	22.8	5.66	1.63	22.6
2014	10.19	4.49	23.2	9.35	2.49	19.1	10.38	1.71	19.0
Average	**7.28**	**4.19**	**23.4**	**6.95**	**2.20**	**20.3**	**7.78**	**1.89**	**20.7**
Median	**7.22**	**4.03**	**23.5**	**6.92**	**2.14**	**20.4**	**7.54**	**1.83**	**21.0**
Max	**10.19**	**6.47**	**32.6**	**9.39**	**3.69**	**31.5**	**10.72**	**3.85**	**31.2**
Min	**5.14**	**2.24**	**13.4**	**4.11**	**1.13**	**7.4**	**4.22**	**0.87**	**8.0**
Std Dev	**1.05**	**1.03**	**4.2**	**1.11**	**0.59**	**5.0**	**1.45**	**0.64**	**4.8**

[1]SM denotes soil moisture.
[2]NDJF P denotes November-February accumulated precipitation.
[3]JFM T denotes January-March average temperature.

Table C-3. Fort Randall, Gavins Point and Sioux City reach average climate division soil moisture (inches), precipitation (inches) and temperature (deg F) for use in MA Method 2. Soil moisture source is NOAA CPC. Precipitation and temperature source is NOAA NCEI.

	Fort Randall Divisions: SD 5,6,8			Gavins Point Divisions: SD 9; NE 1,2			Sioux City Divisions: IA 1; MN 7; ND 5,9; SD 3,7,9		
Year	Feb 28/29 SM[1]	DJF P[2]	JFM T[3]	Feb 28/29 SM[1]	ONDJFM P[2]	JFM T[3]	Feb 28/29 SM[1]	ONDJFM P[2]	JFM T[3]
1932	5.74	1.54	21.4	9.33	5.54	23.3	9.33	7.11	16.6
1933	6.18	0.64	26.6	8.69	3.73	27.6	8.69	4.64	21.0
1934	5.01	1.04	29.9	7.33	2.85	30.4	7.33	2.71	22.8
1935	5.60	1.16	29.5	8.53	3.31	30.6	8.53	5.08	22.8
1936	6.17	2.11	13.2	9.67	3.87	17.0	9.67	4.94	6.4
1937	4.83	1.21	16.7	7.50	4.04	19.0	7.50	5.09	11.4
1938	5.65	1.27	27.0	9.00	4.78	28.7	9.00	4.72	19.7
1939	6.94	1.87	25.1	9.69	3.73	26.4	9.69	3.77	17.6
1940	6.28	1.23	20.0	7.56	4.23	22.6	7.56	4.29	14.9
1941	5.17	1.06	25.0	9.54	4.87	26.3	9.54	5.81	18.3
1942	8.55	0.99	25.9	10.15	5.99	25.9	10.15	6.73	23.0
1943	8.00	0.84	22.4	11.23	3.19	25.5	11.23	4.01	14.9
1944	7.14	1.90	22.7	10.49	5.71	24.9	10.49	5.08	20.5
1945	9.07	1.10	28.8	11.68	4.80	29.7	11.68	4.89	23.5
1946	6.73	0.61	32.0	9.98	4.13	32.0	9.98	5.28	22.7
1947	9.96	1.07	23.8	12.03	6.32	25.3	12.03	6.43	19.3
1948	6.97	0.75	21.9	10.82	5.34	23.7	10.82	6.76	15.2
1949	8.28	1.65	17.7	9.64	6.99	20.0	9.64	6.01	14.4
1950	7.83	1.39	17.6	9.60	4.83	22.2	9.60	6.21	12.0
1951	8.01	0.77	22.0	9.84	3.46	24.5	9.84	5.49	14.3
1952	11.37	2.85	21.3	12.51	5.62	25.2	12.51	6.54	16.6
1953	7.72	2.30	27.9	8.19	4.29	29.8	8.19	4.14	21.3
1954	7.05	0.96	27.9	9.77	5.14	29.0	9.77	5.28	21.1
1955	7.73	1.39	22.9	9.69	3.56	23.3	9.69	3.52	16.7
1956	6.51	1.40	22.6	7.91	3.03	24.1	7.91	3.62	14.7
1957	7.42	0.79	22.4	9.03	3.89	24.7	9.03	4.69	17.6
1958	9.29	1.11	24.5	11.75	5.29	25.0	11.75	5.54	20.6
1959	6.05	0.96	23.6	7.54	3.32	24.8	7.54	3.11	17.0
1960	7.93	1.68	19.4	10.25	6.02	20.1	10.25	6.25	13.3
1961	6.84	0.93	29.5	10.12	4.05	29.1	10.12	4.05	22.0
1962	7.36	1.85	20.8	10.99	4.80	22.5	10.99	6.32	14.6
1963	8.38	0.95	25.7	10.50	3.69	25.9	10.50	3.02	18.6
1964	6.92	0.64	26.7	8.52	3.39	26.8	8.52	3.40	21.5
1965	6.32	1.23	20.8	9.38	2.18	22.5	9.38	3.28	12.1
1966	8.10	1.43	21.0	11.23	3.61	23.4	11.23	4.36	16.0
1967	8.58	1.11	27.3	10.15	2.72	29.4	10.15	4.00	19.5
1968	6.95	1.04	27.1	7.60	2.52	28.6	7.60	3.13	21.3
1969	8.62	2.03	19.3	14.02	6.11	21.2	14.02	8.74	12.8
1970	6.67	0.92	22.8	9.66	5.30	24.7	9.66	5.22	14.3
1971	7.49	1.81	21.8	10.70	5.57	24.2	10.70	6.92	16.2
1972	8.10	0.89	23.4	11.02	4.87	26.2	11.02	7.82	14.5
1973	8.01	1.24	28.9	10.43	7.44	28.8	10.43	6.90	24.8
1974	7.88	0.62	28.5	10.08	4.79	28.2	10.08	5.25	19.3
1975	5.79	1.23	22.0	8.06	3.60	24.0	8.06	5.04	16.5
1976	6.48	1.51	29.1	9.58	4.12	29.3	9.58	5.05	22.7
1977	5.65	1.47	25.1	6.17	5.10	26.5	6.17	5.60	19.6
1978	10.33	1.82	16.5	12.44	4.81	18.9	12.44	6.65	11.4
1979	7.25	1.17	16.5	10.27	4.95	18.2	10.27	5.66	8.8
1980	7.22	0.62	24.2	10.60	6.12	24.9	10.60	5.23	18.0
1981	6.79	0.86	31.7	8.62	3.58	31.7	8.62	4.08	26.0
1982	8.10	1.37	21.2	10.01	4.94	23.5	10.01	6.09	13.6

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Year	Fort Randall Divisions: SD 5,6,8			Gavins Point Divisions: SD 9; NE 1,2			Sioux City Divisions: IA 1; MN 7; ND 5,9; SD 3,7,9		
	Feb 28/29 SM[1]	DJF P[2]	JFM T[3]	Feb 28/29 SM[1]	ONDJFM P[2]	JFM T[3]	Feb 28/29 SM[1]	ONDJFM P[2]	JFM T[3]
1983	10.64	0.54	32.0	12.43	9.23	31.1	12.43	10.70	25.0
1984	8.41	1.09	29.0	11.38	5.94	27.9	11.38	7.24	21.6
1985	7.90	1.04	24.1	10.71	5.16	25.9	10.71	7.57	19.8
1986	9.21	1.44	29.4	11.33	5.05	31.1	11.33	5.47	22.5
1987	10.73	1.92	31.0	12.19	7.26	32.0	12.19	5.92	28.5
1988	7.62	1.56	24.5	9.45	4.62	24.4	9.45	3.66	18.1
1989	6.38	0.98	23.3	8.63	2.63	25.7	8.63	4.40	17.4
1990	6.90	1.06	32.1	7.73	3.47	32.1	7.73	3.42	27.3
1991	7.40	1.67	29.2	9.01	4.24	30.4	9.01	4.15	23.5
1992	8.69	1.44	34.5	10.85	6.41	34.9	10.85	5.74	28.6
1993	8.73	1.68	22.3	11.85	5.27	22.9	11.85	5.91	16.6
1994	10.43	1.73	23.4	13.54	4.46	25.4	13.54	4.84	14.3
1995	8.55	1.22	28.9	11.27	6.40	29.5	11.27	7.75	20.9
1996	10.40	1.19	22.0	12.53	4.86	24.3	12.53	6.48	15.7
1997	11.77	2.98	25.7	13.25	4.45	27.3	13.25	8.34	17.0
1998	9.81	1.00	28.2	10.37	5.23	29.8	10.37	6.16	23.8
1999	10.89	0.85	32.5	12.20	7.52	32.6	12.20	8.82	24.0
2000	9.44	1.23	32.7	9.97	3.21	33.6	9.97	3.23	27.1
2001	8.23	2.02	25.1	11.61	6.01	26.0	11.61	7.31	17.4
2002	7.36	0.37	27.4	9.78	3.92	28.6	9.78	4.78	23.3
2003	6.79	1.25	26.7	9.55	4.56	28.2	9.55	4.31	19.2
2004	6.27	0.85	28.9	8.99	4.14	29.9	8.99	5.19	21.6
2005	8.39	0.68	29.7	11.86	4.49	30.5	11.86	4.52	22.9
2006	7.65	1.14	31.4	11.95	5.15	31.8	11.95	6.16	26.1
2007	7.45	1.42	28.4	10.97	5.91	28.2	10.97	6.22	20.6
2008	8.69	1.26	26.0	11.33	5.68	26.0	11.33	5.79	17.5
2009	10.37	2.01	27.7	12.99	6.89	29.3	12.99	9.45	18.1
2010	10.28	1.84	24.6	14.04	7.17	26.5	14.04	10.04	19.0
2011	9.70	2.72	22.0	14.33	4.92	24.7	14.33	6.54	15.6
2012	8.74	1.55	34.9	9.69	4.34	35.1	9.69	4.17	30.6
2013	5.05	1.54	27.3	7.86	3.68	27.6	7.86	5.28	18.2
2014	9.36	1.14	24.3	10.16	5.60	24.9	10.16	6.47	15.3
Average	**7.85**	**1.31**	**25.3**	**10.28**	**4.80**	**26.6**	**10.28**	**5.54**	**18.9**
Median	**7.94**	**1.23**	**25.1**	**8.97**	**4.80**	**26.2**	**10.15**	**5.28**	**18.6**
Max	**11.77**	**2.98**	**34.9**	**12.41**	**9.23**	**35.1**	**14.33**	**10.70**	**30.6**
Min	**4.85**	**0.37**	**13.2**	**5.05**	**2.18**	**17.0**	**6.17**	**2.71**	**6.4**
Std Dev	**1.55**	**0.51**	**4.5**	**1.56**	**1.30**	**3.8**	**1.69**	**1.63**	**4.6**

[1]SM denotes soil moisture.

[2]DJF P denotes December-February accumulated precipitation, ONDJFM P denotes October-March accumulated precipitation.

[3]JFM T denotes January-March average temperature.

B. Hydrologic Condition Relationships with MA Runoff

The hydrologic conditions (soil moisture, accumulated precipitation, and temperature) were first evaluated separately versus the MA runoff volumes from 1932-2014. The individual hydrologic condition analysis looked for correlation between runoff and each condition. Trendlines were developed to further quantify the strength of the correlation, which might support causation. Perfect correlation would suggest that the hydrologic condition under evaluation is the only condition determining runoff, and would appear on the plot as a perfect trendline intersecting all points. Since a number of hydrologic conditions influence runoff, perfect correlation is not expected. Furthermore, to quantify the strength of the relationship, the coefficient of determination (R^2) statistic was used. R^2 is defined as the proportion of the variability in the dependent variable accounted for by the independent variable(s). The R^2 statistic has a range from 0 to 1.0, and a perfect correlation would result in an R^2 of 1.0.

1. Soil Moisture

The analysis of end-of-February soil moisture versus MA runoff was performed by comparing log-transformed soil moisture to log-transformed MA runoff in a linear regression analysis. The analysis was performed for the upper Basin and for each of the six System reaches. Results of the analysis were evaluated graphically and in a comparison R^2 statistics. An example of the relationship between MA runoff and soil moisture is illustrated in the plot of MA upper Basin runoff versus end-of-February soil moisture **Figure C-2**. In general the relationship shows a relatively strong direct correlation between soil moisture and MA runoff. The trendline

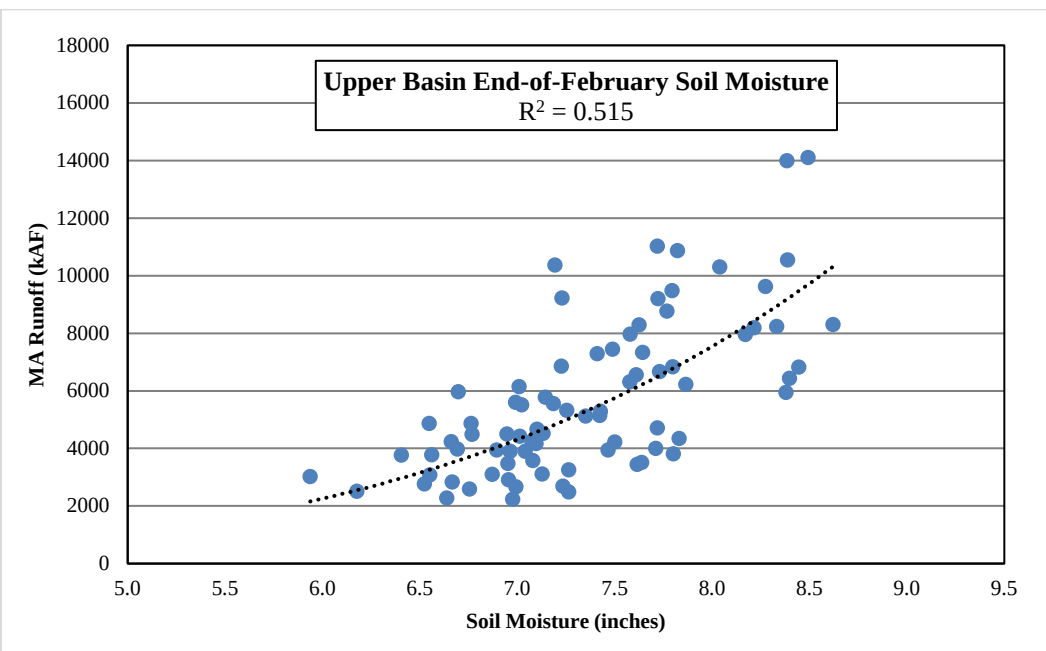

Figure C-2. MA upper Basin runoff (kAF) versus end-of-February modeled soil moisture for 1932-2014.

for the MA runoff versus end-of-February soil moisture has an R^2 of 0.515. This indicates that 52 percent of the variability in MA runoff can be explained by end-of-February soil moisture.

The complete results of the analysis summarizing R^2 statistics for upper Basin runoff and all System reaches are in **Table C-4**. **Table C-4** breaks down the analysis by hydrologic condition and time period. The highest R^2 among runoff periods by reach are highlighted in bold.

Table C-4. R^2 statistics for upper Basin and System reach MA runoff versus hydrologic conditions.

Hydrologic Condition	Period	Upper Basin	Fort Peck	Garrison	Oahe	Fort Randall	Gavins Point	Sioux City
Soil Moisture	End of Feb	**0.515**	**0.565**	0.429	0.418	**0.276**	0.393	0.511
	End of Mar	0.488	0.512	**0.461**	**0.460**	0.232	**0.443**	**0.577**
Precipitation	Oct – Mar (6)	0.426	0.401	0.413	0.445	0.129	**0.288**	**0.483**
	Nov – Feb (4)	**0.572**	**0.456**	**0.548**	**0.591**	0.254	0.175	0.399
	Dec – Feb (3)	0.540	0.398	0.415	0.563	**0.262**	0.104	0.332
Temperature	Dec – Feb (3)	**0.236**	**0.253**	**0.265**	**0.149**	**0.141**	**0.056**	**0.032**
	Jan – Mar (3)	0.188	0.194	**0.265**	0.119	0.127	0.030	0.019

R^2 statistics are based on a trendline analysis. The highest R^2 for each runoff period are highlighted in bold.

With regard to soil moisture, Fort Peck and Sioux City reaches exhibit better R^2 statistics than the other reaches. The highest R^2 statistics were 0.565 for the Fort Peck reach and 0.577 for the Sioux City reach. The Fort Randall R^2 statistics were the lowest and were less than 0.3 while all others were greater than 0.4. R^2 statistics for end-of-February soil moisture is higher for the upper Basin, Fort Peck and Fort Randall runoff, while statistics for end-of-March soil moisture are higher for Garrison, Oahe, Gavins Point and Sioux City MA runoff, though the differences are small. In making predictions of MA runoff, end-of-February soil moisture is the most applicable because it is a known parameter on March 1, whereas end-of-March soil moisture is not known on March 1.

2. Accumulated Precipitation

The accumulated precipitation analysis was performed in the same manner as the soil moisture analysis by comparing log transformed multi-month precipitation to log transformed MA runoff in a linear regression analysis. Accumulated precipitation was evaluated in three-, four- and six-month periods ending in February or March.

Figure C-3 displays MA upper Basin runoff versus four-month accumulated precipitation ending in February. The plot exhibits a relatively strong direct relationship with November-December-January-February precipitation accumulation with an R^2 of 0.572. An R^2 of 0.572 indicates that about 57 percent of the variability in the runoff data can be explained by the multi-month precipitation. Compared to soil moisture (R^2 = 0.515), precipitation has a slightly stronger relationship with upper Basin MA runoff.

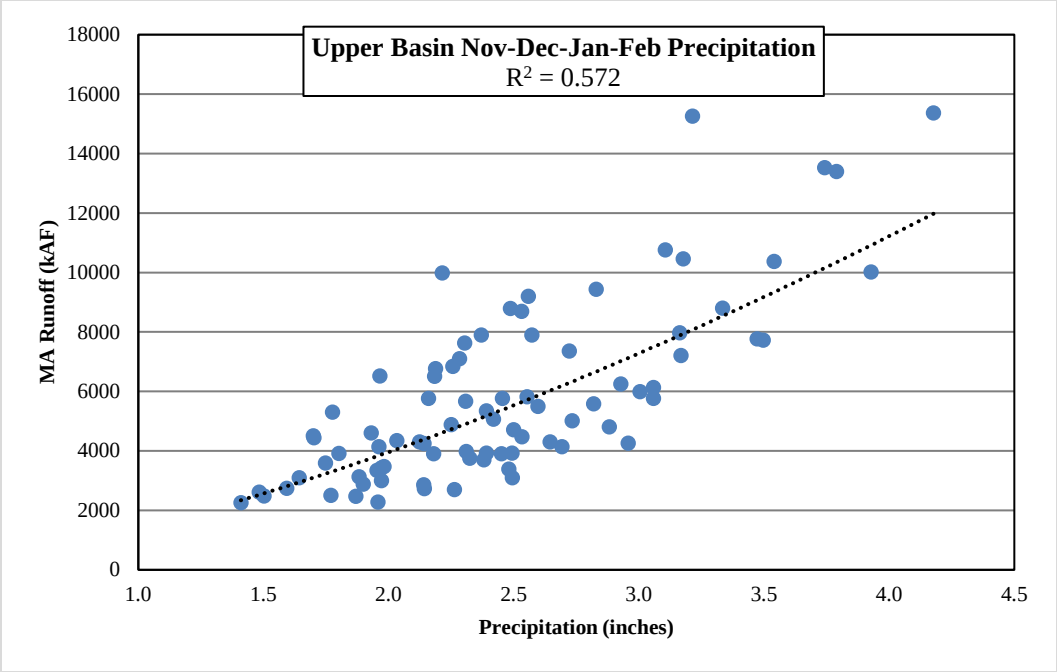

Figure C-3. MA upper Basin runoff (kAF) versus November-December-January-February precipitation for 1932-2014.

R^2 statistics are provided for all relationships in **Table C-4**. Upper Basin runoff R^2 statistics have a tendency to be higher for accumulation periods from November through February. Comparing the multi-monthly accumulation periods over the MA runoff period, the four-month period ending in February exhibited the highest R^2 statistics for the upper Basin, Fort Peck, Garrison and Oahe runoff. R^2 statistics were highest for the three-month accumulation period ending in February for Fort Randall, and the six-month accumulation period ending in March for Gavins Point and Sioux City. The October through March accumulation period is most applicable to the Gavins Point and Sioux City reaches. Since 75 percent of the MA runoff occurs in the upper three System reaches, four-month precipitation ending in February is the most important precipitation accumulation period.

3. Average Temperature

The analysis of average temperature over multi-month periods was performed by comparing log-transformed average three-month temperature to log-transformed MA runoff in a linear regression analysis. Average temperature periods spanned the December-January-February and January-February-March periods. Results of the analysis were evaluated in a comparison of R^2 statistics in **Table C-4** and **Figure C-4**.

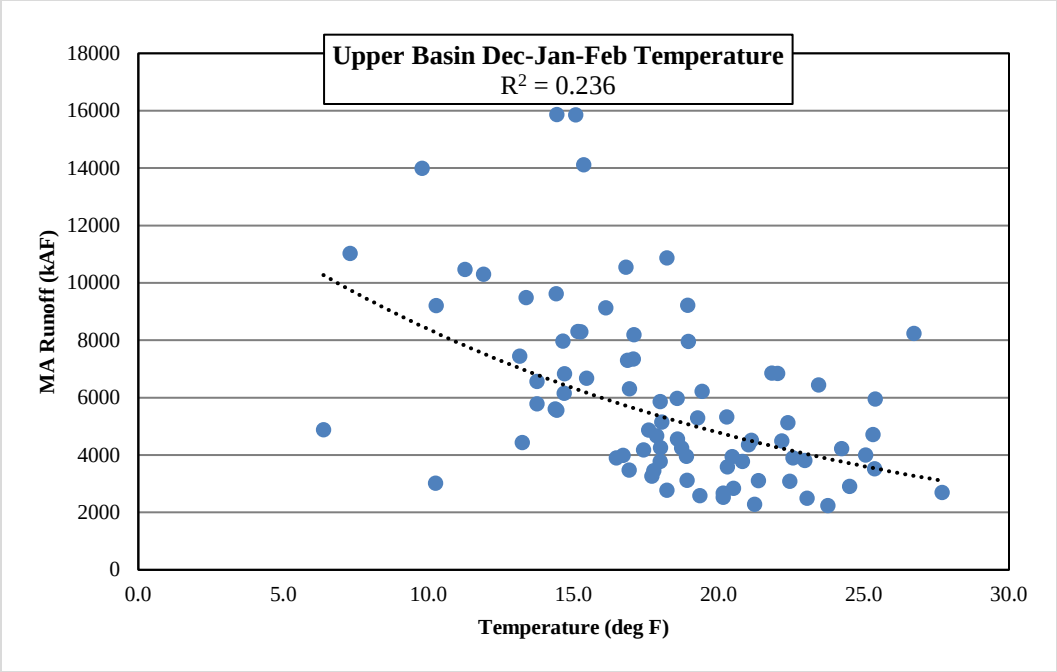

Figure C-4. MA upper Basin runoff (kAF) summation versus Dec-Jan-Feb temperature for 1932-2014.

MA upper Basin runoff versus December-January-February temperature is plotted in **Figure C-4**. December-January-February temperature exhibits a weak, inverse relationship to MA runoff with an R^2 coefficient of 0.236. In general, the relationship shows that as temperature increases, MA runoff volume decreases; however, the relationship does not always hold true because other factors such as precipitation and soil moisture influence runoff. R^2 statistics for three-month runoff periods ending in February and March are much less than soil moisture and precipitation statistics. The three-month period ending in February produced better R^2 statistics than the period ending in March. Although temperature influences runoff by promoting snow formation, accumulation, and melting, it is not a major factor determining MA runoff, but could serve as a supporting factor for runoff prediction.

C. Multiple Variable Regression of MA Runoff

A multiple linear regression analysis was performed to develop relationships between the hydrologic conditions and MA runoff over the 1932-2014 analysis period using least squares multiple linear regression methods. The analysis determined which parameter combinations had the strongest relationships to MA runoff. The hydrologic condition parameters that produced the strongest multiple linear regression relationships with MA runoff by reach are provided below in **Table C-5** with the R^2 statistics. When used in combination with other factors, the best hydrologic conditions do not always correspond to the best single parameters highlighted in **Table C-4**.

Based on the multiple linear regression analysis, the average climate division February 28/29 soil moisture is the best soil moisture indicator of MA runoff. Various periods of accumulated

precipitation were determined to be the best precipitation indicators of MA runoff. November-December-January-February (Nov-Dec-Jan-Feb) accumulated precipitation was the best precipitation parameter for the Fort Peck, Garrison and Oahe reaches. The October-November-December-January-February-March (Oct-Nov-Dec-Jan-Feb-Mar) accumulated precipitation was the best precipitation parameter for the Gavins Point and Sioux City reaches. December-January-February accumulated precipitation was the best precipitation parameter for the Fort Randall reach. The best temperature predictor in combination with soil moisture and precipitation for all reaches was January-February-March (Jan-Feb-Mar) average temperature. The R^2 statistics indicate the best relationships between the hydrologic conditions and MA runoff for the 1932-2014 analysis period are in the Fort Peck reach (R^2=0.738), Garrison reach (R^2=0.743) and Oahe reach (R^2=0.753).

Table C-5. Best combinations of hydrologic conditions used in multiple linear regressions to predict MA reach runoff during the historic 1932-2014 period.

Reach	Climate Divisions	Soil Moisture	Accumulated Precipitation	Average Temperature	R^2
Fort Peck	MT 2,3,4	February 28/29	Nov-Dec-Jan-Feb	Jan-Feb-Mar	0.738
Garrison	MT 3,5,6,7; ND 1,4,7	February 28/29	Nov-Dec-Jan-Feb	Jan-Feb-Mar	0.743
Oahe	ND 4,5,7,8; SD 1,2,4,5,6	February 28/29	Nov-Dec-Jan-Feb	Jan-Feb-Mar	0.753
Fort Randall	SD 5,6,8	February 28/29	Dec-Jan-Feb	Jan-Feb-Mar	0.428
Gavins Point	SD 9; NE 1,2	February 28/29	Oct-Nov-Dec-Jan-Feb-Mar	Jan-Feb-Mar	0.465
Sioux City	IA 1; MN 7; ND 5,9; SD 3,7,9	February 28/29	Oct-Nov-Dec-Jan-Feb-Mar	Jan-Feb-Mar	0.625

Plots comparing predicted MA runoff versus historic MA runoff based on the multiple hydrologic parameter regressions are shown in **Figure C-5** through **Figure C-10**. The plots include one-to-one lines, which help to view the predicted MA runoff closeness of fit to MA historic runoff.

In light of the current difficulty of predicting MA runoff into the three largest System reservoirs (Fort Peck, Garrison and Oahe), these results are particularly encouraging because they indicate that these three factors used in multi-factor regression equations can explain up to 74 percent of the variability in MA runoff in the Fort Peck and Garrison reaches, and 75 percent in the Oahe reach. This is significant because it indicates MA runoff can be predicted more accurately, especially from the upper three reservoirs, which, on average, receive 75 percent of the MA runoff (4.4 MAF of the 5.9 MAF) in the upper Basin.

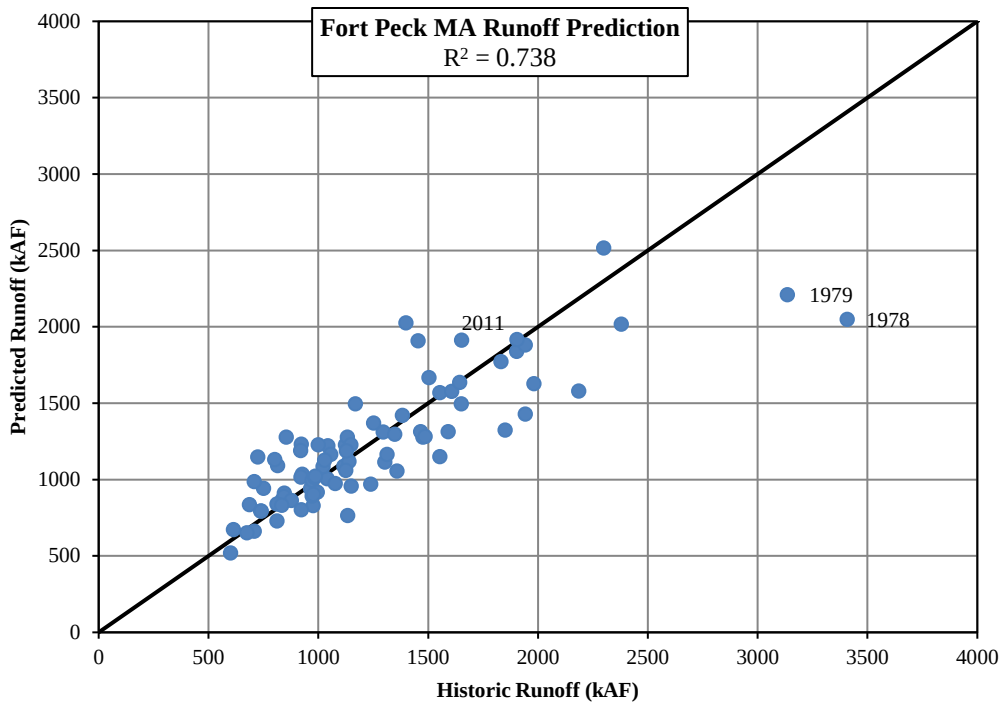

Figure C-5. MA Method 2 –Fort Peck predicted MA runoff versus historic MA runoff for the 1932-2014 period.

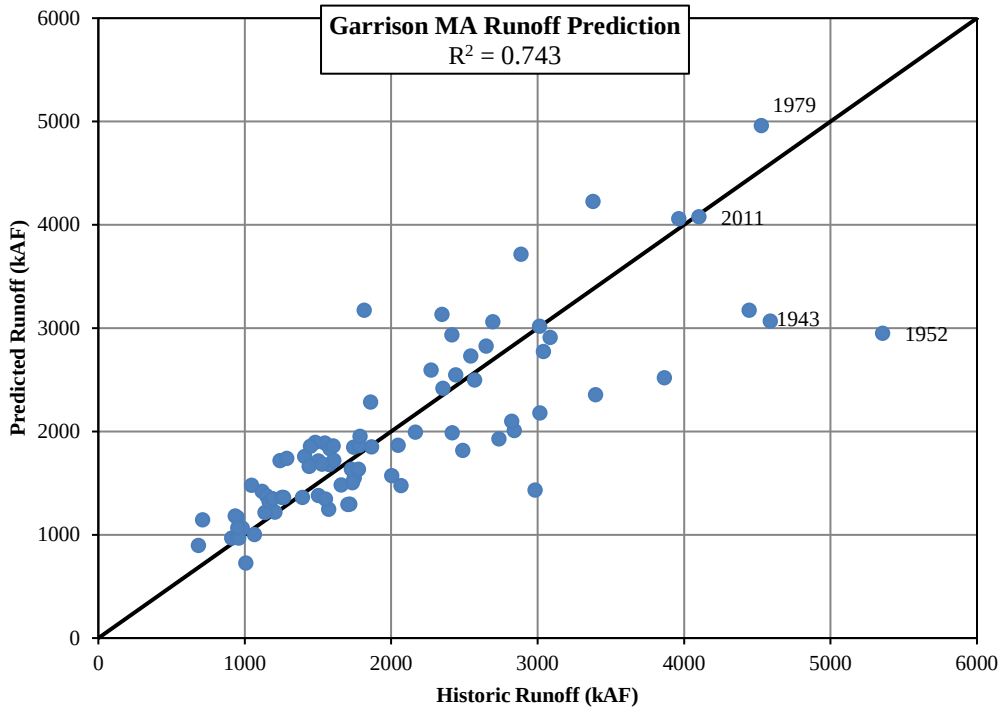

Figure C-6. MA Method 2 –Garrison predicted MA runoff versus historic MA runoff for the 1932-2014 period.

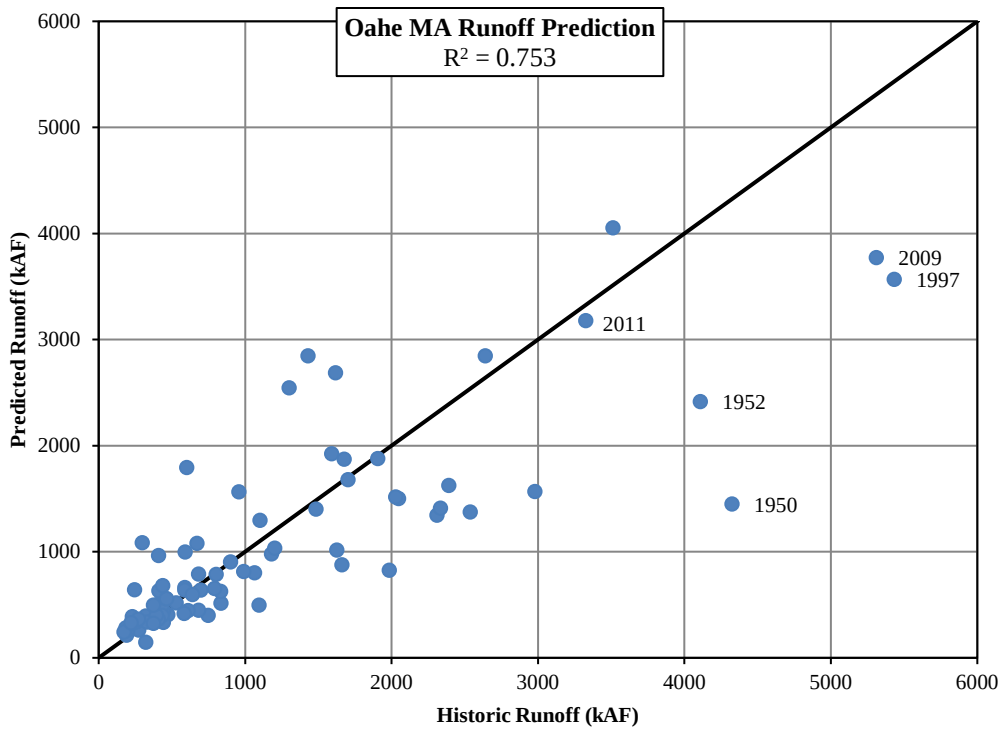

Figure C-7. MA Method 2 –Oahe predicted MA runoff versus historic MA runoff for the 1932-2014 period.

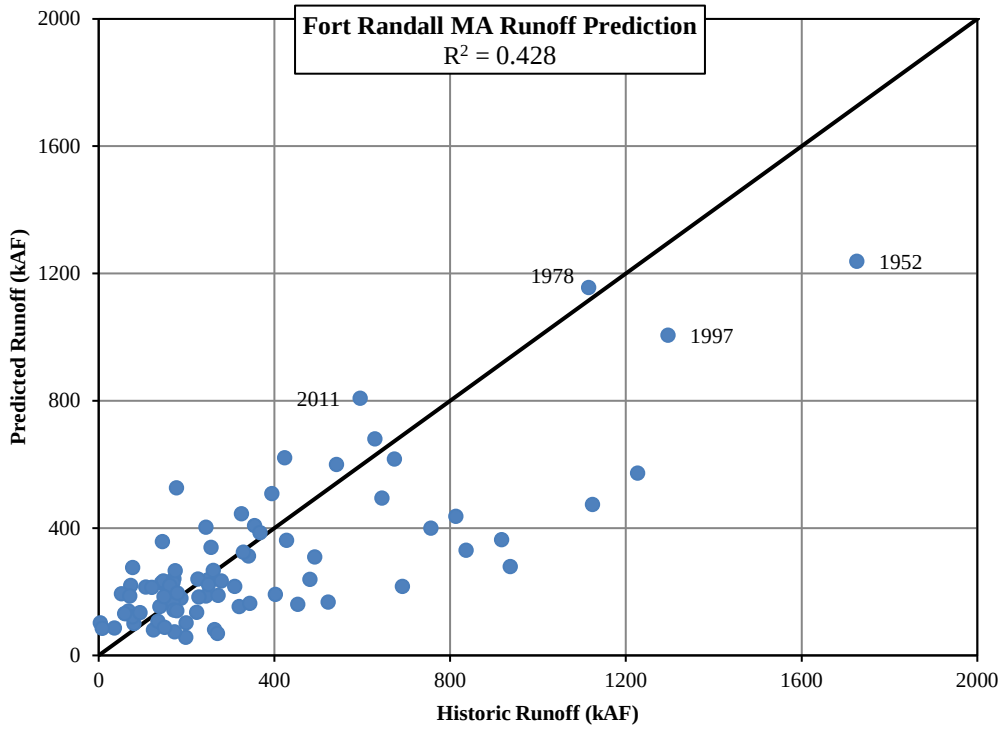

Figure C-8. MA Method 2 –Fort Randall predicted MA runoff versus historic MA runoff for the 1932-2014 period.

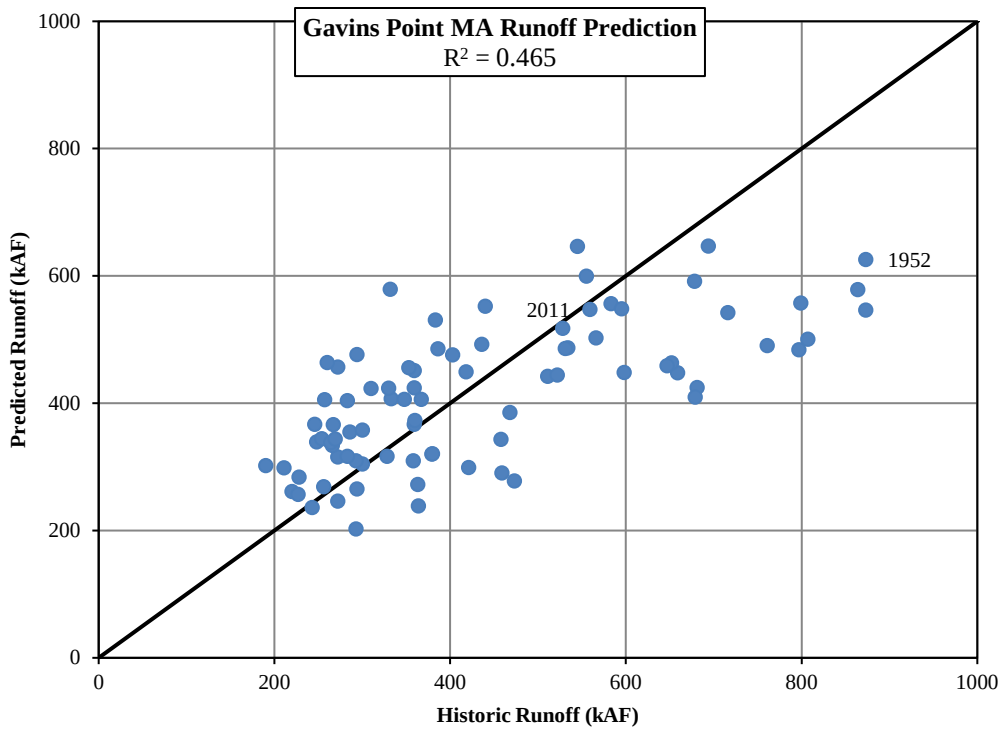

Figure C-9. MA Method 2 –Gavins Point predicted MA runoff versus historic MA runoff for the 1932-2014 period.

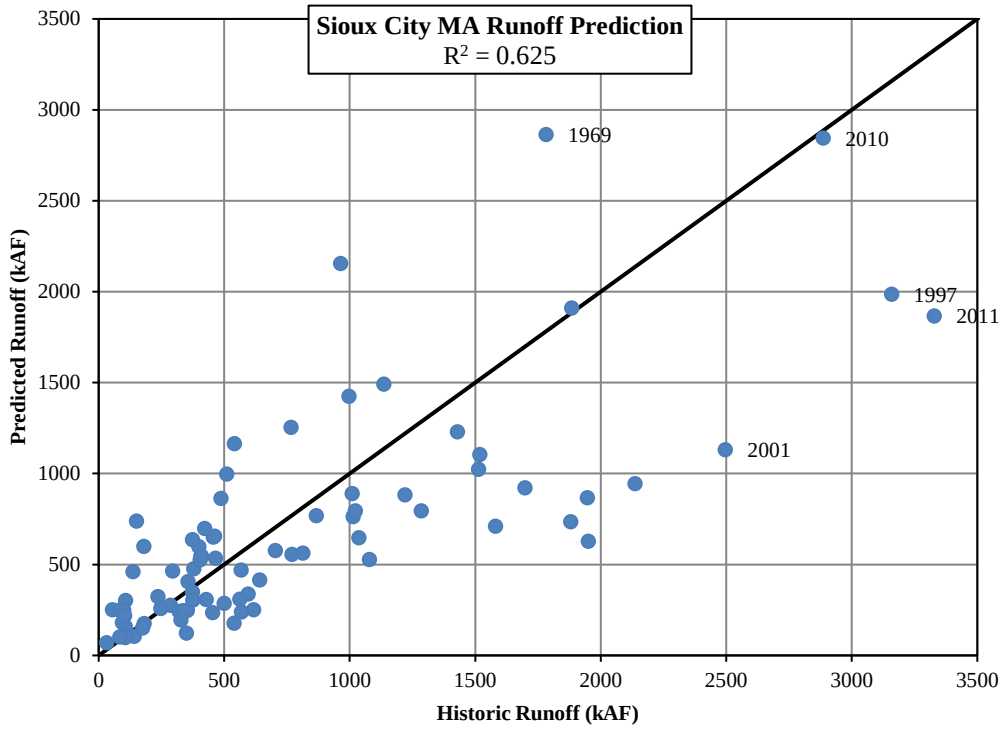

Figure C-10. MA Method 2 –Sioux City predicted MA runoff versus historic MA runoff for the 1932-2014 period.

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APPENDIX D

MAY-JUNE-JULY RUNOFF FORECAST DATA

A. May-June-July Runoff

May-June-July (MJJ) runoff in the Fort Peck and Garrison reaches for 1961-2014 is shown in **Figure D-1**. Monthly runoff and MJJ runoff is also tabulated for all reaches for the 1898-2014 period of record in **Table F-1** through **Table F-6** in Appendix F. The 1961-2014 period of MJJ runoff was used in the regression analysis to derive regression equations for forecasting MJJ runoff based on mountain snowpack, precipitation, temperature and observed runoff. The average Fort Peck reach runoff during this period is 3,564 kAF compared to the long term average of 3,553 kAF for 1898-2014. The average Garrison reach runoff is 5,623 kAF compared to the long-term average of 5,807 kAF for 1898-2014.

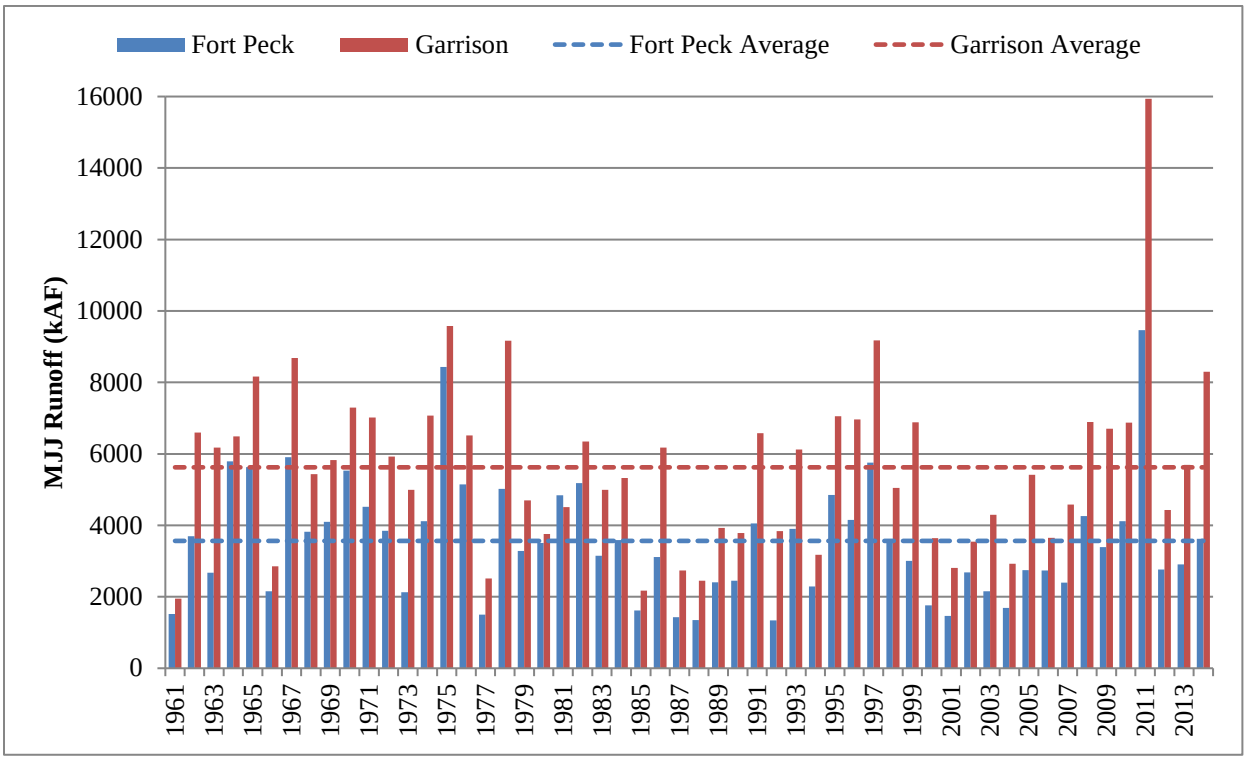

Figure D-1. MJJ runoff (kAF) in the Fort Peck and Garrison reaches for the 1961-2014 period.

B. Mountain Snow Water Equivalent

Mountain SWE is monitored by the USDA NRCS SNOTEL network of automated stations and manually measured snow courses. Snow data has been consistently collected for more than 50 years at many locations in the upper Missouri River Basin through monthly manual snow surveys. The greatest source of mountain snowpack information comes from the SNOTEL network of automated stations that provide daily measurements of snow depth, SWE and temperature. **Figure D-2** shows the location of SNOTEL stations in the Fort Peck and Garrison reaches.

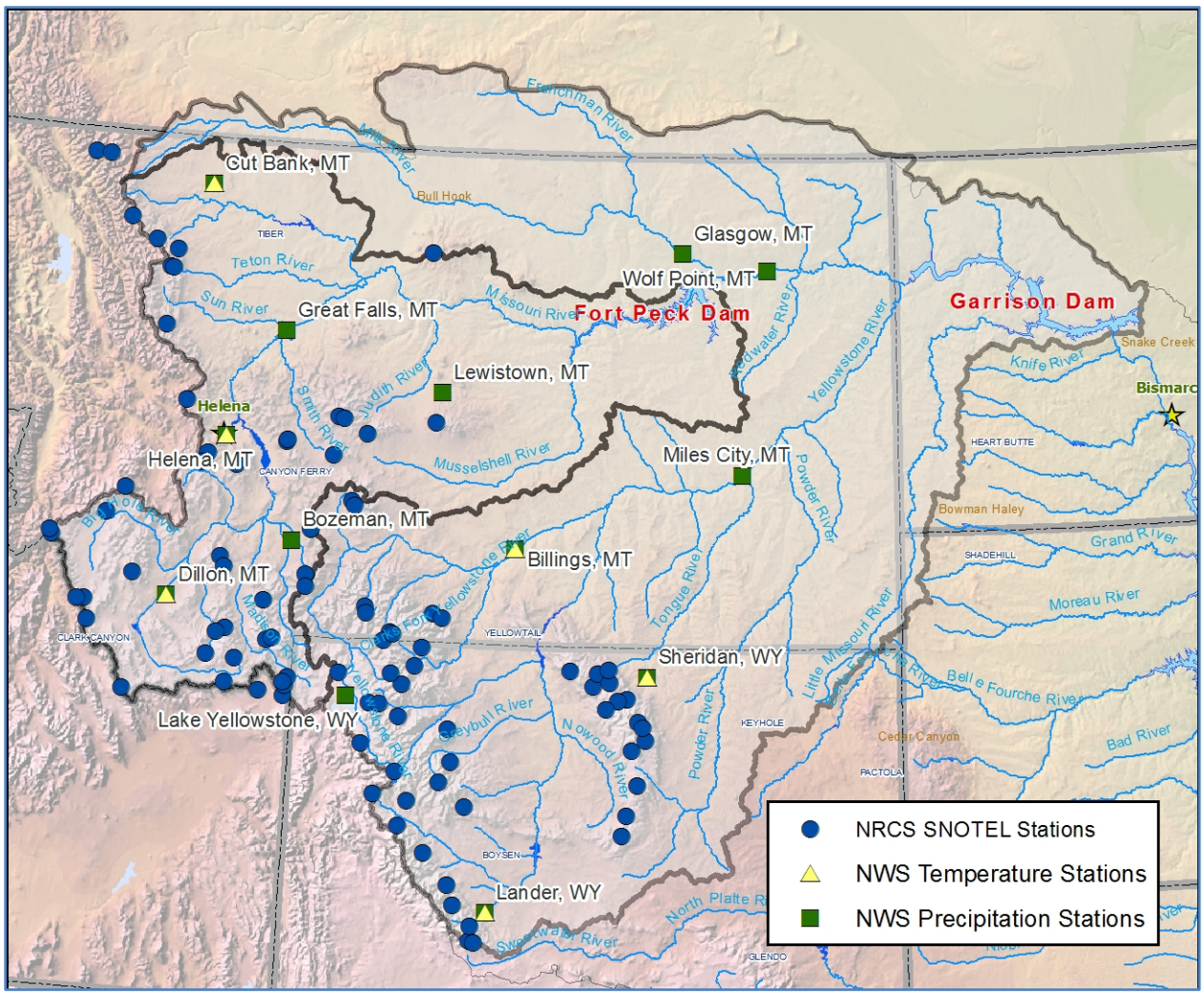

Figure D-2. NRCS SNOTEL stations and NWS weather stations.

The SNOTEL network came into existence during the late 1960s, but it was not extensively expanded until the late 1970s and early 1980s. **Figure D-3** illustrates the number of SNOTEL stations providing SWE data in the Fort Peck and Garrison reaches since the beginning of Water Year 1970. During the past decade, about 48 SNOTEL stations have been used to represent SWE in the Fort Peck reach, and about 45 SNOTEL stations have been used to represent SWE in the Garrison reach. Mountain SWE is represented in the Fort Peck and Garrison reaches as an average of the stations reporting daily SWE for each reach. A list of the stations used in each reach is provided in **Table D-1**.

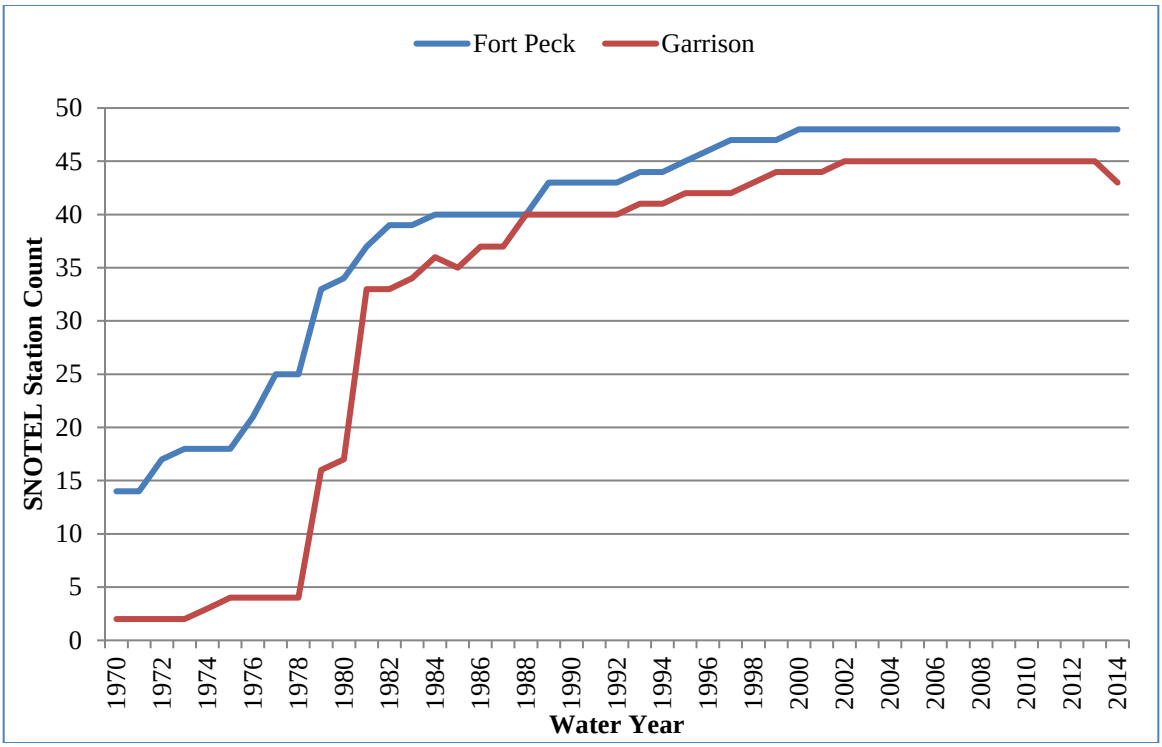

Figure D-3. Number of SNOTEL stations in the Fort Peck and Garrison reaches.

Table D-1. NRCS SNOTEL stations used in the MJJ runoff analysis, station elevations and the beginning date of data for each SNOTEL station.

Stations above Fort Peck			**Stations between Fort Peck and Garrison**		
Name	Elevation, ft	Beginning Date	Name	Elevation, ft	Beginning Date
Albro Lake	8300	September 1996	Bald Mountain	9380	October 1978
Badger Pass	6900	October 1978	Bear Trap Meadow	8200	October 1979
Barker Lakes	8250	October 1979	Beartooth Lake	9360	October 1979
Beagle Springs	8850	October 1978	Big Goose	7990	July 1998
Beaver Creek	7850	October 1966	Blackwater	9780	October 1979
Black Bear	8170	October 1971	Bone Springs Divide	9350	October 1978
Bloody Dick	7600	October 1976	Box Canyon	6670	October 1978
Boulder Mountain	7950	October 1978	Burgess Junction	7880	October 1979
Brackett Creek	7320	September 1994	Burnt Mountain	5880	October 2000
Calvert Creek	6430	October 1975	Burroughs Creek	8750	October 1978
Carrot Basin	9000	October 1966	Canyon	7870	October 1979
Clover Meadow	8600	October 1978	Cloud Peak Reservoir	9860	October 1978
Crystal Lake	6050	October 1978	Cold Springs	9630	October 1983
Daisy Peak	7600	October 1990	Cole Creek	7850	October 1971
Darkhorse Lake	8600	October 1979	Deer Park	9700	August 1997
Deadman Creek	6450	October 1967	Dome Lake	8880	October 1978
Divide	7800	October 1971	Evening Star	9200	October 1979
Dupuyer Creek	5750	October 1982	Fisher Creek	9100	October 1966
Flattop Mountain	6300	October 1969	Grave Springs	8550	October 1991
Frohner Meadow	6480	October 1972	Hansen Sawmill	8360	October 1979
Lakeview Ridge	7400	October 1978	Hobbs Park	10100	October 1978
Lemhi Ridge	8100	October 1971	Kirwin	9550	October 1979
Lick Creek	6860	October 1963	Little Warm	9370	October 1978
Lone Mountain	8880	October 1988	Marquette	8760	October 1979
Lower Twin	7900	October 1979	Middle Powder	7760	October 1978
Madison Plateau	7750	October 1967	Monument Peak	8850	October 1979
Many Glacier	4900	October 1976	Northeast Entrance	7350	October 1996
Moose Creek	6200	October 1979	Owl Creek	8975	October 1979
Mount Lockhart	6400	October 1968	Parker Peak	9400	October 1979
Mule Creek	8300	October 1979	Powder River Pass	9480	October 1978
Nevada Ridge	7020	October 1993	Shell Creek	9580	October 1978
Pickfoot Peak	6650	October 1978	S Fork Shields	8100	October 1978
Pike Creek	5930	October 1976	South Pass	9040	October 1984
Porcupine	6500	October 1976	St Lawrence Alt	8620	October 1983
Rocker Peak	8000	October 1967	Sucker Creek	8880	October 1978
Rocky Boy	4700	October 1967	Sylvan Lake	8420	October 1978
Sacajawea	6550	September 1999	Sylvan Road	7120	October 1986
Saddle Mountain	7940	October 1967	Thumb Divide	7980	October 1987
Short Creek	7000	October 1987	Tie Creek	6870	August 1994
Shower Falls	8100	October 1965	Timber Creek	7950	October 1986
Spur Park	8100	October 1966	Togwotee Pass	9580	October 1979
Tepee Creek	8000	October 1971	Townsend Creek	8700	October 1979
Tizer Basin	6880	October 1987	Two Ocean Plateau	9240	October 1979
Waldron	5600	October 1968	White Mill	8700	October 1973
West Yellowstone	6700	October 1966	Younts Peak	8350	October 1979
Whiskey Creek	6800	October 1971			
White Elephant	7710	October 1979			
Wood Creek	5960	October 1978			

Beginning around October 1, which is the typical start of the mountain snow accumulation season, MRBWMD computes the average daily SWE for each reach and reports it on the MRBWMD website. An example of the figure used to illustrate the average mountain reach SWE is shown in **Figure D-4**. For the purpose of forecasting MJJ runoff due to mountain snowpack, MRBWMD exclusively uses the average reach SWE on January 1, February 1, March 1, April 1, May 1, June 1, and the date of peak.

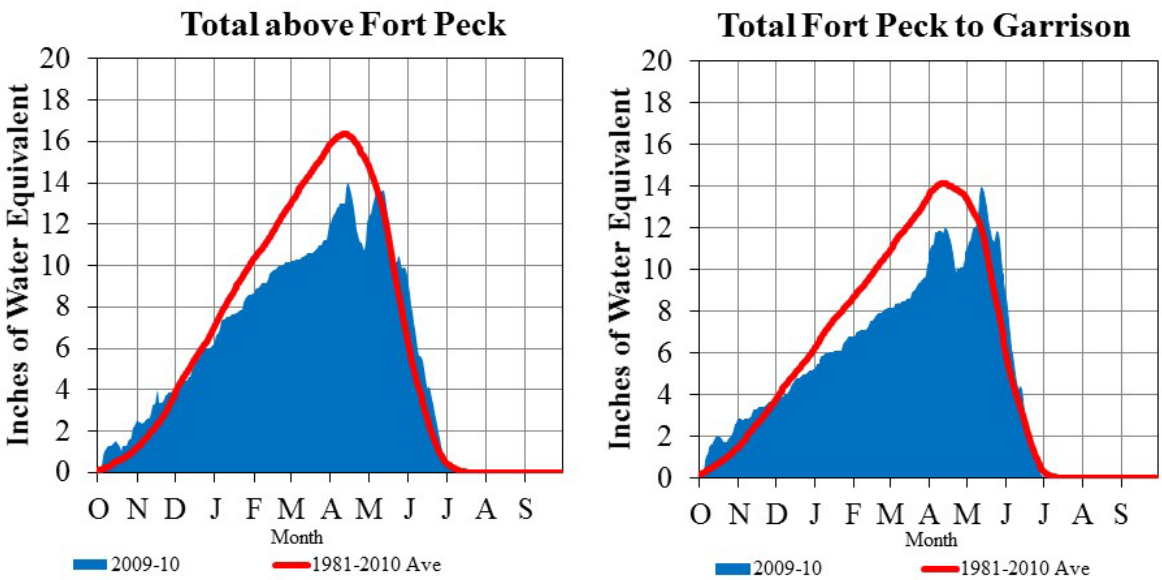

Figure D-4. Example graph of the average mountain SWE (inches) for the System reaches above Fort Peck and from Fort Peck to Garrison compared the 1981-2010 average SWE.

In order to develop regression relationships between mountain SWE and MJJ runoff, the mountain SWE record first had to be normalized to the current number of SNOTEL stations used to represent the average SWE in each System reach. **Figure D-3** shows how the number of stations increased significantly from the late 1970s until the mid-1980s with some additional SNOTEL stations added to the Fort Peck and Garrison reaches in the early to late 1990s. Since mountain SWE is represented as the average reach SWE for the number of available stations, the average SWE through the 1970-2014 time period would not be comparable due to the increasing number of stations. For example, early in the record, when a limited number of stations existed predominantly at higher elevations, the average SWE of the limited number of stations, when compared to the average SWE in the last decade based on the total available stations, were several inches higher in all instances. Thus, the record prior to the current period must be normalized so that it is comparable to the current period which uses 48 stations in the Total above Fort Peck reach (Fort Peck) and 45 stations in the Total Fort Peck to Garrison reach (Garrison) as shown in **Figure D-4**.

Station normalization was accomplished by three steps. First two-station comparisons were made to extend the shorter station records. Step 1 was used to extend the daily record of SWE for SNOTEL stations with shorter records to stations with a longer record. For example, the daily record of a short-record (1997-2014) station was extended to a longer record length using daily station data from a long record (1981-2014). The long-record station was chosen from one

of four radially nearest station sites with an elevation within 1500 vertical feet of elevation. After it was determined that the stations possessed similarities in overlapping records, a ratio of the short-record SWE to the long-record SWE was computed. The short-record SWE was extended to the period of the long record by multiplying the ratio by the daily long-record SWE, then appending the short record (1997-2014) to the adjusted record extension (1981-1996).

Secondly, the average mountain reach SWE during periods with fewer stations was adjusted to a comparable level as the recent record average mountain reach SWE datasets, which used 48 Fort Peck stations and the 45 Garrison stations. The first of month and peak SWE records were adjusted from the longer period of record with fewer SNOTEL stations to a shorter record with more SNOTEL stations. This method was the primary means to adjust the SWE records for the earlier time periods when there were fewer stations to average SWE comparable to the current period. For example, in the Fort Peck reach, after individual stations were extended by the Step 1 comparison, 19 stations now represented the average daily, first of month, and peak SWE of the Fort Peck reach from Water Year 1970-1972; however, 48 stations were used in the current time period. In order to adjust the 19-station SWE dataset to the full 48 station SWE data set, the 19-station averages and the 48-station averages were compared over the 1981-2014 period. Ratios of these two datasets were developed for the first of month and peak SWE dates. The 1970-1972 first of month and peak SWE data for the 19-station average was adjusted by the ratio to a comparable 48-station SWE data set. This step was repeated for additional periods with different numbers of station from 1973-1980 until all average first of month and peak SWE datasets were normalized to the 48-station dataset for Fort Peck. These steps were repeated to adjust average Garrison SWE to a 45-station dataset.

Finally, data used in the D-96 report was incorporated into the average reach SWE datasets in order to extend the analysis record back to the 1961-1969 period. The D-96 SWE record extending from Water Year 1961-1995 was compared to the adjusted average SWE data for 1970-1995. Ratios were developed for the first of month and peak SWE dates for the overlapping period. These ratios were used to adjust the D-96 data for 1961-1969 so that it was comparable to the 48-station dataset for Fort Peck. For Garrison, due to the lack of SNOTEL station data until about 1980 (**Figure D-3**), ratios for the D-96 dataset were created based on comparison of the D-96 dataset and the adjusted 45-station dataset for 1979-1995. In addition to extending the Garrison SWE record for 1961-1969, the adjusted D-96 dataset was used in place of the 45-station dataset for 1970-1980. Therefore, the adjusted D-96 dataset used 20 years (1961-1980) while the 45-station dataset used 34 years (1981-2014).

Average mountain reach SWE at the first of each month and the date of peak SWE for the Fort Peck and Garrison reaches is provided in **Table D-2** and **Table D-3**, respectively.

Table D-2. Mountain SWE (inches) above Fort Peck based on 48 stations.

Year	Snow Water Equivalent (inches)								Peak Date
	Jan 1	Feb 1	Mar 1	Apr 1	May 1	May 15	Jun 1	Peak	
1961	6.77	7.89	11.60	13.96			5.84	16.49	
1962	9.23	13.03	15.47	18.26	18.26	13.36	6.89	18.06	
1963	5.57	8.84	11.47	12.88	0.00	0.00	6.17	14.64	
1964	5.31	10.58	14.44	18.35	18.35	18.15	8.35	19.89	
1965	10.68	17.17	20.69	23.22	17.97	17.97	12.35	24.42	
1966	4.09	8.59	11.93	13.86	13.86	13.36	2.61	15.40	
1967	7.09	13.71	17.64	21.32	21.58	21.58	9.29	23.59	
1968	9.36	12.93	15.87	17.84	17.84	16.80	10.30	19.36	
1969	7.65	15.61	18.46	19.19	10.18	10.18	3.91	19.58	
1970	6.93	12.90	15.49	20.65	25.09	21.29	10.28	25.18	May 1
1971	9.86	15.68	20.00	24.79	24.35	15.85	12.43	25.68	Apr 28
1972	10.02	16.12	20.45	22.84	22.37	17.29	10.85	24.01	Apr 22
1973	6.71	9.04	10.89	14.25	17.47	12.75	4.64	17.79	Apr 25
1974	9.33	13.67	17.11	23.31	21.94	17.45	13.96	25.07	Apr 14
1975	6.66	11.94	15.41	19.84	23.86	22.60	16.51	26.00	May 8
1976	10.84	14.58	18.51	21.00	21.97	15.32	7.23	22.50	Apr 29
1977	4.10	6.65	8.18	12.87	5.17	3.27	2.28	13.31	Apr 5
1978	10.98	14.98	17.87	18.22	16.51	14.61	11.62	19.63	Apr 23
1979	8.10	10.69	15.46	18.06	18.17	14.73	6.89	19.71	Apr 24
1980	5.21	9.48	12.40	17.08	10.33	6.31	4.02	18.83	Apr 12
1981	6.27	7.69	11.02	13.90	10.18	10.28	5.15	15.00	Apr 14
1982	8.21	13.51	16.49	21.76	22.40	19.37	13.88	24.78	Apr 20
1983	8.47	11.01	13.79	17.65	16.42	16.14	7.70	19.01	Apr 14
1984	7.33	9.60	11.63	15.95	17.16	14.02	7.19	17.93	May 7
1985	9.34	10.82	13.41	16.72	12.20	7.48	2.02	17.07	Apr 6
1986	7.07	9.83	14.80	15.87	15.06	15.66	6.89	16.49	Mar 25
1987	6.01	8.41	10.24	12.77	5.50	1.09	0.43	12.84	Mar 31
1988	4.59	7.70	10.39	14.55	12.34	9.58	2.61	15.56	Apr 9
1989	6.90	11.35	13.36	18.31	16.29	10.30	7.40	18.91	Apr 7
1990	6.68	11.39	13.92	16.32	12.71	10.62	7.73	16.49	Mar 29
1991	8.06	11.23	12.57	16.78	20.20	19.47	10.58	20.60	May 5
1992	8.52	10.33	12.26	13.01	9.31	4.67	0.61	13.23	Mar 22
1993	7.42	10.23	12.03	13.96	16.51	11.17	3.74	16.55	Apr 27
1994	5.27	8.36	11.58	12.98	10.46	4.38	1.33	14.50	Apr 9
1995	9.01	12.29	13.92	17.56	20.09	19.88	11.94	20.57	May 8
1996	8.65	13.07	16.58	19.71	19.99	17.25	13.36	20.15	Apr 6
1997	13.79	18.65	21.47	24.97	25.90	19.37	10.30	26.46	Apr 16
1998	5.17	9.67	11.33	13.93	12.75	8.09	4.89	16.28	Apr 18
1999	8.85	13.28	17.99	19.58	18.76	18.36	10.44	20.44	Apr 11
2000	6.00	9.46	12.44	15.15	10.85	9.17	3.72	15.40	Apr 4
2001	5.63	6.78	8.86	11.09	11.54	5.26	0.75	14.11	Apr 22
2002	6.11	9.75	12.26	15.58	16.01	14.49	7.02	16.26	Apr 20
2003	4.84	8.34	11.50	15.72	15.57	15.10	5.73	16.85	Apr 8
2004	7.87	11.25	13.54	13.92	10.85	6.50	5.65	14.82	Mar 18
2005	5.93	7.69	8.73	12.15	12.36	10.17	3.29	13.34	Apr 22
2006	8.11	12.53	15.24	18.04	16.27	11.43	4.55	19.26	Apr 7
2007	6.19	8.43	12.18	12.47	10.66	5.36	2.51	13.45	Apr 22
2008	7.03	11.66	15.05	18.18	19.09	16.87	11.14	19.78	Apr 26
2009	6.98	10.27	12.22	17.34	18.48	17.77	6.43	18.69	May 9
2010	6.41	8.76	10.14	11.98	12.15	12.76	9.27	13.98	Apr 15
2011	8.46	12.36	15.39	19.96	24.94	21.89	18.29	24.96	May 2
2012	6.19	9.65	12.98	16.82	12.86	8.60	5.86	17.24	Apr 9
2013	7.20	9.97	12.00	13.80	13.78	6.73	3.96	15.21	Apr 23
2014	7.78	10.94	15.72	20.97	20.00	17.20	7.36	21.41	Apr 7
Average	**7.42**	**11.12**	**14.01**	**17.06**	**15.94**	**13.01**	**7.22**	**18.64**	**Apr 16**

Table D-3. Mountain SWE (inches) from Garrison based on 45 stations.

Year	Snow Water Equivalent (inches)								Peak Date
	Jan 1	Feb 1	Mar 1	Apr 1	May 1	May 15	Jun 1	Peak	
1961	5.65	6.20	9.01	11.41	0.00	0.00	5.82	13.05	
1962	9.28	12.07	14.55	16.57	16.57	13.66	6.88	16.26	
1963	4.89	7.41	11.17	12.75	12.75	15.01	6.15	15.24	
1964	4.57	7.78	11.33	14.59	14.59	15.97	8.53	16.76	
1965	9.35	14.81	17.93	19.85	19.85	19.44	11.94	20.87	
1966	4.21	6.51	8.43	10.79	10.46	10.46	3.74	12.60	
1967	5.86	10.91	14.12	17.37	17.37	18.52	9.99	19.55	
1968	8.29	9.95	12.46	14.55	14.55	14.50	8.87	15.93	
1969	6.55	10.62	12.40	13.72	13.72	12.10	4.24	14.29	
1970	6.30	10.50	12.39	16.41	16.41	18.25	10.50	19.32	Apr 30
1971	8.51	13.36	16.15	20.65	17.93	17.93	12.05	22.45	Apr 29
1972	8.79	14.02	17.23	19.43	19.43	18.89	9.03	20.89	Apr 22
1973	6.50	7.55	8.75	11.58	11.58	14.46	6.30	15.25	Apr 26
1974	7.50	9.74	12.25	17.03	17.03	17.08	11.43	18.97	Apr 15
1975	5.64	10.04	12.45	15.86	15.86	17.68	12.32	18.82	May 12
1976	9.97	11.88	14.48	18.12	15.92	15.92	7.50	19.69	Apr 29
1977	3.70	5.73	7.28	11.48	5.24	5.24	3.91	11.80	Apr 6
1978	9.82	12.10	15.14	15.57	14.74	14.74	10.71	17.32	May 11
1979	7.62	9.68	12.13	14.40	13.66	13.66	6.62	15.66	Apr 16
1980	4.45	8.47	10.47	13.98	13.98	10.20	4.74	14.74	Apr 13
1981	4.84	5.92	7.79	10.01	7.83	8.23	5.38	11.11	Apr 14
1982	7.23	11.23	12.94	16.89	17.83	16.07	11.58	19.51	Apr 21
1983	7.14	9.28	11.01	14.25	16.19	17.34	12.10	18.02	May 20
1984	7.50	9.02	10.51	13.77	17.56	16.09	9.56	18.76	May 8
1985	6.62	7.5	9.0	1261	10.31	6.61	2.69	13.18	Apr 7
1986	7.96	10.30	16.46	18.55	19.72	19.84	10.32	19.90	May 14
1987	6.41	8.37	9.98	12.43	7.40	1.80	0.83	12.51	Apr 14
1988	4.54	7.06	9.37	12.35	11.45	10.62	3.70	13.21	May 10
1989	5.28	8.18	10.22	14.68	12.99	10.19	6.59	15.47	Apr 11
1990	7.05	10.15	11.79	13.95	13.98	13.69	9.09	14.50	Apr 15
1991	6.48	8.38	10.07	13.91	18.05	17.01	9.62	18.71	May 7
1992	7.28	8.23	9.38	11.42	9.21	4.93	1.39	12.06	Apr 24
1993	6.16	7.90	9.26	11.47	14.52	11.13	4.17	14.75	May 6
1994	4.90	7.85	10.80	12.97	10.99	5.35	0.53	14.17	Apr 12
1995	7.56	10.30	12.22	15.32	18.60	20.29	15.89	20.42	May 14
1996	9.45	13.20	15.82	19.59	20.57	16.94	14.34	20.71	May 5
1997	12.08	15.90	18.20	20.92	22.64	17.75	9.46	23.44	May 3
1998	5.91	9.59	11.16	13.97	14.02	10.39	4.11	16.28	Apr 21
1999	7.19	10.79	14.33	16.06	19.27	18.99	11.36	19.53	Apr 30
2000	4.79	7.87	10.62	12.98	10.95	9.16	3.78	13.48	Apr 8
2001	4.69	5.38	7.13	8.96	8.23	3.51	0.26	10.84	Apr 16
2002	5.19	7.51	8.95	12.36	12.54	11.17	5.00	12.72	Apr 22
2003	5.04	8.01	10.91	15.79	14.10	14.34	5.41	16.09	Apr 8
2004	6.72	8.47	10.89	10.90	10.10	5.21	3.96	11.88	Mar 19
2005	5.71	7.36	8.66	11.32	11.22	11.63	4.82	12.08	Apr 12
2006	7.02	9.57	11.57	13.59	11.63	8.70	3.20	13.72	Apr 8
2007	5.31	7.23	9.88	11.39	10.33	6.40	2.44	12.58	Apr 24
2008	6.63	9.65	12.13	15.93	16.42	16.05	12.14	17.00	Apr 26
2009	6.81	10.12	11.72	15.57	16.97	15.64	5.35	17.45	Apr 17
2010	5.43	6.99	8.26	10.57	11.15	13.96	9.29	14.26	May 13
2011	7.82	10.78	12.96	16.90	21.54	20.51	20.92	21.61	May 2
2012	6.98	9.58	12.94	13.09	10.91	6.90	5.39	14.20	Mar 22
2013	6.08	8.4	9.7	1148	13.18	6.61	3.38	13.85	Apr 25
2014	7.43	10.10	14.92	19.52	19.23	17.48	7.85	20.27	Apr 17
Average	**6.68**	**9.36**	**11.71**	**14.47**	**14.14**	**12.86**	**7.36**	**16.25**	**Apr 22**

C. Precipitation

Prior analysis indicated that average accumulated MJJ precipitation from key NWS COOP weather stations within the Fort Peck and Garrison reaches held the greatest correlation to MJJ runoff compared to any other three-month time period. Average accumulated MJJ precipitation in units of inches was determined from a number of observation stations throughout the upper Missouri River basin. In the Fort Peck reach, average accumulated MJJ precipitation was determined by computing the average of the accumulated MJJ precipitation from NWS COOP stations in Bozeman, MT; Cut Bank, MT; Dillon, MT; Helena, MT; Great Falls, MT; Glasgow, MT; and Lewistown, MT. The locations of these stations are shown in **Figure D-2** and listed in **Table D-4**. In the Garrison reach, average accumulated MJJ precipitation was computed from weather observing stations in Billings, MT; Wolf Point, MT; Glasgow, MT; Miles City, MT; Lake Yellowstone, WY; Lander, WY; and Sheridan, WY as shown in **Figure D-2** and listed in **Table D-4**. Data from Glasgow was used in both reaches because it is geographically suitable for both reaches and it correlated to MJJ runoff in both reaches.

For forecasting purposes, current average accumulated MJJ precipitation can be based on forecast MJJ precipitation and observed MJJ precipitation. Forecast MJJ precipitation can be estimated by adjusting the long-term average accumulated MJJ precipitation according to weather and CPC climate outlooks. Observed accumulated MJJ precipitation is incorporated into the average accumulated MJJ precipitation factor as observations become available.

The historic values of average accumulated MJJ precipitation for the Fort Peck and Garrison reaches are tabulated in **Table D-5**. In the Fort Peck reach, the top three MJJ precipitation periods occurred in 1975, 1993 and 1995 based on recorded precipitation at the seven Fort Peck stations. In the Garrison reach, the top three MJJ precipitation periods occurred in 1978, 1993 and 2011 based on recorded precipitation at the seven Garrison stations. In contrast, the lowest three MJJ precipitation periods in the Fort Peck reach occurred in 1979, 1985 and 2003. In the Garrison reach, the lowest three MJJ precipitation periods occurred in 1973, 1988 and 2006.

Table D-4. NWS COOP stations used to estimate average accumulated MJJ precipitation and average maximum AMJ temperature.

Precipitation Stations	
Above Fort Peck	**Fort Peck and Garrison**
Bozeman Montana SU, MT (COOP: 241044)	Billings Logan Intl Airport, MT (COOP: 240807)
Cut Bank Municipal Airport, MT (COOP: 242173)	Glasgow International Airport, MT (COOP: 243558)
Dillon Airport, MT (COOP: 242404)	Glendive, MT (COOP: 243581)
Glasgow International Airport, MT (COOP: 243558)	Wolf Point, MT (COOP: 249103)
Great Falls International Airport, MT (COOP: 243751)	Lake Yellowstone, WY (COOP: 485345)
Helena Regional Airport, MT (COOP: 244055)	Lander Hunt Field Airport, WY (COOP: 485390)
Lewistown Municipal Airport, MT (COOP: 244985)	Sheridan Airport, WY (COOP: 488155)
Temperature Stations	
Above Fort Peck	**Fort Peck and Garrison**
Cut Bank Municipal Airport, MT (COOP: 242173)	Billings Logan Intl Airport, MT (COOP: 240807)
Dillon Airport, MT (COOP: 242404)	Lander Hunt Field Airport, WY (COOP: 485390)
Helena Regional Airport, MT (COOP: 244055)	Sheridan Airport, WY (COOP: 488155)

D. Temperature

Average maximum AMJ temperature in units of degrees Fahrenheit (deg F) from NWS COOP weather stations within the Fort Peck and Garrison reaches is used to represent the temperature runoff factor of the MJJ forecasting methods. Temperature is an important factor in the accumulation and melt of mountain snowpack. Colder temperatures yield greater snowpack accumulations, later peak accumulations, delayed snowmelt and often greater runoff volumes. Warmer temperatures yield lower snowpack accumulations, earlier peak accumulations, earlier snowmelt and lower runoff volumes. In the Fort Peck reach, average maximum AMJ temperature was computed from Montana weather stations in Cut Bank, Dillon and Helena (**Table D-4**). In the Garrison reach, average maximum AMJ temperature was computed from weather stations in Billings, Montana; Sheridan, Wyoming; and Lander, Wyoming (**Table D-4**). For forecasting purposes, current average maximum AMJ temperature can be based on forecast AMJ temperature and observed AMJ temperature. Forecast AMJ temperature can be estimated by adjusting the long-term average maximum AMJ temperature according to weather and CPC climate outlooks. Observed maximum temperature is incorporated into the average maximum AMJ temperature factor as observations become available.

The historic values of average maximum AMJ temperature for the Fort Peck and Garrison reaches are tabulated in **Table D-6**. At first glance, the temperature difference between the Fort Peck and Garrison reaches is very notable. Fort Peck reach temperatures are always consistently lower than Garrison reach temperatures, due to the northern location of stations relative to Garrison stations. Also, temperatures between the reaches correlate in time. High temperature periods in one reach correlate to temperatures in the other reach, while low temperature periods correlate to low temperatures in the other reach. In the Fort Peck reach, the three coldest average maximum AMJ temperature periods occurred in 1967, 1975 and 2011, while the three warmest AMJ periods occurred in 1985, 1987 and 1992 based on recorded temperature at three weather stations used for Fort Peck. In the Garrison reach, the three coldest average maximum AMJ temperature periods occurred in 1967, 1975 and 2011, while the three warmest AMJ periods occurred in 1987, 1988 and 2006 based on recorded temperature at three weather stations used for Garrison.

Table D-5. Monthly and accumulated May-June-July precipitation (inches) based on the average NWS COOP station data in the Fort Peck and Garrison reaches.

	Fort Peck				Garrison			
Year	**May**	**June**	**July**	**Sum**	**May**	**June**	**July**	**Sum**
1961	1.88	0.85	1.35	4.08	1.80	1.27	1.03	4.10
1962	3.99	2.68	2.60	9.27	3.26	2.29	2.96	8.51
1963	1.86	3.69	1.02	6.57	1.59	4.09	0.87	6.55
1964	3.23	4.10	0.98	8.31	2.49	4.17	0.58	7.23
1965	2.35	4.58	1.01	7.93	2.42	3.05	1.53	7.01
1966	1.54	2.23	1.33	5.10	1.29	1.73	1.17	4.19
1967	1.72	3.21	0.78	5.71	1.82	4.26	0.88	6.96
1968	2.32	2.85	0.51	5.68	1.55	3.17	0.65	5.37
1969	1.08	4.20	1.67	6.94	1.06	4.03	1.96	7.06
1970	2.62	2.16	1.78	6.56	2.85	2.38	1.10	6.32
1971	2.00	1.72	0.45	4.18	2.19	1.42	0.53	4.14
1972	1.67	2.09	1.77	5.53	2.27	1.95	1.39	5.61
1973	1.07	3.16	0.30	4.53	0.80	2.10	0.81	3.71
1974	3.03	0.93	1.15	5.11	2.27	1.21	1.35	4.83
1975	3.32	3.82	2.68	9.81	2.86	2.87	1.99	7.71
1976	1.10	3.26	1.86	6.22	1.45	3.15	1.60	6.20
1977	2.27	1.20	1.65	5.12	1.77	1.26	1.16	4.19
1978	2.88	2.17	2.79	7.84	5.14	2.06	2.02	9.21
1979	1.30	1.93	0.51	3.74	1.92	0.91	1.01	3.85
1980	3.63	2.74	0.76	7.12	2.14	1.55	0.87	4.55
1981	5.72	2.22	1.18	9.12	3.81	2.49	1.87	8.17
1982	3.15	2.62	1.02	6.79	2.81	2.69	1.27	6.77
1983	1.36	2.37	2.63	6.37	1.83	1.07	1.61	4.51
1984	1.25	2.20	0.49	3.93	0.93	2.73	0.63	4.29
1985	2.11	0.51	0.51	3.13	1.83	1.00	1.44	4.27
1986	2.13	1.81	1.59	5.52	1.98	1.75	1.82	5.55
1987	2.87	1.59	3.34	7.81	2.67	1.22	3.05	6.94
1988	2.59	1.42	0.81	4.83	1.40	1.04	0.57	3.00
1989	2.33	1.98	1.67	5.98	2.64	1.43	0.80	4.87
1990	2.47	1.27	0.98	4.72	1.40	1.54	1.15	4.10
1991	2.48	3.90	0.74	7.11	2.87	3.33	0.92	7.12
1992	1.47	3.35	2.11	6.93	1.51	2.65	1.93	6.10
1993	2.00	2.94	5.57	10.52	1.15	3.23	4.30	8.68
1994	1.53	1.87	1.10	4.49	1.51	2.49	0.97	4.97
1995	2.92	4.09	2.60	9.60	2.66	3.07	1.66	7.38
1996	2.69	1.37	0.54	4.60	2.79	1.39	0.70	4.89
1997	2.51	2.89	1.96	7.37	1.55	1.99	3.04	6.58
1998	2.01	4.01	1.73	7.75	1.18	3.65	1.20	6.04
1999	2.29	2.42	0.80	5.51	2.47	2.42	1.06	5.95
2000	1.85	2.13	1.24	5.21	2.32	2.01	1.56	5.89
2001	0.83	3.35	2.36	6.54	0.88	3.61	2.64	7.13
2002	1.77	4.10	1.51	7.39	1.47	1.76	1.63	4.86
2003	1.88	1.55	0.48	3.91	1.84	2.28	0.67	4.79
2004	2.67	2.23	0.99	5.88	1.76	2.07	2.06	5.90
2005	1.57	5.16	0.47	7.20	3.29	3.33	1.09	7.71
2006	1.89	2.28	0.53	4.71	1.36	1.34	0.59	3.29
2007	3.61	1.93	0.81	6.36	3.91	1.78	1.54	7.23
2008	3.76	2.74	1.41	7.90	4.45	2.59	1.31	8.35
2009	0.94	1.82	2.21	4.97	1.05	2.79	2.00	5.84
2010	2.83	3.41	1.15	7.38	3.44	3.72	1.47	8.63
2011	3.99	3.36	1.42	8.77	6.35	2.85	1.79	10.99
2012	1.99	1.55	1.35	4.89	2.19	1.19	1.73	5.11
2013	3.44	3.05	1.00	7.48	3.67	2.32	1.22	7.21
2014	1.47	3.16	0.64	5.27	1.90	2.15	0.68	4.73
Average	**2.32**	**2.60**	**1.41**	**6.32**	**2.26**	**2.33**	**1.43**	**6.02**
Median	**2.20**	**2.39**	**1.16**	**6.29**	**1.95**	**2.28**	**1.29**	**5.92**
Maximum	**5.72**	**5.16**	**5.57**	**10.52**	**6.35**	**4.26**	**4.30**	**10.99**
Minimum	**0.83**	**0.51**	**0.30**	**3.13**	**0.80**	**0.91**	**0.53**	**3.00**
Std Dev	**0.93**	**1.03**	**0.92**	**1.71**	**1.09**	**0.92**	**0.74**	**1.69**

Table D-6. Monthly and average April-May-June maximum temperature (degrees Fahrenheit) based on the average NWS COOP station data in the Fort Peck and Garrison reaches.

	Fort Peck				Garrison			
Year	**April**	**May**	**June**	**Average**	**April**	**May**	**June**	**Average**
1961	51.0	64.8	82.6	66.2	53.8	66.9	84.5	68.4
1962	60.7	62.5	73.9	65.7	61.9	65.7	75.8	67.8
1963	52.7	65.4	69.8	62.7	54.2	66.9	74.5	65.2
1964	52.1	62.7	69.5	61.5	54.8	67.0	72.1	64.6
1965	54.7	60.6	70.1	61.8	57.0	62.4	73.7	64.4
1966	53.1	70.6	70.8	64.8	51.5	70.7	75.7	66.0
1967	45.2	61.8	69.1	58.7	52.8	61.2	68.9	61.0
1968	51.4	60.8	69.6	60.6	53.5	62.7	72.4	62.8
1969	58.8	68.8	69.1	65.6	61.5	70.2	69.5	67.1
1970	46.2	64.5	75.6	62.1	48.0	66.9	77.4	64.1
1971	53.7	63.5	70.0	62.4	55.5	65.1	78.3	66.3
1972	52.1	63.0	75.0	63.3	56.6	65.2	79.2	67.0
1973	50.3	66.7	73.3	63.4	48.5	66.9	78.2	64.5
1974	57.1	58.9	79.2	65.1	58.0	63.2	81.7	67.6
1975	41.1	58.9	67.7	55.9	47.1	62.0	71.8	60.3
1976	54.5	67.0	68.2	63.2	57.7	68.8	74.7	67.0
1977	61.4	61.3	76.4	66.4	62.0	68.8	82.1	70.9
1978	54.0	60.1	74.9	63.0	57.8	61.9	76.8	65.5
1979	51.0	63.7	75.0	63.2	55.6	64.1	78.8	66.2
1980	60.2	65.3	70.0	65.2	63.1	68.7	79.4	70.4
1981	57.8	61.7	69.4	63.0	63.0	64.6	77.5	68.4
1982	50.0	61.1	72.7	61.3	54.9	64.2	73.3	64.1
1983	53.4	63.5	71.3	62.7	53.0	63.5	77.2	64.6
1984	53.6	63.6	70.5	62.6	54.1	68.5	77.1	66.6
1985	59.1	69.1	75.4	67.9	63.1	73.5	78.8	71.8
1986	54.3	65.4	78.9	66.2	56.3	67.0	82.8	68.7
1987	64.6	68.0	77.0	69.9	67.1	71.5	80.5	73.1
1988	59.2	68.1	81.5	69.6	61.9	71.3	90.5	74.6
1989	55.9	62.7	73.9	64.2	57.8	67.3	76.9	67.3
1990	57.4	61.6	73.0	64.0	57.3	65.1	78.0	66.8
1991	53.1	61.8	70.3	61.7	52.5	63.8	77.2	64.5
1992	61.2	71.6	77.0	69.9	62.4	71.1	77.5	70.3
1993	53.8	69.1	68.6	63.8	56.6	70.2	71.9	66.3
1994	56.6	67.9	75.2	66.6	59.6	74.1	80.9	71.5
1995	51.8	61.5	69.3	60.9	52.6	60.7	72.9	62.1
1996	56.3	58.2	75.4	63.3	58.1	61.4	81.0	66.8
1997	49.0	66.6	71.5	62.4	48.4	67.6	76.6	64.2
1998	56.7	67.4	66.2	63.4	56.8	69.6	67.6	64.7
1999	53.4	62.1	70.4	62.0	50.4	63.2	74.8	62.8
2000	59.4	64.5	74.1	66.0	60.2	67.8	77.4	68.5
2001	54.2	69.6	74.3	66.0	58.0	71.7	78.3	69.4
2002	52.3	62.2	73.5	62.7	55.0	65.2	80.6	66.9
2003	55.1	63.7	74.0	64.2	60.9	66.3	74.2	67.1
2004	58.9	60.6	70.7	63.4	59.8	66.4	73.9	66.7
2005	54.8	63.0	68.4	62.1	57.7	64.3	76.2	66.0
2006	57.6	68.2	75.5	67.1	62.0	71.3	84.1	72.5
2007	55.0	66.8	77.0	66.3	55.4	68.6	80.3	68.1
2008	50.9	63.1	72.2	62.1	55.8	63.4	75.0	64.7
2009	51.7	66.5	70.1	62.8	53.8	69.5	71.8	65.0
2010	53.8	57.3	69.1	60.1	55.9	60.5	74.5	63.6
2011	48.6	59.6	68.7	59.0	53.9	58.4	75.1	62.5
2012	59.0	63.3	74.2	65.5	62.8	67.8	84.0	71.5
2013	51.5	66.0	73.8	63.7	51.4	67.8	79.7	66.3
2014	56.0	65.9	70.0	63.9	57.8	67.1	74.4	66.4
Average	**54.4**	**64.1**	**72.6**	**63.7**	**56.6**	**66.5**	**77.0**	**66.7**
Median	**54.1**	**63.5**	**72.4**	**63.4**	**56.6**	**66.9**	**77.2**	**66.5**
Maximum	**64.6**	**71.6**	**82.6**	**69.9**	**67.1**	**74.1**	**90.5**	**74.6**
Minimum	**41.1**	**57.3**	**66.2**	**55.9**	**47.1**	**58.4**	**67.6**	**60.3**
Std Dev	**4.3**	**3.4**	**3.6**	**2.7**	**4.4**	**3.5**	**4.2**	**3.0**

E. Observed Runoff

Fort Peck and Garrison observed May and observed May-June runoff during the calendar year forecast is used to represent the observed runoff factor of the MJJ forecasting methods. In the analysis, historic May and May-June runoff was incorporated into the regression equations in order to improve June-July runoff and July runoff predictions, respectively. Fort Peck and Garrison historic May and June runoff, which was used in the regression analysis, is provided in **Table F-1** and **Table F-2**, respectively, in **Appendix F**.

For forecasting purposes, since current year May observed runoff is first available on June 1 and current year observed runoff is first available on July 1, the MJJ forecasting methods that use current year observed runoff can only be used for the June 1 and July 1 forecasts.

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APPENDIX E

MAY-JUNE-JULY RUNOFF FORECAST METHODS

Simple and multiple linear regression analyses using the least squares method were performed on the runoff, SWE, precipitation, temperature and observed runoff data in order to develop coefficients and exponents for the regression forecasting equations, which relates MJJ runoff to these factors. Log base-10 transformations and non-transformed data were analyzed to determine the least-squares best fit for each data combination and forecasting date. The following sections for the four MJJ forecasting method variations describe the data transformations, the form of the equation, equation coefficients and exponents, and the use of the equations to forecast MJJ runoff. The four variations of the MJJ runoff forecast method described in Chapter III are:

1) MJJ Method 1 – SWE-Only
2) MJJ Method 2 – SWE-Precipitation-Temperature
3) MJJ Method 3 – SWE-Observed Runoff
4) MJJ Method 4 – SWE-Precipitation-Observed Runoff

A. MJJ Method 1 – SWE Only

The MJJ Method 1 – SWE Only method equations for the Fort Peck and Garrison reaches were evaluated with the 1961-2014 runoff record and the adjusted mountain SWE data. Six forecast dates - January 1, February 1, March 1, April 1, May 1 and the peak SWE accumulation date - were evaluated using linear regression analysis. The regression analysis used log-transformed SWE and log-transformed MJJ runoff for January 1, February 1, March 1, April 1, and peak SWE dates. Log-transformed MJJ runoff and non-transformed SWE were used for the May 1 forecast because these data transformations had a stronger relationship.

The results of the analysis in **Figure E-1** and **Figure E-2** compare predicted and historic MJJ runoff volumes and the coefficient of determination (R^2) statistic. Generally an R^2 of 0.50 indicates there is a fair to good relationship between the two variables, indicating that more than 50 percent of the variability in the predicted MJJ runoff can be explained by mountain SWE. Better predicted MJJ runoff is indicated by points plotting closer to the 1:1 ratio line. In general the line fit and R^2 increases as the forecast date progresses from January 1 to May 1. R^2 is below 0.50 for January 1 through April 1 forecast dates for both reaches in **Figure E-1(a-d)** and **Figure E-2(a-d)**. R^2 statistics are considerably higher (above 0.5) for the date of peak SWE and May 1 in both reaches in **Figures E-1(e-f)** and **E-2(e-f)**.

Two notable deviations from the one-to-one line in all **Figure E-1** plots for Fort Peck are the 1975 and 2011 MJJ runoff periods, which are the two highest MJJ runoff periods during the 1961-2014 period. In the **Figure E-2** plots for the Garrison reach, the 2011 MJJ runoff period, which is the highest MJJ runoff period in the 1961-2014 and the 1898-2014 records, deviates significantly from the 1:1 line. The MJJ Method 1 equations would suggest that forecast runoff based on the SWE should be lower than historic runoff; however, runoff factors such as seasonal rainfall, snowmelt timing and snowmelt re-accumulation after the peak influenced runoff during these years.

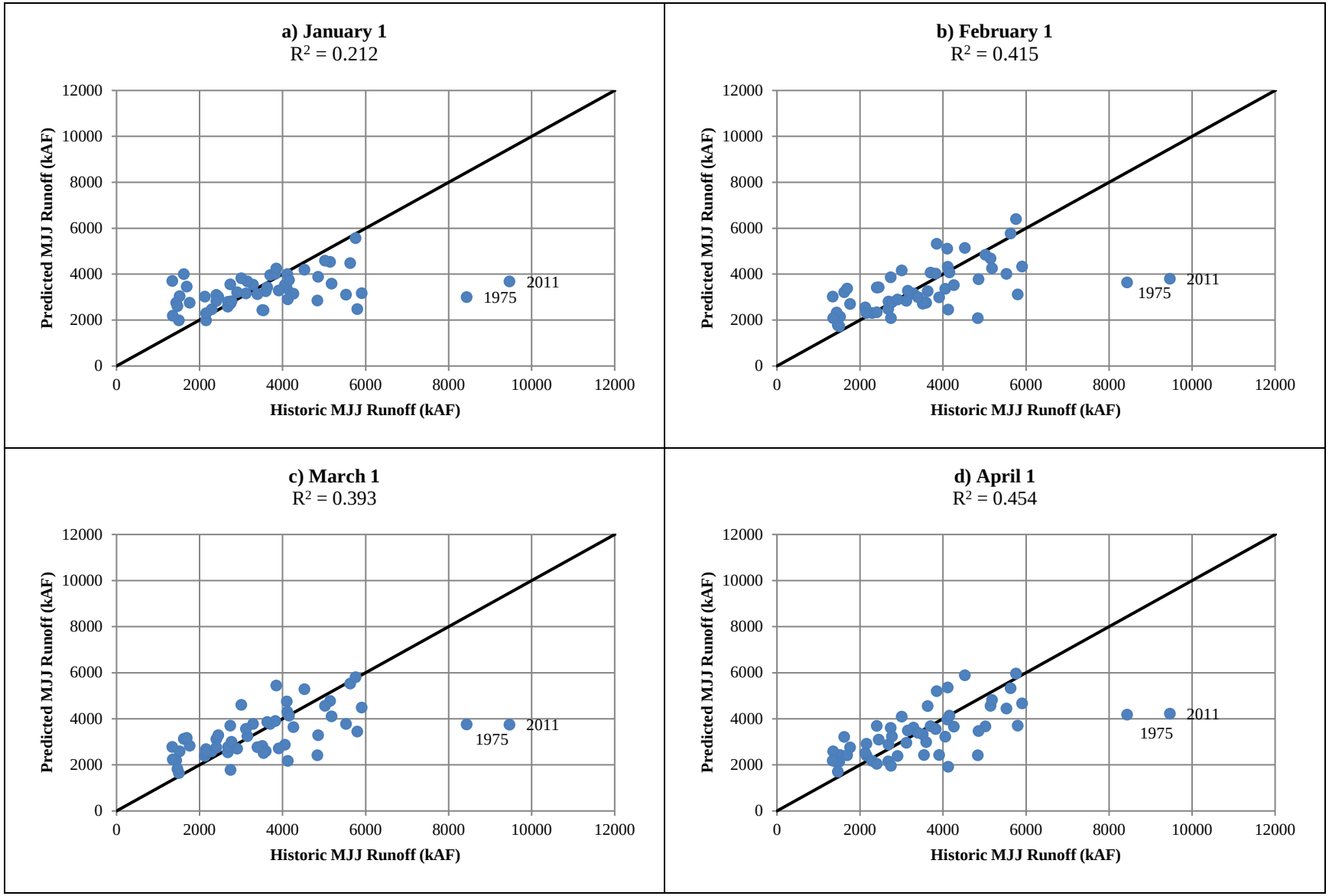

Figure E-1(a-d). MJJ Method 1 - SWE Only: Fort Peck predicted MJJ runoff versus historic MJJ runoff for the 1961-2014 period.

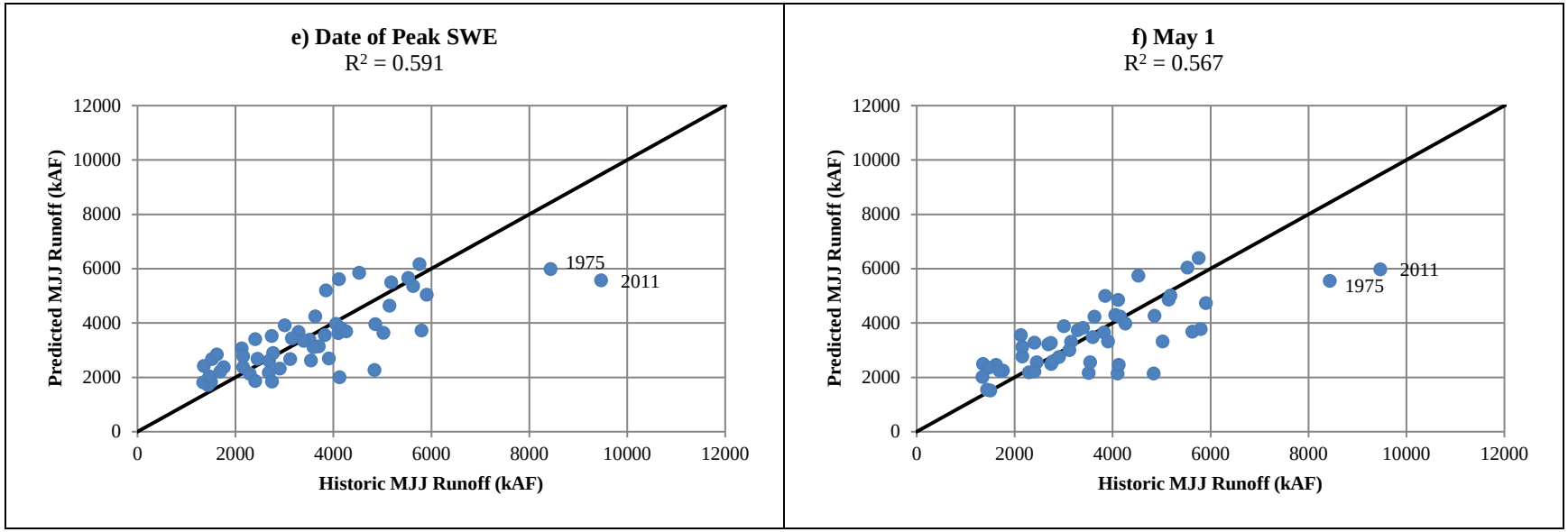

Figure E-1(e-f). MJJ Method 1 - SWE Only: Fort Peck predicted MJJ runoff versus historic MJJ runoff for the 1961-2014 period.

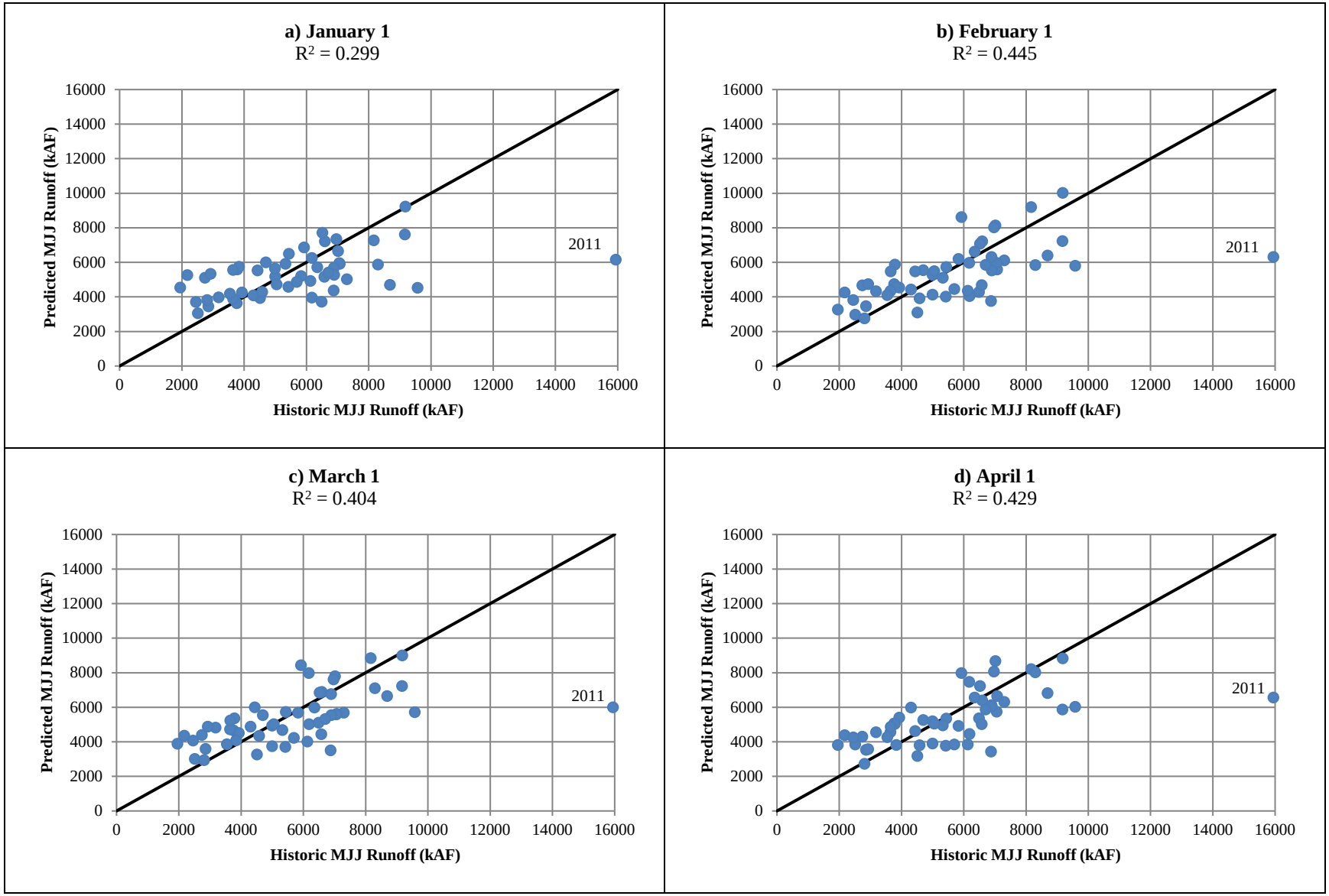

Figure E-2(a-d). MJJ Method 1 - SWE Only: Garrison predicted MJJ runoff versus historic MJJ runoff for the 1961-2014 period.

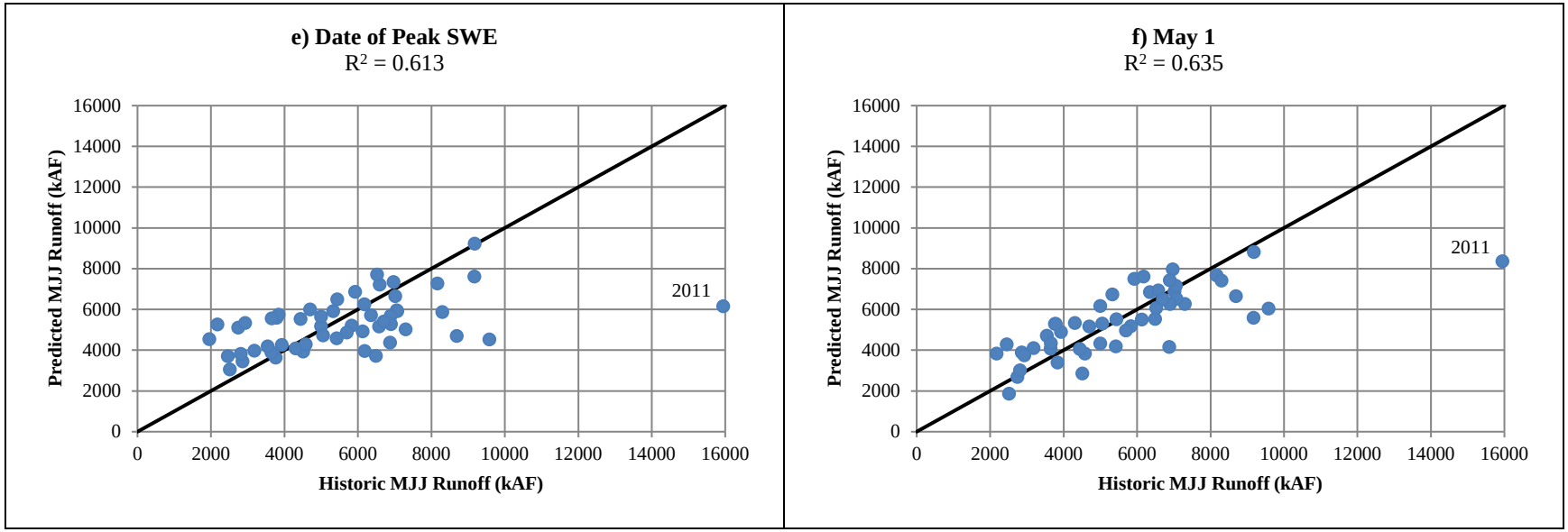

Figure E-2(e-f). MJJ Method 1 - SWE Only: Garrison predicted MJJ runoff versus historic MJJ runoff for the 1961-2014 period.

B. MJJ Method 2 – SWE-Precipitation-Temperature

Later in the snow accumulation season, average reach SWE has its highest predictability as shown by the results of the MJJ Method 1 analysis. Furthermore, seasonal forecasts of precipitation and temperature made by the NWS CPC begin to gain some skill, and precipitation and temperature factors become useful in predicting MJJ runoff. In order to take advantage of these factors to forecast MJJ runoff, accumulated MJJ precipitation and average maximum AMJ temperature from key weather stations are considered in multiple linear regression equations.

Precipitation and temperature factors are incorporated into the MJJ Method 2 – SWE-Precipitation-Temperature equations for April 1, peak SWE and May 1 forecast dates. This method is intended to provide additional runoff predictability given the outlook of future precipitation and temperature conditions. Since the latest forecast date using this method is May 1, all MJJ precipitation data must be determined using precipitation statistics for the weather stations under consideration and seasonal precipitation outlooks such as the NWS CPC seasonal outlook. AMJ temperature data can be determined using CPC seasonal outlooks and temperature statistics; however, for the May 1 forecast, historic average maximum April temperature at the temperature weather stations may be incorporated. It should be understood by the forecaster that precipitation and temperature forecasts used in this method are a subjective interpretation of the CPC outlooks, since the outlooks do not provide amounts of precipitation or a measure of temperature. As the runoff season progresses into May, June and July, historic precipitation and temperature data can be incorporated into the precipitation and temperature predictors.

The results of the analysis in **Figure E-3** and **Figure E-4** compare predicted and historic MJJ runoff volumes and the R^2 statistics for Fort Peck and Garrison, respectively. In general the line fit and R^2 statistics indicate that the MJJ Method 2 equations provide an improved fit to MJJ runoff compared to MJJ Method 1. For example, the R^2 statistics for the Fort Peck reach are 0.591 for the peak SO Equation and 0.810 for the peak SPT Equation. For the Garrison reach, the R^2 statistics are 0.613 for the peak SO Equation and 0.856 for the peak SPT Equation. The best fit and greatest R^2 statistics are achieved in the date of peak SWE plots (**Figure E-3b** and **Figure E-4b**) for both reaches. This improved accuracy shown by the plots is a product of using historic precipitation and temperature in the regression analysis; however, the accuracy of the MJJ runoff forecast will depend on the ability of the forecaster to accurately predict future precipitation and temperature factors for Method 2. The use of current year observed precipitation and temperature when it is available can be beneficial to the forecast; however, forecast accuracy will still depend predominantly on how well precipitation and temperature forecasts verify. Therefore, the best use of Method 2 could be to create a number of likely scenarios that could occur under varying seasonal precipitation and temperatures.

Similar to the results of Method 1, Method 2 results in the regression analysis indicate deviations during the large 1975 and 2011 runoff events in Fort Peck (**Figure E-3**) and in 2011 in Garrison (**Figure E-4**). The fit of the 1975 and 2011 MJJ runoff periods is better when compared to Method 1 results in **Figure E-1** and **Figure E-2**. The MJJ precipitation and AMJ temperature variables help to explain the MJJ runoff variability that occurred in 1975 and 2011.

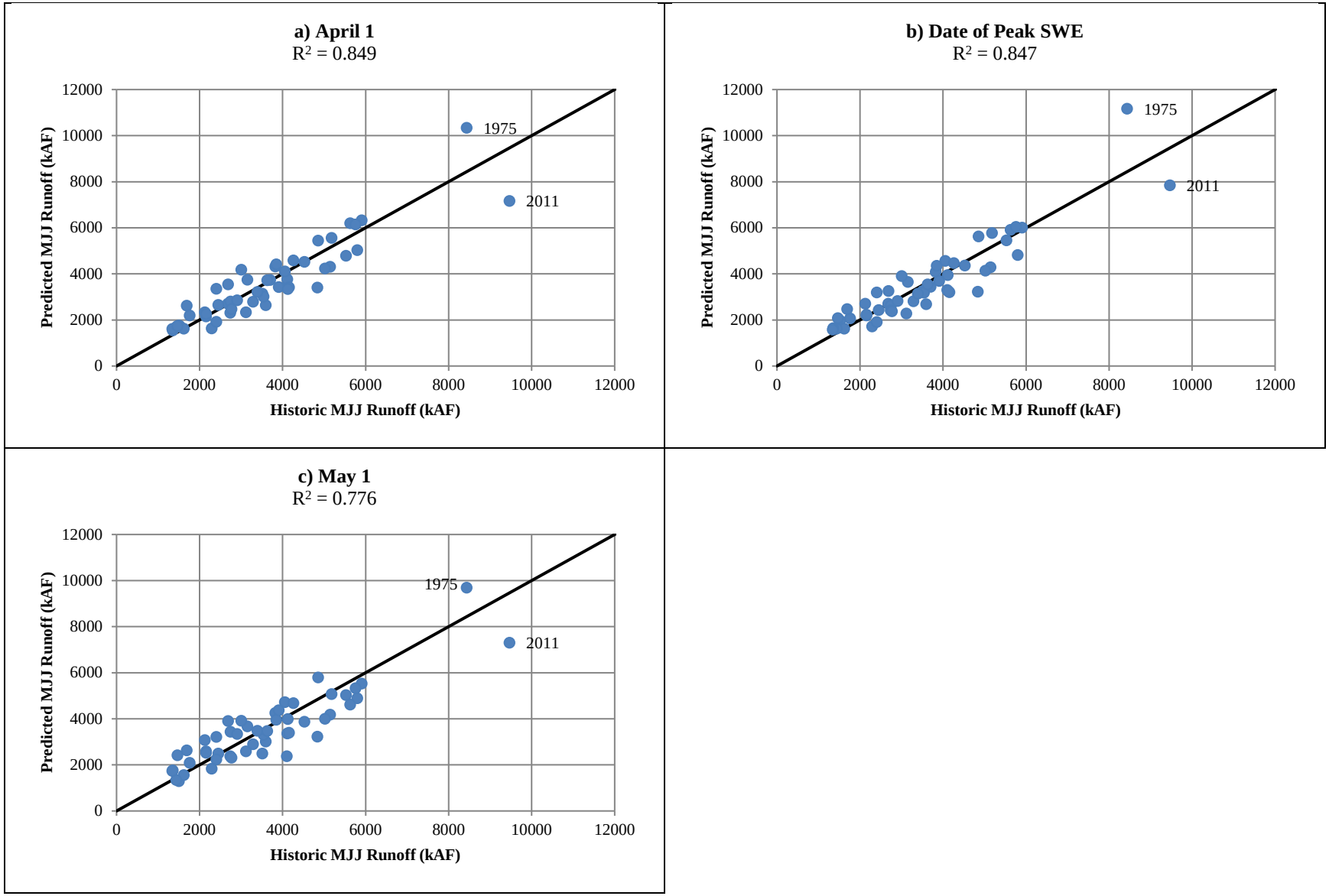

Figure E-4(a-c). MJJ Method 2 – SWE-Precipitation-Temperature: Fort Peck predicted MJJ runoff versus historic MJJ runoff for the 1961-2014 period.

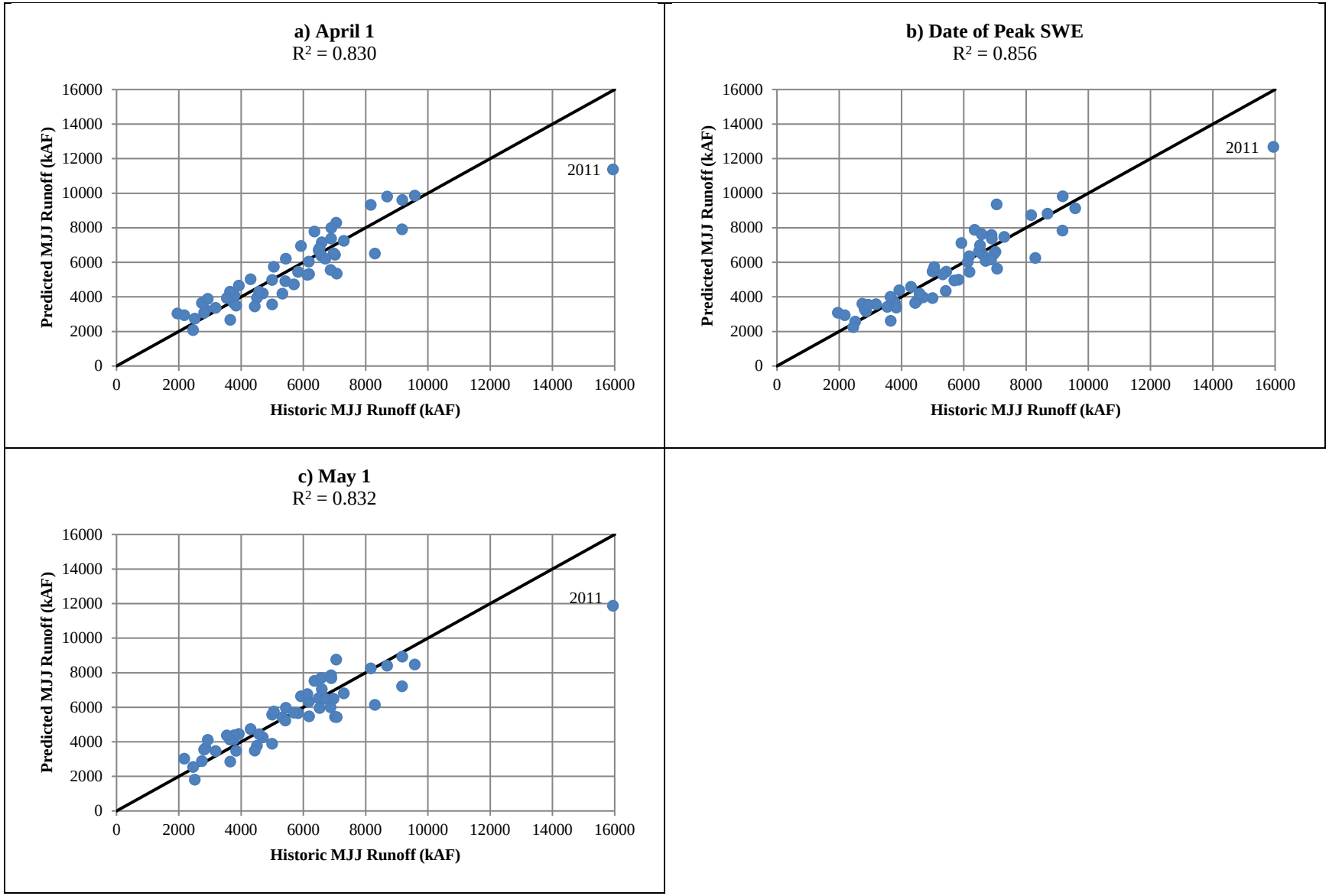

Figure E-4(a-c). MJJ Method 2 – SWE-Precipitation-Temperature: Garrison predicted MJJ runoff versus historic MJJ runoff for the 1961-2014 period.

C. MJJ Method 3 – SWE-Observed Runoff

MJJ Method 3 was developed in order to better predict June-July and July runoff given the average reach SWE and current year observed runoff in the Fort Peck and Garrison reaches. While the overall MJJ runoff forecast is important in the planning and operation of the System, the prediction of June-July runoff is also important because June is usually the peak runoff month in the Fort Peck and Garrison reaches, and in the upper Basin. Current year observed May runoff can be used as an indicator of what will occur during June and July in Fort Peck and Garrison. MJJ Method 3 uses June 1 average reach SWE for both June 1 and July 1 forecast dates. It uses current year observed May runoff for the June 1 forecast and current year observed May-June runoff for the July 1 forecast.

The inclusion of observed runoff with June 1 SWE is the best combination of runoff factors based on the regression analysis predictions. R^2 statistics and **Figure E-5** and **Figure E-6** indicate good regression accuracy for June-July and July runoff. Furthermore, Method 3 provides good closeness of fit for most years in the period of record and particularly the high runoff seasons in 1975 and 2011. Comparing the closeness of fit and the R^2 statistics between Fort Peck and Garrison, Method 3 applied to Garrison provides a better overall fit for predicting June-July and July runoff.

D. MJJ Method 4 - SWE-Precipitation–Observed Runoff Equations

MJJ Method 4 was developed in order to improve upon June-July and July runoff predictions by including current year observed and forecast average accumulated MJJ precipitation. The inclusion of the precipitation parameter in the Method 4 equation improves both the fit and R^2 statistics in both the Fort Peck and Garrison reaches (**Figure E-7** and **Figure E-8**). For example, the Fort Peck R^2 statistics increase from 0.749 for the Method 3 June 1 forecast to 0.842 for the Method 4 June 1 prediction. Similarly, the Garrison R^2 statistics increase from 0.757 for the Method 3 June 1 forecast to 0.839 for the Method 4 June 1 prediction.

The Method 4 equations also improve the accuracy of predicted June-July and July runoff during the 1975 and 2011 high runoff periods. This is especially true for the 2011 June-July runoff period where the current year observed and forecast June-July runoff is nearly equal in the Garrison reach **(Figure E-8a**).

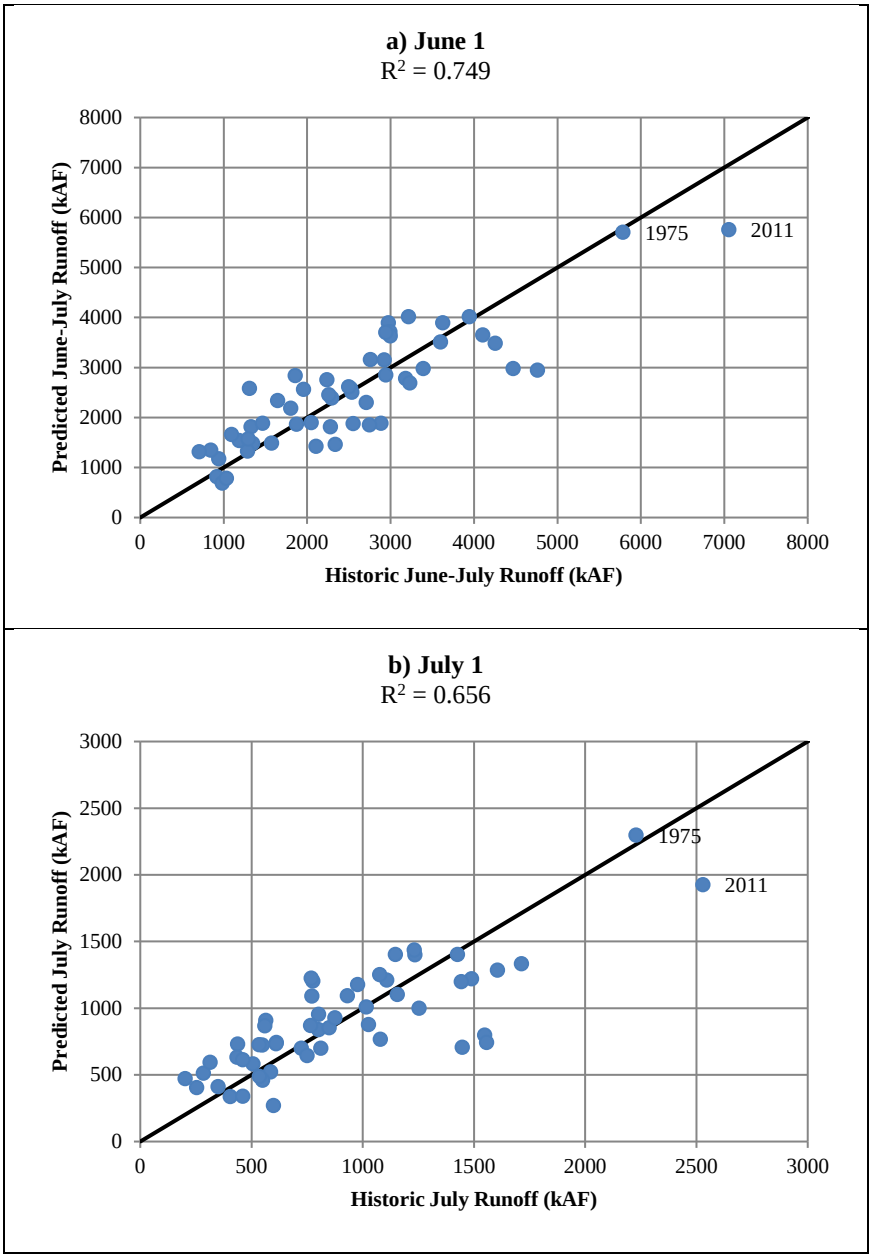

Figure E-5(a-b). MJJ Method 3 – SWE-Observed Runoff: Fort Peck predicted runoff versus historic runoff for the 1961-2014 period.

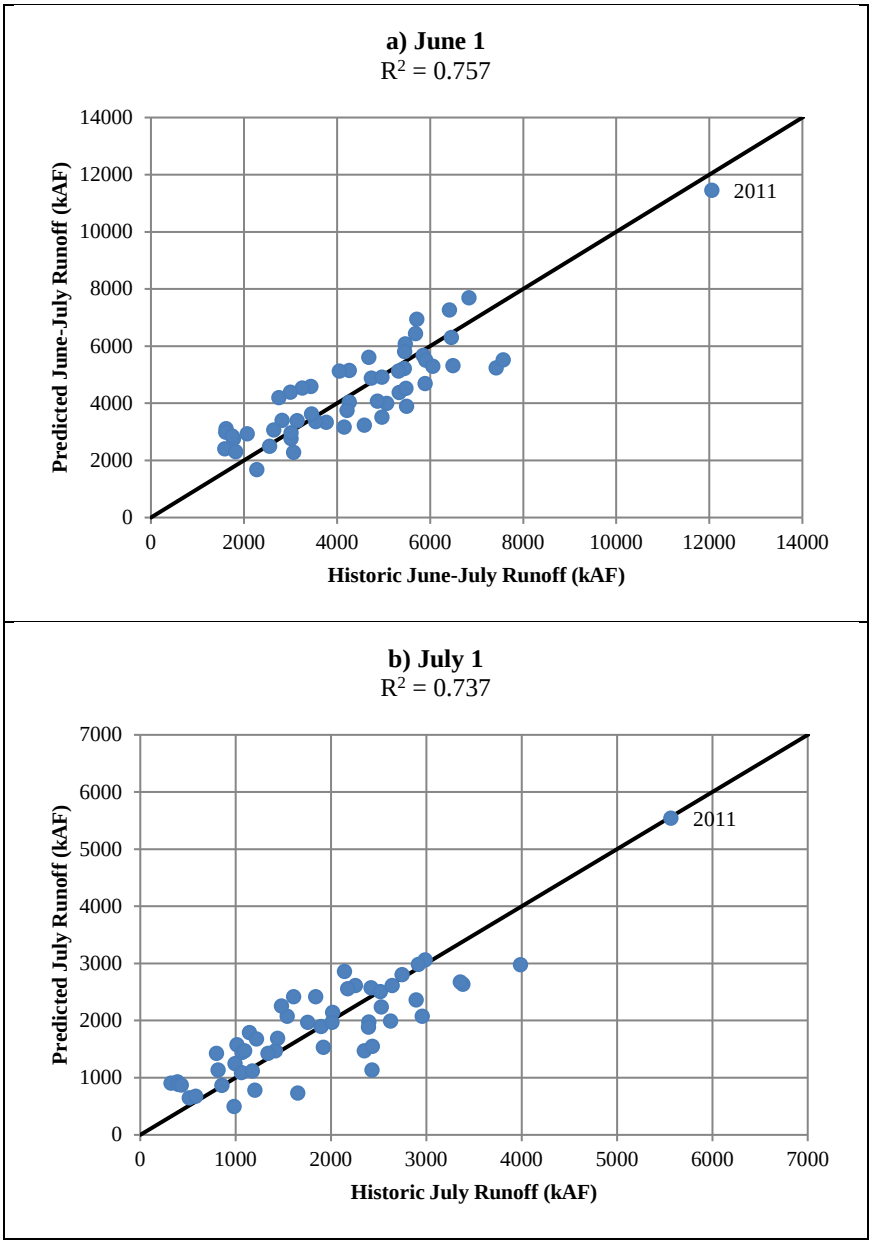

Figure E-6(a-b). MJJ Method 3 – SWE-Observed Runoff: Garrison predicted runoff versus historic runoff for the 1961-2014 period.

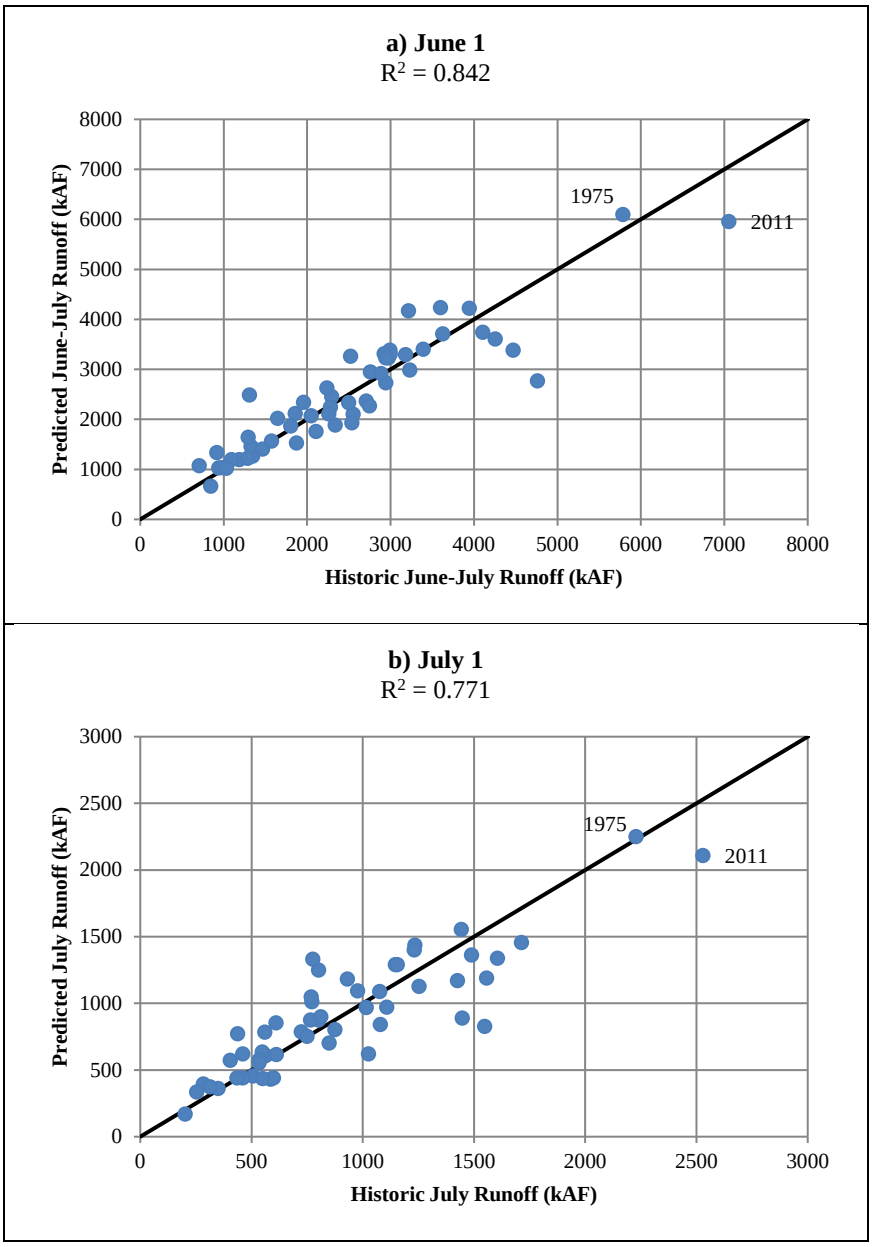

Figure E-7(a-b). MJJ Method 4 – SWE-Observed Runoff-Precipitation: Fort Peck predicted runoff versus historic runoff for the 1961-2014 period.

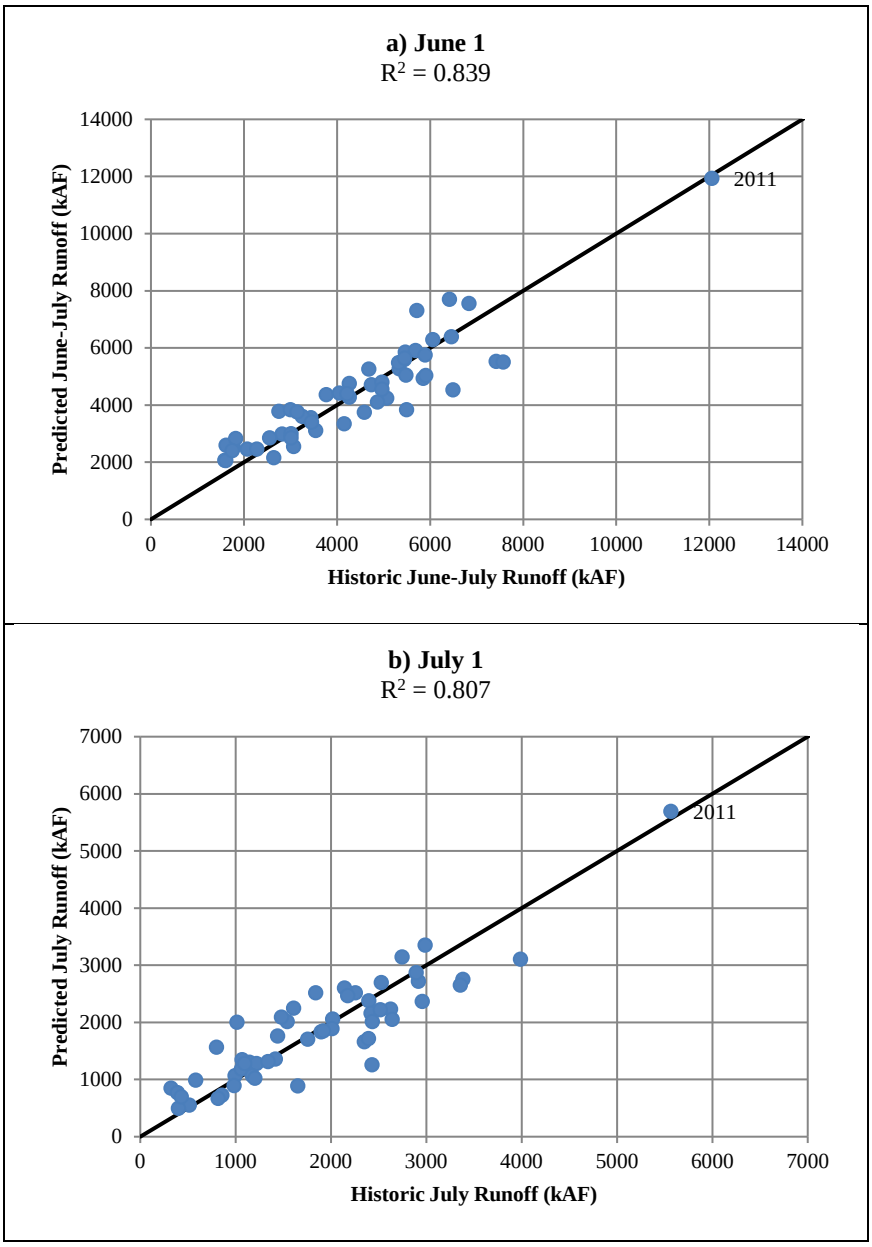

Figure E-8(a-b). MJJ Method 4 – SWE-Observed Runoff-Precipitation: Garrison predicted runoff versus historic runoff for the 1961-2014 period.

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APPENDIX F

Monthly and Annual Historic Runoff Data

Table F-1. Fort Peck historic runoff (kAF), 1949 level of development.

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL	MA	MJJ
1898	313	278	419	776	1436	2668	1176	216	244	353	339	313	8531	1195	5280
1899	232	232	413	746	1323	2456	2027	528	345	413	480	298	9493	1159	5806
1900	309	315	504	730	1732	1379	335	79	194	333	294	349	6553	1234	3446
1901	270	226	371	464	1857	1339	454	67	147	274	284	262	6015	835	3650
1902	240	220	264	331	1182	1644	873	171	179	288	311	268	5971	595	3699
1903	296	236	339	676	968	1936	877	248	214	375	339	411	6915	1015	3781
1904	355	329	672	768	1325	1765	825	248	196	286	309	353	7431	1440	3915
1905	300	296	500	323	405	863	696	284	167	234	284	274	4626	823	1964
1906	272	290	381	668	728	1386	605	216	248	288	260	260	5602	1049	2719
1907	222	296	506	819	1133	2412	2220	645	387	460	367	357	9824	1325	5765
1908	335	298	456	895	1176	4140	1722	563	468	575	587	440	11655	1351	7038
1909	363	365	538	676	1119	2938	1071	436	567	623	462	317	9475	1214	5128
1910	327	301	910	1351	1847	1384	470	311	365	341	377	379	8363	2261	3701
1911	248	270	720	589	893	2152	805	353	383	395	411	333	7552	1309	3850
1912	296	311	282	704	1396	2249	893	492	379	545	526	379	8452	986	4538
1913	256	266	345	1111	1654	3140	1232	553	305	633	520	347	10362	1456	6026
1914	337	347	680	867	1597	2003	591	240	315	494	407	339	8217	1547	4191
1915	315	422	335	916	1148	1751	1010	591	413	474	452	303	8130	1251	3909
1916	315	488	799	712	1307	2612	1847	545	474	409	381	347	10236	1511	5766
1917	375	373	480	655	1914	3055	1325	383	298	321	395	411	9985	1135	6294
1918	395	347	492	607	1085	1503	551	371	270	377	337	351	6686	1099	3139
1919	383	413	672	559	781	520	216	93	169	194	161	220	4381	1231	1517
1920	228	385	553	551	1549	1819	776	325	280	319	393	325	7503	1104	4144
1921	294	296	436	704	1303	1857	583	242	260	282	309	345	6911	1140	3743
1922	282	238	415	666	1321	2249	454	307	309	278	317	321	7157	1081	4024
1923	298	270	428	726	1214	1593	918	452	309	341	357	347	7253	1154	3725
1924	305	399	391	647	1440	996	399	260	252	282	305	319	5995	1038	2835
1925	309	321	484	914	1353	1642	750	317	359	486	490	421	7846	1398	3745
1926	343	456	452	851	1279	589	438	325	337	393	339	351	6153	1303	2306
1927	395	303	659	492	1771	3904	1250	518	545	567	508	421	11333	1151	6925
1928	333	502	966	724	1924	1436	1396	432	377	369	357	298	9114	1690	4756
1929	280	250	391	466	946	1208	498	294	290	317	288	200	5428	857	2652
1930	300	444	407	863	867	555	300	218	236	301	298	303	5092	1270	1722
1931	248	317	557	387	432	424	230	224	210	220	179	157	3585	944	1086
1932	196	157	303	532	825	1406	516	422	240	260	218	194	5269	835	2747
1933	222	212	488	434	908	1412	430	270	256	226	339	177	5374	922	2750
1934	315	450	516	722	781	811	290	141	137	204	256	210	4833	1238	1882
1935	198	236	309	428	593	819	409	228	228	262	182	190	4082	737	1821
1936	179	167	613	430	823	569	264	230	220	246	244	196	4181	1043	1656
1937	169	145	341	383	385	577	343	182	184	260	163	137	3269	724	1305
1938	186	204	599	327	756	1682	1349	298	317	272	327	272	6589	926	3787
1939	254	208	891	585	871	863	311	208	210	238	244	222	5105	1476	2045
1940	198	246	399	415	619	619	236	192	212	246	186	262	3830	814	1474
1941	226	230	359	327	335	613	347	228	305	411	347	349	4077	686	1295
1942	282	298	629	825	1131	2061	599	329	282	331	357	301	7425	1454	3791
1943	325	633	785	1117	1115	2892	1002	426	317	399	375	335	9721	1902	5009
1944	301	290	678	456	565	1740	914	375	309	339	327	270	6564	1134	3219
1945	375	343	492	353	613	1275	569	262	292	345	288	242	5449	845	2457
1946	351	413	450	514	710	855	540	258	359	385	303	399	5537	964	2105
1947	415	422	1226	960	1547	1500	659	272	361	524	407	381	8674	2186	3706
1948	367	351	504	879	1654	3255	1309	541	405	422	417	256	10360	1383	6218
1949	325	294	849	803	1150	1012	440	290	208	323	384	232	6310	1652	2602
1950	236	347	554	804	739	1711	1092	556	440	483	409	436	7807	1358	3542
1951	427	360	680	971	1366	1500	921	440	516	573	512	370	8636	1651	3787
1952	340	484	606	1773	1587	1148	598	394	355	326	304	297	8212	2379	3333
1953	307	358	477	366	872	3880	922	372	371	334	361	312	8932	843	5674
1954	186	414	411	510	776	1142	791	409	288	381	406	247	5961	921	2709
1955	187	241	310	662	824	1284	899	324	265	291	196	292	5775	972	3007
1956	296	263	541	628	1075	1591	481	354	308	336	407	316	6596	1169	3147
1957	208	286	595	521	1005	1449	579	268	334	390	456	382	6473	1116	3033
1958	299	284	525	516	854	1330	711	349	319	386	420	395	6388	1041	2895
1959	323	322	1324	657	835	1510	876	303	314	505	545	663	8177	1981	3221
1960	337	516	877	714	1010	888	363	264	295	280	331	313	6188	1591	2261
1961	311	323	358	242	331	902	283	187	243	388	443	240	4251	600	1516
1962	285	446	423	577	1178	1720	801	381	336	414	391	315	7267	1000	3699
1963	258	616	503	351	627	1326	724	319	353	338	373	275	6063	854	2677

APPENDIX F

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL	MA	MJJ
1964	304	370	364	387	1327	3233	1234	375	392	418	420	354	9178	751	5794
1965	518	568	664	1168	1683	2229	1713	604	585	726	621	489	11568	1832	5625
1966	389	401	828	638	806	762	586	254	288	324	438	381	6095	1466	2154
1967	322	622	729	574	1141	3336	1426	398	506	469	563	261	10347	1303	5903
1968	448	486	752	543	880	1928	1016	474	589	574	557	374	8621	1295	3824
1969	410	432	1035	1264	1392	1161	1548	494	405	443	497	377	9458	2299	4101
1970	278	451	608	531	1902	2479	1147	469	451	535	477	400	9728	1139	5528
1971	409	872	790	763	1550	1865	1108	464	458	517	474	312	9582	1553	4523
1972	392	476	1169	682	1088	1988	771	570	426	492	566	342	8962	1851	3847
1973	364	350	484	492	796	822	507	292	329	406	427	410	5679	976	2125
1974	410	435	489	567	1121	2015	977	525	462	393	448	396	8238	1056	4113
1975	258	289	563	923	2647	3257	2528	788	609	667	666	643	13838	1486	8432
1976	553	603	688	816	2147	1919	1076	562	566	587	557	452	10526	1504	5142
1977	277	444	422	455	559	592	349	265	344	434	336	402	4879	877	1500
1978	312	370	1899	1508	1803	1727	1489	542	810	638	447	423	11968	3407	5019
1979	373	408	1913	1222	1430	1292	564	273	329	311	415	352	8882	3135	3286
1980	278	328	542	608	959	1750	802	282	371	474	464	377	7235	1150	3511
1981	445	392	522	473	1659	2404	775	323	251	492	471	370	8577	995	4838
1982	284	612	841	766	1075	2498	1605	433	400	566	508	502	10090	1607	5178
1983	441	468	550	471	858	1215	1079	419	426	579	560	321	7387	1021	3152
1984	468	543	514	609	1054	1510	1025	479	422	527	535	340	8026	1123	3589
1985	397	320	609	703	771	645	201	288	340	668	476	431	5849	1312	1617
1986	481	385	1288	654	1157	1395	560	289	931	588	431	418	8577	1942	3112
1987	271	378	481	503	516	511	405	403	345	287	346	273	4719	984	1432
1988	220	335	425	387	645	454	253	115	144	239	284	302	3803	812	1352
1989	241	214	840	713	1094	869	438	315	386	388	491	344	6333	1553	2401
1990	454	269	531	601	804	1097	548	294	272	262	363	246	5741	1132	2449
1991	285	345	393	418	1128	1991	931	291	238	326	372	343	7061	811	4050
1992	252	330	377	363	358	384	598	240	204	322	356	200	3984	740	1340
1993	201	270	721	530	1017	1328	1557	981	690	550	533	535	8913	1251	3902
1994	361	331	1006	638	1194	780	313	216	180	272	339	298	5928	1644	2287
1995	257	330	467	505	1256	2155	1443	537	412	504	578	502	8946	972	4854
1996	381	818	947	995	1210	2174	768	306	290	377	362	424	9052	1942	4152
1997	512	582	717	631	1500	3023	1231	586	472	458	491	394	10597	1348	5754
1998	278	458	458	528	792	1300	1447	469	335	379	413	293	7150	986	3539
1999	441	418	504	416	764	1472	766	312	292	269	353	373	6380	920	3002
2000	248	319	417	417	473	737	549	207	164	276	253	237	4297	834	1759
2001	313	234	395	313	432	574	460	256	150	156	243	213	3739	708	1466
2002	206	230	262	412	403	1467	812	336	228	199	258	237	5050	674	2682
2003	200	290	596	481	689	1029	435	266	146	166	204	252	4754	1077	2153
2004	210	247	577	346	392	759	535	243	227	238	274	219	4267	923	1686
2005	209	310	319	295	637	1357	750	327	228	228	326	202	5188	614	2744
2006	413	223	446	702	861	1340	534	275	175	289	347	258	5863	1148	2735
2007	256	362	627	498	826	1114	460	265	171	218	232	208	5237	1125	2400
2008	200	246	393	315	867	2236	1155	388	335	288	332	196	6951	708	4258
2009	359	339	514	514	1130	1411	849	397	350	385	360	300	6908	1028	3390
2010	330	319	582	395	892	1975	1253	459	425	353	329	334	7646	977	4120
2011	398	577	1010	891	2408	4825	2228	635	279	380	416	430	1447	1901	9461
2012	332	455	523	605	961	1193	611	316	147	205	356	297	6001	1128	2765
2013	278	335	416	386	567	1726	610	371	188	251	286	261	5675	802	2903
2014	353	289	814	584	1131	1621	875	907	434	382	307	471	8168	1398	3627
	JAN	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**TOTAL**	**MA**	**MJJ**
Average	**312**	**360**	**597**	**640**	**1082**	**1640**	**831**	**361**	**330**	**380**	**380**	**328**	**7242**	**1237**	**3553**
Median	**305**	**331**	**516**	**605**	**1075**	**1472**	**766**	**323**	**314**	**369**	**363**	**321**	**6951**	**1135**	**3511**
Max	**553**	**872**	**1913**	**1773**	**2647**	**4825**	**2528**	**981**	**931**	**726**	**666**	**663**	**14477**	**3407**	**9461**
Min	**169**	**145**	**262**	**242**	**331**	**384**	**201**	**67**	**137**	**156**	**161**	**137**	**3269**	**595**	**1086**
Std Dev	**80**	**124**	**278**	**258**	**449**	**859**	**467**	**153**	**134**	**124**	**106**	**91**	**2236**	**464**	**1555**
Skew	**0.52**	**1.35**	**2.31**	**1.47**	**0.74**	**1.10**	**1.19**	**1.18**	**1.46**	**0.60**	**0.22**	**0.74**	**0.58**	**1.86**	**0.91**

Table F-2. Garrison historic runoff (kAF), 1949 level of development.

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL	MA	MJJ
1898	238	339	718	1228	1989	4380	2106	676	543	458	309	186	13170	1946	8475
1899	272	280	557	3328	1353	4209	3866	716	395	303	341	268	15888	3885	9428
1900	337	399	1394	924	1749	3001	851	317	349	484	329	216	10350	2318	5601
1901	228	282	1107	672	2725	2618	1488	534	597	468	407	236	11362	1779	6831
1902	262	395	1414	587	1146	2386	1168	536	526	528	325	222	9495	2001	4700
1903	276	474	934	851	696	2438	1805	811	599	500	387	262	10033	1785	4939
1904	319	391	647	1204	1823	3527	2152	811	591	424	301	194	12384	1851	7502
1905	248	311	851	484	672	3021	1660	506	317	329	315	234	8948	1335	5353
1906	294	216	889	825	1837	4088	1896	904	748	444	426	284	12851	1714	7821
1907	327	315	1020	613	1424	3737	4094	1500	724	645	543	272	15214	1633	9255
1908	282	422	889	696	1359	3882	2902	998	528	662	361	335	13316	1585	8143
1909	347	359	1023	607	1263	5086	3453	1067	776	474	357	274	15086	1630	9802
1910	345	424	1065	912	1791	2055	1069	508	405	371	319	97	9361	1977	4915
1911	157	242	724	555	857	3418	1825	962	950	595	313	196	10794	1279	6100
1912	238	294	1525	2360	1634	3328	2884	1335	988	926	666	389	16567	3885	7846
1913	413	335	887	1394	1452	3578	1878	1150	647	510	460	353	13057	2281	6908
1914	381	361	902	783	1859	3406	1428	585	498	573	565	240	11581	1685	6693
1915	264	286	1321	738	1142	2975	2416	1121	962	861	452	422	12960	2059	6533
1916	381	417	1942	1077	1142	3124	3358	984	456	549	498	349	14277	3019	7624
1917	327	333	1022	2573	1906	3864	3497	829	678	559	488	290	16366	3595	9267
1918	456	458	1773	1424	1252	4643	2216	859	593	512	432	319	14937	3197	8111
1919	387	292	807	988	843	724	300	212	196	282	369	321	5721	1795	1867
1920	317	333	1192	948	1712	3465	2479	708	434	357	363	387	12695	2140	7656
1921	280	415	1039	706	1144	4364	1382	367	274	184	260	204	10619	1745	6890
1922	270	393	1212	893	1561	3235	1450	605	407	323	401	218	10968	2105	6246
1923	246	357	841	1113	1210	2095	3094	766	585	1912	902	534	13655	1954	6399
1924	666	908	1396	2735	2079	2934	1827	545	468	666	579	383	15186	4131	6840
1925	694	988	1484	1125	1664	3314	2289	791	520	611	510	405	14395	2609	7267
1926	484	553	1182	1144	1775	1833	1422	603	682	583	490	369	11120	2326	5030
1927	327	615	984	1000	1968	4147	2515	1325	948	678	565	434	15506	1984	8630
1928	436	419	1123	952	2626	2898	2753	833	591	534	472	357	13994	2075	8277
1929	266	216	1575	1176	1585	3031	1747	405	397	524	422	300	11644	2751	6363
1930	254	601	1311	1267	1035	1795	976	883	603	541	415	212	9893	2578	3806
1931	190	290	260	385	653	1634	397	339	186	339	224	180	5077	645	2684
1932	198	173	500	1216	1500	3011	1583	415	432	450	323	250	10051	1716	6094
1933	284	212	1422	625	1632	2876	797	383	581	375	387	131	9705	2047	5305
1934	296	436	645	561	766	837	246	208	161	282	254	109	4801	1206	1849
1935	113	256	397	609	538	2559	1730	403	232	230	212	278	7557	1006	4827
1936	177	190	819	996	1146	1797	659	365	220	383	363	258	7373	1815	3602
1937	167	167	469	649	764	2271	1381	327	208	409	266	200	7278	1118	4416
1938	258	161	1170	577	1014	3189	2138	484	393	417	266	58	10125	1747	6341
1939	341	159	2053	682	1244	2245	837	309	248	432	365	272	9187	2735	4326
1940	145	206	327	821	1000	1726	635	224	177	617	260	349	6487	1148	3361
1941	248	260	391	746	920	2106	659	724	960	984	601	442	9041	1137	3685
1942	268	361	970	889	1410	2963	1626	492	343	440	464	250	10476	1859	5999
1943	296	776	1724	2864	1289	3648	3076	891	518	575	506	218	16381	4588	8013
1944	290	327	920	2063	1228	4346	2469	567	395	460	428	250	13743	2983	8043
1945	238	365	1527	637	780	2362	2194	700	504	498	333	292	10430	2164	5336
1946	415	315	1089	645	930	2136	1557	391	492	690	440	333	9433	1734	4623
1947	286	526	1678	1718	1771	2803	2344	970	476	549	371	280	13772	3396	6918
1948	290	266	956	1317	1220	3511	1787	583	256	403	311	-28	10872	2273	6518
1949	222	224	1212	1674	1125	2101	1037	272	303	510	504	149	9333	2886	4263
1950	292	317	578	2438	1030	2352	2107	801	589	746	294	372	11916	3016	5489
1951	366	337	627	2022	1342	2206	1770	1132	855	783	570	136	12146	2649	5318
1952	389	518	490	4865	2193	2463	1382	609	401	446	457	226	14439	5355	6038
1953	285	361	468	598	820	3020	1444	604	322	429	492	275	9118	1066	5284
1954	287	605	613	1252	1140	1248	1558	625	454	308	392	283	8765	1865	3946
1955	137	272	453	1550	1272	1710	1210	478	228	418	281	412	8421	2003	4192
1956	467	318	734	1010	1069	3063	1304	563	438	346	446	253	10011	1744	5436
1957	258	292	661	747	1244	3423	2147	527	543	569	535	342	11288	1408	6814
1958	300	246	537	703	896	1984	1010	401	326	355	297	247	7302	1240	3890
1959	224	220	1698	742	632	1893	1398	351	326	532	302	476	8794	2440	3923
1960	194	310	1526	1314	515	1183	409	185	191	267	285	150	6529	2840	2107
1961	199	230	462	221	179	1450	321	178	375	513	411	162	4701	683	1950
1962	222	538	559	1100	1258	2938	2396	778	454	567	429	273	11512	1659	6592
1963	163	572	935	612	1112	3524	1542	385	485	468	320	146	10264	1547	6178
1964	223	233	365	585	1012	2852	2624	410	520	372	318	205	9719	950	6488
1965	337	287	420	1926	1705	3073	3383	989	742	710	440	287	14299	2346	8161
1966	143	212	920	662	785	1212	855	273	340	360	333	200	6295	1582	2852

APPENDIX F

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL	MA	MJJ
1967	171	263	986	1431	1271	4060	3356	530	459	475	423	203	13628	2417	8687
1968	249	330	1234	493	569	2969	1898	940	852	567	569	255	10925	1727	5436
1969	238	255	1260	2118	1568	1911	2349	449	244	331	410	215	11348	3378	5828
1970	76	336	558	922	1834	3210	2254	430	410	526	324	224	11104	1480	7298
1971	175	831	1480	1604	1168	3428	2420	682	724	962	564	280	14318	3084	7016
1972	187	402	3571	873	1186	3254	1481	920	662	630	616	259	14041	4444	5921
1973	318	318	882	620	1562	2290	1145	477	852	651	427	343	9885	1502	4997
1974	297	452	705	1076	1165	3387	2519	699	506	395	509	301	12011	1781	7071
1975	141	152	741	1747	2740	2847	3987	983	487	496	374	306	15001	2488	9574
1976	342	641	1361	993	1553	2947	2017	870	483	460	345	273	12285	2354	6517
1977	72	289	595	571	894	1225	391	245	438	492	124	229	5565	1166	2510
1978	104	134	1549	2415	2750	3428	2986	877	876	549	203	290	16161	3964	9164
1979	111	236	1314	3213	1442	2034	1220	537	540	329	357	174	11507	4527	4696
1980	71	166	493	697	945	1823	993	306	458	652	468	110	7182	1190	3761
1981	335	250	505	207	741	2753	1013	272	83	351	488	185	7183	712	4507
1982	12	345	1031	1511	902	2489	2958	1041	561	939	553	368	12710	2542	6349
1983	354	581	981	521	728	2253	2012	528	232	662	581	36	9469	1502	4993
1984	294	458	703	551	1276	2295	1754	683	284	651	502	75	9526	1254	5325
1985	248	165	869	704	587	1072	514	537	367	674	308	218	6263	1573	2173
1986	291	216	2237	586	1491	3076	1608	416	640	1248	459	462	12730	2823	6175
1987	217	383	797	777	919	1239	580	493	426	373	336	96	6636	1574	2738
1988	-41	168	588	346	840	1212	399	-56	62	276	201	146	4141	934	2451
1989	35	107	716	1061	1176	1680	1069	299	299	397	423	26	7288	1777	3925
1990	297	212	760	504	782	1585	1415	405	231	328	430	49	6998	1264	3782
1991	140	216	509	402	1257	3478	1841	260	471	418	478	207	9677	911	6576
1992	182	288	558	390	770	1413	1651	468	312	436	412	70	6950	948	3834
1993	122	294	867	737	1162	2532	2432	1535	490	564	407	319	11461	1604	6126
1994	235	225	2023	671	1431	1317	430	76	135	552	235	168	7498	2694	3178
1995	141	392	921	519	1341	2968	2747	519	234	402	279	166	10629	1440	7056
1996	248	898	1513	1526	1277	3545	2142	382	178	360	246	300	12615	3039	6964
1997	267	646	1890	1974	1609	4652	2917	1271	608	525	551	491	17401	3864	9178
1998	157	608	709	898	895	1722	2431	817	404	875	642	274	10432	1607	5048
1999	393	506	1669	901	1431	3279	2176	672	532	573	454	238	12824	2570	6886
2000	232	342	680	367	635	1946	1062	236	143	550	263	183	6639	1047	3643
2001	348	263	1054	733	537	1290	985	245	34	352	219	182	6242	1787	2812
2002	184	232	345	637	530	1838	1175	384	224	480	238	153	6420	982	3543
2003	143	320	1359	707	757	2446	1095	261	109	355	154	269	7975	2066	4298
2004	162	225	912	616	376	1345	1202	409	276	523	365	142	6553	1528	2923
2005	197	395	557	402	1207	2292	1919	366	129	556	300	93	8413	959	5418
2006	440	253	494	793	1012	1822	815	257	113	507	270	112	6888	1287	3649
2007	184	211	917	635	1439	2340	800	287	119	416	270	154	7772	1552	4579
2008	191	211	456	497	837	3164	2892	720	419	607	314	293	10601	953	6893
2009	400	353	1063	1352	1209	3100	2393	748	495	523	398	247	12281	2415	6702
2010	319	285	754	695	980	3365	2527	616	507	538	219	308	11113	1449	6872
2011	331	460	1436	2666	3887	6485	5566	1542	666	721	368	384	24512	4102	15938
2012	248	539	839	554	980	2112	1340	428	111	429	344	199	8123	1393	4432
2013	199	347	619	1085	1108	3144	1440	534	414	898	358	282	10428	1704	5692
2014	443	388	1812	1201	1807	3850	2640	1160	1043	704	189	516	15753	3013	8297
	JAN	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**TOTAL**	**MA**	**MJJ**
Average	**263**	**355**	**1002**	**1080**	**1265**	**2720**	**1822**	**614**	**453**	**529**	**391**	**251**	**10745**	**2082**	**5807**
Median	**262**	**318**	**917**	**851**	**1207**	**2852**	**1747**	**537**	**454**	**507**	**374**	**250**	**10601**	**1795**	**5921**
Max	**694**	**988**	**3571**	**4865**	**3887**	**6485**	**5566**	**1542**	**1043**	**1912**	**902**	**534**	**24512**	**5355**	**15938**
Max	**-41**	**107**	**260**	**207**	**179**	**724**	**246**	**-56**	**34**	**184**	**124**	**-28**	**4141**	**645**	**1849**
Std Dev	**113**	**165**	**497**	**729**	**545**	**986**	**940**	**319**	**223**	**215**	**122**	**107**	**3331**	**939**	**2146**
Skew	**0.62**	**1.56**	**1.56**	**2.20**	**1.47**	**0.47**	**0.78**	**0.79**	**0.50**	**2.85**	**0.70**	**0.15**	**0.57**	**1.09**	**0.81**

Table F-3. Oahe historic runoff (kAF), 1949 level of development.

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL	MA	MJJ
1898	-85	63	865	478	389	464	286	58	91	46	180	6	2841	1343	1139
1899	12	36	1022	403	472	607	220	97	234	61	77	-61	3180	1425	1299
1900	-95	28	778	337	63	264	208	99	212	69	79	-58	1984	1115	535
1901	-6	28	458	177	67	718	226	30	543	159	-18	-4	2378	635	1011
1902	4	40	752	173	163	266	115	38	349	56	133	-22	2067	925	544
1903	-52	46	526	300	272	343	260	111	714	276	103	-50	2849	826	875
1904	-44	87	573	321	220	791	182	61	212	32	46	-93	2388	894	1193
1905	-91	36	528	194	361	621	454	69	151	-63	-4	28	2284	722	1436
1906	-60	36	520	315	466	486	190	123	885	488	319	161	3929	835	1142
1907	180	58	534	190	468	778	512	44	167	389	405	111	3836	724	1758
1908	60	95	785	363	282	551	177	60	63	-109	184	280	2791	1148	1010
1909	46	127	432	327	781	1214	565	161	186	-2	73	-18	3892	759	2560
1910	-48	67	811	307	151	371	216	67	-54	46	-6	-42	1886	1118	738
1911	12	40	157	165	87	198	101	56	492	329	87	113	1837	322	386
1912	123	38	454	581	284	290	387	111	619	266	341	617	4111	1035	961
1913	252	4	149	44	50	77	38	12	555	161	298	377	2017	193	165
1914	67	30	537	300	232	873	218	60	413	248	641	292	3911	837	1323
1915	296	131	373	458	389	1020	553	85	647	494	387	97	4930	831	1962
1916	-6	65	1250	375	359	607	288	113	111	210	288	-8	3652	1625	1254
1917	8	95	744	629	208	401	204	58	286	298	307	6	3244	1373	813
1918	-85	26	492	460	266	298	260	93	234	-200	-56	-228	1560	952	824
1919	258	56	286	268	159	192	133	20	-61	-42	-125	-103	1041	554	484
1920	-97	56	1004	631	482	946	325	83	52	-40	-77	46	3411	1635	1753
1921	-50	26	631	359	238	300	262	67	121	-60	-54	-89	1751	990	800
1922	-85	163	670	432	500	871	428	60	60	8	63	-105	3065	1102	1799
1923	-97	73	601	561	260	978	563	131	349	571	591	300	4881	1162	1801
1924	-48	46	482	272	44	450	133	40	71	177	309	8	1984	754	627
1925	-175	42	424	484	230	1214	234	54	-40	-8	-2	-133	2324	908	1678
1926	-129	52	244	40	387	712	345	125	446	288	109	-139	2480	284	1444
1927	-137	65	1178	1638	986	893	577	167	345	173	-46	-77	5762	2816	2456
1928	-50	42	726	385	294	1331	633	157	117	-4	77	-99	3609	1111	2258
1929	-18	69	1105	494	258	337	202	40	-18	61	-14	-54	2462	1599	797
1930	-69	-20	676	385	236	151	-99	52	8	125	-69	-81	1295	1061	288
1931	6	71	83	125	-8	6	58	48	18	2	0	22	431	208	56
1932	-32	60	381	421	242	637	-133	151	32	-12	-40	-139	1568	802	746
1933	-8	-32	180	141	647	52	44	42	85	38	34	30	1253	321	743
1934	-30	-149	188	2	-44	-46	77	50	20	28	24	-50	70	190	-13
1935	-22	44	121	200	151	452	79	20	16	4	-42	-61	962	321	682
1936	-8	-2	393	208	-8	-91	-12	40	18	2	10	-8	542	601	-111
1937	-30	-10	202	270	14	712	329	65	28	-10	-44	-16	1510	472	1055
1938	10	34	347	60	93	315	216	-22	69	18	-77	-83	980	407	624
1939	28	12	934	-345	105	198	83	34	54	8	-6	8	1113	589	386
1940	18	8	22	202	77	52	6	24	65	28	-67	30	465	224	135
1941	14	16	113	329	75	1085	117	-48	36	60	0	-65	1732	442	1277
1942	8	4	109	333	1174	522	163	60	-24	24	-54	22	2341	442	1859
1943	54	226	986	1323	40	803	58	38	42	-18	79	-111	3520	2309	901
1944	44	60	18	1644	228	1299	40	145	61	30	153	-105	3617	1662	1567
1945	16	365	1392	284	79	414	79	173	12	83	89	62	3048	1676	572
1946	24	42	317	60	258	628	224	18	107	131	44	40	1893	377	1110
1947	2	91	641	540	117	1065	-54	-56	10	71	-95	-54	2278	1181	1128
1948	4	40	927	1121	254	133	89	-2	-34	79	60	-36	2635	2048	476
1949	46	52	1162	1478	165	115	38	24	6	30	68	-9	3175	2640	318
1950	-43	-31	575	3749	835	216	-103	72	68	49	-89	23	5321	4324	948
1951	67	9	260	943	-2	237	18	87	116	60	-186	-140	1469	1203	253
1952	-32	59	156	3953	238	27	117	-5	-11	-24	-74	-57	4347	4109	382
1953	56	39	551	197	354	1205	-27	84	-13	0	-8	-67	2371	748	1532
1954	-7	107	139	293	91	290	-20	84	135	178	120	-44	1366	432	361
1955	27	15	250	207	94	70	106	25	32	-16	-48	-24	738	457	270
1956	30	20	720	344	69	92	115	60	25	-12	32	-73	1422	1064	276
1957	-45	-42	199	99	370	230	150	-37	-18	-23	39	41	963	298	750
1958	-119	-8	252	418	106	165	269	9	-9	28	-30	-30	1051	670	540
1959	28	8	478	204	69	63	31	-22	3	62	-158	72	838	682	163
1960	6	19	489	501	66	104	-40	34	-18	0	-26	-209	926	990	130
1961	57	61	227	-1	117	37	-32	13	91	-58	60	-198	374	226	122
1962	25	76	287	242	598	1077	343	128	44	42	-24	-132	2706	529	2018
1963	-17	33	253	158	141	326	50	63	42	16	-57	-197	811	411	517
1964	-20	31	81	192	356	634	249	-36	4	31	-110	-138	1274	273	1239
1965	14	42	80	510	664	511	182	58	-80	34	24	39	2078	590	1357
1966	-123	80	1487	498	66	91	169	51	73	-16	37	-25	2388	1985	326

APPENDIX F

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL	MA	MJJ
1967	-30	77	645	256	581	1001	154	102	22	38	112	-112	2846	901	1736
1968	56	41	213	219	65	216	95	37	76	52	66	21	1157	432	376
1969	13	110	530	1087	180	117	555	31	48	34	60	62	2827	1617	852
1970	-68	55	118	579	972	285	136	106	110	45	146	19	2503	697	1393
1971	64	318	1101	805	460	714	147	20	33	112	70	-37	3807	1906	1321
1972	42	112	1835	193	835	541	183	120	-4	8	83	-12	3936	2028	1559
1973	236	183	593	241	247	177	57	30	75	57	81	36	2013	834	481
1974	44	136	220	243	219	118	116	0	29	37	29	112	1303	463	453
1975	-105	68	194	900	1169	327	54	15	-72	-14	-5	45	2576	1094	1550
1976	-24	248	284	153	112	420	149	76	44	-11	33	-9	1475	437	681
1977	46	116	267	140	101	157	88	-49	163	90	-22	24	1121	407	346
1978	65	190	1772	1739	698	295	196	109	87	-48	27	25	5155	3511	1189
1979	87	98	299	1002	207	201	303	111	105	-73	25	-30	2335	1301	711
1980	-42	29	279	83	7	89	-93	-71	9	92	33	65	480	362	3
1981	105	110	201	-1	49	154	119	225	71	52	81	61	1227	200	322
1982	13	243	805	1529	1390	581	210	178	99	324	214	137	5723	2334	2181
1983	-6	156	629	203	358	109	123	74	44	-4	16	-57	1645	832	590
1984	125	261	324	265	467	794	71	-24	-57	-14	38	-17	2233	589	1332
1985	130	113	605	76	56	55	-12	37	17	19	20	60	1176	681	99
1986	123	103	1629	908	1109	266	158	-7	66	162	100	23	4640	2537	1533
1987	-63	203	2027	951	216	231	44	65	28	-10	48	60	3800	2978	491
1988	-18	105	187	43	83	-8	9	-56	-68	17	45	-49	290	230	84
1989	-45	93	338	272	269	62	33	0	110	9	91	-30	1202	610	364
1990	184	90	232	23	79	185	129	92	82	16	88	-25	1175	255	393
1991	89	155	227	104	375	567	124	38	-23	44	71	62	1833	331	1066
1992	79	158	230	41	10	160	195	131	74	27	123	-76	1152	271	365
1993	27	163	780	321	405	336	1064	562	83	53	154	104	4052	1101	1805
1994	65	143	1143	287	257	303	286	37	101	176	67	102	2967	1430	846
1995	91	459	1106	519	1443	657	276	32	119	138	250	62	5152	1625	2376
1996	158	896	1014	688	597	1110	249	185	262	145	340	154	5798	1702	1956
1997	168	516	2604	2828	841	336	263	4	-8	-140	-39	14	7387	5432	1440
1998	-257	94	191	217	34	272	220	85	-15	169	72	-2	1080	408	526
1999	-43	207	687	270	811	482	232	103	31	-79	-41	48	2708	957	1525
2000	-64	99	386	406	400	285	223	48	132	143	154	-16	2196	792	908
2001	146	117	1085	505	140	290	357	237	116	24	95	29	3141	1590	787
2002	19	73	57	130	96	60	49	50	110	23	96	10	773	187	205
2003	-53	61	424	160	344	167	106	41	81	40	-39	7	1339	584	617
2004	-24	27	507	134	46	214	74	134	111	-9	107	-56	1265	641	334
2005	16	93	116	57	189	344	181	105	74	-9	39	-69	1136	173	714
2006	93	32	110	134	96	51	85	48	83	12	70	-60	754	244	232
2007	-9	19	203	190	73	429	134	149	69	10	43	-38	1272	393	636
2008	-5	7	120	102	310	1384	393	118	67	16	106	4	2622	222	2087
2009	29	498	2098	3212	547	421	368	247	120	66	67	0	7673	5310	1336
2010	38	69	1378	1013	592	661	307	175	129	-55	42	59	4408	2391	1560
2011	90	282	1727	1600	912	1080	399	206	55	79	38	106	6574	3327	2391
2012	-71	184	266	108	193	199	145	48	-24	-47	70	58	1129	374	537
2013	14	108	158	215	416	818	260	203	204	1138	176	3	3713	373	1494
2014	180	186	940	543	546	962	599	697	323	108	147	196	5427	1483	2107
	JAN	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**TOTAL**	**MA**	**MJJ**
Average	**13**	**96**	**587**	**508**	**321**	**445**	**189**	**77**	**112**	**73**	**68**	**3**	**2491**	**1095**	**955**
Median	**8**	**63**	**478**	**300**	**238**	**327**	**158**	**60**	**69**	**32**	**46**	**-8**	**2278**	**826**	**813**
Max	**296**	**896**	**2604**	**3953**	**1443**	**1384**	**1064**	**697**	**885**	**1138**	**641**	**617**	**7673**	**5432**	**2560**
Min	**-257**	**-149**	**18**	**-345**	**-44**	**-91**	**-133**	**-71**	**-80**	**-200**	**-186**	**-228**	**70**	**173**	**-111**
Std Dev	**88**	**125**	**491**	**679**	**308**	**357**	**179**	**97**	**168**	**157**	**132**	**113**	**1567**	**999**	**643**
Skew	**0.54**	**3.24**	**1.56**	**3.17**	**1.58**	**0.84**	**1.49**	**3.38**	**2.29**	**3.48**	**1.68**	**1.88**	**1.01**	**2.21**	**0.55**

Table F-4. Fort Randall historic runoff (kAF), 1949 level of development.

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL	MA	MJJ
1898	-54	4	151	111	240	63	190	24	32	14	58	2	835	262	493
1899	4	14	510	143	125	179	67	34	75	20	24	-38	1157	653	371
1900	-58	12	186	200	26	135	214	38	67	22	26	-36	832	386	375
1901	-4	16	228	147	46	284	38	24	175	52	-10	-2	994	375	368
1902	2	6	240	87	30	91	28	26	109	18	42	-12	667	327	149
1903	-32	20	220	179	79	105	141	24	228	87	34	-30	1055	399	325
1904	-26	16	52	125	67	177	139	18	69	10	16	-58	605	177	383
1905	-58	10	248	109	192	226	95	24	48	-40	-2	10	862	357	513
1906	-36	12	276	280	129	119	10	56	282	155	101	58	1442	556	258
1907	58	36	125	105	155	145	220	20	54	125	129	36	1208	230	520
1908	20	20	188	117	157	222	85	26	20	-65	58	89	937	305	464
1909	14	65	192	220	270	184	127	63	60	-2	24	-12	1205	412	581
1910	-30	10	262	111	54	161	77	18	-32	16	-4	-26	617	373	292
1911	4	16	50	111	48	48	44	28	157	103	28	36	673	161	140
1912	40	12	159	226	67	65	139	40	194	83	107	196	1328	385	271
1913	79	4	52	38	20	18	20	6	179	52	95	119	682	90	58
1914	22	24	127	286	75	147	54	18	129	77	204	93	1256	413	276
1915	93	131	502	252	119	274	226	16	204	157	123	32	2129	754	619
1916	-4	10	190	101	151	238	58	40	38	67	91	-4	976	291	447
1917	2	20	417	226	149	113	60	18	89	95	97	2	1288	643	322
1918	-52	14	250	228	111	161	115	28	75	-123	-34	-139	634	478	387
1919	81	26	103	115	48	139	61	10	-36	-26	-77	-63	381	218	248
1920	-60	40	409	377	200	397	89	18	18	-24	-48	16	1432	786	686
1921	-30	4	216	63	117	83	145	38	40	-36	-32	-56	552	279	345
1922	-52	50	266	99	145	264	169	30	20	2	20	-63	950	365	578
1923	-60	6	202	165	103	422	159	93	111	182	188	95	1666	367	684
1924	-30	26	159	40	14	180	22	26	24	56	99	2	618	199	216
1925	-105	16	52	109	32	323	61	24	-24	-4	-2	-79	403	161	416
1926	-77	8	8	4	95	184	149	24	141	91	34	-83	578	12	428
1927	-83	22	710	298	270	171	81	50	111	54	-30	-48	1606	1008	522
1928	-30	46	440	87	123	294	87	40	73	-2	26	-61	1123	527	504
1929	-12	34	329	202	54	125	95	12	-12	-44	-50	-60	673	531	274
1930	-22	-52	409	-52	-18	-54	-53	61	12	10	-32	-91	118	357	-125
1931	-6	169	20	73	67	-95	61	-8	46	4	0	-24	307	93	33
1932	-40	36	188	56	190	180	-163	165	0	-6	-73	-77	456	244	207
1933	0	14	135	129	165	-75	-6	149	-16	26	-22	-48	451	264	84
1934	36	-186	198	0	20	83	93	16	20	-16	-22	-60	182	198	196
1935	-28	18	20	105	186	149	67	-56	22	-18	-42	-91	332	125	402
1936	6	-6	597	32	-63	-65	-40	-6	36	-14	-4	-61	412	629	-168
1937	-2	-16	149	18	50	248	-87	28	-63	-34	0	-32	259	167	211
1938	-18	-4	8	127	155	71	-93	-24	52	2	-36	-30	210	135	133
1939	28	-4	490	-347	67	32	-46	34	-28	-42	-16	-14	154	143	53
1940	-46	-24	-4	111	20	-115	2	-40	34	-38	-12	-40	-152	107	-93
1941	-10	-22	40	-4	-65	32	-16	-48	46	73	54	-24	56	36	-49
1942	-32	-52	-2	149	1660	426	-50	125	67	10	8	-4	2305	147	2036
1943	4	-44	93	-20	54	230	-28	-4	4	-32	71	-99	229	73	256
1944	6	-26	117	224	214	490	179	180	54	-8	50	-174	1306	341	883
1945	-69	55	421	60	-4	-10	8	63	-60	2	16	-36	446	481	-6
1946	8	40	131	139	89	68	79	79	68	87	97	-143	742	270	236
1947	2	12	214	141	-83	395	-179	-2	-60	-8	18	-99	351	355	133
1948	65	111	238	-10	44	75	-141	10	4	-145	52	-38	265	228	-22
1949	-38	10	555	-14	186	16	-91	-26	-6	52	35	2	681	541	111
1950	-76	39	411	234	205	-13	43	34	8	28	0	-30	883	645	235
1951	28	4	145	104	77	234	69	25	59	98	94	3	940	249	380
1952	52	122	379	1347	114	117	58	8	-56	-36	-24	-65	2016	1726	289
1953	-29	48	610	226	577	178	258	218	100	179	29	-50	2344	836	1013
1954	45	92	93	-31	-6	159	23	58	8	-28	-5	-46	362	62	176
1955	-43	12	401	91	55	167	30	130	111	137	-139	41	993	492	252
1956	9	15	52	69	95	96	16	95	-4	-55	39	-40	387	121	207
1957	-23	13	76	111	223	226	98	8	25	8	63	-20	808	187	547
1958	-43	22	126	203	55	29	54	-34	-22	29	0	-13	406	329	138
1959	13	4	59	9	71	32	22	13	49	6	-16	35	297	68	125
1960	-4	32	622	502	112	103	35	70	8	54	-7	-6	1521	1124	250
1961	37	45	47	33	132	121	65	17	9	-9	41	-32	506	80	318
1962	25	27	144	223	412	700	447	86	-39	-52	-8	54	2019	367	1559
1963	29	160	139	32	121	226	128	25	-34	20	-63	208	991	171	475
1964	173	83	12	187	205	218	90	72	-25	-41	23	173	1170	199	513
1965	140	120	91	78	248	146	124	93	102	-18	-30	90	1184	169	518
1966	210	104	591	165	109	158	146	189	90	70	31	128	1991	756	413

APPENDIX F

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL	MA	MJJ
1967	55	87	135	91	169	676	116	81	90	52	41	51	1644	226	961
1968	87	128	76	244	105	366	126	103	65	-8	3	-32	1263	320	597
1969	210	67	329	344	78	93	171	91	28	36	43	10	1500	673	342
1970	151	84	130	323	119	91	24	15	60	14	6	56	1073	453	234
1971	64	148	215	213	164	182	70	132	122	116	55	116	1597	428	416
1972	100	135	183	127	421	193	222	196	139	114	69	137	2036	310	836
1973	127	154	185	87	117	81	103	115	85	47	-26	79	1154	272	301
1974	120	102	109	114	108	82	91	127	72	35	18	50	1028	223	281
1975	48	58	98	246	152	148	111	85	48	81	46	101	1222	344	411
1976	37	50	38	39	27	20	71	48	-18	-54	-45	45	258	77	118
1977	86	27	267	255	109	91	30	40	61	-18	10	75	1033	522	230
1978	69	38	924	191	174	129	93	92	157	66	48	66	2047	1115	396
1979	81	18	216	28	87	125	108	109	31	22	-34	53	844	244	320
1980	-52	77	54	40	46	35	-12	90	17	51	0	-20	326	94	69
1981	26	-2	6	-18	-27	-21	-21	43	-42	-49	-38	-28	-171	-12	-69
1982	29	76	43	102	429	125	-16	-66	-49	43	-266	19	469	145	538
1983	81	76	65	104	356	176	47	44	-22	-4	-17	76	982	169	579
1984	98	157	168	234	95	268	-26	71	40	-39	-86	83	1063	402	337
1985	86	84	210	40	-18	-8	4	36	-91	-149	-134	108	168	250	-22
1986	32	102	460	477	420	201	-8	47	70	-79	-83	23	1662	937	613
1987	114	61	444	369	122	20	11	-17	13	-35	-82	20	1040	813	153
1988	155	67	125	49	208	27	47	-19	34	-153	-8	68	600	174	282
1989	48	33	158	13	24	-35	-27	-24	0	-61	-15	53	167	171	-38
1990	-15	54	7	-3	58	95	-61	-31	-57	-111	-6	-67	-137	4	92
1991	26	-12	21	31	206	445	-24	10	58	-169	48	69	709	52	627
1992	33	88	67	4	3	12	108	78	-77	-30	8	-7	287	71	123
1993	172	11	221	104	108	186	221	31	-56	-81	-77	40	880	325	515
1994	50	137	401	22	24	62	27	-16	2	-57	-100	90	642	423	113
1995	41	51	57	634	812	470	-48	-45	-99	-44	-12	167	1984	691	1234
1996	-24	275	167	10	259	178	-83	-134	-7	-38	17	75	695	177	354
1997	114	589	845	451	415	583	105	154	17	16	-48	191	3432	1296	1103
1998	159	134	156	105	94	259	120	124	24	65	-32	41	1249	261	473
1999	158	78	44	235	736	189	120	14	158	60	-118	37	1711	279	1045
2000	-7	84	42	120	27	-115	-104	-128	-158	-320	20	50	-489	162	-192
2001	67	46	375	542	222	113	18	-2	45	-69	-53	50	1354	917	353
2002	64	25	92	81	36	56	28	48	52	-96	44	39	469	173	120
2003	-3	81	75	64	98	53	40	12	2	-23	-10	15	404	139	191
2004	-4	80	13	-5	29	42	12	5	60	-26	-26	26	206	8	83
2005	41	46	6	53	154	207	-19	-27	-26	-15	-33	47	434	59	342
2006	87	14	67	111	5	-5	-52	8	-15	-63	-24	94	227	178	-52
2007	-17	94	146	3	106	84	-63	92	-61	48	-88	75	419	149	127
2008	-42	101	55	22	109	418	64	-29	-12	0	76	-86	676	77	591
2009	117	217	165	229	32	53	79	64	41	5	6	12	1020	394	164
2010	176	119	955	272	140	440	124	39	7	-8	8	3	2275	1227	704
2011	78	213	347	248	303	855	355	243	123	0	12	84	3161	895	1513
2012	131	127	106	73	91	-1	-63	-5	65	-51	-63	-8	402	179	27
2013	33	94	37	113	141	128	35	94	-3	135	-54	-46	707	150	304
2014	119	111	143	113	223	182	27	118	53	-19	-1	74	1143	256	432
	JAN	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**TOTAL**	**MA**	**MJJ**
Average	**28**	**55**	**214**	**144**	**147**	**160**	**58**	**42**	**37**	**5**	**4**	**12**	**907**	**358**	**365**
Median	**20**	**36**	**156**	**111**	**109**	**135**	**58**	**28**	**34**	**2**	**0**	**3**	**832**	**270**	**318**
Max	**210**	**589**	**955**	**1347**	**1660**	**855**	**447**	**243**	**282**	**182**	**204**	**208**	**3432**	**1726**	**2036**
Min	**-105**	**-186**	**-4**	**-347**	**-83**	**-115**	**-179**	**-134**	**-158**	**-320**	**-266**	**-174**	**-489**	**-12**	**-192**
Std Dev	**68**	**79**	**201**	**173**	**198**	**163**	**95**	**62**	**71**	**74**	**64**	**72**	**668**	**302**	**344**
Skew	**0.62**	**2.84**	**1.57**	**3.21**	**4.61**	**1.51**	**0.64**	**0.54**	**0.56**	**-0.57**	**-0.28**	**0.30**	**1.03**	**1.77**	**1.90**

Table F-5. Gavins Point historic runoff (kAF), 1949 level of development.

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL	MA	MJJ
1898	75	97	143	119	127	127	77	67	73	99	91	75	1170	262	331
1899	73	93	141	115	125	125	73	67	71	95	87	73	1138	256	323
1900	77	99	149	123	133	133	79	69	75	101	93	77	1208	272	345
1901	85	109	165	135	147	147	87	75	83	111	101	85	1330	300	381
1902	83	107	161	131	143	143	85	75	85	109	99	83	1304	292	371
1903	79	101	153	125	135	137	83	73	77	105	95	79	1242	278	355
1904	77	99	149	121	131	133	79	71	75	101	91	77	1204	270	343
1905	89	113	171	139	153	153	91	83	83	117	105	89	1386	310	397
1906	95	123	182	151	163	165	99	89	93	125	113	95	1493	333	427
1907	85	111	165	135	147	147	89	81	85	113	101	85	1344	300	383
1908	85	111	165	135	147	149	89	81	85	113	101	85	1346	300	385
1909	91	117	175	143	157	159	95	85	89	119	109	91	1430	318	411
1910	79	101	151	125	135	137	83	73	77	103	93	79	1236	276	355
1911	75	97	145	117	129	131	79	69	75	97	89	75	1178	262	339
1912	81	103	155	127	139	139	83	75	79	105	95	81	1262	282	361
1913	79	101	153	125	137	137	83	75	77	105	93	79	1244	278	357
1914	79	103	153	125	137	137	83	75	79	105	95	81	1252	278	357
1915	99	127	188	155	169	171	103	91	97	131	117	99	1547	343	443
1916	89	115	173	143	155	157	95	83	89	119	107	91	1416	316	407
1917	75	97	147	119	131	131	79	71	75	99	91	75	1190	266	341
1918	75	97	147	119	131	131	79	71	75	99	91	75	1190	266	341
1919	76	99	150	121	133	135	81	71	77	101	91	76	1211	271	349
1920	85	111	165	135	147	149	89	81	85	113	103	85	1348	300	385
1921	85	111	163	135	147	149	89	79	85	113	103	85	1344	298	385
1922	83	105	159	131	141	143	87	75	81	109	99	83	1296	290	371
1923	89	113	171	139	153	155	93	81	87	117	105	89	1392	310	401
1924	87	111	167	137	149	151	91	79	83	113	103	87	1358	304	391
1925	79	101	151	123	135	137	83	73	77	103	93	79	1234	274	355
1926	75	95	143	117	129	129	79	69	73	97	89	75	1170	260	337
1927	81	103	155	127	139	141	85	85	71	97	73	52	1209	282	365
1928	97	111	171	127	105	105	99	75	83	103	109	99	1284	298	309
1929	56	67	175	109	113	141	89	69	95	105	115	75	1209	284	343
1930	75	155	137	163	196	121	69	81	91	111	99	107	1405	300	386
1931	109	137	125	129	105	79	65	71	67	85	77	103	1152	254	249
1932	79	135	133	113	143	147	71	69	71	91	89	65	1206	246	361
1933	103	83	151	105	131	67	73	91	73	87	97	79	1140	256	271
1934	107	97	125	95	85	81	54	67	101	93	95	77	1077	220	220
1935	69	133	125	147	119	133	75	65	69	83	95	77	1190	272	327
1936	79	79	212	121	129	75	46	58	63	93	85	107	1147	333	250
1937	77	83	79	111	60	67	87	83	155	93	54	91	1040	190	214
1938	81	93	141	131	105	71	87	85	91	95	83	91	1154	272	263
1939	95	63	155	131	71	58	84	95	85	105	89	83	1114	286	213
1940	79	93	167	133	87	109	48	61	63	77	81	111	1109	300	244
1941	75	93	131	117	85	89	81	67	75	97	91	83	1084	248	255
1942	85	91	143	129	339	149	83	77	85	93	91	87	1452	272	571
1943	67	117	137	117	99	139	73	65	65	83	93	77	1132	254	311
1944	89	87	177	182	145	218	137	103	79	101	107	87	1512	359	500
1945	113	133	214	139	115	173	91	111	81	99	97	64	1430	353	379
1946	107	123	165	101	111	89	77	74	115	157	115	93	1327	266	277
1947	99	109	173	159	115	488	171	34	155	107	40	34	1684	332	774
1948	60	97	141	262	149	397	268	186	20	157	67	52	1856	403	814
1949	61	91	438	240	222	153	143	56	163	128	113	33	1841	678	518
1950	89	51	214	445	126	98	250	180	88	151	137	80	1909	659	474
1951	73	91	178	290	230	265	96	276	257	151	105	75	2087	468	591
1952	89	164	652	221	241	136	123	118	83	74	66	45	2012	873	500
1953	138	118	334	124	169	79	20	4	-39	-30	148	158	1223	458	268
1954	76	163	164	103	134	246	51	67	56	114	135	140	1449	267	431
1955	38	42	274	85	75	69	36	-126	-26	-36	102	89	622	359	180
1956	68	77	173	55	3	-110	-27	14	-1	160	166	128	706	228	-134
1957	73	124	190	173	264	258	177	116	98	113	159	126	1871	363	699
1958	85	92	159	227	137	147	192	128	72	89	129	75	1532	386	476
1959	60	99	193	100	211	101	89	118	99	110	156	113	1449	293	401
1960	69	92	408	391	301	141	103	133	115	111	137	92	2093	799	545
1961	73	157	178	86	168	132	125	111	99	143	107	56	1435	264	425
1962	54	103	423	229	269	450	487	200	152	144	158	100	2769	652	1206
1963	91	150	210	157	167	195	167	118	127	97	103	84	1666	367	529
1964	88	111	132	196	188	238	165	145	121	99	109	45	1637	328	591
1965	76	88	87	140	133	176	84	98	129	129	135	122	1397	227	393
1966	59	119	264	154	133	144	114	137	94	72	110	30	1430	418	391

APPENDIX F

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL	MA	MJJ
1967	120	90	123	88	133	369	141	126	130	130	147	37	1634	211	643
1968	111	108	132	162	153	178	162	107	111	140	135	41	1540	294	493
1969	103	82	246	309	180	165	173	218	202	215	176	64	2133	555	518
1970	100	141	133	197	191	142	140	162	138	134	143	79	1700	330	473
1971	67	167	304	207	219	255	238	158	144	159	209	151	2278	511	712
1972	86	160	208	102	315	237	234	145	129	126	208	106	2056	310	786
1973	133	191	347	181	310	215	159	146	234	205	187	113	2421	528	684
1974	170	159	134	160	142	171	153	169	151	184	157	138	1888	294	466
1975	114	122	219	254	183	215	244	308	202	141	114	239	2355	473	642
1976	129	210	176	203	223	172	176	160	227	189	138	113	2116	379	571
1977	100	160	239	220	316	273	230	234	202	214	200	81	2469	459	819
1978	81	101	535	329	311	193	323	193	104	52	57	231	2510	864	827
1979	86	62	319	215	154	136	119	115	108	50	143	150	1657	534	409
1980	99	152	181	202	191	167	88	115	77	51	78	101	1502	383	446
1981	114	114	95	148	180	163	192	170	145	160	136	110	1727	243	535
1982	65	198	187	172	369	241	207	167	141	127	165	84	2123	359	817
1983	222	185	271	274	368	326	250	115	68	59	99	90	2327	545	944
1984	189	260	327	480	368	403	116	17	-12	18	14	125	2305	807	887
1985	142	157	268	254	247	200	197	238	310	277	186	118	2594	522	644
1986	197	195	348	333	292	318	250	134	254	149	124	162	2756	681	860
1987	211	208	497	376	299	218	248	218	215	190	254	161	3095	873	765
1988	89	203	368	279	366	222	242	173	183	197	179	103	2604	647	830
1989	139	97	221	200	217	196	190	194	143	162	115	130	2004	421	603
1990	170	161	157	207	273	245	215	204	178	212	156	59	2237	364	733
1991	173	181	184	196	240	274	160	148	149	172	135	137	2149	380	674
1992	132	127	126	131	149	175	205	165	120	147	131	78	1686	257	529
1993	98	139	370	213	283	199	374	160	132	120	139	137	2364	583	856
1994	122	184	372	223	250	290	257	214	198	186	200	186	2682	595	797
1995	162	198	209	389	610	363	243	292	255	262	208	264	3455	598	1216
1996	151	301	300	266	420	366	275	294	300	248	187	182	3290	566	1061
1997	258	436	405	356	375	337	274	287	244	193	178	230	3573	761	986
1998	184	308	310	369	323	373	332	300	208	254	312	228	3501	679	1028
1999	215	317	308	408	360	346	427	209	224	168	185	191	3358	716	1133
2000	128	201	179	179	222	199	203	218	187	190	96	77	2079	358	624
2001	157	92	360	437	247	127	182	63	66	56	94	127	2008	797	556
2002	138	138	144	156	148	64	16	6	-10	11	56	106	973	300	228
2003	42	116	160	109	154	140	113	80	66	62	93	122	1257	269	407
2004	56	186	165	118	133	119	127	87	115	114	97	76	1393	283	379
2005	83	165	115	168	176	316	123	82	91	103	104	120	1646	283	615
2006	156	77	135	213	120	100	61	85	88	103	90	118	1346	348	281
2007	73	199	335	196	210	147	80	126	82	157	98	102	1805	531	437
2008	41	133	261	175	212	326	124	96	115	148	141	44	1816	436	662
2009	129	188	198	242	169	170	181	147	120	120	118	100	1882	440	520
2010	176	149	496	198	175	567	249	127	198	104	118	120	2677	694	991
2011	61	232	375	184	76	436	263	135	72	66	78	52	2030	559	775
2012	78	188	177	183	189	156	158	137	87	119	188	131	1791	360	503
2013	156	145	142	151	171	160	91	120	50	105	107	77	1475	293	422
2014	121	120	162	98	183	254	78	101	-7	8	38	148	1304	260	515
	JAN	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**TOTAL**	**MA**	**MJJ**
Average	**100**	**132**	**210**	**180**	**185**	**185**	**138**	**116**	**110**	**119**	**118**	**100**	**1693**	**390**	**508**
Median	**86**	**113**	**171**	**148**	**153**	**151**	**99**	**91**	**88**	**111**	**105**	**87**	**1452**	**310**	**427**
Max	**258**	**436**	**652**	**480**	**610**	**567**	**487**	**308**	**310**	**277**	**312**	**264**	**3573**	**873**	**1216**
Min	**38**	**42**	**79**	**55**	**3**	**-110**	**-27**	**-126**	**-39**	**-36**	**14**	**30**	**622**	**190**	**-134**
Std Dev	**41**	**57**	**102**	**85**	**89**	**100**	**85**	**68**	**63**	**51**	**44**	**43**	**608**	**167**	**236**
Skew	**1.51**	**2.18**	**1.80**	**1.59**	**1.59**	**1.19**	**1.39**	**0.64**	**0.83**	**0.31**	**1.27**	**1.54**	**1.21**	**1.37**	**0.89**

Table F-6. Sioux City historic runoff (kAF), 1949 level of development.

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL	MA	MJJ
1898	12	63	220	149	478	252	129	99	71	28	24	16	1541	369	859
1899	10	42	194	157	381	300	91	60	46	107	89	58	1535	351	772
1900	30	161	577	379	71	101	327	228	177	87	79	50	2267	956	499
1901	26	137	524	343	268	508	286	190	147	36	34	20	2519	867	1062
1902	12	56	315	208	232	77	117	75	58	103	91	60	1404	523	426
1903	32	165	631	440	210	139	339	240	180	58	42	28	2504	1071	688
1904	16	75	266	177	155	327	163	109	81	48	36	26	1479	443	645
1905	14	69	246	135	301	307	161	109	61	123	99	65	1690	381	769
1906	34	182	645	436	530	488	365	294	196	99	77	50	3396	1081	1383
1907	28	137	480	393	657	694	284	246	145	65	58	38	3225	873	1635
1908	20	105	379	252	476	629	216	149	113	125	105	69	2638	631	1321
1909	38	194	708	421	589	736	419	284	210	83	75	48	3805	1129	1744
1910	24	129	539	301	67	26	270	180	137	24	18	12	1727	840	363
1911	6	32	111	73	58	26	65	54	44	81	71	46	667	184	149
1912	24	125	430	313	192	16	260	202	139	73	61	42	1877	743	468
1913	22	113	415	268	486	206	228	165	133	42	34	22	2134	683	920
1914	12	60	222	157	242	466	127	85	65	101	85	58	1680	379	835
1915	32	159	573	438	478	462	345	238	175	83	69	46	3098	1011	1285
1916	24	125	476	311	474	343	260	186	133	46	38	24	2440	787	1077
1917	14	67	252	222	129	179	133	93	69	26	22	16	1222	474	441
1918	10	44	204	145	353	232	93	73	54	36	30	20	1294	349	678
1919	10	56	208	129	95	198	111	75	58	87	81	48	1156	337	404
1920	26	129	520	292	706	389	258	179	131	73	65	42	2810	812	1353
1921	22	115	389	244	250	40	238	165	125	16	12	8	1624	633	528
1922	4	22	91	69	99	42	54	34	24	79	99	48	665	160	195
1923	26	131	436	317	244	417	276	206	157	73	56	36	2375	753	937
1924	18	93	353	282	89	674	200	133	103	6	4	2	1957	635	963
1925	2	6	28	20	32	129	16	10	6	12	10	6	277	48	177
1926	4	18	67	42	93	71	40	26	20	48	42	28	499	109	204
1927	14	75	309	198	486	69	157	107	79	32	28	18	1572	507	712
1928	10	50	173	109	91	230	123	71	61	99	79	63	1159	282	444
1929	58	58	1224	621	484	393	192	71	48	34	34	20	3237	1845	1069
1930	14	75	93	77	171	119	32	20	20	12	18	-2	649	170	322
1931	12	16	20	20	-50	50	61	0	4	0	18	-2	149	40	61
1932	20	36	280	119	69	119	139	61	56	12	4	-2	913	399	327
1933	10	10	50	40	20	10	10	18	111	8	-38	-6	243	90	40
1934	12	22	14	18	-10	65	28	24	14	-8	14	8	201	32	83
1935	6	8	65	-10	40	-56	36	75	16	-2	26	-4	200	55	20
1936	-4	-8	371	85	65	24	67	16	54	0	-36	50	684	456	156
1937	-18	-2	137	216	153	54	131	202	30	8	38	10	959	353	338
1938	2	67	391	109	151	42	313	127	149	173	58	12	1594	500	506
1939	18	8	-6	292	-20	16	161	75	32	0	2	20	598	286	157
1940	-6	-2	44	137	-16	58	91	36	14	20	34	-48	362	181	133
1941	30	46	177	117	56	-95	153	6	34	89	97	14	724	294	114
1942	6	-18	101	79	226	180	95	87	173	36	125	16	1106	180	501
1943	36	79	-250	-101	309	71	145	184	-40	-58	10	26	411	-351	525
1944	2	111	175	204	627	69	920	430	226	145	77	-2	2984	379	1616
1945	6	85	398	306	212	530	212	95	26	16	16	24	1926	704	954
1946	-4	89	417	224	0	8	109	50	54	264	200	12	1423	641	117
1947	67	56	20	490	319	214	36	123	44	54	127	-30	1520	510	569
1948	30	97	421	589	208	200	240	171	93	135	123	58	2365	1010	648
1949	8	48	363	450	190	186	220	119	107	19	150	-11	1849	813	596
1950	-6	22	463	-89	288	497	97	108	90	85	52	-74	1533	374	882
1951	-23	59	308	770	428	611	622	278	327	160	4	34	3578	1078	1661
1952	-64	239	384	1045	630	294	357	107	89	59	43	23	3206	1429	1281
1953	17	44	328	211	368	178	-34	220	41	4	22	-20	1379	539	512
1954	21	127	253	103	116	499	137	7	-5	3	26	33	1320	356	752
1955	-11	-2	278	-30	-78	-44	-46	-77	-82	-27	-40	20	-139	248	-168
1956	31	-14	50	56	43	49	48	34	-12	8	2	1	296	106	140
1957	-34	35	63	44	42	246	186	26	6	21	28	13	676	107	474
1958	18	57	58	92	45	22	44	-16	-22	-31	19	6	292	150	111
1959	4	18	64	77	146	92	22	16	0	-20	-8	51	462	141	260
1960	5	31	194	1686	327	169	133	168	126	11	20	-7	2863	1880	629
1961	-3	8	334	94	164	175	107	118	70	41	60	-3	1165	428	446
1962	-6	41	264	1682	330	837	546	206	75	44	29	12	4060	1946	1713
1963	39	40	86	13	54	83	43	82	29	28	31	-10	518	99	180
1964	69	41	61	114	106	73	19	68	78	38	52	8	727	175	198
1965	58	42	116	501	282	334	206	56	95	120	46	91	1947	617	822
1966	31	254	280	185	167	157	66	77	73	66	48	82	1486	465	390

APPENDIX F

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL	MA	MJJ
1967	4	94	146	90	81	352	156	29	-2	-44	2	19	927	236	589
1968	-10	49	84	22	36	32	2	4	15	80	21	-97	238	106	70
1969	-4	51	118	1664	444	210	314	23	8	-21	-28	77	2856	1782	968
1970	-36	101	316	252	235	169	29	4	-18	15	37	100	1204	568	433
1971	-18	372	357	130	85	355	99	39	30	4	63	36	1552	487	539
1972	-8	33	386	154	496	398	197	120	65	20	54	16	1931	540	1091
1973	131	144	733	303	127	128	205	65	26	44	0	82	1988	1036	460
1974	51	84	109	28	25	142	37	-8	-10	-52	39	96	541	137	204
1975	3	33	38	46	122	137	25	-38	31	43	40	67	547	84	284
1976	31	162	222	152	132	95	79	59	79	26	2	-12	1027	374	306
1977	11	91	208	142	93	43	69	74	58	54	115	55	1013	350	205
1978	40	54	525	611	307	254	277	208	160	163	181	13	2793	1136	838
1979	50	57	594	691	551	394	371	412	302	231	343	258	4254	1285	1316
1980	136	164	221	186	179	194	130	177	143	162	199	71	1962	407	503
1981	112	81	63	32	27	89	48	47	23	33	65	96	716	95	164
1982	-4	149	280	182	227	217	188	88	95	266	402	393	2483	462	632
1983	295	283	981	903	477	633	660	260	174	171	172	-17	4992	1884	1770
1984	144	190	431	1706	950	1997	879	393	232	378	248	123	7671	2137	3826
1985	76	75	609	611	353	250	119	113	213	168	85	121	2793	1220	722
1986	116	23	696	1255	1127	580	291	216	603	481	254	196	5838	1951	1998
1987	110	86	411	603	230	127	154	80	56	35	10	122	2024	1014	511
1988	64	129	206	114	118	67	54	23	60	-9	61	27	914	320	239
1989	94	15	185	151	72	33	55	35	37	13	33	-17	706	336	160
1990	8	51	61	23	109	194	115	64	38	33	53	-72	677	84	418
1991	6	8	38	66	132	285	103	67	63	21	47	65	901	104	520
1992	99	165	258	146	125	138	304	293	270	270	195	126	2389	404	567
1993	97	73	569	1129	937	1110	2524	853	473	312	239	170	8486	1698	4571
1994	157	381	930	588	527	598	336	214	142	82	97	90	4142	1518	1461
1995	89	178	329	1184	1775	1196	517	495	249	464	369	149	6994	1513	3488
1996	90	273	304	462	506	904	540	298	214	153	221	177	4142	766	1950
1997	166	134	783	2376	1235	649	360	324	165	184	155	116	6647	3159	2244
1998	198	121	186	584	347	349	208	144	61	123	351	328	3000	770	904
1999	134	178	359	638	589	747	658	221	209	170	117	174	4194	997	1994
2000	199	98	145	183	340	220	131	91	97	76	120	68	1768	328	691
2001	83	115	436	2060	1242	690	464	267	201	154	189	152	6053	2496	2396
2002	120	170	252	344	343	177	121	198	154	110	20	43	2052	596	641
2003	78	136	205	170	257	258	237	47	104	35	78	111	1716	375	752
2004	53	145	371	191	341	503	210	134	175	130	101	124	2478	562	1054
2005	178	112	144	265	367	712	288	213	211	255	205	310	3260	409	1367
2006	195	289	252	771	485	297	130	142	163	105	112	152	3093	1023	912
2007	148	212	932	649	937	513	267	224	127	269	142	187	4607	1581	1717
2008	208	247	449	418	521	972	386	189	125	202	113	135	3965	867	1879
2009	237	165	425	539	677	493	560	245	105	78	76	52	3652	964	1730
2010	262	188	1675	1211	738	1580	1460	1272	831	830	295	215	10557	2886	3778
2011	310	571	1224	2104	1642	1159	1389	631	297	318	323	282	10250	3328	4190
2012	236	187	333	236	627	301	98	78	-3	-17	-27	50	2099	569	1026
2013	49	120	211	243	453	528	333	241	159	171	107	127	2742	454	1314
2014	130	75	204	218	212	1213	496	287	270	112	150	123	3490	422	1921
	JAN	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**TOTAL**	**MA**	**MJJ**
Average	**51**	**101**	**325**	**384**	**322**	**325**	**246**	**149**	**109**	**89**	**81**	**58**	**2240**	**709**	**892**
Median	**24**	**79**	**278**	**216**	**232**	**214**	**157**	**108**	**79**	**54**	**56**	**38**	**1727**	**500**	**641**
Max	**310**	**571**	**1675**	**2376**	**1775**	**1997**	**2524**	**1272**	**831**	**830**	**402**	**393**	**10557**	**3328**	**4571**
Min	**-64**	**-18**	**-250**	**-101**	**-78**	**-95**	**-46**	**-77**	**-82**	**-58**	**-40**	**-97**	**-139**	**-351**	**-168**
Std Dev	**72**	**89**	**276**	**474**	**322**	**341**	**318**	**168**	**119**	**120**	**88**	**79**	**1947**	**659**	**862**
Skew	**1.63**	**1.99**	**1.81**	**2.28**	**2.03**	**2.05**	**4.27**	**3.52**	**2.86**	**2.92**	**1.64**	**1.67**	**2.01**	**1.77**	**2.12**