Investigation of Methods for Obtaining Regionally Consistent Flood Distributions
Upper Mississippi Flood Frequency Study

by

Hydrologic Engineering Center
Davis, California

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Executive Summary

Background

- This report describes another phase in the analysis of the flood frequency distributions for the Upper Mississippi, Missouri and Illinois Rivers. An evaluation of a number of different flood frequency distribution estimation techniques was made in a previous phase of the study (HEC, 2000). Based on this evaluation, the technical and interagency advisory groups (TAG and IAG) recommended adopting the basic flood frequency estimation methodology described in the federal guidelines, Bulletin 17B (IACWD, 1982) for estimating flood frequency curves (see HEC, 2000).
- These guidelines recommend using the log-Pearson III (LPIII) distribution to represent the flood frequency distribution. This distribution is estimated by combining at-site (gage) and regional information on flood statistics. At-site information obtained is the mean, standard deviation and skew of the logarithm of the annual flow series. In the Bulletin 17B guidelines, regional skew information is weighted with the at-site skew value to obtain an adopted skew. The TAG and IAG recommended using regional shape estimation to obtain the adopted skew rather than using the weighted skew value. The LPIII distribution is estimated from the at-site mean and standard deviation, and the regional skew using the method of moments

Purpose

- The purpose of this study is to investigate various approaches for obtaining regionally consistent flood distribution estimates and methods for obtaining estimates at locations between gages in the study area. The investigation will then be provided to the TAG and IAG for review and final recommendations on a regionalization strategy.

Methods

- The TAG and IAG recommended that the flood frequency distributions at locations between gages be estimated by combining the regional skew estimate with mean and standard deviation values obtained by linear interpolation with drainage area or river mile.
- The Corps districts involved in the study had a different perspective on how regionally consistent flood frequency distributions should be obtained. They preferred obtaining a regular variation of estimated flood quantiles (e.g., the 1% chance flow) by using regression between drainage area or river mile and the at-site estimates of the flood quantiles.
- The approach taken to obtain regional consistency is to identify boundaries defining regionally consistent flood regimes and apply statistical techniques to obtain a regular variation in flood distribution characteristics within these boundaries. The TAG/IAG and Corps approaches would be applied within these boundaries.

Data Base

- The cultivation of the study area was essentially complete by the beginning of the 20th century. Furthermore, a great deal of levee construction and channelization had occurred by this time. The overall impact on major floods due to these human activities is difficult to discern. However, a study of the change in flood characteristics from the reach of the Missouri River, which has its near-natural storage characteristics (Yankton to Omaha), to the reach below Omaha shows that this impact must be significant. For this reason, the period of record chosen for the study begins when the period of settlement was almost complete, or about 1898. Gage records exist since that year that allowed the district to develop unregulated flow values for any regulation, diversion or channel modifications that occurred since this date. (see Table 1).

- A major effort was mounted by the Corps Districts to estimate unregulated flow values for the flood frequency analysis. The unregulated flow values were obtained from either gage observations or from model applications.
- Unsteady flow modeling performed by St. Paul indicated that the degree of regulation and channel modifications did not significantly influence observed floods from St. Paul to Clinton. Rock Island district performed flood routing studies to determine the influence of tributary regulation between Clinton and Grafton. Regulation did not significantly influence the observed floods during the period of record on the Illinois River at Marseilles or at Kingston Mines.

- Omaha and Kansas City districts performed a number of difficult and involved modeling studies to account for the regulation and diversions on tributaries to the Missouri River. The unregulated Missouri River unregulated flows were obtained by routing model applications with the tributary flows.

- St. Louis District used the estimated unregulated inflows from the upstream reaches together with model estimated local flows from Grafton to St. Louis (Mississippi River) and Hermann to St. Louis (Missouri River) in an unsteady flow model to route unregulated flows to Thebes (Mississippi River).

Table1: Upper Mississippi Period of Record

Location	DA (sq mi)	*Analysis period	Systematic record	Historic dates
Yankton, Missouri River	279500	1898-1997	-------	-------
Sioux City, Missouri River	314580	1898-1997	-------	-------
Decatur, Missouri River	316200	1898-1997	-------	-------
Omaha, Missouri River	322800	1898-1997	-------	-------
Nebraska City, Missouri River	410000	1898-1997	-------	-------
Rulo, Missouri River	414900	1898-1997	-------	-------
St Joseph, Missouri River	420300	1898-1997	-------	-------
Kansas City, Missouri River	485200	1898-1997	-------	-------
Waverly, Missouri River	487200	1898-1997	-------	-------
Booneville, Missouri River	505690	1898-1997	-------	-------
Hermann, Missouri River	528120	1898-1997	-------	-------
St Paul, Mississippi River	36800	1898-1998	1867-1998	-------
Winona, Mississippi River	59200	1898-1998	1878-1998	-------
Dubuque, Mississippi River	82000	1898-1998	1874-1998	1828
Clinton, Mississippi River	85600	1898-1998	1874-1998	1851
Keokuk, Mississippi River	119000	1898-1998	1878-1998	
Hannibal, Mississippi River	137000	1898-1997	1879-1998	
Louisiana, Mississippi River	141000	1898-1997	-------	
Grafton, Mississippi River	171300	1898-1997	-------	
St Louis, Mississippi River	697000	1898-1997	1861-1998	1785,1844
Chester, Mississippi River	708600	1898-1997	-------	
Thebes, Mississippi River	713200	1898-1997	-------	
Marseilles, Illinois River	8259	1920-1998	-------	
Kingston Mines, Illinois River	15819	1941-1998	-------	
Meredosia, Illinois River	26028	1898-1997	-------	

Peak annual flows used for St. Paul and Winona, maximum annual daily flows for all other gages

- A sensitivity analysis was performed to ascertain the impact of historic information on the flood frequency estimates. The analysis showed that the addition of historic information only made a few percent difference in the 1% flood at most gages where historic information was available. The exception to this was at St. Louis where the difference was about 6% if historic information circa 1750 is used. Given the lack of relevance of the available historic information to present land use and channel conditions, and, the small sensitivity of flood frequency distribution estimates to this information, data prior to 1898 was not used in the estimation of flood quantiles.

Determining flood region boundaries

- The TAG recommended determining regions for obtaining regional skew (the regional shape parameter) by performing statistical analyses: examining the relationship between the coefficient of variation and drainage area, computing discordancy and heterogeneity of gage statistics.

- The characteristics of the existing river channel, and the relationship between climate and flood regime were investigated to provide additional information useful in defining flood regions. The definition of boundaries for obtaining regional shape recommended by the TAG is statistical; whereas using climate considers the natural processes which influence the variation of flood distribution characteristics.

- The statistical analysis used to examine the regional variation in annual flood statistics did not provide a completely conclusive argument for defining regions for the whole study area. Particular difficulty was determining the region for the St. Paul and Winona gages on the Mississippi and the Illinois River gages. These gages have drainage areas in the 10000-30000 square mile range, which seems to be in somewhat of a transition zone of statistics between information available for gages draining about a 1000 square miles and the very large drainage area gages on the Missouri and Mississippi mainstem. A plot of log-standard deviation or coefficient of variation versus drainage area indicates that these gages may have different flood characteristics than the mainstem gages (see figure 1). Discordancy and heterogeneity statistics indicate that St. Paul and Winona probably belong in a separate flood region; whereas, the Illinois River gages probably can be grouped with the Mississippi gages. Consequently, the statistical analysis argued for the following regions:

    - ▪ Mississippi River: Dubuque to Thebes, and the Illinois river
    - ▪ The Missouri River: Yankton to Hermann
    - ▪ St. Paul and Winona on the Mississippi river may belong in a separate region or might be considered part of the Mississippi River

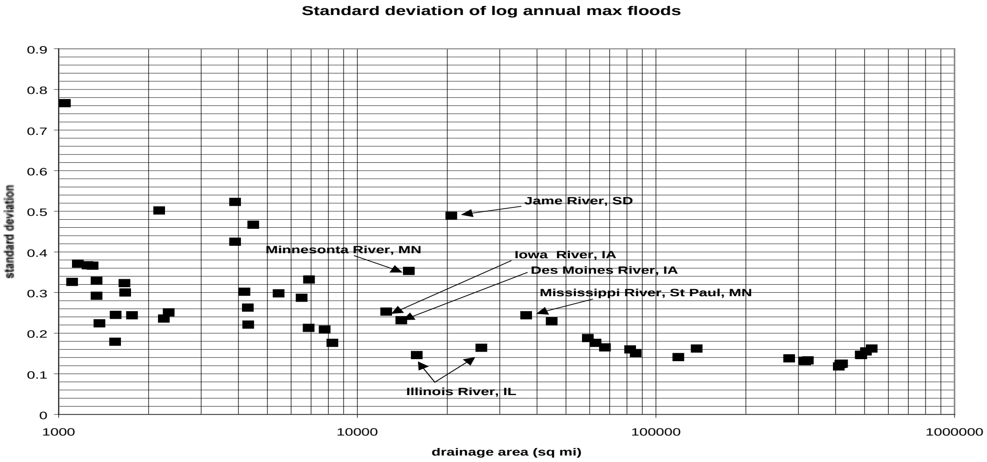

Figure 1: Standard deviation of logarithms versus drainage area

- The investigation of channel characteristics revealed a likely flood boundary at Omaha on the Missouri River that was not identified in the statistical analysis. As in most of the study area, channelization for navigation and levee construction has altered the flood-plain storage characteristics of the river. However, no major levee systems exist above Omaha and the navigation channel only extends to a few miles upstream of Sioux City. Presumably, the observed attenuation in most flood peaks and the decrease in annual mean maximum daily flow from Yankton to Omaha is due to the near-natural storage condition in this river reach. Consequently, the reach from Yankton to Omaha should probably be considered as a separate region on the Missouri.

- Comparison of climate norms and historical floods resulted in a tentative location of boundaries between snowmelt dominated and rainfall dominated floods. A clear boundary was identified at the confluence of the Kansas and Missouri Rivers. A boundary on the Mississippi River was less clear, but a transition certainly occurs between Winona and Keokuk..

- An analysis of mixed distributions was undertaken to better identify transition regions between the snowmelt and rainfall dominated flood region. Possibly, the mixed distribution analysis would indicate the importance of both rainfall and snowmelt flood contributions to the annual flood distributions (see figure 2)

    - Omaha district has identified mixed distributions as being important to the estimation of the annual flood distributions upstream of Kansas City.

    - Mixed distribution analysis was not useful in identifying boundaries on the Mississippi River.

    - The 1993 flood is an extremely difficult event to account for in a standard analysis. This event resulted from an unprecedented late winter, spring and summer distribution of rainfall, resulting in a summer peak. The ranking of the event was consistent in that it was top ranked in the regions where climate norms indicate rainfall should dominate.

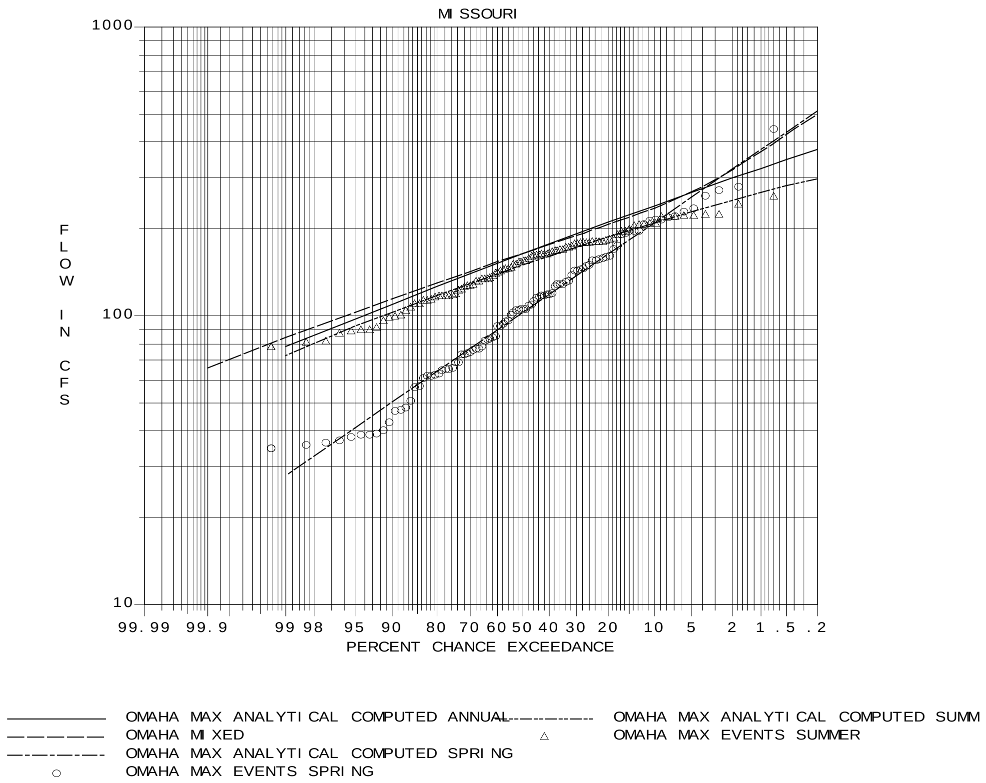

Figure 2: Comparison of annual and mixed distributions at Omaha

- The analysis of channel characteristics, climate and mixed distributions provided additional information for separating the Missouri River into the following flood regions:
    - Yankton to Omaha
    - Omaha to St. Joseph
    - Kansas City to Hermann

- The annual or seasonal LPIII distributions used in developing the TAG/IAG regional shape or Corps regression regional flood quantile estimates were based on the statistics shown in Tables 2-5.

Table 2: Comparison of annual and seasonal statistics of log-flows for Omaha District Gages (mainstem Missouri River), maximum annual daily flows

location	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Yankton	279500	5.187	0.137	0.055	4.985	0.256	-0.003	5.147	0.123	-0.416
Sioux City	314580	5.202	0.132	-0.024	5.004	0.249	-0.085	5.161	0.119	-0.475
Decatur	316200	5.2	0.131	-0.058	4.999	0.246	-0.067	5.16	0.119	-0.472
Omaha	322800	5.214	0.133	-0.066	5.014	0.243	-0.046	5.174	0.121	-0.345
Nebraska City	410000	5.302	0.118	-0.047	5.065	0.221	0.008	5.28	0.111	-0.183
Rulo	414900	5.308	0.124	-0.062	5.06	0.223	0.096	5.287	0.117	-0.1
St Joseph	420300	5.328	0.125	0.047	5.078	0.225	0.126	5.307	0.121	0.013
average				-.022			0.004			-0.283

(1) Drainage area (square miles)
(2) Mean of annual max 1-day log-flows (annual)
(3) Standard deviation of annual max 1-day log-flows (annual)
(4) Skew of annual max 1-day log-flows (annual)
(5) Mean of annual max 1-day log-flows (January-April)
(6) Standard deviation of annual max 1-day log-flows (January-April)
(7) Skew of annual max 1-day log-flows (January-April)
(8) Mean of annual max 1-day log-flows (May-December)
(9) Standard deviation of annual max 1-day log-flows (May-December)
(10) Skew of annual max 1-day log-flows (May-December)

Table 3: Statistics of log flows, Kansas City District Gages (mainstem Missouri river gages)

Location	Area	Mean	Std deviation	skew
Kansas City	485200	5.399	0.145	0.278
Waverly	487200	5.403	0.144	0.337
Booneville	501200	5.444	0.156	0.162
Hermann	524200	5.522	0.166	0.047

Table 4: Statistics of log-flows, Mississippi River

[1]location	area (sq mi)	mean	std dev	skew
St Paul	36800	4.581	0.261	-0.269
Winona	59200	4.942	0.193	-0.079
Dubuque	82000	5.100	0.153	-0.065
Clinton	85600	5.114	0.146	-0.149
Keokuk	119000	5.249	0.142	-0.083
Hannibal	137000	5.322	0.158	-0.183
Louisiana	141000	5.333	0.150	-0.017
Grafton	171300	5.418	0.131	-0.072
St Louis	697000	5.725	0.135	0.030
Chester	708600	5.740	0.136	-0.071
Thebes	713200	5.741	0.135	-0.062
average				-0.1[2]

[1] Statistics based on peak annual flows for St. Paul and Winona, annual maximum daily flows otherwise

[2] St. Paul gage not included in average skew

Table 5: Illinois River log statistics of annual maximum daily flow values

location	area (sq mi)	mean	std dev	skew
Illinois River , Marseilles	8259	4.643	0.176	-0.29
Illinois River, Kingston Mines	15819	4.672	0.146	-0.2
Illinois River, Meredosia	26028	4.763	0.164	-0.07

- The recommended final distributions estimates are shown in Table 6. In viewing the results, note that mixed distribution analysis was used to estimate the flood quantiles from Yankton to St. Joseph. The regression with drainage area estimates of quantiles was somewhat insensitive to the type of regression chosen (linear log-linear or second-degree polynomial).

Table 6: Recommended 1% quantile estimates

Location	area	1% at-site	[1]1% shape	%diff	[2]1% regression	%diff
Yankton	279500	380200	372500	-2.03	380200	
Sioux City	314580	369500	375000	1.49	369500	
Decatur	316200	362300	364900	0.72	362300	
Omaha	322800	372500	371900	-0.16	372500	
Nebraska	410000	389400	400600	2.88	386100	-0.26
Rulo	414900	409400	408200	-0.29	417000	0.79
St. Joseph	420300	445000	433600	-2.56	440700	-0.52
Kansas City	485200	584900	572200	-2.17	563000	-3.25
Waverly	487200	589000	576500	-2.12	604400	1.89
Booneville	501200	675500	677700	0.33	697800	3.27
Hermann	524200	809700	859200	6.11	793900	-1.99
St Paul	36800	134900	147400	9.27	140800	4.34
Winona	59200	237700	237700	0	213100	-10.33
Dubuque	82000	281900	279400	-0.89	283200	0.46
Clinton	85600	274300	277500	1.17	294100	7.22
Keokuk	119000	371700	370200	-0.4	392000	5.48
Hannibal	137000	465300	475900	2.28	443300	-4.73
Louisiana	141000	478200	468200	-2.09	454600	-4.94
Grafton	171300	518700	515600	-0.6	538700	3.87
St Louis	697000	1104800	1072300	-2.94	1104800	
Chester	708600	1117200	1109800	-0.66	1117200	
Thebes	713200	1120800	1111000	-0.87	1120800	
Marseilles	8260	103000	109600	6.41	103000	
Kingston Mines	15820	98000	100400	2.45	98000	
Meredosia	26030	137000	135800	-0.88	137000	

[1] Regional shape estimation, flood frequency distribution estimated using at-site mean and standard deviation, regional skew substituted for at-site skew

[2] At-site estimates used where %difference not shown

- Additional consideration needs to be given to estimating flood quantiles between Hermann and St. Louis and Grafton and St. Louis given the complications due to the confluence of the Missouri and Mississippi Rivers.

- The following decisions were made to obtain the final estimates;

  - General

1) The period of record that best represents the current land use begins in 1898, giving a period of record of 100 years for the gages in the study, except on the Illinois River;
2) Regions for obtaining regular variation of flood quantiles were defined based on examination of channel characteristics, climatology and regional variation of flood statistics;
3) Drainage area will be used to interpolate distribution statistics or quantiles between gages;
4) A mixed population analysis was used to estimate the flood distributions from Yankton to St. Joseph;

  - Regional Shape

5) Missouri River is divided into three regions, Yankton to Omaha, Nebraska City to St. Joseph, and Kansas City to Hermann;
6) The Mississippi River is considered to be one region from St. Paul to Thebes;
7) The Illinois River gages are considered to be part of the Mississippi River Region.

  - Regression of quantile with drainage area

8) The Missouri River is divided into the same regions as in regional shape estimation;
9) At-site estimates are used for gages between Yankton and Omaha;

10) Separate linear regressions were used to obtain regular variation of quantiles between Nebraska City and St. Joseph, Kansas City and Hermann;
11) A single regression with drainage area relationship was used to obtain a regular variation of quantiles between St. Paul and Grafton;
12) Linear interpolation with drainage area will be used to estimate flows between gages on the Missouri River between St. Louis and Thebes.

Concerns

- The following is among the concerns that need to be considered in evaluating the flood distribution estimates:

13) An annual analysis instead of a mixed population analysis might be used for the Yankton to St. Joseph gages on the Missouri River;
14) The decrease in peak annual floods between Yankton and Omaha might be an artifact of sampling error and not due to the available channel storage;
15) St. Paul and Winona do not belong in the Mississippi River region, instead of a regional skew of –0.1, the skew should be somewhat smaller, possibly –0.2;
16) The Illinois River gages do not belong in the Mississippi River region, particularly Marseilles and Kingston Mines, regional skew should be –0.2 rather than –0.1

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1 Introduction

An investigation of flood frequency distribution estimation methods (see HEC, 1999) resulted in a recommendation by the technical and interagency advisory groups (TAG and IAG) to use the basic methodology described in Bulletin 17B (IACWD, 1982) for obtaining at-site estimates of flood distributions for the Upper Mississippi Basin Flood Frequency Study. The Bulletin recommends estimating flood quantiles (e.g., the 1% chance annual peak flow) using the log-Pearson III distribution with method of moment estimation. The TAG and IAG also recommended the use of regional shape estimation to obtain regionally consistent flood quantile estimates. Regional shape estimation involves estimating average skew values for statistically homogenous regions and substituting this average value for the at-site value when estimating the flood-frequency distribution (i.e., the log-Pearson III).

An alternative approach suggested by the Corps Districts participating in the study is to estimate a regression relationship between at-site flood quantile estimates and either drainage area or river mile. As in the case of regional shape estimation, regions would have to be identified to obtain useful regression relationships.

Identifying the region can be difficult because important regional differences may be obscured by the sampling error prevalent in flood statistics. Ideally, a region or flood region is defined by the confluence of major rivers (e.g., Kansas and Missouri, Illinois and Mississippi, Mississippi and Missouri), change in climatology or some other feature that is manifested in the observed flow series.

The purpose of this report is to compare various approaches for locating flood regime boundaries and regionalizing flood frequency distribution estimates within these boundaries. The approaches investigated will be based on suggestions from the Technical Advisory Group and the Corps Districts participating in the study.

Identification of flood regimes and boundaries for regionalizing flood statistics will be based on: 1) the characteristics of the mainstem river channel; 2) the statistical characteristics of the flood record; and 3) the climatology of the region. The mainstem channel characteristics have an important influence on the variation of flood peak along the Missouri River. A potential regional boundary occurs where the most upstream major levee system was constructed at Omaha. The reach of river above this location (from Gavins Point Dam to Omaha) has channel cross-section characteristics approximating the natural condition which provides considerable storage for floods. The natural attenuation of flood peaks observed in this reach is not observed in the downstream channel which has been modified with dikes, levees and dredging for navigation and flood protection.

A statistically based approach proposed was proposed by the Technical Advisory Group (TAG) to obtain regional boundaries (see Hydrologic Engineering Center, 2000). Once regions with statistically similar flood characteristics are defined, a regional skew coefficient (a regional shape parameter) is obtained as an average of the at-site gage estimates within the region. The flood frequency distribution is computed from the at-site mean and standard deviation combined with the regional skew coefficient used as the adopted skew coefficient. Flood distributions in between gages are obtained by a linear interpolation of the mean flow and the standard deviation with either drainage area or river mile.

Hydrologic and climate characteristics of the study region can also be used to obtain boundaries for obtaining regional skew or consistent estimates of flood quantiles. A problem with identifying these boundaries is discerning the difference between an actual change in regime and the variability in sample flood distribution properties due to statistical sampling error or even measurement error. Initially, the approach taken to determining these boundaries was to examine the influence of flood coincidence on the annual peak floods. Attempts at this, (e.g., Illinois and Mississippi Rivers) were inconclusive. A portion of the time, coincidence does occur and has some noticeable influence on the peak flows. However, translating this to an effective means of estimating flood distributions using a coincident frequency analysis is not likely to be fruitful (e.g., comments of Dr. Kenneth Potter, TAG committee member, HEC, 2000). Establishing the distribution of floods by this method requires a reliable estimate of the conditional distribution of tributary flows given a major flood on the mainstem. The sample of data available for this purpose is insufficient.

As an alternative, the influence of climate on flood distributions can be used to define boundaries for regionalizing flood frequency distributions. Discussions provided by Olsen and Stakhiv (1999)) and Clemetson (1998) describes the important relationship between climate and flooding on the Upper Mississippi and Missouri Rivers.

Consequently, the approach taken is to attempt to identify boundaries based on channel characteristics, statistical variation of flood characteristics, and climate across the study area. Flood distribution estimates will be obtained for these regions using both Corps and TAG recommended techniques

Section 2 provides: 1) a brief history of the human settlement of the study area and the corresponding land and channelization projects brought about by this settlement; 2) the gage period of record relevant to present day conditions given this history; 3) the methods used to adjust the gage data for the effects of regulation and channel modification; and finally, 4) the sensitivity of flood frequency distribution estimates to the length of the period of record and historic information employed.

The regional variation of flood statistics and climate is described in section 3. Some potential boundaries for regionalizing flood statistics are identified from this analysis. The analysis of climate pointed to the seasonal variation of flood potential and the need to consider a mixed population analysis for estimating flood distributions, particularly on the Missouri River above Kansas City. Section 4 describes the application of statistical tests and mixed population analysis to identify boundaries for regionalizing flood statistics and obtaining estimates of flood frequency distributions. Finally, section 5 compares estimates of flood frequency distributions obtained by methods preferred by the TAG and the Corps districts for the identified regional boundaries.

2 Background

2.1 Introduction

The compilation of the flood record used for estimating the flood frequency distributions involved an extensive effort to develop a homogenous record unaffected by the influence of reservoir regulation and channel modifications. Developing these records required some difficult decisions with regard to the selection of the period of record to employ and the modeling techniques needed to account for the impacts of the regulation.

Selection of the period of record considered the potential influence of human settlement, agricultural development and channel modification for navigation, on the flood record. Section 2.2 provides a brief history of the impacts of human settlement on the study area. This history provides the base information used to select the period of record selected for the flood frequency analysis. The methods used and decisions made to obtain the unregulated flows for the selected period of record are briefly described in section 2.3. The period of record selected begins in 1898. Historic information or systematic records prior to 1898 were not used in estimating flood frequency distributions because the changes in land use and channel characteristics prior to this date made this data either not relevant to present day conditions; or, the information available made the flood estimates unreliable. Section 2.4 describes the sensitivity of flood frequency estimates to historic flood information to provide a perspective on the importance of this information.

2.2 Impact of settlement on flood characteristics in the Upper Mississippi Basin

2.2.1 Introduction

Human settlement has caused a significant change in the flood characteristics of the Upper Mississippi Basin. The changes have occurred due to the replacement of the natural forest and prairie by agricultural fields, the removal of the natural river meanders, braids and wetland storage by creating channels for navigation, and the introduction of dams and levees for flood control purposes. One perspective on the impact of this change on the Missouri River is expressed by Belt (1980) (see also Schneider (1999) pg. 244):

> *This [navigation] project ….. has greatly reduced the channel and given the river less space to spread out in times of high flow. ….. A water volume of 618,000 cubic feet per second raised the river at Hermann [Missouri] to a gauge height of 33.3 feet in July 1951 at the peak of flooding there ….. a volume of only about 500,000 cubic feet per second produced a higher gauge reading of 33.7 feet in an April 1973 flood.*

This observation only represents one aspect of the change in flood characteristics. Other factors, such as the influence of cultivation are more difficult to quantify.

The changes brought about by human settlement have been astounding not only because of the impact on the hydrology of the study areas (and more importantly on the ecosystem as a whole); but also because of the pace of the change. Settlement of the Upper Mississippi Basin began in earnest in the mid 19th century. The conversion of prairie's and forest, the channelization of hundreds of miles of river, and the construction of some of the largest dams in the world have occurred in a little more than 100-years. Part of this rapid change has been due to an evolution in technology; where fields that were plowed using horse and mule are now cultivated by tractors; and where the revetments used to stabilize channels were constructed of hand made mats of willow and hand placed stone are now constructed using dredges and tows. Those trappers, traders and explorers who were astounded by the first view of the valley from the rivers' bluffs in the late 18th century would certainly be astounded by the change in the same view today.

The purpose of this section is to provide a description and chronology of the changes that have occurred in the study basin. Establishing this chronology is important for selecting the period of streamflow record that can be used to estimate the unregulated flow frequency curves.

Section 2.2.2 provides a description of the changes in land use that have occurred since the study area has been settled. The primary means of support for the new settlers was agriculture. Better transportation systems were needed to move products as more land was cultivated and agriculture became more productive. River transport for these products was established by undertaking a massive channelization project to produce a navigable river. In concert with this effort, reservoirs were constructed to help provide more regular flows for transport (at least on the Missouri River) and, together with levees, to reduce flood risk for the population settling on the flood plain. Section 2.2.3 provides a description of the navigation and flood control system constructed in the study area.

2.2.2 **Land use change**

The land use of the study area has change dramatically from prairie and timber cover to agriculture as settlement from the eastern United States has occurred (see Table 2.1). This change is well documented by the MBIC (1969) and Schneiders (1999). Prior to the migration from the east, the area was populated by Native Americans who lived by hunting an subsistence farming. These activities probably did little to change watershed hydrology, although it is possible that fire was employed to preserve grasslands (see Nelson, et al., 1999).

The settlement of the study area, and the eventual eradication of the Native American culture, began in the early 1800's by government sponsored exploration, the development of a trapper/trading economy and the cultivation of river bottomlands. The initial and probably most well known early exploration was by Lewis and Clark (1804-1806). During this exploration period, the economy of the study area was dominated by the fur trade. The products of the fur trade were transported along the river by steamboats. River bottomland was also cultivated during this period, although it did not have great economic impact. The cultivation of these areas was not likely to influence the watershed hydrology, and the flood characteristics of the mainstem river.

Significant land use change began during the period of settlement during the latter part of the 19th century. The settlement was spurred by a number of factors: lack of opportunity elsewhere, government programs and the end of the Civil War. The western portion of the study area, particularly the Missouri River Basin, was passed over by earlier western settlement partly due to the discovery of gold further west in Colorado and California, and partly due to the harshness of the conditions in the western prairies. Once these western opportunities disappeared, the only land left for settlement was the western prairies. Settlement here was encouraged by the government providing land at nominal prices through legislation such as the Homestead Act (1862). This provided land for a population of men who had been previously engaged in the Civil War.

Agricultural development of the Missouri River Basin was stymied by both lack of water and the need to use plough animals in cultivation. Various government reclamation acts were instituted to aid in bringing more land under cultivation in the 20th century. Even more government sponsored water resource projects were built to provide employment as well as economic benefits during the great depression of the 1930's. These projects engendered a viable agricultural economy during the first half of the 20th century in the Missouri River Basin.

Technological innovation (e.g., replacement of the plough horse by the tractor) resulted in greater production with less land under cultivation (see MBIC, 1999). Rural population decreased during this time as urban centers grew.

The land use change during this time had a significant impact on flood hydrology. Cultivation changed the watershed storage and roughness characteristics that influence the volume and timing of land surface runoff contributions to great floods.

Table 2.1: Chronology of settlement and agricultural development

Activity	Date	Description
Hunting/gathering	Prior 1870	Hunting and subsistence farming by Native Americans
Exploration	1800-1870	Exploration funded by Government (e.g., Lewis and Clark), economy based on trapping and trading, river transport of goods by steamboat, some agricultural development in river valleys
Settlement	1850-1900	Migration of eastern U.S. population to develop land for agriculture in river uplands (prairies and forests), end of Civil War freed a significant population to look for more opportunity, encouraged by government programs (Homestead Act), and more desirable locations had already been settled
Agricultural economy	1900-1940	Irrigation projects spurred by government reclamation acts spurred more cultivation, government public work activities to create work during 1930's depression resulted in large water resource projects beneficial to agriculture
Agricultural industry	1940-present	Technology allows more production with less cultivated acres and labor, rural population decreases and urban areas grow

2.2.3 **Channel modification on the Missouri River**

A description of the history of the development on the navigation on the Missouri River is useful because it provides a glimpse at the chronology and impact of channelization and regulation on this river and parallels that of the Mississippi River. The history of the development of flood control and navigation measures for the Missouri River is described in detail by Schneiders (1999). This section provides a brief summary of the information provided in this reference.

The construction of a navigation channel and mainstem storage has been due to both the efforts of those living in the basin and the efforts of the federal government to improve or enhance the regional economy during the great depression of the 1930's. The Corps of Engineers was not entirely convinced that the cost of modifying the river channel was economically justifiable despite the local desire for these improvements. Furthermore, Congress was not sympathetic to using federal funds to help with public works project in the 1800's. However, this attitude changed as the public saw a need for the government to provide disaster relief and steward the economy through difficult times.

The efforts of the local population to improve navigation in the mid 1800's (see chronology displayed in Table 2.2) was spurred by the expensive rail costs for transporting agricultural goods. The locals perceived river navigation as a means for reducing costs by providing an alternative to the railroad monopoly of transportation. Snags, sand bars, unreliable flow levels, etc. made the river in its natural state barely usable for transportation. The cost of modifying the river could not be born by the locals alone; and, consequently the locals appealed to congress for aid.

The proposals for modifying the river during the history of development focused mostly on constructing a six foot deep navigation channel from Sioux city to the mouth. Constructing the six foot channel was only considered a first step because the Mississippi navigation channel was being constructed to a 9 foot depth. The locals knew a nine foot channel for the Missouri would eventually be necessary to create a significant amount of river traffic.

The navigation channel construction proceeded sporadically prior to the great depression of the 1930's. Both congressional and Corps institutional opposition, as well as World War I detracted from any committed effort to finish the channel. However, the opposition to the channel, as well as many other public works project, dissipated when the federal government's goal was to put people back to work during the great depression. The public works programs involved the construction of many large water resource projects, including Fort Peck Dam (see Table 2.3).

The project building initiated by the public works program for the river was given more momentum by the great flood of 1943. Congress in 1944 legislated the construction of five more mainstem dams in response to these floods. The dams provided not only flood control; but also, the consistent river flow volumes necessary for a 9 foot navigation channel. Subsequently, Congress authorized the construction of this channel in 1945.

The construction of the navigation canals involved placing revetments (channel bank stabilization) and dikes to stabilize and deepen the river channel. Prior to the construction of the mainstem dams and the advent of more modern dredge technology, the dikes were constructed by extending groups of wooden piles from the shoreline perpendicular to the flow. The dikes were staggered in rows and sometimes willow mats were strung between the piles. The dikes induced sedimentation immediately downstream by reducing the river velocities, effectively creating a new river bank geometry. The new shoreline results in a constricted channel, with high velocities that scoured out the main channel to sufficient depth for navigation.

The revetments were put in place to stabilize the river geometry for navigation purposes. The river in its natural state meanders significantly while dropping its sediment load and forms ox-bow lakes. The revetments were used to prevent this meandering from the desired navigation channel. Construction of the revetments was tedious. Willow mats were hand sewn and placed on the bank. Then, rock was manually place on top of the mat to stabilize the bank.

The methods used to construct the navigation channel changed partly because of the reduction in sediment load due to the presence of the mainstem dams and partly to reduce construction costs. The sediment load reduction made it infeasible to create a new bank line with pile dikes. Instead, the new channel was created by partially excavating a channel and the placing crushed rock along its edge. As with past techniques, this created a deeper navigation channel from the enhanced velocities caused by the excavation and rock fill. The revetment requires minimal maintenance because the rock tends to fill in any pocket caused by toe scour. Alternatively, pile dikes were place as before, except now rock is placed in between the staggered dikes to stabilize the channel. These techniques are far less expensive to employ than those used in the past and lead to a more stable channel than those used prior to the construction of the mainstem dams.

Construction of pilot canals was an approach not used previous to dam construction to improve the navigability of the river. These canals were constructed by creating a partial channel to cut off a river bend, effectively straightening the channel. The constricted channel creates larger flow velocities which scour out a wider channel for navigation.

The construction of the dams and the navigation channel had a significant influence on the flood characteristics of the river. The reduction in sediment load due to reservoir construction and reduction in flood plain storage has had some unexpected consequences. Certainly, the risk of floods from the watershed above Gavins Point Dam has been reduced. The flood situation due to tributary inflow below the dam has increased from the loss of flood plain storage, increase in river slope and constricted navigation channel. Below the reservoirs, the lack of sediment has produced a degradation of the river bottom, increasing the slope of both the mainstem and tributary rivers draining to the river (tributary rivers down cut their channel to meet the Missouri).

This concentrates the flood waters in a shorter time. The loss of flood plain storage has reduced the river systems natural ability to reduce peak flows. These factors which tend to increase the flood peaks together with the human encroachment on the flood plain has made for a more severe flood condition. Schneiders (1999, pg. 244) provides an example of the effect of these changes:

> *Confinement of the Missouri between pile dikes and revetments lowered the stream's ability to transport high flows; consequently it took less water for the Missouri to overtop its banks. In the 1920s, before channelization work at Waverly, Missouri, the river carried 150,000 cfs without flooding. But after completion of the navigation project through central Missouri, the river flooded at Waverly in 1931, 1935, 1941 1942, 1943, 1944, 1945, 1947, 1948, 1949, 1950, 1951, and 1952 at 150,000 cfs. ….*

Consequently, there has been significant changes to the river which have had a large impact on flood characteristics.

Table 2.2: Chronology of Missouri channel modifications implemented by Corps of Engineers

Year	Description
1838	Snag removal
1882	Congress endorses use of revetments
1886	Congress appropriates funds for 6 foot navigation channel, funds used for bank stabilization
1891-1896	Initial construction of navigation channel near mouth
1896-1902	Work diminishes to snag removal
1909	Congress appropriates funding to re-start construction of 6 foot navigation channel
1912	Congress authorizes work for 6 foot navigation between Kansas City and Mouth
1917	Construction on navigation channel interrupted as national resources directed towards struggle in World War I
1927	Congress authorizes the upper river project, a 6 foot deep navigation channel from Sioux City to Kansas City
1929-40	Sioux City to Kansas City channel completed, significant progress below Kansas City
1943	Flood of 1943 provides impetus for dam construction that can be used for flood control and regulate flows for navigation
1944	Congress authorizes five mainstem reservoirs
1945	Congress authorizes construction of a 9 foot navigation channel from Sioux City to mouth
1952	Flood of 1952 does significant damage to existing navigation channel dikes and revetments
1970	Construction of navigation channel essentially complete

Table 2.3: Missouri mainstem reservoirs

Reservoir	Location	Initial operation
Fort Peck	Montana	1937
Garrison	North Dakota	1953
Oahe	South Dakota	1958
Big Bend	South Dakota	1963
Fort Randall	South Dakota	1952
Gavins Point	South Dakota	1955

2.3 Methods used to estimate unregulated flow values and period of record selected

The methods employed to estimate unregulated flows depended on the existing regulation influencing flows in a particular reach, and to some extent the hydraulic models available for simulating floods. The analysis on the Mississippi was much simpler than that on the Missouri River because there are no significant flood control reservoirs regulating flows on the Mississippi above the confluence with the Missouri.

Different methods were used to obtain the unregulated flows for gages located: 1) on the Mississippi River between St. Paul and Hannibal; 2) the Mississippi River between Grafton and Thebes; 3) Illinois River from Marseilles to Meredosia ; and, 4) on the Missouri River between Yankton and Hermann. The unregulated record between St. Paul and Clinton was estimated to be equal to those reported in the gage record. Unsteady flow simulations performed by St. Paul district demonstrated no significant influence of the existing minor regulation structures. Rock Island district used an existing routing model to adjust the period of record between Clinton and Hannibal for the influence of reservoirs on the Iowa and Des Moines Rivers.

The computation of unregulated flows on the Missouri River involved estimating the influence of both the reservoirs and water supply diversions on tributaries and the major flood control reservoirs on the mainstem. Estimates of the tributary regulation and diversions were obtained by Kansas City and Omaha District and used as input to Omaha District’s Missouri River flood routing model. Different scenarios were investigated to account for the storage and channel changes occurring in the study area over the period of record.

These computed unregulated flows were provided as inputs to St. Louis District’s unsteady flow model at Hermann and Hannibal. Tributary flows between these locations and Thebes were estimated using continuous simulation watershed modeling. These tributary flows together with inflows from the Hermann (Missouri River), Hannibal (Mississippi River) and Meredosia on the Illinois were routed to obtain Mississippi River unregulated flows between Grafton and Thebes.

The 1898-1997/1998 period of record selected to obtain the Missouri and the Mississippi River corresponds to relatively stable land use conditions. The changes prior to this time, as well as the difficulty involved in obtaining reliable flow estimates made the use of earlier records unreliable. The most convincing evidence for selecting this period is the variation in flood statistics between Yankton and St. Joseph on the Missouri River. The channel between Yankton and Omaha is in a near-natural state. Peak flows tend to attenuate in this reach of river due to the extensive flood plain storage (see section 5). Below Omaha, this storage is not available due to the channelization of the river and the construction of major levees, the most upstream of which are at Omaha . Consequently, much of the record existing prior to complete channelization, from the mid 1800’s, is not relevant to present day conditions. Kansas City and Omaha District have been able to construct models that replicate channel conditions since 1898 to better estimate unregulated flows; but information does not exist to estimate the flows prior to this time. The same problem exists on the Mississippi River.

The period of 1898-1997/1998 represent the longest period where flows can be reliably estimated for flood frequency analysis. Table 2.4 and figure 2.1 provide the period of record available and locations for the gages used in the flood frequency analysis. Note that maximum annual daily flows were used for all the gages; except at St. Paul and Winona where the difference between maximum daily and peak flows was found to be significant to the frequency analysis.

Table 2.4: Upper Mississippi Period of Record

Location	DA (sq mi)	*Analysis period	Systematic record	Historic dates
Yankton, Missouri River	279500	1898-1997	-------	-------
Sioux City, Missouri River	314580	1898-1997	-------	-------
Decatur, Missouri River	316200	1898-1997	-------	-------
Omaha, Missouri River	322800	1898-1997	-------	-------
Nebraska City, Missouri River	410000	1898-1997	-------	-------
Rulo, Missouri River	414900	1898-1997	-------	-------
St Joseph, Missouri River	420300	1898-1997	-------	-------
Kansas City, Missouri River	485200	1898-1997	-------	-------
Waverly, Missouri River	487200	1898-1997	-------	-------
Booneville, Missouri River	505690	1898-1997	-------	-------
Hermann, Missouri River	528120	1898-1997	-------	-------
St Paul, Mississippi River	36800	1898-1998	1867-1998	-------
Winona, Mississippi River	59200	1898-1998	1878-1998	-------
Dubuque, Mississippi River	82000	1898-1998	1874-1998	1828
Clinton, Mississippi River	85600	1898-1998	1874-1998	1851
Keokuk, Mississippi River	119000	1898-1998	1878-1998	
Hannibal, Mississippi River	137000	1898-1997	1879-1998	
Louisiana, Mississippi River	141000	1898-1997	-------	
Grafton, Mississippi River	171300	1898-1997	-------	
St Louis, Mississippi River	697000	1898-1997	1861-1998	1785,1844
Chester, Mississippi River	708600	1898-1997	-------	
Thebes, Mississippi River	713200	1898-1997	-------	
Marseilles, Illinois River	8259	1920-1998	-------	
Kingston Mines, Illinois River	15819	1941-1998	-------	
Meredosia, Illinois River	26028	1898-1997	-------	

Peak annual flows used for St. Paul and Winona, maximum annual daily flows for all other gages

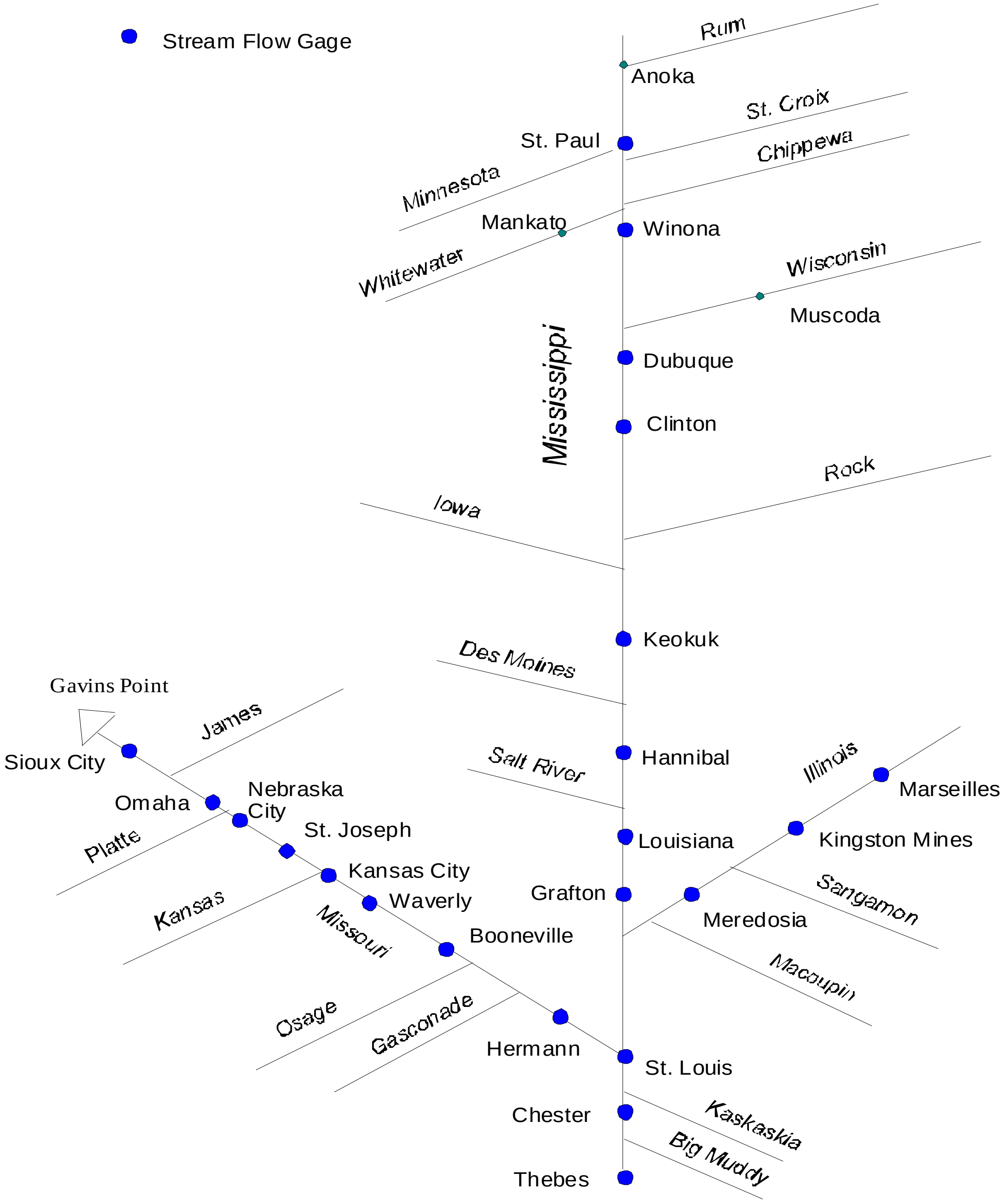


Figure 2.1: Schematic of Upper Mississippi River Basin showing gage locations

2.4 Sensitivity analysis using historic information

Historic information is available for the study area. Application of this information is questionable because the information is not uniformly available throughout the study area, land use and channel characteristics have changed over the period of record and accurate flow measurements do not exist for the observed stages.

The lack of uniformity of this information would cause statistical bias in the at-site estimate of flood frequency distribution estimates. Basically, a significant disparity in record lengths available at various gages would occur in applying this data and causes bias in the regional variation of gage statistics. This bias can be removed by performing correlation studies between long and short period of record gages. However, this type of study is not worthwhile given the other limitations of the data.

The level of flooding which would occur assuming the historic event occurred under present conditions would be difficult to assess given the history of land use and channel changes as described in section 2.2. Furthermore, historic information is mostly available from observed stages, without accurate measurements of discharge. At best, only the historic period for the observed peaks (e.g., the largest systematic peak is known to be the largest in the period of record) can be used to aid in estimating the flood frequency distribution. Applying the historic information without inclusion of historic flood estimates, because it cannot be estimated from the stages, tends to introduce a bias toward lowering flood quantile estimates. This is particularly true because historically large floods have been known to occur in the historic period.

A useful exercise for evaluating the flood distributions estimated from the systematic record is to examine the consistency of these estimates with distributions estimated from various assumptions regarding historic information. Presumably, the distributions estimated from the different periods of record (i.e., systematic versus historic) will be consistent.

Table 2.5 provides a summary of the historic information that could be obtained for the study area by the Corps Districts. The best source of information seems to be at St. Louis (see Table 2.5). The historic period discharges at St. Louis needed to be adjusted for flow measurement errors (see Dieckman and Dyhouse, 1998). The data obtained for the Missouri River is of questionable value, mostly consisting of peak stage information that cannot be related to present day channel or land use conditions. Ice affects also make the data difficult to interpret in the most upstream portions of the river.

The most reliable estimates of historic discharges (see Table 2.6) were used to estimate flood quantiles using the standard Bulletin 17B procedure and compared to those obtained for the selected systematic period. The differences between estimates at the 1% and 0.2% chance events are generally less than 5%, except at St. Louis where historic information from the 1700’s is employed (see Table 2.7). The comparison shows the consistency of flood quantiles obtained between the systematic period chosen and the historic information. Consequently, the application of the historic information does not seem advisable given that: 1) it does not result in very different flood quantile estimates; 2) flood discharge estimates are not as reliable as those obtained during the systematic period; and 3) the relevance of the estimates to the present day land use and the river channel are difficult to evaluate.

Table 2.5: Historic information

Location	Systematic Flow Period	Historic Stages	Historic Flows
[1,2]Sioux City	1898-1997	1878-1997	1881
[1,2]Omaha	1898-1997	1872-1897	1881
[1,2]Nebraska City	1898-1997	1878-1897	1881
[2]Rulo	1898-1997	1844, 1873-1897	
[2]Saint Joseph	1898-1997	1844, 1873-1897	
[2]Kansas City	1898-1997	1844, 1873-1897	
[2]Waverly	1898-1997	1844, 1873-1897	
[2]Boonville	1898-1997	1844, 1873-1897	
[2]Hermann	1898-1997	1844, 1873-1897	
Saint Paul	1867-1997	1866-1891	[3]1866-1891
Keokuk	1898-1998		[3]1851
Marseilles	1898-1998	1881	
Louisiana	1898-1997	1858, 1873-1874,1878-present	[4]1873-1874,1878-present
Grafton	1898-1997	1844, 1858, 1891-present	[5]1891-present
Saint Louis	1898-1997	1785, 1844, 1851, 1854, 1858, 1861-present	[6]1861-present
Chester	1898-1997	1844, 1891-present	[7]1891-present
Thebes	1898-1997	1844, 1903, 1933-present	[8]1933-present

[1] 1844 flood was estimated to be 10 feet higher than flood of April 1881 (ice affected stage), the 1881 flood was reported to be 4.5 feet higher than the 1952 flood stage (the maximum event in systematic period of record)

[2] The Missouri River through the Kansas district was shortened for navigation/stabilization 40 miles from a 538 mile braided channel during the 19th century.

[3] Questionable reliability

[4] Estimated from rating curve

[5] Change in estimates from Corps float measurement to USGS current meter, 1931

[6] Change in estimates from Corps float measurement to USGS current meter, 1926

[7] Change in estimates from Corps float measurement to USGS current meter, 1933

[8] Change in estimates from Corps float measurement to USGS current meter, 1921

Table 2.6: Estimated flows used in sensitivity analysis

Location	Date	Estimated discharge
Clinton	1828	306000
Keokuk	1851	360000
St Louis	1785	1100000
	1844	1000000

Table 2.7: Comparison of Bulletin 17b estimated quantiles obtained from systematic period beginning in 1898 and historic period

location	area	1%quantile	1% historic	%diff	0.2% quantile	0.2% historic	%diff	years
St Paul	36800	134900	137936	2.25	172900	177872	2.88	132
Winona	59200	237700	231079	-2.79	297400	283627	-4.63	121
Dubuque	82000	281900	275873	-2.14	338900	322943	-4.71	125
Clinton	85600	274300	279252	1.81	322600	326147	1.1	171
Keokuk	119000	371700	374198	0.67	439400	441178	0.4	148
Hannibal	137000	465300	471144	1.26	551300	559264	1.44	120
St Louis	697000	1104800	1042080	-5.68	1318200	1222471	-7.26	263

3 Climatology

3.1 Introduction

The relationship between climate and floods is likely to provide useful information on developing the boundaries for regionalizing flood statistics. Climate alone will not be able to explain entirely the variation of sample at-site flood statistics along the mainstem. However, climate studies will be useful for obtaining some initial estimates of flood regions. Further study of the at-site statistics and the physical characteristics of the mainstem channel will be used to refine the boundaries of these regions.

Excellent summaries of the relationship between climate and flooding in the Upper Mississippi Basin are provided by Olsen and Stakhiv (1999) and Clemetson (1998). In section 3.2, a brief summary is provided of major floods . These floods are related to climate norms in section 3.3 to gain a perspective on boundaries that might be used for regionalizing flood statistics.

3.2 Major Floods

The following types of meteorologic events drive major floods in the Upper Mississippi Basin (see Table 3.1 and also Olsen and Stakhiv (1999, figure 2.5):

> 1993 – Major multiple season event, caused primarily by late spring and summer convective rainfall of similar pattern to typical summer events, but of greater persistence, depth and duration. This was the event of record on Missouri from Kansas City to St. Louis, and from Keokuk to St. Louis on the Mississippi, and a significant event on the Missouri upstream of Kansas City to Nebraska City.
>
> 1952 – A winter snowmelt event influenced very little from precipitation. The event of record from Yankton to St. Joseph on the Missouri, and a significant event on the Upper Mississippi between St. Paul and Clinton;
>
> 1965 - A rainfall-snowmelt event occurring in late winter and early spring. The type of event expected for this region. This is the event of record on the Upper Mississippi from St. Paul to Clinton.

Either snowmelt, rain on snow or rainfall can cause major flooding at various locations within the study area. Snowmelt alone seems to be able to cause a major flood in the Upper Missouri, certainly above St. Joseph given the ranking of the 1952 event. Rain on snow probably is a major influence on both the Upper Missouri and the Mississippi above Clinton. Rainfall seems to be most important south of these locations.

Table 3.1: Events of record, and rank of 1993 and 1952 events at various gages

Location	DA (sq mi)	Top Ranked Event	Rank 1993 event	Rank 1952 event
Yankton	279500	1952	84	1
Sioux City	314580	1952	50	1
Decatur	316200	1952	45	1
Omaha	322800	1952	24	1
Nebraska City	410000	1952	3	1
Rulo	414900	1952	2	1
St Joseph	420300	1952	2	1
Kansas City	485200	1993	1	4
Waverly	487200	1993	1	5
Booneville	505690	1993	1	12
Hermann	528120	1993	1	30
St Paul	36800	1965	6	4
Prescott	44800	1965	5	4
Winona	59200	1965	7	4
McGregor	67500	1965	5	4
Dubuque	82000	1965	2	9
Clinton	85600	1965	5	9
Keokuk	119000	1993	1	3
Hannibal	137000	1993	1	28
Louisiana	141000	1993	1	15
St Louis	697000	1993	1	15

3.3 Relationship between climate norms and major floods

The inspection of major historic floods implies the following important climatologic aspects of Upper Mississippi flooding:

Upper Missouri (Yankton to Nebraska City)

Flood regime where snowmelt is an essential component of the flood. Snowmelt alone or rain and snowmelt combinations can cause major flood of record.

Transition Missouri River (Nebraska City to Kansas City)

Rainfall event or snowmelt related (snowmelt alone or rain on snow) events may cause a major flood event of record.

Lower Missouri (Kansas City to St. Louis)

Flood regime due to rainfall events.

Upper Mississippi, Northern Reach (St. Paul to Clinton)

Flood regime dominated by rain on snow events.

Upper Mississippi transition region (Clinton to Keokuk)

Rainfall, rain on snow may cause a major flood event

Upper Mississippi Southern Reach (Keokuk to St. Louis)

Rainfall events cause major floods of record

Inspection of the variation in monthly precipitation and snowpack norms in the study regions (see Tables 3.2 and 3.3) provides insight into the occurrence of these flooding regions. Precipitation increases from northwest to southeast in the study region. Precipitation is greater in Minnesota than the Dakotas, Iowa than Nebraska, Missouri than Kansas and Missouri than states to the north. An interesting anomaly occurs when comparing the Kansas City and St. Louis gages. The precipitation for these gages is about equal, indicating that monthly precipitation in eastern Kansas is about equal to that observed in southern Missouri. Perhaps this combined with temperature explains the change from snowmelt to rainfall dominated flood regimes at the junction of the Kansas and Missouri Rivers.

Comparison of monthly precipitation and snowpack totals, particularly in March through May indicates the relative importance of snowmelt only versus rainfall on snowmelt floods in the Dakotas, Nebraska and Minnesota. Both the monthly snowpack and precipitation totals are greatest at St. Paul, except for the precipitation total in April which is greater at the North Platte station. Basically, the drier climate to the west allows snowmelt alone to be a more dominant, if not the dominant factor, in the occurrence of major floods on the Upper Missouri River.

Moving south from Minnesota to Iowa, the snowpack in late winter and early spring decreases while precipitation amounts increase. This is a bit misleading in that the rainfall occurring in the spring may shift from a more area wide synoptic to smaller scale convective types. This coupled with high evaporation rates and dry soil conditions make summer floods less likely. The occurrence of the 1993 flood is the clear exception to this in that it was a long duration, area-wide persistent occurrence of convective type events. Still, the change in flood regime in Iowa pretty much corresponds to the relative distribution of snowpack and precipitation totals.

The precipitation and snowpack norms are very consistent with the dominance of the rainfall flood regime in Kansas and Missouri (see Dodge City, Kansas City and St. Louis gages). Interestingly, the areal extent of the supposedly anomalous 1993 flood (see rankings in Table 3.1) corresponds perfectly well with the rainfall region described by the precipitation and snowpack norms.

In summary, the flood regime in the study area corresponds closely to the climatologic norms. Perhaps this is not surprising, but the lack of influence of the upper portions of the study area runoff on the lower regions is interesting. One might of suspected that very large floods in the upper basin might have had more influence on flooding in St. Louis. This does not seem to happen, perhaps because the precipitation amounts, particularly in the Dakotas is not that great in relationship to the drainage area involved.

Although useful in providing a general explanation for the flood regimes, the climatologic norms do not provide definitive guidance for locating the boundaries of the region. A more detailed analysis of the flood history is needed to better define the transition region as is discussed in section 4.

Table 3.2: Mean monthly rainfall (period of record ends 1960)

Location	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Bismarck, ND	1.0	0.6	0.4	0.4	0.4	0.8	1.4	2.0	2.4	2.2	1.6	1.6
Fargo, ND	1.4	0.8	0.6	0.6	0.6	0.8	1.8	2.0	3.0	2.4	2.6	1.6
Minneapolis, MN	1.8	1.6	1.8	0.8	0.8	1.4	1.8	3.0	4.2	1.8	1.8	2.9
North Platte, NE	1.2	0.6	0.4	0.4	0.4	1.0	2.2	2.8	3.0	2.4	2.2	1.8
Lincoln, NE	1.8	1.4	0.8	0.8	0.9	1.4	2.4	3.2	4.2	3.2	3.2	3.0
Des Moines, IA	2.4	1.8	1.2	1.2	1.0	2.0	2.4	3.6	5.0	2.8	3.8	2.8
Dubuque, IA	2.4	1.8	1.6	1.4	1.0	2.0	2.4	3.6	5.0	2.8	3.8	2.8
Dodge City, KS	1.6	1.0	0.4	0.4	0.6	1.2	2.4	2.8	3.0	2.8	2.8	1.8
Kansas City, MO	2.8	2.0	1.6	1.4	1.0	2.4	3.6	4.4	5.0	2.8	3.8	3.8
St. Louis, MO	3.2	2.6	2.0	1.8	0.6	3.4	3.8	4.0	4.4	2.6	3.6	3.6

Table 3.3: Mean Monthly Snowpack (inches) (period of record ends 1960)

Location	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Bismarck, ND	1.5	5.5	4.5	7.5	6.0	8.5	3.5	1.0
Fargo, ND	1.0	6.0	7.0	7.0	6.5	6.5	4.0	0.5
Minneapolis, MN	0.5	7.0	7.5	6.0	8.0	10.5	7.0	0.5
North Platte, NE	1.0	3.0	4.0	4.0	5.0	6.5	2.0	0.5
Lincoln, NE	0.5	2.0	5.5	5.5	5.5	5.5	1.0	<0.5
Des Moines, IA	0.5	2.0	7.5	8.5	7.0	6.0	1.0	<0.5
Dubuque, IA	0.5	2.5	7.5	9.5	7.5	7.5	1.5	<0.5
Dodge City, KS	0.5	2.0	3.0	3.5	5.0	4.0	1.0	<0.5
Kansas City, MO	<0.5	1.5	4.0	4.5	3.5	3.5	0.5	<0.5
St. Louis, MO	<0.5	1.5	3.0	4.0	3.0	3.5	<0.5	<0.5

4 Identification of flood regions from statistical and mixed population analysis

4.1 Introduction

The type of meteorologic events influencing the flood distributions transition from snowmelt or rain on snow to rainfall. Presumably, this meteorologic transition should be apparent when examining both the regional variation of flood statistics and the mixed population characteristics of the flood distributions. The transition region should be located where both rainfall and snowmelt related floods have an important influence on the annual distribution. In section 4.2, the regional variation of flood statistics is presented for comparison with the information presented in the previous section on climatology and with the analysis of mixed distribution presented in this section. In sections 4.3 and 4.4, an investigation is made of mixed populations at both mainstem and tributary gages to ascertain if the transition region can be recognized and used for setting regionalization boundaries. The regionalization boundaries corresponding to the mixed distribution analysis need to be consistent with the regional variation in at-site flood statistics. Final recommendations on the regionalization boundaries are provided in section 4.5.

4.2 Regional variation of flood statistics

The regional variation of flood statistics was explored by plotting flood statistics against drainage area, and by computing discordancy and heterogeneity statistics for groups of gages. The difference between regional flood statistics at various gages can readily be discerned from the plot of the standard deviation of the log annual maximums (SD_l) versus drainage area shown in figure 4.0. The SD_l is examined because it is used in estimating the log-Pearson III distribution and it behaves much like the coefficient of variation (CV) for the observed flows (CV is the standard deviation divided by the mean). The variation of SD_l depicts a transition zone between drainage areas of 10,000 and 100,000 square miles. This statistics varies greatly between the St. Paul gage on the Mississippi River and Meredosia and Kingston Mines gages on the Illinois River within this drainage area range. Otherwise, the SD_l is relatively constant for gages with drainage areas exceeding 80,000 square miles, which describes most of the gages of interest in this study.

A different perspective on the variation in flood statistics is provided by the change in mean, standard deviation and CV for observed flows with drainage area shown in figure 4.0a. As can be seen from this comparison, the variation of standard deviation and mean with drainage area is not the same for Missouri and Mississippi Rivers (see values at about 100,000 square miles). This variation is an artifact of the meteorologic differences between the basins.

Figure 4.0b provides some evidence for differences between basins with latitude by comparing SD_l for gages in northern to more southern states in the region. Differences with latitude might be explained by the change in climate (rain on snow versus rain driven floods). However this variation does not exist for the larger basins of interest in the study area.

As a final comparison, discordancy and heterogeneity statistics (see Hosking and Wallis, 1997) were computed for different aggregation of gages to identify potential regions for obtaining regional skew. The discordancy statistic provides a means for identifying flow records at a gage with statistical characteristics which deviate more than would be expected from the average statistical characteristics of gages within a region. The heterogeneity statistics measure the difference between the average sample statistics of an aggregation of gages (a region) and the sample statistics implied by an index flood distribution. More specifically:

> H(1) measures the relative difference between the aggregate sample L-CV and the flood distribution L-CV;
>
> H(2) measures the difference between the average distance from the centroid of the sample and distribution L-CV versus L-skewness relationship;
>
> H(3) measures the difference between the average distance from the centroid of the sample and distribution L-skewness versus L-kurtosis relationship;

The H(I) criteria are used to determine if an aggregation of gages can be considered a region. Values less than 1.0 implies a fairly homogenous region, between 1 and 2 marginally acceptable, and exceeding 3 as heterogeneous and not likely to be acceptable. The TAG recommended focusing on H(3) alone for regional shape estimation type applications. This recommendation assumed that at least 100-year of record would be available at all the gages in the study. Basically, this is true except for the Illinois River gages (see Table 2.1).

Table 4.1 summarizes the application of the discordancy and heterogeneity statistics to various aggregation of gages within the study area. The discordancy statistic (D1 an D2) indicates that the St. Paul and Winona gages should not be part of a Mississippi River Region. The H(3) statistic indicates that an aggregation of all Mississippi gages is acceptable, although consideration of the H(1) statistic would only indicate Dubuque to Thebes as acceptable. If gages were to be aggregated based on similar L-CV, the St. Paul and Winona would not be placed in the same region as the remaining Mississippi River Gages.

The Missouri River gages seem to correspond to a single region according to the statistics shown in the table. The Illinois river mainstem gages were grouped with Mississippi River gages and with gages tributary to the Illinois River that have drainage areas greater than 1000 square miles (see Table 5.15). As can be seen, the H(I) statistics indicate a grouping with the Mississippi gages is more reasonable than with the tributary gages.

In summary, the variation of flood statistics argue for a Mississippi and Missouri river region. Special consideration, possibly in the application of a sensitivity analysis, is needed when considering the Illinois River, St. Paul an possibly the Winona gages. Examination of the variation of log-standard deviation with drainage area, as well as the discordancy and heterogeneity statistics indicate that these gages belong in a region somewhere between gages with drainage areas less than 1000 square miles, and the other large drainage area gages in the study (drainage areas greater than 80,000 square miles). Unfortunately, these transition gages are somewhat unique in terms of drainage area, and may be difficult to place within a regional context.

Table 4.1: Gage region statistical tests using Hosking and Wallis (1997) L-moment criterion, log-flows

Region	D1	D2	H(1)	H(2)	H(3)
All stations	5	3	17.26	-2.15	-2.12
Mississippi, St. Paul-Thebes	4	1	16.03	-2.12	-1.21
Mississippi, Winona-Thebes	4	1	7.05	-2.60	-2.01
Mississippi, Dubuque-Thebes	4		2.26	-2.22	-1.60
Mississippi, **Dubuque**-Thebes, Illinois River	6		6.16	-2.58	-2.25
Illinois River & tributary, area gt 1000 sq mi	3	1	11.34	2.43	3.07
Illinois River & tributary, area gt 2000 sq mi	3		8.45	0.16	1.37
Missouri River	3		10.82	-0.50	0.18

D1 number of stations with discordancy measure greater than 1.0
D2 number of stations with discordancy measure greater than 2.0
H(1) Heterogeneity measure using dispersion of L-CV (coefficient of variation)
H(2) Heterogeneity measure using dispersion from center of L-CV vs L-skewness region
H(2) Heterogeneity measure using dispersion from center of L-skewness vs L-kurtosis region

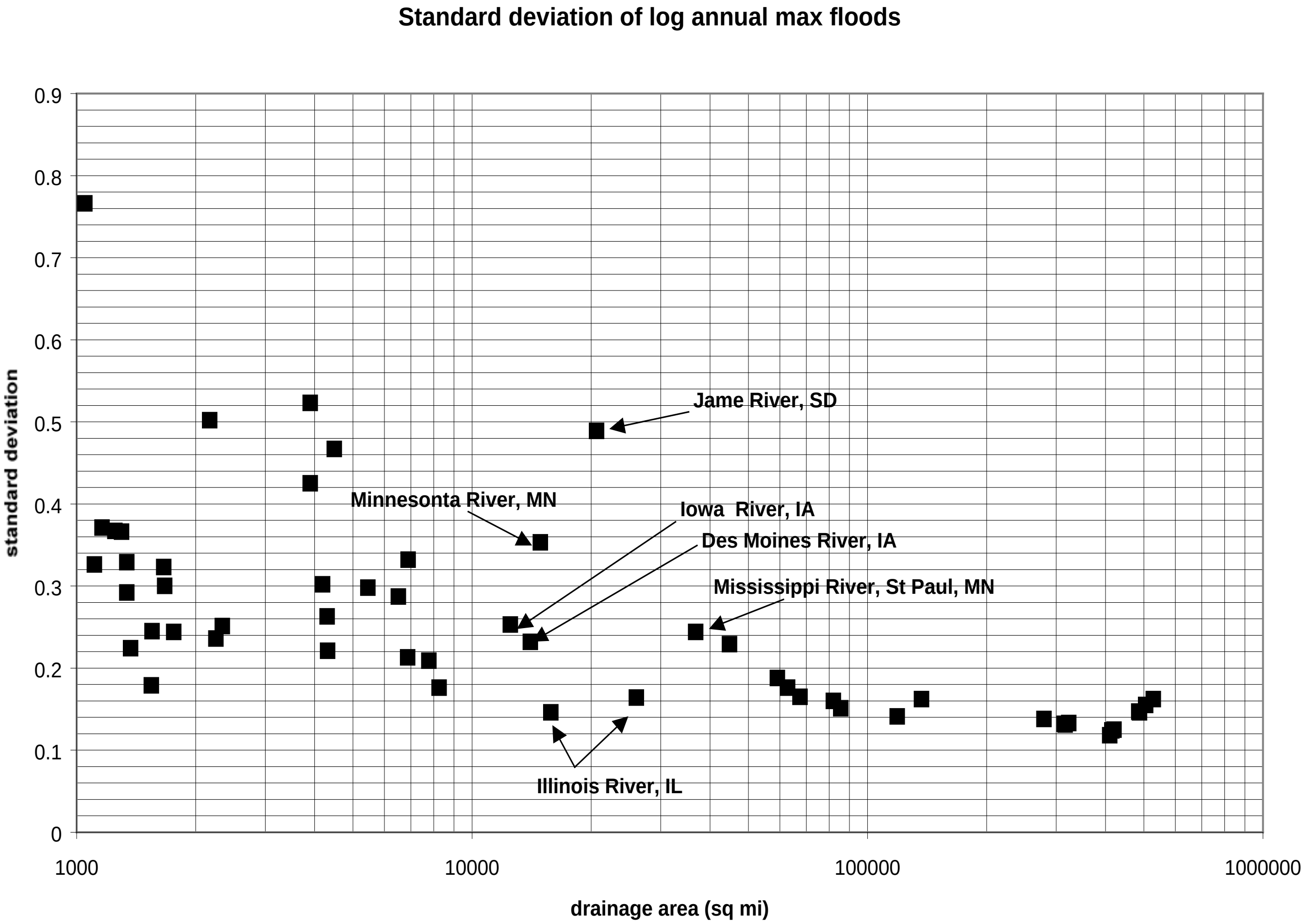


Figure 4.0: Standard deviation of log-annual peaks/maximum daily flows versus drainage area (annual maximum daily flows for areas greater than 70000 square miles)

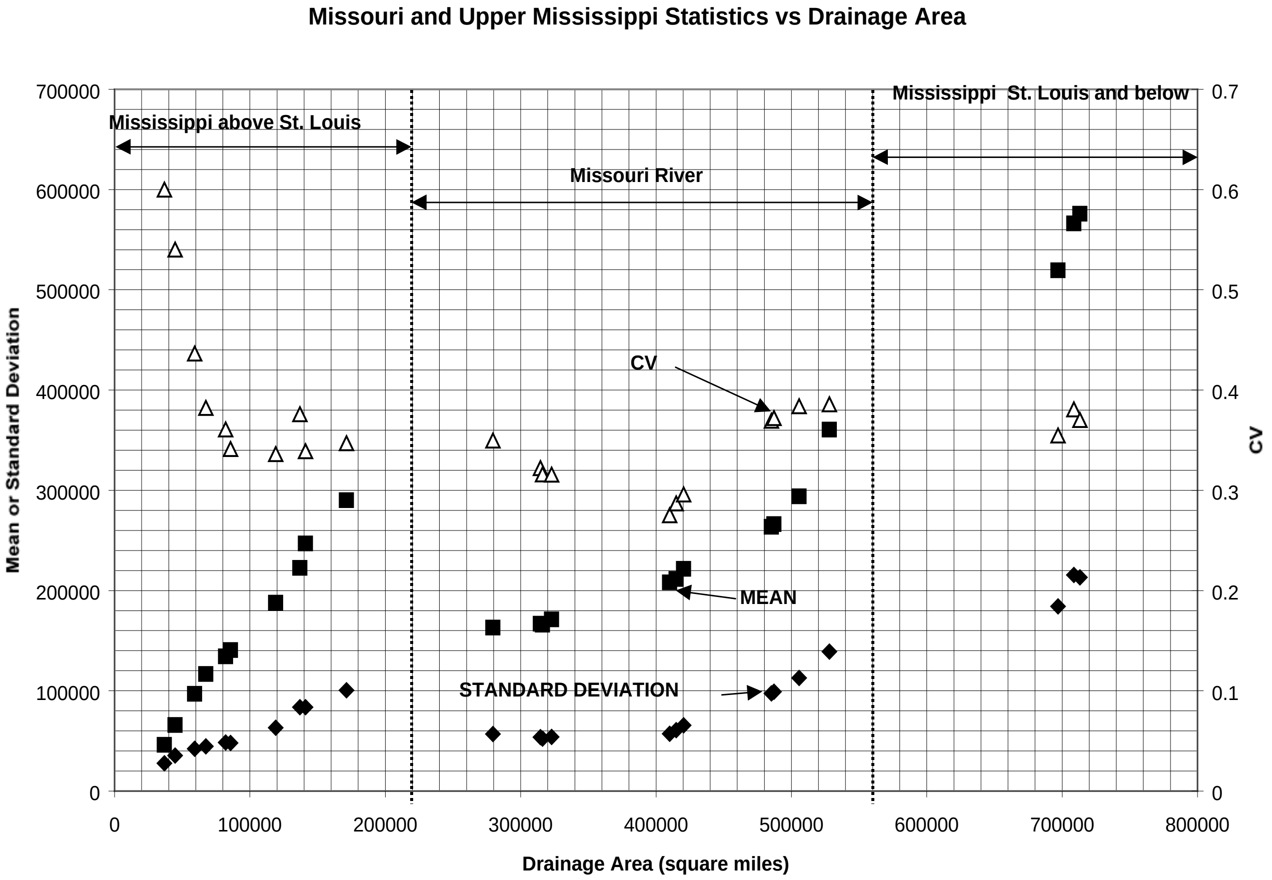


Figure 4.0a: Variation of mean, standard deviation and coefficient of variation of peaks/annual maximum daily flows with drainage area (annual maximum daily flows for areas greater than 70000 square miles)

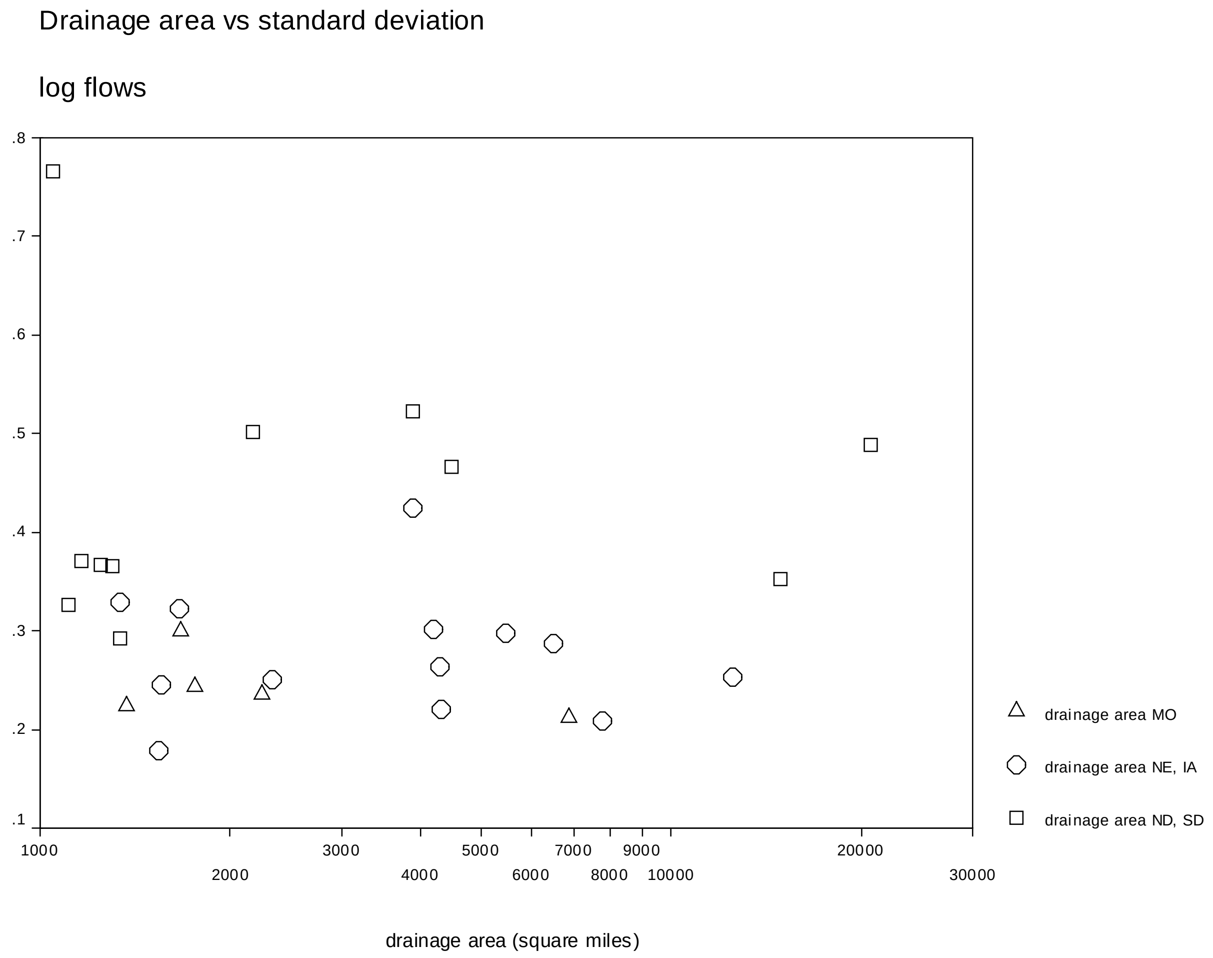


Figure 4.0b: Variation of standard deviation of log annual peaks with drainage area and latitude

4.3 Mixed distribution analysis for the Missouri River

The mixed characteristics of the flood distributions on the Missouri River have been investigated by Kay (1999 and 2000). He found that the importance of seasonal influences on the annual flood distributions corresponds very closely with the climate regions described in section 3. The annual flood distributions upstream of Kansas City are influenced by plains snowmelt flood in the period from January through April, and snowmelt floods generated in the mountainous north western portion of the watershed augmented by general rainfall events over the entire basin from May through September. Rainfall floods clearly replace snowmelt as the dominant factor below the confluence of the mainstem with the Kansas River. The Kansas River is dominated by rainfall floods and this has a major impact on the mainstem flood distribution.

Estimating the annual flood distribution from an analysis of the mixed seasonal flood series results in significantly greater flood quantile estimates (e.g., the 1% chance flood) than obtained from the annual for the mainstem gages upstream of Kansas City (see Tables 5.1-5.3) . Consequently, the evidence for a mixed analysis is evaluated in this section given the significant difference between the estimated quantiles.

The climatic and hydrologic factors influencing the seasonality of the flood distribution can be appreciated by examining the daily annual flow traces shown in Appendix A for the top ranked floods in the period of record. As can be seen from the plots, two distinct flood peaks can be seen in most of the traces, peaks due to plains snowmelt in the period January through April, and May through September due to rain on snow in the mountainous areas in the western portion of the watershed. The notable aspect of these traces is that the snowmelt plain floods in the January through April time period do not contribute to the latter period peaks. This is indicative of separable and independent flood peaks.

Kay (1999) describes the climatologic and hydrologic conditions that cause the differences in the population:

> *a)….. The plains and mountain snowmelt periods are distinctly different, with the plains snowmelt (potentially) covering hundreds of thousands of square miles on frozen or partially frozen soils, while the mountain snowmelt occurs over a relatively small area. The plains snowpack rarely exceeds 5 inches of snow-water equivalent, while the mountain snowpack can contain 40 or more inches of snow-water equivalent. The mountain snowmelt tends to produce a hydrograph with pronounced diurnal effects (at least in the upper basin areas), while that is rarely seen in the plains snowmelt. Additionally, the peak rainfall period (at least in Omaha District* [note: Corps of Engineers District]*) is in the May and June timeframe, which falls on top of the mountain snowmelt period.*
>
> *b)….. The plains snowpack can vary significantly year-to-year, in both depth and coverage. I believe this alone can account for much of the large variance in this population* [note: reference to the January through April season population]. *Climate and runoff characteristics can also account for some of the variance. The western plains area tends to warm up more rapidly in the spring than the eastern Dakotas, increasing the snowmelt rate. Runoff in the western plains also tends to be more rapid due to more rugged topography. Thus, depending on where the snowpack is centered, the peak discharge can vary considerably, even though the total volume may not.*

The differences between the annual distribution determined from either the annual or seasonal periods of record can be readily seen from the plots shown for the mainstem gages (see figure 4.1, Yankton, figure 4.4, Omaha, figure 4.14, St. Joseph, figure 4.15, Kansas City and figure 4.16, Hermann). As can be seen from the plots, the standard deviation (the slope of the plotted distribution) of the January through April (winter-spring) distribution is much greater than that of the annual or May through September (summer) distributions for the gages upstream of Kansas City. The confluence of the Kansas River with the mainstem results in a change in flood regime where mixed distributions are unimportant. At this point, the summer period rainfall driven floods essentially define the annual distribution and the winter-spring floods are unimportant.

An investigation of other gages on tributaries to the Missouri River unaffected by regulation was performed to see if mixed populations contribute to the annual flood distribution for smaller basins. Observation of seasonal influences for these smaller basins would provide more evidence for the mixed distribution application to the mainstem gages.

The gages investigated, corresponding drainage areas, record lengths and period are shown in Table 4.2. The drainage areas of tributary gages investigated range from 78 to 20653 square miles. Top ranked events can occur in the summer for the smaller drainage area gages as shown in Table 4.3. This observation is in some respect influenced by the period of record. Sometimes the period of record for these gages does not include 1952 (the event of record on the mainstem above Kansas City) or the 1952 event is a summer event not related to the major flood occurring on the mainstem. More typically the latest observed peak annual flood at any of the gages is rainfall related occurring in late spring (late June) or summer and is more than likely not influenced by snowmelt As the drainage areas investigated become larger, late summer events become less important.

Interestingly, the 1952 event is not the event of record at any of the tributary gages investigated. For example, consider the two largest tributary basins examined where this event was ranked 12th on the James River at Scotland and 39th on the Elkhorn River at Waterloo. As Kay (1999) points out, the 1952 event was centered between Bismarck and Pierre, influencing tributary streams that are now regulated. Consequently, the tributary streams do not provide any good examples of the influence of the mainstem event of record on the mixed distribution analysis.

An additional perspective on the relative importance of mixed distributions can be judged by comparing mainstem and tributary plots of annual and winter-spring distributions. The summer distributions were not plotted in the case of the tributary gages because there were insufficient non-zero events for the Bulletin 17B procedure to estimate the summer distributions. Comparison plots made between mainstem and tributary distributions are:

- Missouri River, Yankton vs James River at Manfred, Grace City and Scotland, Little Vermillion River at Salem, Vermillion River at Wakonda, Big Sioux River at Brookings and Dell Rapids (figures 4.1-4.8);
- Missouri River, Omaha vs Elkhorn River at West Point and Waterloo, Little Blue River at Fairbury, Big Nemaha at Falls City (figures 4.9-4.13);

The plots for the tributary streams show that, in general, the annual distribution is adequately described by the annual series. The seasonal series do not demonstrate the large standard deviation relative to the annual series distribution, and approximately zero skew of the seasonal series typical of the mainstem gages. The possible explanation for the difference between the mainstem and tributary distributions are: 1) the smaller record lengths; 2) the relatively small ranking of the 1952 event in the period of record (when present) and 3) the importance of drainage area to observed variability. The period of record might play a role in that the drought of the 1930's is not present in some of the tributary gage data. Still, the period of record at both Scotland on the James River figure(4.8, drainage area 20653 sq mi) and at Waterloo on the Elkhorn River (figure 4.13) (drainage area 6900 square miles) is relatively long and includes the drought period. Inspection of these plots does not reveal the need for a mixed distribution analysis for the Scotland Gage; although there is possibly some minor evidence at the Waterloo Gage. The apparently important difference between the annual and seasonal flood series does not exist for these gages as exists for the mainstem gages.

Drainage area may provide an explanation for the differences between the relative importance of seasonal distributions observed at the tributary and mainstem gages. The Scotland and Waterloo gages have the greatest drainage area of the tributary gages investigated but are small drainage areas in comparison to the area draining to the mainstem gages. The spatial distribution of snowpack and basin characteristics might be such as to cause a relatively large variance in annual floods for the large mainstem systems but not for the tributary rivers.

Consequently, a reasonable boundary between flood regimes on the Missouri River is probably at Kansas City, the location of the confluence between the Missouri and Kansas Rivers. This boundary is evident from the analysis of the mixed distribution characteristics of the annual maximum daily flow values. The mixed populations are most evident at the most upstream gage, Yankton and has less influence proceeding downstream to St. Joseph. A change in flood regime characteristics occurs at the confluence of the Kansas and Missouri Rivers where late spring and summer rainfall dominate and early spring snowmelt is not an important factor.

Table 4.2: Gage unaffected by regulation in the Missouri River Basins

Location	DA (sq mi)	Record length	Period
Painted Woods Creek, Wilton, ND	427	40	1958-1998
Big Muddy Creek, Almont, ND	456	36	1946-1998
Rock Creek, Fulton, SD	240	23	1967-1998
Enemy Creek, Mitchell, SD	163	22	1976-1998
Wolf Creek, Clayton, SD	396	23	1976-1998
Little Vermillion, Salem, SD	78	32	1967-1998
James River, Manfred, ND	253	39	1950-1994
James River, Grace City, ND	1060	30	1969-1998
James River, Scotland, SD	20653	70	1929-1998
Vermillion River, Wakonda, SD	2170	53	1946-1998
Big Sioux River, Brookings, SD	3898	45	1954-1998
Big Sioux River, Dell Rapids,SD	4483	50	1949-1998
Big Nemaha River, Falls City, NE	1340	56	1941-1998
Chariton River, Novinger, MO	1370	75	1917-1997
Chariton River, Prairie Hill, MO	1870	68	1928-1997
Elkhorn River, West Point, NE	510	38	1961-1998
Elkhorn River, Waterloo, NE	6900	80	1899-1998
Grand River, Gallatin, MO	2250	61	1922-1997
Grand River, Sumner, MO	6880	74	1922-1997
Little Blue River, Fairbury, NE	2350	78	1908-1998
Little Sioux River, Correctionville, IA	2500	73	1919-1998
Nishnabotna River, Hamburg, IA,	2806	72	1908-1998
Platte River, Agency, MO	1760	71	1917-1998
Thompson River, Trenton, MO,	1670	71	1924-1996
West Nishnabotna River, Randolph, IA	1326	49	1949-1998
Missouri River, Yankton ,SD	279500	100	1898-1997
Missouri River,Sioux City, IA	314580	100	1898-1997
Missouri River,Decatur, NE	316200	100	1898-1997
Missouri River, Omaha, NE	322800	100	1898-1997
Missouri River, Nebraska City, NE	410000	100	1898-1997
Missouri River, Rulo, NE	414900	100	1898-1997
Missouri River, St. Joseph, MO	420300	100	1898-1997
Missouri River, Kansas City, KS	485200	100	1898-1997
Missouri River, Waverly, MO	487200	100	1898-1997
Missouri River, Boonville, MO	505690	100	1898-1997
Missouri River, Hermann, MO	528120	100	1898-1997

Table 4.3: Rank of 1952 event and top ranked events for Missouri River gages

Location	DA (sq mi)	1952 rank	1952 date	Top rank
Painted Woods Creek, Wilton, ND	427		--------------	4/19/1979
Big Muddy Creek, Almont, ND	456		--------------	4/17/1950
Rock Creek, Fulton, SD	240		--------------	3/29/1997
Enemy Creek, Mitchell, SD	163		--------------	6/22/1984
Wolf Creek, Clayton, SD	396		--------------	6/21/1984
Little Vermillion, Salem, SD	78		--------------	7/04/1993
James River, Manfred, ND	253		--------------	7/23/1993
James River, Grace City, ND	1060		--------------	4/03/1993
James River, Scotland, SD	20653	12	4/23	6/23/1984
Vermillion River, Wakonda, SD	2170	11	4/4	6/23/1984
Big Sioux River, Brookings, SD	3898		--------------	4/09/1969
Big Sioux River, Dell Rapids,SD	4483		--------------	7/09/1969
Big Nehama River, Falls City, NE	1340		--------------	10/11/1973
Chariton River, Novinger, MO	1370	56	3/13	6/**/1917
Chariton River, Prairie Hill, MO	1870	58	3/19	10/05/1973
Elkhorn River, West Point, NE	510		--------------	6/15/1967
Elkhorn River, Waterloo, NE	6900	39	3/13	6/12/1944
Grand River, Gallatin, MO	2250	49	3/11	6/04/1944
Grand River, Sumner, MO	6880	36	3/12	6/08/1947
Little Blue River, Fairbury, NE	2350	14	6/28	**/**/1992
Little Sioux River, Correctionville, IA	2500	21	4/4	4/07/1965
Nishnabotna River, Hamburg, IA,	2806	47	6/23	6/17/1998
Platte River, Agency, MO	1760		--------------	7/06/1993
Thompson River, Trenton, MO,	1670	47	6/21	6/06/1947
West Nishnabotna River, Randolph, IA	1326	10	6/22	5/26/1987

Period of record does not include 1952 event or 1952 was not a winter-spring event as indicated by (-------------)

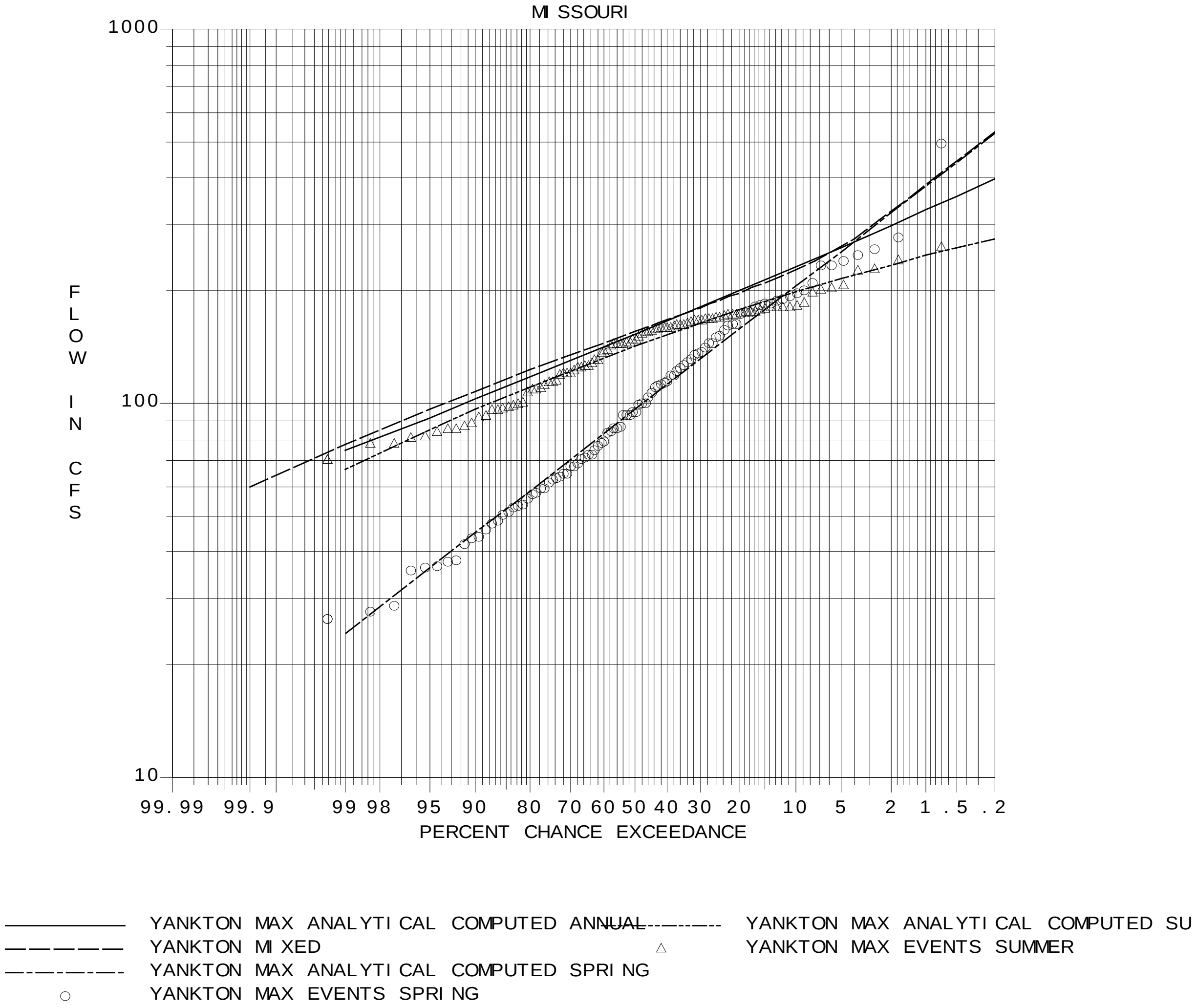


Figure 4.1a: Missouri River, Yankton, SD, (DA 279500 sq mi, period 1898-1997) (Winter-Spring: January 1st – April 30th, Summer May 1 – December 31st)

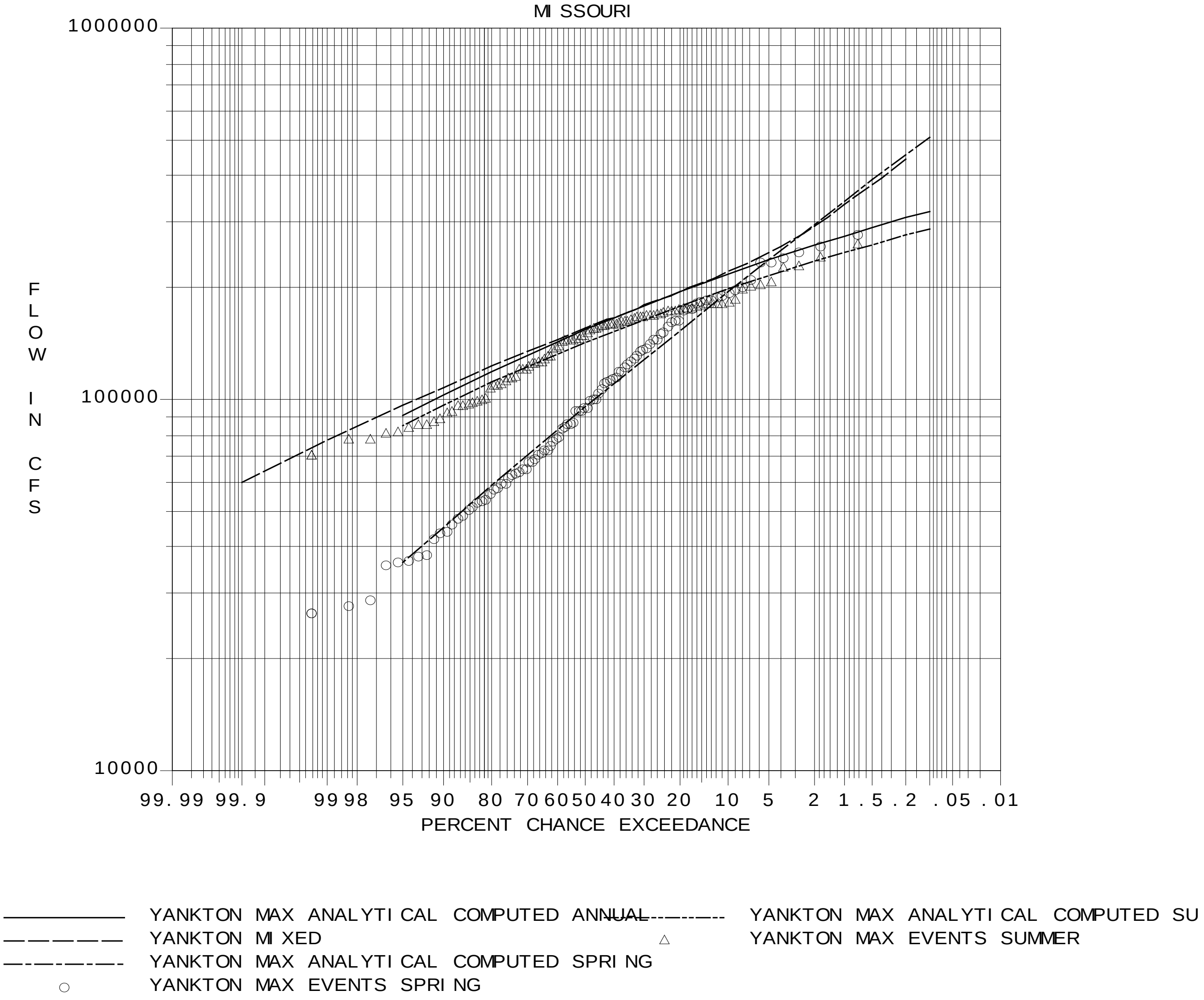


Figure 4.1b: Missouri River, Yankton, SD, (DA 279500 sq mi, period 1898-1997, minus 1952) (Winter-Spring: January 1st – April 30th, Summer May 1 – December 31st)

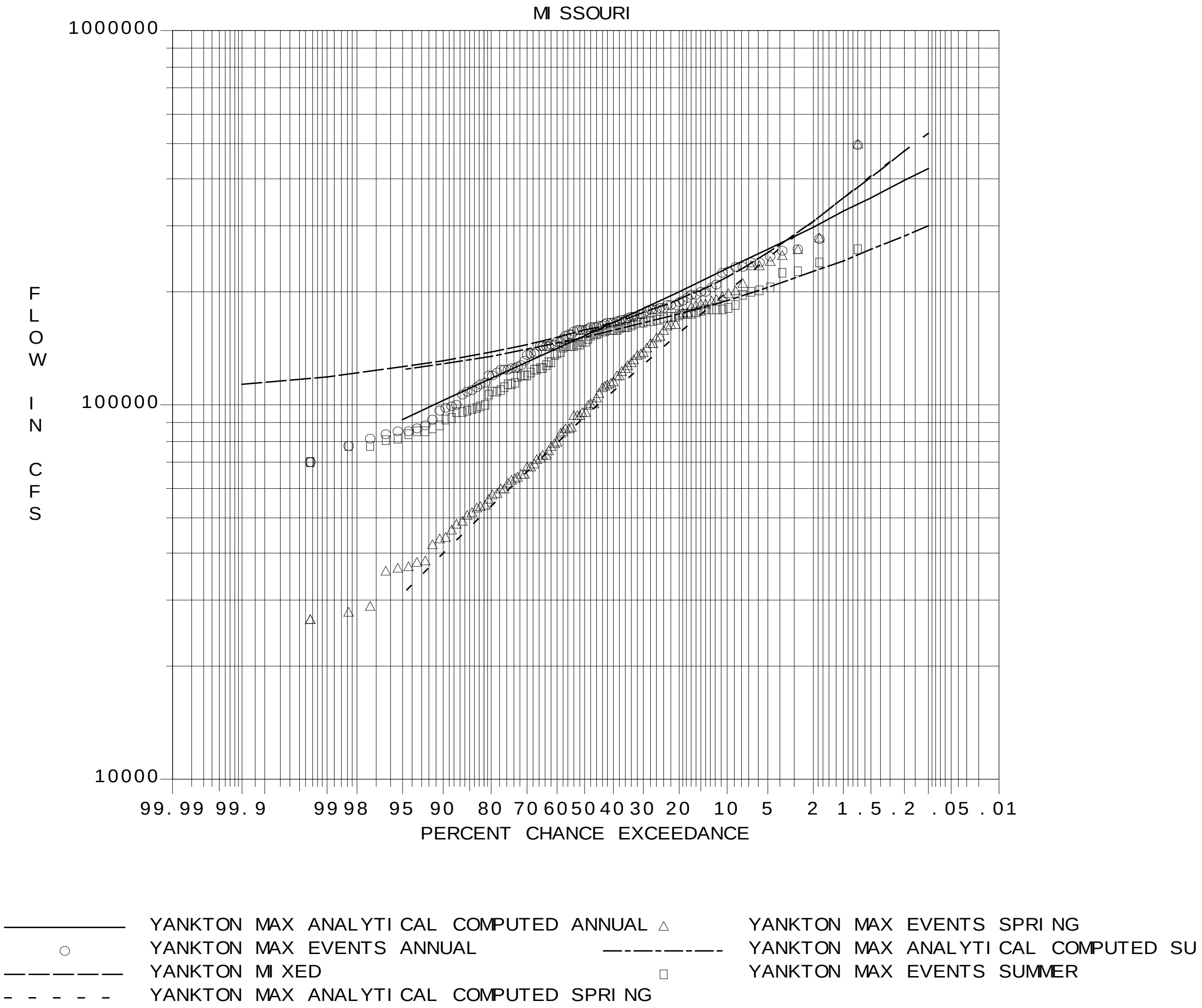


Figure 4.1c: Missouri River, Yankton, SD, (DA 279500 sq mi, period 1898-1997,) (Winter-Spring: January 1st – April 30th, Summer May 1 – December 31st) Distributions other than annual obtained by censoring values less than the median

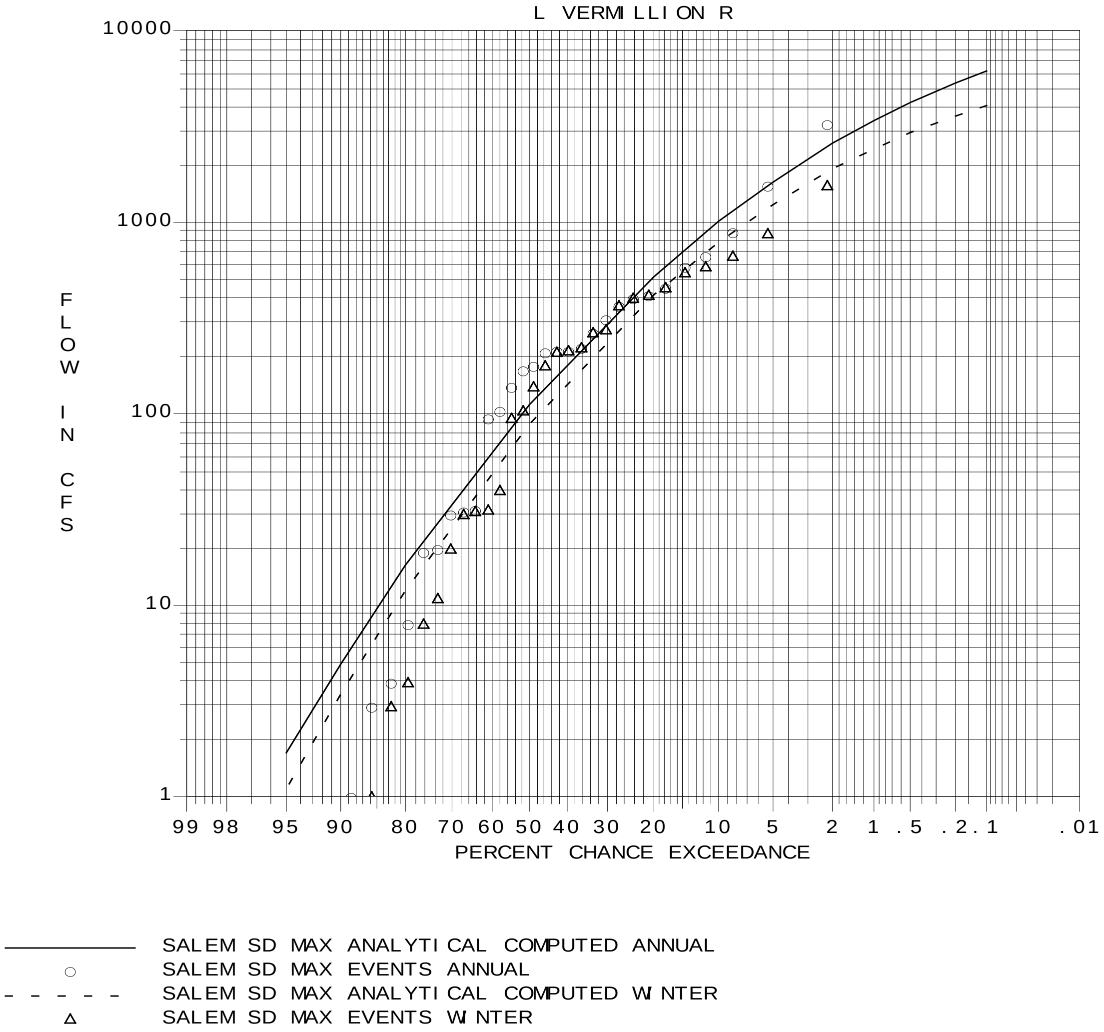


Figure 4.2: Little Vermillion River, Salem, SD, (DA 78 sq mi, Period 1967-1998) (Winter-Spring season, January 1 to April 30th)

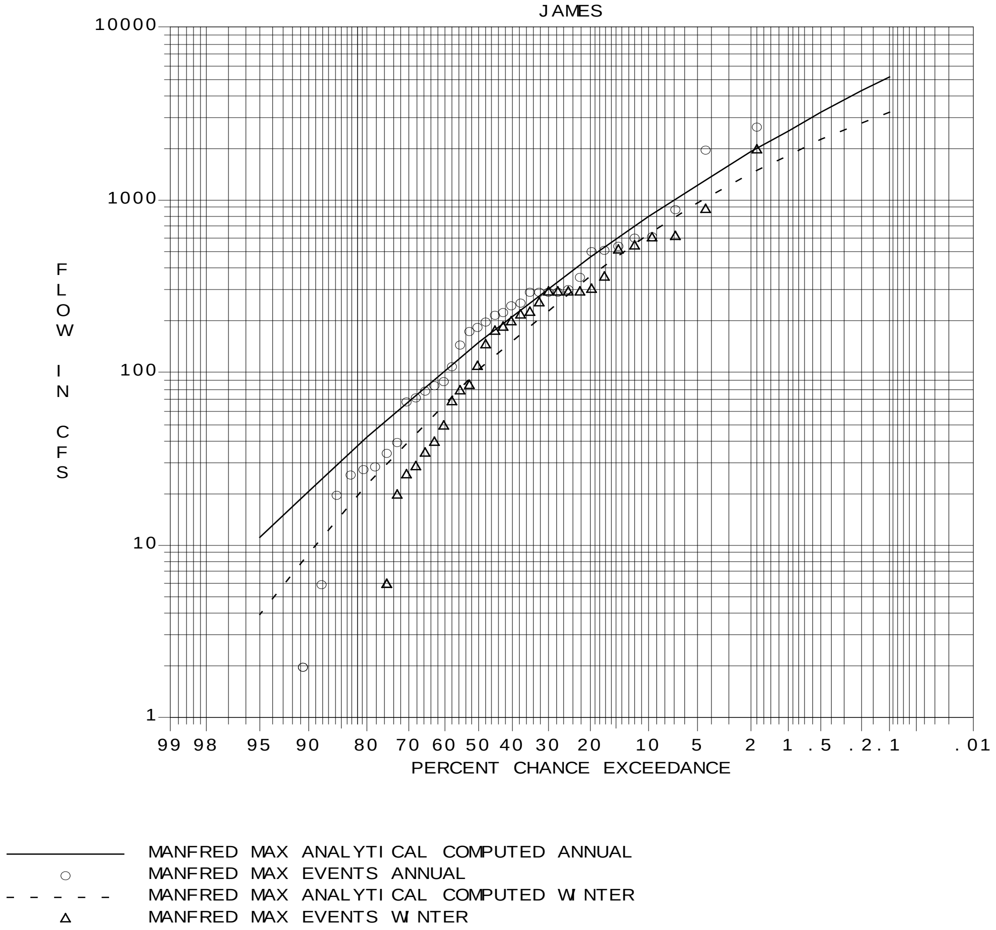


Figure 4.3: James River, Manfred, SD (DA 253 sq mi, period 1950-1994)
(Winter-Spring season, January 1 to April 30th)

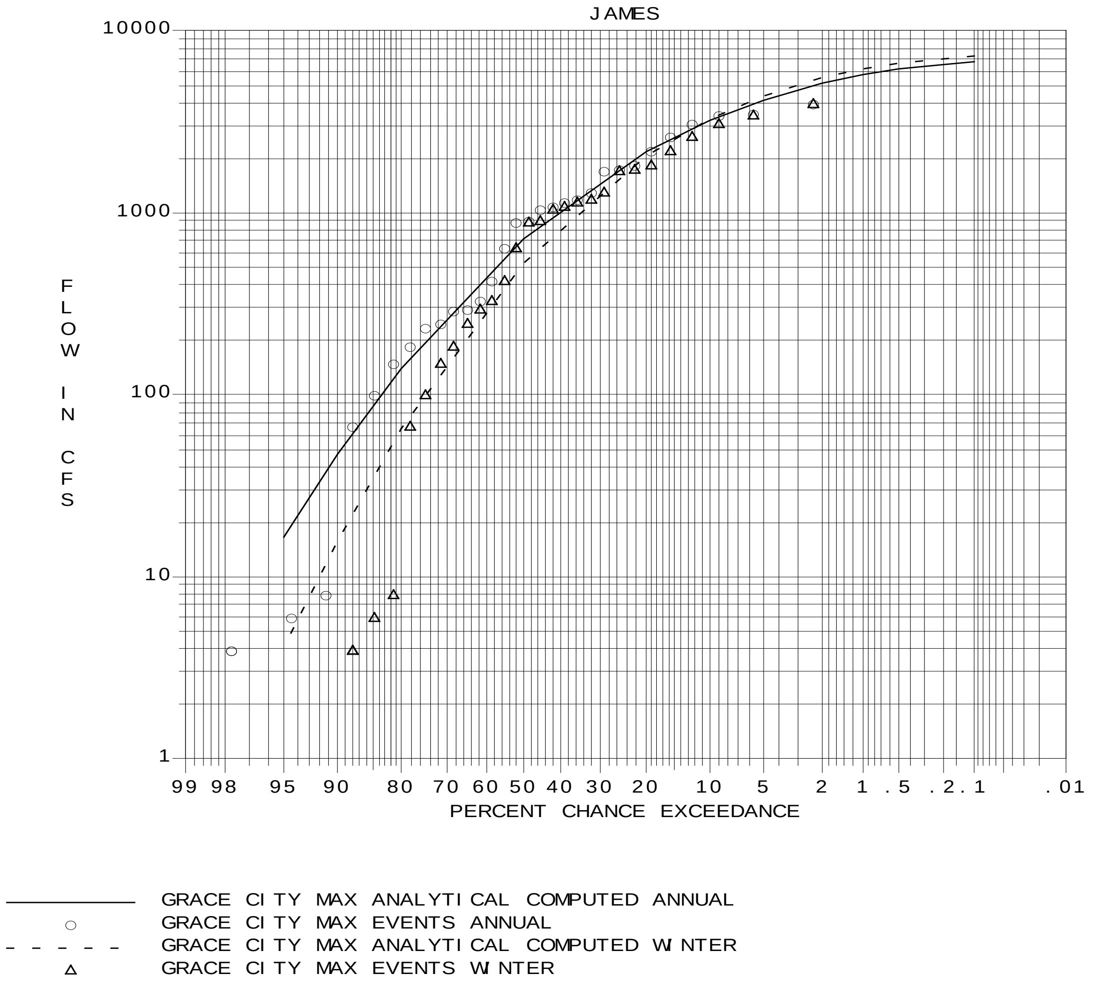


Figure 4.4: James River, Grace City, ND, (DA 1060 sq mi, period 1969-1998) (Winter-Spring season, January 1 to April 30th)

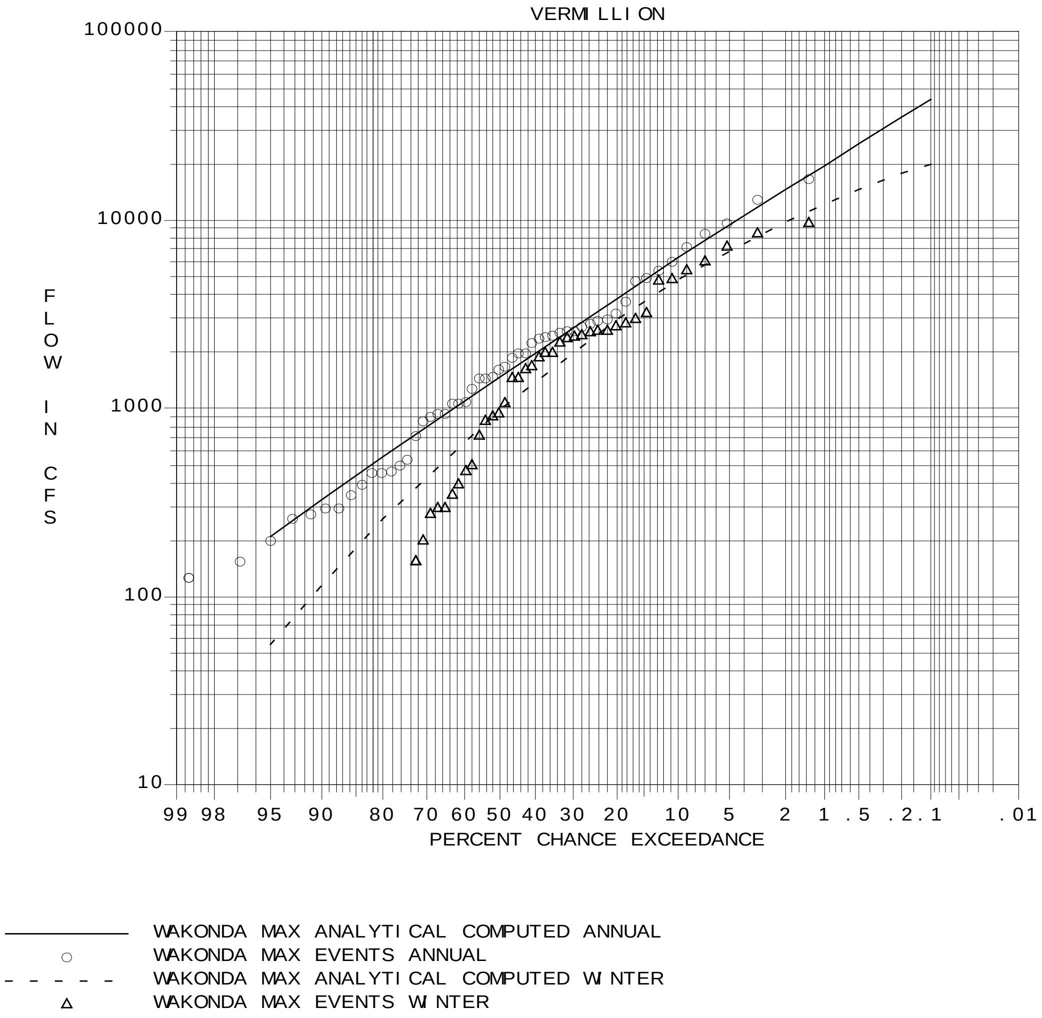


Figure 4.5: Vermillion River, Wakonda, SD (DA 2170 sq mi, Period 1946-1998) (Winter-Spring season, January 1 to April 30th)

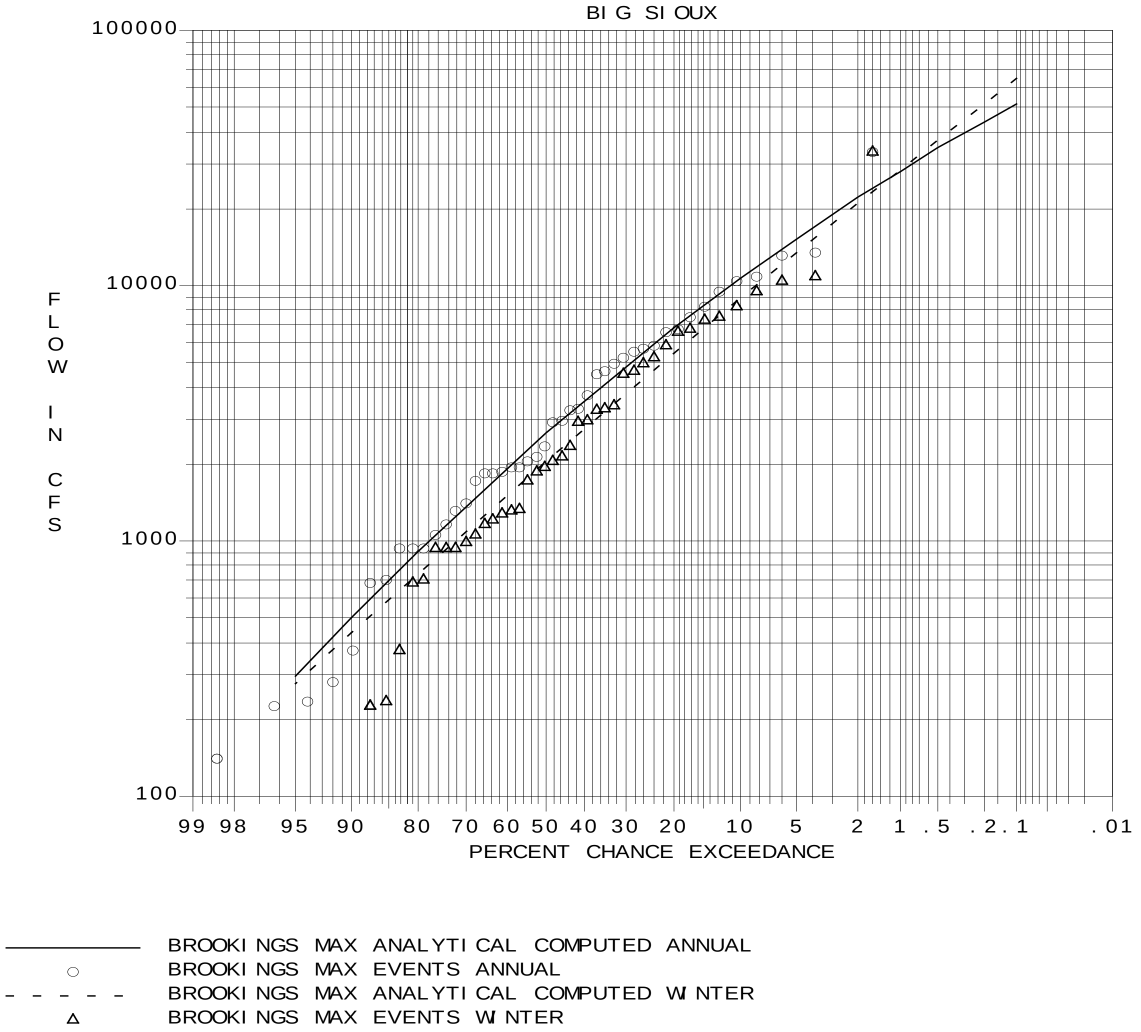


Figure 4.6: Big Sioux River, Brookings, SD (DA 3898 sq mi, Period 1954-1998) (Winter-Spring season, January 1 to April 30th)

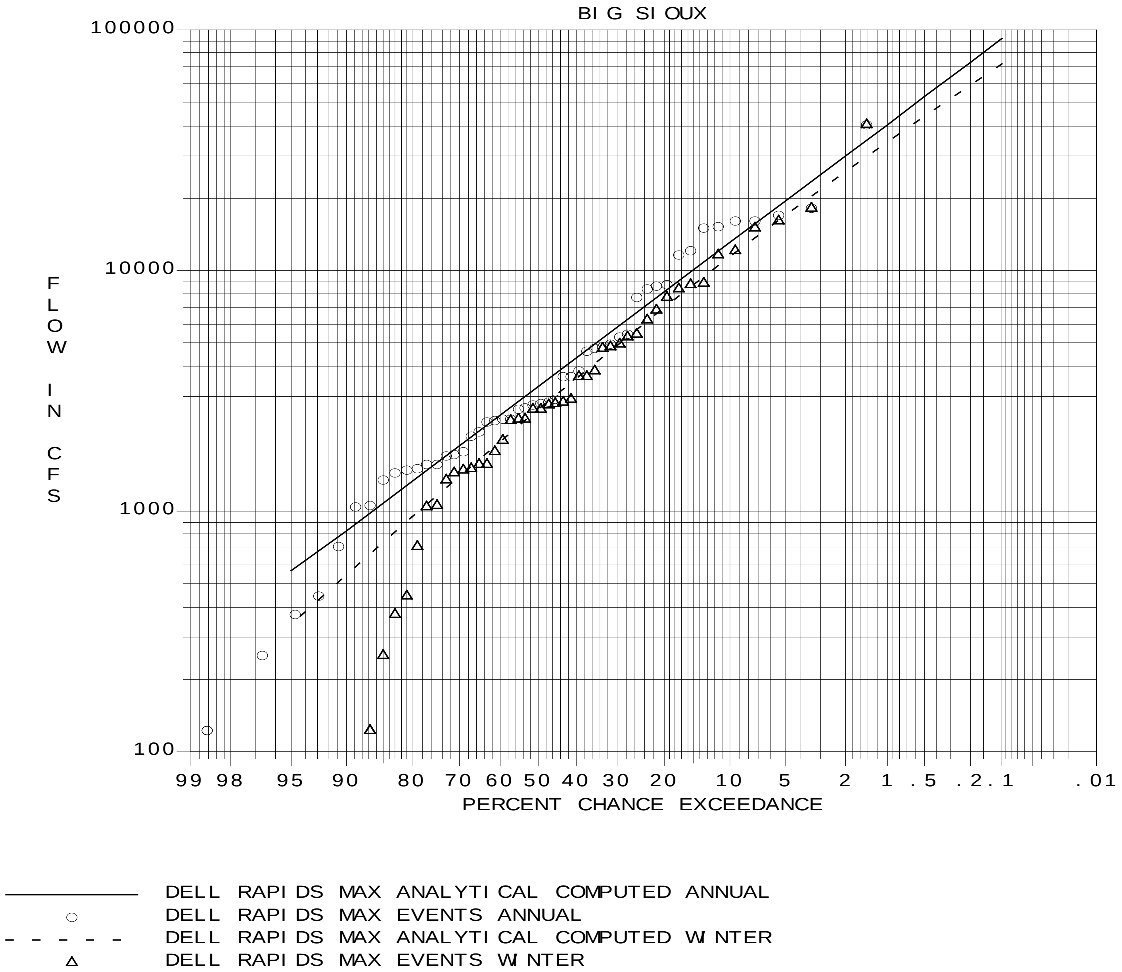


Figure 4.7: Big Sioux River, Dell Rapids, (DA 4483 sq mi, Period 1949-1998) (Winter-Spring: January 1st – April 30th, Summer May 1 – December 31st)

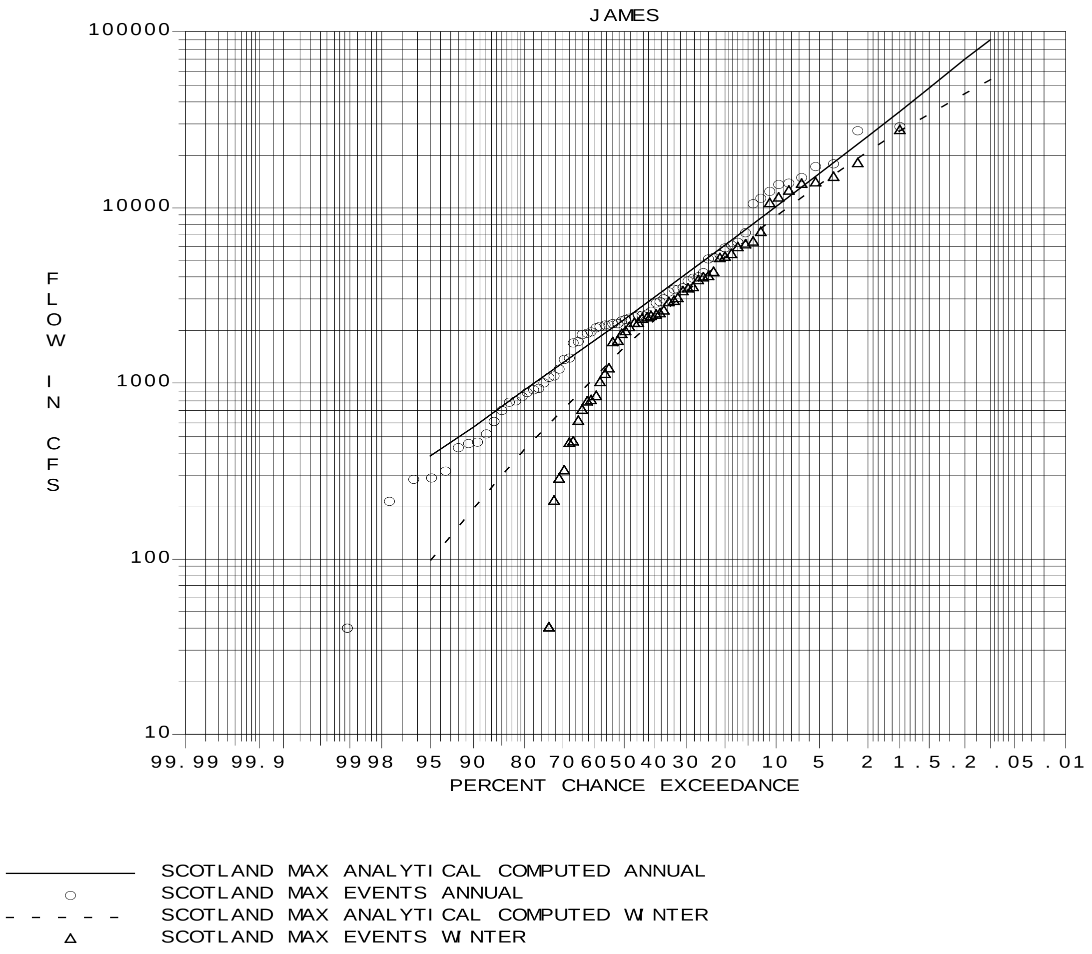


Figure 4.8: James River, Scotland, SD (DA 20653 sq mi, period 1929-1998) (Winter-Spring: January 1st – April 30th, Summer May 1 – December 31st)

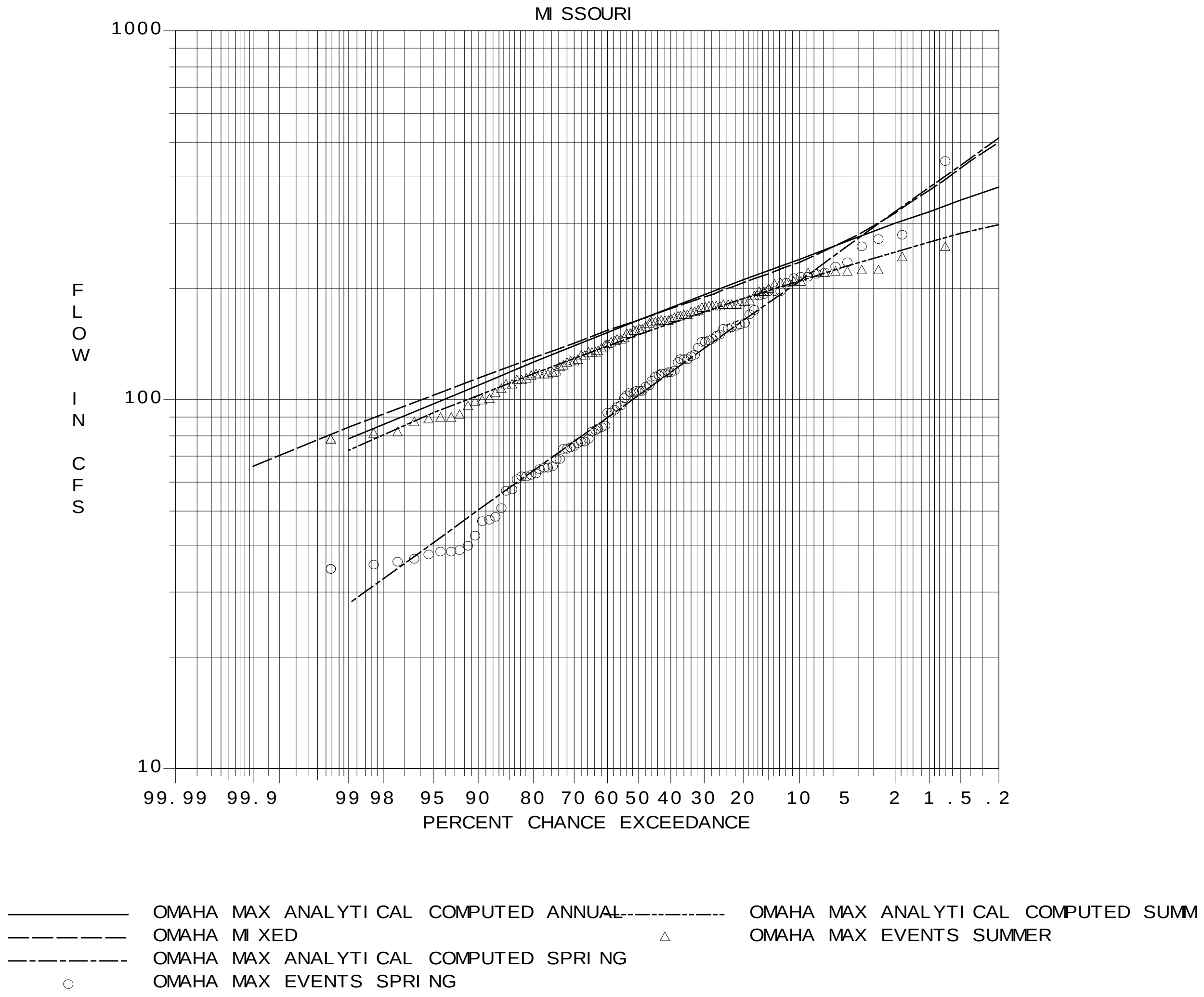


Figure 4.9: Missouri River, Omaha, NE, (DA 322800 sq mi, period 1898-1997) (Winter-Spring: January 1st – April 30th, Summer May 1 – December 31st)

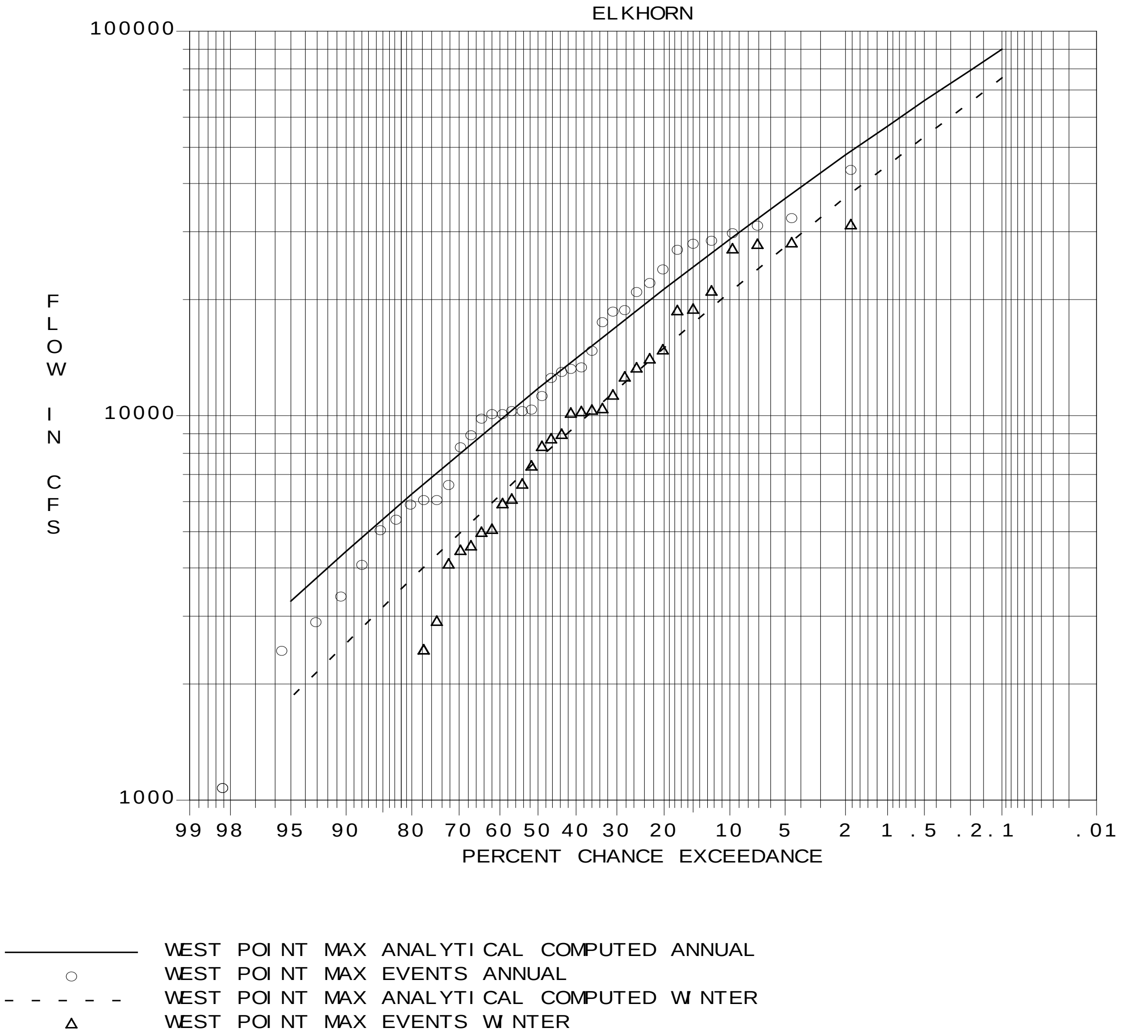


Figure 4.10: Elkhorn River, West Point, NE (DA 510 sq mi, period 1961-1998) (Winter-Spring season, January 1 to April 30th)

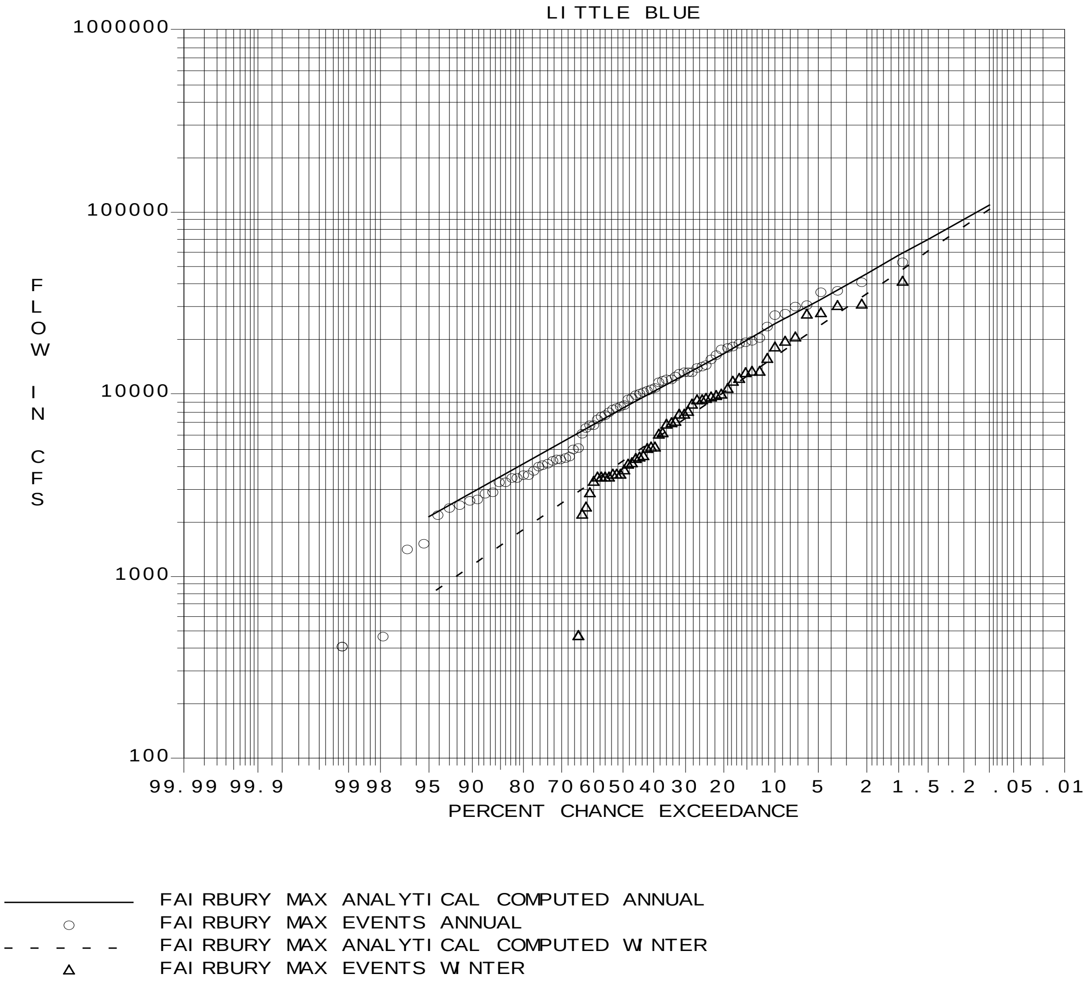


Figure 4.11: Little Blue River, Fairbury, NE (DA 2350 sq mi, Period 1908-1998) (Winter-Spring season, January 1 to April 30th)

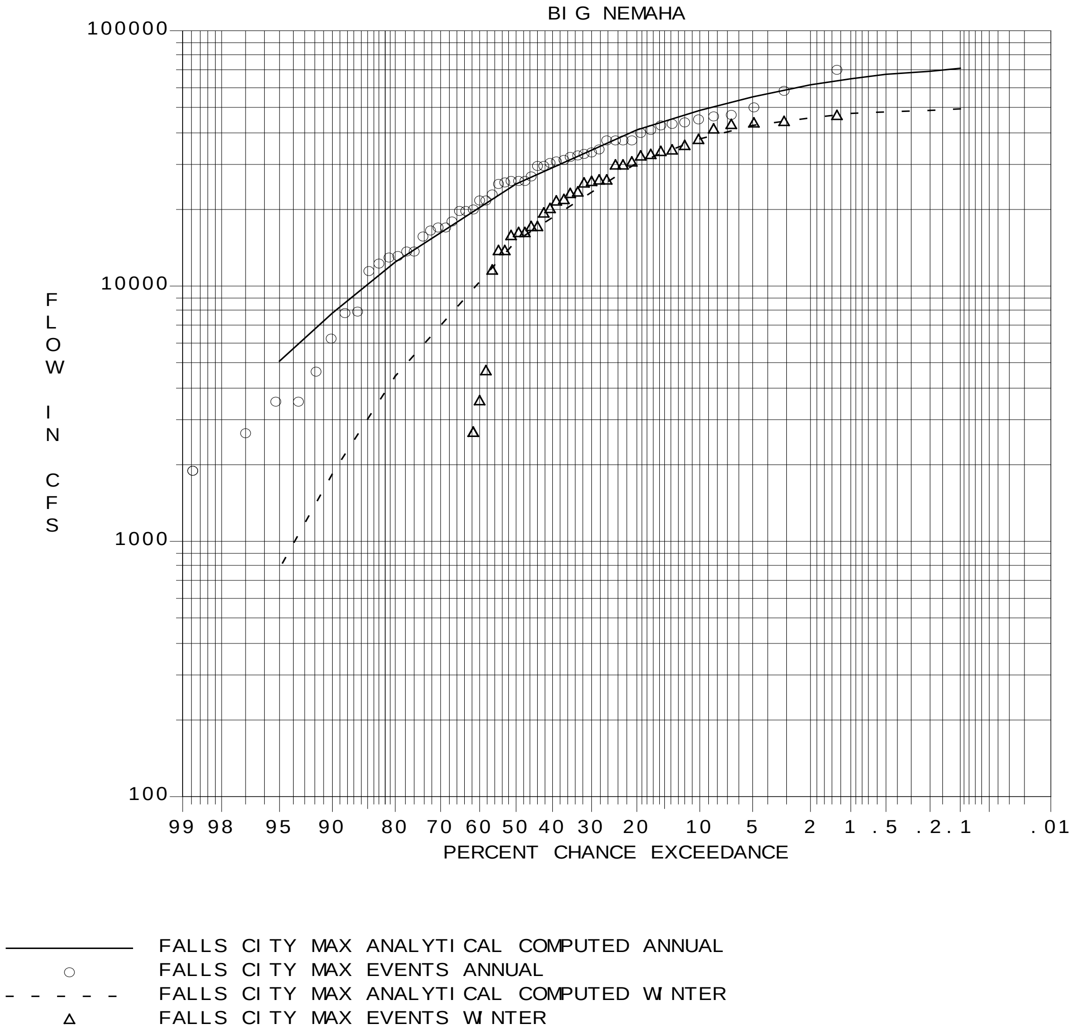


**Figure 4.12: Big Nemaha, Falls City, NE (DA 1340, Period 1941-1998)
(Winter-Spring season, January 1 to April 30th)**

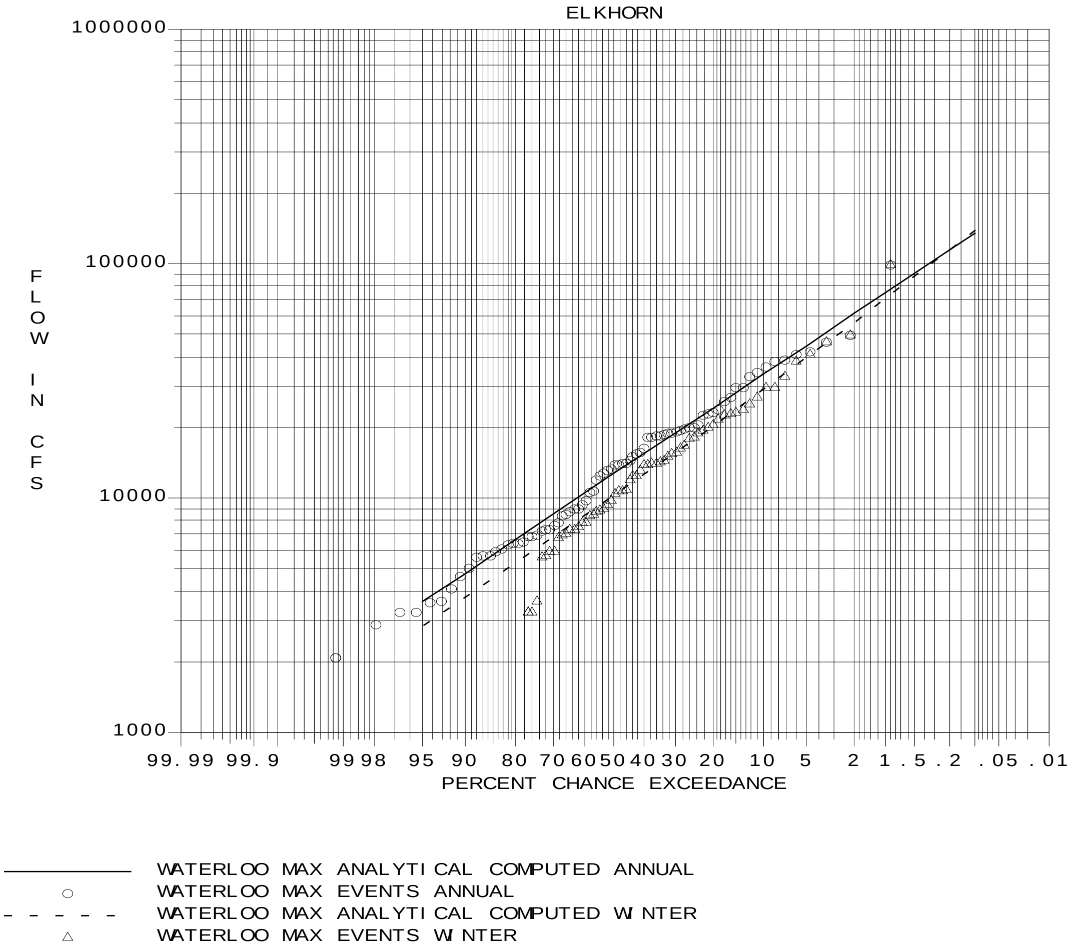


Figure 4.13: Elkhorn River, Waterloo, NE, (DA 6900 sq mi, period 1899-1998) (Winter-Spring season, January 1 to April 30th)

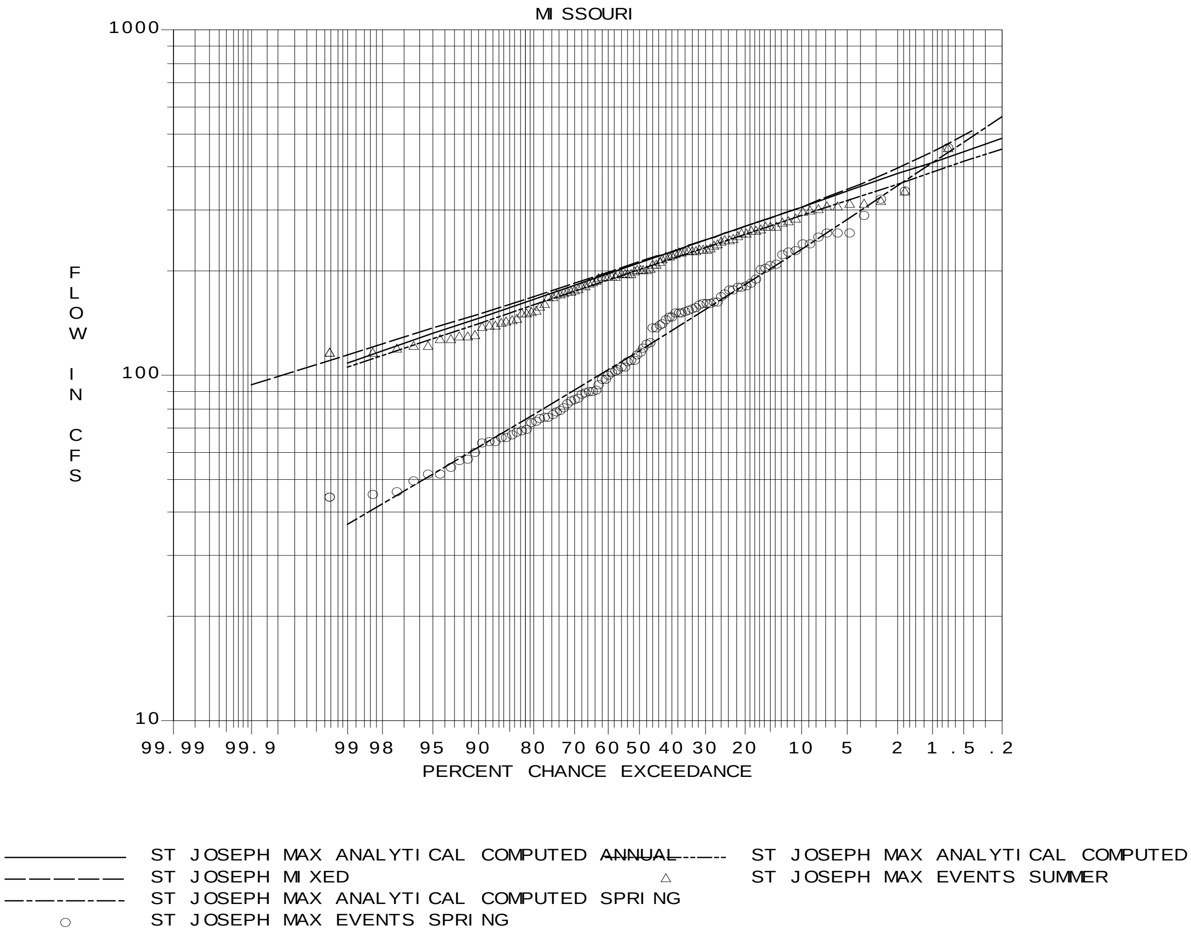


Figure 4.14a: Missouri River, St. Joseph, MO (Drainage Area 420300 sq mi, Period 1898-1997) (Winter-Spring: January 1st – April 30th, Summer May 1 – December 31st)

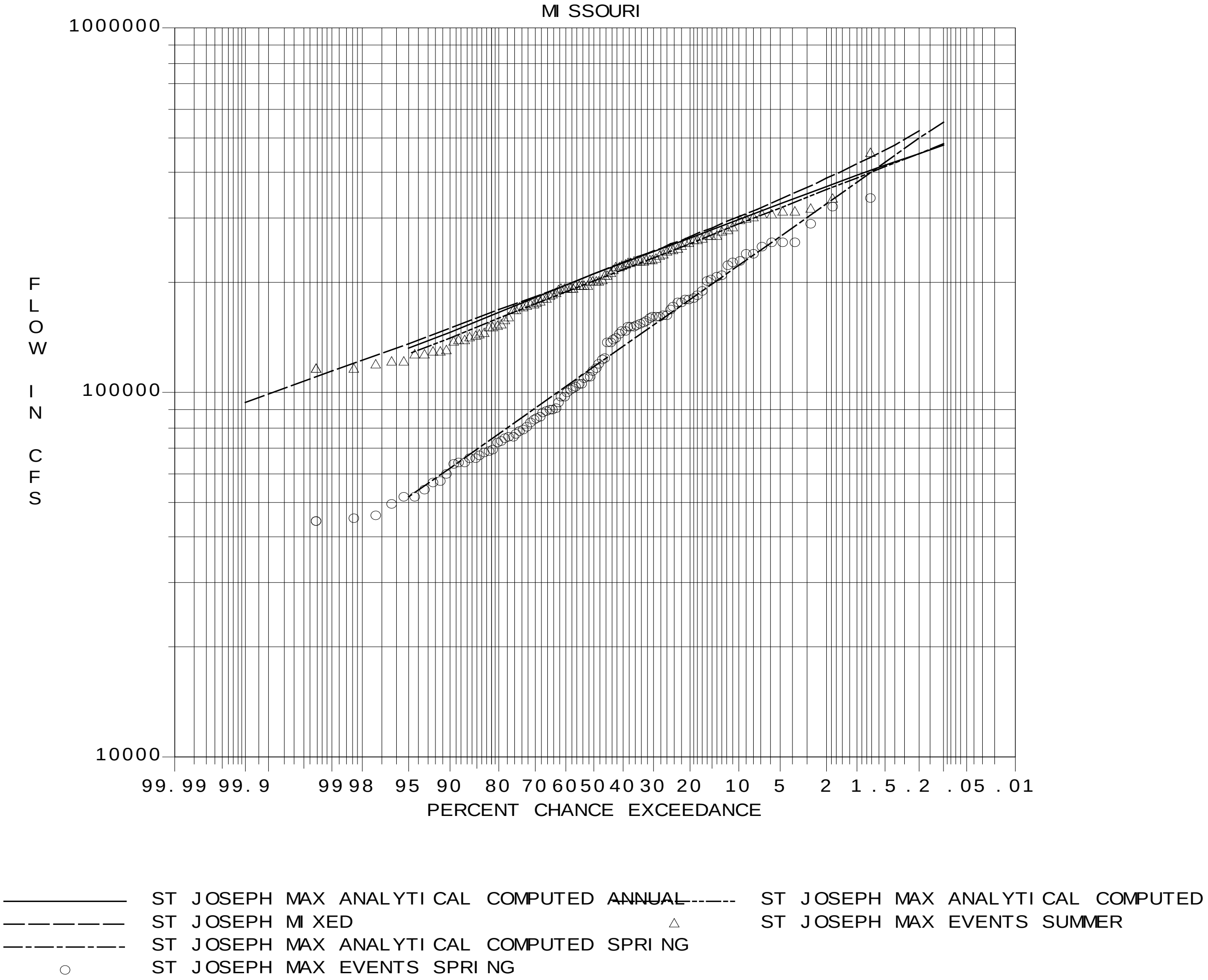


Figure 4.14b: Missouri River, St. Joseph, MO (Drainage Area 420300 sq mi, Period 1898-1997, minus 1952)
(Winter-Spring: January 1st – April 30th, Summer May 1 – December 31st)

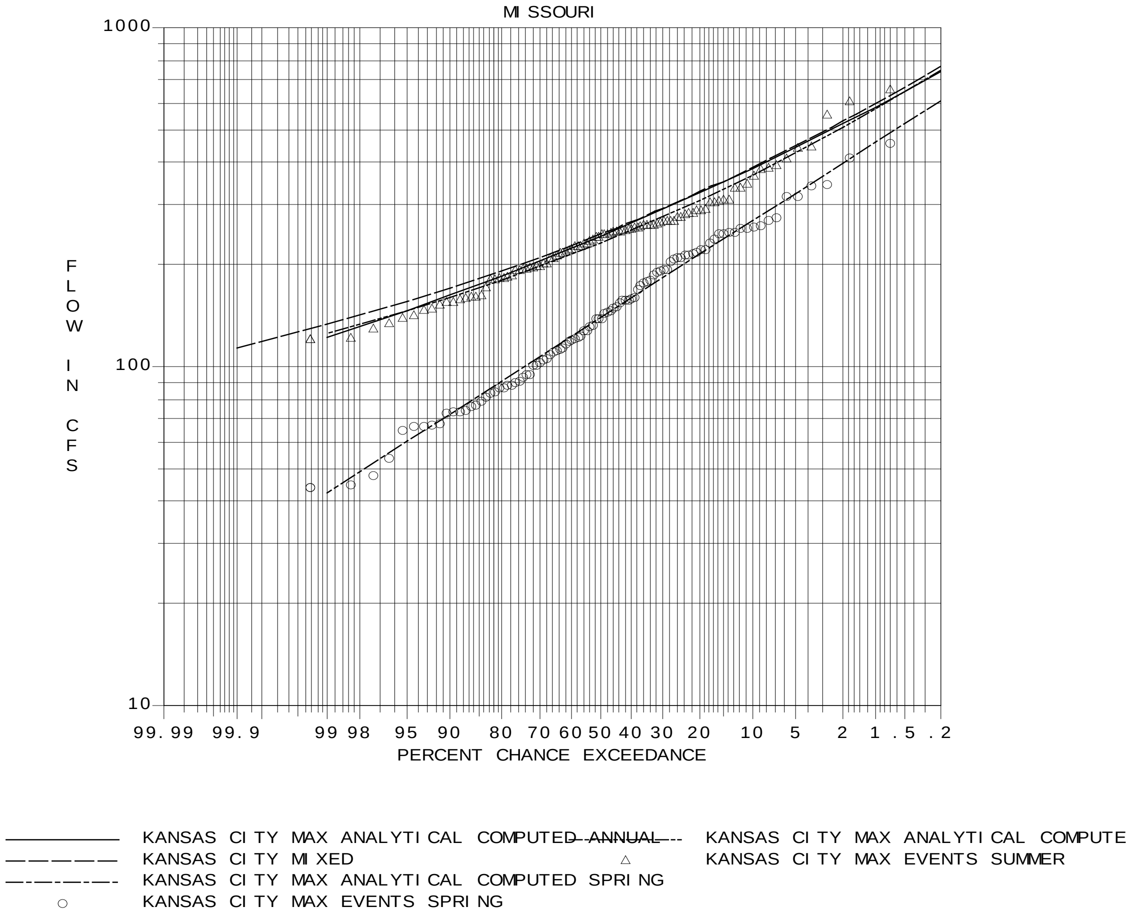


Figure 4.15: Missouri River, Kansas City, KS, (DA 485200 sq mi, period 1898-1997) (Winter-Spring: January 1st – April 30th, Summer May 1 – December 31st)

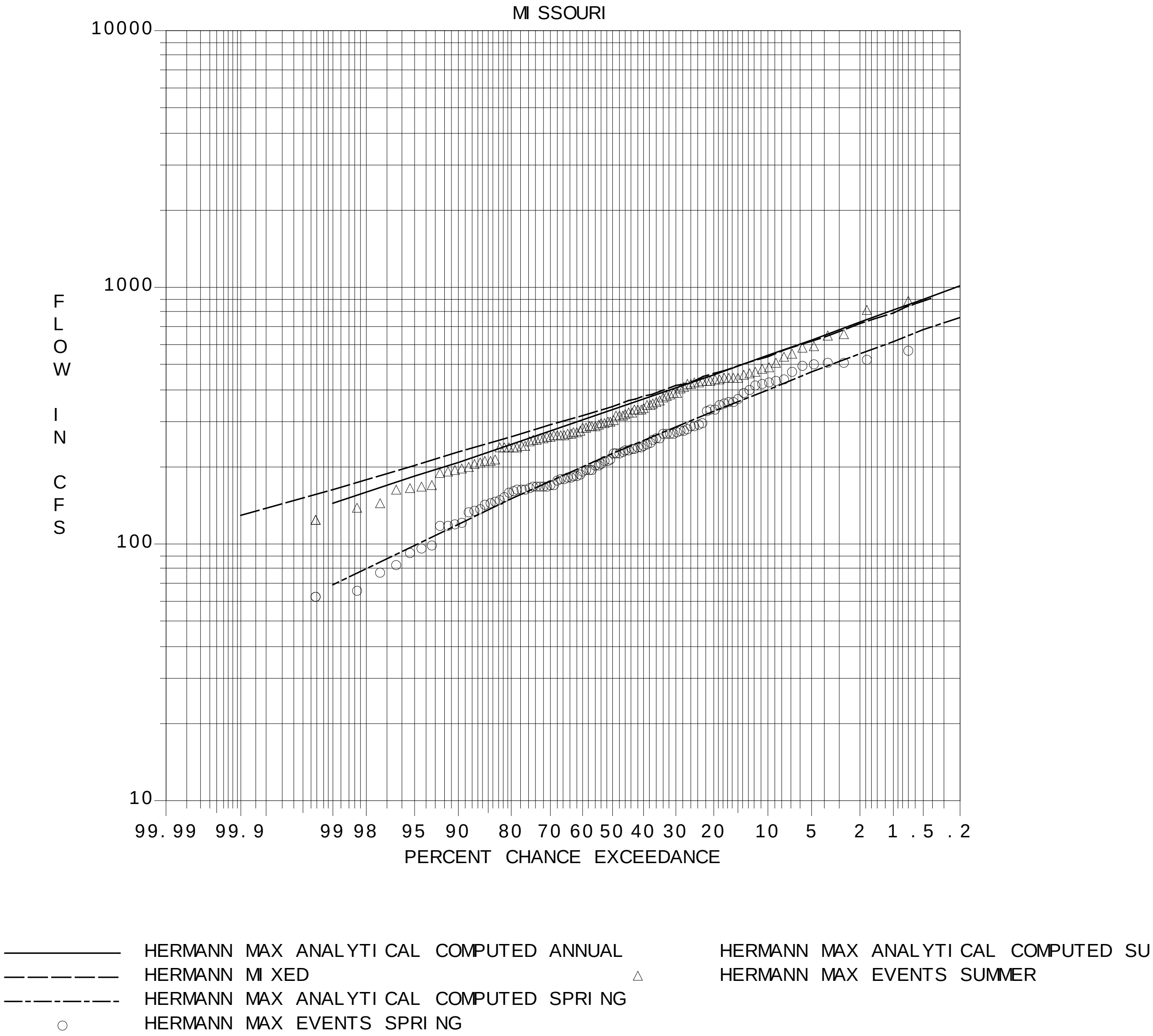


Figure 4.16: Missouri River, Hermann, MO, (DA 528120 sq mi, period 1898-1997) (spring: January 1st – April 30th, summer May 1 – December 31st)

4.4 Mixed Distribution Analysis Upper Mississippi River Basins above confluence with Missouri River

A comparison of annual and seasonal flood distributions was made for both tributary and mainstem gages unaffected by regulation. A comparison of winter-spring and seasonal and annual distributions shown in figures (4.17-4.24) demonstrates the important influence of the 1993 flood (note that in some of these plots the summer season distribution is not shown because the Bulletin 17B procedure could not be used to estimate the distribution due to the number of missing events). In particular, the seasonal and annual distributions provide relatively close estimates of the 1% chance and greater floods for tributary and mainstream gages upstream of Keokuk, where the event of record occurred in 1993. At and downstream of Keokuk, the annual distribution corresponds more closely to the plotting position of the 1993 event than the winter-spring distribution.

The 1993 event presents a particularly difficult interpretation and estimation problem. Although the peak occurred in the summer, other peaks occurred throughout the spring and the summer which rivaled the summer peak. Certainly, this event was a rainfall flood and not typical of snowmelt-rainfall floods occurring upstream of Clinton. This observation is consistent with the regional boundaries proposed based on climatology as described in section 3.

Unfortunately, the mixed distribution analysis does not provide any guidance on the location of the regionalization boundaries. None of the gages investigated show a location where a mixed distribution of snow and rainfall floods would be more appropriate than an investigation of the annual distribution. Primarily the period from late winter to early spring dominates the flooding record. The exception is the 1993 flood which is difficult to explain with either a seasonal or mixed distribution.

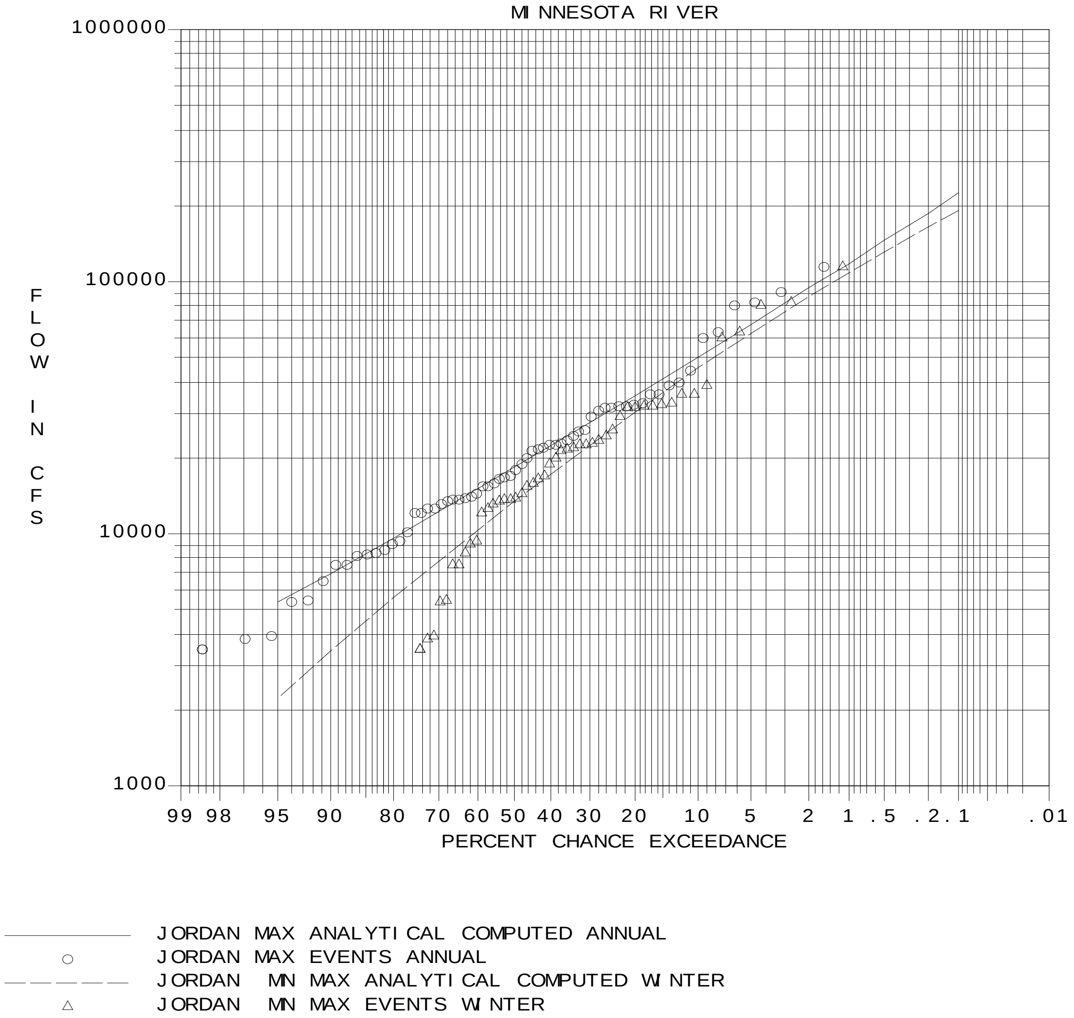


Figure 4.17: Comparison of Annual and Winter-Spring (November 1 to June 15) frequency curves, Minnesota River near Jordan, Minnesota

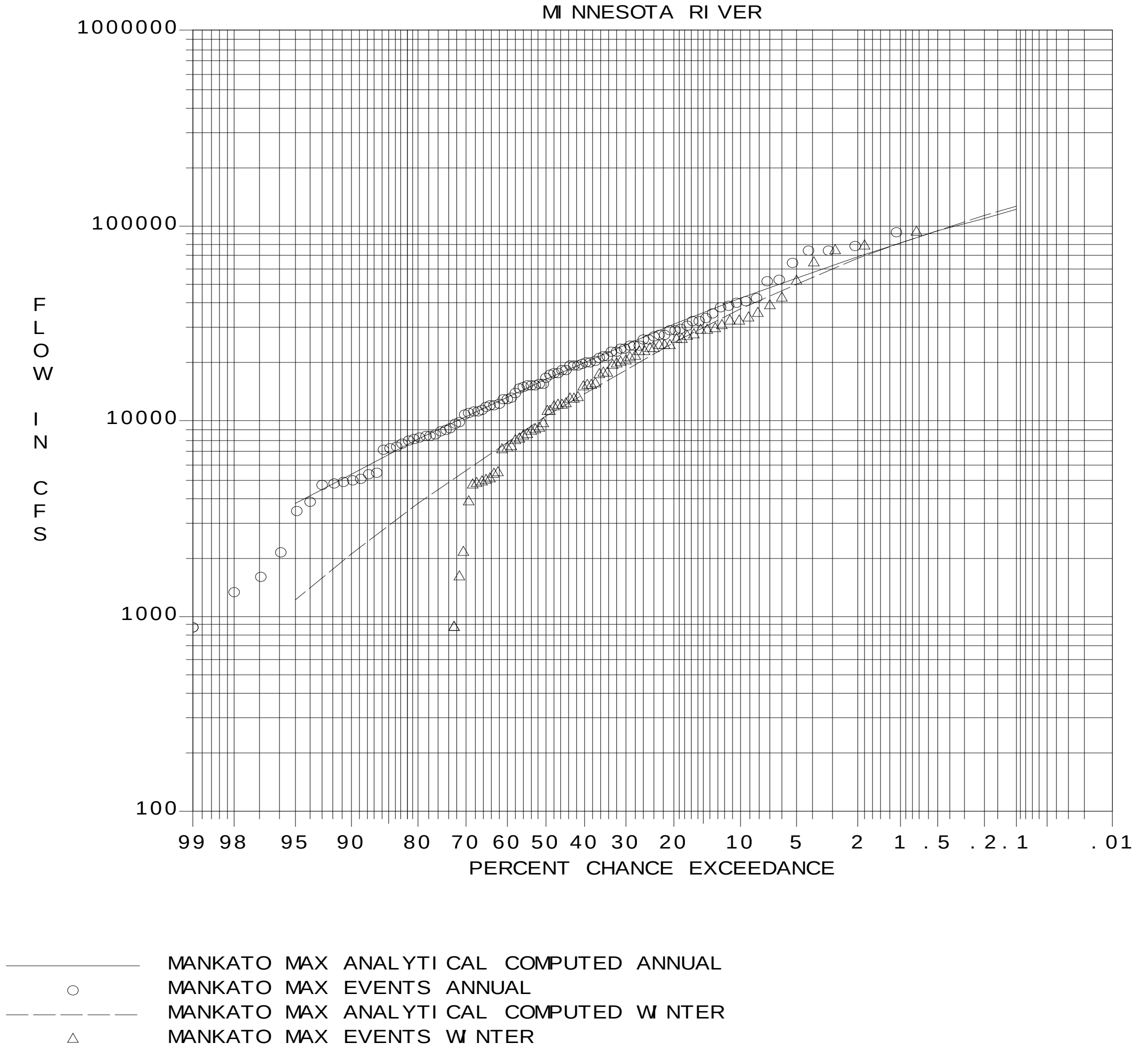


Figure 4.18: Comparison of Annual and Winter-Spring (November 1 to June 15) frequency curves, Minnesota River near Mankato, Minnesota

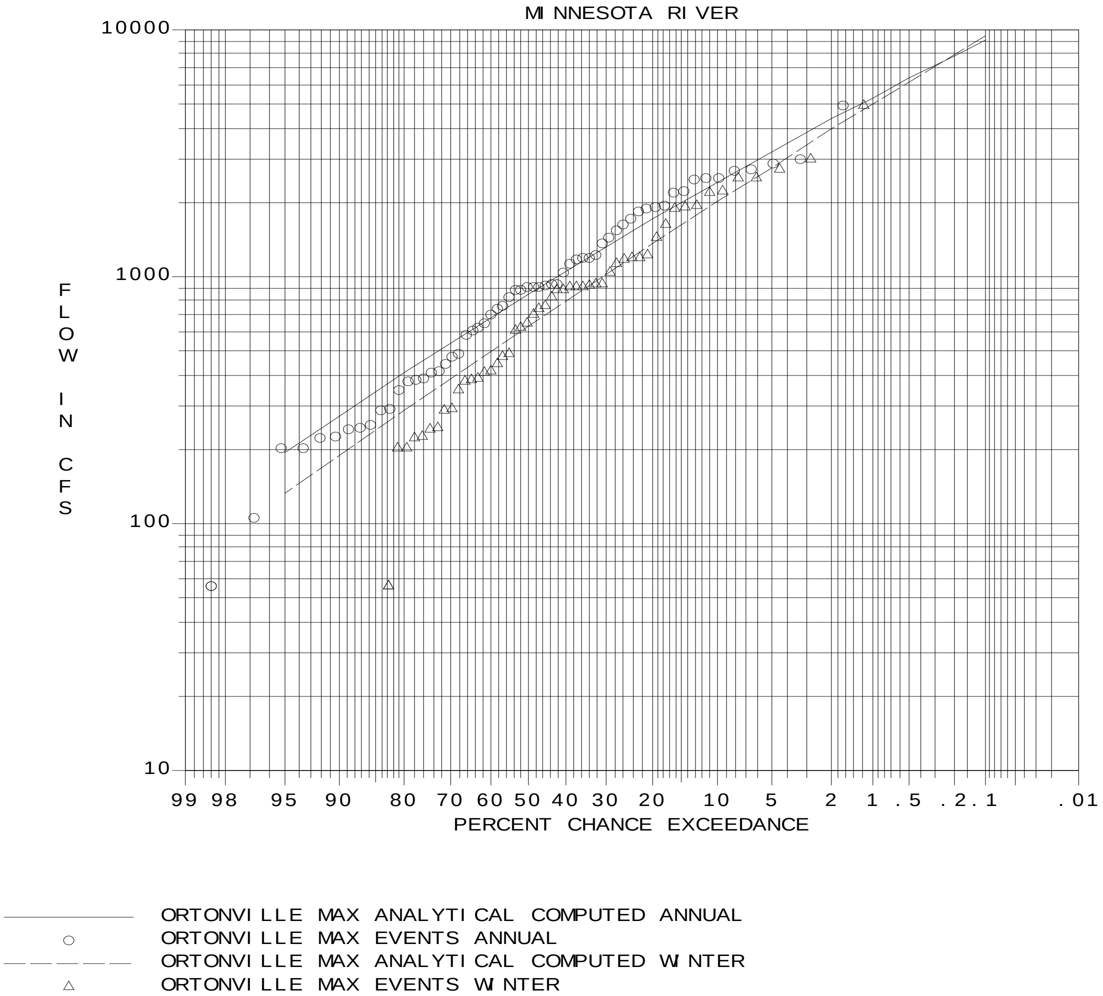


Figure 4.19 Comparison of Annual and Winter-Spring (November 1 to June 15) frequency curves, Minnesota River near Ortonville, Minnesota

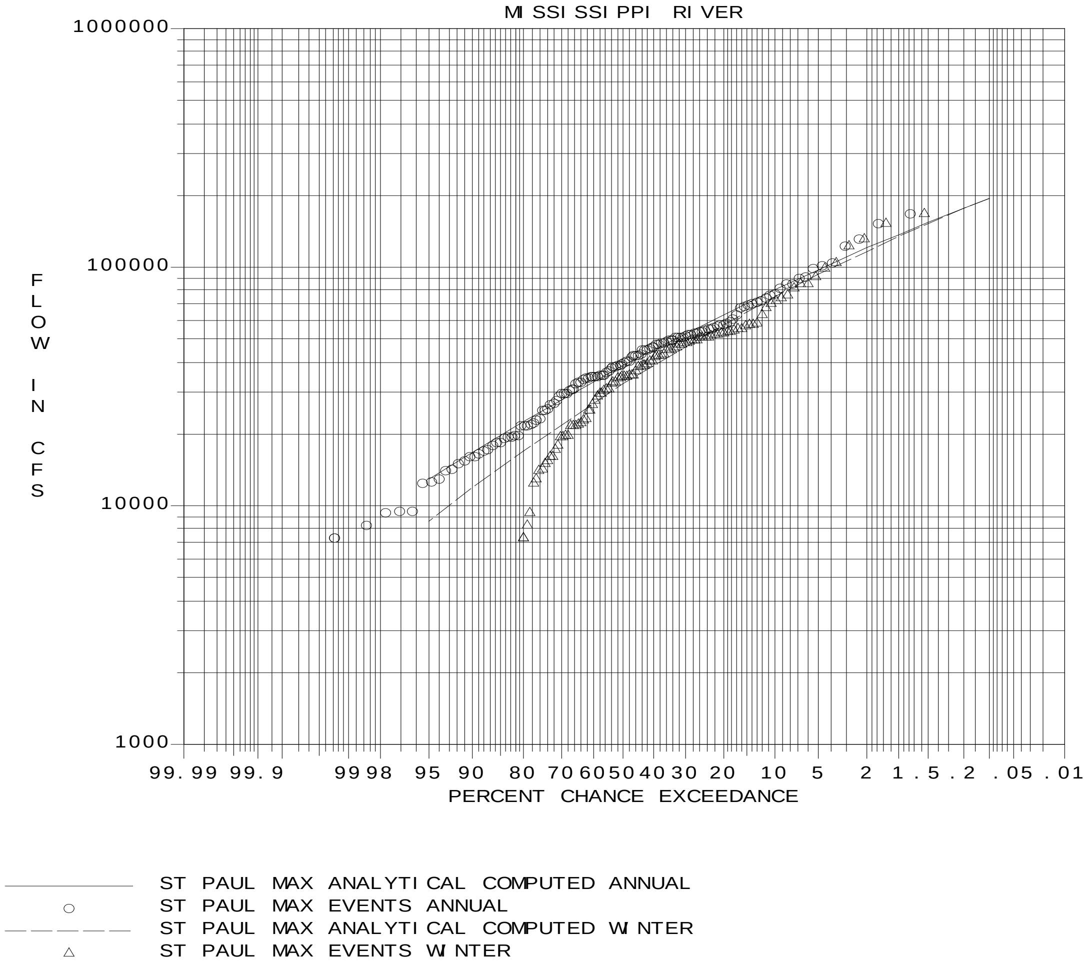


Figure 4.20: Comparison of Annual and Winter-Spring (November 1 to June 15) frequency curves, Mississippi River near St. Paul, Minnesota

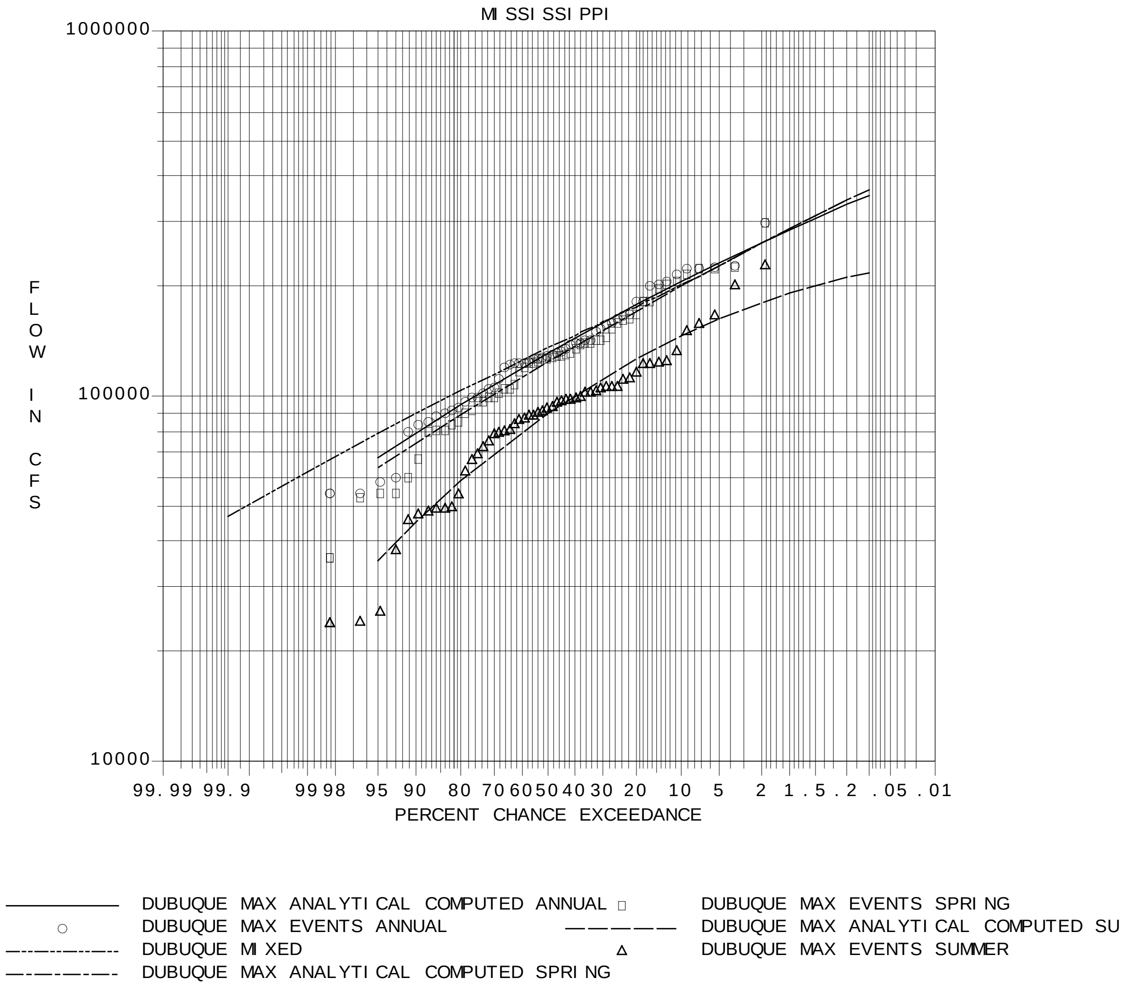


Figure 4.21: Comparison of Annual and Winter-Spring (November 1 to June 15) frequency curves, Mississippi River, Dubuque, Iowa

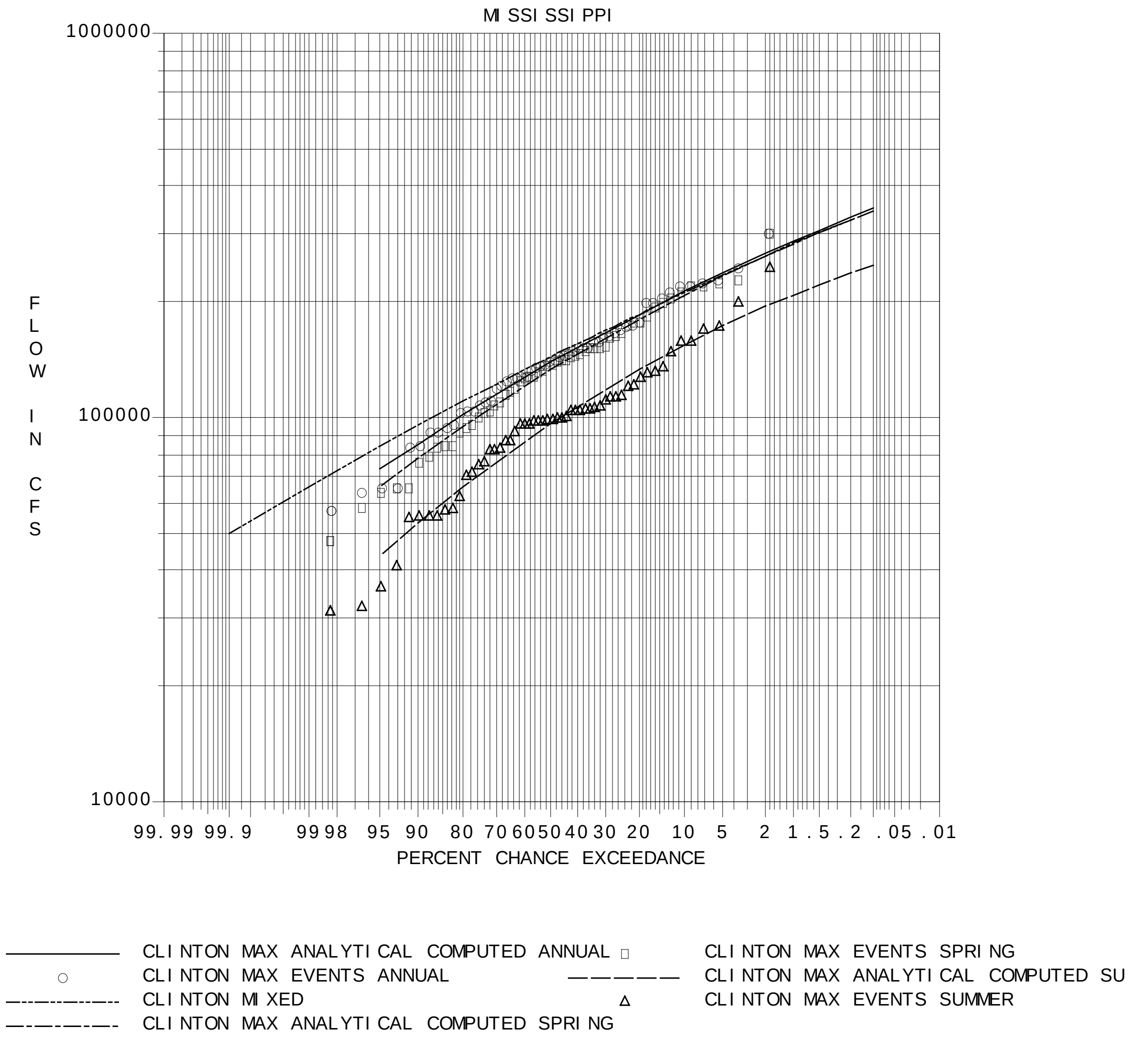


Figure 4.22: Comparison of Annual and Winter-Spring (November 1 to June 15) frequency curves, Mississippi River, Clinton, Iowa

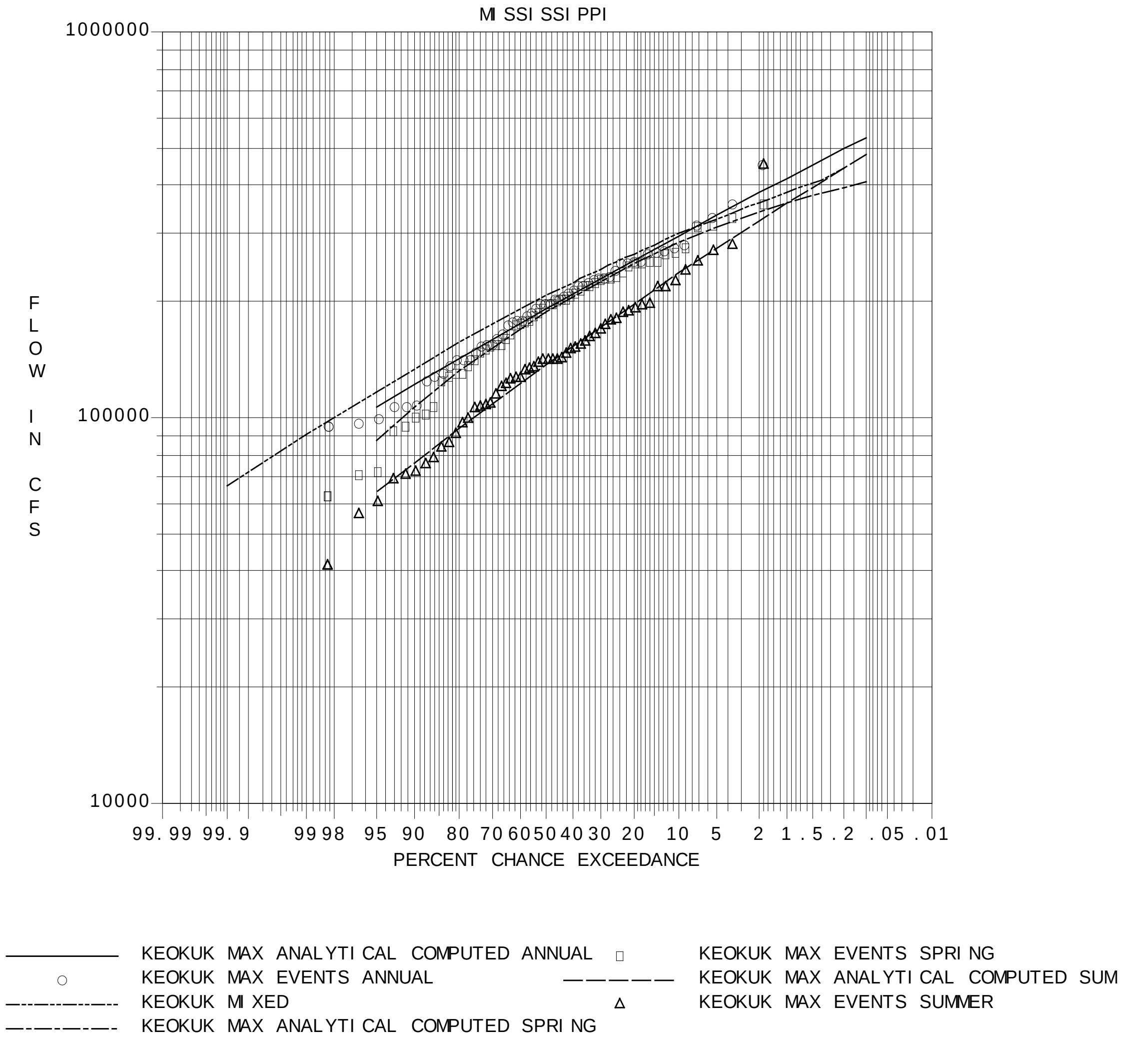


Figure 4.23: Comparison of Annual and Winter-Spring (November 1 to June 15) frequency curves, Mississippi River, Keokuk, Iowa

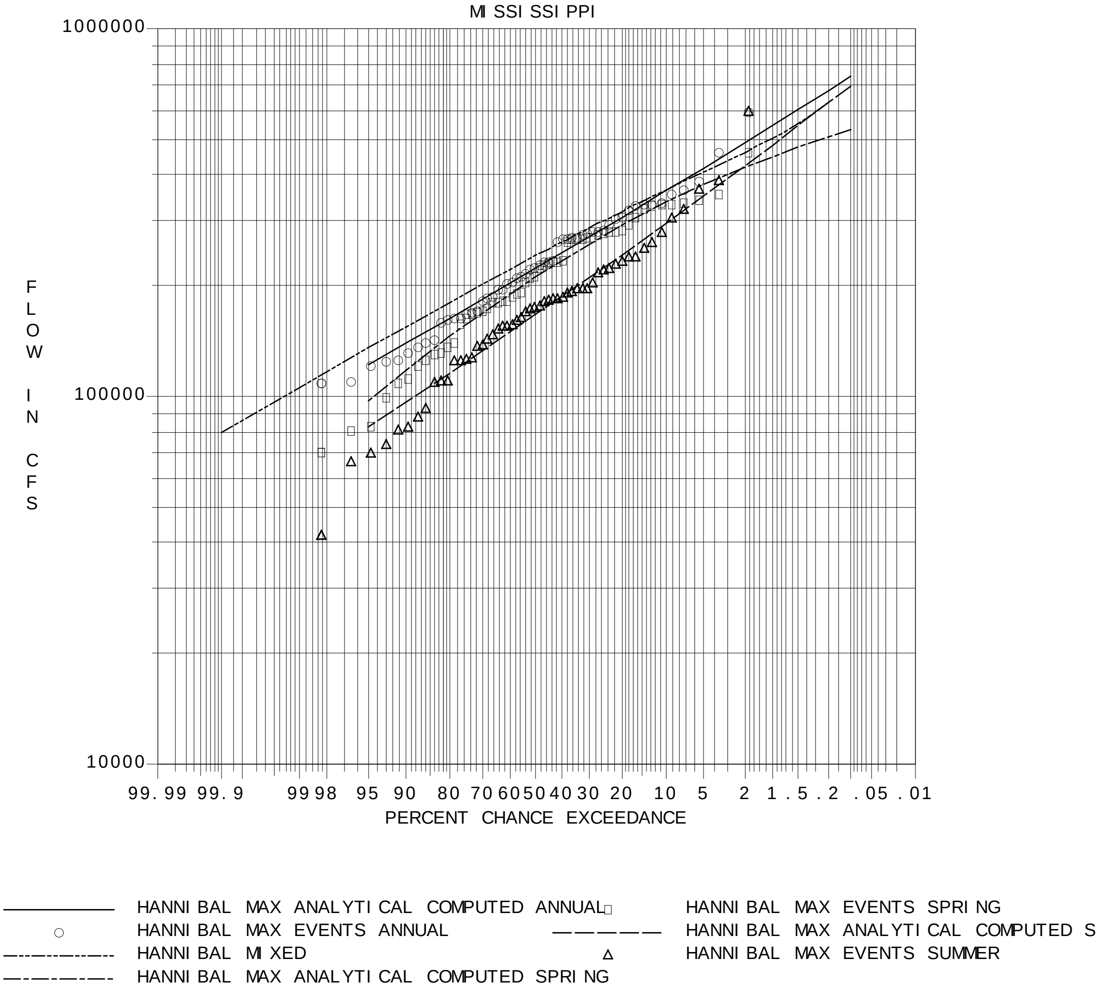


Figure 4.24: Comparison of Annual and Winter-Spring (November 1 to June 15) frequency curves, Mississippi River, Hannibal, Missouri

4.5 **Regional boundary recommendations**

The regional boundaries for estimating flood frequency distributions can be reasonably designated given the importance of channel modifications, the influence of climate, the variation of flood statistics across the study area and the importance of mixed distributions. The Missouri River should be divided into at least two-regions given the mixed distribution nature of the flood population above Kansas City. The transition for the Missouri River from its near natural state at Yankton to the engineered navigation channel beginning at Sioux City may argue for separate regions.

The region to use for the Mississippi are less clear. The St. Paul, Winona and Illinois River gages may not belong in the same region as the remaining gages on the Mississippi River. The sample statistics of the annual flood series for these gages does not correspond well with the statistic of the remaining gages. The lack of correspondence of the St. Paul and Winona gages may be due to the combined influence of drainage area and climate. Perhaps the importance of rain on snow related flooding separates these gages from the other Mississippi River gages. Certainly, these gages do not seem to belong in the same region as the Illinois River gages.

The statistical analysis argues for placing all the gages on the Mississippi River in the same region. This is somewhat surprising given an expected impact of the confluence with the Missouri River. Still, the coefficient of variation, discordancy and heterogeneity statistics do not argue for separating gages at the confluence, nor does any argument with regard to climate.

A sensitivity analysis performed in the next section will reveal the importance of selecting regional boundaries to obtaining final estimates of the flood frequency distributions.

5 Regionalized flood quantiles (flows for given exceedance probabilities)

5.1 Introduction

This section provides flood quantile estimates obtained from various approaches to regionalizing flood distribution statistics. Section 5.2 quantifies the difference between the flood quantiles estimated from the annual series and the mixed population for the gages above Kansas City on the Missouri River. In the remaining analyses the assumption is made that the mixed distribution provides a superior description of the flood distributions in this reach of the river. As is apparent from the comparisons, the mixed distributions lead to significantly greater flood quantile estimates; and consequently is a major decision in the analysis.

The TAG and the Corps Districts have a different perspective on the best method for regionalizing flood frequency distributions. The TAG recommended employing the log-Pearson III/method of moments distribution/estimation pairing as recommend in Bulletin 17B (IACWD, 1982), except a regional skew should be used in place of the at-site skew estimate. The districts felt that it would be simpler to regionalize estimates by developing regression relationships between flood quantiles and either drainage area or river mile. Section 5.3 and section 5.4 explore both methods as applied to different scenarios for defining regional boundaries in the study area. Section 5.5 provides a discussion on the merits of using drainage area versus river mile for interpolation of flood statistics or quantiles. Comparison of estimates and recommendations are presented in section 6.

5.2 Comparison of Annual and Mixed Distribution Quantiles

The annual and mixed distribution estimates were compared for the following scenarios:

1) annual and mixed distributions determined for the full period of record (Table 5.1);
2) annual and mixed distribution determined for the full period of record, 1952 event deleted (Table 5.2)
3) annual distribution full period of record, mixed data censored below the median (Table 5.3)

Scenario (2) was investigated to examine the influence of the 1952 event, which is significantly larger than any other event and might be considered and outlier. Scenario (3) was investigated because the low-outlier censoring procedure in Bulletin 17B was developed for annual series and not for the seasonal series used in the mixed distribution analysis. Plots of the spring series (see section 4.3) reveal the contribution of the small events to the relatively large variance of this season's distribution. Consequently, censoring below the median was investigated to provide an alternative to the low-outlier censoring developed for annual series in Bulletin 17B. As is summarized in Table 5.4, the difference between the 1% and 0.2% annual and mixed series is significant for the scenarios tested, with the smallest difference coming for scenario (3), median censoring.

Consequently, the decision to use the mixed distribution approach will have a significant impact on the frequency analysis irrespective of the scenario chosen. In the following sections, scenario (1) is used in obtaining quantile estimates. Scenarios (2) and (3) were only explored to examine the sensitivity of the estimates to possible undue influence of the 1952 event or the deficiencies of the Bulletin 17B procedure in applications to mixed distributions.

Table 5.1: Comparison of at-site estimates of annual and mixed distributions, Yankton to St. Joseph, Missouri River, maximum annual daily flows

location	[1]Drainage area	1% LPIII	1% Mixed	[2]difference	0.2%LPIII	0.2%Mixed	[2]difference
Yankton	279500	328400	380200	0.16	397000	526000	0.34
Sioux City	314580	323600	369500	0.14	382800	495500	0.29
Decatur	316200	313000	362300	0.16	364500	486500	0.33
Omaha	322800	325800	372500	0.14	380200	501000	0.32
Nebraska	410000	376900	389400	0.03	437700	505200	0.15
Rulo	414900	385700	409400	0.06	445300	534000	0.20
St. Joseph	420300	416000	445000	0.07	487700	576500	0.18
average				0.11			0.26

[1]square miles, [2]fraction difference between annual LPIII and mixed distribution

Table 5.2: Comparison of at-site (systematic record) estimates of annual and mixed distributions, Omaha District Reach Yankton to St. Joseph, Missouri River, maximum annual daily flows, 1952 event deleted

location	[1]Drainage area	1% LPIII	1% Mixed	[2]difference	0.2%LPIII	0.2%Mixed	[2]difference
Yankton	279500	277300	354600	0.28	309300	463400	0.50
Sioux City	314580	275500	353800	0.28	302700	468200	0.55
Decatur	316200	273500	346700	0.27	300200	453600	0.51
Omaha	322800	291400	352500	0.21	324400	458200	0.41
Nebraska	410000	342700	374800	0.09	381300	496000	0.30
Rulo	414900	367600	396800	0.08	417100	498000	0.19
St. Joseph	420300	395600	422500	0.07	455400	515800	0.13
average				0.19			0.37

[1]square miles, [2]fraction difference between annual LPIII and mixed distribution

Table 5.3: Comparison of at-site estimates of annual and mixed distributions, Yankton to St. Joseph, Missouri River, maximum annual daily flows mixed data censored below median

location	[1]Drainage area	1% LPIII	1% Mixed	[2]difference	0.2%LPIII	0.2%Mixed	[2]difference
Yankton	279500	328400	354600	0.08	397000	463400	0.17
Sioux City	314580	323600	353800	0.09	382800	468200	0.22
Decatur	316200	313000	346700	0.11	364500	453600	0.24
Omaha	322800	325800	352500	0.08	380200	458200	0.21
Nebraska	410000	376900	374800	-0.01	437700	496000	0.13
Rulo	414900	385700	396800	0.03	445300	498000	0.12
St. Joseph	420300	416000	422500	0.02	487700	515800	0.06
average				0.06			0.17

[1]square miles, [2]fraction difference between annual LPIII and mixed distribution

Table 5.4 Comparisons between estimates of annual LPIII and mixed population distributions for different estimation and periods of record, Yankton to St. Joseph, Missouri River, maximum annual daily flows

Comparison (at-site statistics only, no regional information)	[1]1% flood difference	[1]0.2% flood difference
annual versus mixed	0.11	0.26
annual versus mixed, 1952 event deleted	0.19	0.37
annual versus mixed censored below median	0.06	0.17
annual versus mixed, historic period beginning 1844	0.11	0.25

[1]Fractional difference between LPIII estimated from maximum annual series and mixed distribution estimated from annual seasonal maximums.

5.3 **Regional shape estimation**

The TAG/IAG recommended adopting regional shape estimation. Regional shape estimation arrives at flood distribution statistics by using the at-site estimation of the mean and standard deviation, and a regional estimate of the skew coefficient. Estimates of the mean and standard deviation between gages sites were recommended by the TAG/IAG to be obtained by linear interpolation with drainage area or river mile. Estimates of flood quantiles for the Missouri, Mississippi and Illinois River are provided in the following sub-sections.

5.3.1 **Missouri River**

Regional skew estimates were obtained from the raw statistics shown in Table 5.5 and 5.6 for the following scenarios:

1) Yankton to Hermann, average reach skew for annual distributions used as regional skew value (see Table 5.5);
2) Same as scenario 1, except separate regional skew estimates obtained for the reaches from Yankton to St. Joseph, Kansas City to Hermann;
3) Yankton to St. Joseph, regional skews estimated for each season, mixed distribution computed from seasonal curves obtained using regional skews (see Table 5.5)
4) Same as scenario (3) except separate regional skew estimates obtained for the reaches from Yankton to Omaha, and Nebraska City to St. Joseph

The mixed distribution for the reach of river between Yankton and St. Joseph was obtained in the spirit of regional shape estimation. Regional skew values were estimated for each season series as would be done for an annual distribution. The seasonal distributions are then estimated by substituting the regional seasonal skew for the at-site seasonal skew.

Scenarios (2) and (4) were investigated because of the difference in the storage characteristics between the Yankton to Omaha and Omaha to St. Joseph reaches. As described in section 2, the major levee systems on the Missouri begin just upstream of Omaha. The river retains much of its natural storage characteristics upstream of this point. Apparently, the decrease in the estimated annual mean of the maximum daily flows (see Table 5.5) is due to the attenuation of flood peaks by the storage in the Yankton to Omaha reach. Separating the Missouri reach in the manner is intended to capture this storage influence on the flood distributions.

Comparisons were made between the at-site distributions and regional estimates in Tables 5.7 and 5.8 (scenarios 1 and 2), and between at-site mixed and mixed regional shape distributions in Tables 5.9 and 5.10 (scenarios 3 and 4) for the 1% and 0.2% maximum annual daily flow values. Comparative plots are provided for selected gages in figures 5.1-5.4 between the annual and mixed regional shape distributions, and the annual at-site distribution. The comparison of the annual series in Tables 5.7 and 5.8 show the expected result where there is a small average difference between at-site and regional shape estimates. Table 5.7 displays a trend in the difference between at-site and regional shape values because only a single region skew was used in the regional shape estimation. The bias occurs because the at-site skew trends from smaller values at Yankton to larger values at Hermann. This bias does not occur when separate regional skew values are used for a region boundary at Kansas City (the confluence of the Kansas and Missouri Rivers).

The comparisons of quantiles in Table 5.8 (and also statistics in Table 5.5) demonstrate the decrease in at-site estimates of flood quantiles from Yankton to Omaha. This decrease is most likely a result of the channel storage characteristics in this reach attenuating peak flows. Consequently, the reach between Yankton and St. Joseph (scenario 3) was divided into two regions, Yankton to Omaha where near-natural conditions characterize the river; and from Nebraska City to St. Joseph where major levee systems have been constructed (scenario 4). Tables 9 and 10 compare the at-site and regional shape 1% and 0.2% quantiles for mixed distributions. Note that the regional quantile estimates form Kansas City to Hermann would be the same as in Table 5.9 because mixed distributions are not used for this river reach. As can be seen, the quantile estimated under scenario 4 (Table 5.10) does a better job of depicting the decrease in peak flows in the Yankton to Omaha reach than scenario 3 (Table 5.9). However, the differences between these two scenarios is not great, as can be seen by comparing the difference at each gage and the average difference shown in Tables 5.9 and 5.10.

Although the different scenarios for selecting regions has some impact on the estimated flood quantiles, a far more important issue is the selection between annual and mixed-population analysis. As can be seen from table 5.1-5.4, and figures 5.1 and 5.2, the mixed population analysis results in significantly greater estimates of flood quantiles than an annual analysis.

Table 5.5: Comparison of annual and seasonal statistics of log-flows for Omaha District Gages (mainstem Missouri River), maximum annual daily flows

location	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Yankton	279500	5.187	0.137	0.055	4.985	0.256	-0.003	5.147	0.123	-0.416
Sioux City	314580	5.202	0.132	-0.024	5.004	0.249	-0.085	5.161	0.119	-0.475
Decatur	316200	5.2	0.131	-0.058	4.999	0.246	-0.067	5.16	0.119	-0.472
Omaha	322800	5.214	0.133	-0.066	5.014	0.243	-0.046	5.174	0.121	-0.345
Nebraska City	410000	5.302	0.118	-0.047	5.065	0.221	0.008	5.28	0.111	-0.183
Rulo	414900	5.308	0.124	-0.062	5.06	0.223	0.096	5.287	0.117	-0.1
St Joseph	420300	5.328	0.125	0.047	5.078	0.225	0.126	5.307	0.121	0.013
average				-.022			0.004			-0.283

(1) Drainage area (square miles)
(2) Mean of annual max 1-day log-flows (annual)
(3) Standard deviation of annual max 1-day log-flows (annual)
(4) Skew of annual max 1-day log-flows (annual)
(5) Mean of annual max 1-day log-flows (January-April)
(6) Standard deviation of annual max 1-day log-flows (January-April)
(7) Skew of annual max 1-day log-flows (January-April)
(8) Mean of annual max 1-day log-flows (May-December)
(9) Standard deviation of annual max 1-day log-flows (May-December)
(10) Skew of annual max 1-day log-flows (May-December)

Table 5.6: Statistics of log flows, Kansas City District Gages (mainstem Missouri river gages)

Location	Area	Mean	Std deviation	skew
Kansas City	485200	5.399	0.145	0.278
Waverly	487200	5.403	0.144	0.337
Booneville	501200	5.444	0.156	0.162
Hermann	524200	5.522	0.166	0.047

Table 5.7: Comparison of quantiles obtained from annual at-site and adopted equal to regional skew annual series for Missouri River (scenario 1), maximum annual daily flows

location	1% lpiii	*1% shape	%difference	0.2% lpiii	*0.2% shape	%difference
Yankton	328400	325200	-0.97	397000	390700	-1.59
Sioux City	323600	327800	1.3	382800	391200	2.19
Decatur	313000	324300	3.61	364500	386500	6.04
Omaha	325800	338100	3.78	380200	403800	6.21
Nebraska City	376900	381100	1.11	437700	446000	1.9
Rulo	385700	399000	3.45	445300	470700	5.7
St Joseph	416000	421500	1.32	487700	498300	2.17
Kansas City	584900	551800	-5.66	738300	669500	-9.32
Waverly	589000	555900	-5.62	743100	674300	-9.26
Booneville	675500	651600	-3.54	853100	802900	-5.88
Hermann	809700	824000	1.77	1000000	1029100	2.91
average			0.05			0.1

*Adopted skew set to reach average regional skew = 0.060, Yankton to Hermann

Table 5.8: Comparison of quantiles obtained from annual at-site and adopted equal to regional skew annual series, Missouri River (scenario 2), maximum annual daily flows

location	1% lpiii	*1% shape	difference	0.2% lpiii	*0.2% shape	difference
Yankton	328400	319300	-2.77	397000	378900	-4.56
Sioux City	323600	322000	-0.49	382800	379800	-0.78
Decatur	313000	318600	1.79	364500	375400	2.99
Omaha	325800	332100	1.93	380200	392000	3.1
Nebraska City	376900	375000	-0.5	437700	434400	-0.75
Rulo	385700	392400	1.74	445300	457900	2.83
St Joseph	416000	414400	-0.38	487700	484500	-0.66
Kansas City	584900	572200	-2.17	738300	711500	-3.63
Waverly	589000	576500	-2.12	743100	716500	-3.58
Booneville	675500	677700	0.33	853100	857400	0.5
Hermann	809700	859200	6.11	1000000	1103700	10.37
average			0.32			0.53

*Adopted skew set to reach average regional skew, Yankton to St. Joseph –0.020, Kansas City to Hermann 0.21 (see Table 5.5)

Table 5.9: Comparison of quantile estimates for mixed at-site and mixed with regional skew estimates, single reach for regional reach(scenario 3), maximum annual daily flows

location	1% lpiii	*1% mixed	difference	0.2% lpiii	*0.2% mixed	difference
Yankton	380200	381400	0.32	525900	528500	0.49
Sioux City	369500	383800	3.87	495500	527100	6.38
Decatur	362300	373300	3.04	486500	510800	4.99
Omaha	372500	380300	2.09	501000	518300	3.45
Nebraska City	389400	384500	-1.26	505200	503700	-0.3
Rulo	409400	391000	-4.49	534000	504900	-5.45
St Joseph	445000	414900	-6.76	576500	533000	-7.55
average			-0.46			0.29

*Regional skew spring, 0.004, summer,-0.283

Table 5.10: Comparison of quantile estimates for mixed at-site and mixed regional skew estimates, regional skew for separate reaches (scenario 4) , maximum annual daily flows

location	1% lpiii	*1% mixed	%difference	0.2% lpiii	*0.2% mixed	%difference
Yankton	380200	372500	-2.03	525900	508500	-3.31
Sioux City	369500	375000	1.49	495500	507700	2.46
Decatur	362300	364900	0.72	486500	492200	1.17
Omaha	372500	371900	-0.16	501000	499700	-0.26
Nebraska City	389400	400600	2.88	505200	526400	4.2
Rulo	409400	408200	-0.29	534000	528000	-1.12
St Joseph	445000	433600	-2.56	576500	558400	-3.14
average			0.0			0.0

*Regional skew spring, -0.050, summer, -0.427, Yankton to Omaha;
Regional skew spring, 0.077, summer, -0.090, Nebraska City to St. Joseph

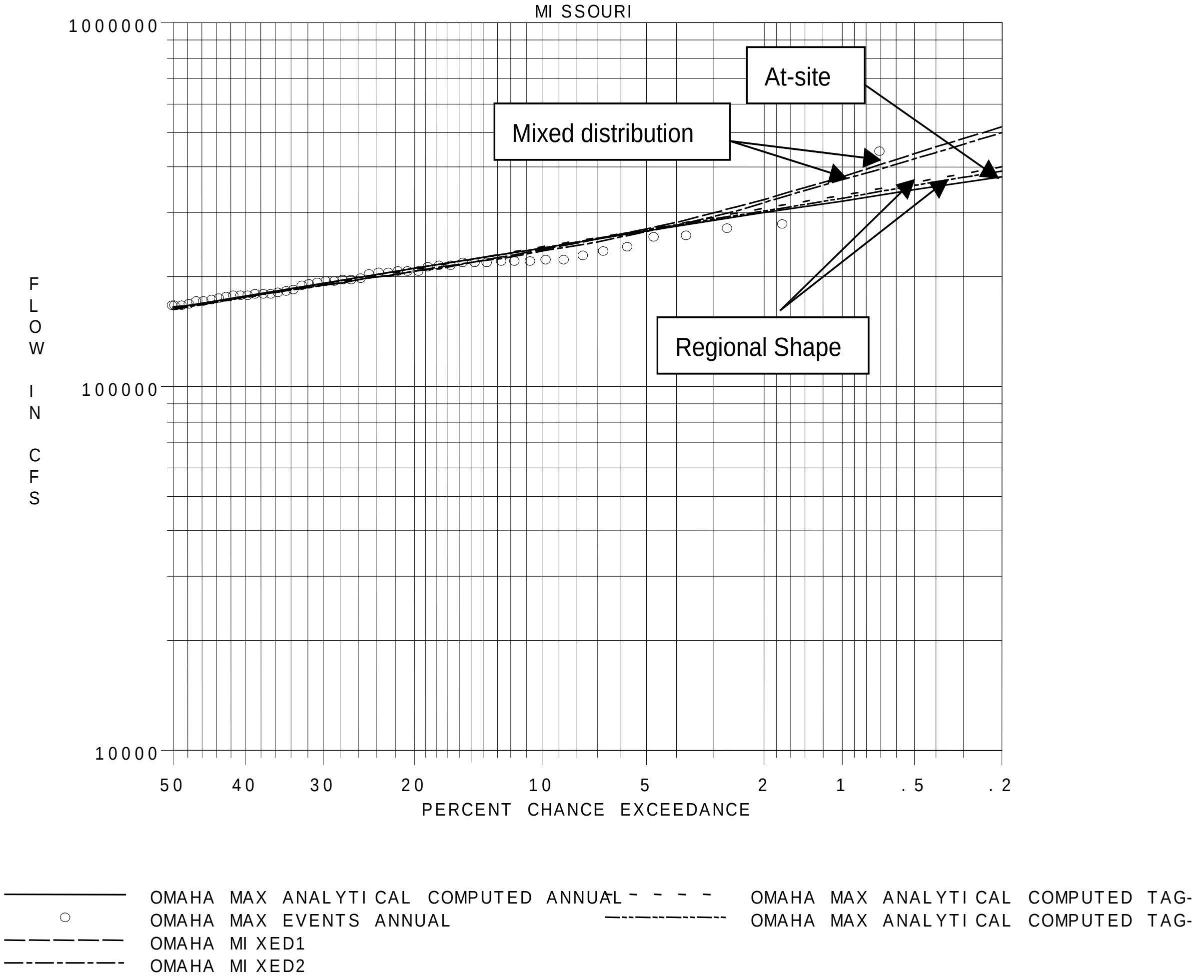


Figure 5.1: Compare annual at-site, mixed distribution/regional shape and regional shape estimates of flood distribution, Omaha, Missouri River, annual maximum daily flows

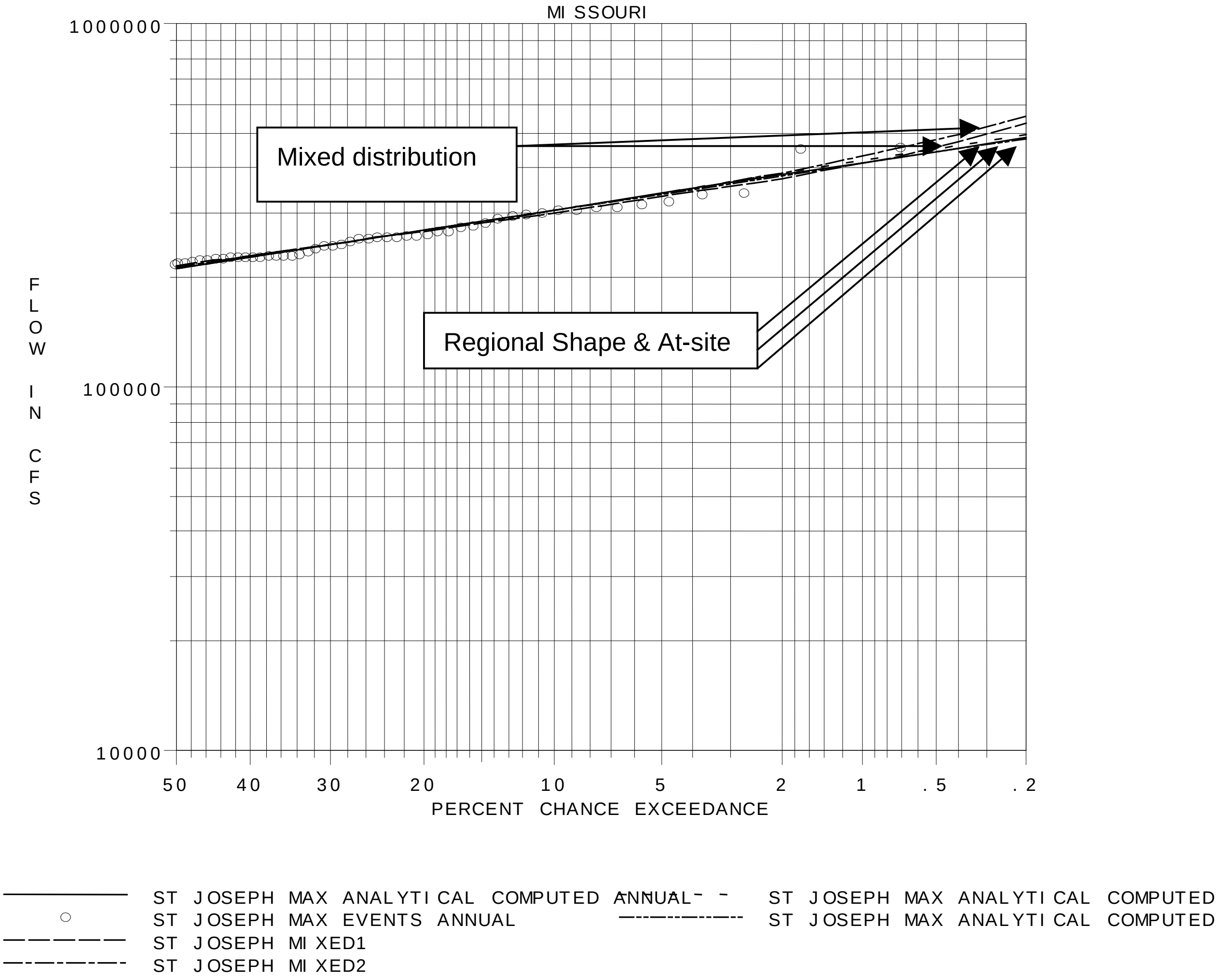


Figure 5.2: Compare at-site, mixed distribution/regional shape and regional shape estimates of flood distribution, St. Joseph, Missouri River, annual maximum daily flows

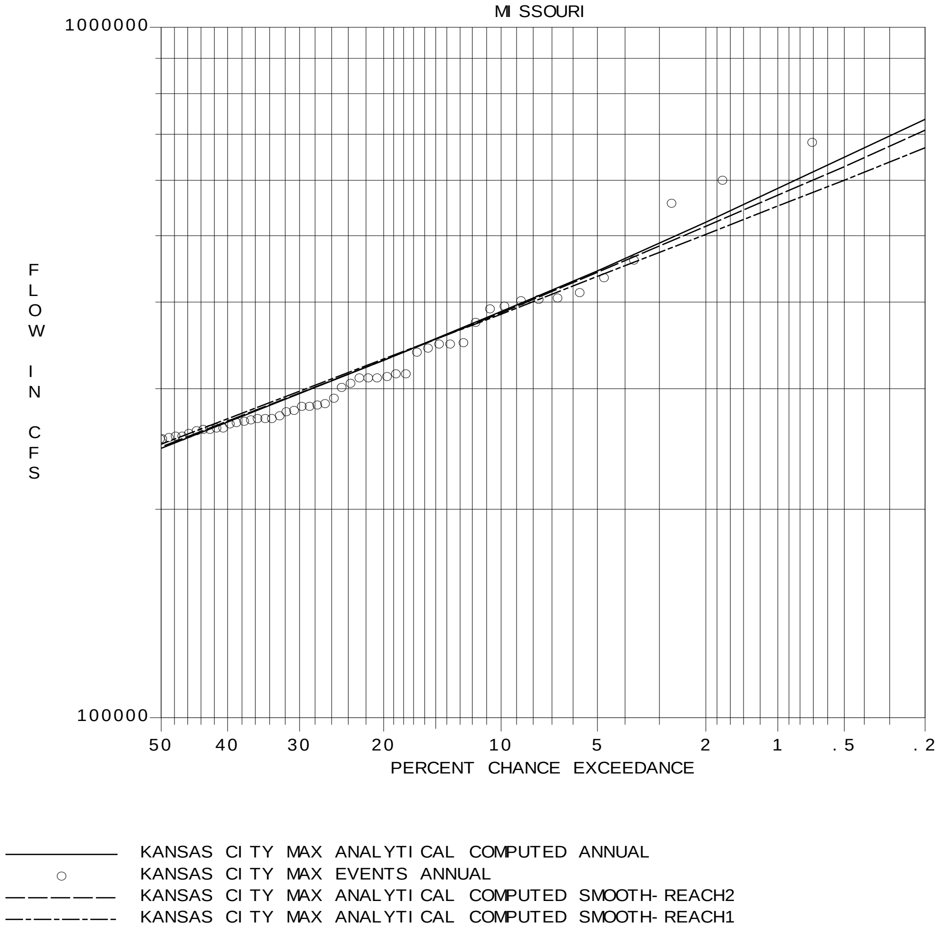


Figure 5.3: Comparison of at-site and regional shape (smooth-reach1 and smooth-reach2) estimates of flood frequency distributions, Kansas City, Missouri River, annual maximum daily flows

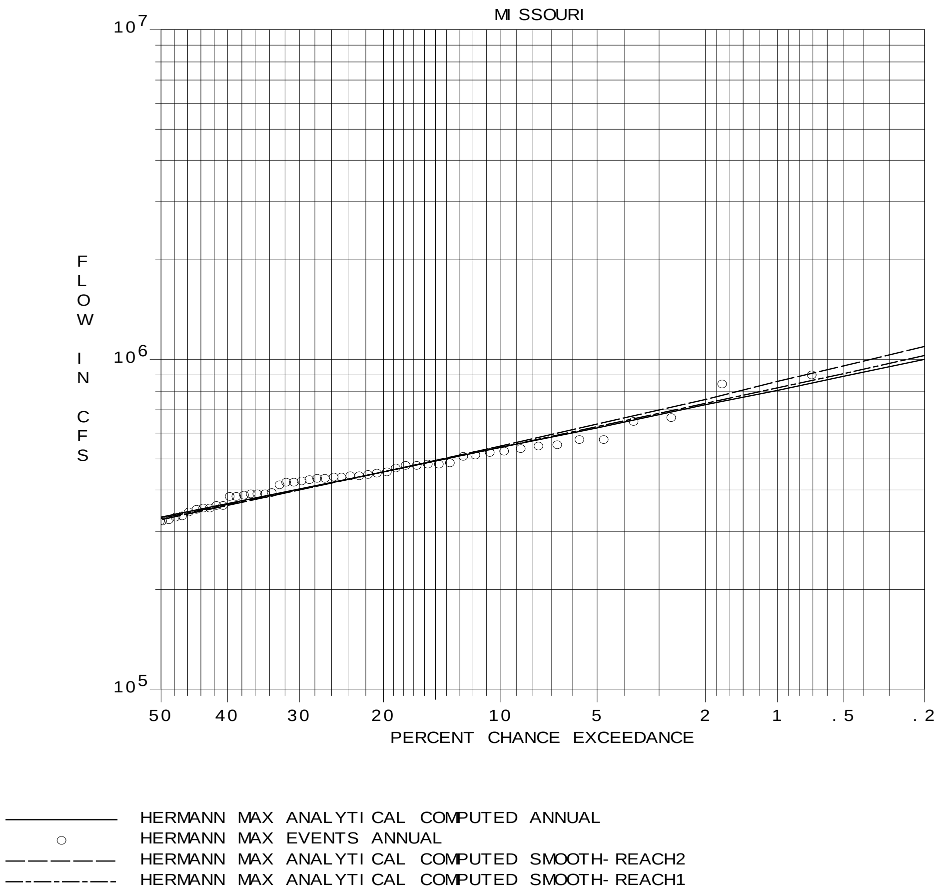


Figure 5.4: Comparison of at-site and regional shape (smooth-reach1 and smooth-reach2) estimates of flood frequency distributions, Hermann, Missouri River, annual maximum daily flows

5.3.2 **Mississippi River**

Regional shape estimation was performed by averaging the skew value shown in Table 5.11 to obtain the 1% and 0.2% quantile estimates shown in Tables 5.12 and 5.13. The St. Paul district gage was deleted in obtaining the average skew because of the statistical analysis performed in section 4.2 showing that this gage did not belong in the same region as the remaining Mississippi River gages. The same argument might be made for the Winona Gage. In any case, the regional skew will be about –0.1 whether or not these gages are included.

As can be seen from the tables and the plots shown in figures 5.5-5.7, the difference between the at-site and regional shape estimated quantiles is not large except at St. Paul. The regional skew used for St. Paul may not be appropriate and perhaps should be –0.2 or smaller. Appendix B provides a more detailed analysis of the frequency curve at St. Paul and provides a recommended estimate for the regional skew at this station.

Table 5.11: Statistics of log-flows, Mississippi River, record starting in 1898

[1]location	area (sq mi)	period of record	mean	std dev	skew
St Paul	36800	101	4.581	0.261	-0.269
Winona	59200	101	4.942	0.193	-0.079
Dubuque	82000	101	5.100	0.153	-0.065
Clinton	85600	101	5.114	0.146	-0.149
Keokuk	119000	101	5.249	0.142	-0.083
Hannibal	137000	101	5.322	0.158	-0.183
Louisiana	141000	100	5.333	0.150	-0.017
Grafton	171300	100	5.418	0.131	-0.072
St Louis	697000	100	5.725	0.135	0.030
Chester	708600	100	5.740	0.136	-0.071
Thebes	713200	100	5.741	0.135	-0.062
average					-0.1[2]

[1]Statistics based on peak annual flows for St. Paul and Winona, annual maximum daily flows otherwise

[2]St. Paul gage not included in average skew

Table 5.12: Comparison of quantiles estimated from at-site and regional shape statistics, Mississippi River, St. Paul to Grafton

location	1%quantile	*1% shape	%diff	0.2% quantile	*0.2% shape	%diff
St Paul	134900	147400	9.27	172900	199600	15.44
Winona	237700	237700	0	297400	297300	-0.03
Dubuque	281900	279400	-0.89	338900	334000	-1.45
Clinton	274300	277500	1.17	322600	328900	1.95
Keokuk	371700	370200	-0.4	439400	436500	-0.66
Hannibal	465300	475900	2.28	551300	571800	3.72
Louisiana	478200	468200	-2.09	576700	557000	-3.42
Grafton	518700	515600	-0.6	606000	600000	-0.99
			1.09			1.82

*Quantiles estimated from at-site mean and standard deviation, and adopted skew = average reach skew = -0.10, St. Paul gage not included in average skew

Table 5.13 Comparison of quantiles estimated from at-site and TAG recommended regional shape statistics, Mississippi River, St. Louis to the Thebes

location	1%quantile	*1% shape	%diff	0.2% quantile	*0.2% shape	%diff
St Louis	1104800	1072300	-2.94	1318200	1254900	-4.8
Chester	1117200	1109800	-0.66	1313400	1299100	-1.09
Thebes	1120800	1111000	-0.87	1318700	1299800	-1.43
			-1.49			-2.44

*Quantiles estimated from at-site mean and standard deviation, and adopted skew = average reach skew = -0.10, St. Paul gage not included in average skew

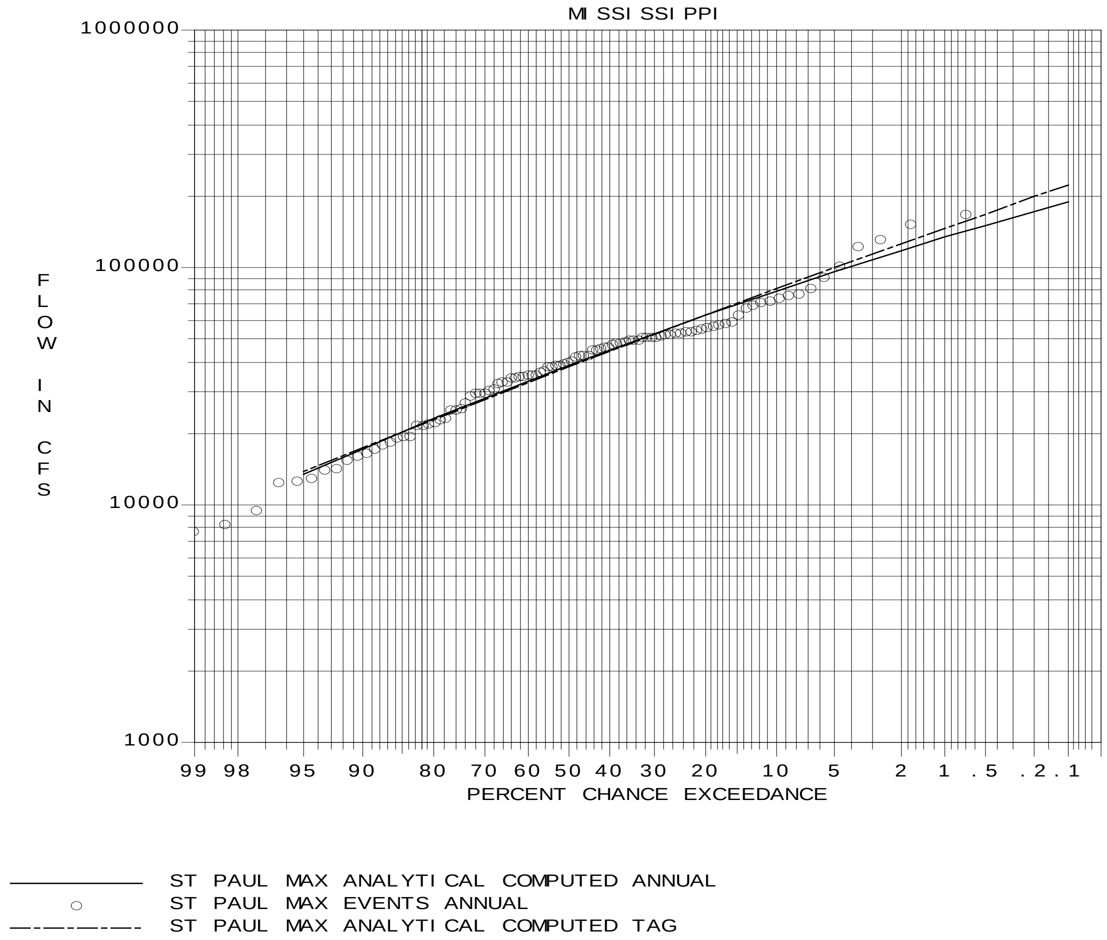


Figure 5.5: Comparison of at-site and regional shape flood frequency distribution estimates, St. Paul, Mississippi River (regional skew = -0.1), peak annual flows

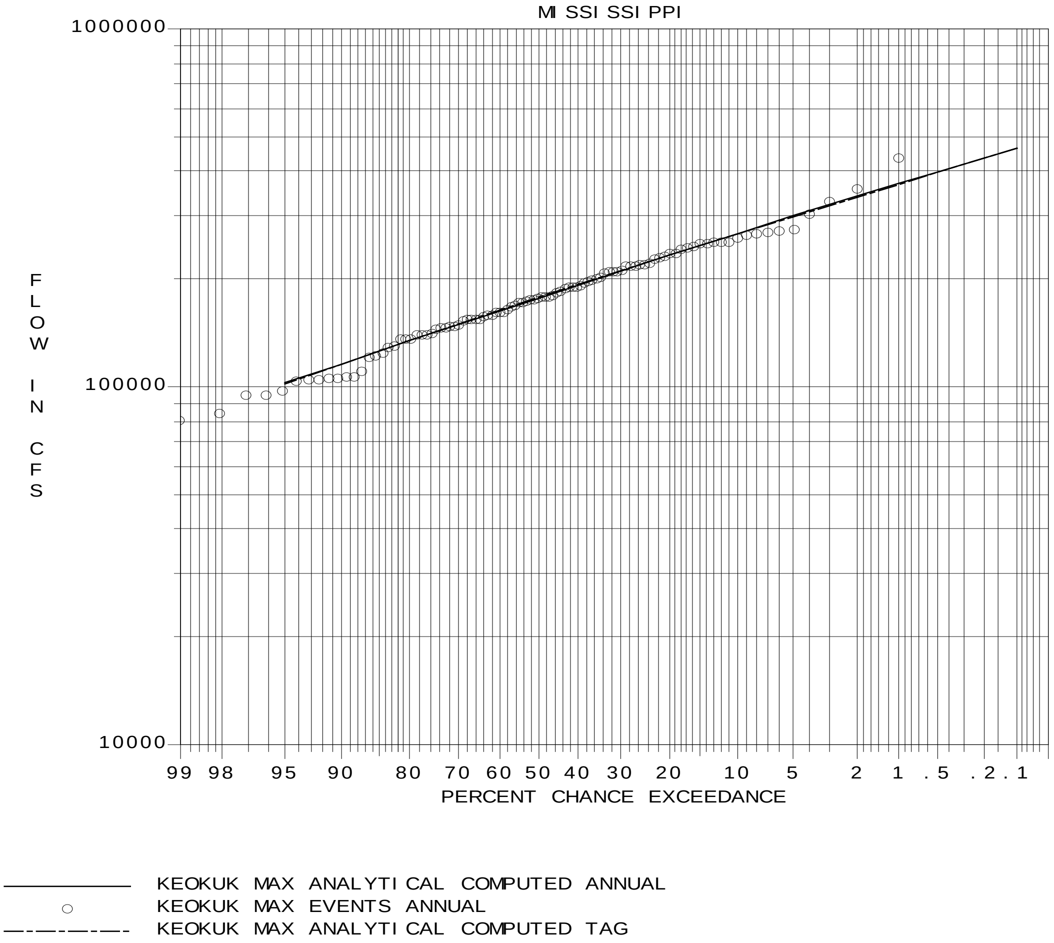


Figure 5.6: Comparison of at-site and regional shape flood frequency distribution estimates, Keokuk, Mississippi River (regional skew = -0.1), annual maximum daily flows

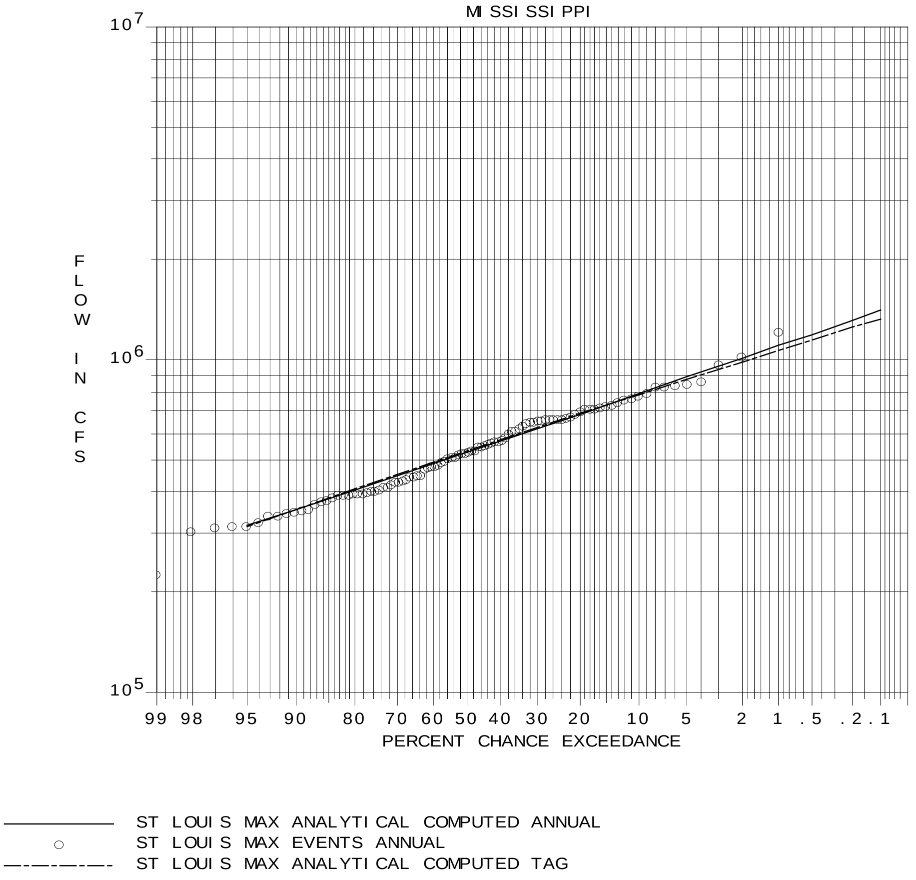


Figure 5.7: Comparison of at-site and regional shape flood frequency distribution estimates, St. Louis, Mississippi River (regional skew = -0.1), annual maximum daily flows

5.3.3 **Illinois River**

The analysis of regional climate and statistics of the annual flood series for the mainstem Illinois River gages argued for including these gages with the Mississippi River gages in the same region. Table 5.14 and provides comparisons of both these gage statistics with tributary gage statistics; and, Table 5.15 compares different average skews for different regions. Notice that the mainstem gages have, on the average, a greater skew than the tributary gages. This may seem somewhat puzzling, but the reach of Illinois River defined from the Kankakee to Lamoine River is relatively flat, providing a significant amount of storage for floods. The regional skew for these tributaries is apparently less than that of the Mississippi mainstem gages.

Inclusion of the Illinois River gages in the Mississippi River region results in a regional skew value of about –0.1. A comparison of the at-site and regional shape estimates in Tables 5.16 and 5.17 shows a maximum difference of about 6% at the 1% level and almost 10% at the 0.2% level occurring at the Marseilles gage. Figure 5.8 displays a comparative plot of the at-site and regional shape estimates of the distributions. An assumed regional skew of –0.2 is shown as a point of comparison and to provide estimates that would be more unbiased when considering the Illinois River gages alone rather than as part of the Mississippi Region.

Table 5.14: Log-statistics of annual peaks Illinois and major tributary gages, gages are listed in downstream direction

location	area (sq mi)	years	mean	std dev	skew
KANKAKEE RIVER, MOMENCE	2294	82	3.811	0.153	-0.54
KANKAKEE RIVER, WILMINGTON	5150	85	4.381	0.222	-0.28
[*]**ILLINOIS RIVER, MARSEILLES**	**8259**	**79**	**4.643**	**0.176**	**-0.29**
FOX RIVER, WILMOT	868	57	3.425	0.189	0.05
FOX RIVER, ALGONQUIN	1403	80	3.503	0.175	-0.27
FOX RIVER, DAYTON	2642	81	4.094	0.23	0.04
VERMILION RIVER, PONTIAC	579	53	3.731	0.233	-0.51
VERMILION RIVER, LEONORE	1251	66	4.048	0.277	-0.51
[*]**ILLINOIS RIVER, KINGSTON MINES**	**15819**	**58**	**4.672**	**0.146**	**-0.2**
MACKINAW RIVER, CONGERVILLE	767	52	3.943	0.314	-0.03
MACKINAW RIVER, NEAR GREEN VALLEY	1073	73	3.935	0.303	0.43
SPOON RIVER, LONDON MILLS	1072	54	4.006	0.224	0.55
SANGAMON RIVER, MAHOMET	362	31	3.607	0.285	-0.07
SANGAMON RIVER, MONTICELLO	550	87	3.73	0.266	-0.2
SANGAMON RIVER, OAKLEY	774	27	3.755	0.25	0.4
S FK SANGAMON RIVER, KINCAID	562	71	3.63	0.311	-0.01
S FK SANGAMON RIVER, ROCHESTER	867	47	3.737	0.311	-0.49
SANGAMON RIVER, RIVERTON	2618	83	4.184	0.263	-0.56
S FK SANGAMON RIVER, KINCAID	562	71	3.63	0.311	-0.01
SANGAMON RIVER, RIVERTON	2618	83	4.184	0.263	-0.56
SANGAMON RIVER, OAKFORD	5093	81	4.336	0.292	-0.56
LA MOINE RIVER, COLMAR	655	52	3.918	0.339	-0.4
LA MOINE RIVER, RIPLEY	1293	76	3.971	0.257	-0.12
[*]**ILLINOIS RIVER, MEREDOSIA**	**26028**	**100**	**4.763**	**0.164**	**-0.07**

[*] Illinois River mainstem gages, annual maximum daily values

Table 5.15 Average skew values for Illinois River Gages

Scenario	Average skew
Illinois River gages (Marseilles, Kingston Mines, Meredosia)	-0.187
Illinois River, major tributary gages, drainage area > 300 sq mi (see Table 5.14)	-0.165
Illinois River, major tributary gages, drainage area > 1000 sq mi (see Table 5.14)	-0.180
Illinois River, Mississippi River gages (Winona to Grafton) (see Tables 5.11,5.14)	-0.101[*]

[*] St. Paul not included in Mississippi River Gages

Table 5.16: Comparison of 1% chance quantiles, regional shape estimation, Illinois River

location	[1]1%quantile	[2]1% shape	[3]%diff	[4]1% shape	[5]%diff	[6]%diff shape
Marseilles	103000	109600	6.41	106400	3.3	-3.01
Kingston Mines	98000	100400	2.45	97900	-0.1	-2.55
Meredosia	137000	135800	-0.88	132000	-3.65	-2.88

[1] Estimate from at-site statistics
[2] Regional shape = regional skew = -0.1
[3] Difference between at-site, regional shape = -0.1
[4] Regional shape = regional skew = -0.2
[5] Difference between at-site, regional shape = -0.2
[6] Difference between regional shape estimates

Table 5.17: Comparison of 0.2% chance quantiles, regional shape estimation, Illinois River

location	[1]0.2%quantile	[2]0.2% shape	[3]%diff	[4]0.2% shape	[5]%diff	[6]%diff shape
Marseilles	122500	134500	9.8	128100	4.57	-5.00
Kingston Mines	114200	119000	4.2	114200	0.00	-4.20
Meredosia	166700	164300	-1.44	157000	-5.82	-4.65

[1] Estimate from at-site statistics
[2] Regional shape = regional skew = -0.1
[3] Difference between at-site, regional shape = -0.1
[4] Regional shape = regional skew = -0.2
[5] Difference between at-site, regional shape = -0.2
[6] Difference between regional shape estimates

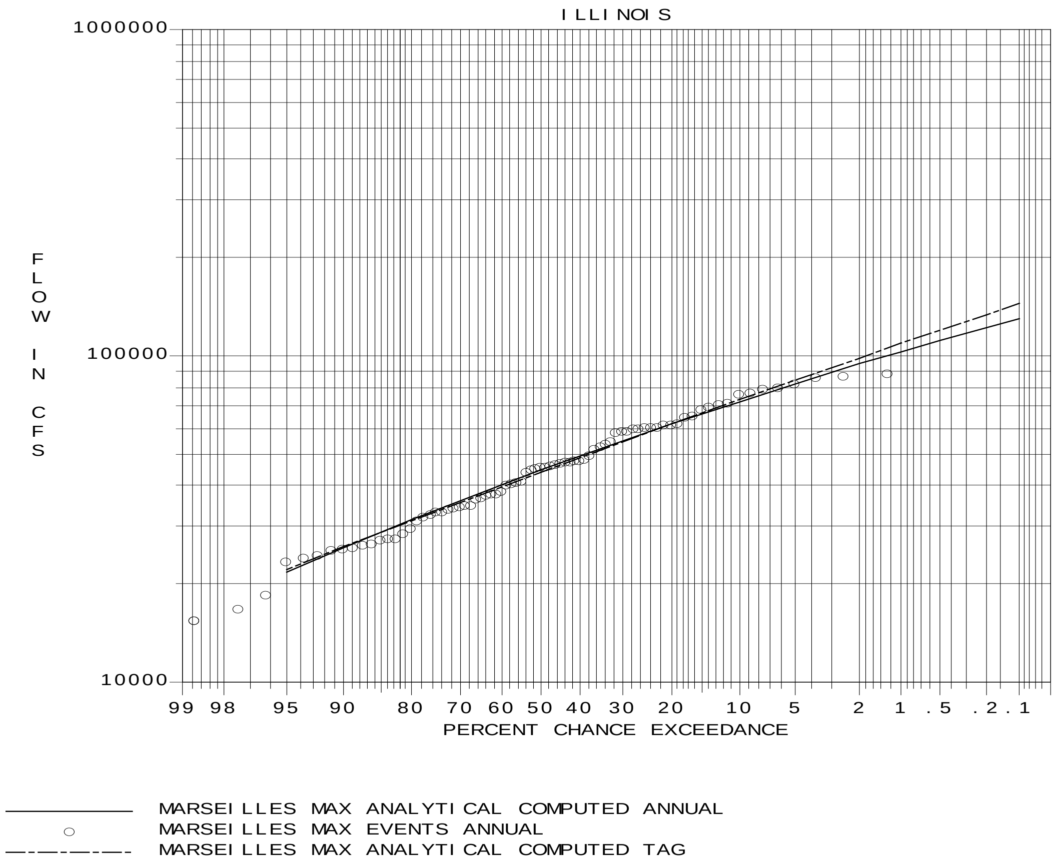


Figure 5.8: Comparison of at-site and regional shape flood frequency distribution estimates, Marseilles, Illinois River (regional skew = -0.1), annual maximum daily flows

5.4 Quantiles from regression with drainage area, river mile

5.4.1 Missouri River

Scenarios for estimating the regression of quantile with drainage area or river mile were obtained for the same regions described for regional shape estimation in section 5.3.1. In this case the regressions were used to find an objective means for fitting a line to the data. Statistical significance should not be ascribed to any of the results because of the lack of data points.

The analysis indicated that regression was not necessarily the best approach for obtaining a regular variation of quantiles with area or river mile for the Missouri River between Yankton and Omaha. The decrease in quantiles with drainage area/river mile in this reach made the selection of a regression encompassing all gages on the river, or at least from Yankton to St. Joseph overly complicated. A simpler approach was preferred where the at-site quantile estimates were used for the Yankton to Omaha reach and regression relationship for the remaining reaches are used to obtain a regular variation of flood quantiles. Estimates of flood quantiles at locations between gages in the Yankton to Omaha reach can be obtained by linear interpolation with drainage area/river mile.

The regression of quantile with drainage area/river mile results are organized as follows:

Table 5.18 – regression relationships between **drainage area** and quantile for reaches Nebraska City to St. Joseph, Kansas City to Hermann
Table 5.19 – Comparison of at-site and regression estimates of quantiles, **drainage area** regression, Yankton to Hermann
Table 5.20 – regression relationships between **river mile** and quantile for reaches Nebraska City to St. Joseph, Kansas City to Hermann
Table 5.21 – Comparison of at-site and regression estimates (linear and polynomial) of 1% quantiles, **river mile** regression, Yankton to Hermann
Table 5.22 – Comparison of at-site and regression estimates (linear and polynomial) of 2% quantiles, **river mile** regression, Yankton to Hermann

The estimation of quantiles by regression was somewhat insensitive to the regression chosen. Linear regressions was used to relate drainage area to quantiles; whereas; both linear and polynomial regression results are displayed for river mile. Inspection of the tables shows that the regression results do not deviate greatly from the at-site estimates while providing a useful means for obtaining a regular variation of quantiles. An exception to this is at Kansas City where the polynomial regression using river mile deviates from the at-site value by 6% for the 1% quantile and almost 12% for the 0.2% quantile.

Table 5.18: Coefficients for regression used to obtain a regular variation of 1% and 0.2% maximum annual daily flows for the Missouri River

	1% flood		0.2% flood	
Reach	Intercept	Slope	Intercept	Slope
Nebraska City to Saint Joseph	$-1.83436*10^6$	5.41831	$-2.25919*10^6$	4.90076
Kansas City to Hermann	$-1.57723*10^6$	5.85435	$-2.57981*10^6$	6.83438

Note R^2 values exceeded 0.98 for all regressions, however no statistical significance should be attached to the regression, rather regression used as objective means for fitting a straight line to the data, quantiles from Nebraska City to St. Joseph based on mixed distribution analysis

Table 5.19: Obtain regular variation of 1% and 0.2% quantiles using regression with drainage area, Missouri River, annual maximum daily flow values

location	[1]area	[2]1% at-site	1% regression	%diff	[2]0.2% at-site	0.2% regression	%diff
Yankton	279500	380200	380200	0	396700	396700	0
Sioux City	314580	369500	369500	0	382800	382800	0
Decatur	316200	362300	362300	0	364500	364500	0
Omaha	322800	372500	372500	0	380200	380200	0
Nebraska City	410000	389400	387100	0.59	437700	437700	0
Rulo	414900	409400	413700	-1.05	445200	456100	2.45
St Joseph	420300	445000	443000	0.45	487700	482600	-1.05
Kansas City	485200	584900	581300	0.62	738300	736200	-0.28
Waverly	487200	589000	593000	-0.68	743100	749900	0.92
Booneville	501200	675500	675000	0.07	853000	845600	-0.87
Hermann	524200	809700	809700	0	1000000	1002800	0.28

[1] Scenario uses linear regression between Nebraska City and St. Joseph, Kansas City and Hermann, quantiles for any cross section between other stations would be based on linear interpolation between at-site estimates (see Table 5.18)

[2] Mixed distribution estimates used for Yankton to St. Joseph

Table 5.20: Regression equations between river mile and 1% and 0.2% maximum annual daily quantiles, Missouri River, annual maximum daily flows

	1% quantile flood			0.2% regression flood		
Reach	b_0	b_1	b_2	b_0	b_1	b_2
Nebraska City to Saint Joseph	654735	-477.47	------------	668862	-421.58	-----------
Kansas City to Hermann	888870	-969.854	------------	1096610	-1137.98	-----------
all gages	968250	-1650.43	1.12857	1238870	-2224.93	1.4223

Regression: $q=b_0 + b_1(x) + b_2x^2$, q is quantile, x is river mile, Nebraska City to St. Joseph quantiles based on mixed distribution analysis

Table 5.21: Regression estimates of 1% quantile flood using river mile, annual daily maximum flow, Missouri River

location	river mile	at-site	*linear	%diff	polynomial	%diff
Yankton	805.8	380200	380200	0	371100	-2.39
Sioux City	732.2	369500	369500	0	364800	-1.27
Decatur	691.0	362300	362300	0	366600	1.19
Omaha	615.9	372500	372500	0	379800	1.96
Nebraska City	562.6	389400	386100	-0.26	396900	2.53
Rulo	498.0	409400	417000	0.79	426200	3.02
St Joseph	448.2	445000	440700	-0.52	455200	2.75
Kansas City	336.1	584900	563000	-3.25	541000	-6.93
Waverly	293.4	589000	604400	1.89	581200	-1.99
Booneville	197.1	675500	697800	3.27	686800	1.75
Hermann	97.9	809700	793900	-1.99	817500	0.96

*Scenario uses linear regression between Nebraska City and St. Joseph, Kansas City and Hermann, quantiles for any cross section between other stations would be based on linear interpolation between at-site estimates (see Table 5.20), Yankton to St. Joseph quantiles estimated based on mixed distribution analysis

Table 5.22: Regression estimates of 0.2% quantile flood using river mile, annual daily maximum flows, Missouri River

location	river mile	at-site	*linear	%diff	polynomial	%diff
Yankton	805.8	396700	396700	0	369500	-6.86
Sioux City	732.2	382800	382800	0	372300	-2.74
Decatur	691.0	364500	364500	0	380600	4.42
Omaha	615.9	380200	380200	0	408100	7.34
Nebraska City	562.6	437700	431700	-1.37	437300	-0.09
Rulo	498.0	445200	458900	0.61	483600	8.63
St Joseph	448.2	487700	479900	-0.56	527400	8.14
Kansas City	336.1	738300	714100	-3	651700	-11.73
Waverly	293.4	743100	762700	1.71	708500	-4.66
Booneville	197.1	853000	872300	3.16	855600	0.3
Hermann	97.9	1000000	985200	-1.76	1034700	3.47

*Scenario uses linear regression between Nebraska City and St. Joseph, Kansas City and Hermann, quantiles for any cross section between Yankton and Sioux City would be based on linear interpolation between at-site estimates (see Table 5.20), Yankton to St. Joseph quantiles estimated based on mixed distribution analysis

5.4.2 **Mississippi River**

Regressions with drainage area/river mile for the Mississippi River was formulated for the reach between St. Paul and Grafton. The variation of quantiles from St. Louis to Thebes is reasonably regular because of the large levee systems in place for that reach of river. Linear interpolation with drainage area between these gage swill probably suffice. Regression relationships were not explored for the Illinois River because only three gages are available. Linear interpolation with drainage area or river mile might be used to obtain quantile estimates between gages for this reach of river.

Tables 5.23-5.25 summarize the regression relationships and differences between at-site and regression prediction of quantiles. Figures 5.9 and 5.10 display typical fits of linear and log-linear regression lines to the data. As can be seen from Table 5.23 there was little to choose between the linear and log-linear regression models for drainage area. Table 5.24 shows that the maximum difference between the log-linear model and at-site estimates occurs at Winona about (10% for the 1% quantile, and 11% for the 0.2% quantile). Winona is also the location for the greatest difference between at-site estimates and linear regression predictions using river mile. These maximum difference could certainly be reduced by using a higher order approximation as is shown in figure 5.11. However, as the order of the polynomial is increased, the prediction value of the independent variable decreases as does the explanatory power of the regression. Under these circumstances, linear interpolation between gages using either drainage area or river mile might be preferred to a polynomial curve fit.

5.4.3 **Hermann to St. Louis, Grafton to St. Louis**

The confluence of the Missouri and Mississippi River probably requires some special considerations. Analysis of this reach may require the consideration of backwater and coincident flooding.

Table 5.23: Summary of regression between quantiles and drainage area (square miles) , Mississippi River from St. Paul to Grafton

	1% quantile			0.2% quantile		
*Transform	Intercept	Slope	**R^2	Intercept	Slope	**R^2
linear	41026	2.9628	0.97	65897	3.33943	0.97
Log_{10}	1.16367	0.872741	0.97	1.51928	0.817586	0.97

**R^2 computed for difference between observed and predicted values (not log-transform)

Table 5.24: Comparison of at-site and drainage area regression estimates of the 1% and 0.2% quantiles, Mississippi River from St. Paul to Grafton

location	area	1% at-site	*1% regression	%diff	0.2% at-site	*0.2% regression	%diff
St Paul	36800	134900	140800	4.34	172900	178800	3.39
Winona	59200	237700	213100	-10.33	297400	263700	-11.34
Dubuque	82000	281900	283200	0.46	338900	344100	1.54
Clinton	85600	274300	294100	7.22	322600	356500	10.5
Keokuk	119000	371700	392000	5.48	439400	466600	6.2
Hannibal	137000	465300	443300	-4.73	551300	523600	-5.03
Louisiana	141000	478200	454600	-4.94	576700	536100	-7.05
Grafton	171300	518700	538700	3.87	606000	628500	3.71

*see $\log_{10}$ Regression with drainage area (see Table 5.23)

Table 5.25: Comparison of at-site and river mile regression estimates of the 1% and 0.2% quantiles, Mississippi River from St. Paul to Grafton

location	river mile	1% at-site	[1]1% regression	%diff	0.2% at-site	[2]0.2% regression	%diff
St Paul	839.3	134900	133900	-0.74	172900	172200	-0.4
Winona	725.6	237700	200700	-15.57	297400	248400	-16.48
Dubuque	579.3	281932	286700	1.69	338928	346400	2.2
Clinton	517.9	274254	322800	17.7	322584	387500	20.12
Keokuk	364.0	371663	413300	11.2	439411	490600	11.65
Hannibal	309.9	465292	445100	-4.34	551303	526900	-4.43
Louisiana	282.9	478176	461000	-3.59	576695	545000	-5.5
Grafton	218.3	518669	499000	-3.79	606029	588300	-2.93

[1] q = 627331 – 587.945(x), q is the quantile, x is the river mile

[2] q = 734545 – 670.049(x)

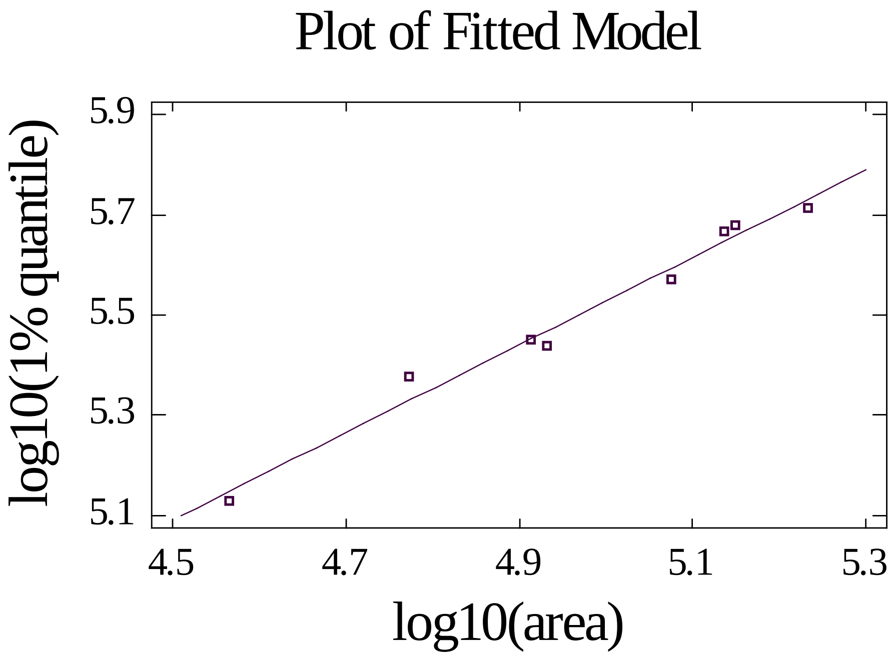


Figure 5.9: Linear regression between 1% annual maximum peak/daily flow and drainage area St. Paul to Grafton, Mississippi River

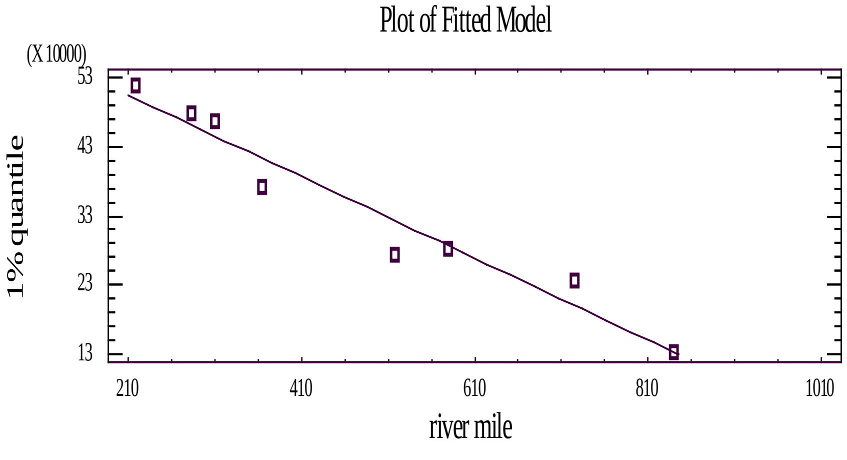


Figure 5.10: Linear regression between 1% annual maximum peak/daily flow and drainage area St. Paul to Grafton, Mississippi River

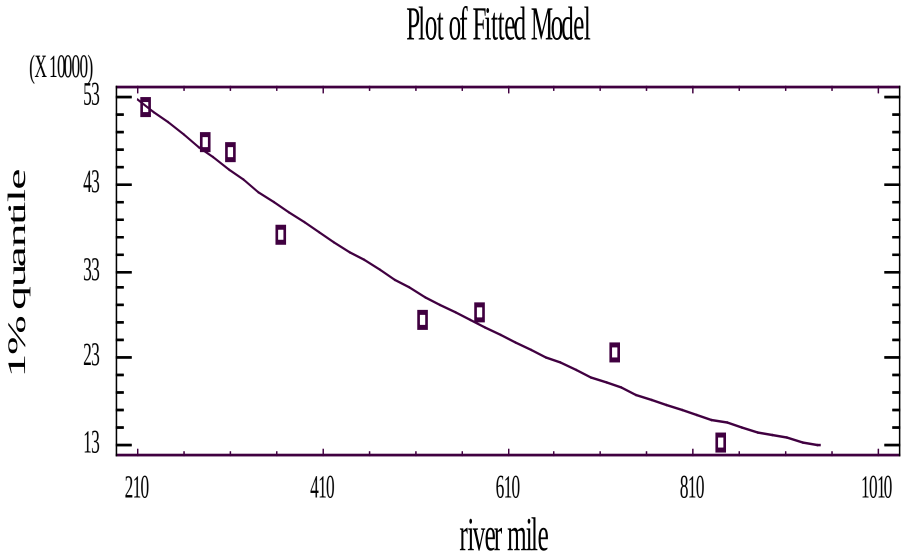


Figure 5.11: Polynomial (quadratic) regression between 1% maximum annual peak/daily flow and river mile St. Paul to Grafton, Mississippi River

5.5 **Drainage Area versus River Mile for Interpolation**

Regional shape estimation or regression analysis has been proposed for estimating flood quantiles at all locations of interest within the study area (i.e., at all river cross-sections). Regional shape estimation can accomplish this by combining interpolated at-site estimates of the mean and standard deviation between gages with either drainage area or river mile and the appropriate regional skew to obtain the flood frequency distribution. Regression relationships using river mile or drainage area provide a method for computing the quantiles between gages from the at-site estimated of the flood frequency distributions.

River mile has some advantage over drainage area as an interpolation variable because it is known for every cross-section surveyed for the study area. However, river mile does not provide nearly as good an explanation of flood variability as drainage area. This can be seen by comparing the variation of drainage area and mean annual maximum daily flow with river mile shown in figure 5.12. The mean flow at available cross sections for the Mississippi River between Dubuque and Grafton was computed from a period of record (1941-1996) simulation performed with the UNET unsteady flow model. The drainage increase was computed by first accumulating drainage area increases at cross sections where tributary inflows occur. Drainage area values between tributaries was linearly interpolated with river mile. As can be seen from the figure, drainage area is superior to river mile in capturing the non-linear variation of the mean flow statistic between gages. This would also be true of standard deviation or a flood quantile.

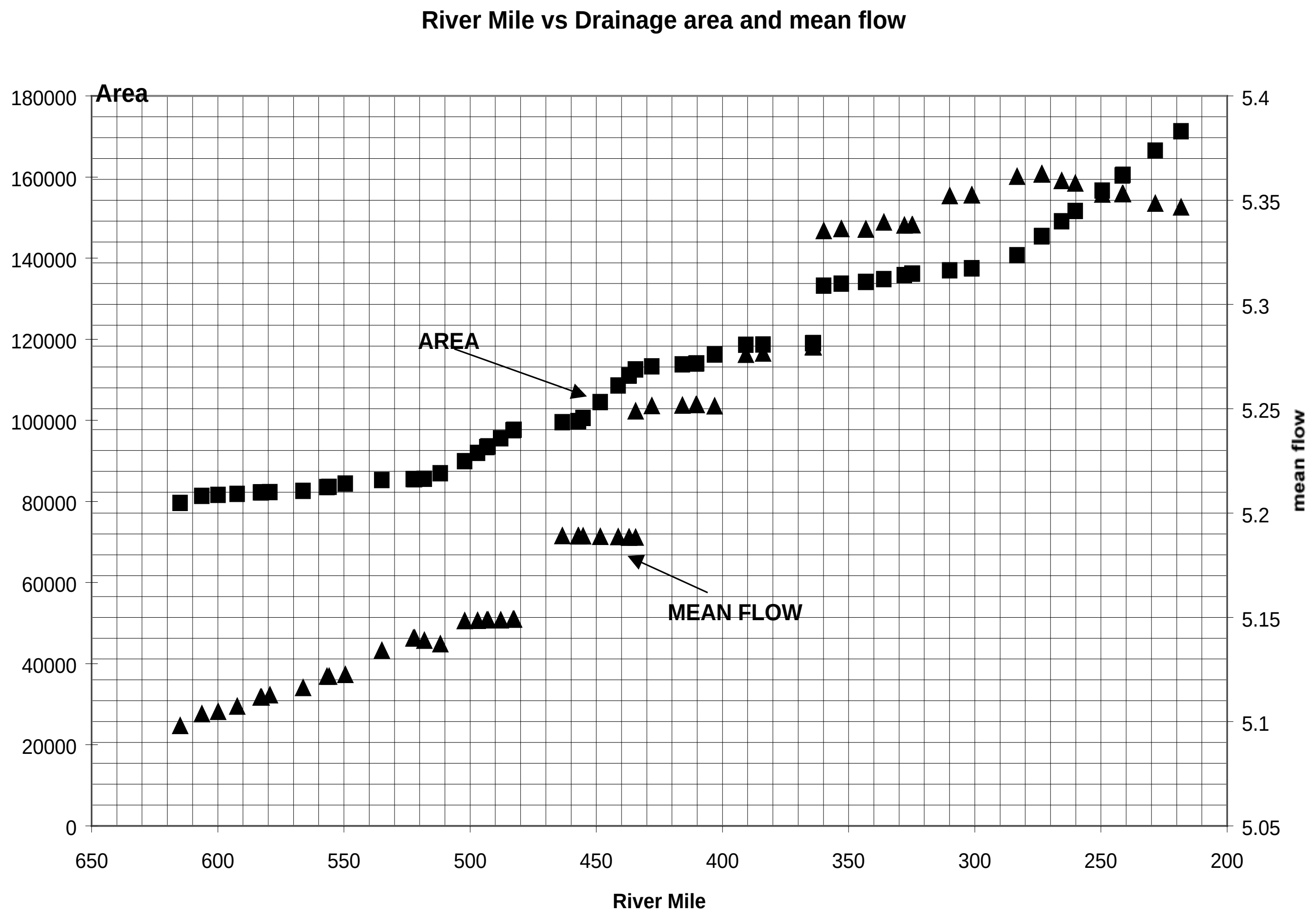


Figure 5.12: UNET simulated mean flow (period 1941-1996) and drainage area versus river mile Rock Island District reach of Mississippi River (approximately Dubuque, IA to Grafton, IL)

5.6 **Recommendations**

Recommended 1% quantile estimates are displayed in Table 5.26. These results are based on the following estimation decisions:

General

1) The period of record that best represents the current land use begins in 1898, giving a period of record of 100 years for the gages in the study, except on the Illinois River;
2) Regions for obtaining regular variation of flood quantiles were defined based on examination of channel characteristics, climatology and regional variation of flood statistics
3) Drainage area will be used to interpolated distribution statistics or quantiles between gages;
4) A mixed population analysis was used to estimate the flood distributions from Yankton to St. Joseph;

Regional Shape

5) Missouri River is divided into three regions, Yankton to Omaha, Nebraska City to St. Joseph, and Kansas City to Hermann;
6) The Mississippi River is considered to be one region from St. Paul to Thebes;
7) The Illinois River Gages are considered to be part of the Mississippi River Region.

Regression of quantile with drainage area

8) The Missouri River is divided into the same regions as in regional shape estimation;
9) At-site mixed distribution estimates are used for gages between Yankton and Omaha;
10) Separate linear regressions were used to obtain regression between Nebraska City and St. Joseph, Kansas City and Hermann;
11) A single regression with drainage area relationship was used to obtain a regular variation of quantiles between St. Paul and Grafton;
12) Linear interpolation with drainage area will be used to estimate flows between gages on the Missouri River and between St. Louis and Thebes.

Concerns

13) An annual analysis instead of a mixed population analysis might be used for the Yankton to St. Joseph gages on the Missouri River;
14) The decrease in peak annual floods between Yankton and Omaha might be an artifact of sampling error and not due to the available channel storage;
15) St. Paul and Winona might not belong in the Mississippi River region, instead of a regional skew of –0.1, the skew should somewhat smaller, possibly –0.2;
16) The Illinois River gages might not belong in the Mississippi River region, particularly Marseilles and Kingston Mines, regional skew should be –0.2 rather than –0.1.

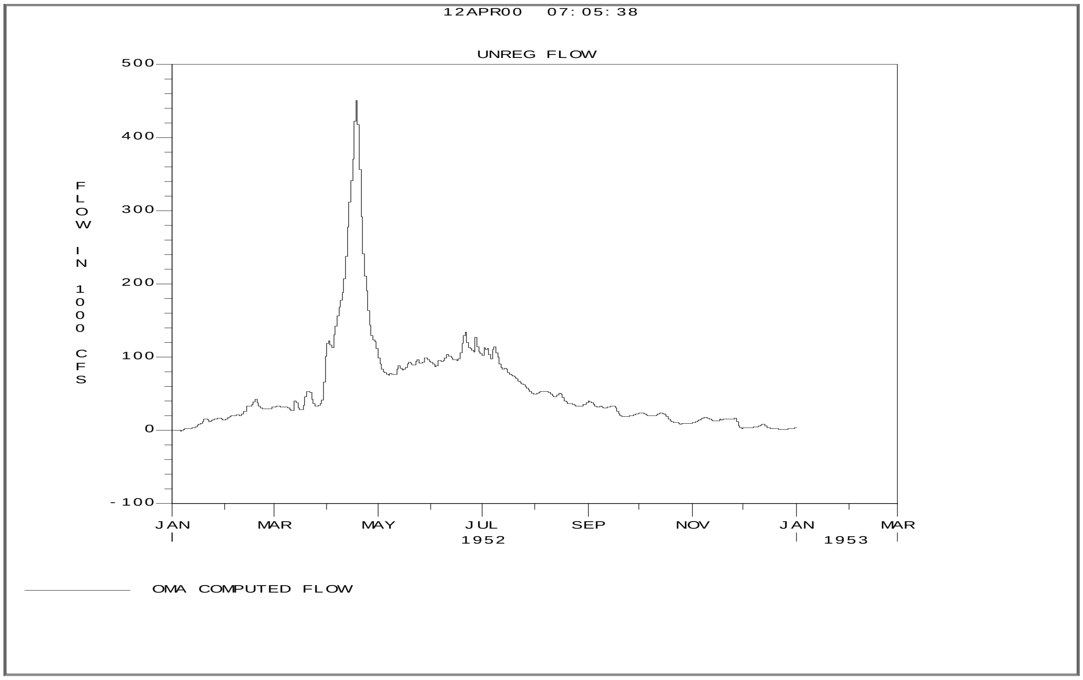
Table 5.26: Recommended 1% quantile estimates

Location	area	1% at-site	[1]1% shape	%diff	[2]1% regression	%diff
Yankton	279500	380200	372500	-2.03	380200	
Sioux City	314580	369500	375000	1.49	369500	
Decatur	316200	362300	364900	0.72	362300	
Omaha	322800	372500	371900	-0.16	372500	
Nebraska	410000	389400	400600	2.88	386100	-0.26
Rulo	414900	409400	408200	-0.29	417000	0.79
St. Joseph	420300	445000	433600	-2.56	440700	-0.52
Kansas City	485200	584900	572200	-2.17	563000	-3.25
Waverly	487200	589000	576500	-2.12	604400	1.89
Booneville	501200	675500	677700	0.33	697800	3.27
Hermann	524200	809700	859200	6.11	793900	-1.99
St Paul	36800	134900	147400	9.27	140800	4.34
Winona	59200	237700	237700	0	213100	-10.33
Dubuque	82000	281900	279400	-0.89	283200	0.46
Clinton	85600	274300	277500	1.17	294100	7.22
Keokuk	119000	371700	370200	-0.4	392000	5.48
Hannibal	137000	465300	475900	2.28	443300	-4.73
Louisiana	141000	478200	468200	-2.09	454600	-4.94
Grafton	171300	518700	515600	-0.6	538700	3.87
St Louis	697000	1104800	1072300	-2.94	1104800	
Chester	708600	1117200	1109800	-0.66	1117200	
Thebes	713200	1120800	1111000	-0.87	1120800	
Marseilles	8260	103000	109600	6.41	103000	
Kingston Mines	15820	98000	100400	2.45	98000	
Meredosia	26030	137000	135800	-0.88	137000	

[1] Regional shape estimation, flood frequency distribution estimated using at-site mean and standard deviation, regional skew substituted for at-site skew

[2] At-site estimates used where %difference not shown

Appendix A: Annual series showing mixed distribution flooding, Omaha, Missouri River



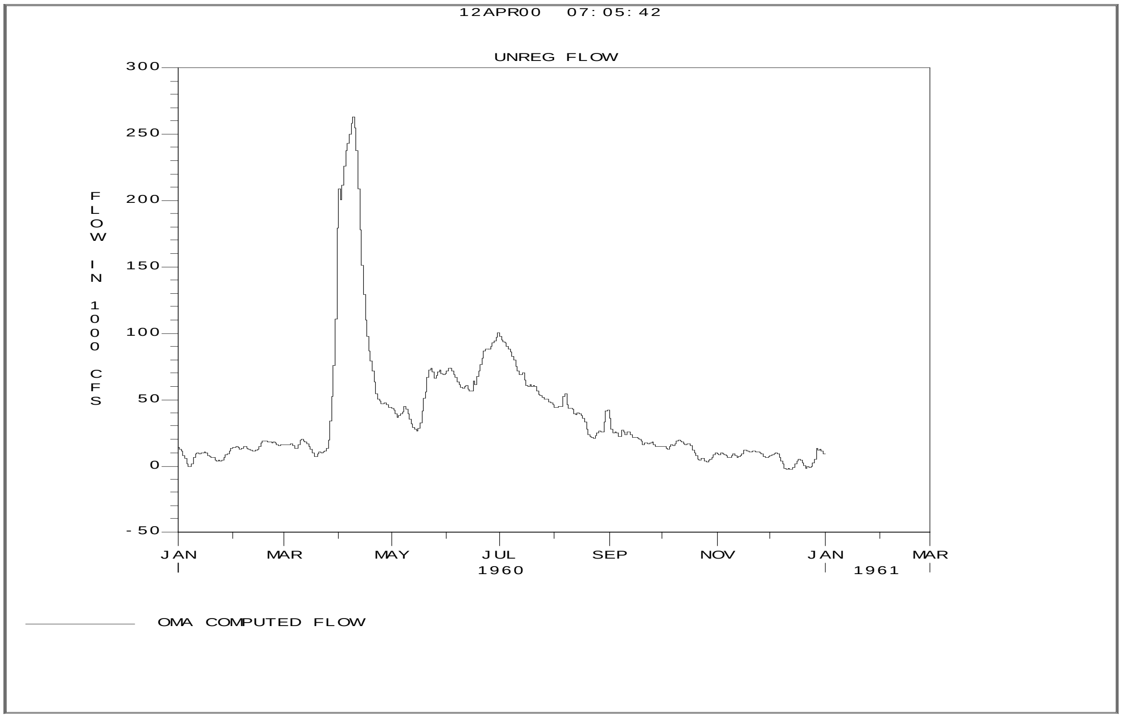
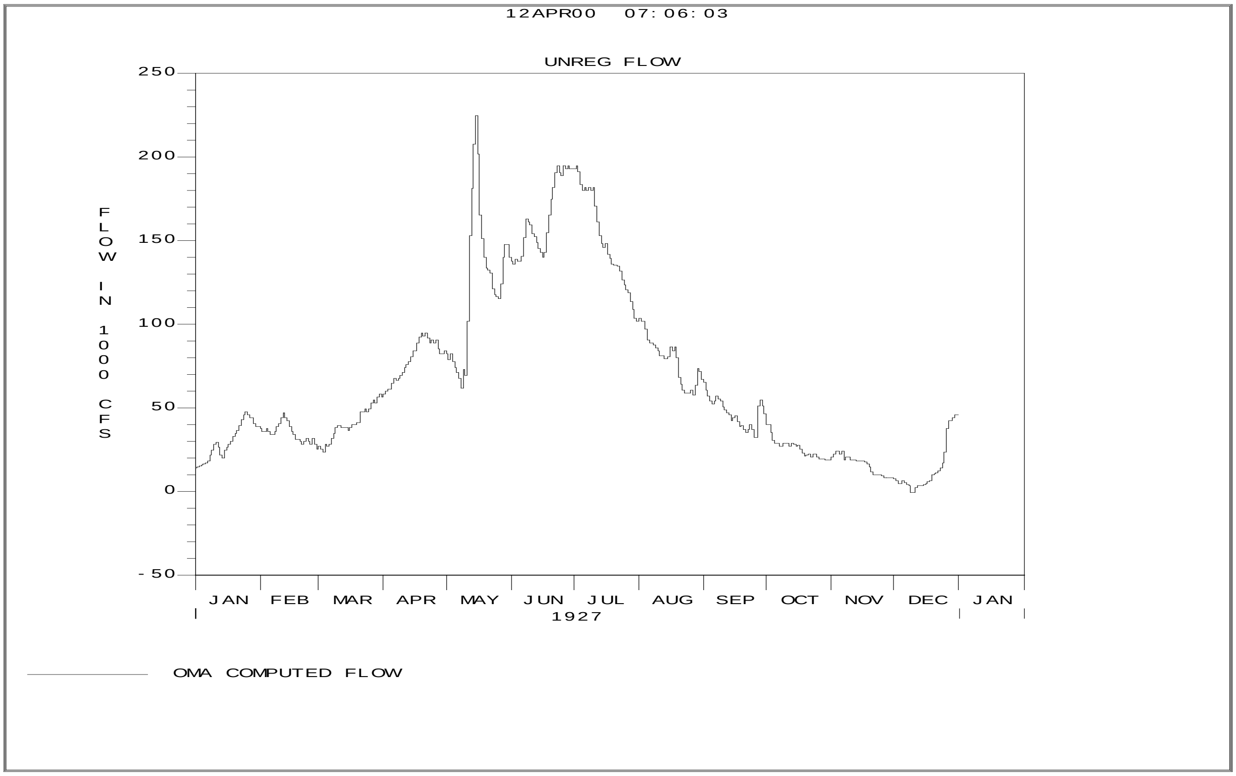


Figure A.1: Spring events, Omaha



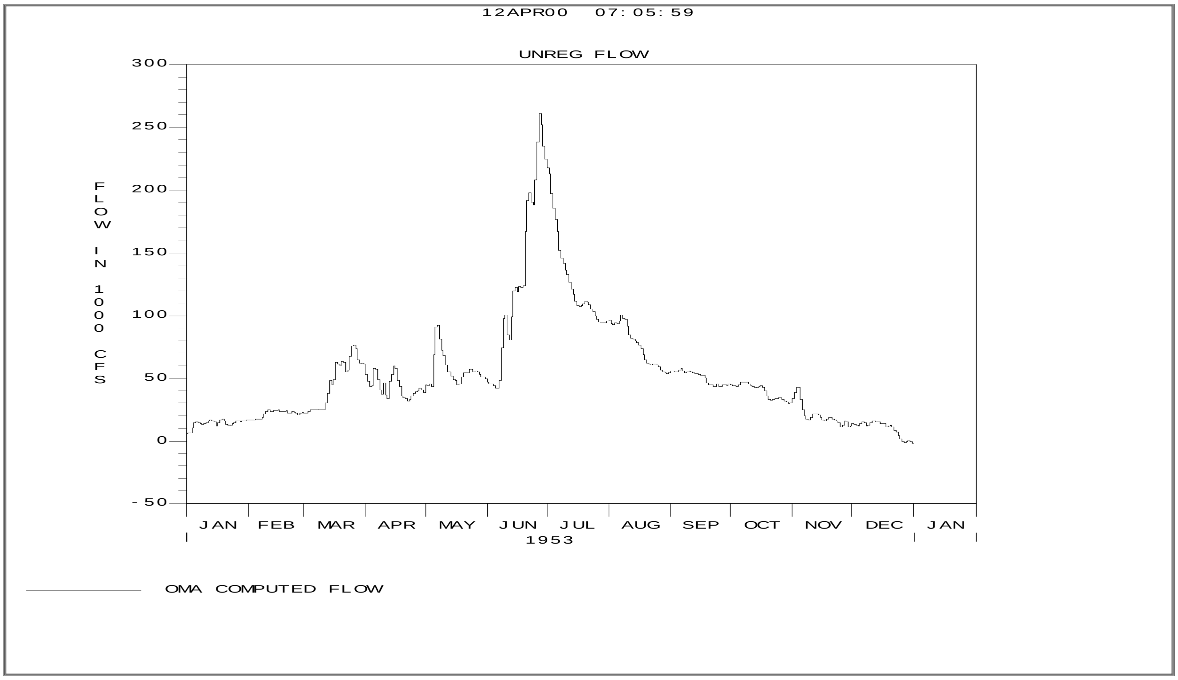


Figure A.2: Summer events, Omaha

Appendix B. Regional skew estimates for the St. Paul Gage

The St. Paul gage presents a difficult problem when compared to the other gages on the Mississippi River. Both an analysis of climate and the regional variation of statistics argue for placing this gage, and possibly the Winona gage, in a different region than the other gages. The sample statistics of other relatively large drainage area gages (greater than 1000 square miles) tributary to the Mississippi above St. Paul were examined to provide additional information on selecting a regional skew for St. Paul. Regional skew values of the annual peak flow series for the large area gages shown in Table B.1 do not indicate on the average that the St. Paul gage should be different than –0.1 given the average of –0.05.

Table B.1: Log statistics of annual peak flows, rivers tributary to Mississippi River above St. Paul

Location	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
CANNON RIVER, WELCH	1340	64	3.792	0.292	-0.001	0	0	0	0
COTTONWOOD RIVER, NEW ULM	1300	68	3.576	0.366	0.231	0	0	2	0
DES MOINES RIVER, JACKSON	1250	68	3.280	0.367	-0.012	0	0	1	0
LE SUEUR RIVER, RAPIDAN	1110	56	3.629	0.326	-0.087	0	0	1	0
MINNESOTA RIVER, JORDAN	16200	64	4.271	0.335	0.100	0	0	0	0
MINNESOTA RIVER, MANKATO	14900	96	4.196	0.353	-0.388	0	0	1	0
MINNESOTA RIVER, ORTONVILLLE	1160	61	2.921	0.371	-0.17	0	0	1	0
MISSISSIPPI RIVER, ST PAUL	36800	131	4.581	0.261	-0.269	0	0	0	0
average			3.780	0.335	-0.07				
standard error			0.513	0.0354	0.19				

(1) Drainage area square miles
(2) Systematic period of record
(3) Mean of log10 flows
(4) Standard deviation of log10 flows
(5) Skew coefficient of log10 flows
(6) Number of historic events
(7) Number of high outliers
(8) Number of low outliers
(9) Number of missing or zero flood years

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