10 APPENDIX D: UPPER MISSISSIPPI AND MISSOURI – ASSESSMENT OF TREND

Nicholas C. Matalas

Introduction

Annual flood sequences have long been assumed to be realizations of stationary, independent processes, such that the observed floods are variate values of independent and identically distributed (iid) random variables. Studies devoted to improving methodology for flood frequency analysis continue to be based on the iid assumption. Current interest in climate change and it's potential impacts on hydrology in general and on floods in particular calls into question the iid assumption. Whether flood frequency analysis should continue to be pursued under the assumption or not is presently unsettled. A few studies have addressed the issue of nonstationarity described as trend in flood flows over time. However, little attention has been given to whether or not the assumption of temporal independence should continue to be accepted or if it should be rejected. The following discussions address both issues – temporal trend and temporal dependence.

A trend, positive or negative, has a beginning and an end. A sustained positive trend would in time become limited by the carrying capacity of the stream's drainage area. And a sustained negative trend would in time render the stream dry. It is reasonable to assume that between these extreme hydrologic states, the slope of a positive (negative) trend decreases (increases) as the flow regime approaches a new state of equilibrium. It is also reasonable to assume that a linear trend begins as a nonlinear trend as the flow regime departs from a state of equilibrium, and that in time, the linear trend will become nonlinear as the flow regime approaches a new state of equilibrium. Such a pattern may be a "trend" rather than a trend. More specifically, the "trend" may be a segment of an oscillatory wave. For hydrologic sequences, it is unlikely that an oscillatory wave would have a fixed periodicity. If the oscillatory wave is itself real, it may perhaps best be described as reflecting persistence of short or long memory. Thus trend assessment is best pursued relative to persistence.

Consequently, an assessment of trend would be enhanced by taking into account the evolution of the sequence. The account provides a focus on the time at which the assessment is made relative to the time the sequence began. By considering the evolution of a sequence, it can be ascertained how trend assessment would have changed over time. This *past to present* view is complimented by a *present to past* view, i.e. by an assessment of trend considering alternate dates at which the sequence began, where the alternate dates are within the historical time span of the sequence. The two views serve to remind us that the future may contradict the past. Paleo-records allow the more remote past to be assessed relative to the historical record (the observed sequence of flows), but the future remains unknown.

Any trend/persistent assessment should consider the extent to which the observed sequences are correlated with one another. The greater the correlation, the greater the redundancy in the information provided by the sequences. The extent to which the temporal pattern of one sequence is reflected in another sequence varies directly with the degree of redundancy in the information content of the sequences.

An evolutionary trend assessment is undertaken for annual flood sequences for selected sites in the Upper Mississippi and Missouri Basins. The sequences are examined to determine if they are characterized by statistically meaningful trends and if detected trends are reflective of hydrologic persistence or whether persistence is a manifestation of trend. Trends are limited to those in the mean defined by the linear regression of time (year) on flow (flood). A statistically meaningful trend is taken to be a statistically significant regression at the 5% level and at the 1% level. As time is regressed on flow for only one sequence, the regression is said to be a simple regression. Each sequence is assessed under the null hypothesis that the regression coefficient is equal to zero. In the case of a simple regression, the null hypothesis is equivalent to the null hypothesis that the coefficient of correlation between time and flow is equal to zero. At a specific level of significance, if the regression coefficient is significant or not, then the correlation coefficient is significant or not at the specified level of significance. Herein, discussions are focused on the correlation coefficients. The issue of temporal dependence is addressed in terms of the estimates of the first order autocorrelation coefficient and the Hurst coefficient.

The assessment draws on selected flood sequences, 7 at sites in the Missouri Basin and 13 at sites in the Upper Mississippi Basin, where the time spans of the sequences are all within the period 1861 to 1997. See Table 1.

Selected Sequences

The locations, drainage areas and lengths of the selected sequences are presented in Table 1.

Table 1: Selected Sites on the Missouri and Mississippi Rivers

All of the Missouri sequences span a common concurrent 100 year period, 1898-1997. There are no years in which observations are missing at any of the 7 sequences. The time spans of the Mississippi sequences range from 59 to 135 years. The starting dates of the sequences vary from 1861 to 1937 (McGregor) and the terminal dates vary from 1995 to 1997. Of the 13 sequences, 6 have a missing year of observation. The drainage areas of the Missouri sites vary from 314,600 sq. mi. to 528,200 sq. mi., whereas the Mississippi sites vary from 19,600 sq. mi. to 171,300 sq. mi. above the confluence of the Missouri River to 713,200 sq. mi. below the confluence.

Location	Drainage Area (mi^2)	Record Length	Time Span	Missing Year	Assessed for Trend
		Missouri River			
Sioux City, Iowa	314,600	100	1898-1997	None	Yes
Omaha, Neb.	322,820	100	1898-1997	None	Yes
Nebraska City, Neb.	414,420	100	1898-1997	None	Yes
St. Joseph, Mo.	429,340	100	1898-1997	None	Yes
Kansas City, Mo.	489,162	100	1898-1997	None	Yes
Booneville, Mo.	505,710	100	1898-1997	None	Yes
Herman, Mo.	528,200	100	1898-1997	None	Yes
		Mississippi River			
Annoka, Minn.	19,600	65	1931-1995	None	Yes
St. Paul, Minn.	36,800	131	1867-1997	1871	Yes
Winona, Minn.	59,200	111	1885-1995	1923	Yes
McGregor, Iowa	67,500	59	1937-1995	1990	No
Dubuque, Iowa	82,000	118	1879-1996	None	Yes
Clinton, Iowa	85,600	122	1875-1996	None	Yes
Keokuk, Iowa	119,000	122	1875-1996	None	Yes
Hannibal, Mo.	137,000	118	1879-1996	None	Yes
Louisiana, Mo.	140,700	68	1928-1995	1976	No
Alton/Grafton, Mo.	171,300	69	1928-1996	1988	No
St. Louis, Mo.	697,013	135	1861-1995	1988	Yes
Chester, Ill.	708,563	71	1926-1996	None	Yes
Thebes, Ill.	713,200	64	1933-1996	None	Yes

Since all of the Missouri sequences and all of the Mississippi sequences relate to sites along the main stem of the Missouri River and the Mississippi River, respectively, there is a fair degree of redundancy of information. A measure of redundancy is provided by the correlations between sequences – zero correlation implying zero redundancy and unit correlation, total redundancy. The correlations between sequences are for the longest concurrent period of observation for each paired sequences. The inter-basin correlations are given in Tables 2 and 3.

Table 2: Inter-Basin (Missouri) Correlations

	Sioux City, Iowa	Omaha, Neb.	Nebras-ka City, Neb.	St. Joseph, Mo.	Kansas City, Mo.	Boon-ville, Mo.	Her-mann, Mo.
Sioux City, Iowa	1						
Omaha, Neb.	0.957	1					
Nebraska City, Neb.	0.895	0.905	1				
St. Joseph, Mo.	0.755	0.847	0.836	1			
Kansas City, Mo.	0.487	0.523	0.594	0.705	1		
Boonville, Mo.	0.399	0.449	0.553	0.681	0.901	1	
Hermann, Mo.	0.296	0.360	0.441	0.590	0.769	0.894	1

The intra-basin correlations, i.e. the correlations between sequences in one basin with those in the other basin, are given in Table 4.

Table 3: Inter-Basin (Mississippi) Correlations

	Anoka, Minn.	St. Paul, Minn.	Winona, Minn.	Dubu-que, Iowa	Clinton, Iowa	Keokuk. Iowa	Han-nibal, Mo.
Anoka, Minn.	1						
St. Paul, Minn.	0.884	1					
Winona, Minn.	0.844	0.888	1				
Dubuque, Iowa	0.737	0.738	0.845	1			
Clinton, Iowa	0.716	0.698	0.825	0.904	1		
Keokuk. Iowa	0.510	0.580	0.588	0.770	0.812	1	
Hannibal, Mo.	0.444	0.576	0.544	0.739	0.677	0.901	1
St. Louis, Mo.	0.1349	0.454	0.341	0.515	0.560	0.681	0.746
Chester, Ill.	0.310	0.413	0.337	0.497	0.557	0.712	0.777
Thebes, Ill.	0.281	0.408	0.334	0.483	0.535	0.714	0.794

Table 3: Inter-Basin (Mississippi) Correlations (Continued)

	St. Louis, Mo.	Chester, Ill.	Thebes, Ill.
St. Louis, Mo.	1		
Chester, Ill.	0.981	1	
Thebes, Ill.	0.975	0.997	1

Table 4: Intra-Basin (Missouri-Mississippi) Correlations

	Sioux City, Iowa	Omaha, Neb.	Nebras-ka City, Neb.	St. Joseph, Mo.	Kansas City, Mo.	Boon-ville, Mo.	Her-mann, Mo.
Anoka, Minn.	0.513	0.520	0.500	0.522	0.343	0.267	0.186
St. Paul, Minn.	0.380	0.446	0.438	0.542	0.457	0.430	0.364
Winona, Minn.	0.329	0.359	0.366	0.435	0.444	0.357	0.271
Dubuque, Iowa	0.268	0.369	0.334	0.486	0.425	0.403	0.439
Clinton, Iowa	0.358	0.426	0.390	0.498	0.486	0.464	0.458
Keokuk. Iowa	0.250	0.347	0.375	0.546	0.557	0.588	0.596
Hannibal, Mo.	0.196	0.309	0.347	0.540	0.508	0.601	0.651
St. Louis, Mo.	0.353	0.386	0.428	0.494	0.675	0.825	0.884
Chester, Ill.	0.348	0.386	0.490	0.549	0.648	0.798	0.876
Thebes, Ill.	0.299	0.336	0.444	0.515	0.631	0.793	0.876

The average inter- basin correlations are 0.659 and 0.639 for the Missouri and Mississippi basins, respectively. The intra-basin correlation is 0.467. The redundancy within and between basins may be measured by the effective information content at time $\boldsymbol{T}$ given approximately as

$$\boldsymbol{I_T} = \frac{\boldsymbol{N_T^2}}{\boldsymbol{N_T} + \rho \sum_{t=1}^{T} \left(\boldsymbol{m_t^2} - \boldsymbol{m_t} \right)} \tag{1}$$

where $\boldsymbol{N_T}$ denotes the number of station-years of data accumulated up to time $\boldsymbol{T}$, $\boldsymbol{m_t}$ denotes the gaging stations operating at time $\boldsymbol{t}$, and ρ denotes the average correlation of the paired sequences. The percent redundancy of information is defined as

$$\boldsymbol{R_T} = \left(1 - \frac{\boldsymbol{I_T}}{\boldsymbol{N_T}} \right) 100\% \tag{2}$$

If $\rho = 0$, then $\boldsymbol{I_T} = \boldsymbol{N_T}$, in which case $\boldsymbol{R_T} = 0$, i.e. there is no redundancy of information. If $\rho = 1$ and $\boldsymbol{m_t} = \boldsymbol{m}\ \forall \boldsymbol{t}$, then $\boldsymbol{I_T} = \boldsymbol{T}$, in which case, $\boldsymbol{R_T} = (\boldsymbol{m}/(\boldsymbol{m}-1))100\%$. And therefore as $\boldsymbol{m} \to \infty$, $\boldsymbol{R_T} \to 0$.

For the Missouri basin, $\boldsymbol{T} = 100$, $\boldsymbol{N_T} = 700$ station-years, $\boldsymbol{m_t} = 7\ \forall \boldsymbol{t}$ and $\rho = 0.659$. Therefore, $\boldsymbol{I_T} \approx 141.3$ station-years. Thus, over the 100-year time span 1898-1997, the percent redundancy of information is $\boldsymbol{R_T} \approx 80\%$. For the Mississippi Basin, it is assumed that the stations begin the year after the year of missing observation and terminate in the year of the last observation. Thus, $\boldsymbol{N_T} = 985$ and summation term in the denominator of Eq. (1) is equal to 4,845. Given $\rho = 0.639$, then $\boldsymbol{I_T} \approx 166.4$, in which case $\boldsymbol{R_T} \approx 83\%$. The redundancy is very nearly the same for the two basins. In the intra-basin

case, $N_T = 6895$ and the summation term in the denominator of Eq. (1) is equal to 11,065. Given $\rho = 0.467$, then $I_T \approx 2{,}647$, in which case, $R_T \approx 62\%$.
If the two basins are treated as a single basin, then $N_T = 8{,}580$ and the summation term in the denominator of Eq. (1) is equal to 19,654. Given $\rho = 0.554$, then $I_T \approx 2{,}607$, in which case $R_T \approx 70\%$.

In the trend assessment, all 7 Missouri sequences are considered, but not all of the Mississippi sequences since some of the sequences have a year of missing observation. Of the 13 Mississippi sequences, 10 are assessed for trends. For the 3 sequences not used in the assessment – McGregor, Louisiana and Alton/Grafton – the missing year of observation occurs late in the record. This is also the case with the St. Louis sequences, however because this is the longest of the selected Mississippi sequences, spanning the period 1861 to 1987, it is included in the assessment. The observations for the 3 sequences not used in the assessment are within the time span 1926-1990. Refer to Table 1 above.

The annual flood sequences for the 7 sites in the Missouri Basin and for the 13 sites in the Upper Mississippi Basin are shown graphically in Appendix C-A. To facilitate visual comparison of one sequence with another, each set of observations was standardized such that the means and standard deviations of the observations equal 0 and 1, respectively. Statistical characteristics of the sequences are given in Appendix C-B.

Trend Assessment

In the following assessment of trend, the evolution of a flood sequence is taken into the account. This account provides a focus on the time at which we make the assessment relative to the time the sequence began. By considering the evolution of the sequence, we can ascertain how our assessment would have changed over time as the length of the sequence increases. This *past to present* view is complimented by a *present to past* view, i.e., an assessment of trend considering alternate dates at which the record began, where the alternate dates are within the historical time span of the sequence.

The trend assessments under the two views are summarily given in Tables 5 and 6.

Table 5: Assessment of Trend in the Missouri Basin

Length of Record	Period of Record	Correlation	Length of Record	Period of Record	Correlation	Length of Record	Period of Record	Correlation
Sioux City			**Omaha**			**Nebraska City**		
Past to Present								
10	(1898-1907)	-0.071	10	(1898-1907)	0.273	10	(1898-1907)	-0.340
20	(1898-1917)	-0.089	20	(1898-1917)	0.061	20	(1898-1917)	0.510*
30	(1898-1927)	-0.356*	30	(1898-1927)	-0.105	30	(1898-1927)	-0.184
40	(1898-1937)	-0.624**	40	(1898-1937)	-0.401**	40	(1898-1927)	-0.515**
50	(1898-1947)	-0.355*	50	(1898-1947)	-0.220	50	(1898-1947)	-0.390**
60	(1898-1957)	-0.103	60	(1898-1957)	0.017	60	(1898-1957)	-0.171
70	(1898-1967)	-0.086	70	(1898-1967)	0.041	70	(1898-1967)	-0.083
80	(1898-1977)	-0.154	80	(1898-1977)	-0.029	80	(1898-1977)	-0.165
90	(1898-1987)	-0.138	90	(1898-1987)	0.007	90	(1898-1987)	-0.087
100	(1898-1997)	-0.173	100	(1898-1997)	-0.009	100	(1898-1997)	-0.078
Present to Past								
10	(1997-1988)	0.526	10	(1997-1988)	0.570	10	(1997-1988)	0.778**
20	(1997-1978)	0.126	20	(1997-1978)	0.203	20	(1997-1978)	0.079
30	(1997-1968)	-0.047	30	(1997-1968)	0.043	30	(1997-1968)	0.208
40	(1997-1958)	-0.062	40	(1997-1958)	0.016	40	(1997-1958)	0.026
50	(1997-1948)	-0.242	50	(1997-1948)	-0.165	50	(1997-1948)	-0.069
60	(1997-1938)	-0.150	60	(1997-1938)	-0.054	60	(1997-1938)	0.000
70	(1997-1928)	-0.029	70	(1997-1928)	0.050	70	(1997-1928)	0.144
80	(1997-1918)	-0.059	80	(1997-1918)	0.040	80	(1997-1918)	0.133
90	(1997-1908)	-0.116	90	(1997-1908)	0.011	90	(1997-1908)	-0.048
100	(1997-1898)	-0.173	100	(1997-1898)	-0.009	100	(1997-1898)	-0.078

* 5% Level of Significance; ** 1% Level of Significance

Table 5: Assessment of Trend in the Missouri Basin (continued)

Length of Record	Period of Record	Correlation	Length of Record	Period of Record	Correlation	Length of Record	Period of Record	Correlation
St. Joseph			**Kansas City**			**Booneville**		
Past to Present								
10	(1898-1907)	0.392	10	(1898-1907)	0.166	10	(1898-1907)	0.180
20	(1898-1917)	0.128	20	(1898-1917)	0.046	20	(1898-1917)	0.130
30	(1898-1927)	0.193	30	(1898-1927)	-0.174	30	(1898-1927)	-0.110
40	(1898-1937)	-0.260	40	(1898-1937)	-0.462**	40	(1898-1937)	-0.357**
50	(1898-1947)	-0.120	50	(1898-1947)	-0.296*	50	(1898-1947)	-0.156
60	(1898-1957)	0.083	60	(1898-1957)	-0.136	60	(1898-1957)	-0.151
70	(1898-1967)	0.190	70	(1898-1967)	-0.135	70	(1898-1967)	-0.138
80	(1898-1977)	0.121	80	(1898-1977)	-0.145	80	(1898-1977)	-0.157
90	(1898-1987)	0.178	90	(1898-1987)	-0.145	90	(1898-1987)	-0.026
100	(1898-1997)	0.223*	100	(1898-1997)	-0.015	100	(1898-1997)	0.101
Present to Past								
10	(1997-1988)	0.654*	10	(1997-1988)	0.446	10	(1997-1988)	0.411
20	(1997-1978)	0.277	20	(1997-1978)	0.402	20	(1997-1978)	0.313
30	(1997-1968)	0.256	30	(1997-1968)	0.336	30	(1997-1968)	0.441
40	(1997-1958)	0.126	40	(1997-1958)	0.264	40	(1997-1958)	0.397**
50	(1997-1948)	0.019	50	(1997-1948)	0.081	50	(1997-1948)	0.320
60	(1997-1938)	0.160	60	(1997-1938)	0.090	60	(1997-1938)	0.242
70	(1997-1928)	0.252	70	(1997-1928)	0.220	70	(1997-1928)	0.304*
80	(1997-1918)	0.226	80	(1997-1918)	0.177	80	(1997-1918)	0.277*
90	(1997-1908)	0.217	90	(1997-1908)	0.053	90	(1997-1908)	0.141
100	(1997-1898)	0.223*	100	(1997-1898)	-0.015	100	(1997-1898)	0.101

* 5% level of significance; ** 1% level of significance

Table 5: Assessment of Trend in the Missouri Basin (continued)

Length of Record	Period of Record	Corre-lation
Herman		
Past to Present		
10	(1898-1907)	0.266
20	(1898-1917)	0.179
30	(1898-1927)	0.100
40	(1898-1937)	-0.159
50	(1898-1947)	0.051
60	(1898-1957)	-0.033
70	(1898-1967)	0.002
80	(1898-1977)	-0.005
90	(1898-1987)	0.114
100	(1898-1997)	-0.224*
Present to Past		
10	(1997-1988)	0.495
20	(1997-1978)	0.374
30	(1997-1968)	0.435
40	(1997-1958)	0.381
50	(1997-1948)	0.372**
60	(1997-1938)	0.263*
70	(1997-1928)	0.325**
80	(1997-1918)	0.296**
90	(1997-1908)	0.234
100	(1997-1898)	-0.224*

* 5% Level of Significance; ** 1% Level of Significance

Table 6: Assessment of Trend in the Upper Mississippi Basin

Length of Record	Period of Record	Corre-lation	Length of Record	Period of Record	Corre-lation	Length of Record	Period of Record	Corre-lation
Anoka			**St. Paul**			**Winona**		
			Past to Present					
7	(1931-1937)	0.717	6	(1872-1877)	-0.120	14	(1924-1937)	0.204
17	(1931-1947)	0.768**	16	(1872-1887)	-0.194	24	(1924-1947)	0.488
27	(1931-1957)	0.613**	26	(1872-1897)	-0.110	34	(1924-1957)	0.562**
37	(1931-1967)	0.424**	36	(1872-1907)	-0.055	44	(1924-1967)	0.419**
47	(1931-1977)	0.315*	46	(1872-1917)	0.013	54	(1924-1977)	0.411**
57	(1931-1987)	0.239	56	(1872-1927)	-0.144	64	(1924-1987)	0.369**
65	(1931-1995)	0.113	66	(1872-1937)	-0.280*	72	(1924-1995)	0.305**
			76	(1872-1947)	-0.159			
			86	(1872-1957)	0.059			
			96	(1872-1967)	0.115			
			106	(1872-1977)	0.157			
			116	(1872-1987)	0.192*			
			125	(1872-1996)	0.199*			
			Present to Past					
8	(1995-1988)	0.819*	9	(1996-1988)	0.580	8	(1995-1988)	0.566
18	(1995-1978)	-0.161	19	(1996-1978)	0.120	18	(1995-1978)	-0.028
28	(1995-1968)	-0.256	29	(1996-1968)	-0.150	28	(1995-1968)	-0.174
38	(1995-1958)	-0.126	39	(1996-1958)	0.043	38	(1995-1958)	0.032
48	(1995-1948)	-0.183	49	(1996-1948)	-0.040	48	(1995-1948)	-0.037
58	(1995-1938)	-0.154	59	(1996-1938)	0.067	58	(1995-1938)	0.074
65	(1995-1931)	0.113	69	(1996-1928)	0.259*	72	(1995-1924)	0.305**
			79	(1996-1918)	0.321**			
			89	(1996-1908)	0.270*			
			99	(1996-1898)	0.262**			
			109	(1996-1888)	0.256**			
			119	(1996-1878)	0.225**			
			125	(1996-1872)	0.199*			

* 5% Level of Significance; 1% Level of Significance

Table 6: Assessment of Trend in the Upper Mississippi Basin (continued)

Length of Record	Period of Record	Corre-lation	Length of Record	Period of Record	Corre-lation	Length of Record	Period of Record	Corre-lation
	Dubuque			**Clinton**			**Keokuk**	
				Past to Present				
9	(1879-1887)	-0.232	13	(1875-1887)	0.154	9	(1879-1887)	-0.151
19	(1879-1897)	-0.193	23	(1875-1897)	0.028	19	(1879-1897)	-0.250
29	(1879-1907)	-0.075	33	(1875-1907)	-0.023	29	(1879-1907)	-0.139
39	(1879-1917)	-0.133	43	(1875-1917)	-0.226	39	(1879-1917)	-0.226
49	(1879-1927)	-0.091	53	(1875-1927)	-0.235	49	(1879-1927)	-0.234
59	(1879-1937)	-0.151	63	(1875-1937)	-0.374	59	(1879-1937)	-0.326*
69	(1879-1947)	0.093	73	(1875-1947)	-0.198	69	(1879-1947)	-0.184
79	(1879-1957)	0.176	83	(1875-1957)	-0.159	79	(1879-1957)	-0.146
89	(1879-1967)	0.223*	93	(1875-1967)	-0.097	89	(1879-1967)	-0.046
99	(1879-1977)	0.286**	103	(1875-1977)	-0.030	99	(1879-1977)	0.044
109	(1879-1987)	0.330**	113	(1875-1987)	0.008	109	(1879-1987)	0.110
118	(1879-1996)	0.310**	122	(1875-1996)	0.007	118	(1879-1996)	0.147
				Present to Past				
9	(1996-1988)	0.519	9	(1996-1988)	0.630	9	(1996-1988)	0.364
19	(1996-1978)	0.096	19	(1996-1978)	0.192	19	(1996-1978)	0.196
29	(1996-1968)	-0.079	29	(1996-1968)	-0.036	29	(1996-1968)	0.104
39	(1996-1958)	0.061	39	(1996-1958)	0.067	39	(1996-1958)	0.130
49	(1996-1948)	0.078	49	(1996-1948)	0.098	49	(1996-1948)	0.188
59	(1996-1938)	0.042	59	(1996-1938)	0.039	59	(1996-1938)	0.202
69	(1996-1928)	0.249*	69	(1996-1928)	0.231	69	(1996-1928)	0.321**
79	(1996-1918)	0.284**	79	(1996-1918)	0.200	79	(1996-1918)	0.309**
98	(1996-1908)	0.351**	89	(1996-1908)	0.237	89	(1996-1908)	0.316**
99	(1996-1898)	0.360**	99	(1996-1898)	0.173	99	(1996-1898)	0.270*
109	(1996-1888)	0.351**	109	(1996-1888)	0.081	109	(1996-1888)	0.223*
118	(1996-1879)	0.310**	122	(1996-1875)	0.007	118	(1996-1879)	0.147

* 5% Level of Significance; ** 1% Level of Significance

Table 6: Assessment of Trend in the Upper Mississippi Basin (continued)

Length of Record	Period of Record	Corre-lation	Length of Record	Period of Record	Corre-lation	Length of Record	Period of Record	Corre-lation
Hannibal			**St. Louis**			**Chester**		
Past to Present								
9	(1879-1887)	-0.051	7	(1861-1867)	0.087	12	(1926-1937)	0.476
19	(1879-1897)	-0.189	17	(1861-1877)	0.146	22	(1926-1947)	0.227
29	(1879-1907)	-0.034	27	(1861-1887)	0.228	32	(1926-1957)	-0.076
39	(1879-1917)	-0.012	37	(1861-1897)	0.112	42	(1926-1967)	-0.095
49	(1879-1927)	0.016	47	(1861-1907)	0.152	52	(1926-1977)	-0.049
59	(1870-1937)	-0.065	57	(1861-1917)	0.202	62	(1926-1987)	0.196
69	(1879-1947)	0.123	67	(1861-1927)	0.134	71	(1926-1996)	0.259*
79	(1879-1957)	0.159	77	(1861-1937)	-0.024			
89	(1879-1967)	0.221*	87	(1861-1947)	0.090			
99	(1879-1977)	0.329**	97	(1861-1957)	0.020			
109	(1879-1987)	0.425**	107	(1861-1967)	0.002			
118	(1879-1996)	0.447**	117	(1861-1977)	0.020			
			127	(1861-1987)	0.139			
Present to Past								
9	(1996-1988)	0.456	10	(1987-1978)	0.501	9	(1996-1988)	0.626*
19	(1996-1978)	0.228	20	(1987-1968)	0.467	19	(1996-1978)	0.179
29	(1996-1968)	0.168	30	(1987-1958)	0.449	29	(1996-1968)	0.356*
39	(1996-1958)	0.290	40	(1987-1948)	0.385	39	(1996-1958)	0.410**
49	(1996-1948)	0.340*	50	(1987-1938)	0.172	49	(1996-1948)	0.413**
59	(1996-1938)	0.341**	60	(1987-1928)	0.282	59	(1996-1938)	0.243
69	(1996-1928)	0.450**	70	(1987-1918)	0.246	71	(1996-1926)	0.259*
79	(1996-1918)	0.458**	80	(1987-1908)	0.141			
89	(1996-1908)	0.475**	90	(1987-1898)	0.115			
99	(1996-1898)	0.475**	100	(1987-1888)	0.123			
109	(1996-1888)	0.477**	110	(1987-1878)	0.094			
118	(1996-1879)	0.447**	120	(1987-1868)	0.120			
			127	(1987-1861)	0.139			

* 5% Level of Significance; 1% Level of Significance

Table 6: Assessment of Trend in the Upper Mississippi Basin (Continued)

Length of Record	Period of Record	Corre-lation
	Thebes	
	Past to Present	
5	(1933-1937)	-0.027
15	(1933-1947)	0.589*
25	(1933-1957)	-0.007
35	(1933-1967)	-0.036
45	(1933-1977)	0.007
55	(1933-1987)	0.280*
64	(1933-1996)	0.319*
	Present to Past	
9	(1996-1988)	0.612
19	(1996-1978)	0.267
29	(1996-1968)	0.349
39	(1996-1958)	0.399*
49	(1996-1948)	0.406**
59	(1996-1938)	0.267*
64	(1996-1933)	0.319*

* 5% Level of Significance; 1% Level of Significance

Missouri Basin

None of the 7 sequences indicate significant trends at the 1% level. For 2 of the 7 sequences, those for St. Joseph and Herman, there are significant trends at the 5% level. In both cases, the significance of the trends attains with the *past to present* view and with the *present to past* view with the inclusion of the observations for the period 1988 through 1997 and for the period 1898 through 1907, respectively. Had the assessment been made in 1988, the *past to present* view would not have revealed a significant trend at the 5% level. Moreover, had there been no observations for the period 1898 through 1907, the *present to past* view would not have indicated a significant trend at 5% level.

There are not strong indications of trends in the Missouri Basin. Whether the trends in the 2 sub-basins, St. Joseph and Herman, can be accounted for by climate change or by land use change or by some other kinds of change remains to be determined. In any case, it is changes that have occurred in the most recent years or changes that have occurred in the past but are just now manifesting themselves that reflect trends for the 2 sequences.

The trends may be reflections of segments of oscillatory movements that may themselves be reflections of segments of persistence. The fact that the estimates of the first order autocorrelation coefficients for the sequences vary from 0.040 to 0.168 indicate that the effects of persistence may be weak. In any case, persistence does not seem to be long memory given that the estimates of the Hurst coefficient vary from 0.582 to 0.686. Refer to Table A-1 in Appendix A.

Mississippi Basin

Of the 13 selected sequences for the Mississippi Basin, 10 were assessed for trends. Over the entire periods of record, 6 of the ten sequences indicate significant trends – 3 (St. Paul, Chester, Thebes) at the 5% level and 3 (Winona, Dubuque, Hannibal) at the 1% level.

With respect to the 125-year St. Paul sequence, had the assessment been made in 1978, there would have been no indication of a significant trend at the 5% level. Thus, it is the inclusion of the most current 19 years of observations that results in a significant trend for the entire record. Had the observed record extended from 1996 back to 1938, there would have been no indication of a significant trend at the 5% level. However, as the record extended further into the past, the indications of significant trend would oscillate about the levels of 5% and 1%. With respect to the 71-year Chester sequence, it is the most current 9 years of observations that bring about a 5% significant trend for the entire record. With respect to the 64-year Thebes sequence, it is the inclusion of the most current 19 years of observations that bring about a 5% significant trend.

With respect to the 72-year Winona sequence, the *past to present* view suggests that the significant trend at the 1% level is well substantiated as the levels of significance persist as the most current observation increases from 1958 to 1995. However, the *present to past* view indicates that if the observations for the period 1924 through 1937 were not available, the there would not be an indication of trend at the 5% level. The Winona sequence begins in 1885 and extends to 1995 with the observation for 1923 being missing. If the missing year of observation is ignored and the sequence is treated as a continuos 110-year sequence, then the correlation between time and flow is 0.157 indicating a significant trend near the 5% level. Thus, it seems as the sequence extends further into the past, the indication of a significant trend weakens. Whether the pattern would persist further into the past can not be addressed at this level of analysis.

With respect to the 118-year Dubuque sequence and the 118-year Hannibal sequence, significant trends at the 1% level are strongly indicated with both the *past to present* and the *present to past* views. These two sequences are in strong contrast to the other 8 sequences. Why this is so is an open question.

With the exception of the St. Louis sequence, the sequences include the most current years of observation. The St. Louis sequence extends from 1861 to 1996, with the 1988 observation being missing. For the period 1861 through 1987, there is no indication of a significant trend at the 5% level. If the missing year of observation is ignored and the sequence is treated as a continuos 127-year sequence, then the correlation between time and flow is 0.202 indicating a significant trend at the 5% level. Thus, it is the most current 9 years of observations that bring about a significant trend at the 5% level.

Appendix D-A Selected Sequences

The sequences relating to the seven sites in the Missouri Basin and to 10 sites in the Mississippi Basin are depicted in Figures 1 through 17.

Missouri Basin

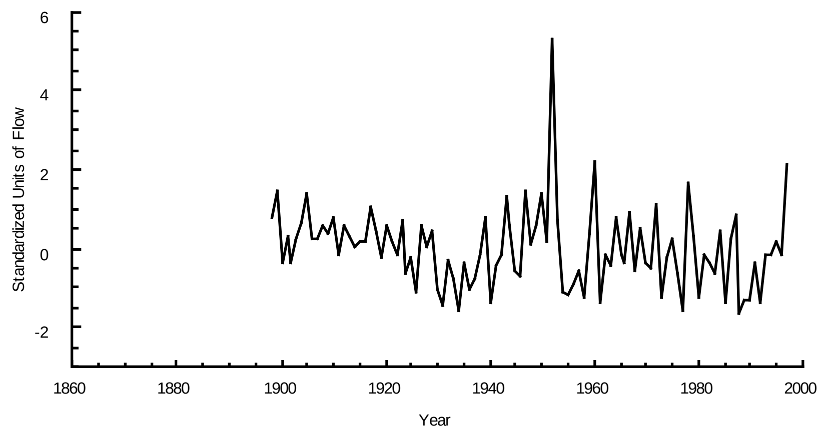

Figure A 1: Sequence of Standardized Annual Floods on the Missouri River at Sioux City, Iowa

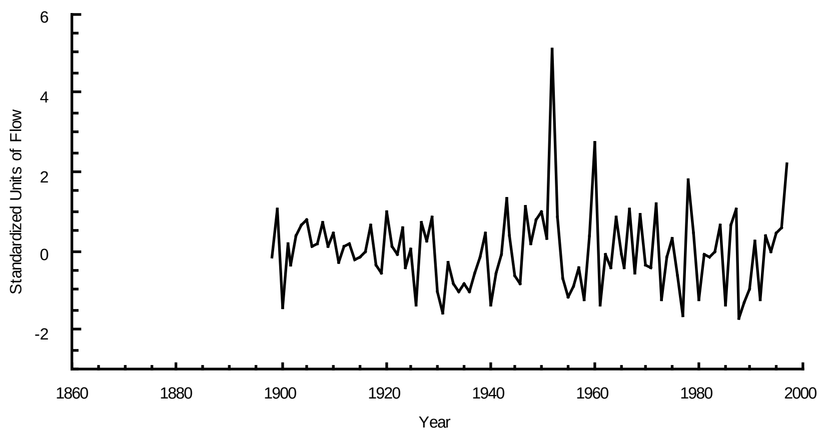

Figure A 2: Sequence of Standardized Annual Floods on the Missouri River at Omaha, Nebraska

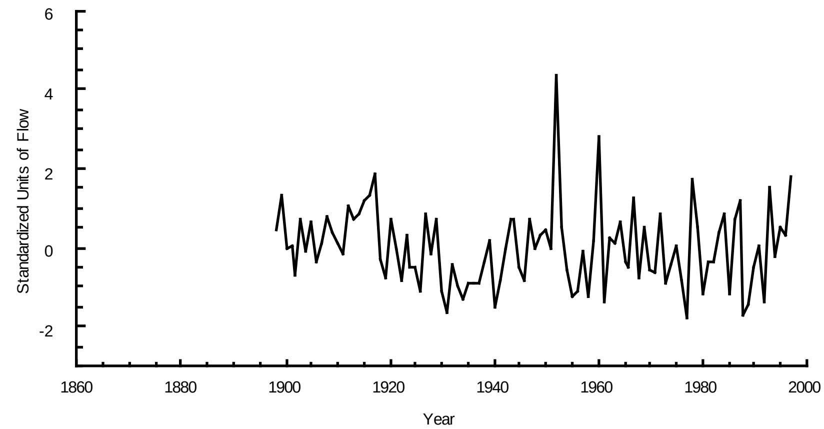

Figure A3: Sequence of Standardized Annual Floods on the Missouri River at Nebraska City, Nebraska

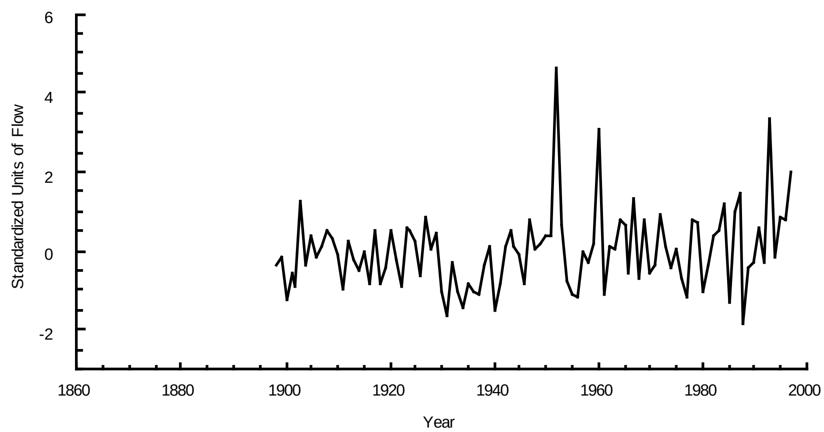

Figure A4: Sequence of Standardized Annual Floods on the Missouri River at St. Joseph, Missouri

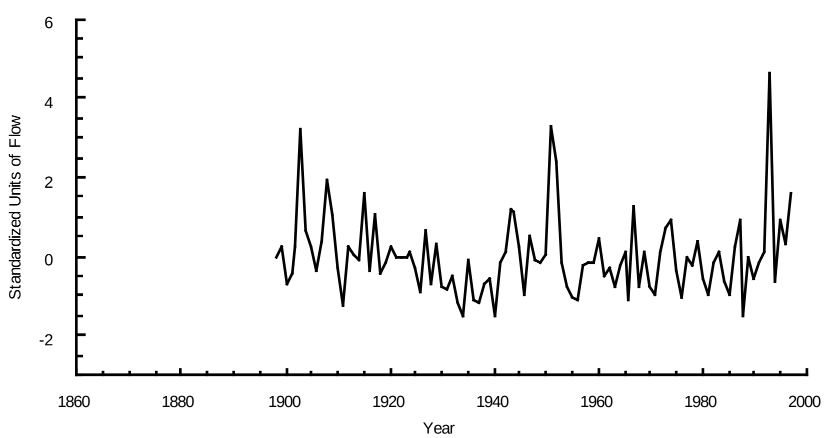

Figure A5: Sequence of Standardized Annual Floods on the Missouri River at Kansas City, Missouri

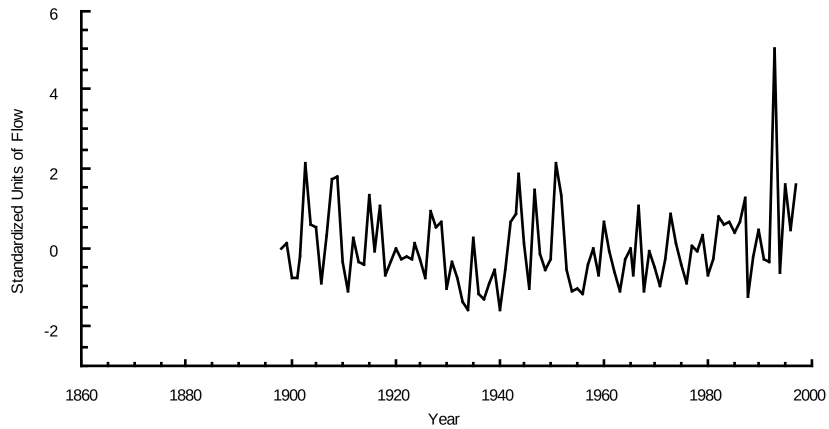

Figure A6: Sequence of Standardized Annual Floods on the Missopuri River at Booneville, Missouri

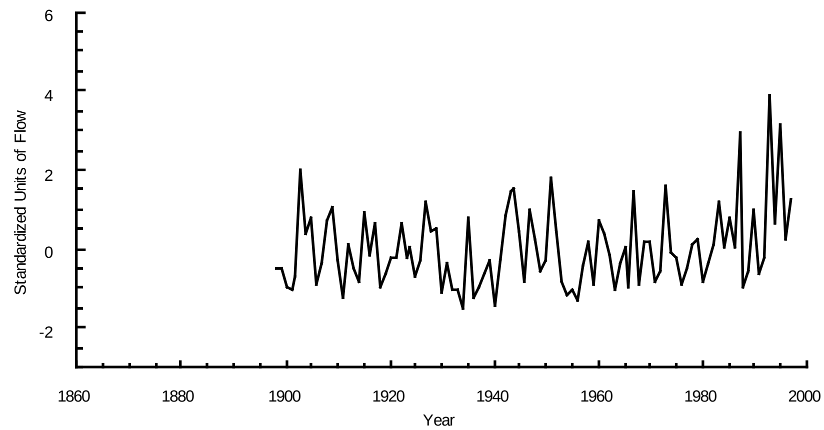

Figure A7: Sequence of Standardized Annual Floods on the Missouri River at Hermann, Missouri

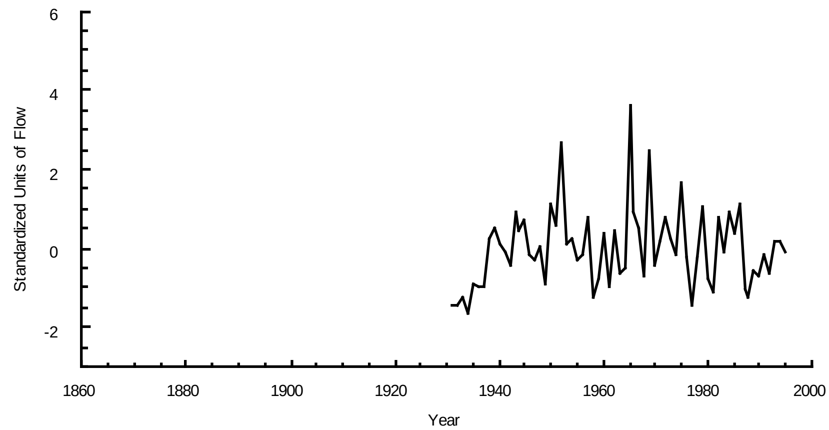

Figure A 8: Sequence of Standardized Annual Floods on the Mississippi River at Amoka, Minnisota

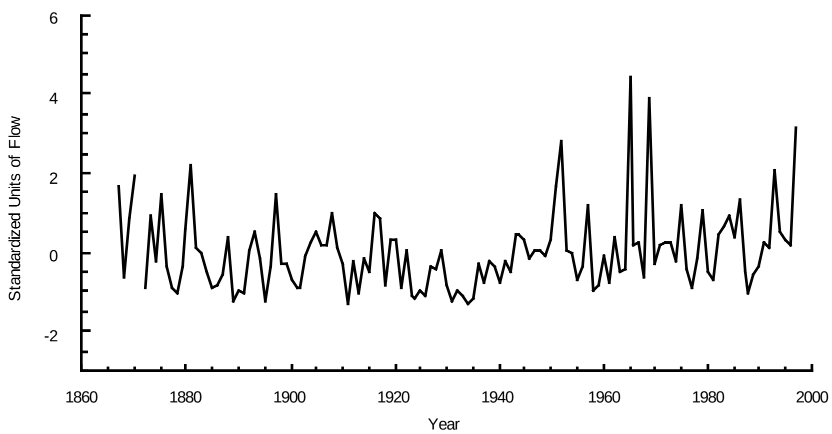

Figure A 9: Sequence of Standardized Annual Floods on the Mississippi River at St. Paul, Minnisota

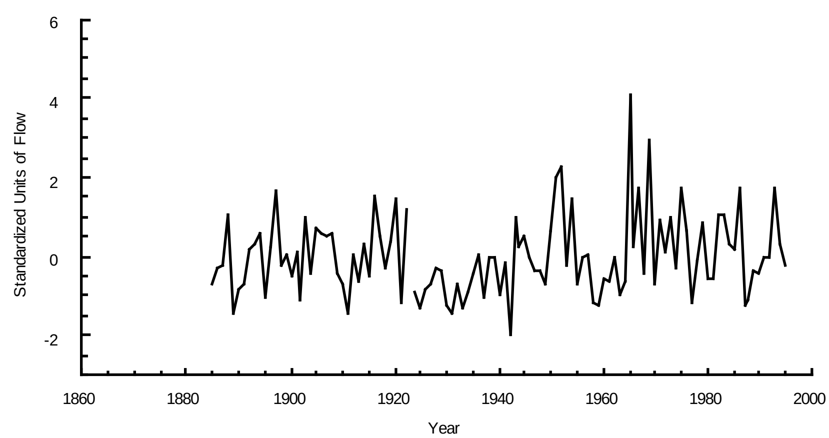

Figure A 10: Sequence of Standardized Annual Floods on the Mississippi River at Winona, Minnisota

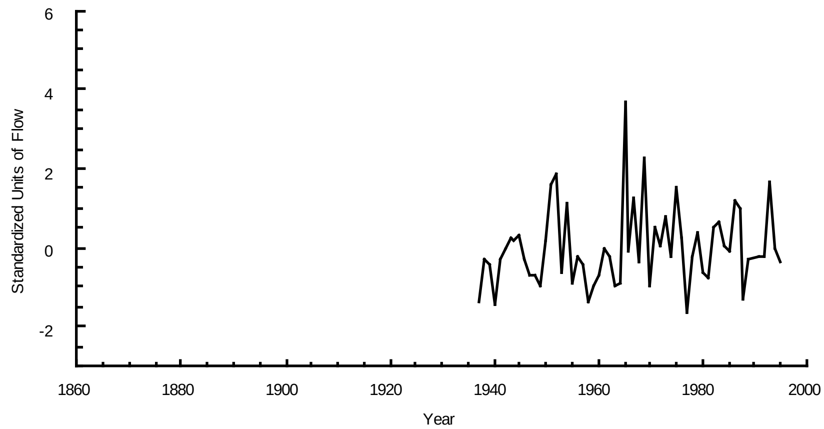

Figure A 11: Sequence of Standardized Floods on the Mississippi River at McGregor, Iowa

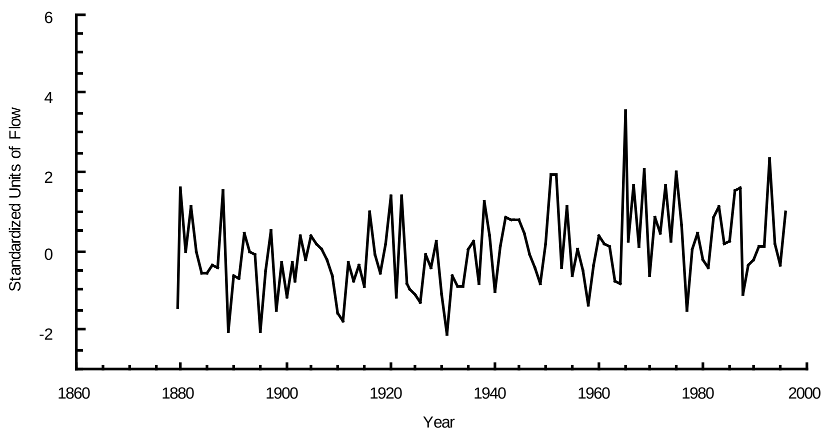

Figure A 12: Sequence of Standardized Floods on the Mississippi River at Dubuque, Iowa

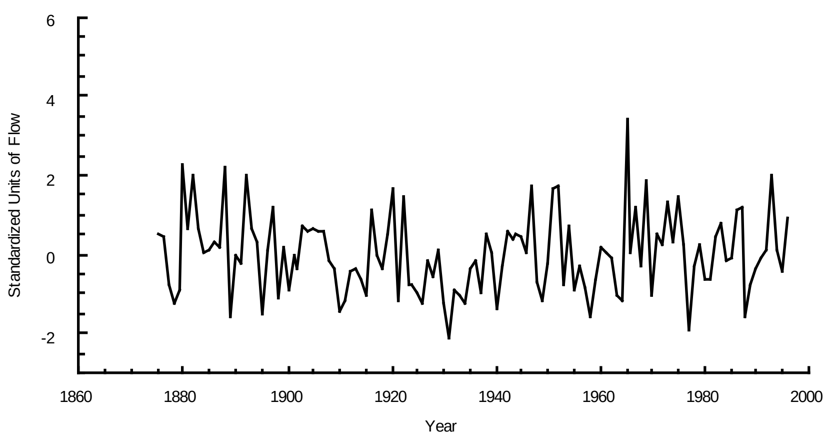

Figure A 13: Sequence of Standardized Annual Floods on the Mississippi River at Clinton, Iowa

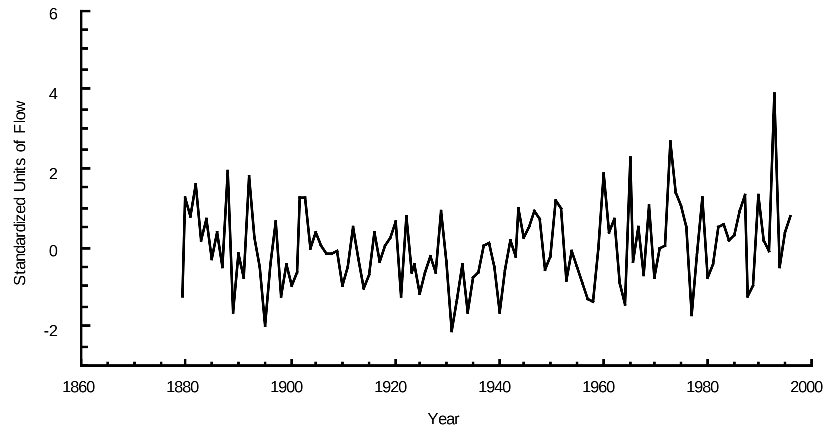

Figure A 14: Sequence of Standardized Annual Floods on the Mississippi River at Keokuk, Iowa

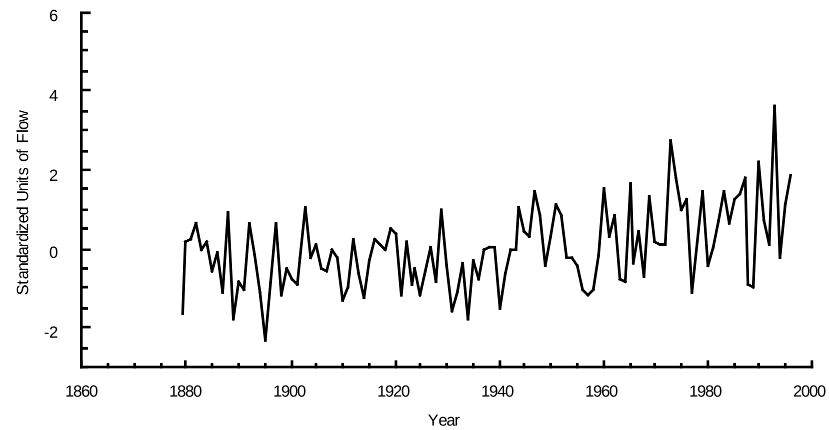

Figure A 15: Sequence of Standardized Annual Floods on the Mississippi River at Hannibal, Missouri

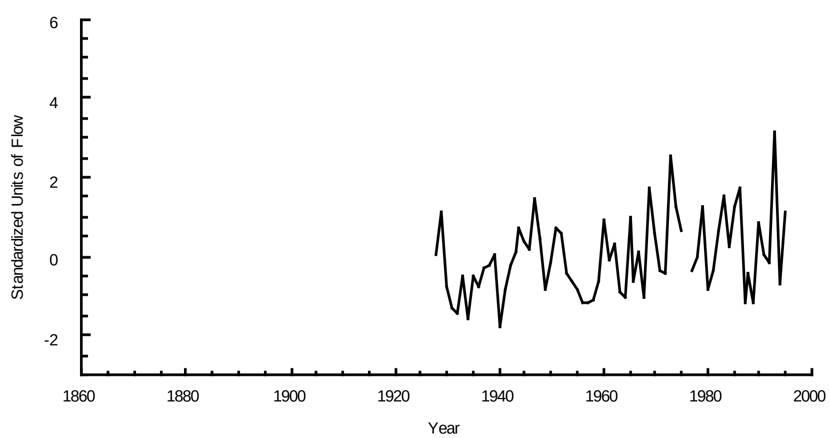

Figure A 16: Sequence of Standardized Annual Floods on the Mississippi River at Louisiana, Missouri

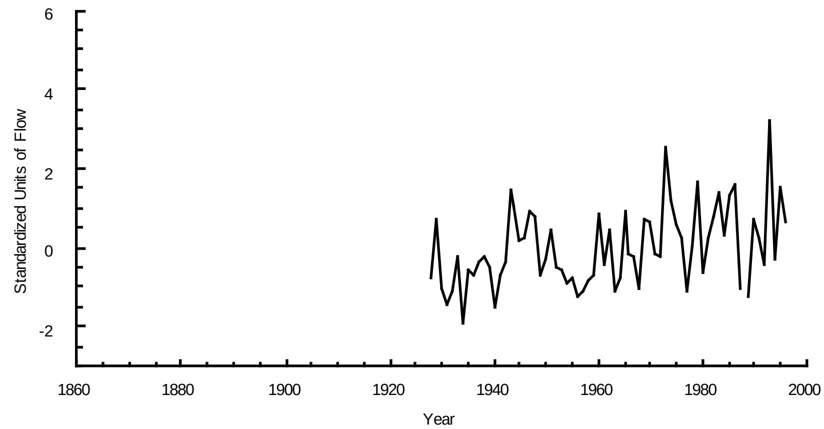

Figure A 17: Sequence of Standardized Annual Floods on the Mississippi River at Alton, Missouri

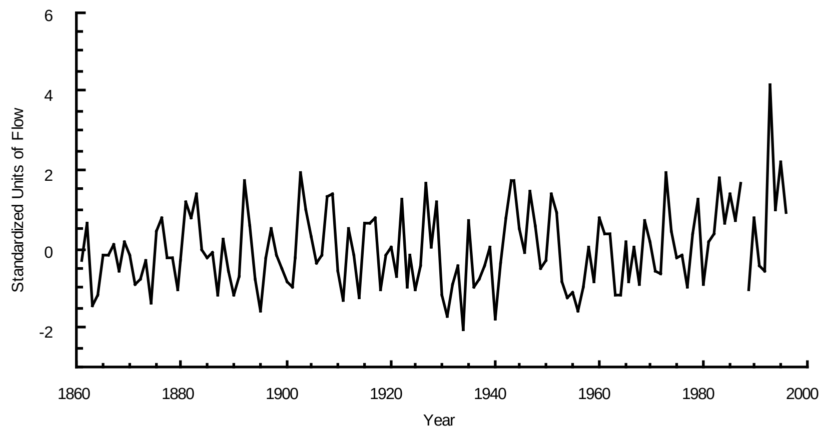

Figure A 18: Sequence of Standardized Annual Floods on the Mississippi River, at St. Louis, Missouri

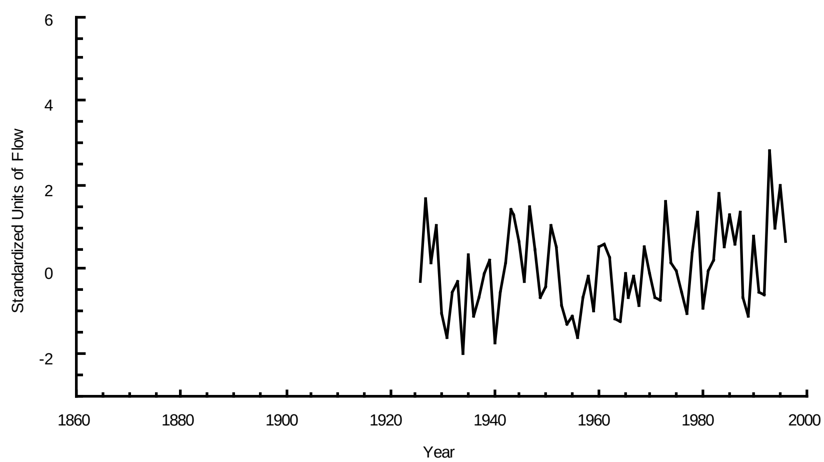

Figure A 19: Sequence of Standardized Flows on the Mississippi River at Chester, Illinois

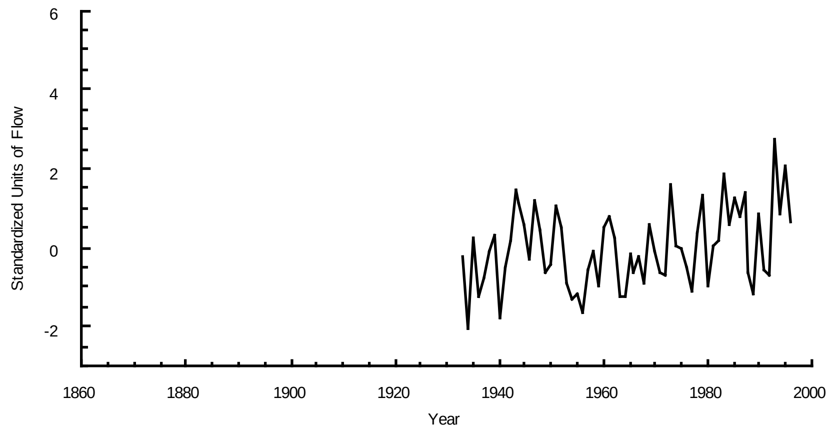

Figure A 20: Sequence of Standardized Annual Floods on the Mississippi River at Thebes, Illinois

Appendix D-B Statistical Characteristics

Sequences used in the trend assessment are characterized by the absolute measures of the mean, standard deviation, maximum, minimum and range, and by the relative measures of the coefficients of variation, skewness, kurtosis, first order autocorrelation and Hurst. See Tables B-1 and B-2.

Table B-1: Statistical Characteristics of Missouri Sequences

Statistic	Sioux City	Omaha	Nebraska City	St. Joseph
Mean	158,040	156,540	179,010	178,220
Std. Dev.	68,809	65,340	73,225	67,468
Maximum	521,000	490,000	498,000	490,000
Minimum	43,000	46,000	50,000	54,000
Range	478,000	444,000	448,000	436,000
Coeff. Var.	0.435	0.417	0.409	0.379
Skewness	1.517	1.443	0.986	1.534
Kurtosis	6.698	5.982	2.758	4.973
Autocorr,	0.106	0.040	0.075	0.057
Hurst Coeff.	0.656	0.581	0.679	0.679

Table B-1: Statistical Characteristics of Missouri Sequences Continued)

Statistic	Kansas City	Booneville	Herman
Mean	229,460	280,990	342,870
Std. Dev.	104,575	125,698	160,621
Maximum	713,000	917,000	970,000
Minimum	69,000	82,000	102,000
Range	644,000	835,000	868,000
Coeff. Var.	0.456	0.477	0.468
Skewness	1.816	1.617	1.289
Kurtosis	5.344	5.501	2.364
Autocorr,	0.168	0.121	0.070
Hurst Coeff.	0.682	0.701	0.655

Table B-2: Statistical Characteristics of Mississippi Sequences

Statistic	Anoka (1931-1995)	St. Paul (1872-1996)	Winona (1924-1995)	Dubuque (1879-1996)
Mean	32,228	43,527	93,200	130,402
Std. Dev.	16,036	26,714	46,065	47,017
Maximum	91,000	171,000	268,000	298,200
Minimum	5,970	7,460	10,300	30,900
Range	85,030	163,540	257,700	267,300
Coeff. Var.	0.498	0.614	0.494	0.361
Skewness	1.115	1.878	1.253	0.549
Kurtosis	2.301	5.765	2.194	0.717
Autocorr,	0.152	0.183	0.120	0.202
Hurst Coeff.	0.731	0.746	0.735	0.779

Table B-2: Statistical Characteristics of Mississippi Sequences (Continued)

Statistic	Clinton (1875-1996)	Keokuk (1879-1996)	Hannibal (1879-1996)	St. Louis (1861-1987)
Mean	141,869	188,542	211,625	509,081
Std. Dev.	48,172	64,314	80,553	169,416
Maximum	307,000	440,717	501,923	875,000
Minimum	40,700	52,500	22,400	136,000
Range	266,300	388,217	479,523	739,000
Coeff. Var.	0.340	0.341	0.381	0.333
Skewness	0.550	0.666	0.607	0.286
Kurtosis	0.343	1.276	0.779	-0.605
Autocorr,	0.080	0.082	0.243	0.235
Hurst Coeff.	0.697	0.724	0.811	0.596

Table B-2: Statistical Characteristics of Mississippi Sequences (Continued)