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THE ANNUAL FLOWS OF THE MISSISSIPPI RIVER

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ABSTRACT The Mississippi River drains two thirds of the lower United States plus 13,000 square miles of Canada. When North America was being colonized by Europeans, the river overflowed its banks about once every 3 years and spread onto the floodplain, which today covers 34,600 square miles of the valley. A natural levee formed alongside the river where the silt was dropped when water left the channel; the levee now slopes away from the river at about 7 feet per mile. This high ground was settled first by the white man at New Orleans in 1717. The spring floods barely topped the natural levee and the original town was protected by a ring levee 3 feet high. As more overflow areas were cut off from the river, the levees increased in height to about 40 feet. The hydraulics of the river became better and today more water and silt flows out to sea. About three fourths of the floodplain is closed off from the river, but in 1882 and 1927, the river took that land back, and in 1973 almost 60% of the 22-million-acre area was flooded. Nevertheless, there have been no levee breaks since the Corps of Engineers took over flood control in 1928.

The mean flow of the river since 1900 has been 646,000 cubic feet per second (cfs) moment to moment. The mode, median, quartiles and deciles of annual flows are given, and the measurements of dispersion, the standard deviation and coefficient of variation are given.

The Atchafalaya River distributary has increased considerably at the expense of the Mississippi River since 1858. During the flood year of 1973, the Atchafalaya carried 37% of the total flow. It is estimated that unless it is brought under control, in about 60 years the Atchafalaya will equal the Mississippi.

Flood years are not especially associated and in several cases low flows and flood years are close together.

Measurements of river flows before 1900 are unreliable or absent. Since then, however, careful measurements of the daily flows of both distributaries have been taken by the Corps of Engineers and used to compile mean flows in cfs by years.

The data extend for a series of 79 years. They were furnished to the author by the New Orleans District of the Corps. These data were used for all calculations given here on flows. The lowest flow recorded for the Atchafalaya was 13,300 cfs on September 22, 1925. The lowest flow for the Mississippi was 75,000 cfs on November 4, 1939. The highest for the Atchafalaya was 781,000 cfs at Simmesport on May 12, 1973; the highest for the Mississippi was at Tarbert Landing on February 19, 1937, at 1,977,000 cfs.

Subjectively described floods of 1782, 1828, and 1882 tie in with 1927 and 1973 as 50-year floods. The 1927 and 1973 floods were remarkably similar; the former was the larger. The largest known flow of the river is only 25% less than the maximum which meteorologists say could be generated. Presumably such a flood could be handled without catastrophe.

INTRODUCTION

The establishment of European civilization in North America may be looked upon as a long march across the continent as the people established settlements, clearings and highways, and undertook utilization of the natural resources. This process can be divided into three large undertakings which resulted in actual change of the physical landscape. The first task was the clearing of the impenetrable eastern forest which was then crossed only by Indian trails. This magnificent area of climax forest was not felled by the lumbermen; instead it was cut and burned piecemeal to make clearings for the settlers. West of the Mississippi River, settlements involved the plowing of the prairie and the killing of the buffalo. These processes brought about destruction of both the tall and short grass prairies. The introduction of livestock and the activities of farming insured the prolonged destruction of the prairies.

Another vast change introduced by the white man has been his attempts to control the preeminent central Mississippi River which drains much of the lower United States and part of Canada. The river and its appurtenances comprise geographic and geological factors. As such, it is difficult to control and, in fact, cannot be controlled except within very definite narrow limits. Thus, unlike the biotic provinces conquered and partially obliterated by man, the Mississippi gives the impression of fighting back at encroachments upon its domain. Obviously, if mankind is to control the river, even to a small extent, we must know as much as possible about it. Herein the writer analyzes to some extent the characteristics of the annual flow. At the end of the present year, 1979, we shall have a time series of only 80 years of adequate data dating from 1900 to consider. Variations in previous flows are considered where they are known.

BACKGROUND INFORMATION

The Mississippi River watershed is exceeded in area on Earth only by the watersheds of the Amazon and the Congo. It drains two thirds of the lower United States (some

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1,244,000 square miles) and about 13,000 square miles of Canada. The average rainfall over this area is about 30 inches and about one fourth of this reaches the sea by way of the river. The economic and historical influences of this great river system have been enormous. Geographical, geological and hydrographical descriptions, and some history of the river have been given by Trowbridge (1930), Elliott (1932), Russell (1936, 1948), Fisk (1944) and Gunter (1952).

The river begins in Minnesota and flows southward within its alluvial plain between the escarpments of its valley. In a few places it touches these escarpments as at the bluffs of Vicksburg and Natchez.

The river has a natural levee all along its floodplain which consists of fine, alluvial soil that forms from sand and silt deposits when the river overflows its banks during high-water periods. Essentially the load is deposited quickly as the current speed falls after it leaves the channel. This levee slopes away from the river, at the rate of about seven feet to a mile, to the low-lying swamps on either side. This natural levee system was the finest land available when the first white man came into the country, and it was better drained than any other land of the area.

High water comes every year between December–January and June–July. A flood ensues when the river overflows its natural levees. The area which is subject to flooding under natural conditions consists of 34,600 square miles or 22.1 million acres south of Cairo, Illinois, including 18,000 square miles of deltaic plain. Floods occur about every three years under natural conditions, but nowadays they are largely restrained by man-made levees.

The fine arable land along the river which remained high and dry after the spring floods had gone down, in contrast to the swampy areas back away from the river, led to extensive settlement up and down the river banks, beginning when New Orleans was first settled in 1717.

The river was the great travel connection from the days of the pirogues and canoes of the Indians and early explorers, to the time of the flatboats and steamboats and today the powerful diesel-motor towboats, with their huge strings of barges, and the ocean-going freighters. The fact that the river was the great avenue of travel and commerce, reinforced the tendency of the Europeans to settle along its banks. The only alternative was for the settlers to go beyond the swamps to the edges of the valley itself, that is to the escarpments, which were sometimes as much as 50 miles away.

The river did not overflow and discommode the settlers every year but rather about once every three years, and even so, the floods were not very high in the beginning, although they filled in the back waters at times and went to the very edges of the valley, being commonly 50 miles wide along the lower river and even 80 miles in the widest place. But the vast areas of swamps lying alongside the river acted as overflow basins for floods and when the white man first came to live along the river, low levees or banquettes, three feet high around the Vieux Carré or Old Square, sufficed to protect the settlement of Nouvelle Orleans.

In brief, it may be said that various situations and conditions constrained the white man to settle in areas which were naturally part of the river's overflow area and which was subject to flooding. Circumstances which were not even recognized and of which the future portent was not foreseen, set the European settler upon the course of opposing and fighting the river rather than trying to live with it. Living with the river would have entailed building human dwellings and other structures on pilings or earthen banks about three feet high. However, it was easier to build a low embankment around the town of New Orleans and this was first completed in 1721. In effect, the colonials built a ring levee. This was a rather innocent beginning, but as settlers moved up and down the river they were forced for their own protection, and later by law, to build levees and the river was cut off more and more from its natural overflow areas. As this took place, the floods and in turn the levees became higher so that now they are up to 40 feet. This situation was aggravated along the lower river by the closure of former distributaries, Bayou Manchac to the east just below Baton Rouge, and both Bayou Plaquemine and Bayou Lafourche lower down on the west bank.

This situation was reviewed and summarized by Gunter (1952, p. 123) in the following words:

> "Levees grew ever higher as the river was cut from its flood basins and so did floods. Today levees at some points are thirty-five feet high. In addition many tributary streams were leveed and they in turn were cut off from their flood basins. Maps of the present system show a bewildering tracery of leeves, quite difficult to describe in detail, which however is unnecessary for our purposes. It is sufficient to say that the total levee system was around 991 miles long in 1880 and 2,130 miles long in 1935.
>
> Up to 1885 the effects of levees were not so great as they have become since. According to Elliott (1932, p. 83) the flood of 1882 may be taken as typical of a major flood prior to extensive levee construction. 'Comparison of succeeding flood crests with this flood gives a definite indication of the increase in flood heights.' He gave figures taken at the Carrollton (New Orleans) gauge showing that the crest was at 14.95 feet in 1882, 16 feet in 1890 and 21 feet in 1912. The Red River Landing gauge registered 48.50 feet in 1882, 53.20 feet in 1912 and 57.45 feet in 1927. The greatest flood of all was in 1927 when numerous crevasses modified flood heights on the lower river, making them useless for comparison. At the Cairo, Illinois gauge the 1927 high water crest was at 56.4 feet. The highest previous crest was at 54.69 feet in 1913. At the time of the 1912 flood the gauge stood at 54.0 feet.
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> In summary, levee construction started in 1717, 235 years ago, at New Orleans and was a gradual

process up until about 1880. From that time the rate was accelerated, until the nineteen-thirties when the whole system was greatly extended and more or less stabilized, following the disastrous flood of 1927. Flood heights became higher as the levee system increased."

Viosca (1927) discussed the developments that would have come about along the river if the white man had not elected to fight it in the beginning and he and Gunter (1956, 1957) discussed the changes which have taken place within the great valley. Gunter (1952) has also discussed some general changes which have taken place around the river's mouth.

At the present time about three fourths of the 35,000-square-mile floodplain area has been cut off from the river by levees. It appears that devegetation of the land also has tended to increase the peaking of annual floods, which means an increase in flood heights. The most disastrous flood of all time came in 1927. Efforts at flood control became coordinated and administered by the Corps of Engineers, U.S. Army, following the 1927 catastrophe.

RIVER FLOW AND MAJOR FLOODS

The Atchafalaya Problem

Table 1 gives the measured flows of the Mississippi River for each year of the twentieth century in terms of mean flow per second for each year. These figures were furnished by the New Orleans District of the Corps of Engineers. Data before 1900 are unavailable or unreliable.

Today the Mississippi River has two large natural distributaries, the main river and the Atchafalaya. The flows of the two distributaries are given in the same terms. According to Elliott (1932) the Atchafalaya in 1858 carried 77,061 cfs of water during high-water stages. Insofar as the flood or high-water flow is at least around 700,000 cfs in the main river, the Atchafalaya had 10% or maybe even less of the flow in 1858. Since that time the Atchafalaya has grown greatly. This growth has been common knowledge and has been written up in the New Orleans newspapers many times. It was known to early writers such as Mark Twain. In the early 1930s the writer talked to old people who had seen footbridges across the original Atchafalaya Bayou (Gunter 1952) in antebellum days. Apparently, it is an old main channel of the river of a thousand years or so ago, which changed to the left of the direction of flow and is now trying to change back again.

According to Comeaux (1970) a raft in the upper Atchafalaya began to grow sometime between 1500 and 1778, but with Shreve's cutoff, which removed a large oxbow in the main river, the Atchafalaya was virtually bypassed and it decreased in size until 1839, when raft removal was first attempted. In 1861, the process was completed and the Atchafalaya began to grow rapidly. Floods decreased along the lower Mississippi and increased on the Atchafalaya until all farming along that stream came to an end.

TABLE 1.

Mississippi River system flows. This consists of the combined Atchafalaya River flow at Simmesport and the Mississippi River flow at Red River Landing (at Tarbert Landing after June 1963), furnished by New Orleans District, Corps of Engineers, U.S. Army. Figures are in thousands of cubic feet per second and each figure is the mean flow per day for 365 days.

Year	Mississippi River at Red River Landing	Atchafalaya River at Simmesport	Combined Flow
1900	432	64.7	497
1901	377	55.4	432
1902	461	70.2	531
1903	639	136	775
1904	465	76.8	542
1905	576	104	680
1906	592	103	695
1907	676	134	810
1908	667	146	813
1909	581	105	686
1910	473	73.7	547
1911	459	70.6	530
1912	646	138	784
1913	584	122	706
1914	409	69.7	479
1915	653	126	779
1916	640	140	780
1917	510	93.8	604
1918	400	61.9	462
1919	602	120	722
1920	657	145	802
1921	527	95.4	622
1922	566	125	691
1923	590	116	706
1924	548	98.3	646
1925	368	50.0	418
1926	476	98.8	575
1927	867	239	1106
1928	601	147	748
1929	643	177	820
1930	419	99.8	519
1931	283	57.8	341
1932	516	139	655
1933	522	145	667
1934	292	71.8	364
1935	574	177	751
1936	346	85.5	432
1937	514	158	672
1938	511	161	672
1939	445	143	588
1940	313	94.9	408
1941	376	114	490
1942	499	157	656
1943	520	165	685
1944	475	159	634
1945	683	264	947
1946	509	202	711
1947	426	165	591
1948	448	173	621
1949	555	226	781

TABLE 1. (Continued)

Year	Mississippi River at Red River Landing	Atchafalaya River at Simmesport	Combined Flow
1950	696	297	993
1951	625	256	881
1952	466	193	659
1953	373	152	525
1954	262	94.2	356
1955	363	139	502
1956	332	131	463
1957	548	238	786
1958	482	233	715
1959	382	161	543
1960	409	176	585
1961	514	236	750
1962	475	223	698
1963	268	110	378
1964	367	105	472
1965	416	187	603
1966	370	133	503
1967	385	170	555
1968	434	220	654
1969	457	225	682
1970	437	216	653
1971	388	191	579
1972	481	239	720
1973	720	377	1097
1974	586	322	908
1975	564	310	874
1976	374	164	538
1977	379	162	541
1978	470	202	672

In the first decade of the present century the Mississippi proper carried 84.5% of the river flow while the Atchafalaya River carried 15.4%. From 1970 to 1978, inclusive, the Atchafalaya carried 32.9% of the total flow and the Mississippi carried 66.1%. The change in the partition of flow has been approximately an 18% decline in 78 years in the Mississipi flow as shown by Table 2, with a commensurate increase in the Atchafalaya. If the present tendency continues, the Atchfalaya River will carry as much water as the Mississippi in about 49 years from the present (1979) or *circa* year 2038. Apparently, aggrandizement by the Atchafalya still continues in spite of attempts by the Corps of Engineers to stop it. In fact, Table 3 shows, in terms of the mean flows for each month, that during the flood year of 1973, the Atchafalaya took over 37% of the flow. Nevertheless, the Old River Control is operated by the Corps to retain approximately the same distribution of flow as would have been obtained under natural river conditions of 1950.

The Larger Floods

Measurements of river flow were not as accurate in the 1800s as they are today, but there are indications (cf. Elliott 1932) that the 1882 flood was about equivalent to those of 1927 and 1973. Thus these three floods are roughly equivalent to 50-year floods.

TABLE 2.

The mean flow of the Mississippi and Atchafalaya rivers in decade intervals from 1900 to 1978 in thousands of cfs. Percentages are given below.

Decade	Mississippi	Atchafalaya	Totals
1900–1909	546.6	99.5	646.1
	84.5	15.4	
1910–1919	537.6	101.7	639.8
	84.0	15.9	
1920–1929	584.3	129.1	713.4
	81.9	18.0	
1930–1939	442.2	123.9	566.1
	78.1	21.8	
1940–1949	480.4	172.0	652.4
	73.6	26.3	
1950–1959	452.9	189.4	642.3
	70.5	29.4	
1960–1969	409.5	178.5	588.0
	69.6	30.3	
1970–1978	439.9	218.3	658.2
	66.1	32.9	

The 1927 flood is rated as the most destructive of all time because there were more and greater crevasses in the lower floodplain and no doubt there were greater areas of flooding. In part this is due to the fact that levees were not as good then as they are today. It is also partly because a major portion of the flood control system, consisting of reservoirs on the upper river, the Bonnet Carré Spillway, and the major floodways of the Atchafalaya River, did not exist at that time. Even so the 1973 flood put 13 million acres of the 22-million-acre floodplain under water at one time. Actually about one fourth of the floodplain today is left free and not cut off from the river by levees.

Final data on the combined daily flow of the Mississippi and Atchafalaya rivers, as shown in Table 4, give a lower total flow for 1973 than 1927. Table 4 shows the daily mean flows for each month. It should be noted, too, that the greater flow of the river fell in the first six months during 1973, while in 1927 flood waters lasted for seven months through July.

The 1973 data and the flood data for 1927 were used to calculate the fact that during 1927 the river put 127.0 cubic nautical miles of water into the Gulf of Mexico, whereas in 1973 the figure was 126.5 cubic nautical miles. Figured another way the river flowed an average of 1,106,000 cfs during 1927 and 1,097,000 cfs in 1973 or 63,000 cfs constantly less during the latter year.

So it appears that the 1927 flood was the greatest of record. The 1973 flood was about the same in magnitude and the two were remarkably similar; but the 1973 flood came and went without flooding on the lower river valley. There is no doubt that the Bonnet Carré Spillway and the floodways of the Atchafalaya played an important part during this period of crisis in flood control.

TABLE 3.

Daily discharges for 1973, computed in thousands of cubic feet per second.

Mississippi River at Tarbert Landing, Mississippi

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	935	822	759	1093	1357	1216	703	367	247	222	394	599
2	936	842	722	1112	1393	1191	643	392	241	225	374	656
3	938	854	686	1154	1327	1159	627	403	239	227	360	700
4	914	863	654	1181	1329	1126	614	408	239	231	346	740
5	888	867	620	1205	1403	1070	596	407	238	231	350	767
6	885	873	594	1241	1388	1090	572	399	237	235	357	785
7	892	875	580	1273	1373	1045	550	388	234	271	374	798
8	897	881	565	1292	1322	1054	535	374	232	307	394	826
9	900	872	559	1291	1447	1029	511	355	230	336	402	844
10	902	861	563	1268	1392	1037	494	335	228	359	403	861
11	904	846	582	1291	1354	1012	467	313	229	377	397	878
12	908	839	591	1352	1428	1014	447	294	232	394	386	892
13	909	842	618	1296	1418	992	441	279	235	408	374	909
14	908	858	660	1342	1426	978	433	269	231	415	362	933
15	911	868	709	1335	1428	983	430	263	227	418	349	946
16	892	873	745	1387	1498	1003	421	260	223	423	342	954
17	882	875	780	1359	1441	979	414	255	220	427	334	962
18	867	880	800	1408	1440	957	404	254	218	430	328	968
19	848	885	814	1323	1402	975	396	260	222	427	321	950
20	819	876	833	1368	1426	964	384	267	216	425	318	954
21	796	871	857	1233	1409	937	372	277	207	430	311	925
22	765	866	868	1286	1392	910	361	283	218	435	302	886
23	742	860	887	1298	1370	878	350	285	213	439	299	834
24	708	856	945	1279	1361	856	339	291	209	437	305	805
25	698	849	983	1285	1299	856	328	296	207	437	314	801
26	699	839	995	1244	1372	850	319	296	210	439	327	791
27	709	819	1005	1280	1299	819	300	297	208	434	355	774
28	727	789	1021	1260	1352	811	293	283	209	430	407	724
29	751		1041	1360	1297	744	294	268	212	427	454	717
30	767		1054	1433	1220	763	308	260	218	420	530	715
31	792		1072		1207		336	256		411		720
Mean	842	857	779	1284	1373	977	441	311	224	372	362	826
Max.	938	885	1072	1433	1498	1216	703	408	247	439	530	968
Min.	698	789	559	1093	1207	744	293	254	207	222	299	599

Atchafalaya River at Simmesport, Louisiana

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	440	399	406	548	722	661	439	202	129	93	208	290
2	440	407	404	558	719	674	429	212	126	97	204	312
3	440	414	385	571	682	648	420	219	123	102	187	330
4	443	416	368	570	685	601	412	222	125	103	181	347
5	439	420	351	573	725	625	405	222	128	115	198	342
6	441	424	339	580	720	620	397	219	136	125	202	341
7	444	423	333	595	709	579	389	214	141	137	216	348
8	446	425	332	603	727	607	382	207	143	146	223	361
9	452	426	330	609	731	606	375	198	142	161	223	375
10	454	427	326	620	740	549	360	187	141	172	224	390
11	456	426	331	622	759	562	344	175	141	177	223	403
12	459	427	340	634	781	570	328	165	142	182	219	399
13	461	429	347	626	727	542	314	162	148	188	215	398
14	464	434	357	626	742	552	305	155	156	195	204	401
15	464	442	376	679	736	574	297	145	155	207	193	416
16	465	439	401	691	763	528	287	138	150	211	183	418
17	464	439	414	710	749	530	277	135	145	217	175	421
18	466	440	424	730	760	539	274	133	140	224	167	414
19	446	439	433	668	739	546	268	134	122	235	159	414
20	429	442	441	686	739	550	265	137	121	238	156	407
21	412	436	445	674	737	534	251	142	121	233	155	387
22	396	433	454	648	727	515	239	146	101	231	151	384
23	383	430	462	596	730	503	228	144	109	229	149	375
24	376	425	483	688	749	513	216	141	113	230	150	373
25	371	421	499	641	727	463	209	142	112	230	156	373
26	369	416	513	683	767	492	201	144	101	227	162	372
27	371	410	528	674	733	475	191	141	91	229	178	366
28	375	408	523	692	704	472	183	138	89	228	206	361
29	381		521	687	706	472	180	137	90	224	232	356
30	386		531	724	687	452	182	134	92	222	260	352
31	392		539		689		193	129		215		351
Mean	427	426	417	640	729	552	298	165	126	188	192	373
Max.	442	399	539	730	781	674	439	222	156	238	260	421
Min.	369	399	326	548	682	452	180	129	89	93	149	290

TABLE 4.

Monthly flow of the Mississippi and Atchafalaya rivers in terms of the mean flows computed in thousands of cubic feet per second.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1927	1117	1311	1395	1662	2223	1818	1317	601	391	450	348	652
1973	1269	1283	1196	1924	2102	1529	739	476	350	560	554	1199

The Periods and Times of Great Floods

De la Vega, the chronicler of De Soto's explorations, recorded a flood that began on March 10, 1543, which was said to have crested 40 days later, and lasted about 80 days. It was said to cover the valley for 20 leagues on each side of the river. In terms of the old Spanish league, this would be a distance of about 105 miles and the flood must have touched both escarpments of the valley. This distance seems to be excessive, but in any case, this was clearly a very large flood 436 years ago. We have nothing to compare it to afterwards. The location was thought to be at Helena, Arkansas.

La Salle recorded another flood in 1664. The French settlers at New Orleans encountered a flood in 1717 and again in 1718 before levees were constructed. The city was flooded by crevasses at least eight times up to 1849. From 1717 to 1816, there were 17 floods recorded on the river according to the summary given by Elliott (1932, pp. 105–113), but between 1817 and 1916, there were 37 recorded floods. Thus, it would appear that levees brought more floods by raising flood heights, if the flood occurrences were reliably reported. However, Elliott says that they were not well recorded before 1799. As he pointed out, the hydraulics of the river have become much more efficient throughout the years so that the river could accommodate a 2,000,000-cfs flow in 1932, although between natural banks it carried only 1,000,000 cfs.

Also according to Elliott, the 1882 flood was the last typical major one before extensive leveeing. In the 47 years prior to and including 1882, there were 19 floods; in the 47 years from 1883 to 1929, there were 16 floods. Thus, the floods were not increased after 1882 (Elliott 1932, p. 104) although levee and flood heights rose on all the gages* from St. Louis to Carrollton (New Orleans).

Actually there were 37 floods in the 1800s and only 27 floods in the first 80 years of this century, counting flows of over 700,000 cfs as a flood year, including the year 1979, which is not over at this writing. There have been only nine floods in the past 30 years by the same token and 17 in the first 50 years of the century. Actually, Elliott's criteria for floods in the twentieth century presumably were gage heights, crevasses, etc., but since 1927, there have been no crevasses.

Looked at another way, from about 1775 on, it seems that considerable attention was paid to floods and in fact measurements by a gage at Natchez were attempted in 1770. From that year to 1929, inclusive, there were 53 floods listed by Elliott (1932) or a flood every 2.87 years. The annual river flow, as shown in Table 1, is generally very high in flood years, but not always. In 1922, the average flow was only 691,000 cfs but there was a flood, of which Elliott said (1932, p. 114), "The 1922 flood stages were well below previous records at all gaging stations above White River, but from that point to Carrollton they exceeded all previous records." Three crevasses occurred.

Because of the last instance, we have listed as a flood year all years in Table 1 in which the total "instantaneous" flow was above 700,000 cfs. There were 25 such years out of the 78 total during this century so far, giving an average of one every 3.00 years. The approach then seems to be fairly consistent with actual overflows in switching to high-water years with no crevasses as a means of measuring floods. But the idea is also arbitrary and floods listed by Elliott for the century up to 1929 were in years 1903, 1907, 1912, 1913, 1916, 1920, 1922, 1927 and 1929. If the year 1927 is removed from this series, the range and mean cfs of flows were 691,000 to 820,000, and 771,000, whereas the same figures for 1908, 1915, 1919, 1923 and 1928, which were not listed as flood years, were 706,000 to 813,000 and 754,000. It is clear that flood years depend a lot on concentration of river flow in certain months, and a nonflood year may have higher average flows than some flood years. These high-water months are nearly always in the first six or seven months of the year. Some high-flow months also come in the latter part of the year, such as December 1973, and if so they contribute to flooding in the following year.

A great drought on this continent began in the early 1930s and ended in the late 1950s, so that possibly there will be more rain in the next 50 years. In fact, Price and Gunter (1943) pointed out that a change to drier weather took place in south Texas about 1870. The idea of a climatic change was laughed out of court by the scientific community at that time, but it is now recognized that a definite change to drier and warmer weather took place in about 1876 in the United States and was reversed again in the late 1950s, 1957–1958 to be precise.

Today we have high waters or "swells" in the river, as some early writers called them, without any flooding at all outside the levees. And so it is to be hoped that in the future, variations in river flow will be shown by gage heights and cfs readings rather than floods and destruction. This does not mean that all-out leveeing is advocated. Rather it would seem that return to the river of the vast overflow areas between the natural levees and the escarpments of the valley should be effected wherever possible. This would permit lower levees and enrichment of the valley by its natural soils rather than their artificial waste into the sea, which prevails today.

Prior to the flood of 1882, there was not extensive leveeing, but there were accounts of floods by various authorities, according to whom the greatest floods were in 1782, 1785, 1791 and 1809. During the latter year the Natchez gage was installed, and people on the lower river thought the Great Lakes were emptying southward through the river. From then on this gage registered at 48.0 feet and above in 1813, 1815, 1823 and 1828. This gage was at 47.8 in 1858 and 49.0 in 1859. It registered 45.75 in 1882. The St. Louis gage came into use in 1826 and most of the other gages in 1844. These gave more objective information on floods. The years 1840 and 1844 had major floods.

The written accounts of Elliott (1932) and the gage readings indicate that the greatest floods were 1782, 1828 and 1882. Thus 1782, 1828, 1882, 1927 and 1973 would be on 48-year intervals, the so-called 50-year floods. Possibly in 1782, 1828 or 1882 there were 100-year floods, but we have no objective data for precise comparisons. But subjectively the accounts leave little doubt that all of these would rank minimally as 50-year floods.

In 1882, the whole Mississippi floodplain, 34,600 square miles, was reported to have been flooded. The 1927 flood followed high rises on all watersheds contributing to the Mississippi River.

It scarcely seems possible that in a relatively stable geologic and climatic era that the river flow could be multiples of times what it has already been in the last few thousand

*A variant of "gauge" used invariably by the Corps of Engineers.

years. That would mean that the so-called 500- or 1,000-year floods would possibly be less than 100% or twice different from the average.

In any case, we are approaching a 250-year record of the river and there seems to be some evidence for a 50-year cycle of great floods in which the river flows a little less than twice the mean flow for an average year. The known minimum annual flow is 341,000 cfs and the known high is 1,106,000 cfs, the mean being 646,000 or rather close to flood-year flows (700,000 cfs) most of the time. The median is 655,000 cfs. These data are all taken from Table 1. It should be remembered that these figures are the means for the whole year. In 1939, there was one day at Red River Landing when the Mississippi flowed only 85,000 cfs for a day.

According to Elliott (1932, p. 95) climatic experts have estimated that the river flow could vary up to about 3,000,000 cfs, which is 21.4% above the 2,261,000 greatest flow which has been observed. Perhaps this would come with a 500-year flood.

Some Statistics of Flows

The mean daily flow of the Mississippi River, as shown by Table 1, ranged from 341,000 in 1931 to 1,106,000 cfs in 1927. The lowest daily combined flow during this 79-year stretch has not been determined but the highest was 2,261,000 on May 16, 1973. The reader should hold in mind that these figures are in terms of the mean flows in cubic feet per second for the whole 24-hour day. The lowest instantaneous flow of the Mississippi proper has been given as 85,000 cfs. For the combined distributaries it must have been 100,000 cfs or a little more.

The statistical measures of the central tendency of an array of figures, such as the Mississippi River flows, are a powerful but simple statistical tool which is often neglected. The mean or average annual flow has already been given as 646,304 cfs. By coincidence, this is almost precisely the annual figure for 1924. In the 1900–1978 time series, 38 years were equal to the mean or below it; 41 years exceeded the mean.

The measurement of the median number shows that it is 655,000 cfs.

The mode of all measurements was at 655,400 cfs, very close to the median. It seems that the central tendency figures are all skewed a little to the left of midpoint or a little less than the point between the extremes. This seems to follow from the fact that the flood and high-water periods are generally not as long or as extensive as the low-water periods, even in some flood years. The years 1927 and 1973 were exceptions. Similarly, Table 5 shows that most flows were in the 500,000 and 600,000 classes, with 53 of the 79 years, or 67%, below 699,000.

In terms of dispersion, the decile annual flows seem to be at 432,000 and 820,000 cfs, and the quartiles are at 531,000 and 748,000 cfs annually. This also shows a certain skewness towards the low side. The standard deviation was calculated to be 159.4 and the coefficient of variation was 0.247.

TABLE 5.

Annual flows of the Mississippi River numbered in class ranges of 100,000 cfs from 300,000 to 1,100,000 for the twentieth century. Figures in thousands.

Class Ranges	Annual Flows
300	3
400	10
500	17
600	23
700	15
800	6
900	3
1,000	1
1,100	1

Inspection of Table 1 shows that high-water years were not particularly associated. In 1903, 1912, 1913, 1916, 1920, 1929 and 1937, there were low-water years (less than 500,000 mean cfs) within the second year before or after a flood year. In contrast, in 1907, 1922, 1950 and 1973, there were high-water years (over 800,000 cfs mean) next to or within the second year of the flood years. In summary, there was continuous high water or a tendency towards several such years together during four flood years, but in seven flood periods the river was variable, so to speak, with high- and low-flow years close together.

One of the lowest river flows of all time occurred in the summer of 1976, three years after the great flood of 1973, and three years before the 1979 flood and the Bonnet Carré Spillway opening.

Biological Importance of the River

The river brings down large amounts of nutrient salts and cool, fresh water into the bays and estuaries of Louisiana and Mississippi during the late winter and spring. These factors have large effects on fisheries production of the area but no exhaustive treatment has been presented. Biologists know that oyster reefs are killed by floods (Gunter 1953) and that larval brown shrimp are repelled sometimes by walls of cold, low-salinity water as they try to enter the estuaries during the early months of the year. But an adequate treatment awaits a better and longer series of biological data. This concerns the most productive fishery area on the continent (Gunter 1963) and presumably the information will be forthcoming.

Ancient Flows

According to Emiliani et al. (1976), the Mississippi River used to flow 2 to 5 times more than at present, but this was 11,000 to 7,000 years ago when the Wisconsin ice sheet of

North America was melting. The climate at that time was nothing like that of the fairly stable present. During an earlier period of glacier melting some 18,000 years ago, a lake containing some 1,800 cubic miles of water behind an ice dam in Washington, Idaho and Montana, made its way to the Pacific some 330 miles away following melting of the dam. The flow was 10 million cubic meters per second or 345 million cfs or 10 times the combined flows of the rivers of the world (Snow 1976). It dug the Grand Coulee and cleared out the Columbia River Gorge. It was all over in 30 days. Such cataclysmic water flows are simply not characteristic of today's climate.

CONCLUSIONS AND SUMMARY

In 1900, the Corps of Engineers instituted measurements of the flow of the Mississippi and Atchafalaya rivers, the two distributaries of the Mississippi River system. These are given in cubic feet per second for the whole year as a mean or average figure. A seriesof 80 integers will have been collected at the end of 1979. The flow has ranged from 341,000 cfs in 1931, four years after the greatest flood, to the greatest annual flow of record in 1927 at 1,106,000 cfs. The mean-annual flow has been 646,000 cfs to the end of 1978. The median is at 655,000 feet and the mode is 655,400 cfs. The decile figures are 432,000 and 820,000 cfs. The quartiles are at 531,000 and 748,000. All of these figures seem to be on the low side or skewed to the left, but most flows are also on the low side and outnumber flood years by two to one, there being one flood in three years.

Since 1928, when the Corps of Engineers took over flood control, there have been virtually no crevasses and levee breaks, and floods are registered by high water, arbitrarily set here with an annual-mean flow of 700,000 cfs. Even so there have been some floods with crevasses at lower flow figures and some high-flow years in the 800,000-cfs class without floods. This comes about because floods depend also on the concentration of runoffs in given months.

The measurements of dispersion show 159,408 cfs for the standard deviation and a coefficient of variation of 0.247, none of which is particularly noteworthy.

Apparently the Atchafalaya carried about 10% of the total flow in 1858. It has grown to approximately 33% of the total flow and, during 1973, it carried 37% of the total flow.

The river's greatest measured flow, 2,261,000 cfs, has been only 6.63 times the mean of its lowest annual flow, 341,000 cfs.

The floods of 1828 and 1882, which covered the floodplain, fit well with 1927 and 1973 as 50-year floods, although the older floods may have been greater. These floods seem to come when all tributaries are contributing heavily. These seem to be about the peak floods that can come under the present climatic regime. The climatologists estimated for Elliott (1932) that the maximum expected flood would be about 3,000,000 cfs. This is only 21.4% greater than the greatest high that has been experienced recently, 2,261,000 cfs, on May 16, 1973. Presumably, the 3,000,000-cfs flood would be a 500- or maybe even a 1000-year flood. With spillways, floodways, reservoirs upstream and strong levees, all operated judiciously along with some sacrifice of the floodplain, it would seem that we could hope to get by such a crises without an overwhelming catastrophe. But such a confrontation between man and the river is certain to come and it must be met with careful planning and relentless vigilance.

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