EA 2004a U

2-2

Reference: EA 2004a, uncited

Analysis Performed by EA Engineering, Science & Technology of Mississippi River Flow Data

EA Engineering Science and Technology (EA) performed an analysis of USGS Mississippi River data to provide flow statistics at the MNGP site. The central task of this analysis was to construct a historical record of flows at the MNGP site based upon drainage scaling from upstream and downstream USGS gaging stations. Because flow was available from different stations in different years, several drainage area scaling relationships were developed. The drainage area scaling relationships also accounted for the flows on two major tributaries. Elk River at Big Lake (USGS station 5275000) has a drainage area of 599 mi^2. The confluence of Elk River with the Mississippi River is 2,500 ft upstream of the Mississippi River gage at Elk River. The Crow River at Rockford has a drainage area of 2,640 mi^2 and enters the Mississippi River between the Elk River and Anoka gaging stations.

The daily flow data at Mississippi River gaging stations were obtained from the USGS NWIS web page. The historical periods available at each station are summarized in the following table.

USGS Station	River Mile	Drainage Area (mi^2)	Available Record
St. Cloud (5270700)	926.3	13,320	1988-2002
Elk River (5275500)	884.6	14,500	1915-1956
Anoka (5288500)	864.8	19,100	1931-2002
Elk River-trib (5275000)		599	1931-2002
Crow River (5280000)		2,640	1930-2002

The river flows downloaded from the USGS NWIS web pager are provided in the following files on the accompanying CD:

http://nwis.waterdata.usgs.gov/mn/nwis/discharge.

St. Cloud MISS-CLD.txt
Elk River MISS-ELK.txt
Anoka MISS-ANK.txt
Elk River at Big Lake ELK-BLAK.txt
Crow River CROWRIV.txt

The USGS flow data was extrapolated to the Monticello site using drainage area scaling to provide a continuous record of daily historical flows. The river flow at the MNGP site was based on the closer USGS gage in operation of that time. Prior to 1956, site flows were scaled from the gage at Elk River. Following 1988, site flows were scaled from the gage at St. Cloud. In the interval between 1956 and 1988, flows were scaled from the

gage at Anoka. The drainage area scaling took into account two major tributaries; Elk River at Big Lake (5275000) and Crow River at Rockfort (5280000).

The MNGP site is located at river mile 900. Interpolating drainage area between St. Cloud and Elk River by river mile, while accounting for the 599-mi^2 area associated with the Elk River tributary, results in a drainage area for the MNGP site of 13,700 mi^2. Site flows were determined using the following relationships:

Prior to 1956	Qsite = 0.9855 (Flow Elk River – Elk River Tributary) Qsite = 0.9448 (Flow Elk River) when missing data at Elk River tributary
1956-1988	Qsite = 0.8638 (Flow Anoka – Elk River Trib.- Crow River Trib.)
1988-2002	Qsite = 1.0285 (Flow St. Cloud)

The USGS flows at the 5 gaging stations were combined into a single file with a separate column for each gaging station (provided as file: USGS-HIS.prn). Using the above scaling relationships, a Fortran program was used to construct the historical Mississippi River flow file at the MNGP site (provided as file: Q_MONT.dat).

The historical Mississippi River flow data set was used to develop flow frequency distributions for periods prior and following MNGP operation. A flow frequency distribution by month for the 1940 to 1970 period is provided in Table 1 and a flow frequency distribution for the 1971 to 2001 period is provided in Table 2. Monthly average Mississippi River flows at the MNGP site are provided in Table 3 for the 1971 to 2001 period.

Minimum 7-Day Average Flow Statistics

Minimum seven-day average Mississippi River flows for a range of recurrence intervals were calculated from the historical flows determined for the MNGP site based on drainage area scaling (Q_MONT.dat). The flow statistics were calculated using a Fortran program containing the standard Log-Pearson procedure (Linsley et al, 1082). Flow statistics were calculated for uniform 40-year periods both prior (1940-1970) and following (1971-2001) MNGP operation. The combined 1940-2001 period was also examined. A print-out from the program containing the minimum 7-day flow (cfs) for each year in the analysis and the calculated flows for a range of recurrence intervals is provided as Table 4.

River Flow Recorded at the MNGP Site by Xcel Energy

The daily Mississippi River flows were recorded at the MNGP site by Xcel Energy from 1984 to 2003 (Holmes 2004). These daily river flows are provided in file MNGP-Q.xls on the accompanying CD. The monthly average flows from this data set are summarized in Table 5 for the 1988-2003 period. A 7Q10 analysis was performed on the 1990-2003 data, the period free from missing data, and the output listing is provided in Table 6. A

7Q10 analysis using the USGS flows scaled to the MNGP site for a similar 1990-2001 period is provided in Table 7.

References

Holmes, Mark. 2004. Nuclear Management Company. Mississippi River Flow Measured at MNGP Site. Personal Communication with J. Yost (EA). 28 April 2004.

Data files were obtained from USGS NWIS on the following website http://nwis.waterdata.usgs.gov/mn/nwis/discharge. Data for the following stations are contained in the identified files on the accompanying CD:

St. Cloud	MISS-CLD.txt
Elk River	MISS-ELK.txt
Anoka	MISS-ANK.txt
Elk River at Big Lake	ELK-BLAK.txt
Crow River	CROWRIV.txt

Table 1 Frequency Distribution of USGS Mississippi River Flows Scaled to the MNGP Site, 1940-1970

PERCENTILE (%)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
	FLOW (CFS)												
0	840.	872.	907.	1867.	2046.	1664.	1049.	810.	866.	1084.	1088.	978.	810.
1	893.	926.	1202.	2438.	2381.	2227.	1256.	993.	1036.	1470.	1463.	1397.	1207.
5	1493.	1373.	1658.	3233.	3797.	3100.	1732.	1441.	1484.	1879.	1930.	1720.	1723.
10	1691.	1720.	2072.	4359.	5294.	3629.	2259.	1687.	1866.	2107.	2183.	1958.	2090.
15	1899.	1955.	2250.	5148.	5973.	4086.	2697.	2010.	2181.	2241.	2398.	2152.	2366.
20	2089.	2113.	2474.	5894.	6482.	4366.	3090.	2306.	2427.	2431.	2671.	2405.	2681.
25	2291.	2259.	2641.	6691.	7000.	4844.	3463.	2663.	2658.	2857.	2938.	2651.	2966.
30	2514.	2354.	2848.	7426.	7440.	5383.	3886.	2947.	2920.	3276.	3154.	2819.	3253.
35	2696.	2587.	3110.	8144.	8007.	6356.	4284.	3170.	3181.	3445.	3429.	2983.	3538.
40	2847.	2700.	3360.	9442.	8583.	6995.	4530.	3451.	3404.	3654.	3564.	3139.	3787.
45	2939.	2893.	3627.	10428.	9179.	7529.	4850.	3705.	3609.	3875.	3753.	3272.	4034.
50	3095.	3036.	3762.	11541.	9879.	8200.	5193.	4043.	3845.	4072.	3972.	3430.	4301.
55	3400.	3292.	3885.	12518.	10454.	9007.	5673.	4297.	4087.	4295.	4189.	3541.	4605.
60	3637.	3637.	4067.	13616.	11277.	9500.	6305.	4565.	4689.	4577.	4375.	3665.	5071.
65	3799.	3769.	4274.	14706.	12229.	10270.	6949.	4804.	5085.	5009.	4555.	3848.	5618.
70	3952.	3877.	4471.	16255.	13737.	11540.	7581.	5129.	5464.	5344.	4819.	3997.	6354.
75	4060.	4031.	5014.	17520.	14783.	12827.	8222.	5635.	6099.	5710.	5206.	4228.	7352.
80	4287.	4238.	5716.	19439.	16291.	14269.	9073.	6331.	6648.	6014.	5575.	4346.	8533.
85	4492.	4779.	6150.	21587.	17411.	16167.	9938.	7425.	7481.	6800.	6289.	4514.	10163.
90	4681.	5150.	7769.	24084.	19944.	19583.	11486.	9055.	8577.	8096.	7019.	4790.	13052.
95	5627.	5445.	12542.	29431.	22497.	23322.	16273.	13140.	9482.	11225.	8075.	6526.	17533.
99	7530.	9769.	25250.	45744.	33010.	27962.	22794.	21879.	11452.	16265.	10982.	8973.	26945.
MEAN	3274.	3287.	4792.	13307.	11436.	9768.	6467.	4899.	4570.	4791.	4332.	3561.	6209.
MAX	8291.	10987.	32080.	54045.	35755.	31112.	26433.	23956.	13194.	17981.	14359.	12170.	54045.
OBS	961	876	961	930	961	930	961	961	930	961	930	961	11323

Table 2 Frequency Distribution of USGS Mississippi River Flows Scaled to the MNGP Site, 1971-2001

PERCENTILE	FLOW (CFS)												
(%)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
----	----	----	----	----	----	----	----	----	----	----	----	----	----
0	819.	986.	1076.	2459.	1696.	911.	682.	707.	586.	815.	860.	624.	586.
1	970.	1121.	1506.	3270.	1985.	1178.	854.	930.	828.	874.	1018.	947.	946.
5	1810.	1807.	2593.	4832.	2935.	2223.	1779.	1183.	2020.	2489.	2674.	2018.	1954.
10	2078.	2006.	3154.	5871.	3899.	2787.	2288.	1677.	2273.	2962.	3178.	2499.	2595.
15	2564.	2737.	3468.	6552.	4474.	3958.	2886.	2119.	2499.	3137.	3625.	2859.	3044.
20	2896.	3086.	3651.	7087.	5688.	4856.	3826.	2445.	2726.	3276.	3950.	3023.	3429.
25	3343.	3271.	3877.	7765.	6518.	5297.	4297.	2708.	2983.	3415.	4515.	3343.	3791.
30	3536.	3462.	4280.	8478.	7354.	5657.	4834.	2996.	3252.	3575.	5040.	3913.	4166.
35	3857.	3703.	4577.	9247.	8197.	6058.	5151.	3316.	3600.	3864.	5321.	4270.	4526.
40	4176.	3806.	4994.	10279.	9041.	6552.	5667.	3754.	3867.	4109.	5734.	4670.	4847.
45	4320.	3928.	5266.	11108.	9802.	7210.	6167.	4279.	4154.	4486.	6134.	4865.	5194.
50	4474.	4114.	5503.	11943.	10812.	7724.	6658.	4587.	4398.	5215.	6541.	5105.	5575.
55	4628.	4268.	5832.	12754.	11931.	8444.	7056.	4893.	4598.	5766.	6866.	5374.	5966.
60	4769.	4432.	6150.	13613.	12987.	9255.	7704.	5165.	4827.	6058.	7179.	5723.	6419.
65	4937.	4559.	6468.	14811.	14181.	9936.	8359.	5494.	5030.	6430.	7487.	5873.	6973.
70	5143.	4625.	6788.	16045.	15499.	10726.	9154.	5960.	5190.	7037.	7746.	6120.	7726.
75	5279.	4988.	7570.	18514.	16868.	11828.	10210.	6418.	5852.	7776.	8218.	6383.	8720.
80	5496.	5262.	9021.	20117.	18102.	12843.	11276.	7210.	6953.	9072.	8660.	6702.	10008.
85	5760.	5554.	10153.	22276.	19542.	13658.	12240.	8413.	8570.	11054.	9180.	7080.	11622.
90	6043.	5863.	11879.	25508.	22230.	14908.	13902.	9822.	9915.	12596.	10183.	7548.	14019.
95	6487.	6038.	16835.	33736.	27154.	16990.	16265.	11108.	11442.	15608.	12034.	8403.	18308.
99	7110.	9743.	22104.	43198.	34870.	29204.	21274.	17586.	22544.	21393.	18738.	10203.	29670.
MEAN	4284.	4135.	6674.	14140.	12304.	8759.	7622.	5155.	5224.	6455.	6715.	5055.	7217.
MAX	7649.	11315.	25403.	46387.	41167.	31370.	35172.	26655.	28711.	25766.	22151.	11747.	46387.
OBS	961	876	961	930	961	930	961	961	930	961	930	961	11323

Table 3 Monthly Average USGS Mississippi River Flows Scaled to the MNGP Site, 1971-2001

				FLOW (CFS)									
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1971	3399.5	3329.7	4596.7	19187.5	11825.0	7327.8	5035.1	2548.6	2485.2	5507.5	17355.9	7965.0	7537.3
1972	6640.6	5664.6	11526.4	18381.1	16993.3	8575.3	12492.3	16522.9	8971.0	7354.5	9431.5	5306.2	10688.5
1973	5317.1	4345.7	13093.5	8704.1	8979.5	6471.8	3627.6	5922.8	4348.0	12670.6	9159.6	5787.3	7396.0
1974	4724.6	4447.0	5666.6	14109.2	16561.1	14286.4	5634.0	5077.5	2781.5	2820.1	5548.3	3961.8	7134.5
1975	3944.9	4467.8	4653.8	17875.4	25073.9	11588.0	14179.8	5259.7	4943.2	4512.4	5062.1	4905.8	8897.5
1976	4339.3	4683.9	7533.4	13307.8	4081.2	2353.3	2030.8	1111.4	852.7	919.9	1113.1	1006.4	3593.6
1977	1029.1	1194.6	2887.5	3630.9	2342.7	2670.8	2538.8	1426.7	4572.3	6949.1	7799.9	7099.8	3688.1
1978	4546.5	3455.5	4801.8	16632.4	8088.9	9320.9	12391.5	7403.2	9213.1	6056.9	4654.7	3654.0	7525.0
1979	3252.6	3154.6	4512.5	21180.2	21348.4	11882.5	11001.9	5413.6	4463.4	3445.8	7998.1	4453.1	8521.4
1980	3855.7	3884.7	4612.5	10879.4	4212.7	4544.2	2279.3	2422.8	4674.4	3574.7	3550.8	2547.4	4238.1
1981	2134.9	2017.7	2701.0	5442.6	6785.5	7396.8	5793.6	5078.9	3848.5	7903.4	7135.1	4126.8	5045.0
1982	3744.9	3805.7	4037.4	23050.8	18790.9	9248.1	5982.9	3223.9	3685.5	10592.0	7978.5	7407.2	8472.9
1983	6143.0	5160.5	12220.0	10689.6	6701.4	8752.1	10661.4	5225.1	4423.8	5812.7	6279.5	6005.3	7355.3
1984	5527.5	6798.0	8279.3	11777.5	11545.2	17816.6	7304.5	3095.3	2740.3	9949.3	9075.2	5734.2	8293.5
1985	4904.2	4051.0	9540.4	12048.0	17194.1	13070.1	12418.6	8832.1	11156.7	11716.9	7257.6	7038.9	9973.7
1986	6507.4	5754.9	6727.1	25916.4	27771.7	12834.1	9940.1	9733.5	17057.8	14705.9	8448.3	7049.5	12724.2
1987	5682.9	5442.2	6840.6	6538.2	5539.7	5912.9	2996.2	3869.5	2935.4	3417.5	3559.6	3031.6	4639.7
1988	2419.7	2642.3	4413.4	7154.0	3742.3	1437.4	880.3	2444.7	7570.3	3782.0	3036.9	2899.8	3528.7
1989	2867.3	3034.2	3969.8	16213.0	10893.1	6007.6	4041.8	1578.3	4455.6	3694.4	3235.4	2452.5	5196.5
1990	2048.1	1867.1	7773.0	6764.0	9152.6	10384.0	4907.1	2160.6	2362.5	4295.6	4059.6	2376.2	4858.9
1991	1981.7	1985.4	4147.9	9356.9	12833.1	6980.3	7411.7	3465.2	4516.3	3242.8	5307.9	5342.7	5566.1
1992	4756.1	3665.1	6947.5	8759.6	6387.2	3850.1	5713.3	2571.6	4201.5	3194.7	3672.2	2947.9	4726.6
1993	3447.2	3298.6	4013.6	11081.4	11061.3	13098.0	17305.8	9338.0	7421.5	6043.1	6415.6	5511.6	8195.1
1994	5259.4	5063.6	9102.2	16099.9	14240.8	7822.0	10348.7	5588.2	5124.8	8058.7	7027.3	5404.4	8279.7
1995	4696.1	3981.9	10900.7	12359.8	12562.0	6013.1	7158.2	6610.8	5955.2	16124.0	9951.4	6337.1	8591.6
1996	5460.5	5691.0	8435.9	19434.7	17743.8	8115.1	6973.4	4784.0	2673.1	4488.7	8341.4	7645.9	8322.7
1997	5776.4	5961.8	6358.3	30444.4	12709.0	6012.4	12687.4	7678.8	5092.2	6233.9	6010.7	5630.0	9213.7
1998	4311.2	5782.5	7042.4	9650.0	5813.8	9673.3	9113.1	3625.7	2371.8	5771.7	7832.9	6906.1	6487.3
1999	4397.8	4270.2	6207.7	14796.8	20154.5	11240.8	10133.7	9963.8	10041.5	8401.8	7074.9	5261.4	9354.3
2000	4678.1	4563.1	8362.9	6309.0	7636.7	5958.6	6232.6	3296.6	3083.9	3908.1	9574.2	5374.9	5752.7
2001	4996.0	4568.9	4983.7	30560.7	22650.8	20892.8	7056.7	4518.2	3911.8	4948.6	5231.8	5530.8	9975.5
2002	4621.1	3817.7	3758.8	10646.0	9661.2	5635.3	13149.6	7163.5	5810.5				5366.1

Table 4 Output Listing from Log-Pearson Program for Flow Analysis at MNGP Site Using Mississippi River Data Scaled from USGS Stations

```
Analysis of 1940-1970 Data Set
 COL=            1
  YEAR LISTING
1940  1310.5   Flow (cfs)
1941  2592.2
1942  3089.0
1943  3074.9
1944  3359.3
1945  2842.6
1946  2800.3
1947  2646.9
1948  1753.6
1949  2425.1
1950  2302.2
1951  4385.4
1952  3139.7
1953  4229.9
1954  2720.9
1955  2118.0
1956  1790.4
1957  2865.8
1958  1329.7
1959  1708.5
1960  1382.0
1961   913.2
1962  1955.8
1963  1758.5
1964  1762.1
1965  2951.8
1966  2487.1
1967  1561.5
1968  2222.4
1969  1908.0
1970  1362.4

 RETURN  FLOW (CFS)
   2 2250.59
   5 1635.53
  10 1366.22
  25 1116.55
  50  975.58
 100  862.33

Analysis of 1971-2001 Data Set
 COL=            1
  YEAR LISTING
1971  2139.8
1972  3582.1
1973  2737.5
1974  2002.7
1975  3986.0
1976   787.1
```

1977	1018.5
1978	2999.8
1979	2939.8
1980	1609.7
1981	2616.9
1982	2597.4
1983	3771.8
1984	2199.4
1985	4755.3
1986	4822.5
1987	2104.9
1988	716.7
1989	1288.6
1990	1748.5
1991	2484.6
1992	2061.5
1993	4722.4
1994	3680.7
1995	3085.6
1996	2475.8
1997	3893.7
1998	2174.6
1999	3560.2
2000	2650.7
2001	3338.3

RETURN	FLOW (CFS)
2	2708.44
5	1735.35
10	1294.12
25	899.69
50	691.88
100	537.05

Analysis of 1940-2001 Data Set

COL= 1

YEAR LISTING

1940	1310.5
1941	2592.2
1942	3089.0
1943	3074.9
1944	3359.3
1945	2842.6
1946	2800.3
1947	2646.9
1948	1753.6
1949	2425.1
1950	2302.2
1951	4385.4
1952	3139.7
1953	4229.9
1954	2720.9
1955	2118.0
1956	1790.4
1957	2865.8
1958	1329.7
1959	1708.5

1960	1382.0
1961	913.2
1962	1955.8
1963	1758.5
1964	1762.1
1965	2951.8
1966	2487.1
1967	1561.5
1968	2222.4
1969	1908.0
1970	1362.4
1971	2139.8
1972	3582.1
1973	2737.5
1974	2002.7
1975	3986.0
1976	787.1
1977	1018.5
1978	2999.8
1979	2939.8
1980	1609.7
1981	2616.9
1982	2597.4
1983	3771.8
1984	2199.4
1985	4755.3
1986	4822.5
1987	2104.9
1988	716.7
1989	1288.6
1990	1748.5
1991	2484.6
1992	2061.5
1993	4722.4
1994	3680.7
1995	3085.6
1996	2475.8
1997	3893.7
1998	2174.6
1999	3560.2
2000	2650.7
2001	3338.3

RETURN	FLOW (CFS)
2	2454.72
5	1666.19
10	1317.73
25	1000.04
50	825.72
100	689.84

Table 5 Monthly Average Mississippi River Flow Recorded at the MNGP Site (1989 – April 2004)

M		Y	Flow (cfs)	Obs
1	1	88	2921.6	25
2	1	88	3312.1	26
3	1	88	4096.0	31
4	1	88	6330.7	29
5	1	88	3252.8	31
6	1	88	1373.7	30
7	1	88	867.2	31
8	1	88	2194.2	31
9	1	88	2474.5	29
10	1	88	3201.7	31
11	1	88	2735.7	30
12	1	88	3144.5	30
1	1	89	3717.6	31
2	1	89	4292.1	28
3	1	89	4517.2	31
4	1	89	13495.3	30
5	1	89	9310.5	31
6	1	89	5095.2	30
7	1	89	3722.1	31
8	1	89	1433.4	31
9	1	89	2279.2	30
10	1	89	3574.8	31
11	1	89	3191.9	30
12	1	89	2757.0	31
1	1	90	3242.7	31
2	1	90	3207.2	28
3	1	90	6705.4	31
4	1	90	5745.7	30
5	1	90	7601.9	31
6	1	90	9191.7	30
7	1	90	4362.1	31
8	1	90	2110.8	31
9	1	90	2256.6	30
10	1	90	3564.4	31
11	1	90	3712.4	30
12	1	90	2512.5	31
1	1	91	3631.9	31
2	1	91	3604.2	28
3	1	91	4762.1	31
4	1	91	8350.0	30
5	1	91	11316.4	31
6	1	91	6267.9	30
7	1	91	6336.8	31
8	1	91	3203.2	31
9	1	91	4198.6	30
10	1	91	3327.8	31
11	1	91	4857.5	30
12	1	91	5082.2	31
1	1	92	4598.9	31
2	1	92	3287.1	29

3	1	92	6529.3	31
4	1	92	7836.9	30
5	1	92	5757.5	31
6	1	92	3482.4	30
7	1	92	4960.7	31
8	1	92	2556.8	31
9	1	92	3641.3	30
10	1	92	2893.4	31
11	1	92	3278.9	30
12	1	92	3141.9	31
1	1	93	4316.8	31
2	1	93	4223.2	28
3	1	93	4121.2	31
4	1	93	9028.4	30
5	1	93	8931.3	31
6	1	93	10478.9	30
7	1	93	14150.6	31
8	1	93	8060.1	31
9	1	93	6457.2	30
10	1	93	5109.7	31
11	1	93	5323.4	30
12	1	93	5276.5	31
1	1	94	4946.4	31
2	1	94	4556.3	28
3	1	94	7647.6	31
4	1	94	12165.6	30
5	1	94	12160.4	31
6	1	94	6375.1	30
7	1	94	8226.3	31
8	1	94	4744.4	31
9	1	94	4319.8	30
10	1	94	7056.3	31
11	1	94	6367.8	30
12	1	94	5132.2	31
1	1	95	4337.0	31
2	1	95	4109.0	28
3	1	95	9791.4	31
4	1	95	10571.1	30
5	1	95	10085.9	31
6	1	95	5313.7	30
7	1	95	6077.4	31
8	1	95	5828.4	31
9	1	95	5240.9	30
10	1	95	12186.2	31
11	1	95	8643.6	30
12	1	95	6181.8	31
1	1	96	5653.7	31
2	1	96	5957.7	29
3	1	96	6621.6	31
4	1	96	18079.4	30
5	1	96	15055.2	31
6	1	96	7075.0	30
7	1	96	6091.6	31
8	1	96	4315.5	31
9	1	96	2696.0	30
10	1	96	4118.8	31
11	1	96	7572.4	30

12	1	96	7139.2	31
1	1	97	8988.3	31
2	1	97	9303.5	28
3	1	97	7134.3	31
4	1	97	30768.0	30
5	1	97	10853.8	31
6	1	97	5847.4	30
7	1	97	10328.6	31
8	1	97	5883.0	31
9	1	97	4594.9	30
10	1	97	5481.5	31
11	1	97	5573.7	30
12	1	97	5332.6	31
1	1	98	4186.3	31
2	1	98	5431.9	28
3	1	98	6398.6	31
4	1	98	8552.7	30
5	1	98	5295.0	31
6	1	98	8061.1	30
7	1	98	7995.1	31
8	1	98	3362.3	31
9	1	98	2432.3	30
10	1	98	5065.4	31
11	1	98	7047.4	30
12	1	98	6209.8	31
1	1	99	5171.3	31
2	1	99	5074.2	28
3	1	99	5672.9	31
4	1	99	11835.0	30
5	1	99	18113.1	31
6	1	99	9163.8	30
7	1	99	8176.8	31
8	1	99	8404.6	31
9	1	99	8507.6	30
10	1	99	7415.0	31
11	1	99	6159.3	30
12	1	99	4772.3	31
1	1	0	5189.9	31
2	1	0	8547.1	29
3	1	0	7451.9	31
4	1	0	5686.1	30
5	1	0	6668.2	31
6	1	0	5365.2	30
7	1	0	5575.0	31
8	1	0	3064.3	31
9	1	0	2876.9	30
10	1	0	3491.6	31
11	1	0	8095.8	30
12	1	0	5240.9	31
1	1	1	4769.1	31
2	1	1	4414.4	28
3	1	1	4614.8	31
4	1	1	30844.8	30
5	1	1	20139.4	31
6	1	1	18867.0	30
7	1	1	6567.2	31
8	1	1	4282.1	31

9	1	1	3344.3	30
10	1	1	4174.9	31
11	1	1	4869.1	30
12	1	1	5212.7	31
1	1	2	4788.8	31
2	1	2	4084.0	28
3	1	2	3905.9	31
4	1	2	9257.6	30
5	1	2	8512.8	31
6	1	2	5048.2	30
7	1	2	11229.9	31
8	1	2	6852.5	31
9	1	2	5936.2	30
10	1	2	6494.6	31
11	1	2	5451.6	30
12	1	2	4271.4	31
1	1	3	3501.4	31
2	1	3	2793.3	28
3	1	3	3486.4	31
4	1	3	6230.2	30
5	1	3	8007.3	31
6	1	3	7306.0	30
7	1	3	9766.5	31
8	1	3	3158.4	31
9	1	3	2227.4	30
10	1	3	2133.5	31
11	1	3	2677.1	30
12	1	3	3290.0	31
1	1	4	3074.4	31
2	1	4	3251.4	29
3	1	4	4105.7	31
4	1	4	6893.5	26

Table 6 Output Listing from Log-Pearson Program for Flow Analysis of Mississippi River Data Recorded at Site

```
Analysis of 1990-2003 Data Set
COL=            1
  YEAR LISTING
1990  1730.7      Flow (cfs)
1991  2379.0
1992  2166.7
1993  4158.6
1994  3541.6
1995  3048.7
1996  2546.3
1997  3771.7
1998  2314.9
1999  3433.3
2000  2366.3
2001  3062.9
2002  2603.4
2003  1905.0

 RETURN  FLOW (CFS)
   2 2696.39
   5 2167.18
  10 1933.69
  25 1713.02
  50 1585.27
 100 1480.19
```

Table 7 Output Listing from Log-Pearson Program for Flow Analysis at MNGP Site Using Mississippi River Data Scaled from USGS Stations, 1990-2001

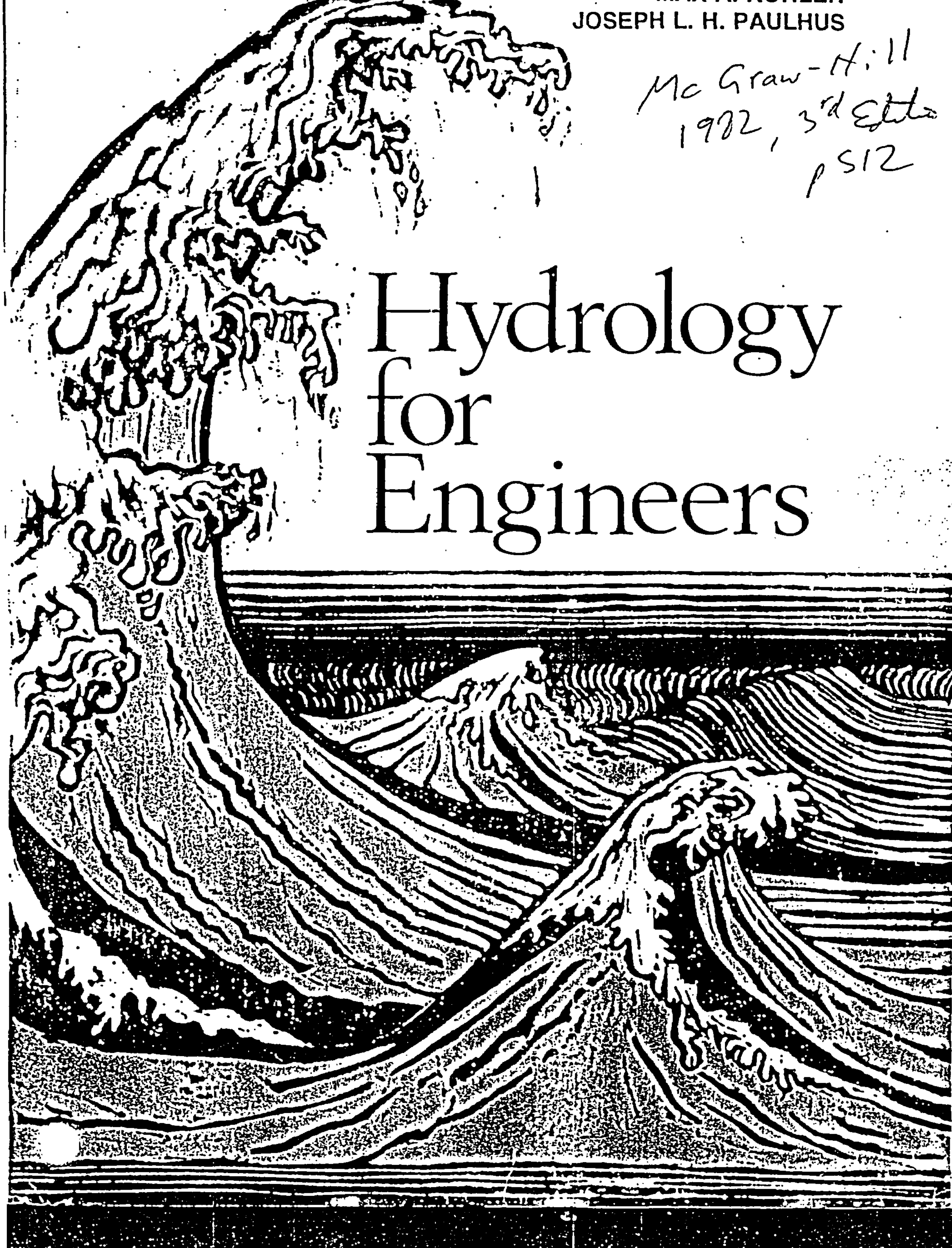
```
Analysis of 1990-2001 Data Set
 COL=            1
  YEAR LISTING
1990  1748.5
1991  2484.6
1992  2061.5
1993  4722.4
1994  3680.7
1995  3085.6
1996  2475.8
1997  3893.7
1998  2174.6
1999  3560.2
2000  2650.7
2001  3338.3

 RETURN  FLOW (CFS)
   2 2881.09   3.458   0.128  -0.052   0.009
   5 2244.81   3.458   0.128  -0.052  -0.837
  10 1965.80   3.458   0.128  -0.052  -1.287
  25 1703.84   3.458   0.128  -0.052  -1.771
  50 1553.25   3.458   0.128  -0.052  -2.085
 100 1430.12   3.458   0.128  -0.052  -2.364
```

RAY K. LINSLEY, JR.
MAX A. KOHLER
JOSEPH L. H. PAULHUS

McGraw-Hill
1982, 3rd Edition
p 512

Hydrology for Engineers



than the period of record. The table shows the uncertainty in the plotting position assigned to the highest event in a series, but for $m \geq 4$ the range of uncertainty is reasonably narrow. If frequency analysis is intended to gain information on floods with return periods less than $n/5$, one may plot flood magnitude against plotting position and fit a curve by eye. For longer return periods it is better to fit a theoretical distribution (Sec. 13-3) to the data. Note that tests for the best theoretical distribution are greatly influenced by the assumed plotting positions.

13-3 Theoretical Distributions of Floods

Statistical distributions are usually demonstrated by use of samples numbering in the thousands. No such samples are available for streamflow and it is not possible to state with certainty that a specific distribution applies to flood peaks. Numerous distributions have been suggested on the basis of their ability to "fit" the plotted [13–15] data from streams (Sec. 13-2). Despite much effort, tests [16] suggest that there is no best distribution for floods. Intuitively at least, there is no reason to expect that a single distribution will apply to all streams worldwide. The log-Pearson Type III has been adopted [17] for use by United States federal agencies for flood analysis. The first asymptotic distribution of extreme values (EV1), commonly called the *Gumbel Type I distribution*, has been widely used and is recommended in the United Kingdom. These two distributions are described in the following sections.

Chow [18] has shown that most frequency functions can be generalized to

$$X = \overline{X} + K\sigma_X \tag{13-5}$$

where X is a flood of specified probability, $\overline{X}$ is the mean of the flood series, σ_X is the standard deviation of the series, and K, a frequency factor defined by a specific distribution, is a function of the probability level of X.

13-4 Log-Pearson Type III Distribution

The recommended procedure for use of the log-Pearson distribution is to convert the data series to logarithms and compute:†

Mean: $$\overline{\log X} = \frac{\Sigma \log X}{n} \tag{13-6}$$

† Alternatively,

$$\sigma_{\log x} = \sqrt{\frac{\Sigma (\log x)^2 - (\Sigma \log x)^2/n}{n - 1}}$$

$$G = \frac{n^2\Sigma (\log x)^3 - 3n\Sigma \log x \Sigma (\log x)^2 + 2(\Sigma \log x)^3}{n(n-1)(n-2)(\sigma_{\log x})^3}$$

where $\log x = \log X - \overline{\log X}$.

Standard deviation: $$\sigma_{\log x} = \sqrt{\frac{\Sigma\,(\log X - \overline{\log X})^2}{n - 1}} \qquad (13\text{-}7)$$

Skew coefficient: $$G = \frac{n\,\Sigma\,(\log X - \overline{\log X})^3}{(n - 1)(n - 2)(\sigma_{\log x})^3} \qquad (13\text{-}8)$$

The value of X for any probability level is computed from Eq. (13-5) modified

$$\log X = \overline{\log X} + K\sigma_{\log x} \qquad (13\text{-}9)$$

where K is taken from Table 13-4. The cumulative frequency distribution will plot as a straight line on log-normal paper when the skew coefficient $G = 0$.

The Type III distribution is one of a family of distributions suggested by Pearson [19]. There are no theoretical arguments for the application of this distribution to hydrologic data. It is a skew distribution bounded on the left and therefore of the general shape of most hydrologic distributions. When skew is zero, the Pearson Type III is identical to the log-normal distribution which was once widely used in hydrology. With a third parameter, skew, the distribution can be "fitted" to most data sets. Reliable estimates of skew require very large samples, however. In lieu of using Eq. (13-8) to compute skew, regional average values are often used [17]; although this may not be more reliable it does lead to more consistency between values for various streams in the region.

The probability density function for Type III is

$$p(X) = p_0 \left(1 - \frac{X}{a}\right)^c e^{-cX/2} \qquad (13\text{-}10)$$

where $$c = \frac{4}{\beta} - 1 \qquad (13\text{-}11)$$

$$a = \frac{c}{2}\,\frac{\mu_3}{\mu_2} \qquad (13\text{-}12)$$

$$p_0 = \frac{n}{a}\,\frac{c^{c+1}}{e^c\Gamma(c + 1)} \qquad (13\text{-}13)$$

$$\beta = \frac{\mu_3^2}{\mu_2^3} \qquad (13\text{-}14)$$

where μ_2 is the variance, μ_3 is the third moment about the mean $= \sigma^6 G$, Γ is the gamma function, and e is the base of napierian logarithms.

13-5 Extreme-Value Type I Distribution

Fisher and Tippett [20] found that the distribution of the maximum (or minimum) values selected from n samples approached a limiting form as the size of the samples increased. When the initial distributions within the samples are exponential, the Type I distribution results. This distribution is given by

$$p = 1 - e^{-e^{-y}} \qquad (13\text{-}15)$$

(13-7)

(13-8)

m Eq. (13-5) modified

(13-9)

iency distribution will w coefficient $G = 0$. ibutions suggested by he application of this ɔunded on the left and utions. When skew is istribution which was ;kew, the distribution ew require very large ‹ew, regional average eliable it does lead to the region.

(13-10)

(13-11)

(13-12)

(13-13)

(13-14)

ɜan = $\sigma^6 G$, Γ is the

ıaximum (or mini- form as the size of n the samples are ı is given by

(13-15)

Table 13-4 *K* Values for the log-Pearson Type III distribution

Skew coefficient	Recurrence interval, years							
	1.0101	1.2500	2	5	10	25	50	100
	Percent chance							
G	99	80	50	20	10	4	2	1
3.0	−0.667	−0.636	−0.396	0.420	1.180	2.278	3.152	4.051
2.8	−0.714	−0.666	−0.384	0.460	1.210	2.275	3.114	3.973
2.6	−0.769	−0.696	−0.368	0.499	1.238	2.267	3.071	3.889
2.4	−0.832	−0.725	−0.351	0.537	1.262	2.256	3.023	3.800
2.2	−0.905	−0.752	−0.330	0.574	1.284	2.240	2.970	3.705
2.0	−0.990	−0.777	−0.307	0.609	1.302	2.219	2.912	3.605
1.8	−1.087	−0.799	−0.282	0.643	1.318	2.193	2.848	3.499
1.6	−1.197	−0.817	−0.254	0.675	1.329	2.163	2.780	3.388
1.4	−1.318	−0.832	−0.225	0.705	1.337	2.128	2.706	3.271
1.2	−1.449	−0.844	−0.195	0.732	1.340	2.087	2.626	3.149
1.0	−1.588	−0.852	−0.164	0.758	1.340	2.043	2.542	3.022
0.8	−1.733	−0.856	−0.132	0.780	1.336	1.993	2.453	2.891
0.6	−1.880	−0.857	−0.099	0.800	1.328	1.939	2.359	2.755
0.4	−2.029	−0.855	−0.066	0.816	1.317	1.880	2.261	2.615
0.2	−2.178	−0.850	−0.033	0.830	1.301	1.818	2.159	2.472
0	−2.326	−0.842	0.	0.842	1.282	1.751	2.054	2.326
−0.2	−2.472	−0.830	0.033	0.850	1.258	1.680	1.945	2.178
−0.4	−2.615	−0.816	0.066	0.855	1.231	1.606	1.834	2.029
−0.6	−2.755	−0.800	0.099	0.857	1.200	1.528	1.720	1.880
−0.8	−2.891	−0.780	0.132	0.856	1.166	1.448	1.606	1.733
−1.0	−3.022	−0.758	0.164	0.852	1.128	1.366	1.492	1.588
−1.2	−3.149	−0.732	0.195	0.844	1.086	1.282	1.379	1.449
−1.4	−3.271	−0.705	0.225	0.832	1.041	1.198	1.270	1.318
−1.6	−3.388	−0.675	0.254	0.817	0.994	1.116	1.166	1.197
−1.8	−3.499	−0.643	0.282	0.799	0.945	1.035	1.069	1.087
−2.0	−3.605	−0.609	0.307	0.777	0.895	0.959	0.980	0.990
−2.2	−3.705	−0.574	0.330	0.752	0.844	0.888	0.900	0.905
−2.4	−3.800	−0.537	0.351	0.725	0.795	0.823	0.830	0.832
−2.6	−3.889	−0.499	0.368	0.696	0.747	0.764	0.768	0.769
−2.8	−3.973	−0.460	0.384	0.666	0.702	0.712	0.714	0.714
−3.0	−4.051	−0.420	0.396	0.636	0.660	0.666	0.666	0.667

Source: Adapted from [10].

where p is the probability of a given flow being equaled or exceeded, e is the base of napierian logarithms, and y, the reduced variate, is a function of probability (Table 13-5). Then

$$X = \overline{X} + (0.7797y - 0.45)\sigma_X \tag{13-16}$$

where $\overline{X}$ is the mean of the data series and σ_X is its standard deviation. This equation is equivalent to Eq. (13-5) with K equal to the term in parentheses.

Table 13-5 Values of K [Eq. (13-5)] for the extreme-value (Type 1) distribution

Return period, years	Probability	Reduced variate y	K
1.58	0.63	0.000	−0.450
2.00	0.50	0.367	−0.164
2.33	0.43	0.579	0.001
5	0.20	1.500	0.719
10	0.10	2.250	1.30
20	0.05	2.970	1.87
50	0.02	3.902	2.59
100	0.01	4.600	3.14
200	0.005	5.296	3.68
400	0.0025	6.000	4.23

Table 13-5 gives values of K for various return periods. When using the Gringorten plotting position [Eq. (13-3)], no correction for record length is considered necessary. Two or more computed values of X define a straight line on extreme-value probability paper. (See Figs. 13-1 and 13-2.)†

From Eq. (13-15)

$$y = -\ln[-\ln(1 - p)] \tag{13-17}$$

Equation (13-3) is a very good approximation to the unbiased mean value of probability associated with a given point assuming the extreme-value distribution [12].

The solution by Eq. (13-16) utilizes the method of moments. The method of maximum likelihood is generally superior but more difficult to solve. Maximizing log likelihood requires the determination of α and β in

$$y_X = \alpha(X - \beta) \tag{13-18}$$

where

$$\beta = \frac{1}{\alpha} \ln \left(\frac{n}{\sum_1^n e^{-\alpha X_m}} \right) \tag{13-19}$$

and

$$F(\alpha) = 0 = \sum_1^n X_m e^{-\alpha X_m} - \left(\bar{X} - \frac{1}{\alpha} \right) \sum_1^n e^{-\alpha X_m} \tag{13-20}$$

† Extrapolation of a straight line is easier than extrapolation of a curve. Hence, frequency analysis is simplified by using special plotting papers scaled so that a specific distribution will plot as a straight line. On such probability paper, the ordinate is normally flowrate, and the abscissa is probability or return period. For some distributions the logarithm of flow is the ordinate. The abscissa scale is warped to achieve the straight-line plot.

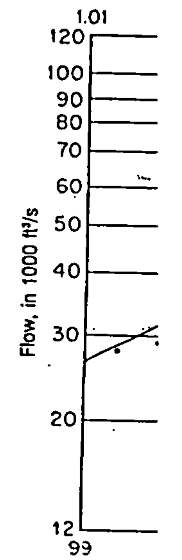


Figure 13-1 F
on log-normal
Eq. (13-2).

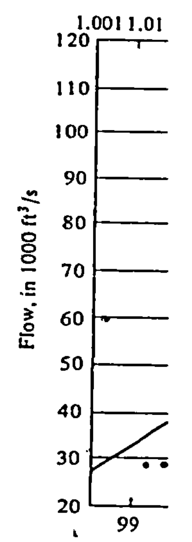


Figure 13-2 Flc
value paper an