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Calculation

Calculation No.: CALC-388996-SW-03 **Revision No.:** 0

Project: Honeywell Metropolis Works Facility

Engineering Discipline: Surface Water Hydrology **Date:** 11/15/2012

Calculation Title & Description:

Title: Probable Maximum Flood (PMF) Analysis

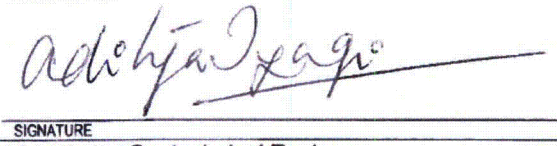
Description: Determination of the PMF discharge and corresponding PMF elevation at the USGS Station # 03611500 on the Ohio River in Metropolis, IL.

Revision History:

Revision No.	Description	Date	Affected Pages
0	Initial Issue	11/15/2012	All

Document Review & Approval:

Originator: Aditya Tyagi/Principal Technologist
NAME/POSITION



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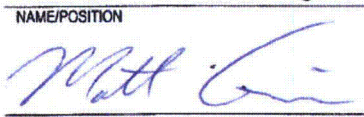
Checked: Matt Gavin/ Geotechnical Engineer
NAME/POSITION



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1. Objective:

The objective of this calculation is to determine the PMF discharge and corresponding PMF elevation at the USGS Station # 03611500 on the Ohio River in Metropolis, IL.

2. Design Standards and Criteria:

The following design standards were used as main references in our analyses and development of our recommendations:

- NRC Regulatory Guide 1.59 (NRC, 1977).

3. Methodology and Assumptions:

Study Area

In order to determine the PMF discharge at the USGS Station # 03611500 on the Ohio River in Metropolis, IL, the drainage area upstream of the USGS Station # 03611500 (Latitude = 370 08' N, and Longitude = 880 44' W) need to be considered. The drainage area of the USGS Station # 03611500 on the Ohio River in Metropolis, IL is 203,000 sq. miles (USGS, 2012a) as depicted in Figure 1 (Attachment B).

Determination of the Maximum Probable Flood

The stepwise procedure outlined in Section B.3.2.2 of the NRC Regulatory Guide 1.59 (NRC, 1977) has been used to estimate the PMF peak discharge at the USGS Station # 03611500 on the Ohio River in Metropolis, IL having a drainage area of 203,000 sq. miles. The procedure used has been described as follows:

1) Located the site (Latitude = 37^0 08' N, and Longitude = 88^0 44' W) on all the six maps (as depicted by a red spot on Figures 2 through 7 of Attachment B), Figure B.2 through B.7 of the NRC Regulatory Guide 1.59 (NRC, 1977), covering index drainage areas of 100, 500, 1,000, 5,000, 10,000, and 20,000 square miles, containing isolines of equal PMF peak discharges for drainage areas of those sizes east of the 103rd meridian.
2) Read the PMF peak discharges for various drainage areas of 100, 500, 1,000, 5,000, 10,000, and 20,000 square miles using the straight line interpolation between the adjacent isolines. The six peak discharges so obtained have been presented in Table 1 (Attachment A).
3) The PMF peak discharges presented in Table 1 (Attachment A) were plotted on a logarithmic paper against the drainage area as shown in Figure 8 (Attachment B). Further, a smooth line through these six peak discharges was fitted. The mathematical equation of the fitted line is given as:

$$PMF = 22{,}121 * Drainage\ Area^{0.43} \quad (1)$$

1) Now, Equation (1) was extended above the 20,000 sq. miles drainage area in order to make the extrapolation for the drainage area of 203,000 sq. miles. Figure 9 (Attachment B) shows the extrapolated line and the extrapolated PMF peak discharge of 4,236,797 cfs corresponding to the drainage area of 203,000 sq. miles. The determined PMF peak discharge of 4,236,797 cfs has been rounded to 4,240,000 cfs.

4) It is worth to mention here that the predicted PMF of 4,240,000 cfs for the Metropolis, IL site is a conservative estimate as the PMF peak discharge reported by Paducah, Kentucky site (PGDP) which is approximately 5 miles downstream of city of Metropolis, IL was 4,000,000 cfs (PGDP, 1995) having its drainage area larger than that of the Metropolis, IL site.

Determination of the Probable Maximum Water Elevation

Having determined the PMF peak discharge, its corresponding water elevation needs to be determined. In order to determine the water elevation for various flood elevation, a discharge – elevation relationship needs to be determined at the USGS Station # 03611500 on the Ohio River in Metropolis. For this purpose two sets of data have been used as described below:

1) Peak stream flow for the USGS 03611500 Ohio River at Metropolis, IL (USGS 2012b). This data has been presented in Table 2 (Attachment A). Figure 10 (Attachment B) plots the time series of these peak stream flows.
2) High water elevations for the Ohio River at the Metropolis site were read from the peak historical profile as shown in Figure 11 of Attachment B (USACE, 1949). The discharge data for various flood events were taken from the peak stream flow data at the USGS Station # 03611500, Metropolis, IL, as presented in Table 2 (Attachment A) by approximately matching the event occurrence date.

In order to increase data points to develop a better statistical relationship, both of these data sets were merged together. The combined data was plotted on a scatter plot. Based on the scatter plot two data points (1,400,000 cfs, 330.57 ft) and (990,000 cfs, 328.20 ft) were removed as water elevation for these discharges are lower than those corresponding to the smaller discharges. It is possible these elevations may be affected by the hysteresis effect. Further based on the scatter plot, it was found that the relationship between peak discharge and water elevation is non-linear in nature. Thus, the peak discharge data was transformed by taking its natural logarithm. Using the water elevation and transformed peak discharge data, a regression analysis was conducted to develop a relationship between peak flow and water elevation as presented in Table 4 (Attachment A). Mathematically, the developed regression relationship is given below:

$$PMF\ Water\ Elevation(ft.NGVD29) = 26.56 * \ln[PMF\ Discharge(cfs)] - 37.64 \quad (2)$$

The goodness of fit of the regression line represented by Equation (2) along with the estimated 95% lower and upper confidence intervals are shown in Figure 12 (Attachment B).

Using the developed Equation (2) for estimating water elevation corresponding to the PGDP reported PMF flow of 4,000,000 cfs (PGDP, 1995), the estimated water elevation has been estimated to be 366.1 ft NGVD29 which is higher than the maximum water elevation of 365 ft NGVD29 as reported by the PGDP corresponding to the flow of 4,000,000 cfs (PGDP, 1995). This shows that the developed equation is conservative and thus can be used to predict the PMF water elevation. Therefore, using the developed Equation (2), the PMF elevation at the USGS 03611500 Ohio River at Metropolis, IL is 367.6 ft NGVD29.

4. Results and Conclusions

1) The peak PMF discharge has been found to be 4,240,000 cfs. This is slightly higher than the calculated PMF of 4,000,000 cfs reported in the SAR for the Paducah Gaseous Diffusion Plant (PGDP, 1995).
2) The estimated PMF elevation at Metropolis corresponding to a discharge rate of 4,240,000 cfs is 367.6 feet NGVD29.

5. List of Attachments

Attachments A & B

6. Additional References

USGS (2012a)
http://nwis.waterdata.usgs.gov/il/nwis/nwismap/?site_no=03611500&agency_cd=USGS
Accessed on Oct. 12, 2012.

USGS (2012b). http://nwis.waterdata.usgs.gov/il/nwis/peak/?site_no=03611500&agency_cd=USGS
Accessed on Oct. 12, 2012.

NRC (1977). Regulatory Guide 1.59, US Nuclear Regulatory Commission, Revision 2, August 1977.

PGDP (1995). Application for the United States Nuclear Commission Certification, Paducah Gaseous Diffusion Plant (PGDP), Rev. 1, September 1995.

USACE (1949). Metropolis 1937 Flood (UNCLASSIFIED), Document2011-09-14-150629.pdf. Obtained on Sept. 14.

Attachment A

TITLE: TABLES

Table 1: PMF Obtained from RG 1.59

A (sq. mi)	PMF (cfs)	Source
100	140,000	RG 1.59 Figure B2
500	350,000	RG 1.59 Figure B3
1,000	450,000	RG 1.59 Figure B4
5,000	900,000	RG 1.59 Figure B5
10,000	1,100,000	RG 1.59 Figure B6
20,000	1,400,000	RG 1.59 Figure B7

Table 2: Historical Ohio River Peak Stream Flow at the USGS Station # 03611500, Metropolis, IL

Date	Peak Discharge (cfs)	Gage Height (ft)	Water Elevation (ft NGVD29)
4/7/1913	1400000	54.3	330.57
3/15/1929	975000		
1/19/1930	853000		
4/11/1931	560000		
2/12/1932	1150000		
4/1/1933	1050000		
3/15/1934	773000		
3/22/1935	936000		
4/15/1936	1100000		
2/1/1937	1850000		
3/31/1938	646000		
2/21/1939	1130000		
5/2/1940	846000		
4/13/1941	309000		
3/24/1942	716000		
3/30/1943	966000		
4/4/1944	798000		
3/10/1945	1120000		
1/20/1946	917000		
1/27/1947	768000		
2/21/1948	990000		
2/5/1949	967000		
2/13/1950	1300000		
2/27/1951	815000		
2/8/1952	892000		
3/7/1953	612000		
1/27/1954	545000		

3/28/1955	1030000		
2/25/1956	885000		
2/10/1957	965000		
5/19/1958	787000		
2/2/1959	707000		
12/22/1959	586000		
3/11/1961	963000		
3/11/1962	1090000		
3/19/1963	1150000		
3/18/1964	1090000		
4/1/1965	864000		
2/23/1966	679000		
3/20/1967	786000		
6/7/1968	711000		
2/9/1969	853000		
5/3/1970	767000		
3/3/1971	795000		
5/1/1972	805000		
3/26/1973	989000		
1/18/1974	1030000		
4/2/1975	1180000		
2/25/1976	800000		
4/10/1977	817000		
3/22/1978	873000		
3/7/1979	1140000		
3/30/1980	993000		
6/9/1981	666000		
2/11/1982	868000		
5/25/1983	1040000		
5/14/1984	1060000		
3/7/1985	724000		
11/24/1985	665000		
3/4/1987	742000		
2/10/1988	621000		
2/24/1989	1040000		
2/19/1990	1060000		
1/1/1991	1190000		
4/2/1993	823000		
4/24/1994	965000		

5/27/1995	821000		
1/31/1996	909000	48.98	325.25
3/11/1997	1210000	59.11	335.38
4/21/1998	850000	51.05	327.32
2/1/1999	961000	51.93	328.2
2/27/2000	729000	43.26	319.53
2/23/2001	777000	45.68	321.95
3/26/2002	940000	50.72	326.99
2/27/2003	1010000	51.83	328.1
2/13/2004	875000	47.71	323.98
1/16/2005	1030000	55.02	331.29
1/29/2006	724000	42.86	319.13
1/25/2007	743000	44.48	320.75
4/11/2008	988000	53.21	329.48
5/11/2009	823000	50.72	326.99
5/5/2010	924000	51.41	327.68
5/5/2011	1260000	61.71	337.98

Notes:

1. Water Elevation (feet NGVD29) = Gage Datum (feet NGVD29)+ Gage Height (feet)
2. Gage Datum = 276.27 feet NGVD29

Table 3: Water Elevation Obtained from the High-water Profiles of the Ohio River at the Metropolis USGS Station, IL

S. No.	Flood Event	Discharge (cfs)	Elevation (ft NGVD29)
1	Jan. 1937	1,850,000	343.38
2	Mar-Apr. 1913	1,400,000	337.17
3	Mar. 1945 Flood	1,120,000	334.07
4	Dec. 1942 – Jan. 1943	966,000	328.20
5	Apr. 1948	990,000	328.20

Notes: The discharge data for various flood events were taken from the Peak Historical Stream flow Data at the USGS Station # 03611500, Metropolis, IL.

Table 4: Regression Analysis to develop a relationship between peak flow and water elevation

Parameter	Xm	Ym	N	Sum(xy)	Sum(x^2)	Sum(y^2)	Ym_P	b	a	E^2	R^2	Std. Error	sb	sa	t
Value	13.79	328.64	20	27.74	1.04	782.35	328.64	26.56	-37.64	45.75	0.94	1.59	1.56	21.52	2.45

Discharge (cfs)	ln(Discharge)	Observed Elevation	x =X-Xm	y=Y-Ym	xy	x^2	y^2	Predicted Elevation	Residual Error	Residual Error^2	Lower 95% CI	Upper 95% CI
724,000	13.49	319.13	-0.30	-9.51	2.85	0.09	90.46	320.70	-1.57	2.45	319.26	322.28
729,000	13.50	319.53	-0.29	-9.11	2.66	0.09	83.01	320.88	-1.35	1.82	319.46	322.42
743,000	13.52	320.75	-0.27	-7.89	2.16	0.07	62.27	321.38	-0.63	0.40	320.02	322.79
777,000	13.56	321.95	-0.23	-6.69	1.53	0.05	44.77	322.57	-0.62	0.39	321.34	323.85
823,000	13.62	326.99	-0.17	-1.65	0.28	0.03	2.73	324.10	2.89	8.36	323.01	325.00
850,000	13.65	327.32	-0.14	-1.32	0.18	0.02	1.75	324.96	2.36	5.59	323.94	325.85
875,000	13.68	323.98	-0.11	-4.66	0.51	0.01	21.73	325.73	-1.75	3.05	324.76	326.81
909,000	13.72	325.25	-0.07	-3.39	0.24	0.01	11.50	326.74	-1.49	2.22	325.83	327.73
924,000	13.74	327.68	-0.06	-0.96	0.05	0.00	0.92	327.17	0.51	0.26	326.28	328.06
940,000	13.75	326.99	-0.04	-1.65	0.06	0.00	2.73	327.63	-0.64	0.41	326.75	328.53
961,000	13.78	328.2	-0.02	-0.44	0.01	0.00	0.19	328.22	-0.02	0.00	327.34	329.09
966,000	13.78	328.20	-0.01	-0.44	0.00	0.00	0.19	328.35	-0.15	0.02	327.48	329.23
988,000	13.80	329.48	0.01	0.84	0.01	0.00	0.70	328.95	0.53	0.28	328.08	329.83
1,010,000	13.83	328.1	0.03	-0.54	-0.02	0.00	0.29	329.54	-1.44	2.07	328.66	330.41
1,030,000	13.85	331.29	0.05	2.65	0.14	0.00	7.02	330.06	1.23	1.52	329.16	331.00

1,120,000	13.93	334.07	0.14	5.43	0.74	0.02	29.46	332.28	1.79	3.19	331.27	333.44
1,210,000	14.01	335.38	0.21	6.74	1.44	0.05	45.41	334.34	1.04	1.09	333.14	335.62
1,260,000	14.05	337.98	0.25	9.34	2.38	0.06	87.22	335.41	2.57	6.60	334.10	336.98
1,400,000	14.15	337.17	0.36	8.53	3.07	0.13	72.78	338.21	-1.04	1.07	336.58	339.68
1,850,000	14.43	343.38	0.64	14.74	9.42	0.41	217.22	345.61	-2.23	4.98	343.02	347.84

Notes:

X= Ln(Discharge) as the independent variable, and Y = Water Elevation as the dependent variable

Attachment B

TITLE: FIGURES

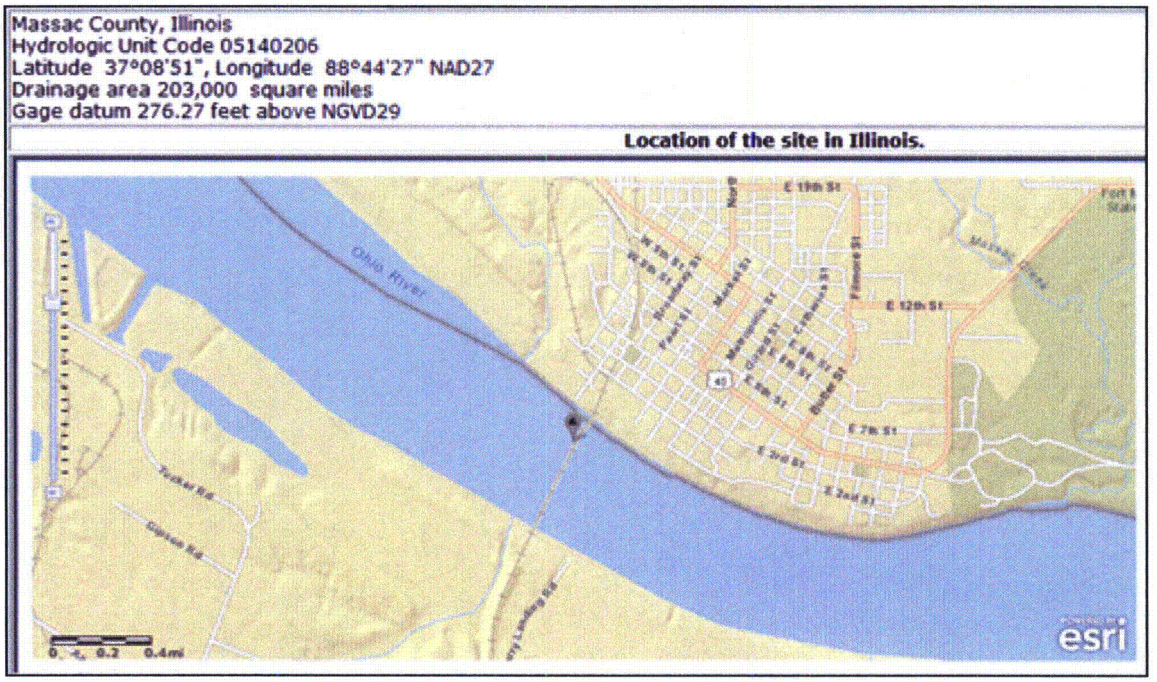

Figure 1: Location of the USGS Station # 03611500 on the Ohio River at Metropolis, IL

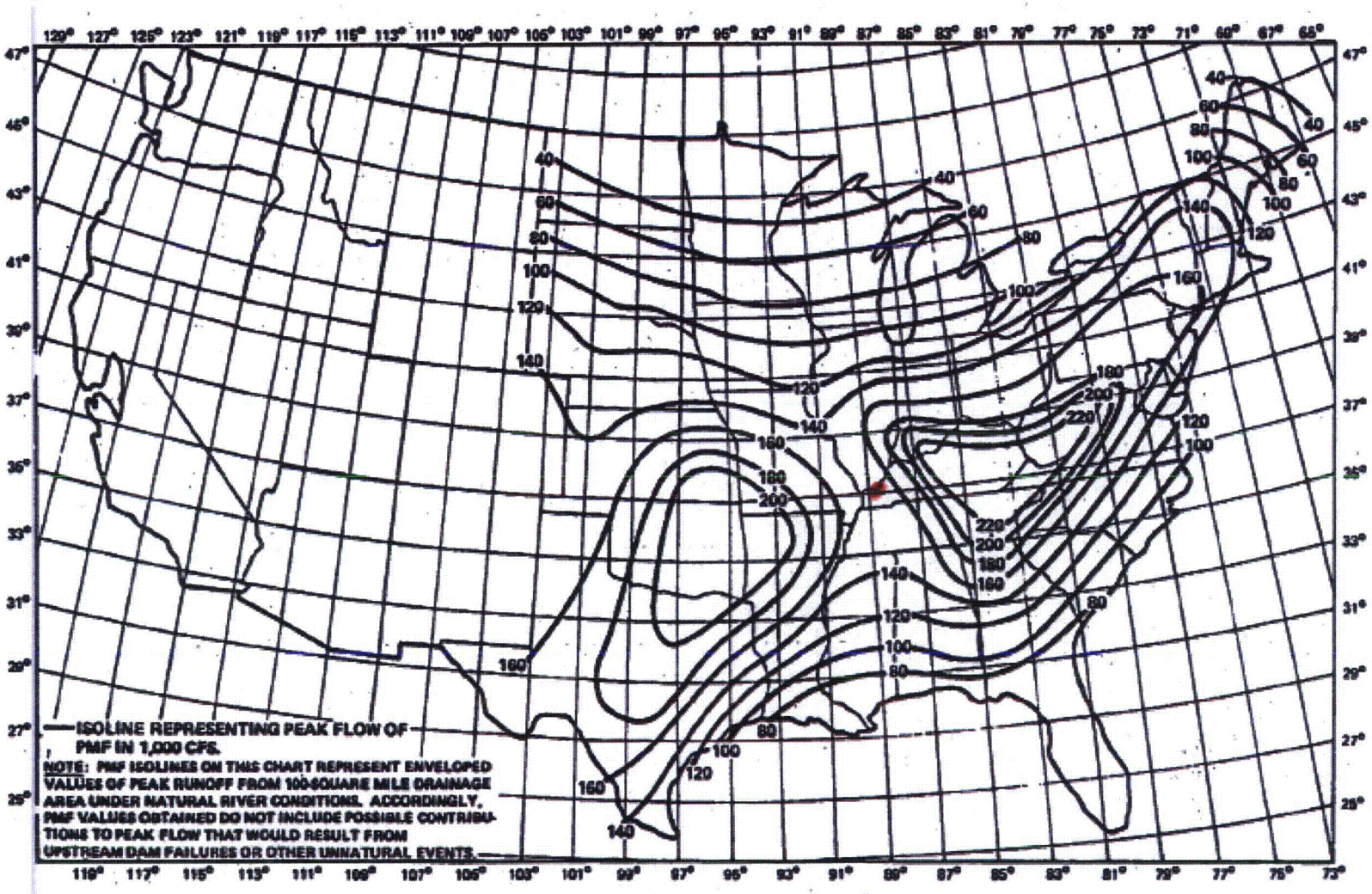

FIGURE 8.2 PROBABLE MAXIMUM FLOOD (ENVELOPING PMF ISOLINES) FOR 100 SQUARE MILES

Figure 2: Enveloping PMF Isolines for 100 sq. miles drainage area (Source RG 1.59, 1977)

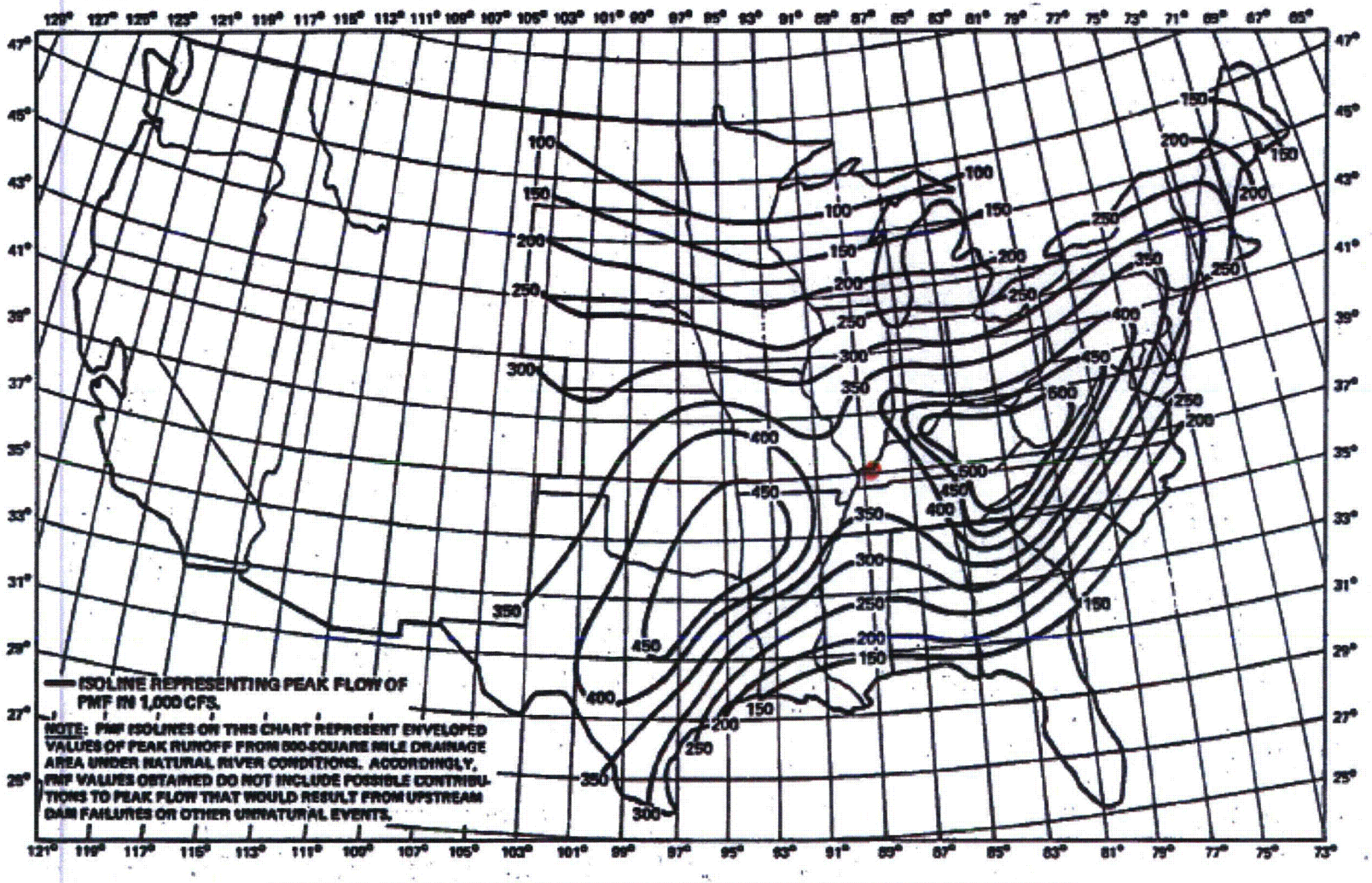

FIGURE B.3 PROBABLE MAXIMUM FLOOD (ENVELOPING PMF ISOLINES) FOR 500 SQUARE MILES

Figure 3: Enveloping PMF Isolines for 500 sq. miles drainage area (Source RG 1.59, 1977)

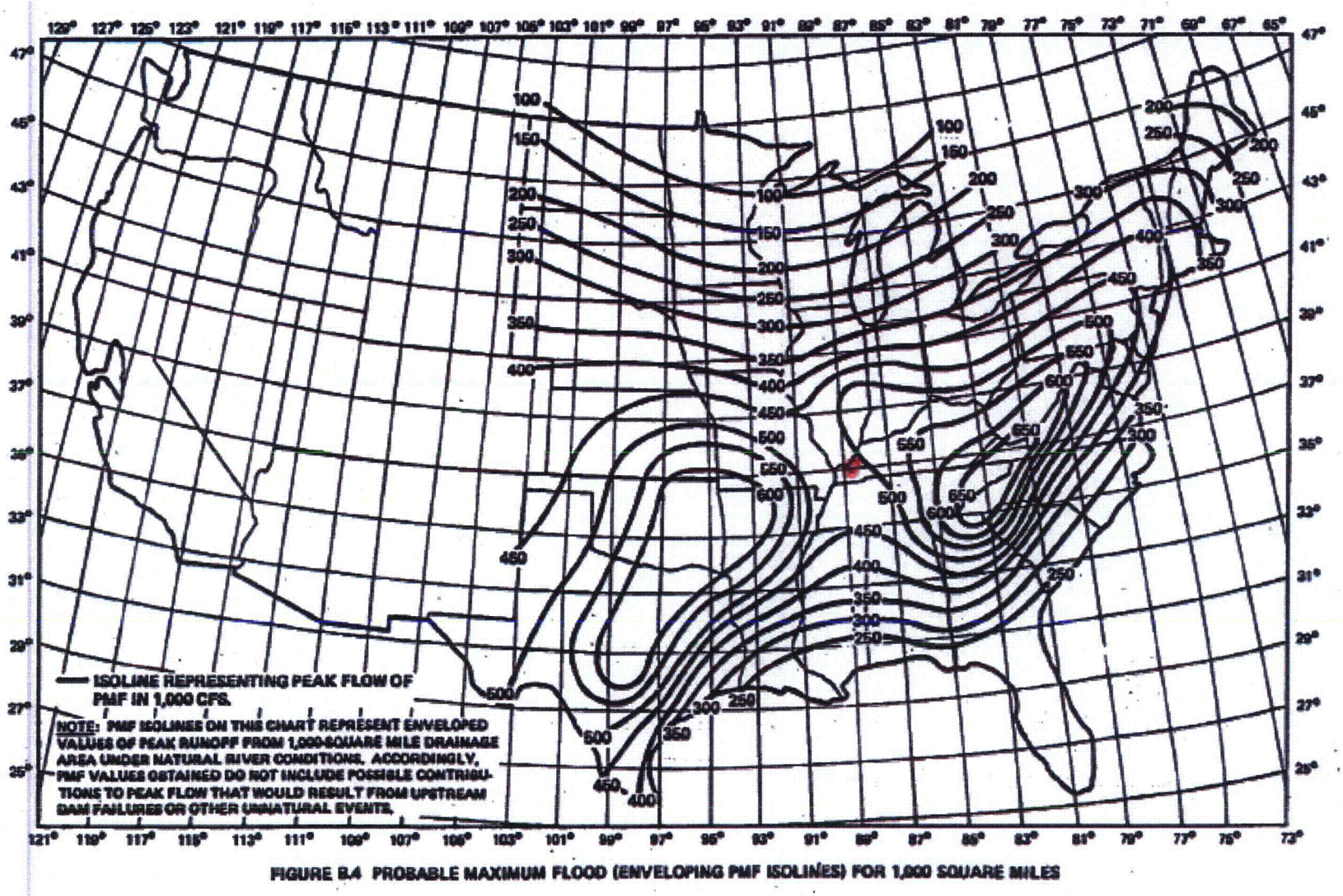

FIGURE 8.4 PROBABLE MAXIMUM FLOOD (ENVELOPING PMF ISOLINES) FOR 1,000 SQUARE MILES

Figure 4: Enveloping PMF Isolines for 1000 sq. miles drainage area (Source RG 1.59, 1977)

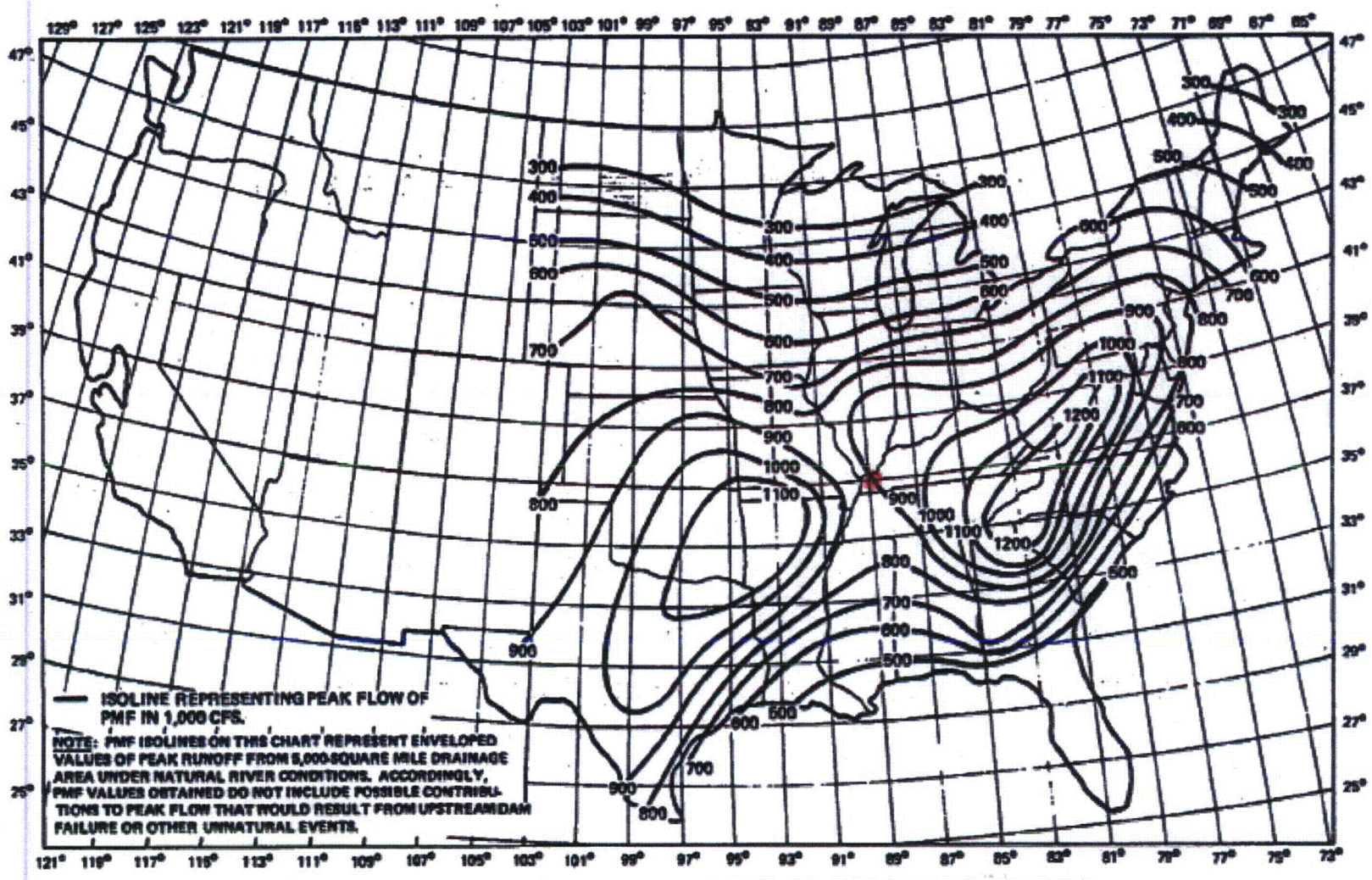

FIGURE 8.5 PROBABLE MAXIMUM FLOOD (ENVELOPING PMF ISOLINES) FOR 5,000 SQUARE MILES

Figure 5: Enveloping PMF Isolines for 5,000 sq. miles drainage area (Source RG 1.59, 1977)

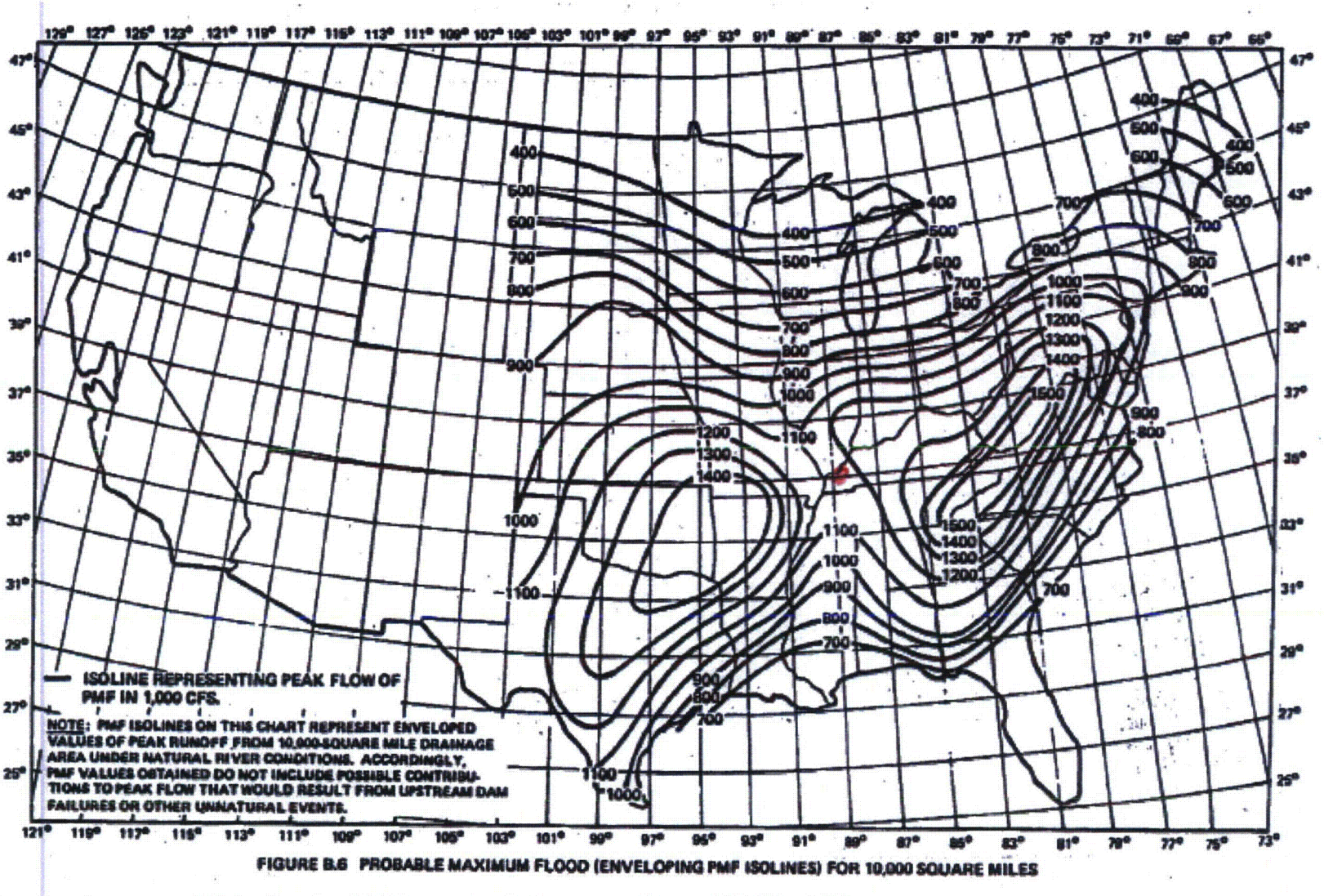

FIGURE B.6 PROBABLE MAXIMUM FLOOD (ENVELOPING PMF ISOLINES) FOR 10,000 SQUARE MILES

Figure 6: Enveloping PMF Isolines for 10,000 sq. miles drainage area (Source RG 1.59, 1977)

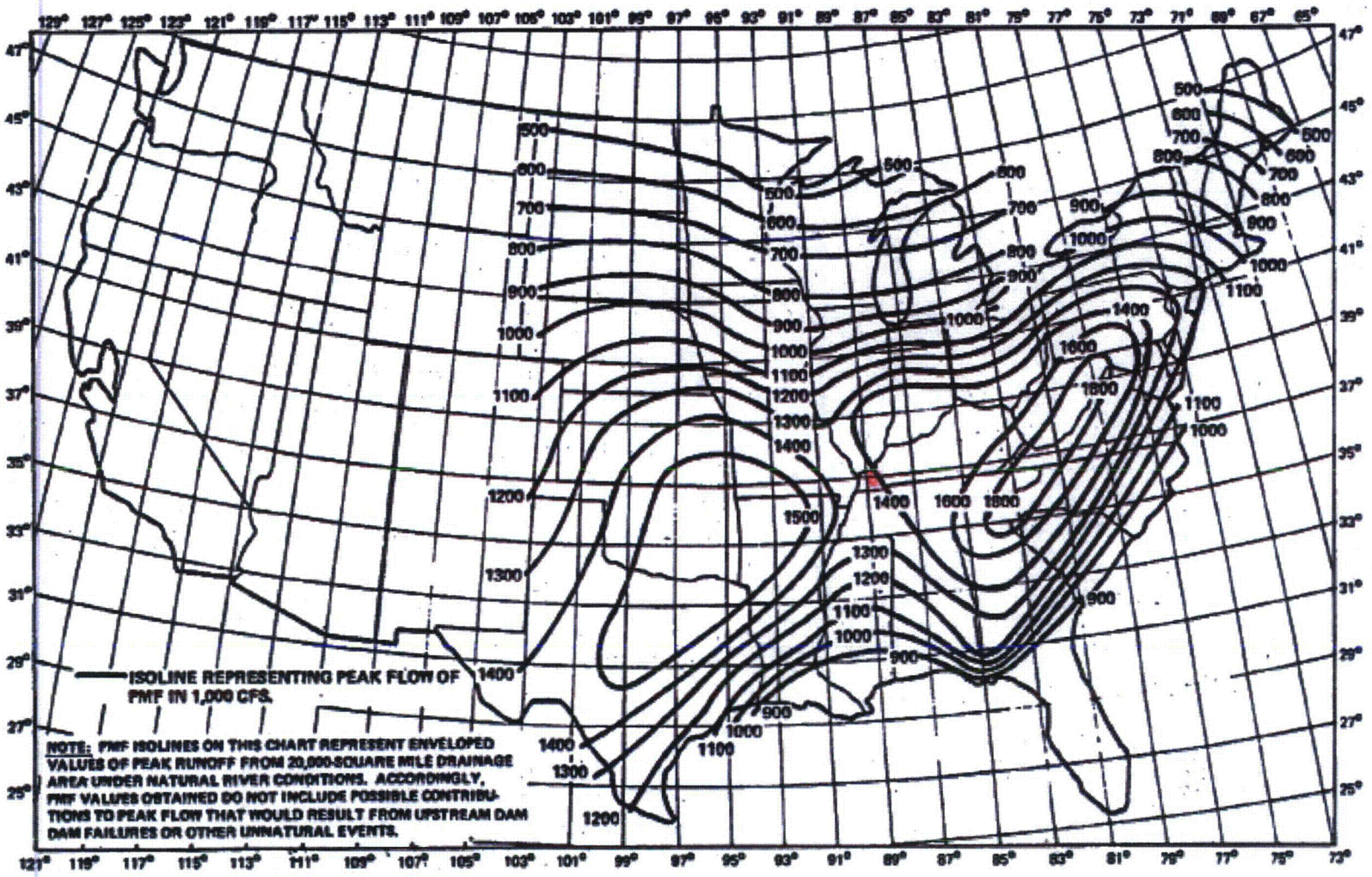

FIGURE 8.7 PROBABLE MAXIMUM FLOOD (ENVELOPING PMF ISOLINES) FOR 20,000 SQUARE MILES

Figure 7: Enveloping PMF Isolines for 20,000 sq. miles drainage area (Source RG 1.59, 1977)

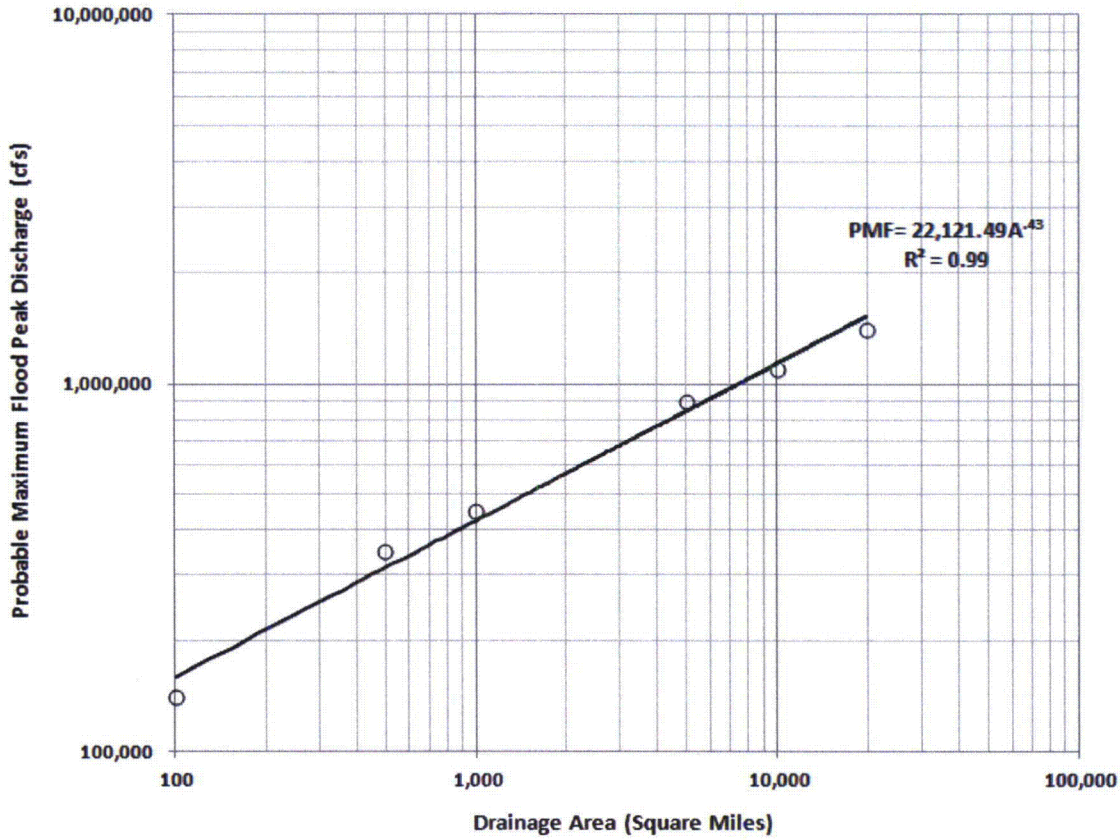

Figure 8: Fitting of a smooth line through the six peak discharges obtained from use of enveloping isolines

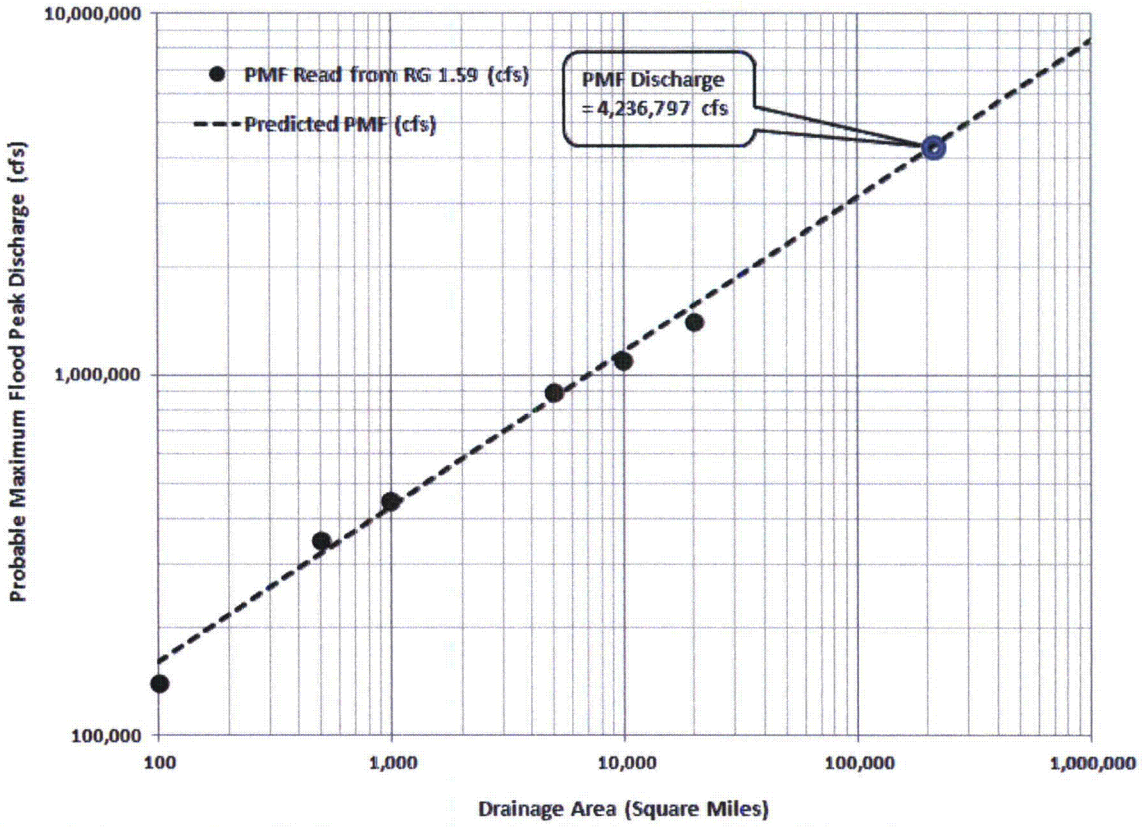

Figure 9: Extrapolation of PMF at the Metropolis USGS Station # 03611500 on the Ohio River

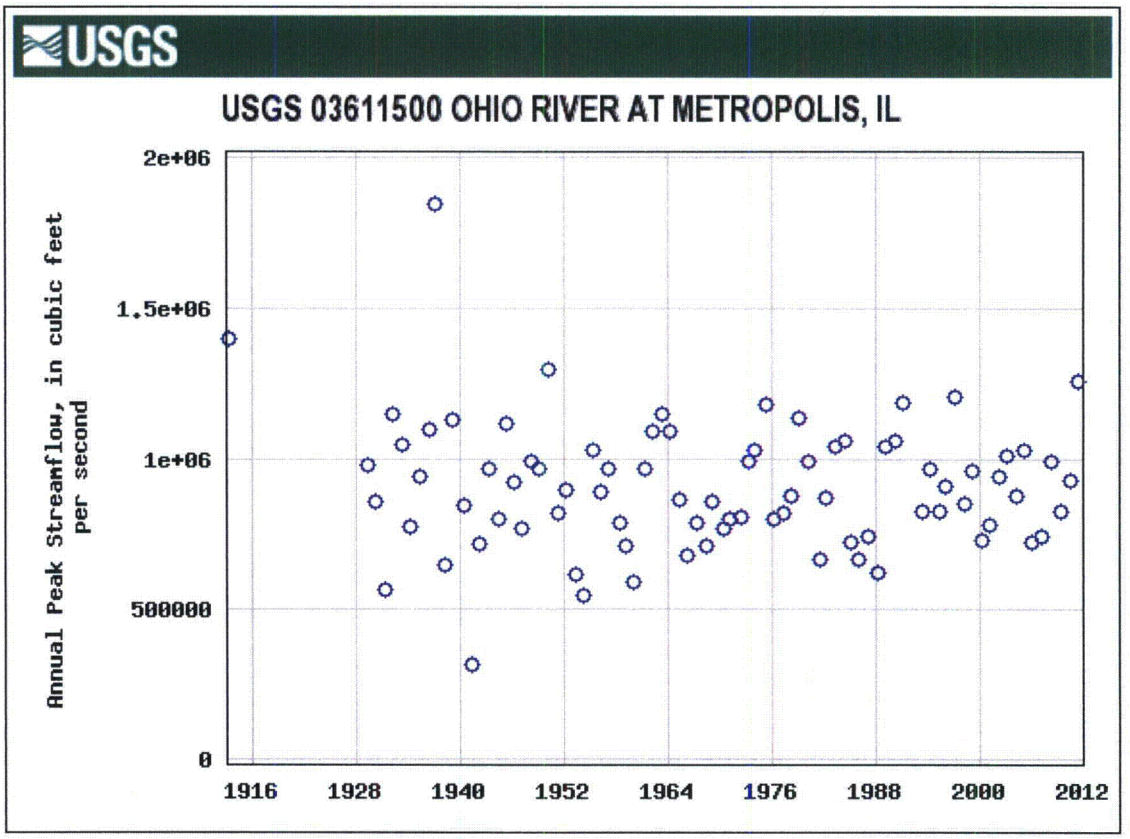

Figure 10: Historical Peak Discharges at the USGS 03611500 on the Ohio River in Metropolis, IL

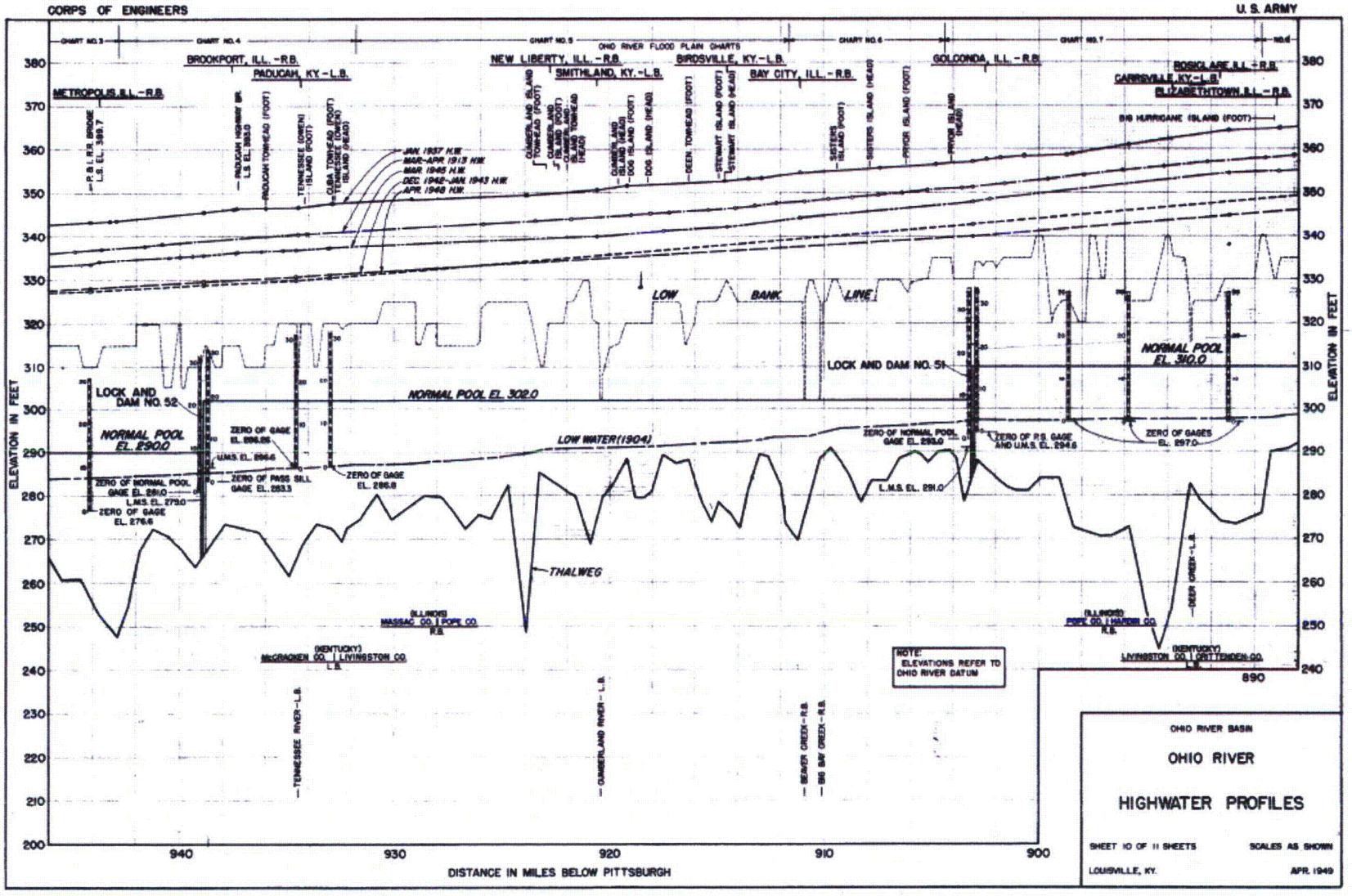

Figure 11: Historical flood profile for the lower portion of the Ohio River

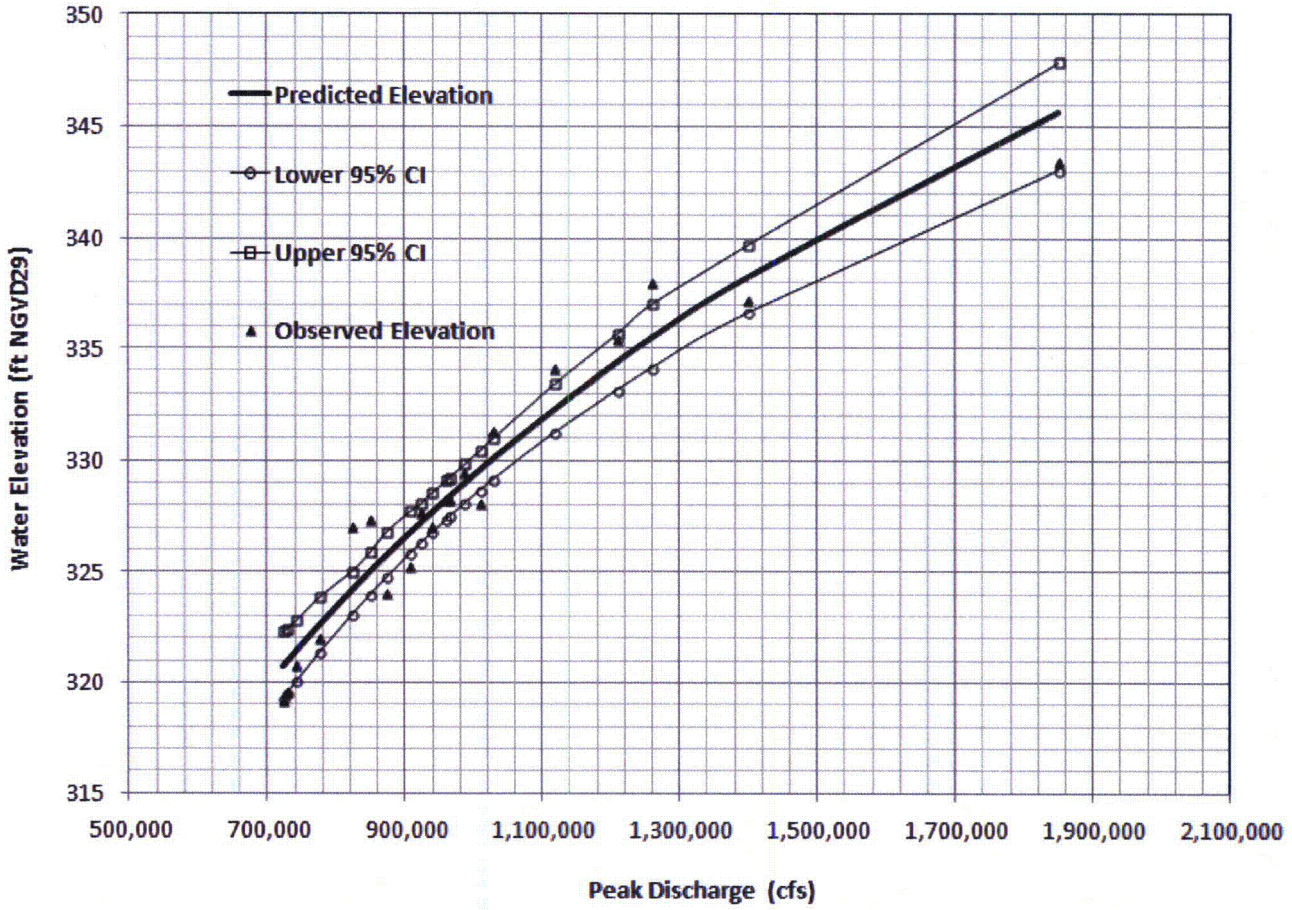

Figure 12: Goodness of Fit of the Regression Relationship between Peak-flow and Water –elevation along with the 95% Confidence Intervals