DEPARTMENT OF THE ARMY
SEATTLE DISTRICT, CORPS OF ENGINEERS
P.O. BOX 3755
SEATTLE, WASHINGTON 98124-2255

REPLY TO
ATTENTION OF

March 15, 1993

Hydrology and Hydraulics

Larry Kunzler
Bogle & Gates
2 Union Square
601 Union Street
Seattle, WA 98101

Dear Larry:

The information you requested on Skagit River is enclosed.

If you have any question, call me at (206) 764-3590.

Sincerely,

Dan Harvey
Chief, Hydrology Section

Skagit River, Washington
Regulated Flood Discharges

Flood	Sedro Woolley 1/	Mt. Vernon 1/	Remarks
10 Yr	132,000	124,000	
20	160,000	150,000	Levee failures & overflow to Samish
30	182,000	152,000	"
40	191,000	155,000	"
50	200,000	162,000	"
60	208,000	170,000	"
70	216,000	175,000	"
80	221,000	179,000	"
90	227,000	183,000	"
100	229,000	185,000	"

1/ Frequency curves dated 21 August 1978 (revised)

CENPS-EN-HH-WM 13 November 1990

MEMORANDUM FOR RECORD PRELIMINARY

SUBJECT: After Action Report- Flooding in Western Washington during 9-12 November 1990.

Weather Statement.

Extremely heavy rainfall occurred in western Washington during the 40 hour period from late Thursday on 8 November 1990 through early Saturday on 10 November 1990. Heaviest rainfall centered in the Cascade Mountains from the Snoqualmie Basin northward into Canada but moderate-to-heavy rainfall also occurred in southern Puget Sound and Olympic Peninsula basin. Temperatures in the 50's and 60's combined to melt most of the early season snow along the Cascades. The combination of heavy rainfall and snowmelt caused major rises in all river basins from the Green River north to Canada including rises to flood stage on the Elwha and Wynoochee Rivers. Rainfall amounts over the 3-day period at principal precipitation stations in the main flood watersheds are listed below:

Precipitation during 8-10 November 1990 (inches)

National Weather Service Stations

Period of Record	Darrington (1931-1965)	Marblemount (1948-pres)	Verlot (1971-pres)	Skykomish (1967-pres.)	Snoqualmie (1948-pres)	Diablo (1948-pres)
8 Nov	.5	.3	.4	.7	.9	3.98 ?**
9 Nov	4.0	5.7	4.5	6.5	6.6	7.32 **
10 Nov	1.3	2.1	1.2	1.8	1.7	.99 **
total	5.8	8.1	6.1	9.0	9.2	12.29
hist. max 24-hr	4.71 Nov 84	6.2 Feb 86	6.4 Nov 77	7.8 Oct 69	7.0 Nov 59	11.50 Jan 74
hist. max 72-hr	9.09 —	9.85 Feb 51	9.5 Jan 71	11.4 Sep 69	15.1 Nov 75	17.0 Jan 74

Note: Precipitation measured from 3:00 pm on 8 November to 10:00 am 10 November.

In addition to the above amounts, Ross Dam reported a 24-hour rainfall amount of 9 inches which is nearly a 100-year rainfall event.

* Climatological Handbook
** 0800-0800 values from Seattle City Light.

HYDROLOGY SUBCOMMITTEE Harvey

Guidelines For Determining Flood Flow Frequency

Bulletin #17B
Revised September 1981
Editorial Corrections March 1982

INTERAGENCY ADVISORY COMMITTEE ON WATER DATA

U.S. Department of the Interior
Geological Survey
Office of Water Data Coordination

A statistical analysis of these data is the primary basis for the determination of the flow frequency curve for each station.

B. Historic Data

At many locations, particularly where man has occupied the flood plain for an extended period, there is information about major floods which occurred either before or after the period of systematic data collection. This information can often be used to make estimates of peak discharge. It also often defines an extended period during which the largest floods, either recorded or historic, are known. The USGS includes some historic flood information in its published reports and computer files. Additional information can sometimes be obtained from the files of other agencies or extracted from newspaper files or by intensive inquiry and investigation near the site for which the flood frequency information is needed.

Historic flood information should be obtained and documented whenever possible, particularly where the systematic record is relatively short. Use of historic data assures that estimates fit community experience and improves the frequency determinations.

C. Comparison With Similar Watersheds

Comparisons between computed frequency curves and maximum flood data of the watershed being investigated and those in a hydrologically similar region are useful for identification of unusual events and for testing the reasonableness of flood flow frequency determinations. Studies have been made and published [e.g., (1), (2), (3), (4)]* which permit comparing flood frequency estimates at a site with generalized estimates for a homogeneous region. Comparisons with information at stations in the immediate region should be made, particularly at gaging stations upstream and downstream, to promote regional consistency and help prevent gross errors.

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*Numbers in parentheses refer to numbered references in Appendix 1.

Appendix 6

HISTORIC DATA

Flood information outside that in the systematic record can often be used to extend the record of the largest events to a historic period much longer than that of the systematic record. In such a situation, the following analytical techniques are used to compute a historically adjusted log-Pearson Type III frequency curve.

1. Historic knowledge is used to define the historically longer period of "H" years. The number "Z" of events that are known to be the largest in the historically longer period "H" are given a weight of 1.0. The remaining "N" events from the systematic record are given a weight of (H-Z)/(N+L) on the assumption that their distribution is representative of the (H-Z) remaining
1 years of the historically longer period.

2. The computations can be done directly by applying the weights to each individual year's data using equations 6-1, 6-2a, 6-3a, and 6-4a. Figure 6-1 is an example of this procedure in which there are 44 years of systematic record and the 1897, 1919 and 1927 floods are known to be the three largest floods in the 77 year period 1897 to 1973. If statistics have been previously computed for the current continuous record, they can be adjusted to give the equivalent historically adjusted values using equations 6-1, 6-2b, 6-3b, and 6-4b, as illustrated in Figure 6-2.

3. The historically adjusted frequency curve is sketched on logarithmic-probability paper through points established by use of equation 6-5. The individual flood events should also be plotted for comparison. The historically adjusted plotting positions for the individual flood events are computed by use of equation 6-8, in which the historically adjusted order number of each event "$\tilde{m}$" is computed from equations 6-6 and 6-7. The computations are illustrated in Figures 6-1 and 6-2, and the completed plotting is shown in Figure 6-3.

4. The following example illustrates the steps in application of the historic peak adjustment only. It does not include the final step of weighting with the generalized skew. The historically adjusted skew developed by this procedure is appropriate to use in developing a generalized skew.

DEFINITION OF SYMBOLS

E	=	event number when events are ranked in order from greatest magnitude to smallest magnitude. The event numbers "E" will range from 1 to (Z + N).
X	=	logarithmic magnitude of systematic peaks excluding zero flood events, peaks below base, high or low outliers
X_z	=	logarithmic magnitude of a historic peak including a high outlier that has historic information
N	=	number of X's
M	=	mean of X's
$\tilde{M}$	=	historically adjusted mean
$\tilde{m}$	=	historically adjusted order number of each event for use in formulas to compute the plotting position on probability paper
S	=	standard deviation of the X's
$\tilde{S}$	=	historically adjusted standard deviation
G	=	skew coefficient of the X's
$\tilde{G}$	=	historically adjusted skew coefficient
K	=	Pearson Type III coordinate expressed in number of standard deviations from the mean for a specified recurrence interval or percent chance
Q	=	computed flood flow for a selected recurrence interval or percent chance
$\tilde{PP}$	=	plotting position in percent
$\tilde{P}$	=	probability that any peak will exceed the truncation level (used in step 1, Appendix 5)
Z	=	number of historic peaks including high outliers that have historic information
H	=	number of years in historic period
L	=	number of low values to be excluded, such as: number of zeros, number of incomplete record years (below measurable base), and low outliers which have been identified
a	=	constant that is characteristic of a given plotting position formula. For Weibull formula, a = 0; for Beard formula, a = 0.3; and for Hazen formula, a = 0.5
W	=	systematic record weight

EQUATIONS

$$W = \frac{H - Z}{N + L} \qquad (6\text{-}1)$$

$$\tilde{M} = \frac{W\Sigma X + \Sigma X_Z}{H\text{-}WL} \qquad (6\text{-}2a)$$

$$\tilde{S}^2 = \frac{W\Sigma(X - \tilde{M})^2 + \Sigma(X_Z - \tilde{M})^2}{(H\text{-}WL\text{-}1)} \qquad (6\text{-}3a)$$

$$\tilde{G} = \frac{H\text{-}WL}{(H\text{-}WL\text{-}1)\ (H\text{-}WL\text{-}2)} \left[\frac{W\Sigma(X - \tilde{M})^3 + \Sigma(X_Z - \tilde{M})^3}{\tilde{S}^3} \right] \qquad (6\text{-}4a)$$

adj. to each individ data pt.

$$\tilde{M} = \frac{WNM + \Sigma X_Z}{H\text{-}WL} \qquad (6\text{-}2b)$$

$$\tilde{S}^2 = \frac{W\ (N - 1)S^2 + WN\ (M - \tilde{M})^2 + \Sigma(X_Z - \tilde{M})^2}{(H\text{-}WL\text{-}1)} \qquad (6\text{-}3b)$$

$$\tilde{G} = \frac{H\text{-}WL}{(H\text{-}WL\text{-}1)\ (H\text{-}WL\text{-}2)\tilde{S}^3} \left[\frac{W(N - 1)\ (N - 2)S^3 G}{N} + 3W\ (N - 1)\ (M - \tilde{M})S^2 + WN\ (M - \tilde{M})^3 + \Sigma(X_Z - \tilde{M})^3 \right] \qquad (6\text{-}4b)$$

adj if stat's prev. computed

$$\text{Log } Q = \tilde{M} + K\tilde{S} \qquad (6\text{-}5)$$

$$\tilde{m} = E;\ \text{when: } 1 \le E \le Z \qquad (6\text{-}6)$$

$$\tilde{m} = WE - (W - 1)\ (Z + 0.5);\ \text{when: } (Z + 1) \le E \le (Z + N + L) \qquad (6\text{-}7)$$

$$\tilde{PP} = \frac{\tilde{m} - a}{H + 1 - 2a}\ 100 \qquad (6\text{-}8)$$

Figure 6-1. HISTORICALLY WEIGHTED LOG PEARSON TYPE III - ANNUAL PEAKS

Station: 3-6065, Big Sandy River at Bruceton, TN. D. A. 205 square miles
Record: 1897, 1919, 1927, 1930-1973 (47 years)
Historical period: 1897-1973 (77 years)
N = 44; Z = 3; H = 77

Year	Q (ft^3/s) = Y	Log Y = X	Departure from mean log x = (X-M̄)	Weight = W	Event Number = E	Weighted order Number = m	Plotting position (Weibull) PP
1897	25,000	4.39794	0.68212	1.00	1	1.00	1.28
1919	21,000	4.32222	0.60640	1.00	2	2.00	2.56
1927	18,500	4.26717	0.55136	1.00	3	3.00	3.85
1935	17,000	4.23045	0.51464	1.68182	4	4.34	5.56
1937	13,800	4.13988	0.42407		5	6.02	7.72
1946	12,000	4.07918	0.36337		6	7.71	9.88
1972	12,000	4.07918	0.36337		7	9.39	12.04
1956	11,800	4.07188	0.35607		8	11.07	14.19
1942	10,100	4.00432	0.28851		9	12.75	16.35
1950	9,880	3.99475	0.27895		10	14.43	18.50
1930	9,100	3.95904	0.24323		11	16.12	20.67
1967	9,060	3.95713	0.24132		12	17.80	22.82
1932	7,820	3.89321	0.17740		13	19.48	24.97
1973	7,640	3.88309	0.16728		14	21.16	27.13
1962	7,480	3.87390	0.15809		15	22.84	29.28
1965	7,180	3.85612	0.14031		16	24.53	31.45
1936	6,740	3.82866	0.11285		17	26.21	33.60
1948	6,130	3.78746	0.07165		18	27.89	35.76
1939	5,940	3.77379	0.05798		19	29.57	37.91
1945	5,630	3.75051	0.03470		20	31.25	40.06
1934	5,580	3.74663	0.03082		21	32.94	42.23
1955	5,480	3.73878	0.02297		22	34.62	44.38
1944	5,340	3.72754	0.01173		23	36.30	46.54
1951	5,230	3.71850	0.00269		24	37.98	48.69
1957	5,150	3.71181	-0.00400		25	39.66	50.85
1971	5,080	3.70586	-0.00995		26	41.35	53.01
1953	5,000	3.69897	-0.01684	W = (H - Z)/N = (77 - 3)/(44) = 1.68182	27	43.03	55.17
1949	4,740	3.67578	-0.04003		28	44.71	57.32
1970	4,330	3.63649	-0.07932		29	46.39	59.47
1938	4,270	3.63043	-0.08538		30	48.07	61.62
1952	4,260	3.62941	-0.08640		31	49.76	63.79
1947	3,980	3.59988	-0.11593		32	51.44	65.95
1943	3,780	3.57749	-0.13832		33	53.12	68.10
1961	3,770	3.57634	-0.13947		34	54.80	70.25
1958	3,350	3.52504	-0.19077		35	56.49	72.42
1954	3,320	3.52114	-0.19467		36	58.17	74.58
1933	3,220	3.50786	-0.20795		37	59.85	76.73
1964	3,100	3.49136	-0.22445		38	61.53	78.88
1968	3,080	3.48855	-0.22725		39	63.21	81.04
1969	2,800	3.44716	-0.26865		40	64.90	83.21
1963	2,740	3.43775	-0.27806		41	66.58	85.36
1959	2,400	3.38021	-0.33560		42	68.26	87.51
1931	2,060	3.31387	-0.40194		43	69.94	89.67
1966	1,920	3.28330	-0.43251		44	71.62	91.82
1940	1,680	3.22531	-0.49050		45	73.31	93.99
1960	1,460	3.16435	-0.55146		46	74.99	96.14
1941	1,200	3.07918	-0.63663	1.68182	47	76.67	98.29

*

Figure 6-1. HISTORICALLY WEIGHTED LOG PEARSON-TYPE III - ANNUAL PEAKS (Continued)

Solving (Eq. 6-2a)

$\Sigma X = 162.40155$

$W \Sigma X = 273.13018$

$\Sigma X_z = \underline{12.98733}$

286.11751

$\underline{\tilde{M}} = 286.11751/77 = \underline{3.71581}$

Solving (Eq. 6-3a)

$\Sigma x^2 = 3.09755$

$W \Sigma x^2 = 5.20952$

$\Sigma x_z^2 = \underline{1.13705}$

6.34657

$\tilde{S}^2 = 6.34657/(77 - 1) = 0.08351$

$\underline{\tilde{S}} = \underline{0.28898}$ $\tilde{S}^3 = 0.02413$

Solving (Eq. 6-4a)

$\Sigma x^3 = -0.37648$

$W \Sigma x^3 = -0.63317$

$\Sigma x_z^3 = \underline{0.70802}$

0.07485

$$\tilde{G} = \frac{(77)\ (0.07485)}{(76)\ (75)\ (0.02413)} = \underline{0.0418}$$

Solving (Eq. 6, Page 13)

N = 77

A = -0.33 + 0.08 (0.0418) = -0.32666

B = 0.94 - 0.26 (0.0418) = 0.92913

$$MSE_G = 10^{[-0.32666\ -\ 0.92913[0.88649]]} = 10^{[-1.150325]} = 0.07074$$

Solving (Eq. 9.5, Page 12)

$$G_w = \frac{0.302(0.0418) + 0.07074(-0.2)}{.302 + 0.07074} = -0.00409$$

Solving (Eq. 6-5)

%	K $G_w = -0.00409$	(S) (K) $\tilde{S} = .28898$	$\tilde{M} + (\tilde{S})$ (K) = Log Q $\tilde{M} = 3.71581$	Q (ft^3/s)
99	-2.32934	-0.67313	3.04269	1,103
95	-1.64599	-0.47566	3.24014	1,738
90	-1.28196	-0.37046	3.34535	2,215
80	-0.84141	-0.24315	3.47266	2,969
50	0.00067	0.00019	3.71600	5,200
20	0.84180	0.24326	3.95907	9,100
10	1.28110	0.37021	4.08602	12,190
4	1.74929	0.50551	4.22132	16,646
2	2.05159	0.59289	4.30868	20,355
1	2.32340	0.67142	4.38723	24,391
.1	3.08455	0.89138	4.60719	40,475
.01	3.71054	1.07227	4.78808	61,387

Solving (Eq. 6-6)

Z = 3

For E = 1; $\tilde{m}$ = E = 1

For E = 2; $\tilde{m}$ = E = 2

For E = 3; $\tilde{m}$ = E = 3

Solving (Eq. 6-8)

For Weibull: a = 0. $\tilde{PP} = (100)\ (\tilde{m})/(78)$

Solving (Eq. 6-7)

(Z + 1) = 4

(Z + N) = 47

For $4 \leq E \leq 47$:

$\tilde{m} = (1.682)\ (E) - (0.682)\ (3.5)$

$\tilde{m} = (1.682)\ (E) - 2.387$

*

*

Figure 6-2. HISTORICALLY WEIGHTED LOG-PEARSON TYPE III - ANNUAL PEAKS

Results of Standard Computation for the Current Continuous Record

Big Sandy River at Bruceton, TN. DA - 205 square miles
#3-6065 (44 years)

N = number of observations used = 44

M = mean of logarithms = 3.69094

S = standard deviation of logarithms = 0.26721

$S^2 = 0.07140 \quad S^3 = 0.01908$

G = coefficient of skewness (logs) = -0.18746

Adjustment to Historically Weighted 77 Years

Historic Peaks (Z = 3 Years)					
Year	Y_z (ft^3/s)	Log $Y_z = X_z$	$X_z - \tilde{M}$	$(X_z - \tilde{M})^2$	$(X_z - \tilde{M})^3$
1897	25,000	4.39794	0.68213	0.46531	0.31740
1919	21,000	4.32222	0.60641	0.36774	0.22300
1927	18,500	4.26717	0.55136	0.30400	0.16762
Summation		12.98733	1.83990	1.13705	0.70802

N = 44 Z = 3 H = 77

Solving (Eq. 6-1): W = (77-3)/44 = 1.68182

Solving (Eq. 6-2b): $\tilde{M} = \dfrac{(1.68182)\ (44)\ (3.69094) + (12.98733)}{77} = 3.71581$

Solving (Eq. 6-3b):

$(M - \tilde{M}) = -0.02487;\ (M - \tilde{M})^2 = 0.000619;\ (M - \tilde{M})^3 = -0.0000154$

$\tilde{S}^2 = \dfrac{(1.68182)(43)(0.07140) + (1.68182)(44)(0.000619) + (1.13705)}{76} = 0.08351$

$\tilde{S}^2 = 0.08351 \qquad \tilde{S} = 0.28898 \qquad \tilde{S}^3 = 0.02413$

Solving (Eq. 6-4b):

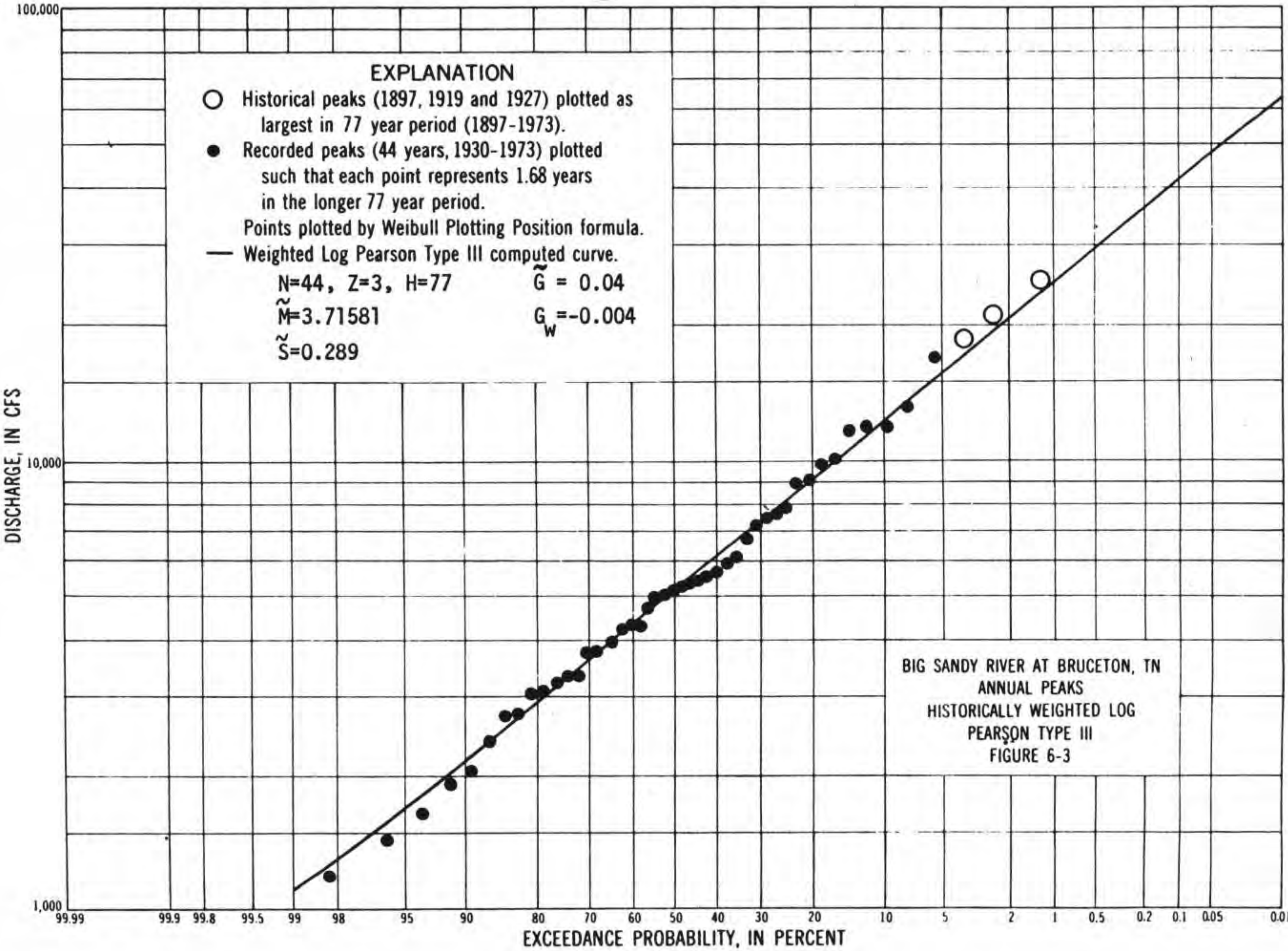
$\tilde{G} = \dfrac{77}{(76)\ (75)\ (0.02413)} \left[\dfrac{(1.68182)\ (43)\ (42)\ (0.01908)\ (-0.18746)}{44} + \right.$

$\left. (3)(1.68182)(43)(-0.02487)(0.07140) + (1.68182)(44)(-0.0000154) + (0.70802) \right]$

$\tilde{G} = 0.0418$

*

final step: wt. with generalized skew


EXPLANATION
Historical peaks (1897, 1919 and 1927) plotted as largest in 77 year period (1897-1973).
Recorded peaks (44 years, 1930-1973) plotted such that each point represents 1.68 years in the longer 77 year period.
Points plotted by Weibull Plotting Position formula.
Weighted Log Pearson Type III computed curve.
N=44, Z=3, H=77
$\tilde{M}$=3.71581
$\tilde{S}$=0.289
$\tilde{G}$ = 0.04
G_W=-0.004
BIG SANDY RIVER AT BRUCETON, TN
ANNUAL PEAKS
HISTORICALLY WEIGHTED LOG
PEARSON TYPE III
FIGURE 6-3
DISCHARGE, IN CFS
100,000
10,000
1,000
99.99
99.9
99.8
99.5
99
98
95
90
80
70
60
50
40
30
20
10
5
2
1
0.5
0.2
0.1
0.05
0.01
EXCEEDANCE PROBABILITY, IN PERCENT