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June 17, 2009

ATTN: Document Control Desk
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

BELL BEND NUCLEAR POWER PLANT
SUBMITTAL OF ADDITIONAL INFORMATION
BNP-2009-123 Docket No. 52-039

The purpose of this letter is to provide calculation packages and a site drawing that were reviewed by the NRC staff during the Hydrology Audit conducted for the Bell Bend Nuclear Power Plant (BBNPP) in May 2008 and were identified in the respective draft Requests for Additional Information.

The calculation packages and provided drawing are:

1. Low Flow Recurrence Interval and Low Flow Statistics, Rizzo and Associates, dated March 31, 2008 – (Draft Request for Information No. 16 (RAI No. 16) - RHEB-2856, Question 02.04.11-1)
2. ESWEMS Retention Pond Sizing, Project 161642, Black and Veatch, dated June 26, 2008 – (Draft Request for Information No. 16 (RAI No. 16) - RHEB-2856, Question 02.04.11-1 and Draft Request for Information No. 23 (RAI No. 23) – RHEB - 2853, Question 02.04.08-1(3))
3. Plant Arrangement ESWEMS Pond Section and Details Drawing 161642-1EMS-S1102, Revision 1, Project 161642, Black and Veatch, Issue Date May 28, 2009 – (Draft Request for Information No. 23 (RAI No. 23) – RHEB -2853, Question 02.04.08-1 (a))

If you have any questions or need additional information, please contact the undersigned at 570.802.8102.

I declare under penalty of perjury that the foregoing is true and correct.

Executed on June 17, 2009

Respectfully,

Rocco R. Sgarro

Enclosures: As stated

RRS/jf

D079
NRO

cc: (w/o Enclosures)

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Purpose:

1. Develop a frequency distribution (or determine the recurrence interval) of low flow events, which could potentially have an adverse impact on the Bell Bend site, based on historic USGS daily flow data recorded at the Wilkes-Barre and Danville gage stations along the Susquehanna River (immediately upstream and downstream from the site, respectively).

2. Estimate low flow statistics $Q_{1,10}$, $Q_{7,10}$, and $Q_{30,10}$ based on historical USGS flow data recorded at Wilkes-Barre and Danville gage stations.

3. Low flow statistics including the $Q_{1,10}$, $Q_{7,10}$, and $Q_{30,10}$ will also be transferred from the upstream and downstream gages to the ungaged site using drainage area ratios (DA_{site}/DA_{gage}) as suggested by the USGS and PaDEP. These analyses will estimate both the recurrence interval and impact of localized drought events.

Assumptions:

When transferring the low flow statistics ($Q_{1,10}$, $Q_{7,10}$, and $Q_{30,10}$) from the upstream and downstream gages to the ungaged site, the following assumptions were made:

- The ungaged drainage area at the site is hydrologically similar to the upstream and downstream gage drainage areas at Wilkes-Barre and Danville, respectively.

- Multiplying any gage low flow statistic by the associated drainage area ratio provides a good estimate of that particular statistic across the site drainage area so long as the drainage area ratio is within the maximum suggested range of 1/3 to 3 as suggested by the USGS and PaDEP (see ***Reference 3***).

Methodology:

Low flow recurrence intervals will be estimated using three (3) different frequency distribution techniques: Weilbull, Gumbel, and log Pearson Type III. Low flow statistics calculated at the upstream and downstream gage stations will be transferred to the site using drainage area ratios as proposed by the USGS and PaDEP (see ***Reference 3***).

Input:

USGS daily streamflow data for Wilkes-Barre (USGS 01536500) and Danville (USGS 01540500) gage stations.

References:

USGS Streamflow Data Website: http://waterdata.usgs.gov/, date accessed: 3/19/2008, daily streamflow data for Wilkes-Barre (USGS 01536500) and Danville (USGS 01540500) gage stations.

Linsley, Ray K., J.B. Franzini, D.L. Freyberg, and G. Tchobanoglous, 1992, "Probability Concepts in Planning," Water-Resources Engineering, B.J. Clark and E. Castellano, ed., 4th ed., McGraw-Hill, Inc., New York, pp. 140-144 and pp. 808-809 (Table A-5). (Attached as "***Reference 1***")

SSES NPP FSAR Report, Rev. 46, Figure 2.4-6, 06/93. (Attached as "***Reference 2***")

"Computing Low-Flow Statistics for Ungaged Locations on Pennsylvania Streams By Use of Drainage-Area Ratios," http://pa.water.usgs.gov/pc38/flowstats/revised_deplowflow.pdf, date accessed: 3/27/2008. (Attached as "***Reference 3***")

Electronic File Locations:

G:\DJW\Berwick NPP (07-3891)\FSAR 2.4.11 (Water Resources)\Wilkes-Barre_River_Data
G:\DJW\Berwick NPP (07-3891)\FSAR 2.4.11 (Water Resources)\Wilkes-Barre Daily Flow Data
G:\DJW\Berwick NPP (07-3891)\FSAR 2.4.11 (Water Resources)\Danville_River_Data
G:\DJW\Berwick NPP (07-3891)\FSAR 2.4.11 (Water Resources)\Danville Daily Flow Data

Calculations:

1. Low Flow Frequency Distributions

   All of the frequency distribution techniques that are developed in this calculation to estimate the recurrence intervals associated with low flow events at each gage station are more commonly used to estimate flood event frequencies. However, by adjusting the procedure slightly to accommodate for low flow events when calculating the Weilbull recurrence intervals to establish an estimated frequency distribution, and by calculating the probability that the flow is *less than* (as opposed to greater than or equal to) a flow event of a given magnitude (instead of solving for P, solving for 1 – P) when developing the other frequency distributions, all three (3) methods can be used effectively to estimate the frequencies of low flow events.

   a. Weilbull Frequency Distribution:

      When considering all three distribution methods being used to conduct this low flow frequency analysis, the Weilbull distribution has the most basic approach when it comes to estimating low flow recurrence intervals. Annual low flows taken from

USGS daily flow data are simply arranged in ascending order based on their magnitude with the lowest flow on record being first, and the recurrence interval is calculated based on how the low flow ranks among all other flows within the period of record. The Weilbull formula for recurrence interval estimation is given below, and the calculated return periods corresponding to the low flows recorded at each gage station (Wilkes-Barre and Danville) can be found in ***Attachment A***. For additional information regarding this approach, see ***Reference 1***. Note that the Weilbull procedure described above has been adjusted for low flow; the procedure given in ***Reference 1*** is for peak flow.

$$P := \frac{1}{T_r} \qquad \text{(Equation 1)}$$

$$T_r := \frac{N+1}{m} \qquad \text{(Equation 2)}$$

P = probability of occurrence.
N = period of record.
m = *m*th smallest flow in data series.
T_r = recurrence interval.

b. Gumbel Frequency Distribution:

Developed under the argument that the distribution of flows within a given area is unlimited, the Gumbel distribution incorporates more advanced statistical applications in its projection of recurrence intervals for various low flow events. The probability of a flow of lesser magnitude occurring is calculated based on a factor "b" as shown in the equations below, and the corresponding recurrence interval is taken as the inverse of the probability of occurrence ($T_r = 1 / P$). The frequency calculations made using the Gumbel approach can be found in ***Attachment A***; for any additional information consult ***Reference 1***. Note that Equation 2 has been adjusted for low flow; the equation given in ***Reference 1*** is for peak flow (probability that a flow of equal or greater magnitude occurs).

$$P := 1 - \left(1 - e^{-e^{-b}}\right) \qquad \text{(Equation 3)}$$

$$b := \frac{1}{0.7797 \cdot \sigma_X} \cdot \left(X - X_{bar} + 0.45 \cdot \sigma_X\right) \qquad \text{(Equation 4)}$$

$$\sigma_x := \left(\frac{\Sigma (X - X_{bar})^2}{N - 1} \right)^{\frac{1}{2}}$$ (Equation 5)

P = probability of occurrence.
X = flood magnitude in cfs.
X_{bar} = average flood magnitude from data series in cfs.
σ_x = standard deviation of annual low flows from data series.

c. Log Pearson Type III Frequency Distribution

Adopted by the U.S. Water Resources Council in 1967 as a standard for use by federal agencies, the log Pearson Type III procedure converts the series of USGS gage station data for annual low flow to logarithms and computes the mean, standard deviation, and skew coefficient (*g*).

$$g_{skew} := \frac{N \cdot \Sigma (X_{log} - X_{log\_bar})^3}{(N - 1) \cdot (N - 2) \cdot (\sigma_{log\_x})^3}$$ (Equation 6)

$$\sigma_{log\_x} := \left(\frac{\Sigma (X_{log} - X_{log\_bar})^2}{N - 1} \right)^{\frac{1}{2}}$$ (Equation 7)

N = period of record.
g_{skew} = skew coefficient.
X_{log} = log X.
X_{log_bar} = average "log X" from data series.
σ_{log_x} = standard deviation of "log X" from data series.

To construct the frequency distribution for the two gage stations, values for the frequency factor K were interpolated from Table A-5 (see ***Reference 1***) at various recurrence intervals (2, 10, 25, 50, 100, and 200 years) for the computed value of *g*. The flow (X) was then estimated for each return period using the following equation:

$$X_{log} := X_{log\_bar} + K \cdot \sigma_{log\_x} \quad \text{(Equation 8)}$$

K = value from Table A-5 (see ***Reference 1***, used linear interpolation based on calculated skew coefficient from data series).

Remember that the probability (P) corresponding to these estimated flows is of a flow of equal or greater magnitude occurring based on the given data series. Therefore, the probability of occurrence of a flow *lower than* the estimated flow (X) can be expressed as 1 – P. This probability is then plotted against flow to develop the low flow frequency distribution. Plots comparing the three (3) calculated frequency distributions, as well as the extrapolation of log Pearson Type III distributions at the Wilkes-Barre and Danville gage stations, can be found in ***Attachment B***. For more information about the log Pearson Type III distribution method, consult ***Reference 1.***

2. Site Low Flow Statistics

Low flow statistics including the 1-day 10-year low flow ($Q_{1,10}$: low stream flow over 1 day which, on a statistical basis, can be expected to occur once every 10 years), 7-day 10-year low flow ($Q_{7,10}$: low stream flow over 7 consecutive days which, on a statistical basis, can be expected to occur once every 10 years), and 30-day 10-year low flow ($Q_{30,10}$: low stream flow over 30 consecutive days which, on a statistical basis, can be expected to occur once every 10 years) were calculated for the Wilkes-Barre and Danville gage stations on the Susquehanna River using USGS daily flow data from water years 1906 through 2006. The overall mean, median and harmonic mean were also calculated at each station. Upstream and downstream low flow statistics ($Q_{1,10}$, $Q_{7,10}$, and $Q_{30,10}$) were transferred to the site using drainage area ratios (DA_{site}/DA_{gage}) as suggested by the USGS and PaDEP (see ***Reference 3***). The upstream and downstream gage drainage areas are measured by the USGS as follows: DA_{ug} = 9,960 square miles and DA_{dg} = 11,220 square miles, respectively. The impact point drainage area (DA_{ip}), or site drainage area, is taken as 10,200 square miles (***Reference 2***). All calculated statistics are summarized in ***Table 2.***

Results:

1. Low Flow Frequency Distributions

The extended tables showing all calculations can be found in ***Attachment A***; plots comparing the three (3) calculated frequency distributions, as well as the extrapolation of log Pearson Type III distributions at the Wilkes-Barre and Danville gage stations, can be found in ***Attachment B***. The table below summarizes the recurrence intervals calculated for the lowest on record flow at each gage station.

TABLE 1 – ESTIMATED RECURRENCE INTERVALS

Gage Station	Water Year of Low Flow Event	Flow [cfs]	Estimated Recurrence Interval		
			Weilbull T_r [yr]	Gumbel T_r [yr]	Log Pearson Type III T_r* [yr]
Wilkes-Barre	1964	532	109	33	4
Danville	1964	558	102	87	4

*T_r estimated using power trentline with $R^2<0.90$ at each gage station (see ***Attachment B***).

2. Site Low Flow Statistics

All low flow statistics are summarized in the table below.

TABLE 2 – SUMMARY OF LOW FLOW STATISTICS

Gage Station	Drainage Area [mi^2]	Period of Record	$Q_{1,10}$ [cfs]	$Q_{7,10}$ [cfs]	$Q_{30,10}$ [cfs]	Mean [cfs]	Median [cfs]	Harmonic Mean [cfs]
Wilkes-Barre (upstream)	9,960	1906 - 2006	799	850	1,032	13,606	7,390	4,283
Danville (downstream)	11,220	1906 - 2006	945	1,017	1,284	15,501	8,770	5,262
Site (using upstream gage)	10,200	-	818	870	1,056	-	-	-
Site (using downstream gage)	10,200	-	859	924	1,167	-	-	-

Excel worksheets showing the calculations of all low flow statistics, along with the USGS daily flow data that was used for analysis at each gage station, can be found in the following file locations:

G:\DJW\Berwick NPP (07-3891)\FSAR 2.4.11 (Water Resources)\Wilkes-Barre Daily Flow Data
G:\DJW\Berwick NPP (07-3891)\FSAR 2.4.11 (Water Resources)\Danville Daily Flow Data

Conclusions:

The safety of the BBNPP site can be evaluated further now that the recurrence interval and impact associated with various low flow events have been estimated.

Attachment A

Calculated Low Flow Frequency Distributions (Weilbull, Gumbel, and Log Pearson Type III) for Wilkes-Barre and Danville USGS Gage Stations

G:\DJW\Berwick NPP (07-3891)\FSAR 2.4.11 (Water Resources)\Wilkes-Barre_River_Data
G:\DJW\Berwick NPP (07-3891)\FSAR 2.4.11 (Water Resources)\Danville_River_Data

Low Flow Probability Distribution Formulas

The Weilbull, Gumbel, and Log Pearson Type III distribution methods are commonly used to determine the probability of a flood event occurence. However, the same models can be used for low flow by solving for the probability that the flow is *less than*, as opposed to greater than or equal to, a flow event of a given magnitude (instead of solving for P, solve for 1 - P).

Weilbull Distribution:

$$P := \frac{1}{T_r} \quad \text{(Equation 1)}$$

$$T_r := \frac{N+1}{m} \quad \text{(Equation 2)}$$

P = probability of occurrence.
N = period of record.
m = *m*th smallest flow in data series.
T_r = recurrence interval.

Gumbel Distribution:

$$P := 1 - \left(1 - e^{-e^{-b}}\right) \quad \text{(Equation 3)}$$

$$b := \frac{1}{0.7797 \cdot \sigma_x} \cdot \left(X - X_{bar} + 0.45 \cdot \sigma_x\right) \quad \text{(Equation 4)}$$

G:\DJW\Berwick NPP (07-3891)\FSAR 2.4.11 (Water Resources)\Wilkes-Barre_River_Data
G:\DJW\Berwick NPP (07-3891)\FSAR 2.4.11 (Water Resources)\Danville_River_Data

$$\sigma_x := \left(\frac{\Sigma (X - X_{bar})^2}{N - 1} \right)^{\frac{1}{2}}$$ (Equation 5)

P = probability of occurrence.
X = flood magnitude in cfs.
X_{bar} = average flood magnitude from data series in cfs.
σ_x = standard deviation of annual low flows from data series.

log Pearson Type III Distribution:

$$g_{skew} := \frac{N \cdot \Sigma (X_{log} - X_{log\_bar})^3}{(N - 1) \cdot (N - 2) \cdot (\sigma_{log\_x})^3}$$ (Equation 6)

$$\sigma_{log\_x} := \left(\frac{\Sigma (X_{log} - X_{log\_bar})^2}{N - 1} \right)^{\frac{1}{2}}$$ (Equation 7)

N = period of record.
g_{skew} = skew coefficient.
X_{log} = log X.
X_{log_bar} = average "log X" from data series.
σ_{log_x} = standard deviation of "log X" from data series.

$$X_{log} := X_{log\_bar} + K \cdot \sigma_{log\_x} \qquad \text{(Equation 8)}$$

K = value from Table A-5 in text (see ***Reference 1***, used linear interpolation based on calculated skew coefficient from data series).

Developing the Log Pearson Type III Distribution for the low flow scenario follows the same appoach as for peak flow: calculate the skew coefficient based on the available gage station flow data, and using that value interpolate the corresponding frequency factor (K) at various recurrence intervals to develop a frequency distribution which can be used to estimate flow. Since the formulas and tables above that are used to develop this distribution were created to determine the probability of peak flow events (probability of occurence / recurrence interval of a flow of equal or greater magnitude), the probability of the estimated flow that is of intrest for low flow analysis is instead the probability that a flow of lower magnitude occurs. Therefore, the distribution is created by plotting the estimated flow against the recurrence interval, which is calculated using 1 - P for probability as opposed to P.

*Text Reference: "Water-Resources Engineering," McGraw-Hill, Fourth Edition. (Chapter 5: Probability Concepts in Planning)

Low Flow Frequency Distributions (Weilbull and Gumbel) for Wilkes-Barre Gage Station

*Calculations based on complete USGS gage station data taken from 1899 to 2006.

N= 108

	Gage Station Data (Wilkes-Barre)			Weilbull Distribution		Gumbel Distribution				
m	Low Flow, 1000 cfs	Low Flow (X), cfs	Year	Weilbull T_r (yr)	P	$X - X_{bar}$	$(X - X_{bar})^2$	b	P	Gumbel T_r (yr)
1	0.53	532	1964	109.0	0.0092	-888	788,051	-1.25	0.0302	33
2	0.63	625	1939	54.5	0.0183	-795	631,583	-1.06	0.0557	18
3	0.66	658	1941	36.3	0.0275	-762	580,221	-0.99	0.0673	15
4	0.69	686	1962	27.3	0.0367	-734	538,348	-0.93	0.0783	13
5	0.70	700	1963	21.8	0.0459	-720	518,000	-0.91	0.0842	12
6	0.72	720	1900	18.2	0.0550	-700	489,611	-0.86	0.0930	11
7	0.72	720	1955	15.6	0.0642	-700	489,611	-0.86	0.0930	11
8	0.75	749	1999	13.6	0.0734	-671	449,868	-0.81	0.1068	9
9	0.76	760	1908	12.1	0.0826	-660	435,233	-0.78	0.1123	9
10	0.78	779	1959	10.9	0.0917	-641	410,525	-0.74	0.1221	8
11	0.78	780	1953	9.9	0.1009	-640	409,245	-0.74	0.1226	8
12	0.80	795	1991	9.1	0.1101	-625	390,278	-0.71	0.1307	8
13	0.81	810	1911	8.4	0.1193	-610	371,761	-0.68	0.1391	7
14	0.82	815	1965	7.8	0.1284	-605	365,689	-0.67	0.1419	7
15	0.82	820	1899	7.3	0.1376	-600	359,667	-0.66	0.1448	7
16	0.82	820	1913	6.8	0.1468	-600	359,667	-0.66	0.1448	7
17	0.83	831	1995	6.4	0.1560	-589	346,594	-0.64	0.1512	7
18	0.86	860	1910	6.1	0.1651	-560	313,289	-0.58	0.1687	6
19	0.87	871	1966	5.7	0.1743	-549	301,096	-0.55	0.1756	6
20	0.89	887	1985	5.5	0.1835	-533	283,793	-0.52	0.1858	5
21	0.89	892	1954	5.2	0.1927	-528	278,491	-0.51	0.1890	5
22	0.89	893	1912	5.0	0.2018	-527	277,436	-0.51	0.1896	5

PAUL C. RIZZO ASSOCIATES, INC.
CONSULTANTS

By DW Date 3/31/2008 Subject Low Flow Recurrence Interval and Low Flow Statistics (BBNPP) Sheet No. A6 of A27
Chkd.By FAM Date 04-30-08 Project No. 07-3891

*Calculations based on complete USGS gage station data taken from 1899 to 2006.

N= 108

	Gage Station Data (Wilkes-Barre)			Weilbull Distribution		Gumbel Distribution				
m	Low Flow, 1000 cfs	Low Flow (X), cfs	Year	Weilbull T_r (yr)	P	$X - X_{bar}$	$(X - X_{bar})^2$	b	P	Gumbel T_r (yr)
23	0.92	924	2002	4.7	0.2110	-496	245,741	-0.44	0.2102	5
24	0.93	932	1932	4.5	0.2202	-488	237,873	-0.43	0.2156	5
25	0.95	951	1918	4.4	0.2294	-469	219,701	-0.39	0.2287	4
26	0.97	970	1907	4.2	0.2385	-450	202,250	-0.35	0.2420	4
27	0.97	970	1909	4.0	0.2477	-450	202,250	-0.35	0.2420	4
28	0.97	970	1930	3.9	0.2569	-450	202,250	-0.35	0.2420	4
29	0.98	980	1983	3.8	0.2661	-440	193,356	-0.33	0.2492	4
30	1.00	1,000	1929	3.6	0.2752	-420	176,167	-0.29	0.2635	4
31	1.01	1,010	1943	3.5	0.2844	-410	167,872	-0.27	0.2708	4
32	1.01	1,010	1949	3.4	0.2936	-410	167,872	-0.27	0.2708	4
33	1.02	1,020	1980	3.3	0.3028	-400	159,778	-0.25	0.2781	4
34	1.05	1,050	1906	3.2	0.3119	-370	136,695	-0.18	0.3003	3
35	1.05	1,050	1982	3.1	0.3211	-370	136,695	-0.18	0.3003	3
36	1.05	1,050	2005	3.0	0.3303	-370	136,695	-0.18	0.3003	3
37	1.06	1,060	1917	2.9	0.3394	-360	129,400	-0.16	0.3078	3
38	1.06	1,060	1923	2.9	0.3486	-360	129,400	-0.16	0.3078	3
39	1.06	1,060	1948	2.8	0.3578	-360	129,400	-0.16	0.3078	3
40	1.06	1,060	1957	2.7	0.3670	-360	129,400	-0.16	0.3078	3
41	1.06	1,060	1988	2.7	0.3761	-360	129,400	-0.16	0.3078	3
42	1.08	1,080	1931	2.6	0.3853	-340	115,411	-0.12	0.3228	3
43	1.09	1,090	1969	2.5	0.3945	-330	108,717	-0.10	0.3303	3
44	1.10	1,100	2001	2.5	0.4037	-320	102,222	-0.08	0.3378	3
45	1.15	1,150	1936	2.4	0.4128	-270	72,750	0.02	0.3757	3
46	1.15	1,150	1944	2.4	0.4220	-270	72,750	0.02	0.3757	3
47	1.16	1,160	1916	2.3	0.4312	-260	67,456	0.04	0.3833	3
48	1.19	1,190	1989	2.3	0.4404	-230	52,772	0.10	0.4060	2

G:\DJW\Berwick NPP (07-3891)\FSAR 2.4.11 (Water Resources)\Wilkes-Barre_River_Data
G:\DJW\Berwick NPP (07-3891)\FSAR 2.4.11 (Water Resources)\Danville_River_Data

*Calculations based on complete USGS gage station data taken from 1899 to 2006.

N= 108

	Gage Station Data (Wilkes-Barre)			Weilbull Distribution		Gumbel Distribution				
m	Low Flow, 1000 cfs	Low Flow (X), cfs	Year	Weilbull T_r (yr)	P	$X - X_{bar}$	$(X - X_{bar})^2$	b	P	Gumbel T_r (yr)
49	1.20	1,200	1934	2.2	0.4495	-220	48,278	0.12	0.4135	2
50	1.21	1,210	1993	2.2	0.4587	-210	43,983	0.14	0.4210	2
51	1.25	1,250	1914	2.1	0.4679	-170	28,806	0.23	0.4508	2
52	1.26	1,260	1987	2.1	0.4771	-160	25,511	0.25	0.4582	2
53	1.28	1,280	1961	2.1	0.4862	-140	19,522	0.29	0.4729	2
54	1.28	1,280	1981	2.0	0.4954	-140	19,522	0.29	0.4729	2
55	1.32	1,320	1952	2.0	0.5046	-100	9,945	0.37	0.5018	2
56	1.33	1,330	1921	1.9	0.5138	-90	8,050	0.39	0.5089	2
57	1.33	1,330	1970	1.9	0.5229	-90	8,050	0.39	0.5089	2
58	1.34	1,340	1933	1.9	0.5321	-80	6,356	0.41	0.5159	2
59	1.35	1,350	1928	1.8	0.5413	-70	4,861	0.43	0.5230	2
60	1.38	1,380	1926	1.8	0.5505	-40	1,578	0.50	0.5437	2
61	1.39	1,390	1951	1.8	0.5596	-30	883	0.52	0.5505	2
62	1.44	1,440	1960	1.8	0.5688	20	411	0.62	0.5836	2
63	1.44	1,440	1997	1.7	0.5780	20	411	0.62	0.5836	2
64	1.45	1,450	1971	1.7	0.5872	30	917	0.64	0.5901	2
65	1.46	1,460	1940	1.7	0.5963	40	1,622	0.66	0.5964	2
66	1.47	1,470	1979	1.7	0.6055	50	2,528	0.68	0.6028	2
67	1.49	1,490	1915	1.6	0.6147	70	4,939	0.72	0.6152	2
68	1.50	1,500	1919	1.6	0.6239	80	6,445	0.74	0.6213	2
69	1.50	1,500	1947	1.6	0.6330	80	6,445	0.74	0.6213	2
70	1.50	1,500	1972	1.6	0.6422	80	6,445	0.74	0.6213	2
71	1.50	1,500	1998	1.5	0.6514	80	6,445	0.74	0.6213	2
72	1.51	1,510	1968	1.5	0.6606	90	8,150	0.76	0.6274	2
73	1.52	1,520	1978	1.5	0.6697	100	10,056	0.78	0.6334	2
74	1.57	1,570	1984	1.5	0.6789	150	22,583	0.89	0.6624	2

*Calculations based on complete USGS gage station data taken from 1899 to 2006.

N= 108

	Gage Station Data (Wilkes-Barre)			Weilbull Distribution		Gumbel Distribution				
m	Low Flow, 1000 cfs	Low Flow (X), cfs	Year	Weilbull T_r (yr)	P	$X - X_{bar}$	$(X - X_{bar})^2$	b	P	Gumbel T_r (yr)
75	1.58	1,580	1938	1.5	0.6881	160	25,689	0.91	0.6679	1
76	1.60	1,600	1927	1.4	0.6972	180	32,500	0.95	0.6789	1
77	1.61	1,610	1922	1.4	0.7064	190	36,206	0.97	0.6843	1
78	1.66	1,660	1935	1.4	0.7156	240	57,733	1.07	0.7102	1
79	1.66	1,660	1974	1.4	0.7248	240	57,733	1.07	0.7102	1
80	1.67	1,670	1924	1.4	0.7339	250	62,639	1.09	0.7152	1
81	1.70	1,700	1958	1.3	0.7431	280	78,556	1.15	0.7297	1
82	1.74	1,740	1925	1.3	0.7523	320	102,578	1.24	0.7481	1
83	1.76	1,760	1956	1.3	0.7615	340	115,789	1.28	0.7569	1
84	1.76	1,760	1986	1.3	0.7706	340	115,789	1.28	0.7569	1
85	1.81	1,810	1901	1.3	0.7798	390	152,317	1.38	0.7779	1
86	1.81	1,810	1903	1.3	0.7890	390	152,317	1.38	0.7779	1
87	1.84	1,840	1973	1.3	0.7982	420	176,633	1.44	0.7897	1
88	1.85	1,850	1946	1.2	0.8073	430	185,139	1.46	0.7935	1
89	1.85	1,850	1950	1.2	0.8165	430	185,139	1.46	0.7935	1
90	1.85	1,850	1977	1.2	0.8257	430	185,139	1.46	0.7935	1
91	1.88	1,880	1937	1.2	0.8349	460	211,856	1.53	0.8046	1
92	1.90	1,900	1975	1.2	0.8440	480	230,667	1.57	0.8117	1
93	1.95	1,950	1996	1.2	0.8532	530	281,195	1.67	0.8284	1
94	2.00	2,000	1902	1.2	0.8624	580	336,722	1.77	0.8438	1
95	2.20	2,200	1904	1.1	0.8716	780	608,833	2.19	0.8936	1
96	2.26	2,260	1942	1.1	0.8807	840	706,067	2.31	0.9054	1
97	2.26	2,260	1990	1.1	0.8899	840	706,067	2.31	0.9054	1
98	2.28	2,280	2000	1.1	0.8991	860	740,078	2.35	0.9090	1
99	2.29	2,290	1920	1.1	0.9083	870	757,383	2.37	0.9108	1
100	2.29	2,290	1992	1.1	0.9174	870	757,383	2.37	0.9108	1

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*Calculations based on complete USGS gage station data taken from 1899 to 2006.

N= 108

	Gage Station Data (Wilkes-Barre)			Weilbull Distribution		Gumbel Distribution				
m	Low Flow, 1000 cfs	Low Flow (X), cfs	Year	Weilbull T_r (yr)	P	$X - X_{bar}$	$(X - X_{bar})^2$	b	P	Gumbel T_r (yr)
101	2.50	2,500	1967	1.1	0.9266	1,080	1,167,000	2.80	0.9412	1
102	2.62	2,620	1905	1.1	0.9358	1,200	1,440,667	3.05	0.9538	1
103	2.71	2,710	1945	1.1	0.9450	1,290	1,664,817	3.24	0.9615	1
104	2.83	2,830	2004	1.0	0.9541	1,410	1,988,883	3.48	0.9698	1
105	2.90	2,900	1994	1.0	0.9633	1,480	2,191,222	3.63	0.9738	1
106	3.15	3,150	2006	1.0	0.9725	1,730	2,993,861	4.14	0.9843	1
107	3.58	3,580	2003	1.0	0.9817	2,160	4,666,800	5.03	0.9935	1
108	3.60	3,600	1976	1.0	0.9908	2,180	4,753,611	5.07	0.9937	1
Avg.=	X_{bar}=	1,420	-	-	-	-	-	-	-	-
Sum=	-	153,330	-	-	-	0	41,440,078	-	-	-

σ_x = 622.3

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Low Flow Frequency Distribution (log Pearson Type III) for Wilkes-Barre Gage Station

*Calculations based on complete USGS gage station data taken from 1899 to 2006.

N= 108

	Gage Station Data (Wilkes-Barre)			Log Pearson Type III Distribution										
m	Low Flow, 1000 cfs	Low Flow (X), cfs	Year	log X	(log X - (log X)$_{bar}$)	(log X - (log X)$_{bar}$)^2	(log X - (log X)$_{bar}$)^3	Skew Coefficient (g)	Selected T_r (yr)	P	1 - P	Low Flow T_r (yr)	K	Estimated Flow (X), cfs
1	0.53	532	1964	2.726	-0.390	0.152	-0.0592	0.3031	2	0.5	0.5	2.0000	-0.0505	1,279
2	0.63	625	1939	2.796	-0.320	0.102	-0.0327	-	10	0.1	0.9	1.1111	1.3092	2,218
3	0.66	658	1941	2.818	-0.297	0.089	-0.0263	-	25	0.04	0.96	1.0417	1.8500	2,761
4	0.69	686	1962	2.836	-0.279	0.078	-0.0218	-	50	0.02	0.98	1.0204	2.2126	3,197
5	0.70	700	1963	2.845	-0.271	0.073	-0.0198	-	100	0.01	0.99	1.0101	2.5462	3,660
6	0.72	720	1900	2.857	-0.258	0.067	-0.0173	-	200	0.005	0.995	1.0050	2.8589	4,154
7	0.72	720	1955	2.857	-0.258	0.067	-0.0173	-	-	-	-	-	-	-
8	0.75	749	1999	2.874	-0.241	0.058	-0.0140	-	-	-	-	-	-	-
9	0.76	760	1908	2.881	-0.235	0.055	-0.0130	-	-	-	-	-	-	-
10	0.78	779	1959	2.892	-0.224	0.050	-0.0113	-	-	-	-	-	-	-
11	0.78	780	1953	2.892	-0.224	0.050	-0.0112	-	-	-	-	-	-	-
12	0.80	795	1991	2.900	-0.215	0.046	-0.0100	-	-	-	-	-	-	-
13	0.81	810	1911	2.908	-0.207	0.043	-0.0089	-	-	-	-	-	-	-
14	0.82	815	1965	2.911	-0.205	0.042	-0.0086	-	-	-	-	-	-	-
15	0.82	820	1899	2.914	-0.202	0.041	-0.0082	-	-	-	-	-	-	-
16	0.82	820	1913	2.914	-0.202	0.041	-0.0082	-	-	-	-	-	-	-
17	0.83	831	1995	2.920	-0.196	0.038	-0.0075	-	-	-	-	-	-	-
18	0.86	860	1910	2.934	-0.181	0.033	-0.0060	-	-	-	-	-	-	-
19	0.87	871	1966	2.940	-0.176	0.031	-0.0054	-	-	-	-	-	-	-
20	0.89	887	1985	2.948	-0.168	0.028	-0.0047	-	-	-	-	-	-	-
21	0.89	892	1954	2.950	-0.165	0.027	-0.0045	-	-	-	-	-	-	-
22	0.89	893	1912	2.951	-0.165	0.027	-0.0045	-	-	-	-	-	-	-

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Chkd.By FAM Date 04-30-08 Project No. 07-3891

*Calculations based on complete USGS gage station data taken from 1899 to 2006.

N= 108

	Gage Station Data (Wilkes-Barre)			Log Pearson Type III Distribution										
m	Low Flow, 1000 cfs	Low Flow (X), cfs	Year	log X	(log X - (log X)$_{bar}$)	(log X - (log X)$_{bar}$)^2	(log X - (log X)$_{bar}$)^3	Skew Coefficient (g)	Selected T$_r$ (yr)	P	1 - P	Low Flow T$_r$ (yr)	K	Estimated Flow (X), cfs
23	0.92	924	2002	2.966	-0.150	0.023	-0.0034	-	-	-	-	-	-	-
24	0.93	932	1932	2.969	-0.146	0.021	-0.0031	-	-	-	-	-	-	-
25	0.95	951	1918	2.978	-0.138	0.019	-0.0026	-	-	-	-	-	-	-
26	0.97	970	1907	2.987	-0.129	0.017	-0.0021	-	-	-	-	-	-	-
27	0.97	970	1909	2.987	-0.129	0.017	-0.0021	-	-	-	-	-	-	-
28	0.97	970	1930	2.987	-0.129	0.017	-0.0021	-	-	-	-	-	-	-
29	0.98	980	1983	2.991	-0.124	0.016	-0.0019	-	-	-	-	-	-	-
30	1.00	1,000	1929	3.000	-0.116	0.013	-0.0015	-	-	-	-	-	-	-
31	1.01	1,010	1943	3.004	-0.111	0.012	-0.0014	-	-	-	-	-	-	-
32	1.01	1,010	1949	3.004	-0.111	0.012	-0.0014	-	-	-	-	-	-	-
33	1.02	1,020	1980	3.009	-0.107	0.011	-0.0012	-	-	-	-	-	-	-
34	1.05	1,050	1906	3.021	-0.095	0.009	-0.0008	-	-	-	-	-	-	-
35	1.05	1,050	1982	3.021	-0.095	0.009	-0.0008	-	-	-	-	-	-	-
36	1.05	1,050	2005	3.021	-0.095	0.009	-0.0008	-	-	-	-	-	-	-
37	1.06	1,060	1917	3.025	-0.090	0.008	-0.0007	-	-	-	-	-	-	-
38	1.06	1,060	1923	3.025	-0.090	0.008	-0.0007	-	-	-	-	-	-	-
39	1.06	1,060	1948	3.025	-0.090	0.008	-0.0007	-	-	-	-	-	-	-
40	1.06	1,060	1957	3.025	-0.090	0.008	-0.0007	-	-	-	-	-	-	-
41	1.06	1,060	1988	3.025	-0.090	0.008	-0.0007	-	-	-	-	-	-	-
42	1.08	1,080	1931	3.033	-0.082	0.007	-0.0006	-	-	-	-	-	-	-
43	1.09	1,090	1969	3.037	-0.078	0.006	-0.0005	-	-	-	-	-	-	-
44	1.10	1,100	2001	3.041	-0.074	0.006	-0.0004	-	-	-	-	-	-	-
45	1.15	1,150	1936	3.061	-0.055	0.003	-0.0002	-	-	-	-	-	-	-
46	1.15	1,150	1944	3.061	-0.055	0.003	-0.0002	-	-	-	-	-	-	-
47	1.16	1,160	1916	3.064	-0.051	0.003	-0.0001	-	-	-	-	-	-	-
48	1.19	1,190	1989	3.076	-0.040	0.002	-0.0001	-	-	-	-	-	-	-

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By DW Date 3/31/2008 Subject Low Flow Recurrence Interval and Low Flow Statistics (BBNPP) Sheet No. A12 of A27
Chkd.By FAM Date 04-30-08 Project No. 07-3891

*Calculations based on complete USGS gage station data taken from 1899 to 2006.

N= 108

	Gage Station Data (Wilkes-Barre)			Log Pearson Type III Distribution										
m	Low Flow, 1000 cfs	Low Flow (X), cfs	Year	log X	(log X - (log X)$_{bar}$)	(log X - (log X)$_{bar}$)^2	(log X - (log X)$_{bar}$)^3	Skew Coefficient (g)	Selected T_r (yr)	P	1 - P	Low Flow T_r (yr)	K	Estimated Flow (X), cfs
49	1.20	1,200	1934	3.079	-0.037	0.001	0.0000	-	-	-	-	-	-	-
50	1.21	1,210	1993	3.083	-0.033	0.001	0.0000	-	-	-	-	-	-	-
51	1.25	1,250	1914	3.097	-0.019	0.000	0.0000	-	-	-	-	-	-	-
52	1.26	1,260	1987	3.100	-0.015	0.000	0.0000	-	-	-	-	-	-	-
53	1.28	1,280	1961	3.107	-0.009	0.000	0.0000	-	-	-	-	-	-	-
54	1.28	1,280	1981	3.107	-0.009	0.000	0.0000	-	-	-	-	-	-	-
55	1.32	1,320	1952	3.121	0.005	0.000	0.0000	-	-	-	-	-	-	-
56	1.33	1,330	1921	3.124	0.008	0.000	0.0000	-	-	-	-	-	-	-
57	1.33	1,330	1970	3.124	0.008	0.000	0.0000	-	-	-	-	-	-	-
58	1.34	1,340	1933	3.127	0.011	0.000	0.0000	-	-	-	-	-	-	-
59	1.35	1,350	1928	3.130	0.015	0.000	0.0000	-	-	-	-	-	-	-
60	1.38	1,380	1926	3.140	0.024	0.001	0.0000	-	-	-	-	-	-	-
61	1.39	1,390	1951	3.143	0.027	0.001	0.0000	-	-	-	-	-	-	-
62	1.44	1,440	1960	3.158	0.043	0.002	0.0001	-	-	-	-	-	-	-
63	1.44	1,440	1997	3.158	0.043	0.002	0.0001	-	-	-	-	-	-	-
64	1.45	1,450	1971	3.161	0.046	0.002	0.0001	-	-	-	-	-	-	-
65	1.46	1,460	1940	3.164	0.049	0.002	0.0001	-	-	-	-	-	-	-
66	1.47	1,470	1979	3.167	0.052	0.003	0.0001	-	-	-	-	-	-	-
67	1.49	1,490	1915	3.173	0.057	0.003	0.0002	-	-	-	-	-	-	-
68	1.50	1,500	1919	3.176	0.060	0.004	0.0002	-	-	-	-	-	-	-
69	1.50	1,500	1947	3.176	0.060	0.004	0.0002	-	-	-	-	-	-	-
70	1.50	1,500	1972	3.176	0.060	0.004	0.0002	-	-	-	-	-	-	-
71	1.50	1,500	1998	3.176	0.060	0.004	0.0002	-	-	-	-	-	-	-
72	1.51	1,510	1968	3.179	0.063	0.004	0.0003	-	-	-	-	-	-	-
73	1.52	1,520	1978	3.182	0.066	0.004	0.0003	-	-	-	-	-	-	-
74	1.57	1,570	1984	3.196	0.080	0.006	0.0005	-	-	-	-	-	-	-

*Calculations based on complete USGS gage station data taken from 1899 to 2006.

N= 108

	Gage Station Data (Wilkes-Barre)			Log Pearson Type III Distribution										
m	Low Flow, 1000 cfs	Low Flow (X), cfs	Year	log X	(log X - (log X)$_{bar}$)	(log X - (log X)$_{bar}$)^2	(log X - (log X)$_{bar}$)^3	Skew Coefficient (g)	Selected T, (yr)	P	1 - P	Low Flow T, (yr)	K	Estimated Flow (X), cfs
75	1.58	1,580	1938	3.199	0.083	0.007	0.0006	-	-	-	-	-	-	-
76	1.60	1,600	1927	3.204	0.088	0.008	0.0007	-	-	-	-	-	-	-
77	1.61	1,610	1922	3.207	0.091	0.008	0.0008	-	-	-	-	-	-	-
78	1.66	1,660	1935	3.220	0.104	0.011	0.0011	-	-	-	-	-	-	-
79	1.66	1,660	1974	3.220	0.104	0.011	0.0011	-	-	-	-	-	-	-
80	1.67	1,670	1924	3.223	0.107	0.011	0.0012	-	-	-	-	-	-	-
81	1.70	1,700	1958	3.230	0.115	0.013	0.0015	-	-	-	-	-	-	-
82	1.74	1,740	1925	3.241	0.125	0.016	0.0019	-	-	-	-	-	-	-
83	1.76	1,760	1956	3.246	0.130	0.017	0.0022	-	-	-	-	-	-	-
84	1.76	1,760	1986	3.246	0.130	0.017	0.0022	-	-	-	-	-	-	-
85	1.81	1,810	1901	3.258	0.142	0.020	0.0029	-	-	-	-	-	-	-
86	1.81	1,810	1903	3.258	0.142	0.020	0.0029	-	-	-	-	-	-	-
87	1.84	1,840	1973	3.265	0.149	0.022	0.0033	-	-	-	-	-	-	-
88	1.85	1,850	1946	3.267	0.151	0.023	0.0035	-	-	-	-	-	-	-
89	1.85	1,850	1950	3.267	0.151	0.023	0.0035	-	-	-	-	-	-	-
90	1.85	1,850	1977	3.267	0.151	0.023	0.0035	-	-	-	-	-	-	-
91	1.88	1,880	1937	3.274	0.158	0.025	0.0040	-	-	-	-	-	-	-
92	1.90	1,900	1975	3.279	0.163	0.027	0.0043	-	-	-	-	-	-	-
93	1.95	1,950	1996	3.290	0.174	0.030	0.0053	-	-	-	-	-	-	-
94	2.00	2,000	1902	3.301	0.185	0.034	0.0064	-	-	-	-	-	-	-
95	2.20	2,200	1904	3.342	0.227	0.051	0.0117	-	-	-	-	-	-	-
96	2.26	2,260	1942	3.354	0.238	0.057	0.0135	-	-	-	-	-	-	-
97	2.26	2,260	1990	3.354	0.238	0.057	0.0135	-	-	-	-	-	-	-
98	2.28	2,280	2000	3.358	0.242	0.059	0.0142	-	-	-	-	-	-	-
99	2.29	2,290	1920	3.360	0.244	0.060	0.0145	-	-	-	-	-	-	-
100	2.29	2,290	1992	3.360	0.244	0.060	0.0145	-	-	-	-	-	-	-

*Calculations based on complete USGS gage station data taken from 1899 to 2006.

N= 108

	Gage Station Data (Wilkes-Barre)			Log Pearson Type III Distribution										
m	Low Flow, 1000 cfs	Low Flow (X), cfs	Year	log X	$(\log X - (\log X)_{bar})$	$(\log X - (\log X)_{bar})^2$	$(\log X - (\log X)_{bar})^3$	Skew Coefficient (g)	Selected T_r (yr)	P	1 - P	Low Flow T_r (yr)	K	Estimated Flow (X), cfs
101	2.50	2,500	1967	3.398	0.282	0.080	0.0225	-	-	-	-	-	-	-
102	2.62	2,620	1905	3.418	0.303	0.092	0.0277	-	-	-	-	-	-	-
103	2.71	2,710	1945	3.433	0.317	0.101	0.0319	-	-	-	-	-	-	-
104	2.83	2,830	2004	3.452	0.336	0.113	0.0380	-	-	-	-	-	-	-
105	2.90	2,900	1994	3.462	0.347	0.120	0.0417	-	-	-	-	-	-	-
106	3.15	3,150	2006	3.498	0.383	0.146	0.0560	-	-	-	-	-	-	-
107	3.58	3,580	2003	3.554	0.438	0.192	0.0841	-	-	-	-	-	-	-
108	3.60	3,600	1976	3.556	0.441	0.194	0.0855	-	-	-	-	-	-	-
Avg.=	X_{bar}=	1,420	$(\log X)_{bar}$=	3.116	-	-	-	-	-	-	-	-	-	-
Sum=	-	153,330	-	336.498	-	3.308	0.1731	-	-	-	-	-	-	-

$\sigma_{\log x}$ = 0.176

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Low Flow Probability Distribution Formulas

The Weilbull, Gumbel, and Log Pearson Type III distribution methods are commonly used to determine the probability of a flood event occurence. However, the same models can be used for low flow by solving for the probability that the flow is *less than*, as opposed to greater than or equal to, a flow event of a given magnitude (instead of solving for P, solve for 1 - P).

Weilbull Distribution:

$$P := \frac{1}{T_r} \qquad \text{(Equation 1)}$$

$$T_r := \frac{N+1}{m} \qquad \text{(Equation 2)}$$

P = probability of occurrence.
N = period of record.
m = *m*th smallest flow in data series.
T_r = recurrence interval.

Gumbel Distribution:

$$P := 1 - \left(1 - e^{-e^{-b}}\right) \qquad \text{(Equation 3)}$$

$$b := \frac{1}{0.7797 \cdot \sigma_x} \cdot \left(X - X_{bar} + 0.45 \cdot \sigma_x\right) \qquad \text{(Equation 4)}$$

$$\sigma_x := \left(\frac{\Sigma (X - X_{bar})^2}{N - 1} \right)^{\frac{1}{2}} \quad \text{(Equation 5)}$$

P = probability of occurrence.
X = flood magnitude in cfs.
X_{bar} = average flood magnitude from data series in cfs.
σ_x = standard deviation of annual low flows from data series.

log Pearson Type III Distribution:

$$g_{skew} := \frac{N \cdot \Sigma (X_{log} - X_{log\_bar})^3}{(N-1) \cdot (N-2) \cdot (\sigma_{log\_x})^3} \quad \text{(Equation 6)}$$

$$\sigma_{log\_x} := \left(\frac{\Sigma (X_{log} - X_{log\_bar})^2}{N - 1} \right)^{\frac{1}{2}} \quad \text{(Equation 7)}$$

N = period of record.
g_{skew} = skew coefficient.
X_{log} = log X.
X_{log_bar} = average "log X" from data series.
σ_{log_x} = standard deviation of "log X" from data series.

$$X_{log} := X_{log\_bar} + K \cdot \sigma_{log\_x}$$ (Equation 8)

K = value from Table A-5 in text (see ***Reference 1***, used linear interpolation based on calculated skew coefficient from data series).

Developing the Log Pearson Type III Distribution for the low flow scenario follows the same appoach as for peak flow: calculate the skew coefficient based on the available gage station flow data, and using that value interpolate the corresponding frequency factor (K) at various recurrence intervals to develop a frequency distribution which can be used to estimate flow. Since the formulas and tables above that are used to develop this distribution were created to determine the probability of peak flow events (probability of occurence / recurrence interval of a flow of equal or greater magnitude), the probability of the estimated flow that is of intrest for low flow analysis is instead the probability that a flow of lower magnitude occurs. Therefore, the distribution is created by plotting the estimated flow against the recurrence interval, which is calculated using 1 - P for probability as opposed to P.

*Text Reference: "Water-Resources Engineering," McGraw-Hill, Fourth Edition. (Chapter 5: Probability Concepts in Planning)

Low Flow Frequency Distributions (Weilbull and Gumbel) for Danville Gage Station

*Calculations based on complete USGS gage station data taken from 1906 to 2006.

N= 101

	Gage Station Data (Danville)			Weilbull Distribution		Gumbel Distribution				
m	Low Flow, 1000 cfs	Low Flow (X), cfs	Year	Weilbull T_r(yr)	P	$X - X_{bar}$	$(X - X_{bar})^2$	b	P	Gumbel T_r (yr)
1	0.56	558	1964	102.0	0.0098	-1,160	1,346,588	-1.50	0.0116	87
2	0.72	722	1939	51.0	0.0196	-996	992,864	-1.20	0.0359	28
3	0.84	839	1963	34.0	0.0294	-879	773,390	-0.99	0.0672	15
4	0.84	840	1999	25.5	0.0392	-878	771,632	-0.99	0.0675	15
5	0.86	855	1908	20.4	0.0490	-863	745,504	-0.96	0.0725	14
6	0.88	876	1955	17.0	0.0588	-842	709,681	-0.93	0.0798	13
7	0.89	888	1962	14.6	0.0686	-830	689,607	-0.91	0.0842	12
8	0.90	900	1965	12.8	0.0784	-818	669,821	-0.88	0.0888	11
9	0.92	918	1959	11.3	0.0882	-800	640,681	-0.85	0.0958	10
10	0.92	920	1913	10.2	0.0980	-798	637,484	-0.85	0.0966	10
11	0.92	920	1930	9.3	0.1078	-798	637,484	-0.85	0.0966	10
12	0.92	920	1932	8.5	0.1176	-798	637,484	-0.85	0.0966	10
13	0.95	952	1941	7.8	0.1275	-766	587,408	-0.79	0.1100	9
14	0.98	982	1991	7.3	0.1373	-736	542,323	-0.74	0.1235	8
15	0.99	991	1953	6.8	0.1471	-727	529,148	-0.72	0.1276	8
16	1.02	1,020	1936	6.4	0.1569	-698	487,799	-0.67	0.1416	7
17	1.06	1,060	1966	6.0	0.1667	-658	433,524	-0.60	0.1620	6
18	1.09	1,090	2002	5.7	0.1765	-628	394,919	-0.55	0.1782	6
19	1.10	1,100	1910	5.4	0.1863	-618	382,450	-0.53	0.1837	5
20	1.11	1,110	1954	5.1	0.1961	-608	370,182	-0.51	0.1893	5
21	1.12	1,120	1909	4.9	0.2059	-598	358,113	-0.49	0.1950	5
22	1.15	1,150	1949	4.6	0.2157	-568	323,108	-0.44	0.2123	5

*Calculations based on complete USGS gage station data taken from 1906 to 2006.

N= 101

	Gage Station Data (Danville)			Weilbull Distribution		Gumbel Distribution				
m	Low Flow, 1000 cfs	Low Flow (X), cfs	Year	Weilbull T_r (yr)	P	$X - X_{bar}$	$(X - X_{bar})^2$	b	P	Gumbel T_r (yr)
23	1.21	1,210	1911	4.4	0.2255	-508	258,497	-0.33	0.2485	4
24	1.21	1,210	1948	4.3	0.2353	-508	258,497	-0.33	0.2485	4
25	1.22	1,220	1923	4.1	0.2451	-498	248,428	-0.31	0.2547	4
26	1.22	1,220	1931	3.9	0.2549	-498	248,428	-0.31	0.2547	4
27	1.24	1,240	1907	3.8	0.2647	-478	228,891	-0.28	0.2673	4
28	1.24	1,240	1980	3.6	0.2745	-478	228,891	-0.28	0.2673	4
29	1.25	1,250	1943	3.5	0.2843	-468	219,423	-0.26	0.2736	4
30	1.27	1,270	1944	3.4	0.2941	-448	201,086	-0.22	0.2863	3
31	1.28	1,280	2005	3.3	0.3039	-438	192,217	-0.21	0.2927	3
32	1.29	1,290	1952	3.2	0.3137	-428	183,549	-0.19	0.2991	3
33	1.30	1,300	1983	3.1	0.3235	-418	175,080	-0.17	0.3056	3
34	1.31	1,310	1934	3.0	0.3333	-408	166,812	-0.15	0.3121	3
35	1.31	1,310	1957	2.9	0.3431	-408	166,812	-0.15	0.3121	3
36	1.31	1,310	1961	2.8	0.3529	-408	166,812	-0.15	0.3121	3
37	1.40	1,400	1929	2.8	0.3627	-318	101,395	0.01	0.3710	3
38	1.42	1,420	1997	2.7	0.3725	-298	89,058	0.04	0.3841	3
39	1.43	1,430	1982	2.6	0.3824	-288	83,189	0.06	0.3907	3
40	1.45	1,450	1969	2.6	0.3922	-268	72,052	0.10	0.4038	2
41	1.45	1,450	1988	2.5	0.4020	-268	72,052	0.10	0.4038	2
42	1.47	1,470	1940	2.4	0.4118	-248	61,715	0.13	0.4168	2
43	1.48	1,480	1995	2.4	0.4216	-238	56,847	0.15	0.4233	2
44	1.51	1,510	1993	2.3	0.4314	-208	43,441	0.20	0.4428	2
45	1.54	1,540	1971	2.3	0.4412	-178	31,836	0.26	0.4620	2
46	1.57	1,570	1985	2.2	0.4510	-148	22,030	0.31	0.4810	2
47	1.58	1,580	1970	2.2	0.4608	-138	19,162	0.33	0.4873	2
48	1.60	1,600	1912	2.1	0.4706	-118	14,025	0.37	0.4997	2

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*Calculations based on complete USGS gage station data taken from 1906 to 2006.

N= 101

	Gage Station Data (Danville)			Weilbull Distribution		Gumbel Distribution				
m	Low Flow, 1000 cfs	Low Flow (X), cfs	Year	Weilbull T_r (yr)	P	$X - X_{bar}$	$(X - X_{bar})^2$	b	P	Gumbel T_r (yr)
49	1.61	1,610	1987	2.1	0.4804	-108	11,756	0.38	0.5059	2
50	1.63	1,630	1947	2.0	0.4902	-88	7,819	0.42	0.5181	2
51	1.64	1,640	1906	2.0	0.5000	-78	6,151	0.44	0.5242	2
52	1.64	1,640	1951	2.0	0.5098	-78	6,151	0.44	0.5242	2
53	1.66	1,660	1989	1.9	0.5196	-58	3,414	0.47	0.5362	2
54	1.68	1,680	2001	1.9	0.5294	-38	1,477	0.51	0.5481	2
55	1.70	1,700	1914	1.9	0.5392	-18	340	0.54	0.5597	2
56	1.70	1,700	1915	1.8	0.5490	-18	340	0.54	0.5597	2
57	1.70	1,700	1918	1.8	0.5588	-18	340	0.54	0.5597	2
58	1.70	1,700	1998	1.8	0.5686	-18	340	0.54	0.5597	2
59	1.71	1,710	1968	1.7	0.5784	-8	71	0.56	0.5655	2
60	1.71	1,710	1981	1.7	0.5882	-8	71	0.56	0.5655	2
61	1.72	1,720	1938	1.7	0.5980	2	2	0.58	0.5713	2
62	1.73	1,730	1933	1.6	0.6078	12	134	0.60	0.5769	2
63	1.73	1,730	1935	1.6	0.6176	12	134	0.60	0.5769	2
64	1.80	1,800	1922	1.6	0.6275	82	6,654	0.72	0.6155	2
65	1.81	1,810	1919	1.6	0.6373	92	8,386	0.74	0.6208	2
66	1.81	1,810	1921	1.5	0.6471	92	8,386	0.74	0.6208	2
67	1.81	1,810	1926	1.5	0.6569	92	8,386	0.74	0.6208	2
68	1.90	1,900	1979	1.5	0.6667	182	32,969	0.90	0.6663	2
69	1.92	1,920	1928	1.5	0.6765	202	40,632	0.94	0.6759	1
70	1.96	1,960	1937	1.5	0.6863	242	58,358	1.01	0.6944	1
71	1.96	1,960	1974	1.4	0.6961	242	58,358	1.01	0.6944	1
72	1.97	1,970	1984	1.4	0.7059	252	63,290	1.03	0.6989	1
73	1.99	1,990	1972	1.4	0.7157	272	73,753	1.06	0.7077	1
74	2.00	2,000	1920	1.4	0.7255	282	79,284	1.08	0.7121	1

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By DW Date 3/31/2008 Subject Low Flow Recurrence Interval and Low Flow Statistics (BBNPP) Sheet No. A21 of A27
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*Calculations based on complete USGS gage station data taken from 1906 to 2006.

N= 101

	Gage Station Data (Danville)			Weilbull Distribution		Gumbel Distribution				
m	Low Flow, 1000 cfs	Low Flow (X), cfs	Year	Weilbull T_r (yr)	P	$X - X_{bar}$	$(X - X_{bar})^2$	b	P	Gumbel T_r (yr)
75	2.03	2,030	1927	1.4	0.7353	312	97,079	1.13	0.7248	1
76	2.04	2,040	1946	1.3	0.7451	322	103,410	1.15	0.7289	1
77	2.06	2,060	1916	1.3	0.7549	342	116,673	1.19	0.7371	1
78	2.10	2,100	1960	1.3	0.7647	382	145,599	1.26	0.7527	1
79	2.11	2,110	1978	1.3	0.7745	392	153,330	1.28	0.7565	1
80	2.14	2,140	1956	1.3	0.7843	422	177,725	1.33	0.7676	1
81	2.15	2,150	1917	1.3	0.7941	432	186,256	1.35	0.7712	1
82	2.15	2,150	1925	1.2	0.8039	432	186,256	1.35	0.7712	1
83	2.15	2,150	1950	1.2	0.8137	432	186,256	1.35	0.7712	1
84	2.16	2,160	1977	1.2	0.8235	442	194,988	1.37	0.7748	1
85	2.20	2,200	1958	1.2	0.8333	482	231,914	1.44	0.7885	1
86	2.20	2,200	1986	1.2	0.8431	482	231,914	1.44	0.7885	1
87	2.27	2,270	1924	1.2	0.8529	552	304,234	1.56	0.8109	1
88	2.30	2,300	1973	1.2	0.8627	582	338,229	1.62	0.8198	1
89	2.38	2,380	1942	1.1	0.8725	662	437,680	1.76	0.8417	1
90	2.49	2,490	1975	1.1	0.8824	772	595,327	1.96	0.8680	1
91	2.64	2,640	1996	1.1	0.8922	922	849,299	2.22	0.8974	1
92	2.70	2,700	1967	1.1	0.9020	982	963,488	2.33	0.9073	1
93	2.83	2,830	2000	1.1	0.9118	1,112	1,235,597	2.56	0.9258	1
94	2.87	2,870	1992	1.1	0.9216	1,152	1,326,123	2.63	0.9307	1
95	3.09	3,090	1990	1.1	0.9314	1,372	1,881,216	3.03	0.9527	1
96	3.22	3,220	1945	1.1	0.9412	1,502	2,254,725	3.26	0.9623	1
97	3.35	3,350	2004	1.1	0.9510	1,632	2,662,035	3.49	0.9700	1
98	3.37	3,370	1994	1.0	0.9608	1,652	2,727,698	3.53	0.9710	1
99	3.64	3,640	2006	1.0	0.9706	1,922	3,692,448	4.01	0.9820	1
100	4.10	4,100	1976	1.0	0.9804	2,382	5,671,896	4.83	0.9920	1

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*Calculations based on complete USGS gage station data taken from 1906 to 2006.

N= 101

	Gage Station Data (Danville)			Weilbull Distribution		Gumbel Distribution				
m	Low Flow, 1000 cfs	Low Flow (X), cfs	Year	Weilbull T_r (yr)	P	$X - X_{bar}$	$(X - X_{bar})^2$	b	P	Gumbel T_r (yr)
101	4.34	4,340	2003	1.0	0.9902	2,622	6,872,652	5.26	0.9948	1
102	-	-	-	-	-	-	-	-	-	-
103	-	-	-	-	-	-	-	-	-	-
104	-	-	-	-	-	-	-	-	-	-
105	-	-	-	-	-	-	-	-	-	-
106	-	-	-	-	-	-	-	-	-	-
107	-	-	-	-	-	-	-	-	-	-
108	-	-	-	-	-	-	-	-	-	-
Avg.=	X_{bar}=	1,718	-	-	-	-	-	-	-	-
Sum=	-	173,561	-	-	-	0	51,572,457	-	-	-

σ_x = 718.1

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By DW Date 3/31/2008 Subject Low Flow Recurrence Interval and Low Flow Statistics (BBNPP) Sheet No. A23 of A27
Chkd.By FAm Date 04-30-08 Project No. 07-3891

Low Flow Frequency Distribution (log Pearson Type III) for Danville Gage Station

*Calculations based on complete USGS gage station data taken from 1906 to 2006.

N= 101

	Gage Station Data (Danville)			Log Pearson Type III Distribution											
m	Low Flow, 1000 cfs	Low Flow (X), cfs	Year	log X	(log X - (log X)$_{bar}$)	(log X - (log X)$_{bar}$)^2	(log X - (log X)$_{bar}$)^3	Skew Coefficient (g)	Selected T_r (yr)	P	1 - P	Low Flow T_r (yr)	K	Estimated Flow (X), cfs
1	0.56	558	1964	2.747	-0.454	0.207	-0.0939	0.1110	2	0.5	0.5	2.0000	-0.0188	1,577
2	0.72	722	1939	2.859	-0.343	0.117	-0.0402	-	10	0.1	0.9	1.1111	1.2930	2,649
3	0.84	839	1963	2.924	-0.277	0.077	-0.0213	-	25	0.04	0.96	1.0417	1.7886	3,222
4	0.84	840	1999	2.924	-0.277	0.077	-0.0212	-	50	0.02	0.98	1.0204	2.1127	3,663
5	0.86	855	1908	2.932	-0.269	0.072	-0.0195	-	100	0.01	0.99	1.0101	2.4079	4,116
6	0.88	876	1955	2.943	-0.259	0.067	-0.0173	-	200	0.005	0.995	1.0050	2.6802	4,584
7	0.89	888	1962	2.948	-0.253	0.064	-0.0161	-	-	-	-	-	-	-
8	0.90	900	1965	2.954	-0.247	0.061	-0.0150	-	-	-	-	-	-	-
9	0.92	918	1959	2.963	-0.238	0.057	-0.0135	-	-	-	-	-	-	-
10	0.92	920	1913	2.964	-0.237	0.056	-0.0134	-	-	-	-	-	-	-
11	0.92	920	1930	2.964	-0.237	0.056	-0.0134	-	-	-	-	-	-	-
12	0.92	920	1932	2.964	-0.237	0.056	-0.0134	-	-	-	-	-	-	-
13	0.95	952	1941	2.979	-0.222	0.049	-0.0110	-	-	-	-	-	-	-
14	0.98	982	1991	2.992	-0.209	0.044	-0.0091	-	-	-	-	-	-	-
15	0.99	991	1953	2.996	-0.205	0.042	-0.0086	-	-	-	-	-	-	-
16	1.02	1,020	1936	3.009	-0.192	0.037	-0.0071	-	-	-	-	-	-	-
17	1.06	1,060	1966	3.025	-0.176	0.031	-0.0054	-	-	-	-	-	-	-
18	1.09	1,090	2002	3.037	-0.164	0.027	-0.0044	-	-	-	-	-	-	-
19	1.10	1,100	1910	3.041	-0.160	0.026	-0.0041	-	-	-	-	-	-	-
20	1.11	1,110	1954	3.045	-0.156	0.024	-0.0038	-	-	-	-	-	-	-
21	1.12	1,120	1909	3.049	-0.152	0.023	-0.0035	-	-	-	-	-	-	-
22	1.15	1,150	1949	3.061	-0.140	0.020	-0.0028	-	-	-	-	-	-	-
23	1.21	1,210	1911	3.083	-0.118	0.014	-0.0017	-	-	-	-	-	-	-

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Chkd.By FAM Date 04-30-08 Project No. 07-3891

*Calculations based on complete USGS gage station data taken from 1906 to 2006.

N= 101

	Gage Station Data (Danville)			Log Pearson Type III Distribution										
m	Low Flow, 1000 cfs	Low Flow (X), cfs	Year	log X	(log X - (log X)$_{bar}$)	(log X - (log X)$_{bar}$)^2	(log X - (log X)$_{bar}$)^3	Skew Coefficient (g)	Selected T, (yr)	P	1 - P	Low Flow T, (yr)	K	Estimated Flow (X), cfs
24	1.21	1,210	1948	3.083	-0.118	0.014	-0.0017	-	-	-	-	-	-	-
25	1.22	1,220	1923	3.086	-0.115	0.013	-0.0015	-	-	-	-	-	-	-
26	1.22	1,220	1931	3.086	-0.115	0.013	-0.0015	-	-	-	-	-	-	-
27	1.24	1,240	1907	3.093	-0.108	0.012	-0.0012	-	-	-	-	-	-	-
28	1.24	1,240	1980	3.093	-0.108	0.012	-0.0012	-	-	-	-	-	-	-
29	1.25	1,250	1943	3.097	-0.104	0.011	-0.0011	-	-	-	-	-	-	-
30	1.27	1,270	1944	3.104	-0.097	0.009	-0.0009	-	-	-	-	-	-	-
31	1.28	1,280	2005	3.107	-0.094	0.009	-0.0008	-	-	-	-	-	-	-
32	1.29	1,290	1952	3.111	-0.091	0.008	-0.0007	-	-	-	-	-	-	-
33	1.30	1,300	1983	3.114	-0.087	0.008	-0.0007	-	-	-	-	-	-	-
34	1.31	1,310	1934	3.117	-0.084	0.007	-0.0006	-	-	-	-	-	-	-
35	1.31	1,310	1957	3.117	-0.084	0.007	-0.0006	-	-	-	-	-	-	-
36	1.31	1,310	1961	3.117	-0.084	0.007	-0.0006	-	-	-	-	-	-	-
37	1.40	1,400	1929	3.146	-0.055	0.003	-0.0002	-	-	-	-	-	-	-
38	1.42	1,420	1997	3.152	-0.049	0.002	-0.0001	-	-	-	-	-	-	-
39	1.43	1,430	1982	3.155	-0.046	0.002	-0.0001	-	-	-	-	-	-	-
40	1.45	1,450	1969	3.161	-0.040	0.002	-0.0001	-	-	-	-	-	-	-
41	1.45	1,450	1988	3.161	-0.040	0.002	-0.0001	-	-	-	-	-	-	-
42	1.47	1,470	1940	3.167	-0.034	0.001	0.0000	-	-	-	-	-	-	-
43	1.48	1,480	1995	3.170	-0.031	0.001	0.0000	-	-	-	-	-	-	-
44	1.51	1,510	1993	3.179	-0.022	0.000	0.0000	-	-	-	-	-	-	-
45	1.54	1,540	1971	3.188	-0.014	0.000	0.0000	-	-	-	-	-	-	-
46	1.57	1,570	1985	3.196	-0.005	0.000	0.0000	-	-	-	-	-	-	-
47	1.58	1,580	1970	3.199	-0.002	0.000	0.0000	-	-	-	-	-	-	-
48	1.60	1,600	1912	3.204	0.003	0.000	0.0000	-	-	-	-	-	-	-
49	1.61	1,610	1987	3.207	0.006	0.000	0.0000	-	-	-	-	-	-	-

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*Calculations based on complete USGS gage station data taken from 1906 to 2006.

N= 101

m	Gage Station Data (Danville) Low Flow, 1000 cfs	Low Flow (X), cfs	Year	log X	(log X - (log X)bar)	(log X - (log X)bar)²	(log X - (log X)bar)³	Skew Coefficient (g)	Selected T, (yr)	P	1 - P	Low Flow T, (yr)	K	Estimated Flow (X), cfs
50	1.63	1,630	1947	3.212	0.011	0.000	0.0000	-	-	-	-	-	-	-
51	1.64	1,640	1906	3.215	0.014	0.000	0.0000	-	-	-	-	-	-	-
52	1.64	1,640	1951	3.215	0.014	0.000	0.0000	-	-	-	-	-	-	-
53	1.66	1,660	1989	3.220	0.019	0.000	0.0000	-	-	-	-	-	-	-
54	1.68	1,680	2001	3.225	0.024	0.001	0.0000	-	-	-	-	-	-	-
55	1.70	1,700	1914	3.230	0.029	0.001	0.0000	-	-	-	-	-	-	-
56	1.70	1,700	1915	3.230	0.029	0.001	0.0000	-	-	-	-	-	-	-
57	1.70	1,700	1918	3.230	0.029	0.001	0.0000	-	-	-	-	-	-	-
58	1.70	1,700	1998	3.230	0.029	0.001	0.0000	-	-	-	-	-	-	-
59	1.71	1,710	1968	3.233	0.032	0.001	0.0000	-	-	-	-	-	-	-
60	1.71	1,710	1981	3.233	0.032	0.001	0.0000	-	-	-	-	-	-	-
61	1.72	1,720	1938	3.236	0.034	0.001	0.0000	-	-	-	-	-	-	-
62	1.73	1,730	1933	3.238	0.037	0.001	0.0001	-	-	-	-	-	-	-
63	1.73	1,730	1935	3.238	0.037	0.001	0.0001	-	-	-	-	-	-	-
64	1.80	1,800	1922	3.255	0.054	0.003	0.0002	-	-	-	-	-	-	-
65	1.81	1,810	1919	3.258	0.057	0.003	0.0002	-	-	-	-	-	-	-
66	1.81	1,810	1921	3.258	0.057	0.003	0.0002	-	-	-	-	-	-	-
67	1.81	1,810	1926	3.258	0.057	0.003	0.0002	-	-	-	-	-	-	-
68	1.90	1,900	1979	3.279	0.078	0.006	0.0005	-	-	-	-	-	-	-
69	1.92	1,920	1928	3.283	0.082	0.007	0.0006	-	-	-	-	-	-	-
70	1.96	1,960	1937	3.292	0.091	0.008	0.0008	-	-	-	-	-	-	-
71	1.96	1,960	1974	3.292	0.091	0.008	0.0008	-	-	-	-	-	-	-
72	1.97	1,970	1984	3.294	0.093	0.009	0.0008	-	-	-	-	-	-	-
73	1.99	1,990	1972	3.299	0.098	0.010	0.0009	-	-	-	-	-	-	-
74	2.00	2,000	1920	3.301	0.100	0.010	0.0010	-	-	-	-	-	-	-
75	2.03	2,030	1927	3.307	0.106	0.011	0.0012	-	-	-	-	-	-	-

PAUL C. RIZZO ASSOCIATES, INC.
CONSULTANTS

By DW Date 3/31/2008 Subject Low Flow Recurrence Interval and Low Flow Statistics (BBNPP) Sheet No. A26 of A27
Chkd.By FAM Date 04-30-08 Project No. 07-3891

*Calculations based on complete USGS gage station data taken from 1906 to 2006.

N= 101

	Gage Station Data (Danville)			Log Pearson Type III Distribution										
m	Low Flow, 1000 cfs	Low Flow (X), cfs	Year	log X	(log X - (log X)bar)	(log X - (log X)bar)^2	(log X - (log X)bar)^3	Skew Coefficient (g)	Selected T, (yr)	P	1 - P	Low Flow T, (yr)	K	Estimated Flow (X), cfs
76	2.04	2,040	1946	3.310	0.109	0.012	0.0013	-	-	-	-	-	-	-
77	2.06	2,060	1916	3.314	0.113	0.013	0.0014	-	-	-	-	-	-	-
78	2.10	2,100	1960	3.322	0.121	0.015	0.0018	-	-	-	-	-	-	-
79	2.11	2,110	1978	3.324	0.123	0.015	0.0019	-	-	-	-	-	-	-
80	2.14	2,140	1956	3.330	0.129	0.017	0.0022	-	-	-	-	-	-	-
81	2.15	2,150	1917	3.332	0.131	0.017	0.0023	-	-	-	-	-	-	-
82	2.15	2,150	1925	3.332	0.131	0.017	0.0023	-	-	-	-	-	-	-
83	2.15	2,150	1950	3.332	0.131	0.017	0.0023	-	-	-	-	-	-	-
84	2.16	2,160	1977	3.334	0.133	0.018	0.0024	-	-	-	-	-	-	-
85	2.20	2,200	1958	3.342	0.141	0.020	0.0028	-	-	-	-	-	-	-
86	2.20	2,200	1986	3.342	0.141	0.020	0.0028	-	-	-	-	-	-	-
87	2.27	2,270	1924	3.356	0.155	0.024	0.0037	-	-	-	-	-	-	-
88	2.30	2,300	1973	3.362	0.161	0.026	0.0041	-	-	-	-	-	-	-
89	2.38	2,380	1942	3.377	0.175	0.031	0.0054	-	-	-	-	-	-	-
90	2.49	2,490	1975	3.396	0.195	0.038	0.0074	-	-	-	-	-	-	-
91	2.64	2,640	1996	3.422	0.221	0.049	0.0107	-	-	-	-	-	-	-
92	2.70	2,700	1967	3.431	0.230	0.053	0.0122	-	-	-	-	-	-	-
93	2.83	2,830	2000	3.452	0.251	0.063	0.0158	-	-	-	-	-	-	-
94	2.87	2,870	1992	3.458	0.257	0.066	0.0169	-	-	-	-	-	-	-
95	3.09	3,090	1990	3.490	0.289	0.083	0.0241	-	-	-	-	-	-	-
96	3.22	3,220	1945	3.508	0.307	0.094	0.0289	-	-	-	-	-	-	-
97	3.35	3,350	2004	3.525	0.324	0.105	0.0340	-	-	-	-	-	-	-
98	3.37	3,370	1994	3.528	0.327	0.107	0.0348	-	-	-	-	-	-	-
99	3.64	3,640	2006	3.561	0.360	0.130	0.0467	-	-	-	-	-	-	-
100	4.10	4,100	1976	3.613	0.412	0.169	0.0698	-	-	-	-	-	-	-
101	4.34	4,340	2003	3.637	0.436	0.190	0.0831	-	-	-	-	-	-	-

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PAUL C. RIZZO ASSOCIATES, INC.
CONSULTANTS

By __DW__ Date _3/31/2008_ Subject __Low Flow Recurrence Interval and__ Sheet No. _A27_ of _A27_
Chkd.By _Fmm_ Date _04-30-08_ __Low Flow Statistics (BBNPP)__ Project No. _07-3891_

*Calculations based on complete USGS gage station data taken from 1906 to 2006.

N= 101

	Gage Station Data (Danville)			Log Pearson Type III Distribution										
m	Low Flow, 1000 cfs	Low Flow (X), cfs	Year	log X	(log X - (log X)$_{bar}$)	(log X - (log X)$_{bar}$)^2	(log X - (log X)$_{bar}$)^3	Skew Coefficient (g)	Selected T, (yr)	P	1 - P	Low Flow T_r (yr)	K	Estimated Flow (X), cfs
102	-	-	-	-	-	-	-	-	-	-	-	-	-	-
103	-	-	-	-	-	-	-	-	-	-	-	-	-	-
104	-	-	-	-	-	-	-	-	-	-	-	-	-	-
105	-	-	-	-	-	-	-	-	-	-	-	-	-	-
106	-	-	-	-	-	-	-	-	-	-	-	-	-	-
107	-	-	-	-	-	-	-	-	-	-	-	-	-	-
108	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Avg.=	X_{bar}=	1,718	(logX)$_{bar}$=	3.201	-	-	-	-	-	-	-	-	-	-
Sum=	-	173,561	-	323.310	-	2.947	0.0551	-	-	-	-	-	-	-

$\sigma_{\log x}$ = 0.172

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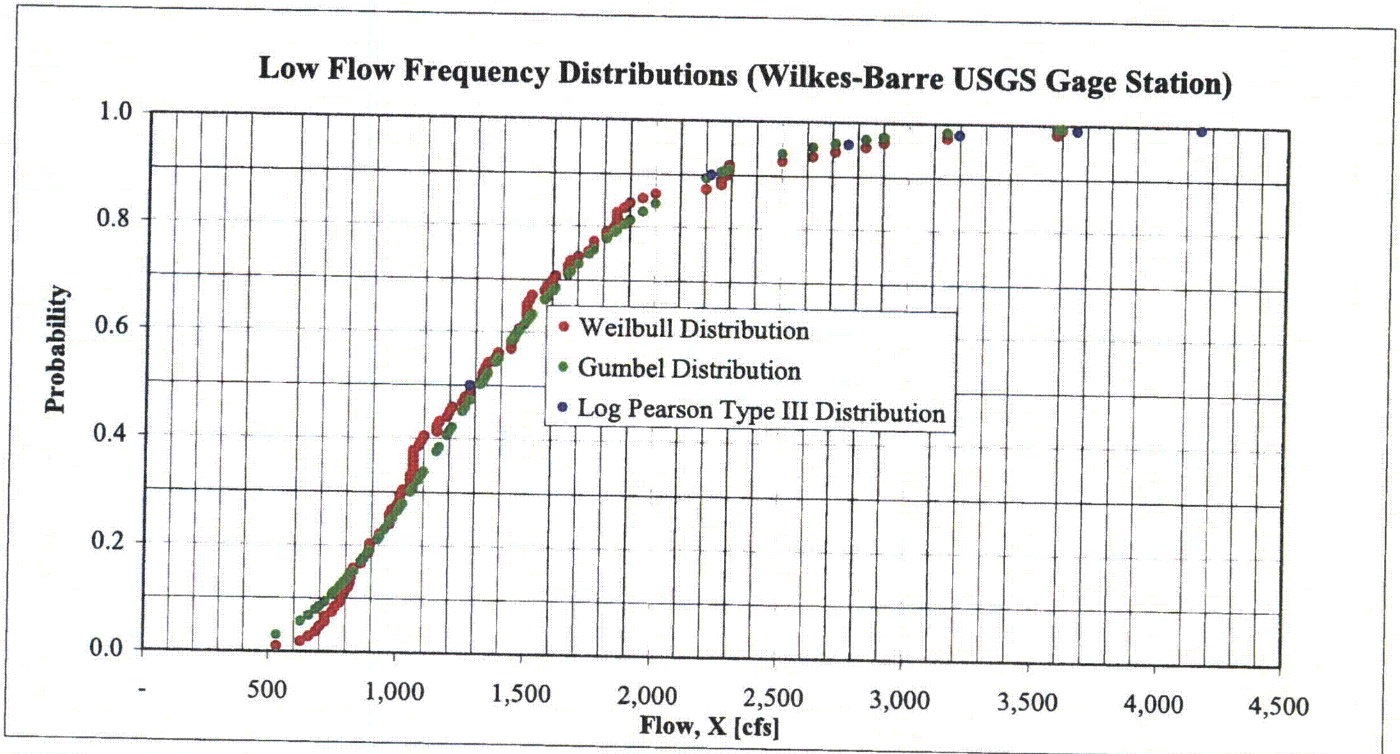
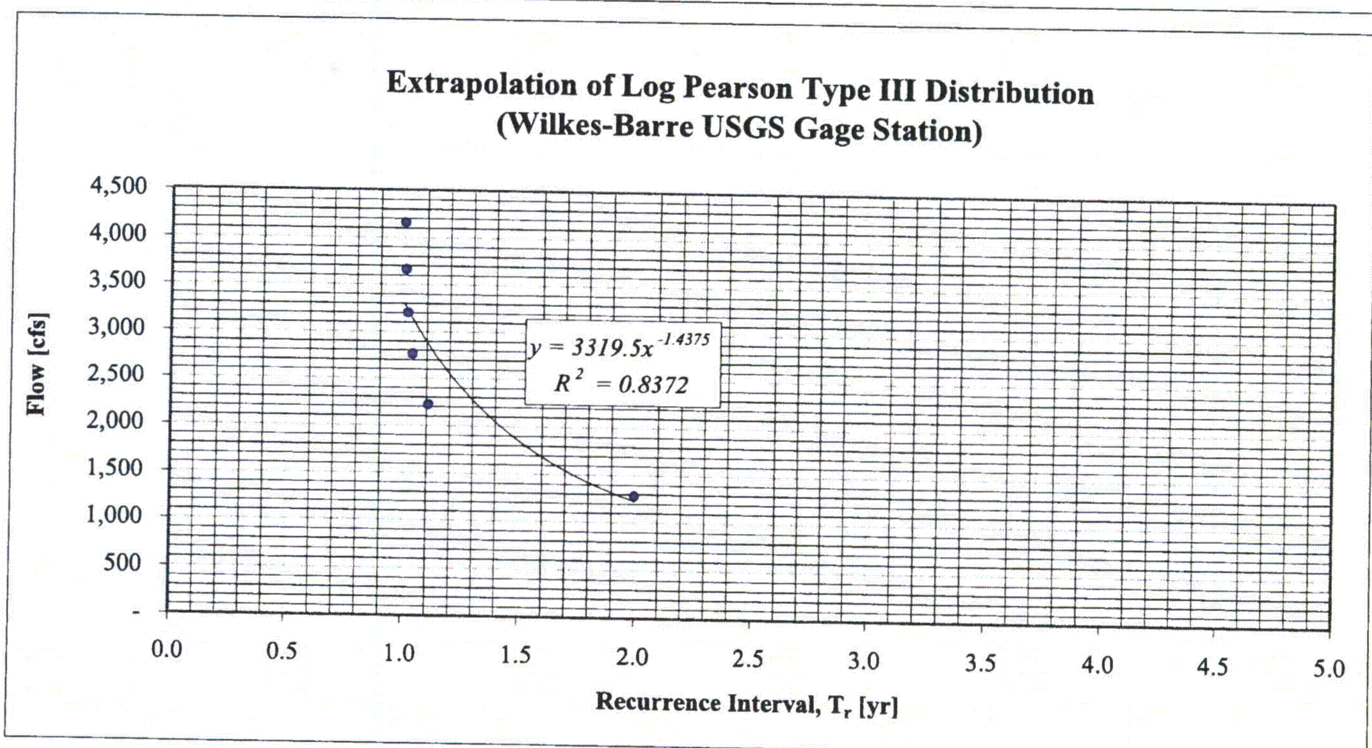
Attachment B

Low Flow Frequency Distribution Plots for Wilkes-Barre and Danville USGS Gage Stations





*Trendline obtained from the extrapolation of the log Pearson Type III Distribution used to estimate flow for a given recurrence interval.

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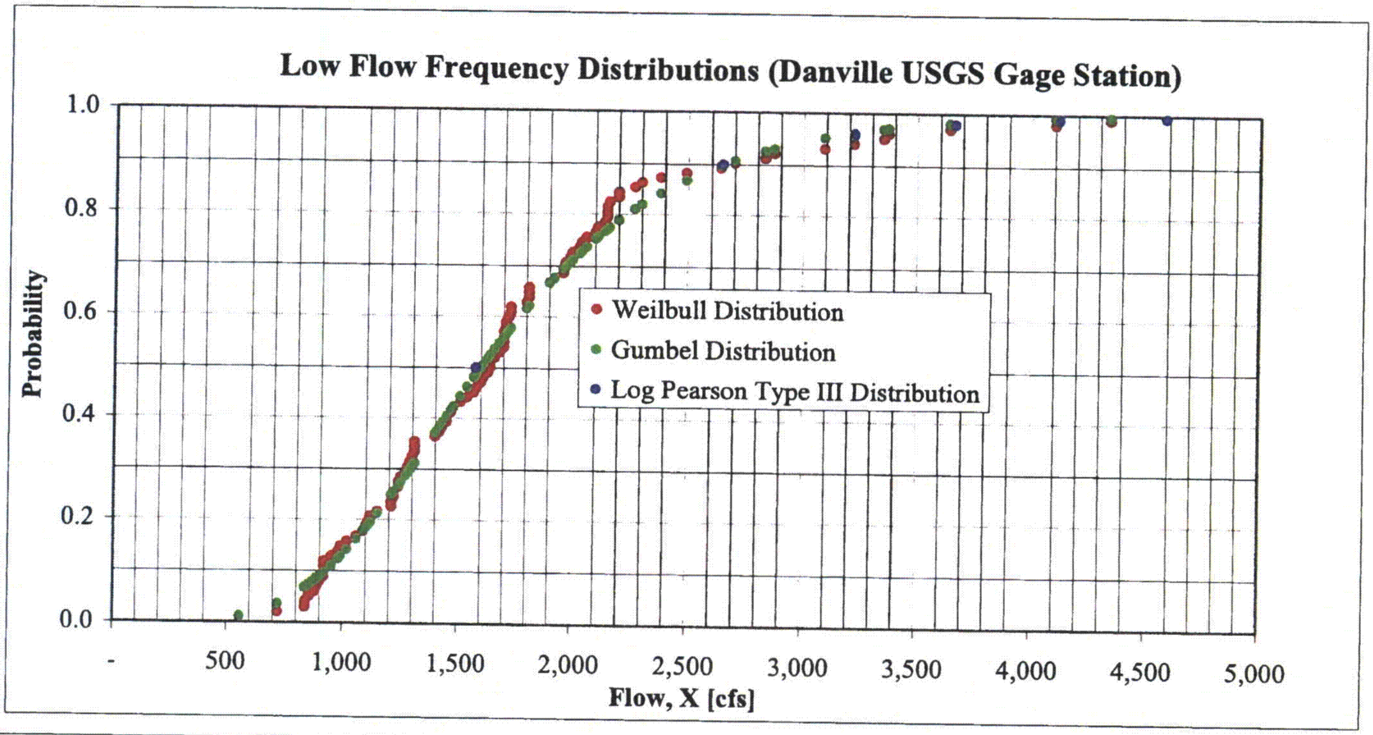

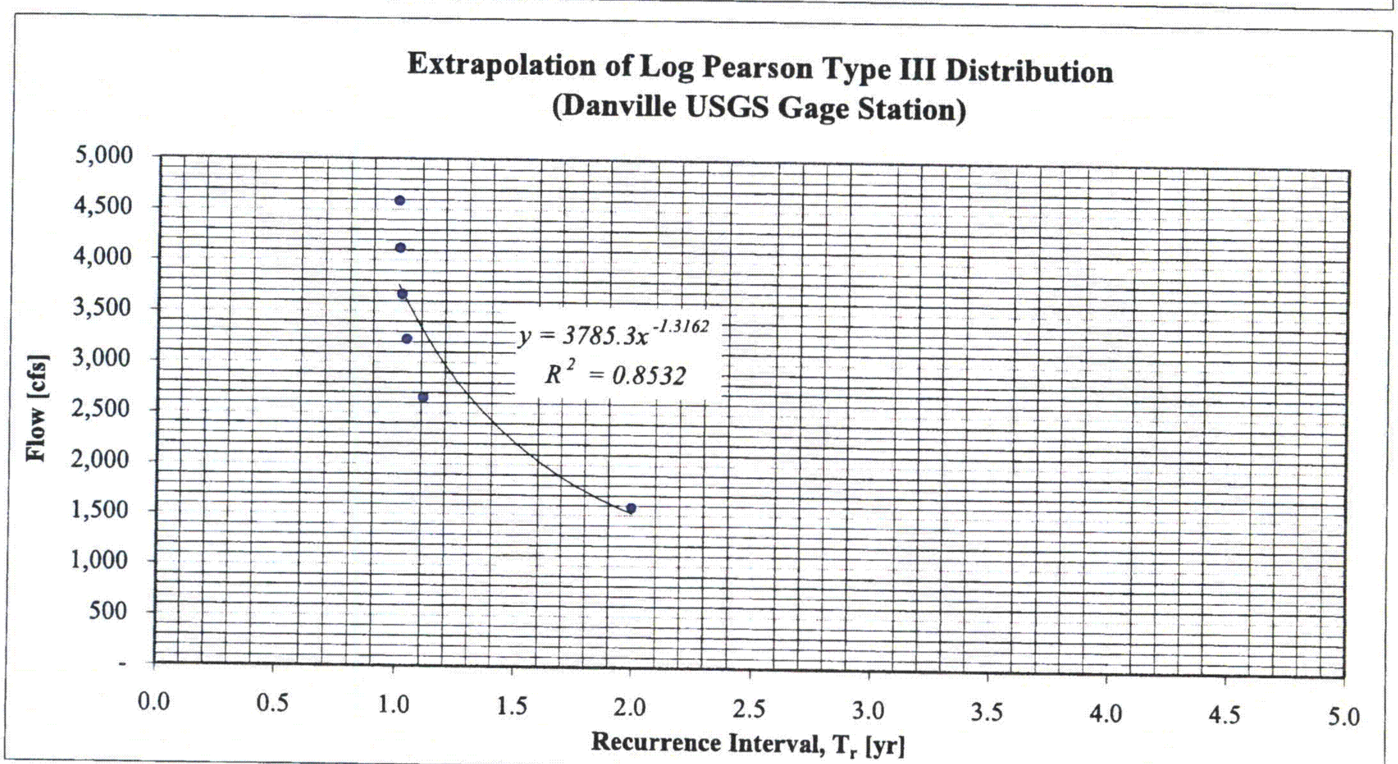

*Trendline obtained from the extrapolation of the log Pearson Type III Distribution used to estimate flow for a given recurrence interval.

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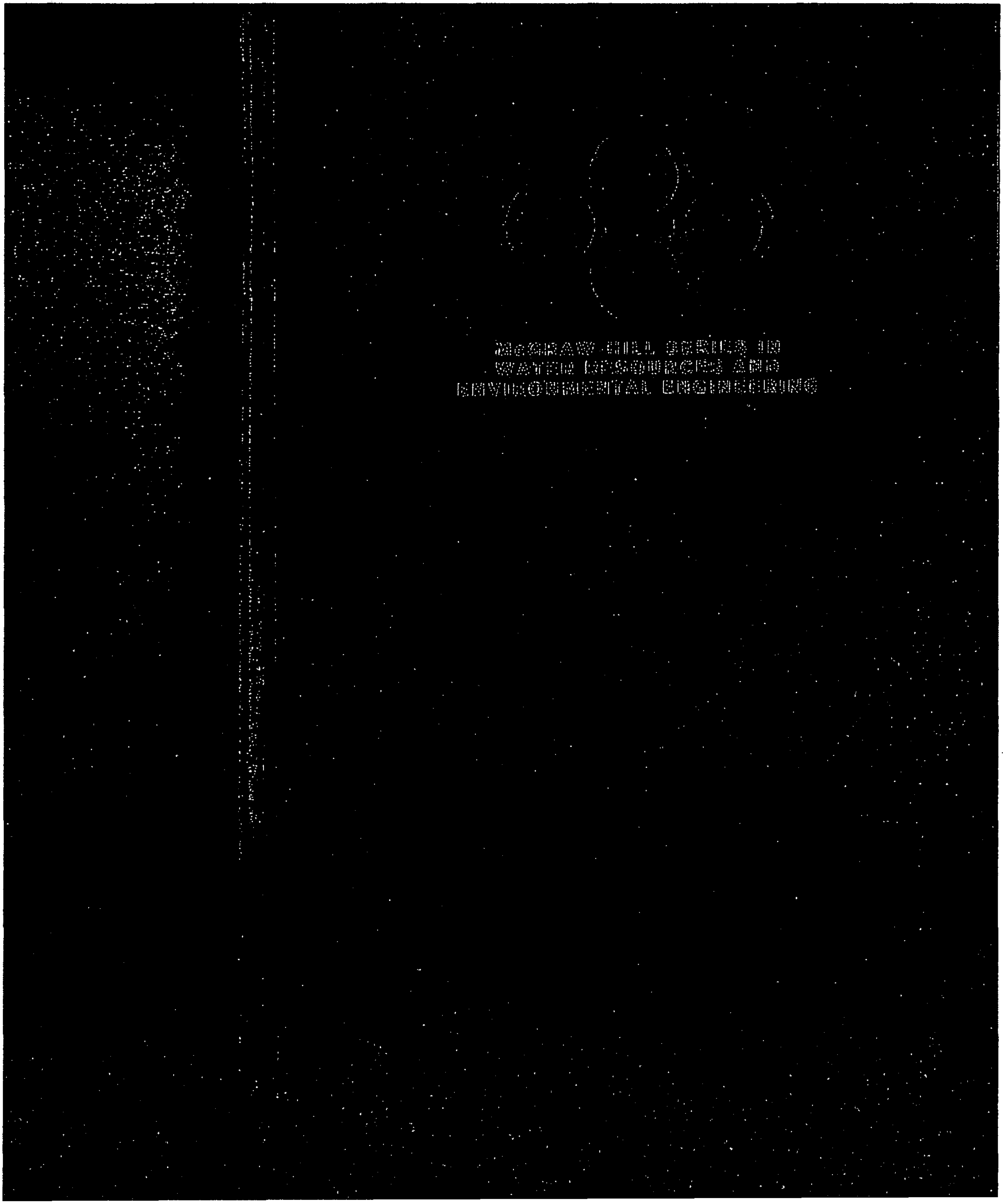
Reference 1

"Water-Resource Engineering" Text
(Frequency Distribution Formulas and Table A-5 Included)



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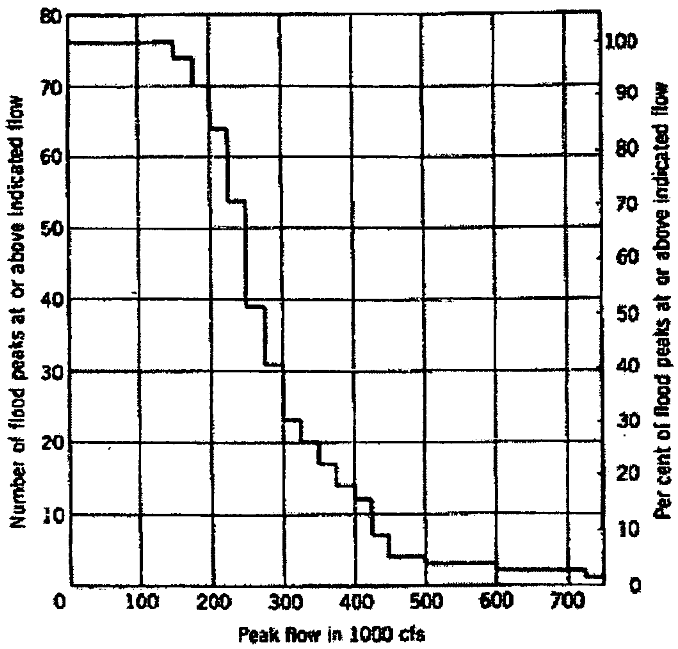


FIGURE 5.2
Integrated histogram of annual flood peaks for the Susquehanna River at Harrisburg, Pennsylvania (1874–1949).

5.2 Recurrence Interval

The recurrence interval[1] is defined as the average interval in years between the occurrence of a flood of specified magnitude and an equal or larger flood. The *m*th largest flood in a data series has been equaled or exceeded *m* times in the period of record. *N* years and an estimate of its recurrence interval T_r as given by the Weilbull formula is

$$T_r = \frac{N+1}{m} \tag{5.1}$$

Several other formulas have been suggested for the calculation of recurrence interval or return period. The disagreement between the various formulas is limited to the larger floods, where *m* is small. If *m* equals 5 or more, the calculated values of T_r by all methods are almost identical. Equation (5.1) can be used to define *plotting positions* (Fig. 5.3), which provide a good estimate of flood flows with return periods of less than 20 yr.

[1] Recurrence interval is also referred to as *return period*. There is no implication that floods with a return period of T_r will recur precisely T_r years apart. For example, one would expect the 5-yr flood to be equaled or exceeded approximately 20 times in a 100-yr period. The recurrence could occur in successive years or there might be a span of considerably more than 5 yr between recurrences.

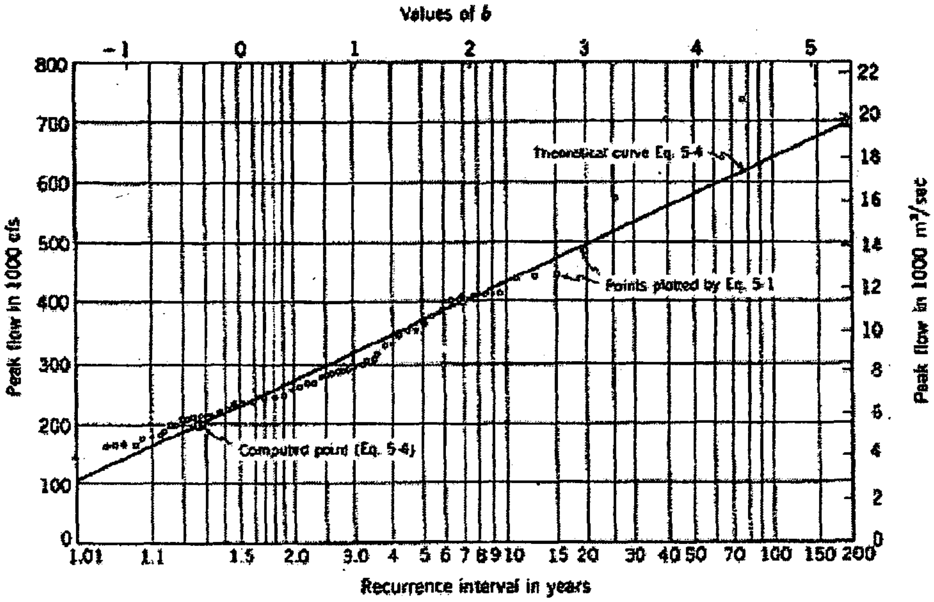


FIGURE 5.3
Frequency curve of annual floods for the Susquehanna River at Harrisburg, Pennsylvania (1874–1949).

If an event has a true recurrence interval of T_r years, then the probability P that it will be equaled or exceeded in any one year is

$$P = \frac{1}{T_r} \quad (5.2)$$

Since the only possibilities are that the event will or will not occur in any year, the probability that it will not occur in a given year is $1 - P$. From the principles of probability, the probability J that at least one event that equals or exceeds the T_r-year event will occur in any series of N years is

$$J = 1 - (1 - P)^N \quad (5.3)$$

This equation is derived as follows:

P is the probability of the occurrence of an event

$1 - P$ is the probability that the event will not occur.

$(1 - P)(1 - P)$ is the probability the event will not occur in two successive years.

$(1 - P)^3$ is the probability that the event will not occur in three successive years.

$(1 - P)^N$ is the probability that the event will not occur during a span of N successive years.

Hence $J = 1 - (1 - P)^N$ is the probability that the event will occur during a span of N years.

TABLE 5.2
Probability that an event of given recurrence interval will be equaled or exceeded during periods of various lengths

	Probability J for Various Periods							
T_r, yr	1 yr	5 yr	10 yr	25 yr	50 yr	100 yr	200 yr	500 yr
1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2	0.5	0.97	0.999	*	*	*	*	*
5	0.2	0.67	0.89	0.996	*	*	*	*
10	0.1	0.41	0.65	0.93	0.995	*	*	*
50	0.02	0.10	0.18	0.40	0.64	0.87	0.98	*
100	0.01	0.05	0.10	0.22	0.40	0.63	0.87	0.993
200	0.005	0.02	0.05	0.12	0.22	0.39	0.63	0.92

* In these cases J can never be exactly 1, but for all practical purposes its value may be taken as unity.

Table 5.2, which has been computed from Eq. (5.3), shows that there are 4 chances in 10 that the 100-yr flood (or greater) will occur in any 50-yr period and even a 22 percent probability that the 200-yr flood (or greater) might occur in the 50-yr period. On the other hand, there are 36 chances in 100 that the 50-yr flood will not occur in any 50-yr period. Equation 5.3 (or Table 5.2) may be used to estimate the risk of failure during the lifetime of a project when using different design criteria.

Table 5.2 illustrates also that there can be no inference that the "N-year flood" will be equaled or exceeded exactly once in every period of N years. All that is meant is that in a long period, say 10,000 years, there will be 10,000/N floods equal to or greater than the N-year flood. All such floods might occur in consecutive years, but this is not very probable.

If the design flood for a particular project is to have a recurrence interval much shorter than the period of record, its value may be determined by plotting peak flows versus T_r as computed from Eq. (5.1) and sketching a curve through the plotted points (Fig. 5.3). Because of inaccuracies in the plotted positions of the larger floods, a line sketched to conform to these floods may depart substantially from the location of the true frequency curve.

5.3 Statistical Methods for Estimating the Frequency of Rare Events

With an extremely long period of record it would be possible to use a smaller class interval, and Fig. 5.1 might approach a smooth frequency distribution such as Fig. 5.4. The ordinates of Fig. 5.4 are probability density and the abscissas are the magnitudes of the floods. The ratio of the area under the curve above any magnitude X_1 to the area under the entire curve is the probability that X_1 will be equaled or exceeded in any year.

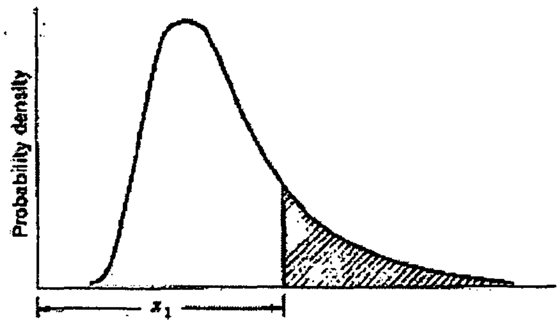


FIGURE 5.4
Idealized flood frequency distribution.

Many kinds of events conform to one of several standard frequency distributions that have been studied at length and the equation of the distribution well established. The probability of such events can be determined quite easily. Only a very large number of samples (i.e., a long record length) will permit accurate definition of a distribution, and no streamflow records are long enough to positively establish the appropriate distribution. It is known that X must be greater than zero and that future floods will exceed those that have been observed.

Several distributions have been suggested[1] as appropriate for streamflow, but there is no real proof of their validity. Fisher and Tippett[2] showed that if one selected the largest event from each of many large samples, the distribution of these extreme values was independent of the original distribution and conformed to a limiting function. Gumbel[3] suggested that this distribution of extreme values was appropriate for flood analysis since the annual flood could be assumed to be the largest of a sample of 365 possible values each year. Based on the argument that the distribution of floods is unlimited, i.e., that there is no physical limit to the maximum flood, he proposed that the probability P of the occurrence of a value equal to or greater than any X be expressed as

$$P = 1 - e^{-e^{-b}} \tag{5.4}$$

where e is the base of Natural logarithms and b is given by

$$b = \frac{1}{0.7797\sigma}(X - \bar{X} + 0.45\sigma) \tag{5.5}$$

[1] H. A. Foster, Theoretical Frequency Curves, *Trans. ASCE*, Vol. 87, pp. 142–173, 1924; Allen Hazen, "Flood Flows," Wiley, New York, 1930; and L. R. Beard, Statistical Analysis in Hydrology, *Trans. ASCE*, Vol. 108, pp. 1110–1160, 1943.

[2] R. A. Fisher and L. H. C. Tippett, Limiting Forms of the Frequency Distribution of the Largest or Smallest Member of a Sample, *Proc. Cambridge Philos. Soc.*, Vol. 24, pp. 180–190, 1928.

[3] E. J. Gumbel, Floods Estimated by the Probability Method, *Eng. News-Record*, Vol. 134, pp. 833–837, 1945.

In Eq. (5.5), X is the flood magnitude with the probability P, $\bar{X}$ is the arithmetic average of all floods in the series, and σ is the standard deviation of the series computed from

$$\sigma = \left[\frac{\sum(X-\bar{X})^2}{N-1}\right]^{1/2} \tag{5.6}$$

where N is the number of items in the series (the number of years of record). The probability P is related to the recurrence interval T_r by Eq. (5.2). Values of b corresponding to various return periods are given in Appendix A-4.

Example 5.1. Using the data of Table 5.1, find the theoretical recurrence interval for a flood flow of 700,000 cfs using the Gumbel approach.

Solution. Expressing all flows in thousands of cfs, from the table, $\bar{X} = 287.8$ and $\sigma = (962{,}367/75)^{0.5} = 113.3$. When $X = 700$,

$$b = \frac{1}{0.7797 \times 113.3}[700 - 288 + 0.45(113.3)] = 5.24$$

The recurrence interval for $X = 700$ is, from Eqs. (5.2) and (5.4),

$$T_r = \frac{1}{1 - e^{-e^{-5.24}}} = 189 \text{ yr}$$

By the same method $T_r = 1.28$ yr when $X = 200$ and 6.89 yr when $X = 400$. These points are shown on Fig. 5.3 by the large circles.

The plotting paper used for Fig. 5.3 is constructed by laying out on a linear scale of b the corresponding values of $T_r = 1/P$ from Eq. (5.4). Thus the computed line will be straight, and it is sufficient to calculate the return period corresponding to two flows. A third point is a convenient check.

In 1967, the U.S. Water Resources Council[1] adopted the log Pearson Type III distribution (of which the lognormal is a special case) as a standard for use by federal agencies. The purpose was to achieve standardization of procedures. The recommended procedure[2] is to convert the series to logarithms and compute the mean, standard deviation, and skew coefficient g, which is

$$g = \frac{N\sum(\log X - \overline{\log X})^3}{(N-1)(N-2)(\sigma_{\log X})^3} \tag{5.7}$$

The values of X for various periods are computed from

$$\log X = \overline{\log X} + K\sigma_{\log X} \tag{5.8}$$

⇒ magnitude of the flood = $10^{\log X}$

[1] A Uniform Technique for Determining Flood Flow Frequencies, *U.S. Water Resources Council Hydrol. Comm. Bull.* 15, December 1967, Revised June 1977.

[2] Subcommittee on Hydrology, Methods of Flow Frequency Analysis, *Interagency Comm. Water Resources Bull.* 13, U.S. Government Printing Office, Washington, D.C., April 1966.

Table A-4 Values of the reduced variate b corresponding to various values of return period and probability of exceedance [Eq. (5.5)]

Reduced variate b	Return period t_p = T_R	Probability of exceedance P
0.000	1.58	0.632
0.367	2.00	0.500
0.579	2.33	0.429
1.500	5.00	0.200
2.250	10.0	0.100
2.970	20.0	0.050
3.902	50.0	0.020
4.600	100	0.010
5.296	200	0.005
6.000	403	0.0025

Table A-5 Values of K for use with the log Pearson type III distribution

Skew coefficient g	Recurrence interval, yr: 2	10	25	50	100	200
	Chance, %: 50	10	4	2	1	0.5
3.0	−0.396	1.180	2.278	3.152	4.051	4.970
2.5	−0.360	1.250	2.262	3.048	3.845	4.652
2.0	−0.307	1.302	2.219	2.912	3.605	4.298
1.8	−0.282	1.318	2.193	2.848	3.499	4.147
1.6	−0.254	1.329	2.163	2.780	3.388	3.990
1.4	−0.225	1.337	2.128	2.706	3.271	3.828
1.2	−0.195	1.340	2.087	2.626	3.149	3.661
1.0	−0.164	1.340	2.043	2.542	3.022	3.489
0.9	−0.148	1.339	2.018	2.498	2.957	3.401
0.8	−0.132	1.336	1.993	2.453	2.891	3.312
0.7	−0.116	1.333	1.967	2.407	2.824	3.223
0.6	−0.099	1.328	1.939	2.359	2.755	3.132
0.5	−0.083	1.323	1.910	2.311	2.686	3.041
0.4	−0.066	1.317	1.880	2.261	2.615	2.949
0.3	−0.050	1.309	1.849	2.211	2.544	2.856
0.2	−0.033	1.301	1.818	2.159	2.472	2.763
0.1	−0.017	1.292	1.785	2.107	2.400	2.670

(continued)

Skew coefficient g	Recurrence interval, yr: 2 / Chance, %: 50	10 / 10	25 / 4	50 / 2	100 / 1	200 / 0.5
0	0	1.282	1.751	2.054	2.326	2.576
−0.1	0.017	1.270	1.716	2.000	2.252	2.482
−0.2	0.033	1.258	1.680	1.945	2.178	2.388
−0.3	0.050	1.245	1.643	1.890	2.104	2.294
−0.4	0.066	1.231	1.606	1.834	2.029	2.201
−0.5	0.083	1.216	1.567	1.777	1.955	2.108
−0.6	0.099	1.200	1.528	1.720	1.880	2.016
−0.7	0.116	1.183	1.488	1.663	1.806	1.926
−0.8	0.132	1.166	1.448	1.606	1.733	1.837
−0.9	0.148	1.147	1.407	1.549	1.660	1.749
−1.0	0.164	1.128	1.366	1.492	1.588	1.664
−1.2	0.195	1.086	1.282	1.379	1.449	1.501
−1.4	0.225	1.041	1.198	1.270	1.318	1.351
−1.6	0.254	0.994	1.116	1.166	1.197	1.216
−1.8	0.282	0.945	1.035	1.069	1.087	1.097
−2.0	0.307	0.895	0.959	0.980	0.990	0.995
−2.5	0.360	0.771	0.793	0.798	0.799	0.800
−3.0	0.396	0.660	0.666	0.666	0.667	0.667

Table A-6a Areas of circles (English units)

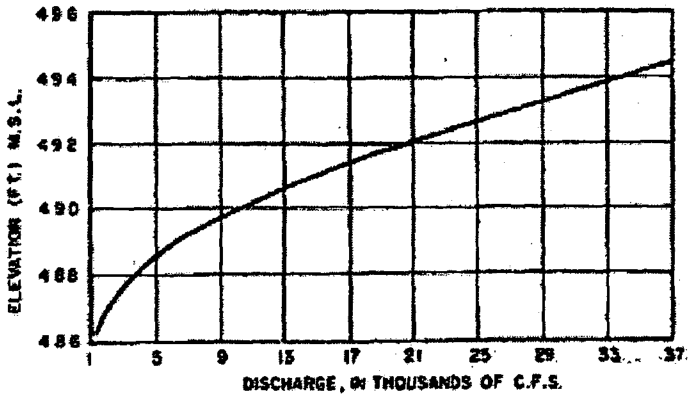
Diameter, in.	Area: in^2	ft^2
0.25	0.049	0.00034
0.5	0.196	0.00136
1.0	0.785	0.00545
2.0	3.142	0.0218
3.0	7.069	0.0491
4.0	12.57	0.0873
6.0	28.27	0.196
8.0	50.27	0.349
10.0	78.54	0.545
12.0	113.10	0.785

Paul C. Rizzo Associates, Inc.
Consultants

By DW Date 3/31/2008 Subject Low Flow Recurrence Interval and Low Flow Statistics (BBNPP) Sheet No. Ref2 1 of Ref2 2
Chkd.By fmm Date 04-30-08 Project No. 07-3891

Reference 2

Impact Point Drainage Area (DA_{ip})
SSES Unit 1 & 2 FSAR



NOTES: ELEVATIONS MEASURED BY GAGE AT SUSQUEHANNA SITE

FLOWS MEASURED AT WILKES-BARRE AND DANVILLE. FLOW AT SITE OBTAINED BY INTERPOLATION ON BASIS OF DRAINAGE AREA.

DRAINAGE AREAS :

WILKES-BARRE 9960 SQ MILES (25795 SQ KM)

SUSQUEHANNA SITE 10200 SQ MI (26416 SQ KM)

DANVILLE 11220 SQ MI (29058 SQ KM)

FSAR REV. 46, 06/93

SUSQUEHANNA STEAM ELECTRIC STATION
UNITS 1 AND 2
FINAL SAFETY ANALYSIS REPORT

STAGE DISCHARGE CURVE,
DISCHARGE RANGE
1000 - 37000 CFS

FSAR FIGURE 2.4-6

PP&L DRAWING

Reference 3

USGS / PaDEP: Computing Low Flow Statistics for Ungaged Sites Using Drainage Area Ratios

http://pa.water.usgs.gov/pc38/flowstats/revised_deplowflow.pdf

Computing Low-Flow Statistics for Ungaged Locations on Pennsylvania Streams By Use of Drainage-Area Ratios

Introduction

The U.S. Geological Survey (USGS), in cooperation with the Pennsylvania Department of Environmental Protection (PaDEP), developed low-flow statistics for approximately 2,800 ungaged locations on streams in Pennsylvania by use of streamflow statistics from streamflow-gaging stations and drainage-area ratios ranging from one-third to three times. These low-flow statistics will aid PaDEP in reviewing requests for permits associated with stream-water withdrawals from, and effluent discharges to, Pennsylvania streams.

Methodology

Low-flow statistics from 312 USGS streamflow-gaging stations (gages) were computed as described in Ehlke and Reed (1999). The gages used in the computations were active and discontinued stations with at least 10 years of continuous record and were representative of the hydrologic conditions encountered throughout Pennsylvania. The computed low-flow statistics include the 1-day 10-year low flow ($Q_{1,10}$), 7-day 10-year low flow ($Q_{7,10}$), 30-day 10-year low flow ($Q_{30,10}$), mean, median, harmonic mean, and flow-duration table.

Regulation and diversion of streamflow can significantly modify low-flow discharges. Large reservoirs are often required to release a predetermined amount of water to supplement streamflow during droughts; diversions can decrease streamflow during droughts. Occasionally, these withdrawals are discharged to different stream basin, increasing the streamflow in the discharge basin. Regulation is defined for this website as a stream with an upstream flood-control reservoir(s) which controls 10 percent or more of the contributing basin. If regulation began while the gage was in operation, records were analyzed for pre-regulation, post-regulation, and entire period of record streamflow conditions. In the case of multiple upstream reservoirs controlling the streamflow, the year in which the reservoir was built that makes the cumulative controlled area equal to 10 percent determines the break in record. Because diversions are more difficult to quantify and are not always published, basin with diversion of streamflow were analyzed the same as a basin without any diversion.

The low-flow statistics presented in this web application were transferred upstream to one-third and downstream to three times the drainage area of a nearby, hydrologically similar gage. While statistics were computed for pre-regulation, post-regulation and the entire period of record for gages with upstream regulation, only the post-regulation conditions are transferred to bridges. To transfer either pre-regulation or entire period statistics to sites upstream and downstream based on drainage area ratios, follow the example shown below.

Example. Transfer the $Q_{7,10}$ computed from pre-regulation conditions from gage 01541500 on Clearfield Creek to a site upstream with a drainage area of 194 mi^2. The drainage area at the gage is 371 mi^2 and the $Q_{7,10}$ is 21 ft^3/s.

1 Determine the drainage area (DA) ratio:

$DA_{site} / DA_{gage} = 194 / 371 = 0.52$

2. Multiply the calculated ratio times the low-flow statistic at the gage:

$0.52 * 21 = 11$ ft^3/s

The period of record for a gage can also influence computed low-flow statistics. Short period of records which include one or more droughts can result in a lowered low-flow statistic. A gage which was operated for a short period during wet conditions, with the absence of any drought periods, can have associated elevated low-flow statistics. A gage should ideally have a period of record which contains both normal and drought conditions extended throughout a long period of time. The period of record shown for each gage in the website application should be inspected to ensure that the computed low-flow statistic is applicable to the specified needs of the user.

Low-flow statistics from gages were transferred to approximately 2,700 hydrologically similar (including streams affected by carbonate bedrock, mining, and regulation) ungaged locations upstream and downstream from the gages on the basis of drainage-area ratios (ratios). To determine a ratio range appropriate for transferring low-flow statistics, the $Q_{7,10}$ statistics from 74 gages reported by Ehlke and Reed (1999) were compared. To maximize the number of applicable paired gages used in the analysis, some gages were used in multiple paired comparisons. This analysis produced 92 comparisons from 46 paired gages that are hydrologically similar and have ratios ranging from 0.24 to 4.2 times.

Low-flow regionalization was last done in Pennsylvania by the USGS in 1982. Flippo (1982b) presented 12 regional regression equations for estimating $Q_{7,10}$ statistics at ungaged locations in Pennsylvania and reported that two-thirds of the regression estimates were expected to be within standard errors of estimate, that range from 20 to 45 percent (Flippo, 1982a, 1982b). For this study, the $Q_{7,10}$ statistic and the median standard error of estimate from Flippo (1982b), 33 percent, were selected as analysis tools for testing the transferred statistics.The $Q_{7,10}$ statistic was chosen as the representative statistic because it is the only commonly used low-flow statistic the regression equations predict.

Results of the analyses are listed in table 1 and shown in figures 1, 2, and 3. Included in table 1 for each paired comparison are the gage numbers, periods of record by climatic year, drainage areas, drainage-area ratios, the $Q_{7,10}$ statistics reported in Ehlke and Reed (1999), the transferred $Q_{7,10}$ statistics that use the ratios, and the absolute percent differences between the reported and the transferred $Q_{7,10}$ statistics. The largest absolute percent difference, 125 percent, is at a 1.8 ratio, and the smallest percent difference, 0.29 percent, is at a 0.41 ratio (table 1).

http://pa.water.usgs.gov/pc38/flowstats/revised_deplowflow.pdf

The relation between ratio and absolute percent difference for the 92 comparisons is shown in figure 1. Vertical solid and dashed lines are superimposed at ratio ranges of one-third to three times and one-half to two times, respectively. The median standard error of estimate for regression from Flippo (1982b), 33 percent, is superimposed as a horizontal dashed line for validity testing. Of the 76 comparisons that fall within the ratio range of one-third to three times, 62, or 82 percent, have absolute percent differences less than or equal to the median standard error of estimate for regression. Of the 64 comparisons that fall within the ratio range of one-half to two times, 53, or 83 percent, have absolute percent differences less than or equal to the median standard error of estimate for regression. Extending the range from one-half to two times to one-third to three times results in 12 additional sites, 9 of which have absolute percent differences less than or equal to the median standard error of estimate for regression. The median absolute percent difference for both the one-third to three times ratio and the one-half to two times ratio ranges is 14 percent, which is lower than the median standard error of estimate for regression from Flippo (1982b). Of the 16 comparisons that fall outside the one-third to three times ratio, only 3, or 19 percent, have absolute percent differences less than the median standard error of estimate for regression.

A comparison between the computed $Q_{7,10}$ statistics as reported in Ehlke and Reed (1999) and the 76 transferred $Q_{7,10}$ statistics that are within the one-third to three times ratio is shown in figure 2. The greatest outlier occurs at 3,210 ft^3/s, with a transferred $Q_{7,10}$ equalling 2,110 ft^3/s (fig. 2). An analysis of the relation between absolute percent difference and drainage area, not included herein, revealed no bias.

The relation between the absolute percent difference and the gage period of record for the 76 transferred $Q_{7,10}$ statistics that are within the one-third to three times ratio is shown in figure 3. Vertical dashed lines are superimposed at 20 and 40 years of record, and the median standard error of estimate for regression from Flippo (1982b), 33 percent, is superimposed as a horizontal dashed line. Of the 33 gages with less than 20 years of record, 8, or 24 percent, have absolute percent differences that exceed the median standard error of estimate for regression. Of the 20 gages with periods of record between 20 and 40 years, 4, or 20 percent, have absolute percent differences that exceed the median standard error of estimate for regression. And of the 23 gages with more than 40 years of record, only 1, or 4 percent, has an absolute percent difference that exceeds the median standard error of estimate for regression.

Conclusions

While the analyses discussed herein do not categorically preclude the use of ratios outside the one-third to three times range to transfer computed low-flow statistics on hydrologically similar streams in Pennsylvania, they do suggest the one-third to three times ratio is as appropriate as a one-half to two times ratio as a maximum range. In addition, the validity tests discussed herein indicate that transferring low-flow statistics computed at long-term gages to hydrologically similar, upstream and downstream ungaged locations within a one-third to three times ratio range is as reliable as, if not more than, the regression equations developed by Flippo (1982b) to estimate $Q_{7,10}$. Because the $Q_{7,10}$ statistic is representative of what is often considered very low-flow conditions, the method discussed herein should produce similar results with other low-flow statistics.

Table 1. Comparison of 7-day 10-year low-flow statistics ($Q_{7,10}$) with those developed using drainage-area ratios as a basis for transferring statistics upstream and downstream to hydrologically similar locations

[climatic year, 12-month period from April 1 to March 31; mi^2, square miles; $Q_{7,10}$ statistics from Ehlke and Reed (1999); ft^3/s, cubic feet per second; transferred $Q_{7,10}$ values were computed using unrounded drainage-area ratios]

U.S. Geological Survey Stream-flow-gaging station	Period of record (climatic year)	Drainage area (mi^2)	Drainage-area ratio	$Q_{7,10}$ (ft^3/s)	Transferred $Q_{7,10}$ (ft^3/s)	Absolute value of percent difference
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
01447500	1945-96	91.7	.28	13.3	19.2	44
01448000	1918-59	322	3.5	67.4	46.7	31
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
01465770	1966-81	5.08	.24	.44	.54	23
01465798	1967-94	21.4	4.2	2.26	1.85	18
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
01467086	1967-88	16.6	.55	4.36	1.93	56
01467087	1984-94	30.4	1.8	3.55	7.98	125
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
01467087	1984-94	30.4	.90	3.55	5.92	67
01467089	1967-81	33.8	1.1	6.58	3.95	40
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
01470960	1967-78	175	.83	38.5	39.4	2.3
01471000	1952-79	211	1.2	47.5	46.4	2.3
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
01471510	1979-95	880	.77	245	216	12
01472000	1935-96	1,147	1.3	281	319	14
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
01472500	1886-1913	152	.54	14.4	8.17	43
01473000	1916-55	279	1.8	15.0	26.4	76
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
01480700	1975-96	60.6	.67	14.5	19.3	33
01480870	1975-94	89.9	1.5	28.6	21.5	25
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
01518862	1985-95	90.6	.30	1.14	.64	44
01520000	1953-76	298	3.3	2.10	3.75	79
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

http://pa.water.usgs.gov/pc38/flowstats/revised_deplowflow.pdf

Table 1. Comparison of 7-day 10-year low-flow statistics ($Q_{7,10}$) with those developed using drainage-area ratios as a basis for transferring statistics upstream and downstream to hydrologically similar locations

[climatic year, 12-month period from April 1 to March 31; mi^2, square miles; $Q_{7,10}$ statistics from Ehlke and Reed (1999); ft^3/s, cubic feet per second; transferred $Q_{7,10}$ values were computed using unrounded drainage-area ratios]

U.S. Geological Survey Stream-flow-gaging station	Period of record (climatic year)	Drainage area (mi^2)	Drainage-area ratio	$Q_{7,10}$ (ft^3/s)	Transferred $Q_{7,10}$ (ft^3/s)	Absolute value of percent difference
01533400	1978-96	8,720	1.1	622	650	4.4
01531500	1915-95	7,797	.78	581	643	11
01536500	1900-96	9,960 Wilkes-Barre	1.3	821	742	9.6
01534500	1961-96	108	.33	18.0	11.6	36
01536000	1961-95	332	3.1	35.2	55.3	57
01536500	1900-96	9,960	.89	821	898	9.4
01540500	1906-96	11,200	1.1	1,010	923	8.6
01536500	1981-96	9,960	.41	874	1,320	52
01570500	1981-95	24,100	2.4	3,210	2,110	34
01541200	1967-95	367	.77	43.6	45.5	4.4
01541303	1980-95	474	1.3	58.8	56.3	4.3
01546400	1985-95	58.5	.67	15.0	19.3	29
01546500	1942-94	87.2	1.5	28.7	22.4	22
01547200	1957-96	265	.78	99.9	75.0	25
01547500	1956-70	339	1.3	96.0	128	33
01548500	1919-95	604	.81	23.8	26.4	11
01549000	1910-20	750	1.2	32.8	29.6	9.8
01548500	1919-95	604	.64	23.8	24.2	1.7
01549700	1962-95	944	1.6	37.9	37.2	1.8
01551500	1958-95	5,682	.83	584	604	3.4
01553500	1962-95	6,847	1.2	728	704	3.3
01554000	1981-95	18,300	1.6	2,150	1,960	8.8
01540500	1981-95	11,220 Danville	.61	1,200	1,320	10
01554000	1981-96	18,300	.76	2,150	2,440	13
01570500	1981-96	24,100	1.3	3,210	2,830	12
01563500	1939-71	2,030	.61	241	222	7.9
01567000	1901-71	3,354	1.7	367	398	8.4
01570500	1892-1978	24,100	.93	2,530	2,510	.79
01576000	1933-96	25,990	1.1	2,710	2,730	.74
03016000	1943-96	3,660	.48	394	368	6.6
03031500	1934-95	7,671	2.1	772	826	7.0
03019500	1940-79	233	.50	16.4	12.2	26
03019000	1924-40	469	2.0	24.6	33.0	34
03020500	1934-96	300	.95	30.6	32.1	4.9
03021000	1911-32	315	1.0	33.7	32.1	4.7
03022500	1925-39	629	.63	31.7	45.6	47
03023500	1910-25	998	1.6	72.5	49.2	32

http://pa.water.usgs.gov/pc38/flowstats/revised_deplowflow.pdf

***Table 1.** Comparison of 7-day 10-year low-flow statistics ($Q_{7,10}$) with those developed using drainage-area ratios as a basis for transferring statistics upstream and downstream to hydrologically similar locations*

[climatic year, 12-month period from April 1 to March 31; mi^2, square miles; $Q_{7,10}$ statistics from Ehlke and Reed (1999); ft^3/s, cubic feet per second; transferred $Q_{7,10}$ values were computed using unrounded drainage-area ratios]

U.S. Geological Survey Stream-flow-gaging station	Period of record (climatic year)	Drainage area (mi^2)	Drainage-area ratio	$Q_{7,10}$ (ft^3/s)	Transferred $Q_{7,10}$ (ft^3/s)	Absolute value of percent difference
03023500	1910-25	998	.97	72.3	60.2	17
03024000	1934-70	1,028	1.0	62.0	74.5	20
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
03029000	1941-51	303	.38	25.3	21.6	15
03029500	1940-51	807	2.7	57.4	67.4	17
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
03063000	1938-55	2,720	.62	290	286	1.4
03072500	1940-95	4,407	1.6	463	470	1.5
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
03082500	1927-96	1,326	.77	209	244	17
03083500	1928-95	1,715	1.3	316	270	15
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
03104000	1912-32	608	.77	14.7	12.5	15
03104500	1914-32	792	1.3	16.3	19.1	17

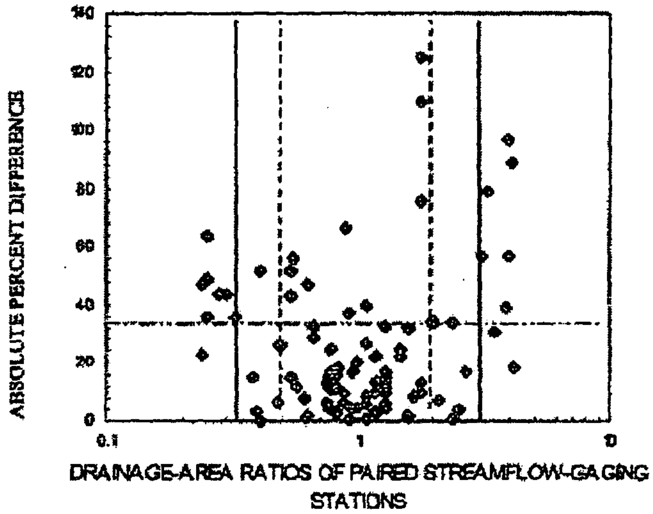


Figure 1.–Relation between drainage-area ratios and absolute percent differences for the streamflow-gaging stations (vertical, black solid lines encompass the one-third to three times ratio, vertical, blue dashed lines encompass the one-half to two times ratio, and horizontal red dashed line represents the median standard error of estimate for regression from Flippo, 1982b)

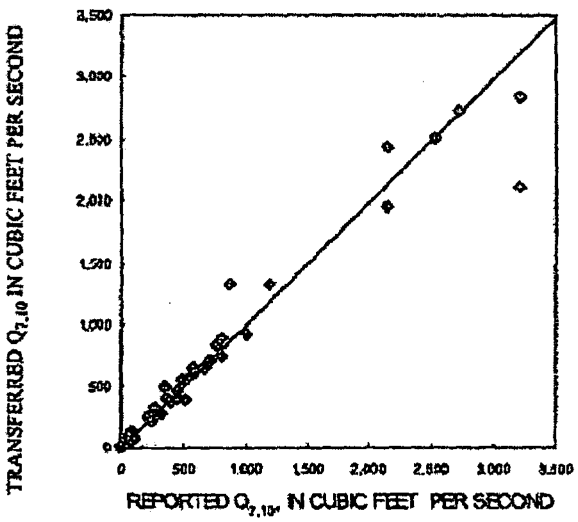


Figure 2.–Comparison between the $Q_{7,10}$ statistics reported in Ehlke and Reed (1999) and the corresponding transferred $Q_{7,10}$ statistics within the one-third to three times ratio range

http://pa.water.usgs.gov/pc38/flowstats/revised_deplowflow.pdf

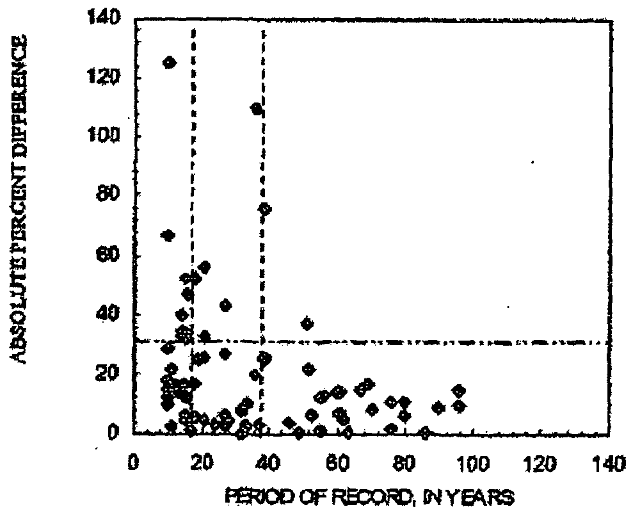


Figure 3.--Relation between the periods of record and the absolute percent differences (vertical, blue dashed lines represent 20 and 40 years of record, and horizontal red dashed line represents the median standard error of estimate for regression from Flippo, 1982b)

Glossary

1-day 10-year low flow ($Q_{1,10}$), in cubic feet per second, is the average minimum streamflow expected for 1 day once every 10 years.

7-day 10-year low flow ($Q_{7,10}$), in cubic feet per second, is the average minimum streamflow expected for 7 consecutive days once every 10 years.

30-day 10-year low flow ($Q_{30,10}$), in cubic feet per second, is the average minimum streamflow expected for 30 consecutive days once every 10 years.

Climatic year is a 12-month period from April 1 to March 31.

Flow-duration table, in cubic feet per second, includes the streamflow that was equaled or exceeded for indicated percentage of time.

Harmonic mean, in cubic feet per second, is the reciprocal of the arithmetic mean of the reciprocals of a set of streamflow values for a specific period of record (Spiegel, 1961).

Mean, in cubic feet per second, is the average flow for a stream during a specific period of record.

Median, in cubic feet per second, is the flow of a stream for which there are equal numbers greater than or less than flow occurrences during a specific period of record.

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