

Effect of Recurring Large Floods on Estimated Base Flood Elevations along the Delaware River

D. Brandes[1] and D. A. Kucz[2]

[1]Associate Professor and [2]Student, Department of Civil & Environmental Engineering, Acopian Engineering Center, Lafayette College, Easton, PA 18042; PH (610) 330-5441; email: brandesd@lafayette.edu

Abstract

The past three annual peak flows on the Delaware River (September 19, 2004; April 4, 2005; and June 29, 2006) all placed within the top ten on record. This unusual succession of events has led to much speculation about the possible causes of the floods, ranging from urbanization to climate change to improper upstream reservoir operation. Regardless of the causes, these events suggest that the flood frequency relationships and the associated 100-yr floodplain boundaries shown on current FEMA flood insurance rate maps (based on pre-1985 data) need to be revised. In this paper we conduct flood frequency analysis on data from four USGS gages along the non-tidal Delaware River to determine: 1) how much the estimated 100-, 50-, and 25-yr floods and corresponding flood elevations are affected by inclusion of the past 20 years of annual peak flow data; and 2) which of four candidate probability distributions best fits the systematic records. Based on the conventional Log Pearson Type III (LP3) method, including the last 20 years of data has increased the estimated 100-yr flood elevations by 1.4–3.3 feet at the four gages. However, the Wakeby distribution provides a better fit than LP3 for large flood events ($p_{exc} < 0.1$) at three of the four stations, and results in further increases (0.6 to 1.8 ft) in the estimated 100-yr flood elevations. These increases have significant implications to delineation of the 100-yr floodplain and associated land use regulations.

Background

Floods have caused more economic damage than any other natural hazard in the U.S. (USGAO, 2003), and continue to result in several billion dollars worth of damage annually (Pielke et al., 2002). The 100-yr floodplain boundaries shown on FEMA flood insurance rate maps have major implications to land use decisions and floodplain policy. However, the inherent uncertainty in these maps is not well appreciated by the public or municipal officials, nor is the fact that additional years of record may have a significant impact on the estimated floodplain boundaries. For example, existing floodplain mapping along the Delaware River is based on studies conducted prior to 1985 (NJFMTF, 2006); however, the past three annual maximum peak flows on the Delaware (September 19, 2004; April 4, 2005; and June 29, 2006) all placed within the top ten floods in approximately 100 years of systematic record and another 100+ years of historic records. This unusual succession of events has led to questions from the public such as “how could we have three 100-yr floods in a row?” and much speculation by affected residents about the causes of the floods, ranging from urbanization to climate change to improper upstream reservoir operation. Rather than the investigating the causality issue, this paper focuses on the question of how these events (and others since the last flood insurance study) have affected the estimated 100-yr flow and corresponding stage height at representative streamflow gages along the Delaware River.

Methods

Gage selection. Data from four USGS gages with relatively long records were selected for analysis (see Table 1 and Figure 1). The annual peak flow data from each gage was segregated into two groups: pre-1985 only, and the entire record through 2006.

Table 1. Gaging stations used for frequency analyses

Gage station	USGS ID	Years of Record	Drainage Area (mi^2)
Riegelsville, NJ	01457500	1907-present	6328
Belvidere, NJ	01446500	1923-present	4535
Port Jervis, NY	01434000	1904-present	3070
Barryville, NY	01428500	1940-present	2020

Figure 1. Location of selected USGS gaging stations in the Delaware River basin (basemap from www.state.nj.us/drbc/edweb/maps.htm)

Figure 2 shows the annual peak flow data for the Riegelsville gage, the farthest downstream of the four gages included in the study. Note the magnitude of the peak flows for the three most recent years, as well as the 1955 flood of record.

Although there are no dams along the mainstem of the Delaware River, there are several on tributaries (see Figure 1). These include the Cannonsville and Pepacton water supply reservoirs in the basin headwaters, Lake Wallenpaupack Hydroelectric Station, and Francis Walter Dam, a flood control/recreation facility on the Lehigh River. Although these facilities likely have some impact on the magnitude of floods at the selected gages, based on the Mann-Kendall test there are no significant trends in the annual peak flows at any of the four gages.

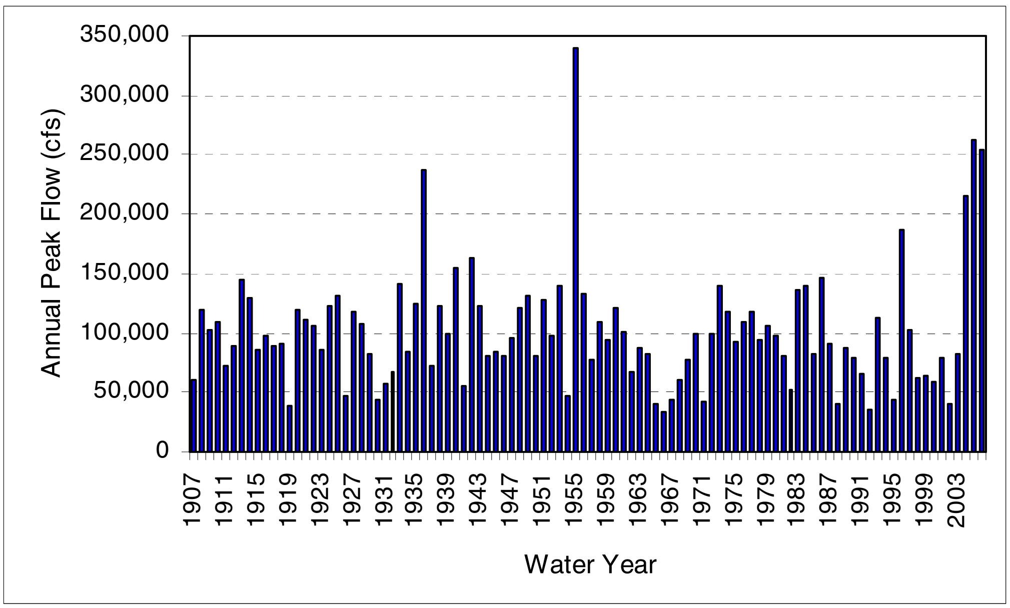

Figure 2. Annual peak flows for the Delaware River at Riegelsville (USGS 01457500)

Frequency Distributions. Four frequency distributions were used in the study: log-Pearson Type III (LP3) (Bulletin 17B, USWRC, 1982), Wakeby (WA), 3-parameter log-normal (3PLN), and generalized extreme value (GEV). These distributions have also been used in much of the recent work on flood frequency analysis (e.g. Vogel and Wilson, 1996; Douglas and Vogel, 2006). For the LP3 method, conventional moments and weighted station/generalized (map) skew was used as per Bulletin 17B. Although the 1955 flood of record exceeds the Bulletin 17B "high outlier threshold" for the pre-1985 dataset, it does not exceed this threshold for the entire dataset (through 2006). For consistency in methodology across both time periods, the 1955 flood was treated the same as all other datapoints. The empirical peak flow data was plotted using the Weibull formula, and goodness-of-fit was determined by mean square error (MSE) calculated for datapoints with $p_{exc} < 0.1$ (i.e., only 10-year and larger peak flows were included in the MSE calculation). The WA, 3PLN, and GEV distributions were fit using the EasyFit 3.0 software package (MathWave Technologies, 2006).

Historical Flood Data. Historical stage heights at Easton, PA were obtained from a compilation by Miller et al. (1939), which includes many flood events from the 18th and 19th centuries. Because there is no systematic flow gaging at Easton, these historic stage values were translated to the Belvidere, NJ gage (approx 10 miles upstream) by linear correlation, using data for more recent events when peak stages were recorded at both locations. A close correlation was found ($r^2 = 0.99$) between flood stages at Easton and Belvidere. The Bulletin 17B weighted moments methodology was then used to assess the impact of these historical data on the estimated 100-yr, 50-yr, and 25-yr flows for the Belvidere, NJ gage.

Results

LP3 fit of pre-1985 vs through WY2006 annual peak flows. The LP3 method was used to determine the effect of inclusion of the recent annual peak flow data on the estimated 100-yr, 50-yr, and 25-yr flows. Results are summarized in Table 2, and indicate that the estimated 100-yr flows increase by ~15%, the 50-yr flows increase by ~12%, and the 25-yr flows increase by ~9%. The corresponding stage height increases are also shown in Table 2. For the 100-yr flow, the stage increases vary from 1.4 ft to 2.9 ft.

Table 2. Estimated 100-, 50-, and 25-year flows via LP3 method

	100-year flow				50-year flow			
	Pre-1985 flow (cfs)	Up to 2006 flow (cfs)	% Change	Δ in Stage ht. (ft)	Pre-1985 flow (cfs)	Up to 2006 flow (cfs)	% Change	Δ in Stage ht. (ft)
Riegel	232,444	267,568	15.1	2.9	209,314	234,357	12.0	2.2
Belv	208,167	242,821	16.6	2.1	185,720	209,837	13.0	1.6
Port J	165,239	189,129	14.5	1.4	146,968	163,595	11.3	1.0
Barryv	125,743	152,014	20.9	3.3	111,469	130,049	16.7	2.4

	25-year flood			
	Pre-1985 flow (cfs)	Up to 2006 flow (cfs)	% Change	Δ in Stage ht. (ft)
Riegel	186,855	203,546	8.9	1.5
Belv	164,177	179,823	9.5	1.1
Port J	129,490	140,261	8.3	0.7
Barryv	97,892	110,261	12.6	1.7

Comparison of frequency distributions. The four candidate frequency distributions were ranked based on MSE ($p_{exc} < 0.1$) at each of the four gaging stations using the entire record through WY2006. Table 3 indicates that the LP3, WA, and GEV methods performed better than the 3PLN method, with the WA method performing best at three of the four stations. Figure 3 gives a visual comparison of LP3 and WA fits for the Belvidere, NJ data. Although the differences appear minor, the effect on estimated 100-yr flows is significant, as shown in Table 4. It is apparent that the WA method results in a higher estimated flow than the LP3 in almost all cases, with a maximum of 8.6% increase for the estimated 100-yr flow (and corresponding 1.8 ft stage increase) at the Riegelsville gage.

Table 3. MSE rank (for $p_{exc} < 0.1$) for candidate PDFs at each gaging station

	LP3	WA	GEV	3PLN
Riegel	2	1	3	4
Belv	2	1	3	4
Port J	3	1	2	4
Barryv	3	4	2	1

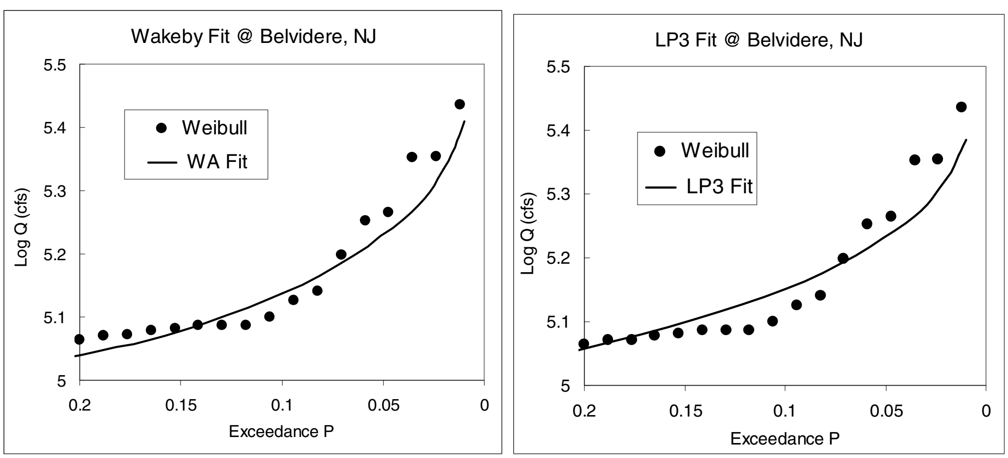

Figure 3. Visual comparison of WA and LP3 fits for the Belvidere, NJ data

Effect of Historical Flood Data. The historical data included four events (1841, 1862, 1901, and 1903) which are among the ten largest ever recorded as well as many others that are within the top 20 events. However, the three largest events (1955, 2005, and 2006) are within the period of record of the gage. Following the Bulletin 17B weighted-moments procedure, values of 252,557 cfs, 217,363 cfs, and 185,150 cfs were found for the 100-yr, 50-yr, and 25-yr flows at Belvidere, respectively. These are 3-4% larger than the estimated values using only the systematic record. So it appears that the impact of historical data is relatively minor in this particular case. However, further work is being conducted on this issue as others (e.g. Stedinger and Cohn, 1986) have shown limitations with the Bulletin 17B method for incorporating historical data into flood frequency analysis.

Table 4. Estimated 100-, 50-, and 25-yr flows and stages for the LP3, WA, and GEV fits.

		LP3	WA			GEV		
	T (yr)	Q (cfs)	Q (cfs)	Δh from LP3 (ft)	% Diff in Q	Q (cfs)	Δh from LP3 (ft)	% Diff in Q
Riegel	25	203,546	195,640	-0.71	-3.9%	199,950	-0.28	-1.8%
	50	234,357	238,070	0.31	1.6%	230,350	-0.29	-1.7%
	100	267,568	290,631	1.81	8.6%	262,110	-0.37	-2.0%
Belv	25	179,823	179,179	-0.04	-0.4%	178,070	-0.12	-1.0%
	50	209,837	215,858	0.38	2.9%	209,520	-0.02	-0.2%
	100	242,821	257,279	0.84	6.0%	243,630	0.05	0.3%
Port J	25	140,261	140,903	0.04	0.5%	139,620	-0.04	-0.5%
	50	163,595	169,149	0.33	3.4%	164,870	0.08	0.8%
	100	189,129	200,467	0.63	6.0%	192,390	0.18	1.7%
Barryv	25	110,261	110,507	0.03	0.2%	109,370	-0.12	-0.8%
	50	130,049	134,153	0.52	3.2%	130,570	0.07	0.4%
	100	152,014	160,700	1.04	5.7%	154,030	0.24	1.3%

Conclusion

The results of this study suggest that estimated 100-yr flows on the Delaware River have increased by approximately 15-20% since the last flood insurance study due to the additional data available for estimating flood frequency relationships. Corresponding 100-yr stage increases are approximately 1.4 to 3.3 feet, depending on location. The Wakeby distribution provides a better fit than LP3 for large flood events ($p_{exc} < 0.1$) at three of the four stations, and results in further increases (0.6 to 1.8 ft) in the estimated 100-yr flood elevations. The LP3 and the GEV distributions performed similarly.

The results illustrate the fact that consecutive large flood events can have significant impact on the estimated 100-yr floodplain boundaries and flood frequency relationships need to be updated following such occurrences. The rigidity with which floodplain boundaries are typically interpreted to delineate the boundary of flood risk does not reflect the reality that these boundaries are simply estimates (due to lack of data, as well as uncertainty in the underlying flood frequency distribution) that are subject to change. Considering that the result of *over*estimation of the floodplain boundary might be limited to unnecessary development restrictions, while the eventual result of *under*estimation of the floodplain boundary could be catastrophic loss of property and life, it seems prudent to adopt a conservative approach to floodplain delineation along the Delaware River and elsewhere.

Acknowledgment

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