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COMPARISON OF ABOVE AVERAGE SNOWFALL SEASONS TO THE OCCURRENCE OF WINTER AND SPRING TIME RIVER FLOODING IN THE SUSQUEHANNA RIVER BASIN

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1. INTRODUCTION

A common perception in Pennsylvania, and, in particular, the Susquehanna River Basin, is that a winter season with above average snowfall usually yields a winter or early spring flood. An examination was made to compare years with above average snowfall to the occurrence of winter/spring flooding in the Susquehanna River Basin. Of particular interest was whether seasonal snowfall totals alone were a strong indicator of winter/spring flooding. Data from the past 70 snow seasons was used to analyze flooding across both the winter and early spring time frames.

2. METHODOLOGY

Annual snowfall data was obtained for a 70-year period spanning the winter seasons of 1926-27 through 1995-1996 for Harrisburg, Williamsport, and Wilkes-Barre, PA as well as Binghamton, NY. An average basin annual snowfall value was calculated by first determining the mean annual snowfall for each of the four stations and secondly, determining the average of the four station mean values. This technique produces an average annual snowfall of 51 inches for the Susquehanna Basin. This value is not entirely representative as a basin average snowfall, in part because no station data from the westernmost portion of the basin was included. It does, however, contain enough information to enable comparisons between snow seasons.

There were some minor gaps in the data for all locations except Harrisburg. When data was missing for one of the locations, data was available for the other three stations. For instance, when snowfall data was not available for Binghamton, such as during the 1939-1940 snow season, the data was still available for Wilkes-Barre, Williamsport, and Harrisburg. For these situations, the basin average snowfall was calculated using data from the three available stations and was compared to the long term 70 year mean for just those three stations. The long term basin average snowfall calculated with only three stations varied somewhat from the value derived from all four.

At times, early in the observation record, cooperative observers supplemented snowfall data when National Weather Service (NWS) observing sites were not yet established at Binghamton, Wilkes Barre, and Williamsport. Consequently, changes in observer locations at these cities produced variations in average seasonal snowfalls. The cooperative observers' snowfall measurements were "corrected" using a weighting factor to adjust the values to coincide with average snowfall values obtained from NWS observing sites. These variations were all taken into account to reach an average snowfall. For example, at Binghamton, NY, the average seasonal snowfall at the official NWS site is 81.5 inches. These observations were available since the 1948-49 snow season. Prior to that, a cooperative observer took snowfall measurements. Due to variations in observing locations, time of observations, and observing techniques, the average snowfall for these seasons was only 49.4 inches. To "correct" these observations, the snowfall values were multiplied by a weighting factor of 1.65 to make them more representative of NWS observations. Similarly, weighting factors were used at both Wilkes-Barre and Williamsport. At Wilkes-Barre, a weighting factor of 1.44 was used for the seasons 1926-27 through 1951-52. A second cooperative observer supplied observations from 1958-59 through 1963-64. For these observations, a weighting factor of 1.50 was used to standardize observations. At Williamsport, a weighting factor of 1.25 was used for snow seasons 1926-27 through 1944-45. Table 1, "Seasonal Snowfall Statistics in Inches," summarizes the adjusted snowfall data.

A snow season was considered to be snowier than average if the averaged snowfall for that season for the reporting stations was higher than the average annual basin snowfall, even if by only one tenth of an inch. Basin-wide, 33 of the 70 snow seasons were identified as snowier than average.

The maximum winter and spring river discharges at Williamsport (West Branch Susquehanna River), Towanda and Wilkes-Barre (upper Main Stem of the Susquehanna River), Newport (Juniata River), and Harrisburg (lower Main Stem of the Susquehanna River) for each year were reviewed to identify flood events. A flood occurred if peak flow exceeded flood flow as officially defined by the NWS. A basin-wide flood occurred if flood flow was exceeded for at least three of the five locations during the December 1 through May 1 time-frame. The peak flows and corresponding dates are included in Table 2, "Annual Peak Flows for Winter/Spring Season in the Susquehanna Basin." Above average snowfall seasons are shaded. Those readings that were above flood flow are also shaded. Table 3, "Basin Comparison of Above Normal Snowfall to Flooding in the Susquehanna Basin" contains the summary of results.

3. RESULTS AND CONCLUSIONS

A binomial probability distribution (Equation 1, below), was applied to the data set in Table 2 to examine whether an increase in the frequency of floods observed for above average snowfall seasons was likely given the historical flood frequency derived from the 70 year data set.

$$\text{Prob}\begin{pmatrix}\text{observing x successes}\\ \text{in n trials}\end{pmatrix} = \binom{n}{x} p^{x}(1-p)^{n-x}$$

{Eq. 1}

where n = number of above average snowfall seasons,
x = number of above average snowfall seasons with observed flooding,
p = probability of observing a flood in any given year, and

$$\binom{n}{x} = \frac{n!}{x!(n-x)!}$$

Using Equation 1 in conjunction with the data set yields the following results.

In the 70-year time frame, 16 basin-wide floods occurred. Therefore, the "expected" probability of flooding, p, for any season is 16 out of 70 years, 0.23 or 23%. The number of above average snow seasons, *n*, was 33. The "observed" number of basin-wide floods, *x*, that occurred during or at the end of an above average snowfall season was 12. During seasons with above average snowfall, 12 of 33 years experienced basin-wide flooding. Given the 23% chance for flooding, one would "expect" 0.23*33 = 7.5 floods in 33 years. Since 12 floods actually occurred, the increase over what was expected was 60%. Using the binomial distribution above, the probability of experiencing exactly 12 floods in a 33-year period is only 0.032 or 3.2%.

Hypothesis testing and a summation of binomials can be used to assess whether the 12 basin-wide floods in 33 years with above average snowfall is, statistically, significantly higher than the 70-year average. Using a significance level of 0.10, a probability derived from the summation of binomials of less than 0.10 means that the event occurred significantly more often than the historical average. A confidence level of 90% (significance level of 0.10) was selected rather than perhaps a more typical value of 95% in recognition of the following:

a) The assignment of individual snow seasons as above or below average was not always straightforward; consequently, the probability statistics would change slightly based on the techniques used,
b) The criterion for basin-wide flooding was somewhat arbitrary, and
c) A relatively small number of observing stations were used to represent the Susquehanna Basin.

The null hypothesis, which is expected to be false, is winter seasons with above average snowfall are followed by the same or less winter/early spring flooding than usually observed. The alternative hypothesis, which is expected to be true, is winter seasons with above average snowfall seasons are followed by more winter/early spring flooding than usually observed. Applying Equation 2

$$\text{Prob}\begin{pmatrix}\text{observing b or more}\\ \text{successes in n trials}\end{pmatrix} = \sum_{x=b}^{n} \binom{n}{x} p^{x} (1-p)^{n-x}$$

{Eq. 2}

where n = number of above average snowfall seasons,
b = number of seasons where flooding and above average seasonal snowfall are coincident, and
p = probability of observing a flood in any given year.

to the data set using $n = 33$, $b = 12$ and $p = 0.23$ yields the following results. In this case, the probability from the summation of binomials is 0.058, which is less than 0.10. Thus, the alternative hypothesis is true. That is, basin-wide flooding occurred significantly more often in above average snow years than in the entire 70 year observation period. It is concluded with 90% confidence that basin-wide flooding occurs significantly more often in above average snowfall years.

Similar analyses were performed for Towanda, Wilkes-Barre, Williamsport, Newport, and Harrisburg. For the sake of consistency, above average snowfall on a basin-wide scale was used instead of an average snowfall for subareas, or individual stations, within the basin. This was still considered to be a useful test because it addresses the question of whether a snowier than average season increases the potential for flooding at individual locations. The results are presented in Table 4, "Statistical Analysis of the Susquehanna Basin." Flood frequency increases significantly for years with above average snowfall at all locations except Newport. At Newport, flooding is infrequent, four times in 70 years, and snow does not appear to be a significant factor. Seasons with above average snowfall produced floods 70%

of the time at Towanda, 52% at Wilkes-Barre, 33% at Williamsport, 45% of the seasons at Harrisburg, and 9% of the time at Newport.

The findings indicate that above average seasonal snowfall totals are not an absolute indicator of winter or spring flooding. But, when the basin averaged snowfall totals are above average, an increased likelihood for flooding exists. Accordingly, seasonal snowfall totals can be a useful indicator for determining the likelihood of winter/early spring flooding.

The analysis is still quite limited. Additional information, such as the water equivalents during the entire winter and spring seasons, could be used to determine the occurrence of flooding when the snow packs contained higher than average water equivalents. However, it is fair to say that in the Susquehanna River Basin above average seasonal snowfall does not necessarily result in winter or spring flooding. In the past 70 years, basin-wide river flooding has occurred in roughly one third of the winter and spring seasons with above average annual snowfalls. Two very important factors that limit the strong relation between years with above average seasonal snowfall and the occurrence of winter/spring flooding in the Susquehanna Basin are the variability of temperatures during the winter season and the relatively rapid hydrologic response of the basin. Multiple, significant melt events are common in Pennsylvania and southern New York during the course of a winter so that the water equivalent in the snow pack during periods of maximum melting might be significantly less than that represented by seasonal snowfall totals. A season with above average snowfall may not present a threat for snow melt flooding because periods of melting throughout the winter preclude the development of a deep snow pack. Additionally, the steep terrain and soil composition in the basin enables meltwater from contributing portions of the basin to work its way quickly through the basin. If a melt period occurs in the absence of heavy rain, the meltwater can pass through the basin without any resultant flooding.

This study is not intended to be used as a predictor in the middle of a snow season. However, it is intended to show that, when a season is viewed as a whole, above average snowfall increases the likelihood for flooding but does not make flooding a certainty. The conclusions of the study are only valid when applied to seasonal snowfall totals and do not address the potential for snow melt flooding at intermediate time frames within a snow season.

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Table 1. Seasonal Snowfall Statistics in Inches.

Season	Binghamton	Wilkes-Barre	Williamsport	Harrisburg	Basin Ave.	Season Ave.	Departure
1926-'27	104.9	54.1	50.0	19.2	51.0	57.1	6.1 above
1927-'28	94.4	42.0	47.6	36.6	51.0	55.2	4.2 above
1928-'29	59.1	26.1	19.0	22.1	51.0	31.6	-19.4
1929-'30	54.0	34.0	22.5	27.1	51.0	34.4	-16.6
1930-'31	76.4	57.2	32.5	10.9	51.0	44.3	-6.7
1931-'32	72.6	74.7	30.9	15.3	51.0	48.4	-2.6
1932-'33	59.2	49.7	24.1	24.6	51.0	39.4	-11.6
1933-'34	75.4	66.5	46.3	24.7	51.0	53.2	2.2 above
1934-'35	78.2	57.0	48.1	35.4	51.0	54.7	3.7 above
1935-'36	80.4	88.7	61.1	47.6	51.0	69.5	18.5 above
1936-'37	68.6	36.6	28.4	24.4	51.0	39.5	-11.5
1937-'38	38.6	47.1	25.6	8.8	51.0	30.0	-21.0
1938-'39	96.5	61.2	45.9	31.8	51.0	58.9	7.9 above
1939-'40	MISSING	61.6	54.3	26.9	40.8	47.6	6.8 above
1940-'41	MISSING	71.1	72.6	34.3	40.8	59.3	18.5 above
1941-'42	73.9	15.8	49.8	23.2	51.0	40.7	-10.3
1942-'43	82.7	51.1	40.1	35.3	51.0	52.3	1.3 above
1943-'44	68.1	6.5	28.3	25.9	51.0	32.2	-18.8
1944-'45	153.9	38.6	49.9	51.6	51.0	73.5	22.5 above
1945-'46	69.1	12.2	MISSING	28.1	54.3	36.5	-17.8
1946-'47	95.0	16.3	MISSING	28.3	54.3	46.5	-7.8
1947-'48	93.7	66.0	MISSING	41.8	54.3	67.2	12.9 above
1948-'49	25.3	40.6	22.3	33.1	51.0	30.3	-20.7
1949-'50	67.3	61.5	36.8	9.8	51.0	43.9	-7.1
1950-'51	69.3	45.9	43.2	19.6	51.0	44.5	-6.5
1951-'52	72.2	71.9	50.2	35.6	51.0	57.5	6.5 above
1952-'53	70.4	MISSING	22.7	24.2	51.8	39.1	-12.7
1953-'54	65.1	MISSING	28.8	28.9	51.8	40.9	-10.9
1954-'55	94.8	MISSING	36.7	19.3	51.8	50.3	-1.5
1955-'56	122.6	MISSING	45.4	38.2	51.8	68.7	16.9 above
1956-'57	90.2	MISSING	50.7	32.0	51.8	57.6	5.8 above
1957-'58	111.0	MISSING	49.1	41.6	51.8	67.2	15.4 above
1958-'59	78.7	31.7	39.6	25.4	51.0	43.9	-7.1
1959-'60	101.4	54.3	51.9	40.9	51.0	62.1	11.1 above
1960-'61	99.7	85.2	80.2	81.3	51.0	86.6	35.6 above
1961-'62	65.2	38.0	49.6	51.6	51.0	51.1	0.1 above
1962-'63	94.3	67.2	62.0	50.5	51.0	68.5	17.5 above
1963-'64	103.3	99.1	76.2	74.7	51.0	88.3	37.3 above
1964-'65	76.4	31.9	26.7	31.8	51.0	41.7	-9.3
1965-'66	80.3	45.1	39.1	42.6	51.0	51.8	0.8 above
1966-'67	88.3	74.9	64.7	48.4	51.0	69.1	18.1 above
1967-'68	63.6	32.6	29.0	31.0	51.0	39.1	-11.9

Table 1. Seasonal Snowfall Statistics in Inches (continued).

Season	Binghamton	Wilkes-Barre	Williamsport	Harrisburg	Basin Ave.	Season Ave.	Departure
1968-'69	64.5	36.7	18.3	25.0	**51.0**	**36.1**	**-14.9**
1969-'70	115.8	76.8	82.6	60.6	**51.0**	**84.0**	**33.0 above**
1970-'71	108.6	57.1	61.4	32.9	**51.0**	**65.0**	**14.0 above**
1971-'72	106.2	62.6	59.5	34.6	**51.0**	**65.7**	**14.7 above**
1972-'73	65.9	22.8	30.6	13.3	**51.0**	**33.2**	**-17.8**
1973-'74	86.7	52.2	40.6	27.8	**51.0**	**51.8**	**0.8 above**
1974-'75	67.1	43.2	38.8	31.0	**51.0**	**45.0**	**-6.0**
1975-'76	76.3	36.2	28.9	15.8	**51.0**	**39.3**	**-11.7**
1976-'77	72.3	54.0	41.9	23.1	**51.0**	**47.8**	**-3.2**
1977-'78	115.3	75.3	83.6	70.6	**51.0**	**86.2**	**35.2 above**
1978-'79	80.0	44.5	42.6	39.5	**51.0**	**51.7**	**0.7 above**
1979-'80	56.8	25.5	20.5	14.8	**51.0**	**29.4**	**-21.6**
1980-'81	59.3	40.5	41.6	24.8	**51.0**	**41.6**	**-9.4**
1981-'82	81.6	59.6	54.9	58.5	**51.0**	**63.7**	**12.7 above**
1982-'83	80.8	59.1	17.6	36.0	**51.0**	**48.4**	**-2.6**
1983-'84	70.9	39.4	42.5	31.6	**51.0**	**46.1**	**-4.9**
1984-'85	62.5	37.9	27.3	30.1	**51.0**	**39.5**	**-11.5**
1985-'86	76.3	49.3	31.2	36.5	**51.0**	**48.3**	**-2.7**
1986-'87	78.8	47.5	53.5	45.9	**51.0**	**56.4**	**5.4 above**
1987-'88	81.6	47.5	36.8	26.7	**51.0**	**48.1**	**-2.9**
1988-'89	46.4	7.3	7.0	19.9	**51.0**	**20.2**	**-30.8**
1989-'90	74.8	37.3	31.3	19.3	**51.0**	**40.7**	**-10.3**
1990-'91	67.3	31.3	28.1	21.1	**51.0**	**37.0**	**-14.0**
1991-'92	56.0	24.5	20.0	12.9	**51.0**	**28.4**	**-22.6**
1992-'93	122.7	60.3	55.8	47.2	**51.0**	**71.5**	**20.5 above**
1993-'94	131.3	91.8	89.5	75.9	**51.0**	**97.1**	**46.1 above**
1994-'95	52.8	25.0	12.8	9.0	**51.0**	**24.9**	**-26.1**
1995-'96	131.1	98.3	85.9	78.0	**51.0**	**98.3**	**47.3 above**
	Avg = 81.5 inches	**Avg = 48.4 inches**	**Avg = 41.0 inches**	**Avg = 33.0 inches**			

Table 2. Annual Peak Flows for Winter/Spring Season in the Susquehanna Basin.

Season	Towanda Flood Flow = 96,000 cfs	Wilkes-Barre Flood Flow = 127,000 cfs	Williamsport Flood Flow = 117,000 cfs	Harrisburg Flood Flow = 305,000 cfs	Newport Flood Flow = 83,000 cfs
Spr. 27	96,200 on 3/15 (fld)	92,700 on 3/15	117,000 on 1/22	208,000 on 3/23	34,000 on 3/9
28	70,900 on 3/27	71,500 on 3/26	69,100 on 12/17/27	246,000 on 4/30	55,000 on 4/29
29	165,000 on 4/22 (fld)	159,000 on 4/22 (fld)	94,500 on 3/15	235,000 on 3/17	47,500 on 4/17
30	65,100 on 3/8	67,600 on 3/9	54,700 on 2/27	177,000 on 2/28	30,500 on 2/26
31	67,500 on 3/29	74,700 on 3/30	46,500 on 4/3	153,000 on 3/31	19,500 on 4/2
32	88,000 on 4/1	107,000 on 4/2	75,600 on 4/1	245,000 on 4/2	40,600 on 4/1
33	54,500 on 3/13	62,500 on 3/23	71,800 on 3/16	168,000 on 3/22	38,000 on 3/16
34	77,400 on 3/6	85,500 on 3/6	48,800 on 1/2	141,000 on 4/14	23,500 on 1/10
35	99,500 on 1/10 (fld)	107,000 on 1/11	53,900 on 1/10	242,000 on 12/2/34	41,400 on 12/1/34
36	188,000 on 3/19 (fld)	232,000 on 3/20 (fld)	264,000 on 3/18	740,000 on 3/19 (fld)	190,000 on 3/19 (fld)
37	73,300 on 1/23	77,300 on 1/23	95,000 on 1/24	231,000 on 1/24	100,000 on 4/27 (fld)
38	62,100 on 1/26	50,000 on 3/27	80,600 on 12/19/37	178,000 on 12/20/37	20,500 on 3/16
39	128,000 on 2/21 (fld)	137,000 on 2/22 (fld)	51,600 on 2/21	210,000 on 2/23	28,400 on 2/4
40	176,000 on 4/1 (fld)	212,000 on 4/1 (fld)	146,000 on 4/1 (fld)	418,000 on 4/2 (fld)	58,000 on 4/1
41	122,000 on 4/6 (fld)	138,000 on 4/7 (fld)	72,500 on 4/6	244,000 on 4/7	21,000 on 4/6
42	109,000 on 3/10 (fld)	111,000 on 3/11	82,600 on 3/10	216,000 on 3/11	33,100 on 4/10
43	171,000 on 12/31/42 (fld)	191,000 on 1/1 (fld)	148,000 on 12/31/42 (fld)	412,000 on 1/1 (fld)	70,000 on 12/31/42
44	81,300 on 3/18	71,000 on 3/19	68,000 on 3/18	184,000 on 3/19	27,100 on 3/14 & 4/2
45	99,400 on 3/4 (fld)	119,000 on 3/5	97,000 on 3/4	252,000 on 3/5	39,200 on 3/8
46	84,500 on 3/10	94,800 on 3/10	58,800 on 3/9	212,000 on 3/10	33,500 on 12/1/45
47	132,000 on 4/6 (fld)	151,000 on 4/7 (fld)	49,600 on 4/6	214,000 on 4/7	12,800 on 3/17
48	168,000 on 3/23 (fld)	193,000 on 3/23 (fld)	124,000 on 4/15 (fld)	308,000 on 4/16 (fld)	51,000 on 4/15
49	72,500 on 12/31/48	82,700 on 12/31/48	51,500 on 12/31/48	220,000 on 1/1	30,500 on 12/31/48
50	148,000 on 3/29 (fld)	172,000 on 3/30 (fld)	101,000 on 3/29	300,000 on 3/30	32,200 on 2/15
51	124,000 on 3/31 (fld)	128,000 on 4/1 (fld)	119,000 on 3/31 (fld)	293,000 on 12/5/50	44,100 on 3/31
52	111,000 on 3/12 (fld)	124,000 on 3/13	96,000 on 3/12	324,000 on 3/13 (fld)	55,000 on 3/12
53	91,500 on 12/12/52	98,000 on 12/12/52	83,200 on 3/25	216,000 on 3/26	44,100 on 3/25
54	52,500 on 2/16	64,500 on 3/3	117,000 on 3/2	242,000 on 3/3	51,000 on 3/2
55	84,300 on 3/2	85,900 on 3/3	58,600 on 3/6	177,000 on 3/6	34,500 on 3/23
56	160,000 on 3/8 (fld)	186,000 on 3/9 (fld)	121,000 on 3/9 (fld)	338,000 on 3/10 (fld)	34,500 on 3/9
57	91,500 on 4/7	107,000 on 4/7	70,900 on 4/7	250,000 on 4/7	30,000 on 4/6
58	144,000 on 4/8 (fld)	170,000 on 4/8 (fld)	75,100 on 4/7	281,000 on 4/9	21,500 on 2/2
59	130,000 on 1/23 (fld)	113,000 on 1/23	150,000 on 1/22 (fld)	230,000 on 1/24	18,800 on 1/22
60	165,000 on 4/1 (fld)	201,000 on 4/2 (fld)	127,000 on 4/1 (fld)	382,000 on 4/2 (fld)	43,100 on 3/31
61	147,000 on 2/27 (fld)	163,000 on 2/27 (fld)	136,000 on 2/26 (fld)	392,000 on 2/27 (fld)	56,200 on 2/27
62	106,000 on 4/1 (fld)	128,000 on 4/2 (fld)	93,000 on 4/1	270,000 on 4/2	37,700 on 3/1
63	113,000 on 3/28 (fld)	131,000 on 3/28 (fld)	100,000 on 3/27	249,000 on 3/28	37,200 on 3/7
64	174,000 on 3/6 (fld)	228,000 on 3/10 (fld)	197,000 on 3/11 (fld)	484,000 on 3/12 (fld)	40,600 on 3/11
65	45,400 on 2/9	44,600 on 2/14	68,900 on 2/10	136,000 on 2/11	25,200 on 3/6
66	82,600 on 2/14	93,500 on 2/15	84,900 on 2/14	265,000 on 2/15	49,600 on 2/14

Table 2. Annual Peak Flows for Winter/Spring Season in the Susquehanna Basin (Continued).

Season	Towanda Flood Flow = 96,000 cfs	Wilkes-Barre Flood Flow = 127,000 cfs	Williamsport Flood Flow = 117,000 cfs	Harrisburg Flood Flow = 305,000 cfs	Newport Flood Flow = 83,000 cfs
67	70,200 on 3/29	84,800 on 3/29	67,300 on 3/16	182,000 on 3/17	47,500 on 3/7
68	89,200 on 3/24	101,000 on 3/24	52,600 on 3/24	202,000 on 3/25	20,100 on 3/24
69	72,900 on 4/6	80,500 on 4/7	32,300 on 4/7	127,000 on 4/8	9,800 on 3/27
70	95,400 on 4/3	115,000 on 4/4	91,400 on 4/3	343,000 on 4/4 (fld)	67,500 on 4/3
71	94,200 on 3/16	110,000 on 3/17	66,500 on 2/28	224,000 on 3/1	48,700 on 2/24
72	112,000 on 3/3 (fld)	121,000 on 3/4	97,900 on 3/3	324,000 on 3/4 (fld)	55,900 on 3/3
73	79,000 on 4/5	91,800 on 4/6	80,600 on 2/3	209,000 on 2/4	34,900 on 2/3
74	76,900 on 12/28/73	73,700 on 4/5	67,700 on 4/4	188,000 on 4/5	21,900 on 1/23
75	137,000 on 2/25 (fld)	154,000 on 2/26 (fld)	131,000 on 2/25 (fld)	364,000 on 2/26 (fld)	35,600 on 2/25
76	101,000 on 2/18(fld)	118,000 on 2/19	82,400 on 2/18	239,000 on 2/19	32,200 on 2/18
77	95,500 on 3/14	113,000 on 3/14	77,400 on 4/3	217,000 on 4/4	29,200 on 4/4
78	97,700 on 1/27 (fld)	115,000 on 3/23	71,000 on 3/24	252,000 on 3/24	30,500 on 3/23
79	179,000 on 3/6 (fld)	210,000 on 3/7 (fld)	147,000 on 3/6 (fld)	416,000 on 3/7 (fld)	49,200 on 3/6
80	89,100 on 3/22	104,000 on 3/23	56,300 on 3/22	205,000 on 3/23	30,700 on 3/22
81	84,600 on 2/21	104,000 on 2/22	105,000 on 2/21	291,000 on 2/24	41,100 on 2/24
82	51,800 on 3/27	66,100 on 3/27	61,600 on 3/27	151,000 on 3/16	29,600 on 3/14
83	85,100 on 4/16	138,000 on 4/16 (fld)	45,600 on 3/22	244,000 on 4/17	27,500 on 4/11
84	146,000 on 2/15 (fld)	186,000 on 2/16 (fld)	178,000 on 2/15 (fld)	426,000 on 2/16 (fld)	90,500 on 2/15 (fld)
85	48,800 on 3/13	55,800 on 3/14	50,500 on 4/2	129,000 on 4/3	34,000 on 4/2
86	131,000 on 3/16 (fld)	172,000 on 3/16 (fld)	90,900 on 3/15	357,000 on 3/16 (fld)	51,700 on 3/16
87	75,500 on 4/5	98,500 on 4/5	48,800 on 4/6	221,000 on 4/6	43,000 on 4/5
88	45,300 on 3/27	54,000 on 3/28	51,900 on 2/3	156,000 on 2/4	17,300 on 2/5
89	69,300 on 4/1	87,900 on 4/1	71,600 on 4/1	182,000 on 4/2	18,600 on 3/26
90	68,300 on 2/17	74,900 on 2/18	42,100 on 2/5	131,000 on 2/6	15,100 on 1/31
91	74,400 on 3/5	88,800 on 3/5	75,900 on 3/5	191,000 on 3/6	18,100 on 3/5
92	80,700 on 3/28	92,000 on 3/28	28,800 on 3/28	160,000 on 3/29	21,600 on 3/28
93	152,000 on 4/2 (fld)	185,000 on 4/2 (fld)	122,000 on 4/1 (fld)	410,000 on 4/2 (fld)	46,500 on 3/29
94	111,000 on 3/25 (fld)	148,000 on 3/26 (fld)	88,200 on 3/25	334,000 on 3/26 (fld)	52,600 on 3/25
95	59,600 on 1/21	72,100 on 1/22	64,500 on 1/21	175,000 on 1/21	31,900 on 1/21
96	180,000 on 1/20 (fld)	221,000 on 1/20 (fld)	191,000 on 1/20 (fld)	568,000 on 1/21 (fld)	103,000 on 1/20 (fld)

Note: **Shading under the "Season" column indicates an above average snowfall season.**
Shaded blocks with "fld" indicate when a flood occurred.

Table 3. Basin Comparison of Above Average Snowfall to Flooding in the Susquehanna Basin.

Above Normal Snowfall Seasons	Basin-wide Flooding	Towanda Flood	Wilkes-Barre Flood	Williamsport Flood	Harrisburg Flood	Newport Flood
1926-'27		YES				
1927-'28						
1933-'34						
1934-'35		YES				
1935-'36	YES	YES	YES		YES	YES
1938-'39		YES	YES			
1939-'40	YES	YES	YES	YES	YES	
1940-'41		YES	YES			
1942-'43	YES	YES	YES	YES	YES	
1944-'45		YES				
1947-'48	YES	YES	YES	YES	YES	
1951-'52		YES			YES	
1955-'56	YES	YES	YES	YES	YES	
1956-'57						
1957-'58		YES	YES			
1959-'60	YES	YES	YES	YES	YES	
1960-'61	YES	YES	YES	YES	YES	
1961-'62		YES	YES			
1962-'63		YES	YES			
1963-'64	YES	YES	YES	YES	YES	
1965-'66						
1966-'67						
1969-'70					YES	
1970-'71						
1971-'72		YES			YES	
1973-'74						
1977-'78		YES				
1978-'79	YES	YES	YES	YES	YES	
1981-'82						
1986-'87						
1992-'93	YES	YES	YES	YES	YES	
1993-'94	YES	YES	YES		YES	
1995-'96	YES	YES	YES	YES	YES	YES

Table 4. Statistical Analysis of the Susquehanna Basin.

	Basin-wide	Towanda	Wilkes-Barre	Williamsport	Harrisburg	Newport
Overall Winter/ Early Spring Flood Frequency	16 floods in 70 year 23%	33 floods in 70 year 47%	25 floods in 70 year 36%	15 floods in 70 year 21%	18 floods in 70 year 26%	4 floods in 70 years 6%
Flood Frequency in Above Average Snowfall Years	12 floods in 33 year 36%	23 floods in 33 year 70%	17 floods in 33 year 52%	11 floods in 33 year 33%	15 floods in 33 year 45%	2 floods in 33 years 9%
Floods Expected in 33 Years Given Overall Flood Frequency	7.5	15.5	11.9	6.9	8.6	1.9
Percent Increase in Flood Frequency for Above Average Snow Seasons	60%	48%	43%	59%	74%	5%
Probability of Observing at Least the Number of Floods that Occurred in Above Average Snowfall Seasons	0.058	0.007	0.049	0.069	0.012	0.597