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NWS ER-103

A CLIMATOLOGY OF FLASH FLOOD EVENTS FOR THE NATIONAL WEATHER SERVICE EASTERN REGION

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U.S. DEPARTMENT OF COMMERCE | National Oceanic and Atmospheric Administration | National Weather Service

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1. Abstract

A climatology of flash flood events for the National Weather Service Eastern Region (NWS-ER) is presented. Flash flood events from 1986 to 2007 within NWS-ER were stratified by year, month, hour of the day, and county of occurrence. Results are shown, in both tabular and graphical form, for the entire NWS-ER, for four “sub-regions”, and for individual forecast offices within the region.

2. Introduction

Floods and flash floods pose a serious threat to life and property throughout the NWS-ER. Flash floods are an especially dangerous threat to the public because of their relatively rapid onset following the causative rainfall. To alert the public to the possibility or imminent threat of flash flooding, Weather Forecast Offices (WFOs) in the NWS issue Flash Flood Watches and Warnings. This climatology has been prepared to help NWS forecasters understand better the nature of flash flooding in their area of responsibility and hence, it is hoped, issue more timely and accurate flash flood warnings.

3. Data and Methodology

The definition of a flash flood is somewhat subjective and flash flood verification procedures no doubt vary somewhat from one WFO to another. A new regional policy was established in 2001 requiring that flooding must occur within six hours of the causative rainfall in order for an event to be considered a flash flood. This change resulted in a significant decrease in the number of cool season flash flood events after 2001.

Flash flood events from all offices within NWS-ER from 1986 through 2007 were obtained from the NWS verification website [https://verification.nws.noaa.gov], also known as "Stats on Demand". Each event report consisted of a three-letter weather forecast office (WFO) ID, year, month, day, beginning hour (UTC), state-ID and county. All events were imported into a spreadsheet program, one page per WFO. For each WFO, the events were grouped by year, month and hour of occurrence, and also by county location within the WFO. Total flash flood events by year, month and hour of the day were graphed as bar or line charts, and events by county were plotted on a map for each county warning area (CWA).

The flash flood event totals from the various WFOs were also grouped into four "sub-regions" within NWS-ER: New England, Mid-Atlantic, Ohio Valley, and South (Figs. 1a-1d). The sub-regional totals were then combined to create yearly, monthly and hourly totals for the entire NWS-ER. Sub-regional maps of flash flood density, area-normalized by county, were also created. Sub-regional boundaries were necessarily somewhat subjective. For example, while ALY and OKX might be considered at best "borderline" New England offices (Fig. 1a), their areas do include parts of New England, and they were included to increase the total number of flash flood events for this sub-region, which otherwise would have been far smaller than the other sub-regions.

4. Results

The results of the study are described below and are illustrated in Figs. 2 through 21. The data used to create the charts are shown in tabular form in Appendix A. Climatological charts for individual WFOs may be found in Appendix B.

4.1 NWS Eastern Region and Sub-Regions

The total number of flash floods for each WFO in the NWS-ER is shown in Fig. 2 Flash floods occur most frequently from the mid-Atlantic region westward through the Ohio Valley, and also southward along the Appalachian Mountains. Lesser numbers are found over southern coastal areas and over much of New England. These variations are likely due to a combination of terrain, degree of urbanization and proximity to source regions for warm, moist air masses. The long-term trend since 1986 (Figs. 3a, 3b) depicts an overall increase in the frequency of flash flooding, although there is great year-to-year variability. This increase would likely be more pronounced without the decrease in cool-season events after 2001, as noted above.

As for the monthly distribution (Figs. 4a, 4b), most NWS-ER flash floods (68 percent) occur during the warm season, specifically May through September. There is some variation between sub-regions, as the Ohio Valley flash-flood "season" is primarily May through August, while for the mid-Atlantic and the South it is mainly June through September. The latter probably reflects the influence of heavy rainfall associated with tropical systems. New England activity is more focused on the summer months, June, July and August.

The diurnal distribution of flash floods (Figs. 5a, 5b) in NWS-ER exhibits a peak in activity during the late afternoon and early evening hour, and a minimum during the overnight period, from around midnight through early morning. (The line graphs in Figs. 5a, 8a, 12a, 16a and 20a are all smoothed using a three-hour running mean.) Again, there is some variation between sub-regions, with New England peaking earliest, the South latest, and the mid-Atlantic and Ohio Valley in between. Note that New England is about 15 degrees longitude, or one hour solar time, ahead of the Ohio Valley (less for the other two sub-regions), which could partially account for the earlier New England maximum.

4.2 New England Sub-Region and Constituent WFOs

New England has the lowest number of flash floods among the four sub-regions. The majority of events occur within the OKX and ALY forecast areas, on the southern and western fringes of New England. The long-term trend (Figs. 6a, 6b) shows an overall increase, with perhaps a maximum during the mid-to-late 1990's. The seasonal trend, as noted above, shows a peak period from June through August (Figs 7a, 7b), although the OKX contribution skews the results somewhat towards the fall months. The diurnal distribution (Figs. 8a, 8b) shows a peak during the late afternoon and minimal activity overnight, but the OKX data show a relatively greater frequency from mid-morning through early afternoon. Also, the four WFOs east of ALY and north of OKX show a much weaker diurnal signal.

The geographic distribution of flash flood density (flash floods per year per 1000 sq.mi.) across New England is depicted in Fig. 9. The lowest frequency of flash flood occurrence in all of NWS-ER is found in central and northern Maine, while the highest concentration occurs in the New York City metropolitan area. Besides New York, other cities such as Boston, MA, Providence, RI, Albany, NY and Montpelier, VT, also exhibit a higher flash flood frequency. This tendency is found throughout NWS-ER, and may be due to the hydrologic effects of urbanization, or better reporting, or a combination of both.

4.3 Mid-Atlantic Sub-Region and Constituent WFOs

The mid-Atlantic sub-region has the second highest total of flash flood events. The greatest contributions come from WFOs LWX and PHI in the south and east, while the least amount comes from the BUF office in the northwest. The long-term trend (Figs. 10a, 10b) shows a general increase in events from the mid 1980's through the mid 2000's, although 1996 stands out as a particularly active year. The monthly trend (Figs. 11a, 11b) shows a peak in June, with enhanced activity through September. The LWX office, in particular, shows a relatively high number of September events. The diurnal pattern (Figs. 12a, 12b) again shows a late-afternoon through early evening maximum, with relatively little activity from midnight through early morning.

The geographic distribution of mid-Atlantic flash flood events is depicted in Fig. 13. Overall, the frequency of flash flooding increases from north to south across this area. The urban corridor from New York to Philadelphia to Baltimore to Washington, D.C. stands out with a markedly higher concentration. Also, several counties along the Blue Ridge in northern Virginia exhibit a higher flash-flood density. The lowest concentrations are found in parts of upstate New York and north-central Pennsylvania.

4.4 Ohio Valley Sub-Region and Constituent WFOs

The Ohio Valley sub-region has the highest total number of flash flood events within the NWS-ER. In particular, the PBZ county warning area has the highest number of events among all Eastern Region WFOs, and the other three offices are among the highest, each having over a thousand events during the 1986-2007 study period. The long-term trend (Figs. 14a, 14b) suggests a peak in flash flood activity during the 1990's, although 2003 was also a very active year for PBZ. The monthly pattern (Figs. 15a, 15b) shows peak activity in June and July. However, unlike other sub-regions, May is the third most active month and August is fourth, followed by a very sharp drop-off in September. It is possible that this earlier activity in the Ohio Valley is due to more direct access to moisture from the Gulf of Mexico in the mid-to-late springtime. The diurnal pattern (Figs. 16a, 16b) resembles the other sub-regions with maximum activity in late afternoon through early evening. Note, however, the PBZ office shows more activity in the early-to-mid afternoon.

Fig. 17 shows the spatial distribution of Ohio Valley flash flood events. Overall, this sub-region has the greatest concentration and a more uniform distribution of flash flooding. Still, higher densities are found in southwest Pennsylvania, including the city of Pittsburg, as well the major metropolitan areas of Ohio. Some of the smaller counties along the Ohio River, including the West Virginia panhandle, also have a high flash-flood concentration.

4.5 South Sub-Region and Constituent WFOs

The South sub-region has only the third highest total number of flash flood events, even though it includes the greatest number of WFOs (eight). Much of this area falls within the Atlantic Coastal Plain, a region with sandy soil and a relatively slow rise in elevation westward from the coast, conditions generally not conducive to flash flooding. The greatest contributions come from the western-most offices, GSP and RNK, which include a great deal of the southern Appalachian Mountains. The long-term trend (Figs. 18a, 18b) shows an overall increase in activity during the past couple of decades, with 2003 being the most active year. The monthly distribution (Figs. 19a, 19b) shows high activity from June through September, with a slight peak in August. October is also fairly active, with a sharp drop-off in November. This enhanced flash-flood activity through early- and mid-fall is likely due at least in part to heavy rainfall from tropical systems. The diurnal trend (Figs. 20a, 20b) is similar to the other sub-regions, although the peak activity is around 2300 UTC, which is one to two hours later than the others.

The geographic distribution of flash flood events in the South is illustrated in Fig. 21. As with the other sub-regions, many of the more urbanized counties exhibit a higher flash flood density, especially those comprising a smaller geographic area such as Norfolk, VA and Wilmington, NC. In general, higher flash flood concentrations occur over the southern Appalachian Mountains, with decreasing values toward the Atlantic Coast. However, the lowest values are found over central South Carolina and a small part of adjacent southeastern North Carolina.

4.6 Individual WFOs

A simple flash flood climatology for each WFO within the NWS-ER is presented in appendix B. Each climatology consists of charts showing the distribution of flash flood events by year, by month and by hour of the day within the WFO's county warning area. There is also a map of the total number of flash flood events by county. These charts are presented here without discussion, but are made available for interpretation at each office.

5. Conclusions

The results of this climatological study of flash flooding in the NWS-ER show that flash flooding is primarily a warm-season phenomenon (May through September), but with some variations between sub-regions. In particular, the Ohio Valley experiences a relatively high frequency of flash flooding in May, while the South, and to some extent the mid-Atlantic sub-region, show more activity in September and October. Diurnally, flash flooding peaks during the late afternoon and early evening hours throughout the NWS-ER, but there are notable differences at individual WFOs. The long-term trend from 1986 through 2007 suggests an overall increase in the number of flash flood events with NWS-ER, but there is considerable variation from year to year.

6. Acknowledgements

Much of the preparation of graphs and maps used in this report was accomplished by two student volunteers at the WFO PHI office, Jamie Husson and Bryan Losier. All flash flood event data were obtained from the NWS

"Stats on Demand" website, [https://verification.nws.noaa.gov]. This work is part of the C-STAR program in association with the State University of New York at Albany.

Figures

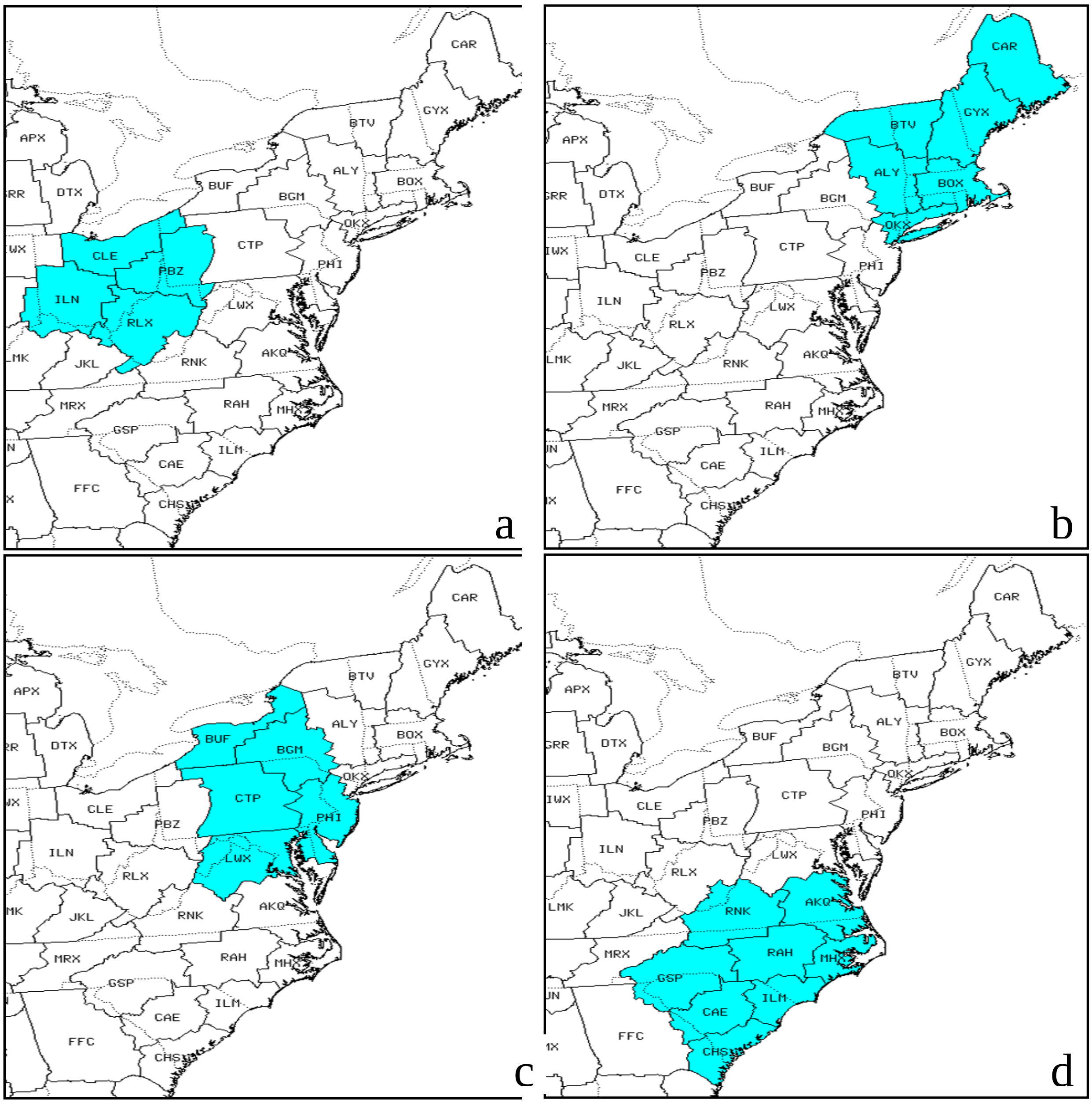


Figure 1. (a) Ohio Valley sub-region (b) New England sub-region (c) Mid-Atlantic sub-region (d) South sub-region. Sub-regions are highlighted in blue.

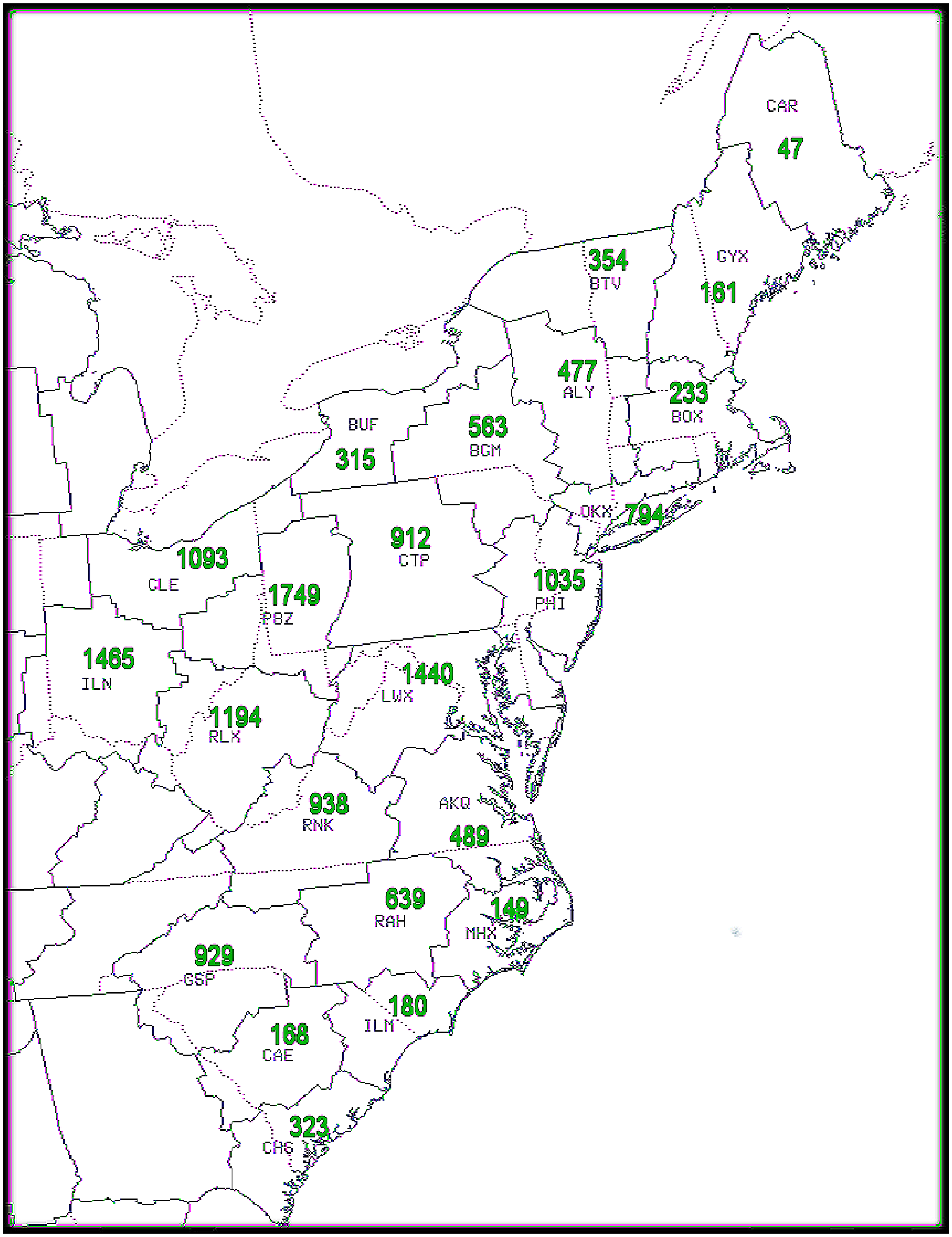
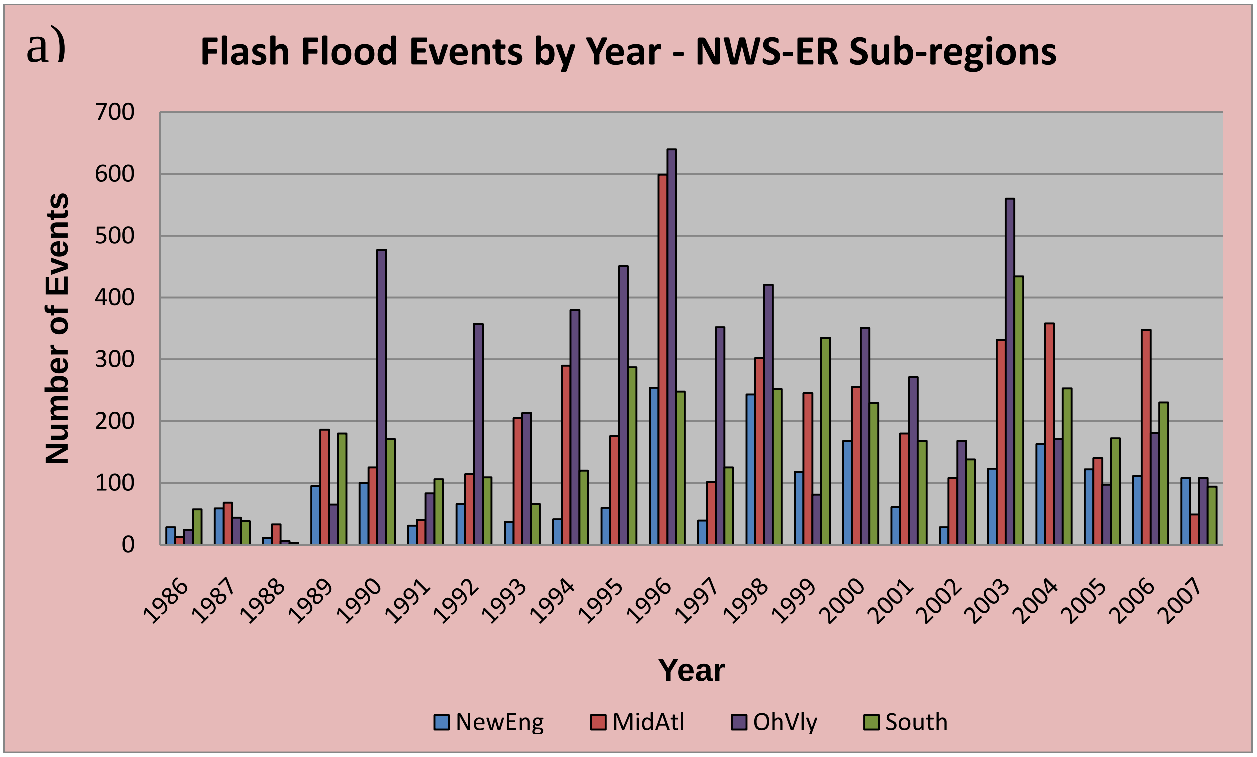


Figure 2. Total number of flash flood events in each NWS-ER WFO area, 1986 to 2007.



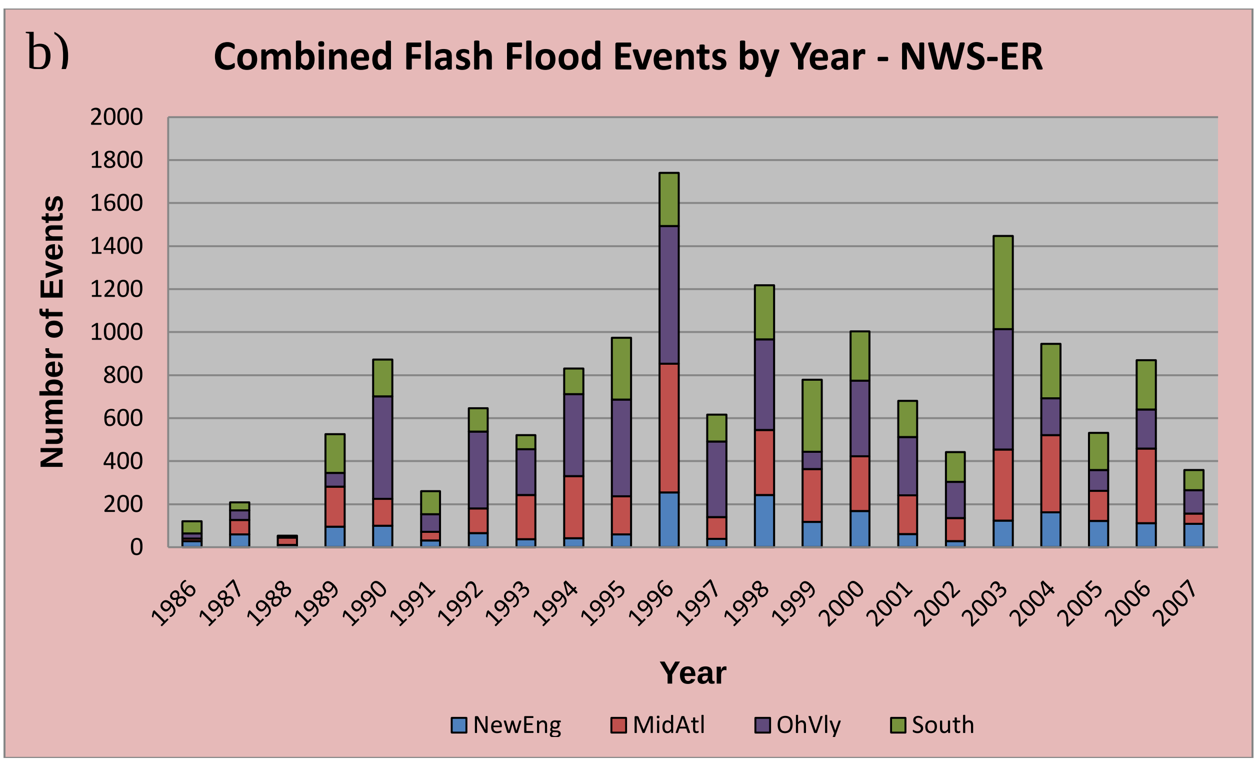


Figure 3. (a) Flash flood events by year for NWS-ER sub-regions. (b) Flash flood events by year for the entire NWS Eastern Region.

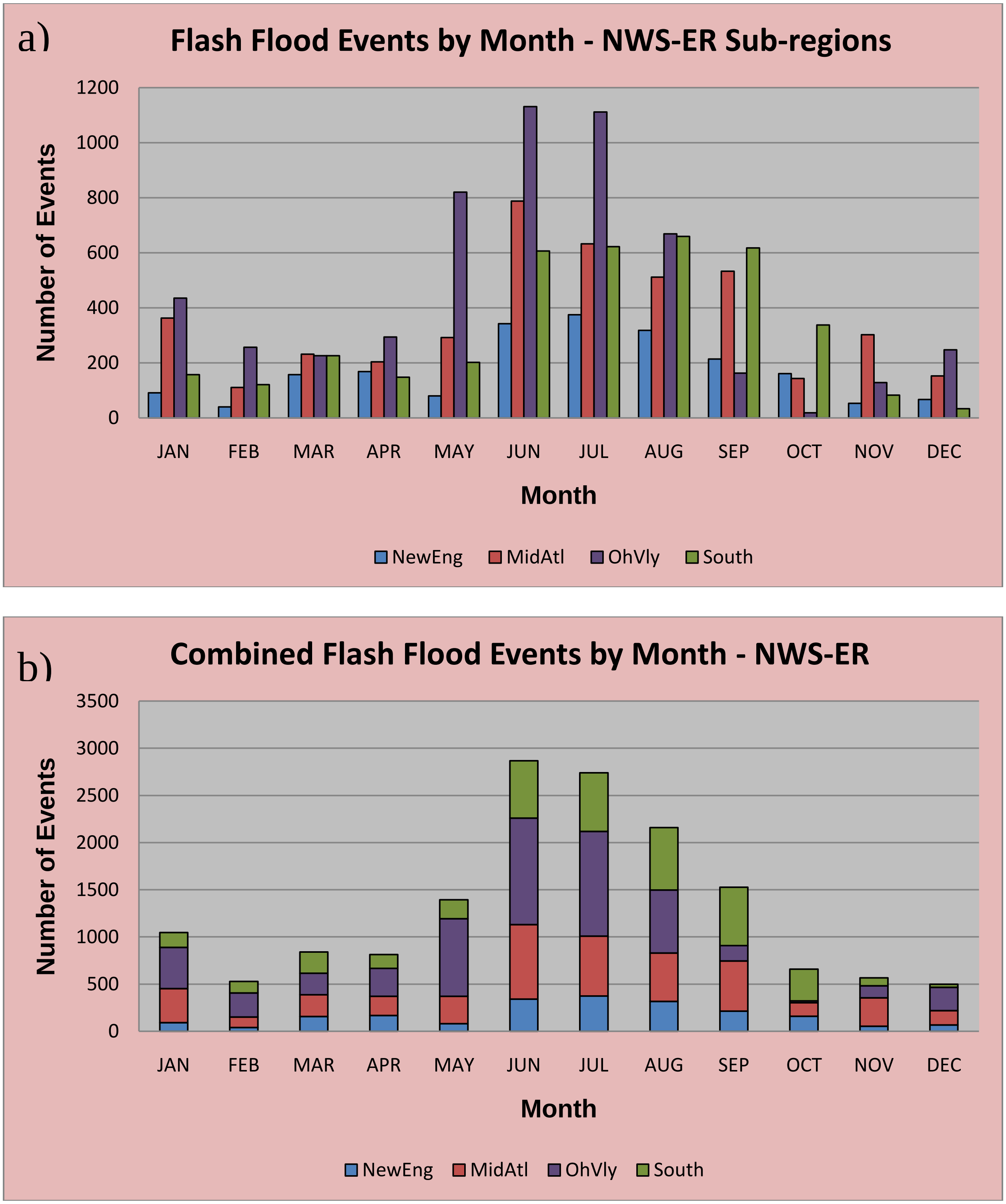


Figure 4. (a) Flash flood events by month for NWS-ER sub-regions. (b) Combined flash flood events by month for the entire NWS-ER.

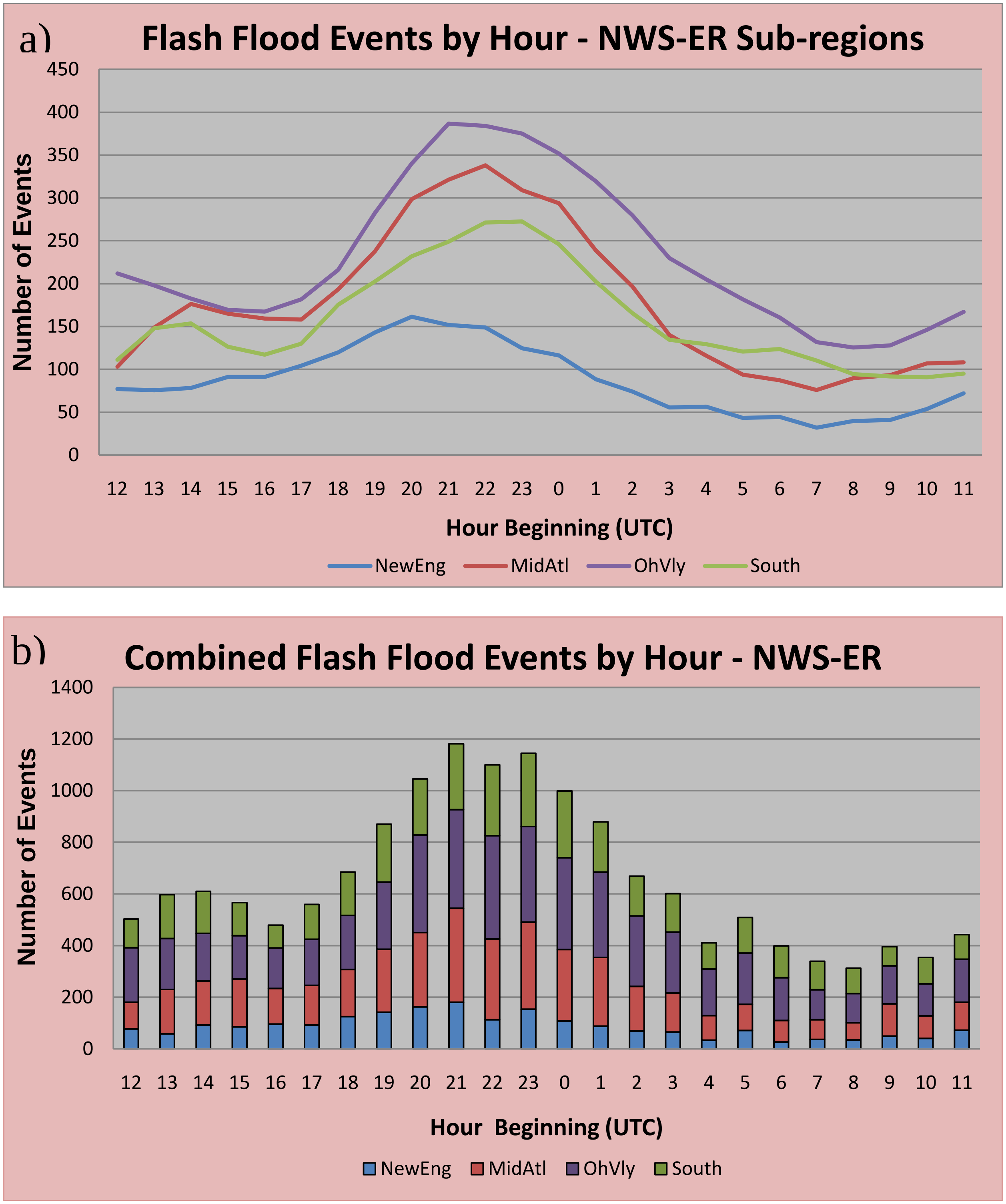
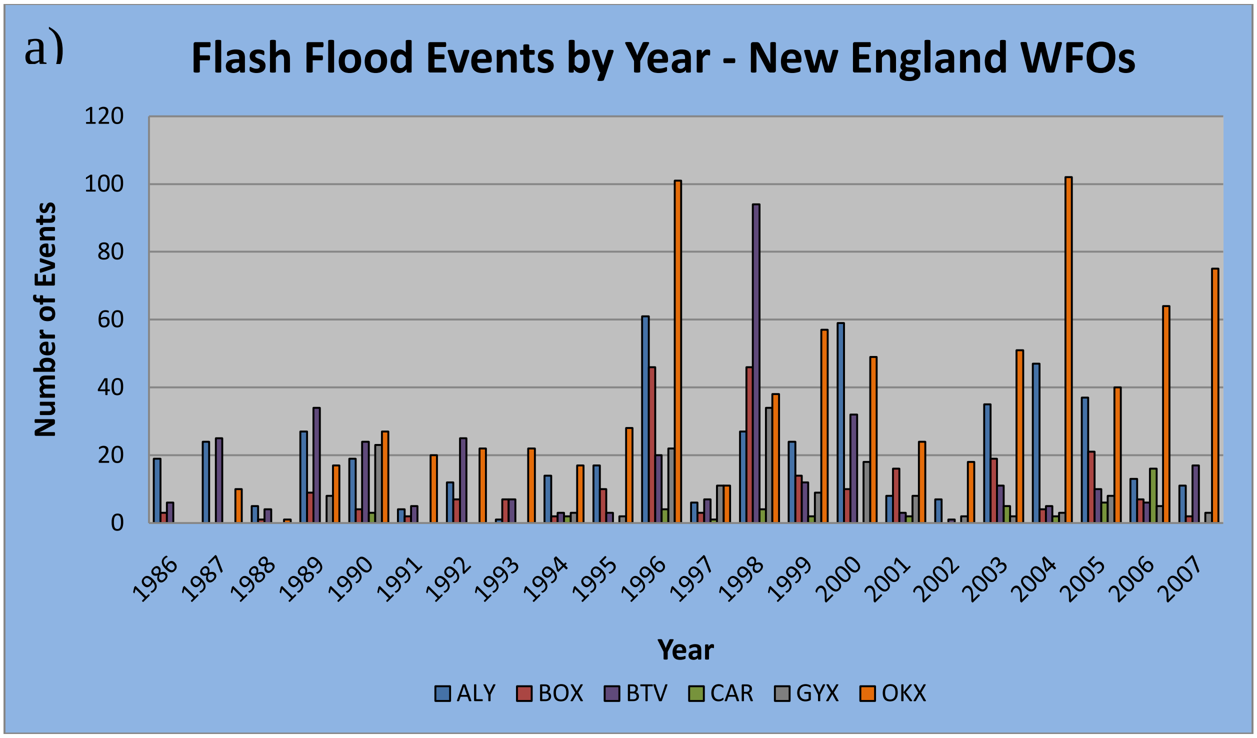


Figure 5. (a) Flash flood events by hour of the day for NWS-ER sub-regions (smoothed). (b) Combined flash flood events by hour for the entire NWS-ER.



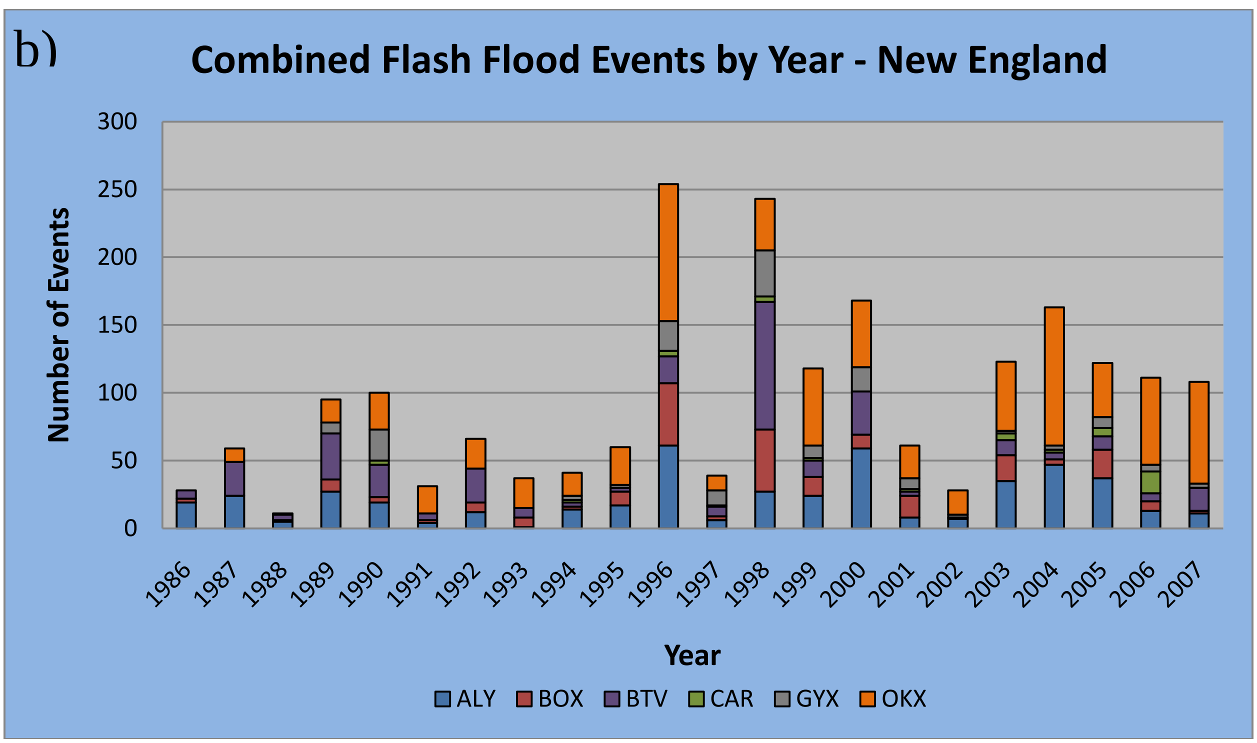
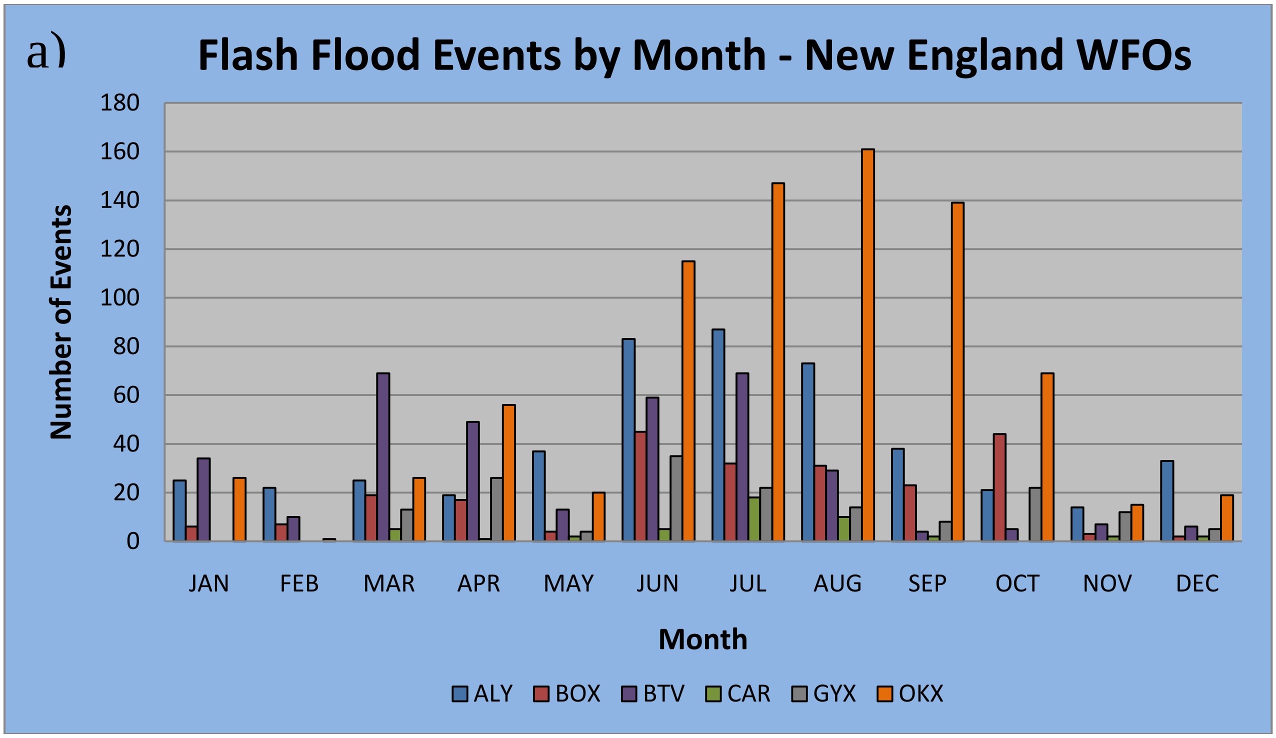
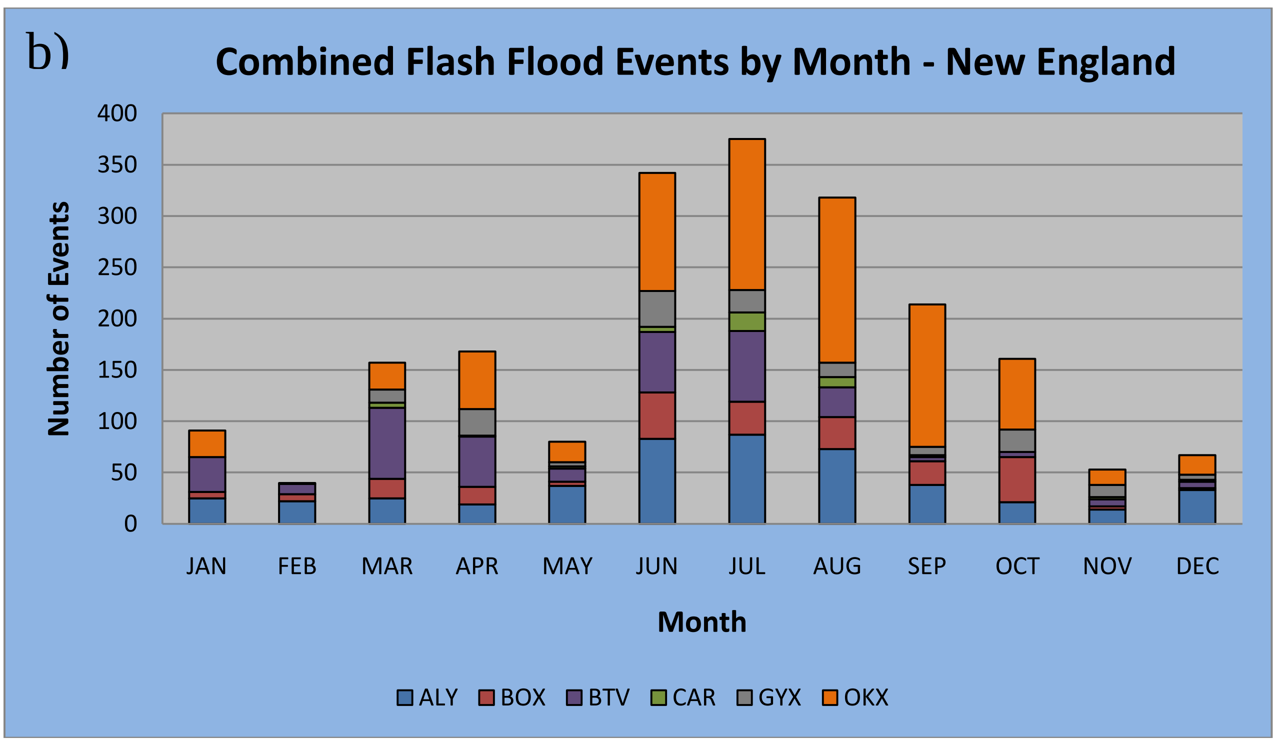


Figure 6. (a) Flash flood events by year for WFOs in the New England sub-region. (b) Combined flash flood events by year for the New England sub-region.





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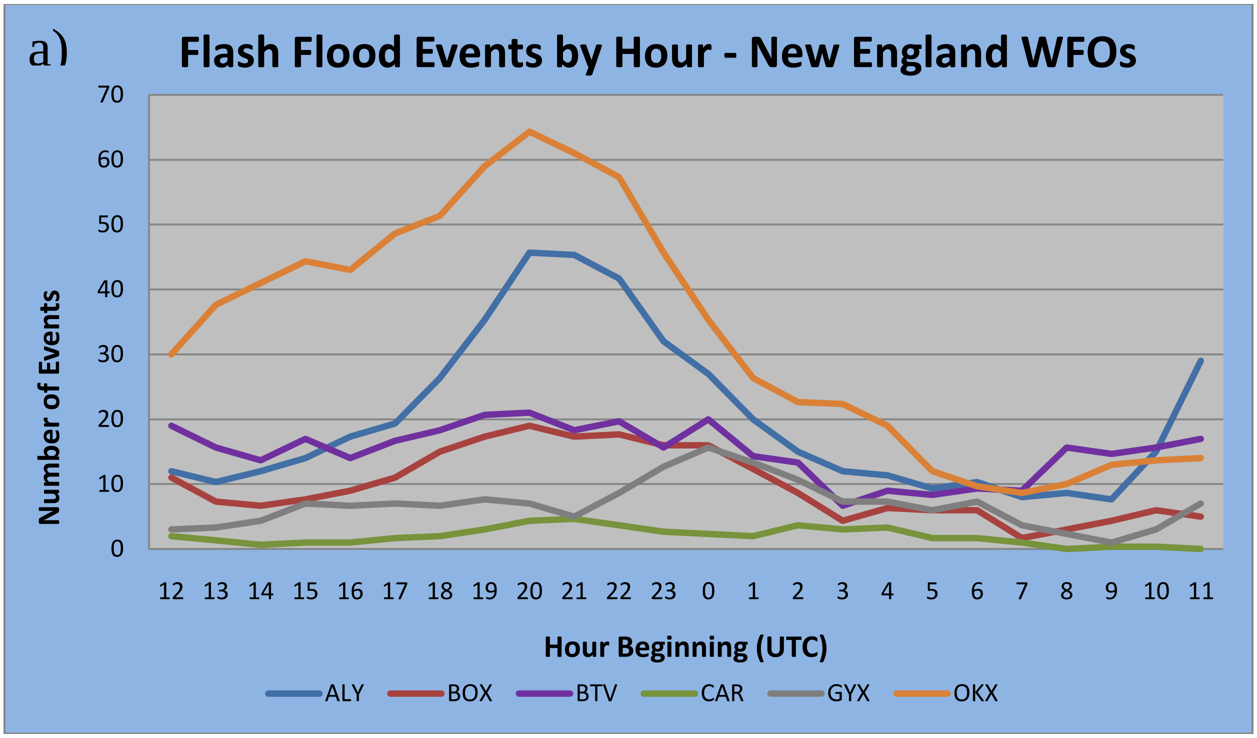


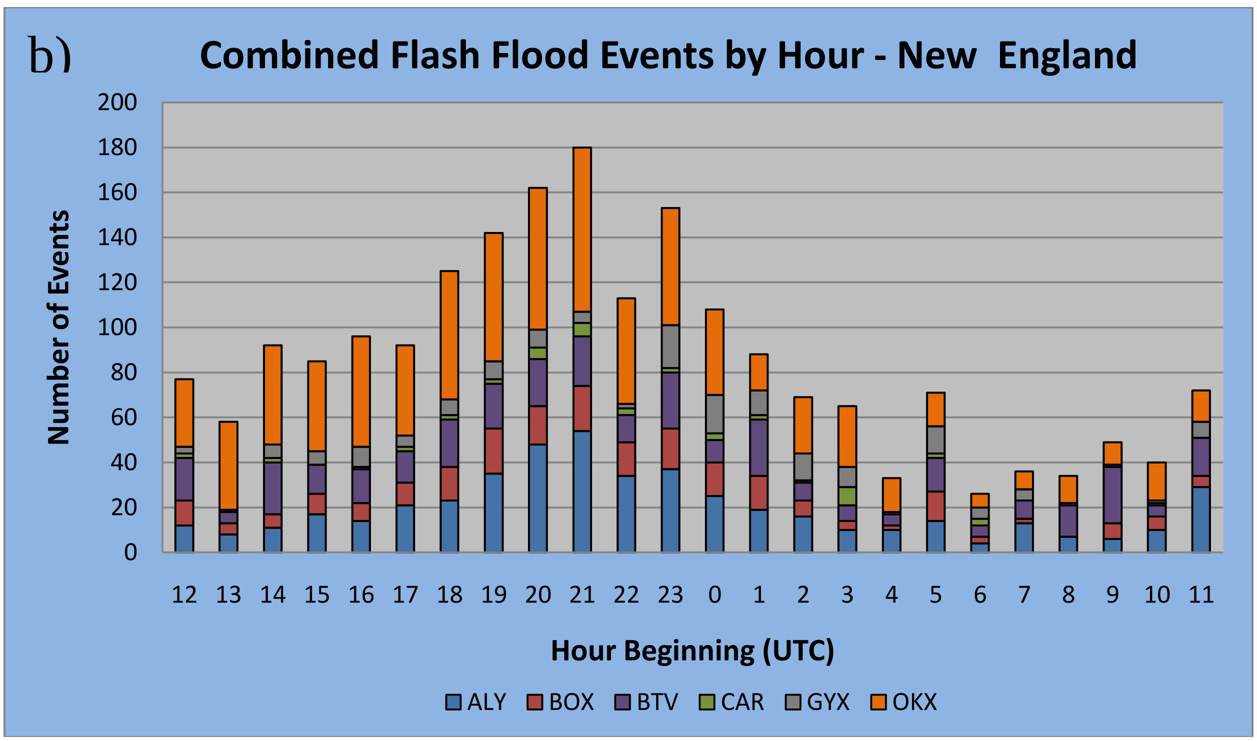


Figure 8. (a) Flash flood events by hour for WFOs in the New England sub-region (smoothed). (b) Combined flash flood events by hour for the New England sub-region.

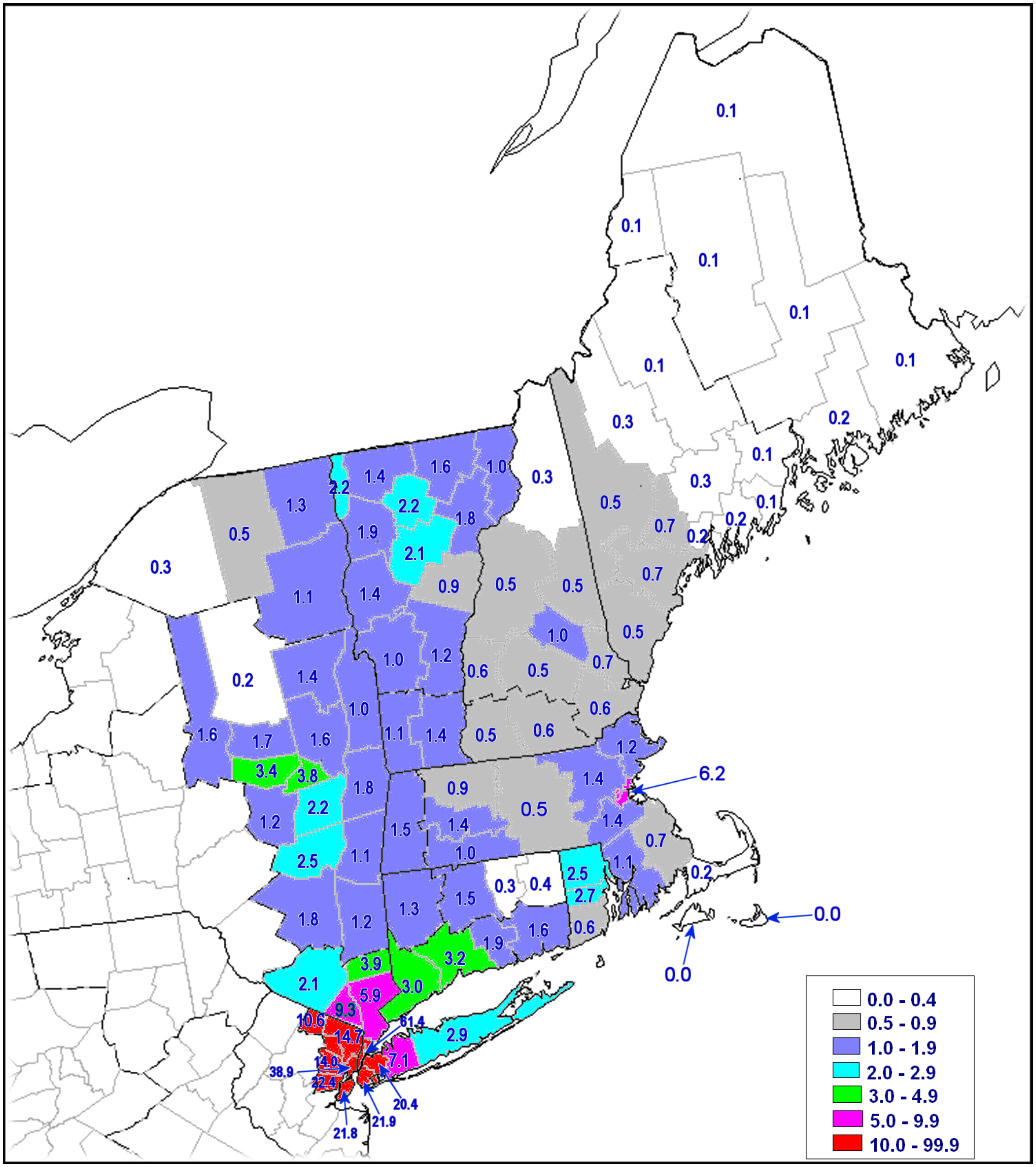
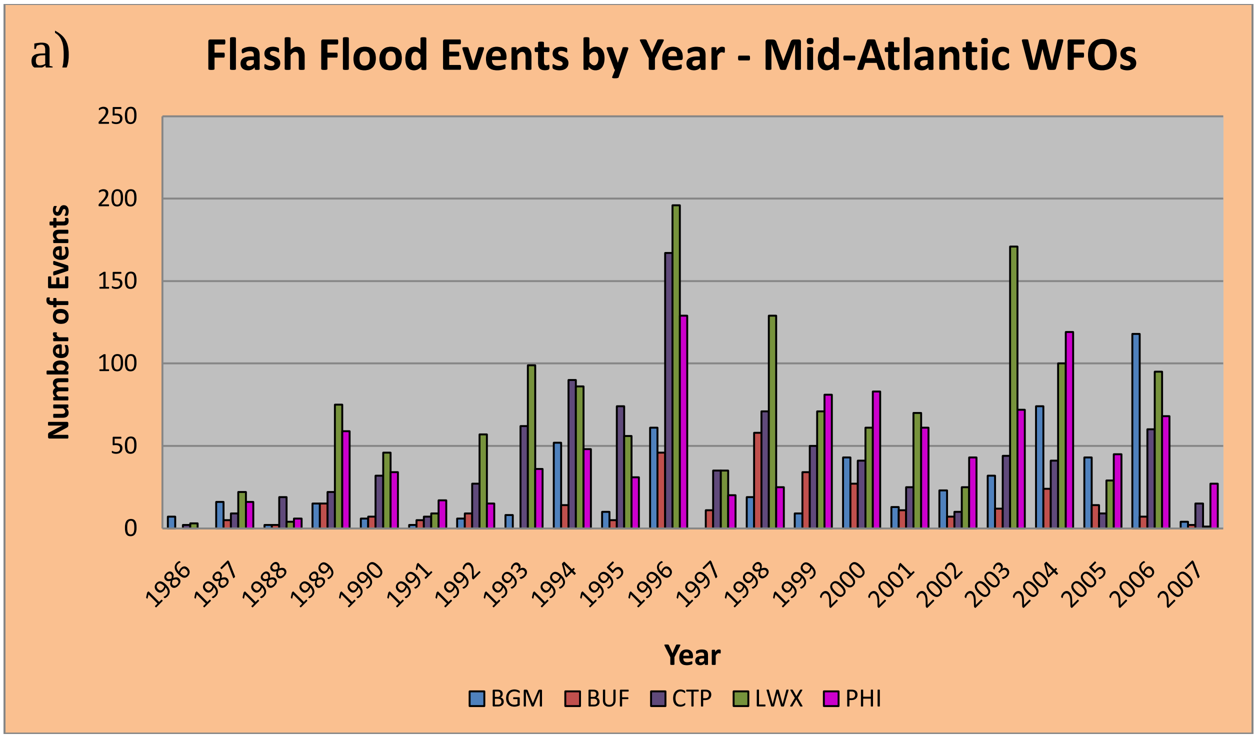


Figure 9. Flash flood events per year per 1000 sq.mi., by county for the New England sub-region.



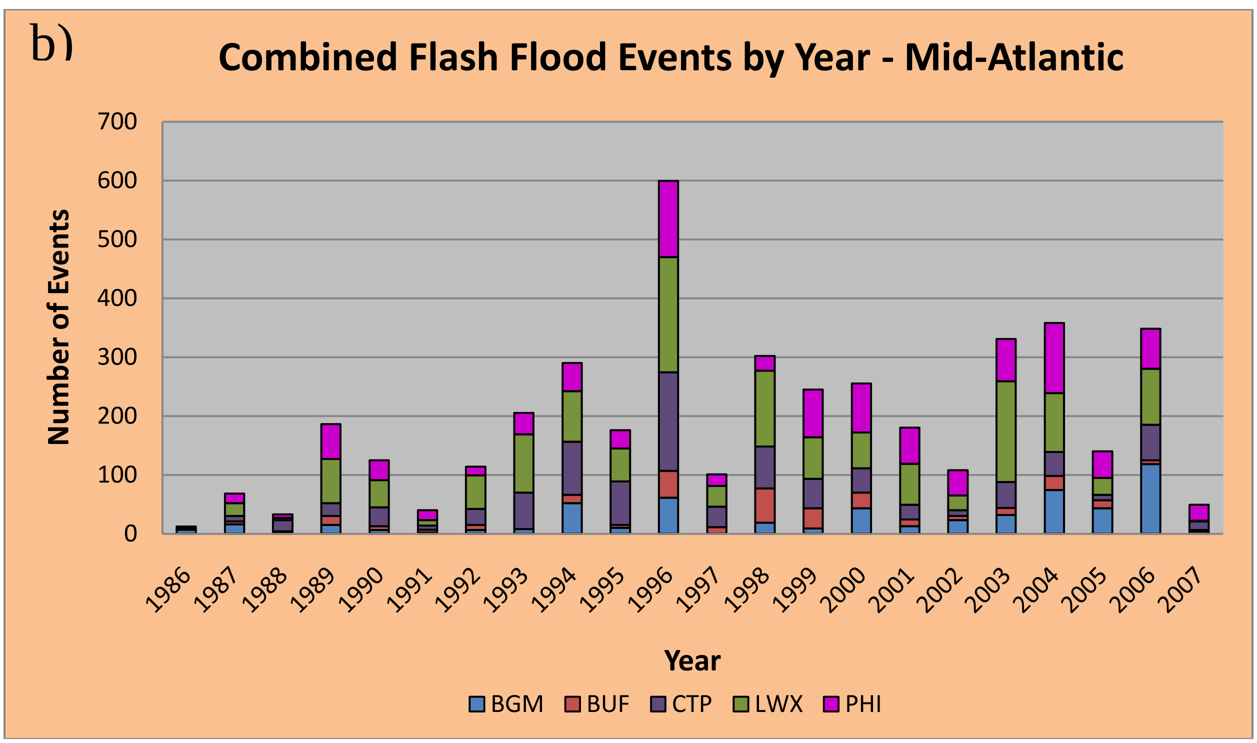


Figure 10. (a) Flash flood events by year for WFOs in the mid-Atlantic sub-region (b) Combined flash flood events by year for the entire mid-Atlantic sub-region.

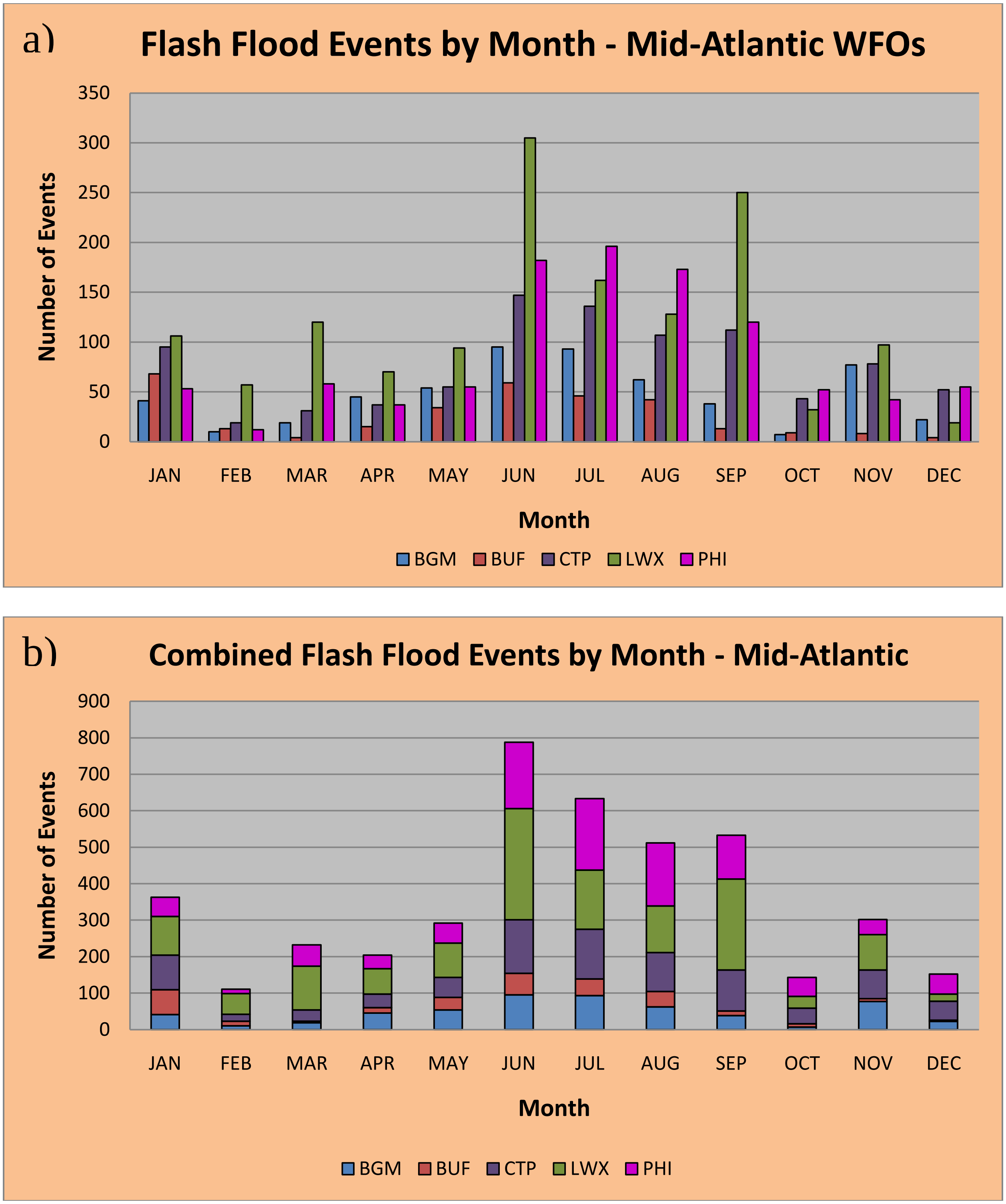
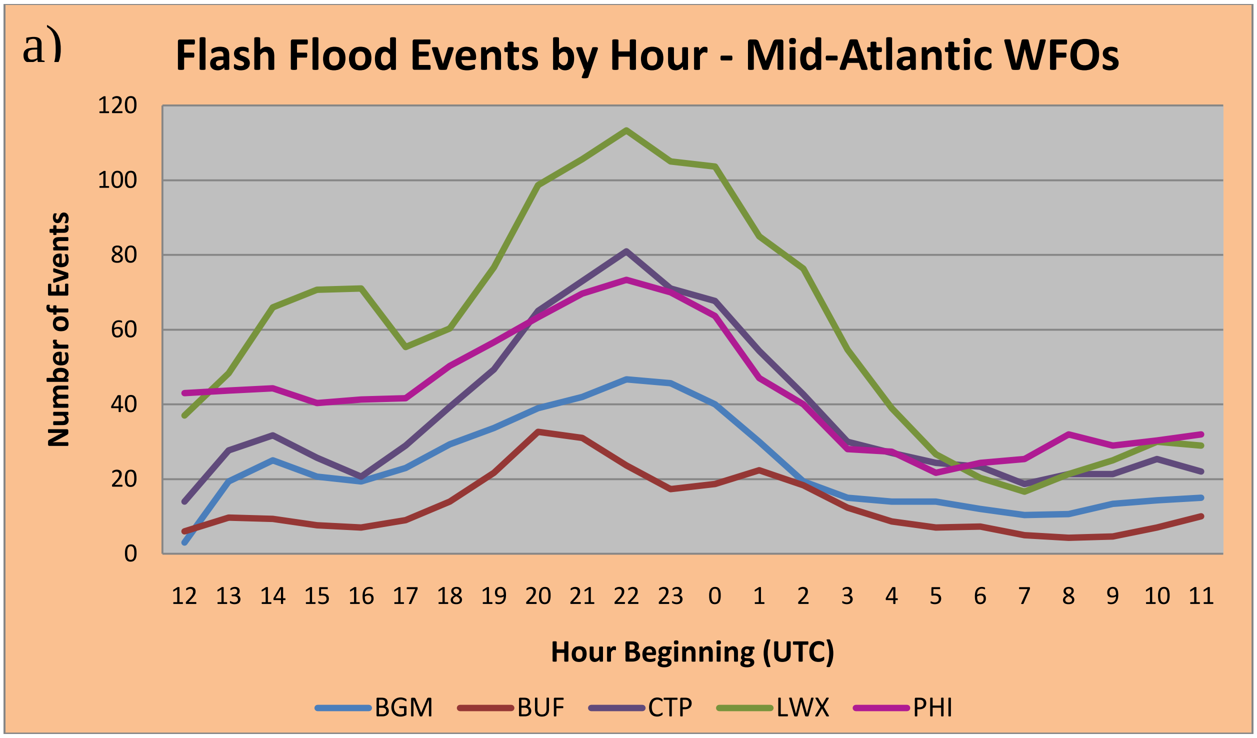


Figure 11. (a) Flash flood events by month for WFOs in the mid-Atlantic sub-region. (b) Combined flash flood events by month for the entire mid-Atlantic sub-region.



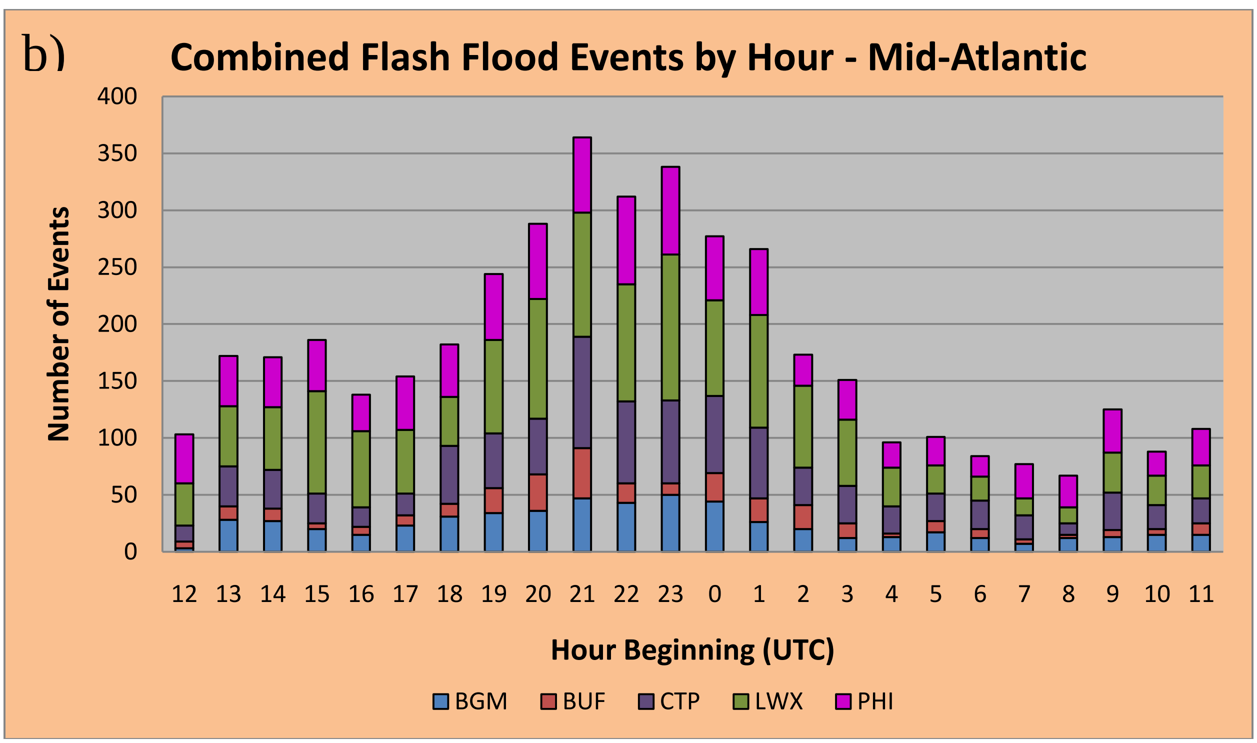


Figure 12. (a) Flash flood events by hour for WFOs in the mid-Atlantic sub-region (smoothed). (b) Combined flash flood events by hour for the entire mid-Atlantic sub-region.

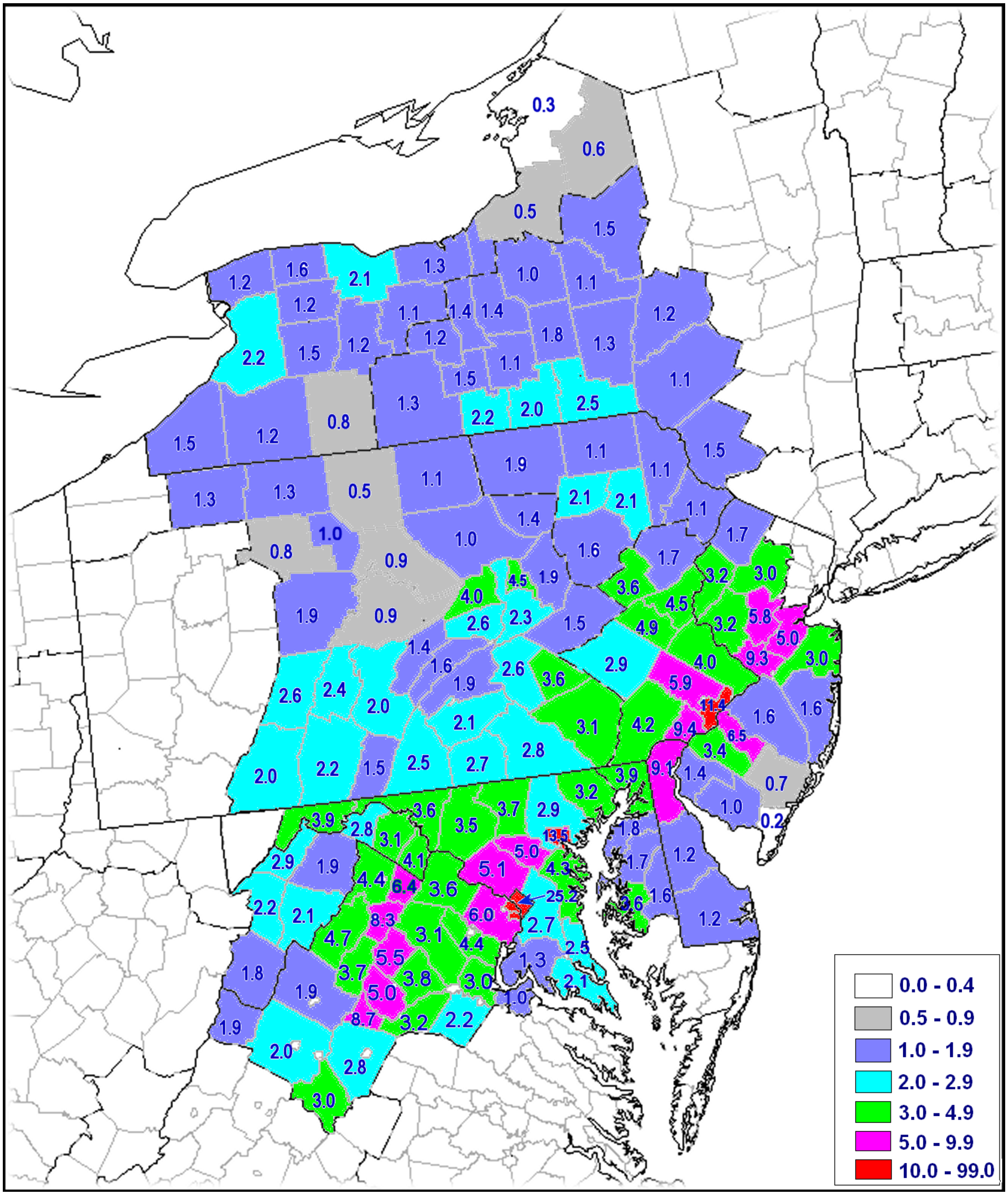
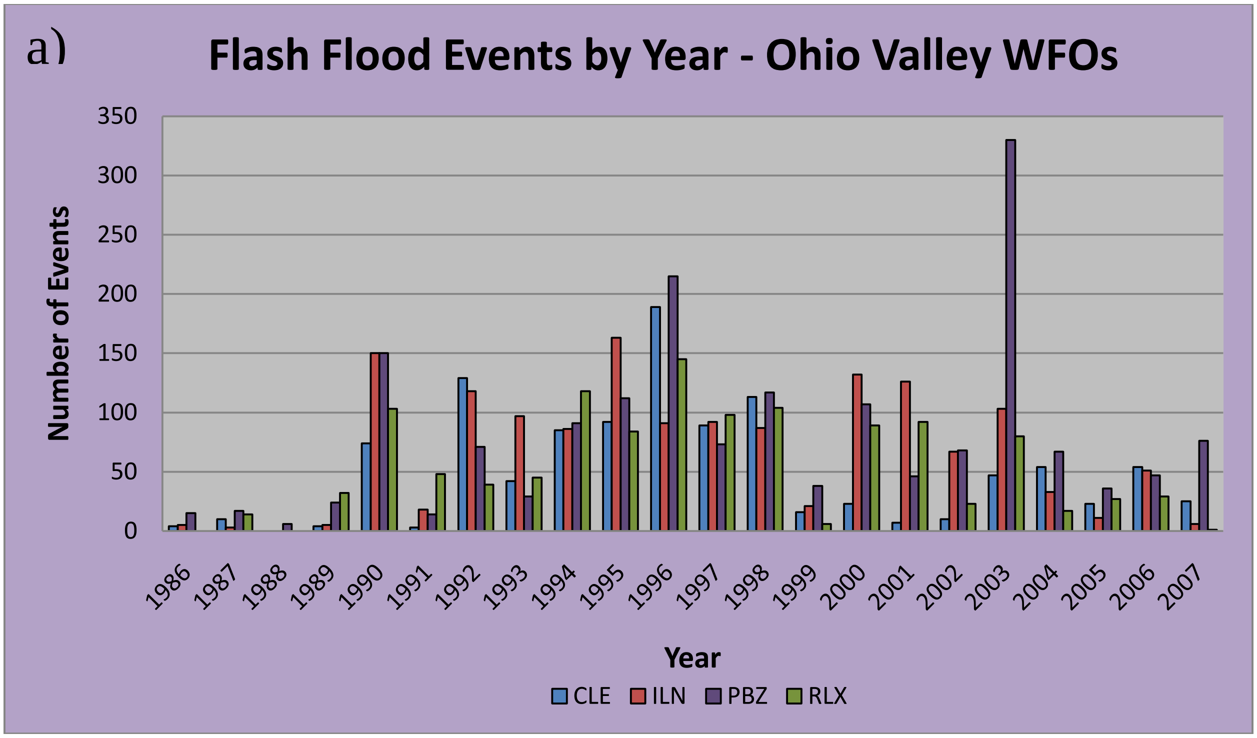


Figure 13. Flash flood events per year per 1000 sq.mi., by county for the mid-Atlantic sub-region.



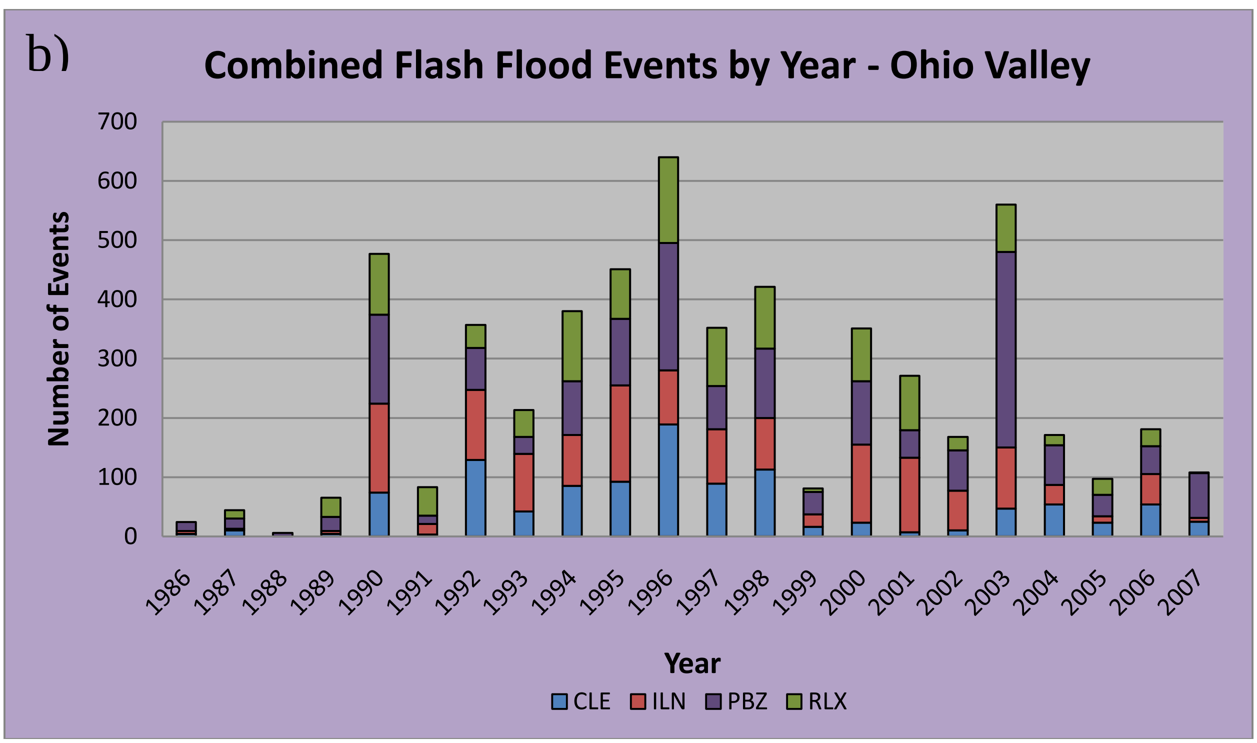
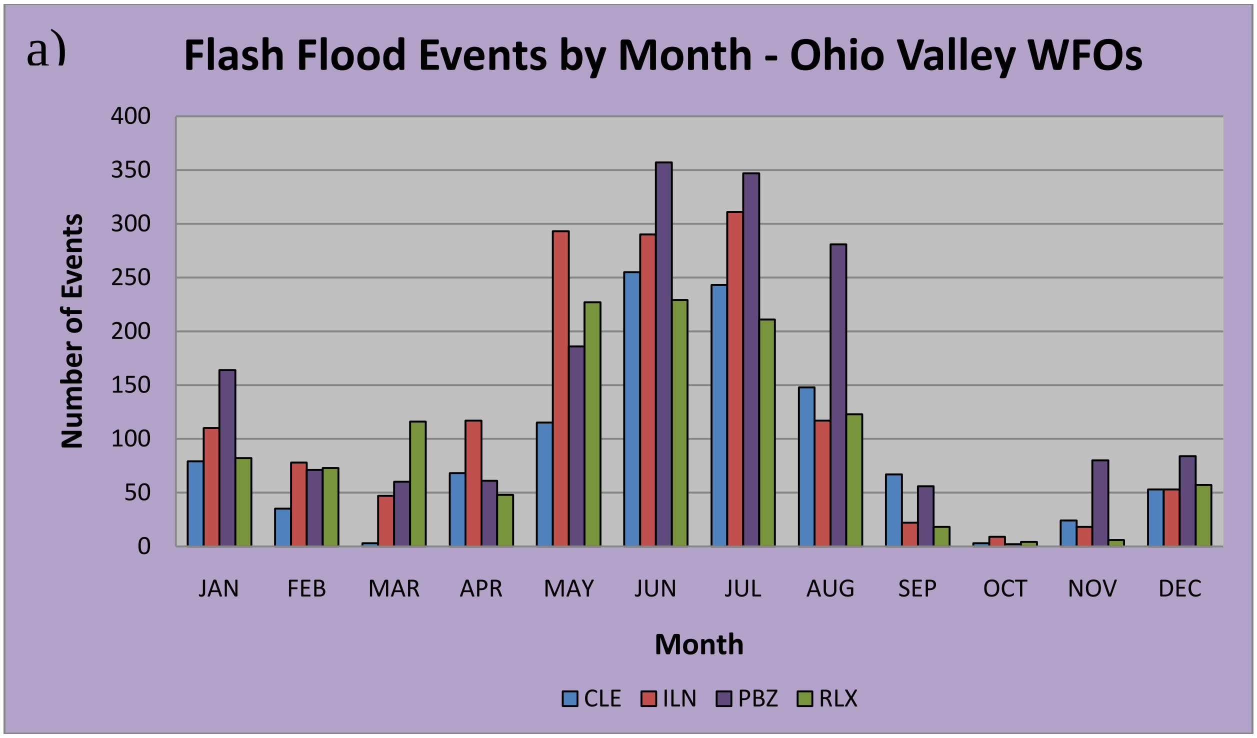


Figure 14. (a) Flash flood events by year for WFOs in the Ohio Valley sub-region. (b) Combined flash flood events by year for the entire Ohio Valley sub-region.



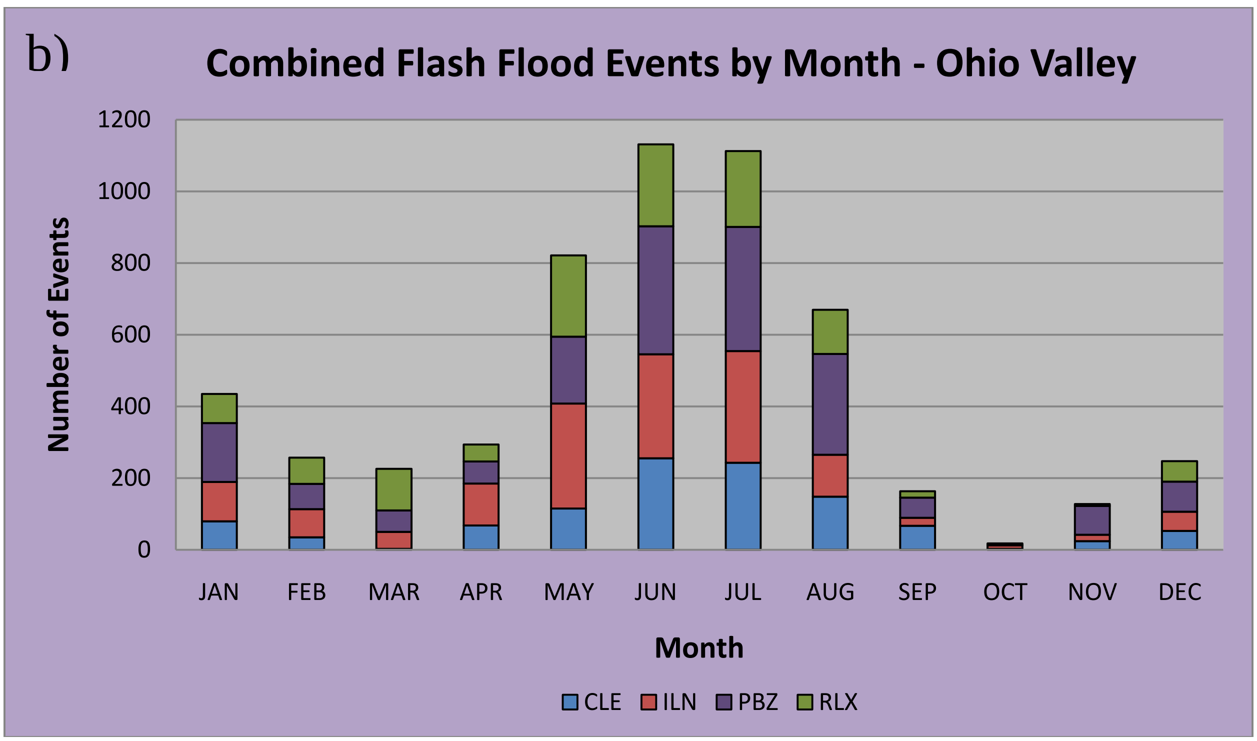
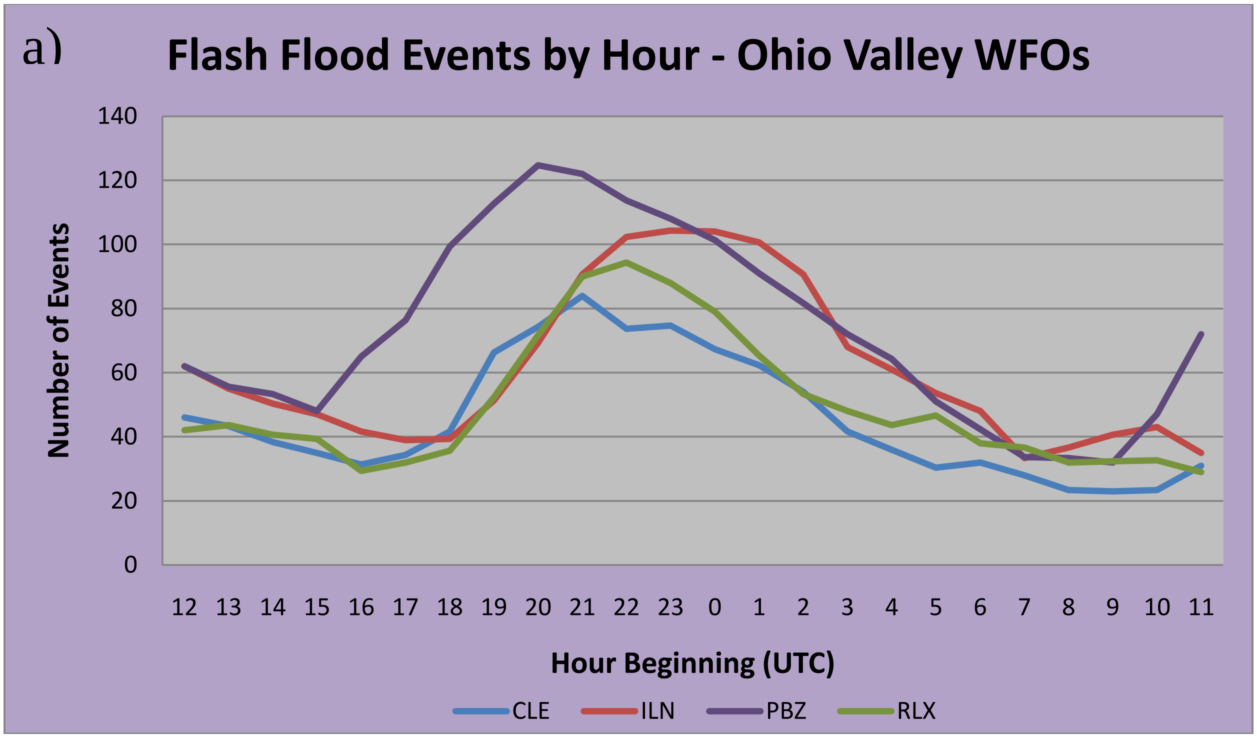


Figure 15. (a) Flash flood events by month for WFOs in the Ohio Valley sub-region. (b) Combined flash flood events by month for the entire Ohio Valley sub-region.



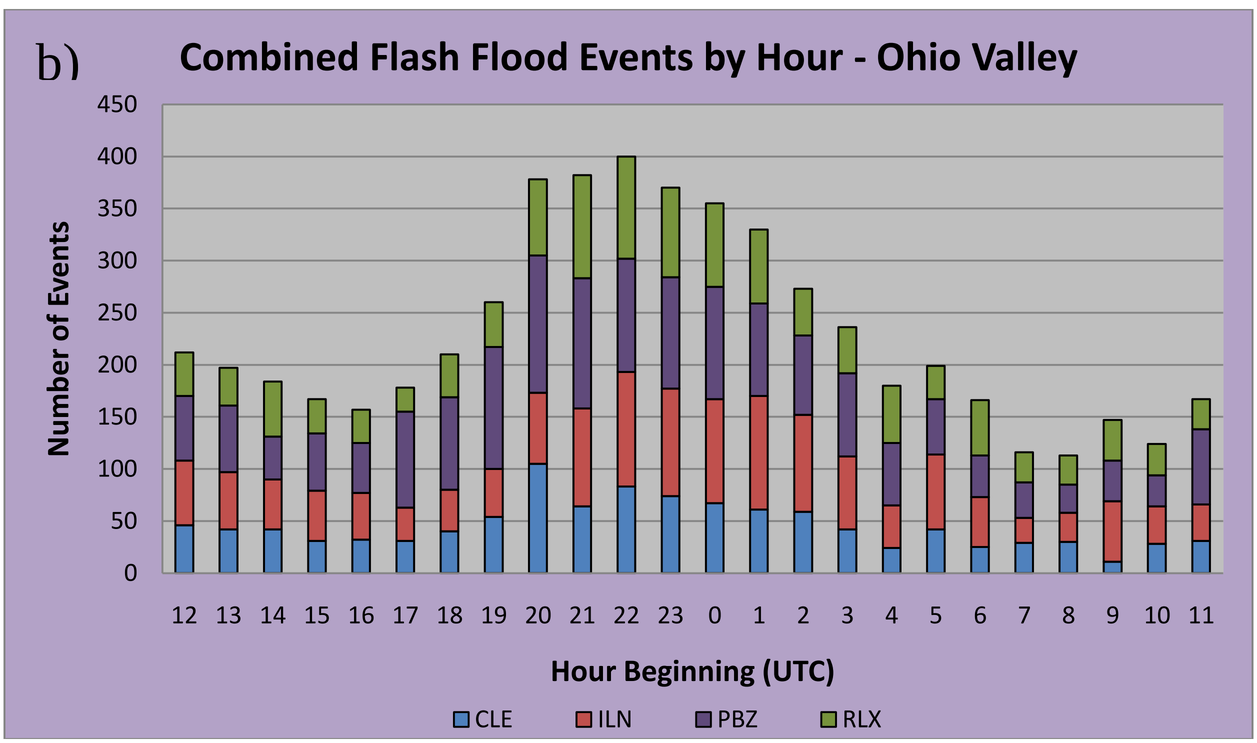


Figure 16. (a) Flash flood events by hour for WFOs in the Ohio Valley sub-region (smoothed). (b) Combined flash flood events by hour for the entire Ohio Valley sub-region.

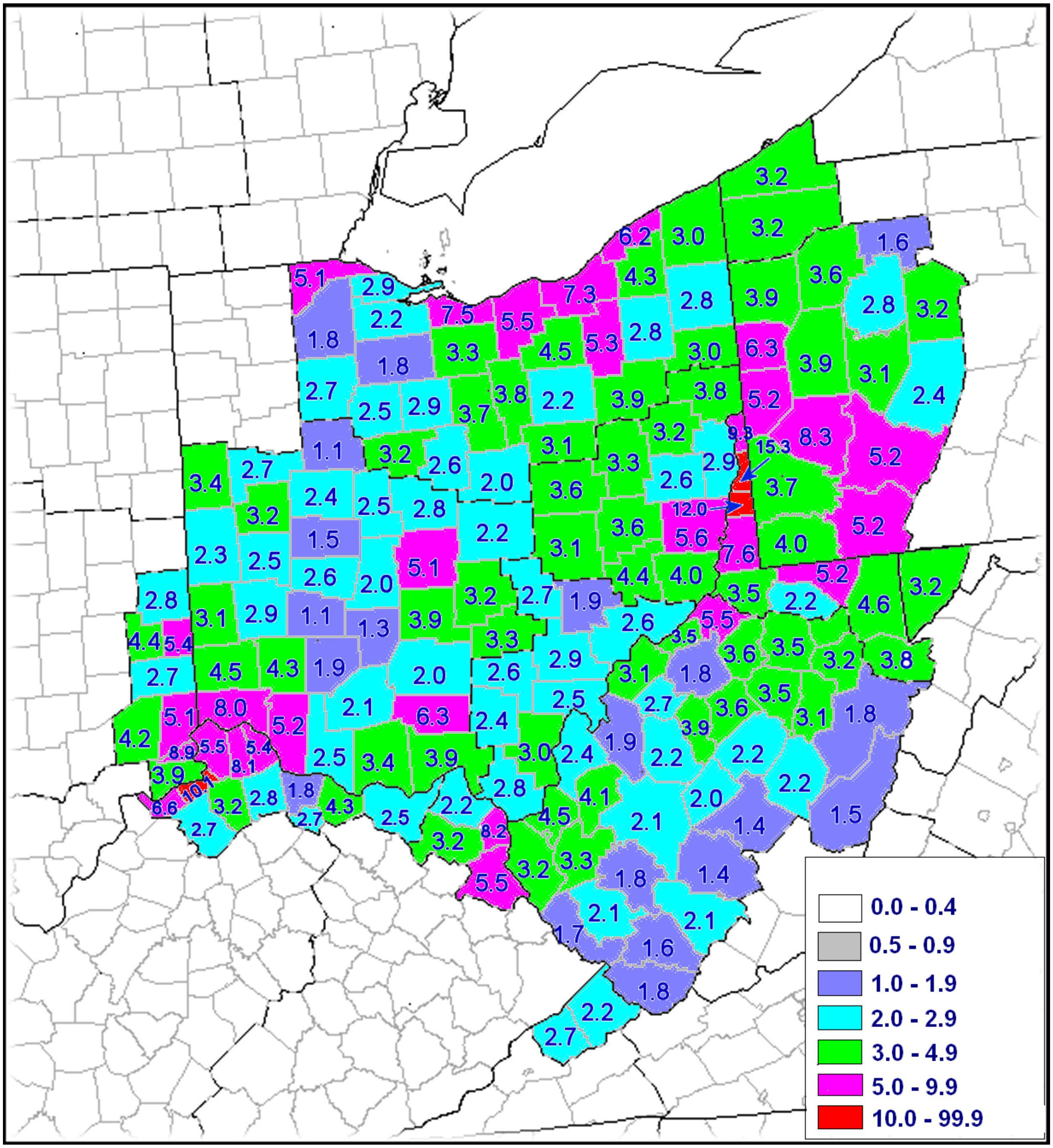
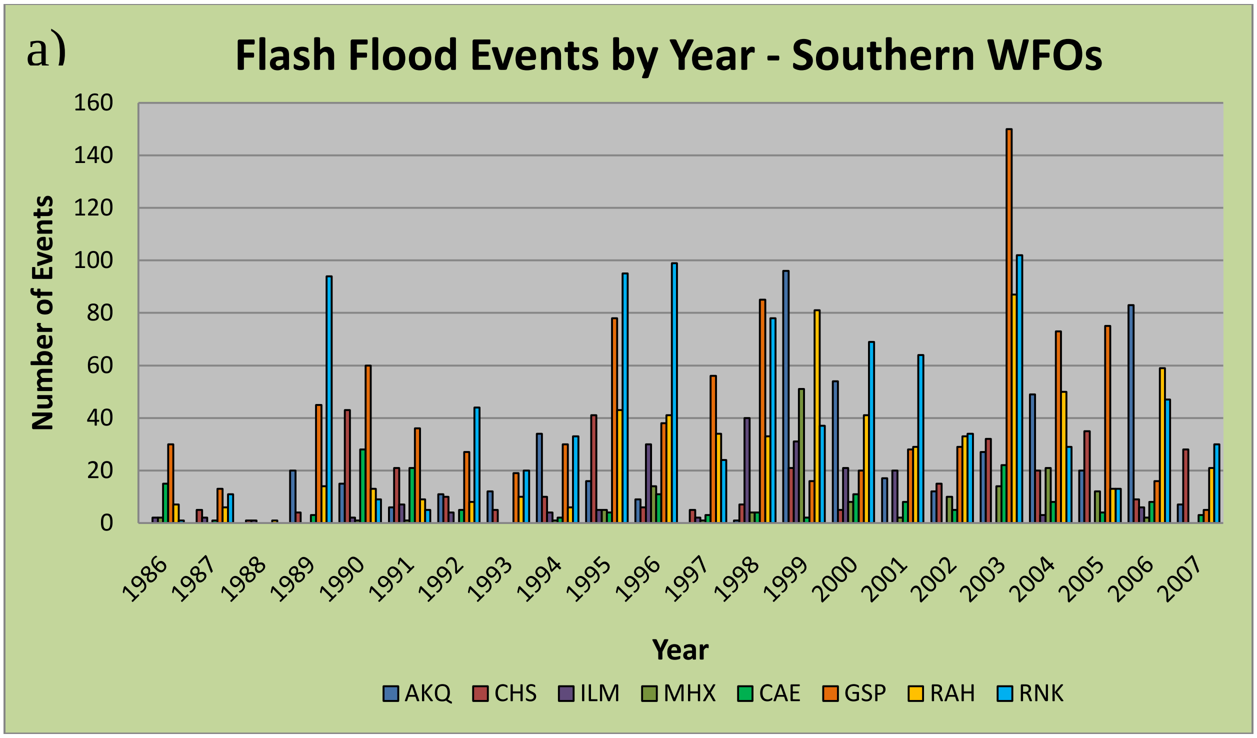


Figure 17. Flash flood events per year per 1000 sq.mi., by county for the Ohio Valley sub-region.



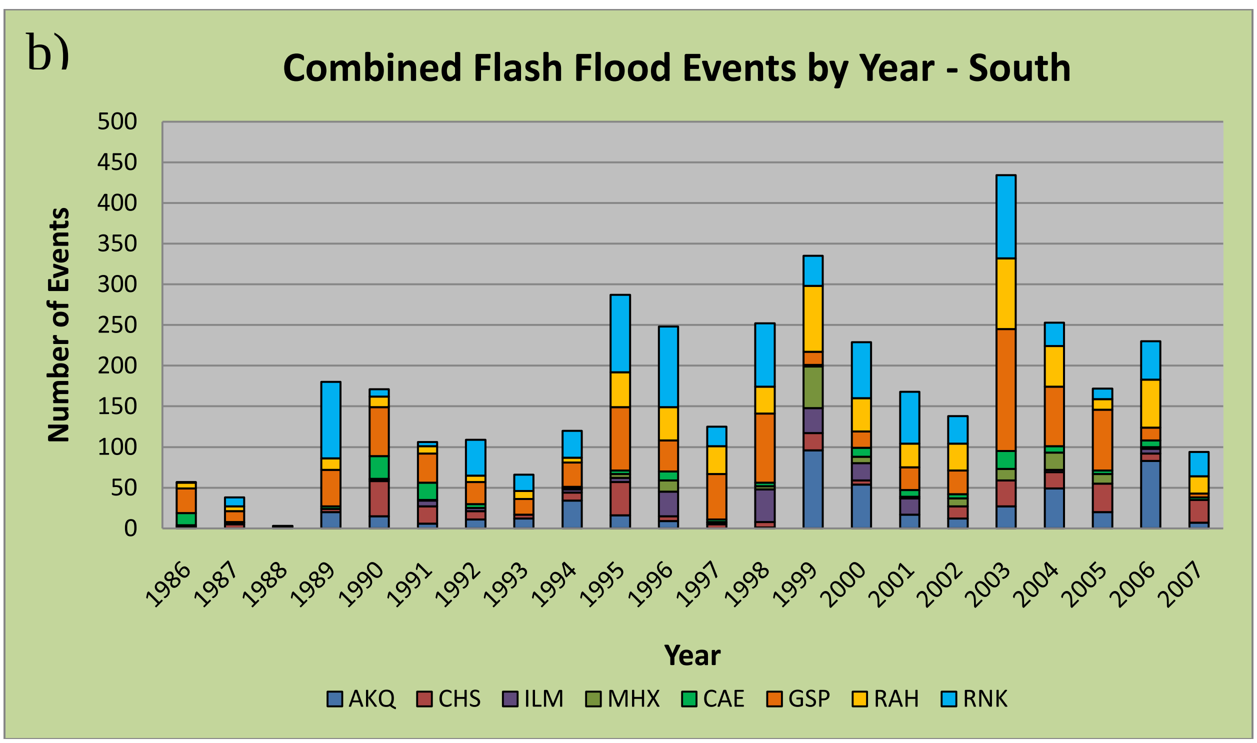


Figure 18. (a) Flash flood events by year for WFOs in the South sub-region. (b) Combined flash flood events by year for the entire South sub-region.

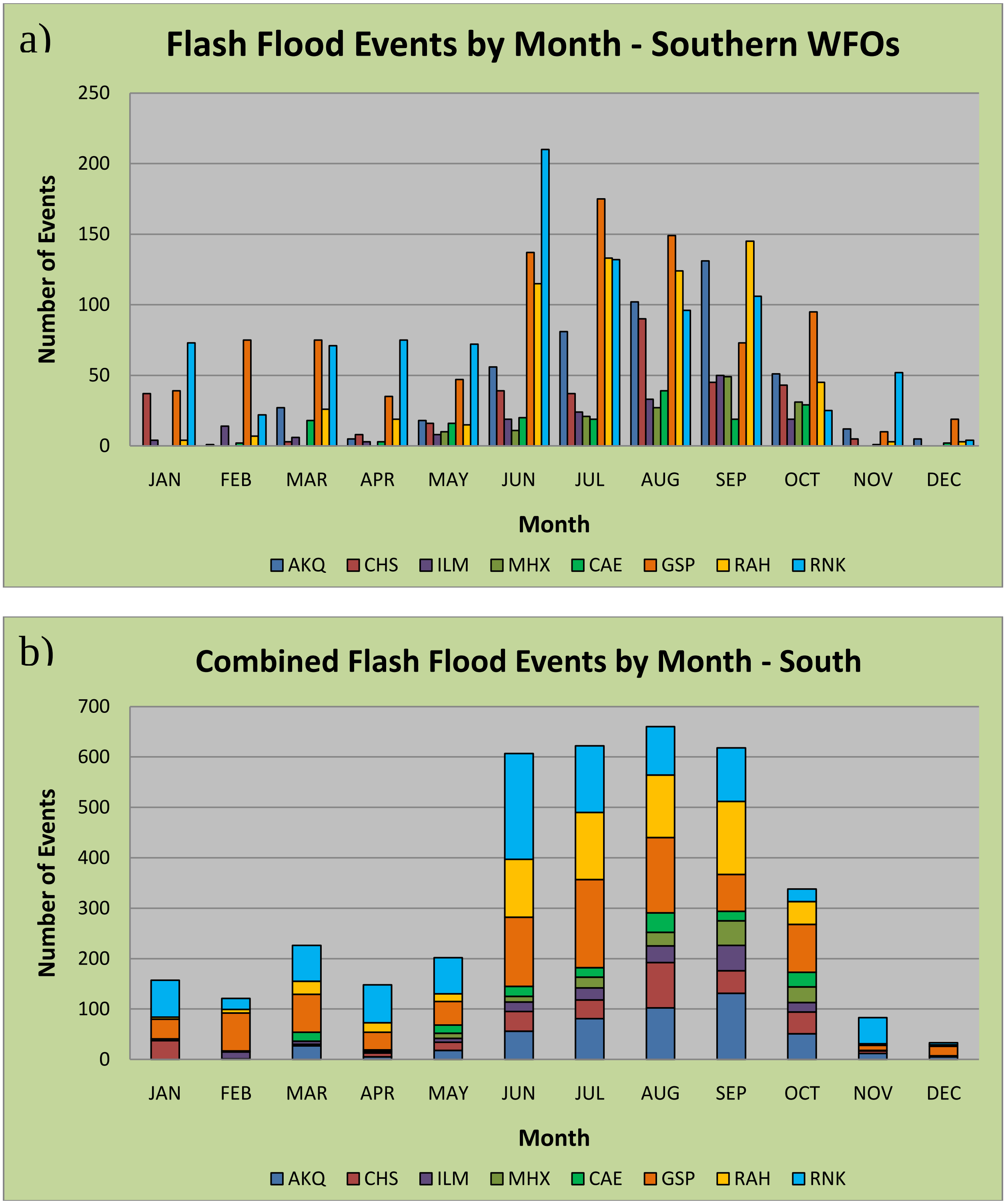
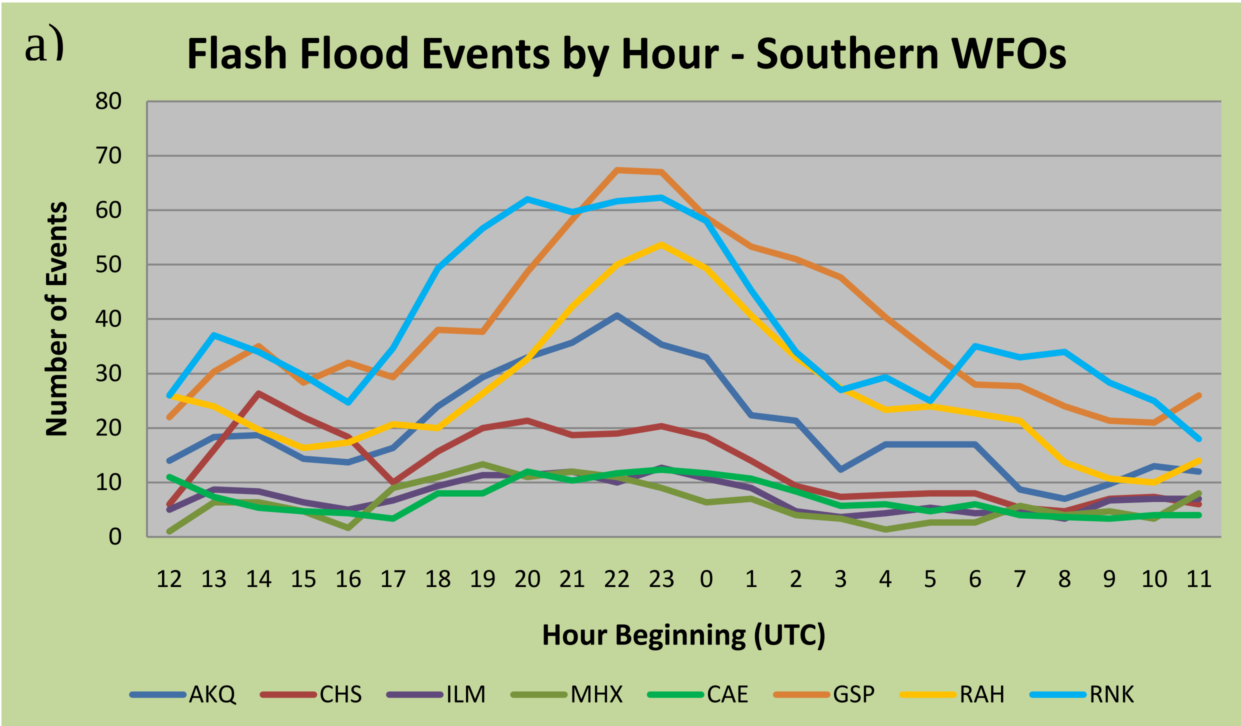


Figure 19. (a) Flash flood events by month for WFOs in the South sub-region. (b) Combined flash flood events by month for the entire South sub-region.



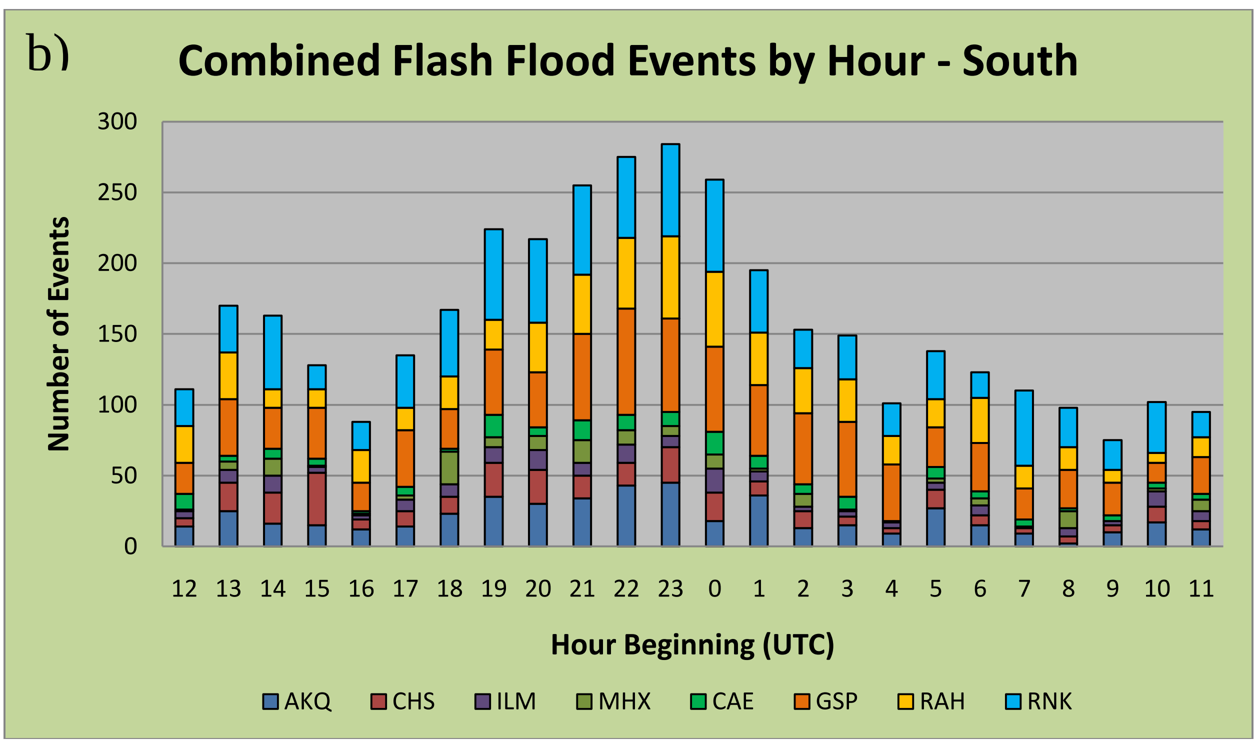


Figure 20. (a) Flash flood events by hour for WFOs in the South sub-region (smoothed). (b) Combined flash flood events by hour for the entire South sub-region.

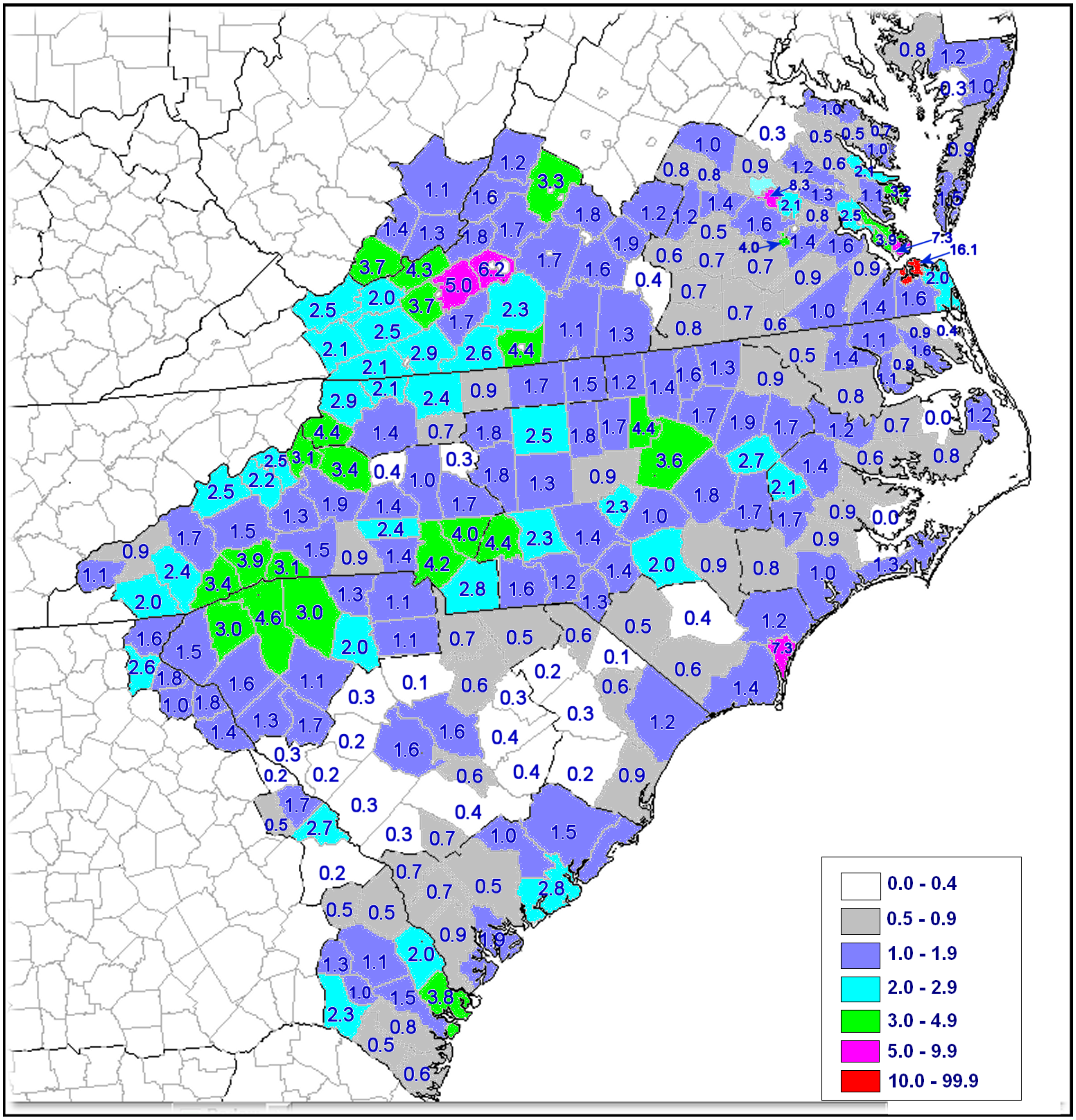


Figure 21. Flash flood events per year per 1000 sq.mi., by county for the South sub-region.

APPENDIX A

Flash Flood Climatology Data

for the National Weather Service Eastern Region,

Sub-Regions and Individual Weather Forecast Offices

Table A1. Flash flood events by year for the NWS Eastern Region and sub-regions.

Year	NewEng	MidAtl	OhVly	South	NWS-ER
1986	28	12	24	57	121
1987	59	68	44	38	209
1988	11	33	6	3	53
1989	95	186	65	180	526
1990	100	125	477	171	873
1991	31	40	83	106	260
1992	66	114	357	109	646
1993	37	205	213	66	521
1994	41	290	380	120	831
1995	60	176	451	287	974
1996	254	599	640	248	1741
1997	39	101	352	125	617
1998	243	302	421	252	1218
1999	118	245	81	335	779
2000	168	255	351	229	1003
2001	61	180	271	168	680
2002	28	108	168	138	442
2003	123	331	560	434	1448
2004	163	358	171	253	945
2005	122	140	97	172	531
2006	111	348	181	230	870
2007	108	49	108	94	359
Total	**2066**	**4265**	**5501**	**3815**	**15647**

Table A2. Flash flood events by month for the NWS Eastern Region and sub-regions.

Month	NewEng	MidAtl	OhVly	South	NWS-ER
JAN	91	363	435	157	1046
FEB	40	111	257	121	529
MAR	157	232	226	226	841
APR	168	204	294	148	814
MAY	80	292	821	202	1395
JUN	342	788	1131	607	2868
JUL	375	633	1112	622	2742
AUG	318	512	669	660	2159
SEP	214	533	163	618	1528
OCT	161	143	18	338	660
NOV	53	302	128	83	566
DEC	67	152	247	33	499
Total	**2066**	**4265**	**5501**	**3815**	**15647**

Table A3. Flash flood events by hour (UTC) for the NWS Eastern Region and sub-regions.

Begin Hour	NewEng	MidAtl	OhVly	South	NWS-ER
12	77	103	212	111	503
13	58	172	197	170	597
14	92	171	184	163	610
15	85	186	167	128	566
16	96	138	157	88	479
17	92	154	178	135	559
18	125	182	210	167	684
19	142	244	260	224	870
20	162	288	378	217	1045
21	180	364	382	255	1181
22	113	312	400	275	1100
23	153	338	370	284	1145
0	108	277	355	259	999
1	88	266	330	195	879
2	69	173	273	153	668
3	65	151	236	149	601
4	33	96	180	101	410
5	71	101	199	138	509
6	26	84	166	123	399
7	36	77	116	110	339
8	34	67	113	98	312
9	49	125	147	75	396
10	40	88	124	102	354
11	72	108	167	95	442
Total	**2066**	**4265**	**5501**	**3815**	**15647**

Table A4. Flash flood events by year for WFOs in the New England sub-region.

Year	ALY	BOX	BTV	CAR	GYX	OKX	NewEng
1986	19	3	6	0	0	0	28
1987	24	0	25	0	0	10	59
1988	5	1	4	0	0	1	11
1989	27	9	34	0	8	17	95
1990	19	4	24	3	23	27	100
1991	4	2	5	0	0	20	31
1992	12	7	25	0	0	22	66
1993	1	7	7	0	0	22	37
1994	14	2	3	2	3	17	41
1995	17	10	3	0	2	28	60
1996	61	46	20	4	22	101	254
1997	6	3	7	1	11	11	39
1998	27	46	94	4	34	38	243
1999	24	14	12	2	9	57	118
2000	59	10	32	0	18	49	168
2001	8	16	3	2	8	24	61
2002	7	0	1	0	2	18	28
2003	35	19	11	5	2	51	123
2004	47	4	5	2	3	102	163
2005	37	21	10	6	8	40	122
2006	13	7	6	16	5	64	111
2007	11	2	17	0	3	75	108
Total	**477**	**233**	**354**	**47**	**161**	**794**	**2066**

Table A5. Flash flood events by month for WFOs in the New England sub-region.

Month	ALY	BOX	BTV	CAR	GYX	OKX	NewEng
JAN	25	6	34	0	0	26	91
FEB	22	7	10	0	0	1	40
MAR	25	19	69	5	13	26	157
APR	19	17	49	1	26	56	168
MAY	37	4	13	2	4	20	80
JUN	83	45	59	5	35	115	342
JUL	87	32	69	18	22	147	375
AUG	73	31	29	10	14	161	318
SEP	38	23	4	2	8	139	214
OCT	21	44	5	0	22	69	161
NOV	14	3	7	2	12	15	53
DEC	33	2	6	2	5	19	67
Total	**477**	**233**	**354**	**47**	**161**	**794**	**2066**

Table A6. Flash flood events by hour (UTC) for WFOs in the New England sub-region.

Begin Hour	ALY	BOX	BTV	CAR	GYX	OKX	NewEng
12	12	11	19	2	3	30	77
13	8	5	5	0	1	39	58
14	11	6	23	2	6	44	92
15	17	9	13	0	6	40	85
16	14	8	15	1	9	49	96
17	21	10	14	2	5	40	92
18	23	15	21	2	7	57	125
19	35	20	20	2	8	57	142
20	48	17	21	5	8	63	162
21	54	20	22	6	5	73	180
22	34	15	12	3	2	47	113
23	37	18	25	2	19	52	153
0	25	15	10	3	17	38	108
1	19	15	25	2	11	16	88
2	16	7	8	1	12	25	69
3	10	4	7	8	9	27	65
4	10	2	5	0	1	15	33
5	14	13	15	2	12	15	71
6	4	3	5	3	5	6	26
7	13	2	8	0	5	8	36
8	7	0	14	0	1	12	34
9	6	7	25	0	1	10	49
10	10	6	5	1	1	17	40
11	29	5	17	0	7	14	72
Total	**477**	**233**	**354**	**47**	**161**	**794**	**2066**

Table A7. Flash flood events by year for WFOs in the mid-Atlantic sub-region.

Year	BGM	BUF	CTP	LWX	PHI	MidAtl
1986	7	0	2	3	0	12
1987	16	5	9	22	16	68
1988	2	2	19	4	6	33
1989	15	15	22	75	59	186
1990	6	7	32	46	34	125
1991	2	5	7	9	17	40
1992	6	9	27	57	15	114
1993	8	0	62	99	36	205
1994	52	14	90	86	48	290
1995	10	5	74	56	31	176
1996	61	46	167	196	129	599
1997	0	11	35	35	20	101
1998	19	58	71	129	25	302
1999	9	34	50	71	81	245
2000	43	27	41	61	83	255
2001	13	11	25	70	61	180
2002	23	7	10	25	43	108
2003	32	12	44	171	72	331
2004	74	24	41	100	119	358
2005	43	14	9	29	45	140
2006	118	7	60	95	68	348
2007	4	2	15	1	27	49
Total	**563**	**315**	**912**	**1440**	**1035**	**4265**

Table A8. Flash flood events by month for WFOs in the mid-Atlantic sub-region.

Month	BGM	BUF	CTP	LWX	PHI	MidAtl
JAN	41	68	95	106	53	363
FEB	10	13	19	57	12	111
MAR	19	4	31	120	58	232
APR	45	15	37	70	37	204
MAY	54	34	55	94	55	292
JUN	95	59	147	305	182	788
JUL	93	46	136	162	196	633
AUG	62	42	107	128	173	512
SEP	38	13	112	250	120	533
OCT	7	9	43	32	52	143
NOV	77	8	78	97	42	302
DEC	22	4	52	19	55	152
Total	**563**	**315**	**912**	**1440**	**1035**	**4265**

Table A9. Flash flood events by hour (UTC) for WFOs in the mid-Atlantic sub-region.

Begin Hour	BGM	BUF	CTP	LWX	PHI	MidAtl
12	3	6	14	37	43	103
13	28	12	35	53	44	172
14	27	11	34	55	44	171
15	20	5	26	90	45	186
16	15	7	17	67	32	138
17	23	9	19	56	47	154
18	31	11	51	43	46	182
19	34	22	48	82	58	244
20	36	32	49	105	66	288
21	47	44	98	109	66	364
22	43	17	72	103	77	312
23	50	10	73	128	77	338
0	44	25	68	84	56	277
1	26	21	62	99	58	266
2	20	21	33	72	27	173
3	12	13	33	58	35	151
4	13	3	24	34	22	96
5	17	10	24	25	25	101
6	12	8	25	21	18	84
7	7	4	21	15	30	77
8	12	3	10	14	28	67
9	13	6	33	35	38	125
10	15	5	21	26	21	88
11	15	10	22	29	32	108
Total	**563**	**315**	**912**	**1440**	**1035**	**4265**

Table A10. Flash flood events by year for WFOs in the Ohio Valley sub-region.

Year	CLE	ILN	PBZ	RLX	OhVly
1986	4	5	15	0	24
1987	10	3	17	14	44
1988	0	0	6	0	6
1989	4	5	24	32	65
1990	74	150	150	103	477
1991	3	18	14	48	83
1992	129	118	71	39	357
1993	42	97	29	45	213
1994	85	86	91	118	380
1995	92	163	112	84	451
1996	189	91	215	145	640
1997	89	92	73	98	352
1998	113	87	117	104	421
1999	16	21	38	6	81
2000	23	132	107	89	351
2001	7	126	46	92	271
2002	10	67	68	23	168
2003	47	103	330	80	560
2004	54	33	67	17	171
2005	23	11	36	27	97
2006	54	51	47	29	181
2007	25	6	76	1	108
Total	**1093**	**1465**	**1749**	**1194**	**5501**

Table A11. Flash flood events by month for WFOs in the Ohio Valley sub-region.

Month	CLE	ILN	PBZ	RLX	OhVly
JAN	79	110	164	82	435
FEB	35	78	71	73	257
MAR	3	47	60	116	226
APR	68	117	61	48	294
MAY	115	293	186	227	821
JUN	255	290	357	229	1131
JUL	243	311	347	211	1112
AUG	148	117	281	123	669
SEP	67	22	56	18	163
OCT	3	9	2	4	18
NOV	24	18	80	6	128
DEC	53	53	84	57	247
Total	**1093**	**1465**	**1749**	**1194**	**5501**

Table A12. Flash flood events by hour (UTC) day for WFOs in the Ohio Valley sub-region.

Begin Hour	CLE	ILN	PBZ	RLX	OhVly
12	46	62	62	42	212
13	42	55	64	36	197
14	42	48	41	53	184
15	31	48	55	33	167
16	32	45	48	32	157
17	31	32	92	23	178
18	40	40	89	41	210
19	54	46	117	43	260
20	105	68	132	73	378
21	64	94	125	99	382
22	83	110	109	98	400
23	74	103	107	86	370
0	67	100	108	80	355
1	61	109	89	71	330
2	59	93	76	45	273
3	42	70	80	44	236
4	24	41	60	55	180
5	42	72	53	32	199
6	25	48	40	53	166
7	29	24	34	29	116
8	30	28	27	28	113
9	11	58	39	39	147
10	28	36	30	30	124
11	31	35	72	29	167
Total	**1093**	**1465**	**1749**	**1194**	**5501**

Table A13. Flash flood events by year for WFOs in the South sub-region.

Year	AKQ	CHS	ILM	MHX	CAE	GSP	RAH	RNK	South
1986	0	0	2	2	15	30	7	1	57
1987	0	5	2	0	1	13	6	11	38
1988	0	1	1	0	0	0	1	0	3
1989	20	4	0	0	3	45	14	94	180
1990	15	43	2	1	28	60	13	9	171
1991	6	21	7	1	21	36	9	5	106
1992	11	10	4	0	5	27	8	44	109
1993	12	5	0	0	0	19	10	20	66
1994	34	10	4	1	2	30	6	33	120
1995	16	41	5	5	4	78	43	95	287
1996	9	6	30	14	11	38	41	99	248
1997	0	5	2	1	3	56	34	24	125
1998	1	7	40	4	4	85	33	78	252
1999	96	21	31	51	2	16	81	37	335
2000	54	5	21	8	11	20	41	69	229
2001	17	0	20	2	8	28	29	64	168
2002	12	15	0	10	5	29	33	34	138
2003	27	32	0	14	22	150	87	102	434
2004	49	20	3	21	8	73	50	29	253
2005	20	35	0	12	4	75	13	13	172
2006	83	9	6	2	8	16	59	47	230
2007	7	28	0	0	3	5	21	30	94
Total	**489**	**323**	**180**	**149**	**168**	**929**	**639**	**938**	**3815**

Table A14. Flash flood events by month for WFOs in the South sub-region.

Month	AKQ	CHS	ILM	MHX	CAE	GSP	RAH	RNK	South
JAN	0	37	4	0	0	39	4	73	157
FEB	1	0	14	0	2	75	7	22	121
MAR	27	3	6	0	18	75	26	71	226
APR	5	8	3	0	3	35	19	75	148
MAY	18	16	8	10	16	47	15	72	202
JUN	56	39	19	11	20	137	115	210	607
JUL	81	37	24	21	19	175	133	132	622
AUG	102	90	33	27	39	149	124	96	660
SEP	131	45	50	49	19	73	145	106	618
OCT	51	43	19	31	29	95	45	25	338
NOV	12	5	0	0	1	10	3	52	83
DEC	5	0	0	0	2	19	3	4	33
Total	**489**	**323**	**180**	**149**	**168**	**929**	**639**	**938**	**3815**

Table A15. Flash flood events by hour (UTC) for WFOs in the South sub-region.

Begin Hour	AKQ	CHS	ILM	MHX	CAE	GSP	RAH	RNK	South
12	14	6	5	1	11	22	26	26	111
13	25	20	9	6	4	40	33	33	170
14	16	22	12	12	7	29	13	52	163
15	15	37	4	1	5	36	13	17	128
16	12	7	3	1	2	20	23	20	88
17	14	11	8	3	6	40	16	37	135
18	23	12	9	23	2	28	23	47	167
19	35	24	11	7	16	46	21	64	224
20	30	24	14	10	6	39	35	59	217
21	34	16	9	16	14	61	42	63	255
22	43	16	13	10	11	75	50	57	275
23	45	25	8	7	10	66	58	65	284
0	18	20	17	10	16	60	53	65	259
1	36	10	7	2	9	50	37	44	195
2	13	12	3	9	7	50	32	27	153
3	15	6	4	1	9	53	30	31	149
4	9	4	4	0	1	40	20	23	101
5	27	13	5	3	8	28	20	34	138
6	15	7	7	5	5	34	32	18	123
7	9	4	1	0	5	22	16	53	110
8	2	5	6	12	2	27	16	28	98
9	10	5	3	0	4	23	9	21	75
10	17	11	11	2	4	14	7	36	102
11	12	6	7	8	4	26	14	18	95
Total	**489**	**323**	**180**	**149**	**168**	**929**	**639**	**938**	**3815**

APPENDIX B

Flash Flood Climatology

for Individual Weather Forecast Offices

in the National Weather Service Eastern Region

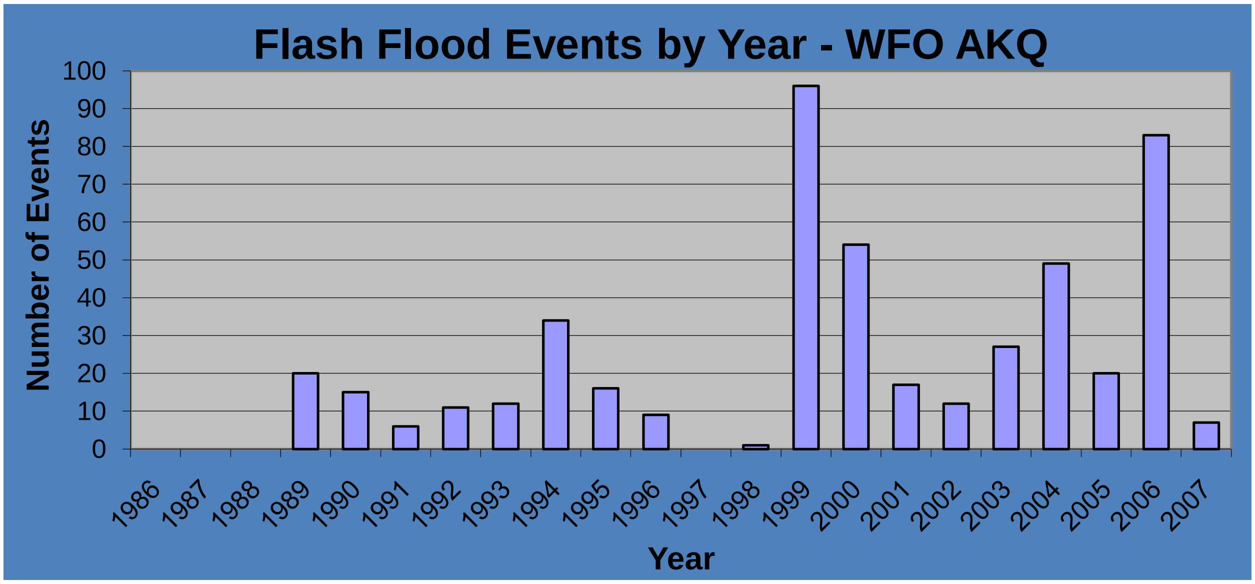


Figure B1. Flash flood events by year for the AKQ county warning area.

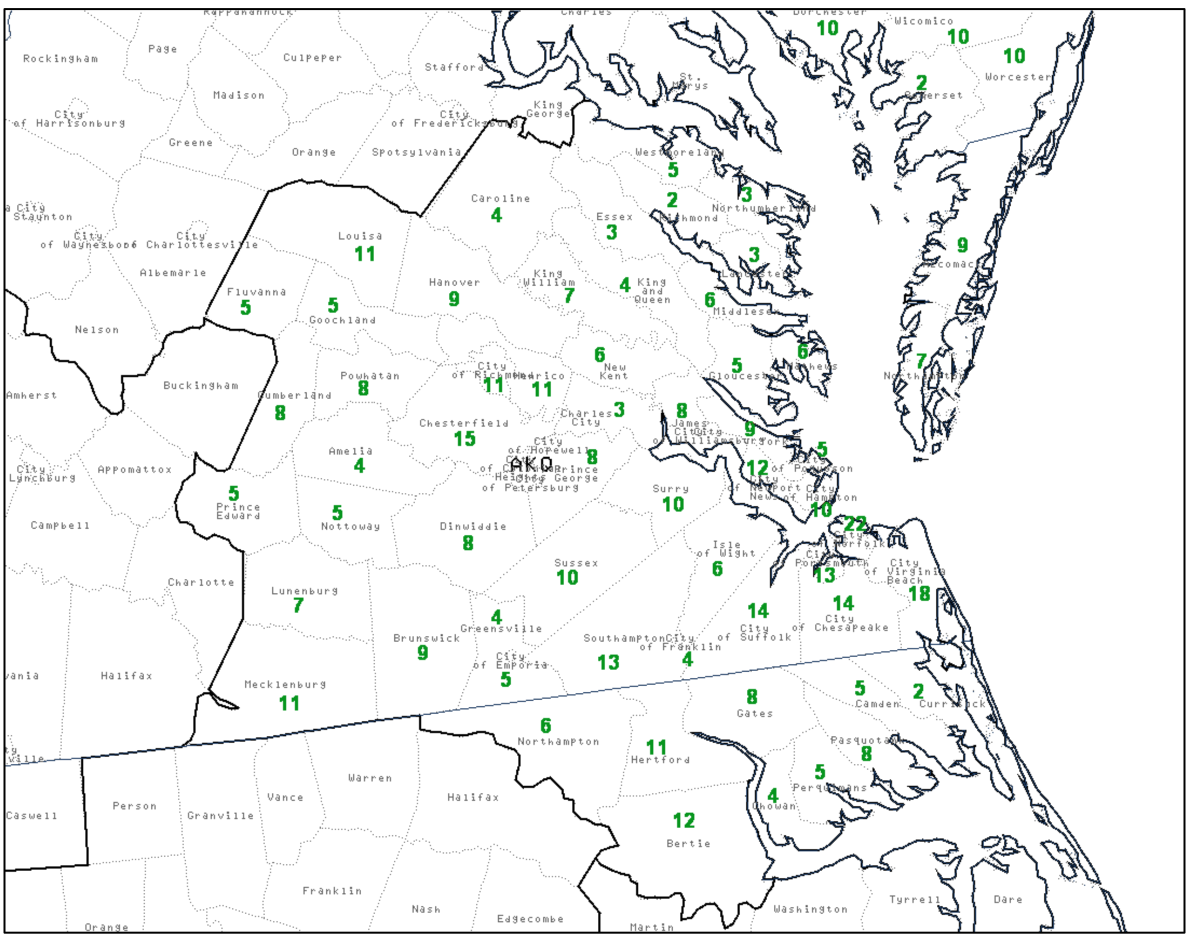


Figure B2. Flash flood events by county for the AKQ county warning area.

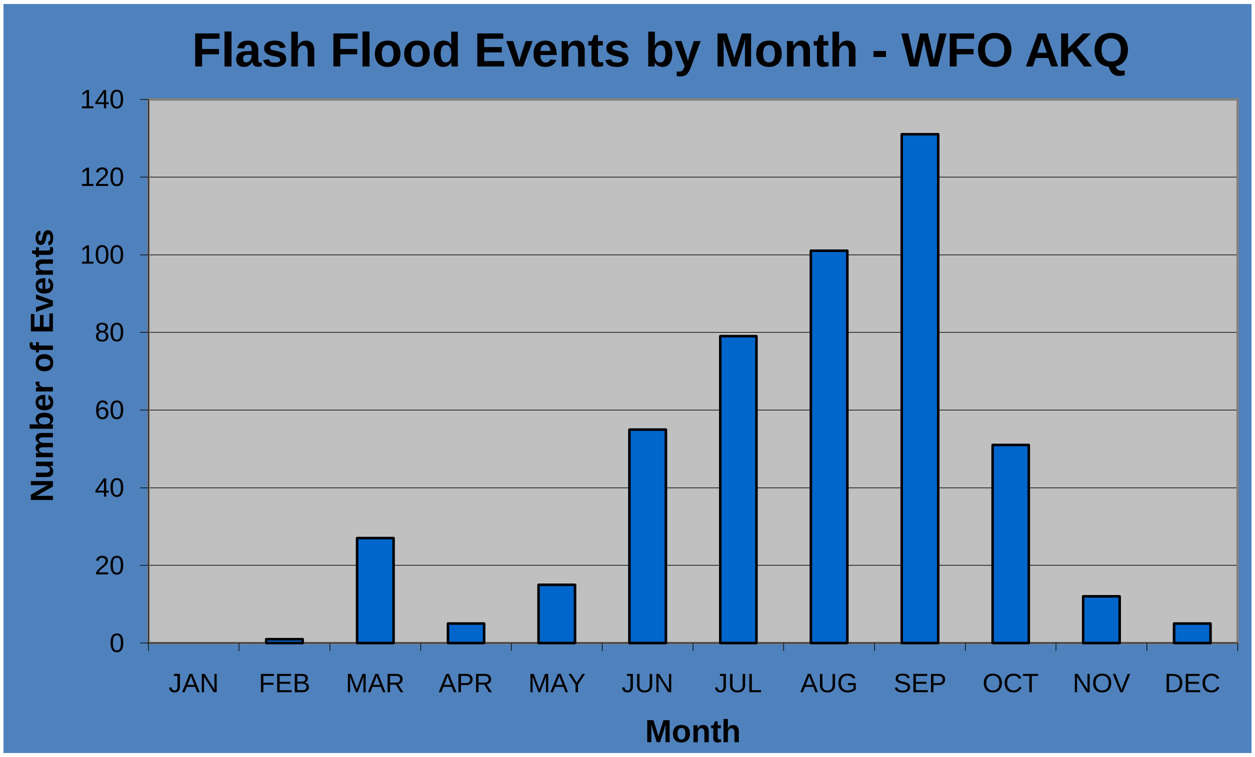


Figure B3. Flash flood events by month in the AKQ county warning area.

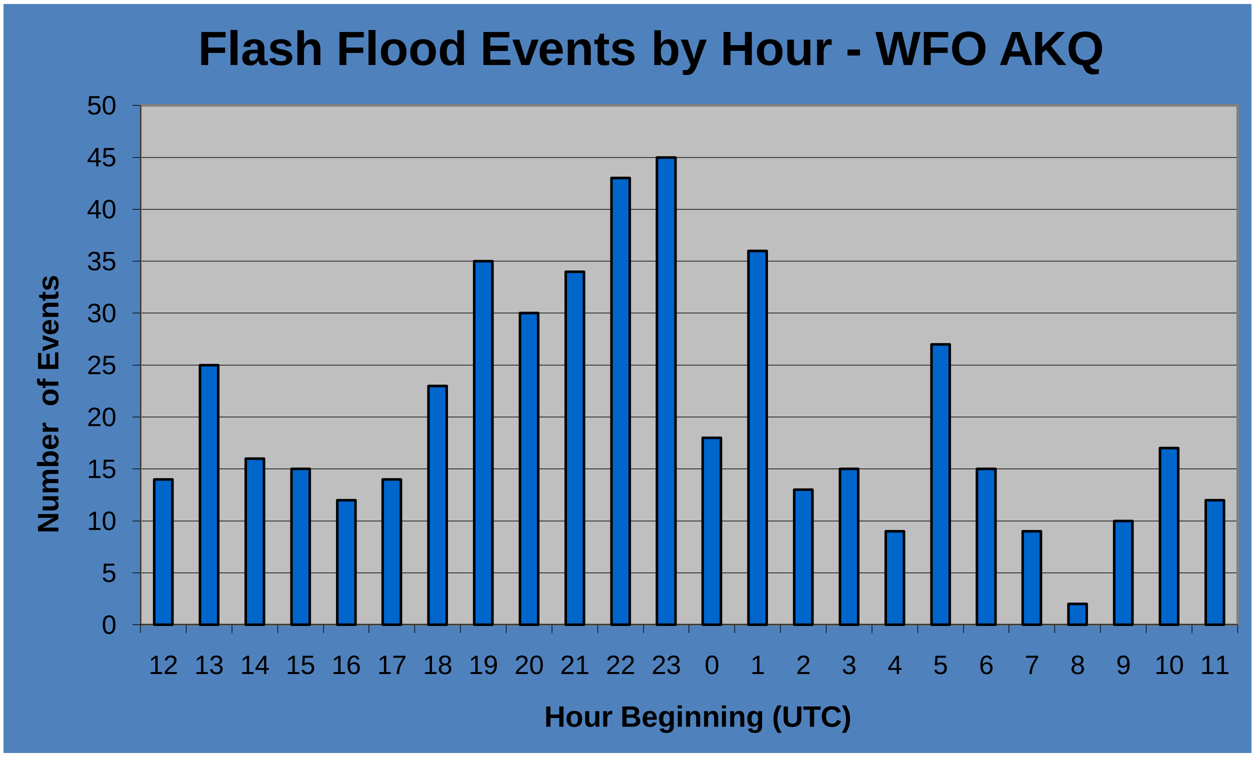


Figure B4. Flash flood events by hour of the day for the AKQ county warning area.

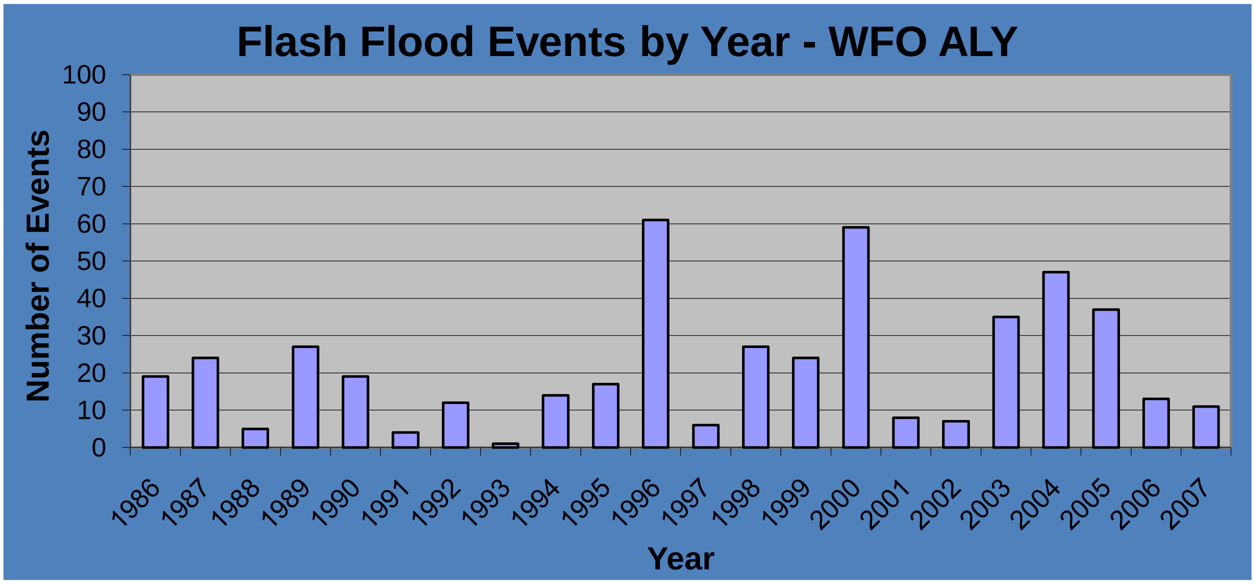


Figure B5. Flash flood events by year for the ALY county warning area.

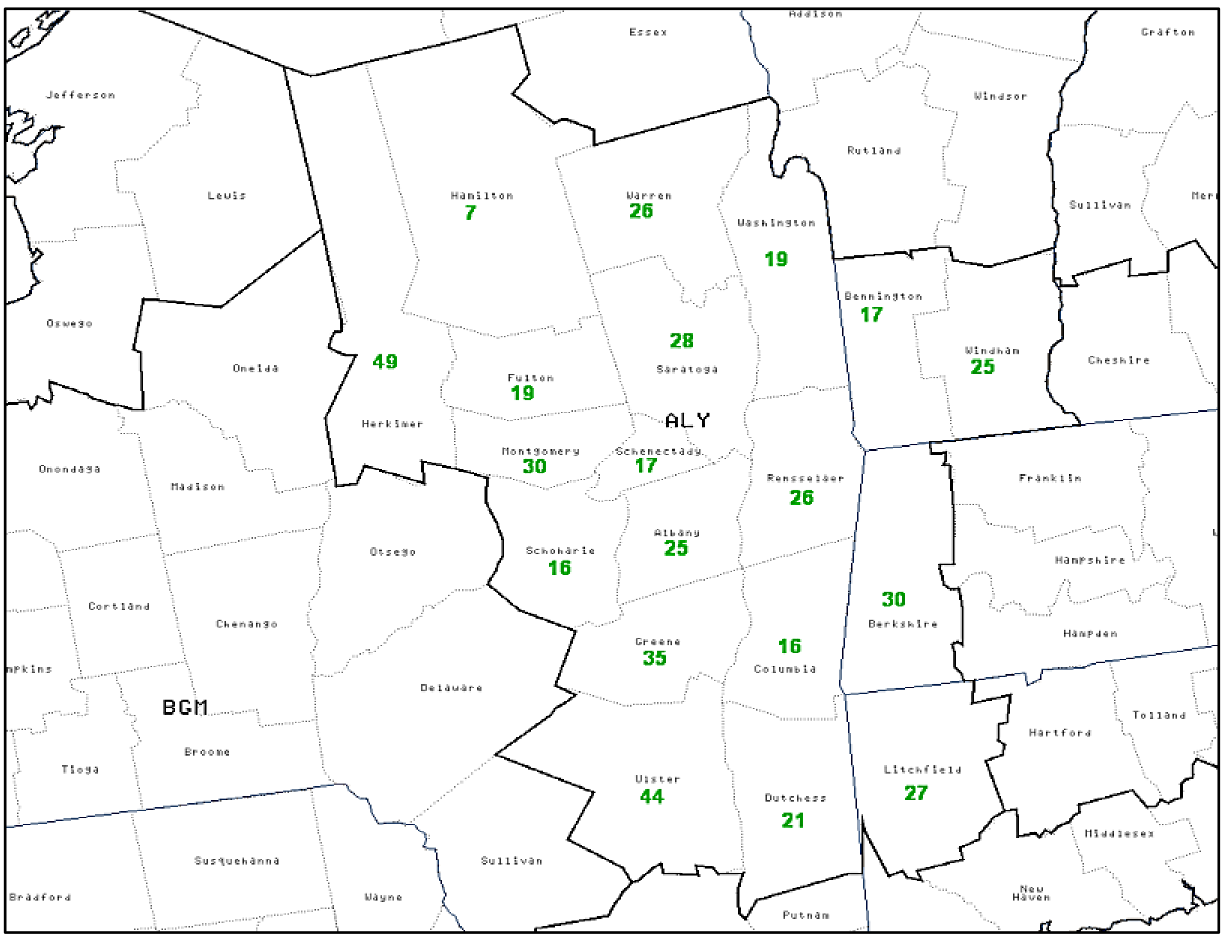


Figure B6. Flash flood events by county for the ALY county warning area.

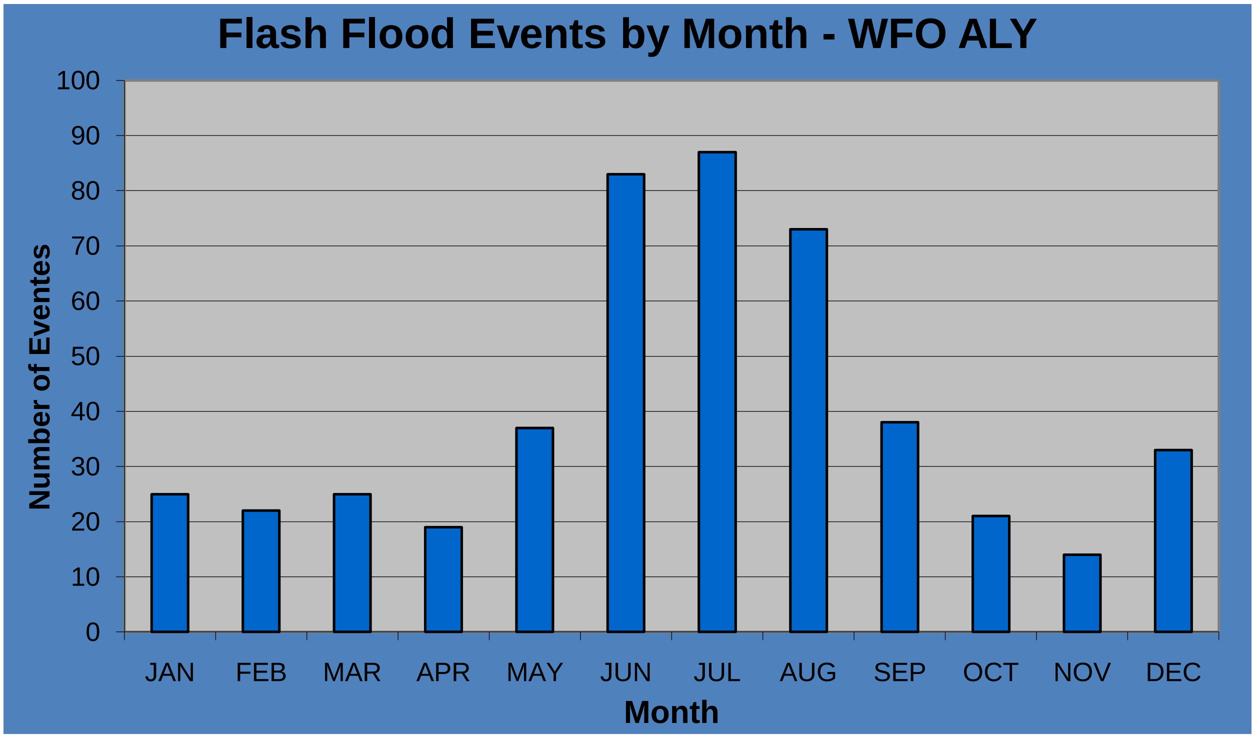


Figure B7. Flash flood events by month for the ALY county warning area.

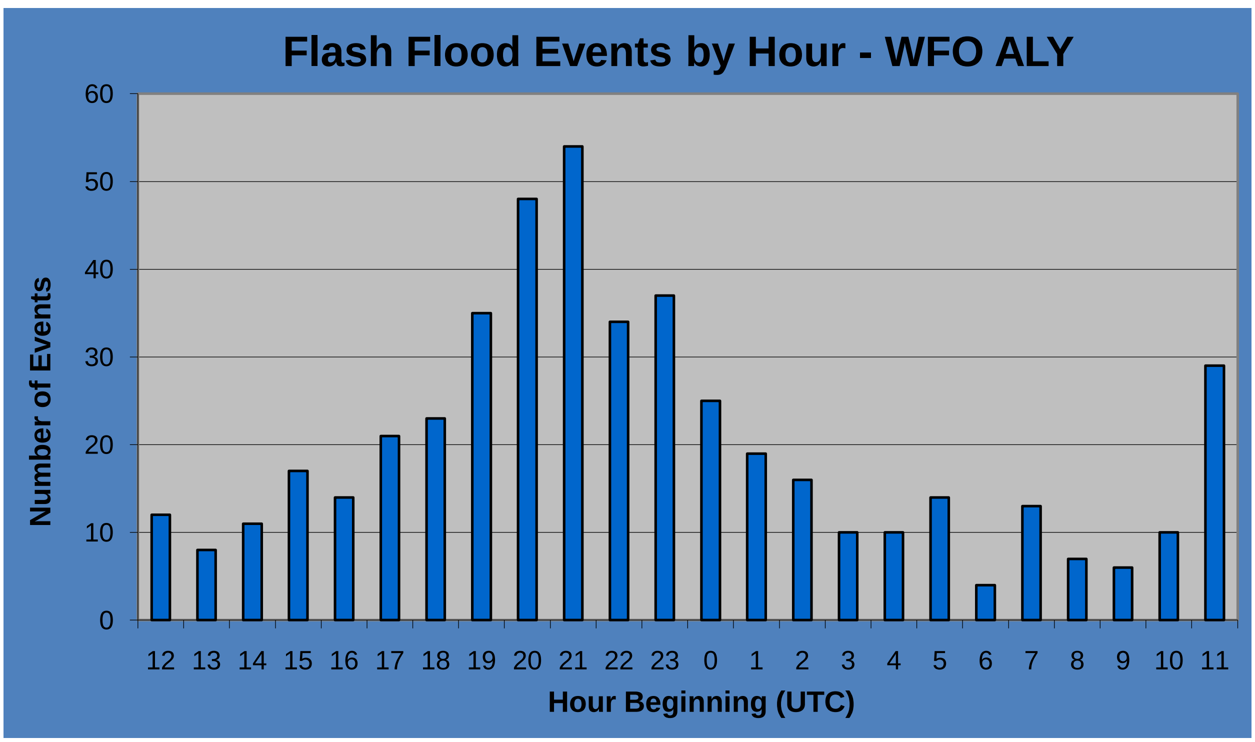


Figure B8. Flash flood events by hour of the day for the ALY county warning area.

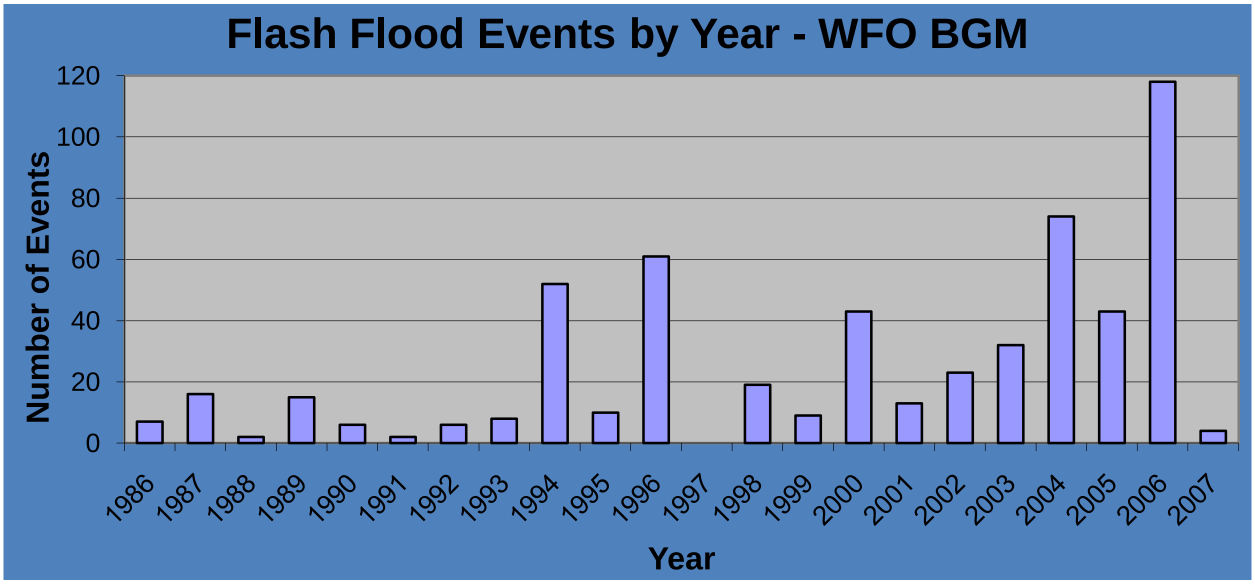


Figure B9. Flash flood events by year for the BGM county warning area.

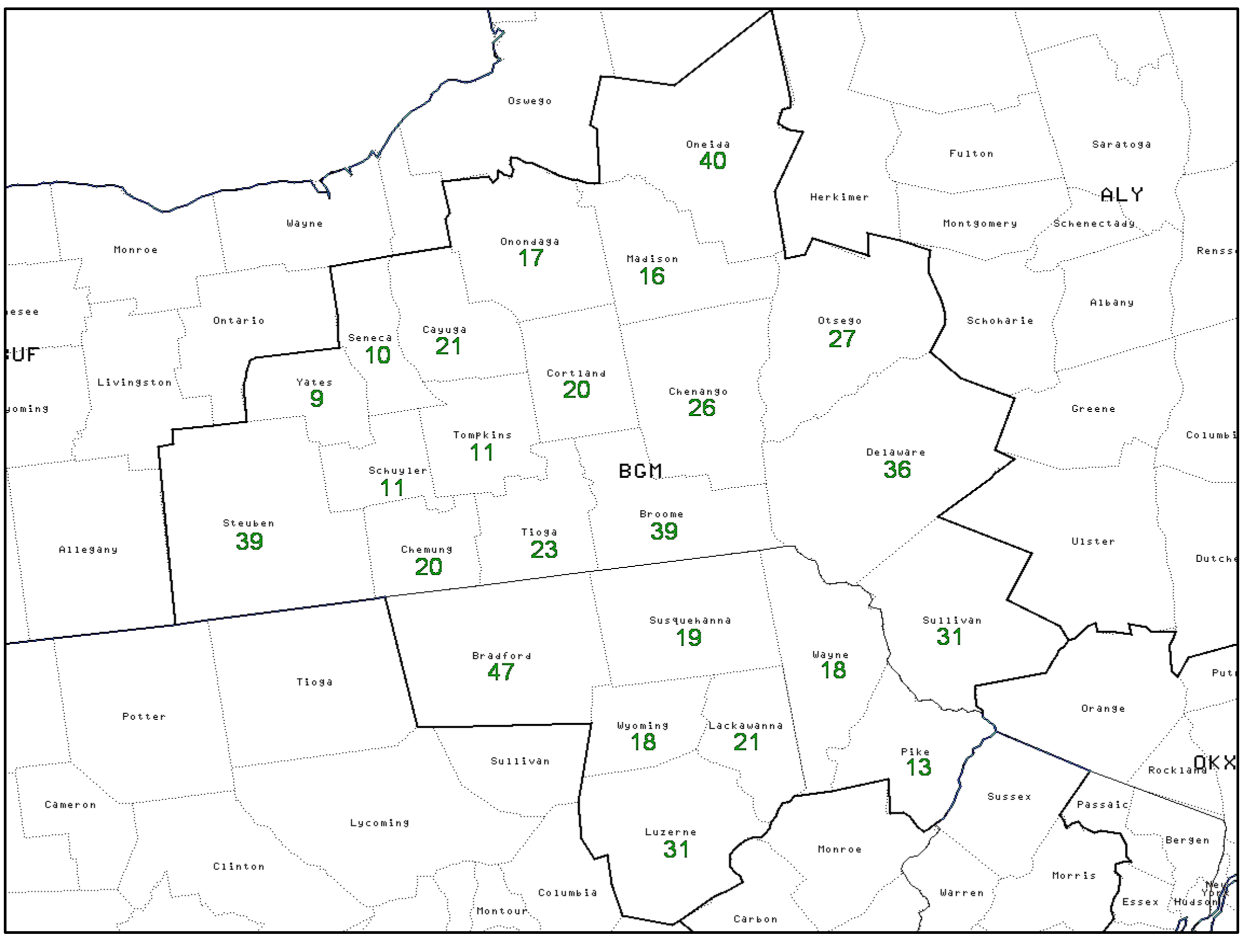


Figure B10. Flash flood events by county for the BGM county warning area.

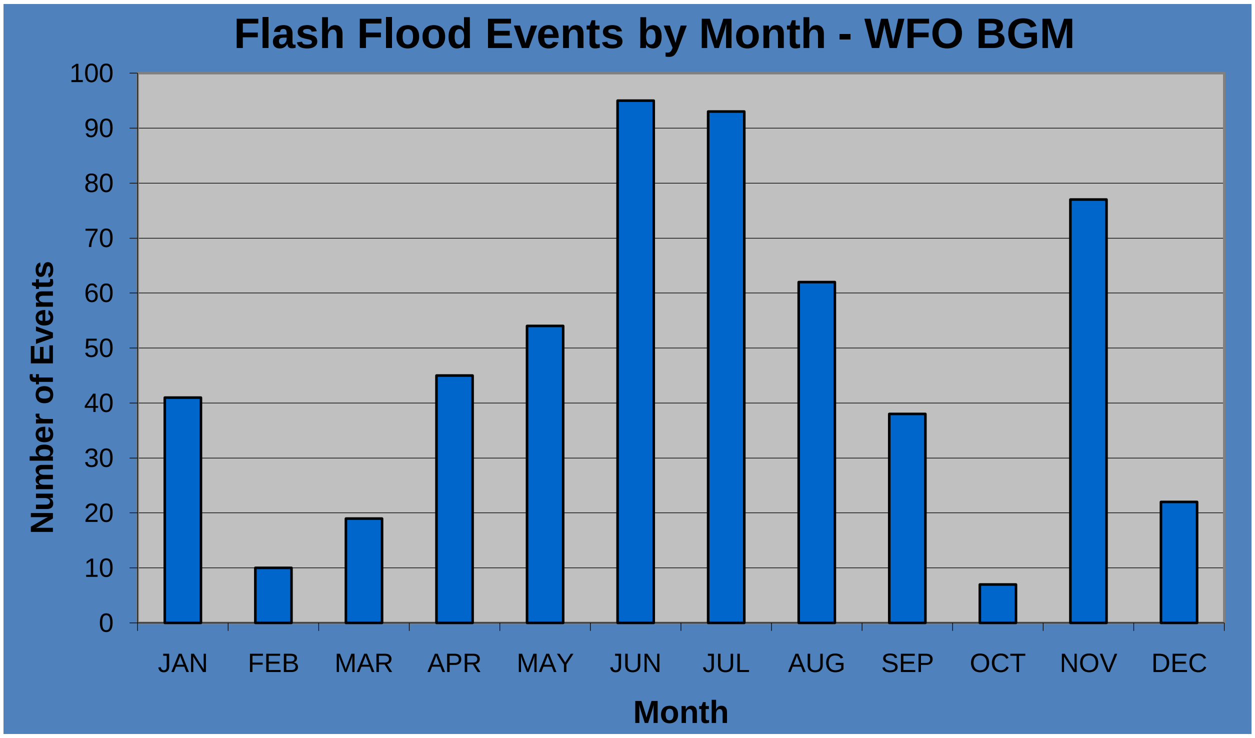


Figure B11. Flash flood events by month for the BGM county warning area.

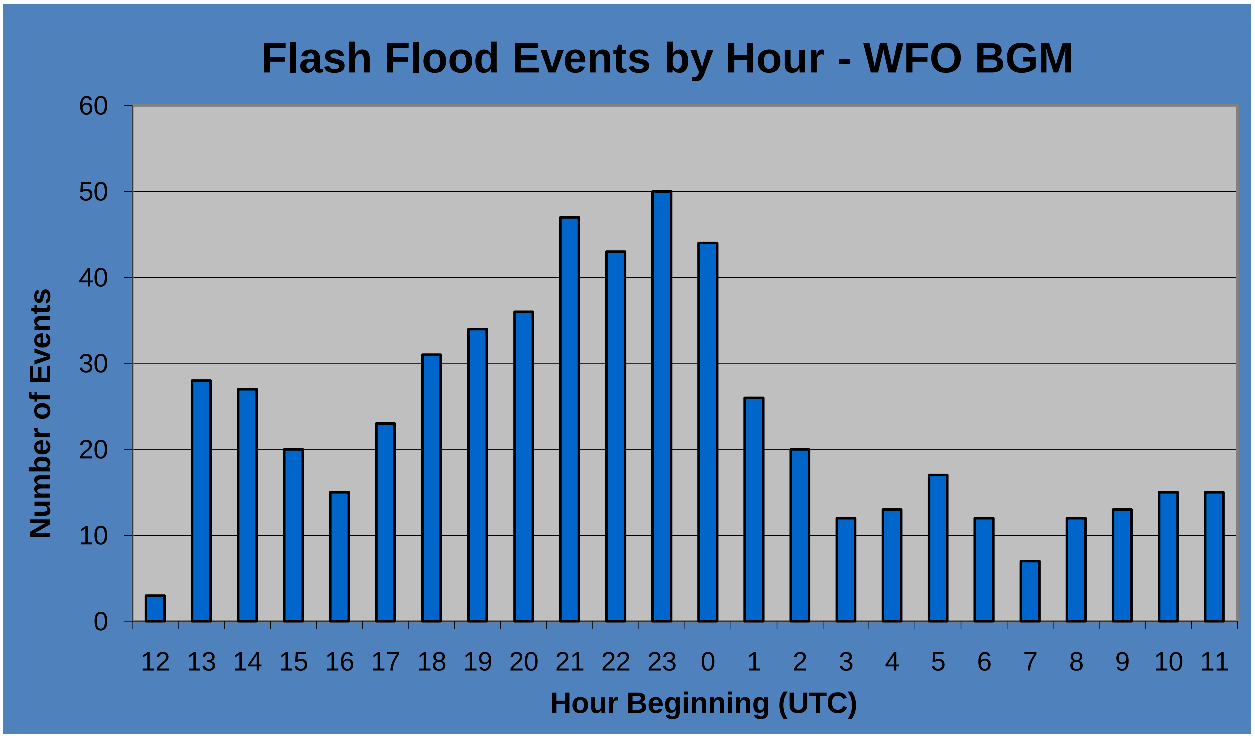


Figure B12. Flash flood events by hour of the day for the BGM county warning area.

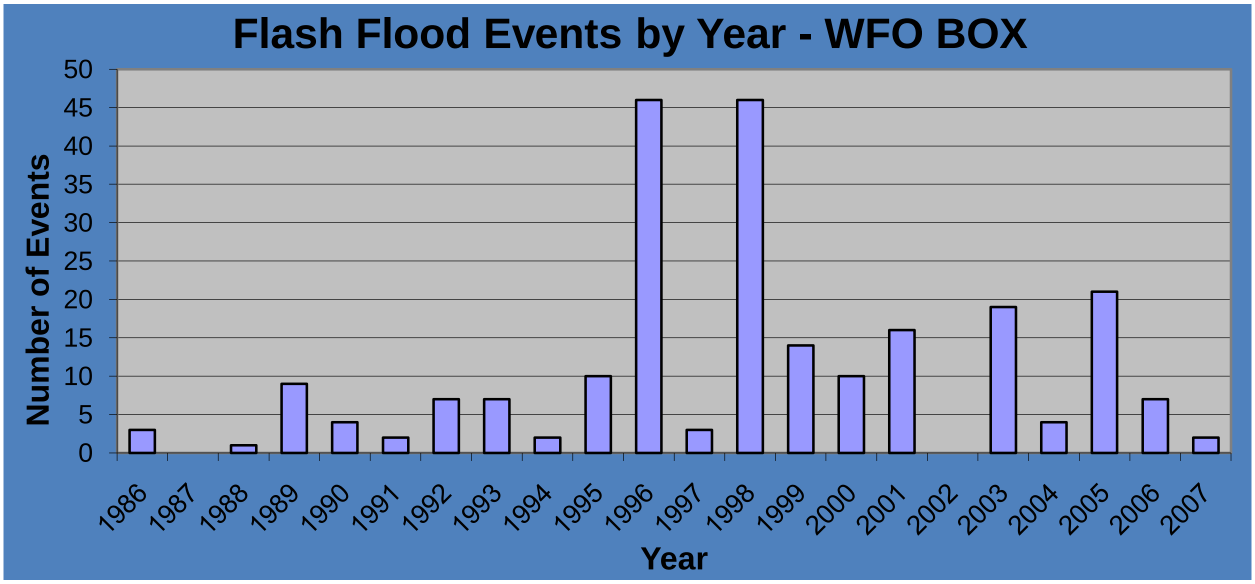


Figure B13. Flash flood events by year for the BOX county warning area.

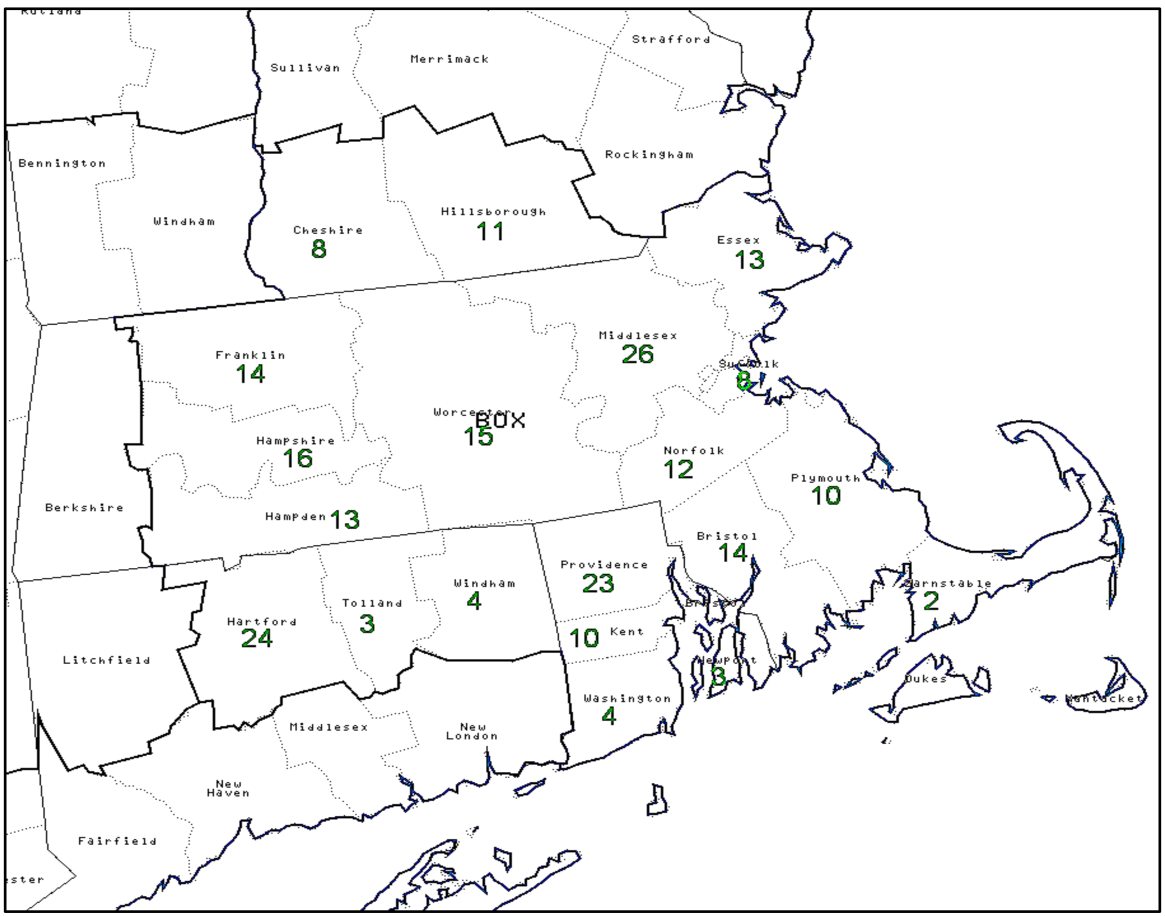


Figure B14. Flash flood events by county for the BOX county warning area.

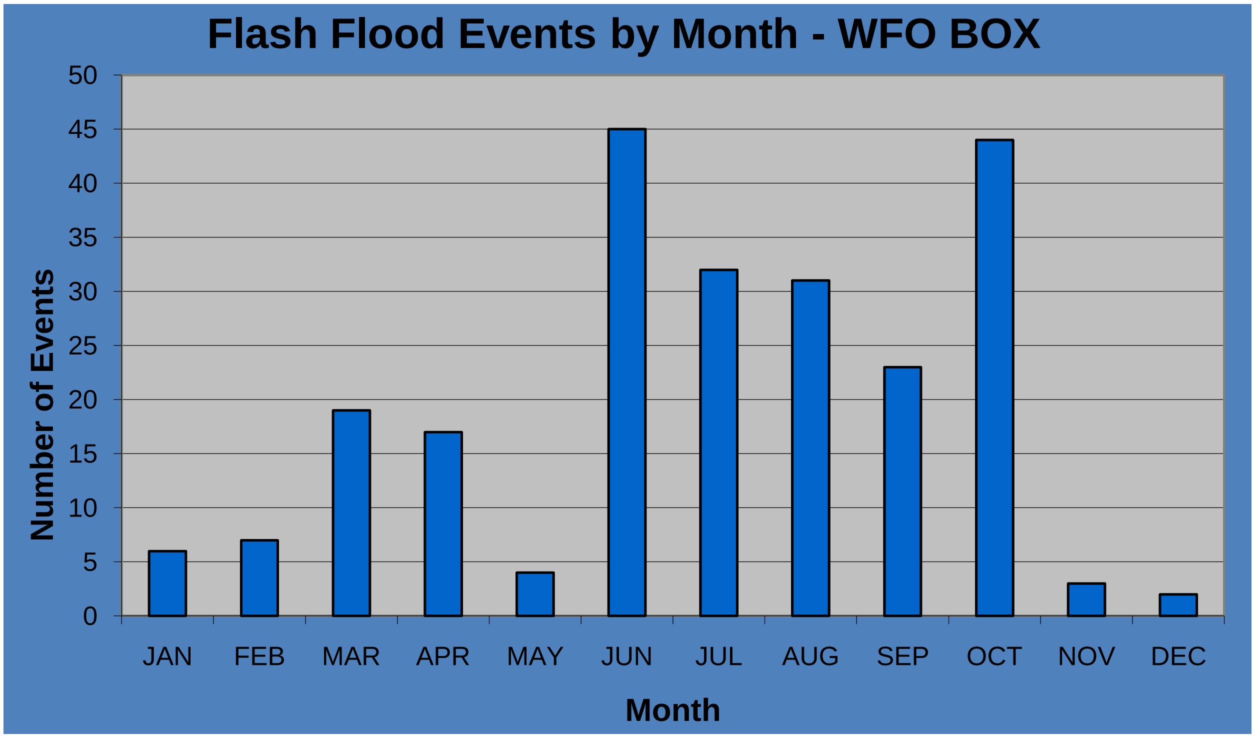


Figure B15. Flash flood events by month for the BOX county warning area.

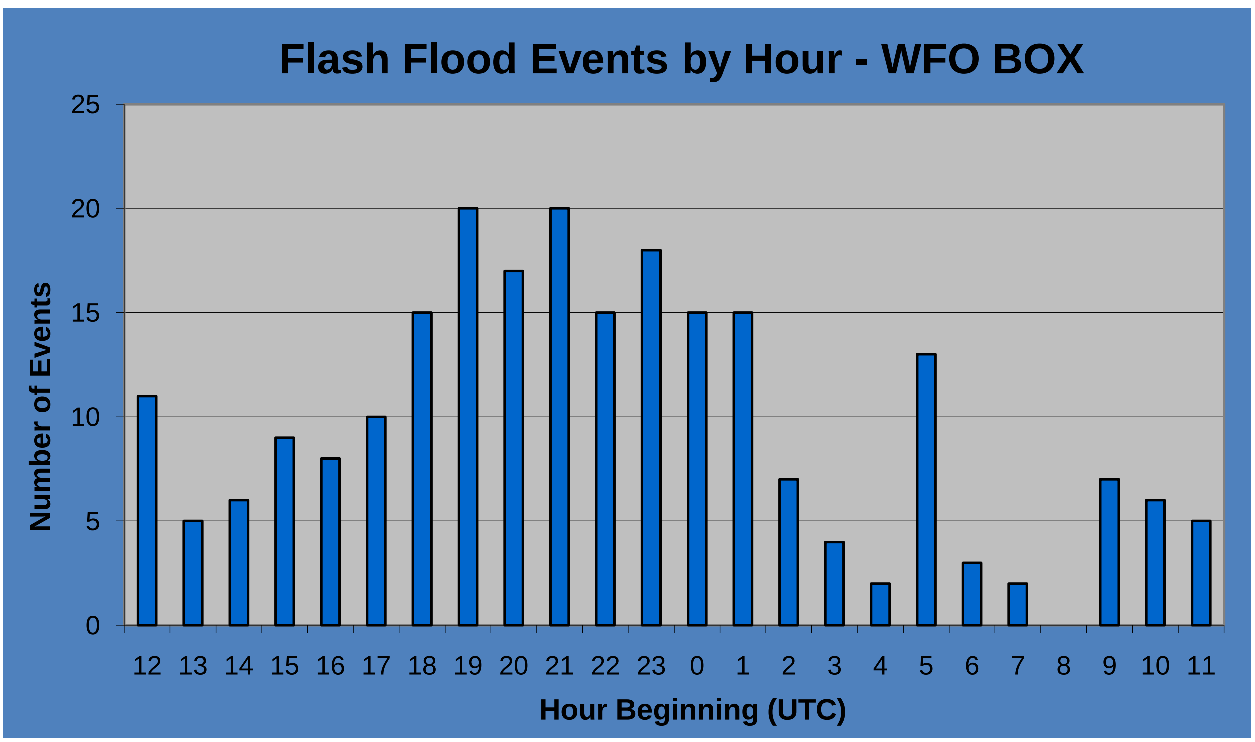


Figure B16. Flash flood events by hour of the day for the BOX county warning area.

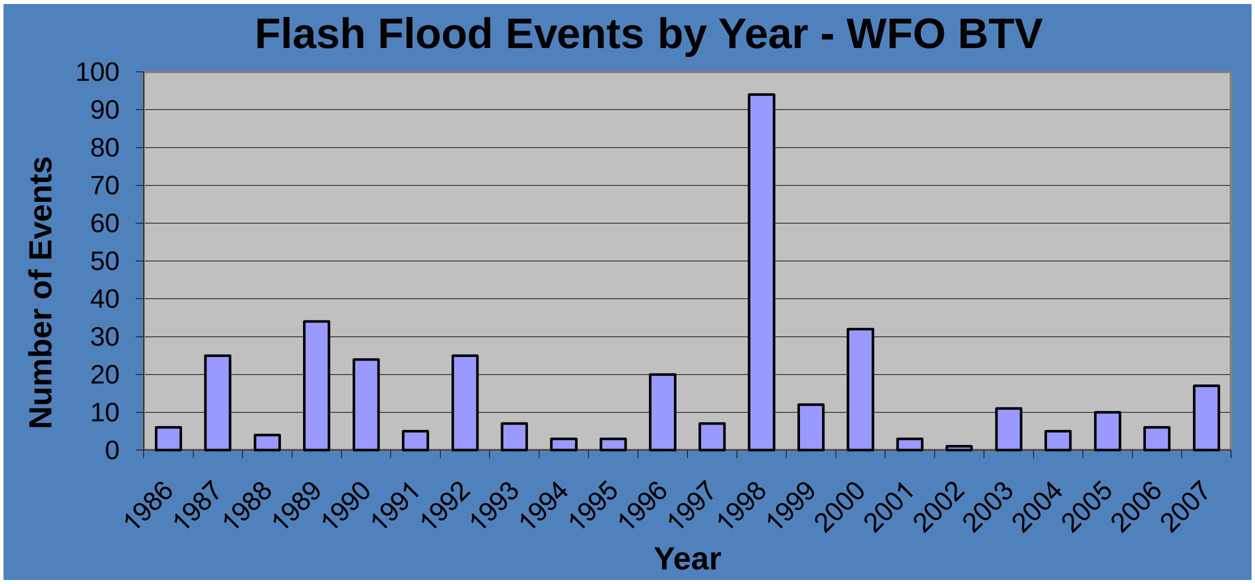


Figure B17. Flash flood events by year for the BTV county warning area.

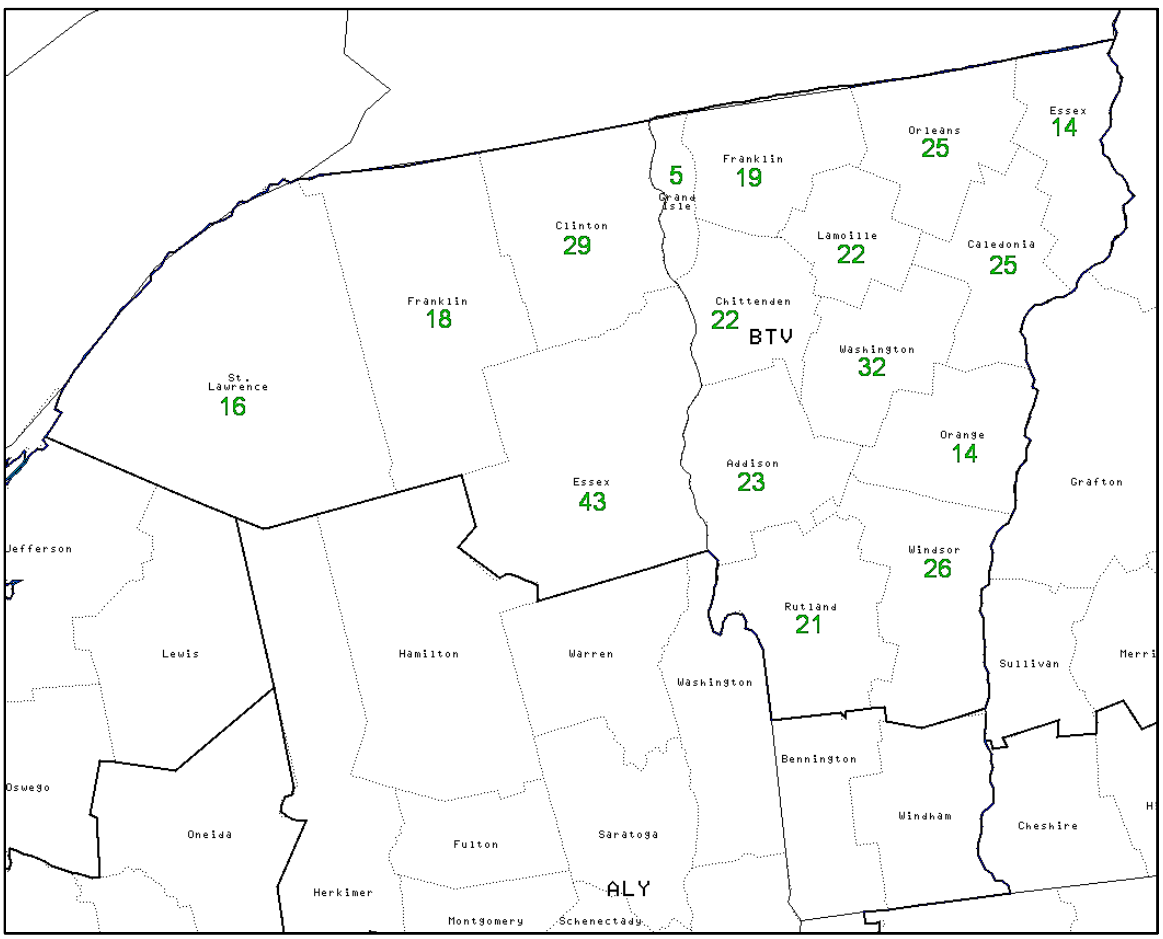


Figure B18. Flash flood events by county for the BTV county warning area.

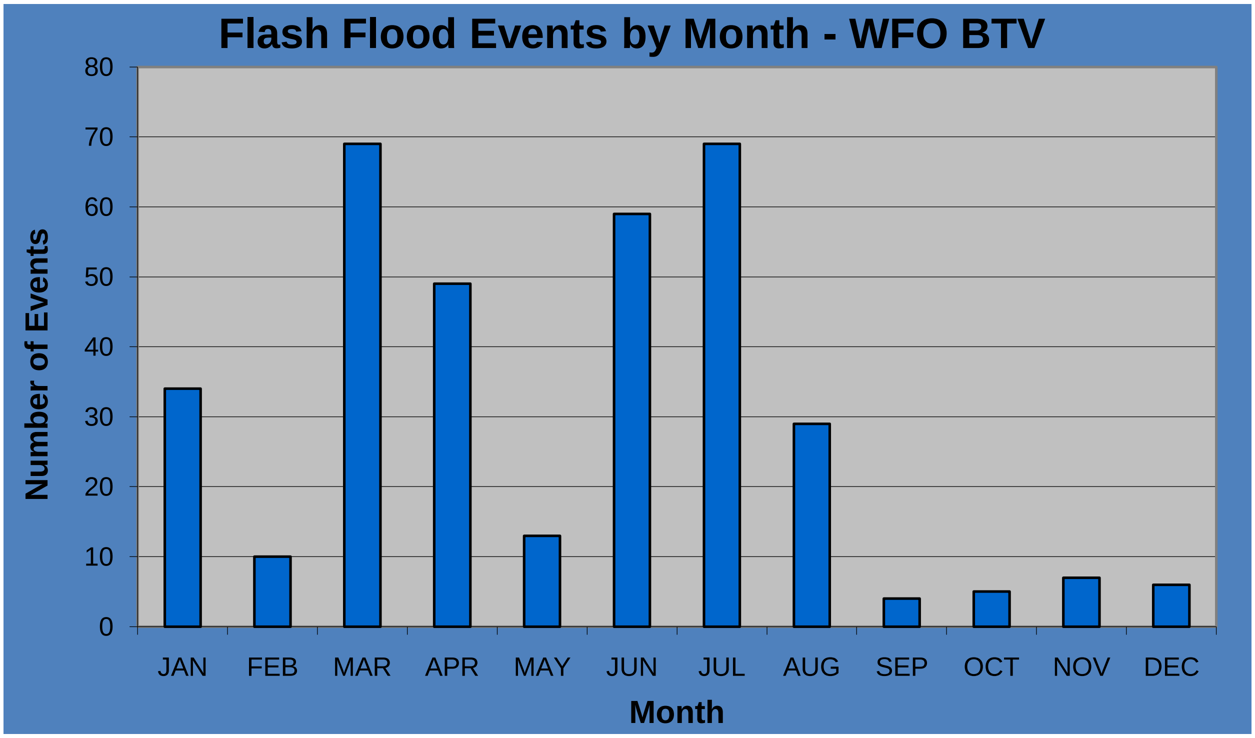


Figure B19. Flash flood events by month for the BTV county warning area.

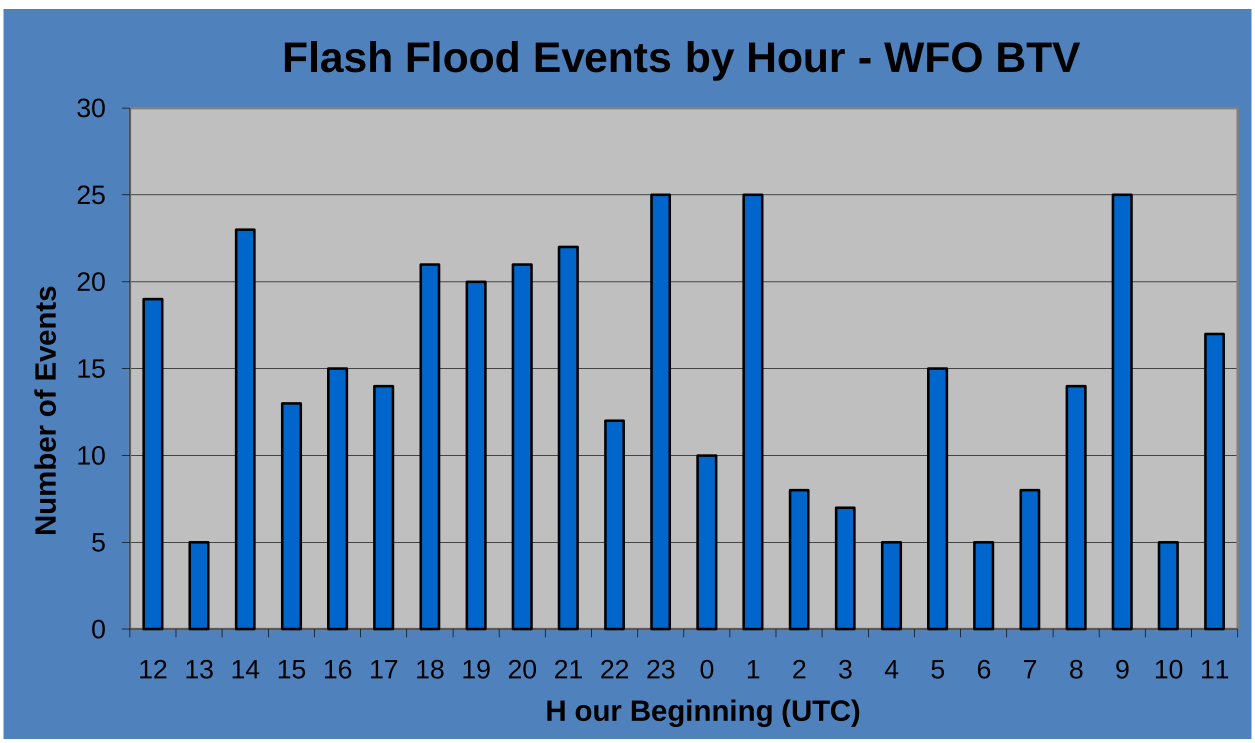


Figure B20. Flash flood events by hour of the day for the BTV county warning area.

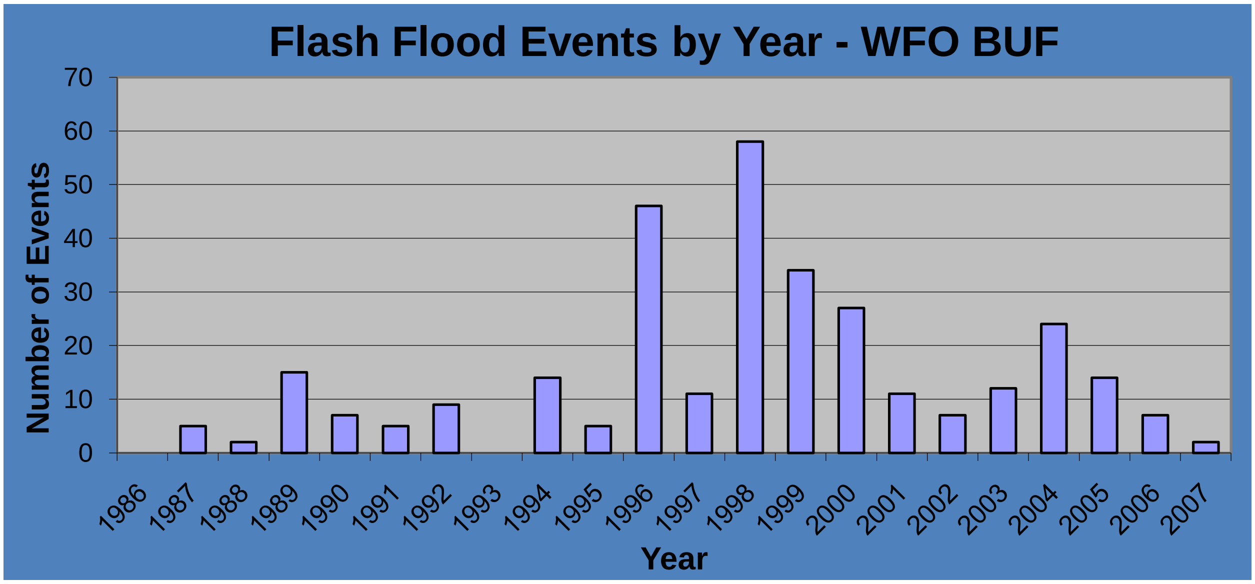


Figure B21. Flash flood events by year for the BUF county warning area.

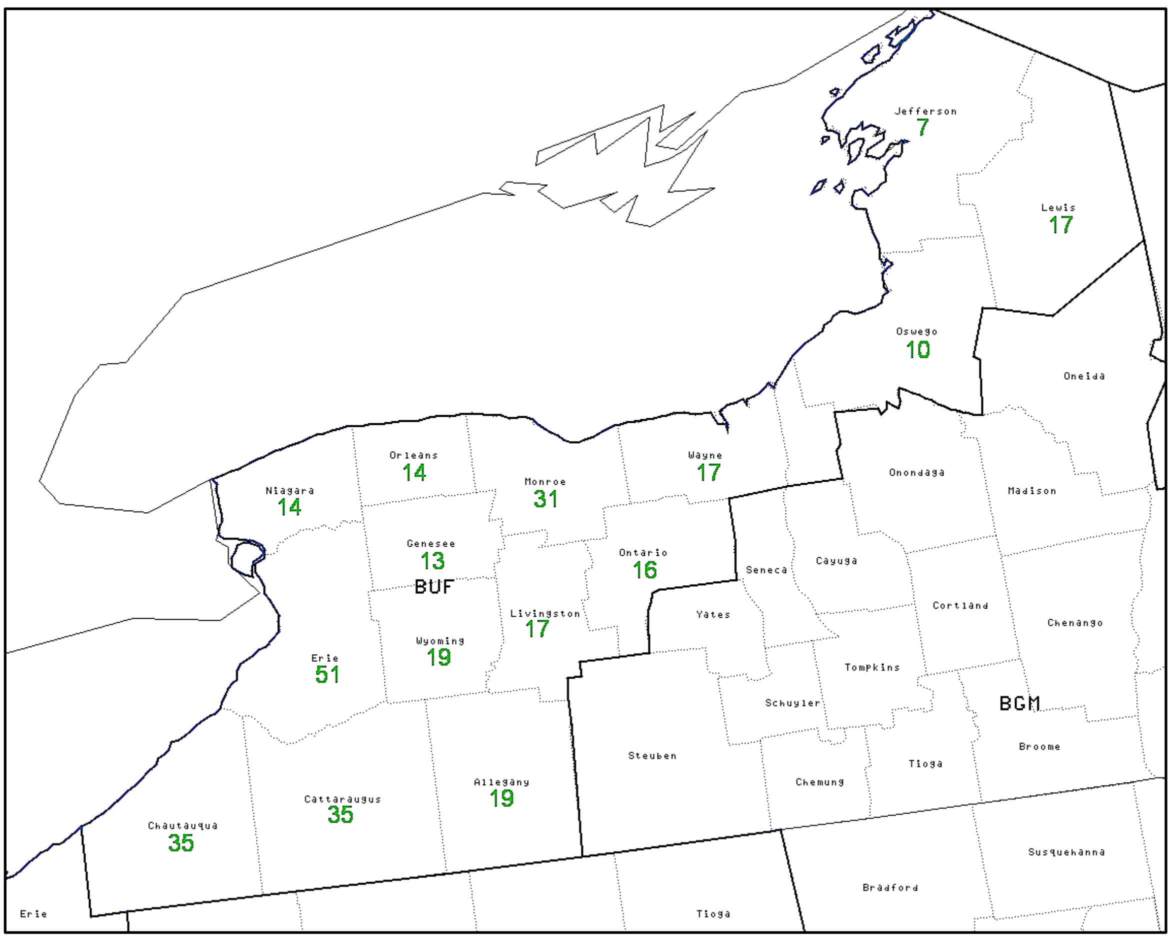


Figure B22. Flash flood events by county for the BUF county warning area.

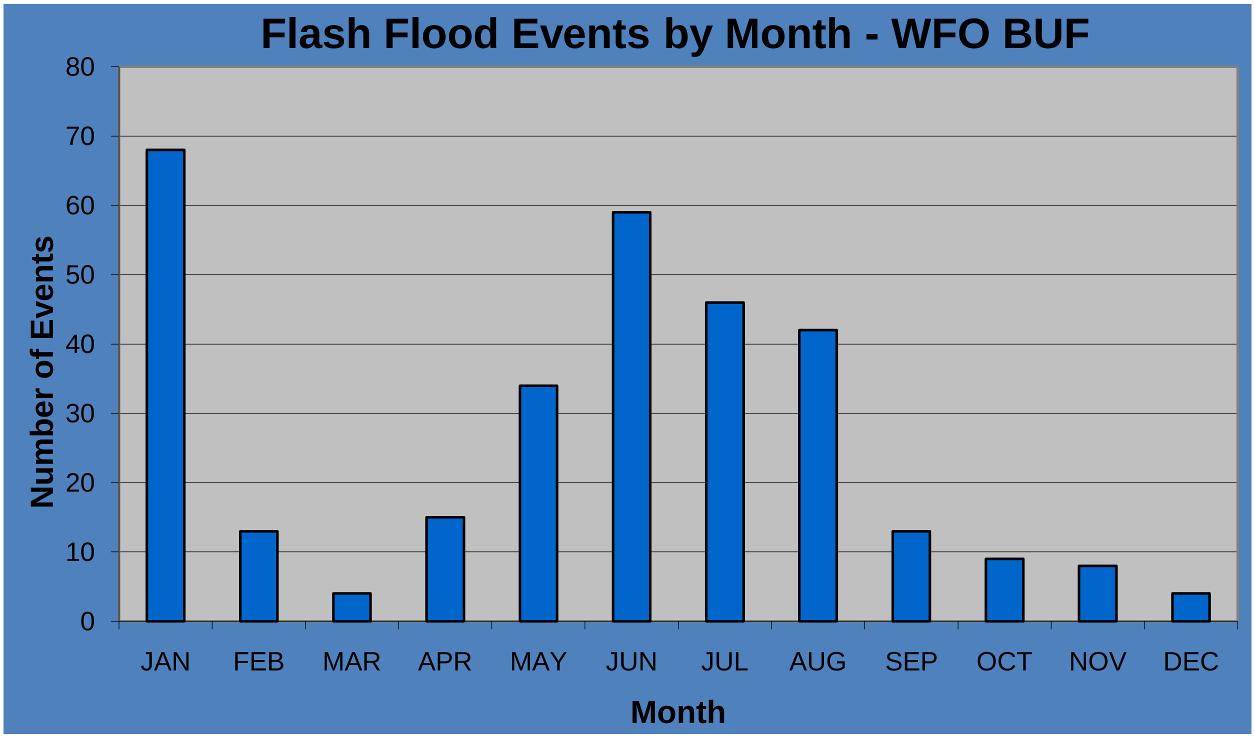


Figure B23. Flash flood events by month for the BUF county warning area.

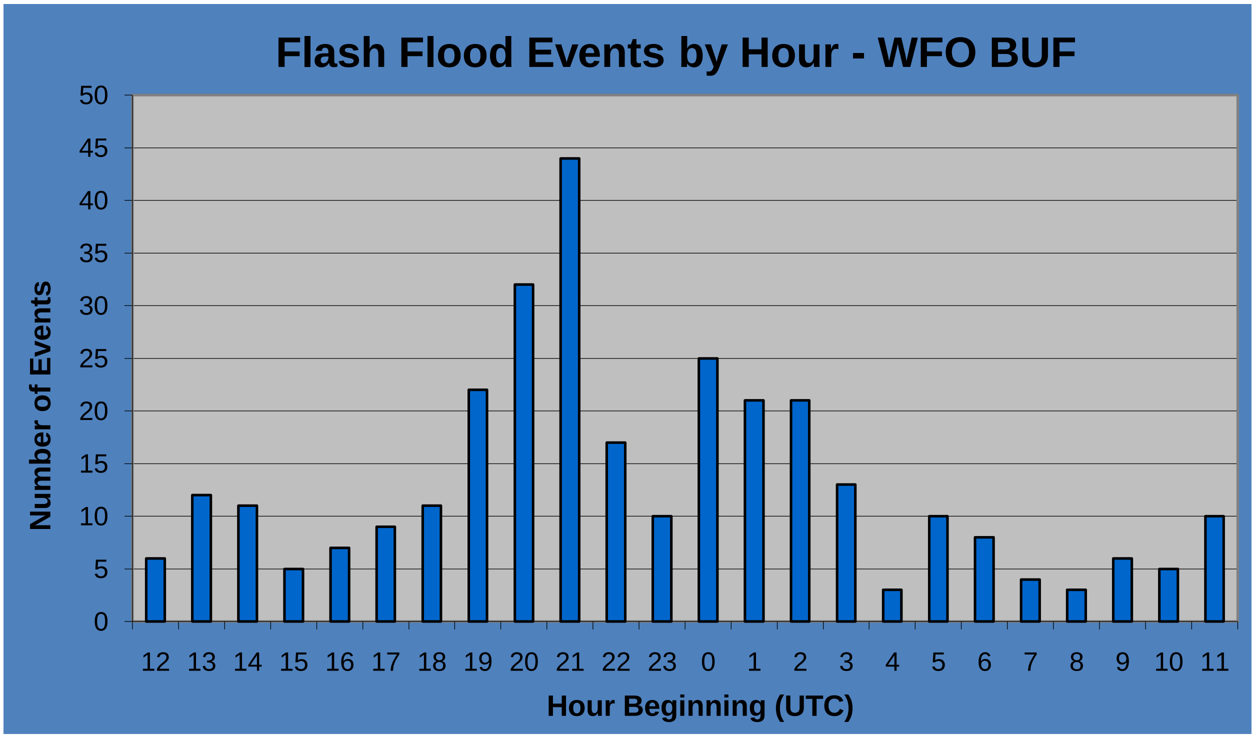


Figure B24. Flash flood events by hour of the day for the BUF county warning area.

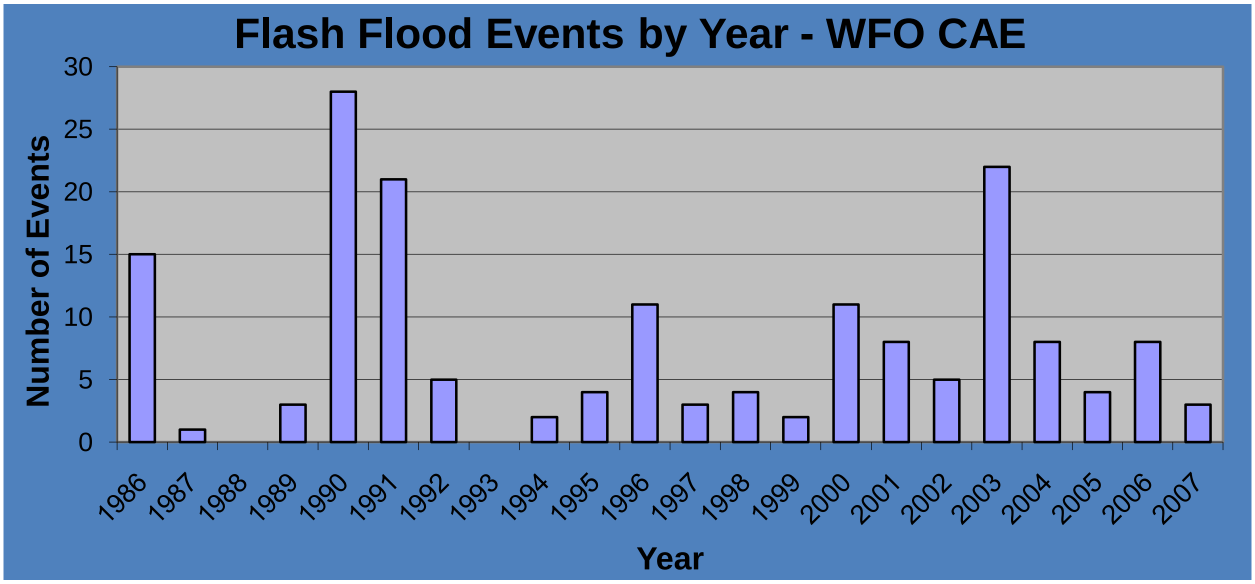


Figure B25. Flash flood events by year for the CAE county warning area.

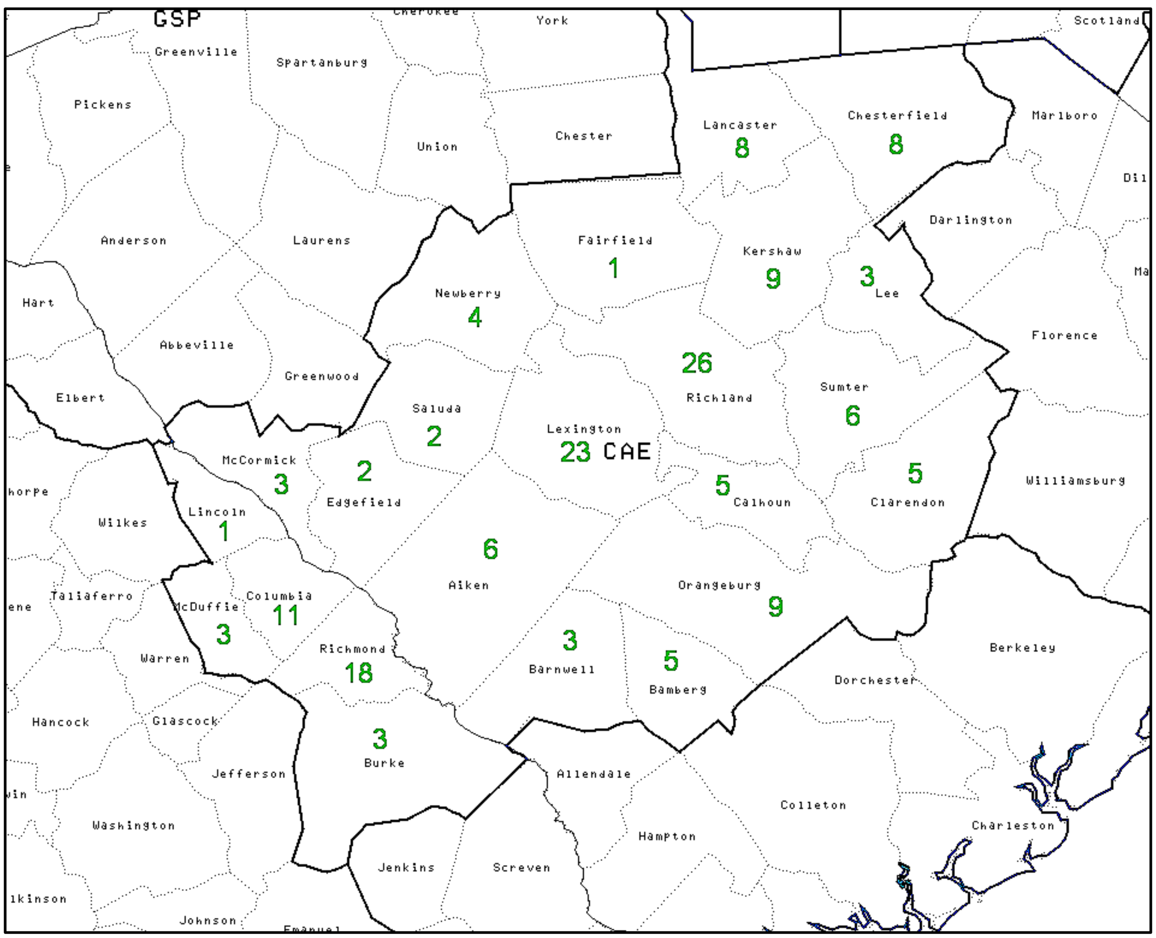


Figure B26. Flash flood events by county for the CAE county warning area.

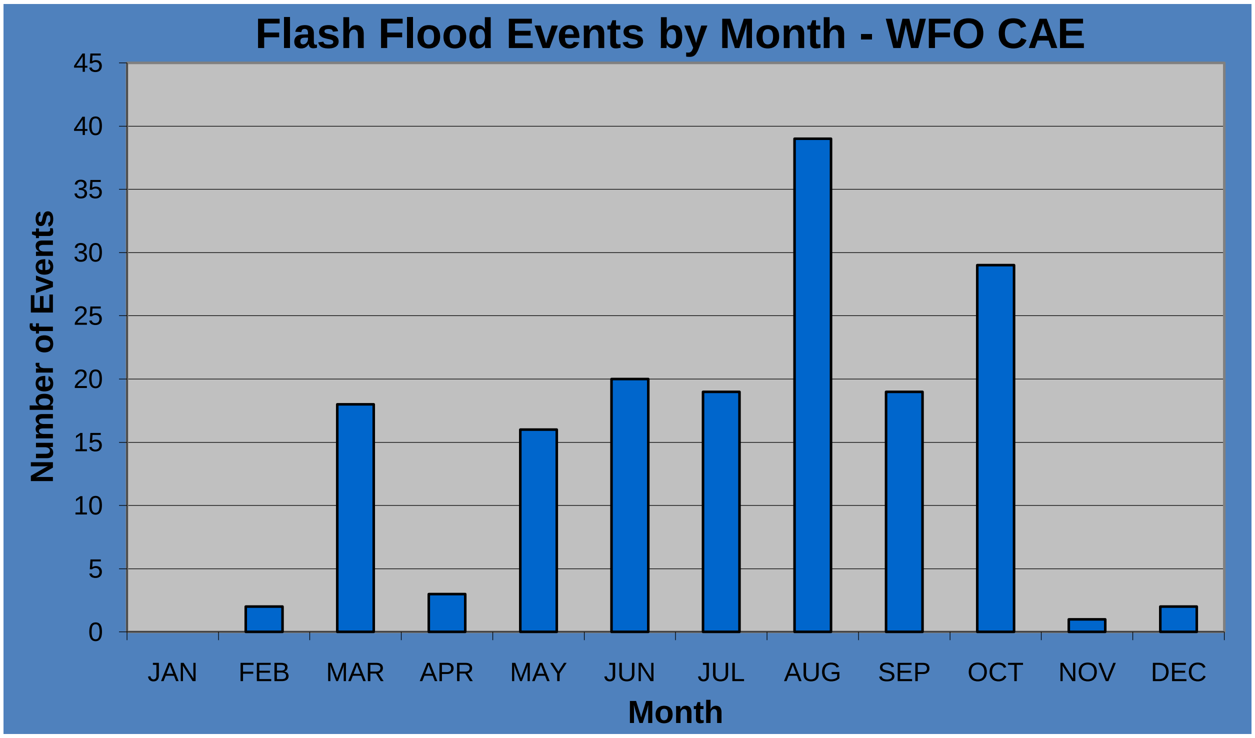


Figure B27. Flash flood events by month for the CAE county warning area.

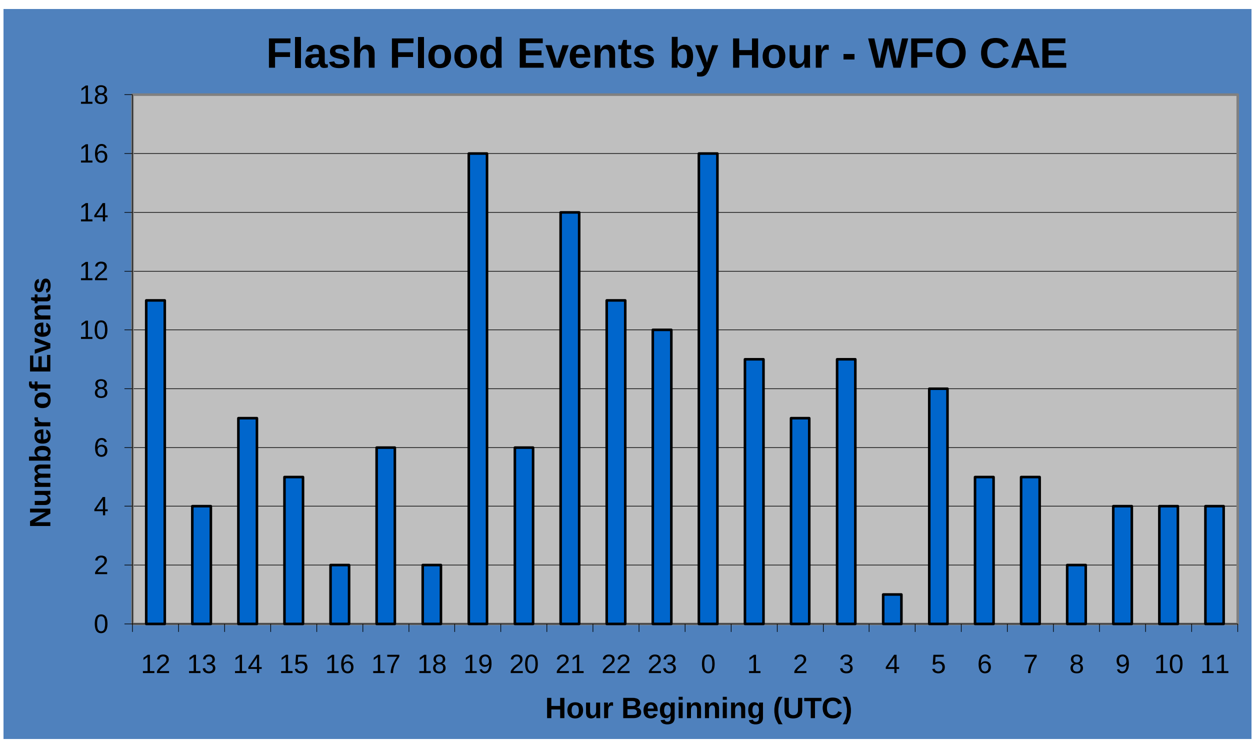


Figure B28. Flash flood events by hour of the day for the CAE county warning area.

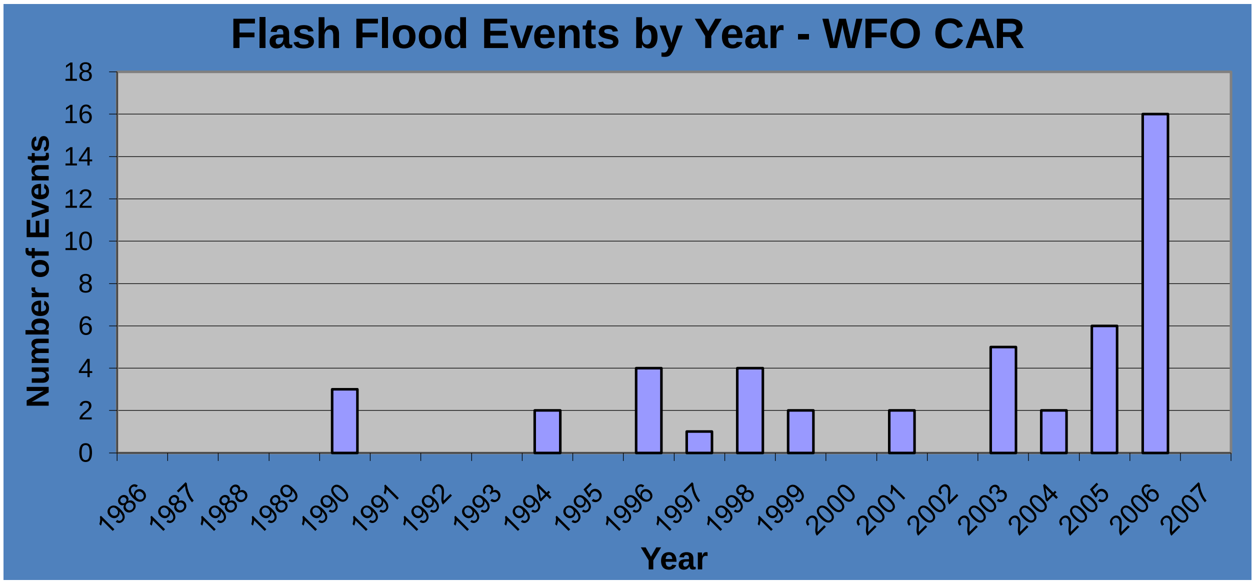


Figure B29. Flash flood events by year for the CAR county warning area.

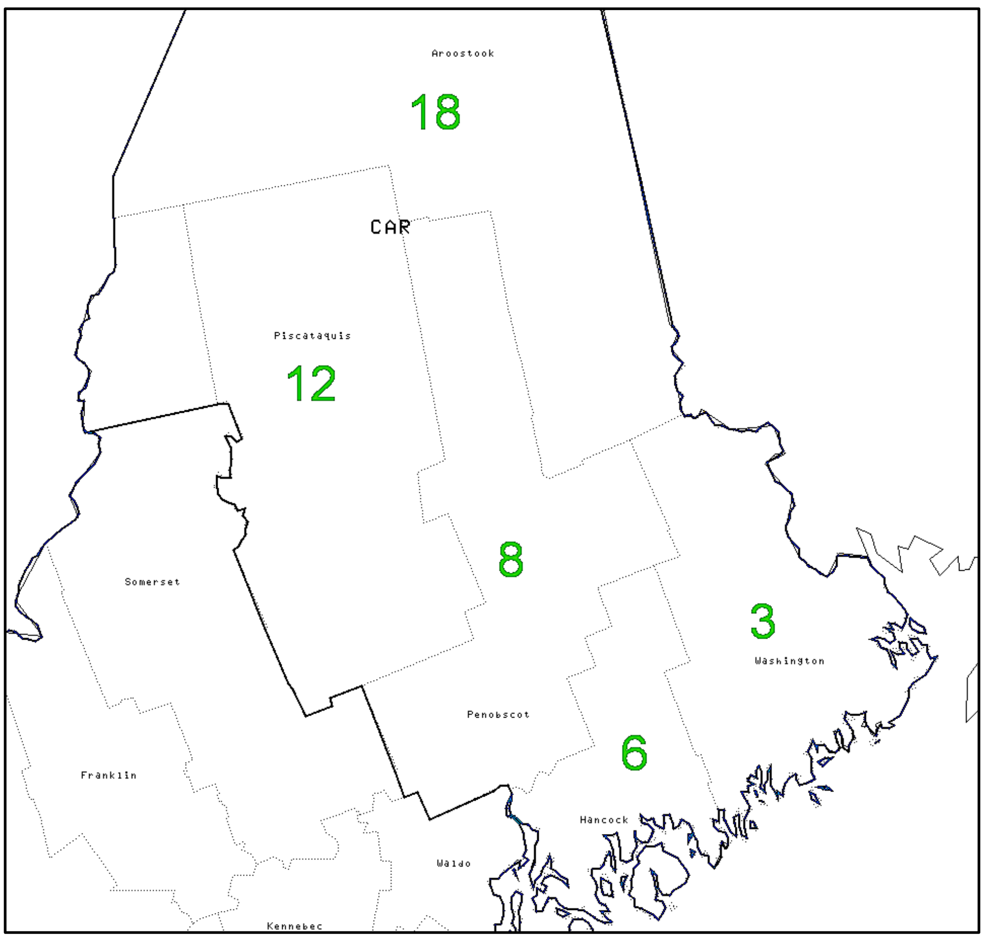


Figure B30. Flash flood events by county for the CAR county warning area.

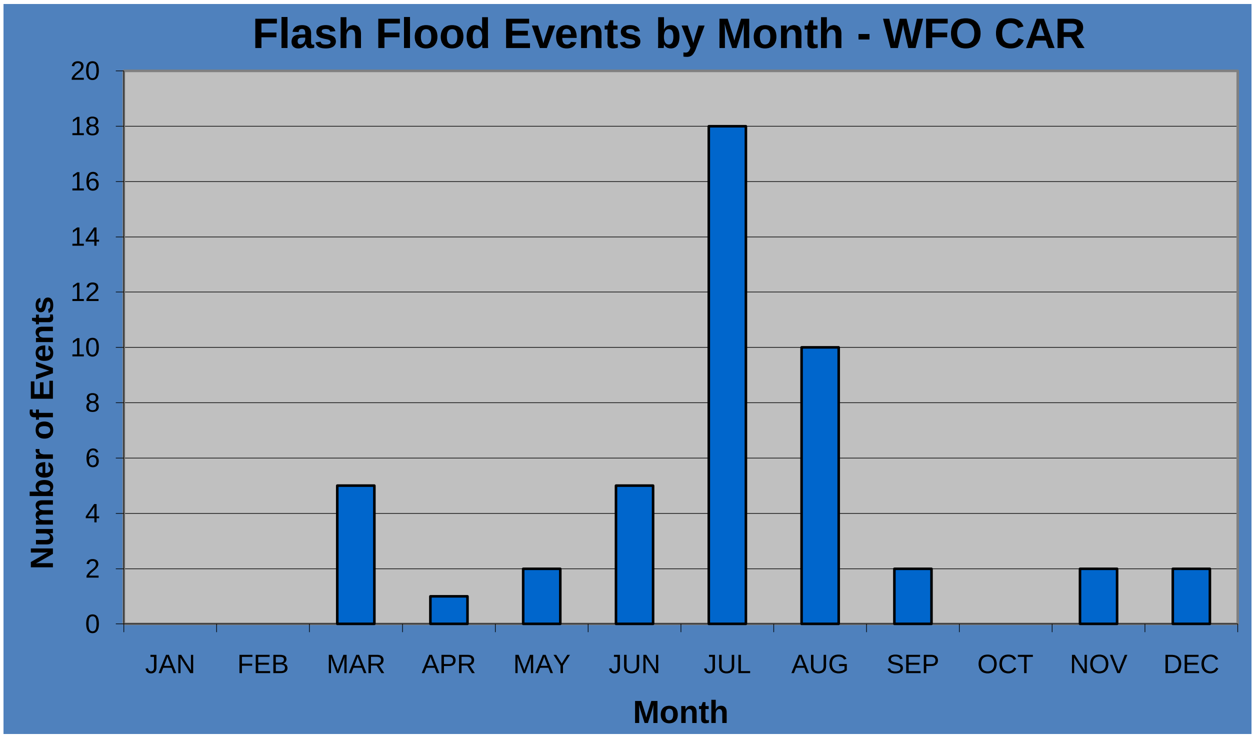


Figure B31. Flash flood events by month for the CAR county warning area.

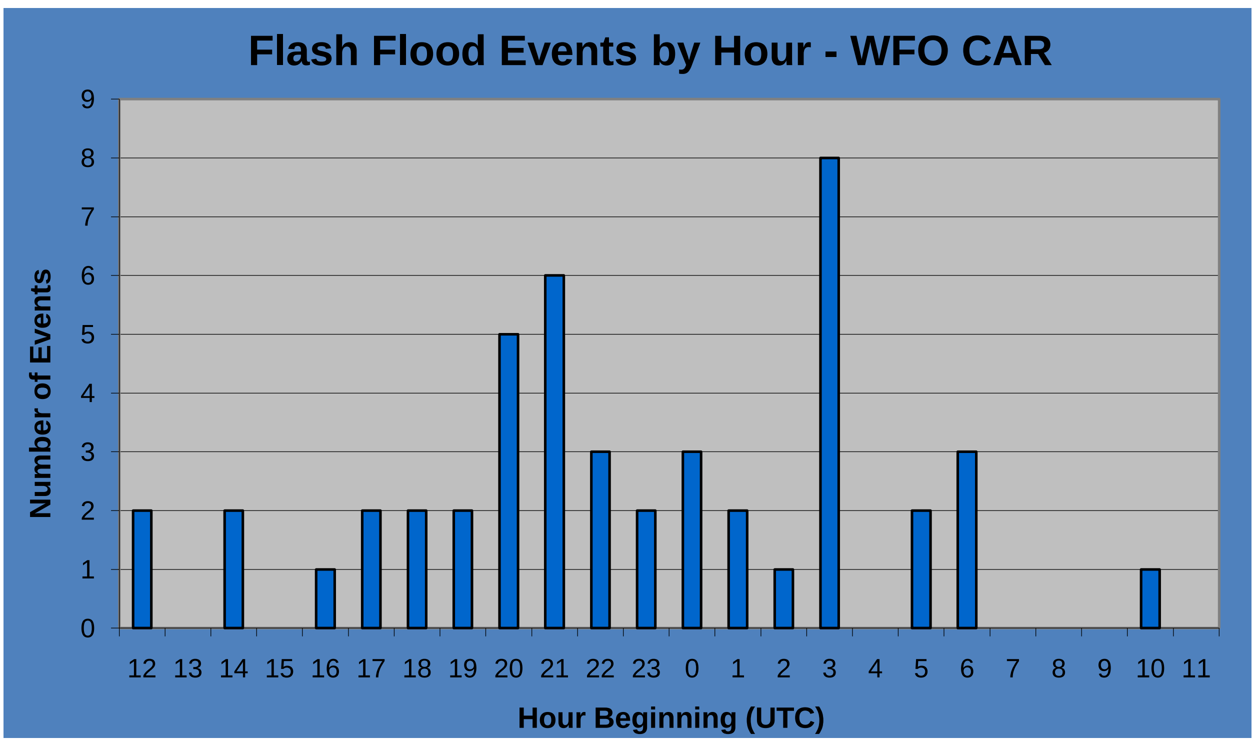


Figure B32. Flash flood events by hour of the day for the CAR county warning area.

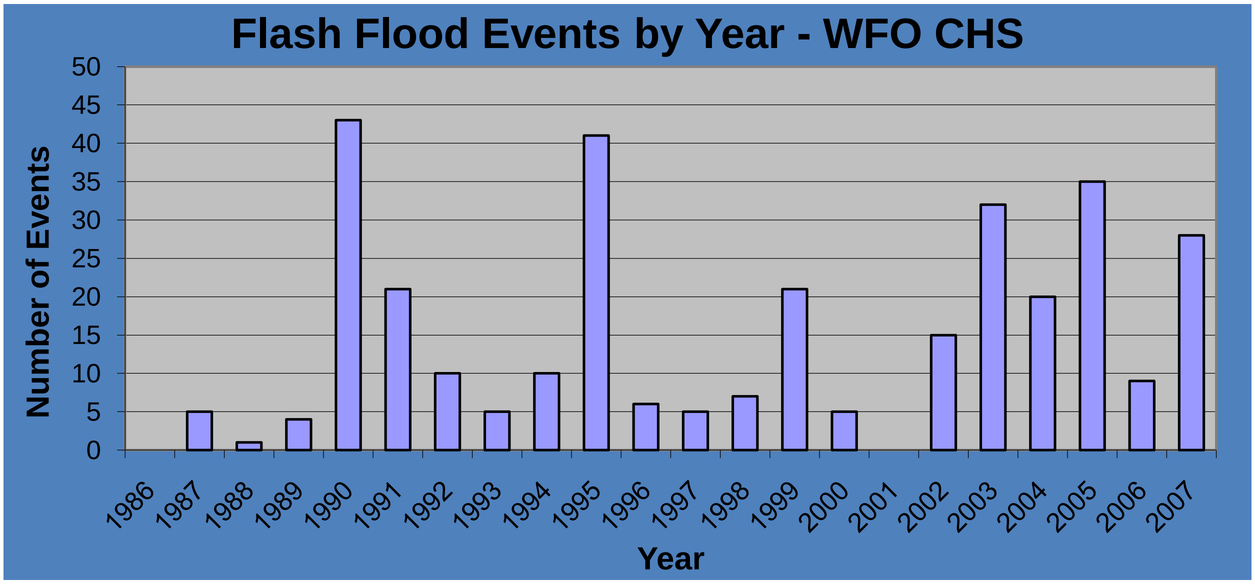


Fig B33. Flash flood events by year for the CHS county warning area.

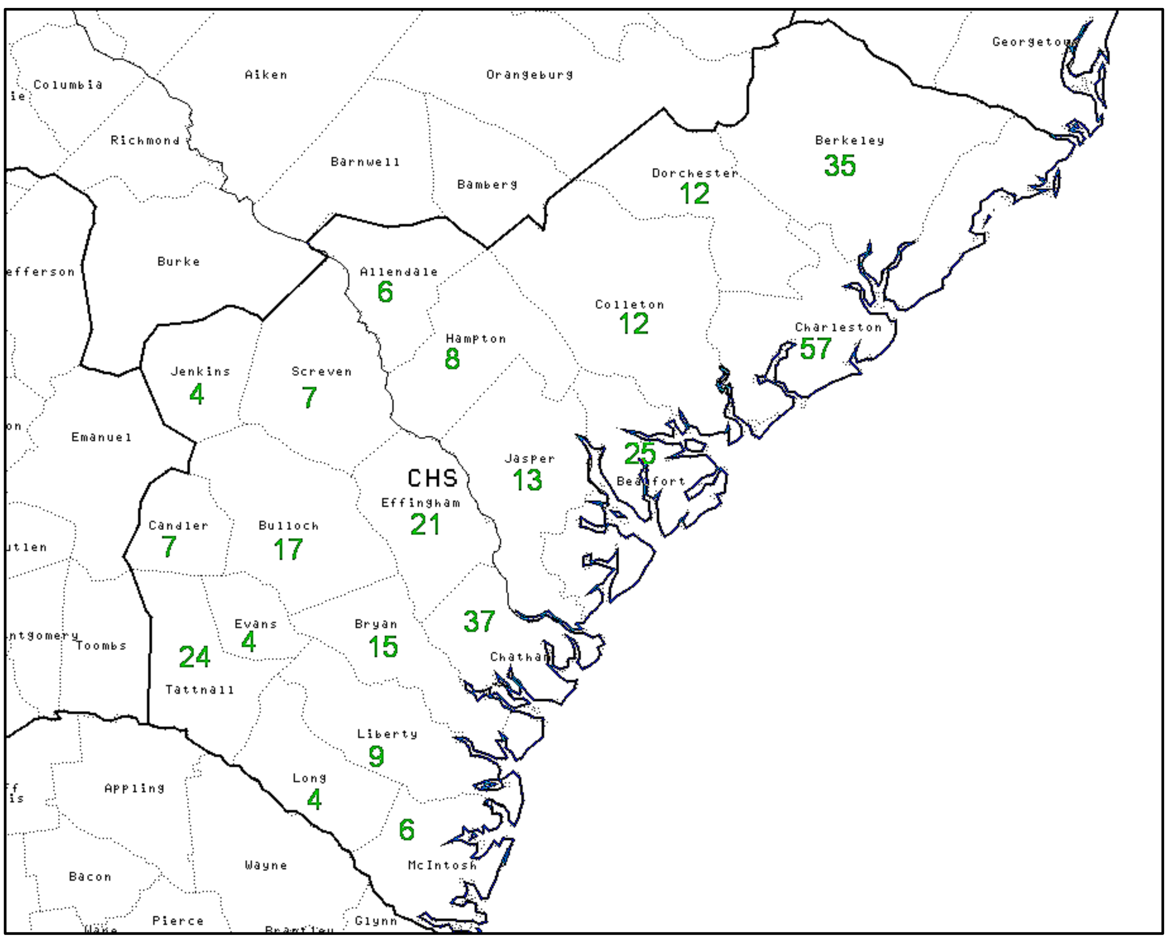


Figure B34. Flash flood events by county for the CHS county warning area.

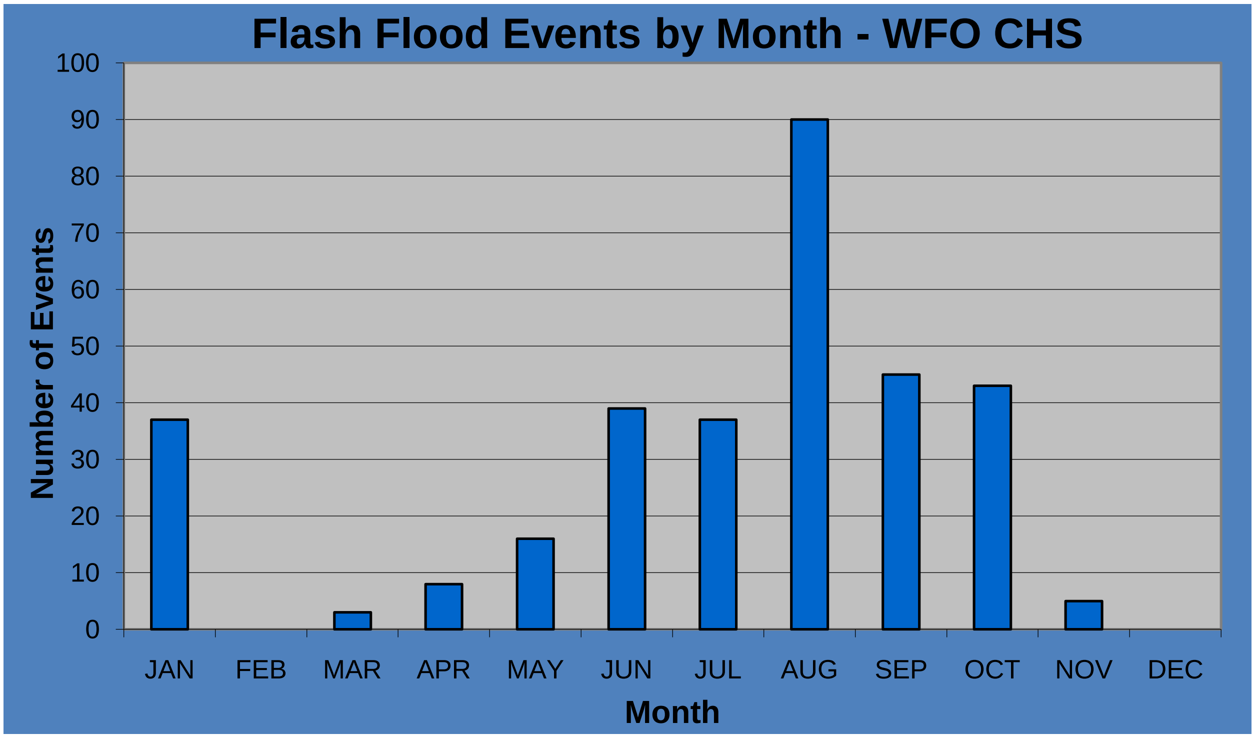


Figure B35. Flash flood events by month for the CHS county warning area.

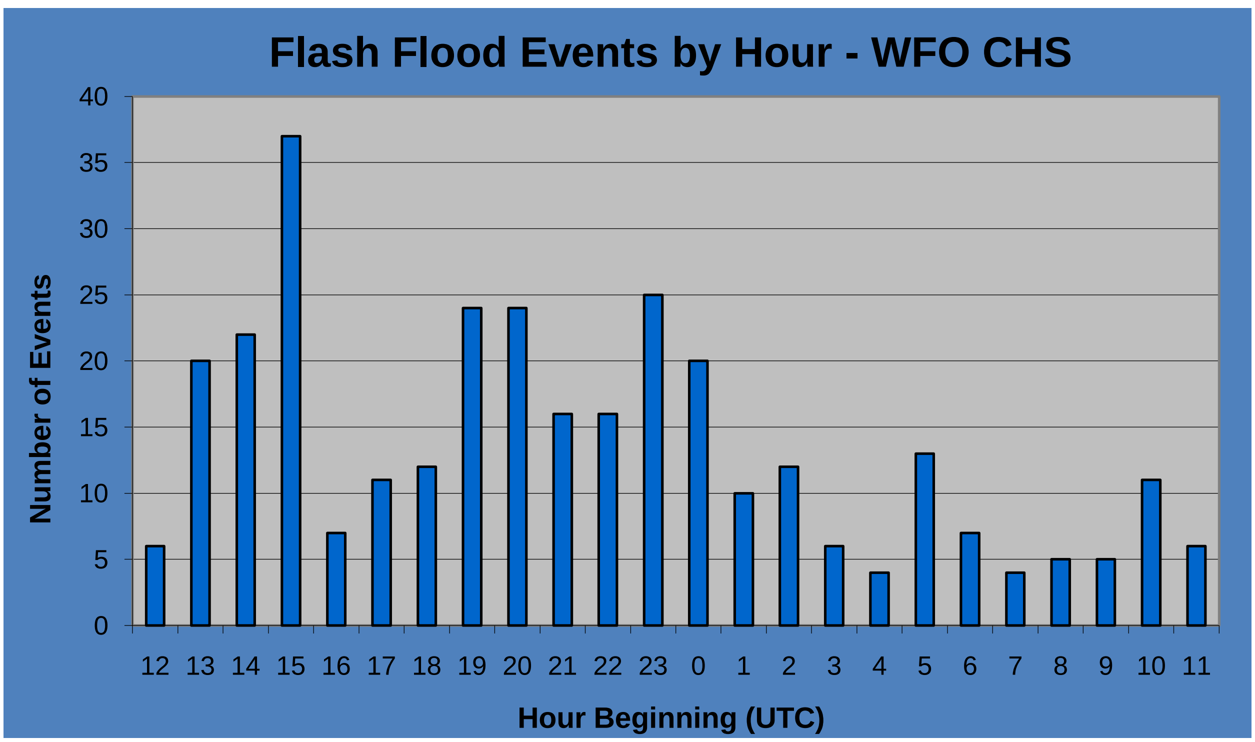


Figure B36. Flash flood events by hour of the day for the CHS county warning area.

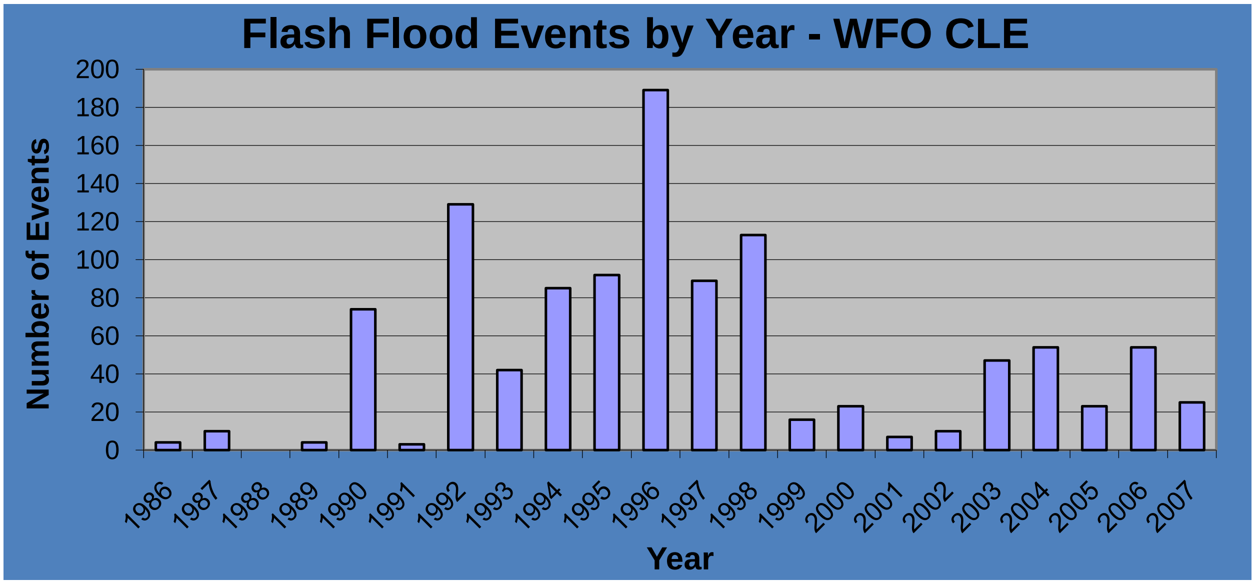


Figure B37. Flash flood events by year for the CLE county warning area.

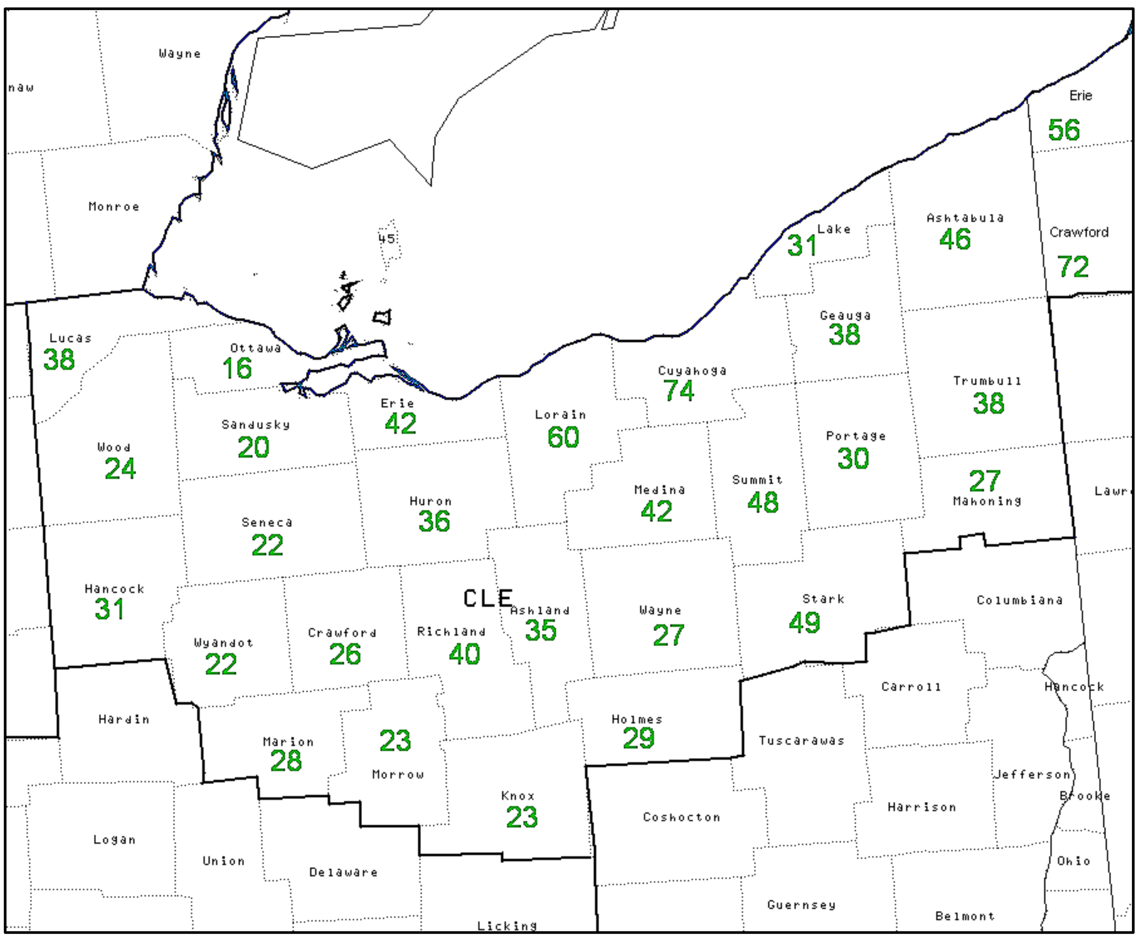


Figure B38. Flash flood events by county for the CLE county warning area.

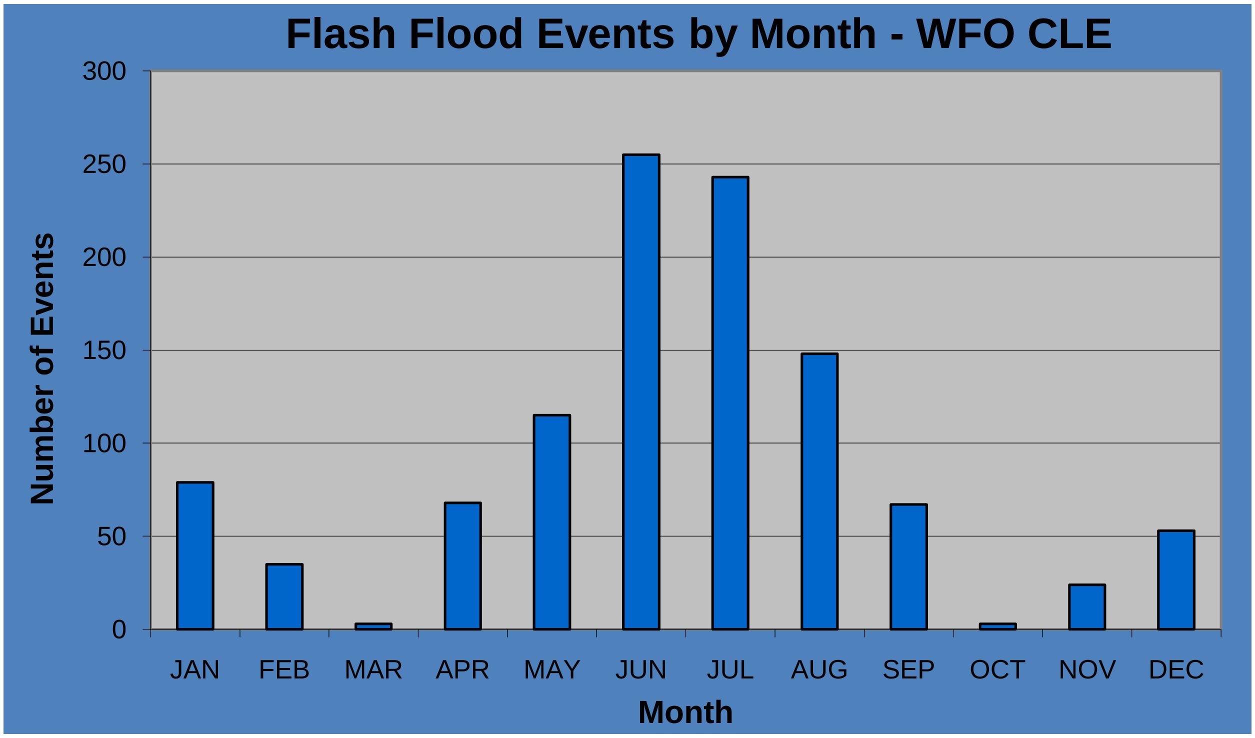


Figure B39. Flash flood events by month for the CLE county warning area.

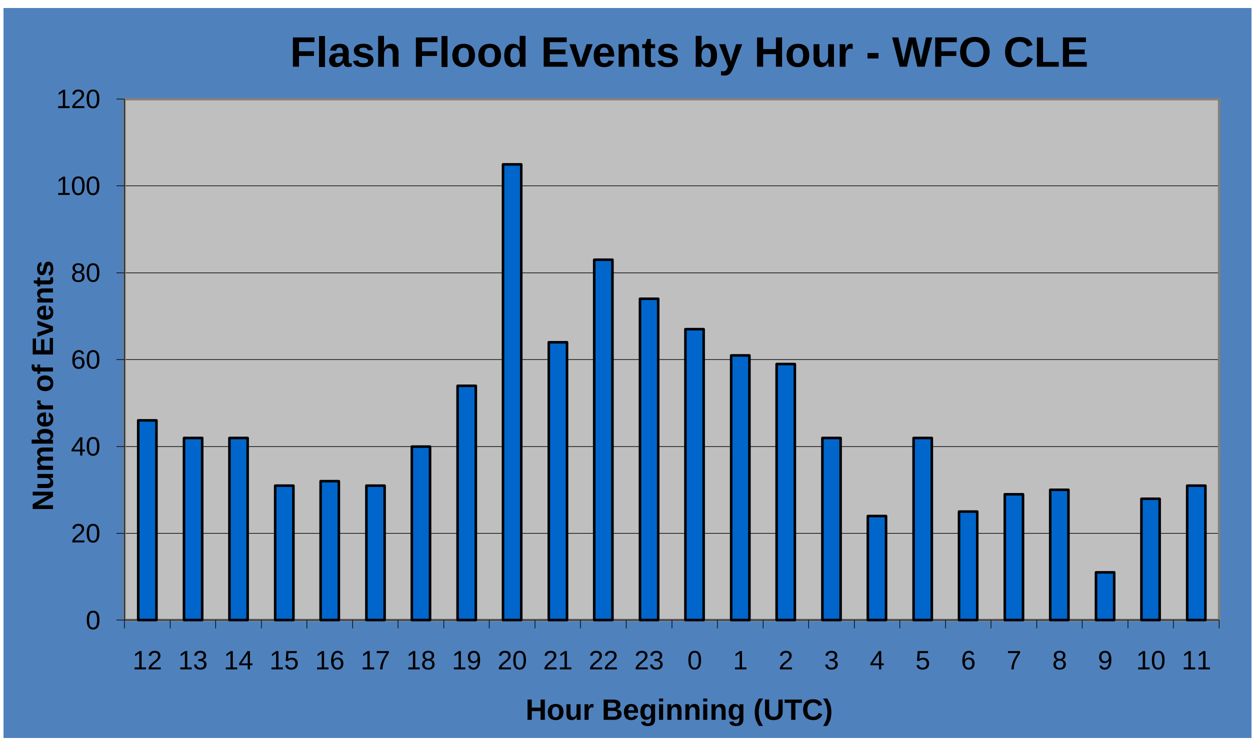


Figure B40. Flash flood events by hour of the day for the CLE county warning area.

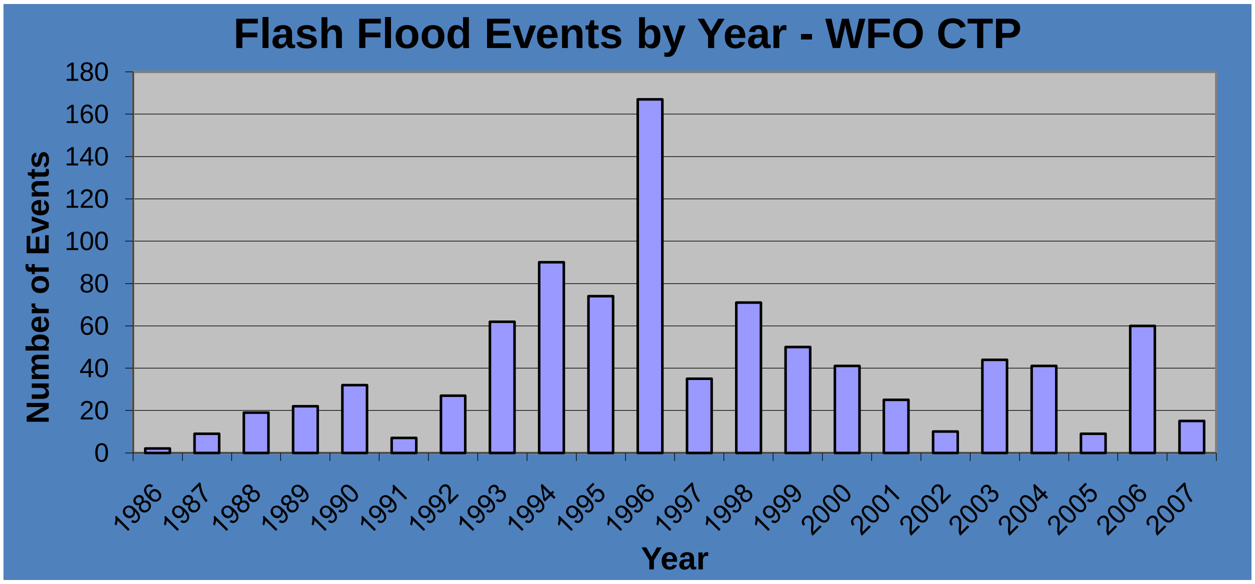


Figure B41. Flash flood events by year for the CTP county warning area.

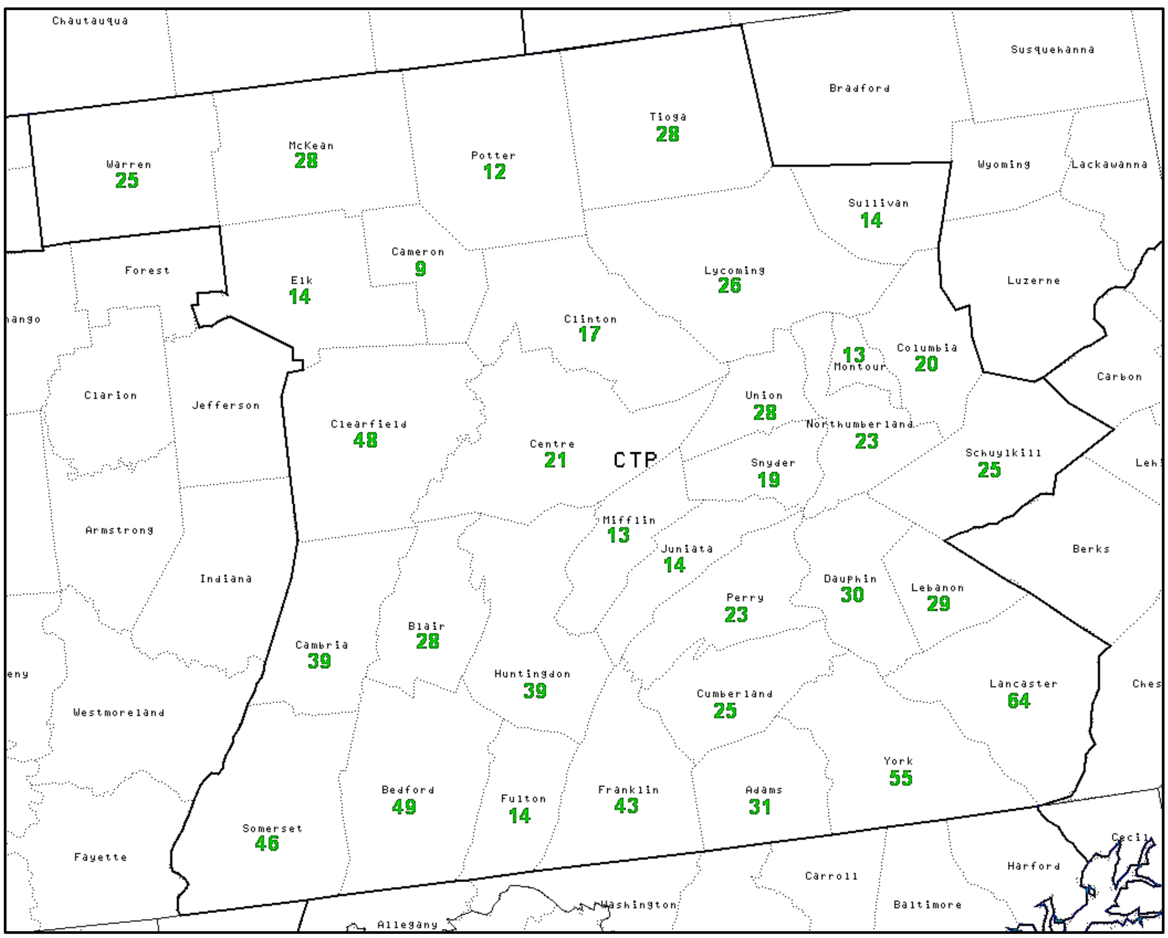


Figure B42. Flash flood events by county for the CTP county warning area.

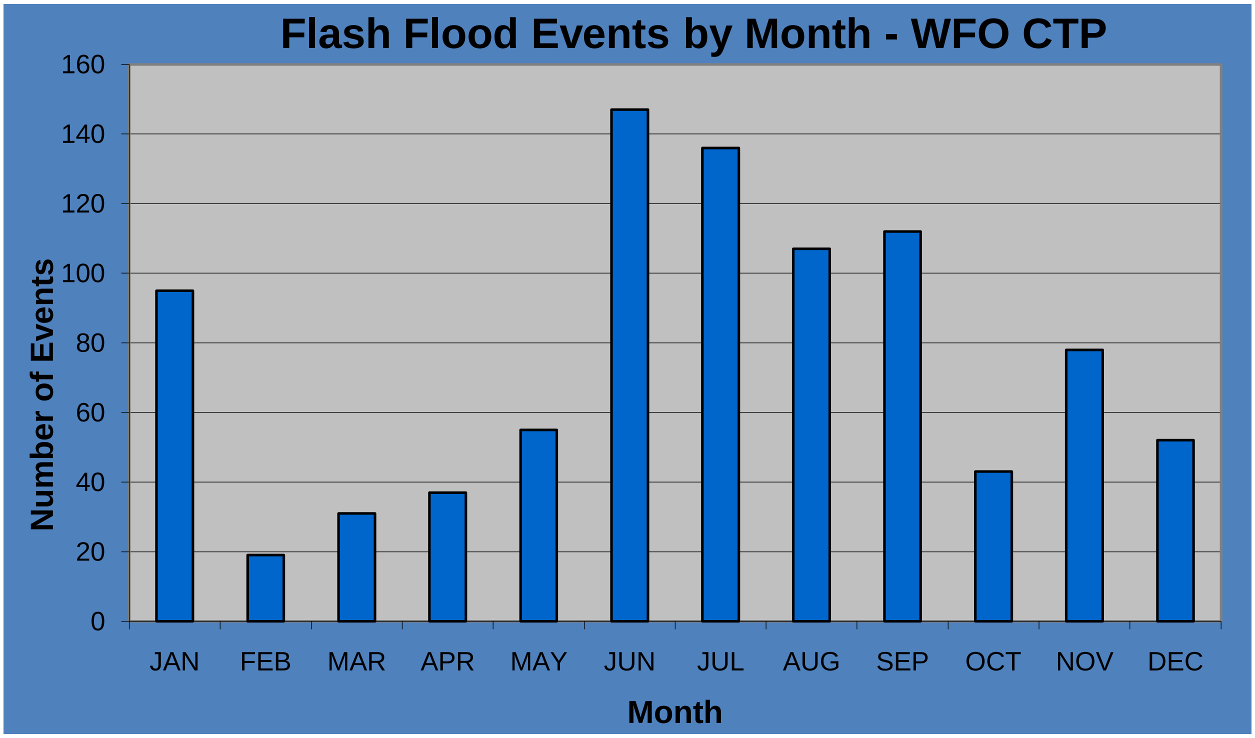


Figure B43. Flash flood events by month for the CTP county warning area.

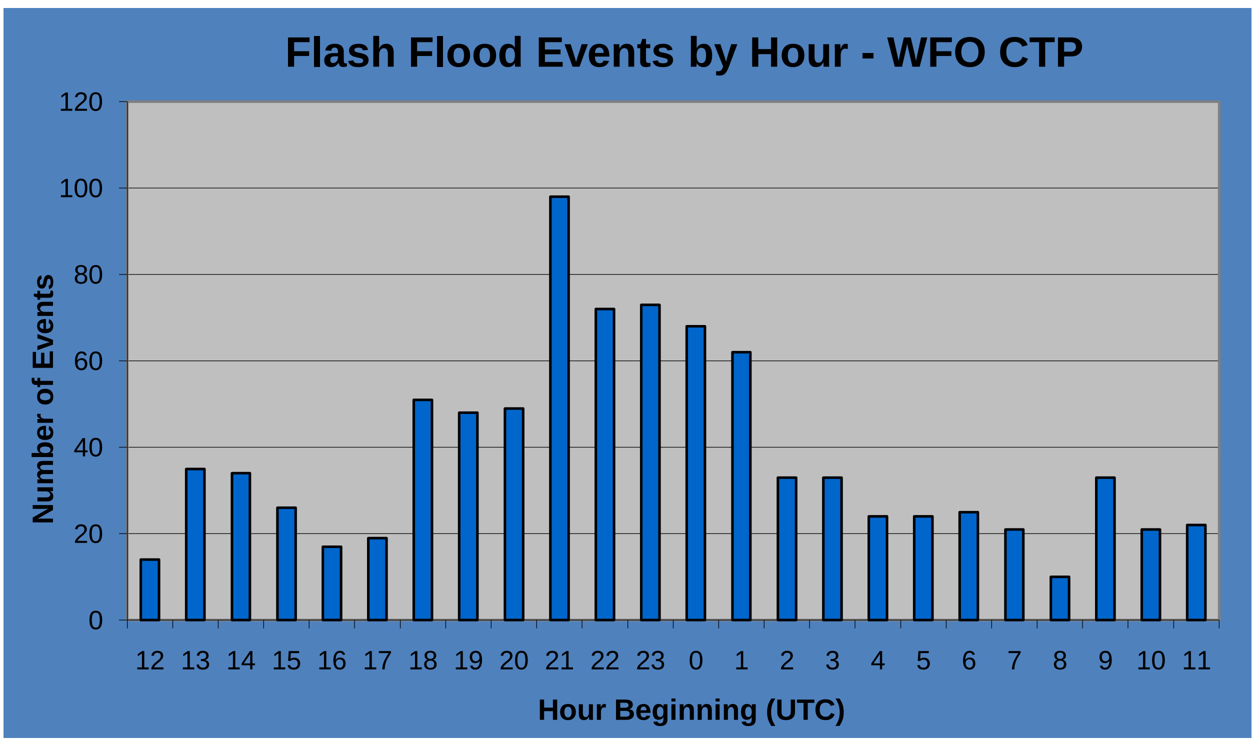


Figure B44. Flash flood events by hour of the day for the CTP county warning area.

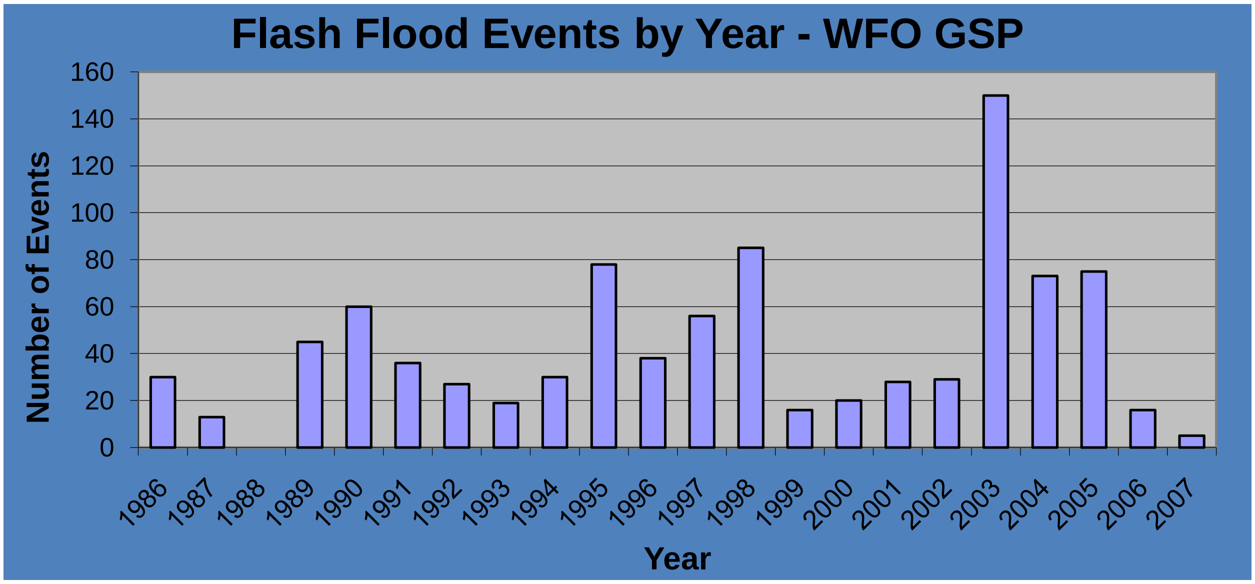


Figure B45. Flash flood events by year for the GSP county warning area.

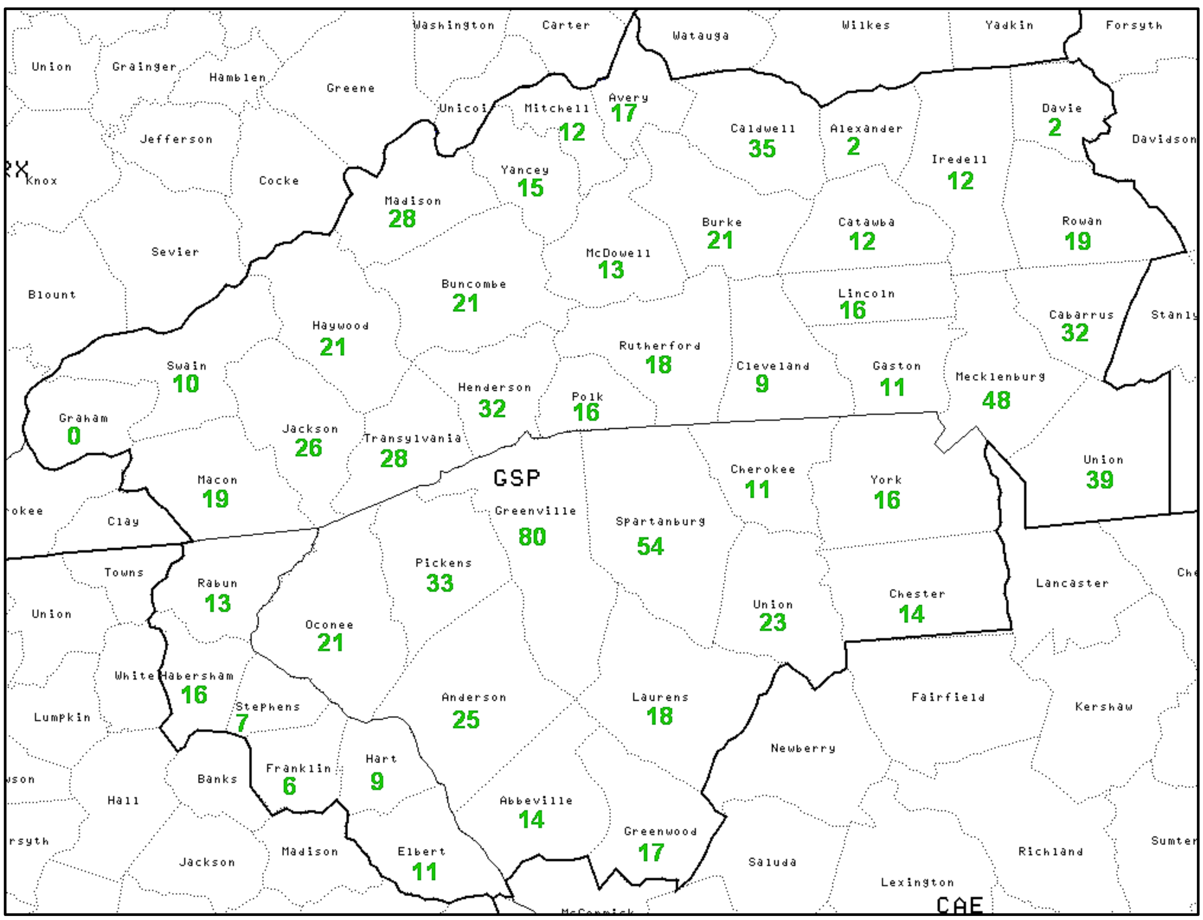


Figure B46. Flash flood events by county for the GSP county warning area.

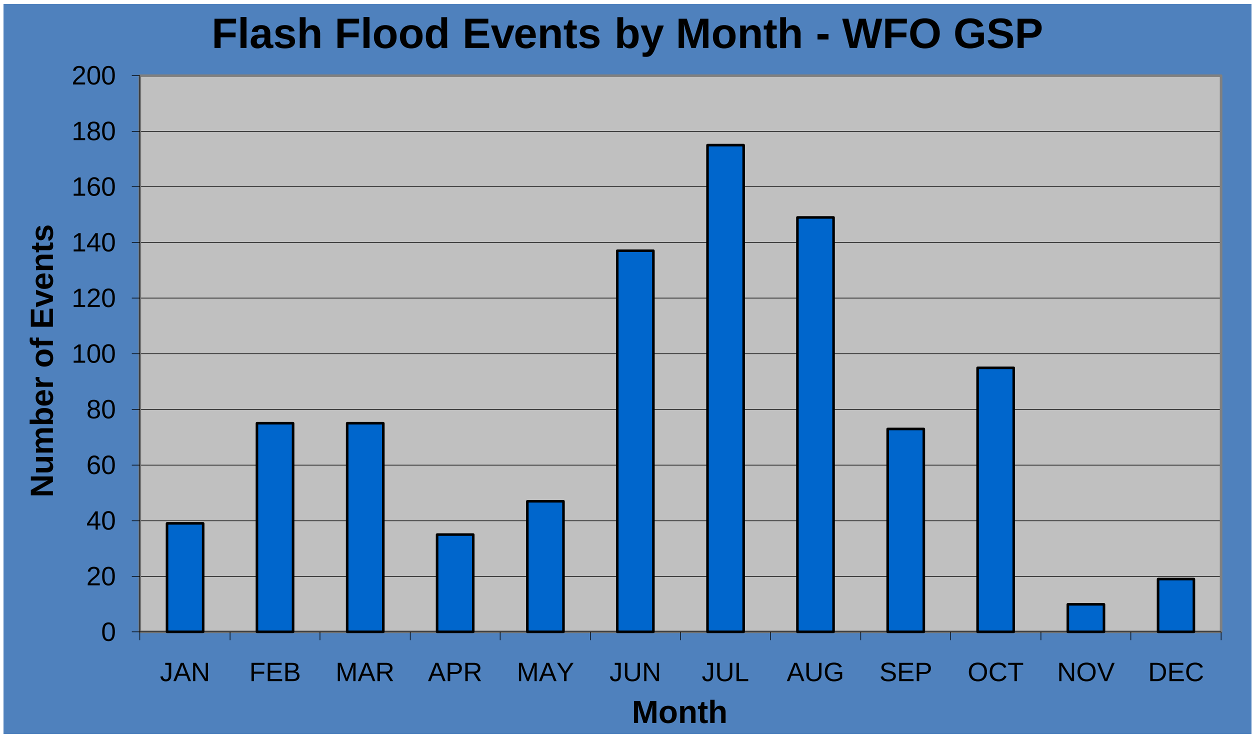


Figure B47. Flash flood events by month for the GSP county warning area.

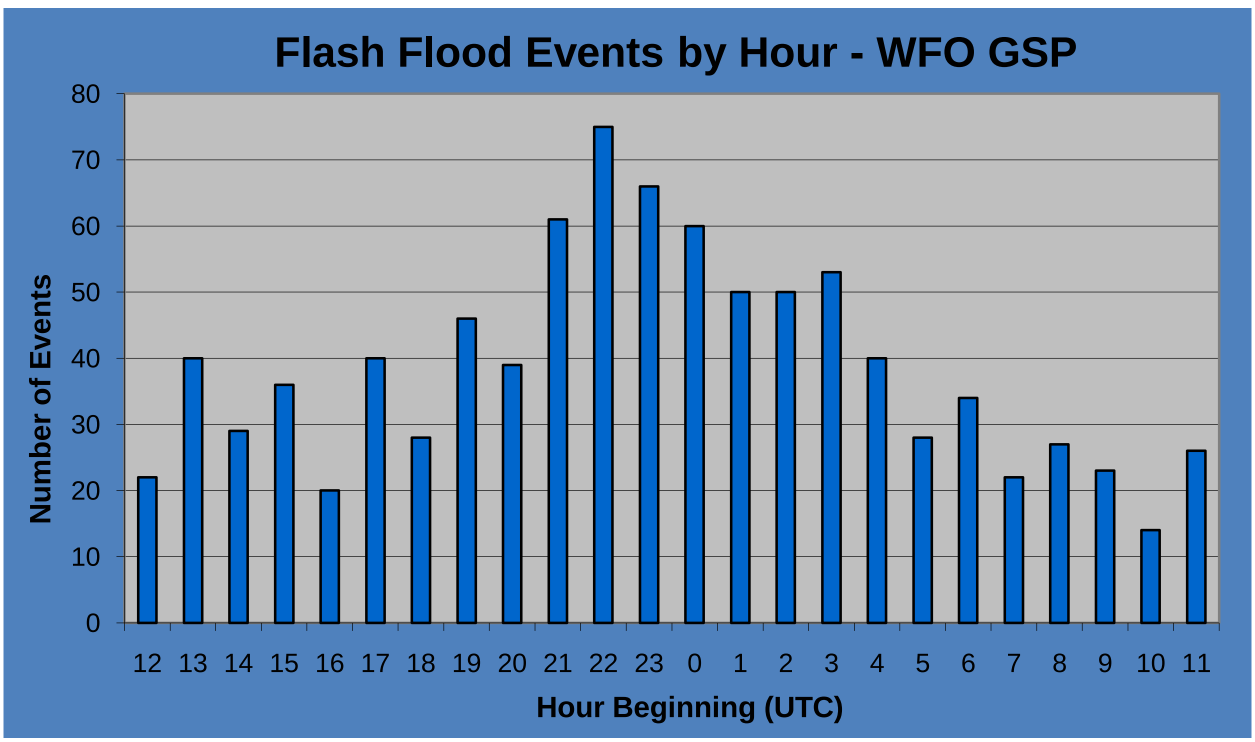


Figure B48. Flash flood events by hour of the day for the GSP county warning area.

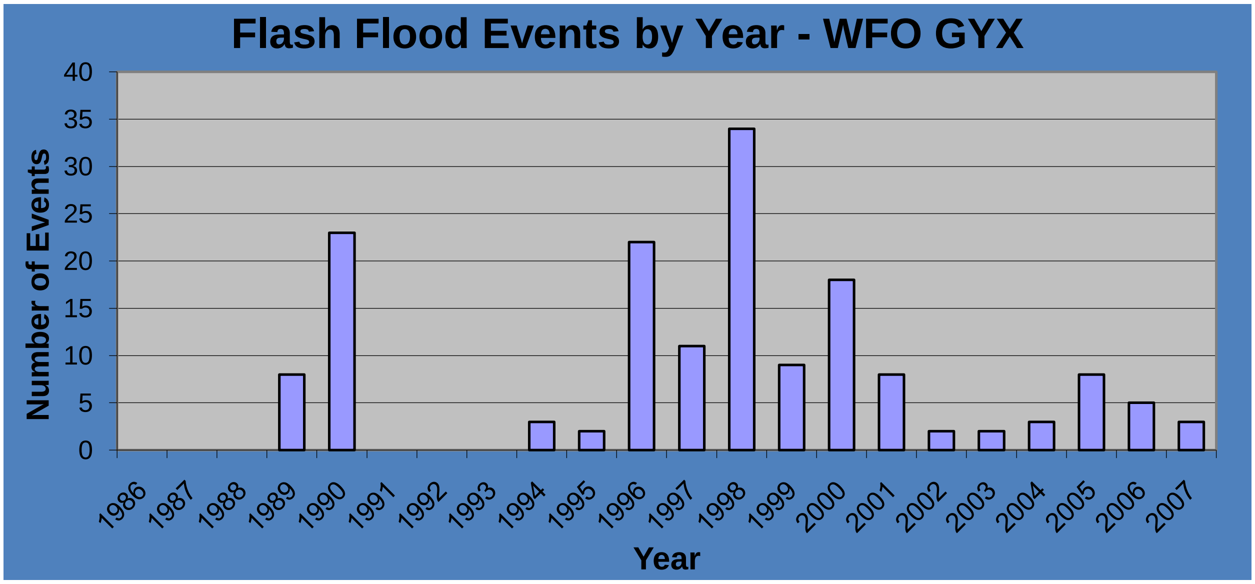


Figure B49. Flash flood events by year for the GYX county warning area.

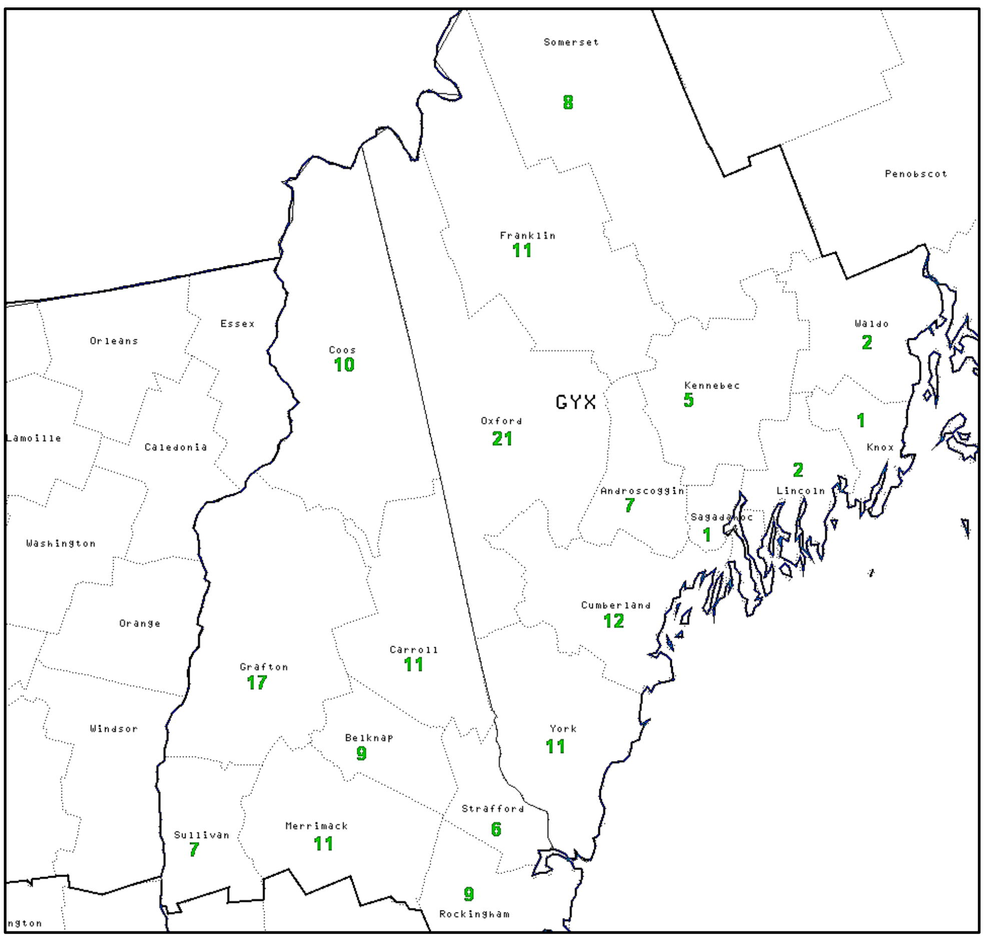


Figure B50. Flash flood events by county for the GYX county warning area.

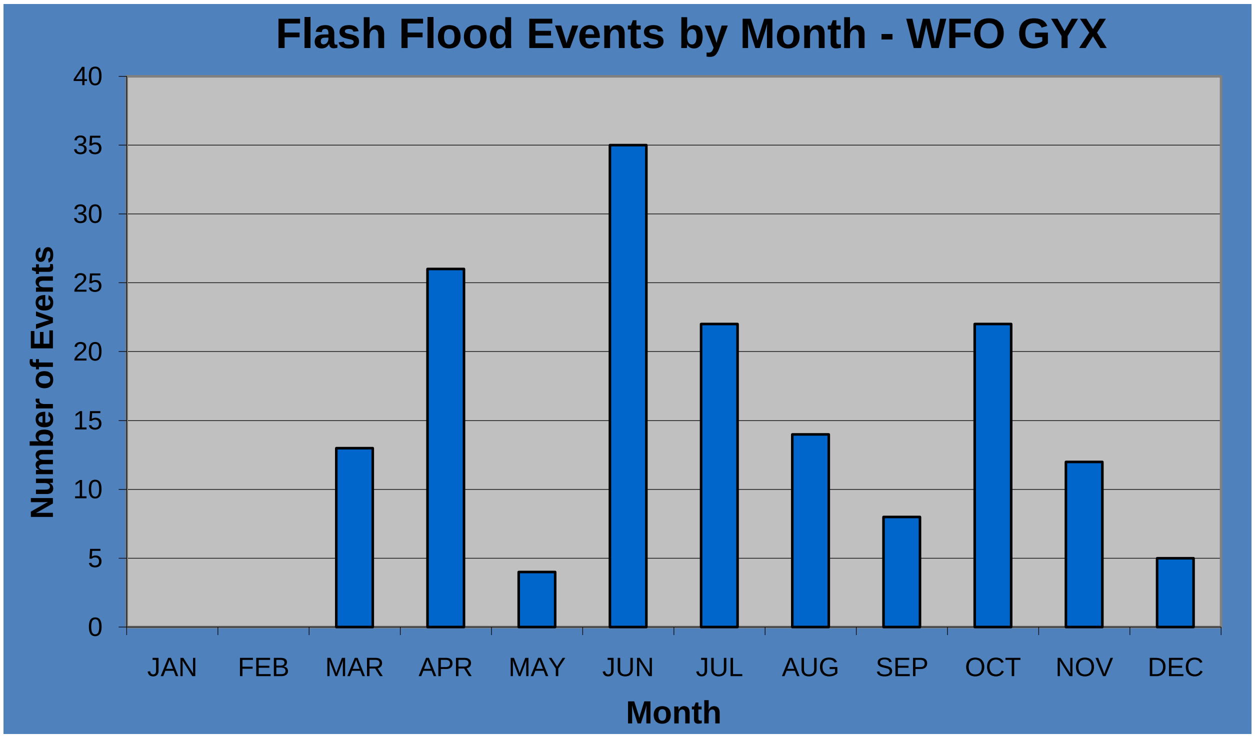


Figure B51. Flash flood events by month for the GYX county warning area.

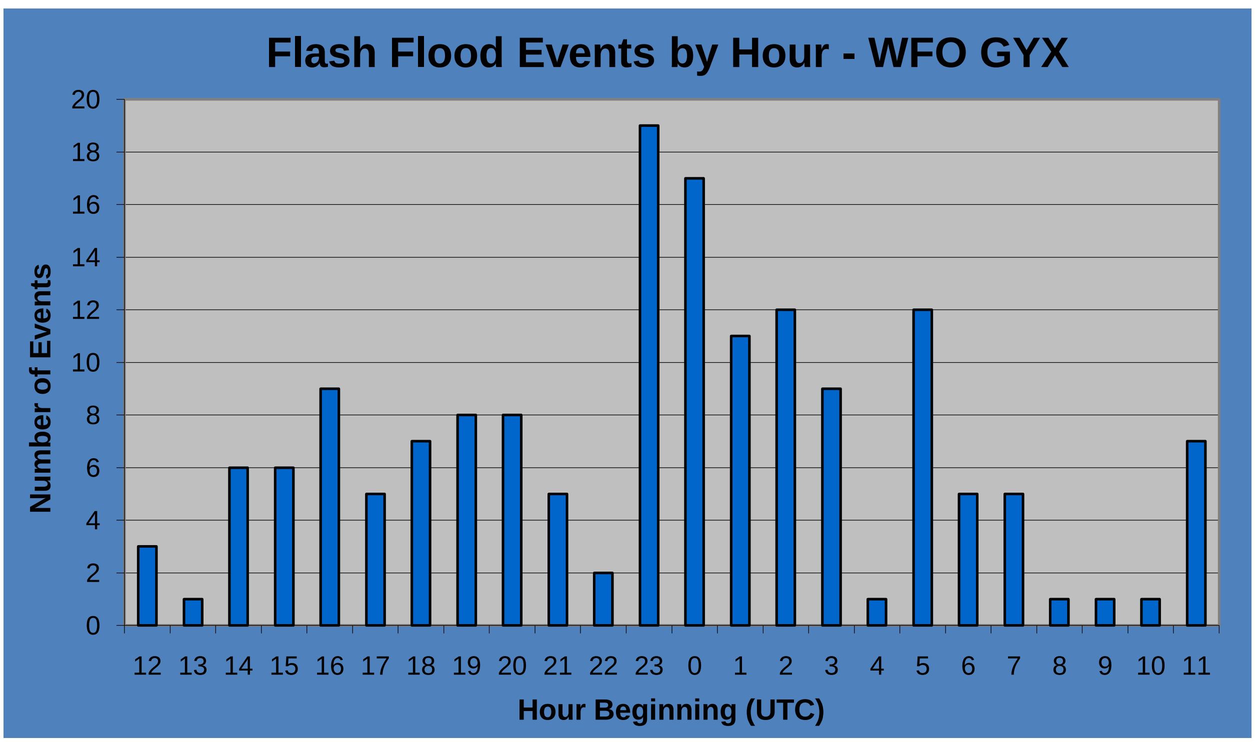


Figure B52. Flash flood events by hour of the day for the GYX county warning area.

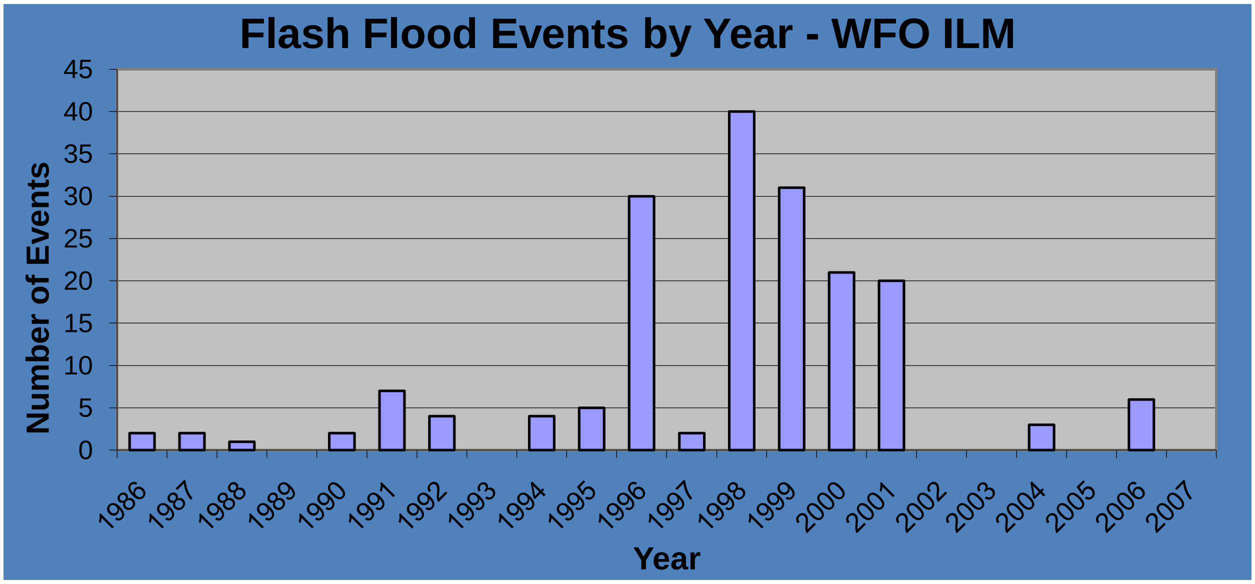


Figure B53. Flash flood events by year for the ILM county warning area.

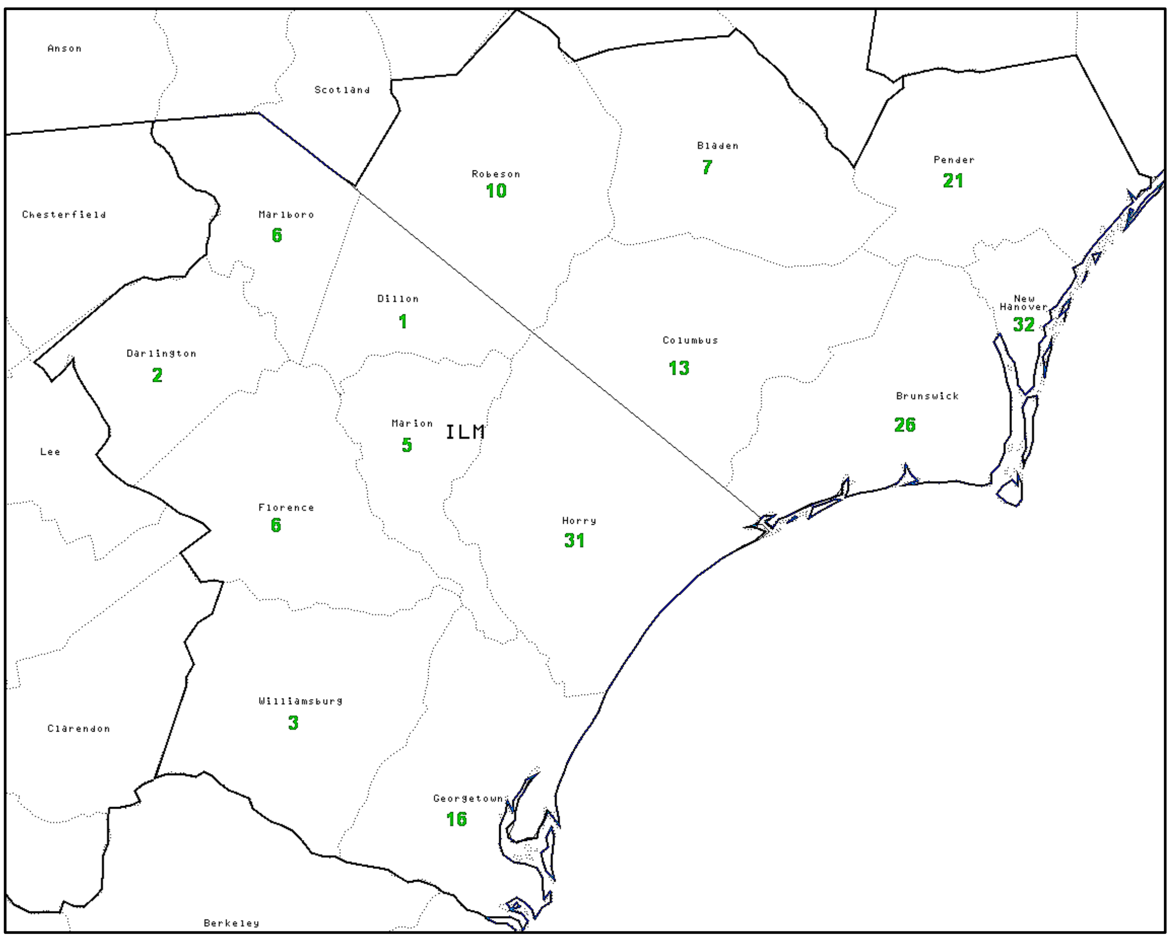


Figure B54. Flash flood events by county for the ILM county warning area.

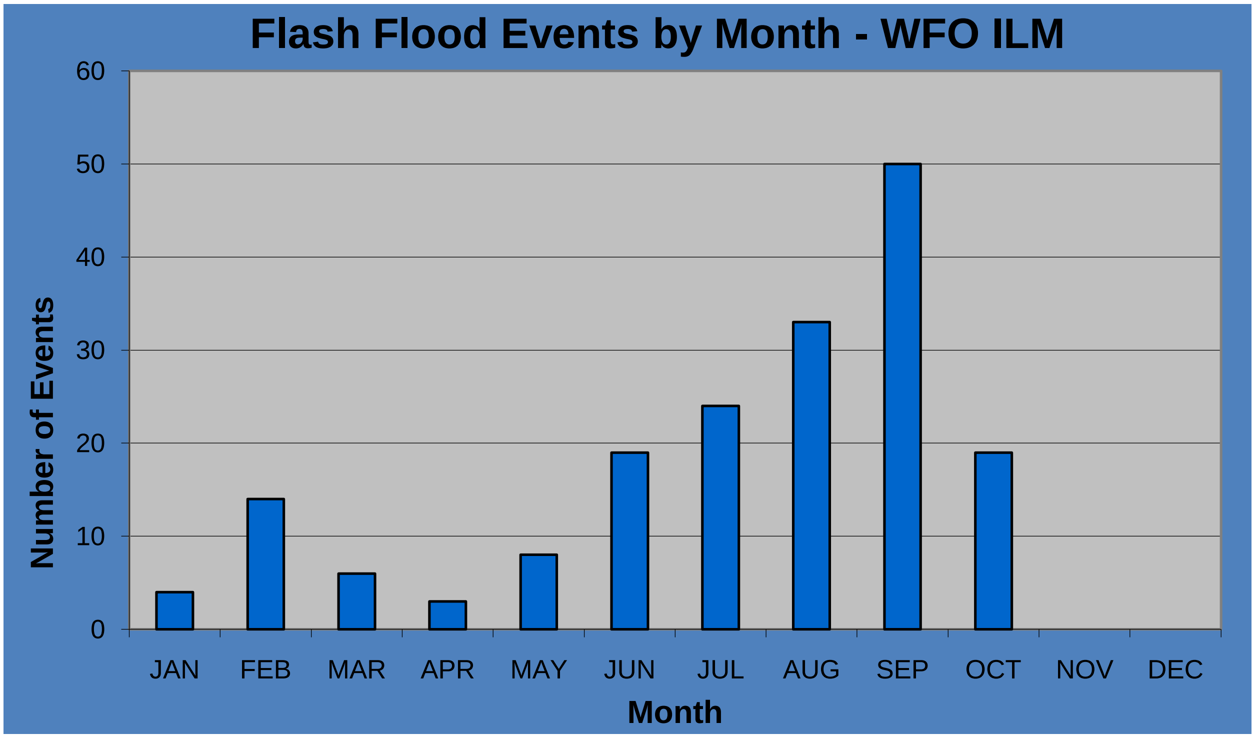


Figure B55. Flash flood events by month for the ILM county warning area.

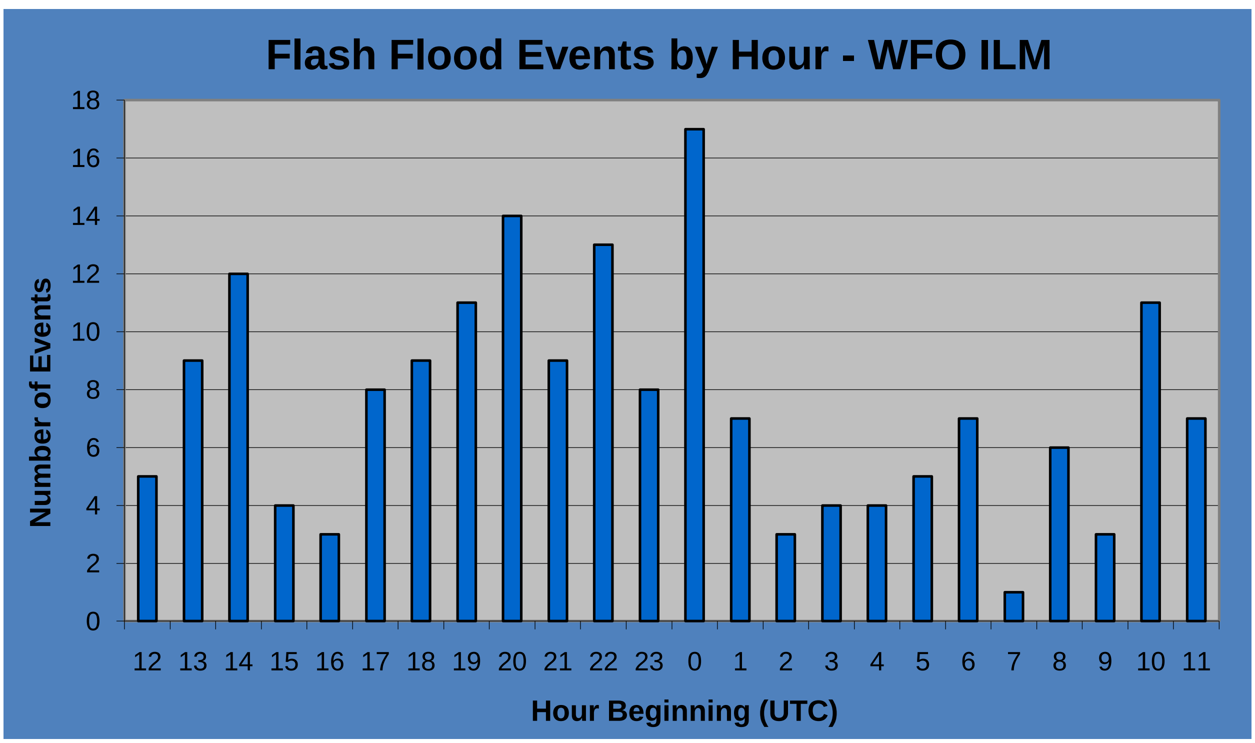


Figure B56. Flash flood events by hour of the day for the ILM county warning area.

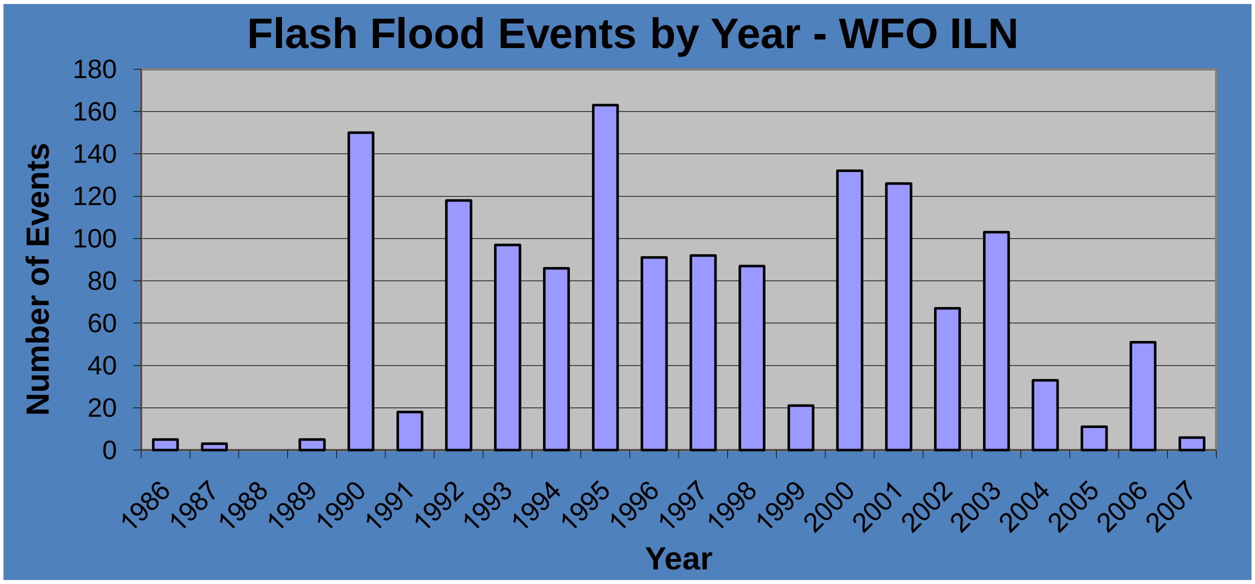


Figure B57. Flash flood events by year for the ILN county warning area.

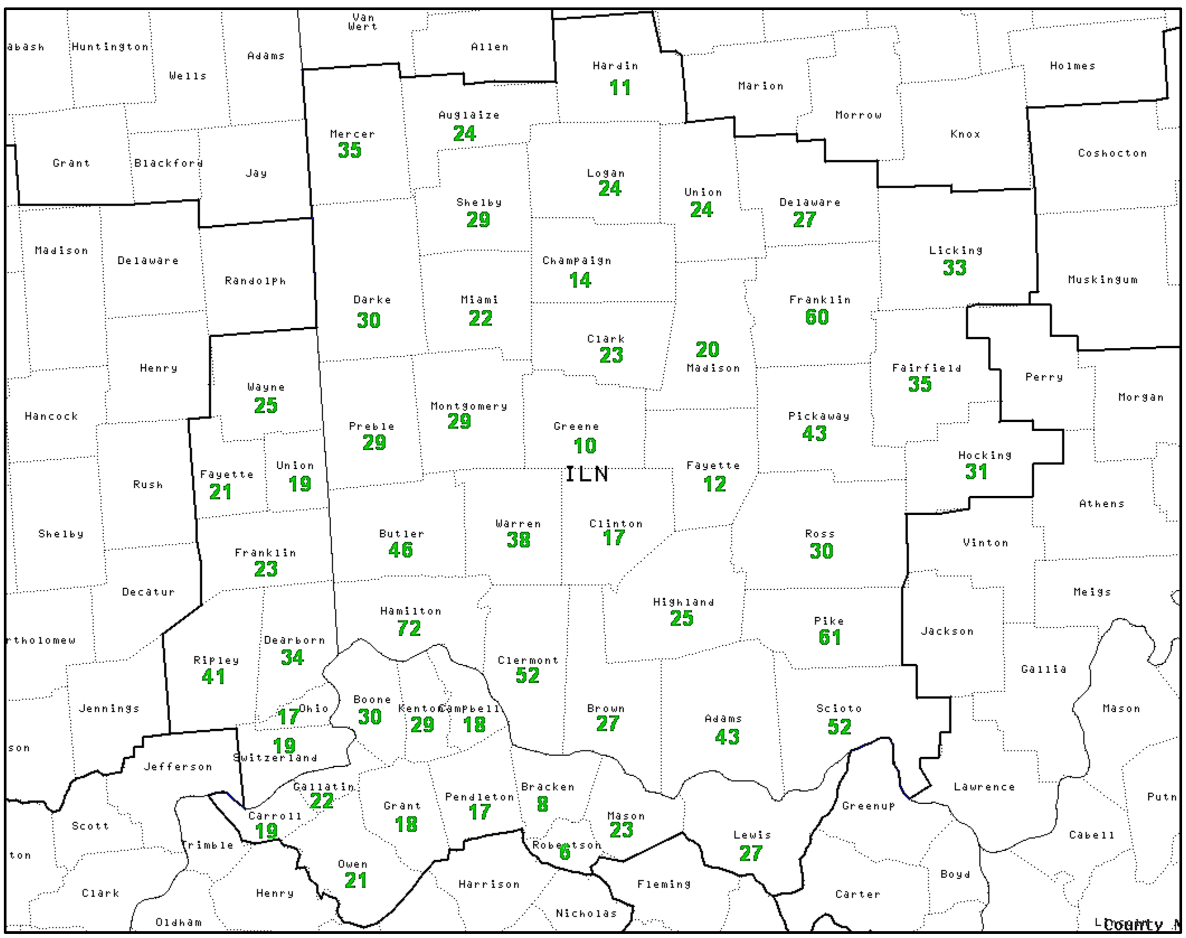


Figure B58. Flash flood events by county for the ILN county warning area.

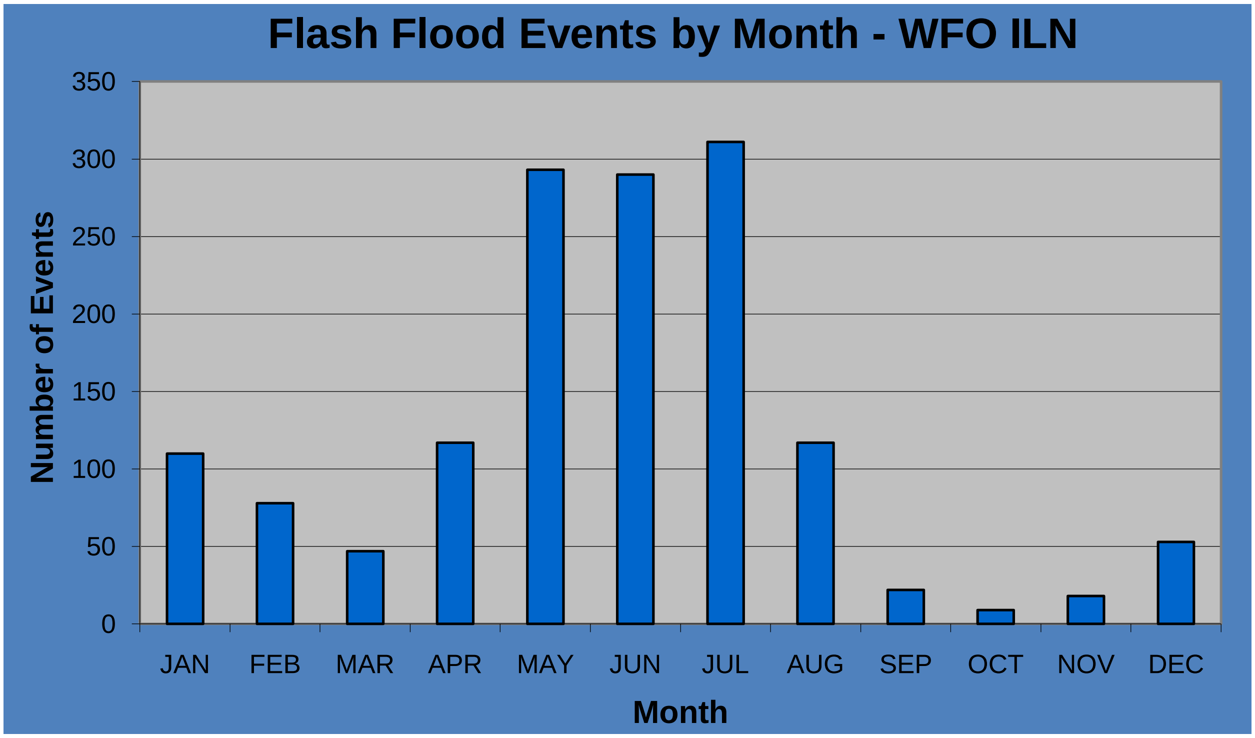


Figure B59. Flash flood events by month for the ILN county warning area.

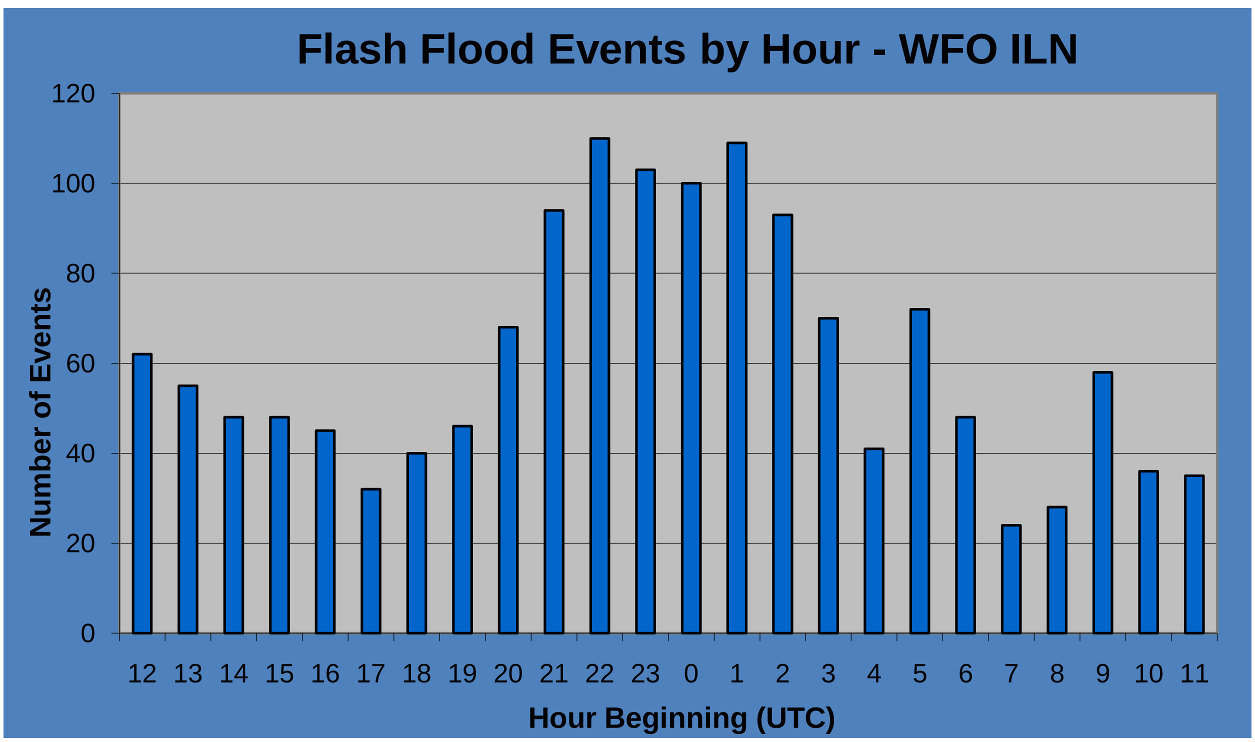


Figure B60. Flash flood events by hour of the day for the ILN county warning area.

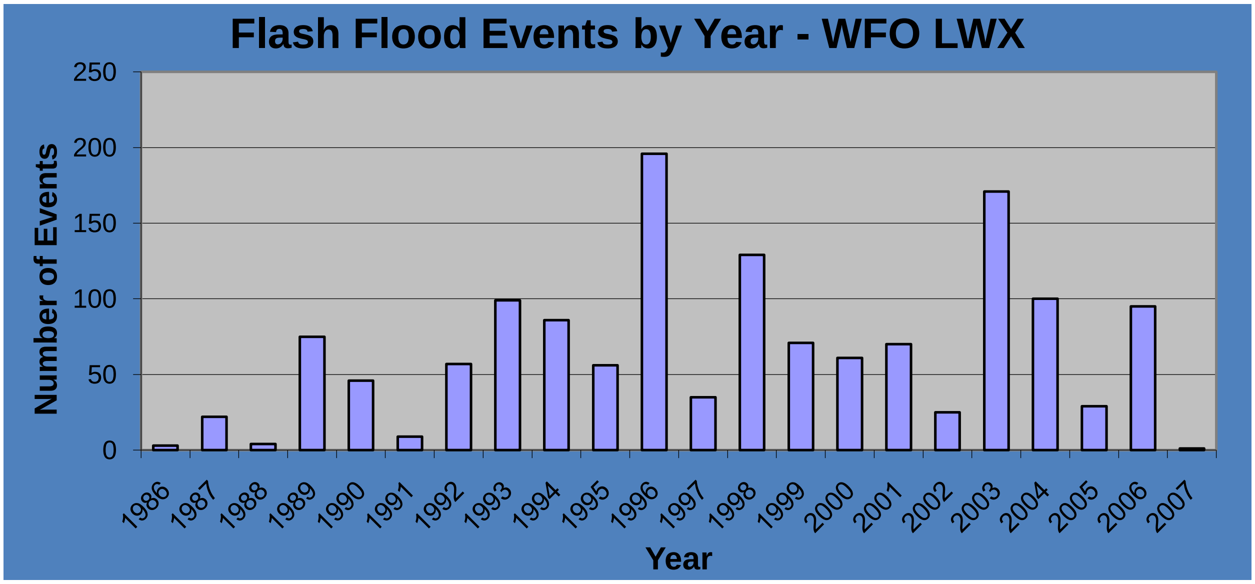


Figure B61. Flash flood events by year for the LWX county warning area.

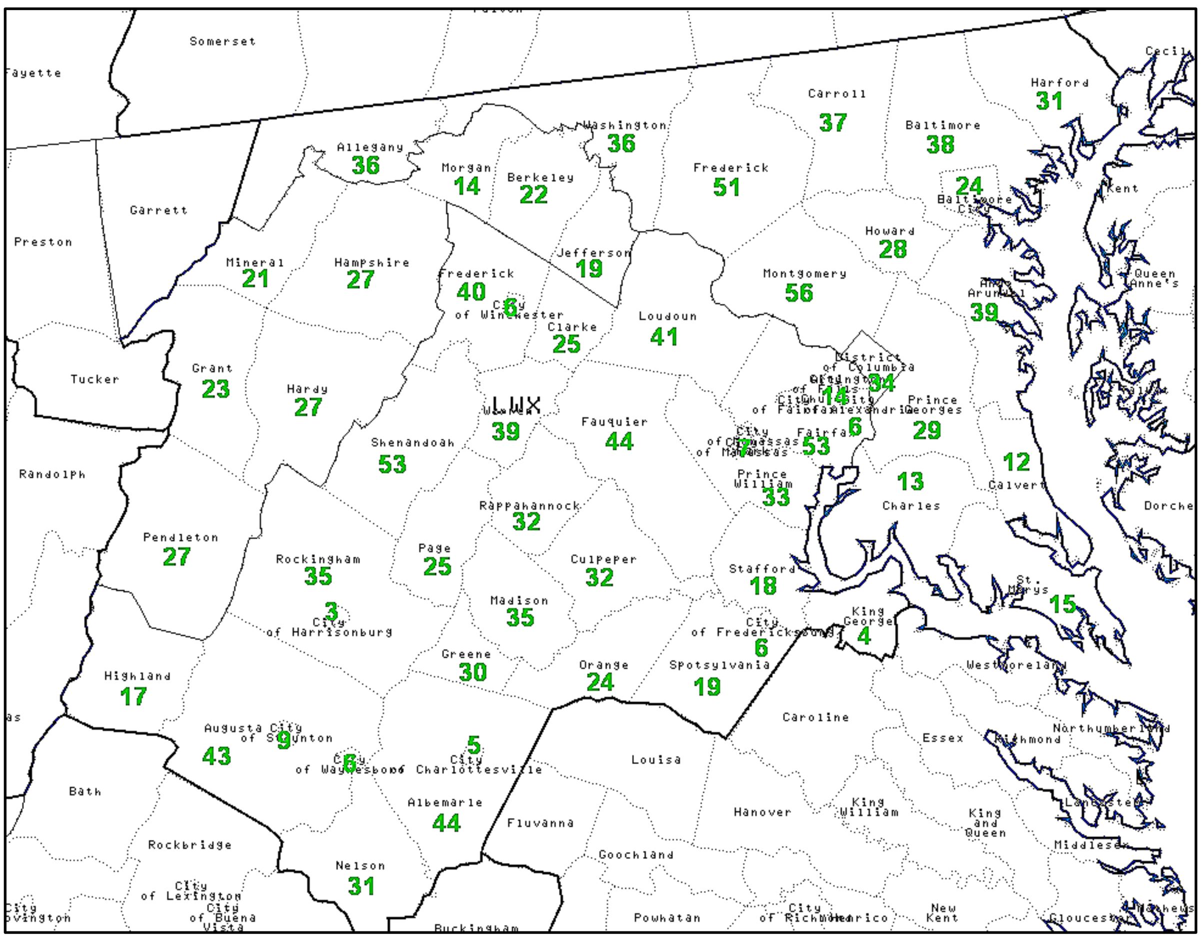


Figure B62. Flash flood events by county for the LWX county warning area.

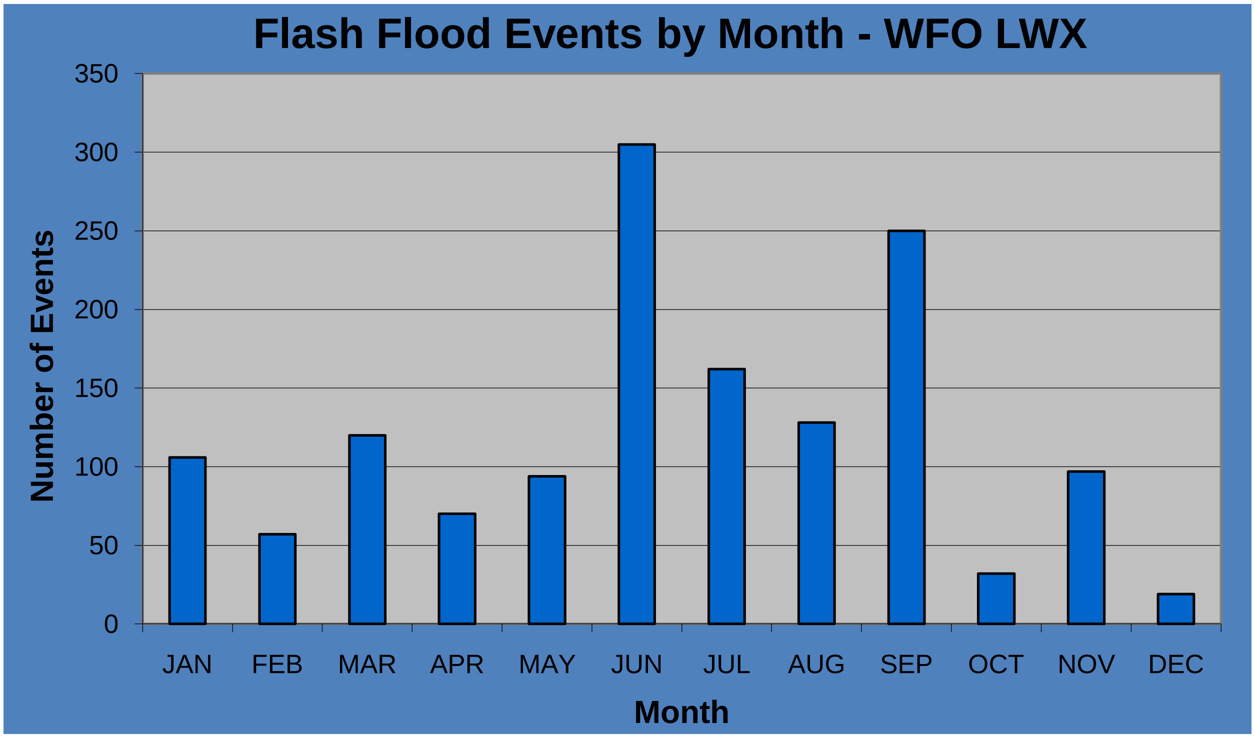


Figure B63. Flash flood events by month for the LWX county warning area.

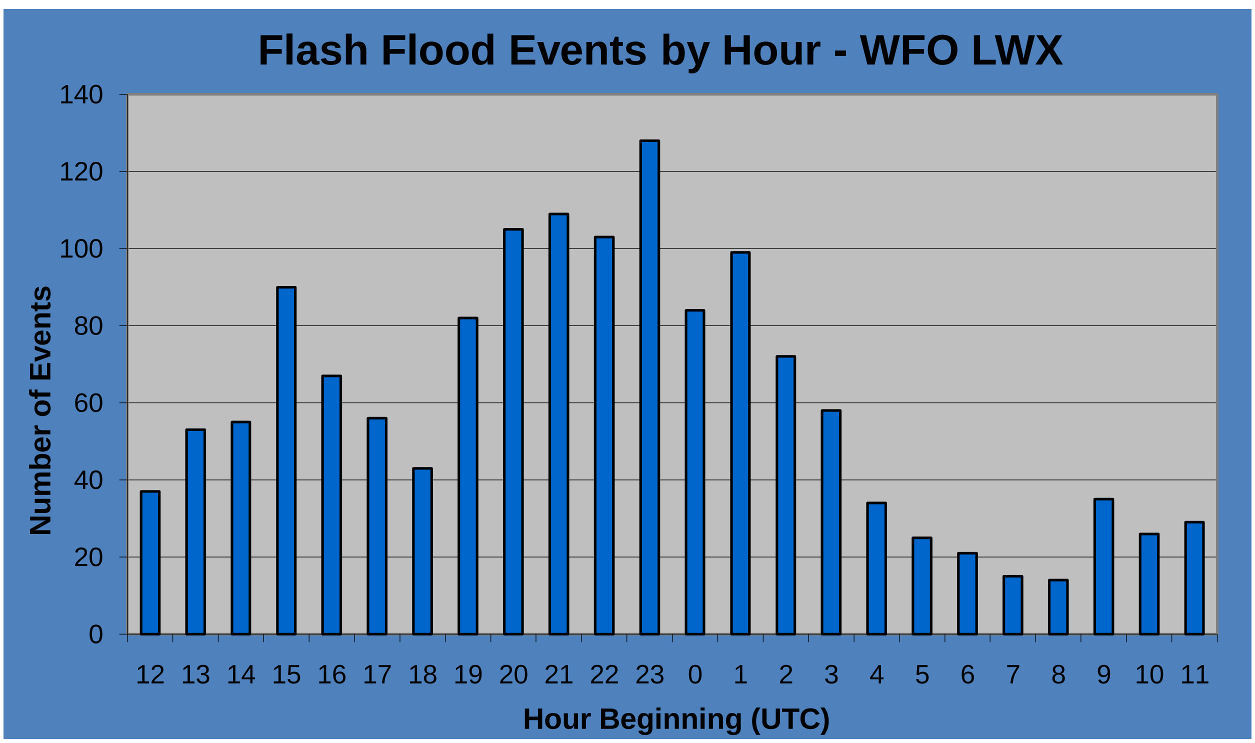


Figure B64. Flash flood events by hour of the day for the LWX county warning area.

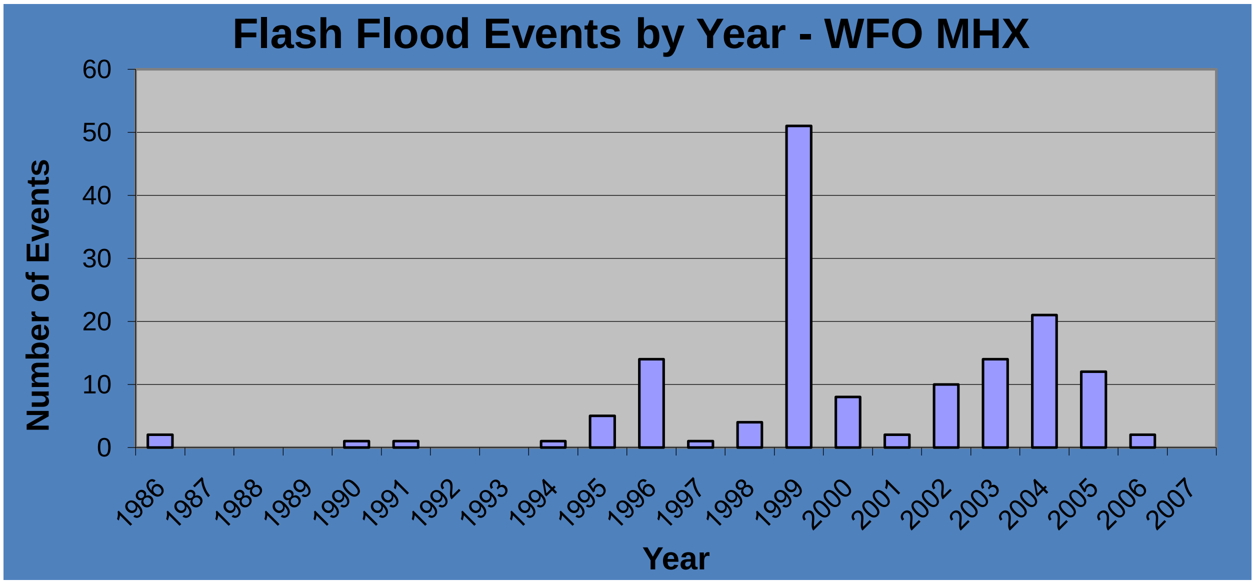


Figure B65. Flash flood events by year for the MHX county warning area.

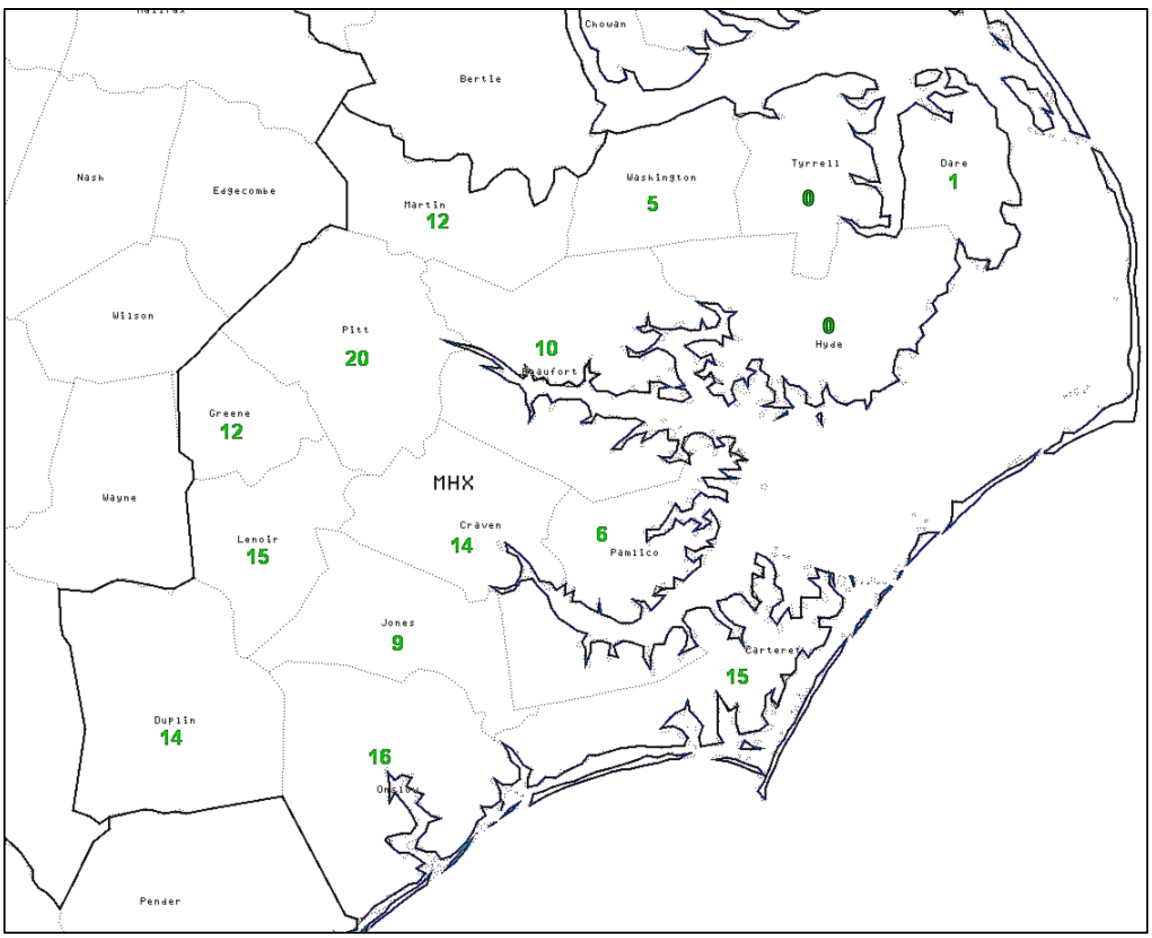


Figure B66. Flash flood events by county for the MHX county warning area.

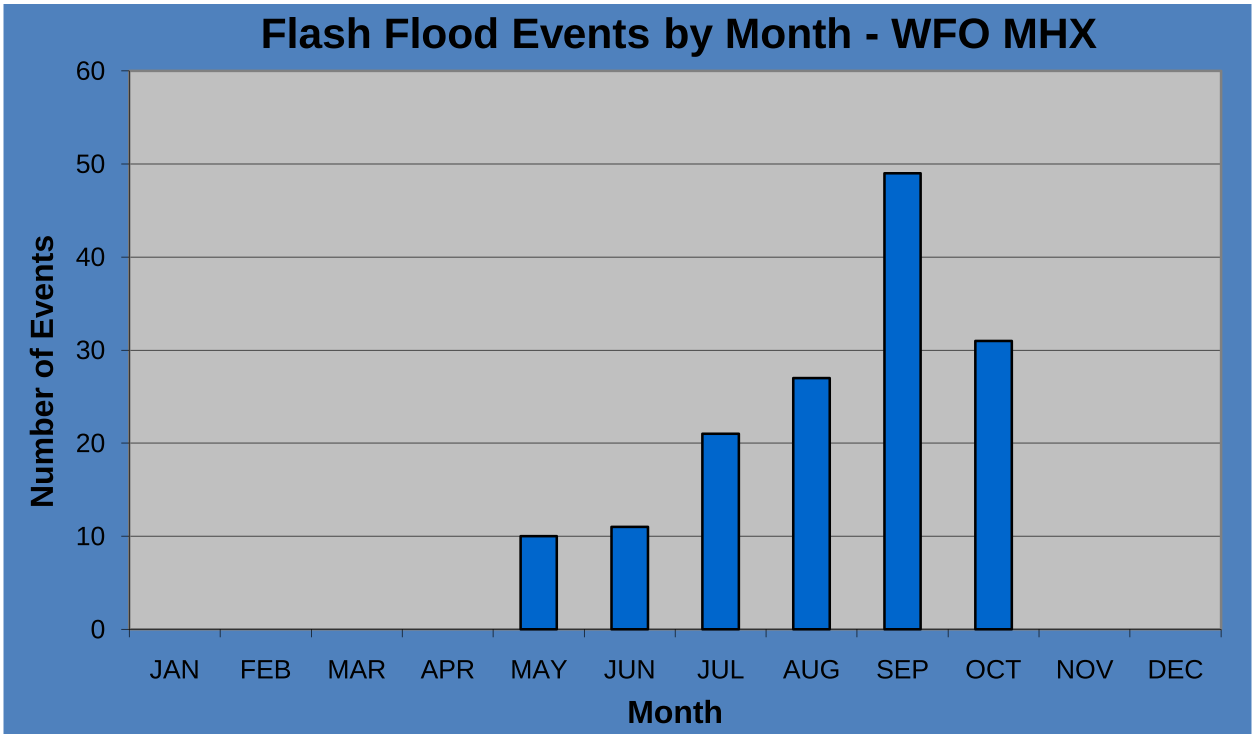


Figure B67. Flash flood events by month for the MHX county warning area.

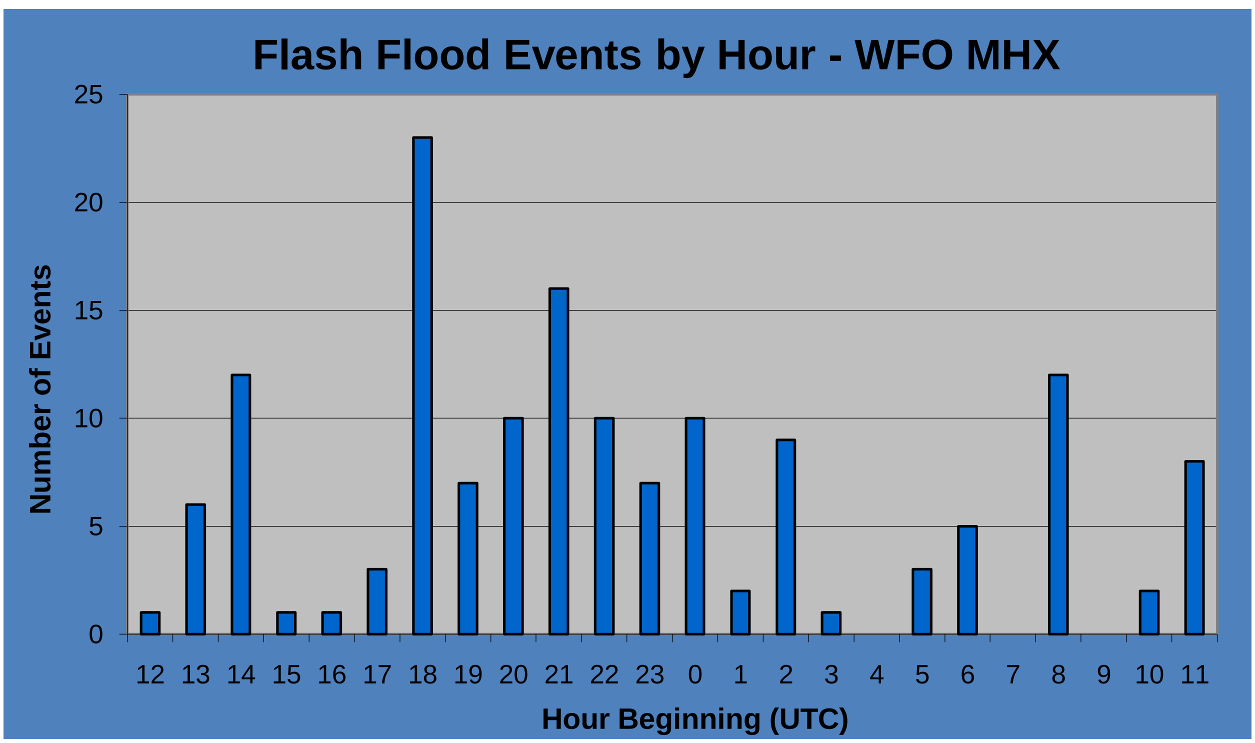


Figure B68. Flash flood events by hour of the day for the MHX county warning area.

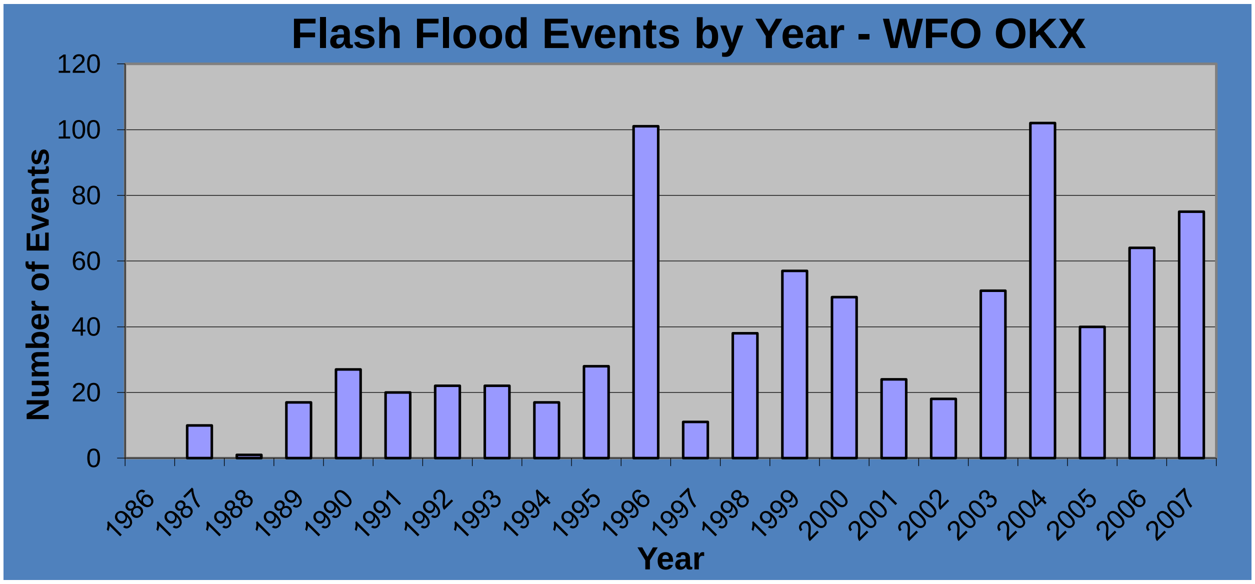


Figure B69. Flash flood events by year for the OKX county warning area.

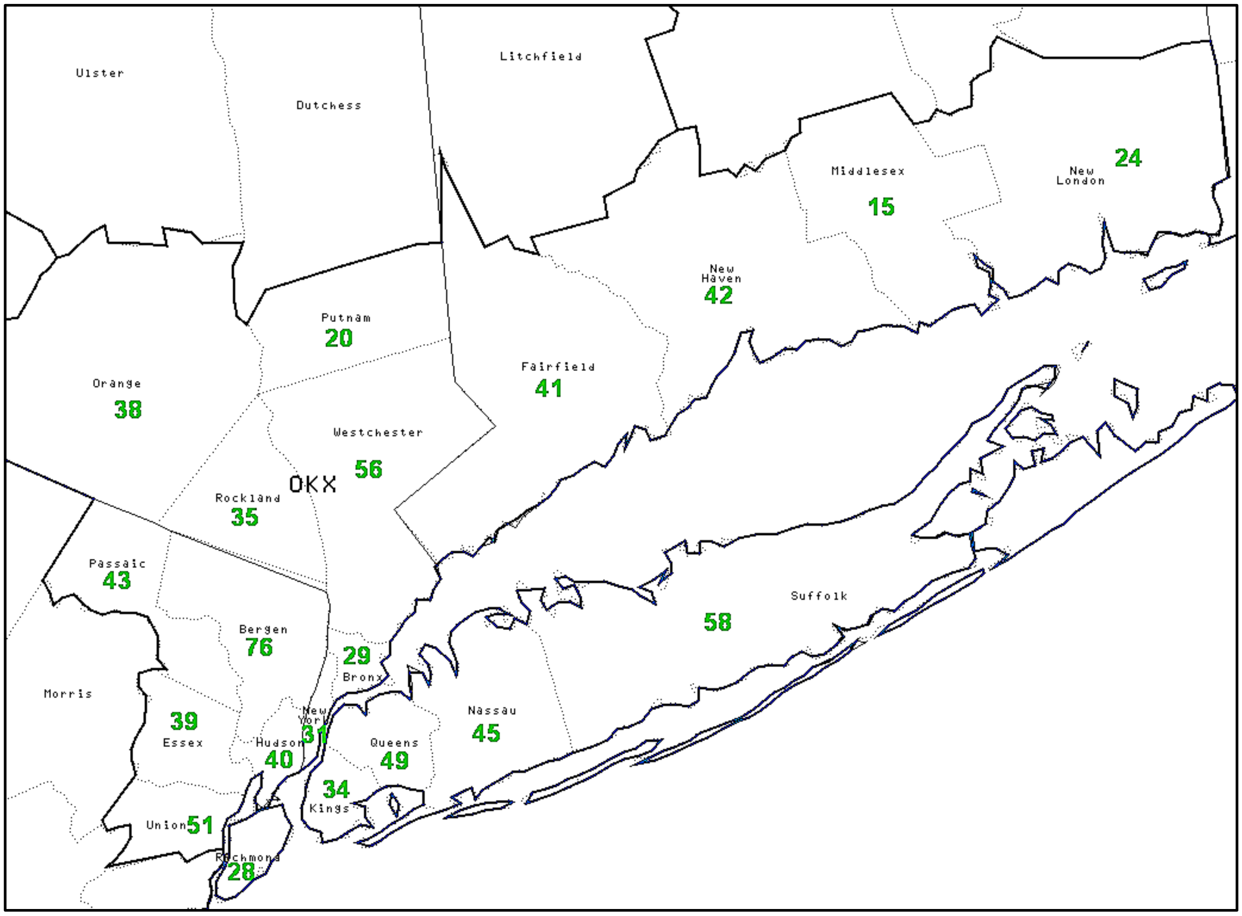


Figure B70. Flash flood events by county for the OKX county warning area.

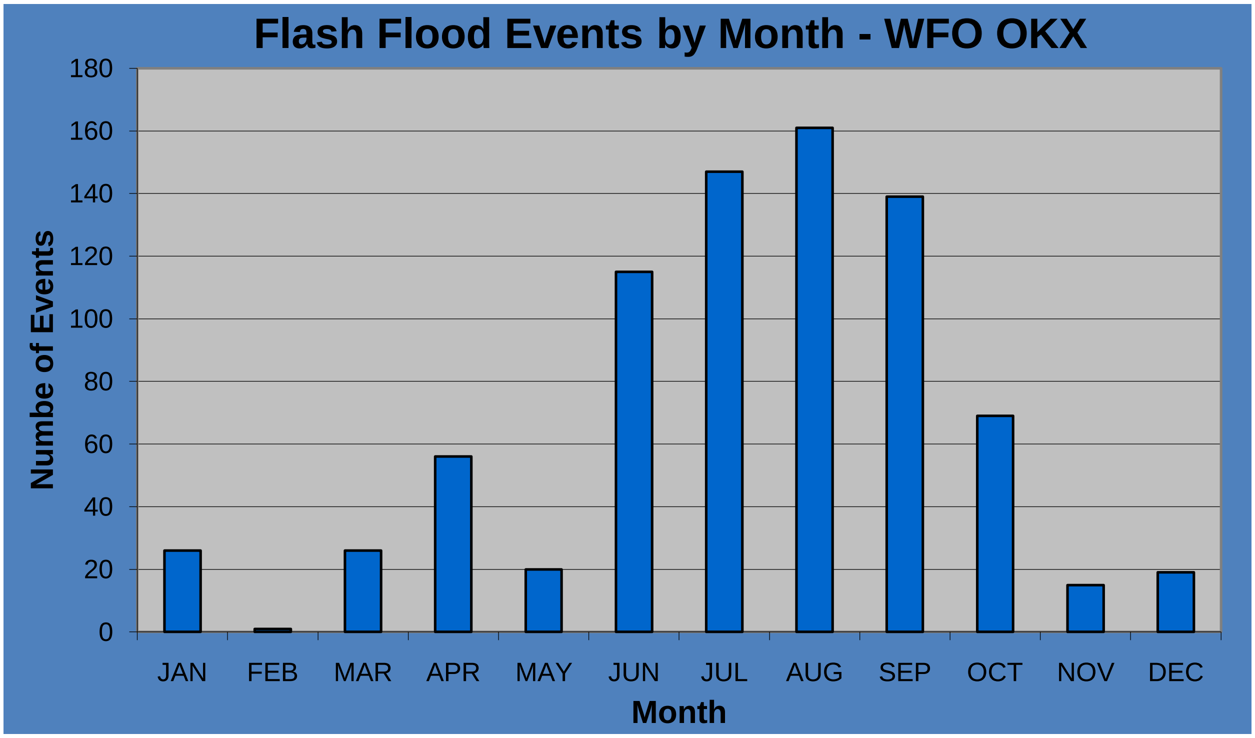


Figure B71. Flash flood events by month for the OKX county warning area.

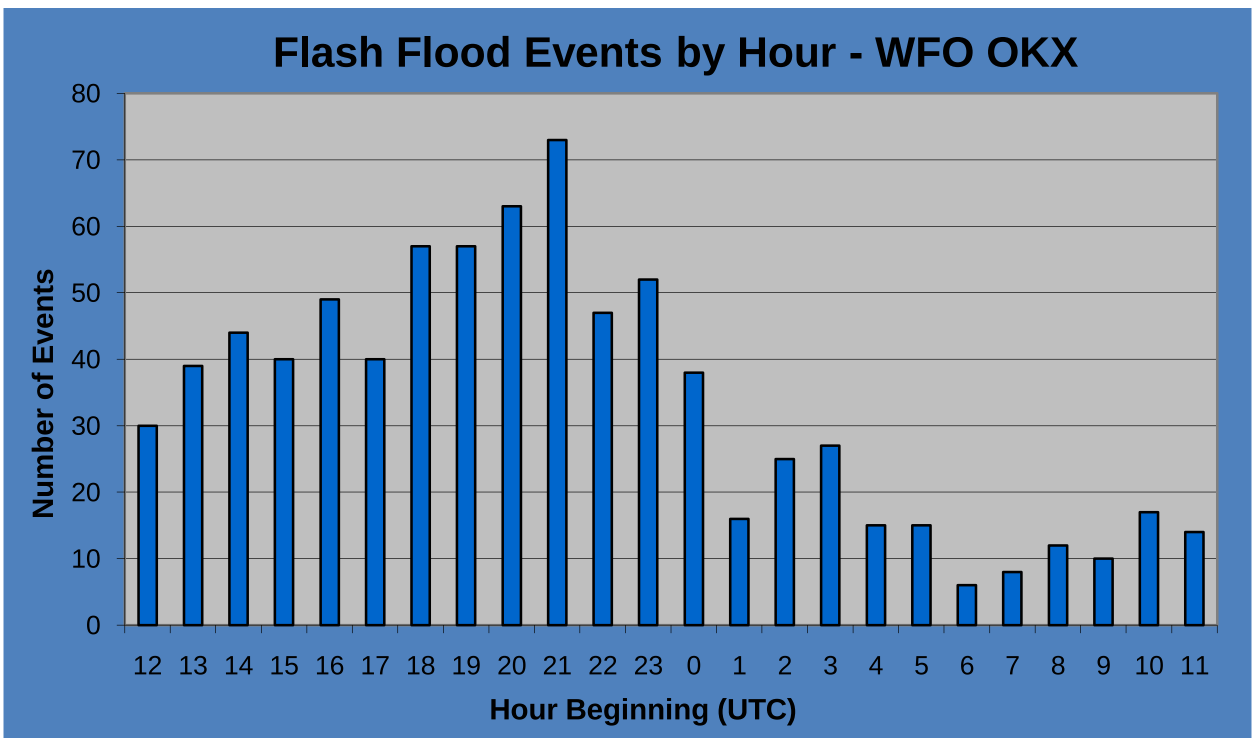


Figure B72. Flash flood events by hour of the day for the OKX county warning area.

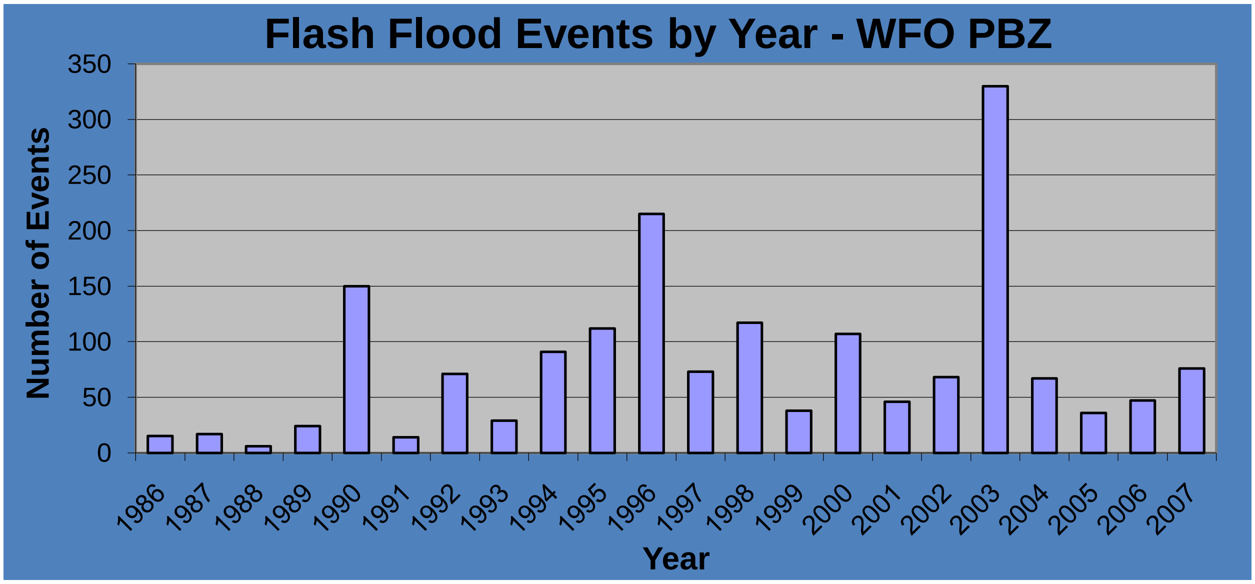


Figure B73. Flash flood events by year for the PBZ county warning area.

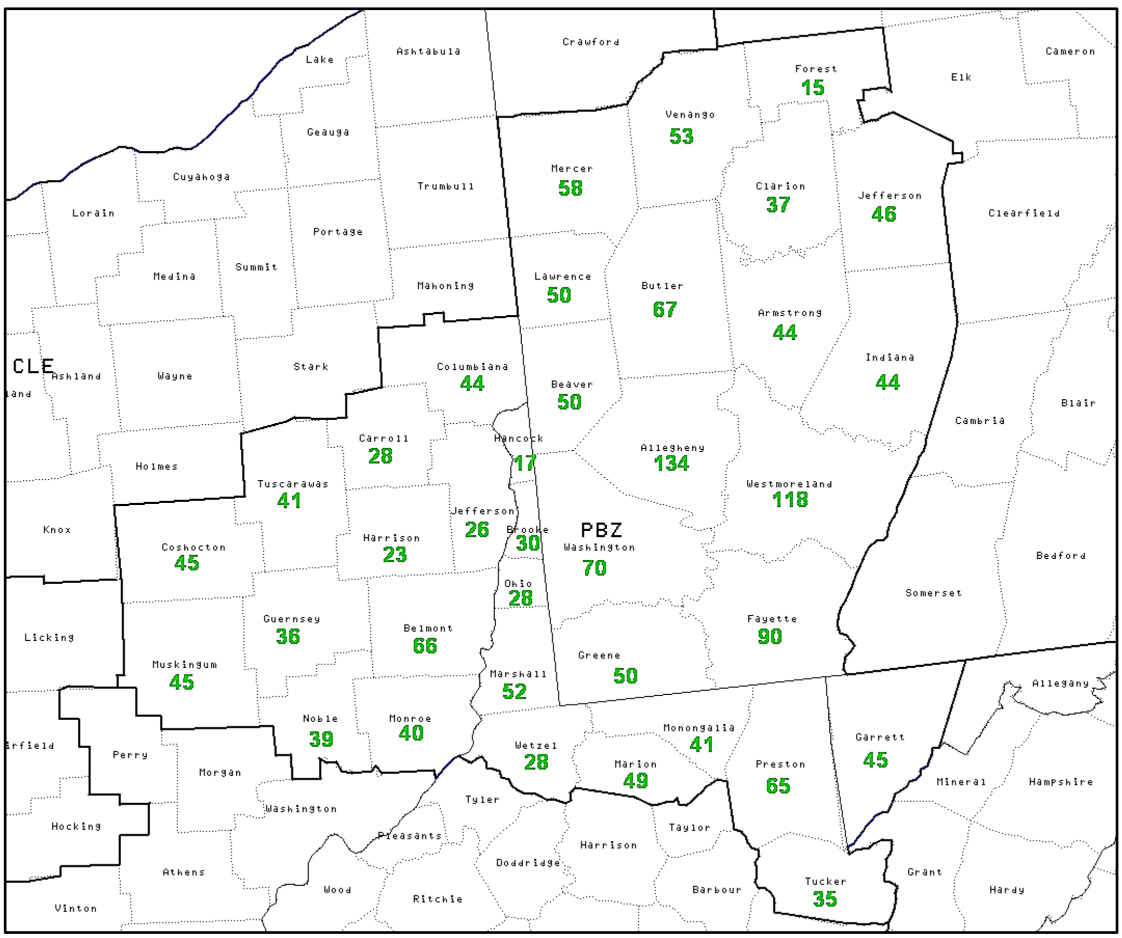


Figure B74. Flash flood events by county for the PBZ county warning area.

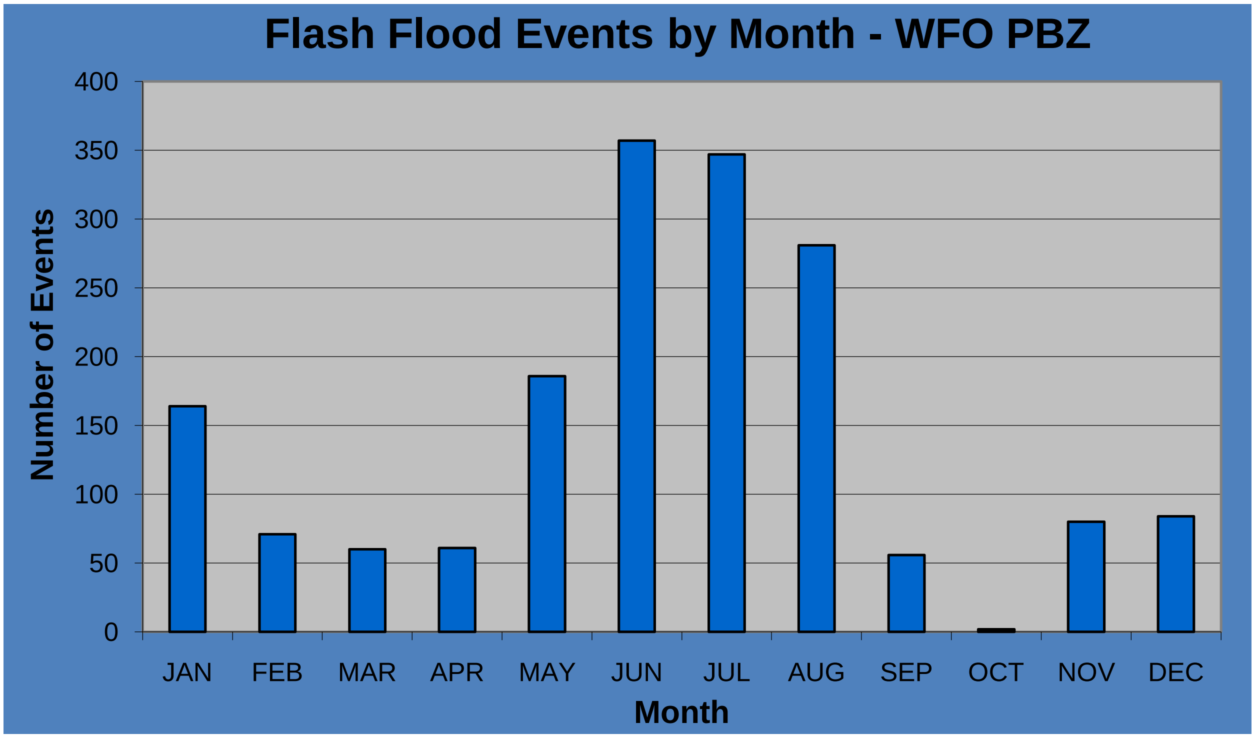


Figure B75. Flash flood events by month for the PBZ county warning area.

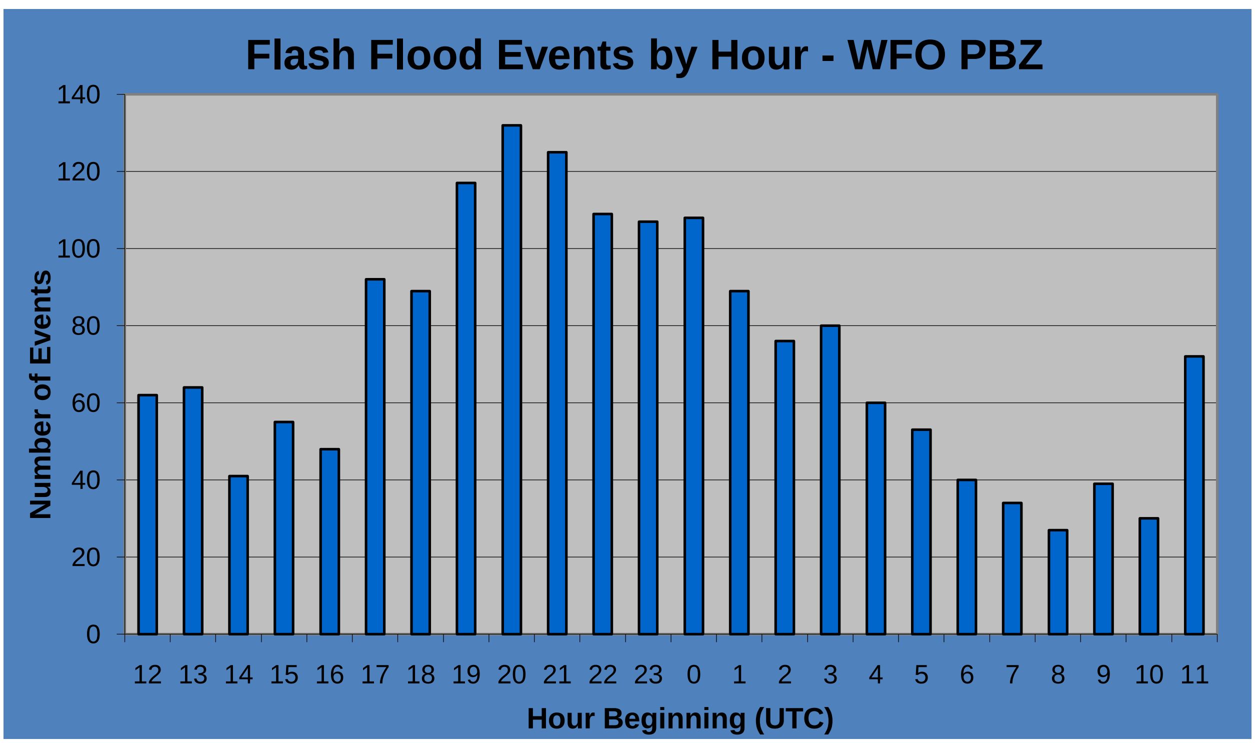


Figure B76. Flash flood events by hour of the day for the PBZ county warning area.

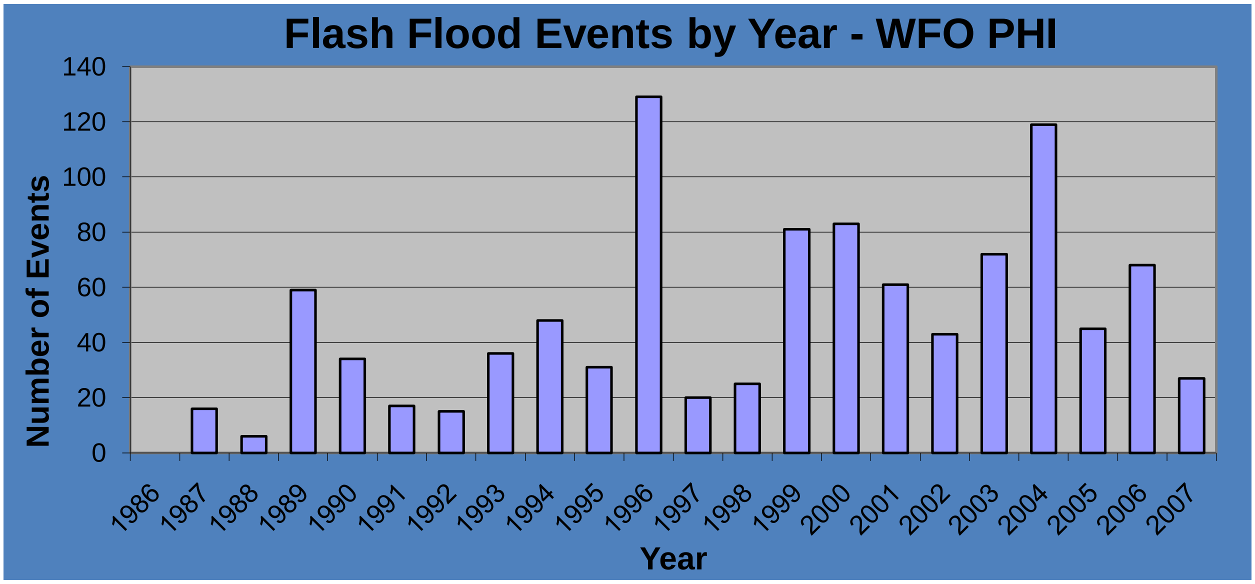


Figure B77. Flash flood events by year for the PHI county warning area.

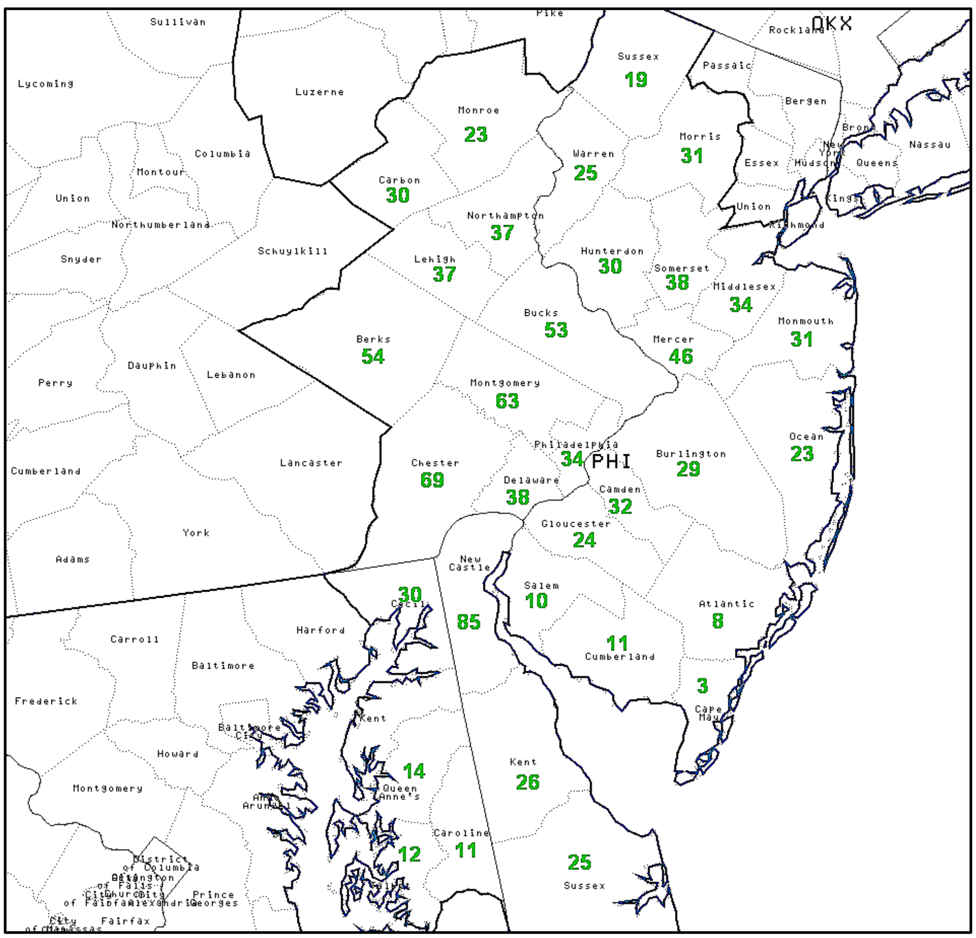


Figure B78. Flash flood events by county for the PHI county warning area.

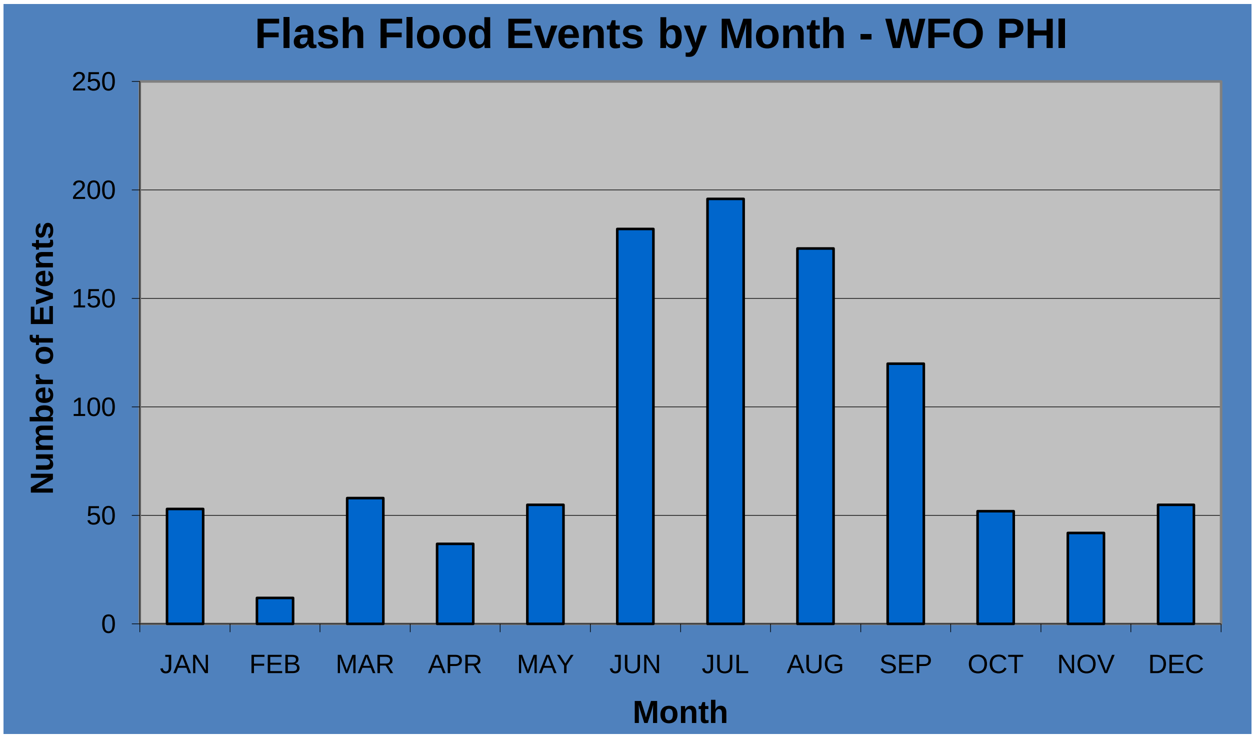


Figure B79. Flash flood events by month for the PHI county warning area.

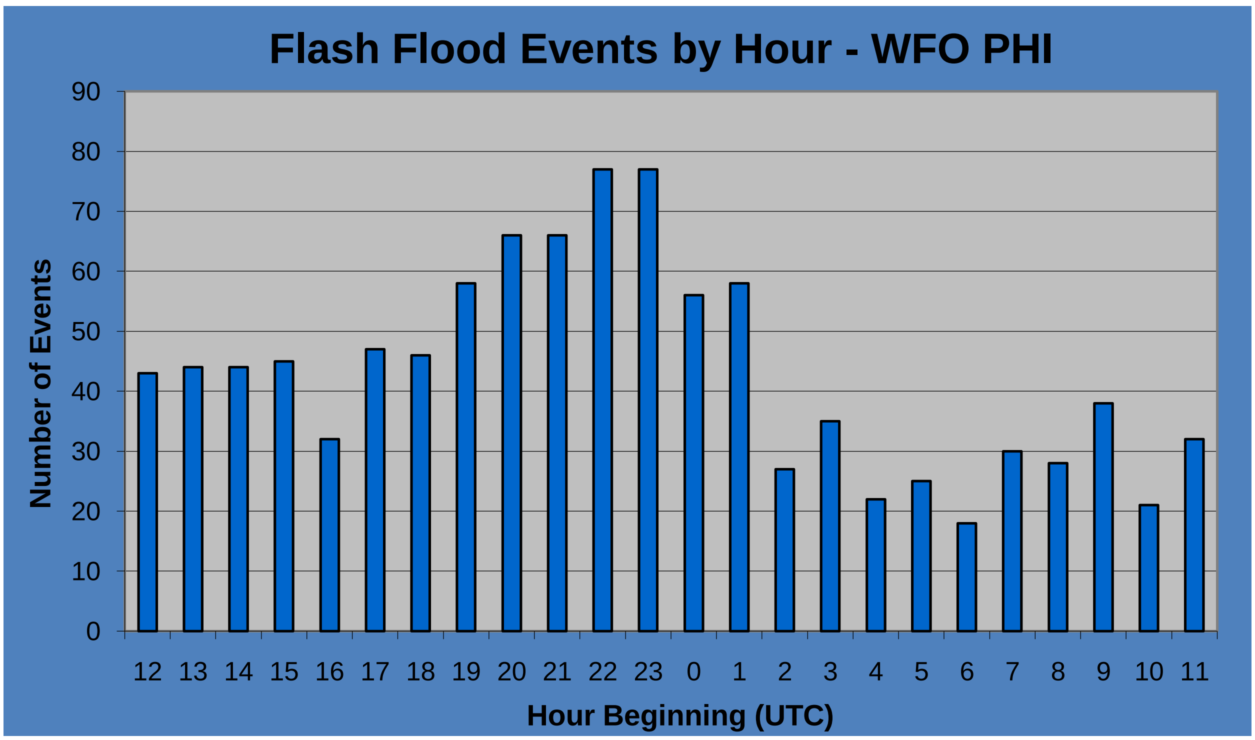


Figure B80. Flash flood events by hour of the day for the PHI county warning area.

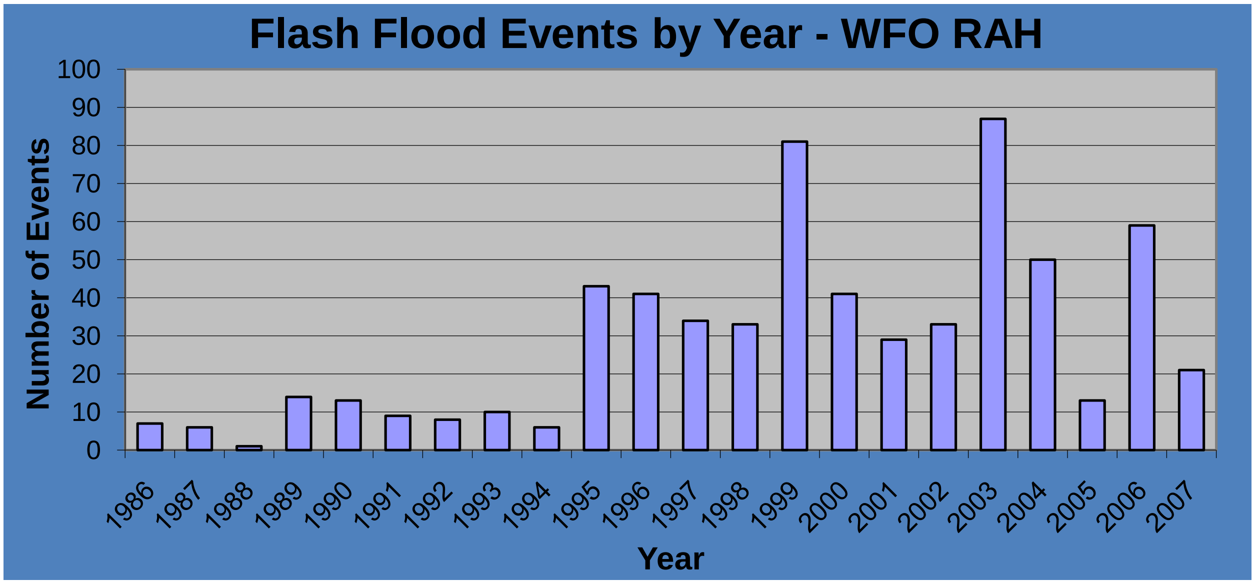


Figure B81. Flash flood events by year for the RAH county warning area.

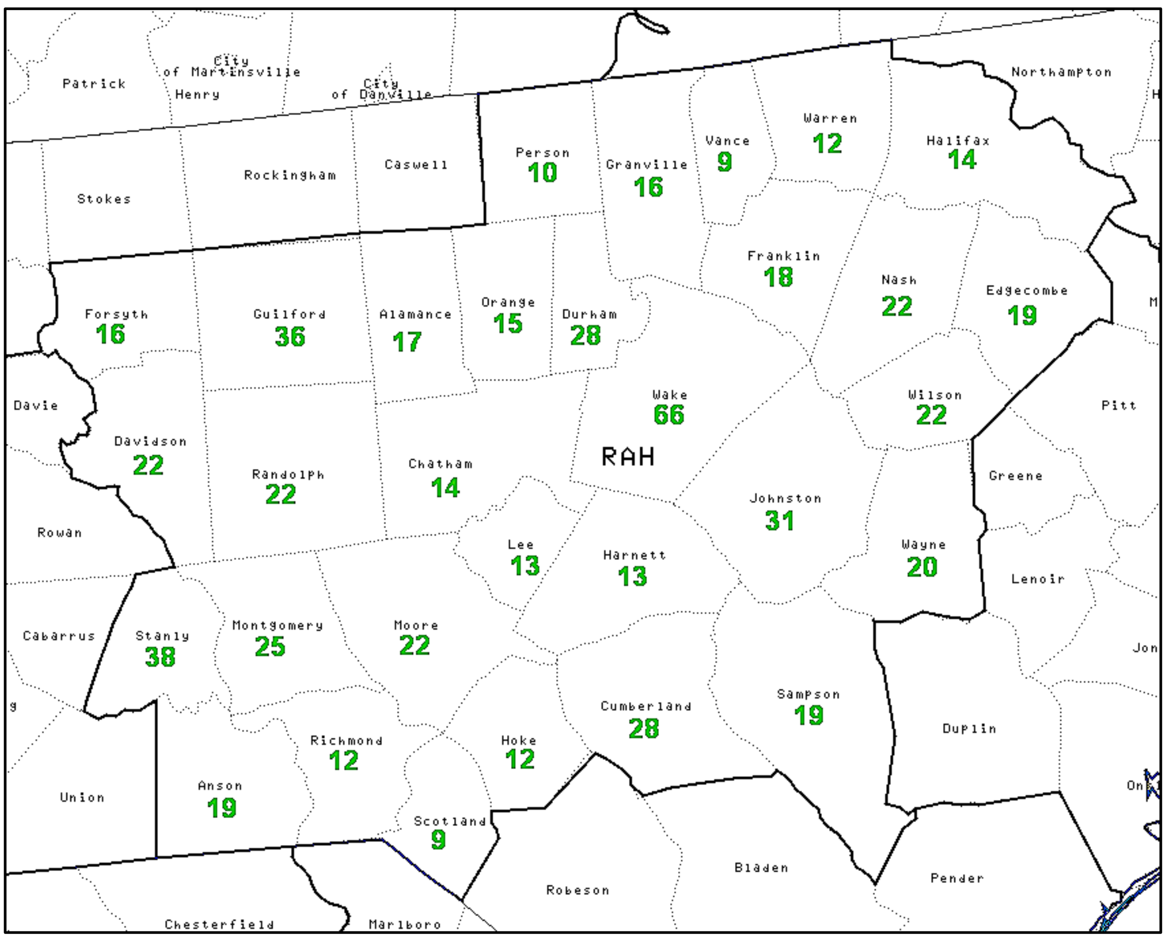


Figure B82. Flash flood events by county for the RAH county warning area.

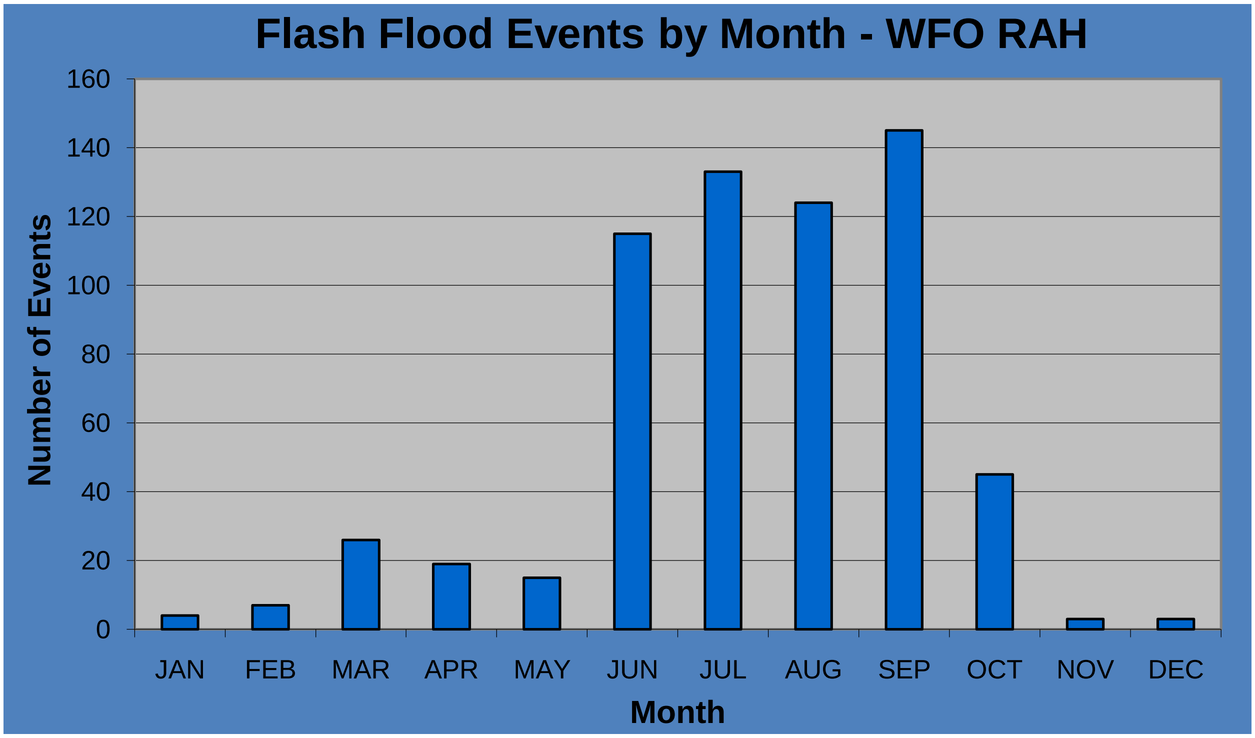


Figure B83. Flash flood events by month for the RAH county warning area.

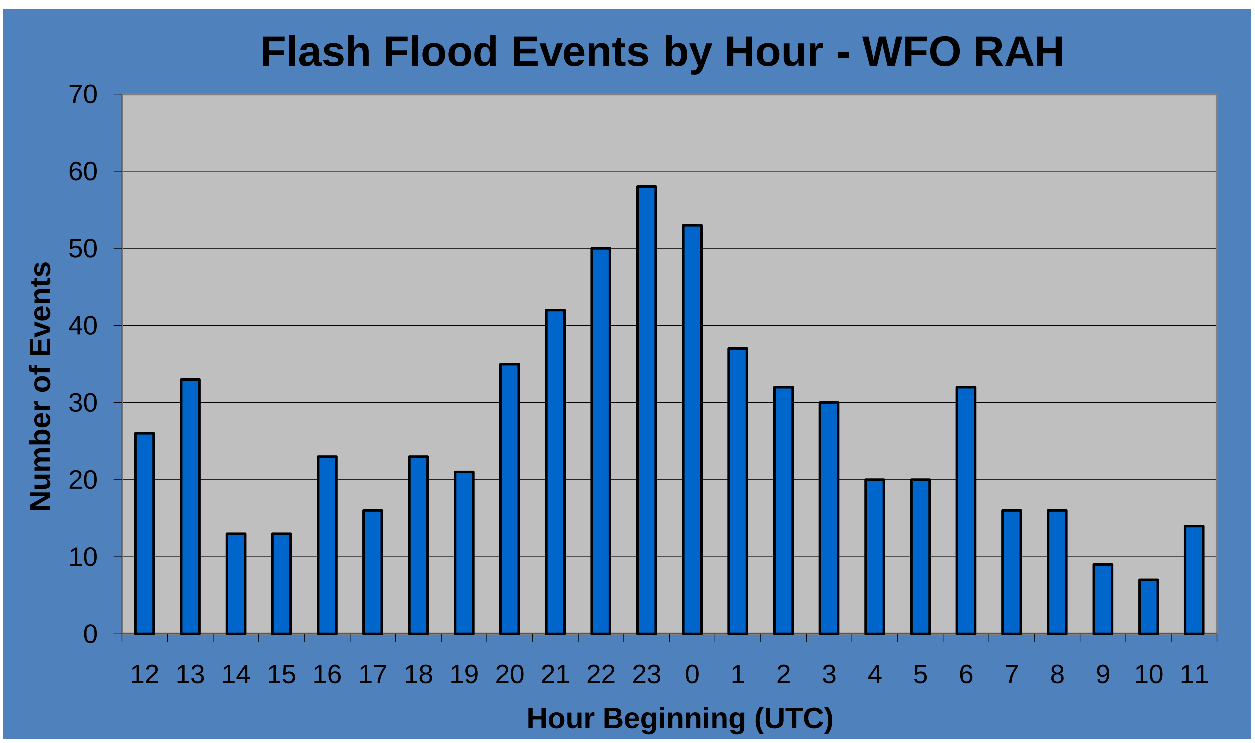


Figure B84. Flash flood events by hour of the day for the RAH county warning area.

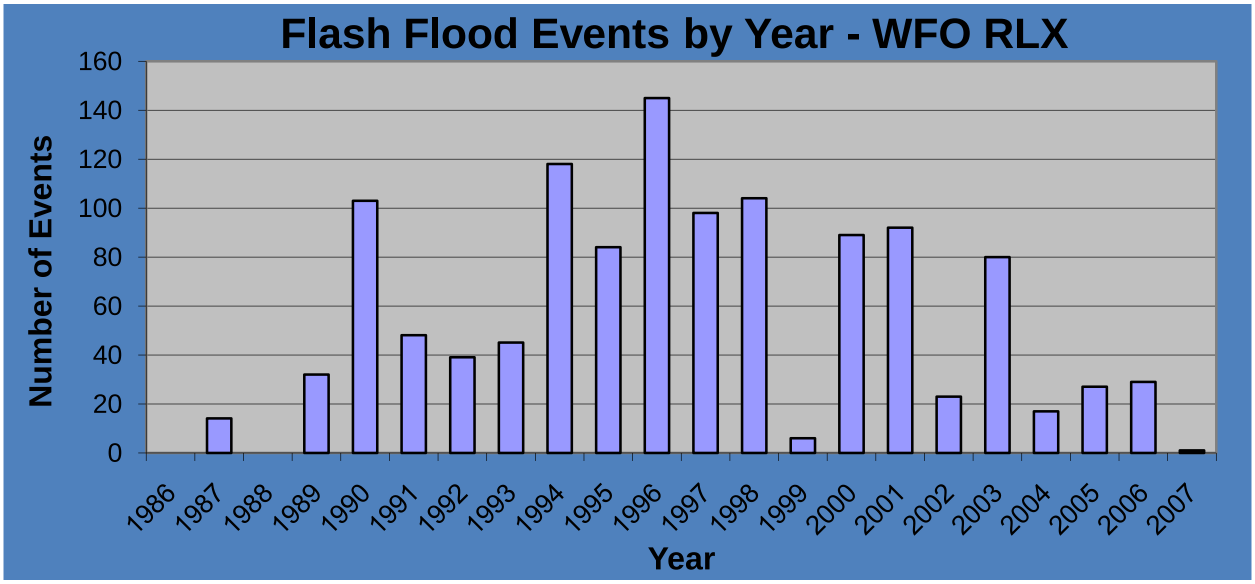


Figure B85. Flash flood events by year for the RLX county warning area.

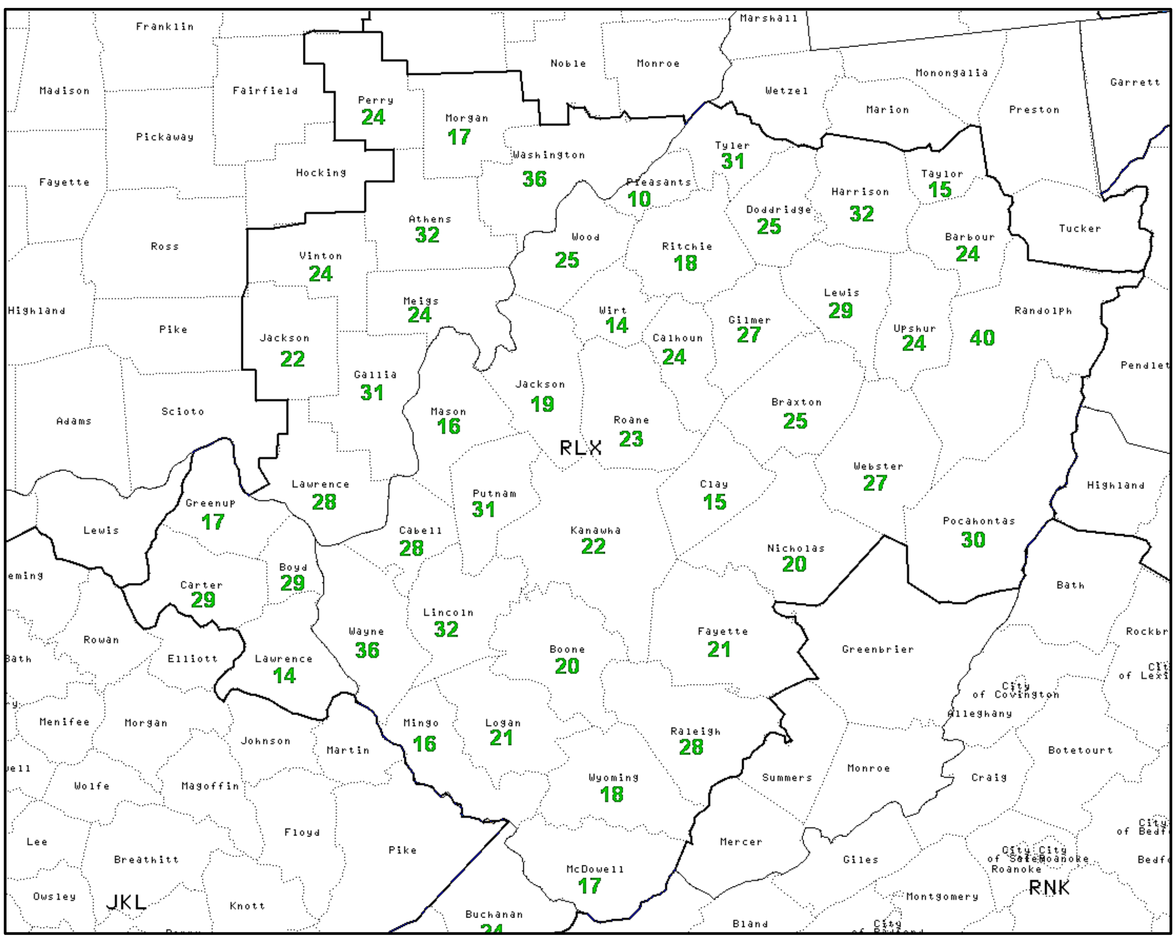


Figure B86. Flash flood events by county for the RLX county warning area.

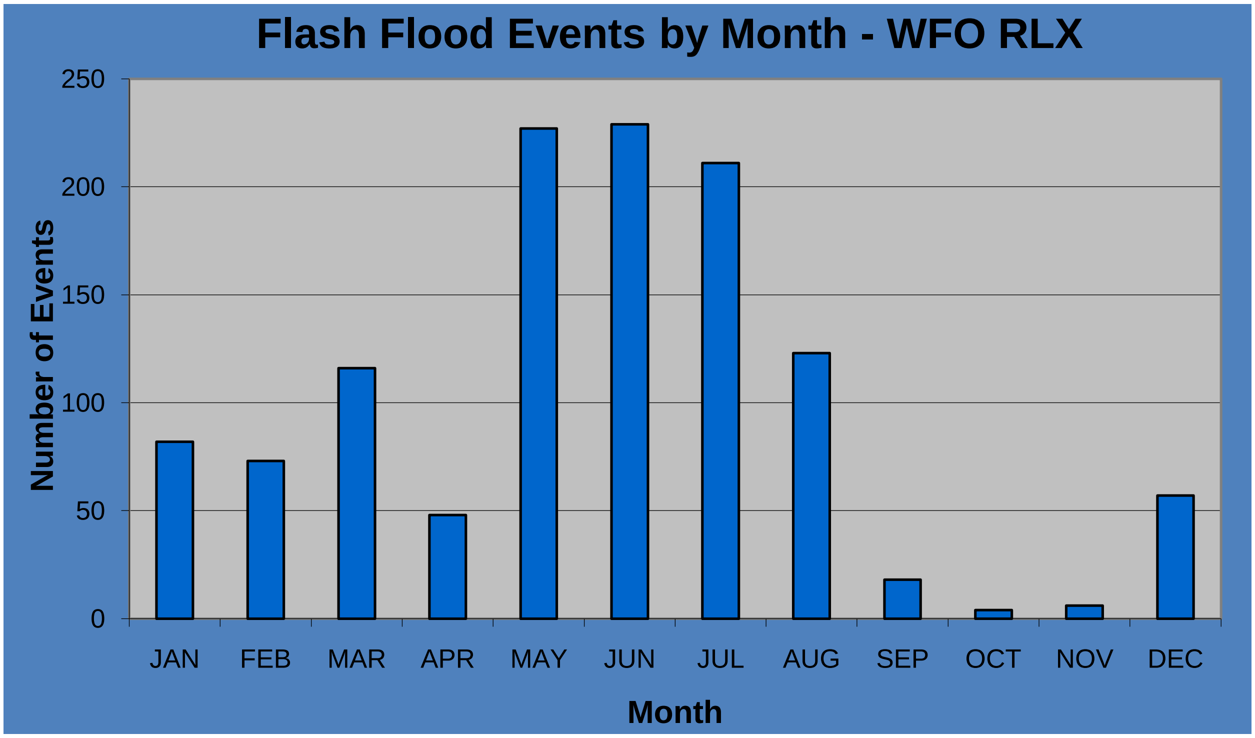


Figure B87. Flash flood events by month for the RLX county warning area.

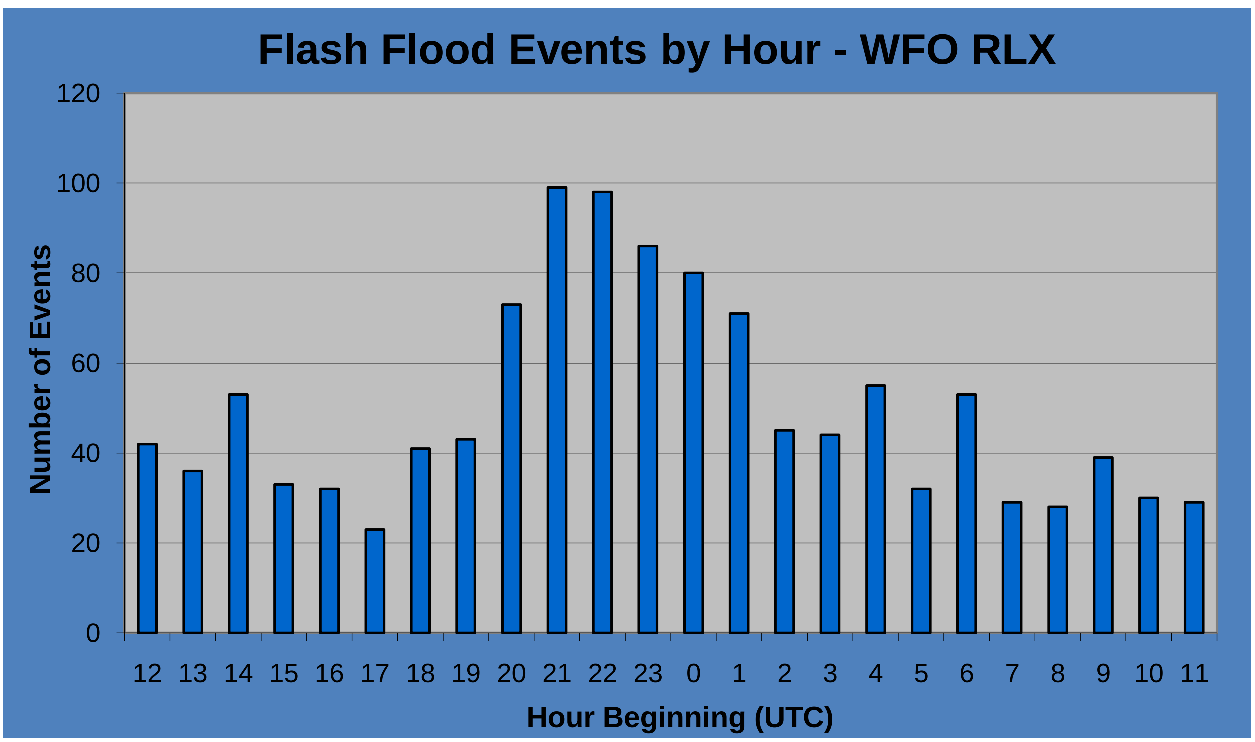


Figure B88. Flash flood events by hour of the day for the RLX county warning area.

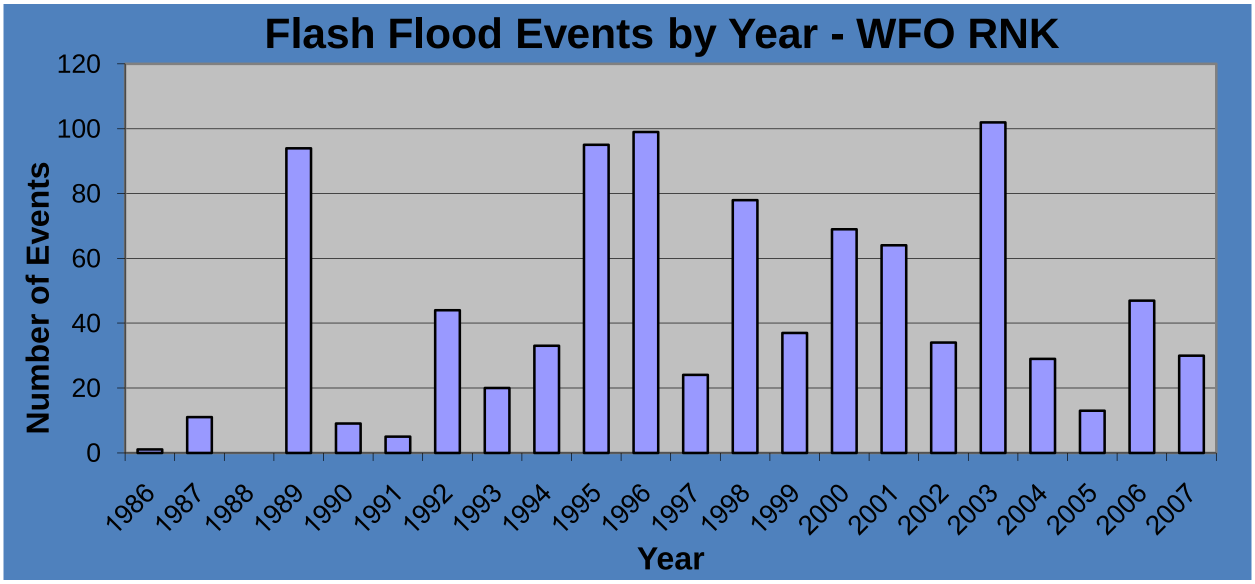


Figure B89. Flash flood events by year for the RNK county warning area.

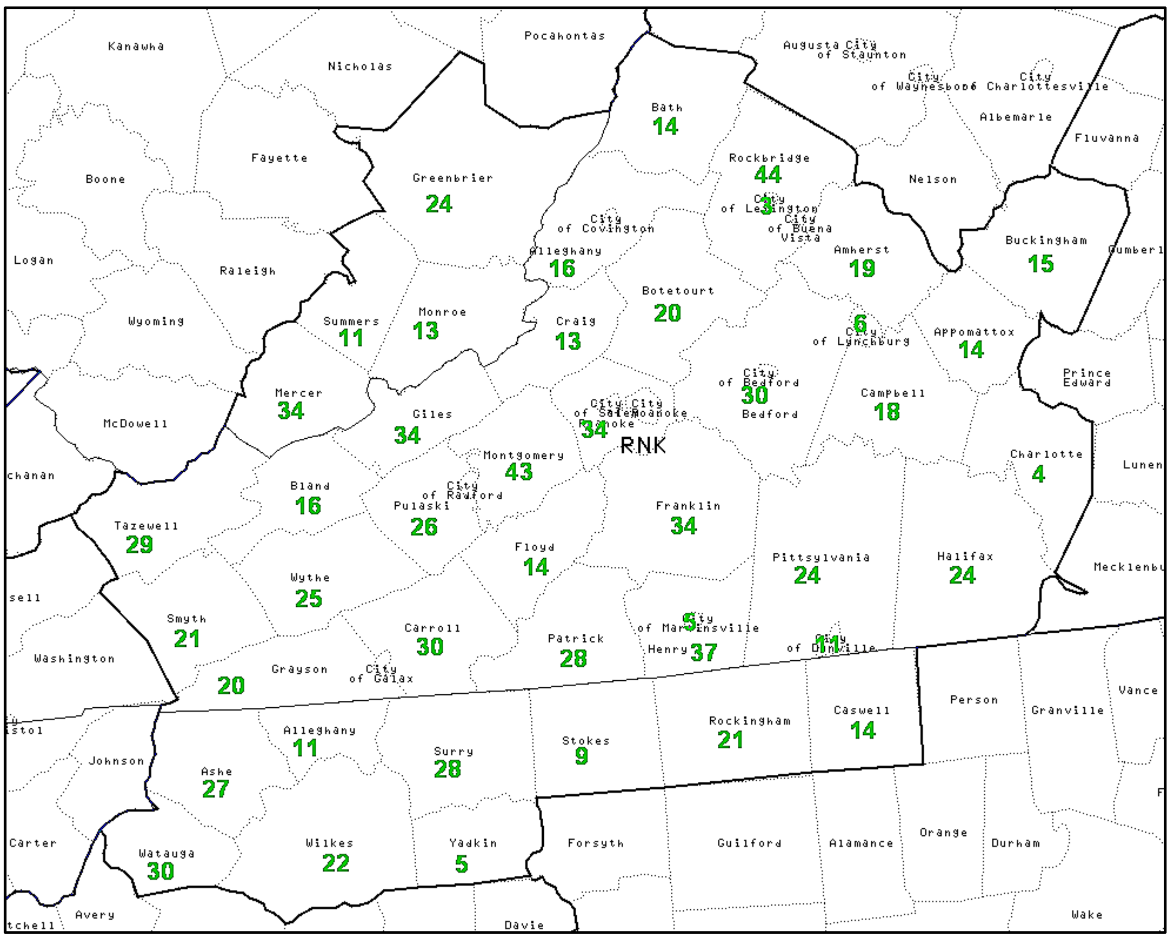


Figure B90. Flash flood events by county for the RNK county warning area.

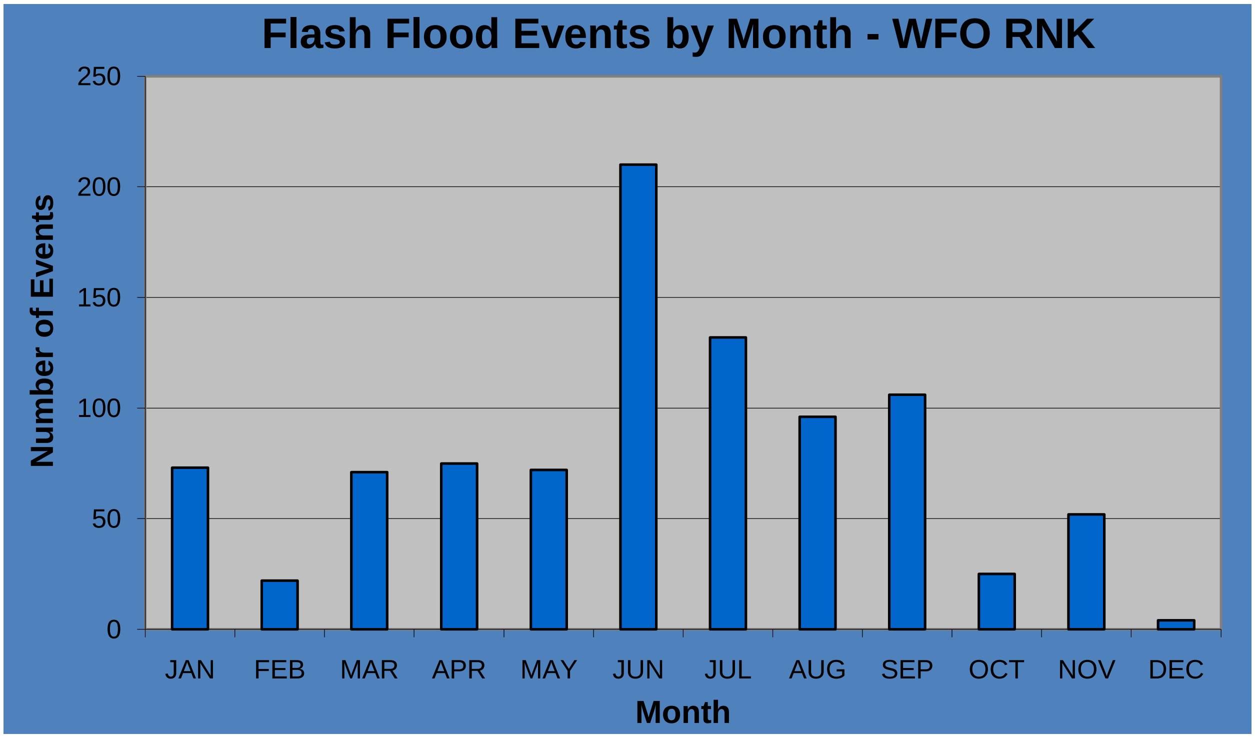


Figure B91. Flash flood events by month for the RNK county warning area.

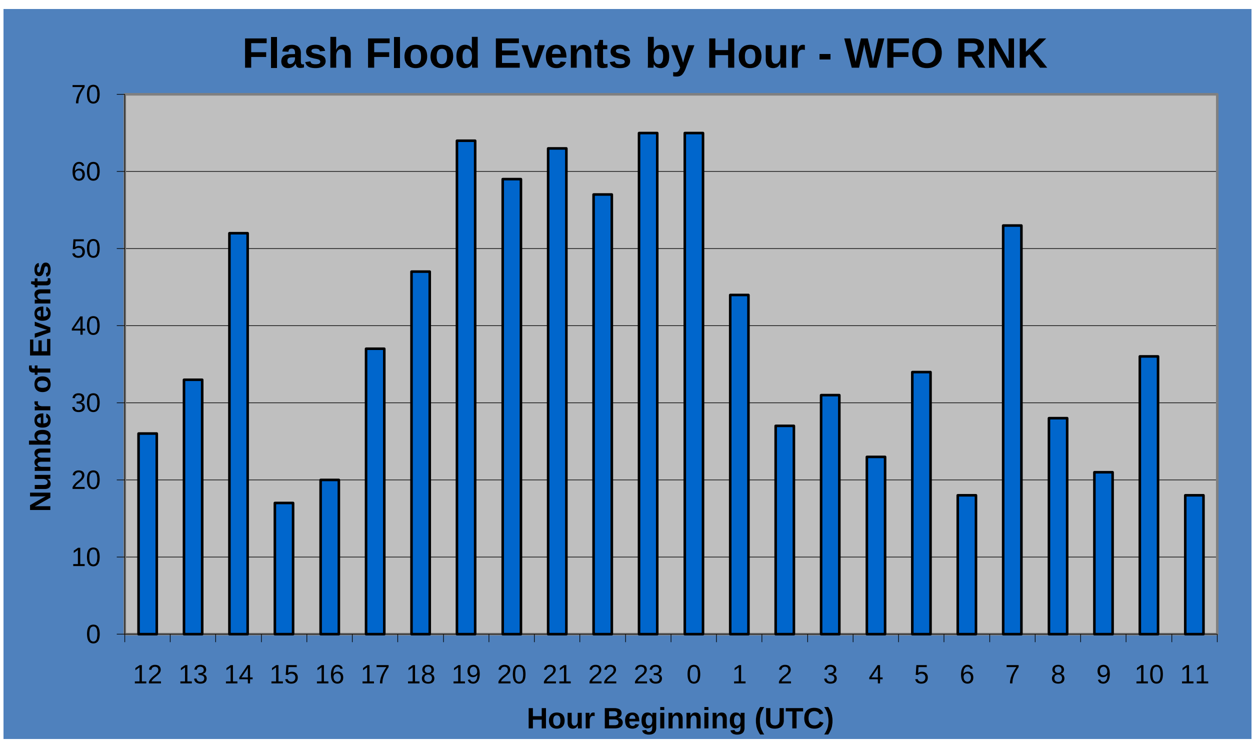


Figure B92. Flash flood events by hour of the day for the RNK county warning area.

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