Updated Precipitation Frequency Results and Synthesis of New IDF Curves for the City of Alexandria, Virginia

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Contents

Tables

Introduction

The City of Alexandria, Virginia, has experienced repeated and increasingly frequent flooding events attributable to old infrastructure, inconsistent design criteria, and perhaps climate change. The purpose of the project at hand is to provide a program that, over a period of up to 5 years, will analyze storm sewer capacity issues, identify problem areas, develop and prioritize solutions, and provide support for public outreach and education.

The purpose of the first task is to review and propose revisions to the City's stormwater design criteria, through a series of four subtasks. This Technical Memorandum documents an analysis undertaken in subtask 1.2 to update the intensity-duration-frequency (IDF) precipitation curves currently used by the City. The approach was to utilize data from precipitation stations that were used by the National Weather Service (NWS) in the update of National Oceanic and Atmospheric Administration (NOAA) Atlas 14, Volume 2, *Ohio River Basin & Surrounding States*, that was published in 2004 and revised in 2006 (http://www.nws.noaa.gov/oh/hdsc/PF_documents/Atlas14_Volume2.pdf). The NOAA Atlas 14 analysis used annual maximum precipitation data through 2000 for several hourly and daily stations in Virginia and Maryland in the vicinity of Alexandria. These stations served as a basis for identifying stations that were applicable in updating the IDF curves for the city. All stations considered for this analysis had in excess of 30 years of record.

The other three Task 1 subtasks that will inform the recommendations for updating the City's stormwater design criteria are:

- Subtask 1.1 - Comparison of Alexandria's Storm Design Criteria to Neighboring Jurisdictions
- Subtask 1.3 – Rainfall Frequency and Global Climate Change Model Options for Study Area
- Subtask 1.4 - Sea Level Rise

Sources of Data

The approach taken by NWS in preparing Atlas 14 was to define homogeneous regions of similar precipitation characteristics using the method of L-moments, as described by Hosking and Wallis (1997). The L-moment approach, described later, defines a collection of precipitation stations that have similar statistical properties.

The hourly and daily precipitation stations used by NWS in the Atlas 14 analysis were reviewed. The City of Alexandria falls within Region 1 for hourly stations and Region 8 for daily stations. The hourly stations were used to define precipitation frequency values for durations of 24 hours or less, and the daily stations were used for durations greater than 24 hours. Our analysis updated the Atlas 14 analysis using data through 2008.

There are 25 stations in hourly Region 1 as defined by NWS, and 10 of those were still being operated in 2000, the cutoff date for the Atlas 14 analysis. Several of the 10 stations are far removed from Alexandria, but the 3 stations closest to Alexandria were chosen for analysis (see Table 1). The period of record for the hourly stations is from 1948 to 2008 (61 years) but data for 1994 were missing for Beltsville.

TABLE 1
Summary of Hourly Precipitation Stations used in the L-Moment Analysis

Station ID	Station Name	State	Longitude	Latitude	Years of record
18-0465	Baltimore WSO Airport	MD	-76.6839	39.1722	61
18-0700	Beltsville	MD	-76.9314	39.0303	60
44-8906	Washington Reagan National Airport	VA	-77.0342	38.8650	61

At least 15 daily stations in the vicinity of Alexandria have data up to 2008, and an evaluation of these data resulted in selecting 13 daily stations for analysis (see Table 2).

TABLE 2
Summary of Daily Precipitation Stations used in the L-Moment Analysis

Station ID	Station Name	State	Longitude	Latitude	Years of record
18-0700	Beltsville	MD	-76.9314	39.0303	66
18-2325	Dalecarlia Resvr DC	MD/DC	-77.1131	38.9400	64
18-3675	Glenn Dale Bell Stn	MD	-76.8033	38.9692	87
18-5111	Laurel 3 W	MD	-76.9003	39.0847	110
18-6350	National Arboretum DC	MD/DC	-76.9700	38.9133	61
18-7272	Potomac Filter Plant	MD	-77.2542	39.0400	47
18-7705	Rockville 1 NE	MD	-77.1486	39.1008	71
18-9070	Upper Marlboro 3 NNW	MD	-76.7767	38.8653	51
44-3204	Fredericksburg Sewerage	VA	-77.4511	38.2872	115
44-8396	The Plains 2 NNE	VA	-77.7547	38.8956	55
44-8737	Vienna Tysons Corner	VA	-77.2664	38.9000	67
44-8903	Washington WB Chantilly	VA	-77.4836	38.9408	52
44-8906	Washington Reagan National Airport	VA	-77.0342	38.8483	64

The annual maximum precipitation values up to year 2000 for the stations in Tables 1 and 2 were obtained from the NWS Web site (http://hdsc.nws.noaa.gov/hdsc/pfds/index.html). Hourly and daily data from 2001 to 2008 were obtained from the National Climatic Data Center and the NOAA Applied Climate Information System, respectively.

The hourly data were analyzed to obtain annual maximum values for durations of 1, 2, 3, 6, 12, and 24 hours. The 1-hour data were converted to 60-minute data by multiplying by a conversion factor of 1.16, and the 2-hour data were converted to 120-minute data with a conversion factor of 1.05, as obtained from Table 4.1.7 in the Atlas 14, Volume 2, documentation (http://www.nws.noaa.gov/oh/hdsc/PF_documents/Atlas14_Volume2.pdf).

The daily data were analyzed to obtain annual maximum values for durations of 1, 2, and 4 days, consistent with the data used by NWS in the Atlas 14 analysis. The 1-day data were converted to 24-hour data using a conversion factor of 1.13, and the 2-day data were converted to 48-hour data using a conversion factor of 1.04, as obtained from Table 4.1.7 in Atlas 14,. No conversion factor was used for the 4-day data. The 24-hour duration was analyzed using both hourly and daily data; comparisons are discussed later.

The annual maximum series (AMS) data consists of the annual maximum data, or one value per year. The AMS data were used for all durations in the frequency analysis because that is consistent with the concept of frequency analysis (i.e., exceedance probability in any given year). However, to remain consistent with previous precipitation frequency analyses (TP-40, NOAA Atlas 2, NOAA Atlas 14), the frequency data are presented in terms of the partial duration series (PDS). The PDS series can consist of more than one event per year and allows for estimating events that have recurrence intervals of 1 year or less.

Analysis Approach

Regional flood frequency analysis involves augmenting at-site data with data from other sites with similar probability distributions. The procedure for regional flood frequency analysis involves: (1) screening of data, (2) partitioning of data into homogeneous subregions, and (3) fitting probability distributions to data within each subregion. These tasks involve subjective and objective decisions regarding outliers, heterogeneity, and goodness-of-fit. The LMOMENTS package (Hosking, 1996; Hosking and Wallis, 1997) provides convenient routines for screening, clustering, and frequency analysis of regional data sets based on the L-moment method. The LMOMENTS package (Hosking, 1996) was used to perform the frequency analysis of the precipitation data in this study, which is the same methodology used by the authors of NOAA Atlas 14. Details of this methodology are provided in the Appendix.

Analysis Results

Updated IDF Curves

Rainfall frequency analyses for durations of 60 and 120 minutes, 3, 6, 12, and 24 hours were performed using data for the three hourly stations listed in Table 1 (Baltimore, Beltsville and Reagan National). Based on the homogeneity tests described in the Appendix (H1, H2, and H3), it was concluded that the data for Baltimore were not homogeneous with the other two stations; that is, the slope of the frequency curve was sufficiently different. The homogeneity tests H2 and H3 were 1.49 and 1.37, respectively, indicating that the region is likely heterogeneous. Therefore, the frequency data were based on the stations at Reagan National Airport and Beltsville, Maryland.

Rainfall frequency analyses for durations of 24 and 48 hours and 4 days were performed using data for the 13 daily stations listed in Table 2. Different combination of stations were analyzed, and using all 13 stations provided reasonable results.

Based on the goodness-of-fit tests in the LMOMENTS package, the Generalized Extreme Value (GEV) distribution was found to have the most applicable distribution across all the durations. All subsequent results are based on the GEV distribution. The GEV distribution was also used by NWS in the Atlas 14 hourly Region 1 and daily Region 8 analyses.

The L-moment analysis is similar to an index flood analysis whereby the frequency estimates for various recurrence intervals are estimated as a ratio to some index value. In this analysis, the frequency values for various recurrence intervals are estimated as a ratio to the mean of the annual maximum events (l_1 as defined in the Appendix). This ratio is called the Regional Growth Factor (RGF).

The RGF is an average ratio for each duration for all stations in the homogeneous region. For durations of 24 hours or less, RGF was defined using the data for Beltsville and Reagan National Airport. For durations longer than 24 hours, RGF was defined using data for the 13 stations listed in Table 2. RGF values were reasonably consistent across all durations and were averaged to provide the results given in Table 3. The RGF values for 120 minutes and 3 hours for the 50-, 100-, and 500-year events were believed to be unreasonably low, based on engineering judgment, and were not used in the averaging process. The frequencies given in Table 3 were those estimated in the LMOMENTS package and correspond to exceedance probabilities of 0.90, 0.80, 0.50, 0.20, 0.10, 0.05, 0.02, 0.01, and 0.002 (1.11- to 500-year recurrence intervals).

TABLE 3
RGF Values for Various Frequencies for the City of Alexandria
Based on the annual maximum series (AMS) and the GEV distribution

1.11 yr	1.25 yr	2 yr	5 yr	10 yr	20 yr	50 yr	100 yr	500 yr
0.58	0.68	0.90	1.26	1.52	1.79	2.22	2.57	3.54

The AMS ratios in Table 3 were converted to applicable ratios for the PDS in order to estimate events having recurrence intervals of 1 year or less. The following equation from the Atlas 14 was used to convert AMS recurrence intervals to PDS recurrence intervals:

$$T_{PDS} = [\ln(T_{AMS}/(T_{AMS}-1))]^{-1} \qquad (1)$$

where T_{PDS} is the recurrence interval for the PDS, and T_{AMS} is the corresponding recurrence interval for the AMS. Recurrence intervals for the PDS can be less than 1.0, implying a return period of less than 1 year.

Using Equation 1, the relation between recurrence intervals for the AMS and PDS can be determined, as shown in Table 4.

TABLE 4
Relation between Recurrence Intervals for the Annual Maximum and Partial Duration Series for Selected Recurrence Intervals

Annual Maximum Series, years	Partial Duration Series, years
1.16	0.5
1.58	1.0
2.54	2.0
5.52	5.0

The RGF values in Table 3 for the AMS were then converted to RGF factors for the PDS. The RGF values from Table 3 were plotted on graph paper, and the RGF values from recurrence intervals of 1.16, 1.58, 2.54, and 5.52 years were estimated. The difference between AMS and PDS recurrence intervals is insignificant for recurrence intervals of 10 years or more, so these values are unchanged from those in Table 3.

TABLE 5
RGF Values for Various Frequencies for the City of Alexandria
Based on the PDS and the GEV distribution

0.5 yr	1.0 yr	2 yr	5 yr	10 yr	20 yr	50 yr	100 yr	500 yr
0.60	0.79	1.00	1.30	1.52	1.79	2.22	2.57	3.54

The RGF values in Table 5 were then multiplied by the mean of the annual maximum events (index value) for all durations to obtain the precipitation frequency estimates. If the mean of the annual events for Reagan National Airport is assumed to be reasonable for the City of Alexandria, the frequency estimates shown in Table 6 can be obtained. The mean of the annual maximum events at Reagan National Airport, in inches, is given in Table 6. This value was multiplied by the RGF values in Table 5 to obtain the desired frequency events for a given duration of rainfall. For example, the 100-year, 60-minute rainfall of 3.86 inches is estimated as 1.502 inches * 2.57 (RGF) = 3.86 inches.

TABLE 6
Precipitation Frequency Estimates (in) for the City of Alexandria
Based on the PDS for various durations, based on using the mean of the annual maximum events at Reagan Nation Airport and the GEV distribution

	Precipitation (Inches) for Indicated Durations and							
Recurrence interval, years	**60-min**	**120-min**	**3-hour**	**6-hour**	**12-hour**	**24-hour**	**48-hour**	**4-day**
Mean at Reagan	**1.502**	**1.740**	**1.844**	**2.212**	**2.665**	**3.164**	**3.522**	**3.975**
0.50	0.90	1.04	1.11	1.33	1.60	1.90	2.11	2.38
1.0	1.19	1.37	1.46	1.75	2.10	2.50	2.78	3.14
2	1.50	1.74	1.84	2.21	2.66	3.16	3.52	3.98
5	1.95	2.26	2.40	2.88	3.46	4.11	4.58	5.17
10	2.28	2.64	2.80	3.36	4.05	4.81	5.35	6.04
20	2.69	3.11	3.30	3.96	4.77	5.66	6.30	7.12
50	3.33	3.86	4.09	4.91	5.92	7.02	7.82	8.82
100	3.86	4.47	4.74	5.68	6.85	8.13	9.05	10.22
500	5.32	6.16	6.53	7.83	9.43	11.20	12.47	14.07

If there are short-term precipitation stations throughout Alexandria, the mean of the annual maximums could be estimated at those stations and the RGF values from Table 5 could be used to obtain frequency estimates for the PDS, similar to those in Table 6.

The frequency estimates for durations of 5, 10, 15, and 30 minutes were obtained by applying a ratio to the 60-minute estimates. The ratios used were obtained from Table 4.1.4 of the Atlas 14 documentation (http://www.nws.noaa.gov/oh/hdsc/PF_documents/ Atlas14_Volume2.pdf). NWS defined the ratios as part of the Atlas 14 analysis for two regions, using data for 96 n-minute precipitations stations. The City of Alexandria is in the Southern Region, as defined by NWS.

TABLE 7
N-minute Ratios for Converting 60-minute data to 5-, 10-, 15-, and 30-minute Data

Recurrence interval, years	5-minute	10-minute	15-minute	30-minute
1.0	0.293	0.468	0.585	0.802
2	0.287	0.459	0.577	0.797
5	0.271	0.434	0.549	0.780
10	0.262	0.419	0.530	0.768
20	0.251	0.400	0.507	0.751
50	0.243	0.387	0.490	0.738
100	0.236	0.375	0.474	0.726
500	0.220	0.348	0.438	0.697

For our analysis, the ratios for the 1.0-year event were also used for 0.5-year event, and the 25-year event ratios were used for the 20-year event. The ratios in Table 7 were applied to the 60-minute estimates in Table 6 to obtain the 5-, 10-, 15-, and 30-minute estimates listed in Table 8. The 60-minute data from Table 6 are provided for reference.

TABLE 8
Precipitation Frequency Estimates for 5-, 10-, 30-, and 60-minute Durations
Based on the PDS series and the GEV distribution

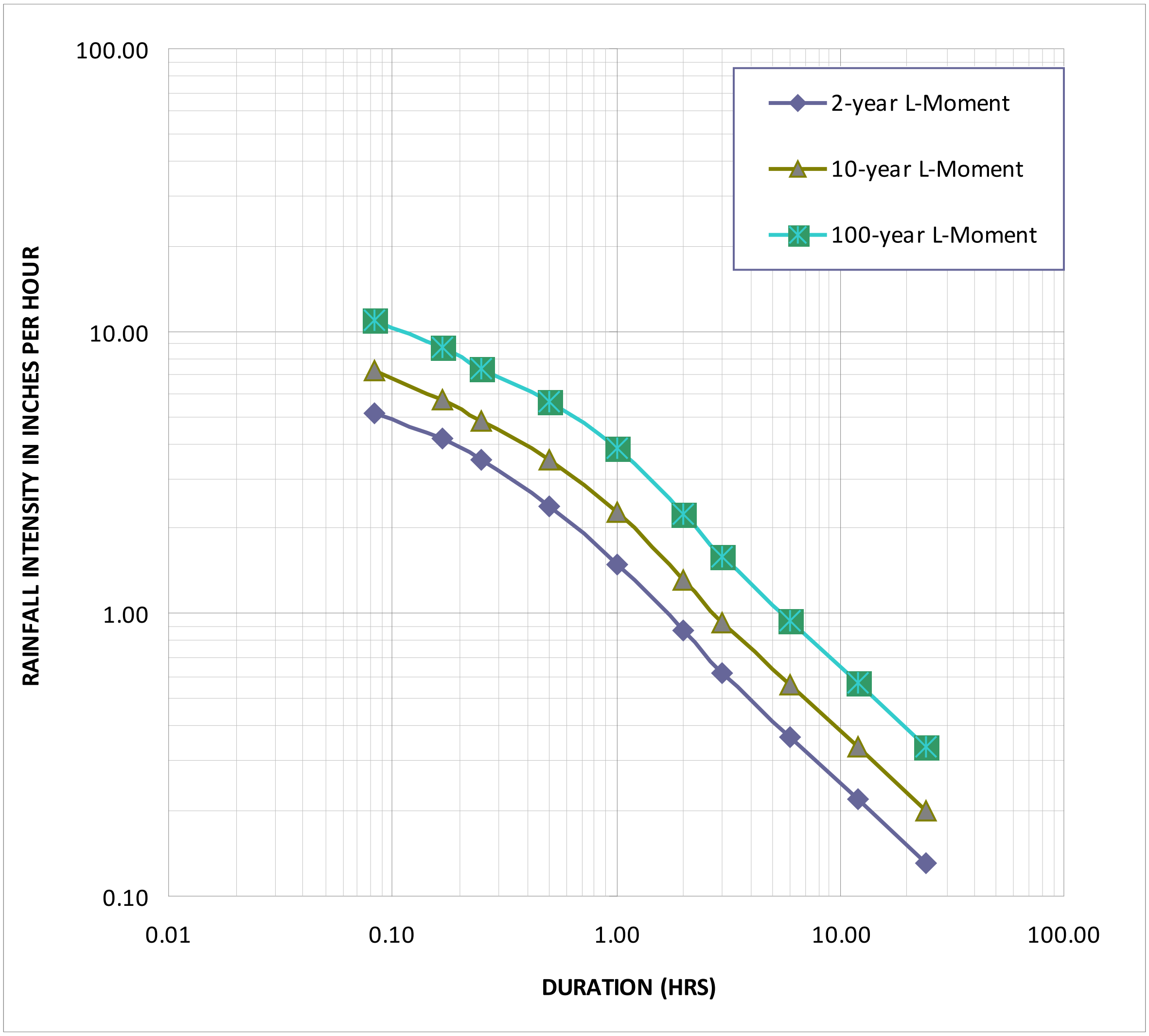
Recurrence interval, years	5-minute (inches)	10-minute (inches)	15-minute (inches)	30-minute (inches)	60-minute (inches)
0.50	0.26	0.42	0.53	0.72	0.90
1.0	0.35	0.56	0.70	0.95	1.19
2	0.43	0.69	0.87	1.20	1.50
5	0.53	0.85	1.07	1.52	1.95
10	0.60	0.96	1.21	1.75	2.28
20	0.68	1.08	1.36	2.02	2.69
50	0.81	1.29	1.63	2.46	3.33
100	0.91	1.45	1.83	2.80	3.86
500	1.17	1.85	2.33	3.71	5.32

The precipitation frequency estimates for 60-minute durations up to 4 days are given in Table 6, and the 5-, 10-, 15-, and 30-minute durations are given in Table 8. These two tables provide the updated IDF data for the City of Alexandria.

The 2-, 10-, and 100-year events for the 5-minute to 24-hour durations from Tables 6 and 8 are plotted in Figure 1.

FIGURE 1

IDF CURVES FOR THE 2-, 10- , AND 100-YEAR EVENTS FOR DURATIONS OF 5-MINUTES TO 24-HOURS, BASED ON THE UPDATED L-MOMENT ANALYSIS



Comparison to Existing IDF Curves

The existing IDF curves being used by the City of Alexandria are based on the period 1941 to 1969. The existing IDF curves were compared to the L-moment analysis using the data shown in Tables 6 and 8. Results for the 2-, 10-, 100-year values for durations of 5 minutes to 24 hours are given in Figures 2, 3, and 4.

FIGURE 2

COMPARISON OF EXISTING IDF CURVE FOR THE CITY OF ALEXANDRIA TO THE L-MOMENT ANALYSIS FOR THE 2-YEAR EVENT

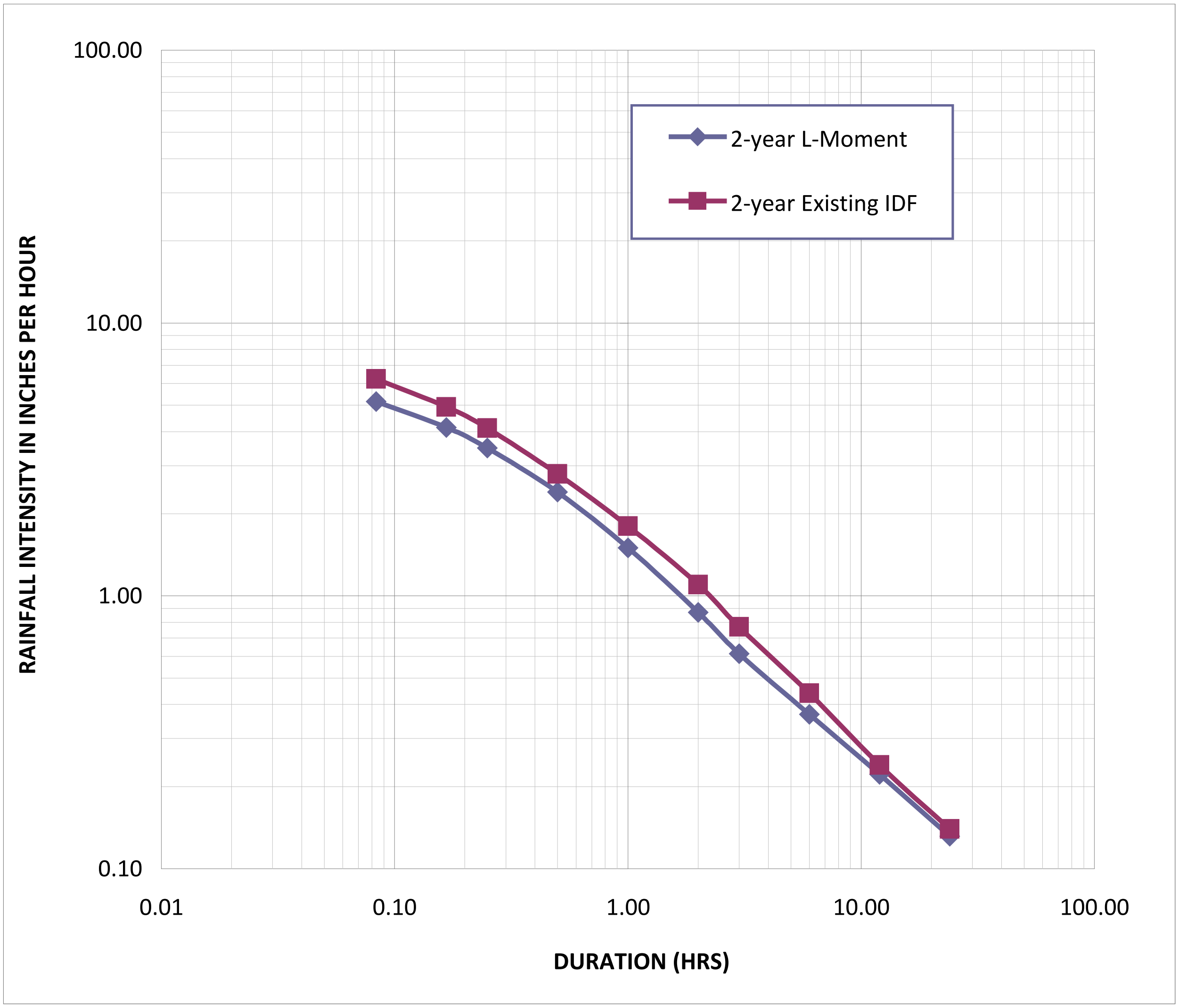


FIGURE 3

COMPARISON OF EXISTING IDF CURVE FOR THE CITY OF ALEXANDRIA TO THE L-MOMENT ANALYSIS FOR THE 10-YEAR EVENT

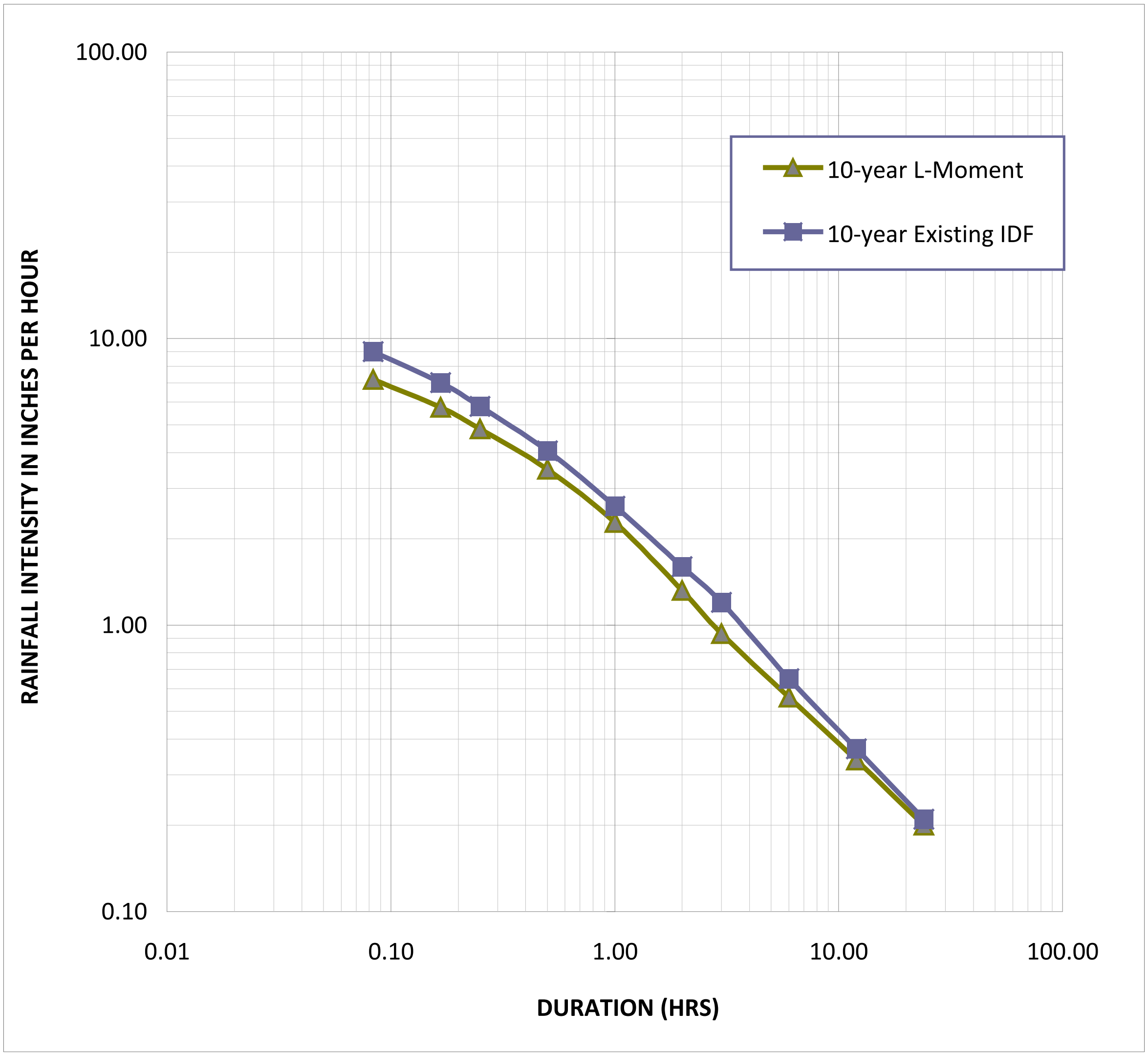
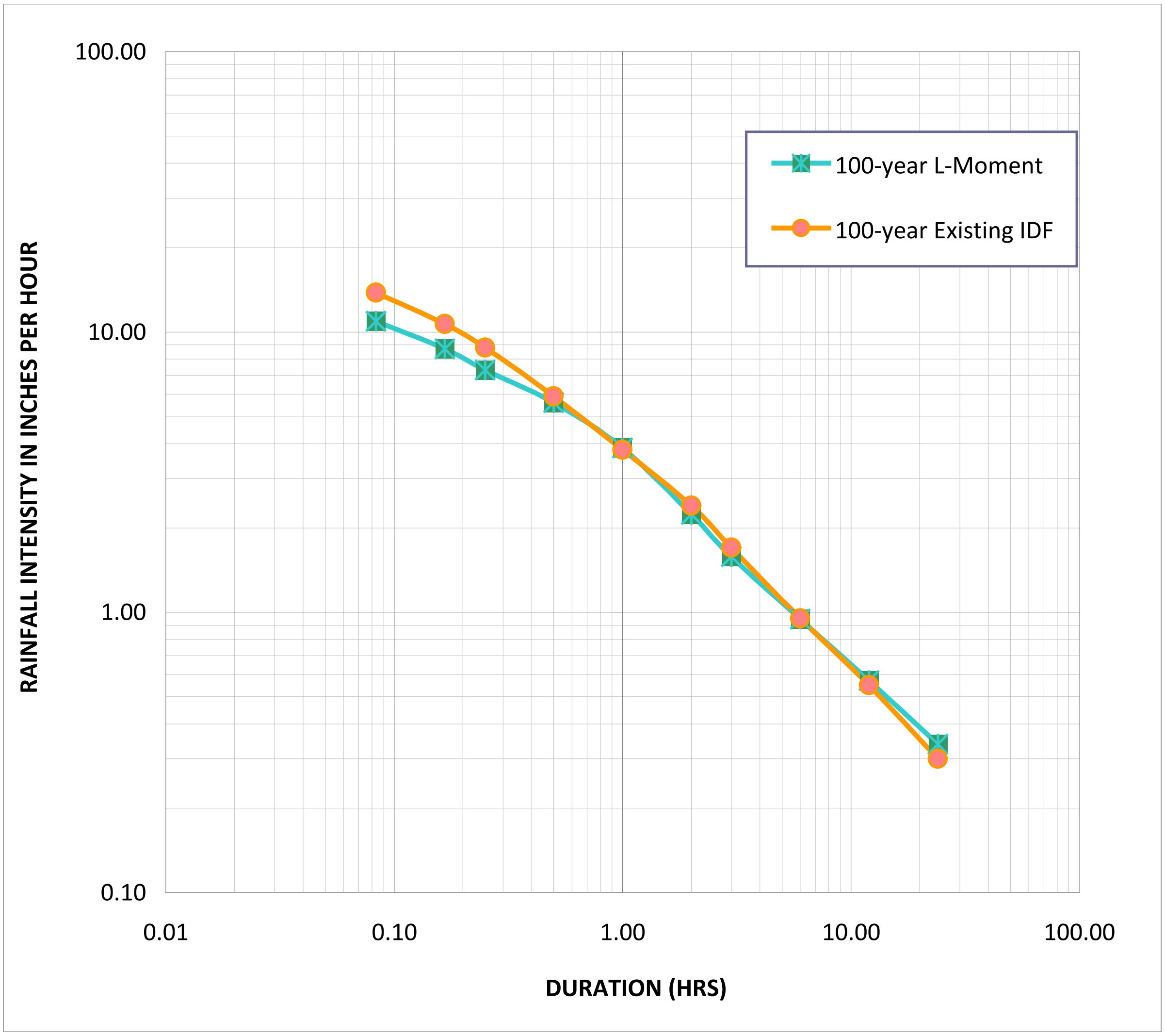


FIGURE 4

COMPARISON OF EXISTING IDF CURVE FOR THE CITY OF ALEXANDRIA TO THE L-MOMENT ANALYSIS FOR THE 100-YEAR EVENT



All three IDF curves essentially converge at the 24-hour duration. The 100-year IDF curves are essentially similar for 60-minute durations and greater. However, for the 2- and 10-year curves, the existing IDF values are greater than the updated L-moment analysis. The primary reason for this difference is that the period of record (1941 to 1969) for the existing IDF curves is wetter than the long-term period (1948 to 2008), as illustrated later.

Trend Analysis

Annual maximum data for the 60-minute and 24-hour durations for Reagan National Airport and Beltsville were plotted versus time. The data for Reagan National Airport are given in Figures 5 and 6 and for Beltsville in Figures 7 and 8.

FIGURE 5

TIME SERIES PLOT OF 60-MINUTE ANNUAL MAXIMUM DATA VERSUS CALENDAR YEAR FOR REAGAN NATIONAL AIRPORT

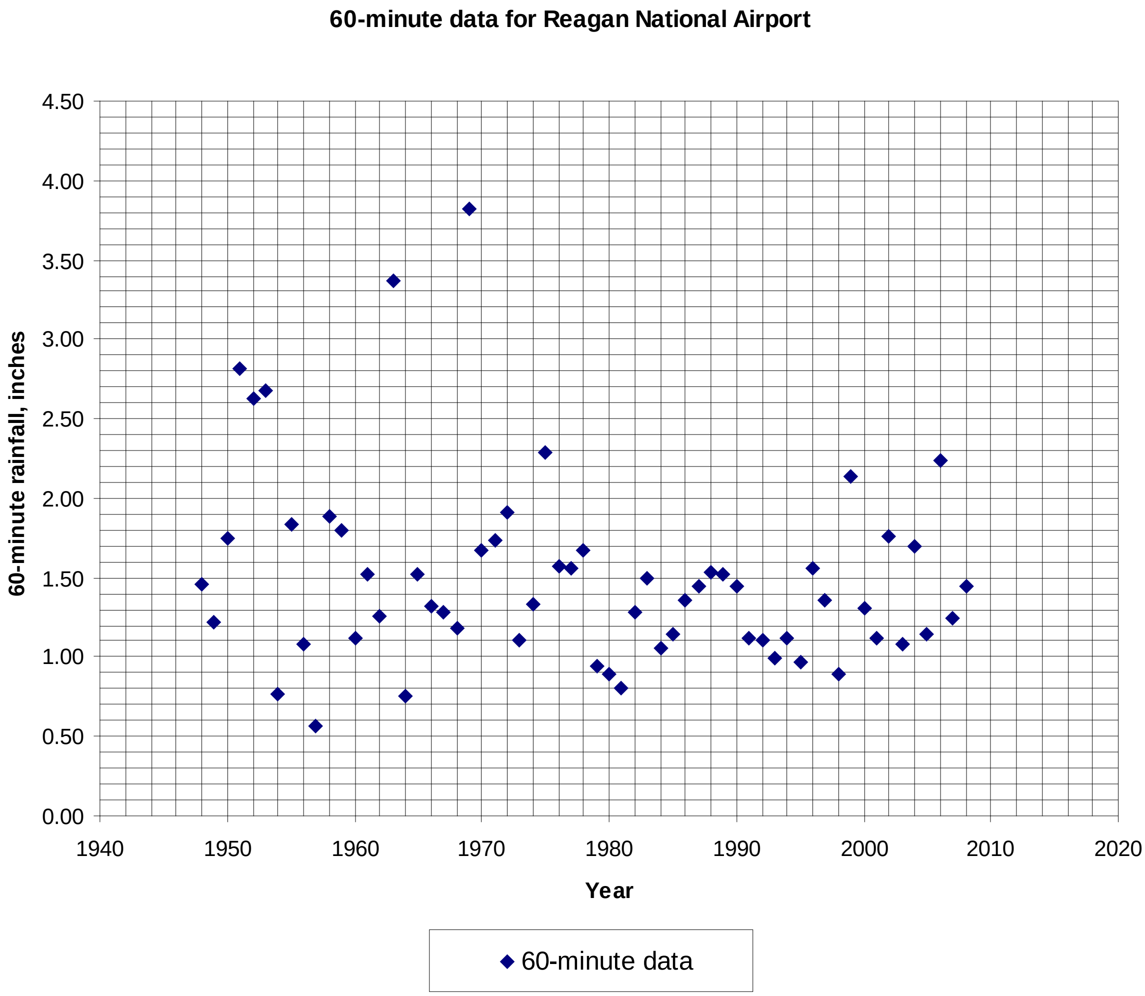


Figure 5 illustrates that the largest 60-minute events occurred in the period 1948 to 1969, a period comparable to that used in developing the existing IDF curves for Alexandria. The largest annual maximum event is in 1969 (Hurricane Camille). This figure illustrates that the IDF values based on the period prior to 1969 will be larger than using the full period of record up to 2008 for Reagan National Airport. Because the larger events occurred early in the period of record, a trend analysis would indicate a downward trend.

FIGURE 6

TIME SERIES PLOT OF A 24-HOUR ANNUAL MAXIMUM DATA VERSUS CALENDAR YEAR FOR REAGAN NATIONAL AIRPORT

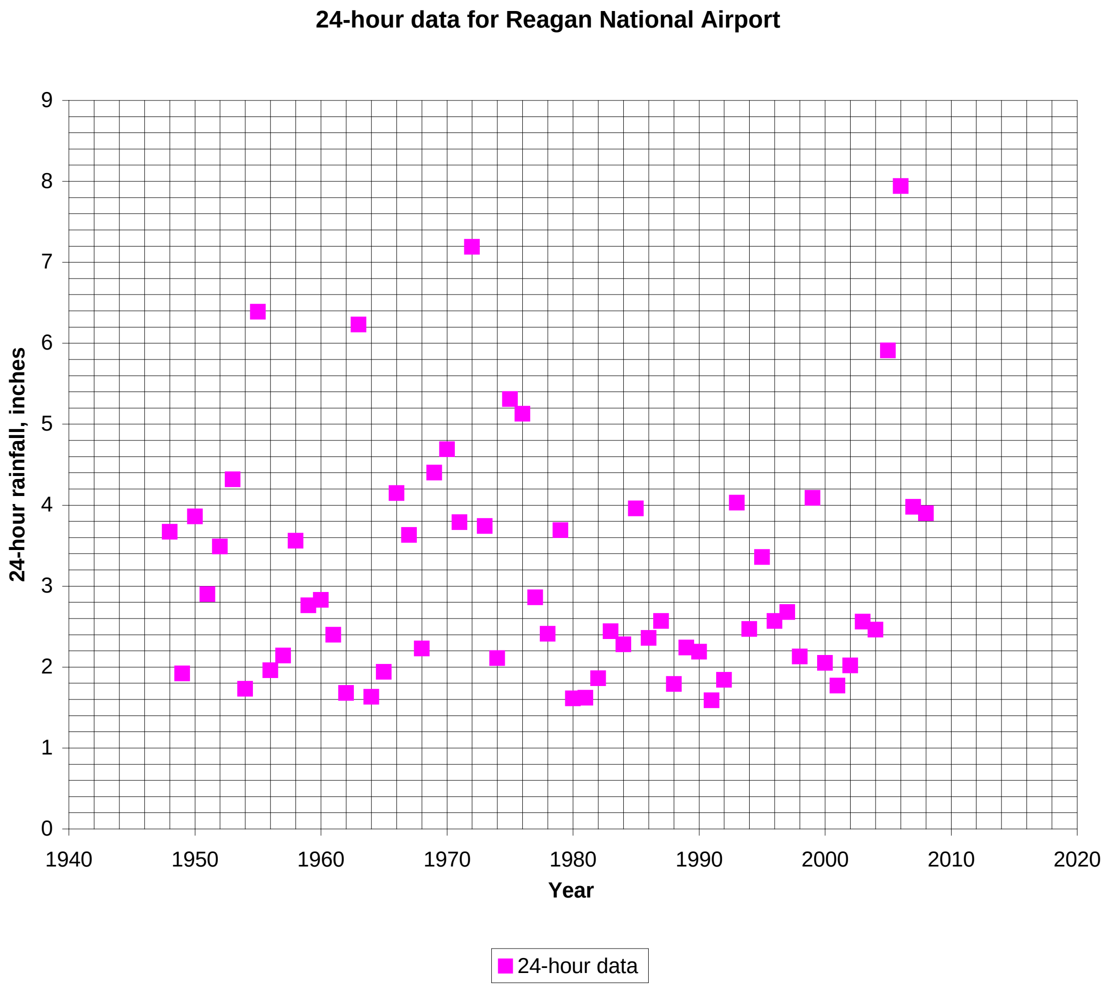


Figure 6 illustrates that the period prior to 1972 generally has larger 24-hour events, with the exception of the peak of record event in 2006. There might be an upward trend in the annual maximum 24-hour events at Reagan National Airport because of the large events occurring in 2005 and 2006. However, it does not appear that the 24-hour data have changed significantly over the period of record.

FIGURE 7

TIME SERIES PLOT OF 60-MINUTE ANNUAL MAXIMUM DATA VERSUS CALENDAR YEAR FOR BELTSVILLE, MD

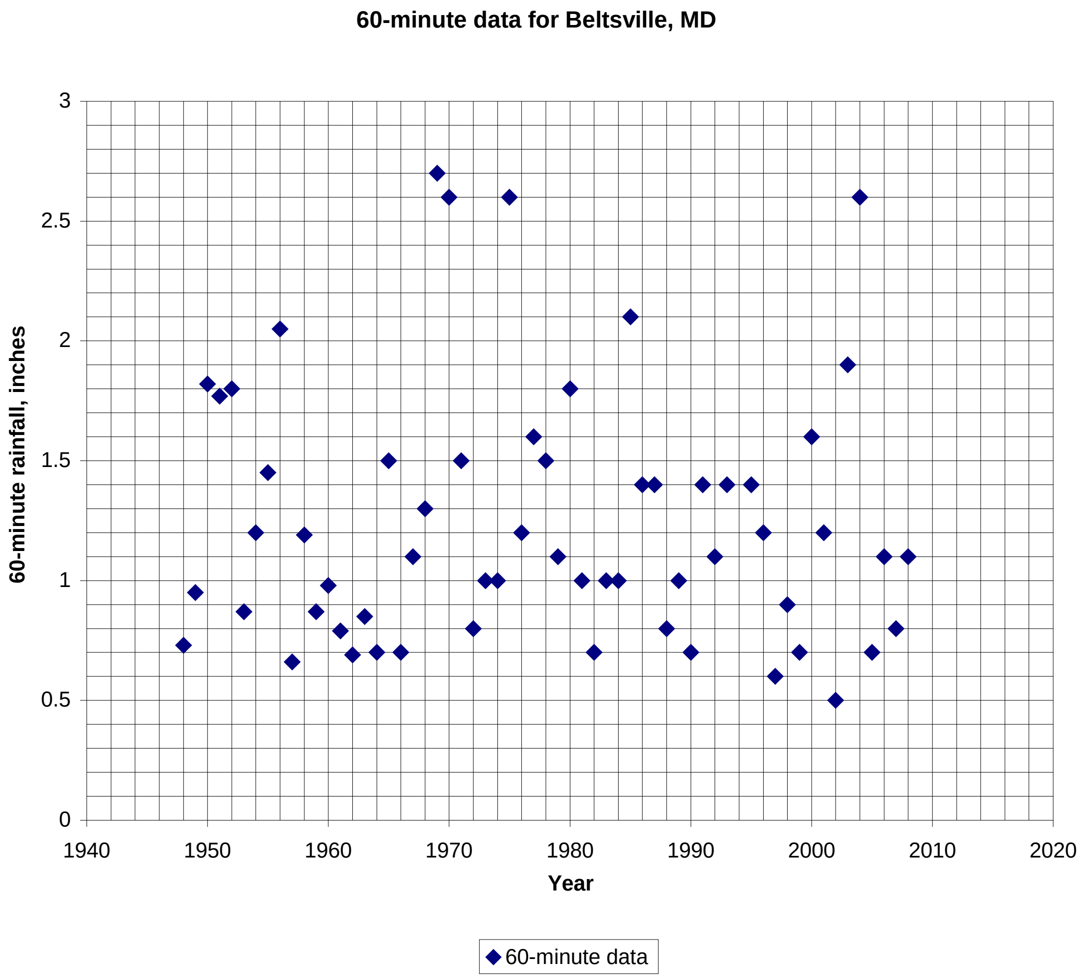


Figure 7 illustrates that the period prior to 1975 was slightly wetter than the period after 1975, with the exception of the 2004 event. The data in Figure 4 do not exhibit a significant trend in the 60-minute data at Beltsville. If anything, there may be a slight downward trend.

FIGURE 8

TIME SERIES PLOT OF 24-HOUR ANNUAL MAXIMUM DATA VERSUS CALENDAR YEAR FOR BELTSVILLE, MD

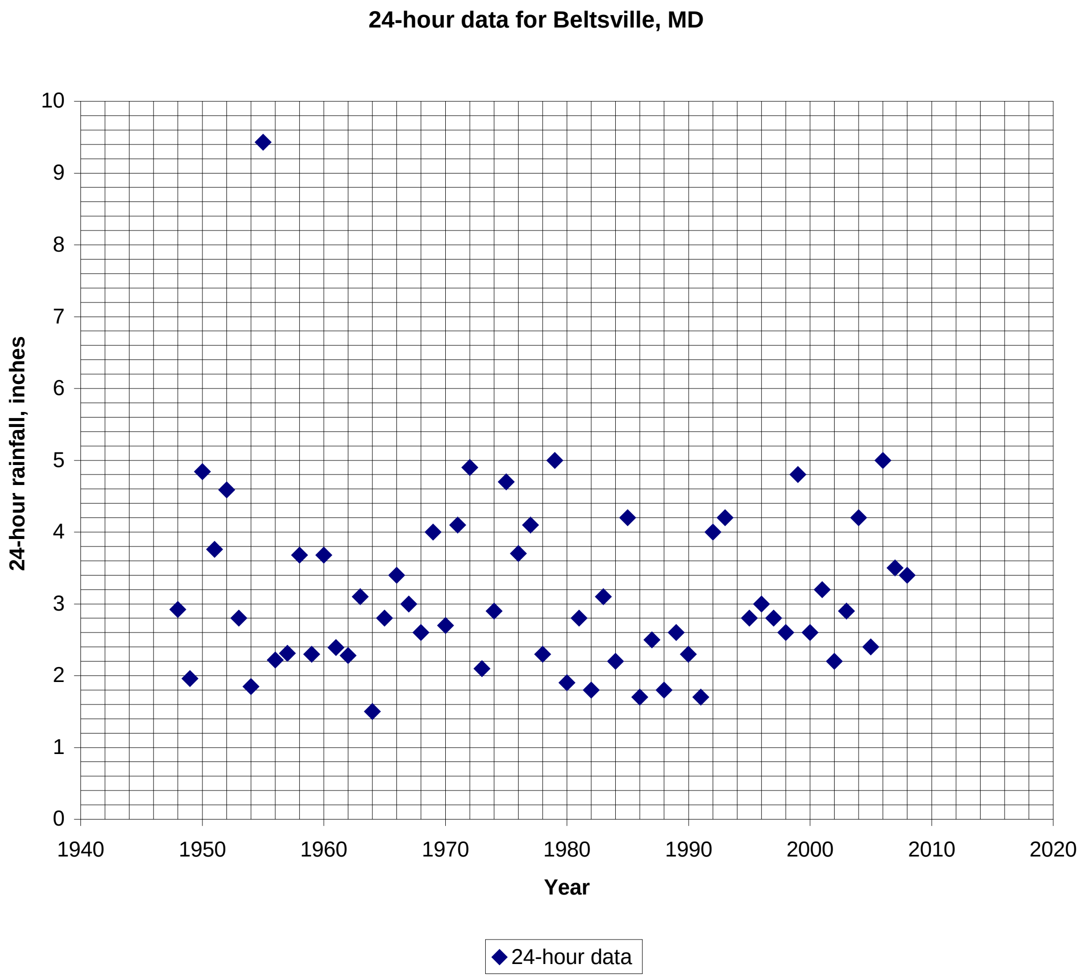


Figure 8 illustrates that the 24-hour maximum data are very consistent, with the exception of the very large event in 1955 (Hurricane Diane). There is no significant trend in the 24-hour data for Beltsville. If a trend analysis was performed, there would be a slight downward trend, based on the 1955 event occurring near the beginning of the period of record.

The data in Figures 5 through -8 indicate that there has not been a significant increase in either the 60-minute or 24-hour data at the two hourly stations of Reagan National Airport and Beltsville.

Frequency Analyses for the Period up to 1969

Frequency analyses were performed on the hourly annual maximum data from 1948 to 1969 to be consistent with the period of record used for the existing IDF curves (1941 to 1969). Data comparisons for the 10- and 100-year events for selected durations are given in Table 9.

TABLE 9
Comparison of Precipitation Frequency Estimates for the Period of Record prior to 1969 to the Full Period of Record from 1948 to 2008

Recurrence interval, years	60-minute 1948-1969 (inches)	60-minute 1948-2008 (inches)	6-hour 1948-1969 (inches)	6-hour 1948-2008 (inches)	24-hour 1948-1969 (inches)	24-hour 1948-2008 (inches)
10	2.76	2.28	3.74	3.36	4.96	4.81
100	4.96	3.86	6.23	5.68	8.89	8.13

The data for the full period of record (1948 to 2008) were taken from Table 6. As shown in Table 9, the period 1948 to 1969 yields higher estimates, particularly for the 60-minute duration, a difference of about 25 percent. For the 24-hour duration, the difference is only about 6 percent.

Frequency Analyses for the Period 1979 to 2008

Frequency analyses were also performed for the last 30 years of hourly data, from 1979 to 2008. Data comparisons for the 10- and 100-year events for selected durations are given in Table 10.

TABLE 10
Comparison of Precipitation Frequency Estimates for the Period of Record 1979 to 2008 to the Full Period of Record from 1948 to 2008

Recurrence interval, years	60-minute 1979-2008 (inches)	60-minute 1948-2008 (inches)	6-hour 1979-2008 (inches)	6-hour 1948-2000 (inches)	24-hour 1979-2000 (inches)	24-hour 1948-2008 (inches)
10	1.89	2.28	2.88	3.36	4.33	4.81
100	2.83	3.86	4.96	5.68	7.38	8.13

The data for the full period of record (1948 to 2008) were taken from Table 6. As shown in Table 10, the period of record of 1979 to 2008 yields lower estimates than using the full period of record. For the 60-minute data, the estimates for the period 1979 to 2008 are 20 to 30 percent less than the full period of record. For the 24-hour data, the differences are on the order of 10 percent.

The data in Tables 9 and 10 indicate that the frequency estimates for the period 1948 to 1969 are higher than the full period, and estimates based on the period 1979 to 2008 are lower. The recommendation is to use the full period of record because it is longer and provides more-accurate estimates.

Comparison to NOAA Atlas 14

The frequency estimates from the updated L-moment analysis (Table 6) are compared to estimates from NOAA Atlas 14 in Table 11. The Atlas 14 estimates are based on the PDS to be consistent with the updated L-moment analysis.

TABLE 11
Comparison of the Updated L-Moment Frequency Estimates with NOAA Atlas 14 for Selected Durations

RI, years	L-moment 60-min (inches)	Atlas 14 60-min (inches)	L-moment 6 hour (inches)	Atlas 14 6-hour (inches)	L-moment 24 hour (inches)	Atlas 14 24-hour (inches)
0.50	0.90	---	1.33	---	1.90	---
1.0	1.19	1.22	1.75	1.84	2.50	2.56
2	1.50	1.50	2.21	2.23	3.16	3.10
5	1.95	1.88	2.88	2.81	4.11	3.99
10	2.28	2.17	3.36	3.29	4.81	4.77
20	2.69	---	3.96	---	5.66	---
50	3.33	2.89	4.91	4.61	7.02	7.03
100	3.86	3.21	5.68	5.26	8.13	8.23
500	5.32	4.00	7.83	7.01	11.20	11.67

As shown in Table 11, the differences between the updated L-moment estimates and those from Atlas 14 are small. The largest differences are for the 50- to 500-year estimates for the 60-minute durations, where the updated L-moment estimates range from 15 to 30 percent higher than Atlas 14 estimates. Because the 60-minute data were used to estimate the 5-, 10-, 15-, and 30-minute durations, the comparisons to Atlas 14 are similar to those for the 60-minute duration shown in Table 11.

It is not surprising that the results from the updated L-moment analysis are similar to Atlas 14. A smaller number of stations were used in the L-moment analysis, but these stations are a subset of the stations used in the Atlas 14 analysis. Also, the same annual maximum data up to 2000 were used for the stations in the analysis, and the same frequency distribution (GEV) was chosen as being most applicable.

Summary and Conclusions

Annual maximum data up to 2000 from the NWS were combined with data from 2001 to 2008 to perform frequency analyses using the LMOMENTS package that utilizes five different frequency distributions. The GEV distribution was shown to be most appropriate.

The L-moment approach is to identify those stations for which the slopes of the frequency curves are similar statistically. The slopes of the frequency curves are represented by RGFs that are ratios to an index value. The index value used in this analysis was the mean of the annual maximum events (l_1).

The frequency analyses were performed using the AMS because that is consistent with the concept of frequency analysis (probability of an event being exceeded in any given year). To be consistent with previous analyses (TP-40, NOAA Atlas 2 and NOAA Atlas 14), the frequency data were converted to the PDS in order to obtain estimates for recurrence intervals of 0.5 and 1.0 year.

Estimates for durations of 5, 10, 15 and 30 minutes were calculated as ratios to the 60-minute data, using data from Table 4.1.4 of the Atlas 14 documentation (http://www.nws.noaa.gov/oh/hdsc/PF_documents/Atlas14_Volume2.pdf).

The updated IDF curves for Alexandria are given in Table 6 (durations of 60-minutes and longer) and Table 8 (durations of less than 60 minutes) and are compared to the existing IDF curves for the 2-, 10-, and 100-year events in Figure 1. All three IDF curves essentially converge at the 24-hour duration. The 100-year IDF curves are essentially similar for durations of 60 minutes and longer. However, for the 2- and 10-year curves, the existing IDF values are greater than the updated L-moment analysis. The primary reason for this difference is that the period of record (1941 to 1969) for the existing IDF curves is wetter than the long-term period (1948 to 2008).

Plots of the 60-minute and 24-hour annual maximums at Reagan National Airport and Beltsville illustrate that the period 1948 to 1969 was generally wetter and experienced larger events than the period after 1969.

Estimates from the updated L-moment analysis (Table 6) were also compared to those from Atlas 14 (Table 11). The differences are small because the data used in the two analyses are similar and the same frequency distribution (GEV) was shown to be applicable. The largest differences are for the 50-, 100-, and 500-year estimates for the 60-minute durations, where the updated L-moment estimates range from 15 to 30 percent higher, respectively, than the Atlas 14 estimates. In short, the use of NOAA Atlas 14 would essentially give the same results as using the updated L-moments analysis.

The IDF curves shown in Tables 6 and 8 and Figure 1 are based on the assumption that mean of the annual maximum events at Reagan National Airport is representative of the City of Alexandria. If there are other short-term records in the City, the mean of the annual maximum events could be determined and the RGFs in Table 5 could be used to estimate different but similar IDF curves to those given in Tables 6 and 8.

References

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Appendix
L-Moment Methodology

L-Moment Regional Method

Regional flood frequency analysis involves augmenting at-site data with data from other sites with similar probability distributions. The procedure for regional flood frequency analysis involves: (1) screening of data, (2) partitioning of data into homogeneous subregions, and (3) fitting probability distributions to data within each subregion. These tasks involve subjective and objective decisions regarding outliers, heterogeneity, and goodness-of-fit. The LMOMENTS package (Hosking, 1996; Hosking and Wallis, 1997) provides convenient routines for screening, clustering, and frequency analysis of regional data sets based on the L-moment method. L-moments have been shown in various Monte Carlo studies (e.g., Delicado and Goria, 2008) to outperform other estimation methods, such as the method of moments and method of maximum likelihood, in terms of bias and robustness. The LMOMENTS package (Hosking, 1996) was used to perform the frequency analysis of the precipitation data in this study.

The annual maximum precipitation data for various durations were fitted to selected frequency distributions, using L-moments to estimate the distribution parameters. In the L-moment method, a regional frequency curve is obtained by averaging the slopes of the station frequency curves in a given homogeneous region. L-moments are analogous to ordinary moments in that the purpose is to summarize theoretical probability distributions and observed samples. Because L-moments are computed as linear combinations of the ranked observations (instead of squaring and cubing the observations), they are subject to less variability in small samples than ordinary moments (Hosking, 1990).

The sample L-moments or sample L-moment ratios needed to describe the frequency distributions and apply various statistical tests are as follows:

- l_1 = first L-moment, measure of location (mean)
- l_2 = second L-moment, measure of scale (dispersion)
- l_2/l_1 = L coefficient of variation (L-CV)
- l_3 = third L-moment
- l_4 = fourth L-moment
- l_3/l_2 = measure of skewness (L skewness)
- l_4/l_2 = measure of kurtosis (L kurtosis)

Regionalization involves forming clusters of subregions from the entire data set based on site characteristics. The primary goal is to choose site characteristics that best capture the relevant indicators upon which climatological homogeneity can be predicated.

After the initial formation of subregions, the next goal is to ascertain that the sites within the tentative subregions can reasonably be assumed to be homogeneous. The LMOMENTS package incorporates three tests for homogeneity:

- H1 – the weighted standard deviation of the sample L-CVs
- H2 – the average distance from the site to the regional average on a graph of L-CV vs. L skewness
- H3 – the average distance from the site to the regional average on a graph of L skewness vs. L kurtosis

These compare the between-site variations in sample L-moments for sites in a subregion. The use of only one of the three options is often adequate. A subregion is acceptably homogeneous if $H < 1$, likely heterogeneous if H > 1, and most likely heterogeneous if H > 2. These thresholds are based on expert judgment but are not definitive. Several adjustments are required when a given subregion is not homogenous. The options include moving sites between subregions, deleting sites from the data set, subdividing subregions, merging subregions, etc. The three tests noted above were used in defining homogeneous regions for this analysis.

Fitting Frequency Distributions

Given homogeneous regions, the objective is to find the regional frequency distributions that, on average, describe the observations at each site. The LMOMENTS package fits sample data to the following three-parameter (location, scale, and skewness) frequency distributions:

- Generalized Logistic
- Generalized Extreme Value
- Generalized Normal
- Pearson Type III
- Generalized Pareto

The goodness-of-fit is quantified using test statistics internal to the LMOMENTS package at a 90-percent confidence level (implying only a 10-percent chance of choosing an erroneous distribution). More details on the goodness-of-fit test are provided by Hosking (1990), Hosking (1996), and Hosking and Wallis (1997).