Flood Frequency Analysis

for Four Mile Run at USGS Gaging Station 1652500

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The Northern Virginia Regional Commission (NVRC) developed this analysis for Arlington County and the City of Alexandria in coordination with the US Army Corps of Engineers, Baltimore District for use in the Four Mile Run Restoration Project. The project manager and primary author of this report is Bill Hicks, P.E.. This analysis has been strengthened by contributions from the work of the Hydraulics and Hydrology Workgroup of the Four Mile Run Restoration Project. The author wishes to specifically acknowledge those members who participated in the development of this analysis.

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The Northern Virginia Regional Commission (NVRC) is an independent public agency chartered in 1969 to plan for the physical, social and economic development of the region. The Commission serves in an advisory capacity to local, state, and federal governments and as an advocate for Northern Virginia and its 1.9 millions residents. The Commission's policies and programs are established by a forty-two member Board of Commissioners comprised of elected officials and private citizens appointed by the governing bodies of Arlington, Fairfax, Loudoun and Prince William; the Cities of Alexandria, Fairfax, Falls Church, Manassas and Manassas Park, and the Towns of Dumfries, Herndon, Leesburg, Purcellville and Vienna.

Since 1977, NVRC has administered the Four Mile Run Watershed Management Program under the Memorandum of Understanding signed by Arlington and Fairfax Counties and the Cities of Alexandria and Falls Church.

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Cover photo snipped from the 2001 documentary film "Four Mile Run, Reviving an Urban Stream" written produced and directed by Dave Eckert.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Executive Summary

The purpose of this study is twofold. The primary purpose of this study is to perform a current flood flow frequency analysis for Four Mile Run with the existing stream gage data recorded through water year 2003 at the US Geological Survey (USGS) Station at the Shirlington Road Bridge. This analysis follows the federally recommended guidelines described in Bulletin 17B, "Guidelines for Determining Flood Flow Frequency" by the Interagency Advisory Committee on Water Data. A secondary purpose of this study is to name and cite similar such analyses performed on analogous Four Mile Run data and consolidate their frequency curves into one document.

To meet the first objective, annual peak flow data for Four Mile Run collected at the USGS gaging station (Station 1652500) was compiled for water years 1947 through 2003. Using the methodologies prescribed by Bulletin 17B, generally conforming to a Log Pearson III distribution, frequency curves were developed with the data. The effect of urbanization on the response of Four Mile Run was incorporated into the study by comparing three different frequency curves developed from various manipulations of the data record. The first frequency curve ignores the effect caused by urbanization and was developed using all of the data set from 1952 through 2003 without altering any of the data and omitting only the historical record from 1947. The second frequency curve is based on data that has been manipulated to normalize for the effects of urbanization for the years 1952 through 1961. The third frequency curve reflects an abbreviated data set, 1961 through 2003, beginning with the effective year of build-out in the watershed. The third frequency curve is recommended by this analysis as appropriate for the Four Mile Run gaging data recorded at the USGS gaging station 1652500 located at Shirlington Road. Column 4 of the following table, Table 1, includes data from that curve:

Table 1 Results of Analysis compared to the 1972 US Army Corps of Engineer (USACE) Frequency Curve

(1) Recurrence Interval [years]	(2) Probability	[3] 1972 USACE Analysis [cubic feet per second (cfs)]	(4) June 2004 Analysis 1961 – 2003 (cfs)
2	0.5	2,450	3,352
5	0.2	5,200	5,511
10	0.1	8,600	7,363
25	0.04	12,500	10,270
50	0.02	16,000	12,890
100	0.01	20,000	15,970
500	0.002	31,500	25,280

Also included in Table 1 is the frequency curve developed by the US Army Corps of Engineers (USACE) in 1972 during the design phase of the now-existing levee corridor. The

100-year event, or the event with a one percent (1%) chance of occurring during any given year, is often used as a target when designing flood protection projects like the Four Mile Run levee corridor. It can be noted when comparing 100-year event flow predicted in the current analysis, 15,970 cubic feet per second (cfs), to 100-year flow predicted by the 1972 USACE analysis, 20,000 cfs, there is an approximate 20% decrease in magnitude. This change can be primarily attributed to a longer data set from which to develop the frequency distribution.

The analysis provided by this study will be used in the development of a current hydraulics and hydrology (H&H) study for use in the Four Mile Run Restoration Project ongoing with Arlington County, the City of Alexandria and the US Army Corps of Engineers (USACE). The decrease in predicted 100-year event flows offers promise that opportunities exist to enhance the environmental viability of the channel without diminishing perceived flood protection. Data and results from this exercise may also be incorporated in future dealings with the US Federal Emergency Management Agency (FEMA) regarding floodplain delineation.

Background

Four Mile Run is a direct tributary of the Potomac River (Hydrologic Unit Code (HUC) 02070010). The Potomac River Basin cradles the Four Mile Run watershed and ultimately drains it to the Chesapeake Bay. For the stream's approximate 9.2-mile length, Four Mile Run flows through some of Northern Virginia's most densely populated areas. Data from the 2000 Census show that the 19.7 square mile watershed is home to 183,000 people or approximately 9,000 people per square mile. With no fewer than seven central business districts in the watershed, the population during business days exceeds the number of its permanent residents. Two major interstate highways, I-66 and I-395, bisect the watershed. Those highways, along with numerous arterial and secondary roadways, and densely sited buildings with their associated parking areas, contribute to the watershed's total impervious coverage, an area estimated to be 40% of the total watershed area. The entire watershed can be classified as highly urbanized with no agricultural uses beyond that of a backyard or community garden.

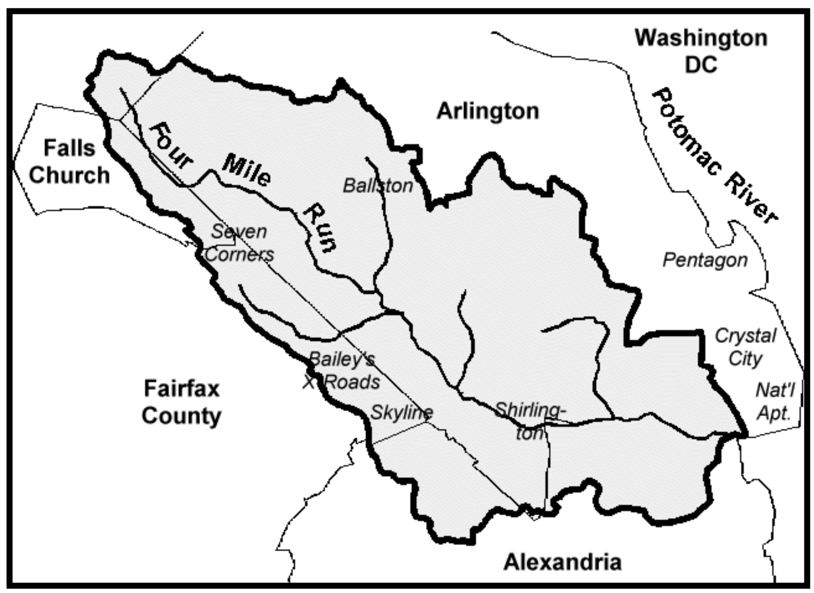

Figure 1. Four Mile Run Watershed with Jurisdictional Boundaries

Four Mile Run rises in Fairfax County and flows downstream through the City of Falls Church and on to Arlington County. The final 2.3 miles of the run, before it opens to the Potomac

River, are contained in a flood control channel designed in the early 1970s by the US Army Corps of Engineers (USACE). That channel straddles the jurisdictional boundary between Arlington County and the City of Alexandria. At approximately 1,100 feet upstream from the beginning of the USACE flood control project is a USGS gaging station located on the upstream side of the Shirlington Road Bridge.

Figure 2 USGS Gaging Station on Four Mile Run (1652500)

USGS Gage Data

The USGS gaging station on Four Mile Run located at the Shirlington Road Bridge has collected stream flow data since 1951. The location of the gage allows capture of flow data from a 13.80 square mile sub-basin of the watershed, about 70% of the entire watershed (USGS website). In 1998, the station was converted from crest-stage gage to a mean daily discharge station with remote instrumentation to provide continuous stream-flow, precipitation and temperature records. This information is served on the Internet at http://waterdata.usgs.gov/va/nwis/uv?01652500 .

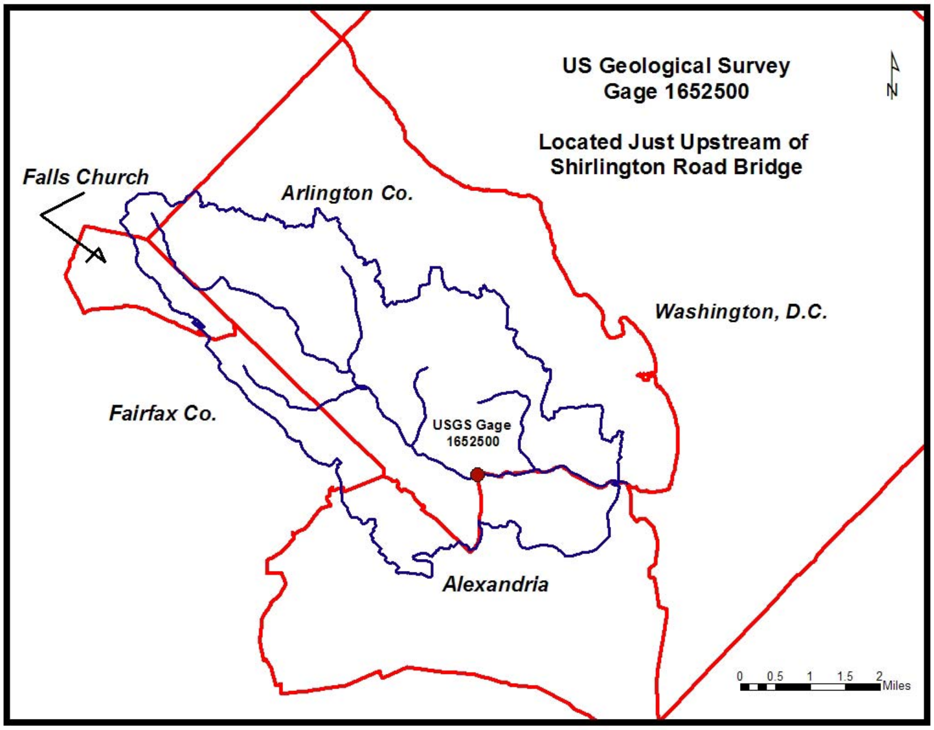

Figure 3 USGS Gage 1652500 Location

Although the lower portion of Four Mile Run is impacted by the tidal influence of the Potomac River, the USGS gage location is roughly 6,000 feet upstream of the extent of those impacts.

Figure 4 Collapse of the Walter Reed Bridge in Arlington County – Just Upstream of the USGS Gaging Station. Flooding on June 22, 1972 was due to the remnants of Hurricane Agnes.

Annual peak flow measurements recorded at the station are included in Table 2. The values presented were extracted from data downloaded from the USGS website for the Four Mile Run station on July 27, 2004. Original USGS data for the 1652500 station was provided electronically in the standard USGS WATSTORE electronic data format.

TABLE 2. USGS Stream Gage Information for Station 1652500 Four Mile Run, Virginia

Water Year	Date	Flow (cfs)	Gage Height
1947	07-Jun-1947	*2250	7.20
1952	09-Jul-1952	1600	5.60
1953	05-May-1953	3450	8.50
1954	03-May-1954	854	4.22
1955	08-Jul-1955	2120	6.91
1956	22-Jul-1956	1350	5.10
1957	23-Jan-1957	810	4.12
1958	08-Jul-1958	1450	5.27
1959	13-Jun-1959	1250	4.90
1960	13-Jun-1960	810	4.08
1961	26-Aug-1961	**3600	7.00
1962	31-May-1962	1060	4.45
1963	20-Aug-1963	11700	9.89
1964	13-May-1964	1800	5.41
1965	18-Jul-1965	2560	6.15
1966	14-Sep-1966	6900	7.83
1967	24-Aug-1967	6290	7.93
1968	27-Jun-1968	5040	7.28
1969	22-Jul-1969	14600	11.60
1970	09-Jul-1970	8800	10.70
1971	29-Jul-1971	4300	6.90
1972	21-Jun-1972	10000	12.40
1973	20-Aug-1973	4900	9.20
1974	30-Aug-1974	2930	8.55
1975	26-Sep-1975	6350	13.07
1976	16-Sep-1976	2200	

Water Year	Date	Flow (cfs)	Gage Height
1977	12-Jul-1977	3600	9.28
1979	05-Sep-1979	3080	8.36
1980	01-Oct-1979	2470	7.49
1981	04-Jul-1981	2800	7.96
1982	01-Jun-1982	2960	8.20
1983	21-Jun-1983	2770	7.92
1984	29-Mar-1984	2400	7.90
1985	10-Sep-1985	4480	10.36
1986	20-Jul-1986	2930	8.15
1987	26-Jun-1987	4310	10.12
1988	06-May-1988	2740	7.87
1989	05-May-1989	3100	8.25
1990	09-May-1990	3090	8.38
1991	23-Oct-1990	3990	9.66
1992	24-Jul-1992	3460	8.90
1993	23-Nov-1992	2480	8.10
1994	28-Nov-1993	4310	10.23
1995	08-Mar-1995	1610	7.28
1996	19-Jan-1996	1500	7.18
1997	26-May-1997	407	5.90
1998	22-Sep-1998	2310	7.94
1999	14-Jun-1999	3160	8.58
2000	22-Jun-2000	4300	9.79
2001	22-May-2001	3590	9.01
2002	19-Apr-2002	2080	7.48
2003	23-Sep-2003	6040	11.83

* Historic Peak
** Value is an Estimate

There are fifty-two (52) records available through the WATSTORE file, including an historical peak value for record-year 1947 (An historic record reflects a record that would have otherwise not been observed except for evidence indicating its unusual magnitude.). The series corresponds to “Water Years” where the water year is defined as the period between October 1st of one year and September 30th of the next. The record omits data from water year 1978. The USGS attributes this omission to historic “funding problems” for this gage.

The “Event of Record” was recorded in 1969. It coincided with a torrential thunderstorm on July 22, 1969 and resulted in a recorded peak flow of 14,600 cfs.

Plots of the Data Record

The following plots are included to better visualize the magnitude of individual data points in relation to one another and to spot trends in the data. The following chart presents the Annual Peak events available in the WATSTORE file in chronological order.

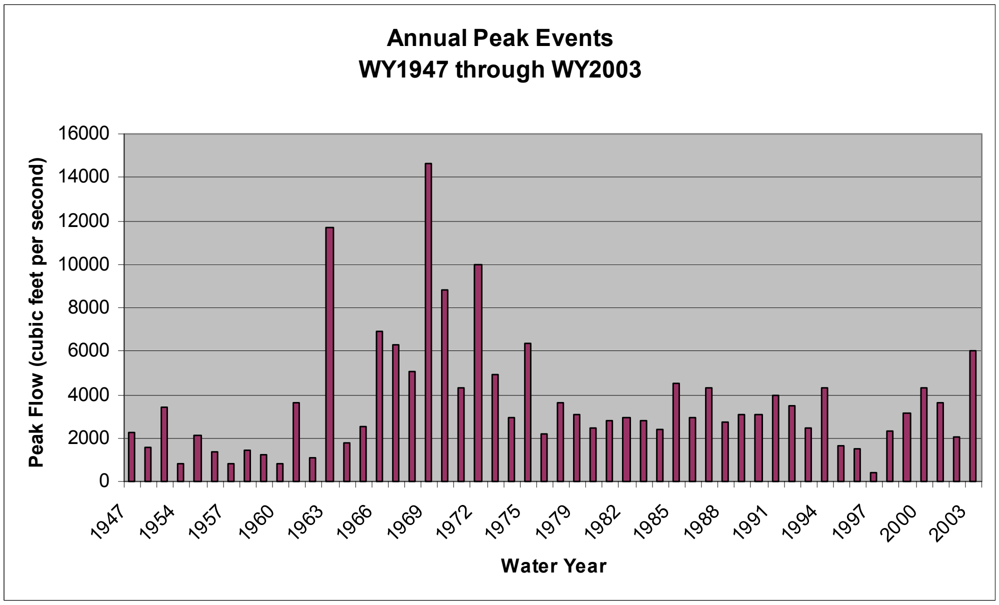

Figure 5. **Annual Peak Flows in Chronological Order**

The chart in Figure 6 presents the same event data in order of decreasing peak magnitude.

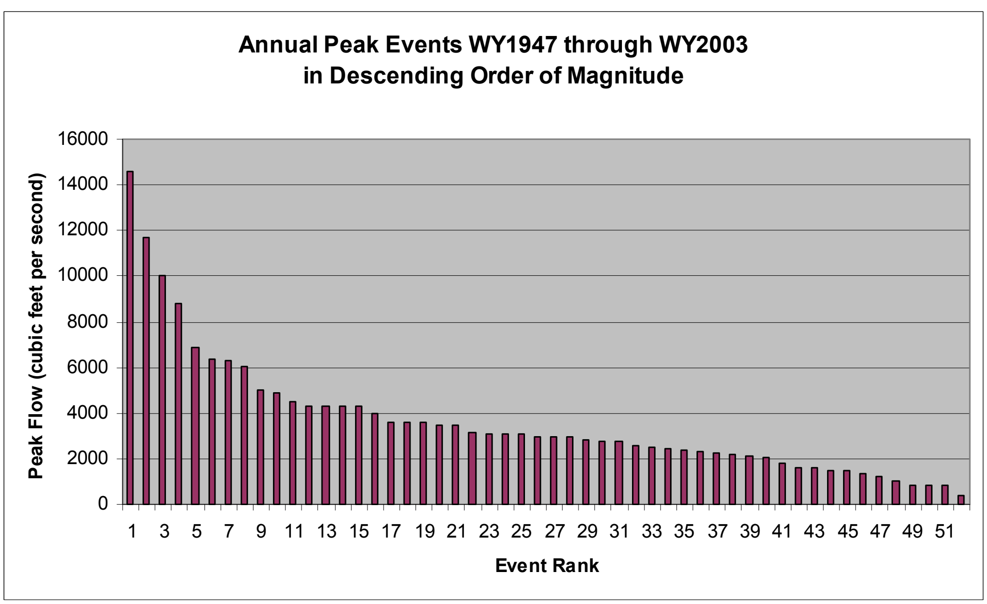

Figure 6. **Annual Peaks in Descending Order**

The following scatter plot represents each annual peak flow with a data point.

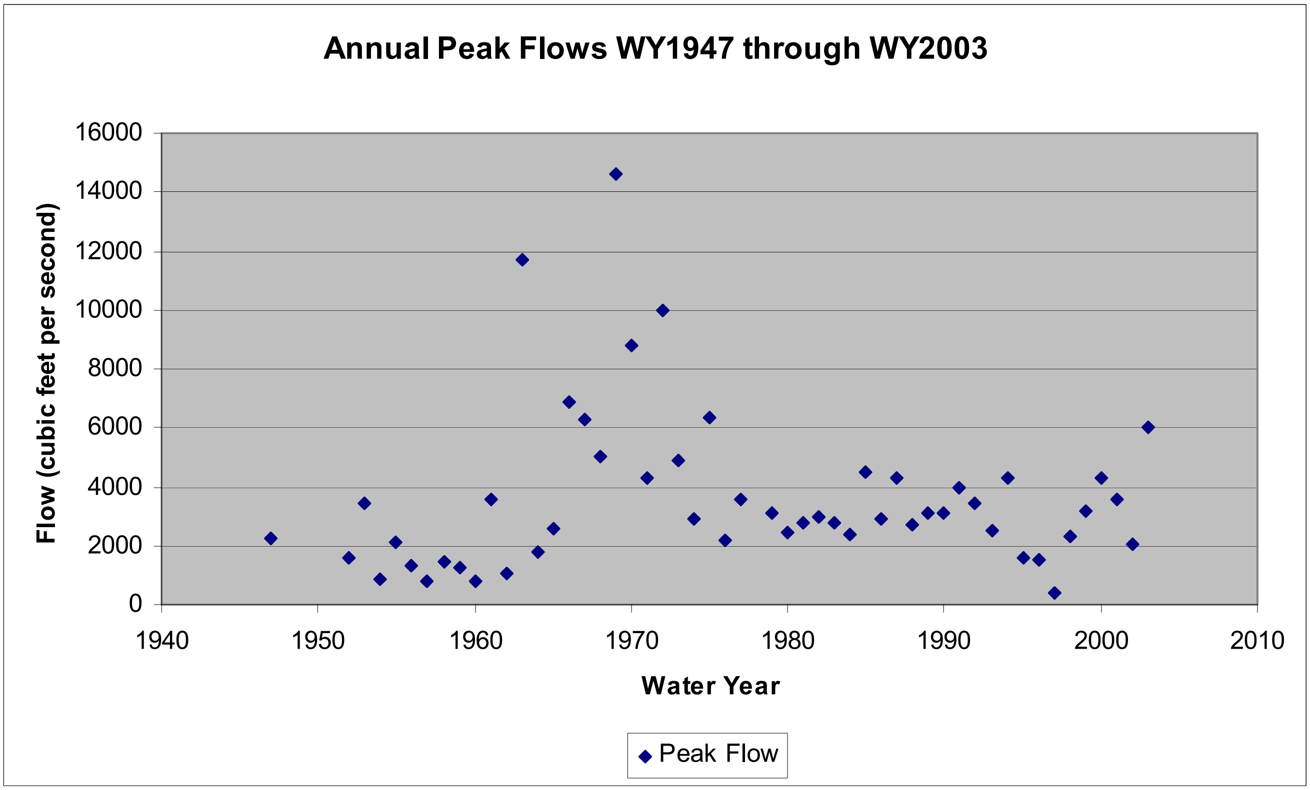

Figure 7 **Annual Peak Events – Water Years from 1947 through 2003**

It is apparent from both the first bar chart (Figure 5) and the scatter plot (Figure 7) that there is a grouping of events of generally higher magnitude during the late 1960s and early 1970s. In order to clarify the general trend of the data a trend line, calculated by linear regression of the data record, is overlain on the scatter plot (Figure 8). Only 0.03% of the variance is accounted for by the trend line (as given by the R^2 value). With such a limited correlation of the data it would not be prudent to draw any conclusions from the trend line. A mean peak flow of approximately 3,600 cfs was calculated with the peak flow data.

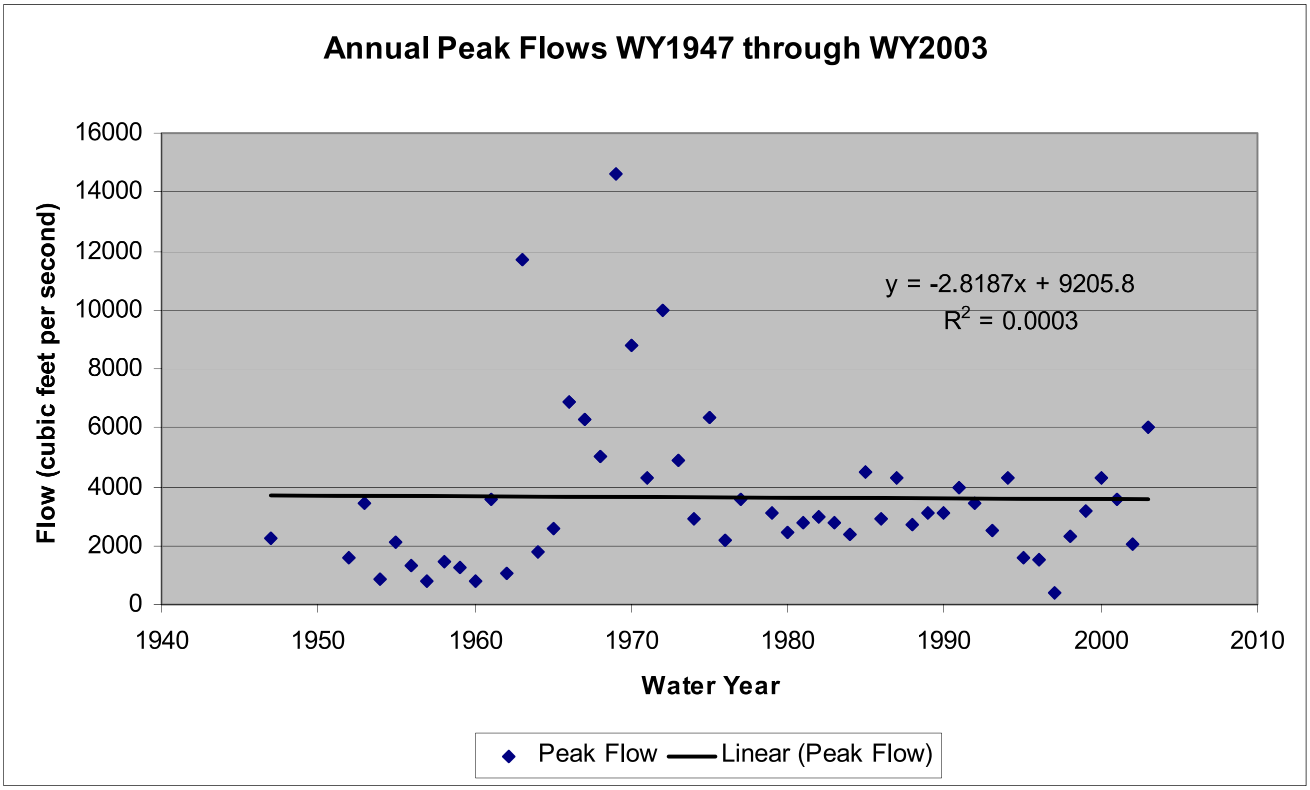

Figure 8 **Annual Peak Events – Water Years from 1947 through 2003 overlain with a trend line**

Rainfall Data

In order to evaluate climatological trends regarding rainfall in the watershed and to compare the peak flow events recorded on Four Mile Run to the peak rainfall events in the watershed, the daily rainfall records for the National Weather Service station at Washington Reagan National Airport (DCA) (448906) were compiled for the period of record. The weather station at DCA is located just outside of the watershed at 38° 51' N / 77°02'W as depicted in Figure 9.

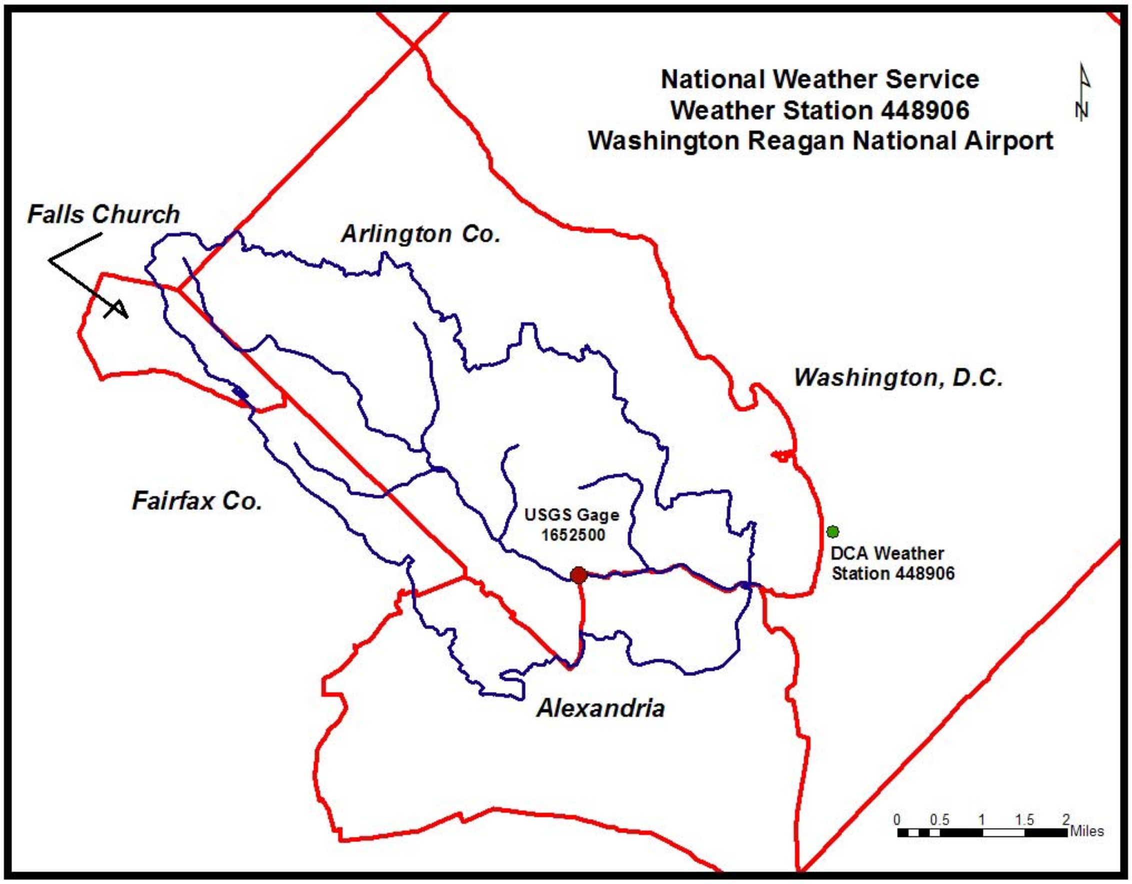

Figure 9 **Location of National Weather Service Station 448906**

Although the DCA weather station lies outside of the Four Mile Run watershed, the station is only three (3) miles from the USGS gage. The rainfall data record at the DCA station dates back to 1941. Hourly precipitation data is served on the web at http://www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwDI~StnSrch~StnID~20027254. The flood frequency analysis in this study is performed on the annual maximum series of flood events. In order to parallel this analysis similar sets of data were extracted from the DCA station record: the daily total corresponding to the peak flow event on Four Mile Run and the peak daily rainfall for each year. Data were extracted from the record dating back to 1952[1].

The rainfall records corresponding to the peak flow events on Four Mile Run and the annual peak daily rainfall totals are presented in bar graph form in Figure 10. A trend analysis is shown for the data in Figure 11. Like the peak flow data, only a small portion of the variance (~11%) was explained by the linear regression equation. Without a better correlation it is difficult to draw any valid conclusions regarding trend in the data.

[1] The daily rainfall totals represent rainfall recorded from midnight to midnight and do not necessarily capture discrete rainfall events, i.e. those rainstorms beginning on one day and extending through a subsequent day(s). Future work planned for inclusion in the full hydrology and hydraulics report for Four Mile Run will include more detailed examinations of discrete rainfall events in the record.

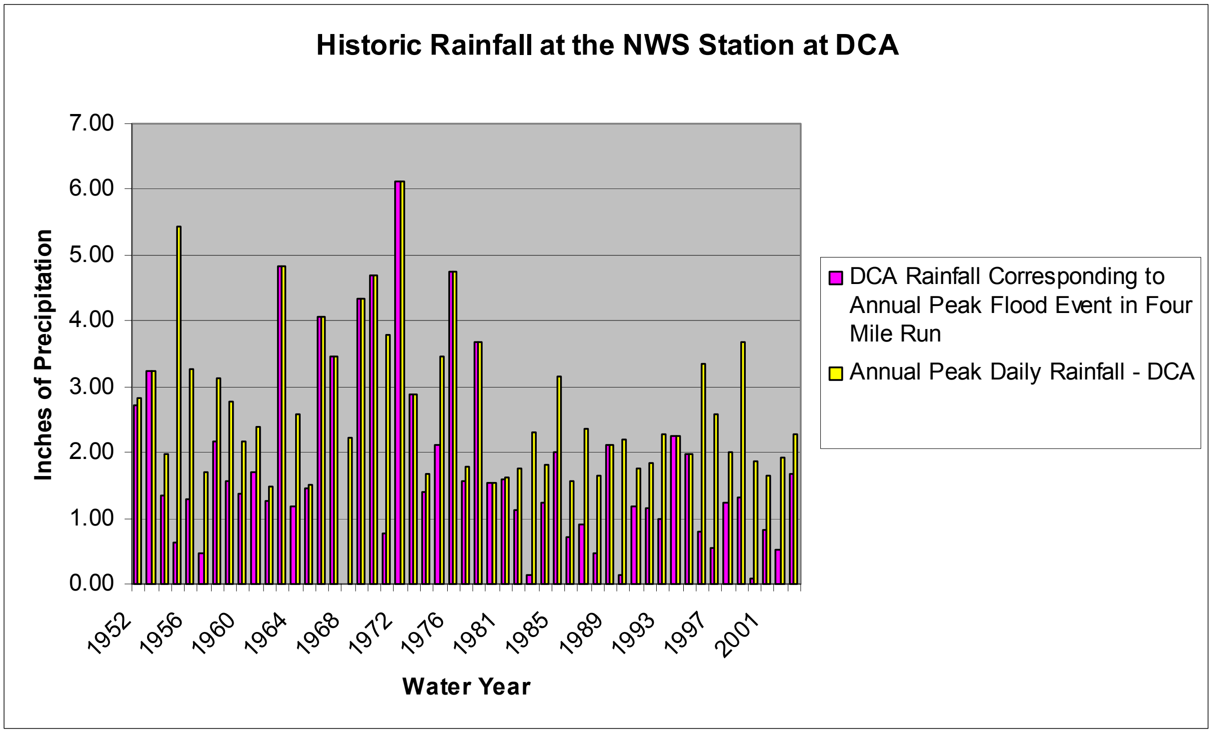

Figure 10 Daily Rainfall Data at NCDC Weather Station at DCA Relating to Peak Flow Events in Four Mile Run

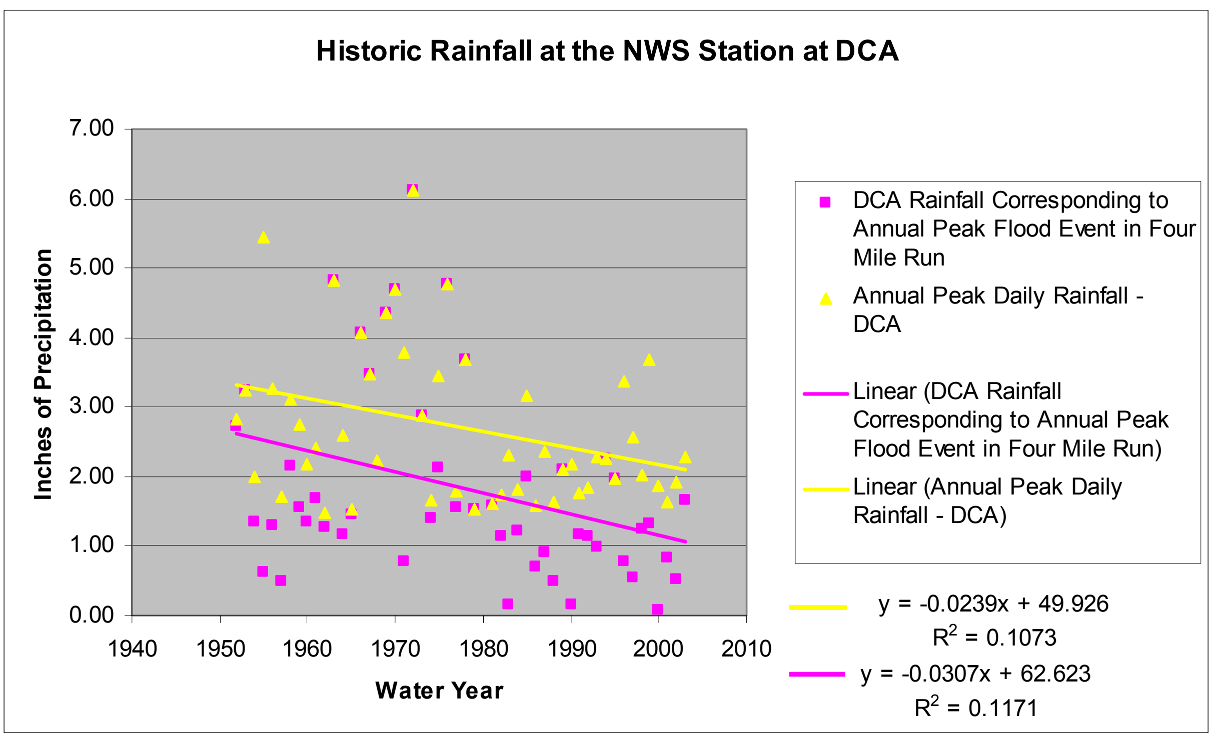

Figure 11 Daily Rainfall Data at NCDC Weather Station at DCA Relating to Peak Flow Events in Four Mile Run with Trend Lines

The scatter plot in Figure 12 presents the rainfall data from the DCA weather station superimposed on the peak flow data recorded at the USGS station on Four Mile Run. As expected, the high peak flow records of the late 1960s generally follow the high rainfall records during the same timeframe.

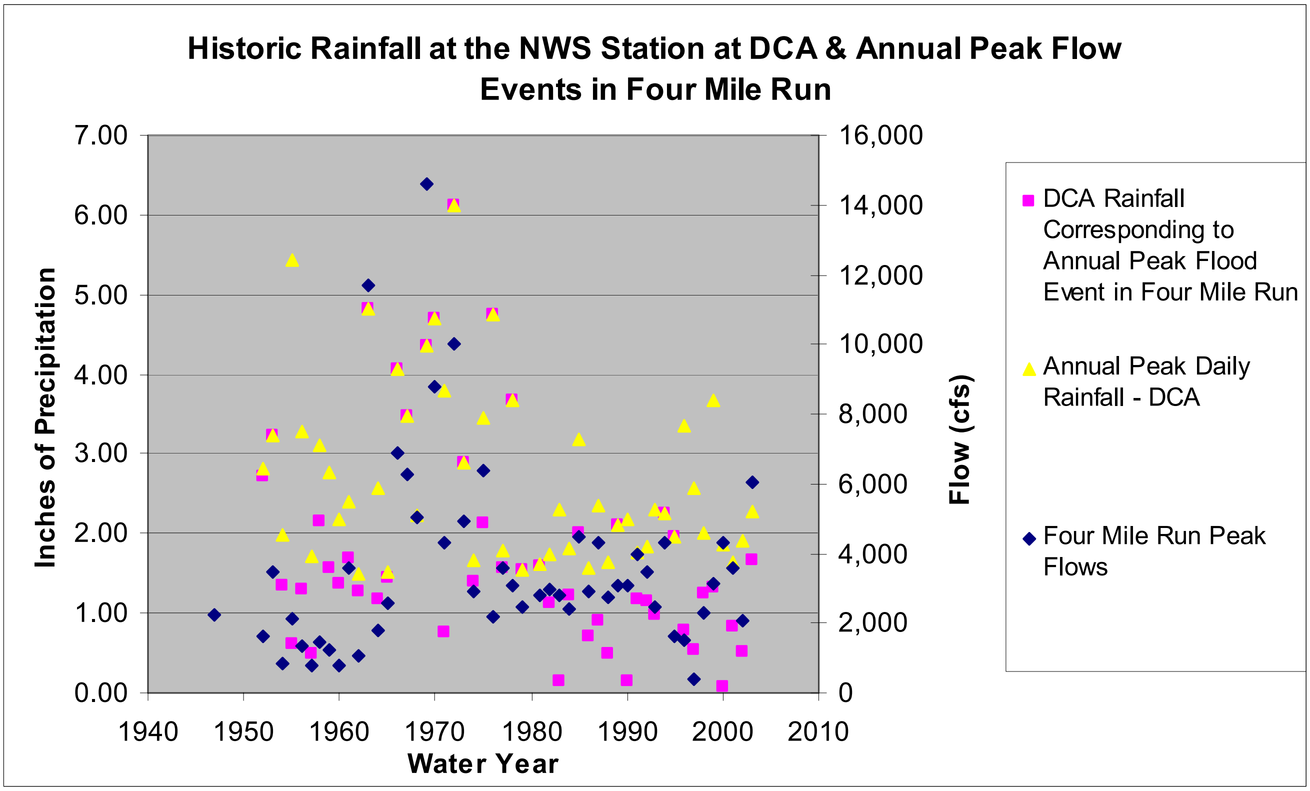

Figure 12 **Scatter Plot of Peak Flow Events in Four Mile Run Superimposed on Daily Rainfall Peaks from the DCA Weather Station**

The scatter plot depicted in Figure 13 presents the annual rainfall totals recorded at the DCA weather station dating back to 1952. The plot also shows the number of days for each year receiving precipitation. A trend line developed by linear regression for each plot was overlain on the chart but neither analysis correlated to the data well (having low R^2 values).

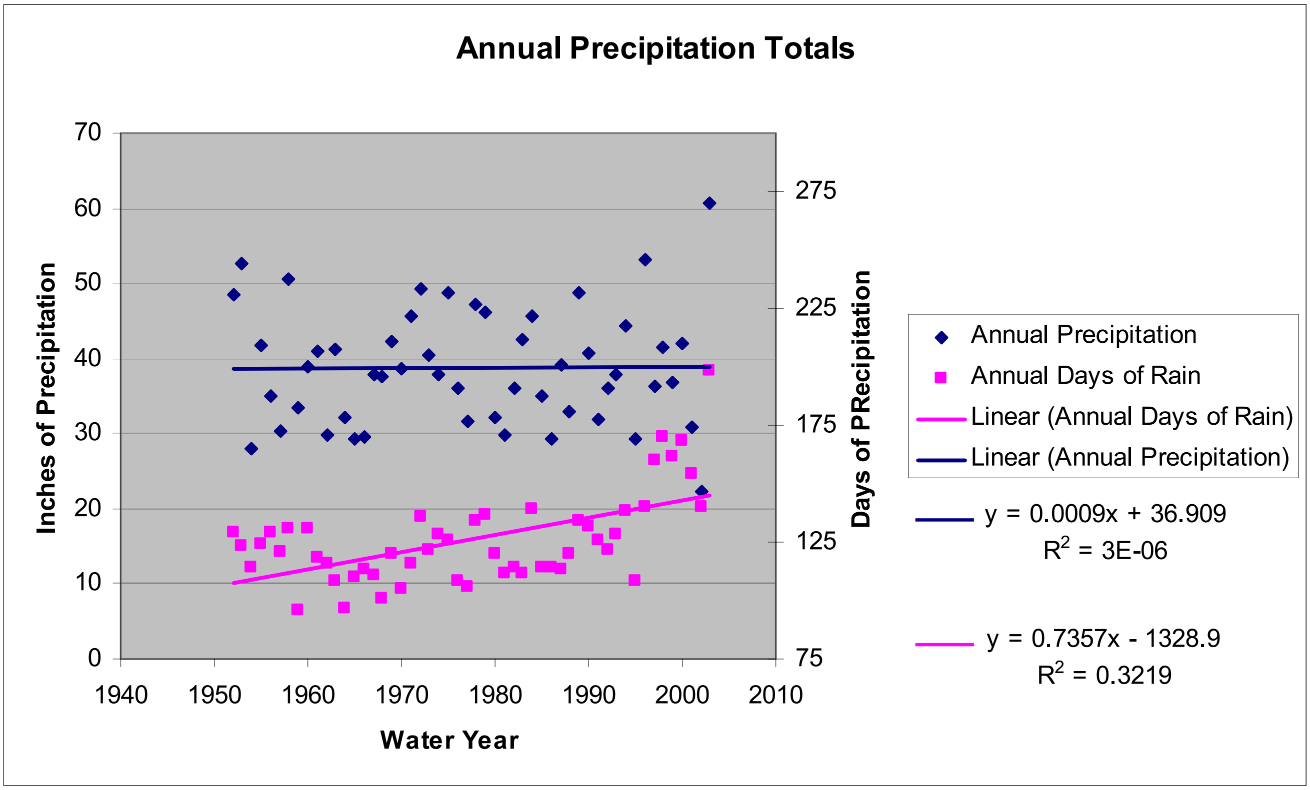

Figure 13 Scatter Plot of Annual Precipitation and Annual Days of Precipitation versus Water Year

The Effect of Urbanization on the Data Set

In regard to stormwater runoff, how urbanized a watershed is or how developed a watershed is can be characterized by the degree of imperviousness found in the watershed. That is to say, a more urbanized watershed will have a greater percentage of area covered by impervious structures, i.e., roadways, rooftops, sidewalks, parking lots, etc. The effects of these impervious areas create higher peak flows and lower base flows in the watershed tributaries. These effects are most evident in the higher frequency rain/flood events, and they diminish as the range of magnitudes increases, i.e. the initial abstractions (infiltration, interception, and surface storage) become less significant when measured against rainfall for a large event, e.g. a 100-year rainfall event.

The USGS published a 1970 paper by Daniel G. Anderson titled "Effects of Urban Development on Floods in Northern Virginia" (Anderson, 1970). In this paper, relationships were developed in order to predict peak flows of flood events in urbanizing basins. The use of this technique was incorporated in the development of the USACE flood frequency analysis contained in Design Memorandum No. 1 – FourMile Run, Local Flood Protection Project (1972). The USACE used the relationships to adjust or normalize the data in the flood record from 1952 through 1960 as follows:

Table 3 Adjustments to the Peak Values Following the Anderson Factors

Year	USGS data Peak Q	Anderson Adjustment *	Adjusted USGS data
1947	2250	Omitted	Omitted
1952	1600	46%	2336
1953	3450	46%	5037
1954	854	46%	1247
1955	2120	46%	3095
1956	1350	39%	1877
1957	810	31%*	1061
1958	1450	23%*	1784
1959	1250	15%*	1438
1960	810	7%	867
1961 thru 2003		No Adjustments to the record	No Adjustments to the Record

* *The exact value of these adjustments is not clearly specified in the USACE Design Memorandum No.1 document so a linear interpolation was assumed.*

The USACE states that the watershed was considered "built-out" by 1961 and that "any additional development will have a negligible effect on flood peaks." Although not stated explicitly in the USACE document, it should be noted that in 1961 there still existed vacant lots in the watershed. It should also be noted that the redevelopment projects that have occurred since 1961 have increased the total percentage of impervious surface coverage in the watershed. However, the increment of impervious cover change caused by both the development of the vacant lots and the redevelopment projects in the watershed since 1961 is minor when compared to the preceding change from an undeveloped forested watershed up to the assumed built-out state of the watershed in 1961.

The period of time from 1952 through 1960 was factored into the current analysis in two manners. First, a frequency curve was developed using the record data 1952 through 2003, with the peak flow values for 1952 through 1960 modified in accordance with the Anderson factors as calculated by the USACE study (1972). Secondly, a frequency curve was developed for period from 1961 through 2003 thus eliminating the years up to the assumed state of watershed build-out in 1961.

Assumptions Regarding the Data Record

In order to develop the flood frequency analysis certain assumptions were made by the study author. These assumptions relate to the completeness and cleanliness of the data provided by USGS and to watershed characteristics. Those assumptions are listed below:

- The missing data from water year 1978 was the result of a funding shortage and, thus, is independent of flood levels, i.e. the gage was not damaged during an elevated event and did not record, thereby skewing the data.

- All necessary evaluation of the raw data was performed by the USGS prior to posting the data in the WATSTORE format to ensure that all peak events are accurate and representative of independent events. No effort was made through this analysis to review the raw data used for creating the WATSTORE file for the period of record.

Method of Analysis

Analysis of these data adheres to the statistical methodology described in the 1982 edition of the Guidelines for Determining Flood Flow Frequency, Bulletin 17B, developed by the Hydrology Subcommittee for the Interagency Advisory Committee on Water Data (published under USGS cover). In summary, the methodology outlined in Bulletin 17B requires log transformation of the annual peak flow data to fit to the Pearson Type III distribution (log-Pearson Type III) for development of the annual flood series (Bulletin 17B). The method of moments is employed to develop the statistical parameters (mean, standard deviation and skew) of the distribution from the station data (Bulletin 17B).

Bulletin 17B follows the December 1967 Bulletin 15 “A Uniform Technique for Determining Flood Flow Frequencies,” issued by the Hydrology Committee of the Water Resources Council. Its general purpose was to provide a “consistent approach to flood-flow frequency determination.” Bulletin 17 (March, 1976) and Bulletin 17A (June, 1977) and Bulletin 17B (issued 1981 and reissued 1982) were expansions on the 1967 publication (Bulletin 17B).

The US Federal Emergency Management Agency (FEMA) recommends specific computer programs for flood frequency analyses (FEMA Website, March 2004, http://www.fema.gov/fhm/en_stat.shtm). The USGS-developed PeakFQ computer program is listed by FEMA as an acceptable statistical model for determining Flood Frequency Analysis consistent with Bulletin 17B. The accepted USGS PeakFQ computer program was employed for this study.

Data was inputted into the PEAKFQ computer program through the WATSTORE ASCII text file. The output from the PEAKFQ program produces both a graphical plot of the calculated frequency curve with the observed peaks and confidence bands and an ASCII text file detailing the input data and the calculated probabilities with their associated confidence bands. Plots and text outputs for use in this study are included in the appendices.

Three runs were conducted for this analysis; their descriptions are below. Actual data used in the analysis is reproduced in the appendices.

Run 1 – WY1952 thru WY2003

This run includes the entire record as found on the USGS provided WASTORE file for water years 1952 - 2003. The historical record for WY1947 (2250 cfs) was eliminated from the dataset for two reasons. First, it was recorded prior to the installation of the USGS station. Second, its use in the dataset for Run 1 made drawing parallels with the dataset used for Run 2 problematic. Using any of the derived frequency curves, the peak flow record for WY1947 equates to less than a 2-year event, Because the focus of this study is primarily on the low-frequency events, e.g. the 100-year event, the omission of the WY1947 event was justifiable.

The purpose of Run 1 is to produce a frequency curve of the Four Mile Run data with no accounting made for the developing stages of the watershed contained in the period of record. No adjustments to the time series have been made other than the omission the historical value for WY1947. The broken period of record (with the gap for water year 1978) is pieced together as one complete time series with 51 data points.

Run 2 – WY1952 thru WY2003 Adjusted with Anderson Factors

This run includes the time series from 1952 through 2003 with the annual peak values for water years 1952 through 1961 adjusted using the Anderson factors as calculated in the USACE flood frequency analysis (1972) and shown in Table 3. The purpose of this run was to produce a frequency curve from the entire record (minus water year 1947) that included an accounting for the effects of urbanization included in the dataset through the assumed time of watershed build-out in 1961. The broken period of record (with the gap for water year 1978) is pieced together as one complete time series with 51 data points.

Run 3 – WY1961 – WY2003

This run includes the time series from 1961 through 2003. The purpose of this run was to produce a frequency curve with only data from the post-development period (post 1960). All records from the urbanizing years (pre-1961) have been removed from the record. Other than eliminating data from water years 1947 through 1960 no other adjustments to the time series have been made to the record. The broken period of record (with the gap for water year 1978) is pieced together as one complete time series with 42 data points.

Results

The frequency curves for the results of the three computational runs are summarized below:

Table 4 Frequency Curves Generated by Runs 1, 2 & 3

Recurrence Interval	Probability	Run 1 - PeakFQ 1952 - 2003	Run 2 - PeakFQ 1952 - 2003 (adjusted)	Run 3 - PeakFQ 1961 - 2003
2	0.5	2,885	3,007	3,352
5	0.2	5,110	5,149	5,511
10	0.1	6,994	6,968	7,363
25	0.04	9,886	9,782	10,270
50	0.02	12,440	12,290	12,890
100	0.01	15,370	15,190	15,970
500	0.002	23,860	23,740	25,280

Each frequency curve is graphed below. Each curve is bounded by its correlating associated bands and is overlain with the observed annual peaks.

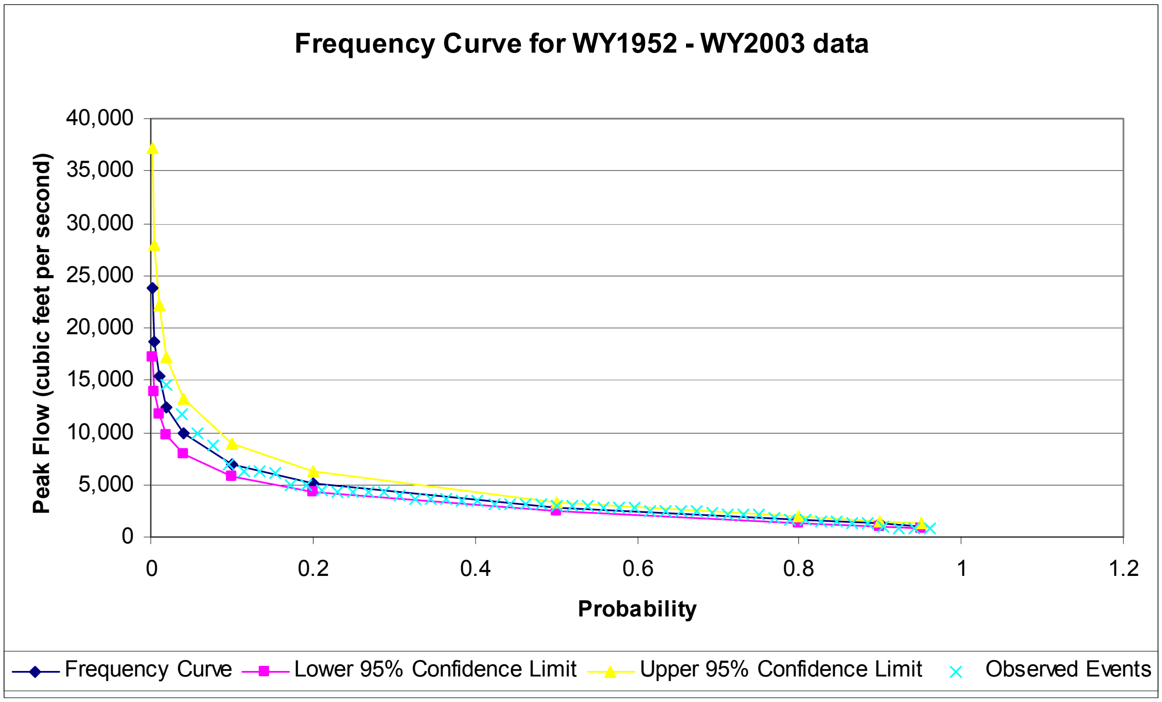

Figure 14 **Frequency Curve for WY1952 – WY2003 Data (without adjustment)**

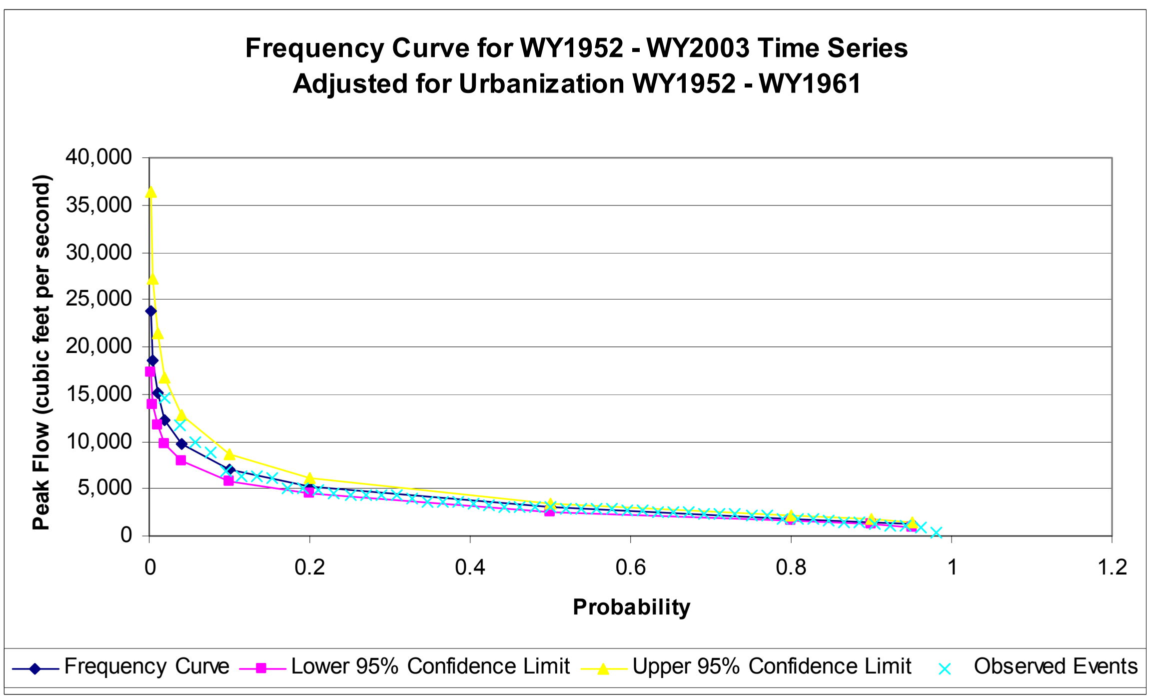

Figure 15 **Frequency Curve for WY1952 – WY2003 Data (with adjustment for urbanizing of the watershed in the 1950s)**

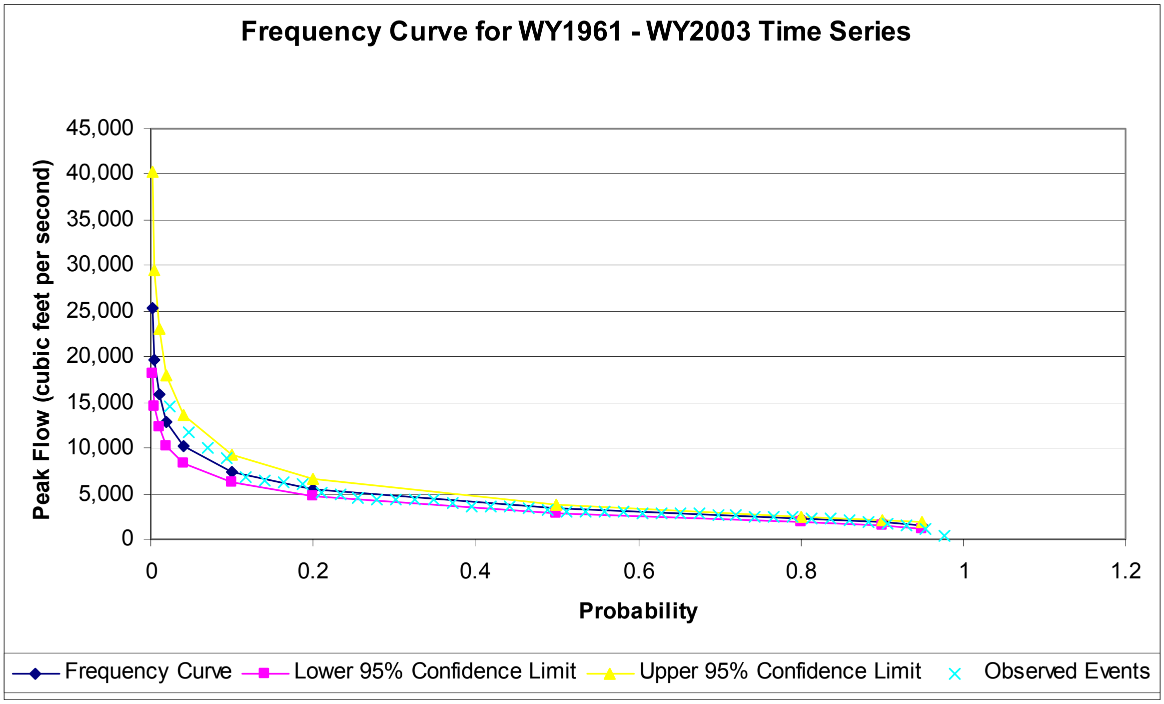

Figure 16 Frequency Curve for WY1961 – WY2003 Data

In order to compare all three frequency curves the following chart is included that includes the three curves on one plot.

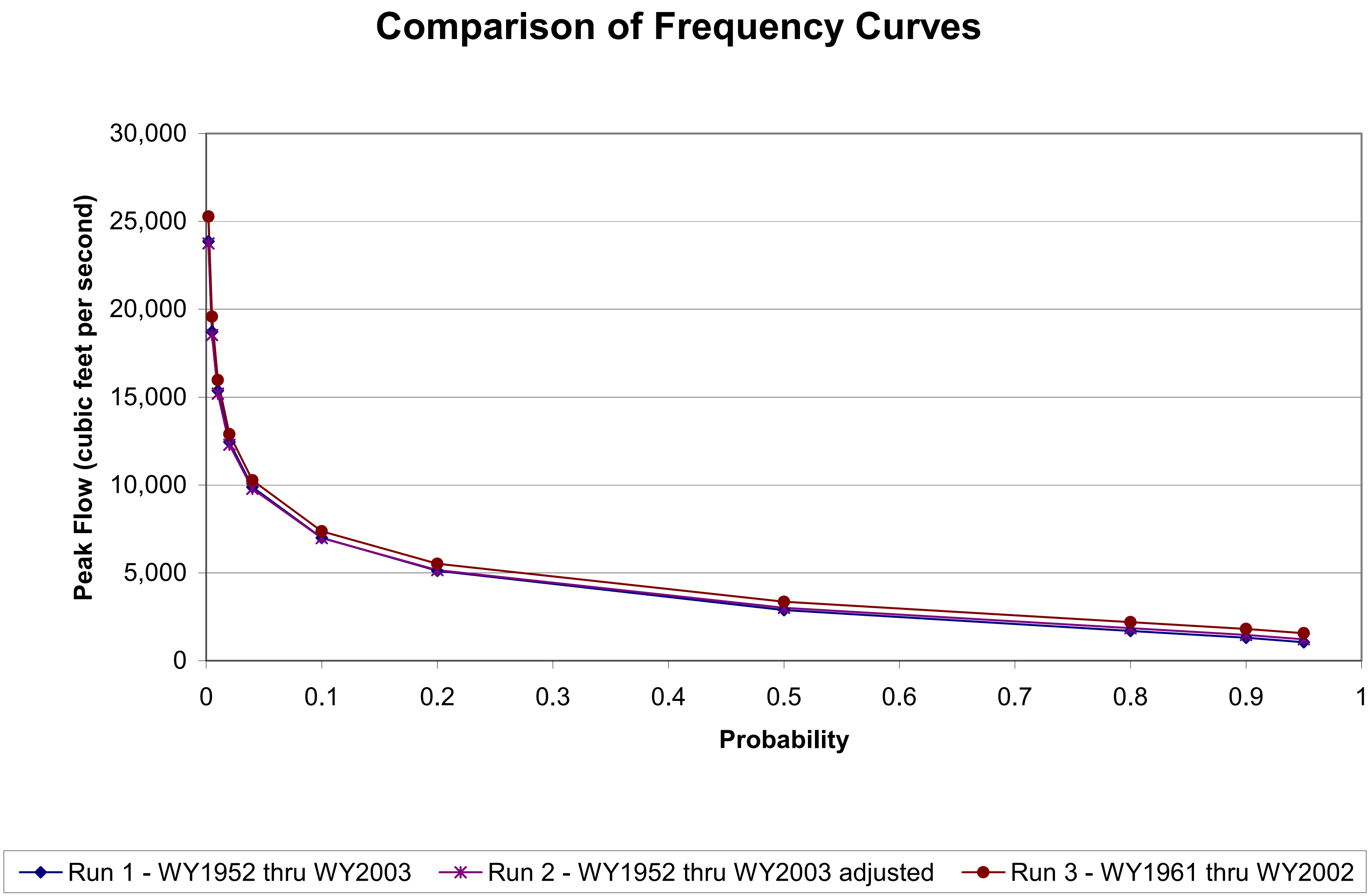

Figure 17 **Comparison of the Frequency Curves Generate by the Three Runs**

Analysis

All three runs produced similar frequency curves. The manner by which the urbanizing period in the watershed is accounted for does not alter the magnitude of the curve appreciably. It is the recommendation of the author and the Four Mile Run Restoration Project Workgroup that the more conservative approach is taken for engineering designs. Therefore, the frequency curve generated by excluding data records prior to 1961 will be used for engineering designs.

The following table, Table 6, cites previous flood frequency analyses performed on the data provided by USGS gage on Four Mile Run. By comparing the current analysis (column 9) to the one the USACE performed for development of the original project designs (column 2) (USACE, 1972 – Design Memo No. 1), the 100-year peak flow event shows a decrease of 20% from the 20,000 cfs predicted in 1972 to 15,970 cfs predicted in the current analysis. Although there are likely several reasons for a decline in the magnitude of low frequency peak flow events predicted by the frequency analysis, by and large the decline has been caused by the addition of nearly 30 years of data to the record. Those additional years generally show magnitudes less than those observed during the late 1960s and early 1970s, and the lesser magnitudes work to moderate the frequency predictions.

Since the late 1970s, the Four Mile Run watershed has been a “managed” watershed requiring stormwater to be detained on development sites and released at artificially slow rates, e.g., in Arlington County some development projects are required to detain the 100-year post development runoff to the pre-development 10-year runoff rate. Although the potential of this program to diminish the peak rates associated with low frequency events exists, to this moment, it is estimated that less than 10% of the watershed’s impervious surfaces drain to such detention facilities.

It should also be noted that the 2- and 5-year predicted flow events increased with the chosen curve (column 9) from the earlier USACE curve (column 2), from 2450 cfs to 3352 cfs respectively for the 2-year event and 5200 cfs to 5511 cfs respectively for the 5-year event. These increased values will have implications on designs and management efforts focused on the higher frequency events, i.e., bank full channel design.

Although development has had a minor effect on the low frequency events since the early 1960s this is likely not the case for the higher frequency events, including events through the 5-year event. One factor in particular lends itself to this thesis, the increased efficiency of neighborhood storm drain networks both above ground with the increased impervious surface coverage and underground with expanded storm drain piping. As development increases in a watershed so to will the storm drain network. The expanded network will usually be through the creation of neighborhood-type developments not necessarily the replacement of large trunk lines or open channel sections that are typically designed for higher capacities. The drainage systems in these neighborhood areas will be designed under a dual requirement. Firstly, these systems must adequately convey the 10-year storm event. Secondly, drainage pipes must meet a minimum size requirement, typically 15-inches in diameter. Because of the smaller collection basins in a neighborhood system a 15-inch diameter storm drain will often carry significantly more flow from the basin area than a 10-year storm event will produce. Consequently, the higher frequency flows will have a more efficient conduit to reach the lower portions of the watershed. This efficiency of conveyance added to the combining of flows as they move to the lower portions of the watershed will work to distort the hydrograph and is likely one of the causes of higher peak flows for the lower magnitude events.

When considering why this effect cannot be extrapolated to the higher magnitude events it is important to realize that much of the storm flows associated with the higher magnitude events are not necessarily contained within the storm drain network where they can readily be carried to the downstream portions of the watershed. The stormwater in excess of the capacity of the storm drain network will contribute to localized flooding and thereby be stored, or detained, awaiting downstream capacity. With regard to why the 10-year event does not also show higher magnitude flows, it is probable that inefficient designs, infrastructure remaining in the watershed that predates the 10-year conveyance capacity and minimum size requirements, and temporary partial blockages in the drainage network all work to diminish this effect preceding the 10-year frequency event.

The data included and the analysis presented offer some understanding and statistical prediction derived from the actual flow data recorded at the USGS gage. Neither the data nor the analysis presented describes all of the factors acting on the watershed or the levee corridor to allow a reader to draw definitive conclusions about flow predictions at any location beyond that of the USGS gaging station location. A thorough examination of precipitation is not presented here, nor are factors such as existing channel capacity or sediment transport included in any manner in this study. Such items, and others, are crucial to a thorough understanding of the hydrology and hydraulics of Four Mile Run. It should be noted that 30% of the runoff from the watershed enters the stream downstream of the USGS gage and is therefore not recorded by the gage. The magnitude of flood waves downstream must be examined through deterministic models of the watershed and hydraulic corridor. Even so, this flood flow frequency analysis does offer the reader and decision-makers a current understanding of what flow magnitudes can be expected in Four Mile Run at the gaging station. Because the methodology used in this study subscribes to industry-standard techniques (Bulletin #17B) its results can easily be used by decision-makers for meaningful discussion and application in the broader hydrology and hydraulics context.

Table 5 **Summary Table of Frequency Analyses for Four Mile Run**

Recurrence Interval	Probability	[1] USACE 1969	[2] USACE 1972	[3] WRE 1975	[4] A. Rowley & USACE 1947 - 1979	[5] USGS 1947 - 1991 by System Analysis	[6] A. Rowley 1947 - 1996	[7] Run 1 - PeakFQ 1952 - 2003	[8] Run 2 - PeakFQ 1952 - 2003 (adjusted)	[9] Run 3 - PeakFQ 1961 - 2003
2	0.5	2,450	2,450	3,300		2,900		2,885	3,007	3,352
5	0.2	4,200	5,200	6,800		5,270		5,110	5,149	5,511
10	0.1	7,000	8,600	9,500	8,726	7,320	7,337	6,994	6,968	7,363
25	0.04	10,500	12,500	16,000		10,500		9,886	9,782	10,270
50	0.02	13,500	16,000	19,500	17,400	13,400	13,060	12,440	12,290	12,890
100	0.01	18,500	20,000	23,000	22,330	16,700	16,078	15,370	15,190	15,970
500	0.002	36,000	31,500	32,000	28,133	26,600	24,661	23,860	23,740	25,280

- The original USACE design provided 22,500 cfs capacity downstream of the USGS stream gage.
- The current USGS rating curve for the USGS Stream gage site shows a maximum of 10,000 cfs at a staff gage level of 17.80 feet.

[1] Values were pulled Figure A-4 from USACE Study, "Fourmile Run City of Alexandria & Arlington County, Virginia: Review Report on Flood Control," September 1969.
[2] Values were estimated from Plate 1-8 from USACE study, "Fourmile Run Local Flood Protection Project," June 1972.
[3] Values were estimated from Figure 34, Flow Frequency Curves at USGS Gaging Station Using USACE Method and Model STORM, from Water Resources Engineers' Report, "Four Mile Run Hydrology Report," dated 1975.
[4] USACE confirmation of A. Rowley Study (Error in K values used for 500 year event actually predicts the 200 year event.)
[5] USGS Analysis published 1995
[6] Unpublished A. Rowley Study 1947 through 1996.
[7] NVRC analysis (PEAKFQ) post built-out study that includes all station data from 1952 to 2003 with no adjustment for partial build-out of the watershed.
[8] NVRC analysis (PEAKFQ) study that includes station data from WY1952 through WY2003 (1952 thru 1961 adjusted for ultimate build-out)
[9] NVRC analysis (PEAKFQ) post built-out study that includes only data from WY1961 to WY2003.

References

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US Army Corps of Engineers. 1994. Flood Runoff Analysis – EM 1110-2-1417

Appendices

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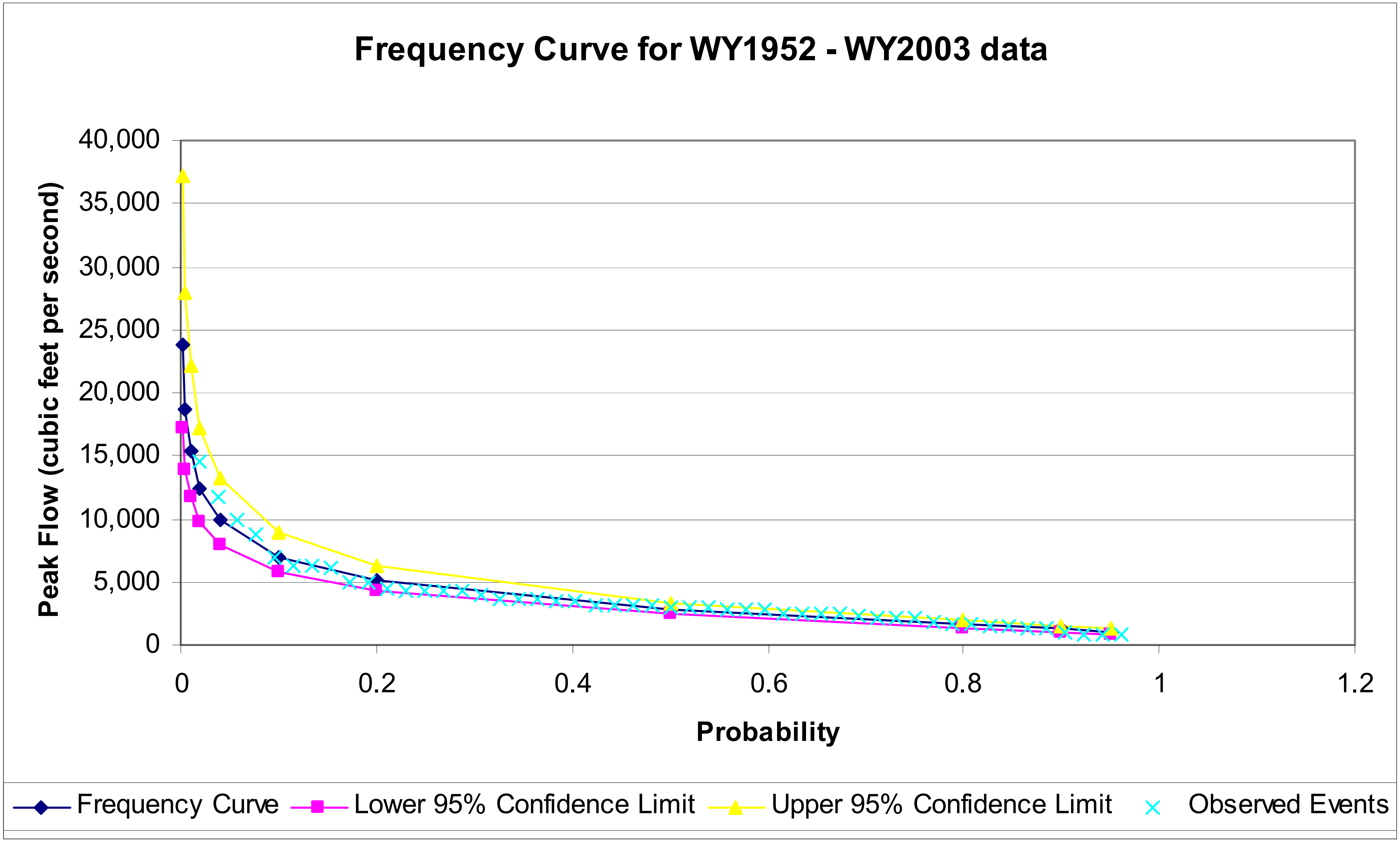
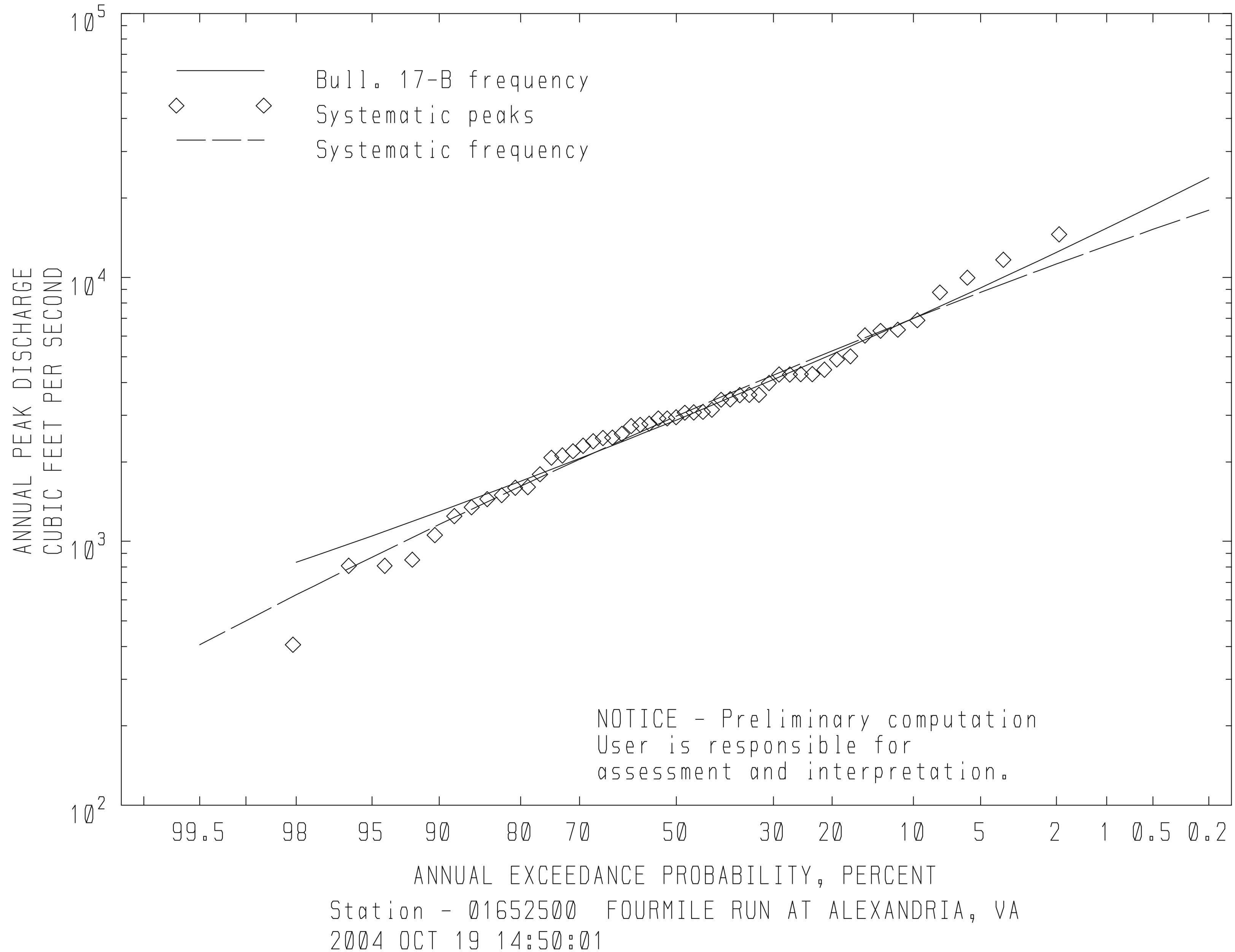
Flood Frequency Analysis

for

WY1952 – WY2003 Data


Frequency Curve for WY1952 - WY2003 data
Peak Flow (cubic feet per second)
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
0
0.2
0.4
0.6
0.8
1
1.2
Probability
Frequency Curve
Lower 95% Confidence Limit
Upper 95% Confidence Limit
Observed Events



Run 1 – WY1952 Thru WY2003

Run 1 – WY1952 thru WY2003 – Input WATSTORE file

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N01652500       FOURMILE RUN AT ALEXANDRIA, VA
Y01652500
301652500       19520709   1600                5.60
301652500       19530505   3450                8.50
301652500       19540503    854                4.22
301652500       19550708   2120                6.91
301652500       19560722   1350                5.10
301652500       19570123    810                4.12
301652500       19580708   1450                5.27
301652500       19590613   1250                4.90
301652500       19600613    810                4.08
301652500       19610826   3600                7.00
301652500       19620531   1060                4.45
301652500       19630820  11700                9.89
301652500       19640513   1800                5.41
301652500       19650718   2560                6.15
301652500       19660914   6900                7.83
301652500       19670824   6290                7.93
301652500       19680627   5040                7.28
301652500       19690722  14600               11.60
301652500       19700709   8800               10.70
301652500       19710729   4300                6.90
301652500       19720621  10000               12.40
301652500       19730820   4900                9.20
301652500       19740830   2930                8.55
301652500       19750926   6350               13.07
301652500       19760916   2200
301652500       19770712   36002               9.28
301652500       19790905   3080                8.36
301652500       19791001   2470                7.49
301652500       19810704   2800                7.96
301652500       19820601   2960                8.20
301652500       19830621   2770                7.92
301652500       19840329   2400                7.90
301652500       19850910   4480               10.36
301652500       19860720   2930                8.15
301652500       19870626   4310               10.12
301652500       19880506   2740                7.87
301652500       19890505   3100                8.25
301652500       19900509   3090                8.38
301652500       19901023   3990                9.66
301652500       19920724   3460                8.90
301652500       19921123   2480                8.10
301652500       19931128   4310               10.23
301652500       19950308   1610                7.28
301652500       19960119   1500                7.18
301652500       19970526    407                5.90
301652500       19980922   2310                7.94
301652500       19990614   3160                8.58
301652500       20000622   4300                9.79
301652500       20010522   3590                9.01
301652500       20020419   2080                7.48
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Run 2 – WY1952 Thru WY2003 Adjusted with the Anderson Factors

301652500	20030923	6040	11.83

Run 1 – WY1952 thru WY2003 – PeakFQ Output File

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                     U. S. GEOLOGICAL SURVEY
                 ANNUAL PEAK FLOW FREQUENCY ANALYSIS
                 Following Bulletin 17-B Guidelines
                           Program peakfq
                     (Version 4.1, February, 2002)


                    --- PROCESSING DATE/TIME ---

                        2004 OCT 19 14:50:01

                     --- PROCESSING OPTIONS ---

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                  Basin char output   = None
                  Print option        = Yes
                  Debug print         = No
                  Input peaks listing = Long
                  Input peaks format  = WATSTORE peak file

1

                     U. S. GEOLOGICAL SURVEY
                 ANNUAL PEAK FLOW FREQUENCY ANALYSIS
                 Following Bulletin 17-B Guidelines
                           Program peakfq
                     (Version 4.1, February, 2002)



             Station - 01652500  FOURMILE RUN AT ALEXANDRIA, VA
                        2004 OCT 19 14:50:01


                 I N P U T   D A T A   S U M M A R Y

               Number of peaks in record            =       51
               Peaks not used in analysis           =        0
               Systematic peaks in analysis         =       51
               Historic peaks in analysis           =        0
               Years of historic record             =        0
               Generalized skew                     =    0.687
               Standard error of generalized skew   =    0.550
               Skew option                          =   WEIGHTED
               Gage base discharge                  =      0.0
               User supplied high outlier threshold =   --
               User supplied low outlier criterion  =   --
               Plotting position parameter          =     0.00


 *********  NOTICE  --  Preliminary machine computations.        *********
 *********  User responsible for assessment and interpretation.  *********
```

WCF134I-NO SYSTEMATIC PEAKS WERE BELOW GAGE BASE. 0.0
WCF198I-LOW OUTLIERS BELOW FLOOD BASE WERE DROPPED. 1 411.5
WCF163I-NO HIGH OUTLIERS OR HISTORIC PEAKS EXCEEDED HHBASE. 20308.1

1

Station - 01652500 FOURMILE RUN AT ALEXANDRIA, VA
2004 OCT 19 14:50:01

ANNUAL FREQUENCY CURVE PARAMETERS -- LOG-PEARSON TYPE III

	FLOOD BASE		LOGARITHMIC		
	DISCHARGE	EXCEEDANCE PROBABILITY	MEAN	STANDARD DEVIATION	SKEW
SYSTEMATIC RECORD	0.0	1.0000	3.4621	0.3055	-0.234
BULL.17B ESTIMATE	411.5	0.9804	3.4715	0.2861	0.237

ANNUAL FREQUENCY CURVE -- DISCHARGES AT SELECTED EXCEEDANCE PROBABILITIES

ANNUAL EXCEEDANCE PROBABILITY	BULL.17B ESTIMATE	SYSTEMATIC RECORD	'EXPECTED PROBABILITY' ESTIMATE	95-PCT CONFIDENCE LIMITS FOR BULL. 17B ESTIMATES LOWER	UPPER
0.9950	--	405.9	--	--	--
0.9900	--	500.5	--	--	--
0.9500	1049.0	871.2	1021.0	807.2	1287.0
0.9000	1297.0	1158.0	1274.0	1029.0	1560.0
0.8000	1690.0	1618.0	1675.0	1389.0	1994.0
0.5000	2885.0	2978.0	2885.0	2472.0	3363.0
0.2000	5110.0	5273.0	5166.0	4336.0	6208.0
0.1000	6994.0	7001.0	7151.0	5796.0	8851.0
0.0400	9886.0	9366.0	10300.0	7919.0	13200.0
0.0200	12440.0	11240.0	13200.0	9714.0	17260.0
0.0100	15370.0	13180.0	16650.0	11700.0	22110.0
0.0050	18710.0	15200.0	20760.0	13910.0	27880.0
0.0020	23860.0	18000.0	27420.0	17210.0	37160.0
0.6667	2186.1	(1.50-year flood)			
0.4292	3241.1	(2.33-year flood)			

1

Station - 01652500 FOURMILE RUN AT ALEXANDRIA, VA
2004 OCT 19 14:50:01

I N P U T D A T A L I S T I N G

WATER YEAR	DISCHARGE	CODES	WATER YEAR	DISCHARGE	CODES
1952	1600.0		1979	3080.0	

1953	3450.0	1980	2470.0
1954	854.0	1981	2800.0
1955	2120.0	1982	2960.0
1956	1350.0	1983	2770.0
1957	810.0	1984	2400.0
1958	1450.0	1985	4480.0
1959	1250.0	1986	2930.0
1960	810.0	1987	4310.0
1961	3600.0	1988	2740.0
1962	1060.0	1989	3100.0
1963	11700.0	1990	3090.0
1964	1800.0	1991	3990.0
1965	2560.0	1992	3460.0
1966	6900.0	1993	2480.0
1967	6290.0	1994	4310.0
1968	5040.0	1995	1610.0
1969	14600.0	1996	1500.0
1970	8800.0	1997	407.0
1971	4300.0	1998	2310.0
1972	10000.0	1999	3160.0
1973	4900.0	2000	4300.0
1974	2930.0	2001	3590.0
1975	6350.0	2002	2080.0
1976	2200.0	2003	6040.0
1977	3600.0		

Explanation of peak discharge qualification codes

PEAKFQ CODE	WATSTORE CODE	DEFINITION
D	3	Dam failure, non-recurrent flow anomaly
G	8	Discharge greater than stated value
X	3+8	Both of the above
L	4	Discharge less than stated value
K	6 OR C	Known effect of regulation or urbanization
H	7	Historic peak

1

Station - 01652500 FOURMILE RUN AT ALEXANDRIA, VA
2004 OCT 19 14:50:01

EMPIRICAL FREQUENCY CURVES -- WEIBULL PLOTTING POSITIONS

WATER YEAR	RANKED DISCHARGE	SYSTEMATIC RECORD	BULL.17B ESTIMATE
1969	14600.0	0.0192	0.0192
1963	11700.0	0.0385	0.0385
1972	10000.0	0.0577	0.0577

1970	8800.0	0.0769	0.0769
1966	6900.0	0.0962	0.0962
1975	6350.0	0.1154	0.1154
1967	6290.0	0.1346	0.1346
2003	6040.0	0.1538	0.1538
1968	5040.0	0.1731	0.1731
1973	4900.0	0.1923	0.1923
1985	4480.0	0.2115	0.2115
1987	4310.0	0.2308	0.2308
1994	4310.0	0.2500	0.2500
1971	4300.0	0.2692	0.2692
2000	4300.0	0.2885	0.2885
1991	3990.0	0.3077	0.3077
1961	3600.0	0.3269	0.3269
1977	3600.0	0.3462	0.3462
2001	3590.0	0.3654	0.3654
1992	3460.0	0.3846	0.3846
1953	3450.0	0.4038	0.4038
1999	3160.0	0.4231	0.4231
1989	3100.0	0.4423	0.4423
1990	3090.0	0.4615	0.4615
1979	3080.0	0.4808	0.4808
1982	2960.0	0.5000	0.5000
1974	2930.0	0.5192	0.5192
1986	2930.0	0.5385	0.5385
1981	2800.0	0.5577	0.5577
1983	2770.0	0.5769	0.5769
1988	2740.0	0.5962	0.5962
1965	2560.0	0.6154	0.6154
1993	2480.0	0.6346	0.6346
1980	2470.0	0.6538	0.6538
1984	2400.0	0.6731	0.6731
1998	2310.0	0.6923	0.6923
1976	2200.0	0.7115	0.7115
1955	2120.0	0.7308	0.7308
2002	2080.0	0.7500	0.7500
1964	1800.0	0.7692	0.7692
1995	1610.0	0.7885	0.7885
1952	1600.0	0.8077	0.8077
1996	1500.0	0.8269	0.8269
1958	1450.0	0.8462	0.8462
1956	1350.0	0.8654	0.8654
1959	1250.0	0.8846	0.8846
1962	1060.0	0.9038	0.9038
1954	854.0	0.9231	0.9231
1957	810.0	0.9423	0.9423
1960	810.0	0.9615	0.9615
1997	407.0	0.9808	0.9808

1

U. S. GEOLOGICAL SURVEY
ANNUAL PEAK FLOW FREQUENCY ANALYSIS
Following Bulletin 17-B Guidelines
Program peakfq
(Version 4.1, February, 2002)

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End PEAKFQ analysis.
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  Number of errors   :       0
  Stations skipped   :       0
  Station years      :      51
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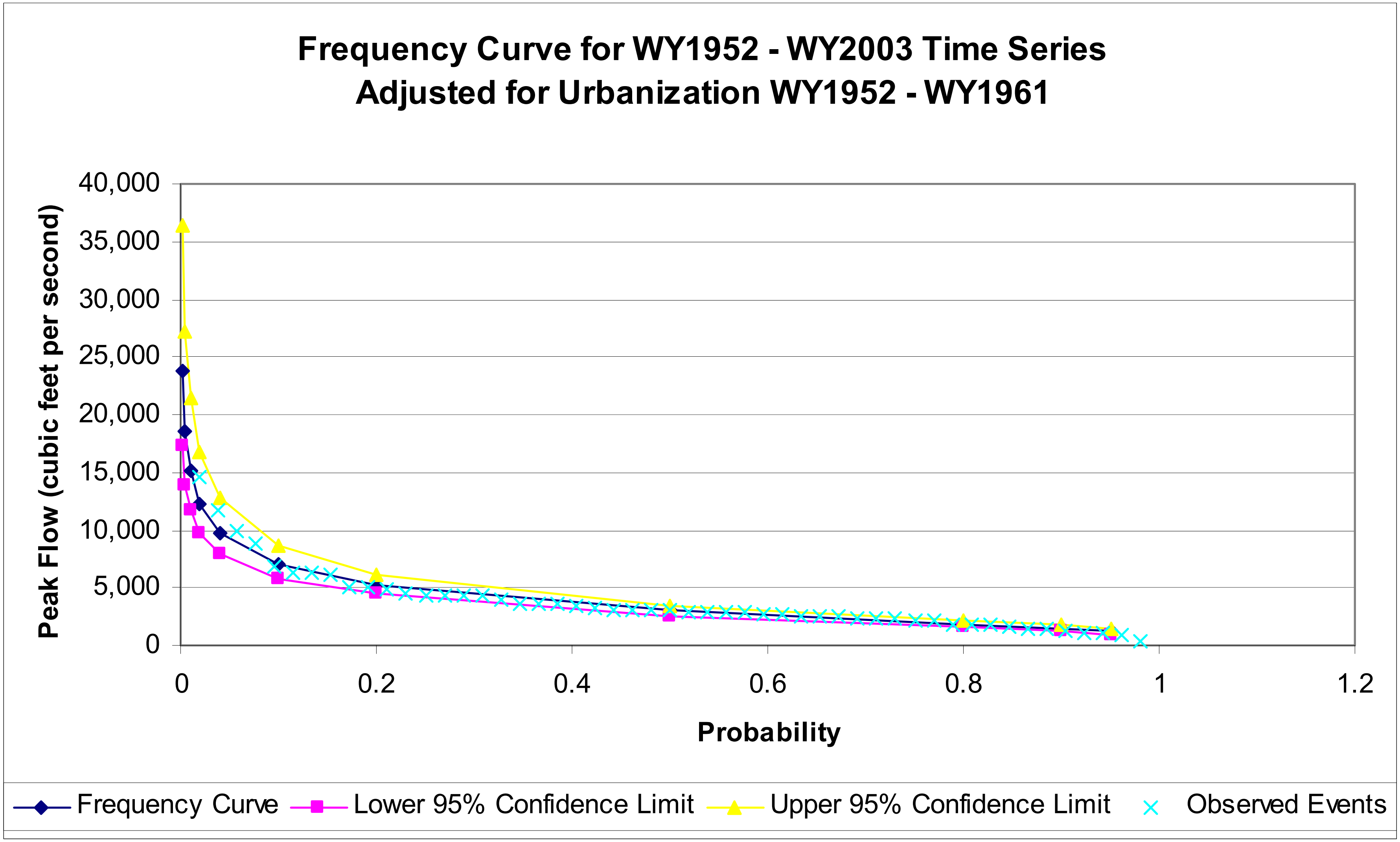
Flood Frequency Analysis

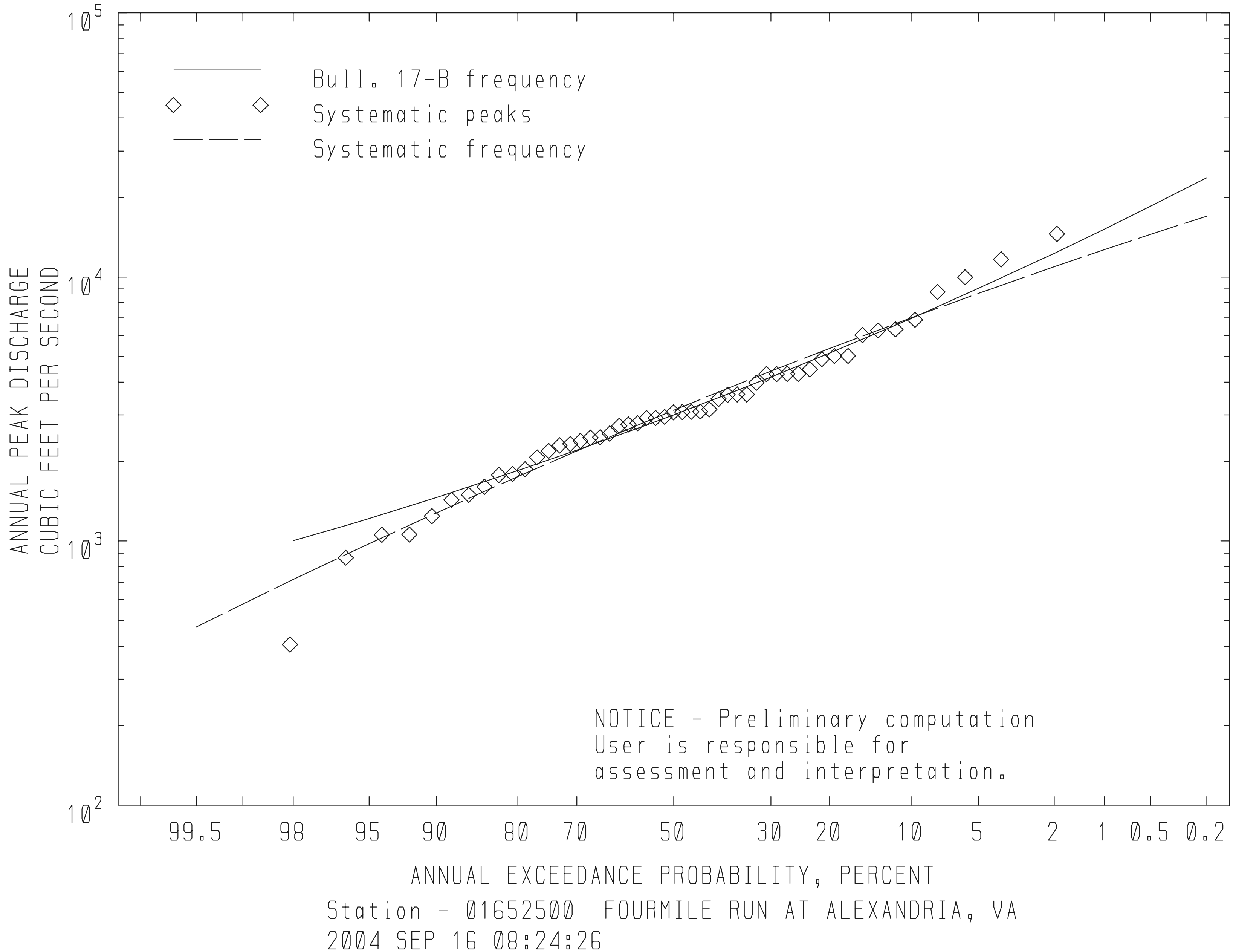
for

WY1952 – WY2003 Data

Adjusted with the Anderson Factors

Run WY1952 through WY2003 adjusted with the Anderson Factors





Run 2 – WY1952 Thru WY2003 Adjusted with the Anderson Factors

Run 2 – WY1952 thru WY2003 adjusted with Anderson Factors – WATSTORE Input File

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N01652500      FOURMILE RUN AT ALEXANDRIA, VA
Y01652500
301652500      19520709   2336                   5.60
301652500      19530505   5037                   8.50
301652500      19540503   1247                   4.22
301652500      19550708   3095                   6.91
301652500      19560722   1877                   5.10
301652500      19570123   1061                   4.12
301652500      19580708   1784                   5.27
301652500      19590613   1438                   4.90
301652500      19600613    867                   4.08
301652500      19610826   3600                   7.00
301652500      19620531   1060                   4.45
301652500      19630820  11700                   9.89
301652500      19640513   1800                   5.41
301652500      19650718   2560                   6.15
301652500      19660914   6900                   7.83
301652500      19670824   6290                   7.93
301652500      19680627   5040                   7.28
301652500      19690722  14600                  11.60
301652500      19700709   8800                  10.70
301652500      19710729   4300                   6.90
301652500      19720621  10000                  12.40
301652500      19730820   4900                   9.20
301652500      19740830   2930                   8.55
301652500      19750926   6350                  13.07
301652500      19760916   2200
301652500      19770712   36002                  9.28
301652500      19790905   3080                   8.36
301652500      19791001   2470                   7.49
301652500      19810704   2800                   7.96
301652500      19820601   2960                   8.20
301652500      19830621   2770                   7.92
301652500      19840329   2400                   7.90
301652500      19850910   4480                  10.36
301652500      19860720   2930                   8.15
301652500      19870626   4310                  10.12
301652500      19880506   2740                   7.87
301652500      19890505   3100                   8.25
301652500      19900509   3090                   8.38
301652500      19901023   3990                   9.66
301652500      19920724   3460                   8.90
301652500      19921123   2480                   8.10
301652500      19931128   4310                  10.23
301652500      19950308   1610                   7.28
301652500      19960119   1500                   7.18
301652500      19970526    407                   5.90
301652500      19980922   2310                   7.94
301652500      19990614   3160                   8.58
301652500      20000622   4300                   9.79
301652500      20010522   3590                   9.01
301652500      20020419   2080                   7.48
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301652500	20030923	6040	11.83

Run 2 – WY1952 thru WY2003 – PeakFQ Output File

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                        U. S. GEOLOGICAL SURVEY
                  ANNUAL PEAK FLOW FREQUENCY ANALYSIS
                  Following Bulletin 17-B Guidelines
                            Program peakfq
                       (Version 4.1, February, 2002)


                      --- PROCESSING DATE/TIME ---

                          2004 SEP 16 08:24:26

                       --- PROCESSING OPTIONS ---

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                   Debug print         = No
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                   Input peaks format  = WATSTORE peak file

1

                        U. S. GEOLOGICAL SURVEY
                  ANNUAL PEAK FLOW FREQUENCY ANALYSIS
                  Following Bulletin 17-B Guidelines
                            Program peakfq
                       (Version 4.1, February, 2002)



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                          2004 SEP 16 08:24:26


                  I N P U T   D A T A   S U M M A R Y

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             Peaks not used in analysis          =        0
             Systematic peaks in analysis        =       51
             Historic peaks in analysis          =        0
             Years of historic record            =        0
             Generalized skew                    =    0.687
             Standard error of generalized skew  =    0.550
             Skew option                         =   WEIGHTED
             Gage base discharge                 =      0.0
             User supplied high outlier threshold =   --
             User supplied low outlier criterion  =   --
             Plotting position parameter         =     0.00


  *********  NOTICE  --  Preliminary machine computations.        *********
  *********  User responsible for assessment and interpretation.  *********
```

```
    WCF134I-NO SYSTEMATIC PEAKS WERE BELOW GAGE BASE.                     0.0
    WCF198I-LOW OUTLIERS BELOW FLOOD BASE WERE DROPPED.         1    481.9
    WCF163I-NO HIGH OUTLIERS OR HISTORIC PEAKS EXCEEDED HHBASE.     19154.0
1
```

Station - 01652500 FOURMILE RUN AT ALEXANDRIA, VA
2004 SEP 16 08:24:26

ANNUAL FREQUENCY CURVE PARAMETERS -- LOG-PEARSON TYPE III

	FLOOD BASE		LOGARITHMIC		
	DISCHARGE	EXCEEDANCE PROBABILITY	MEAN	STANDARD DEVIATION	SKEW
SYSTEMATIC RECORD	0.0	1.0000	3.4836	0.2885	-0.239
BULL.17B ESTIMATE	481.9	0.9804	3.4940	0.2657	0.361

ANNUAL FREQUENCY CURVE -- DISCHARGES AT SELECTED EXCEEDANCE PROBABILITIES

ANNUAL EXCEEDANCE PROBABILITY	BULL.17B ESTIMATE	SYSTEMATIC RECORD	'EXPECTED PROBABILITY' ESTIMATE	95-PCT CONFIDENCE LIMITS FOR BULL. 17B ESTIMATES LOWER	UPPER
0.9950	--	473.9	--	--	--
0.9900	--	578.2	--	--	--
0.9500	1219.0	977.7	1191.0	959.0	1470.0
0.9000	1464.0	1280.0	1442.0	1183.0	1736.0
0.8000	1850.0	1757.0	1835.0	1541.0	2156.0
0.5000	3007.0	3127.0	3007.0	2603.0	3465.0
0.2000	5149.0	5360.0	5203.0	4422.0	6165.0
0.1000	6968.0	7002.0	7121.0	5850.0	8679.0
0.0400	9782.0	9208.0	10190.0	7941.0	12840.0
0.0200	12290.0	10930.0	13040.0	9725.0	16770.0
0.0100	15190.0	12700.0	16470.0	11720.0	21500.0
0.0050	18530.0	14520.0	20600.0	13950.0	27180.0
0.0020	23740.0	17010.0	27380.0	17320.0	36440.0
0.6667	2331.8	(1.50-year flood)			
0.4292	3346.5	(2.33-year flood)			

1

Station - 01652500 FOURMILE RUN AT ALEXANDRIA, VA
2004 SEP 16 08:24:26

I N P U T   D A T A   L I S T I N G

WATER YEAR	DISCHARGE	CODES	WATER YEAR	DISCHARGE	CODES
1952	2336.0		1979	3080.0	

1953	5037.0	1980	2470.0
1954	1247.0	1981	2800.0
1955	3095.0	1982	2960.0
1956	1877.0	1983	2770.0
1957	1061.0	1984	2400.0
1958	1784.0	1985	4480.0
1959	1438.0	1986	2930.0
1960	867.0	1987	4310.0
1961	3600.0	1988	2740.0
1962	1060.0	1989	3100.0
1963	11700.0	1990	3090.0
1964	1800.0	1991	3990.0
1965	2560.0	1992	3460.0
1966	6900.0	1993	2480.0
1967	6290.0	1994	4310.0
1968	5040.0	1995	1610.0
1969	14600.0	1996	1500.0
1970	8800.0	1997	407.0
1971	4300.0	1998	2310.0
1972	10000.0	1999	3160.0
1973	4900.0	2000	4300.0
1974	2930.0	2001	3590.0
1975	6350.0	2002	2080.0
1976	2200.0	2003	6040.0
1977	3600.0		

Explanation of peak discharge qualification codes

PEAKFQ CODE	WATSTORE CODE	DEFINITION
D	3	Dam failure, non-recurrent flow anomaly
G	8	Discharge greater than stated value
X	3+8	Both of the above
L	4	Discharge less than stated value
K	6 OR C	Known effect of regulation or urbanization
H	7	Historic peak

1

Station - 01652500 FOURMILE RUN AT ALEXANDRIA, VA
2004 SEP 16 08:24:26

EMPIRICAL FREQUENCY CURVES -- WEIBULL PLOTTING POSITIONS

WATER YEAR	RANKED DISCHARGE	SYSTEMATIC RECORD	BULL.17B ESTIMATE
1969	14600.0	0.0192	0.0192
1963	11700.0	0.0385	0.0385

1972	10000.0	0.0577	0.0577
1970	8800.0	0.0769	0.0769
1966	6900.0	0.0962	0.0962
1975	6350.0	0.1154	0.1154
1967	6290.0	0.1346	0.1346
2003	6040.0	0.1538	0.1538
1968	5040.0	0.1731	0.1731
1953	5037.0	0.1923	0.1923
1973	4900.0	0.2115	0.2115
1985	4480.0	0.2308	0.2308
1987	4310.0	0.2500	0.2500
1994	4310.0	0.2692	0.2692
1971	4300.0	0.2885	0.2885
2000	4300.0	0.3077	0.3077
1991	3990.0	0.3269	0.3269
1961	3600.0	0.3462	0.3462
1977	3600.0	0.3654	0.3654
2001	3590.0	0.3846	0.3846
1992	3460.0	0.4038	0.4038
1999	3160.0	0.4231	0.4231
1989	3100.0	0.4423	0.4423
1955	3095.0	0.4615	0.4615
1990	3090.0	0.4808	0.4808
1979	3080.0	0.5000	0.5000
1982	2960.0	0.5192	0.5192
1974	2930.0	0.5385	0.5385
1986	2930.0	0.5577	0.5577
1981	2800.0	0.5769	0.5769
1983	2770.0	0.5962	0.5962
1988	2740.0	0.6154	0.6154
1965	2560.0	0.6346	0.6346
1993	2480.0	0.6538	0.6538
1980	2470.0	0.6731	0.6731
1984	2400.0	0.6923	0.6923
1952	2336.0	0.7115	0.7115
1998	2310.0	0.7308	0.7308
1976	2200.0	0.7500	0.7500
2002	2080.0	0.7692	0.7692
1956	1877.0	0.7885	0.7885
1964	1800.0	0.8077	0.8077
1958	1784.0	0.8269	0.8269
1995	1610.0	0.8462	0.8462
1996	1500.0	0.8654	0.8654
1959	1438.0	0.8846	0.8846
1954	1247.0	0.9038	0.9038
1957	1061.0	0.9231	0.9231
1962	1060.0	0.9423	0.9423
1960	867.0	0.9615	0.9615
1997	407.0	0.9808	0.9808

1

U. S. GEOLOGICAL SURVEY
ANNUAL PEAK FLOW FREQUENCY ANALYSIS
Following Bulletin 17-B Guidelines
Program peakfq

(Version 4.1, February, 2002)

```
End PEAKFQ analysis.
  Stations processed :       1
  Number of errors   :       0
  Stations skipped   :       0
  Station years      :      51
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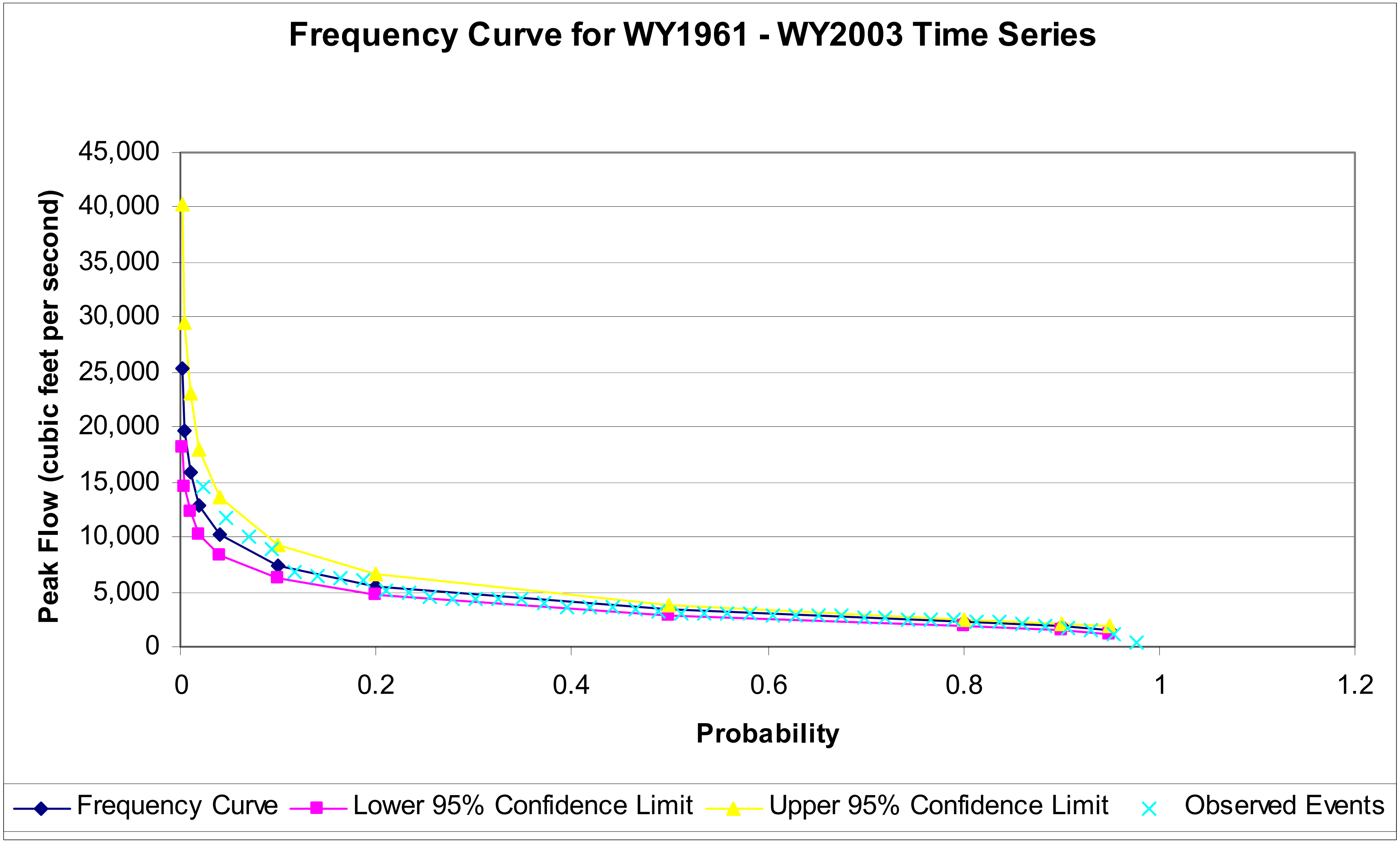
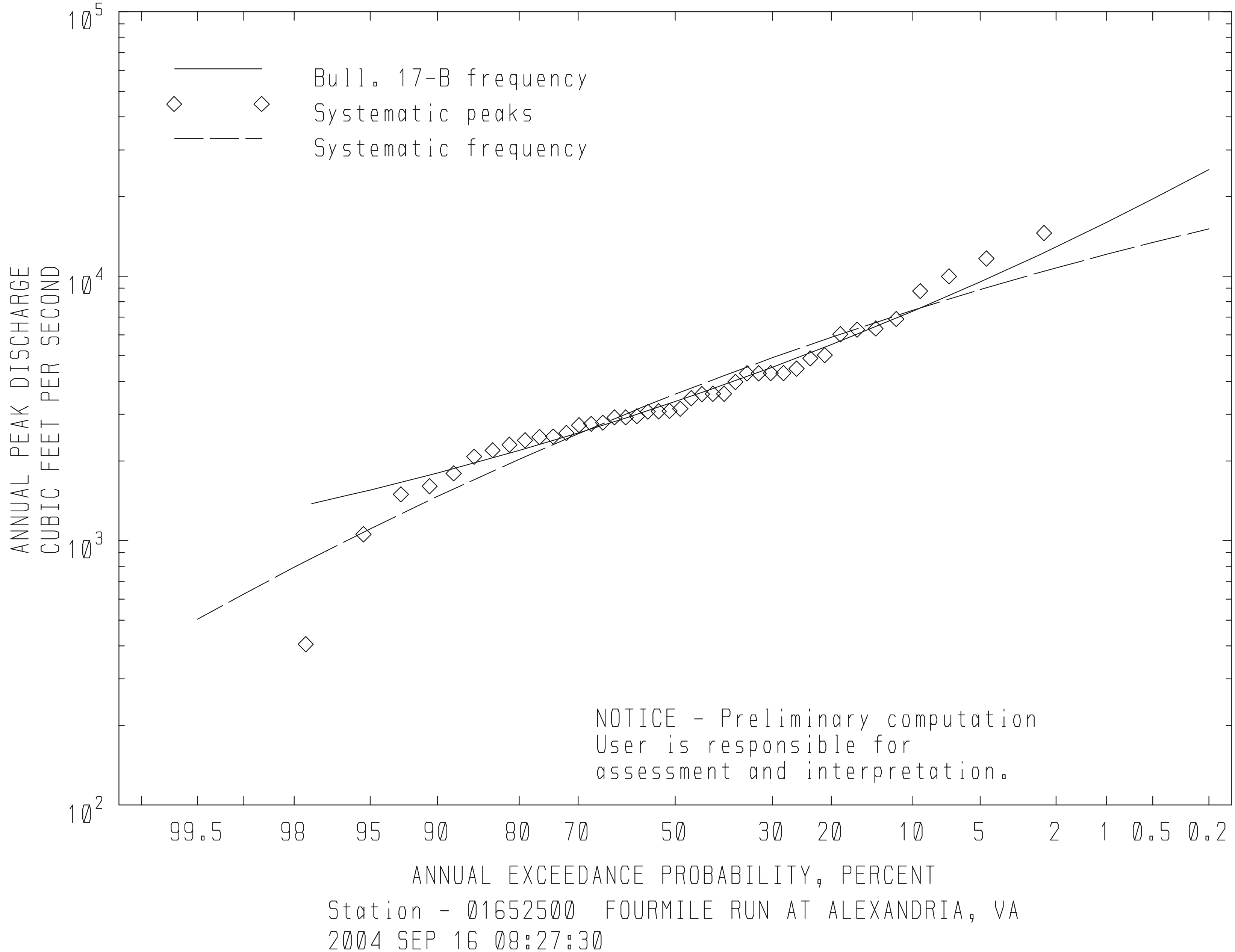
Flood Frequency Analysis

for

WY1961 – WY2003 Data

Run 1961 through 2002





Run 3 – WY1961 Thru WY2003

Run 3 – WY1961 thru WY2003 – Input WATSTORE File

```
Z01652500                        USGS
H01652500       385036077044600515151OSW0207001013.80            28.57
N01652500       FOURMILE RUN AT ALEXANDRIA, VA
Y01652500
301652500       19610826   3600               7.00
301652500       19620531   1060               4.45
301652500       19630820  11700               9.89
301652500       19640513   1800               5.41
301652500       19650718   2560               6.15
301652500       19660914   6900               7.83
301652500       19670824   6290               7.93
301652500       19680627   5040               7.28
301652500       19690722  14600              11.60
301652500       19700709   8800              10.70
301652500       19710729   4300               6.90
301652500       19720621  10000              12.40
301652500       19730820   4900               9.20
301652500       19740830   2930               8.55
301652500       19750926   6350              13.07
301652500       19760916   2200
301652500       19770712   36002              9.28
301652500       19790905   3080               8.36
301652500       19791001   2470               7.49
301652500       19810704   2800               7.96
301652500       19820601   2960               8.20
301652500       19830621   2770               7.92
301652500       19840329   2400               7.90
301652500       19850910   4480              10.36
301652500       19860720   2930               8.15
301652500       19870626   4310              10.12
301652500       19880506   2740               7.87
301652500       19890505   3100               8.25
301652500       19900509   3090               8.38
301652500       19901023   3990               9.66
301652500       19920724   3460               8.90
301652500       19921123   2480               8.10
301652500       19931128   4310              10.23
301652500       19950308   1610               7.28
301652500       19960119   1500               7.18
301652500       19970526    407               5.90
301652500       19980922   2310               7.94
301652500       19990614   3160               8.58
301652500       20000622   4300               9.79
301652500       20010522   3590               9.01
301652500       20020419   2080               7.48
301652500       20030923   6040              11.83
```

Run 3 – WY1961 thru WY2003 – PeakFQ Output File

```
1
                          U. S. GEOLOGICAL SURVEY
                    ANNUAL PEAK FLOW FREQUENCY ANALYSIS
                    Following Bulletin 17-B Guidelines
                              Program peakfq
                         (Version 4.1, February, 2002)


                       --- PROCESSING DATE/TIME ---

                            2004 SEP 16 08:27:30

                        --- PROCESSING OPTIONS ---

                     Plot option         = Graphics device
                     Basin char output   = None
                     Print option        = Yes
                     Debug print         = No
                     Input peaks listing = Long
                     Input peaks format  = WATSTORE peak file

1

                          U. S. GEOLOGICAL SURVEY
                    ANNUAL PEAK FLOW FREQUENCY ANALYSIS
                    Following Bulletin 17-B Guidelines
                              Program peakfq
                         (Version 4.1, February, 2002)



              Station - 01652500  FOURMILE RUN AT ALEXANDRIA, VA
                            2004 SEP 16 08:27:30


                    I N P U T   D A T A   S U M M A R Y

               Number of peaks in record            =       42
               Peaks not used in analysis           =        0
               Systematic peaks in analysis         =       42
               Historic peaks in analysis           =        0
               Years of historic record             =        0
               Generalized skew                     =    0.687
               Standard error of generalized skew   =    0.550
               Skew option                          =   WEIGHTED
               Gage base discharge                  =      0.0
               User supplied high outlier threshold =   --
               User supplied low outlier criterion  =   --
               Plotting position parameter          =     0.00


  *********  NOTICE  --  Preliminary machine computations.        *********
  *********  User responsible for assessment and interpretation.  *********
```

```
    WCF134I-NO SYSTEMATIC PEAKS WERE BELOW GAGE BASE.                    0.0
    WCF198I-LOW OUTLIERS BELOW FLOOD BASE WERE DROPPED.          1    609.9
    WCF163I-NO HIGH OUTLIERS OR HISTORIC PEAKS EXCEEDED HHBASE.     15696.1
1
```

Station - 01652500 FOURMILE RUN AT ALEXANDRIA, VA
2004 SEP 16 08:27:30

ANNUAL FREQUENCY CURVE PARAMETERS -- LOG-PEARSON TYPE III

	FLOOD BASE		LOGARITHMIC		
	DISCHARGE	EXCEEDANCE PROBABILITY	MEAN	STANDARD DEVIATION	SKEW
SYSTEMATIC RECORD	0.0	1.0000	3.5324	0.2767	-0.455
BULL.17B ESTIMATE	609.9	0.9762	3.5472	0.2413	0.548

ANNUAL FREQUENCY CURVE -- DISCHARGES AT SELECTED EXCEEDANCE PROBABILITIES

ANNUAL EXCEEDANCE PROBABILITY	BULL.17B ESTIMATE	SYSTEMATIC RECORD	'EXPECTED PROBABILITY' ESTIMATE	95-PCT CONFIDENCE LIMITS FOR BULL. 17B ESTIMATES LOWER	UPPER
0.9950	--	503.9	--	--	--
0.9900	--	628.0	--	--	--
0.9500	1554.0	1108.0	1519.0	1224.0	1865.0
0.9000	1802.0	1469.0	1775.0	1455.0	2131.0
0.8000	2190.0	2031.0	2172.0	1820.0	2552.0
0.5000	3352.0	3575.0	3352.0	2898.0	3863.0
0.2000	5511.0	5878.0	5579.0	4739.0	6607.0
0.1000	7363.0	7427.0	7556.0	6187.0	9216.0
0.0400	10270.0	9352.0	10790.0	8320.0	13630.0
0.0200	12890.0	10740.0	13880.0	10160.0	17880.0
0.0100	15970.0	12090.0	17670.0	12230.0	23110.0
0.0050	19570.0	13410.0	22370.0	14580.0	29520.0
0.0020	25280.0	15090.0	30350.0	18180.0	40210.0
0.6667	2675.2	(1.50-year flood)			
0.4292	3688.9	(2.33-year flood)			

1

Station - 01652500 FOURMILE RUN AT ALEXANDRIA, VA
2004 SEP 16 08:27:30

I N P U T   D A T A   L I S T I N G

WATER YEAR	DISCHARGE	CODES	WATER YEAR	DISCHARGE	CODES
1961	3600.0		1983	2770.0	

1962	1060.0	1984	2400.0
1963	11700.0	1985	4480.0
1964	1800.0	1986	2930.0
1965	2560.0	1987	4310.0
1966	6900.0	1988	2740.0
1967	6290.0	1989	3100.0
1968	5040.0	1990	3090.0
1969	14600.0	1991	3990.0
1970	8800.0	1992	3460.0
1971	4300.0	1993	2480.0
1972	10000.0	1994	4310.0
1973	4900.0	1995	1610.0
1974	2930.0	1996	1500.0
1975	6350.0	1997	407.0
1976	2200.0	1998	2310.0
1977	3600.0	1999	3160.0
1979	3080.0	2000	4300.0
1980	2470.0	2001	3590.0
1981	2800.0	2002	2080.0
1982	2960.0	2003	6040.0

Explanation of peak discharge qualification codes

PEAKFQ CODE	WATSTORE CODE	DEFINITION
D	3	Dam failure, non-recurrent flow anomaly
G	8	Discharge greater than stated value
X	3+8	Both of the above
L	4	Discharge less than stated value
K	6 OR C	Known effect of regulation or urbanization
H	7	Historic peak

1

Station - 01652500 FOURMILE RUN AT ALEXANDRIA, VA
2004 SEP 16 08:27:30

EMPIRICAL FREQUENCY CURVES -- WEIBULL PLOTTING POSITIONS

WATER YEAR	RANKED DISCHARGE	SYSTEMATIC RECORD	BULL.17B ESTIMATE
1969	14600.0	0.0233	0.0233
1963	11700.0	0.0465	0.0465
1972	10000.0	0.0698	0.0698
1970	8800.0	0.0930	0.0930
1966	6900.0	0.1163	0.1163
1975	6350.0	0.1395	0.1395
1967	6290.0	0.1628	0.1628
2003	6040.0	0.1860	0.1860

1968	5040.0	0.2093	0.2093
1973	4900.0	0.2326	0.2326
1985	4480.0	0.2558	0.2558
1987	4310.0	0.2791	0.2791
1994	4310.0	0.3023	0.3023
1971	4300.0	0.3256	0.3256
2000	4300.0	0.3488	0.3488
1991	3990.0	0.3721	0.3721
1961	3600.0	0.3953	0.3953
1977	3600.0	0.4186	0.4186
2001	3590.0	0.4419	0.4419
1992	3460.0	0.4651	0.4651
1999	3160.0	0.4884	0.4884
1989	3100.0	0.5116	0.5116
1990	3090.0	0.5349	0.5349
1979	3080.0	0.5581	0.5581
1982	2960.0	0.5814	0.5814
1974	2930.0	0.6047	0.6047
1986	2930.0	0.6279	0.6279
1981	2800.0	0.6512	0.6512
1983	2770.0	0.6744	0.6744
1988	2740.0	0.6977	0.6977
1965	2560.0	0.7209	0.7209
1993	2480.0	0.7442	0.7442
1980	2470.0	0.7674	0.7674
1984	2400.0	0.7907	0.7907
1998	2310.0	0.8140	0.8140
1976	2200.0	0.8372	0.8372
2002	2080.0	0.8605	0.8605
1964	1800.0	0.8837	0.8837
1995	1610.0	0.9070	0.9070
1996	1500.0	0.9302	0.9302
1962	1060.0	0.9535	0.9535
1997	407.0	0.9767	0.9767

1

U. S. GEOLOGICAL SURVEY
ANNUAL PEAK FLOW FREQUENCY ANALYSIS
Following Bulletin 17-B Guidelines
Program peakfq
(Version 4.1, February, 2002)

```
 End PEAKFQ analysis.
   Stations processed :       1
   Number of errors   :       0
   Stations skipped   :       0
   Station years      :      42
```

USGS Data

For

Station 1652500 on Four Mile Run

Peak Streamflow for Virginia

USGS 01652500 FOURMILE RUN AT ALEXANDRIA, VA

Alexandria City, Virginia Hydrologic Unit Code 02070010 Latitude 38°50'36", Longitude 77°04'46" NAD27	Drainage area 13.80 square miles Gage datum 28.57 feet above sea level NGVD29

Water Year	Date	Gage Height (feet)	Stream-flow (cfs)
1947	Jun. 07, 1947	7.20	2,250[7]
1952	Jul. 09, 1952	5.60	1,600
1953	May 05, 1953	8.50	3,450
1954	May 03, 1954	4.22	854
1955	Jul. 08, 1955	6.91	2,120
1956	Jul. 22, 1956	5.10	1,350
1957	Jan. 23, 1957	4.12	810
1958	Jul. 08, 1958	5.27	1,450
1959	Jun. 13, 1959	4.90	1,250
1960	Jun. 13, 1960	4.08	810
1961	Aug. 26, 1961	7.00	3,600
1962	May 31, 1962	4.45	1,060
1963	Aug. 20, 1963	9.89	11,700
1964	May 13, 1964	5.41	1,800
1965	Jul. 18, 1965	6.15	2,560
1966	Sep. 14, 1966	7.83	6,900
1967	Aug. 24, 1967	7.93	6,290
1968	Jun. 27, 1968	7.28	5,040
1969	Jul. 22, 1969	11.60	14,600
1970	Jul. 09, 1970	10.70	8,800
1971	Jul. 29, 1971	6.90	4,300
1972	Jun. 21, 1972	12.40	10,000
1973	Aug. 20, 1973	9.20	4,900
1974	Aug. 30, 1974	8.55	2,930
1975	Sep. 26, 1975	13.07	6,350
1976	Sep. 16, 1976		2,200

Water Year	Date	Gage Height (feet)	Stream-flow (cfs)
1977	Jul. 12, 1977	9.28	3,600[2]
1979	Sep. 05, 1979	8.36	3,080
1980	Oct. 01, 1979	7.49	2,470
1981	Jul. 04, 1981	7.96	2,800
1982	Jun. 01, 1982	8.20	2,960
1983	Jun. 21, 1983	7.92	2,770
1984	Mar. 29, 1984	7.90	2,400
1985	Sep. 10, 1985	10.36	4,480
1986	Jul. 20, 1986	8.15	2,930
1987	Jun. 26, 1987	10.12	4,310
1988	May 06, 1988	7.87	2,740
1989	May 05, 1989	8.25	3,100
1990	May 09, 1990	8.38	3,090
1991	Oct. 23, 1990	9.66	3,990
1992	Jul. 24, 1992	8.90	3,460
1993	Nov. 23, 1992	8.10	2,480
1994	Nov. 28, 1993	10.23	4,310
1995	Mar. 08, 1995	7.28	1,610
1996	Jan. 19, 1996	7.18	1,500
1997	May 26, 1997	5.90	407
1998	Sep. 22, 1998	7.94	2,310
1999	Jun. 14, 1999	8.58	3,160
2000	Jun. 22, 2000	9.79	4,300
2001	May 22, 2001	9.01	3,590
2002	Apr. 19, 2002	7.48	2,080
2003	Sep. 23, 2003	11.83	6040

Peak Streamflow Qualification Codes.

- 2 -- Discharge is an Estimate
- 7 -- Discharge is an Historic Peak