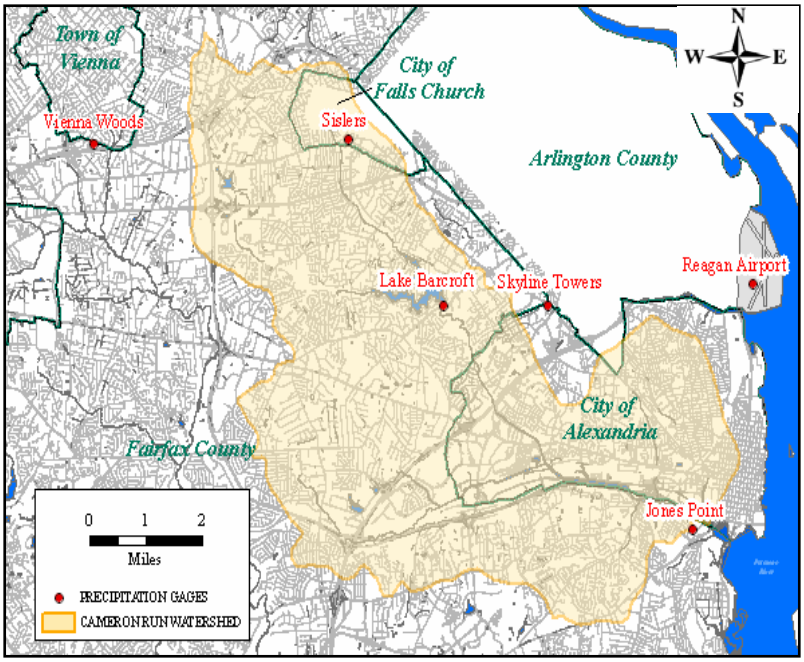
5.0 HYDROLOGIC ANALYSIS

5.1 PRECIPITATION DATA

There are six precipitation gages located in or within close proximity of the Cameron Run watershed (Figure 5.1). The Ronald Reagan National Airport precipitation gage is operated by NOAA's National Climatic Data Center (NCDC). The following gages are owned and operated by Fairfax County: Sislers, Skyline Towers, Jones Point, and Vienna Woods. The Lake Barcroft precipitation gage is owned and operated by LBWID.

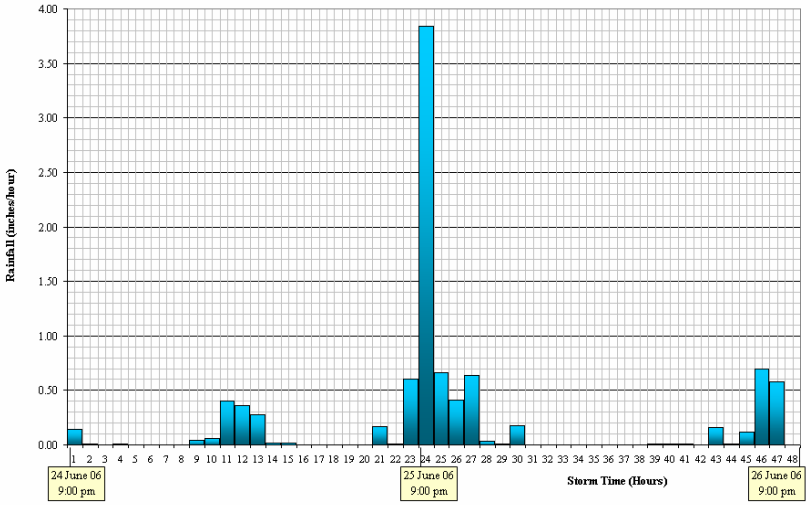
Figure 5.1. Precipitation Gages in or near the Cameron Run Watershed



During the June 2006 flood event, all gages shown in Figure 5.1 were functional and recorded precipitation data. The storm duration was approximately 48 hours in length, starting at roughly 9:00 pm on June 24, 2006 and ending at approximately 9:00 pm on June 26, 2006. Hyetographs and total precipitation curves for each gage are located in Appendix B.

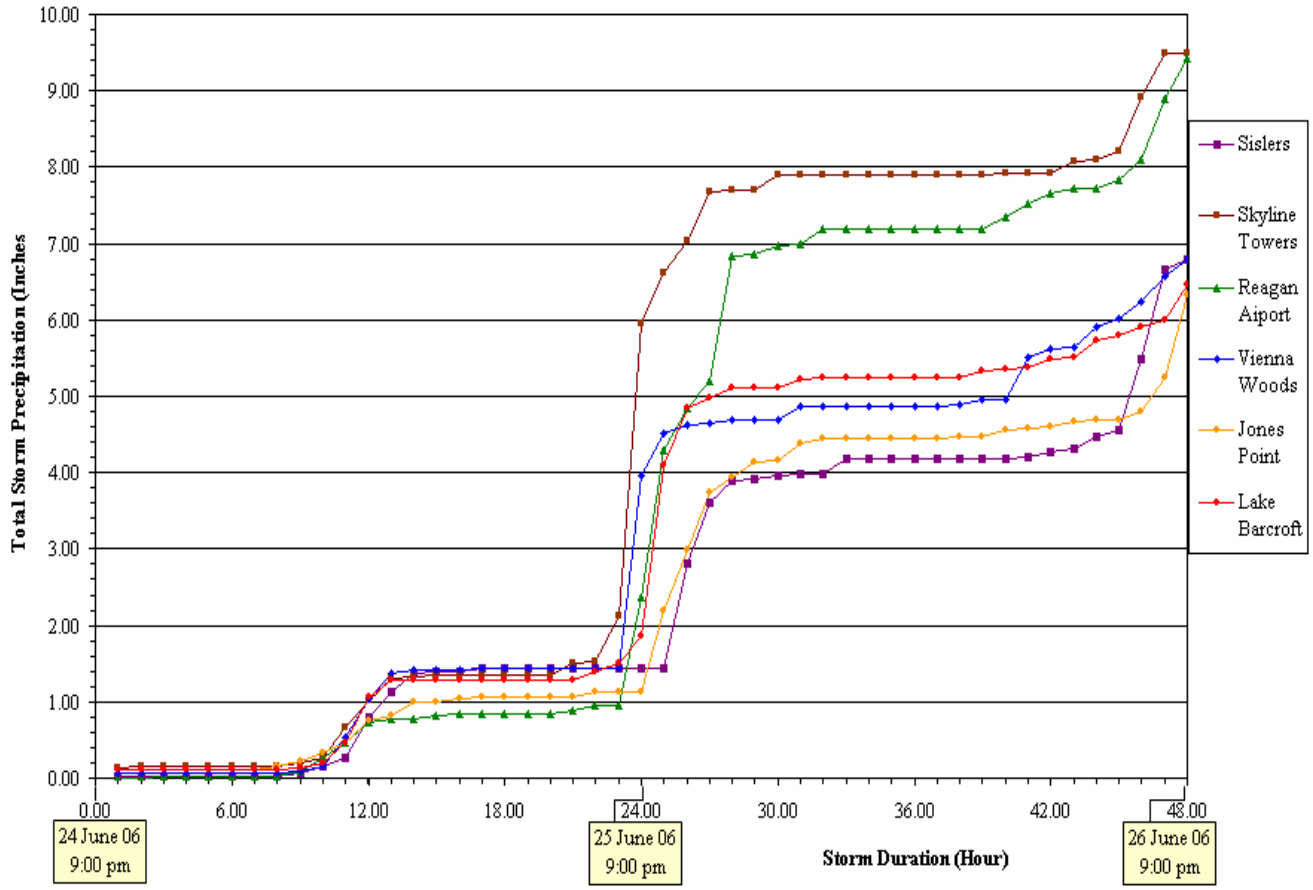
The precipitation gages recorded the same pattern of precipitation: low rainfall totals from the beginning of the storm to about hour 22 of the storm (approximately 7:00 pm on June 25, 2006). At approximately 7:00 pm on June 25, 2006, rainfall intensities began to increase. The Skyline Towers gage located in the Four Mile Run watershed recorded approximately 3.8 inches of rainfall between 8:00 pm and 9:00 pm on June 25, 2006 (Figure 5.2). Vienna Woods recorded over 2.5 inches of rain in the same time period. Overall, the heaviest rains occurred between 7:00 pm on June 25, 2006 and 1:00 am on June 26, 2006.

Figure 5.2. Storm Hyetograph for Skyline Towers



Precipitation totals over the 48-hour storm duration were nine to ten inches in some areas (Figure 5.3). The Skyline Towers and Ronald Reagan National Airport gages recorded between 9 and 10 inches of total rainfall over the 48-hour period. The other four precipitation gages recorded rainfall totals between 6 and 7 inches.

Figure 5.3. Total Storm Precipitation Curves for All Gages

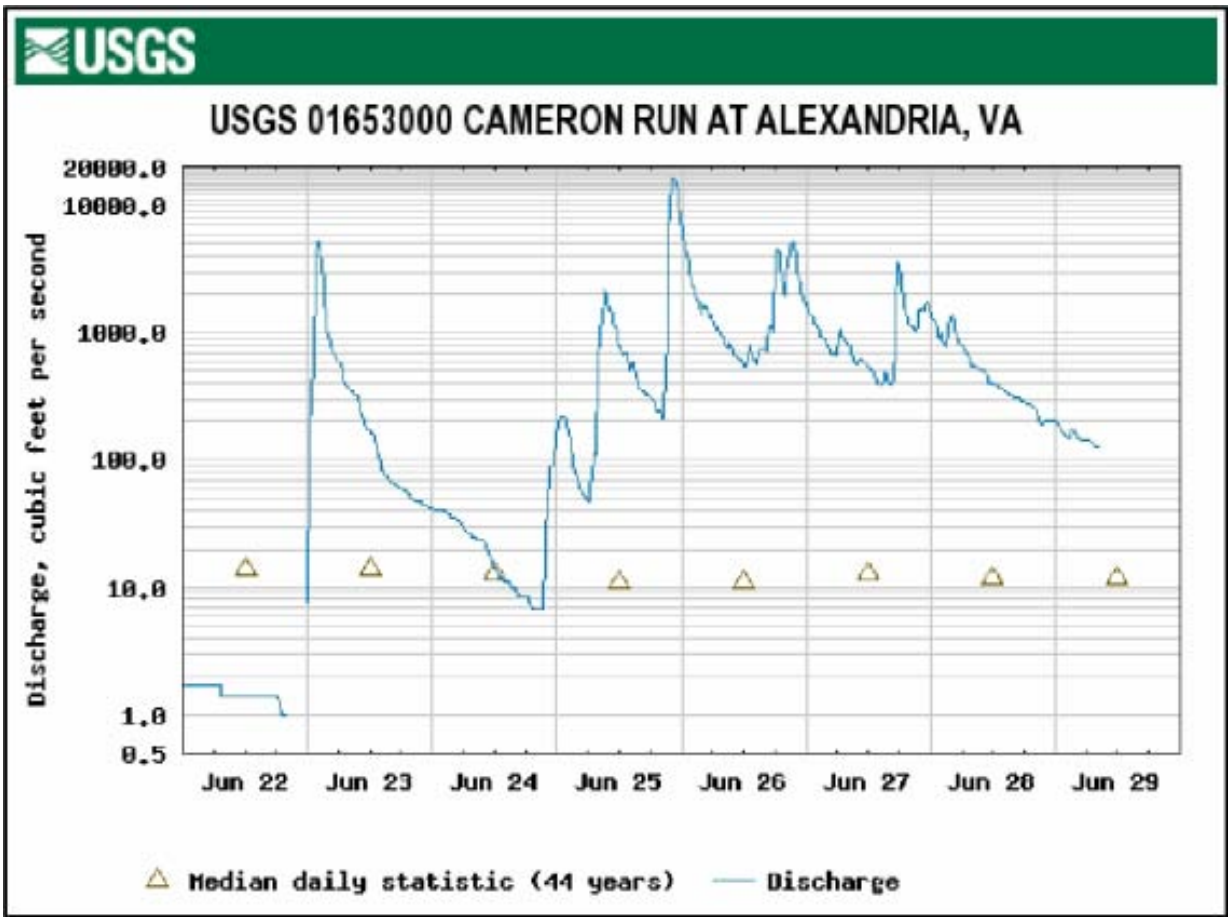


5.2 USGS GAGE DATA

USGS operates a continuous streamflow measurement gage along Cameron Run in the City of Alexandria; the gage location is shown in Figure 1.1. The gage, identified as USGS 01653000, has a record of flows from 1955 to present, and was functional during the June 2006 flood event. The drainage area to the gage is 33.7 square miles and the base gage elevation is 31.74 feet NGVD29.

The USGS gage recorded a peak discharge of 16,500 cfs for Cameron Run at 10:15 pm on June 25, 2006 (Figure 5.4). The stage at the gage for this peak flow was 15.52 feet (elevation 47.26 feet NGVD29). The peak discharge of 16,500 cfs was the second highest recorded at the gage. On June 22, 1972, the gage recorded a peak flow of 19,900 cfs, which was flow associated with rainfall from remnants of Tropical Storm Agnes. A table showing the recorded peak flows for the entire June 2006 flood event is located in Appendix C.

Figure 5.4. Observed Hydrograph for June 2006 Flood Event at USGS 01653000



5.3 LAKE BARCROFT RELEASE

Lake Barcroft is a man-made reservoir that is operated and managed by the Lake Barcroft Watershed Improvement District (LBWID). The LBWID is governed by the Commonwealth of Virginia via the Northern Virginia Soil and Water Conservation District, and is regulated, monitored, and inspected by the Virginia Dam Safety Board. The drainage area to the 135-acre Lake Barcroft is 14.5 square miles (approximately 35% of the entire Cameron Run watershed). The LBWID published a report titled "*Report on the Response of Lake Barcroft Dam to Heavy Rains during the Period of June 23 through June 29, 2006.*" This report is located in Appendix D.

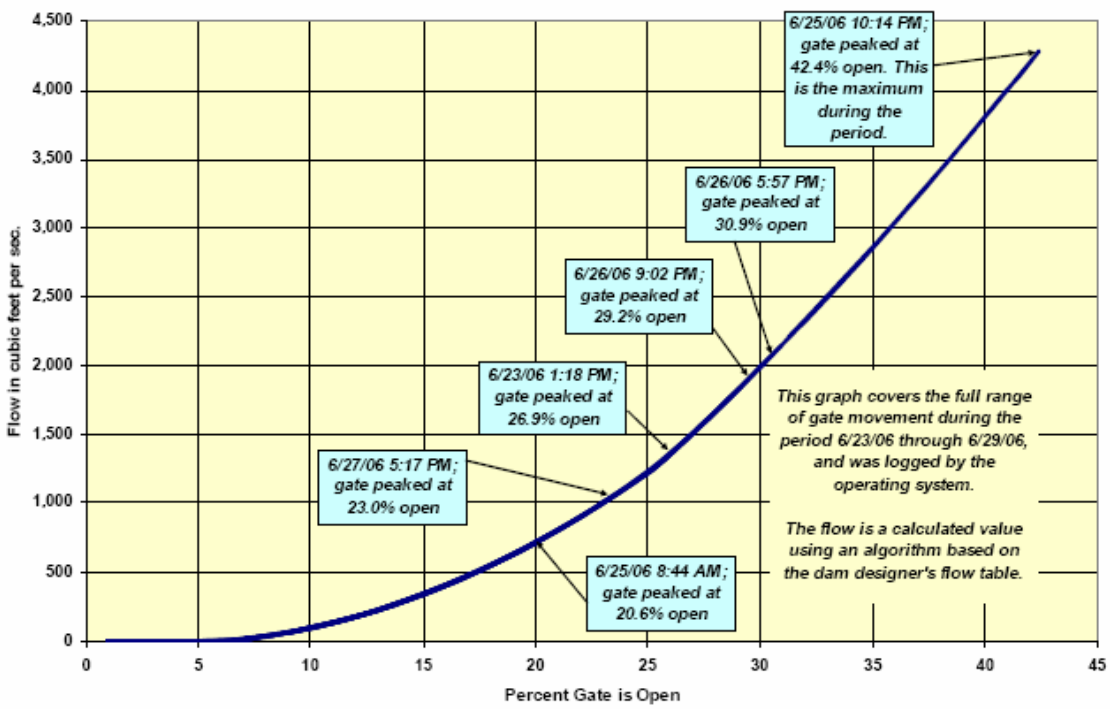
The dam that impounds the water in Lake Barcroft was originally constructed as a masonry dam with earthen embankments at the sides in the early 1900s as a water supply reservoir for the City of Alexandria. The lake and adjoining land was sold in the 1950s, when residential development of the land began. In 1972, during Tropical Storm Agnes, the earthen embankment of the dam eroded at the western end due to the high water in the lake; the erosion scoured the embankment and drained the lake. The dam was rebuilt after this event and was fitted with a 151-foot wide by

12-foot high bascule gate on top of the original masonry. Four hydraulic rams open and close the gate in response to a computer-operated monitoring control system. The system was designed to maintain the lake at a constant level (208.5 to 209.0 feet, NGVD29) to remove the risk of the dam failing.

The control systems for the gates include sensors that measure the water level accurately to the nearest 0.01-foot. The control system updates its readings every second, so as inflowing water begins to increase the elevation of Lake Barcroft, the computer begins the process of sending instructions to the gates to open the specific amount to allow the desired lake level to be maintained. Therefore, by design, Lake Barcroft is an inflow-outflow facility. Hydrologically, it provides minimal storage of excess runoff, and also will not, barring failure, release more water than is entering the lake.

During the June 2006 flood event, the maximum peak discharge exiting the Lake Barcroft facility was 4,300 cfs at 10:14 pm on June 25, 2006. This release rate was based upon the gates being 42.4% open (Figure 5.5).

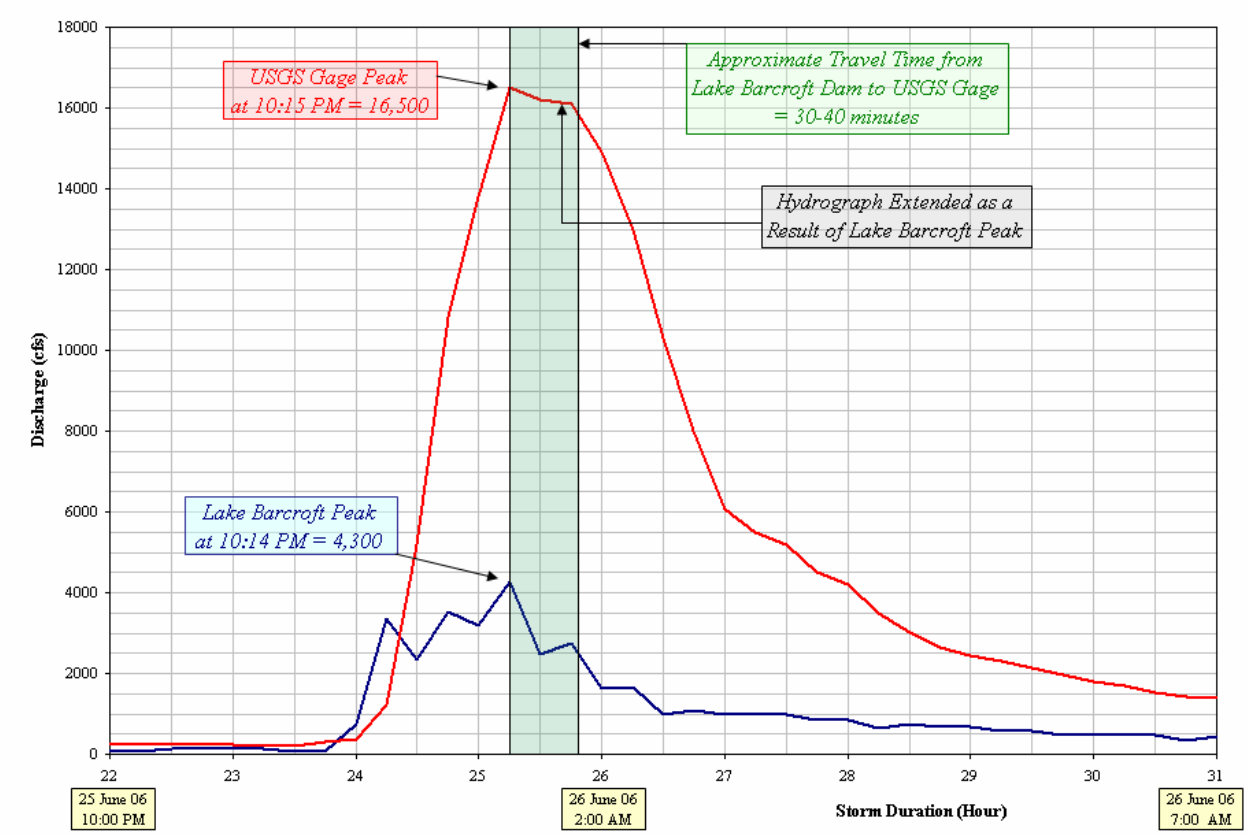
Figure 5.5. Relationship to Gate Opening to Flow over Lake Barcroft Dam during June 2006 Flood Event



Based upon Manning's equation, the estimated channel flow time from the outlet of Lake Barcroft to the USGS gage location is 30 to 40 minutes, depending on exact velocities. For the June 2006 flood event, the peak flow of 16,500 cfs at the USGS stream flow gage was measured at 10:15 PM on June 25, 2006. The peak flow from Lake Barcroft of 4,300 cfs was released between 10:11 and 10:15 PM on June 25, 2006. Therefore, the peak flow from Lake Barcroft did not contribute to the peak flow measured at the USGS gage, as the peaks occurred nearly

simultaneously. Lake Barcroft was releasing approximately 3,700 cfs at roughly 9:45 PM on June 25, 2006, about 30 minutes prior to the peak at the USGS gage. The flows from Lake Barcroft obviously contribute to the peak flows recorded in downstream areas; however, for this storm event, the peak from Lake Barcroft only extended the hydrograph at the USGS gage (Figure 5.6), rather than being the contributing factor to the actual peak recorded at the USGS gage. Based upon the available data, it appears that Lake Barcroft was operating normally, maintaining its design function, and did not release a wave of water that may have intensified the peak flows in Huntington.

Figure 5.6. Comparison of USGS Gage and Lake Barcroft Hydrographs for June 2006 Flood Event



5.4 DEVELOPMENT OF JUNE 2006 PEAK FLOW ESTIMATES

At the present time, there is no hydrologic model that covers the entire Cameron Run watershed. An Environmental Protection Agency (EPA) Storm Water Management Model (SWMM) was prepared by Versar, Inc. for the Fairfax County Stormwater Planning Division in June 2005; however, this model only includes portions of the watershed upstream of the USGS gage as well as the Pike Branch watershed; it does not include areas downstream of the USGS gage or the Taylor Run watershed, which drains approximately 1.6 square miles of the highly urbanized City of Alexandria. Therefore, the model could not be utilized for this investigation. Thus, the USGS

steamflow gage data was relied on exclusively to estimate peak flows for the June 2006 flood event.

The ideal situation for estimating the peak flows for Huntington for the June 2006 flood event would be to have a streamflow gage upstream and downstream of the study area in order to produce a peak flow discharge curve between the two gages. Unfortunately, only one gage exists. Therefore, in order to estimate the peak flows in the study area, three commonly used methods were used and compared. These are the drainage area ratio method, the Anderson method, and USGS regression analysis.

For the purpose of this investigation, four "hydrologic study points" were identified. These points are the Capital Beltway (U.S. Route 495) crossing, Telegraph Road crossing along Cameron Run, the upstream end of Huntington, and the U.S. Route 1 crossing.

5.4.1 DRAINAGE AREA RATIO METHOD

This method is widely used by the U.S. Army Corps of Engineers and other agencies throughout the country to estimate peak flows for ungaged sites that lie upstream or downstream of a gaged site. It assumes a homogenious watershed in which the drainage area to the ungaged site responds to hydrologic factors in the same fashion as the gaged site. Typically, the drainage area of the ungaged site must be within 50 to 150 percent of the gaged site. This method was deemed reasonable for this investigation because nearly 95 percent of the watershed is highly urbanized (Virginia Tech, 2003), with little land use variability between sub-watersheds. The equation used to estimate the peak flows to the hydrologic study points is:

$$\mathbf{Q}_{ungaged} = \mathbf{Q}_{gaged}\,(\mathbf{A}_{ungaged}/\mathbf{A}_{gaged})^{0.8}$$

Where:

$\mathbf{Q}_{ungaged}$ = Peak discharge of ungaged site in cubic feet per second
$\mathbf{Q}_{gaged}$ = Peak discharge of gaged site in cubic feet per second
$\mathbf{A}_{ungaged}$ = Drainage area of ungaged site in square miles
$\mathbf{A}_{gaged}$ = Drainage area of gaged site in square miles

The drainage area to the gaged site, USGS 01653000, is 33.7 square miles, with a June 2006 flood event peak flow of 16,500 cubic feet per second. This method was considered valid for the area in question because (1) the majority of the watershed to the gage and the ungaged site is relatively urbanized evenly across the entire watershed, and (2) Lake Barcroft is an inflow-outflow facility and does not cause bias in the results. An exponent of 1.0 in the equation would imply that the streamflow at the ungaged site is the same per unit area as the gaged site. However, it is characteristic of river basins that discharge of any flood frequency will increase

less rapidly than drainage area. Therefore, an exponent of 0.8 was applied to the equation. The results of the analysis using this method are shown in Table 5.1.

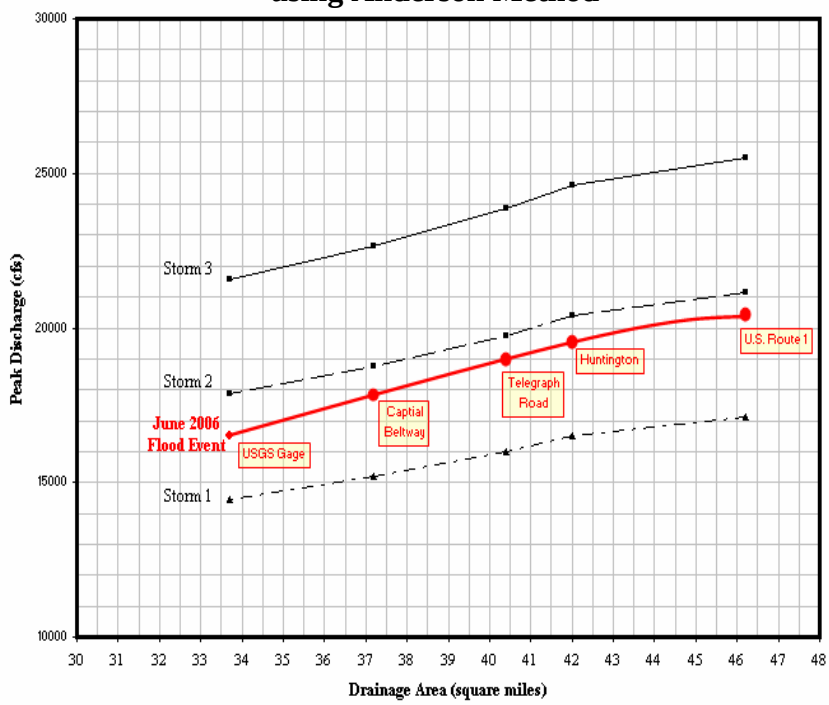
Table 5.1. Estimation of Peak Flows for the June 2006 Flood Event using the Drainage Area Ratio Method

Hydrologic Point	Drainage Area (square miles)	Estimated Peak Flow Using Drainage Area Ratio Method (cfs)
Capital Beltway	37.2	17,900
Telegraph Road	40.4	19,100
Huntington	42.0	19,700
U.S. Route 1	46.2	21,200

5.4.2 ANDERSON METHOD

The Anderson method, outlined in USGS Water Supply Paper 2001, utilizes five independent variables to perform peak flow calculations: the size, length, and slope of the watershed, and the percentage of impervious area and type of drainage system. This method was used by the USGS in Fairfax County's initial flood insurance studies to produce flood maps in the 1970's, as well as in the VDOT Woodrow Wilson Bridge Study (at the direction of FEMA).

Figure 5.7. Peak Discharge vs. Drainage Area Relationship using Anderson Method



For the purposes of estimating the peak flows for the June 2006 flood event, relationships were established for the hydrologic study points along the study reach, based upon the size of the drainage area. The Anderson method was used to estimate flood events of different frequency at each hydrologic study point. The results for each hydrologic study point using the Anderson method were used to develop a graphical peak discharge vs. drainage area relationship. The known flow at the USGS gage for the June 2006 Flood Event was plotted as well, and a curve was interpolated following the relationship established using the Anderson method. Peak discharge estimates for the June 2006 flood event were then estimated for each

hydrologic study point using the developed curve (Figure 5.7). The results of the analysis using the Anderson Method are shown in Table 5.2.

Table 5.2. Estimation of Peak Flows for the June 2006 Flood Event using the Anderson Method

Hydrologic Point	Drainage Area (square miles)	Estimated Peak Flow Using Anderson Method (cfs)
Capital Beltway	37.2	17,800
Telegraph Road	40.4	19,000
Huntington	42.0	19,500
U.S. Route 1	46.2	20,400

5.4.3 REGRESSION ANALYSIS

A regional method for estimating peak discharge at ungaged sites located on a gaged stream is described in *USGS Water-Resources Investigations Report 94-4148, Methods for Estimating the Magnitude and Frequency of Peak Discharges for Rural, Unregulated Streams in Virginia.* This method involves the following steps: (1) estimating the peak discharge of the ungaged site using a regression equation; (2) computation of a correction factor for the gaged site using weighted peak discharge and regional regression peak charge data; (3) computation of a correction factor for the ungaged site using drainage area relationships; and (4) estimation of the peak discharge at the ungaged site using the data developed in previous steps. This method also requires the drainage area of the ungaged site must be within 50 to 150 percent of the gaged site's drainage area, and the watershed be homogenous in nature.

Typically this method is applied when a specific frequency peak discharge is needed, as the regression equations are developed for the 2- through 500-year flood event. However, for this investigation, the frequency storm does not correspond to a defined regression event. In order to develop a reasonable estimation of the peak discharge at the hydrologic study points, a relationship of the overall drainage area was developed using this method. The technique was used to develop peak discharges for floods of various frequencies for Lake Barcroft, the USGS gage, and the hydrologic study points. The results were plotted to develop a relationship between the drainage areas at each site to the peak flows for each frequency storm. This relationship was then used with observed peak flows (16,500 cfs at the USGS gage and 4,300 cfs at Lake Barcroft) to estimate the peak flows for the hydrologic study points (Figure 5.8). The results of the analysis using USGS regression analysis are shown in Table 5.3.

Figure 5.8. Peak Discharge vs. Drainage Area Relationship using Regression Analysis

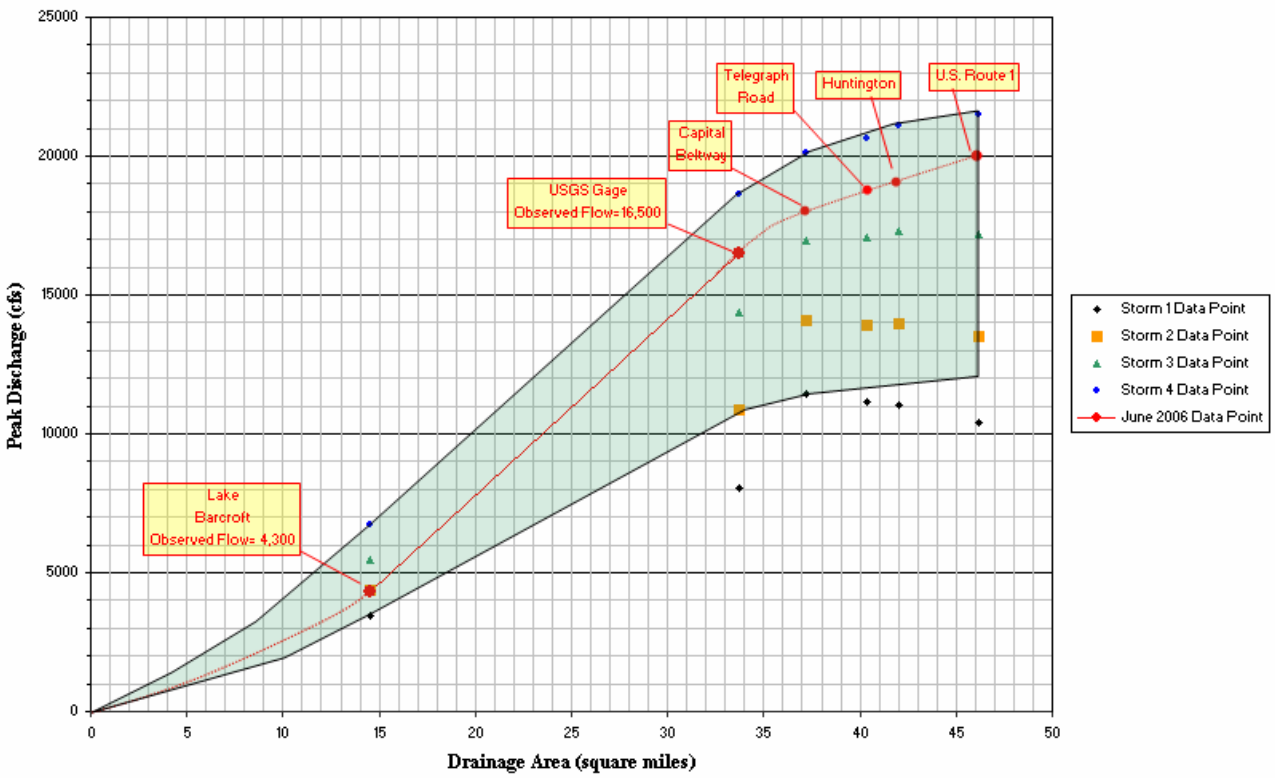


Table 5.3. Estimation of Peak Flows for the June 2006 Flood Event using Regression Analysis

Hydrologic Point	Drainage Area (square miles)	Estimated Peak Flow Using Regression Analysis (cfs)
Capital Beltway	37.2	17,900
Telegraph Road	40.4	18,800
Huntington	42.0	19,100
U.S. Route 1	46.2	20,000

5.4.4 COMPARISON OF RESULTS

A comparison of June 2006 peak flows estimated using the three outlined methods is shown in Table 5. 4.

Table 5.4. Comparison of Peak Flow Results for June 2006 Flood Event

Hydrologic Point	Estimated Peak Flow (cfs)		
	Drainage Area Ratio Method	Anderson Method	Regression Analysis
Capital Beltway	17,900	17,800	17,900
Telegraph Road	19,100	19,000	18,800
Huntington	19,700	19,500	19,100
U.S. Route 1	21,200	20,400	20,000

For the purposes of this investigation, the flows calculated using the drainage area ratio method were used for the hydraulic analysis. The results of the Anderson method and USGS regression analysis confirm that the estimation of peak flows using the drainage area ratio method is reasonable for this highly urbanized watershed.