Proof of Concept Hydrology Studies for the Grand River in Michigan, Skagit River in Washington and Anacostia River in Maryland

Study 1 - Grand River at Grand Rapids, Michigan

Background

The effective flood insurance study for the City of Grand Rapids, Kent County, Michigan is dated November 1982. The major flooding source in the City of Grand Rapids is the Grand River and the drainage area is 4,900 square miles at the U.S. Geological Survey (USGS) gaging station (04119000) located at Fulton Street (see Figure 1). The 1-percent annual chance flood discharge used in the effective study for the Grand River was 55,000 cfs. There are levees or floodwalls on both banks of the Grand River throughout much of the reach through the City of Grand Rapids. For the effective study, the levees and floodwalls were considered to provide protection from the 100-year or 1-percent annual chance flood. The effective study was completed in the late 1970s and published in November 1982 before publication of CFR 65.10 in August 1986.

FEMA recently conducted a restudy of the Grand River in the City of Grand Rapids. A revised HEC-RAS model was completed in March 2008 using a 1-percent annual chance (base) flood discharge of 50,000 cfs. The flood frequency analysis using Bulletin 17B, *Guidelines For Determining Flood Flow Frequency*, was completed for the Grand River gaging station (04119000) by the Michigan Department of Environmental Quality (MDEQ). A revised base flood discharge of 50,000 cfs was estimated based on 107 years of record from 1901 to 2007. For the new restudy, the levees and floodwalls do not provide base flood protection because of lack of freeboard. In some reaches the levees/floodwalls are overtopped by the base flood.

The City of Grand Rapids contested the Preliminary restudy and provided alternative analyses. For the last couple of years, FEMA and the City of Grand Rapids have been discussing the various issues and the Preliminary restudy is on hold.

Method of Estimating Flood Hydrographs

The profiles for the Preliminary restudy were based on a steady state HEC-RAS model and peak discharges only. The objective of this Proof of Concept study was to develop flood hydrographs for the Grand River that could be used in an unsteady hydraulic analysis. As described in the Hydrology Technical Memorandum, there are three general approaches for estimating flood hydrographs for riverine reaches:

- Scale a major historic flood hydrograph to be consistent with the base flood discharge,

- Use a dimensionless hydrograph approach,
- Use a rainfall-runoff model developed for the flood insurance study or use a model developed for another purpose.

Figure 1. Location of the Grand River gaging station (04119000) at Fulton Street in the City of Grand Rapids, Michigan.

The Grand River at Grand Rapids is a 4,900-square-mile watershed and there is no rainfall-runoff model available. The dimensionless hydrograph approach requires regression equations for estimating the base flood peak discharge and basin lag time or time to peak. There are no regression equations that are applicable to this large watershed. As noted above, there is a gaging station on Fulton Street in the City of Grand Rapids (Figure 1). Therefore, data for major historic flood hydrographs were used to estimate the 1- and 0.2-percent annual chance flood hydrographs.

Flood hydrograph data (30-minute intervals) are available for the Grand River (04119000) from October 1, 1989 to September 30, 2009 in the USGS Instantaneous Data Archive File (http://ida.water.usgs.gov/ida). The four largest floods since October 1989 are:

- Flood of February 25, 1997, peak discharge of 23,500 cfs,
- Flood of May 22, 2000, peak discharge of 21,400 cfs,
- Flood of May 27, 2004, peak discharge of 29,000 cfs,
- Flood of December 31, 2008, peak discharge of 24,700 cfs.

There were some missing data on the rise of the December 31, 2008 flood hydrograph and it was not used for comparison purposes. The other three flood hydrographs are shown in Figure 2. The peak discharges are plotted at the same time for comparison of hydrograph shape.

The February 1997 hydrograph has a small secondary peak due to additional rainfall and was not used further in this analysis. For the remaining two hydrographs, the May 2004 flood has the largest peak discharge and flood volume and was chosen to estimate the 1- and 0.2-percent chance flood hydrographs. The May 2004 flood is the largest flood since 1985 and has about a 10-percent chance of exceedance.

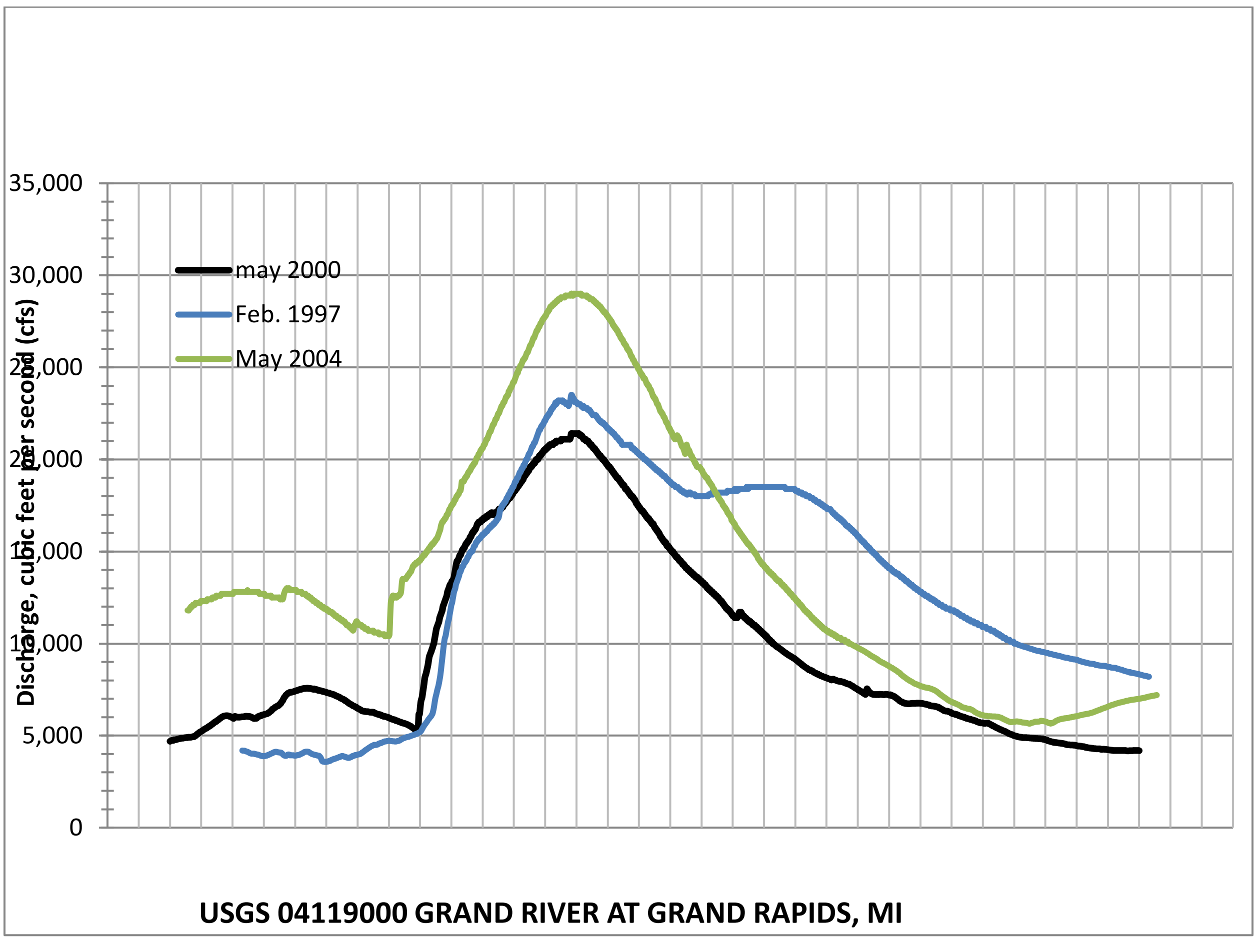

Figure 2. Comparison of historic flood hydrographs for the Grand River at Grand Rapids, MI (04119000).

The May 2004 flood hydrograph is plotted in Figure 3. The discharges were smoothed slightly from the plot given in Figure 2.

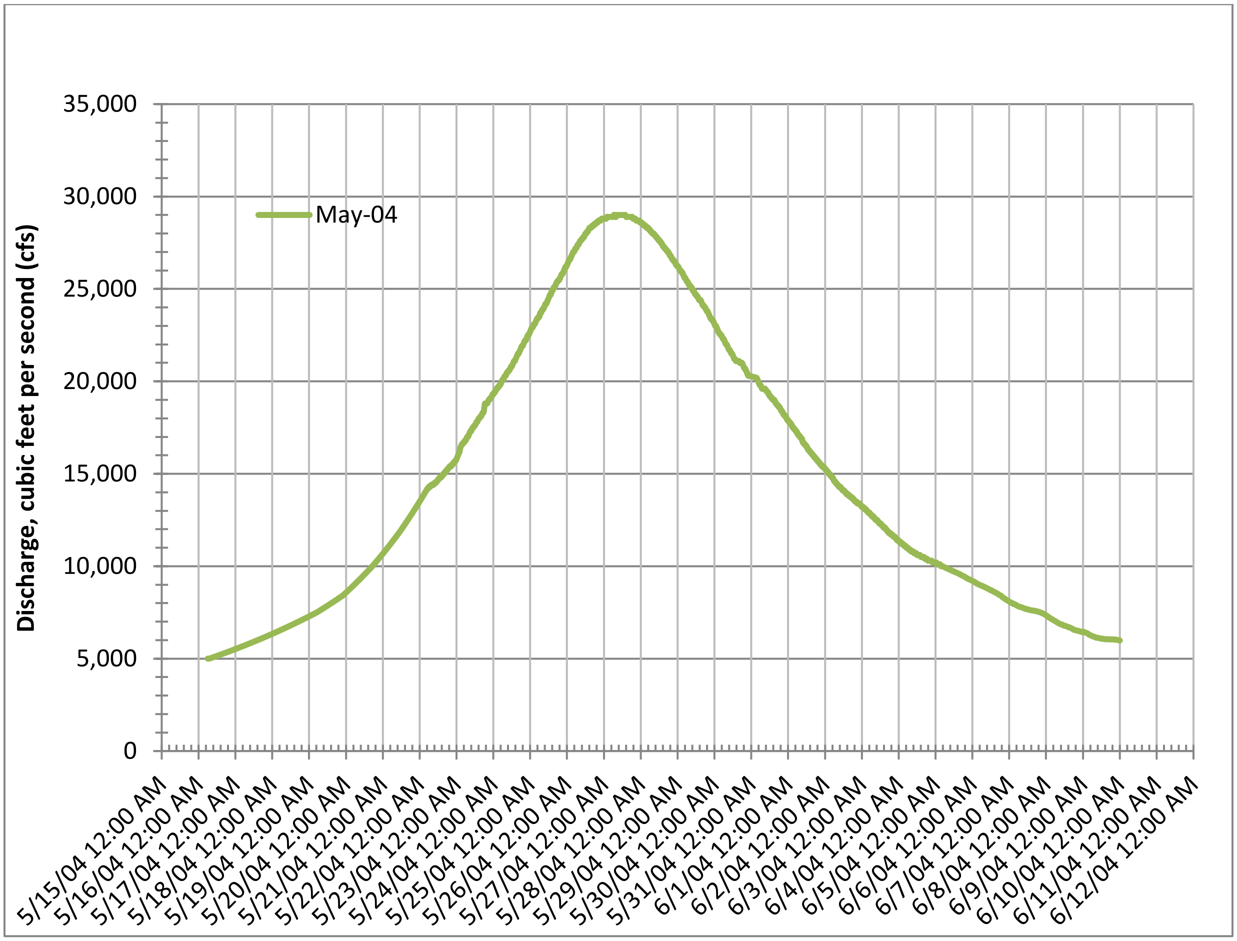

Figure 3. May 2004 flood hydrograph for the Grand River at Grand Rapids, MI (04119000).

The 1-percent chance peak discharge is 50,000 cfs and the 0.2-percent chance peak discharge is 65,200 cfs for the Grand River at Grand Rapids from the MDEQ Bulletin 17B frequency analysis. The discharge ordinates of the May 2004 flood hydrograph (Figure 3) were multiplied by:

- 50,000/29,000 = 1.724 to obtain the 1-percent chance flood hydrograph,
- 65,200/29,000 = 2.248 to obtain the 0.2-percent chance flood hydrograph.

The estimated 1- and 0.2-percent chance flood hydrographs are shown in Figure 4.

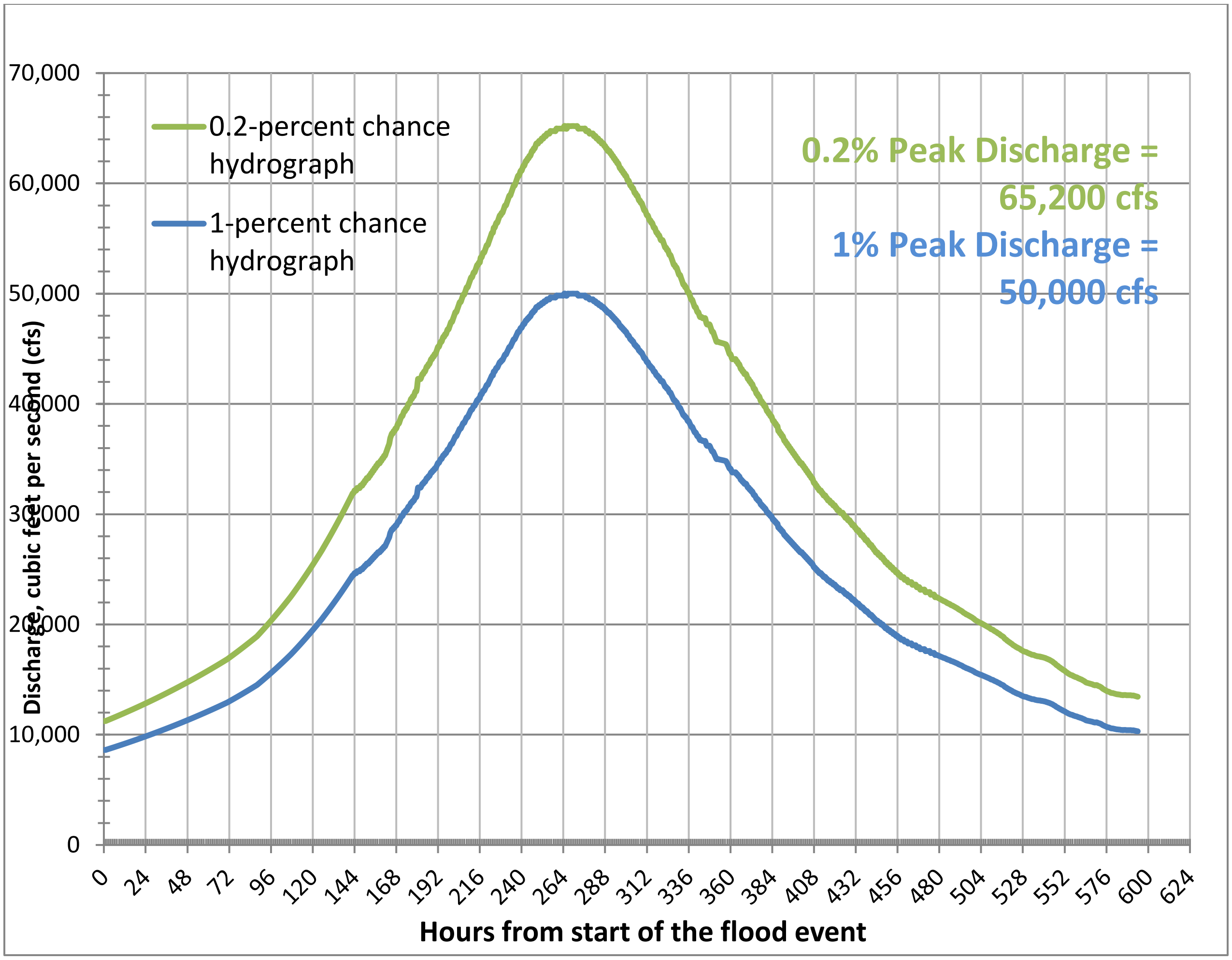

Figure 4. The estimated 1- and 0.2-percent chance flood hydrographs for the Grand River at Grand Rapids, MI (04119000).

The flood hydrographs shown in Figure 4 are defined for 30-minute intervals and can be used in an unsteady hydraulic analysis for evaluating levee breach or overtopping analyses.

Evaluation of Flood Hydrographs

The estimated 1- and 0.2-percent chance flood hydrographs were based on a historic flood hydrograph whose peak discharge had a 10-percent chance of exceedance. The design flood hydrographs were estimated by scaling up the May 2004 hydrograph with no change in the time base consistent with the basic concepts of unit hydrograph theory:

- The time duration of the base of the surface runoff hydrograph resulting from rainfall excess of a given duration is constant,
- Ordinates of the surface runoff hydrograph are proportional to the amount of rainfall excess.

There are no other flood hydrographs readily available for comparison to the design flood hydrographs shown in Figure 4. As a crude reality check, the runoff volumes under the May 2004, 1-, and 0.2-percent chance hydrographs were estimated as 2.78 inches, 4.79 inches and 6.25 inches. The Grand River at Grand Rapids is 209 miles long. Assuming the channel velocity is 2-3 feet per second, the travel time or time of concentration would be on the order of 4-6 days. From the Technical Paper No. 49, the 100-year 4-day rainfall is about 6.6 inches and the 100-year 7-day rainfall is about 7.4 inches for the Grand River watershed. This would imply 65 percent (4.79/6.6) to 73 percent (4.79/7.4) runoff for the 1-percent chance event. This approximate analysis indicates the design hydrographs are reasonable.

The frequency of the flood hydrograph is determined by frequency of the peak discharge. The frequency of the flood volume is unknown but is assumed to be a typical flood volume for a 1- or 0.2-percent chance flood.

Concluding Comments

The Grand River restudy in 2008 was performed using peak discharges only and a steady state HEC-RAS analysis. The levees and floodwalls were determined not to provide protection from the 1-percent chance flood. The purpose of this Proof of Concept study was to demonstrate a cost-effective approach for estimating flood hydrographs that could be used in an unsteady hydraulic analysis for evaluating levee breaching and/or overtopping analyses. A historic flood hydrograph (May 2004) was used to estimate the 1- and 0.2-percent chance flood hydrographs that could be used in an unsteady hydraulic analysis for evaluating the levees. Although there are no other flood hydrographs available to determine the reasonableness of the 1- and 0.2-percent hydrographs, an approximate analysis of flood volumes indicates the design hydrographs are reasonable.

Study 2 - Skagit River near Mount Vernon, Washington

Background

The effective flood insurance study for Skagit County, Washington is dated September 29, 1989. The major flooding source in the county is the Skagit River, a 3,115 square mile watershed that originates in British Columbia, Canada and drains into the Puget Sound north of Seattle, Washington. There are two gaging stations on the Skagit River in Skagit County:

- Skagit River near Concrete, WA (station 12194000), located 54.1 miles upstream from the mouth, drainage area = 2,737 square miles, systematic annual peak flow data from 1924 to present with six historic peaks prior to 1924,
- Skagit River near Mount Vernon, WA (station 12200500), located 15.7 miles upstream from the mouth, drainage area = 3,093 square miles, systematic annual peak flow data from 1940 to present with one historic peak prior to 1940.

FEMA recently conducted a restudy on the Skagit River in Skagit County. The study contractor was the Seattle District, U.S. Army Corps of Engineers (USACE, 2008). The gaging station near Concrete (12194000), with the longer flood record, was used to determine the frequency of flooding but data at the Mount Vernon (12200500) were used in estimating the flood hydrographs. There are levees along both banks of the Skagit River for most of the lower 24 miles of channel. The gaging station at Mount Vernon is within the study reach with levees and is shown in Figure 5. The levees were determined not to provide 1-percent annual chance (base) flood protection for the 1989 effective study or for the recent restudy.

Flood frequency analyses for the Skagit River are complicated by the construction of five hydroelectric power reservoirs with flood-control capabilities in the watershed from 1924 to 1961 plus changes in the regulation procedures for these reservoirs. All reservoirs are located upstream of the two gaging stations. The general modeling approach by USACE was to develop unregulated flows, perform frequency analyses on the unregulated flows, route the unregulated flood hydrographs through the current reservoir system, and then perform frequency analyses on the regulated peak flows. The hydrologic analyses are described in a report entitled “Skagit River Basin, Washington Revised Flood Insurance Study Hydrology Summary” dated May 1, 2008.

For the restudy, a two dimensional unsteady hydraulic model (FLO-2D) was used to model the lower 24-mile reach of the Skagit River because of the wide floodplain and multiple flow paths. USACE developed a base flood hydrograph for the restudy and use in the FLO-2D model.

Figure 5. Location of the Skagit River gaging (12200500) at Riverside Drive (U.S. 99) near Mount Vernon, Washington.

Method of Estimating Flood Hydrographs

The objective of this Proof of Concept study is to demonstrate an alternative cost-effective approach for developing a flood hydrograph for the Skagit River for the reach with levees. As described in the Hydrology Technical Memorandum, there are three general approaches for estimating flood hydrographs for riverine reaches:

- Scale a major historic flood hydrograph to be consistent with the base flood discharge,
- Use a dimensionless hydrograph approach,
- Use a rainfall-runoff model developed for the flood insurance study or use a model developed for another purpose.

The Skagit River near Mount Vernon is a 3,093-square-mile regulated watershed and there is no rainfall-runoff model readily available. Because the watershed is regulated by five hydroelectric power reservoirs, there are no applicable regression equations for estimating peak discharges or basin lag time or time to peak. Therefore, the dimensionless hydrograph approach is not applicable for this watershed. However, there are flood hydrograph data available for the Skagit River near Mount Vernon gaging station which is in the restudy reach with levees. Therefore, a historic flood will be scaled to estimate a base flood hydrograph.

Flood hydrograph data (15-minute intervals) are available for the Skagit River near Mount Vernon (12200500) from October 1, 1988 to September 30, 2009 in the USGS Instantaneous Data Archive (http://ida.water.usgs.gov/ida). The largest flood in the systematic record since 1940 at the Mount Vernon gaging station was the November 25, 1990 flood with a peak discharge of 152,000 cfs. Data are missing for November 24-25 in the USGS IDA file but data were available from USACE for this flood. Hourly data were obtained from USACE for the November 25, 1990 flood event and the flood hydrograph is shown in Figure 6.

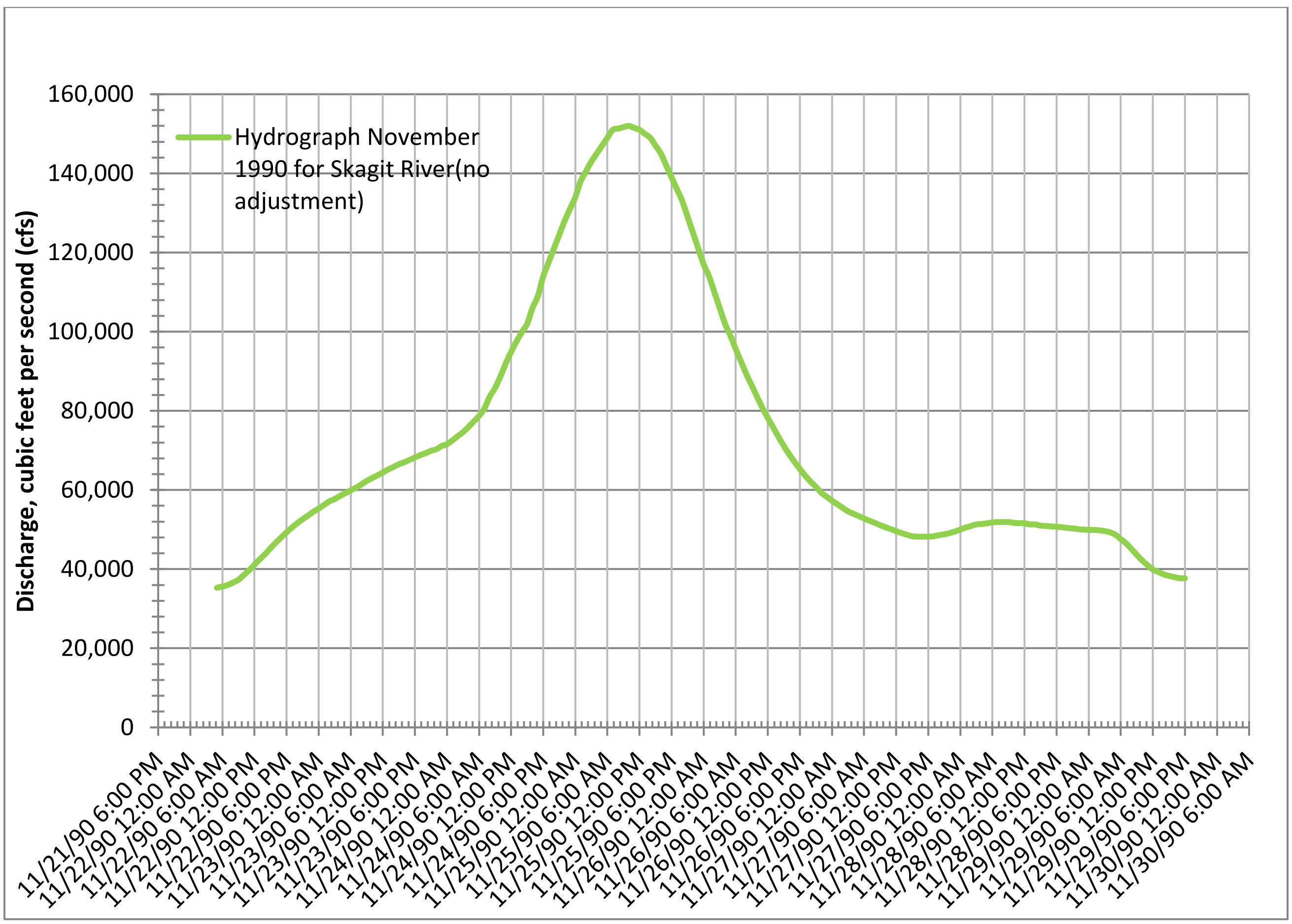

Figure 6. November 25, 1990 flood event for the Skagit River near Mount Vernon, WA (12200500).

The regulated base flood peak discharge for the Skagit River near Mount Vernon was estimated by USACE to be 215,270 cfs. The discharge ordinates of the November 1990 flood hydrograph (Figure 6) were multiplied by 1.41625 (215,270/152,000) to obtain an estimate of the base flood hydrograph for the Skagit River near Mount Vernon. The estimated base flood hydrograph is given below in Figure 7 and compared to the USACE base flood hydrograph used as input to the FLO-2D model.

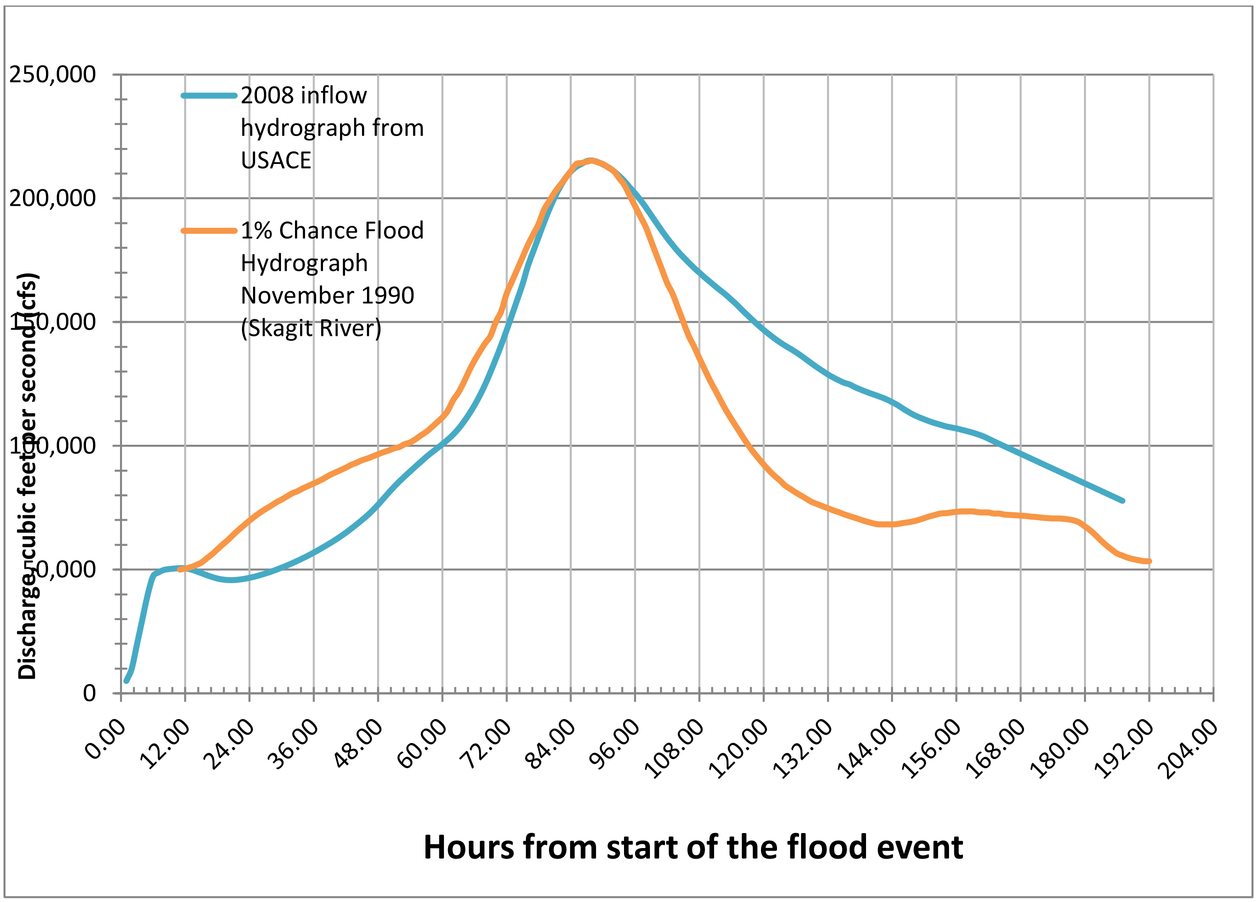

Figure 7. Comparison of USACE base flood hydrograph to the base flood hydrograph based on scaling the November 1990 flood for the Skagit River near Mount Vernon, WA.

Evaluation of Flood Hydrographs

The USACE flood frequency analysis for the Skagit River was a detailed process that involved developing unregulated flows, developing relations between n-day flows and peak flows, developing unregulated balanced flood hydrographs and routing these flood hydrographs through the current reservoir system. The premise for the Proof of Concept study was that we knew the regulated base flood peak discharge and needed to estimate a flood hydrograph.

The base flood hydrograph estimated by scaling the November 1990 flood hydrograph is compared to the USACE base flood hydrograph in Figure 7. For the USACE analysis, a synthetic balanced flood hydrograph was developed for unregulated conditions and this hydrograph was routed through the reservoir system. In our analysis the regulated flood hydrograph for the November 1990 flood was scaled up to give a peak discharge consistent with the USACE analysis.

It is obvious that the volume under the USACE hydrograph is larger than the scaled hydrograph based on the November 1990 flood. However, the volume only differs by 13 percent. According to the effective Flood Insurance Study report, the Skagit River channel can contain about 110,000 cfs. At a flow of 110,000 cfs, the USACE hydrograph has a width of 81 hours while the scaled hydrograph has a width of 54 hours. However, i~~t~~f we assume the levees only partially fail or breach and that 150,000 cfs can be contained between the levees, then the USACE hydrograph width is 47 hours and the scaled hydrograph width is 38 hours. For the latter condition, the floodplain defined by the two flood hydrographs would be similar.

Concluding Comments

The November 1990 flood was the largest flood for the Skagit River near Mount Vernon since 1940. The flood hydrograph for this event was scaled up to get a peak discharge consistent with the regulated peak discharge determined by USACE in the recent restudy. The volume under the USACE base flood hydrograph was about 13 percent larger than the scaled flood hydrograph. If flows greater than about 150,000 cfs can be contained within the levee, then the volume of water flowing into the floodplain and the floodplain elevations would be similar.

This comparison demonstrates that scaling a historic flood hydrograph to obtain a base flood hydrograph is a viable procedure. For this Proof of Concept study, the USACE base flood hydrograph was based on a much more detailed analysis. Therefore, the recommendation is to use the USACE base flood hydrograph to evaluate any breaching or overtopping scenarios. USACE has already investigated several failure modes for the levees. Using the USACE base flood hydrograph for future hydraulic analyses will enable a comparison with previous USACE analyses.

Study 3 – Anacostia River in Maryland

Background

The effective flood insurance study for Prince George's County, Maryland is dated September 6, 1996. A major flooding source in the County is the Anacostia River that flows into the Potomac River near Fort McNair and the Naval Station in the southern portion of the District of Columbia. There are two long-term gaging stations in the Anacostia River Basin in Prince George's County and the location of the stations is shown in Figure 8 (gaging station names in red). Information on the two gaging stations is as follows:

- Northeast Branch Anacostia River at Riverdale, MD (station 01649500), located 1.8 miles upstream of the confluence with the Northwest Branch at Riverdale Road, drainage area of 73.35 square miles, systematic peak flow data from 1939 to present with one historic flood in 1933,
- Northwest Branch Anacostia River near Hyattsville, MD (station 01651000), located 1.6 miles upstream of the confluence with the Northeast Branch at Queens Chapel Road, drainage area of 49.42 square miles, systematic peak flow data from 1939 to present with one historic peak in 1933.

The NE Branch and NW Branch of the Anacostia River are highly urbanized watersheds (see Figure 8) but are not regulated by any significant flood control structures. The Maryland Hydrology Panel (2010) recently updated the regional regression equations for Maryland streams and the regression equations are documented in Appendix 3 of the report entitled "Application of Hydrologic Methods in Maryland", dated September 2010 (http://www.gishydro.umd.edu/HydroPanel/hydrology_panel_report_3rd_edition_final.pdf).

The watershed characteristics needed for this Proof of Concept hydrology study are as follows (Maryland Hydrology Panel report (2010), Appendix 1):

- NE Branch Anacostia River at Riverdale (01649500): 83 percent of watershed is in the Western Coastal Plain, 17 percent in the Piedmont; impervious area = 27.4 percent; forest cover = 30.5 percent; channel slope = 27.3 ft/mi,
- NW Branch Anacostia River near Hyattsville (01 651000): 69 percent of the watershed is in the Piedmont, 31 percent in the Western Coastal Plain; impervious area = 27.5 percent; forest cover = 16.7 percent; channel slope = 20.5 ft/mi.

The percentages of impervious area and forest cover were obtained from 2002 land use data provided by the Maryland Office of Planning.

Figure 8. Location of the NE Branch and NW Branch of the Anacostia River in Prince George's County, MD (the confluence of the two branches is in the lower center of the map).

The NE Branch and NW Branch are located in the Western Coastal Plain Region of Maryland but a portion of each watershed is located in the Piedmont Region. The hydrologic regions of Maryland are shown in Figure 9. Prince George's County is in the Western Coastal Plain Region but the headwaters of the NE Branch and NW Branch originate in the Piedmont Region.

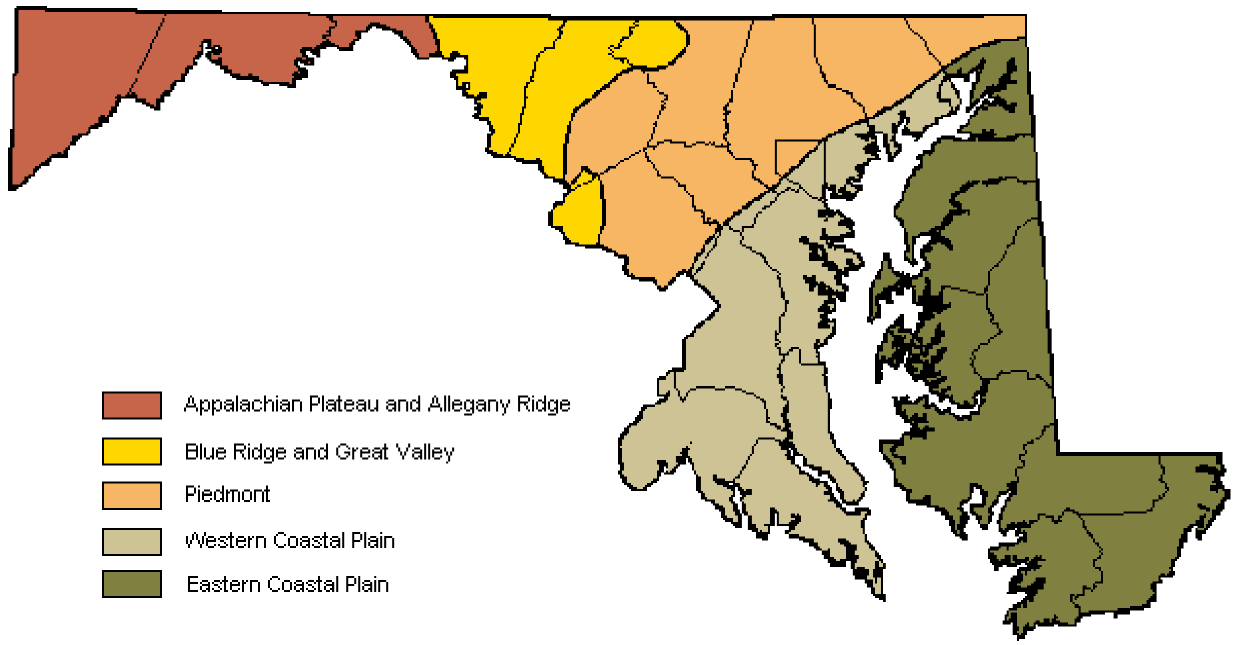

Figure 9. Hydrologic regions for Maryland from the Maryland Hydrology Panel report (2010).

FEMA and the Maryland Department of the Environment recently conducted a restudy for the Anacostia River in Prince George's County. The study contractor was the Baltimore District, U.S. Army Corps of Engineers (USACE). The study began in 2000 and the first report was completed in 2003. The study was updated in 2008 with the second report completed in 2010. The two USACE hydrology reports are:

- *Anacostia River Basin Flood Frequency Analysis*, dated August 2003. This report describes the calibration of the HEC-HMS rainfall-runoff models for the NE Branch and NW Branch Anacostia River and Bulletin 17B analyses of the annual peak flow data through 2001 at the two gaging stations.
- *Anacostia River Risk Analysis and Flow-Frequency Update*, dated January 2010. This report updated the HEC-HMS models and the Bulletin 17B analyses using annual peak flows through 2007 and also describes the risk-based analyses for the levees.

As described in the January 2010 USACE report, the peak discharges used to evaluate the levees (steady-state HEC-RAS analysis) were based on the 2003 HEC-HMS model for the NE Branch and the 2008 HEC-HMS model for the NW Branch. The levees on the NE Branch are from the gaging station at Riverdale Road downstream to the confluence with the NW Branch (1.8 miles). The levees on the NW Branch are from the gaging station at Queens Chapel Road downstream to the confluence with the NE Branch (1.6 miles). There is also about one mile of levees along the main stem Anacostia River after the confluence of the two branches. The USACE risk-based analyses documented in the January 2010 report indicate the levees do NOT meet FEMA criteria. For the September 1996 effective FIS report, all the levees in Prince George's County had three feet of freeboard and met FEMA requirements.

Methods of Estimating Flood Hydrographs

The objective of this Proof of Concept hydrology study is to demonstrate alternative cost-effective approaches for developing flood hydrographs for the NE Branch and NW Branch Anacostia River. As described in the Hydrology Technical Memorandum, there are three general approaches for estimating flood hydrographs for riverine reaches:

- Scale a major historic flood hydrograph to be consistent with the base flood discharge,
- Use a dimensionless hydrograph approach,
- Use a rainfall-runoff model developed for the flood insurance study or use a model developed for another purpose.

For the Anacostia River study, USACE did develop HEC-HMS models at the two gaging stations. Therefore, flood hydrographs are available from a rainfall-runoff model but the flood hydrographs were not used in evaluating the levees because a steady-state HEC-RAS model was used for that purpose. For this Proof of Concept hydrology study, flood hydrographs were developed by scaling major historic flood hydrographs and by using USGS dimensionless hydrographs developed specifically for Maryland streams, "Techniques for Simulating Peak-Flow Hydrographs in Maryland", USGS Water-Resources Investigations Report 97-4279 (Dillow, 1998).

<u>NE Branch Anacostia River at Riverdale, MD (01649500)</u>

Flood hydrograph data are available from October 2, 1990 to September 30, 2009 for the NE Branch Anacostia River at Riverdale (01649500) in the USGS Instantaneous Data Archive (http://ida.water.usgs.gov/ida). Hydrograph data for four major floods since 1990 were plotted to investigate hydrographs shapes and determine the best historic hydrograph to scale up to obtain the 1-percent annual chance (base) hydrograph. The four hydrographs that are plotted in Figure 10 include:

- Flood of September 16, 1999,
- Flood of July 4, 2004,
- Flood of June 26, 2006,
- Flood of June 10, 2009.

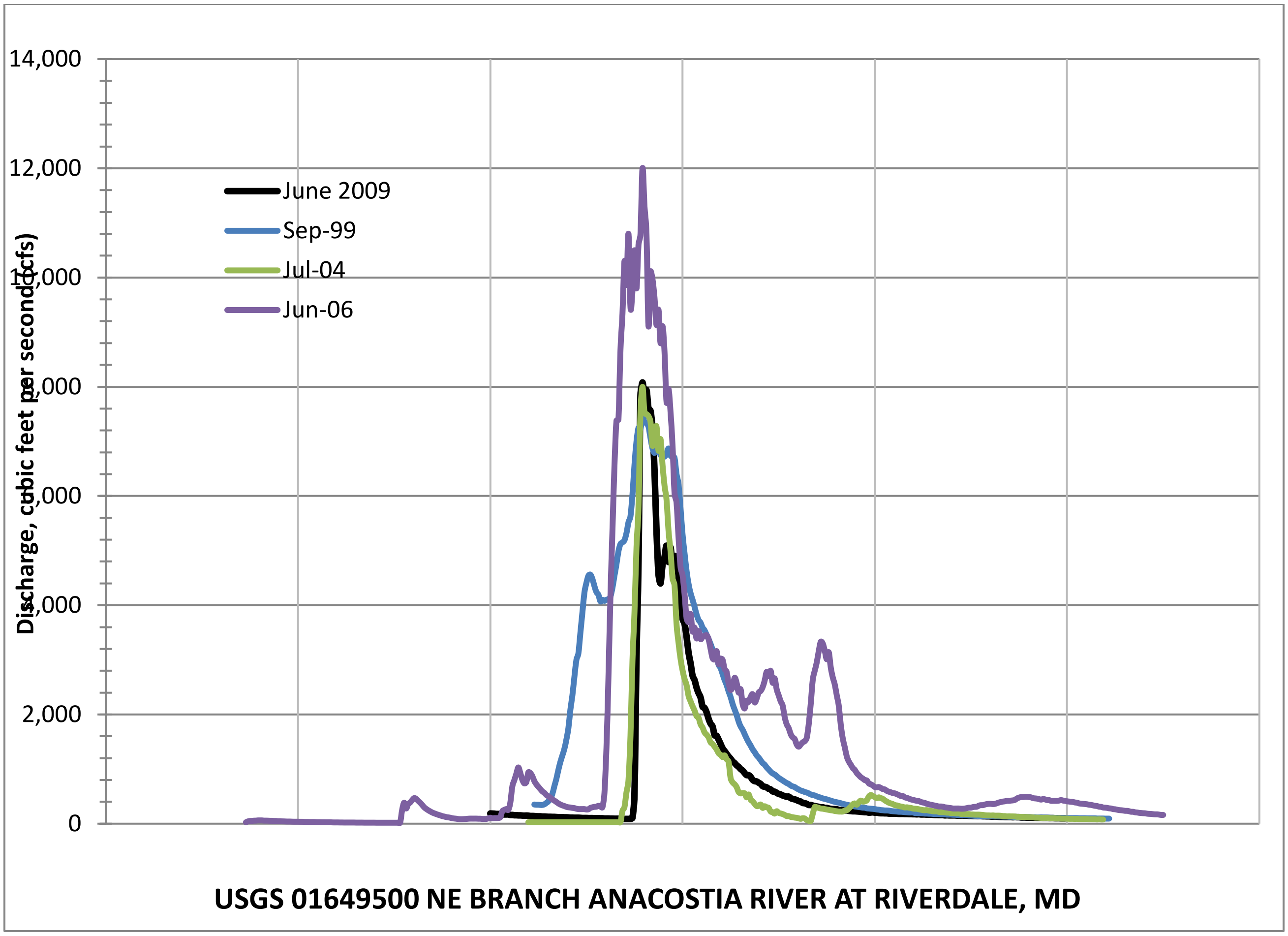

Figure 10. Comparison of historic flood hydrographs for the NE Branch Anacostia River at Riverdale, MD (01649500).

The July 2004 and June 2009 floods were caused by summer thunderstorms of rather short duration and the resultant flood hydrographs are of shorter duration as shown in Figure 10. The September 1999 flood was a result of a hurricane but the peak discharge was less than the other floods. The June 2006 flood was caused by a longer duration rainfall event with total rainfall exceeding six inches. The peak discharge of the June 2006 flood was 12,000 cfs, the same as the peak discharge from Hurricane Agnes in June 1972. The June 2006 and June 1972 floods are the two highest floods on the NE Branch Anacostia River since at least 1933. The June 2006 peak discharge of 12,000 cfs has a 2-percent chance of exceedance.

The June 2006 flood is the highest flood since 1972 and has a fairly long duration. The June 2006 was chosen as the historic flood hydrograph to scale up to obtain the 1-percent chance flood hydrograph. A smoothed version of the June 2006 flood hydrograph is shown in Figure 11.

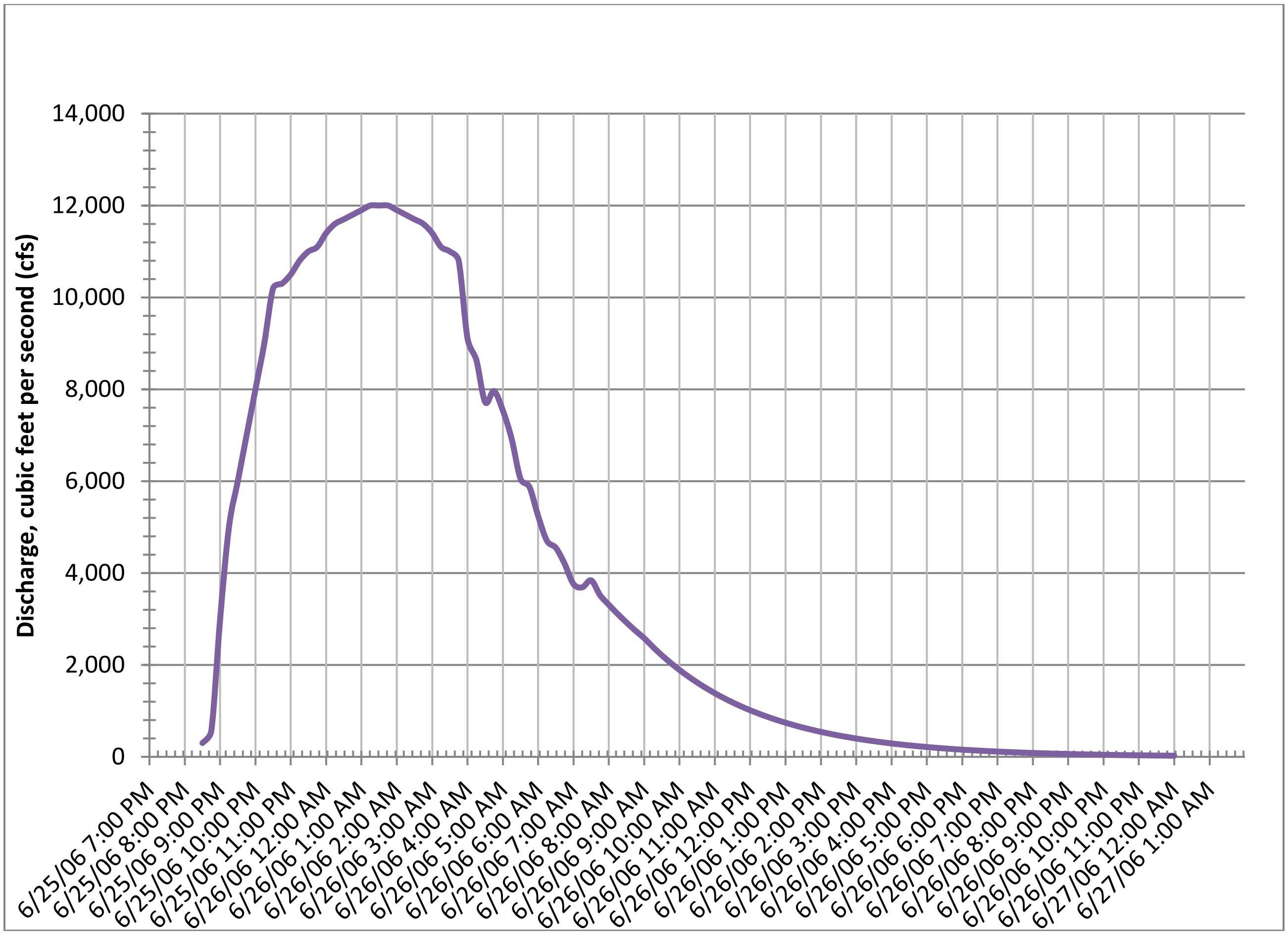

Figure 11. June 2006 flood hydrograph for the NE Branch Anacostia River at Riverdale, MD (01649500).

The most current Bulletin 17B estimates (through the 2008 water year) of flood peak discharges for the NE Branch Anacostia River at Riverdale, MD are available from Appendix 2 of the Maryland Hydrology Panel report (2010) referenced earlier. The 1-percent chance flood discharge is 14,700 cfs for the NE Branch. The discharge ordinates of the June 2006 flood (Figure 11) were multiplied by 1.225 (14,700/12,000) to obtain the 1-percent chance flood hydrograph that is plotted in Figure 12.

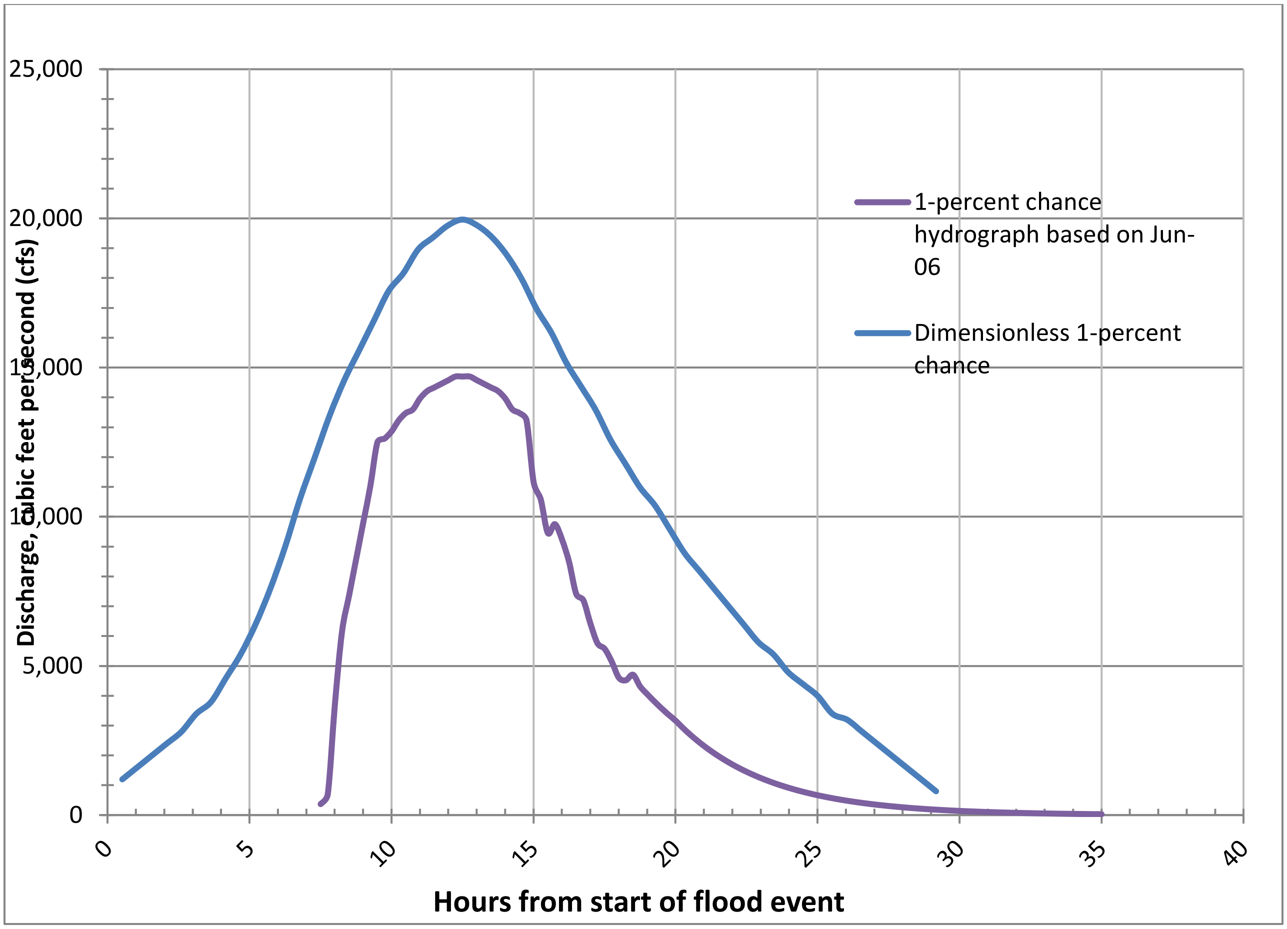

Figure 12. Comparison of 1-percent chance hydrographs based on the June 2006 flood and the USGS dimensionless hydrograph for NE Branch Anacostia River at Riverdale, MD (01649500).

Also shown in Figure 12 is the 1-percent chance flood hydrograph based on the USGS dimensionless hydrographs developed for Maryland streams (Dillow, 1998). Dillow (1998) developed three dimensionless hydrographs for the Appalachian Plateau Region, Piedmont/Blue Ridge Region and the Western/Eastern Coastal Plain Region. The dimensionless hydrographs are defined by a ratio of the discharge to peak discharge and by a ratio of time to base lag time. The dimensionless hydrograph is converted to an actual hydrograph by multiplying the discharge ordinate by the peak discharge and the time ordinate by the basin lag time.

Eighty three percent of the NE Branch Anacostia River watershed is in the Western Coastal Plain Region so:

- The 1-percent chance peak discharge was estimated from the Western Coastal Plain regression equation given in Appendix 3 of the Hydrology Panel report (2010). The 1-percent peak discharge was 19,960 cfs.
- The basin lag time was estimated from Equation 1 in Dillow (1998) assuming the watershed was in the Western Coastal Plain. The basin lag time was 10.42 hours. BY comparison, an estimate of 10.13 hours was obtained for basin lag time using three **observed** rainfall-runoff events that Dillow (1998) compiled for the NE Branch.

The watershed characteristics used in estimating the 1-percent chance discharge and the basin lag time were obtained from Appendix 1 of the Maryland Hydrology Panel report (2010) and were listed earlier.

Note: The 1-percent chance hydrographs in Figure 12 will be compared to the USACE HEC-HMS hydrographs when obtained from USACE.

NW Branch Anacostia River near Hyattsville, MD (01651000)

Flood hydrograph data are available from October 1, 1990 to September 30, 2009 for the NW Branch Anacostia River near Hyattsville (01651000) in the USGS Instantaneous Data Archive (http://ida.water.usgs.gov/ida). Hydrograph data for four major floods since 1990 were plotted to investigate hydrographs shapes and determine the best historic hydrograph to scale up to obtain the 1-percent annual chance (base) hydrograph. The four hydrographs that are plotted in Figure 13 include:

- Flood of September 16, 1999,
- Flood of September 23, 2003,
- Flood of July 27, 2004,
- Flood of May 26, 2009.

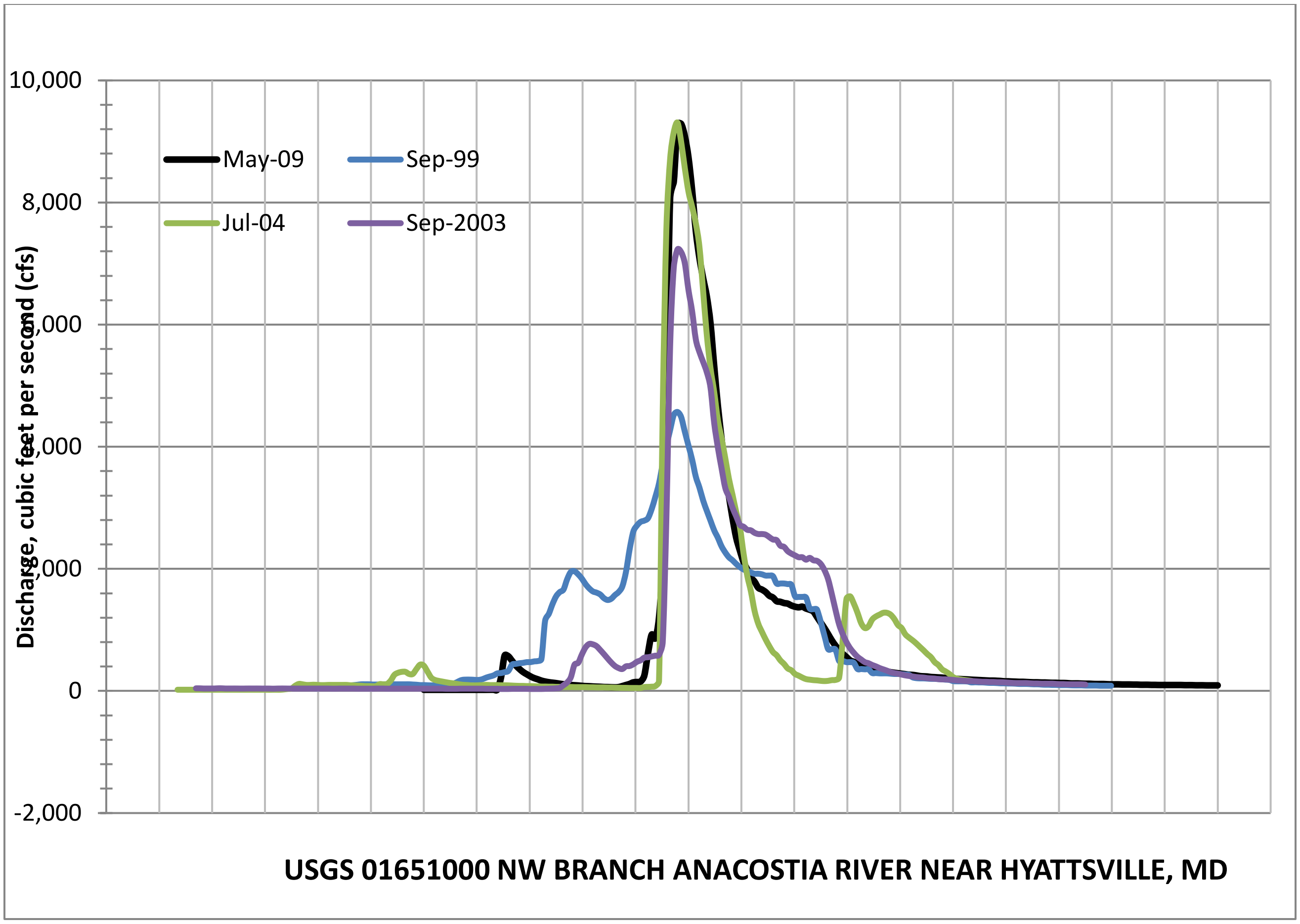

Figure 13. Comparison of historic flood hydrographs for the NW Branch Anacostia River near Hyattsville, MD (01651000).

The flood of June 2006 flood event had missing data for the NW Branch Anacostia River and this flood was not useable. This was unfortunate because the June 26, 2006 peak discharge was 13,900 cfs and was the third highest flood in the record since 1933.

The difference between the July 2004 and May 2009 flood hydrographs is minimal but the May 2009 hydrograph was chosen to scale up to obtain the 1-percent chance flood hydrograph because the flood volume was slightly larger. The peak discharge for the May 2009 flood has about a 10-percent chance of exceedance. The May 2009 flood hydrograph is shown in Figure 14.

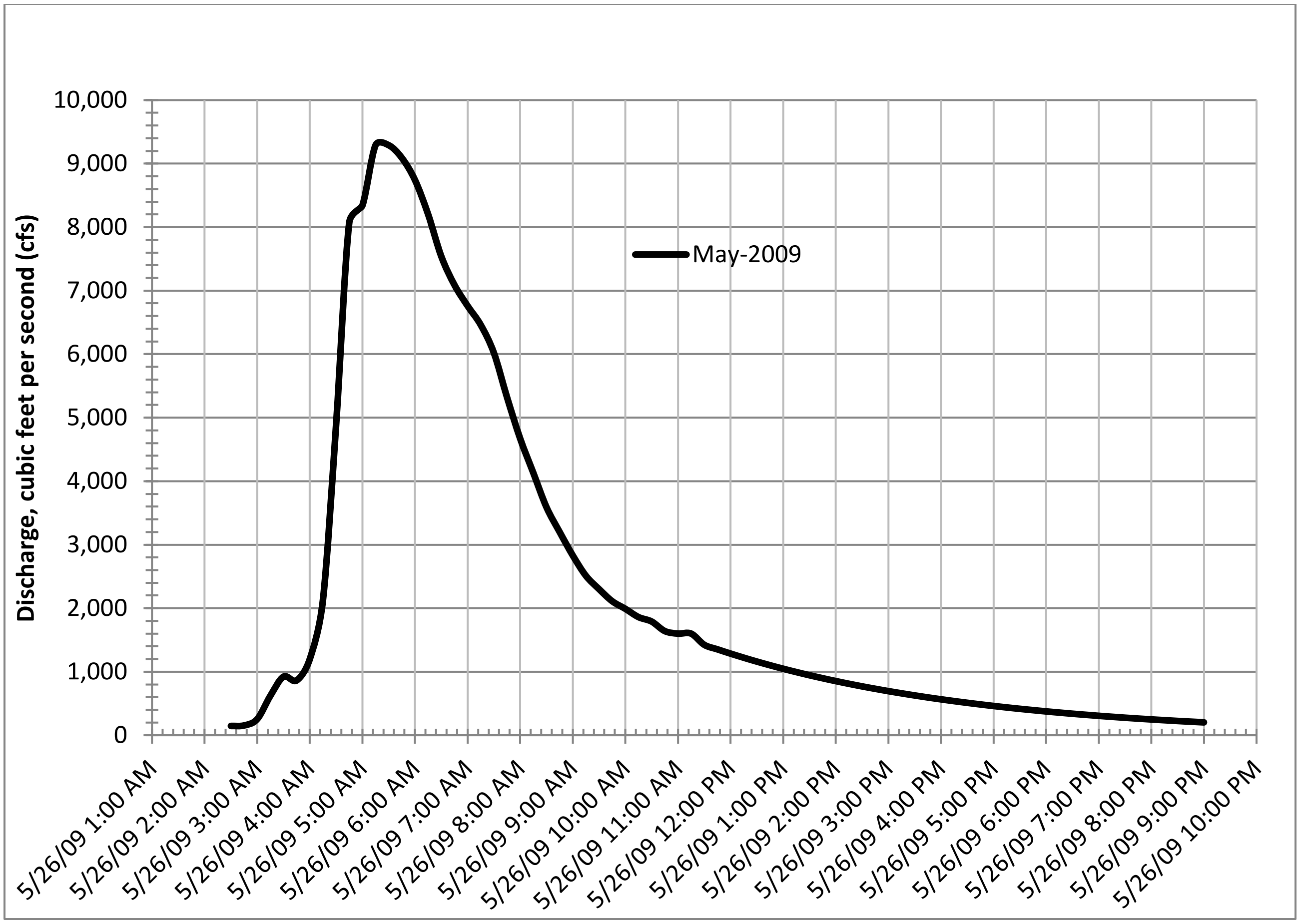

Figure 14. May 2009 flood hydrograph for the NW Branch Anacostia River near Hyattsville, MD (01651000).

The most current Bulletin 17B estimates (through the 2008 water year) of flood peak discharges for the NW Branch Anacostia River near Hyattsville, MD are available from Appendix 2 of the Maryland Hydrology Panel report (2010) referenced earlier. The 1-percent chance flood discharge is 21,700 cfs for the NW Branch. The discharge ordinates of the May 2009 flood (Figure 14) were multiplied by 2.3358 (21,700/9,290) to obtain the 1-percent chance flood hydrograph that is plotted in Figure 15.

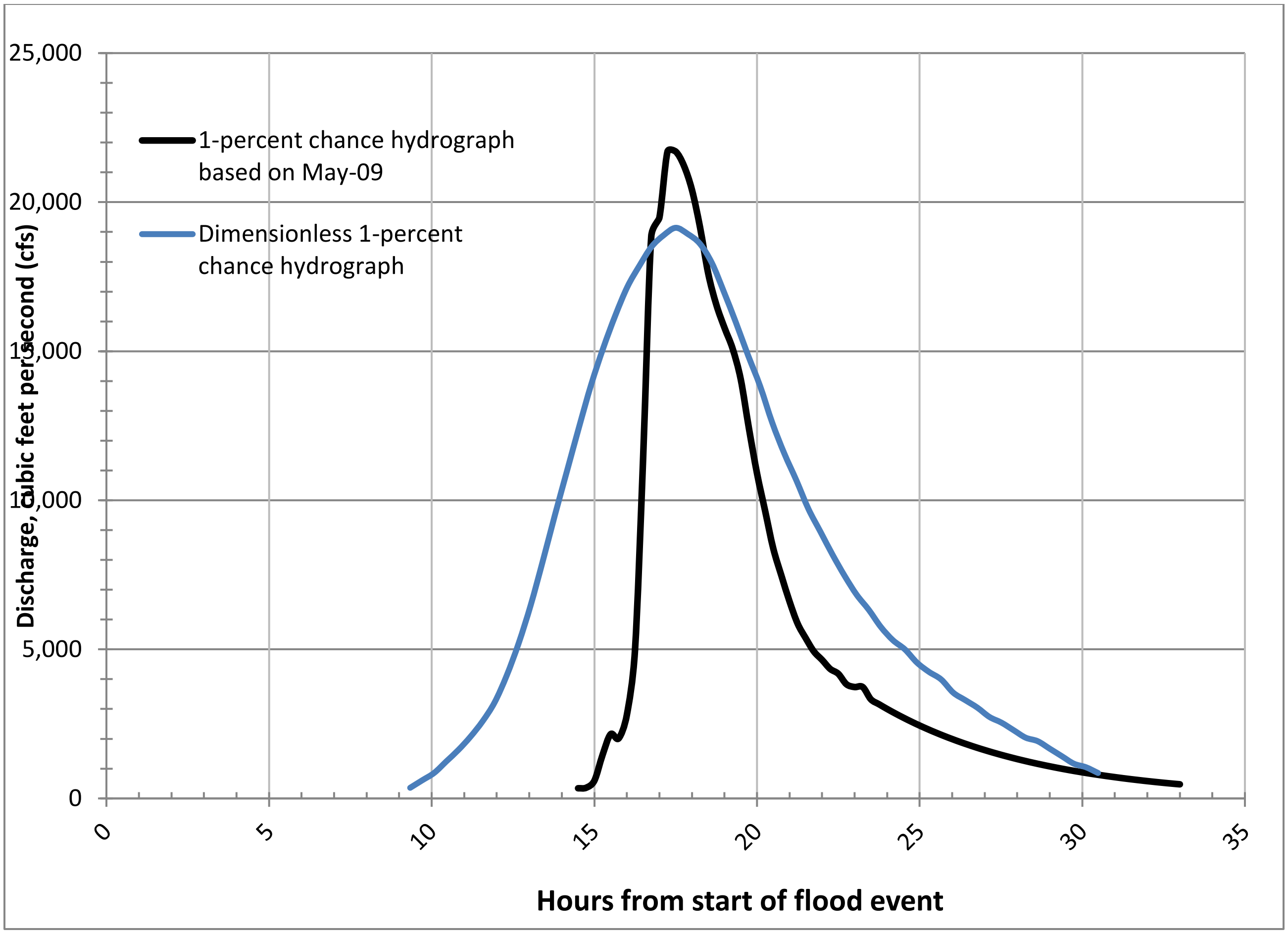

Figure 15. Comparison of 1-percent chance hydrographs based on the May 2009 flood and the USGS dimensionless hydrograph for the NW Branch Anacostia River near Hyattsville, MD (01651000).

Also shown in Figure 15 is the 1-percent chance flood hydrograph based on the USGS dimensionless hydrographs developed for Maryland streams (Dillow, 1998). Dillow (1998) developed three dimensionless hydrographs for the Appalachian Plateau Region, Piedmont/Blue Ridge Region and the Western/Eastern Coastal Plain Region. The dimensionless hydrographs are defined by a ratio of the discharge to peak discharge and by a ratio of time to base lag time. The dimensionless hydrograph is converted to an actual hydrograph by multiplying the discharge ordinate by the peak discharge and the time ordinate by the basin lag time.

The NW Branch Anacostia River gaging station is located in the Western Coastal Plain but 69 percent of the watershed is in the Piedmont Region and 31 percent in the Western Coastal

Plain Region. Therefore, the estimates of the 1-percent chance discharge and basin lag time were obtained by weighting the regression results.

- The 1-percent chance peak discharge was estimated by weighting the estimates from the Piedmont Urban and the Western Coastal Plain regression equations given in Appendix 3 of the Hydrology Panel report (2010). The weighted 1-percent peak discharge was 19,200 cfs.
- The basin lag time was estimated from Equation 1 in Dillow (1998) assuming the watershed was 69 percent in the Piedmont and 31 percent in the Western Coastal Plain. The weighted basin lag time was 7.42 hours. An estimate of 5.13 hours was obtained for basin lag time using three **observed** rainfall-runoff events that Dillow (1998) compiled for the NW Branch.

The watershed characteristics used in estimating the 1-percent chance discharge and the basin lag time were obtained from Appendix 1 of the Maryland Hydrology Panel report (2010) and were listed earlier.

Note: The 1-percent chance hydrographs in Figure 15 will be compared to the USACE HEC-HMS hydrographs when obtained from USACE.

Evaluation of Flood Hydrographs

<u>NE Branch Anacostia River at Riverdale, MD (01649500)</u>

Flood hydrographs were estimated for the NE Branch of the Anacostia River for the 1-percent chance flood by:

- Scaling the June 2006 flood hydrograph to obtain a 1-percent chance flood hydrograph,
- Using the USGS dimensionless hydrograph for the Coastal Plain developed by Dillow (1998).

The difference in 1-percent chance flood hydrographs in Figure 12 for the NE Branch is primarily due to the difference in the estimate of the 1-percent chance peak discharge:

- Bulletin 17B estimate of 14,700 cfs was used in scaling the June 2006 hydrograph to a 1-percent chance hydrograph,
- Regression estimate of 19,960 cfs was used in developing the 1-percent chance hydrograph based on the USGS dimensionless hydrograph,

- Dimensionless hydrograph approach assumes the watershed is ungaged and relies on regression estimates for the 1-percent chance peak discharge and the basin lag time.

The regression estimate of the 1-percent chance peak discharge of 19,960 cfs for the NE Branch is 35.8 percent higher than the Bulletin 17B estimate of 14,700 cfs. This difference is well within the standard error of 61.2 percent for the 1-percent chance regression equation for the Western Coastal Plain. If the discharge ordinates of the USGS dimensionless hydrograph were reduced by 35.8 percent, then the two estimated flood hydrographs would be very similar. Obviously, the accuracy of the dimensionless hydrograph is dependent on the accuracy of the estimated peak discharge.

The basin lag time is not considered a major factor in the difference in 1-percent chance hydrographs in Figure 12 for the NE Branch because the estimated basin lag time of 10.42 hours is reasonably consistent with the lag time of 10.13 hours based on three observed rainfall-runoff data.

NW Branch Anacostia River near Hyattsville, MD (01651000)

Flood hydrographs were estimated for the NW Branch of the Anacostia River for the 1-percent chance flood by:

- Scaling the May 2009 flood hydrograph to obtain a 1-percent chance flood hydrograph,
- Using the USGS dimensionless hydrographs for the Piedmont and Coastal Plain developed by Dillow (1998).

The difference in 1-percent chance flood hydrographs in Figure 15 for the NW Branch is primarily due to the duration of the May 2009 flood hydrograph. The May 2009 event was caused by a relatively short duration rainfall event. The June 2006 event, which was a longer duration storm, would have been a better choice for analysis but data were missing for part of the flood hydrograph. This illustrates the importance of having a representative historic hydrograph to scale to obtain the 1-percent chance hydrograph.

The peak discharge of 19,200 cfs from the weighted regression analysis is reasonably close to 21,700 cfs from the Bulletin 17B analysis. So the peak discharges are more similar for the NW Branch than for the NE Branch. The estimated basin lag time of 7.42 hours for the NW Branch is a little higher than the estimate of 5.13 hours based on three observed rainfall-runoff events so this is a minor factor in the difference in 1-percent chance flood hydrographs for the NW Branch (Figure 15).

Concluding Comments

These comments will be added when the HEC-HMS flood hydrographs are obtained from USACE.

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