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MARYLAND DEPARTMENT OF TRANPORTATION
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RESEARCH REPORT

REGRESSION EQUATIONS FOR ESTIMATING FLOOD DISCHARGES FOR THE WESTERN COASTAL PLAIN REGION OF MARYLAND

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Michael Baker International

FINAL REPORT

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16. Abstract

Regression equations were updated for estimating the 1.25-. 1.50-, 2-, 5-, 10-, 25-, 50-, 100-, 200- and 500-year flood discharges for the Western Coastal Plain Region of Maryland. The regression equations were based on flood discharges for 23 stations and drainage area, in square miles; impervious area, in percent of the watershed; and hydrologic soils group A, in percent of the watershed. For the 23 stations used in the analysis, 11 stations are still active and 12 are discontinued stations. For the active stations, six stations had significant upward trends in annual peak flows due to increasing urbanization and major floods near the end of the record. These trends were accounted for by using a time-varying mean and using a more homogeneous period of record. The updated regression equations will be used by the Maryland Department of Transportation State Highway Administration in the design of bridges and culverts in Maryland. The updated regression equations will also be included in the fifth version of the Maryland Hydrology Panel report entitled "Application of Hydrologic Methods in Maryland" that will be published in 2020.

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Executive Summary

Updated regression equations were developed for the Western Coastal Plain (WCP) regression equations for estimating the 1.25-, 1.5-, 2-, 5-, 10-, 25-, 50-, 100-, 200- and 500-year flood discharges. Flood frequency analyses were performed for 27 gaging stations using Bulletin 17C (England and others, 2018) and data through the 2017 water year if available: 11 active stations, four rural stations and seven urban stations (impervious area greater than 10 percent at the midpoint of the record); 16 discontinued stations, 11 rural stations and five urban stations. During the regression analysis, four stations were identified as outliers so data for 23 stations were used in developing the regression equations.

A regional skew analysis was performed using data for eight rural gaging stations in the Western Coastal Plain Region and 15 rural stations in the Eastern Coastal Plain (ECP) Region. Only the rural stations with consistent land use over time were used. A mean skew of 0.38 with standard error of 0.38 was determined in this analysis. The regional skew was weighted with the station skew for all rural watersheds (less than 10 percent impervious area at the midpoint of the record). For the urban gaging stations, station skew was used because the regional skew is not applicable due to changing land use conditions.

The Mann-Kendall test for trend is included as output in the U.S. Geological Survey (USGS) PeakFQ program and was used to determine if there is a statistically significant monotonic trend in the annual peak flow data (https://water.usgs.gov/software/PeakFQ/). For the 11 active stations, there were six stations with statistically significant upward trends. The trends were primarily related to increasing urbanization but also related to major floods that occurred in the period 1999 to 2014. These trends were accounted for by using a shorter more homogeneous period of record for two stations, a time-varying mean approach as described by Kilgore and others (2016) for three stations and a graphical analysis for one station. For the active stations, the T-year flood discharges generally increased over the 2010 analysis due to large floods primarily in 2011 and 2014 at most of the stations.

The regression equations are based on drainage area, in square miles, impervious area, in percent, at the midpoint of the gaging station record, and percent A soils based on the May 2018 SSURGO data. The regression equations were compared to the gaging station data and shown to be reasonably unbiased for the 10- and 100-year flood discharges. The updated 2019 regression estimates were also compared to the 2010 regression equations for the 10- and 100-year discharges and the 2019 regression estimates tend to higher estimates, particularly for the larger watersheds. This is consistent with the increase in flood discharges for the active gaging stations that are generally larger watersheds.

The updated regression equations will be used by the Maryland Department of Transportation State Highway Administration (MDOT SHA) in the design of bridges and culverts in Maryland. The updated regression equations will be included in the fifth edition of the Maryland Hydrology Panel report entitled "Application of Hydrologic Methods in Maryland" that will be published in 2020.

Regression Equations for Estimating Flood Discharges for the Western Coastal Plain Region of Maryland

Introduction

Fixed region regression equations are used to estimate flood discharges for bridge and culvert design and floodplain mapping in Maryland by several state and local agencies. These empirical equations are developed based on relations between flood discharges at gaging stations and watershed characteristics that can be estimated from available digital data layers. For ungaged locations, the watershed characteristics are used in the regression equations to predict the flood discharges. The Maryland Department of Transportation State Highway Administration (MDOT SHA) uses the regression equations to primarily evaluate the reasonableness of flood discharges estimated using the TR-20 watershed model (Maryland Hydrology Panel, 2016). The objective of the current analysis is to update the Fixed Region regression equations for the Western Coastal Plain Region for estimating the 1.25-, 1.5-, 2-, 5-, 10-, 25-, 50-, 100-, 200-, and 500-year flood discharges using the following data:

- Annual peak flow data through the 2017 water year if available,
- Flood frequency analyses using Bulletin 17C (England and others, 2018),
- Watershed characteristics computed using GISHydroNXT (land use data for various time periods, DEM data and legacy SSURGO data in GISHydroNXT), and
- SSURGO data downloaded from the Natural Resources Conservation Service (NRCS) Soil Survey web site in May 2018.

Both sets of SSURGO data were evaluated as explanatory variables to determine which data set is most applicable for estimating flood discharges using regression equations.

Previous Studies

Several studies have been completed since 1980 that developed regional regression equations for Maryland. Following is a brief description of the data used in the development of previous regression equations for the Western Coastal Plain Region (WCP) of Maryland:

- U.S. Geological Survey (USGS) Open-File Report 80-1016 (Carpenter, 1980) – used only drainage area as the explanatory variable and annual peak flow data through the 1977 water year,
- USGS Water-Resources Investigations Report 95-4154 (Dillow, 1996) – used drainage area and percent forest as explanatory variables and annual peak flow data through the 1990 water year,
- Maryland Hydrology Panel (2006) and Moglen and others (2006) – used drainage area, percent impervious area for 1985 land use conditions, percent D soils based on **STATSGO** soils data as explanatory variables and annual peak flow data through the 1999 water year, and
- Maryland Hydrology Panel (2010) – used drainage area, percent impervious area for land use conditions near the middle of the gaging station record, sum of the percent of C and D soils based on **SSURGO** data as explanatory variables and annual peak flow data through the 2008 water year.

A water year is from October 1 to September 30 with the ending month determining the water year. For example, the 2017 water year is from October 1, 2016 to September 30, 2017. The 2016 Maryland Hydrology Panel report has the same regression equations for the WCP Region as the 2010 Panel report because the regression equations for the coastal plain regions have not been updated since 2010.

Regression Equations for Estimating Flood Discharges for the Western Coastal Plain Region of Maryland

Flood Frequency Analyses at Gaging Stations

Flood frequency estimates were updated at the gaging stations with annual peak flow data through 2017 if available using the USGS PeakFQ program (https://water.usgs.gov/software/PeakFQ/) that implements Bulletin 17C (England and others, 2018). For gaging stations that are still active, this represents an increase of nine years of record since 2008 (end of record used in the 2010 analysis). Flood data were compiled and analyzed for 27 gaging stations in the WCP: 11 active stations and 16 discontinued station; 15 rural stations (less than 10 percent impervious area) and 12 urban stations. The locations of the gaging stations in the WCP are shown in Figure 1 that defines the four major hydrologic regions in Maryland: Appalachian Plateau and Allegheny Ridge, Blue Ridge-Piedmont, Western and Eastern Coastal Plains. The gaging stations are numbered in Figure 1 in terms of their USGS downstream order with the station names and numbers identified in Appendix 4 at the end of this report.

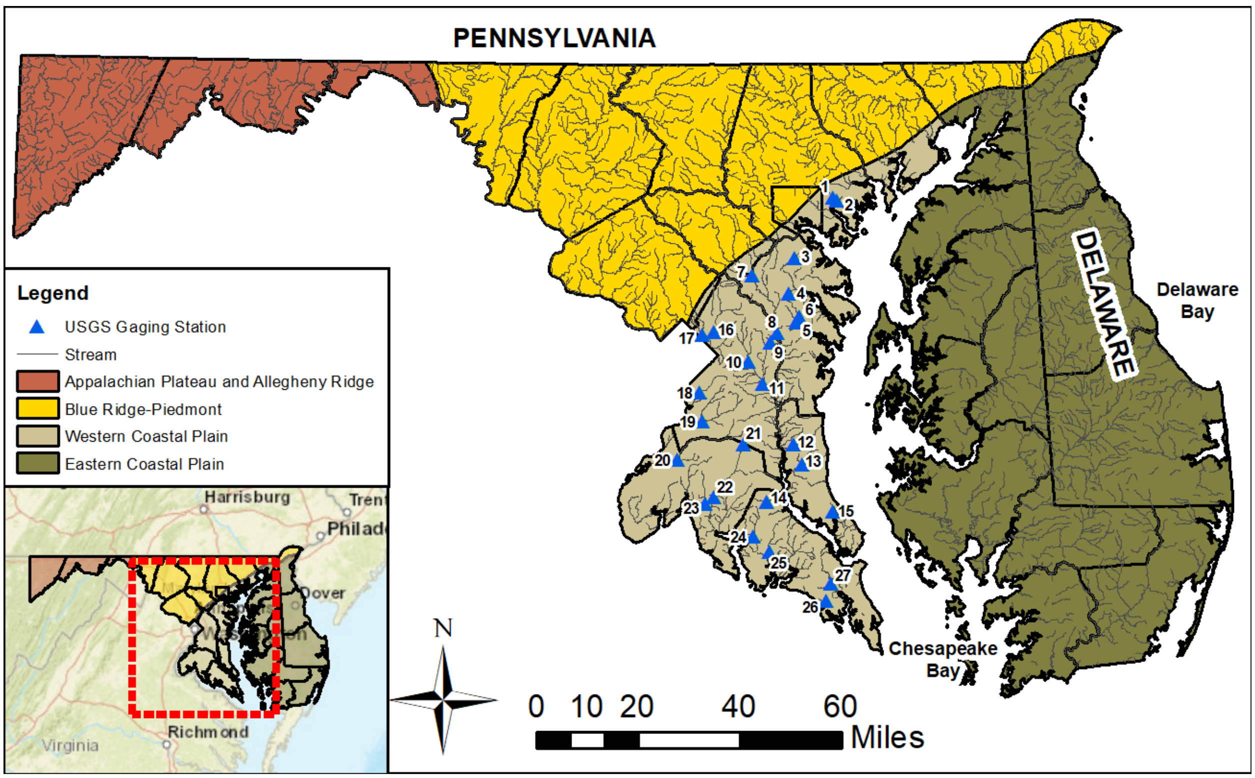


Figure 1. Location of 27 gaging stations in the Western Coastal Plain Region.

Regional Skew Analysis

Bulletin 17C flood frequency guidance (England and others, 2018) recommends fitting a Pearson Type III distribution to the logarithms of the annual peak flows using the method of moments. The Pearson Type III distribution is defined by three sample moments: mean, standard deviation and skew of the logarithms of the annual peak flows. To reduce the uncertainty in the sample or station skew, Bulletin 17C recommends weighting the station skew with a regional or generalized skew determined from unregulated long-term records in the region. Frequency analyses were first performed using station skew to get an updated estimate of skew at all gaging stations in order to estimate a regional or generalized skew value. The analyses were performed at rural gaging stations with 19 or more years of record. Urban gaging stations were not used because each site represents different land use conditions over the period of record. There are only eight rural gaging stations in the WCP with 19 or more years of record. The mean skew for the eight stations was 0.380 and the standard deviation of the skew was 0.386. This is a small sample for estimating skew so the eight stations in the WCP were combined with 15 rural stations from the Eastern Coastal Plain (ECP) Region with 19 or more years of record. The mean skew for the 23 stations was also 0.38 and the standard deviation or standard error of the skew was 0.38, essentially the same as for the limited sample of WCP stations. The mean skew of 0.38 with standard error of 0.38 was used to weight with the station skew in the final frequency analyses for all rural stations in the WCP. For the urban gaging stations where the impervious area exceeded 10 percent at the midpoint of the gaging record, station skew was used in the final frequency analyses.

Trend Analysis

The time series of annual peak flows exhibited upward trends at several of the WCP gaging stations because of increasing urbanization and/or major floods near the end of record. A common test for trend in a time series is the Mann-Kendall test (Helsel and Hirsch, 2002). This test uses Kendall's tau as the test statistic to measure the strength of the monotonic relation between annual peak flows and the year in which it occurred. The Mann-Kendall test is nonparametric and does not require the data to conform to any specific statistical distribution and does not utilize the actual magnitude of the peak flows. All peak flows are compared to those following it in time and the number of increasing and decreasing flows are recorded. The test statistic is based on the number of increasing or decreasing flows with time.

The USGS PeakFQ program includes the Mann-Kendall test and Kendall's test statistic is provided as part of the standard output. Time series graphs of annual peak flows for the 11 active gaging stations are given in Appendix 1 along with Kendall's tau and comments on what is causing any upward trend in annual peak flows. All 11 active stations have 22 years or more of record with eight of the stations having more than 40 years of record. Time series were not provided for the discontinued stations because those records generally ended in 1990 or before and generally are rural watersheds with limited urbanization and generally short records. Hence, trends in the annual peak flows were not an issue or the record was too short to adequately evaluate if a trend existed for the discontinued stations.

Of the 11 active stations shown in Appendix 1, seven stations are urban watersheds where impervious area was greater than 10 percent near the midpoint of the gaging station record. Six of those urban stations had statistically significant upward trends (at the five percent level of significance) when analyzing the full record due to increasing urbanization and major floods near the end of the record. The trend was accommodated as following for the six urban stations:

- **Sawmill Creek at Glen Burnie (station 01589500)** – drainage area = 5.04 square miles with record from 1945 to 2017. The upward trend is related to increasing urbanization and the peak of record in 2014. The more homogeneous period from 1984 to 2017 was used in the final frequency analysis.
- **Patuxent River near Bowie (station 01594440)** – drainage area = 350.21 square miles with record from 1972 to 2017. The upward trend is related to increasing urbanization and four large floods

from 2006 to 2014. A time-varying mean approach was used for the final frequency analysis as described in Kilgore and others (2016). This approach is briefly discussed in Appendix 2.

- **Western Branch at Upper Marlboro (station 01594526)** – drainage area = 89.38 square miles with record from 1986 to 2017. The upward trend is related to increasing urbanization and large floods in 2008 and 2011. A time-varying mean approach was used for the final frequency analysis.
- **Northeast Branch Anacostia River at Riverdale (01649500)** – drainage area = 73.2 square miles with record from 1933 to 2017. The upward trend is related to increasing urbanization and a large flood in 2006. A time-varying mean approach was used for the final frequency analysis.
- **Northwest Branch Anacostia River near Hyattsville (01651000)** – drainage area = 49.33 square miles with record from 1939 to 2017. The upward trend is related to increasing urbanization and large floods in 2006 and 2014. The more homogeneous period 1972 to 2017 was used in the final frequency analysis.
- **Piscataway Creek at Piscataway (01653600)** – drainage area = 39.43 square miles with record from 1966 to 2017. The upward trend is related to increasing urbanization and five large floods from 1999 to 2014. For this station, the upward trend was barely significant at the five percent level and the bigger issue was that the Pearson Type III distribution did not fit the data very well. The final frequency analysis was based on a graphical analysis.

The six stations with significant upward trends in annual peak flows are all urban watersheds and the increasing urbanization with time contributes to that trend. None of the long-term rural stations in the WCP exhibited significant trends.

There was one small-stream station, Clark Run near Bel Alton (01660930), where rainfall-runoff modeling results were available from an earlier study by Carpenter (1980). The flood discharges as determined by Carpenter (1980) were used in this study because these estimates were more reasonable than estimates based on 11 years of data (1966-76).

For the active gaging stations, nine additional years of record were added to analysis since 2008, the end of the record used in the 2010 analysis. There were some major floods in the period 2009 to 2017 particularly major floods in 2011 (Tropical Storm Lee or Hurricane Irene) and 2014. In general, the flood discharges increased for the active stations implying that the new regression equations may provide increased estimates. The updated flood discharges for the 1.25-, 1.5-. 2-, 5-, 10-, 25-, 50-, 100-, 200- and 500-year events are given in Appendix 3 for all 27 stations.

Watershed Characteristics Evaluated for the Regression Analysis

The watershed characteristics evaluated for the regression analysis included those that were statistically significant in previous regression analyses and were estimated using the digital data in GISHydroNXT (http://www.gishydro.eng.umd.edu/document.htm). The watershed characteristics included:

- Drainage area (DA), in square miles,
- Channel slope (CSL), in feet per mile,
- Land slope (LANDSL), in feet per feet and used as a percentage in the regression analysis (this is basin or watershed slope perpendicular to the stream)
- Basin Relief (BR), in feet,
- Percent impervious area near the middle of the gaging station record, impervious area is available for 1985, 1990, 1997, 2002 and 2010 land use conditions,

- Forest cover (FOR), in percent of the drainage area at the middle of the gaging station record, available for 1985, 1990, 1997, 2002, and 2010 land use conditions,
- Percent A, B, C and D SSURGO soils based on the legacy data in GISHydroNXT, and
- Percent A, B, C and D SSURGO soils based on soils data downloaded from the NRCS web site in May 2018.

The legacy SSURGO soils data in GISHydroNXT are shown in Figure 2 for the four Hydrologic Soil Groups A, B, C and D where A has the high infiltration rate and D the lowest infiltration rate. These data were added to GISHydroNXT over time and were representative of different dates for each county in the state.

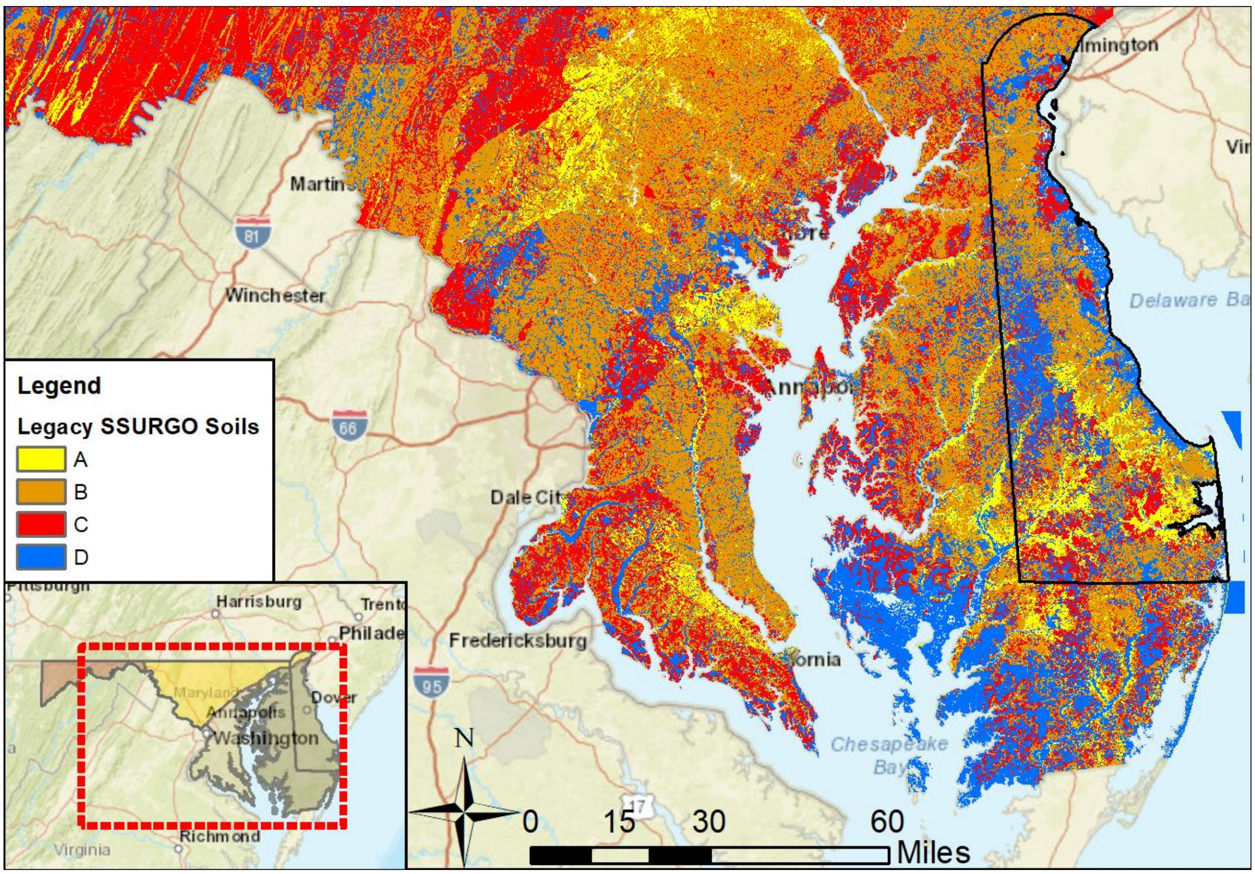


Figure 2. Legacy SSURGO soils data in GISHydroNXT.

The SSURGO soils data downloaded from the NRCS soil survey web site in May 2018 are shown in Figure 3. The NRCS procedures for estimating the Hydrologic Soils Groups (HSGs) were updated prior to 2009 and documented in the NRCS Part 630 Hydrology, National Engineering Handbook, Chapter 7, Hydrologic Soils Group (HSG) dated January 2009. The calculations for the new HSGs were completed for Maryland in 2014 and the updated HSGs were posted to the NRCS Web Soil Survey database in 2016. The new criteria for assigning HSGs use soil properties that influence runoff potential such as:

- Depth to a seasonal high-water table,
- Saturated hydraulic conductivity (Ksat) after prolonged wetting, and

- Depth to a layer with a very slow water transmission rate.

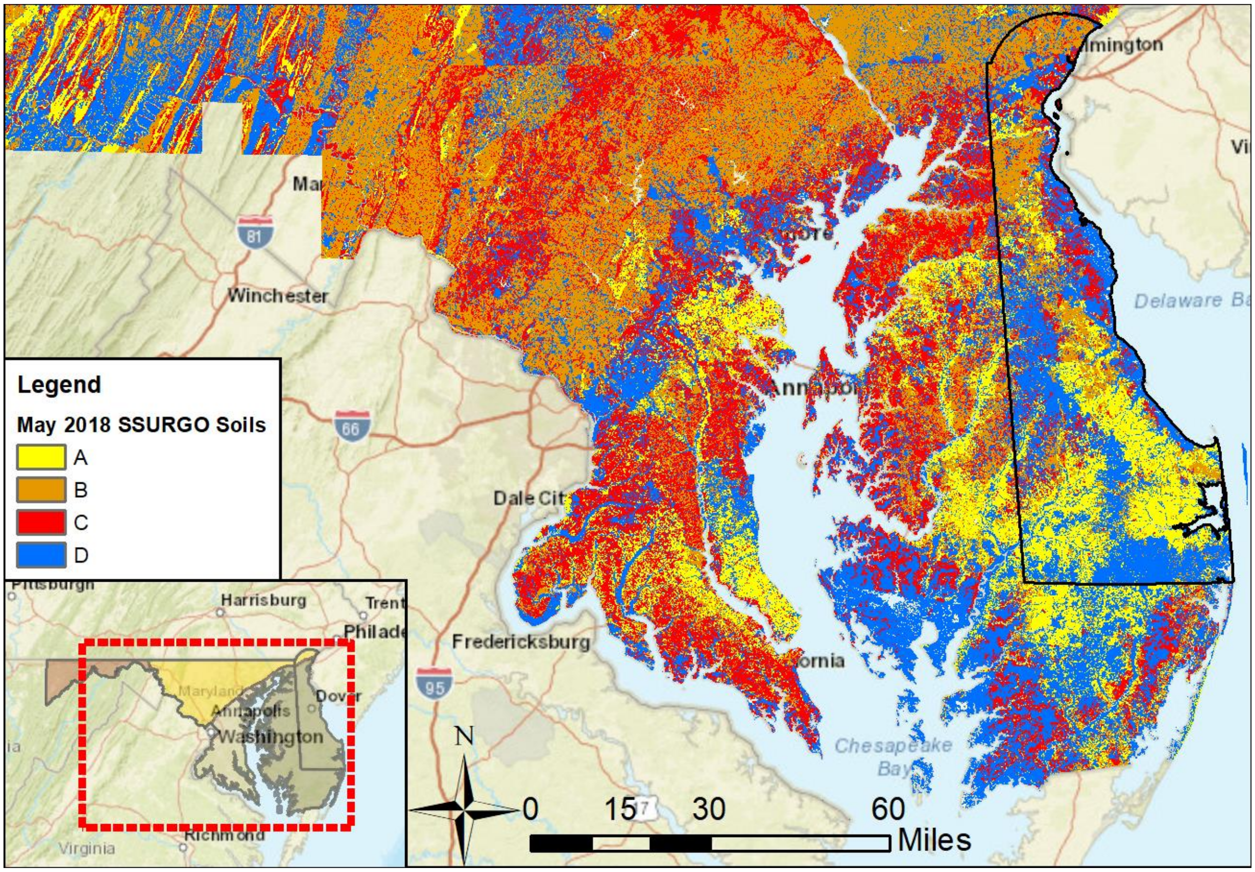


Figure 3. The May 2018 SSURGO soils data.

Development of Regression Equations

Multiple regression analyses were performed using all 27 gaging stations and the list of explanatory variables discussed earlier using the Statistical Analysis System (SAS) computer software developed by the SAS Institute, Inc., Cary, NC (https://www.sas.com/en_us/home.html). In this process, four gaging stations (all discontinued stations) were identified as outliers because the flood discharges for these stations were low for the size of the drainage area. A brief description follows as to why these stations were considered outliers:

1. **Dorsey Run near Jessup (01594400)**, 11.91 square miles, 16.7 percent IA (1985), 7.9 percent A soils (May 2018), 40.9 percent forest cover. There are 20 years of record from 1949-68, and 2009. Largest flood is 1,730 cfs in 2009. The gaging station 100-year flood is 2,690 cfs and the regression estimate is 5,710 cfs when this station is in the analysis.
2. **Western Branch near Largo (01594500)**, 30.04 square miles, 11.4 percent IA (1985), 19.8 percent A soils (May 2018), 41.6 percent forest cover. There are 25 years of record from 1950-74. Largest flood is 1,760 cfs in 1971. The gaging station 100-year flood is 2,600 cfs and the regression estimate is 7,270 cfs when this station is in the analysis.
3. **Killpeck Creek at Huntersville (01594710),** 3.46 square miles, 7.8 percent IA (1990), 60.3 percent A soils (May 2018), 60.4 percent forest cover. There are 12 years of record from 1986-97. Largest

flood is 255 cfs in 1990. The gaging station 100-year flood is 356 cfs and the regression estimate is 816 cfs when this station is in the analysis.

4. **Glebe Branch at Valley Lee (01661430),** 0.24 square miles, 2.1 percent IA (1985), 2.6 percent A soils (May 2018), 42.5 percent forest cover. There are 11 years of record from 1968-78. Largest flood is 110 cfs in 1969. The gaging station 100-year flood is 148 cfs and the regression estimate is 382 cfs when this station is in the analysis.

The regression analysis proceeded with 23 gaging stations. Separate sets of regression equations were developed using the legacy SSURGO soils data and the May 2018 SSURGO soils data. All flood discharges and topographic explanatory variables were transformed to logarithms prior to the regression analysis because tradition has shown that the logarithms of flood discharges are linearly related to logarithms of the watershed characteristics. The percent impervious area and percent soils data were evaluated for the logarithmic transformed data and untransformed data. Based on several regression analyses, the following observations are pertinent:

- The percent A, B and D soils based on the legacy SSURGO data in GISHydroNXT were **NOT** statistically significant in the same equation with percent impervious area. The percent C soils based on legacy SSURGO data was statistically significant (range of C soils from 0.8 to 64.6 percent).
- The percent B, C and D soils based on the May 2018 SSURGO data were **NOT** statistically significant in the same equation with impervious area.
- The percent A soils based on the May 2018 SSURGO was statistically significant at the five percent level in the same equation with percent impervious area (both logs and untransformed) from the 1.25- to the 500-year flood. Range of the May 2018 A soils is 0.0 to 85.2 percent.
- The percent A soils data are a better predictor when **NOT** transformed to logarithms. Note in Figure 4, the correlation between the 100-year discharge (lq100) and A soils is highest for the untransformed A soils data (Anew = May 2018 soils data). The “l” in Figure 4 before the variable name denotes logarithm.
- The percent forest cover is not statistically significant when used in the same equation with percent impervious area due to their high correlation (-0.76 for log transformed values as shown in Figure 4).
- The topographic/slope variables, channel slope, land slope and basin relief, are not statistically significant when used in the same equation with drainage area. Basin relief is highly correlated with drainage area (0.81 as shown in Figure 4) and channel slope is also highly correlated with drainage area (-0.78 as shown in Figure 4).
- The percent impervious area **NOT** transformed to logarithms is a better predictor up to the 10-year flood; percent impervious area transformed to logarithms is a better predictor for the 25- to 500-year flood. The log transformation is considered best for developing the regression equations since the larger floods are more important for design. Note in Figure 4, the correlation between the 100-year discharge (lq100) and impervious area is highest for the logarithmic transformed data (lia).

The correlation matrix of the explanatory variables and the 100-year discharge (lq100) is given in Figure 4 for 23 gaging stations. Anew is the SSURGO soils data dated May 2018. The highly significant or most important correlations are highlighted in yellow.

Regression Equations for Estimating Flood Discharges for the Western Coastal Plain Region of Maryland

Pearson Correlation Coefficients, N = 23
Prob > |r| under H0: Rho=0

	lq100	lda	lbr	lcsl	llandsl	lanew	anew	lia	ia	lfor
lq100	1.00000	0.82244	0.73297	-0.59026	-0.15114	-0.50772	-0.65519	0.49194	0.30455	-0.17808
		<.0001	<.0001	0.0030	0.4912	0.0134	0.0007	0.0171	0.1577	0.4163
lda	0.82244	1.00000	0.80679	-0.78143	0.10460	-0.13921	-0.26059	0.20169	0.04266	0.15669
	<.0001		<.0001	<.0001	0.6348	0.5264	0.2298	0.3561	0.8467	0.4752
lbr	0.73297	0.80679	1.00000	-0.34956	0.32497	-0.33087	-0.27853	0.38170	0.26857	-0.12057
	<.0001	<.0001		0.1020	0.1303	0.1230	0.1981	0.0723	0.2153	0.5837
lcsl	-0.59026	-0.78143	-0.34956	1.00000	0.06648	-0.15360	0.13908	0.15237	0.29986	-0.44705
	0.0030	<.0001	0.1020		0.7631	0.4841	0.5268	0.4876	0.1645	0.0325
llandsl	-0.15114	0.10460	0.32497	0.06648	1.00000	0.25793	0.35709	-0.24348	-0.26892	0.27732
	0.4912	0.6348	0.1303	0.7631		0.2347	0.0944	0.2629	0.2147	0.2001
lanew	-0.50772	-0.13921	-0.33087	-0.15360	0.25793	1.00000	0.84352	-0.42834	-0.42875	0.49072
	0.0134	0.5264	0.1230	0.4841	0.2347		<.0001	0.0414	0.0412	0.0174
anew	-0.65519	-0.26059	-0.27853	0.13908	0.35709	0.84352	1.00000	-0.33240	-0.25642	0.37306
	0.0007	0.2298	0.1981	0.5268	0.0944	<.0001		0.1212	0.2376	0.0796
lia	0.49194	0.20169	0.38170	0.15237	-0.24348	-0.42834	-0.33240	1.00000	0.92246	-0.75753
	0.0171	0.3561	0.0723	0.4876	0.2629	0.0414	0.1212		<.0001	<.0001
ia	0.30455	0.04266	0.26857	0.29986	-0.26892	-0.42875	-0.25642	0.92246	1.00000	-0.76281
	0.1577	0.8467	0.2153	0.1645	0.2147	0.0412	0.2376	<.0001		<.0001
lfor	-0.17808	0.15669	-0.12057	-0.44705	0.27732	0.49072	0.37306	-0.75753	-0.76281	1.00000
	0.4163	0.4752	0.5837	0.0325	0.2001	0.0174	0.0796	<.0001	<.0001	

Figure 4. Correlation matrix of logarithm of 100-year discharge (lq100) and potential explanatory variables.

The statistical significance of the explanatory variables in a regression analysis is dependent on the correlation with other variables. If two variables are highly correlated, then only one of the variables will be significant in reducing the standard error of the regression equation.

Based on the regression analyses, the May 2018 SSURGO soils is a better predictor than the legacy SSURGO data for the WCP. The May 2018 SSURGO data are now the default SSURGO data in GISHydroNXT. The three most significant explanatory variables for the WCP are: logarithm of drainage area, logarithm of percent impervious area, and percent A soils (May 2018 data with no transformation). The watershed characteristics used in the regression analysis are given in Appendix 4 for all 27 stations. The date of the land use data for determining impervious area is also given in Appendix 4 along with the period of record for the gaging stations.

The regression equations based on 23 stations for the WCP are as follows where DA = drainage area, in square miles, ranging from 0.96 to 350.21 square miles; IA = impervious area, in percent, ranging from 0.0

to 36.8 percent; Anew = the May 2018 A soils data, in percent, ranging from 0.0 to 85.2 percent; SE = standard error in percent and EY = Equivalent Years of record. All the explanatory variables are statistically significant at the five percent level of significance for all recurrence intervals. Equivalent years of record (EY) is defined as the number of years of actual streamflow record required at a site to achieve an accuracy equivalent to the standard error of the regression equation. EY is used to weight the gaging station estimates with the regression estimates following the approach documented by Dillow (1996) and described in the Maryland Hydrology Panel report (2016). The computation of EY is described in Appendix 5.

$Q_{1.25} = 40.7\ DA^{0.683}\ (IA+1)^{0.366}\ 10^{-0.00849*Anew}$ SE = 45.6 percent EY = 2.8 (1)

$Q_{1.5} = 56.3\ DA^{0.671}\ (IA+1)^{0.354}\ 10^{-0.00865*Anew}$ SE = 45.3 percent EY = 2.8 (2)

$Q_{2} = 81.3\ DA^{0.656}\ (IA+1)^{0.340}\ 10^{-0.00878*Anew}$ SE = 45.9 percent EY = 2.7 (3)

$Q_{5} = 185.5\ DA^{0.622}\ (IA+1)^{0.311}\ 10^{-0.00916*Anew}$ SE = 41.2 percent EY = 6.3 (4)

$Q_{10} = 301.4\ DA^{0.607}\ (IA+1)^{0.296}\ 10^{-0.00943*Anew}$ SE = 37.3 percent EY = 12 (5)

$Q_{25} = 536.1\ DA^{0.570}\ (IA+1)^{0.275}\ 10^{-0.00954*Anew}$ SE = 34.0 percent EY = 21 (6)

$Q_{50} = 791.3\ DA^{0.546}\ (IA+1)^{0.260}\ 10^{-0.00956*Anew}$ SE = 33.3 percent EY =29 (7)

$Q_{100} = 1{,}132.3\ DA^{0.526}\ (IA+1)^{0.247}\ 10^{-0.00957*Anew}$ SE = 35.2 percent EY = 32 (8)

$Q_{200} = 1610.4\ DA^{0.501}\ (IA+1)^{0.234}\ 10^{-0.00955*Anew}$ SE = 39.8 percent EY = 31 (9)

$Q_{500} = 2523.0\ DA^{0.469}\ (IA+1)^{0.216}\ 10^{-0.00956*Anew}$ SE = 49.5 percent EY = 26 (10)

The impervious area at the middle of the gaging station record was used in developing the regression equations but the impervious area for existing land use conditions (latest data are based on 2010) should be used in application of the equations for ungaged watersheds.

For Equations 1-10, the drainage area exponent decreases with an increasing recurrence interval, consistent with earlier results. A possible explanation is that the storm rainfall for the larger storms varies considerably across a watershed and does not have a uniform impact across the entire watershed (that is, the effective drainage area is less). The exponent on impervious area decreases with increasing recurrence interval, implying that impervious area has less influence as the floods become larger. This is a well-known result in which soils become more saturated for the larger floods, and impervious area has relatively less impact on runoff volumes. The exponent on Anew increases from the 1.25-year flood up to the 25-year flood and then is fairly constant up to the 500-year flood. This implies the soils become more significant as storm rainfall increases until the 25-year flood when the soils may become saturated.

The higher standard errors for the shorter recurrence interval (1.25- to 5-year) floods imply that explanatory variables other than drainage area, the percentage of impervious area, and percentage of A soils influence these floods. The time-sampling error (error in T-year flood discharge) is actually less for these smaller floods, so one would expect a lower standard error in the regression analysis. Instead, the standard errors of the regression equations for the smaller events are influenced by the model error, indicating that other important explanatory variables may be missing from the equations.

The 100-year regression estimates (Q100 from Equation 8) are plotted versus the 100-year gaging station estimates in Figure 5 for the equation based on 23 stations. The trend (best-fit) line is close to the equal discharge line indicating the regression estimates are reasonably unbiased for all gaging stations.

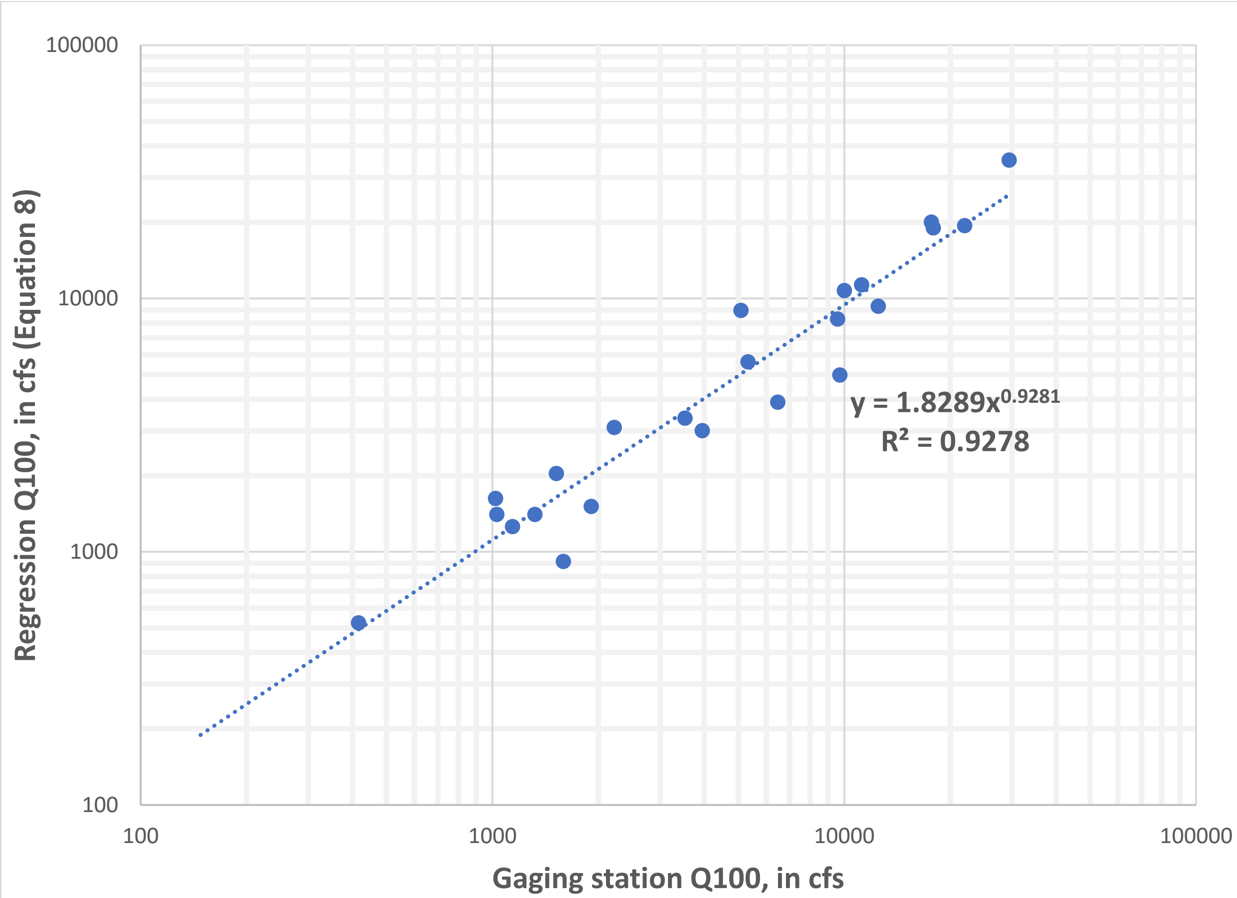


Figure 5. The 100-year regression estimates from Equation 8 plotted versus the 100-year estimates based on gaging station data for 23 stations in the Western Coastal Plain Region.

The 10-year regression estimates (Q10 from Equation 5) are plotted versus the 10-year gaging station estimates in Figure 6 for the equations based on 23 stations. The trend line is close to the equal discharge line for the smaller discharges indicating the regression estimates are reasonably unbiased. For the larger discharges, there is a tendency for the regression equation to underestimate the gaging station data. For a gaging station estimate of 10,000 cfs, the regression equation is predicting about 8,000 cfs, on average.

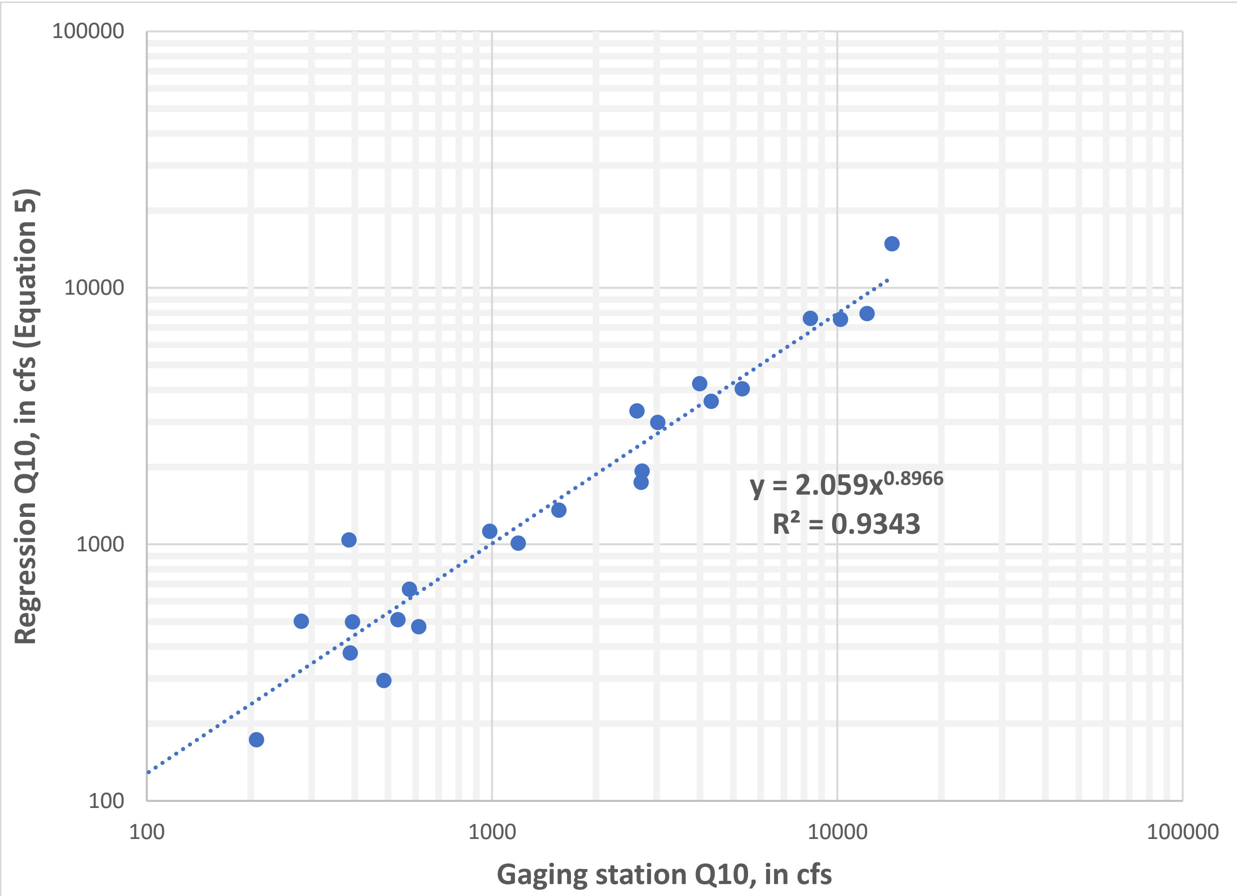


Figure 6. The 10-year regression estimates from Equation 5 plotted versus the 10-year estimates based on gaging station data for 23 stations in the Western Coastal Plain Region.

The 2010 regression equations are compared to the 2019 regression equations in Figure 7 for the 100-year flood using data for 23 gaging stations. There is a tendency for the 2019 regression estimates to be higher than the 2010 estimates for the larger discharges. For example, when the 2019 equation is predicting 10,000 cfs, the 2010 regression equation is predicting about 8,000 cfs, on average.

Regression Equations for Estimating Flood Discharges for the Western Coastal Plain Region of Maryland

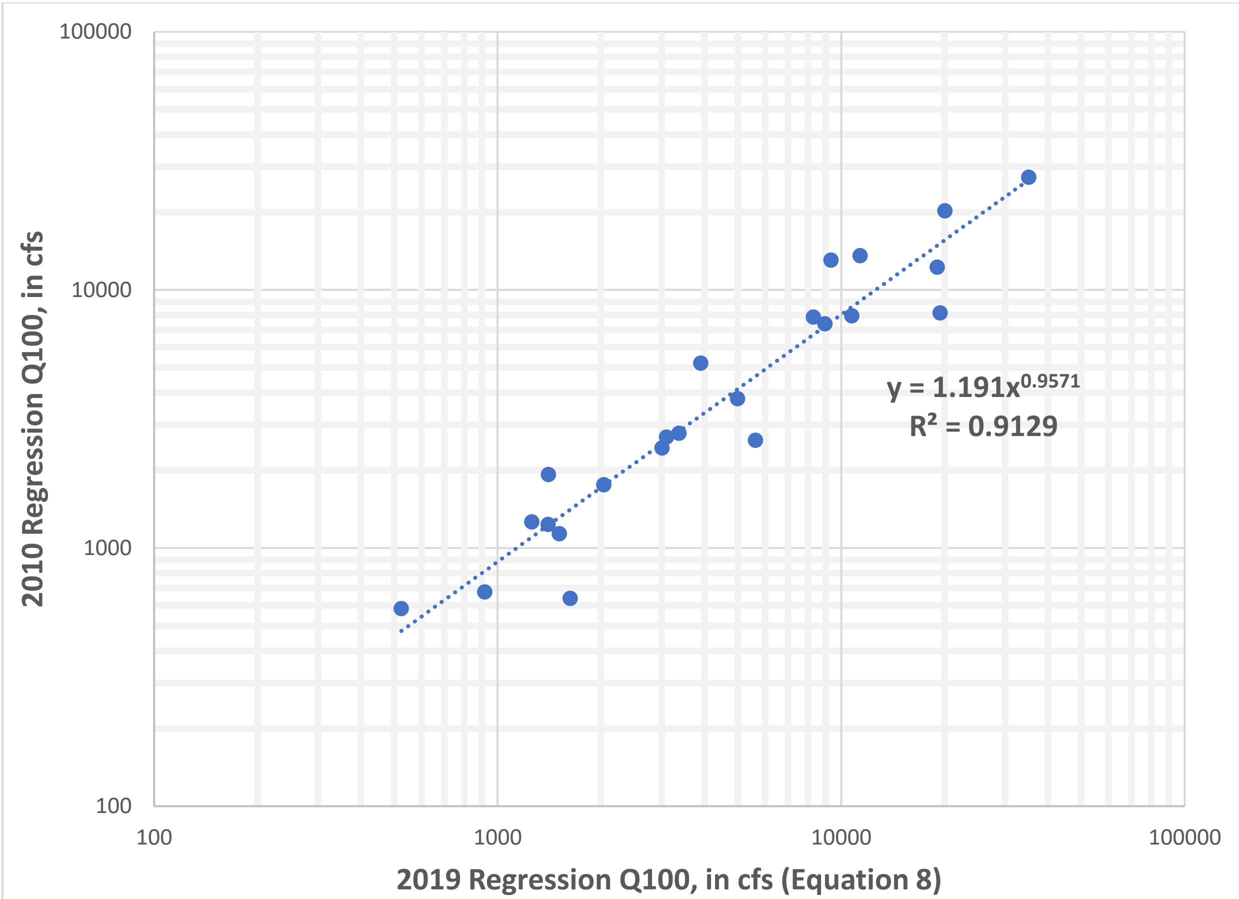


Figure 7. Comparison of the 100-year flood discharges for the 2010 and 2019 regression equations.

The 2010 regression equations are compared to the 2019 regression equations in Figure 8 for the 10-year flood using data for 23 gaging stations. There is a tendency for the 2019 regression estimates to be higher than the 2010 estimates for the larger discharges. For example, when the 2019 regression equation predicts 10,000 cfs, the 2010 regression equations are predicting about 8,000 cfs, on average.

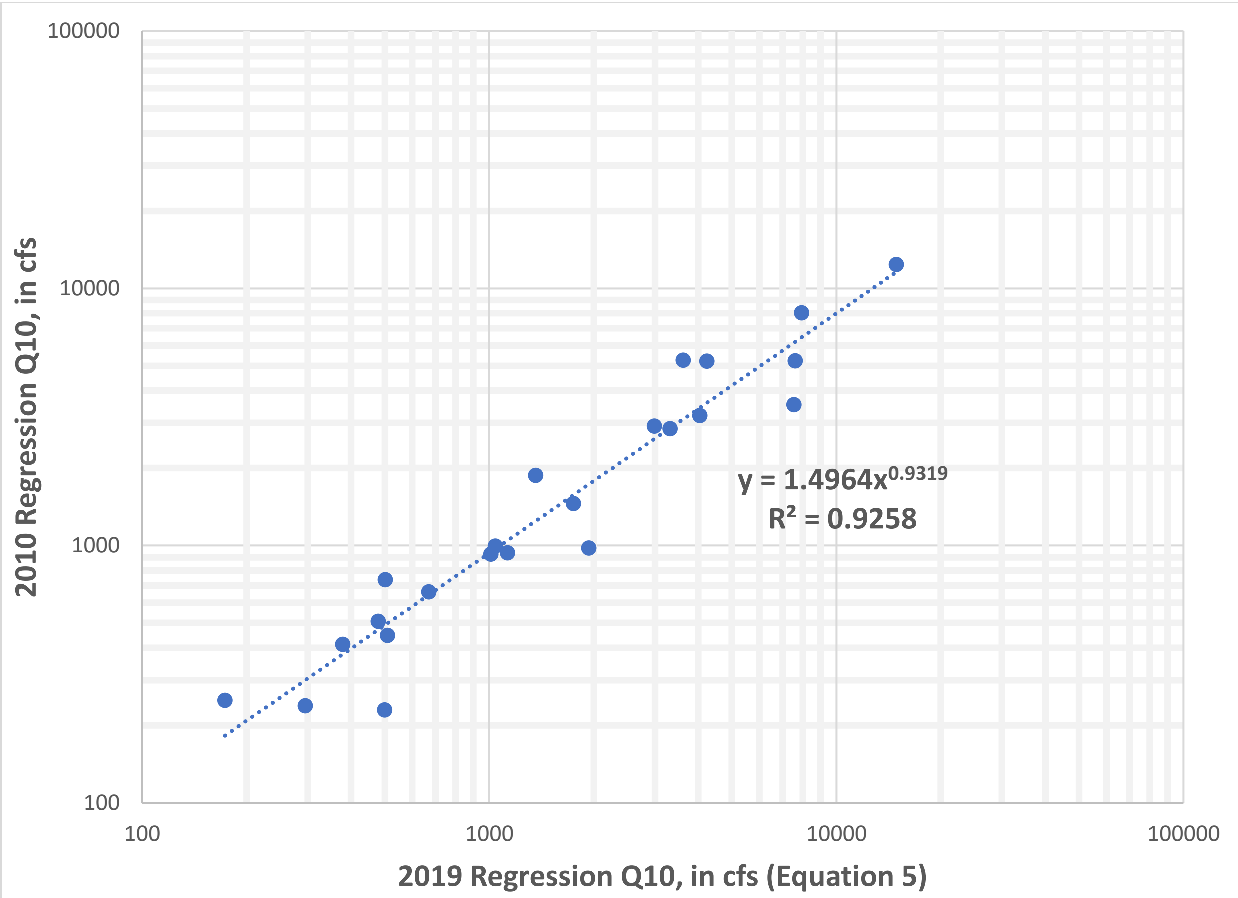


Figure 8. Comparison of the 10-year flood discharges for the 2010 and 2019 regression equations.

Regression Equations for Estimating Flood Discharges for the Western Coastal Plain Region of Maryland

Summary and Conclusions

The Fixed Region regression equations for the Western Coastal Plain Region of Maryland were updated using annual peak flow data through the 2017 water year using Bulletin 17C (England and others, 2018). The regression equations were based on 23 stations (11 active and 12 discontinued stations) and the statistically significant explanatory variables were drainage area, in square miles; percent impervious area at the midpoint of the gaging station record; and percent of A soils based on SSURGO data downloaded from the NRCS soil survey web site in May 2018. The legacy SSURGO data in GISHydroNXT and the May 2018 SSURGO data were both evaluated in the regression analysis to determine which set of soils data provided the most accurate regression equations. The May 2018 SSURGO data provided the most accurate regression equations and is now the default soils data in GISHydroNXT.

Of the 11 active gaging stations, six stations had statistically significant upward trends in the annual peak flow data due to increasing urbanization and major floods near the end of the record. These trends were accounted for by using a time-varying mean and using a more homogeneous period of record.

The regression estimate for the 100-year discharge was compared to gaging station data and shown to be unbiased. For the 10-year discharge, the regression estimates tend to be about 20 percent less than the gaging station estimates for the largest watersheds. The 2019 regression equations for the 10- and 100-year flood discharges were also compared to the 2010 regression equations that were based on annual peak flow data through the 2008 water year. The 2019 regression estimates tend to be higher than the 2010 estimates, particularly for the larger watersheds. This is consistent with the increase in flood discharges for the active gaging stations that tend to be larger watersheds. The increase in flood discharges for the active stations are related to increasing urbanization and major floods in 2011 and 2014 at many of the stations.

The updated regression equations will be used by the MDOT SHA in the design of bridges and culverts in Maryland. The updated regression equations will be included in the fifth version of the Maryland Hydrology Panel report entitled “Application of Hydrologic Methods in Maryland” that will be published in 2020.

References

Carpenter, D.H., 1980, ***Technique for estimating magnitude and frequency of floods in Maryland*:** U.S. Geological Survey Water-Resources Investigations Open-File Report 80-1016, 79 p.

Dillow, J.J.A., 1996, ***Technique for estimating magnitude and frequency of peak flows in Maryland***: U.S. Geological Survey Water-Resources Investigations Report 95-4154, 55 p.

England, J.F., Jr., Cohn, T.A., Faber, B.A., Stedinger, J.R., Thomas, W.O. Jr., Veilleux, A.G., Kiang, J.E., and Mason, R.R., Jr., 2018. ***Guidelines for Determining Flood Flow Frequency – Bulletin 17C***: U.S. Geological Survey Techniques and Methods, Book 4, Chapter B5, 148 p.

Hardison, C.H., 1971, ***Prediction error of regression estimates of streamflow characteristics at ungaged sites***: U.S. Geological Survey Professional Paper 750-C, pp. C228-C236.

Helsel, D.R., and Hirsch, R.M., 2002. ***Statistical Methods in Water Resources***: Techniques of Water Resources Investigations of the U.S. Geological Survey, Book 4, Hydrologic Analysis and Interpretation, Chapter A3, 503 p.

Kilgore, R., Herrmann, G.R., Thomas, W.O., Jr., and Thompson, D.B., 2016. ***Highways in the River Environment – Floodplains, Extreme Events, Risk and Resilience***. Hydraulic Engineering Circular No. 17 (HEC-17), Federal Highway Administration, FHWS-HIF-16-018.

Maryland Hydrology Panel, 2006. ***Application of Hydrologic Methods in Maryland – Second Edition***: A report prepared by the Hydrology Panel for the Maryland State Highway Administration and Maryland Department of the Environment, August 2006.

Maryland Hydrology Panel, 2010. ***Application of Hydrologic Methods in Maryland -Third Edition***: A report prepared by the Hydrology Panel for the Maryland State Highway Administration and Maryland Department of the Environment, September 2010.

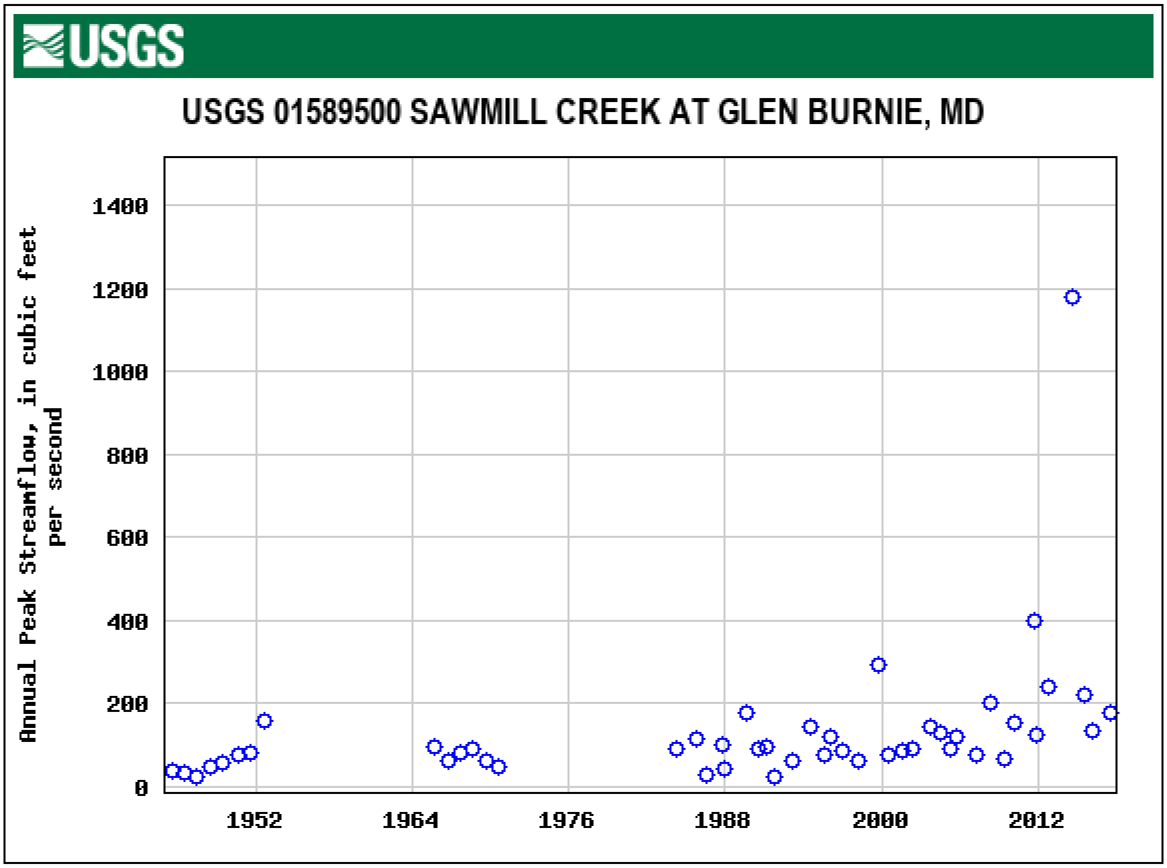
Maryland Hydrology Panel, 2016. ***Application of Hydrologic Methods in Maryland -Fourth Edition***: A report prepared by the Hydrology Panel for the Maryland State Highway Administration and Maryland Department of the Environment, July 2016.

Moglen, G.E., Thomas, W.O., Jr., and Cuneo, Carlos, 2006, ***Evaluation of alternative statistical methods for estimating frequency of peak flows in Maryland***: Final report (SP907C4B), Maryland State Highway Administration, Baltimore, Maryland.

Natural Resources Conservation Service, 2009. ***Chapter 7 Hydrologic Soil Groups***. Part 630 Hydrology National Engineering Handbook, U.S. Department of Agriculture, January 2009, 10 p.

Stedinger, J.R., Vogel, R.M., and Foufoula-Georgiou, E., 1993, Chapter 18 ***Frequency Analysis of Extreme Events***: *in* Handbook of Hydrology, David Maidment, Editor in Chief, McGraw-Hill, Inc.

Appendix 1. Time series graphs of the annual peak flows for the 11 active gaging stations in the Western Coastal Plain Region.



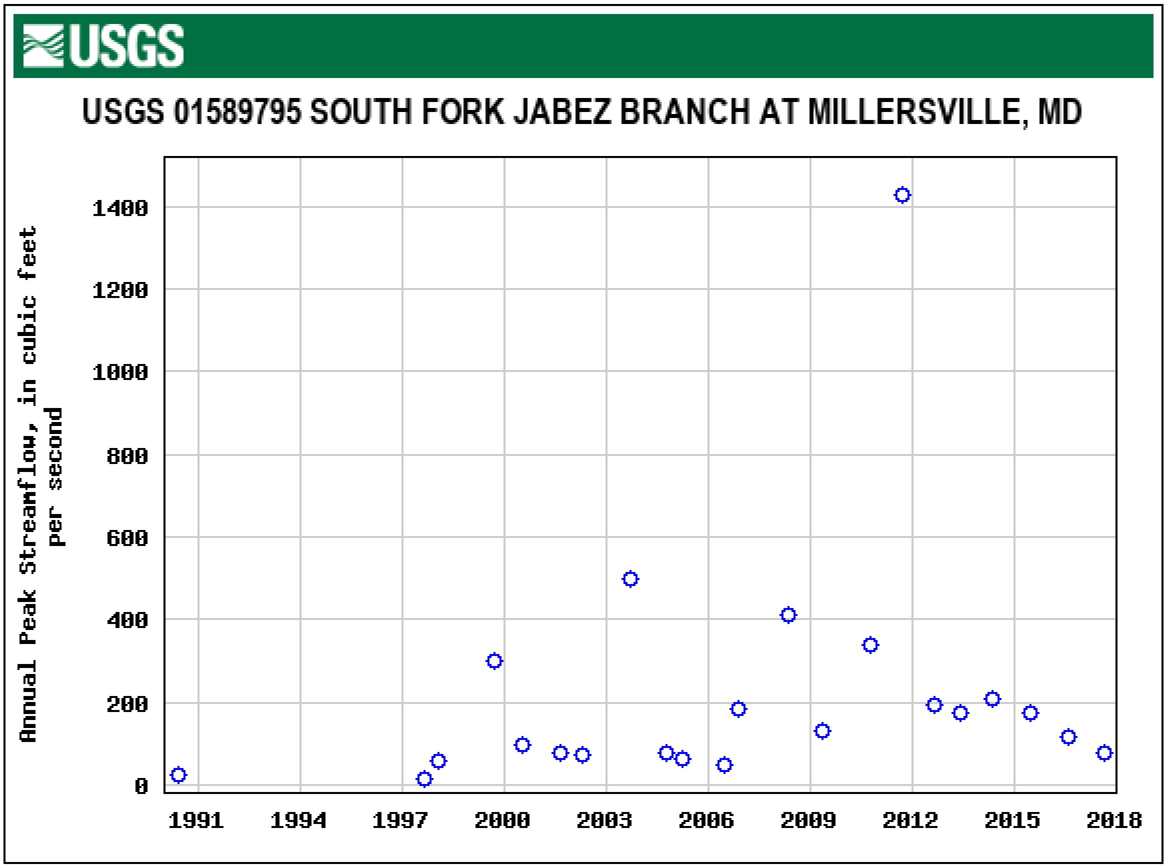
48 years of record – 1945 to 2017; drainage area = 5.04 square miles

Kendall's Tau = 0.455 for 1945 to 2017; Kendall's Tau = 0.360 for 1984 to 2017

P value = 0.00 for 1945 to 2017; P value = 0.003 for 1984 to 2017

Conclusion: Significant upward trend in annual peak flows since the P value is less than 0.05 (five percent level of significance).

Comments: This is an urban watershed where the impervious area went from 11.7 percent in 1985 to 29.7 percent in 2002 to 33.5 percent in 2010. The flood of record is 1180 cfs in 2014 near the end of the record. These are contributing factors to the upward trend. The more homogeneous period 1984-2017 was used for the frequency analyses (34 years). Still an upward trend due primarily to the 2014 flood. Used IA02 = 29.7 percent in the regression analysis.



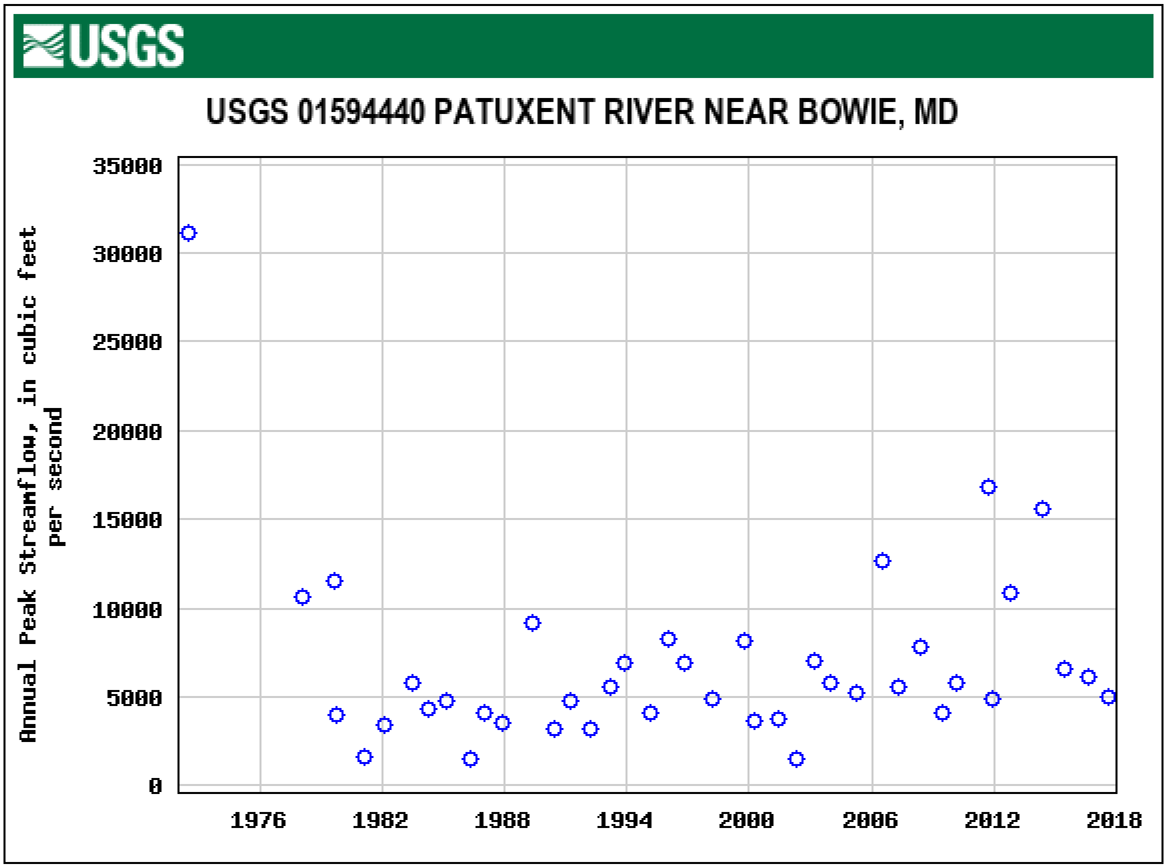
22 years of record – 1990, 1997-2017; drainage area = 0.96 square miles

Kendall's tau = 0.0.264

P value = 0.091

Conclusion: No significant upward trend in annual peak flows since the P value is greater than 0.05 (five percent level of significance).

Comments: No upward trend even though the flood of record (1,490 cfs) occurred in 2011 near the end of the record. IA85 = 8.2%, IA02 = 16.8% and IA10 = 20.0%. IA10 = 20.0% was used in the regression analysis.



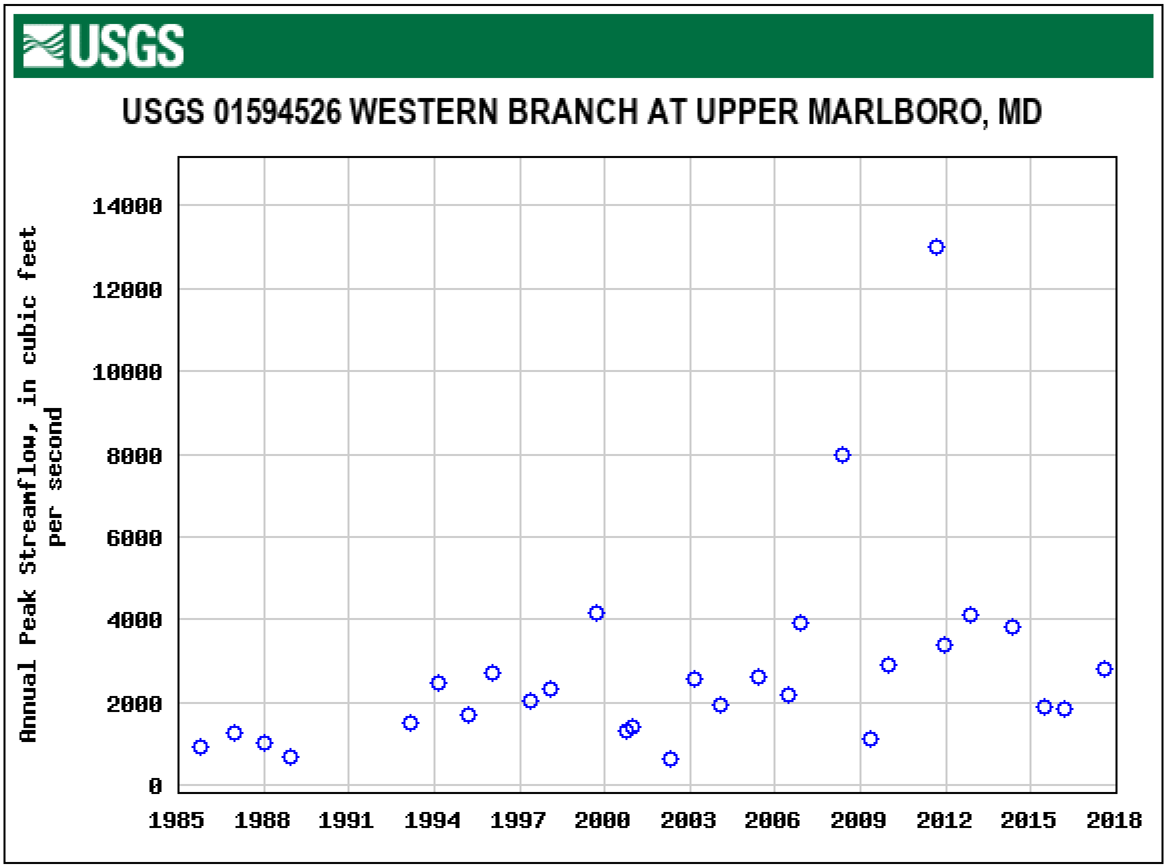
41 years of record 1972 (Tropical Storm Agnes) 1978-2017; drainage area = 350.21 square miles

Kendall's Tau = 0.241

P value = 0.029

Conclusion: Significant upward trend in annual peak flows since the P value is less than 0.05 (five percent level of significance).

Comments: This is an urban watershed with IA85 = 8.6%, IA90 = 10.7%, IA97 = 12.9%, IA02 = 14.9% and IA10 = 17.6%. Upward trend partly related to increased urbanization and four large floods from 2006 to 2014. Used the time-varying mean for the frequency analysis and used IA02 = 14.9% in the regression analysis.



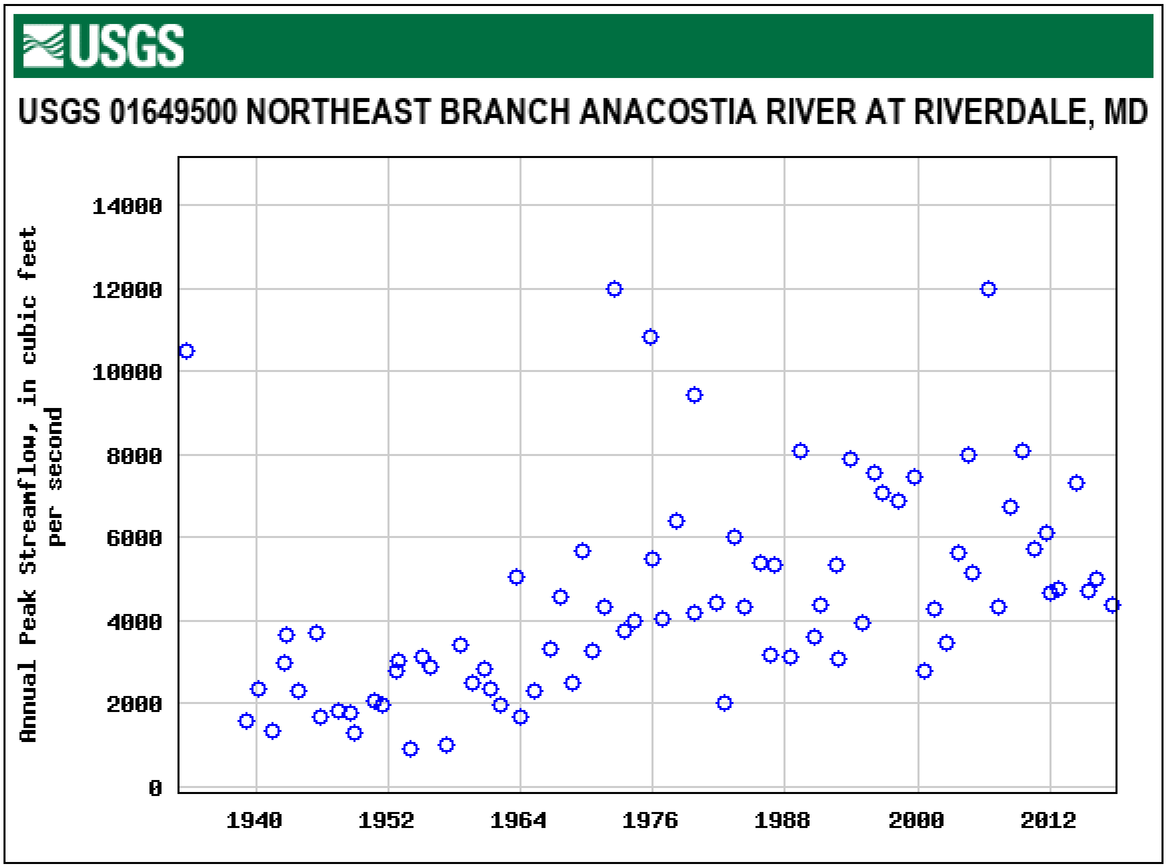
29 years of record from 1986-2017; drainage area = 89.38 square miles

Kendall's Tau = 0.384

P value = 0.004

Conclusion: Significant upward trend in annual peak flows since the P value is less than 0.05 (five percent level of significance).

Comments: This is an urban watershed with IA85 = 9.5%, IA90 = 11.8%, IA97 = 17.5%, IA02 = 21.4%, IA10 = 24.6% (ultimate development = 35.9 percent). Upward trend partly related to increased urbanization but mostly to big floods in 2011 (13,000 cfs) and 2008 (7,980 cfs). The time-varying mean approach was chosen for frequency analysis. Used IA02 = 21.4% in regression analysis.



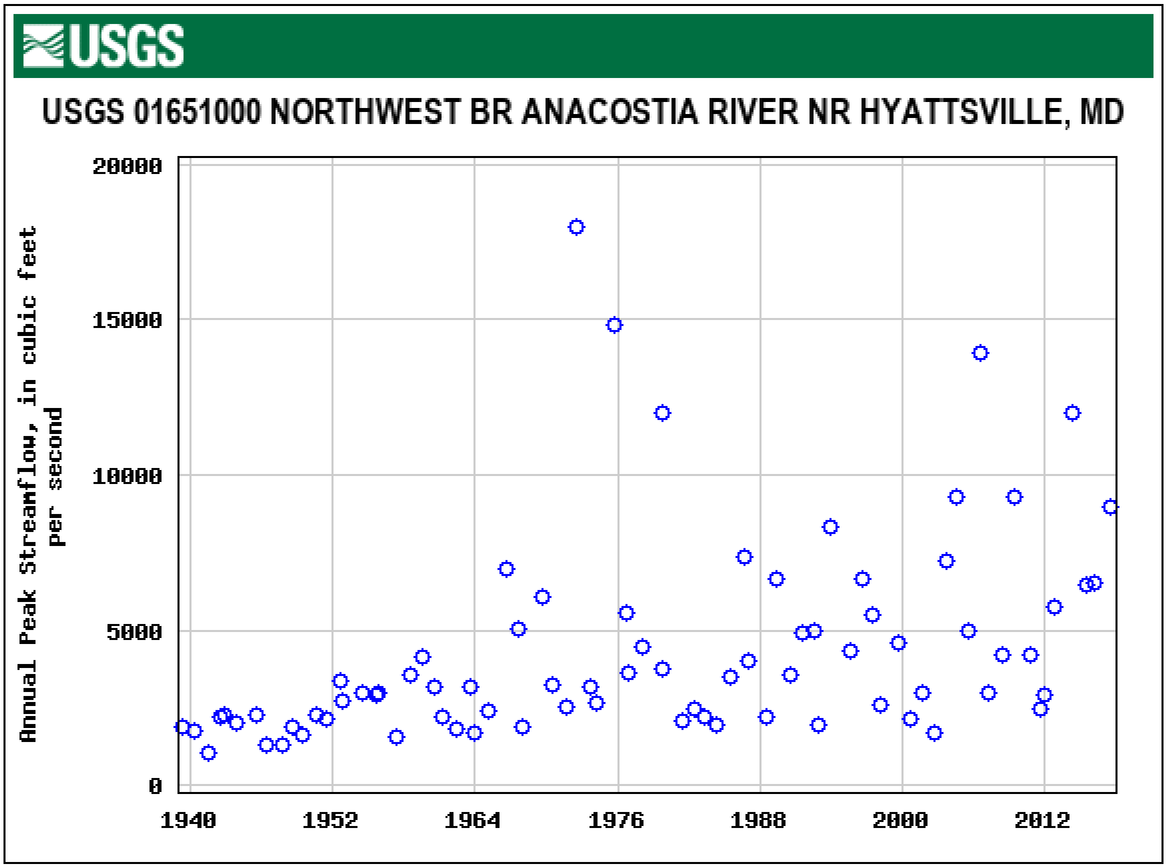
80 years of record 1933, 1939 – 2017; drainage area = 73.2 square miles

Kendall's Tau = 0.055

P value = 0.596

Conclusion: No significant upward trend in annual peak flows for 1972 to 2017 since the P value is greater than 0.05 (five percent level of significance).

Comments: This is an urban watershed with IA85 = 18.9%, IA90 = 21.4%, IA97 = 24.8%, IA02 = 27.4% and IA10 = 28.4% (ultimate development = 34.9 percent). Upward trend for the full period of record related to increased urbanization. A more homogeneous period (1972-2017) was analyzed as well. The time-varying mean approach was chosen for frequency analysis rather than the more homogeneous period. Used IA97 = 24.8% in regression analysis.



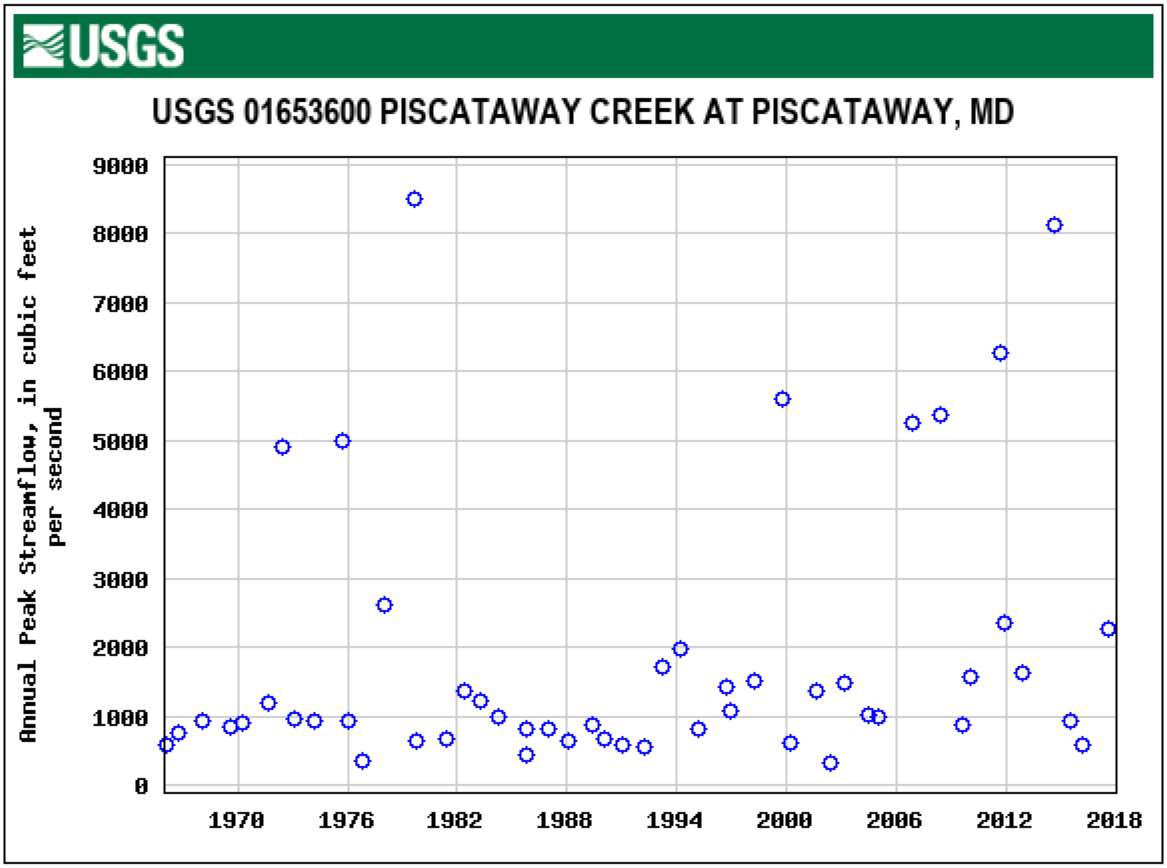
79 years of record 1939– 2017; drainage area = 49.3 square miles

Kendall's Tau = 0.106

P value = 0.302

Conclusion: No significant upward trend in annual peak flows for 1972 to 2017 since the P value is greater than 0.05 (five percent level of significance).

Comments: This is an urban watershed with IA85 = 22.3%, IA90 = 25.1%, IA97 = 27.8%, IA02 = 28.4% and IA10 = 30.3%. Upward trend for the full length of record related to increased urbanization. The more homogeneous period (1972-2017) was chosen for frequency analysis. Used IA97 = 27.8% in regression analysis.



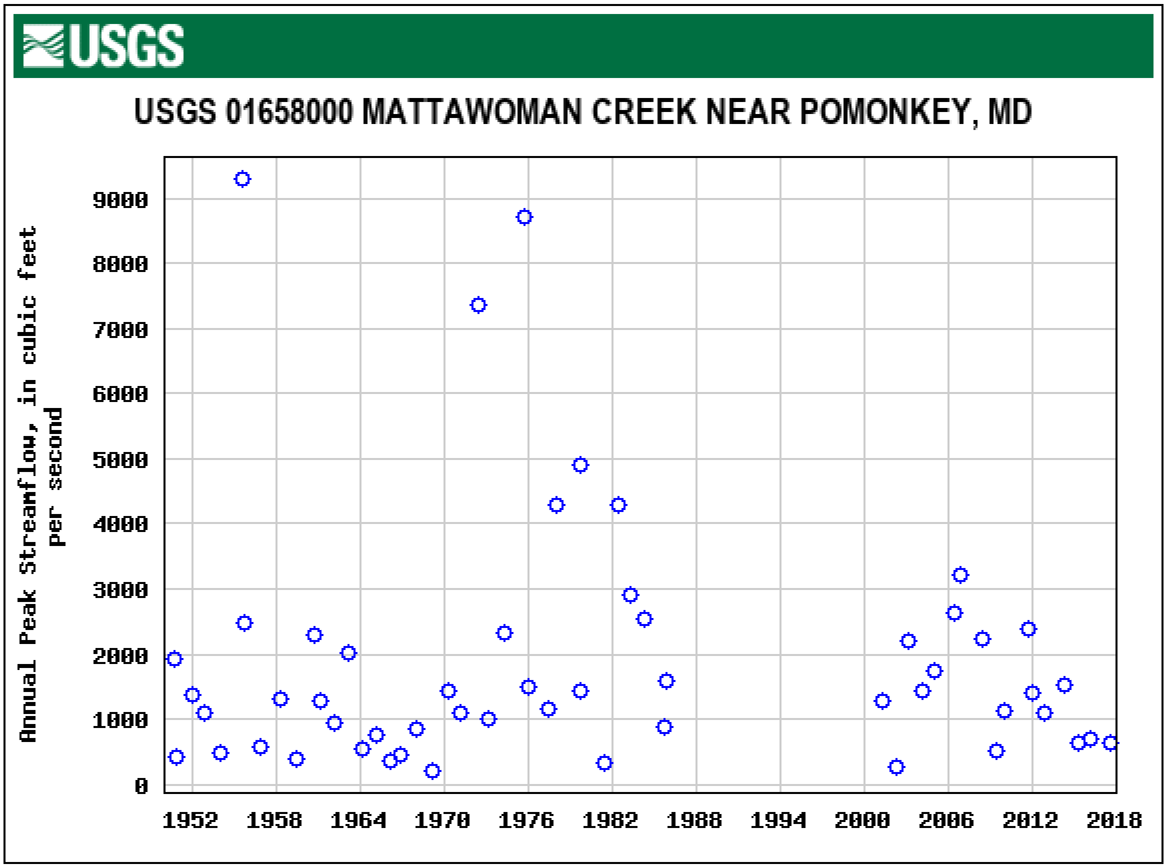
51 years of record – 1966 to 2017; drainage area = 39.4 square miles

Kendall's Tau = 0.196

P value = 0.043

Conclusion: Significant upward trend in annual peak flows since the P value is slightly less than 0.05 (five percent level of significance).

Comments: This is a watershed where the impervious area went from IA85 = 7.7%, IA90 = 9.9%, IA97 = 11.6%, IA02 = 14.3%, IA10 = 17.0%. Five large floods from 1999 to 2014 and the increased urbanization contribute to the upward trend. Used IA97 = 11.6% in the regression analysis.



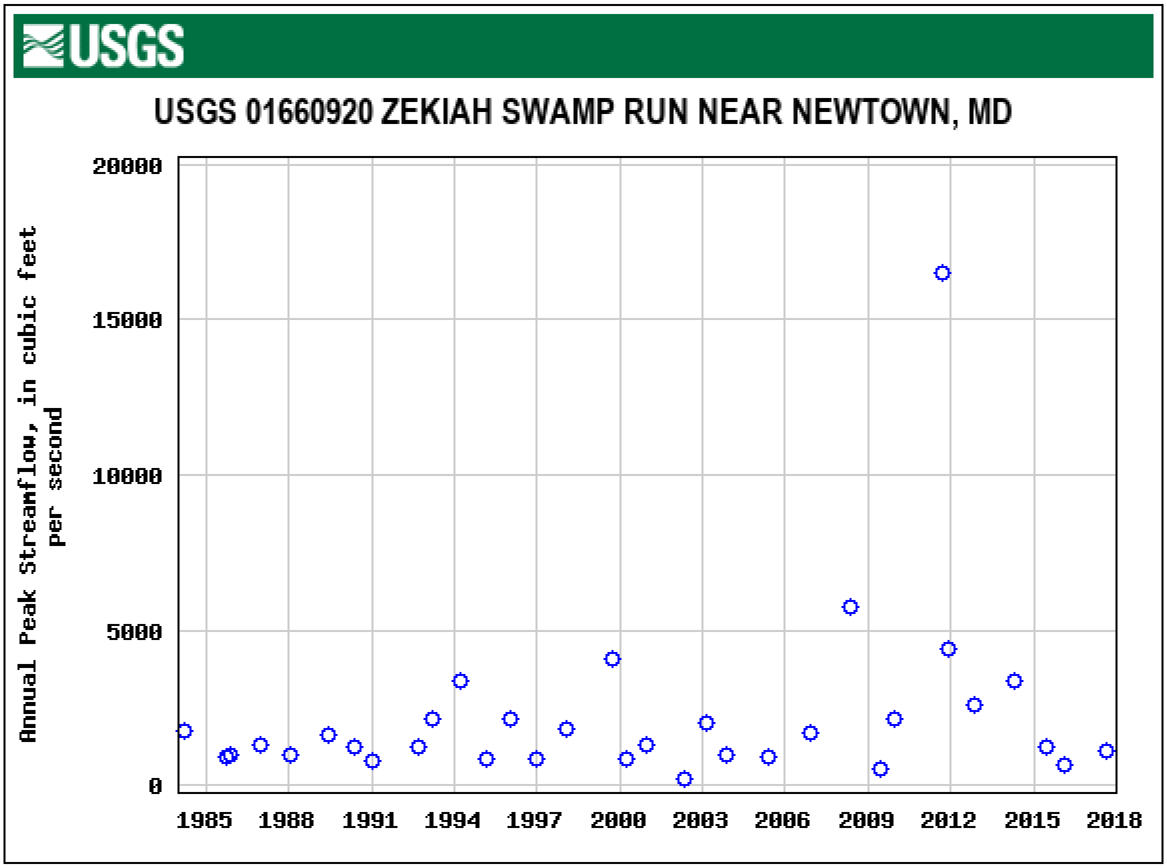
54 years of record – 1950 to 2017; drainage area = 55.6 square miles

Kendall's Tau = 0.052

P value = 0.586

Conclusion: No significant upward trend in annual peak flows since the P value is greater than 0.05 (five percent level of significance).

Comments: No upward trend since the major floods occurred early in the record and no significant increase in urbanization. Large floods prior to 1975 occurred when watershed was mostly rural. IA85 = 5% was used in the regression analysis. The most recent impervious area IA10 = 15.3%.



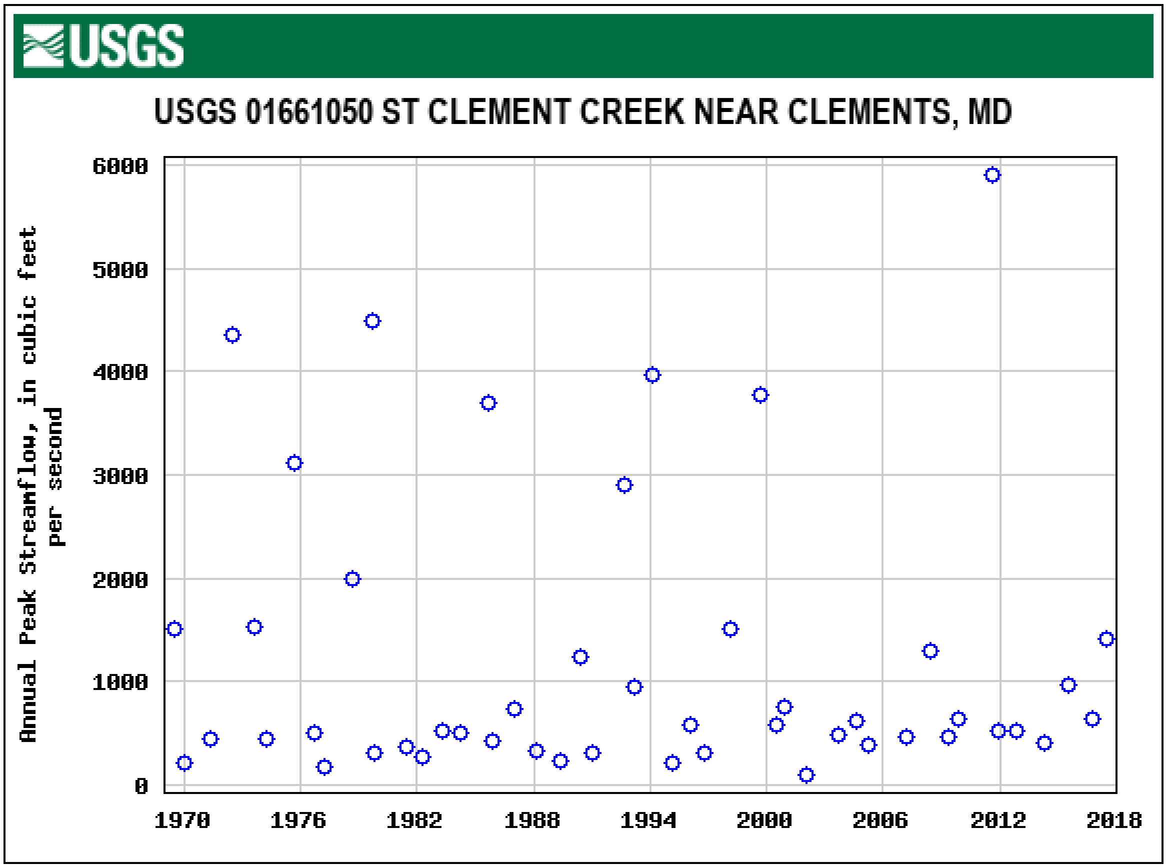
33 years of record – 1984-2017; drainage area = 81.6 square miles

Kendall's tau = 0.119

P value = 0.337

Conclusion: No significant upward trend in annual peak flows since the P value is greater than 0.05 (five percent level of significance).

Comments: No upward trend even though the flood of record (16,500 cfs) occurred in 2011 near the end of the record. IA85 = 4.0%, IA90 = 5.3%, IA97 = 6.7% IA02 = 7.2% and IA10 = 9.2%. No significant increase in urbanization. IA02 = 7.2% was used in the regression analysis.



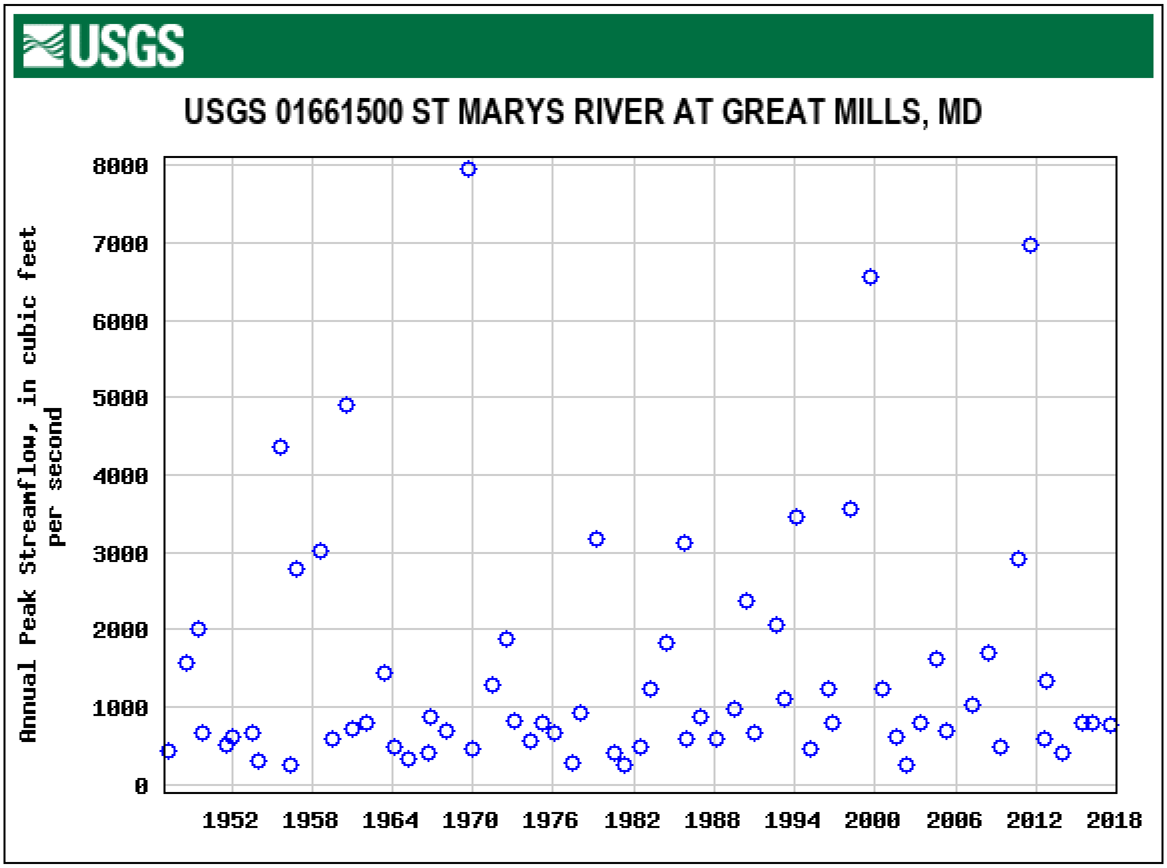
48 years of record – 1969 to 2017; drainage area = 18.2 square miles

Kendall's Tau = 0.045

P value = 0.657

Conclusion: No significant upward trend in annual peak flows since the P value is greater than 0.05 (five percent level of significance).

Comments: No upward trend since the major floods occurred throughout the record and no significant increase in urbanization. IA97 = 3.4% was used in the regression analysis with IA10 = 6.0%.



70 years of record – 1947 to 2017; drainage area = 25.3 square miles

Kendall's Tau = 0.084

P value = 0.306

Conclusion: No significant upward trend in annual peak flows since the P value is less than 0.05 (five percent level of significance).

Comments: No upward trend since the major floods occurred throughout the record and no significant increase in urbanization. IA90 = 6.1% was used in the regression analysis with IA85 = 4.0 % and IA10 = 14.9%.

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Appendix 2. Brief description of the time-varying mean approach for frequency analysis.

The time-varying mean approach is described and illustrated using data for Western Branch at Upper Marlboro (station 01594526). The annual peak flows from 1986 to 2017 are plotted in Figure A2-1.

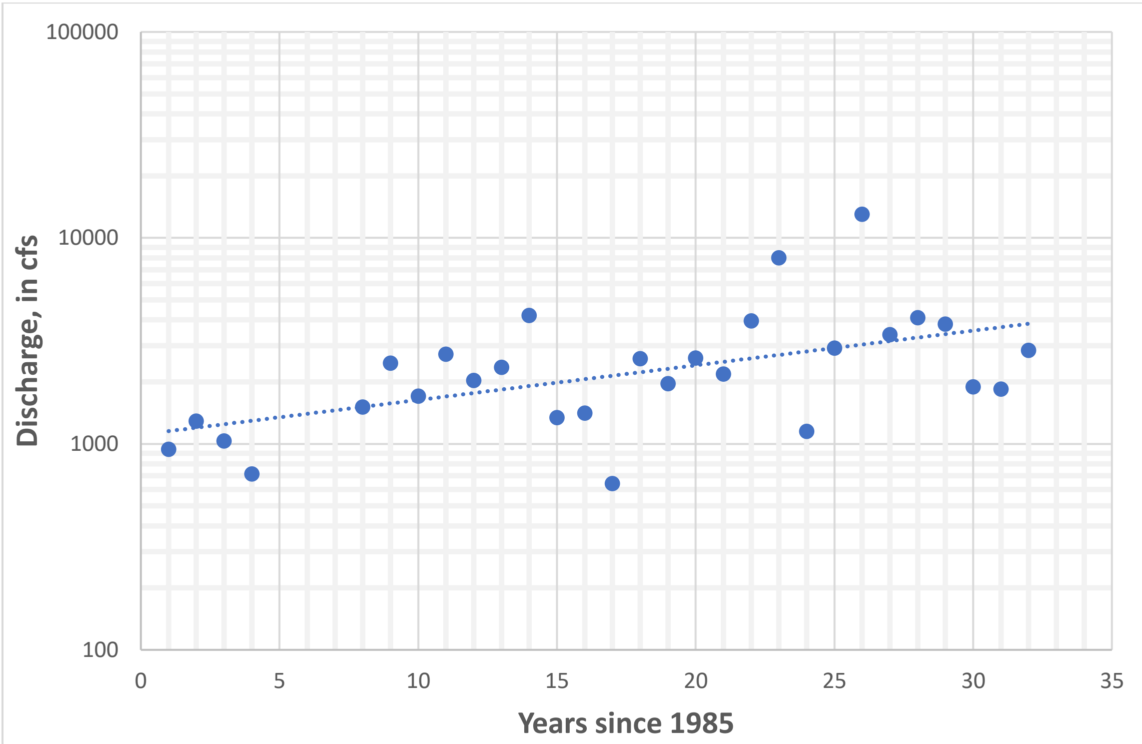

Figure A2-1. Relation between annual peak flows and years since 1985.

An equation for the trend line in Figure A2-1 is:

$$\log_{10}(Q) = 3.04502 + 0.01682 * t \quad \text{(A2-1)}$$

where Q is the annual peak flow in cubic feet per second (cfs) and t is the time in years since 1985. The coefficient for t indicates the annual peak flows are increasing 1.68 percent a year. The trend in the peak flows is statistically significant (based on a Kendall's Tau value of 0.384). The upward trend indicates the annual time series is not stationary and independent which violates an assumption of conventional flood frequency analysis.

The time-varying mean approach utilizes the trend line (Equation A2-1) in Figure A2-1 and provides an estimate of the flood discharges that accounts for changing land use. The approach for the time-varying mean is described by Kilgore and others (2016).

Equation A2-1 can be rewritten using the mean of $\log_{10}(Q)$ ($\overline{LQ}$) and the mean of t ($\bar{t}$) as follows:

$$\log_{10}(Q) = \overline{LQ} + 0.01682\ (t - \bar{t}) \quad \text{(A2-2)}$$

where t ranges from 1 to 60 with $\bar{t} = \frac{(n+1)}{2}$ and n is the years of record. Equation A2-2 can be rewritten as:

$$\log_{10}(Q) = \overline{LQ} + 0.01682\left(t - \frac{(n+1)}{2}\right) \quad \text{(A2-3)}$$

The equation for estimating the x-percent chance flood discharge $(\log_{10}(Q_x))$ assuming the logarithms are Pearson Type III distributed is:

$$\log_{10}(Q_x) = \overline{LQ} + 0.01682\left(t - \frac{(n+1)}{2}\right) + K_x\, S \quad \text{(A2-4)}$$

where:

- $\overline{LQ}$ = mean of the logarithms = 3.340877 log units,
- S is the standard deviation of the logarithmic residuals about Equation A2-1 = 0.24189 log units.
- K_x is the Pearson Type III frequency factor that is a function of the percent chance exceedance (x) and skew, and
- skew = 0.508 for the logarithms of the annual peak flows.

The Bulletin 17C analysis using station skew and the results of the time-varying mean approach are compared in Table A2-1 for Western Branch at Upper Marlboro (station 01594526) for selected recurrence intervals. The increases in flood discharges using the time-varying mean ranges from 78 percent for the 2-year flood to 37 percent for the 100-year flood to 28 percent for the 500-year flood.

Table A2-1 . Comparison of Bulletin 17C analysis and time-varying mean analysis for Western Branch at Upper Marlboro (station 01594526).

Recurrence Interval (year)	Gaging station analysis	Gaging station analysis
	Bulletin 17C analysis for 1986-2017 (ft^3/s)	Time-varying mean approach (ft^3/s)
2	2,140	3,810
10	5,415	8,350
25	7,930	11,600
50	10,300	14,500
100	13,100	17,900
500	21,900	28,000

Appendix 3. Flood discharges for the 1.25-, 1.5-, 2-, 5-, 10-, 25-, 50-, 100-, 200-, and 500-year events (in cubic feet per second) for 27 gaging stations in the Western Coastal Plain Region of Maryland.

Station No.	Stream name	DA (mi^2)	Q1.25 (cfs)	Q1.5 (cfs)	Q2 (cfs)	Q5 (cfs)	Q10 (cfs)	Q25 (cfs)	Q50 (cfs)	Q100 (cfs)	Q200 (cfs)	Q500 (cfs)
01585300	Stemmers Run at Rossville	4.54	790	991	1260	2080	2720	3660	4450	5330	6290	7720
01585400	Brien Run at Stemmers Run	1.96	188	237	316	633	984	1680	2450	3530	5030	7930
01589500	Sawmill Branch at Glen Burnie	5.04	69	81	101	184	280	475	703	1030	1510	2480
01589795	SF Jabez Branch at Millersville	0.96	51	78	122	300	486	823	1160	1590	2140	3050
01590000	North River near Annapolis	8.63	92	102	122	231	385	767	1300	2220	3800	7760
01590500	Bacon Ridge Branch at Chesterfield	6.97	112	149	204	396	576	879	1170	1520	1950	2660
01594400	Dorsey Run near Jessup	11.91	326	379	459	750	1030	1530	2040	2690	3520	5000
01594440	Patuxent River near Bowie	350.21	3880	4900	6370	10800	14400	18300	22700	29400	35100	43800
01594445	Mill Branch near Mitchellville	1.25	73	99	137	270	394	598	790	1020	1300	1750
01594500	Western Branch near Largo	30.04	601	724	880	1300	1590	1980	2280	2600	2920	3370
01594526	Western Branch at Upper Marlboro	89.38	2480	3000	3810	6265	8350	11600	14500	17900	21800	28000
01594600	Cocktown Creek near Huntington	3.9	71	99	145	331	534	923	1340	1910	2660	4040
01594670	Hunting Creek near Huntingtown	9.33	149	193	255	450	613	860	1080	1320	1600	2020
01594710	Killpeck Creek at Huntersville	3.46	123	139	159	209	243	287	321	356	392	441
01594800	St. Leonard Creek near St. Leonard	7.23	62	77	98	159	208	282	345	416	496	616
01649500	NE Branch Anacostia River at Riverdale	73.2	5090	6000	7350	10300	12200	14500	16100	17700	19200	21100
01651000	NW Branch Anacostia River near Hyattsville	49.33	2760	3460	4450	7570	10200	14250	17800	22000	26800	34200
01653500	Henson Creek at Oxon Hill	17.19	756	952	1220	2010	2630	3520	4270	5090	5990	7310
01653600	Piscataway Creek at Piscataway	39.43	650	840	990	2200	5300	7400	8700	10000	11000	12500
01658000	Mattawoman Creek near Pomonkey	55.57	630	877	1260	2650	3990	6280	8500	11200	14500	20000
01660900	Wolf Den Branch near Cedarville	2.31	70	92	128	258	388	617	847	1140	1510	2160
01660920	Zekiah Swamp Run near Newtown	81.61	782	1040	1440	2880	4310	6820	9320	12500	16500	23300
01660930	Clark Run near Bel Alton	11.27	240	312	430	954	1560	2810	4280	6470	9650	16100
01661000	Chaptico Creek at Chaptico	10.23	195	260	362	763	1190	1980	2830	3950	5440	8160
01661050	St. Clement Creek near Clements	18.18	325	466	697	1650	2700	4700	6840	9720	13500	20500
01661430	Glebe Branch at Valley Lee	0.24	16	20	26	46	64	92	117	148	184	241
01661500	St. Marys River at Great Mills	25.29	481	653	923	1960	3020	4970	6970	9570	12900	18900

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Regression Equations for Estimating Flood Discharges for the Western Coastal Plain Region of Maryland

Appendix 4. Watershed characteristics for 27 gaging stations in the Western Coastal Plain Region of Maryland. The Map Number corresponds to the numbering of the stations in Figure 1. A soils in the regression equations is based on the May 2018 SSURGO data from the NRCS Soil Survey web site. Impervious area (IA) is defined at the midpoint of the gaging station record with date of the land use identified.

Map No.	Station No.	Stream name	Period of record	Years of record	DA (mi^2)	A soils (%)	IA (%)	Year for IA
1	1585300	Stemmers Run at Rossville	1960-1989	29	4.54	0.0	25.3	1985
2	1585400	Brien Run at Stemmers Run	1957-1987	29	1.96	7.3	36.8	1985
3	1589500	Sawmill Branch at Glen Burnie	1984-2017	34	5.04	67.2	29.7	2002
4	1589795	SF Jabez Branch at Millersville	1990, 1997-2017	22	0.96	42.7	20.0	2010
5	1590000	North River near Annapolis	1932-1974	43	8.63	20.4	2.7	1985
6	1590500	Bacon Ridge Branch at Chesterfield	1944-1990	35	6.97	30.0	1.5	1985
7	1594400	Dorsey Run near Jessup	1949-1968, 2009	20	11.91	7.9	16.7	1985
8	1594440	Patuxent River near Bowie	1972, 1978-2017	41	350.21	14.9	14.9	2002
9	1594445	Mill Branch near Mitchellville	1966-1976	11	1.25	8.0	4.5	1985
10	1594500	Western Branch near Largo	1950-1974	25	30.04	19.8	11.4	1985
11	1594526	Western Branch at Upper Marlboro	1986-1989, 1993-2017	29	89.38	14.0	21.4	2002
12	1594600	Cocktown Creek near Huntington	1958-1976	19	3.9	44.8	8.7	1985
13	1594670	Hunting Creek near Huntingtown	1989-1998	10	9.33	57.3	2.4	1990
14	1594710	Killpeck Creek at Huntersville	1986-1997	12	3.46	60.3	7.8	1990
15	1594800	St. Leonard Creek near St. Leonard	1958-1968, 2001-2003	14	7.23	85.2	0.3	1985
16	1649500	NE Branch Anacostia River at Riverdale	1939-2016	78	73.2	8.5	24.8	1997
17	1651000	NW Branch Anacostia River near Hyattsville	1972-2017	46	49.33	1.8	27.8	1997
18	1653500	Henson Creek at Oxon Hill	1949-1978	30	17.19	11.1	26.5	1985
19	1653600	Piscataway Creek at Piscataway	1966-2017	51	39.43	14.0	11.6	1997
20	1658000	Mattawoman Creek near Pomonkey	1950-1986, 2001-2017	54	55.57	11.4	5.0	1985
21	1660900	Wolf Den Branch near Cedarville	1967-1980	14	2.31	15.2	0.0	1985
22	1660920	Zekiah Swamp Run near Newtown	1984-2017	33	81.61	32.9	7.2	2002
23	1660930	Clark Run near Bel Alton	1966-1976	11	11.27	24.1	6.4	1985
24	1661000	Chaptico Creek at Chaptico	1948-1972	25	10.23	23.1	1.9	1985
25	1661050	St. Clement Creek near Clements	1969-2017	48	18.18	18.5	3.4	1997
26	1661430	Glebe Branch at Valley Lee	1968-1978	11	0.24	2.6	2.1	1985
27	1661500	St. Marys River at Great Mills	1947-2017	70	25.29	8.7	6.1	1990

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Appendix 5. Computation of the Equivalent Years of Record for Regression Equations for the Western Coastal Plain Region.

Computational Procedure

The variance (standard error squared (SE^2)) of the x-year flood at a gaging station is estimated as

$$SE_x^2 = (S^2/N) * R_x^2 \quad \text{(A5-1)}$$

where S is the standard deviation of the logarithms (log units) of the annual peak discharges at the gaging station, N is the actual record length in years and R_x is a function of recurrence interval x and skew (G) at the gaging station. The standard error increases as the recurrence interval increases, given the same record length.

In Equation A5-1, the standard error of the x-year flood at a gaging station is inversely related to record length N and directly related to the variability of annual peak flows represented by S (standard deviation) and G (skew). If the standard error of the x-year flood is interchanged with the standard error of estimate (SE) of the regression equation, then Equation A5-1 can be used to estimate the years of record needed to obtain that standard error of estimate. Rearranging Equation A5-1 and solving for N gives Equation A5-2 below.

The equivalent years of record of the regression estimate is defined as the number of years of actual streamflow record required at a site to achieve an accuracy equivalent to the standard error of the regional regression equation. The equivalent years of record are used to weight the gaging station and regression estimates. The equivalent years of record (N_r) of a regression equation is computed as follows (Hardison, 1971):

$$N_r = (S/SE)^2 * R^2 \quad \text{(A5-2)}$$

where S is an estimate of the standard deviation of the logarithms of the annual peak discharges at the ungaged site, SE is the standard error of estimate of the regional regression estimates in logarithmic units, and R^2 is a function of recurrence interval and skew and is computed as (Stedinger and others, 1993):

$$R^2 = 1 + G*K_x + 0.5 *(1+0.75*G^2)*K_x^2 \quad \text{(A5-3)}$$

where G is an estimate of the average skew for a given hydrologic region, and K_x is the Pearson Type III frequency factor for the x-year flood and skew G.

Computational Details

The equivalent years of record are estimated for the regional regression equations and using Equations A5-2 and A5-3 and an estimate of the average standard deviation and average skew for all gaging stations in a given region. For the Western Coastal Plain Region, the average standard deviation (S) is 0.3196 log units and the average skew (G) is 0.541.

Regression Equations for Estimating Flood Discharges for the Western Coastal Plain Region of Maryland

Recurrence Interval (years)	K_x value	SE^2 (log units squared)	Equivalent years of record
1.25	-0.856796	0.03563	2.8
1.50			(2.8) Estimated
2	-0.089756	0.03612	2.7
5	0.804686	0.02960	6.3
10	1.325308	0.02451	12
25	1.922003	0.02067	21
50	2.330713	0.01987	29
100	2.714182	0.02197	32
200	3.078453	0.02776	31
500	3.537124	0.04128	26