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STATE HIGHWAY ADMINISTRATION

RESEARCH REPORT

REGRESSION EQUATIONS FOR ESTIMATING FLOOD DISCHARGES FOR THE PIEDMONT, BLUE RIDGE, AND APPALACHIAN PLATEAU REGIONS IN WESTERN MARYLAND

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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 Piedmont, Blue Ridge and Appalachian Plateau Regions in western Maryland. The regression equations applicable to the Piedmont and Blue Ridge Region were based on flood discharges for 96 stations and drainage area, in square miles; impervious area, in percent of the watershed; limestone, in percent of the watershed; and forest cover, in percent of the watershed. The regression equations applicable to the Appalachian Plateau Region were based on flood discharges for 24 stations and drainage area, in square miles and land slope, in feet per foot. The revised regression equations will be used by the Maryland State Highway Administration in the design of bridges and culverts in Maryland. The updated regression equations will be included in the fourth version of the Maryland Hydrology Panel report entitled "Application of Hydrologic Methods in Maryland".

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Executive Summary

The current regression equations used by the Maryland State Highway Administration (SHA) for estimating flood discharges for bridge and culvert design were documented in the September 2010 version of the Maryland Hydrology Panel report entitled “Application of Hydrologic Methods in Maryland” (http://www.gishydro.eng.umd.edu/panel.htm). The regression equations for the Piedmont, Blue Ridge and Appalachian Plateau Regions in western Maryland were updated using flood data through the 2012 water year and watershed characteristics determined with GISHydro2000. Bulletin 17B frequency analyses were performed at 133 gaging stations in Maryland where there were at least 10 years of record through the 2012 water year. A water year is defined as the time from October 1 to September 30 with the ending year determining the water year. A regional skew analysis was performed using long-term gaging stations where the annual peak data were not affected by urbanization or limestone (karst) topography. A regional skew of 0.43 with a standard error of 0.42 was estimated for western Maryland. The final frequency curves were based on weighting the station and regional skew.

Regression equations were developed for estimating the 1.25-. 1.50-, 2-, 5-, 10-, 25-, 50-, 100-, 200- and 500-year flood discharges using data for 120 gaging stations. Eleven stations were identified as outliers and two stations were combined with gaging stations within close proximity on the same stream. The regression equations applicable to the Piedmont and Blue Ridge Region were based on flood discharges for 96 rural and urban stations and drainage area, in square miles; impervious area, in percentage of the watershed; limestone, in percentage of the watershed; and forest cover, in percentage of the watershed. The regression equations applicable to the Appalachian Plateau Region were based on flood discharges for 24 rural stations and drainage area, in square miles and land slope, in feet per foot. The updated regression equations will be included in the next edition of the Maryland Hydrology Panel report.

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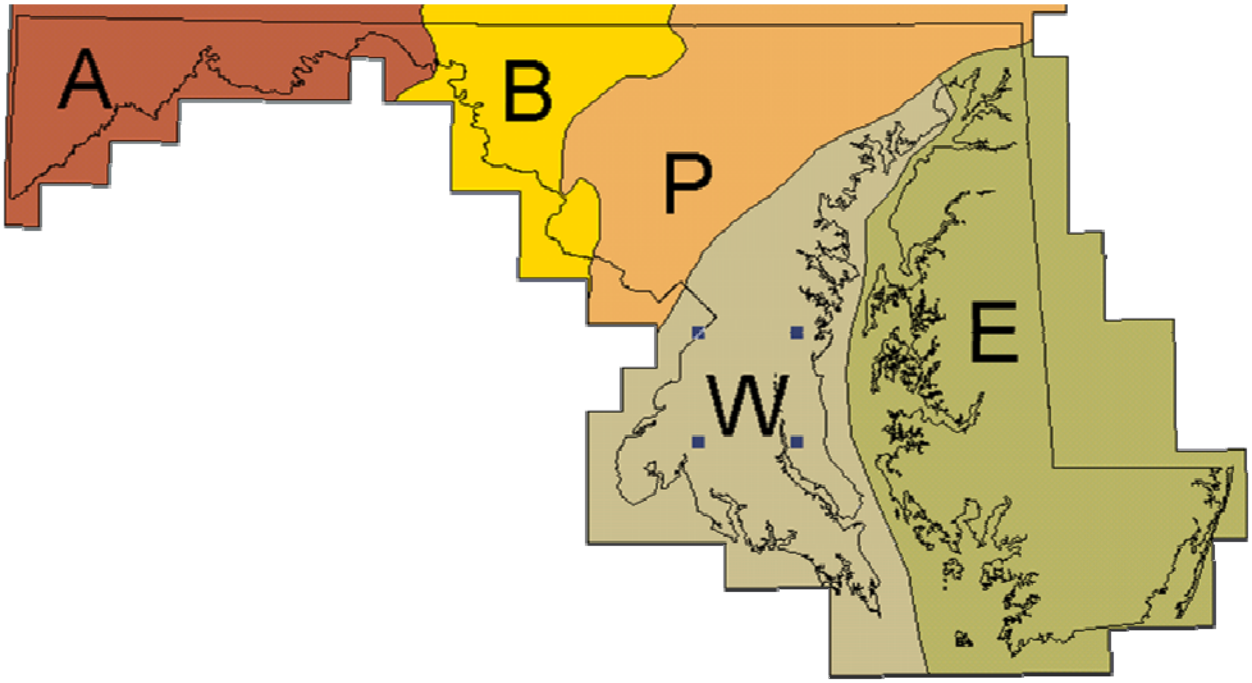
Regression Equations for Estimating Flood Discharges for the Piedmont, Blue Ridge and Appalachian Plateau Regions in Western Maryland

Introduction

Regression equations currently (2015) used by the Maryland State Highway Administration (MSHA) for estimating flood discharges for bridge and culvert design are documented in the *Application of Hydrologic Methods in Maryland*, Third Edition, September 2010, a report prepared by the Maryland Hydrology Panel (http://www.gishydro.eng.umd.edu/panel.htm). The 2010 regression equations for estimating the 1.25-, 1.5-, 2-, 5-, 10-, 25-, 50-, 100-, 200- and 500-year flood discharges were updated for the three western hydrologic/physiographic regions of Maryland as shown in Figure 1. The three western regions are identified as Appalachian Plateau, Blue Ridge, and Piedmont (originally defined by Dillow, 1996). A single set of regression equations was shown to be applicable to the Piedmont and Blue Ridge Regions, and separate equations were developed for the Appalachian Plateau Region.



A = Appalachian Plateau and Allegheny Ridge
B = Blue Ridge and Great Valley
P = Piedmont
W = Western Coastal Plain
E = Eastern Coastal Plain

Figure 1. Hydrologic regions for regression equations in Maryland (after Dillow, 1996)

Updating Flood Discharges at the Gaging Stations

Frequency (Bulletin 17B) analyses were run for 133 gaging stations, including all current and discontinued stations in the three western regions that have 10 or more years of essentially unregulated annual peak flows through the 2012 water year (Interagency Advisory Committee on Water, 1982). The current regression equations for the Appalachian Plateau, Blue Ridge, and Piedmont Regions, documented in the September 2010 version of the Hydrology Panel report, were based on annual peak data through the 1999 water year. Some of the stations have 13 additional years of record. The 133 stations used in the new regional regression analysis include the following:

- 55 stations that were discontinued prior to 1999;
- 52 stations with additional data since 1999; and
- 26 new stations with at least 10 years of record.

The locations for the 133 stations are shown in Figure 2.

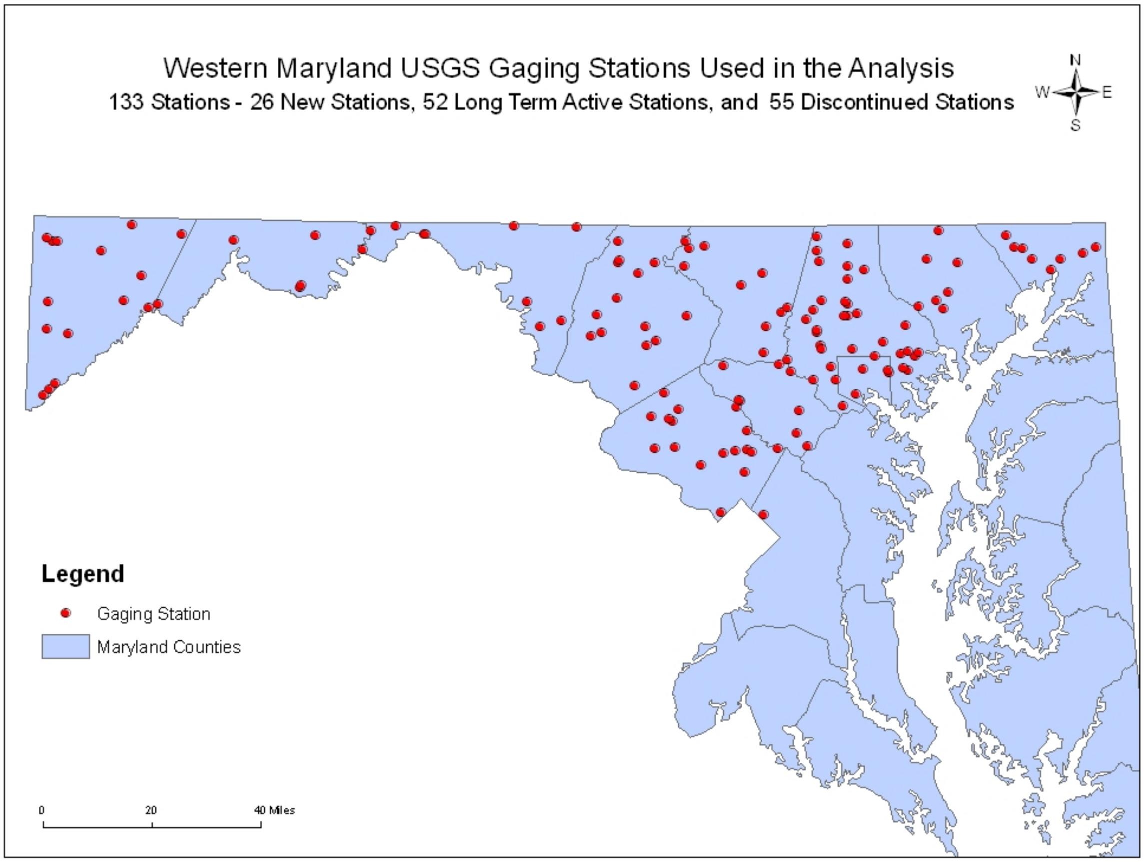


Figure 2. Map showing the location of the 133 stations available for updating the regression equations for western Maryland

Regional Skew Analysis

A regional skew analysis was performed by plotting on a map the station skews for 47 **rural** stations (10 percent or less impervious area) with 23 or more years of record. The geographic distribution of the station skews are shown in Figure 3. Stations for areas where a significant portion of the watershed was underlain with limestone were omitted from the regional analysis.

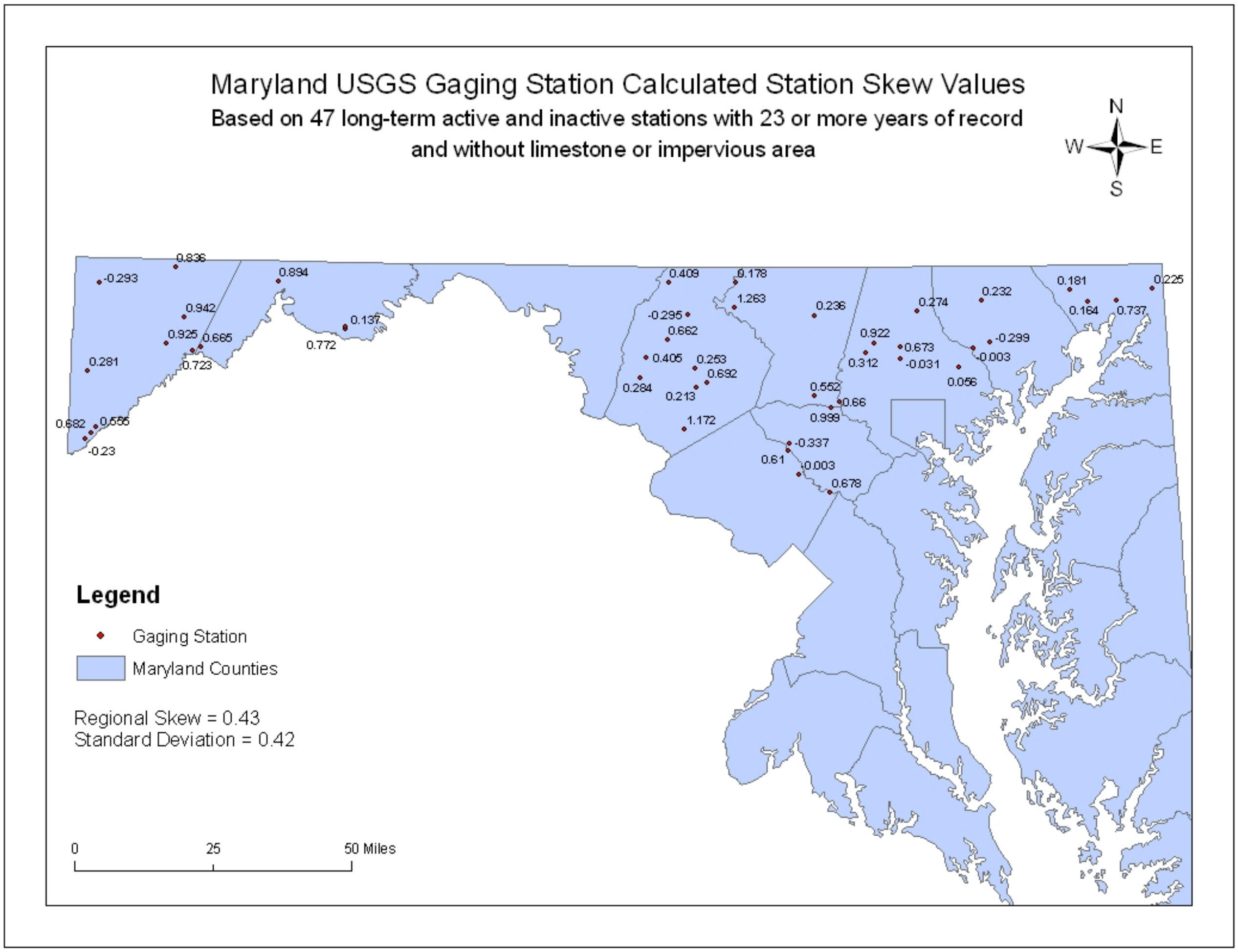


Figure 3. Geographic distribution of station skews for 47 long-term stations in Maryland

There is no geographic pattern to the station skews, as shown in Figure 3. The average station skew for the 47 stations is 0.43, with a standard deviation (standard error) of 0.42. This contrasts with the regional skew of 0.55 and standard error of 0.45 that were used in the development of the previous regression equations.

The station skews were plotted against drainage area, as shown in Figure 4, and no trend with drainage area was observed. A multiple linear regression analysis for skew indicated that the only statistically significant variables for estimating skew were land slope and the percentage of forest cover. Land slope had an inverse relation with skew (steeper slope, smaller skew) and forest cover had a direct relation (higher forest cover, larger skew). Intuitively, the regression equation did not make sense. Land slope and forest cover are highly correlated, and this correlation may have had an impact on the rationality of the regression equation. The average skew of 0.43 with a standard error of 0.42, as defined above, was considered a more defensible approach.

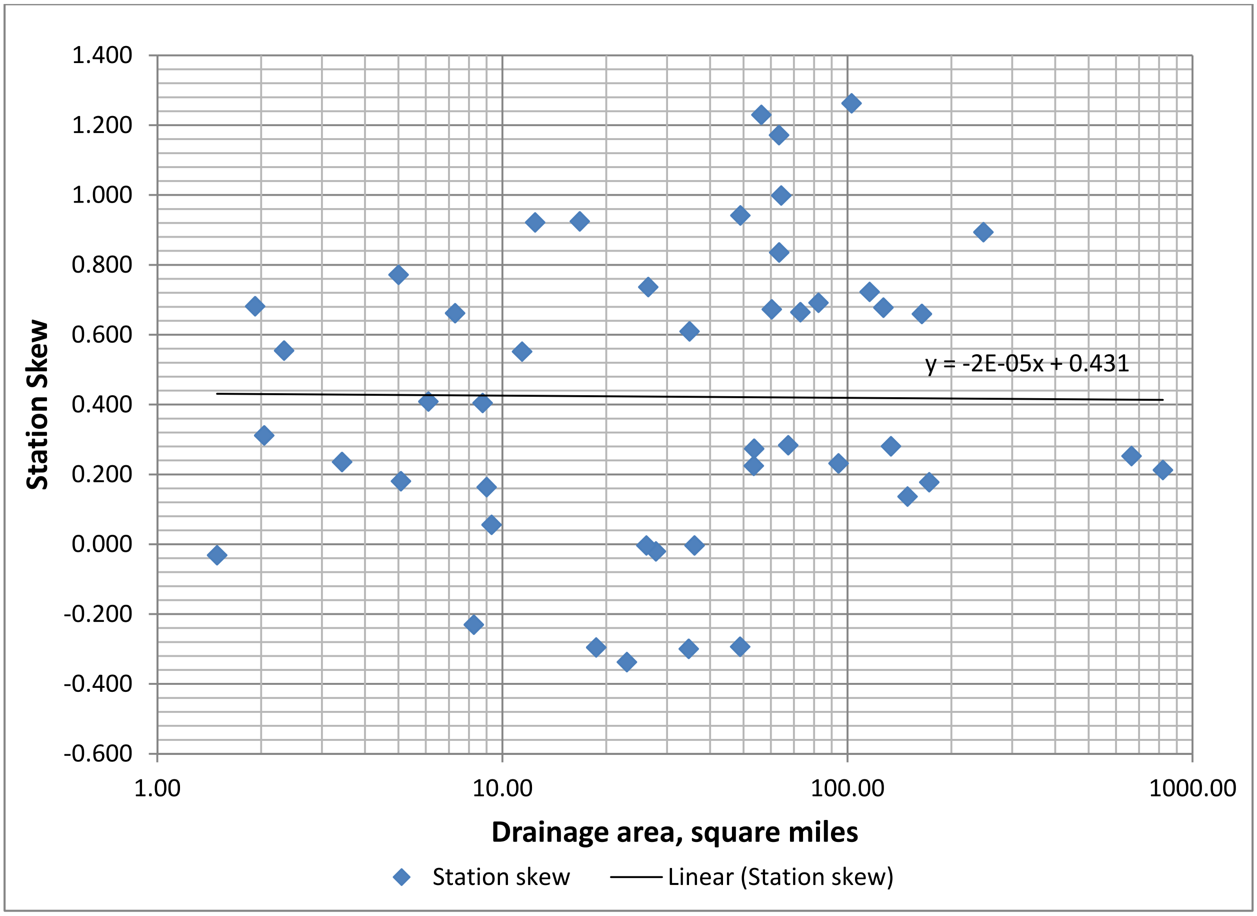


Figure 4. Relation between station skew and drainage area for rural stations

Final Flood Frequency Analysis

The flood frequency curves were rerun using a weighted skew (combination of station and regional skew) for the rural watersheds. The station and regional skew were weighted inversely proportional to the Mean Square Error (standard error squared) using procedures described in Bulletin 17B (Interagency Advisory Committee on Water Data, 1982). Station skew was generally used for the urban watersheds, unless the flood discharges based on the weighted skew were more reasonable based on engineering judgment. The following statistics describe the urban gaging stations with impervious area greater than 10 percent (based on Maryland Department of Planning generalized land use):

- 37 stations with impervious area greater than 10 percent;
- 25 stations with impervious area greater than 20 percent;
- 18 stations with impervious area greater than 30 percent;

- 11 stations with impervious area greater than 40 percent; and
- 1 station with impervious area greater than 50 percent (53.5 percent).

For eight stations, the log-Pearson Type III distribution did not provide a reasonable fit to the annual peak flows; therefore, the data were plotted on lognormal probability paper and the frequency curves defined by drawing a smooth curve through the plotting positions. These stations were generally short record stations (17 or fewer years of data) or stations where there appeared to be excessive floodplain storage. The eight stations are listed below:

- Mingo Branch near Hereford (01581940), 10 years of record;
- North Fork Whitemarsh Run near White Marsh (01585095), 17 years of record;
- Moores Run Tributary near Todd Avenue at Baltimore (01585225), 16 years of record;
- Gwynns Falls at Glyndon (01589180), 14 years of record;
- Cabin Branch near Boyds (01644380), 9 years of record (a few stations used in the analysis had 9 years of record);
- Northwest Branch of the Anacostia River at Norwood (01650050), 10 years of record;
- Nursery Run at Cloverly (01650085), 10 years of record; and
- Bear Creek at Friendsville (03076600), 48 years of record (an S-shaped frequency curve likely related to floodplain storage).

In addition, records were extended at four short-record stations to obtain estimated flood discharges that were more representative of long-record stations. This record extension was accomplished by establishing a graphical relationship between concurrent peak flows at the short- and long-term stations and using the T-year flood discharges at the long-term station to estimate comparable values at the short-term station. The four stations with record extensions and the nearby long-term stations are listed below:

- Great Seneca Creek near Quince Orchard (01644600), drainage area of 53.9 square miles, using the long-term record at Seneca Creek at Dawsonville (01645000), drainage area of 102.2 square miles;
- North Branch Rock Creek near Norbeck (01647720), drainage area of 9.68 square miles, using the long-term record at the Northwest Branch Anacostia River near Coleville (01650500), drainage area of 21.2 square miles;
- Little Youghiogheny River Tributary near Deer Park (03075450), drainage area of 0.55 square miles, using the long-term record at the Youghiogheny River near Oakland (03075500), drainage area of 134 square miles; and
- North Branch Casselman River Tributary at Foxtown (03077700), drainage area of 1.07 square miles, using the long-term record at the Casselman River at Grantsville (03078000), drainage area of 62.5 square miles.

The latter two stations are in the Appalachian Plateau Region, and their annual peak data are from 1965 to 1976. This was a drought period in this region, and the flood discharges based on the short period of record are very low. Even though the drainage area of the long-term station is much larger than that of the short-term station, the flood discharges based on the extended record are considered more accurate than the short-term estimates, due to a reasonable correlation between the annual peak flows for the two stations.

The T-year flood discharges for all stations used in the regression analysis are given in Appendix 1.

Overview of the Regional Regression Analyses

Watershed characteristics were determined for all stations using GISHydro2000. The watershed characteristics that were evaluated in the regression analysis included:

- Drainage area, in square miles;
- Channel slope, in feet per mile;
- Land or watershed slope, in feet per foot;
- Percentage of the watershed underlain by limestone;
- Percentage of the watershed with A, B, C, and D soils using the latest SSURGO data; and
- Percentage of the watershed with forest, storage, and impervious area for 1985, 1990, 1997, 2000, 2002, and 2010 land use conditions.

For the 55 gaging stations discontinued before 1999, the land use conditions for 2000, 2002, and 2010 were not determined. With the exception of the percentage of soils, the watershed characteristics documented in the September 2010 version of the Hydrology Panel report were used for these 55 discontinued stations. The percentages of A, B, C, and D soils, based on SSURGO data, were determined for the 55 discontinued stations because the SSURGO data were not available at the time of the previous regression analysis.

The percentage of forest cover and percentage of impervious area used in the regression analysis for the current stations were the values near the middle of the gaging station record to be most representative of the annual peak flows. For the stations discontinued before 1999, the 1985 forest cover and impervious area were generally used, as was the case for the previous regression analysis.

Initially, regression analyses were performed for all 133 stations in one regional analysis with qualitative variables identifying stations in the three physiographic regions (Appalachian Plateau, Blue Ridge, and Piedmont). The qualitative variable for the Appalachian Plateau was statistically significant, implying that the flood discharges for this region were different from those of the other two regions after accounting for the effects of the watershed characteristics. The qualitative variables for the Blue Ridge and Piedmont Regions were not statistically significant, implying that the flood characteristics for the two regions are similar. This result was consistent with that of previous regression analysis, as the Blue Ridge and Piedmont Regions were combined in the 2010 analysis, and a separate region was defined for the Appalachian Plateau.

Several regression analyses were performed for the Piedmont - Blue Ridge Region and the Appalachian Plateau Region, and 11 stations were identified as outliers. Ten outlier stations were in the Piedmont -

Blue Ridge Region, and one station was in the Appalachian Plateau Region. The outlier stations were those where the predicted and observed flood discharges differed by a factor of 2 or more; that is, the predicted values were either more than twice the observed value or less than half of the observed value (criteria based on engineering judgment). The 11 stations and the reasons they were omitted from the regression analysis are given below:

- Grave Run near Beckleysville (01581830) – drainage area of 7.56 square miles, 13 years of record, impervious area of 5.4 percent – low annual peaks for the drainage area;
- Slade Run near Glyndon (01583000), drainage area of 2.05 square miles, 36 years of record, impervious area of 1.2 percent – low annual peaks for the drainage area;
- Pond Branch at Oregon Ridge (01583570) – drainage area of 0.131 square miles, 13 years of record, impervious area of 0.0 percent – low annual peaks for the drainage area and significant storage in the watershed;
- Beaverdam Run at Cockeysville (01583600) – drainage area of 20.9 square miles, 29 years of record, impervious area of 22.0 percent – low annual peaks for the drainage area;
- Beaver Run near Finksburg (01586210) – drainage area of 14.1 square miles, 30 years of record, impervious area of 11.9 percent – low annual peaks for the drainage area;
- Gwynns Falls Tributary at McDonogh (01589238) – drainage area of 0.027 square miles, 13 years of record, impervious area of 0.0 percent – very small drainage area with one large flood in a short record, and difficult to get reasonable estimates of the flood discharges;
- Patuxent River near Burtonsville (01592000) – drainage area of 127.0 square miles, 32 years of record, impervious area of 3.1 percent – low annual peaks for the drainage area;
- Little Patuxent River at Guilford (01593500) – drainage area of 38.1 square miles, 80 years of record, impervious area of 18.5 percent – low annual peaks for the drainage area;
- Marsh Run at Grimes (01617800) – drainage area of 18.3 square miles, 48 years of record, impervious area of 3.4 percent – 100 percent of watershed underlain with limestone and an outlier even with limestone in the regression equation;
- Piney Creek Tributary at Taneytown (01639095) – drainage area of 0.61 square miles, 10 years of record, impervious area of 11.4 percent – low annual peaks for the drainage area; and
- Youghiogheny River Tributary near Friendsville (03076505) – drainage area of 0.21 square miles, 12 years of record, impervious area of 0.0 percent – low annual peaks for the drainage area.

The first five outlier stations are located in an area north of Baltimore, and all have a high percentage of A and B soils. However, the sum of A and B soils was not statistically significant in the regression analysis. The close proximity of these stations suggests there may be a common factor as to why the annual peaks are low. Further research beyond this project is warranted to determine what variables may be causing the low annual peak flows for these stations north of Baltimore.

In addition, two stations were combined with nearby stations on the same stream due to the small differences in drainage area. The annual peak flows at the short record station were adjusted using a drainage area ratio and combined with the data at the station with the longer record. The following stations were combined with upstream or downstream stations:

- Patapsco River at Woodstock (01588500), with a drainage area of 251 square miles, was combined with the downstream station 01589000 at Hollofield, with a drainage area of 284.7 square miles and the latter station was used in the regression analysis; and
- Cattail Creek at Roxbury Mills (01591500), with a drainage area of 27.7 square miles, was combined with the upstream station 01591400 near Glenwood, with a drainage area of 22.9 square miles and the latter station was used in the regression analysis.

Station 01589000 at Hollofield had a combined record length of 23 years of unregulated annual peak flows, including three historical peak flows. Station 01591400 near Glenwood had a combined record length of 46 years. Therefore, a total of 120 stations were used in the regression analysis, 96 stations in the Blue Ridge and Piedmont Regions, and 24 stations in the Appalachian Plateau. The watershed characteristics used in the regression analysis are given in Appendix 2 for the Piedmont-Blue Ridge Region and in Appendix 3 for the Appalachian Plateau Region.

Piedmont and Blue Ridge Region Regression Analysis

Development of Regression Equations

For the Piedmont and Blue Ridge combined region, based on 96 stations, the most significant watershed characteristics were drainage area (DA) in square miles, percentage of limestone (LIME), percentage of impervious area (IA), and percentage of forest cover (FOR). All variables were converted to logarithms, and a multiple linear regression analysis was performed using the Statistical Analysis System (SAS) package. Regression analyses were also performed without converting LIME, IA, and FOR to logarithms, and the regression equations had essentially equal accuracy to the logarithmic transformed analysis. The exponents in the regression equations varied more logically by recurrence interval with the logarithmic analysis, and those results were used. The equations for the 1.25- to 500-year flood discharges were then converted to exponential form for easier use. They are presented below with the associated standard error of estimate (percent) and the equivalent years of record:

Equation	**Standard error (%)**	**Equivalent years**	
$Q_{1\_25} = 283.3\ DA^{0.724}\ (LIME+1)^{-0.124}\ (IA+1)^{0.143}(FOR+1^{)-0.412}$	44.3	2.8	(1)
$Q_{1\_50} = 352.4\ DA^{0.704}\ (LIME+1)^{-0.131}\ (IA+1)^{0.123}(FOR+1)^{-0.373}$	40.9	3.2	(2)
$Q_{2} = 453.4\ DA^{0.683}\ (LIME+1)^{-0.140}\ (IA+1)^{0.105}(FOR+1)^{-0.334}$	37.5	3.7	(3)
$Q_{5} = 746.8\ DA^{0.640}\ (LIME+1)^{-0.158}\ (IA+1)^{0.083}(FOR+1)^{-0.249}$	31.9	9.2	(4)
$Q_{10} = 972.3\ DA^{0.615}\ (LIME+1)^{-0.169}\ (IA+1)^{0.076}(FOR+1)^{-0.195}$	29.6	16	(5)
$Q_{25} = 1{,}327.6\ DA^{0.593}\ (LIME+1)^{-0.182}\ (IA+1)^{0.074}(FOR+1)^{-0.145}$	29.0	25	(6)
$Q_{50} = 1{,}608.2\ DA^{0.576}\ (LIME+1)^{-0.191}\ (IA+1)^{0.073}(FOR+1)^{-0.103}$	29.8	31	(7)
$Q_{100} = 1{,}928.5\ DA^{0.561}\ (LIME+1)^{-0.198}\ (IA+1)^{0.073}(FOR+1)^{-0.067}$	31.8	34	(8)
$Q_{200} = 3{,}153.5\ DA^{0.550}\ (LIME+1)^{-0.222}\ (FOR+1)^{-0.090}$	35.7	32	(9)
$Q_{500} = 3{,}905.3\ DA^{0.533}\ (LIME+1)^{-0.233}\ (FOR+1)^{-.0.045}$	42.0	30	(10)

The standard error of estimate, expressed in percent, is the standard deviation of the residuals about the regression equation. It is a measure of the agreement between the regression estimates and the gaging station data used in the analysis. The equivalent years of record are defined as the number of years of actual streamflow record required at a site to achieve an accuracy equivalent to the standard error of estimate for the regression equations. Equivalent years of record are used to weight the regression estimate with the gaging station estimate, as described in Chapter Two of the Maryland Hydrology Panel report (2010). The computation of the equivalent years of record is described in Appendix 4.

All explanatory variables are significant at the 5-percent level (p-level of 0.05 or less) of significance with the following exceptions: forest cover is statistically significant up to the 50-year flood, and impervious area is statistically significant up to the 100-year flood. The 5-percent level of significance, typically used for including explanatory variables in the regression equations, means there is less than a 5-percent chance of erroneously including a variable in the regression equation. Impervious area and forest cover are correlated, and the exponent on impervious area increased from the 100- to 200-year flood. In addition, impervious area was not statistically significant for the 500-year flood. Therefore, impervious area was omitted from the 200- and 500-year equations because, from a hydrologic perspective, impervious area should not be a major factor for these extreme events.

Rationale for Regression Equations

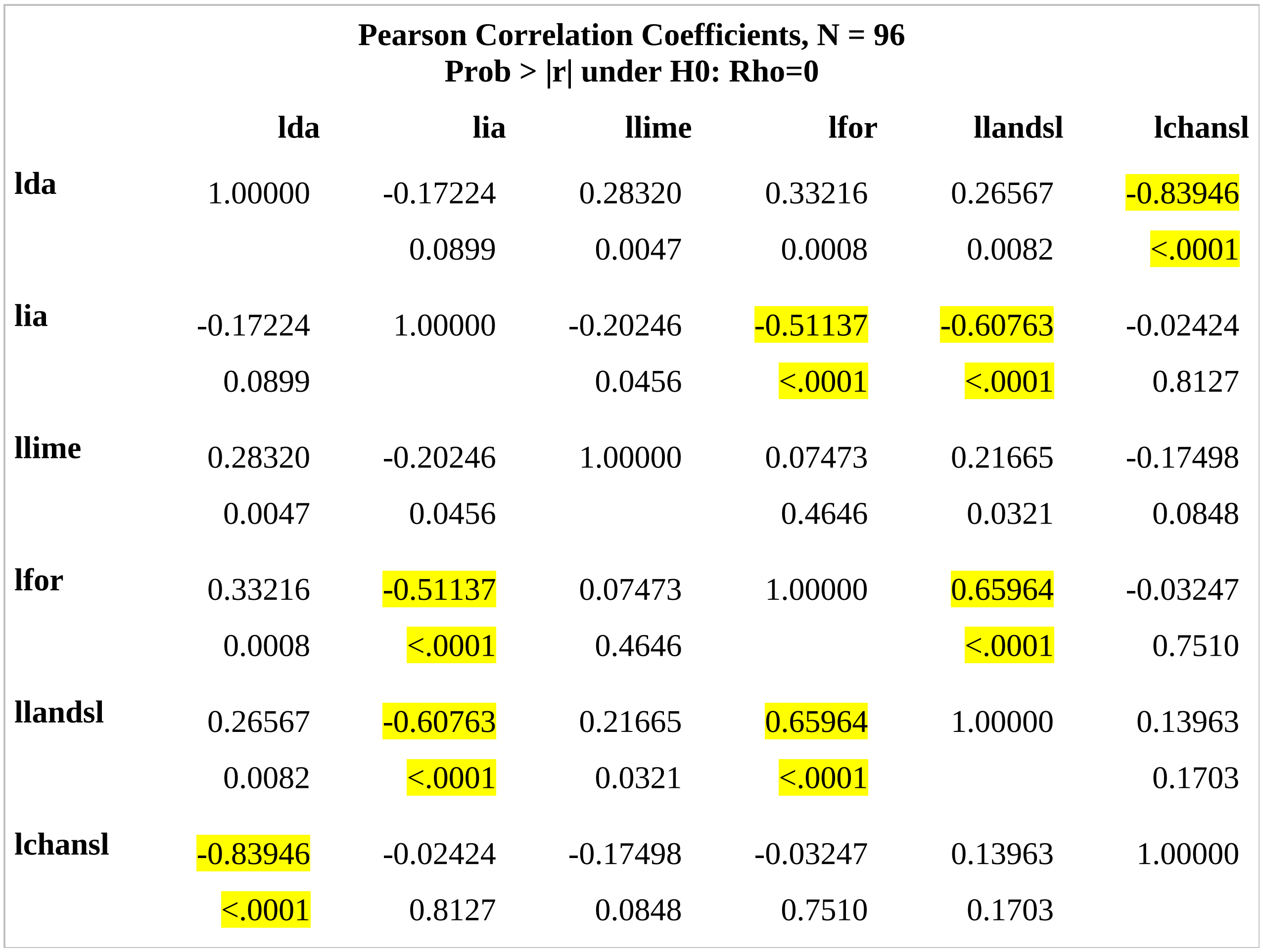
For Equations 1-10, the drainage area exponent decreases with an increasing recurrence interval, consistent with earlier results. A possible explanation is that the storm rainfall for the more intense storms varies considerably across a watershed and does not have a uniform impact across the entire watershed (that is, the effective drainage area is less). The limestone exponent is an increasing negative value (inverse relation) with the recurrence interval, implying that the percentage of limestone becomes more important for the larger floods. A likely reason is that the increased rainfall depth in the larger floods leads to more abstraction in the karst watersheds and results in relatively lower runoff volumes. The exponents on impervious area and forest cover decrease with the recurrence interval, implying that impervious area and forest cover have 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 and forest cover have relatively less impact on runoff volumes.

The higher standard errors for the shorter recurrence interval (1.25- to 2-year) floods imply that explanatory variables other than drainage area and the percentage of limestone, impervious area, and forest cover 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 inclusion of forest cover in the regression equations resulted in a reduction of 7 to 9 percent in the standard error for the 1.25- to 2-year floods, but other explanatory variables are missing from the equations that would further reduce the standard error.

As noted above and shown in Figure 5, the correlation between the logarithms of the percentage of forest cover (lfor) and the logarithm of the percentage of impervious area (lia) is -0.51. This correlation value is statistically different from zero, as indicated by the small p-level of <.0001. The relatively high correlation between impervious area and forest cover is one reason why impervious area was not statistically significant and included as an explanatory variable in the 200- and 500-year equations (Equations 9 and 10).

Figure 5 indicates several other high correlations between explanatory variables, which explain why other variables, such as channel slope and land slope, were not included in Equations 1-10. For example, the following significant correlations are highlighted in Figure 5:

- Channel slope (lchansl) is inversely correlated with drainage area (lda) (correlation = -0.84) because small watersheds have large channel slopes and vice versa;
- Land slope (llandsl) is inversely correlated with impervious area (lia) (correlation = -0.61), implying that steep land slopes are not conducive to development; and
- Land slope (llandsl) and forest cover (lfor) are directly correlated (correlation = 0.66), implying that steep land slopes are conducive to forest cover.



Pearson Correlation Coefficients, N = 96
Prob > |r| under H0: Rho=0

	lda	lia	llime	lfor	llandsl	lchansl
lda	1.00000	-0.17224	0.28320	0.33216	0.26567	-0.83946
		0.0899	0.0047	0.0008	0.0082	<.0001
lia	-0.17224	1.00000	-0.20246	-0.51137	-0.60763	-0.02424
	0.0899		0.0456	<.0001	<.0001	0.8127
llime	0.28320	-0.20246	1.00000	0.07473	0.21665	-0.17498
	0.0047	0.0456		0.4646	0.0321	0.0848
lfor	0.33216	-0.51137	0.07473	1.00000	0.65964	-0.03247
	0.0008	<.0001	0.4646		<.0001	0.7510
llandsl	0.26567	-0.60763	0.21665	0.65964	1.00000	0.13963
	0.0082	<.0001	0.0321	<.0001		0.1703
lchansl	-0.83946	-0.02424	-0.17498	-0.03247	0.13963	1.00000
	<.0001	0.8127	0.0848	0.7510	0.1703	

Figure 5. Correlation matrix for selected watershed characteristics for the 96 stations in the Piedmont Piedmont-Blue Ridge Region

The percentages of the watershed in A, B, C, and D soils, based on SSURGO data, were also evaluated as explanatory variables. Consistent with the approach used in the Western Coastal Plain regression analysis in 2010, the sum of A and B soils and the sum of C and D soils were evaluated as explanatory variables. The sum of A and B soils represents higher infiltration soils, and the sum of C and D soils represents lower infiltration soils. Neither these sums were statistically significant for the combined Piedmont-Blue Ridge Region.

Equations 1-10 are applicable to rural and urban watersheds for the following ranges of the explanatory variables:

- Drainage area ranging from 0.111 to 816.4 square miles;
- Percentage of limestone ranging from 0.0 to 81.7 percent;
- Percentage of impervious area ranging from 0.0 to 53.5 percent; and

- Percentage of forest cover ranging from 0.5 to 100 percent.

Other sets of regression equations that were developed include the following:

- Regression equations applicable to rural and urban watersheds based on drainage area, limestone, and impervious area, omitting forest cover; and
- Separate regression equations for rural watersheds (drainage area, limestone, and forest cover) and urban watersheds (drainage area, limestone, and impervious area).

Based on review comments from the Maryland SHA and the Hydrology Panel, both impervious area and forest cover (up to the 100-year flood) were used as indicators of urbanization or the lack of urbanization. In addition, the separate regression equations for rural and urban watersheds did not exhibit good agreement for watersheds with 10 percent impervious area, the breakpoint for determining whether the watershed was rural or urban. One set of regression equations for both rural and urban watersheds (Equations 1-10) resolved the issue of the discontinuity of estimates in transitioning from rural to urban watersheds.

In Figure 6, the regression estimates of the 100-year flood discharge from Equation 8 were plotted against the gaging station estimates to illustrate the variability of the estimates. The green lines in Figure 6 are plus and minus one standard error of estimate (plus 36.4 percent and minus 26.7 percent, for an average of 31.8 percent). Plus or minus one standard error encompasses approximately two thirds of the data, implying that one third, or 32 stations, should fall outside the green lines in Figure 6. The data in Figure 6 illustrate the linear relation between the estimated and observed 100-year discharges. Although the regression equation has a tendency to underestimate the 100-year flood for discharges greater than 30,000 cfs, no reason or correction for this tendency was determined.

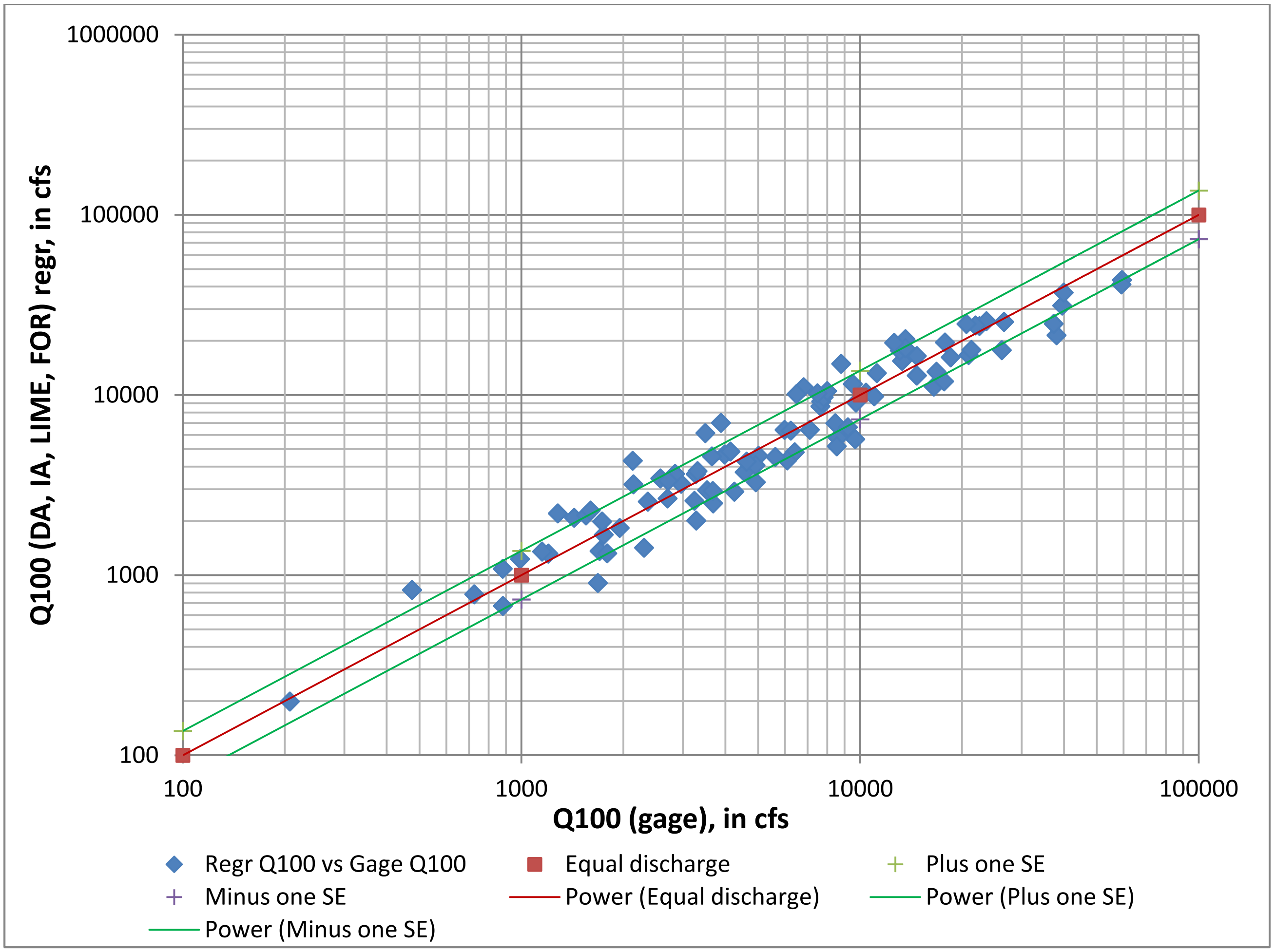


Figure 6. Comparison of the estimated 100-year discharges from Equation 8 to the gaging station estimates

Figure 7 presents a similar graph, comparing the regression estimates (Equation 5) to the gaging station estimates for the 10-year flood discharge. The green lines in Figure 7 are plus and minus one standard error of estimate (plus 33.6 percent and minus 25.2 percent, for an average of 29.6 percent). The data in Figure 7 illustrate the linear relation between the estimated and observed 10-year discharges. Although the regression equation has a tendency to underestimate the 10-year flood for discharges greater than about 15,000 cfs, no reason or correction for this tendency was determined.

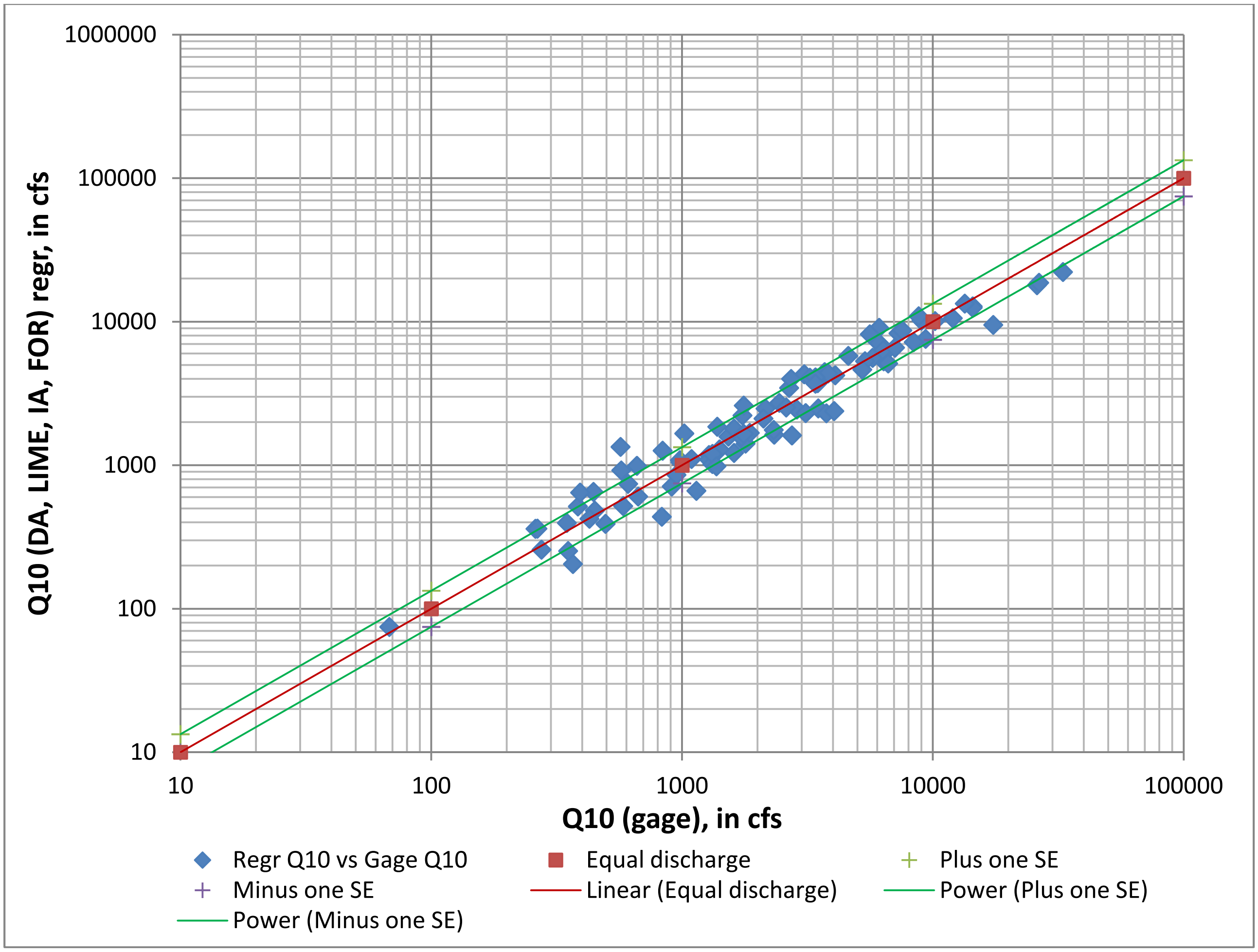


Figure 7. Comparison of the estimated 10-year discharges from Equation 5 to the gaging station estimates

Comparisons of the Current and 2010 Regression Equations

Of the three western regions in Maryland, urban regression equations are only available at this time for the Piedmont Region. When the previous regression analysis was completed in 2006, only 16 stations in the Piedmont Region had an impervious area of 10 percent or greater and 10 years or more of annual peak flows. The 16 urban stations were used to define regression equations based on drainage area and the percentage of impervious area. These equations were documented in the August 2006 and September 2010 versions of the Hydrology Panel report.

For the current analysis, 32 stations with impervious area of 10 percent or greater were used in the regression analysis for the Piedmont-Blue Ridge Region.

The 100- and 10-year floods estimated from the regression equations developed for this analysis (Equation 8 and Equation 5, respectively) were compared with the 2010 urban and rural regression equations for the Piedmont Region. Figure 8 compares the 100-year estimates from the 2010 urban equation, based on drainage area and impervious area, to estimates from Equation 8 for the 32 stations used in the current (2015) analysis. As shown in Figure 8, the two sets of equations give nearly the same 100-year estimates, with a slight tendency for the 2015 equation to give higher estimates for the smaller watersheds and lower estimates for the larger watersheds.

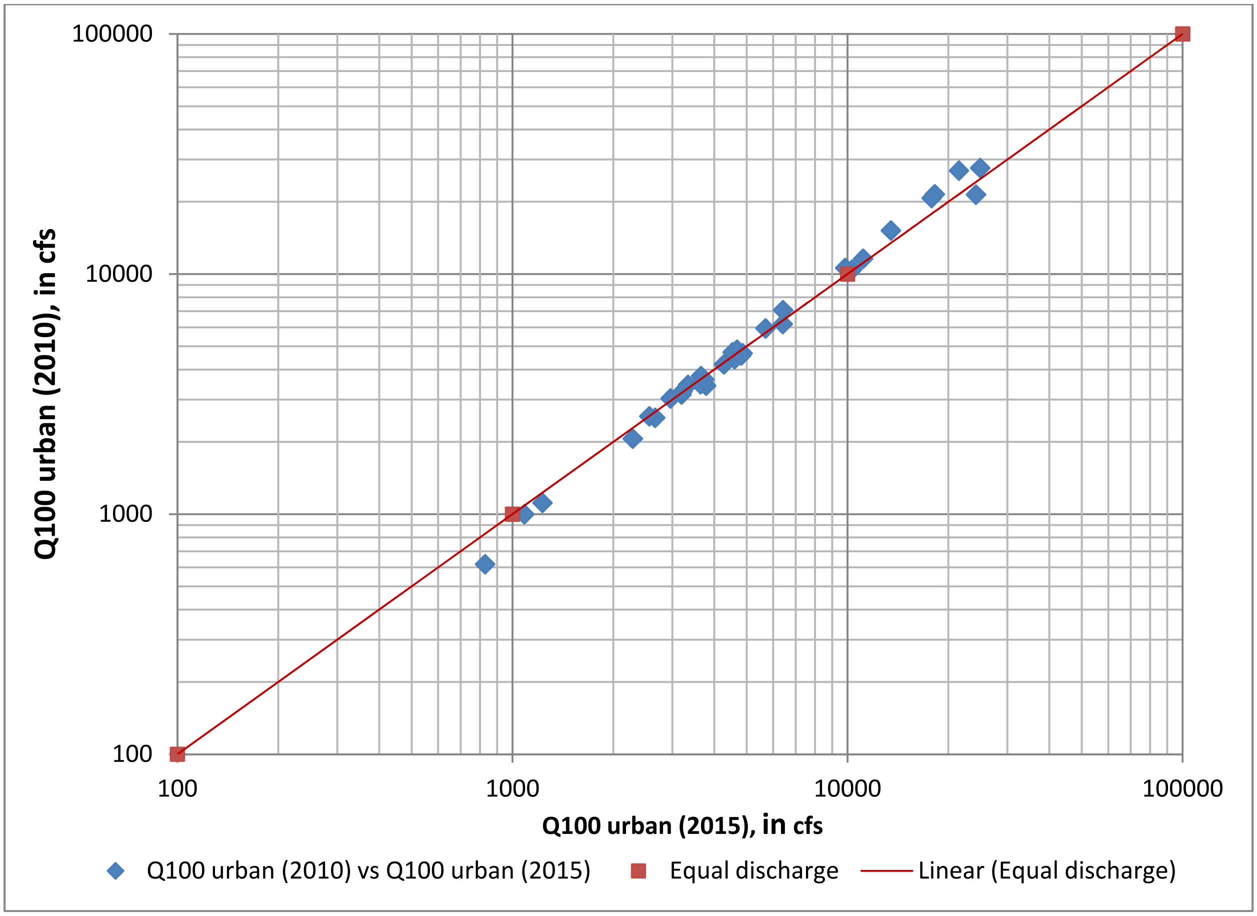


Figure 8. Comparison of 100-year flood discharges from the 2010 urban equation to estimates from Equation 8 for the 32 urban stations used in the 2015 analysis

Figure 9 compares the 10-year flood estimated from the 2010 urban equation, based on drainage area and impervious area, to estimates from Equation 5 using the 32 stations from the current (2015) analysis. On average, the 2015 equation (Equation 5) gives 10-year estimates about 17 percent less than the 2010 equation.

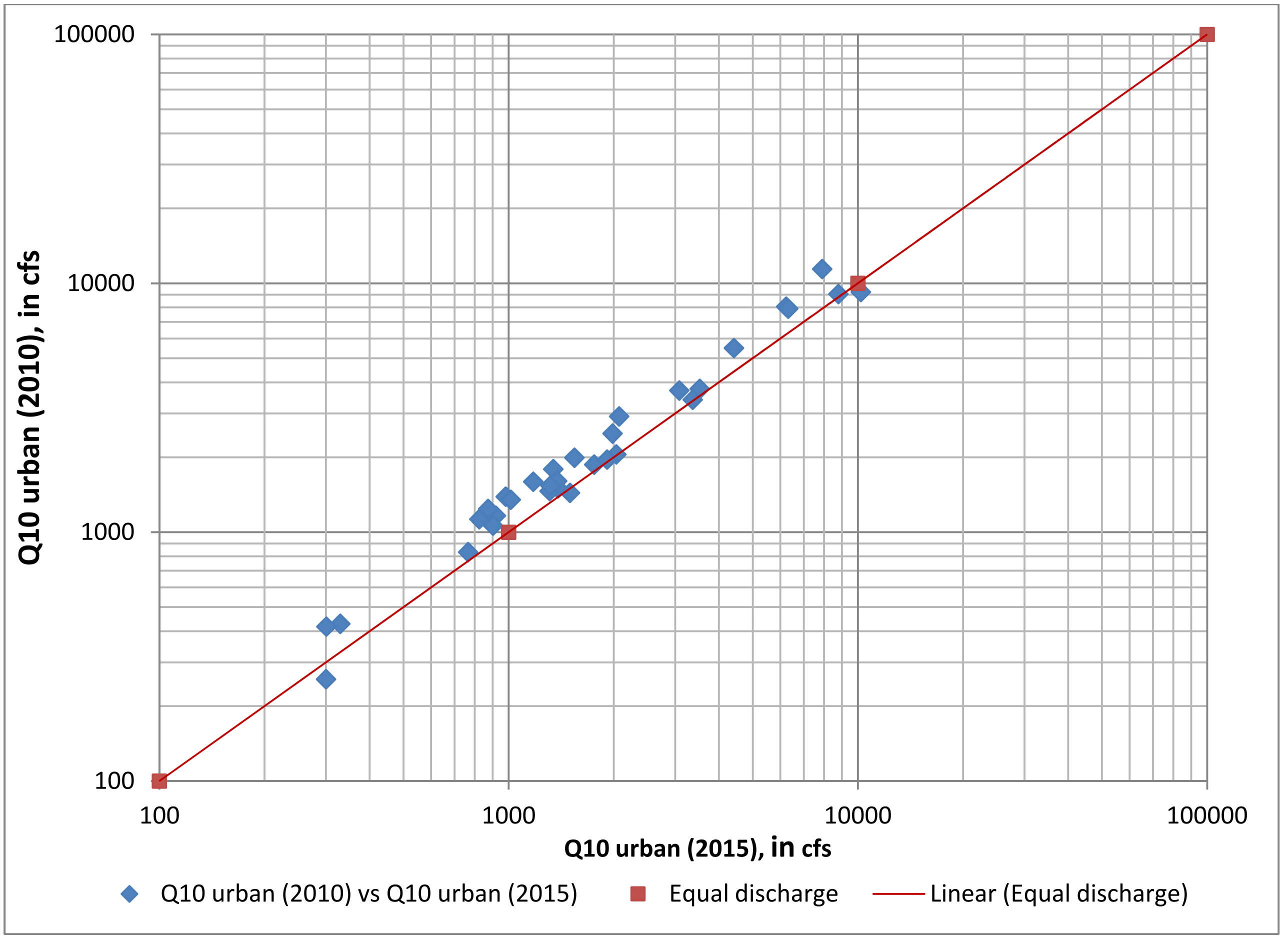


Figure 9. Comparison of 10-year flood discharges from the 2010 urban equation to estimates from Equation 5 for the 32 urban stations used in the 2015 analysis

Similar comparisons were made for the 100- and 10-year floods for the 64 rural stations used in the current (2015) analysis. Figure 10 compares the 100-year flood estimated from the 2010 rural equation, based on drainage area and the percentage of limestone and forest cover, to estimates from Equation 8 for the current analysis. As shown in Figure 10, the 2015 equation (Equation 8) gives higher estimates for the smaller watersheds and lower estimates for the largest watersheds.

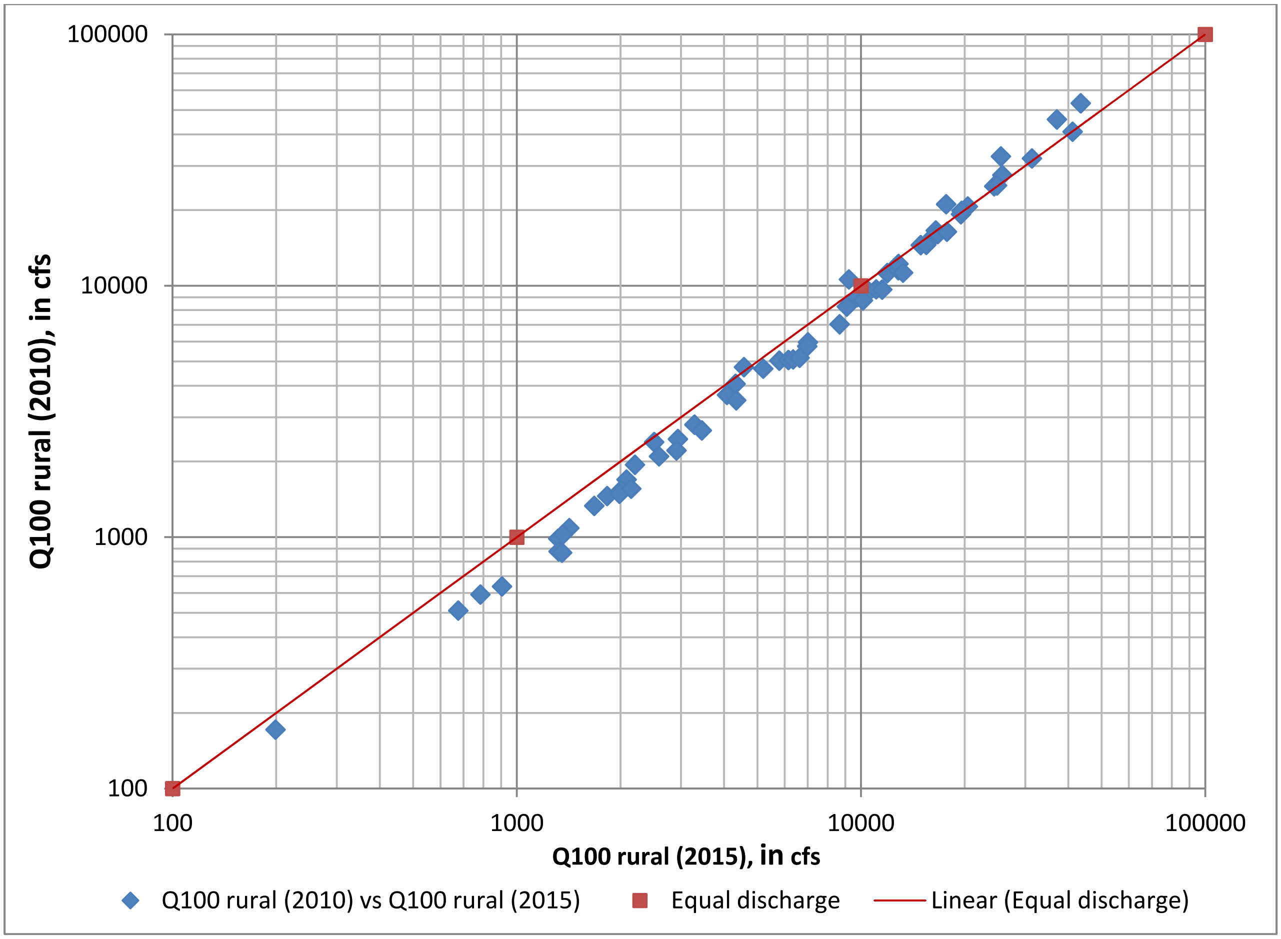


Figure 10. Comparison of 100-year flood discharges from the 2010 rural equation to estimates from Equation 8 for the 64 rural stations used in the 2015 analysis

Figure 11 compares the 10-year flood estimates from the 2010 rural equation, based on drainage area and the percentage of limestone and forest cover, to estimates from Equation 5 for the current analysis. As shown in Figure 11, the 2015 equation (Equation 5) gives higher estimates for the smaller watersheds and lower estimates for the largest watersheds.

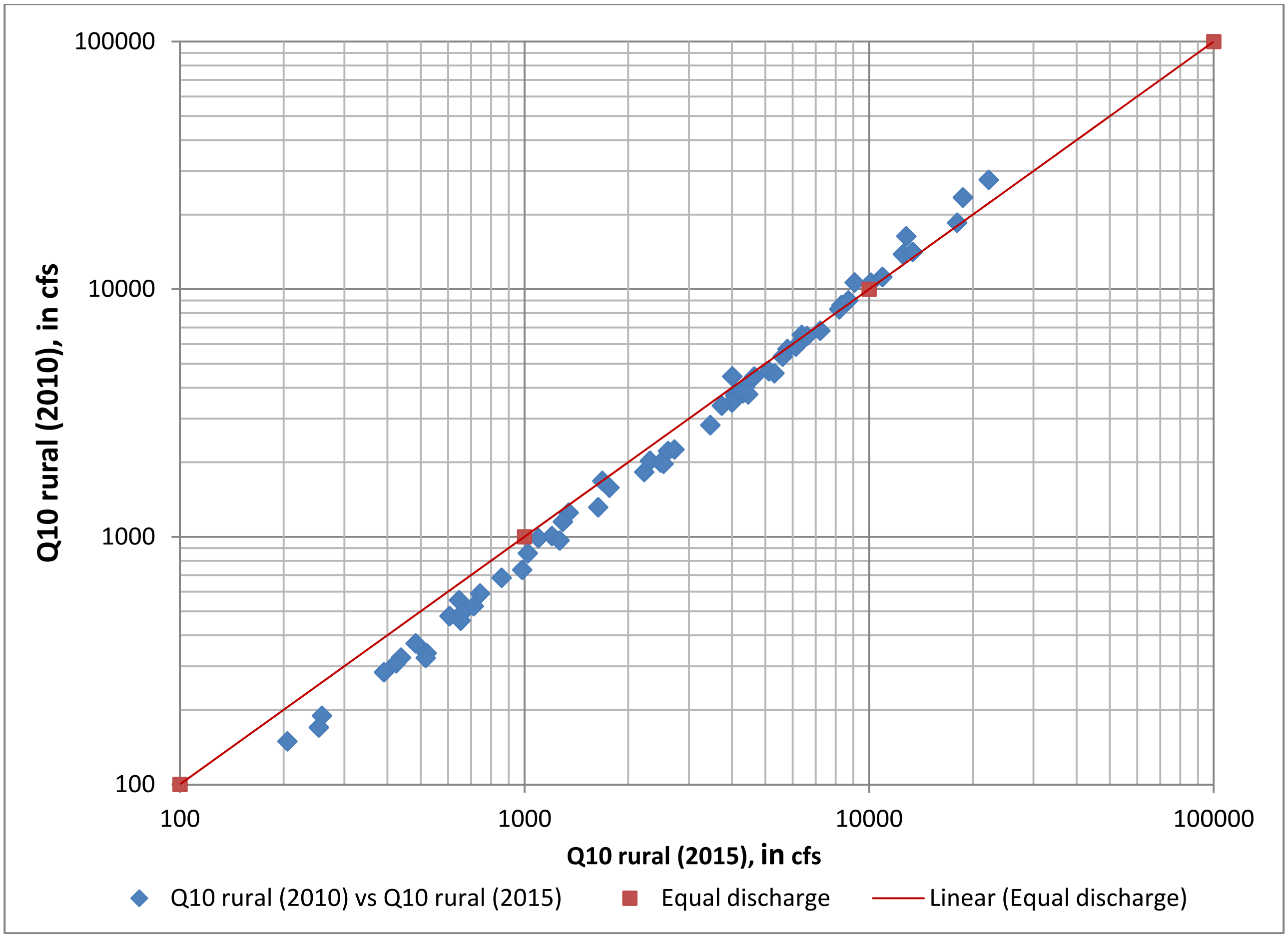


Figure 11. Comparison of 10-year flood discharges from the 2010 rural equation to estimates from Equation 5 for the 64 rural stations used in the 2015 analysis

In summary, the comparisons between the 2010 regression equations and the new regression equations (Equations 8 and 5) for the Piedmont-Blue Ridge Region revealed the following:

- The 2015 equation (Equation 8) and the 2010 urban equation give nearly the same estimates for urban watersheds for the 100-year flood;
- The 2015 equation (Equation 5) for the 10-year flood gives estimates for urban watersheds that average about 17 percent less than the 2010 urban equation;
- The 2015 equation (Equation 8) for the 100-year flood in rural watersheds gives higher estimates for the smaller watersheds and lower estimates for the largest watersheds than the 2010 rural equation; and
- The 2015 equation (Equation 5) for the 10-year flood in rural watersheds gives higher estimates for the smaller watersheds and lower estimates for the larger watersheds than the 2010 rural equation.

Appalachian Plateau Region Regression Analysis

Development of the Regression Equations

For the Appalachian Plateau, based on 24 stations, the two most significant watershed characteristics are drainage area (DA) in square miles and land (watershed) slope (LSLOPE) in feet per foot. As discussed earlier, the Youghiogheny River Tributary near Friendsville (03076505) gaging station was deleted from the analysis as an outlier. The annual flood peaks were very low for this 0.21-square-mile watershed. The Youghiogheny River Tributary station was also considered an outlier in the 2006 analysis. The Appalachian Plateau regression equations were not updated in the 2010 Hydrology Panel Report so this current update is the first update since 2006.

Land slope was only significant at the 10-percent level up to the 50-year flood. LSLOPE was included in the regression equations because it reduces the standard error of all the recurrence interval floods, consistent with the 2006 analysis, and makes the equations more robust in a predictive mode. As with the Piedmont-Blue Ridge Region analysis, all variables were converted to logarithms, and a multiple linear regression analysis was performed using SAS. The equations for the 1.25- to 500-year flood discharges were then converted to exponential form for easier use and are presented below with the associated standard error and equivalent years of record:

Equation	**Standard error (%)**	**Equivalent years**	
$Q_{1\_25} = 71.0\ DA^{0.848}\ LSLOPE^{0.342}$	30.9	1.2	(11)
$Q_{1\_5} = 86.3\ DA^{0.837}\ LSLOPE^{0.312}$	23.3	3.7	(12)
$Q_{2} = 112.7\ DA^{0.829}\ LSLOPE^{0.319}$	21.1	6.6	(13)
$Q_{5} = 199.1\ DA^{0.813}\ LSLOPE^{0.339}$	21.1	11	(14)
$Q_{10} = 272.2\ DA^{0.801}\ LSLOPE^{0.338}$	24.5	12	(15)
$Q_{25} = 416.9\ DA^{0.794}\ LSLOPE^{0.380}$	27.9	14	(16)
$Q_{50} = 570.5\ DA^{0.790}\ LSLOPE^{0.422}$	32.5	14	(17)
$Q_{100} = 722.0\ DA^{0.783}\ LSLOPE^{0.429}$	37.1	13	(18)
$Q_{200} = 914.5\ DA^{0.777}\ LSLOPE^{0.445}$	42.6	12	(19)
$Q_{500} = 1{,}174.3\ DA^{0.768}\ LSLOPE^{0.437}$	49.8	11	(20)

The standard error of estimate, expressed in percent, is the standard deviation of the residuals about the regression equation. It is a measure of the agreement between the regression estimates and the gaging station data used in the analysis. The equivalent years of record are defined as the number of years of actual streamflow record required at a site to achieve an accuracy equivalent to the standard error of estimate for the regression equations. Equivalent years of record are used to weight the regression estimate with the gaging station estimate, as described in Chapter Two of the Maryland Hydrology Panel report (2010). The computation of the equivalent years of record is described in Appendix 4.

Regression analyses were also performed by including the Appalachian Plateau stations in an analysis with the Piedmont-Blue Ridge stations and using a qualitative variable to account for differences in the Appalachian Plateau Region (total of 120 stations). The regression equations, based on 120 stations, had a significant bias for under-predicting flood discharges for the larger watersheds in the Appalachian Plateau Region. Therefore, the equations above, based on a separate Appalachian Plateau Region, were considered more reasonable.

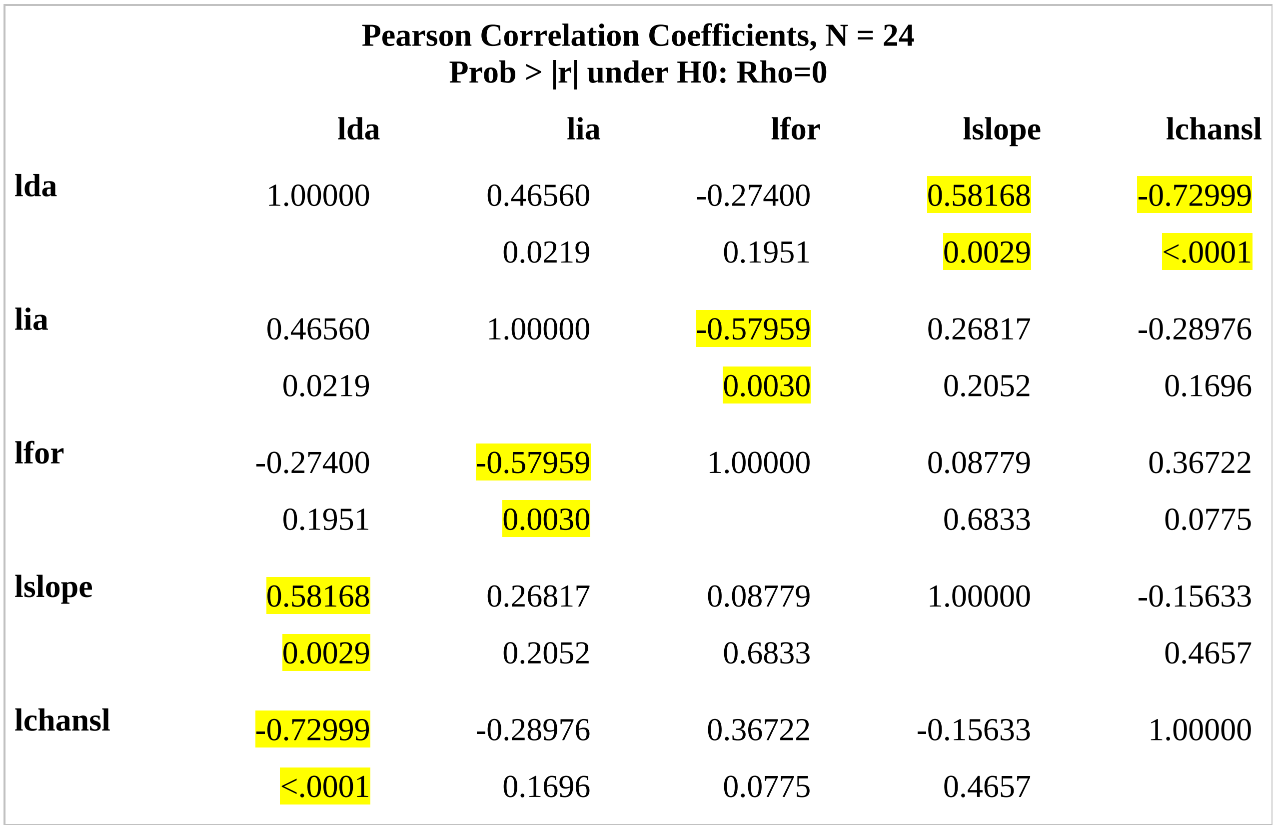
Rationale for the Regression Equations

For Equations 11-20, the drainage area exponent decreases with drainage area, the same trend observed for the Piedmont-Blue Ridge Region. For the larger storms, the rainfall intensity tends to vary across the watershed so that all parts of the watershed do not contribute equally to runoff. The drainage area exponents are larger than for the Piedmont-Blue Ridge Region, implying that the storms are more uniform or tend to cover more of the watershed. The Piedmont-Blue Ridge Region is more susceptible to the more intense storms from hurricane events. The land slope exponent increases with the recurrence interval, probably because the slope of the watershed becomes more critical to the runoff process as the flood magnitudes increase.

The standard errors for Equations 11-20 are slightly higher than the 2006 standard errors. Only one new station was added to the regression analysis. Channel slope is also significant at the 10-percent level for many recurrence interval floods, being the third most significant variable after drainage area and land slope. However, using land slope rather than channel slope results in lower standard errors for the regression equations. Figure 12 shows the correlations between the logarithms of selected watershed characteristics for the 24 stations in the Appalachian Plateau Region. Some significant correlations are as follows:

- Channel slope (lchansl) and drainage area (lda) have a correlation of -0.73;
- Land slope (llandsl) and drainage area (lda) have a correlation of 0.58; and
- Forest cover (lfor) and impervious area (lia) have a correlation of -0.58.

Land slope and drainage area have a lower correlation than channel slope and drainage area, so land slope is explaining more variability in flood discharge than channel slope in a regression equation including drainage area. Forest cover and impervious area are not statistically significant, because forest cover does not exhibit much variability at the gaged watersheds in the Appalachian Plateau Region and impervious area also has a very limited range (from 0 to 4.2 percent).



Pearson Correlation Coefficients, N = 24
Prob > |r| under H0: Rho=0

	lda	lia	lfor	lslope	lchansl
lda	1.00000	0.46560	-0.27400	0.58168	-0.72999
		0.0219	0.1951	0.0029	<.0001
lia	0.46560	1.00000	-0.57959	0.26817	-0.28976
	0.0219		0.0030	0.2052	0.1696
lfor	-0.27400	-0.57959	1.00000	0.08779	0.36722
	0.1951	0.0030		0.6833	0.0775
lslope	0.58168	0.26817	0.08779	1.00000	-0.15633
	0.0029	0.2052	0.6833		0.4657
lchansl	-0.72999	-0.28976	0.36722	-0.15633	1.00000
	<.0001	0.1696	0.0775	0.4657	

Figure 12. Correlation matrix for selected watershed characteristics for the 24 stations in the Appalachian Plateau Region

Watershed shape was also evaluated as a possible explanatory variable in the Appalachian Plateau Region. Watershed shape was defined as channel length squared divided by drainage area, essentially a measure of the length of the watershed divided by the width of the watershed. The watershed shape factor was not statistically significant.

The sums of A and B soils and C and D soils were also evaluated. The sum of C and D soils does not vary much across the gaging stations in the Appalachian Plateau Region and was not statistically significant. The sum of A and B soils was statistically significant for recurrence intervals of 10 years and less and reduced the standard error somewhat from the equations using drainage area and land slope. However, for recurrence intervals of 25 years and greater, the sum of A and B soils was not significant, and the standard errors were higher than the equations using drainage area and land slope. The latter variables were judged to be the two best variables for predicting flood discharges in the Appalachian Plateau.

Equations 11-20 are applicable to rural watershed for the following ranges of the explanatory variables:

- Drainage area ranging from 0.52 to 294.14 square miles, and
- Land slope ranging from 0.066 to 0.227 ft/ft.

Comparison of 2006 and 2015 Regression Equations

The 100-year flood discharges from the current (2015) equation (Equation 18) were compared to the 100-year discharges from the 2006 equations. As shown in Figure 13, the two equations, both based on drainage area and land slope, give about the same estimates for the 24 gaging stations. There is a slight tendency for the 2006 equations to give higher estimates for the larger watersheds and for the 2015 equations to give higher estimates for the smaller watersheds.

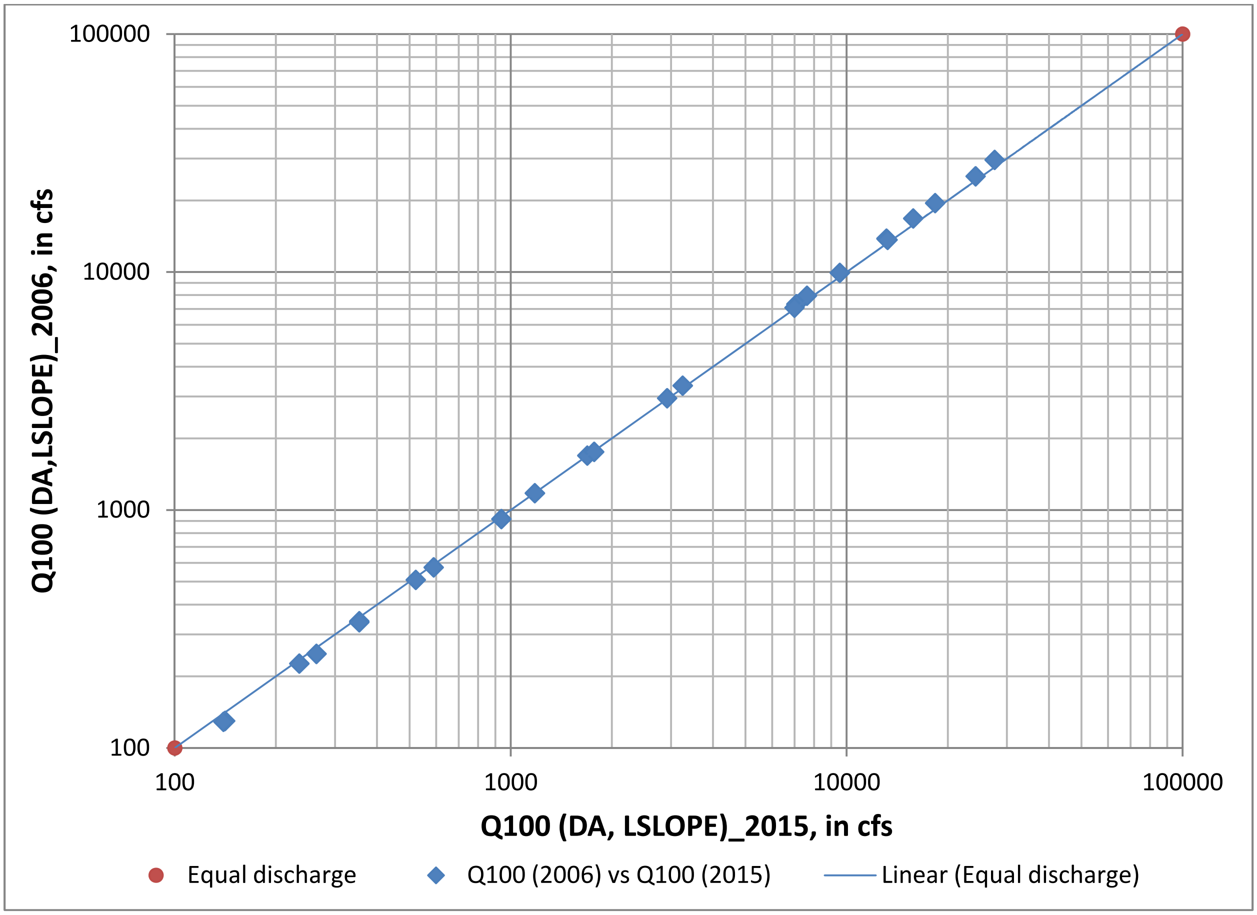


Figure 13. Comparison of 100-year flood discharges from the 2006 and 2015 equations using the 24 gaging stations in the Appalachian Plateau Region

The same comparison was made for the 10-year flood discharges. The 2015 flood discharges are based on Equation 15. The results, in Figure 14, are essentially the same as for the 100-year flood, where the 2006 equations give slightly higher estimates for the larger watersheds and the 2015 equations give slightly higher estimates for the smaller watersheds. The 2015 equations for the 100- and 10-year flood discharges have not changed much from the 2006 equations, which are published in both the August 2006 and September 2010 versions of the Hydrology Panel report.

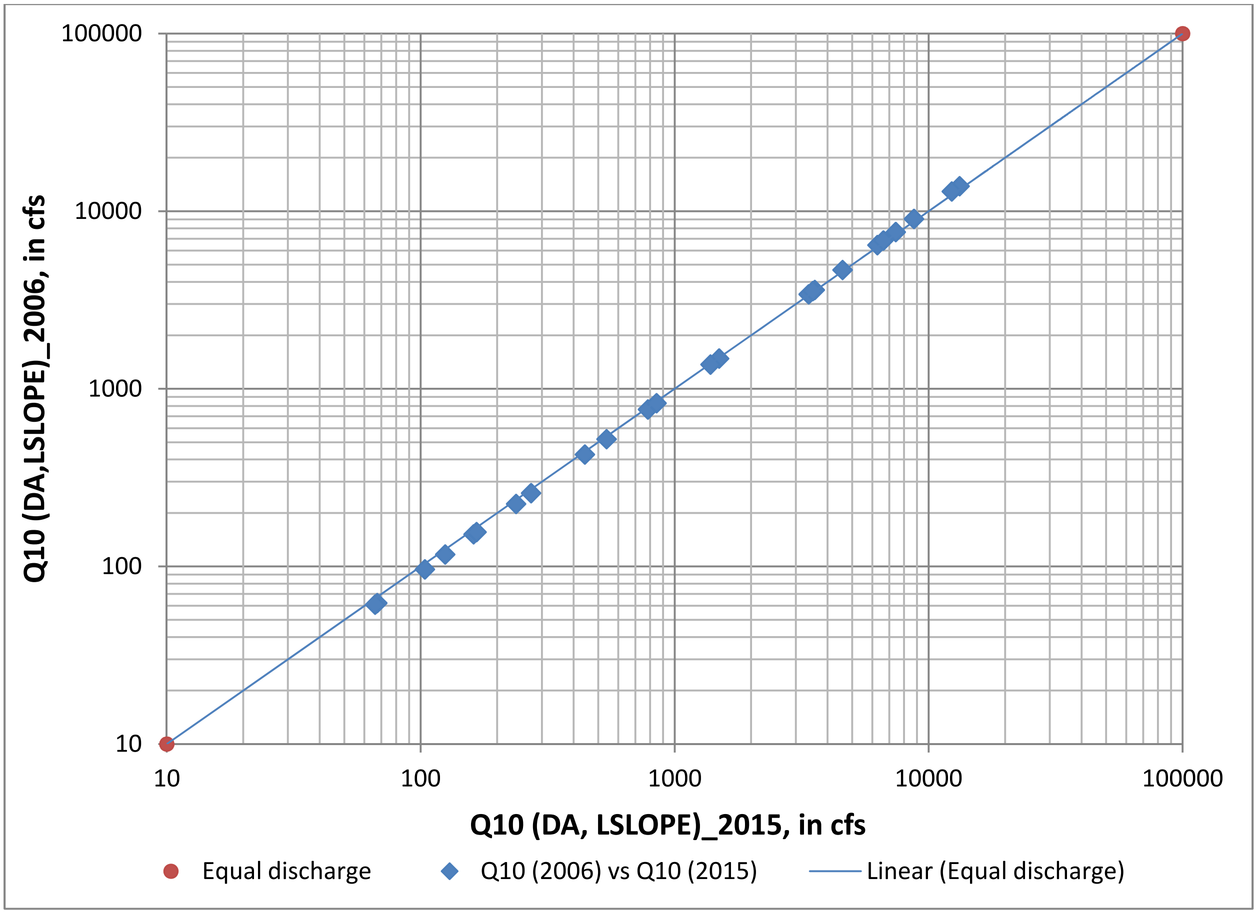


Figure 14. Comparison of 10-year flood discharges from the 2006 and 2015 equations using the 24 gaging stations in the Appalachian Plateau Region

Summary

The regression equations for estimating the 1.25-, 1.5-, 2-, 5-, 10-, 25-, 50-, 100-, 200-, and 500-year flood discharges were updated for the combined Piedmont-Blue Ridge Region and the Appalachian Plateau Region in western Maryland. A new regional skew analysis was performed, and flood frequency curves were updated and revised for 133 stations, including 55 stations that were discontinued prior to 1999, 52 stations with additional data since 1999 (additional 13 years of record), and 26 new stations with at least 10 years of record. Most of the new stations are urban watersheds in Baltimore County or the City of Baltimore.

Eleven stations were identified as outliers in the regression analysis and two stations were combined with nearby stations, resulting in 120 stations being used in the regression analysis: 96 stations in the Piedmont-Blue Ridge Region and 24 stations in the Appalachian Plateau Region. The final regression equations for the Piedmont-Blue Ridge Region were based on drainage area in square miles and the percentages of limestone, impervious area, and forest cover. These were the most statistically significant explanatory variables across all recurrence intervals. With the addition of the new stations in Baltimore County and the City of Baltimore, there are now 37 stations with impervious area greater than

10 percent (only 32 urban stations were used in equations), based on the Maryland Office of Planning generalized land use data. The urban regression equations documented in the September 2010 Hydrology Panel report are only applicable to the Piedmont Region and were based on just 16 stations. Equations 1-10 are now applicable to urban watersheds in the Piedmont and Blue Ridge Regions.

A comparison of the new urban equations to the previous equations for the Piedmont Region revealed that the 100-year discharge estimates from the 2015 and 2010 equations are nearly the same for the 32 stations used in the current (2015) analysis. The same comparison for the 10-year discharge estimates indicated that the new equation gives estimates approximately 17 percent higher than the 2010 urban equation. The new equations are based on more data and are more defensible.

Comparison of the new regression equations for the 100- and 10-year discharges to the 2010 equations for the Piedmont-Blue Ridge Region indicated that the 2015 equations give higher estimates for the smaller watersheds and lower estimates for the larger watersheds. The differences are not large, and the 2015 equations are considered more defensible since they are based on more data.

The final regression equations for the Appalachian Plateau are based on drainage area in square miles and land slope in feet per foot, the same explanatory variables used in the 2006 analysis. Comparisons of the new and previous equations indicate little difference for the 100- and 10-year flood discharges, because only one new station was added to the Appalachian Plateau Region analysis.

Equations 1-10 will replace the following equations in the September 2010 version of the Hydrology Panel report:

- Rural equations for the combined Piedmont-Blue Ridge Region; and
- Urban equations for the Piedmont Region.

Equations 11-20 will replace the equations in the September 2010 version of the Hydrology Panel report for the Appalachian Plateau Region.

The regression equations documented in this report are based on updated annual peak data through the 2012 water year where the data are available. This is an additional 13 years of record at many of the gaging stations including several major floods that occurred since 1999. In addition, 26 new stations (mostly urban stations) were used in the regression analysis. The number of urban gaging stations used in the regression analysis doubled from 16 to 32 stations for the current analysis. The regression equations (Equations 1-10) for the Piedmont-Blue Ridge Region are applicable to both rural and urban watersheds. The regression equations for the Appalachian Plateau Region (Equations 11-20) are only applicable to rural watersheds and give essentially the same estimates of the T-year discharges as the previous equations but are based on additional data.

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Appendix 1. T-year flood discharges (QT) for the 120 stations used in the regression analysis for the Piedmont-Blue Ridge Region and the Appalachian Plateau Region

Station Number	Q1.25 (cfs)	Q1.50 (cfs)	Q2 (cfs)	Q5 (cfs)	Q10 (cfs)	Q25 (cfs)	Q50 (cfs)	Q100 (cfs)	Q200 (cfs)	Q500 (cfs)
01495000	1790	2250	2890	4850	6450	8860	10950	13300	16000	20000
01495500	1320	1440	1650	2440	3230	4650	6100	7990	10400	14800
01496000	1010	1220	1540	2530	3400	4760	6010	7480	9220	12000
01496080	125	212	280	491	668	935	1170	1430	1730	2190
01496200	617	808	1090	2120	3110	4820	6490	8590	11200	15600
01577940	92	118	156	293	427	663	899	1200	1580	2240
01578500	2490	3280	4480	8920	13400	21200	29200	39500	52500	75300
01578800	272	340	432	700	909	1210	1460	1730	2030	2460
01579000	441	591	816	1600	2330	3540	4700	6090	7780	10500
01580000	2430	2950	3660	5700	7290	9580	11500	13600	15900	19400
01580200	2890	3580	4550	7610	10200	14200	17800	21900	26700	34200
01581500	756	962	1250	2140	2870	3960	4910	5980	7180	9000
01581700	1270	1830	2600	4800	6360	8340	9790	11200	12600	14300
01581752	276	365	502	1010	1530	2440	3370	4560	6090	8740
01581810	686	897	1220	2360	3470	5410	7320	9720	12700	17900
01581870	531	690	930	1810	2670	4190	5700	7630	10100	14300
01581940	36	53	83	225	495	730	1140	1700	2500	4100
01581960	491	618	794	1320	1740	2370	2900	3490	4150	5140
01582000	1500	1820	2270	3570	4600	6100	7380	8790	10400	12700
01582510	112	178	288	715	1140	1840	2500	3280	4190	5620
01583100	524	636	796	1310	1760	2460	3110	3880	4780	6230
01583495	52	77	116	249	367	547	705	881	1080	1370
01583500	1240	1630	2210	4330	6420	10100	13800	18500	24400	34800
01583580	45	68	107	268	443	768	1110	1550	2110	3100
01583979	500	625	789	1260	1610	2110	2520	2960	3430	4100
01584050	310	441	645	1400	2150	3440	4690	6240	8140	11300
01584500	1460	1930	2610	4790	6630	9440	11900	14700	17900	22700
01585090	704	844	1020	1480	1790	2200	2520	2840	3170	3620
01585095	320	340	405	680	980	1500	2050	2700	3600	5000
01585100	1140	1370	1690	2670	3490	4740	5840	7100	8550	10800
01585104	337	415	521	838	1090	1470	1790	2140	2540	3140
01585200	421	559	749	1300	1720	2310	2770	3270	3780	4519
01585225	134	142	156	210	260	333	400	475	560	680
01585230	1400	1680	2040	3030	3760	4760	5560	6410	7320	8630
01585300	788	982	1250	2070	2740	3750	4630	5620	6740	8450
01585400	188	237	316	633	984	1680	2450	3530	5030	7930

Station Number	Q1.25 (cfs)	Q1.50 (cfs)	Q2 (cfs)	Q5 (cfs)	Q10 (cfs)	Q25 (cfs)	Q50 (cfs)	Q100 (cfs)	Q200 (cfs)	Q500 (cfs)
01585500	117	166	243	538	836	1370	1900	2570	3410	4860
01586000	1520	1850	2360	4100	5750	8560	11300	14700	19000	26300
01586610	711	928	1240	2230	3070	4360	5510	6810	8310	10600
01587000	2270	2840	3660	6360	8770	12600	16300	20600	25700	34000
01587050	68	91	126	255	384	615	849	1150	1530	2200
01587500	1520	1990	2720	5510	8380	13600	19100	26200	35500	52100
01588000	332	463	674	1520	2440	4160	6000	8440	11700	17500
01589000	6120	7920	10500	18800	26000	37300	47400	59100	72700	93900
01589100	465	540	645	986	1280	1760	2190	2710	3320	4320
01589180	58	66	85	175	265	430	630	880	1200	1800
01589197	495	548	636	995	1380	2110	2900	3980	5440	8230
01589200	147	190	262	596	1020	1970	3160	5010	7850	14000
01589240	599	787	1080	2210	3400	5600	7910	11000	15000	22300
01589300	1310	1580	2000	3640	5360	8610	12100	16800	23200	35100
01589330	1260	1490	1830	2980	4040	5820	7540	9670	12300	16700
01589352	4730	5920	7580	12900	17400	24400	30700	38000	46500	59700
01589440	636	830	1150	2500	4080	7320	11100	16500	24200	39700
01589464	420	538	703	1200	1610	2210	2730	3310	3950	4910
01591000	768	1050	1510	3310	5230	8840	12700	17700	24400	36500
01591400	669	846	1100	1960	2720	3960	5110	6490	8140	10800
01591700	652	895	1260	2530	3700	5610	7390	9510	12000	16000
01593350	94	130	185	382	572	896	1210	1600	2070	2850
01594000	2090	2660	3500	6370	9000	13400	17500	22500	28600	38600
01594930	253	308	381	581	729	934	1100	1270	1460	1730
01594936	69	92	127	258	389	624	861	1170	1550	2230
01594950	76	98	130	242	345	517	681	880	1120	1530
01596005	20	39	50	82	107	144	177	212	252	312
01596500	1060	1250	1520	2380	3100	4220	5240	6420	7800	10000
01597000	305	378	485	844	1170	1720	2230	2860	3630	4900
01598000	2180	2710	3450	5880	8030	11500	14600	18400	22900	30100
01599000	1270	1520	1880	2970	3890	5310	6580	8040	9730	12400
01601500	4140	4900	6040	10100	14000	20900	27800	36600	47800	67500
01609000	2490	3120	3970	6510	8540	11500	14000	16800	19900	24500
01609500	190	223	267	398	502	657	789	938	1110	1360
01610105	41	46	54	74	88	107	121	137	153	176
01610150	219	283	375	666	912	1290	1620	2000	2440	3110
01610155	2180	2880	3860	6930	9460	13200	16400	20000	24100	30000
01612500	315	399	518	896	1220	1720	2160	2680	3280	4210
01613150	155	189	236	376	489	656	800	960	1140	1410

Station Number	Q1.25 (cfs)	Q1.50 (cfs)	Q2 (cfs)	Q5 (cfs)	Q10 (cfs)	Q25 (cfs)	Q50 (cfs)	Q100 (cfs)	Q200 (cfs)	Q500 (cfs)
01613160	60	74	94	151	197	263	319	380	448	550
01614500	5380	6340	7620	11400	14400	18700	22400	26600	31200	38200
01619000	986	1210	1540	2570	3460	4880	6160	7670	9450	12300
01619475	11	15	21	44	68	109	152	207	276	398
01619500	1580	2020	2620	4520	6100	8520	10600	13100	15800	20100
01637000	268	387	584	1410	2320	4080	5980	8530	11900	18100
01637500	1470	1900	2510	4540	6320	9140	11700	14700	18300	23900
01637600	141	192	274	600	949	1610	2310	3240	4480	6730
01639000	6690	7580	8740	12000	14400	17800	20600	23600	26900	31700
01639140	1310	1550	1890	2940	3820	5180	6390	7800	9430	12000
01639500	2250	2700	3360	5560	7550	10900	14000	17800	22400	30100
01640000	228	306	424	857	1280	2020	2760	3680	4830	6800
01640500	179	255	378	876	1410	2420	3490	4910	6760	10100
01640700	102	136	190	396	609	1000	1410	1950	2670	3920
01640965	59	80	115	251	392	653	925	1280	1740	2570
01640970	146	213	325	796	1320	2340	3440	4920	6900	10500
01641000	482	624	821	1400	1860	2520	3060	3650	4300	5230
01641500	71	100	148	346	568	1000	1480	2130	3020	4670
01642000	13000	14800	16900	22600	26500	31700	35700	39900	44300	50400
01642400	232	314	440	891	1320	2070	2780	3670	4760	6580
01642500	1600	1960	2480	4150	5600	7920	10000	12600	15500	20300
01643000	13900	15900	18600	26600	33000	42400	50400	59300	69300	84500
01643395	46	68	105	266	449	811	1210	1750	2490	3850
01643500	1500	1900	2520	4780	7060	11200	15400	20900	28000	40600
01644371	87	106	134	241	347	538	734	990	1320	1920
01644375	93	128	184	411	660	1140	1660	2360	3310	5060
01644380	45	88	175	530	830	1320	1800	2300	2900	3850
01644420	53	70	97	189	275	419	557	725	928	1260
01644600	1720	2100	2600	4400	5900	8400	10800	13600	17400	23100
01645000	2340	3010	4050	7980	12000	19400	27100	37300	50500	74400
01645200	341	454	622	1210	1760	2680	3560	4620	5910	8040
01646550	492	657	887	1570	2110	2860	3480	4140	4850	5860
01647720	520	660	850	1700	2600	4350	7500	9200	13500	27000
01650050	313	368	470	910	1370	2250	3150	4250	5700	8300
01650085	40	53	79	200	351	681	1080	1680	2400	4000
01650190	94	128	181	380	582	945	1310	1790	2390	3440
01650500	829	1000	1280	2320	3400	5400	7530	10400	14200	21200
01651000	2580	3190	4050	6870	9350	13300	17000	21300	26400	34700
03075450	20	23	28	41	51	68	74	91	105	140

Station Number	Q1.25 (cfs)	Q1.50 (cfs)	Q2 (cfs)	Q5 (cfs)	Q10 (cfs)	Q25 (cfs)	Q50 (cfs)	Q100 (cfs)	Q200 (cfs)	Q500 (cfs)
03075500	2910	3490	4280	6660	8580	11400	13900	16700	19800	24600
03075600	18	23	30	54	75	111	144	184	232	310
03076500	4570	5360	6350	8920	10700	13100	14900	16800	18700	21400
03076600	1150	1370	1640	2040	2340	3600	4800	5400	5800	6400
03077700	18	25	36	78	145	220	320	450	640	1000
03078000	1500	1730	2040	3000	3690	4780	5710	6750	7930	9720

Appendix 2. Watershed characteristics used in the regression analysis for the 96 gaging stations in the Piedmont-Blue Ridge Region

Station number	Years of record	Drainage area (sq mi)	Limestone (percent)	Impervious area (percent)	Forest cover (percent)
01495000	80	53.36	0	2.5	35.4
01495500	12	26.46	0	2.5	30.9
01496000	37	24.87	0	1.9	22.8
01496080	10	1.75	0	1.5	94.3
01496200	27	9.00	0	1	14.8
01577940	16	0.67	0	1.6	28
01578500	19	191.66	0	1.9	33.6
01578800	10	1.25	0	2.5	15.3
01579000	22	5.08	0	2.9	18.9
01580000	86	94.31	0	1	35.8
01580200	11	127.16	0	1.2	34.7
01581500	38	8.79	0	12.9	22.3
01581700	45	34.64	0	8.1	27.1
01581752	11	2.47	0	42.9	5.2
01581810	12	27.46	2	4.9	25.7
01581870	13	15.76	0	7.8	19.8
01581940	10	0.77	0	2.5	74.1
01581960	13	9.66	0	4.8	35.4
01582000	69	53.70	0	1.3	41
01582510	14	1.39	0	2.4	31.2
01583100	23	12.45	0	3.4	31.2
01583495	10	0.23	0	0	27.5
01583500	68	60.31	0	1.5	34
01583580	26	1.49	0	8.4	64.5
01583979	11	2.10	0	40.2	12.7
01584050	37	9.31	0	5.7	18.5
01584500	72	36.04	0	3.5	28.2
01585090	18	2.58	0	44	11.7
01585095	17	1.36	0	42.9	5.6
01585100	40	7.56	0	37.7	18.6
01585104	13	2.44	0	22.5	28.6
01585200	46	2.31	0	42.1	4.1
01585225	16	0.14	0	41.1	0.5
01585230	16	3.50	0	45.4	1.8
01585300	29	4.52	0	25.3	29.9
01585400	29	1.94	0	36.8	21.4

Station number	Years of record	Drainage area (sq mi)	Limestone (percent)	Impervious area (percent)	Forest cover (percent)
01585500	64	3.26	0	4.2	19.5
01586000	67	55.48	3.1	5.4	23
01586610	30	28.01	0.1	4.9	31.7
01587000	24	164.23	1.74	4.6	31.5
01587050	11	0.49	0	10	5.9
01587500	32	64.26	0	4	31.4
01588000	43	11.40	0	4.6	20.5
01589000	23	284.71	0	4.7	33.3
01589100	47	2.47	0	33.8	24.5
01589180	14	0.31	0	42	15.8
01589197	14	4.09	0	37.7	11.8
01589200	17	4.89	0	14.6	26.5
01589240	12	19.27	0	16.6	35.1
01589300	34	32.59	0	19.5	30.7
01589330	31	5.52	0	41.1	8.4
01589352	14	63.57	0	41.3	16.5
01589440	47	25.21	0	11.4	35.9
01589464	9	2.26	0	41.7	1.4
01591000	68	34.95	0	1.4	33.3
01591400	46	22.86	0	4.3	25.3
01591700	34	27.31	0	8.9	32.7
01593350	11	1.06	0	34.8	5.4
01594000	59	98.25	0	11	28.6
01614500	85	502.44	41.5	1.6	32.6
01619000	27	93.90	64.6	3.9	56.9
01619475	11	0.11	81.72	0	9.7
01619500	85	280.89	75.6	4.8	24.8
01637000	30	8.76	0	0.8	54.8
01637500	65	67.33	0	0.8	46.6
01637600	11	2.32	0	1.5	37.6
01639000	72	172.7	1.3	0.8	13.1
01639140	12	31.07	2.4	3.7	13.6
01639500	65	102.98	1.1	1.8	22
01640000	31	8.11	76.53	6.9	19.5
01640500	53	6.10	0	0.5	80.8
01640700	11	1.12	0	0	4.7
01640965	13	2.19	0	0	96
01640970	10	3.91	0	1.2	76.7

Station number	Years of record	Drainage area (sq mi)	Limestone (percent)	Impervious area (percent)	Forest cover (percent)
01641000	43	18.69	16.23	1.8	77.3
01641500	39	7.30	0	0	100
01642000	35	665.1	14.14	1.7	28
01642400	10	2.67	0	0.1	6.8
01642500	49	82.37	0	1.3	26.4
01643000	84	816.45	12.3	2.4	27
01643395	9	1.18	0	1.5	86.4
01643500	62	62.94	0	2	38.3
01644371	9	0.42	0	28	23.5
01644375	9	1.29	0	53.5	8.6
01644380	9	0.81	0	1.5	42.5
01644420	10	0.28	0	0	15.2
01644600	12	53.89	0	23.1	27.2
01645000	48	102.19	0	11.6	27.2
01645200	30	3.70	0	26.2	13.6
01646550	40	4.09	0	32.4	5.2
01647720	11	9.68	0	9.9	23.2
01650050	10	2.51	0	5.1	33.6
01650085	10	0.35	0	3.8	66.2
01650190	10	0.49	0	5.4	4.4
01650500	75	21.23	0	11.6	26.3
01651000	47	49.43	0	25.1	19.7

Appendix 3. Watershed characteristics used in the regression analysis for the 24 gaging stations in the Appalachian Plateau Region

Station Number	Years of Record	Drainage area (sq mi)	Land Slope (ft/ft)
01594930	26	8.23	0.155
01594936	28	1.91	0.144
01594950	25	2.36	0.130
01596005	14	1.43	0.099
01596500	64	48.53	0.203
01597000	33	16.75	0.194
01598000	24	115.87	0.227
01599000	82	72.74	0.164
01601500	83	247.03	0.209
01609000	33	149.45	0.202
01609500	25	5.00	0.166
01610105	15	0.65	0.160
01610150	18	10.27	0.115
01610155	24	102.71	0.184
01612500	17	17.28	0.143
01613150	22	4.60	0.113
01613160	12	1.24	0.129
03075450	12	0.55	0.066
03075500	72	134.16	0.115
03075600	22	0.52	0.071
03076500	89	294.14	0.112
03076600	48	49.07	0.168
03077700	12	1.07	0.085
03078000	65	63.77	0.101

Appendix 4. Computation of the Equivalent Years of Record for Regression Equations for the Piedmont-Blue Ridge Region and the Appalachian Plateau Region in Maryland

Computational Procedure

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

$$SE_x^2 = (S^2/N) * R_x^2 \qquad \text{(A1)}$$

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 A1, 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 A1 can be used to estimate the years of record needed to obtain that standard error of estimate. Rearranging Equation A1 and solving for N gives Equation A2 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 (N_r) of a regression equation is computed as follows (Hardison, 1971):

$$N_r = (S/SE)^2 * R^2 \qquad \text{(A2)}$$

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):

$$R^2 = 1 + G*K_x + 0.5 *(1+0.75*G^2)*K_x^2 \qquad \text{(A3)}$$

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 computations in Equations A2 and A3 require an estimate of the average standard deviation and average skew for all gaging stations in a given region. For the Piedmont-Blue Ridge Region, the average standard deviation

(S) is 0.3070 log units and the average skew (G) is 0.48. For the Appalachian Plateau Region, the average standard deviation (S) is 0.2353 log units and the average skew (G) is 0.39. The lower standard deviation and skew in the Appalachian Plateau Region is indicative of less variability in the annual peak flows in this region.

For the Piedmont-Blue Ridge Region, the pertinent data are S=0.3070 log units and G=0.48 and:

Recurrence Interval (years)	**K value**	**SE^2 (log units squared)**	**Equivalent years of record**
1.25	-0.85624	0.03378	2.8
1.50			(3.2) Estimated
2	-0.07972	0.02488	3.7
5	0.80991	0.01825	9.2
10	1.32181	0.01583	16
25	1.90425	0.01525	25
50	2.30094	0.01602	31
100	2.67165	0.01816	34
200	3.02262	0.02266	32
500	3.46270	0.03063	30

The equivalent years of record are estimated using Equations A2 and A3 using the above data.

For the Appalachian Plateau Region, the pertinent data are S=0.2353 log units and G=0.39 and:

Recurrence Interval (years)	**K value**	**SE^2 (log units squared)**	**Equivalent years of record**
1.25	-0.85500	0.01723	1.2
1.50			(3.7) Estimated
2	-0.06485	0.00825	6.6
5	0.81712	0.00826	11
10	1.31597	0.01099	12
25	1.87730	0.01420	14
50	2.25628	0.01893	14
100	2.60827	0.02431	13
200	2.93974	0.03150	12
500	3.35346	0.04188	11