IV. WATER RESOURCE AVAILABILITY

The source of almost all water in the Deer Creek Watershed is, ultimately, precipitation within the watershed boundaries. Only very small amounts of water are imported to the watershed for public supply in York County. Consequently, this analysis starts with an evaluation of precipitation, followed by an assessment of runoff and recharge to the aquifers underlying the watershed.

A. Precipitation

There are data available from four National Climatic Data Center (NCDC) stations in or near the Deer Creek Watershed: New Park in Pennsylvania, and Conowingo Dam, Maryland Line, and the Conowingo Dam Police Barracks in Maryland. The period of record and locations of each of these stations is shown on Figure 8. The longest periods of precipitation records are for the first two stations. The precipitation values for these stations vary little, with the average and median values for monthly precipitation varying by 2 percent to 4 percent for the period of record.

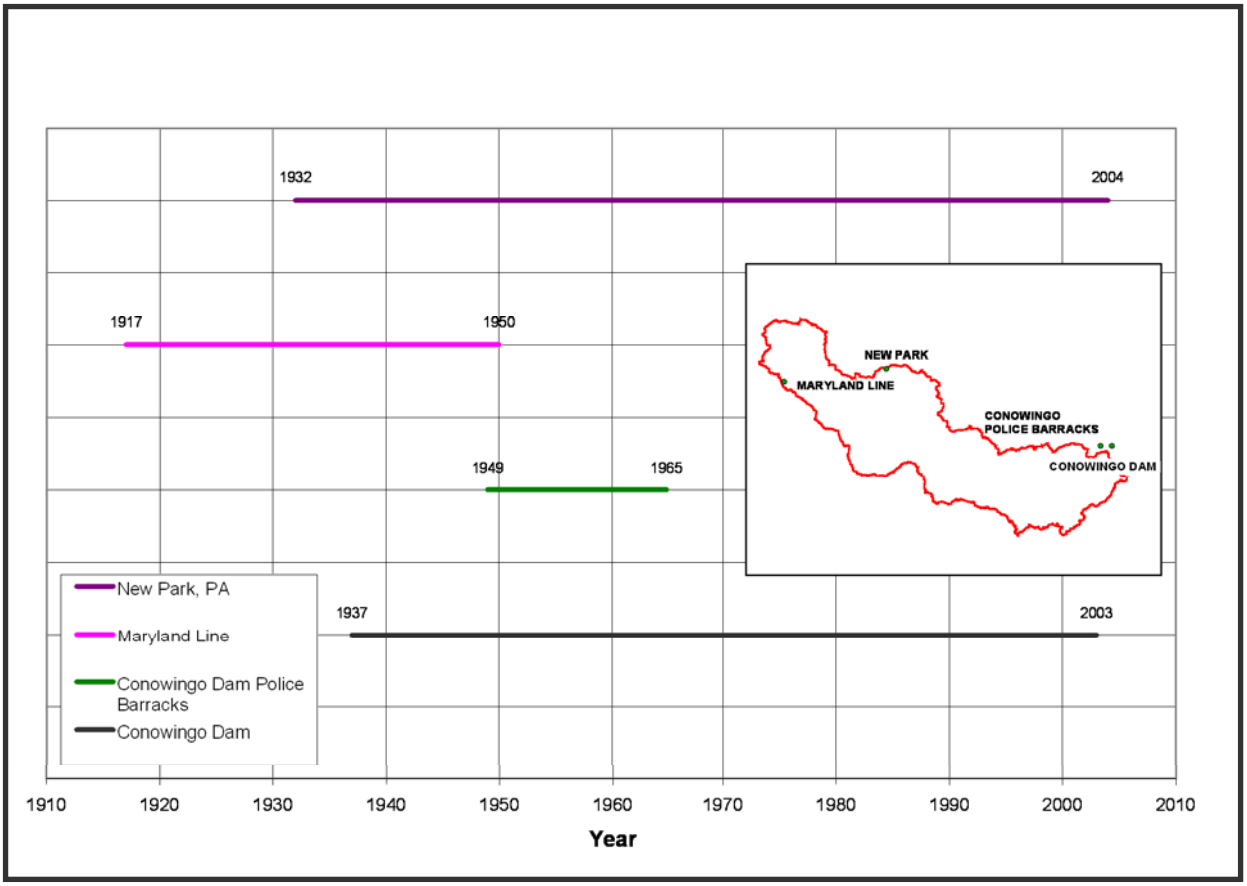

Figure 8. Precipitation Stations and Periods of Record

A record of annual precipitation for the Deer Creek Watershed was developed by averaging all available stations for each year in the period 1917 to 2004. In addition to considering the entire record, it is also useful to observe the most recent 30-year period of the record (1975-2004), which is defined as the climate normal. Analysis of the record shows that precipitation in most years (each year shown with an "x" on Figure 9) falls between 30 and 60 inches, with a few outliers. For the purpose of observing trends in precipitation, 5-year running averages were calculated over the record and are also displayed. The 5-year averages for the early record are shown with blue symbols, and those for the climate normal period are shown in pink.

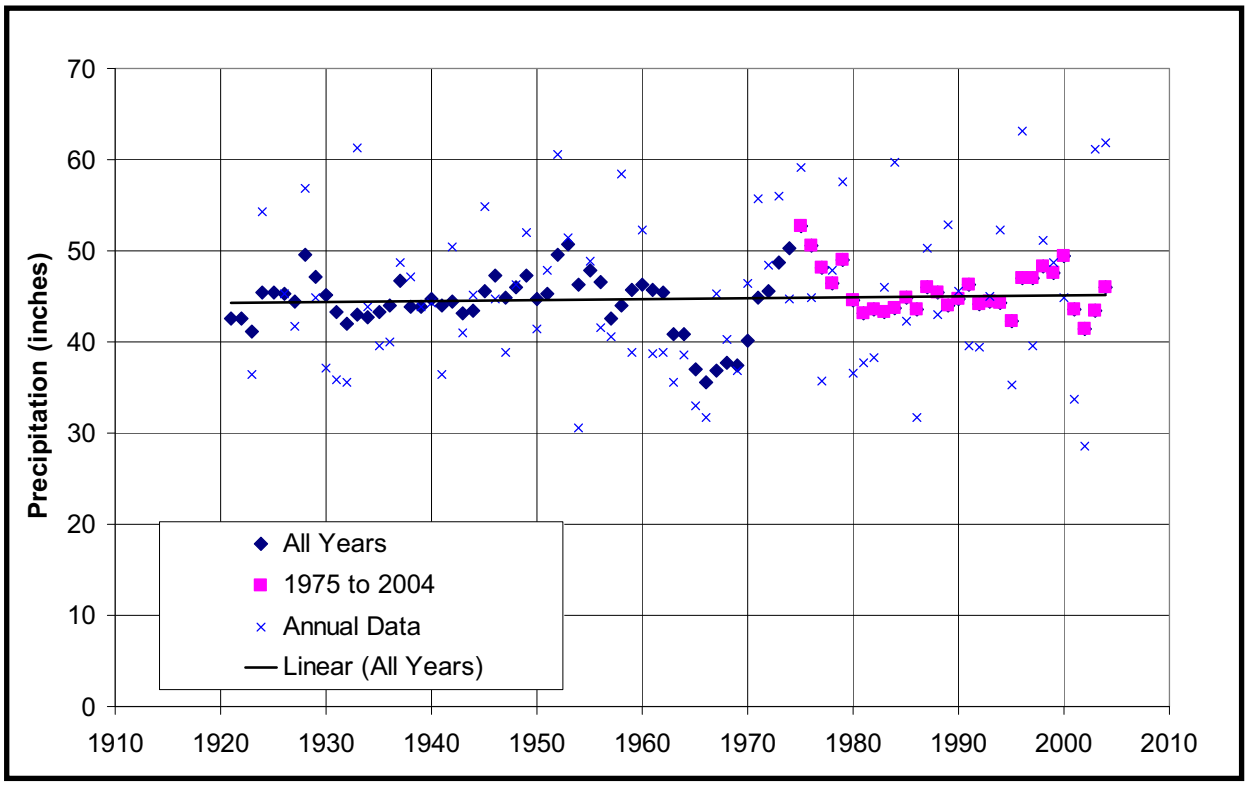

Figure 9. Long-Term Precipitation Record

Although the 1960s and 1970s stand out as relatively dry and wet periods, respectively, there does not appear to be a significant long-term increasing or decreasing trend in the annual precipitation data. However, the average precipitation for the climate normal period, at 45.78 inches, is about an inch greater than the long-term average over the entire record. This increase may result in greater water availability in the watershed.

The precipitation record can be used to develop an estimated record of total available water supply in the watershed. Assuming the annual precipitation values fall over the entire watershed area of 109,521 acres, an estimate for the quantity of water received by the watershed is developed. Based on this method, Table 4 shows statistics for precipitation and the available water supply (in cubic feet per second [cfs]) for the watershed, based upon both the 1917 to 2004 record, and the 30-year climate normal period. The average precipitation during the climate normal period contributes just over 577 cfs to the watershed on an annual average basis, while the long-term average precipitation contributes just under 566 cfs.

Table 4. Precipitation Statistics

	Period of Record (1917-2004)		**Climate Normal (1975-2004)**	
	(inches)	**(cfs)***	**(inches)**	**(cfs)***
Average	44.88	565.8	45.78	577.1
Median	44.76	564.3	44.93	566.4
25th Percentile	38.82	489.4	38.60	486.6
10th Percentile	35.67	449.7	35.07	442.2
5th Percentile	33.13	417.7	32.66	411.7
1st Percentile	30.18	380.5	29.53	372.3

* cfs based upon watershed area of 109,521 acres.

An analysis of return frequency of precipitation is useful for water resource planning. Figure 10 shows the recurrence interval plot for annual precipitation in the Deer Creek Watershed. As noted above, the average annual precipitation (recurrence interval of 2 years) is about 45 inches. The driest year on record (2002) had a total precipitation of about 28 inches, with an expected recurrence interval of approximately 80 years. Note, the recurrence interval chart on Figure 10, as with all such charts in this report, have been configured to illustrate the recurrence of *low flow* events, not floods. As a result, they are opposite in orientation to recurrence interval charts constructed for evaluating flood events.

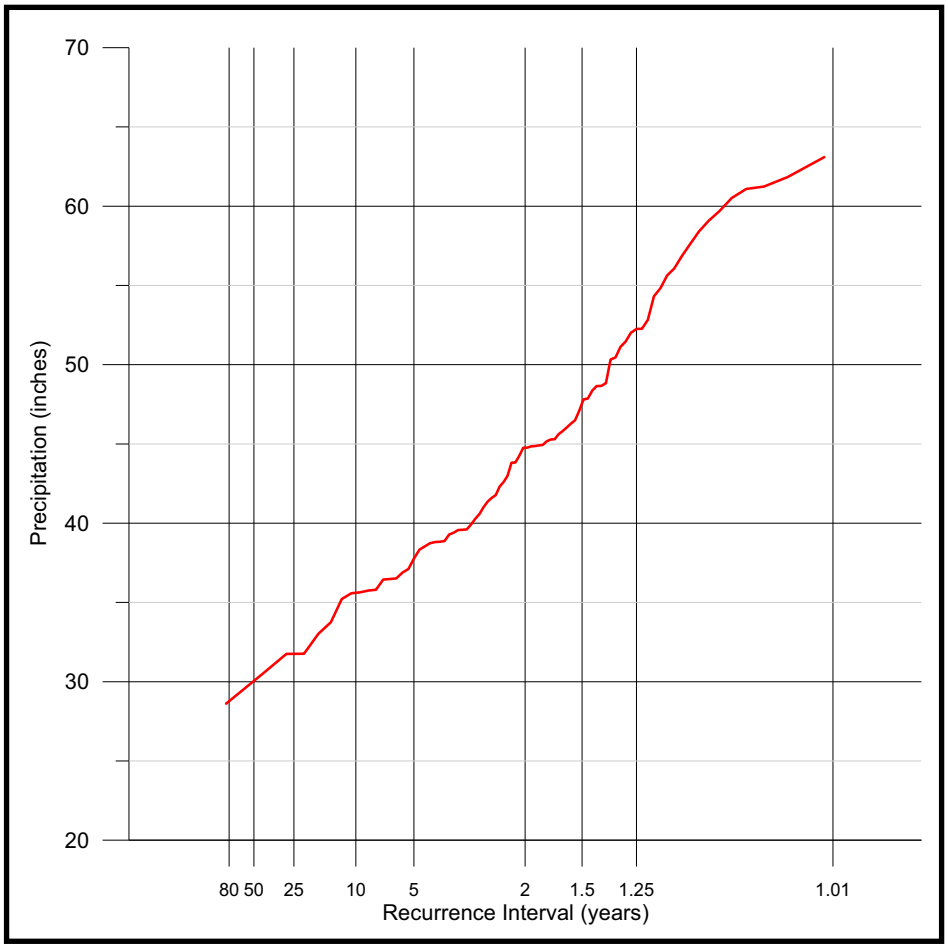

Figure 10. Recurrence Intervals for Annual Precipitation

B. Streamflow

The flow in Deer Creek has been monitored by three U.S. Geological Survey (USGS) gages over the past 100 years (Figure 1, Table 5). The longest record (79 years) is from the station on Deer Creek near Rocks, Maryland. Figure 11 is the flow duration curve for the period of record at Rocks based upon average daily flows. The flow duration curve is approximately log normal in form, with a relatively flat shape. The median flow value (50 percent exceedence) is 94 cfs, which is nearly coincident with the average value for the log-normal distribution (97 cfs). Approximately 67 percent (±1 standard deviation) of the daily flow values fall within the range of 50 cfs to 188 cfs. These statistics indicate that the watershed is groundwater-dominated, and that discharge from groundwater (base flow) is a large component of the total flow.

Table 5. U.S. Geological Survey Gaging Stations

Station Name	USGS ID Number	Upstream Area (square miles)	Period of Record
Deer Creek near Rocks, Md.	1580000	94.4	1927 to present
Deer Creek near Kalmia, Md.	1580200	125	1967 to 1977
Deer Creek near Darlington, Md.	1580520	168	2000 to present

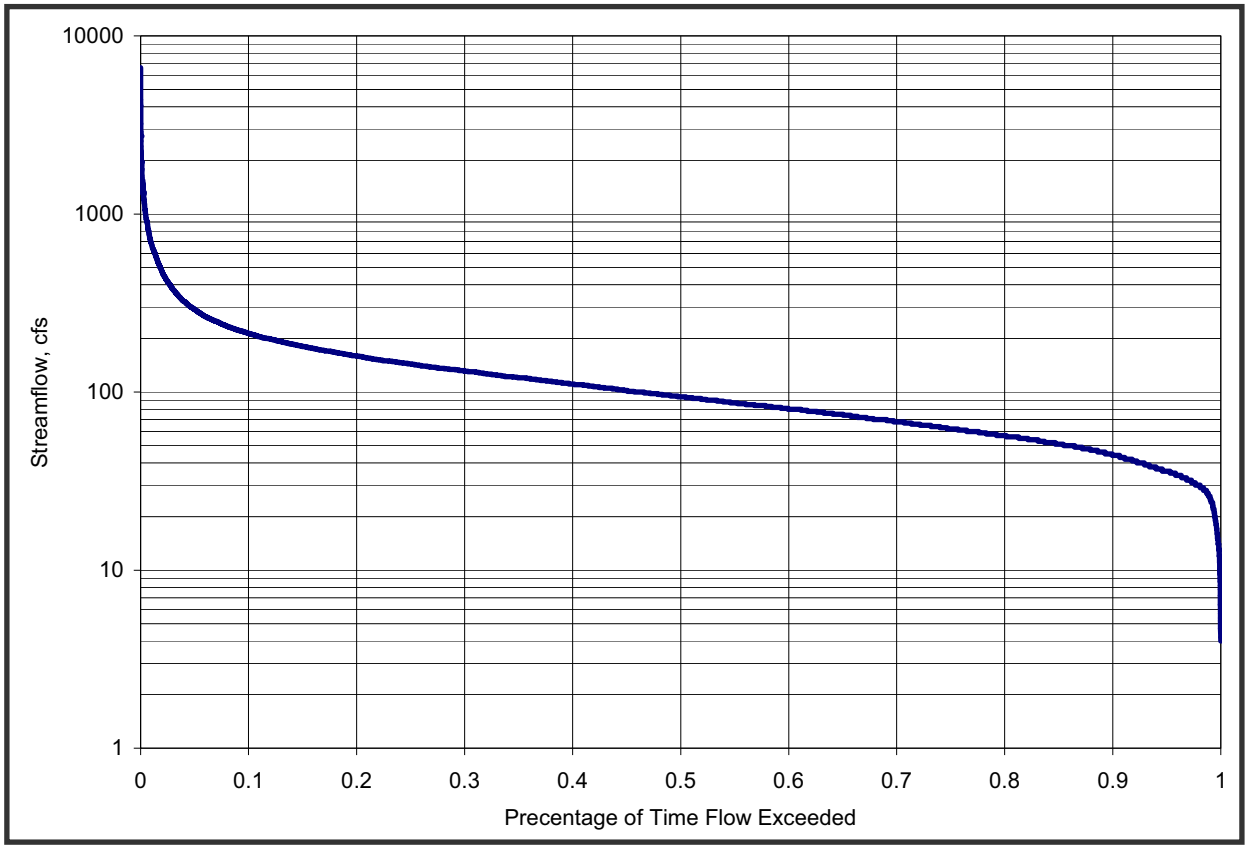

Figure 11. Flow Duration Curve for Rocks Gage

To verify the role groundwater plays in the surface hydrology of Deer Creek, base flow separations were performed for all three gages for their entire periods of record. Base flow separation is a technique used to determine the components of total flow in a stream that result from groundwater discharge (base flow) and from direct surface runoff. Figure 12 shows an example of the base flow separation for the Rocks gage for the 2002 calendar year, which is the driest year on record for this gage.

The U.S. Bureau of Reclamation's (USBR's) base flow index (BFI) program was used for the Deer Creek Watershed base flow analysis, as it has been proven to be useful for estimating long-term base flow trends on unregulated streams. The process computes an annual BFI, which gives the ratio of base flow to total flow volume at one or more gage sites. The use

of a 7-day averaging period was found to be most suitable for application of the BFI program to Deer Creek. The results of the base flow separations are presented in Table 6.

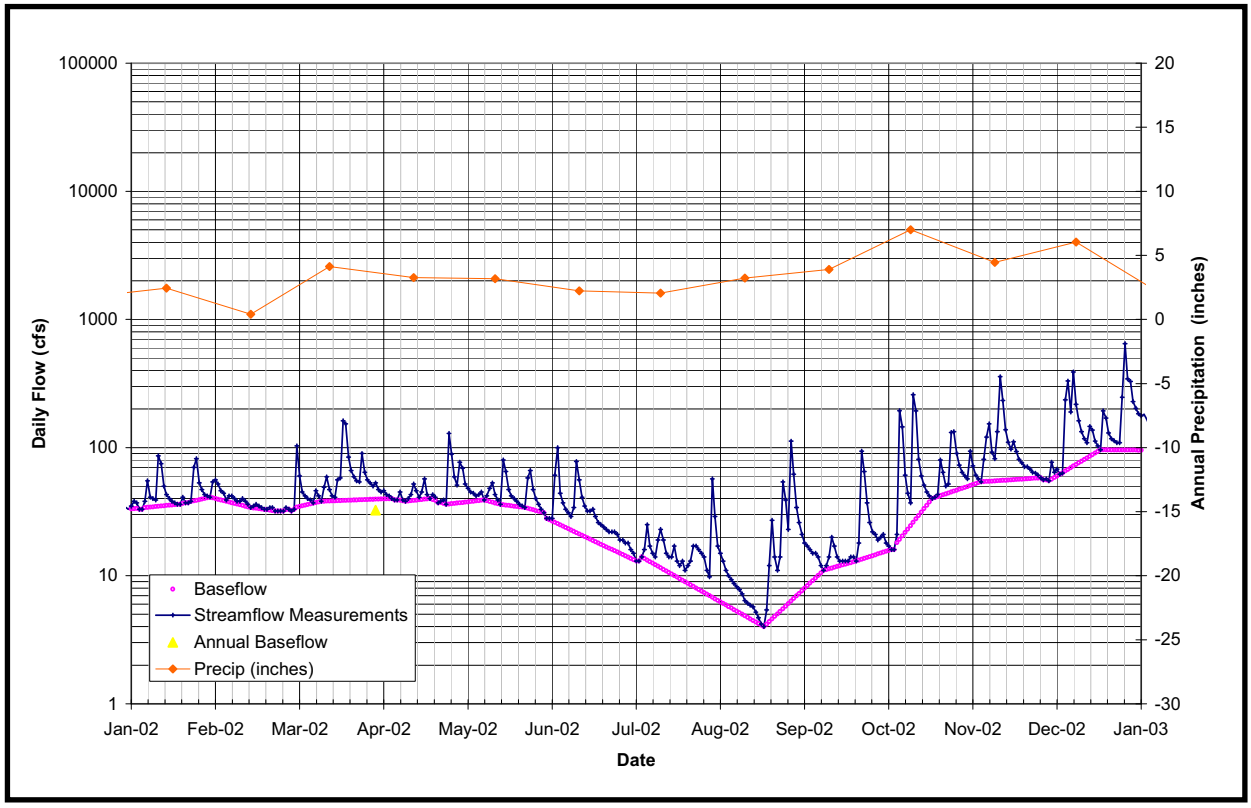

Figure 12. Base Flow Separation for 2002 at Rocks Gage

Table 6. Calculated Flow Parameters for U.S. Geological Survey Stations

Station Name	Average Flow* (cfs)	Average Base Flow* (cfs)	Average Percentage of Base Flow to Total Flow* (cfs)	Average Percentage of Base Flow to Total Flow (30-year normal)
Deer Creek near Rocks, Md.	125.7	83.4	66.9%	67.8%
Deer Creek near Kalmia, Md.	198.1	130.7	66.6%	---
Deer Creek near Darlington, Md.	225.2	150.1	67.8%	---

* Results for Kalmia and Darlington locations from limited data (10 years or less).

Averaged over the period of record, base flow represents 67 percent of the total flow at Rocks. The year with the highest proportion of base flow to total flow was 2002 (90 percent) when record low flows and precipitation deficits occurred. The ratios for Kalmia and Darlington are similar at 66 percent and 67 percent, respectively. Because of the similarity in BFIs at the different locations on Deer Creek, it can reasonably be concluded that the proportion of

precipitation contributing to groundwater recharge is fairly uniform throughout the watershed when averaged at this scale.

In addition to comparing base flow at locations throughout the watershed, it is also useful to consider long-term trends at a given location, particularly a site with a relatively long period of record. An analysis of the Rocks gage shows that, on average, the BFI has been increasing over the period of record (Figure 13). This trend may reflect the impact of increased infiltration and decreased runoff due to factors such as increasing forestation in the twentieth century.

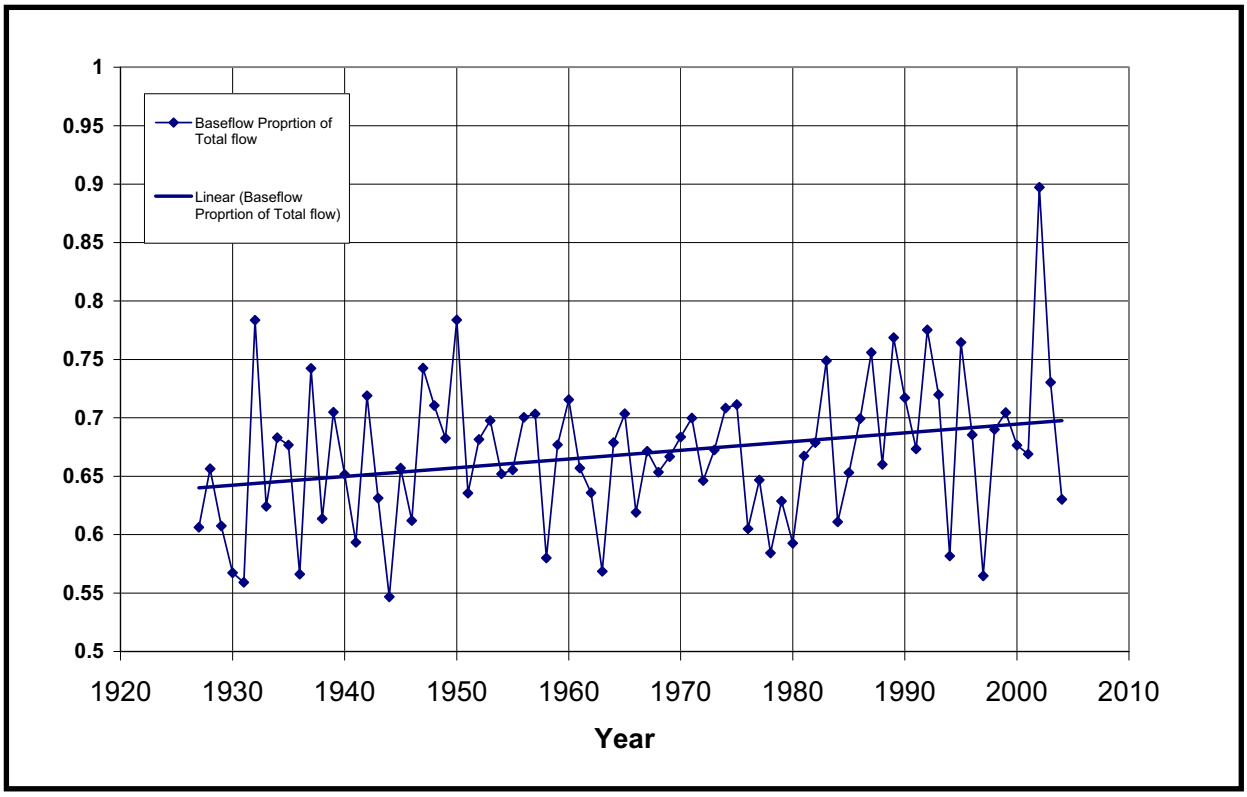

Figure 13. Ratio of Annual Base Flow to Total Flow

In terms of variations in basin hydrology from the headwaters to the outlet, a key measure is the ratio of flow at a location to its upstream drainage area. The area upstream of the USGS gage near Kalmia was 125 square miles, or 1.32 times the area of the drainage upstream of the Rocks gage (94.4 square miles). As depicted on Figure 14, the ratio of total flows and base flows between the two gaging stations is, within error, identical to the drainage area ratio of 1.32.

Comparing the Darlington and Rocks gages, the ratio of drainage areas is 1.78, whereas the ratio of base flows is 1.69, ±0.06. Because the Darlington gage is located much farther downstream than Rocks and receives base flow from a larger and potentially more varied drainage area than either the Rocks or Kalmia gage, the difference between the ratios may be attributable to variations in recharge in the lower Deer Creek Watershed (see section on local variations in streamflow below). The downstream location of the Darlington gage may also explain differences in the ratio of total flow to the Rocks gage. Because the creek at Darlington

drains nearly twice the area drained at Rocks, it is more likely to capture isolated thundershowers that fall elsewhere in the watershed. That phenomenon may have been particularly important in 2002, the year of lowest recorded rainfall. Any isolated rain falling in the drainage between Rocks and Darlington would have had a much more pronounced effect on total flow for the year. However, in general, these ratios demonstrate that contribution of base flow per unit of drainage area is fairly uniform along the main stem of Deer Creek.

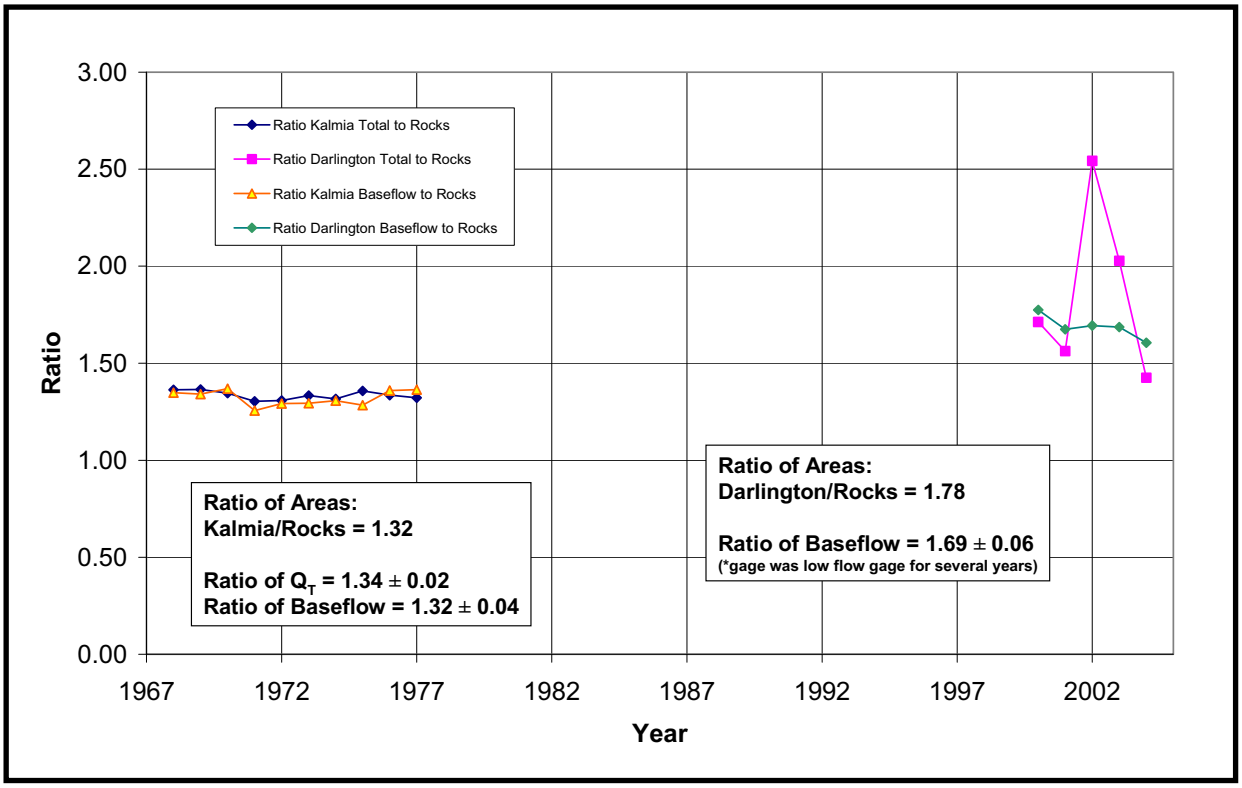

Figure 14. Ratio of Total Flow to Base Flow at Rocks Gage

Because a primary concern of this study is the availability of water during periods of low flow, the low flow periods were also examined from gaging records. Using the 79-year record at the Rocks gage, an assessment was made of the 5 percent and 10 percent lowest daily flow values. The average monthly flows were then considered for the same period and compared to the low flow values. As can be seen from Figure 15, the months that most frequently averaged less than the 5 percent and 10 percent lowest daily flows are July through November. Of those months, September most frequently averaged below the thresholds, for a total of 11 and 22 years out of the 79 on record. In contrast, flows in March never, over the 79 years, averaged less than the 5 percent and 10 percent lowest total flows. This seasonal variation in flow is attributed primarily to the influence of evapotranspiration and temperature, which is strongest during the summer and early fall months. As noted above, the seasonality of precipitation is insignificant for the Deer Creek Watershed.

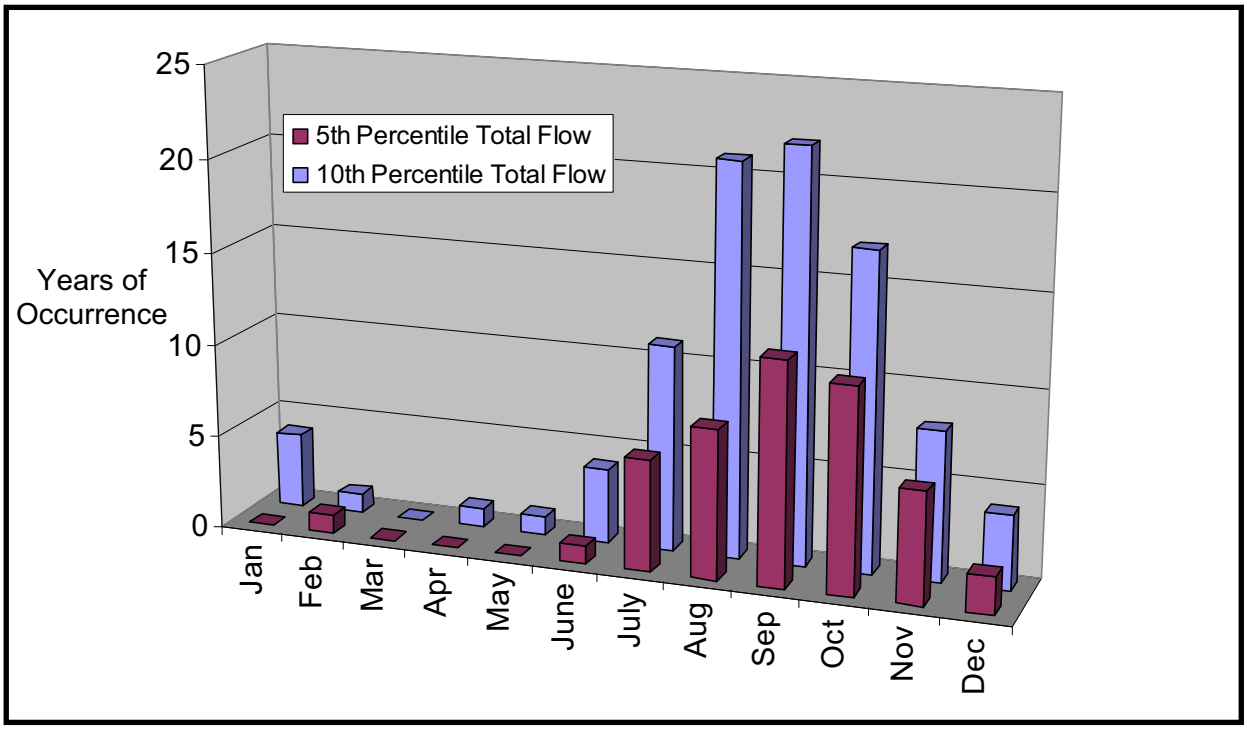

Figure 15. Frequency in Years that Average Monthly Flow Occurs Within 5th or 10th Percentile of Flow at Rocks Gage

Existing gage data has shown that recharge and discharge are fairly uniform across the watershed on the main stem of Deer Creek on a large-scale average basis. However, the same is likely not true on a smaller scale, and local variations may be responsible for the difference in the ratios between base flow and drainage at Darlington and Rocks, as noted above. To evaluate local variations in recharge/discharge across the watershed, a field program was initiated in the spring of 2006. The Deer Creek Watershed was subdivided into subwatersheds, and these were evaluated in terms of the geology and hydrogeologic units (Table 7, Figure 16).

Table 7. Subwatershed Areas

	Name	Area (m^2)	Area (mi^2)
1	Cool Branch Run	6,408,565	2.47
2	Stout Bottle Branch - Cabbage Run	18,773,175	7.25
3	Thomas Run	21,060,427	8.13
4	Mill Brook	12,102,327	4.67
5	Hollands Branch	8,742,998	3.38
6	UNT at Thomas Bridge Rd	11,297,080	4.36
7	Saint Omer Branch	29,140,343	11.25
8	Deer Creek - Mid	13,709,287	5.29
9	South Stirrup - North Stirrup Run	16,964,124	6.55
10	Rock Hollow - Kellogg - Gladden Branches	32,376,604	12.50

Table 7. Subwatershed Areas (continued)

	Name	Area (m^2)	Area (mi^2)
11	UNT south of Falling Branch	1,622,061	0.63
12	UNT west of Falling Branch	982,215	0.38
13	Little Deer Creek	37,185,714	14.36
14	Falling Branch	16,750,609	6.47
15	Big Branch	20,703,352	7.99
16	Island - Jackson - Plumtree Branches	75,124,140	29.01
17	Ebaugh's Creek	17,889,318	6.91
18	Deer Creek Headwaters	44,894,766	17.33
19	Graveyard Creek	4,183,434	1.62
20	Hopkins Branch	5,912,009	2.28
21	Tobacco Run	20,695,099	7.99
22	Buck Branch - Elbow Branch	26,562,599	10.26
23	UNT east of Hollands Branch	140,029	0.05

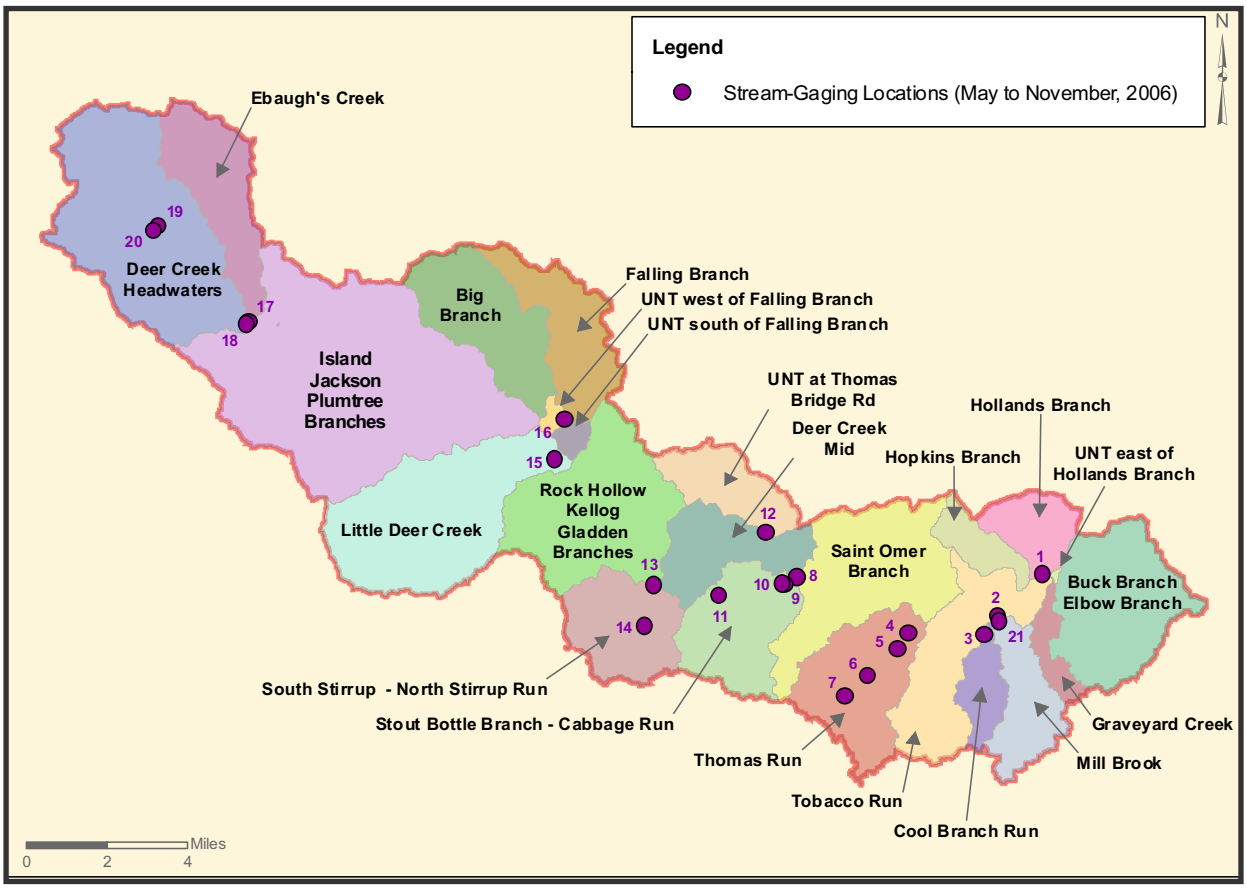

Figure 16. Subwatersheds

Twenty-three locations in the main stem of Deer Creek and its tributaries were selected for stream gaging (Table 8, Figure 16). These locations were selected so as to sample upstream basin areas underlain by a variety of geological and hydrogeologic units. Between May and November 2006, each subwatershed was gaged at least three times in one or more locations. The goal of this gaging exercise was to measure base flow. The field days were selected accordingly following several days without precipitation so as to minimize the amount of surface runoff present in the streams.

A combination of a Swoffer 2100 velocity meter with a digital readout and manual counting with Pygmy meters was used during the gaging. Gaging protocols were similar, however, and based upon USGS standard protocols (Buchanan and Somers, 1969). When implemented correctly, this procedure yields flow measurements accurate to within 5 percent.

Within the Deer Creek Watershed, there are several wastewater treatment plants that discharge directly to Deer Creek tributaries. These include a Stewartstown facility which discharges into Ebaugh's Creek. With a discharge limit of 0.4 million gallons per day (mgd), the outflow from this plant can potentially increase the flow in Ebaugh's Creek up to about 0.6 cfs. During the field studies, Ebaugh's Creek was gaged three times, with values ranging from 6.9 to 8.2 cfs.

As can be seen in Table 9, the gaging data were collected over a period of 6 months, under varying base flow conditions. All measurements were collected at least 3 or 4 days after the last rainfall event. Corresponding flows at the Rocks gage, for the same dates the gaging data were collected, varied between 79 cfs and 130 cfs. To remove the impact of varying base flow conditions during the different dates flow measurements were taken, all flow measurements were normalized to an arbitrary value – the median flow at the Rocks gaging station, or 94 cfs. The normalized stream gaging results and the corresponding drainage area upstream of the gaging location are presented on Figure 17. The normalized flows for each gaging location were averaged for each subwatershed and then divided by the drainage area of the subwatershed to yield the subwatershed average normalized flow per recharge area. The results are plotted for each of the gaged subwatersheds on Figure 18. The results indicate that recharge to the groundwater varies throughout the watershed between 0.67 cfs/mi^2 and 1.05 cfs/mi^2. In general, there is a geographic variation with lower values being associated with watersheds developed on the Baltimore Gabbro and Port Deposit Gneiss (lower Deer Creek Watershed) and higher values associated with the other bedrock units. On average, the recharge per unit area in the upper portion of the watershed is 1.02 cfs/mi^2. The average recharge in the lower portion of the basin is 0.76 cfs/mi^2.

Table 8. Subwatershed Stream Gage Characteristics

Name	Sub-watershed	Location Comment	Lat. (dd)	Long. (dd)	Total Sub-watershed Drainage Area (mi^2)	Area Upstream of Gaging Location (mi^2)	Geology	Hydro Unit	# of Site Visits	First Site Visit	Last Site Visit
Holland Branch	Holland Branch	n/a	39.62253	-76.21986	3.35	3.34	Gabbro and Qtz Diorite Gneiss and Baltimore Gabbro	Unit 4 and Unit 3	3	5/4/06	7/28/06
Mill Brook near Harmony Church Rd	Mill Brook	about 100 ft downstream of Harmony Church Rd	39.60708	-76.24036	4.67	4.64	Port Deposit Gneiss and Wissahickon Undiff and James Run Fm	Unit 4	3	3/30/06	11/29/06
Cool Branch Run	Cool Branch Run	about 800 feet upstream from Harmony Church Rd	39.60039	-76.24625	2.47	2.37	Port Deposit Gneiss and Wissahickon Undiff	Unit 4	3	4/21/06	6/2/06
Thomas Run - #1	Thomas Run	about 1/2 mile downstream (NE of Thomas Run Rd)	39.60053	-76.28166	8.13	7.66	Baltimore Gabbro and Port Deposit Gneiss	Unit 4	2	3/30/06	5/3/06
Thomas Run - #2	Thomas Run	downstream of Thomas Run Rd; just upstream of 90° bend, pasture location	39.59472	-76.28647	6.87	6.96	Baltimore Gabbro and Port Deposit Gneiss	Unit 4	3	5/4/06	6/2/06
Thomas Run (5), UNT 5B	Thomas Run	just upstream from 1st big tree fall	39.58492	-76.30025	0.86	0.84	Baltimore Gabbro and Port Deposit Gneiss	Unit 4	2	5/4/06	5/25/06
Thomas Run (5), UNT 5C	Thomas Run	about 50 ft downstream from bridge	39.57758	-76.31056	1.72	1.48	Baltimore Gabbro and Port Deposit Gneiss	Unit 4	2	5/4/06	5/18/06
Stout Bottle Run at Walters Mill Bridge	Stout Bottle Run	about 200 ft upstream from Walters Mill Bridge	39.61994	-76.33367	7.24	7.25	Boulder Gneiss and Lower Pelitic Schist	Unit 4 and 5	3	3/30/06	5/4/06
Stout Bottle Run above confluence with UNT	Stout Bottle Run	about 100 ft from Deer Creek Church Rd	39.61744	-76.33936	4.86	4.88	Boulder Gneiss member of Wissahickon	Unit 4	3	4/21/06	11/29/06
UNT to Stout Bottle Run, above confluence	Stout Bottle Run	about 200 ft upstream from confluence	39.61761	-76.34050	2.18	2.16	Boulder Gneiss and Lower Pelitic Schist	Unit 5 and 4	3	4/21/06	11/29/06
UNT to Stout Bottle Run at Pyle Bridge Rd	Stout Bottle Run	same UNT sampled above confluence with Stout Bottle Run	39.61289	-76.36994	1.09	0.84	Lower Pelitic Schist	Unit 5	3	5/4/06	6/2/06

Table 8. Subwatershed Stream Gage Characteristics (continued)

Name	Sub-watershed	Location Comment	Lat (dd)	Long (dd)	Total Sub-watershed Drainage Area (mi^2)	Area Upstream of Gaging Location (mi^2)	Geology	Hydro Unit	# of Site Visits	First Site Visit	Last Site Visit
UNT to Deer Creek at Thomas Bridge Rd	Upper Deer Creek	about 1/4 mile SE of Thomas Bridge Rd	39.63592	-76.34831	4.36	4.31	Boulder Gneiss member of Wissahickon	Unit 4 and 5	2	4/21/06	6/2/06
Stirrup Run	Stirrup Run	Just E of bridge on Rte 24	39.61653	-76.40019	6.55	6.54	Lower Pelitic Schist and ultramafic rocks	Unit 5	3	3/30/06	5/4/06
South Stirrup Run	Stirrup Run	downstream of Sharon Rd bridge	39.60172	-76.40417	2.65	1.63	Lower Pelitic Schist	Unit 5	2	5/4/06	5/18/06
Little Deer Creek #1	Little Deer Creek	about 500 ft S of bridge on Rte 156	39.66106	-76.44714	14.35	14.19	Lower Pelitic Schist and Wissahickon Undiff	Unit 5 and 4	3	3/31/06	5/3/06
Falling Branch #1	Falling Branch	just upstream from bridge off Red Bridge Rd	39.67553	-76.44272	6.46	6.47	Octoraro Fm / Wissahickon	Unit 4	3	3/30/06	5/4/06
Ebaugh's Creek #1	Ebaugh's Creek	at S. side of bridge on Harris Mill Rd	39.70853	-76.59028	6.90	6.93	Octoraro Fm / Wissahickon	Unit 4	3	3/31/06	5/3/06
Deer Creek upstr of Ebaugh's Creek	Upper Deer Creek	off of Bond Rd, ~ 200 ft upstream of confluence with Ebaugh's Creek	39.70764	-76.59153	17.33	17.29	Octoraro Fm / Wissahickon	Unit 4	3	3/31/06	5/3/06
Deer Creek at Gemmill Rd	Upper Deer Creek	about 100 ft downstream of bridge	39.74224	-76.63331	5.77	5.63	Octoraro Fm / Wissahickon	Unit 4	3	5/3/06	11/29/06
UNT to Deer Creek on Gemmill Rd	Upper Deer Creek	n/a	39.74092	-76.63567	3.65	3.99	Octoraro Fm / Wissahickon	Unit 4	3	5/3/06	11/29/06
Mill Brook near Harmony Church Rd – 2nd location	Mill Brook	alternate location	39.60519	-76.23964	4.67	4.52	Port Deposit Gneiss and Wissahickon Undiff and James Run Fm	Unit 4	1	5/4/06	5/4/06
Hopkins Branch, near Trappe Church Rd	Hopkins Branch	Off of Nobles Mill Rd, about 50 ft upstream of Driveway bridge	39.61767	-76.23094	2.28	2.28	Baltimore Gabbro and Quartz Diorite Gneiss	Unit 4	3	11/29/06	12/1/06

Table 9. Subwatershed Stream Gaging Results

Name	Sub-watershed	Date	Measured Flow (cfs)	Area Upstream of Gaging Location (mi^2)	Flow at Rocks Gage (cfs)	Flow Normalized to Median Flow at Rocks Gage (cfs)	Normalized Flow Per Recharge Area (cfs/mi^2)	Subwatershed Average Normalized Flow per Recharge Area (cfs/mi^2)
Hollands Branch 1	Hollands Branch	5/4/06	2.38	3.343582	116	1.929	0.577	0.75
Hollands Branch 1		5/18/06	3.13	3.343582	104	2.829	0.846	
Hollands Branch 1		7/28/06	2.77	3.343582	93	2.800	0.837	
Mill Brook 2	Mill Brook	3/30/06	4.76	4.642738	96	4.661	1.004	0.86
Mill Brook 2		5/3/06	3.46	4.642738	120	2.710	0.584	
Mill Brook 2		11/29/06	7.26	4.642738	130	5.250	1.131	
Mill Brook 3 (Alternate Location)		5/4/06	3.99	4.522714	116	3.233	0.715	
Cool Branch	Cool Branch Run	4/21/06	2.3	2.369016	85	2.544	1.074	0.77
Cool Branch		5/3/06	1.89	2.369016	120	1.481	0.625	
Cool Branch		6/2/06	1.66	2.369016	108	1.445	0.610	
Thomas Run 1	Thomas Run	3/30/06	6.41	7.657706	96	6.276	0.820	0.67
Thomas Run 1		5/3/06	5.14	7.657706	120	4.026	0.526	
Thomas Run 2		5/4/06	4.76	6.956385	116	3.857	0.554	
Thomas Run 2		5/25/06	3.98	6.956385	85	4.401	0.633	
Thomas Run 2		6/2/06	3.68	6.956385	79	4.379	0.629	
Thomas Run 5B UNT		5/4/06	0.58	0.840787	119	0.458	0.545	
Thomas Run 5B UNT		5/25/06	0.52	0.840787	85	0.575	0.684	
Thomas Run 5C UNT		5/4/06	1.16	1.481029	116	0.940	0.635	
Thomas Run 5C UNT		5/18/06	1.69	1.481029	104	1.528	1.031	
Stout Bottle Creek 1 - at mouth	Stout Bottle Branch - Cabbage Run	3/30/06	9.44	7.252223	96	9.243	1.275	1.04
Stout Bottle Creek 1 - at mouth		4/21/06	7.47	7.252223	85	8.261	1.139	
Stout Bottle Creek 1 - at mouth		5/4/06	6.91	7.252223	116	5.599	0.772	
Stout Bottle Run 2		4/21/06	5.03	4.87653	85	5.563	1.141	
Stout Bottle Run 2		5/3/06	4.79	4.87653	120	3.752	0.769	
Stout Bottle Run 2		11/29/06	8.68	4.87653	126	6.476	1.328	
UNT above Stout Bottle Run		4/21/06	2.27	2.15849	85	2.510	1.163	
UNT above Stout Bottle Run		5/3/06	2.44	2.15849	120	1.911	0.885	
UNT above Stout Bottle Run		11/29/06	3.93	2.15849	126	2.932	1.358	
UNT to Stout Bottle Run at Pyle Road Bridge		5/4/06	0.75	0.836988	116	0.608	0.726	
UNT to Stout Bottle Run at Pyle Road Bridge		5/18/06	0.84	0.836988	104	0.759	0.907	
UNT to Stout Bottle Run at Pyle Road Bridge		6/2/06	0.77	0.836988	83	0.872	1.042	

Table 9. Subwatershed Stream Gaging Results (continued)

Name	Sub-watershed	Date	Measured Flow (cfs)	Area Upstream of Gaging Location (mi^2)	Flow at Rocks Gage (cfs)	Flow Normalized to Median Flow at Rocks Gage (cfs)	Normalized Flow Per Recharge Area (cfs/ mi^2)	Subwatershed Average Normalized Flow per Recharge Area (cfs/ mi^2)
UNT at Thomas Bridge Rd	UNT at Thomas Bridge Rd	4/21/06	4.36	4.311394	85	4.822	1.118	1.01
UNT at Thomas Bridge Rd		6/2/06	3.35	4.311394	81	3.888	0.902	
Stirrup Run 1	South Stirrup - North Stirrup Run	3/30/06	7.7	6.538213	96	7.540	1.153	1.04
Stirrup Run 1		4/21/06	6.62	6.538213	85	7.321	1.120	
Stirrup Run 1		5/4/06	6.56	6.538213	116	5.316	0.813	
South Stirrup Run		5/4/06	1.84	1.633827	116	1.491	0.913	
South Stirrup Run		5/18/06	2.24	1.633827	108	1.950	1.193	
Little Deer Creek 1	Little Deer Creek	3/31/06	13.44	14.188769	96	13.160	0.927	0.92
Little Deer Creek 1		4/21/06	12.94	14.188769	85	14.310	1.009	
Little Deer Creek 1		5/3/06	14.89	14.188769	119	11.762	0.829	
Falling Branch 1	Falling Branch	3/30/06	7.4	6.469462	96	7.246	1.120	1.03
Falling Branch 1		4/21/06	5.89	6.469462	85	6.514	1.007	
Falling Branch 1		5/4/06	7.62	6.469462	116	6.175	0.954	
Ebaugh's Creek 1	Ebaugh's Creek	3/31/06	8.24	6.929445	96	8.068	1.164	1.03
Ebaugh's Creek 1		4/21/06	6.93	6.929445	85	7.664	1.106	
Ebaugh's Creek 1		5/3/06	7.27	6.929445	119	5.743	0.829	
Deer Creek 1	Upper Deer Creek	3/31/06	20.79	17.29136	96	20.357	1.177	1.05
Deer Creek 2		4/21/06	18.88	17.29136	85	20.879	1.207	
Deer Creek 3		5/3/06	20.65	17.29136	119	16.312	0.943	
Deer Creek at Gemmill Rd		5/3/06	6.54	5.625919	121	5.081	0.903	
Deer Creek at Gemmill Rd		5/25/06	6	5.625919	83	6.795	1.208	
Deer Creek at Gemmill Rd		11/29/06	12.59	5.625919	130	9.104	1.618	
UNT to Deer Creek - Gemmill Rd		5/3/06	4.02	3.987076	121	3.123	0.783	
UNT to Deer Creek - Gemmill Rd		5/25/06	2.81	3.987076	85	3.108	0.779	
UNT to Deer Creek - Gemmill Rd		11/29/06	4.81	3.987076	130	3.478	0.872	
Hopkins Branch	Hopkins Branch	11/29/06	2.85	2.282639755	130	2.061	0.903	0.80
Hopkins Branch		11/30/06	2.37	2.282639755	126	1.768	0.775	
Hopkins Branch		12/1/06	2.22	2.282639755	126	1.656	0.726	

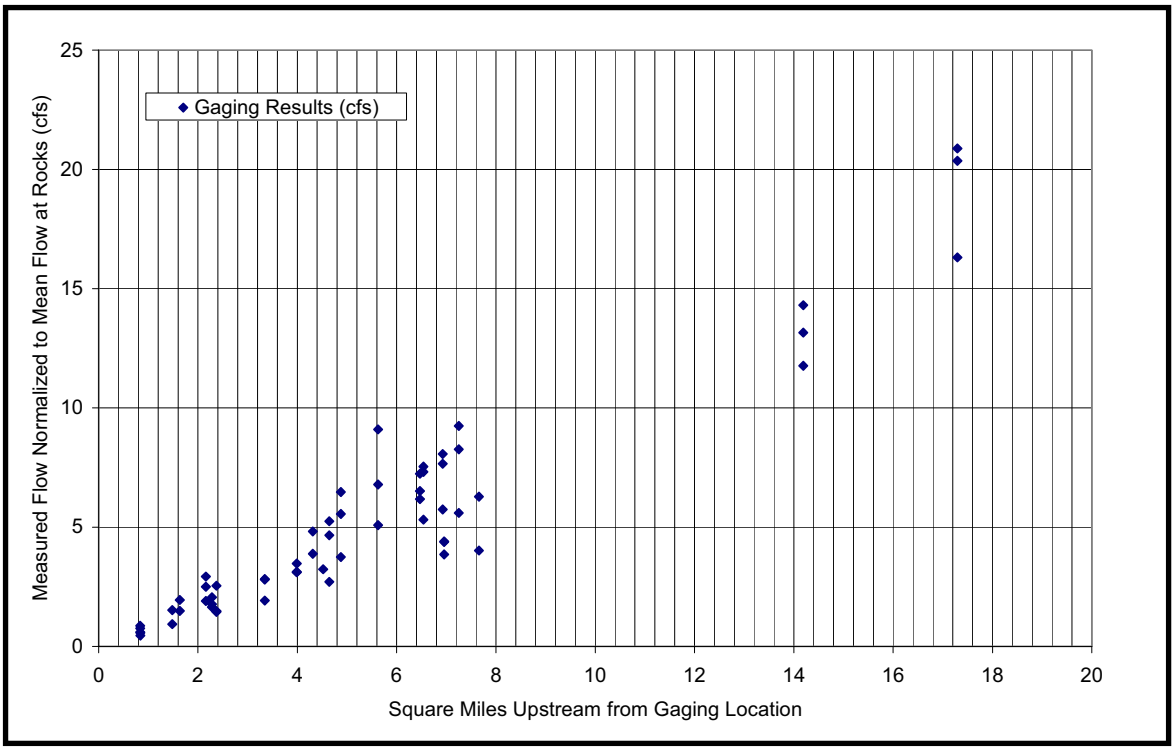

Figure 17. Subwatershed Stream Gaging Results

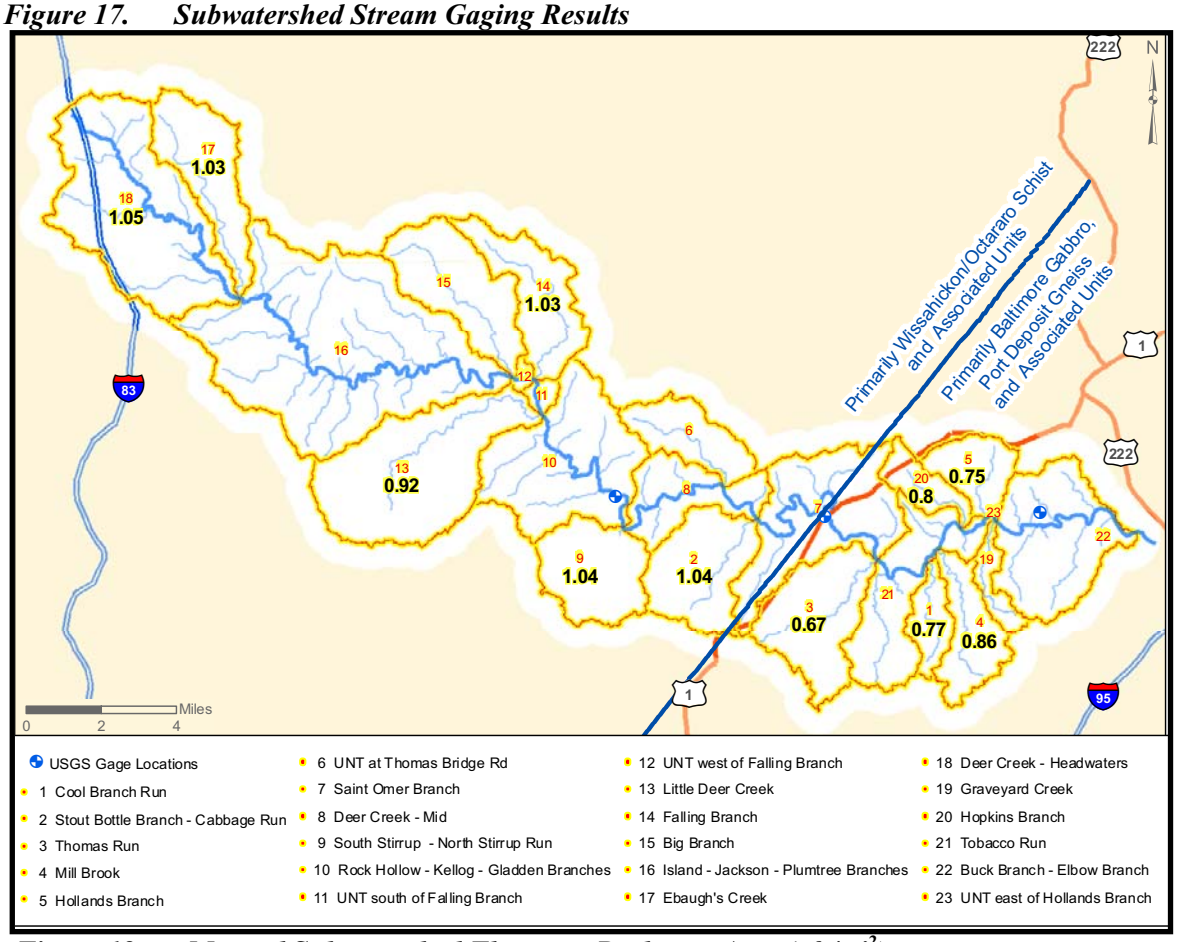

Figure 18. Mapped Subwatershed Flows per Recharge Area (cfs/mi^2)

C. Extrapolating Results of Field Data to Entire Watershed

The only long-term record for the Deer Creek Watershed is that from the gage at Rocks. To extrapolate this data to the entire watershed requires either: (1) the assumption of homogeneity; or (2) data on actual geographic variations in hydraulic behavior. The field data collected in 2006 provide a basis for extrapolation based upon actual observations.

As noted earlier, the ratio of base flows between the Rocks gage, and the limited record from the Darlington gage (1.69, ±0.6) is somewhat lower than the actual ratio of watershed areas between these gages (1.78). This cannot be explained assuming a homogeneous basin. Using the field data, normalized to median base flow conditions, however, a weighted average of recharge per surface area upstream of Darlington can be calculated:

Area of Upper Watershed	126.7 mi^2
Area of Lower Watershed (above Darlington Gage)	41.4 mi^2
Area of Watershed above Rocks Gage	94.4 mi^2
Average Recharge in Upper Watershed	1.02 cfs/mi^2
Average Recharge in Lower Watershed	0.76 cfs/mi^2

Total Recharge above Darlington Gage:

$$(126.65 * 1.02) + (41.35 * 0.77) = 161.02 \text{ cfs}$$

Ratio of Recharge at Darlington to Median Recharge at Rocks, Maryland:

$$\left(\frac{161.02}{94.4 * 1.02}\right) = 1.67$$

This ratio is consistent with the recent stream gaging data, as well as the limited data from the Darlington gage. It can provide a basis for extrapolating probability values for base flow at Rocks to Darlington. Figures 19 and 20 show recurrence intervals for the total flow at Rocks and a similar chart extrapolated for the Darlington gage location, based upon the ratio of upstream watershed areas.

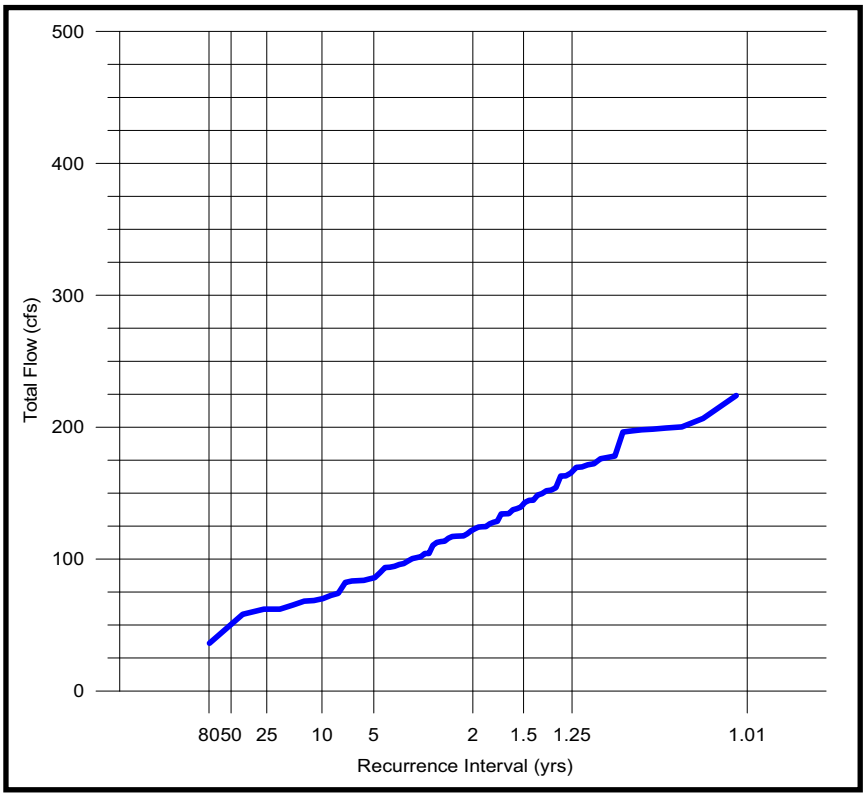

Figure 19. Total Flow at Rocks Gage

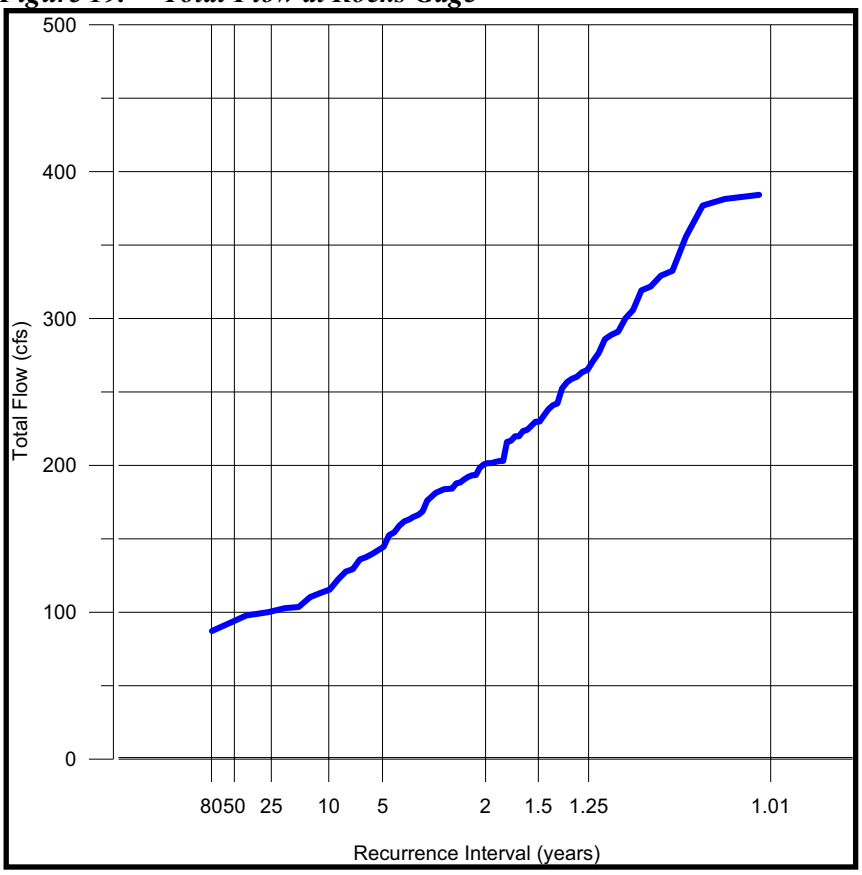

Figure 20. Total Flow at Darlington Gage

A commonly used measure of low flow – the 7Q10, is depicted in Table 10 and on Figure 21. The 7Q10 value is defined as the 7-day, consecutive low flow with a 10-year return frequency, or the lowest streamflow for 7 consecutive days that would be expected to occur once in 10 years. The 7Q10 curves for Rocks and Darlington are both based upon the Rocks data, but extrapolated as explained above. The value calculated here (26.9 cfs) for the 7Q10 at Rocks is similar to that calculated by the Maryland Department of the Environment (MDE) for permitting purposes (25.7 cfs). The 7Q10 data was calculated using both water years and calendar years. The results differ by about 8 percent. For the sake of being conservative, as well as being consistent with other calculations discussed above, it was decided to use the higher value, or that calculated based upon the calendar year.

Table 10. 7Q10 Values for Rocks and Darlington Gages

Location	7Q10 (cfs) (from Water Year)	7Q10 (cfs) (from Calendar Year)
USGS Gage at Rocks, Md.	24.8	26.9
USGS Gage at Darlington, Md.*	41.5	44.9

* Values generated by extrapolating from Rocks gage data based on drainage area.

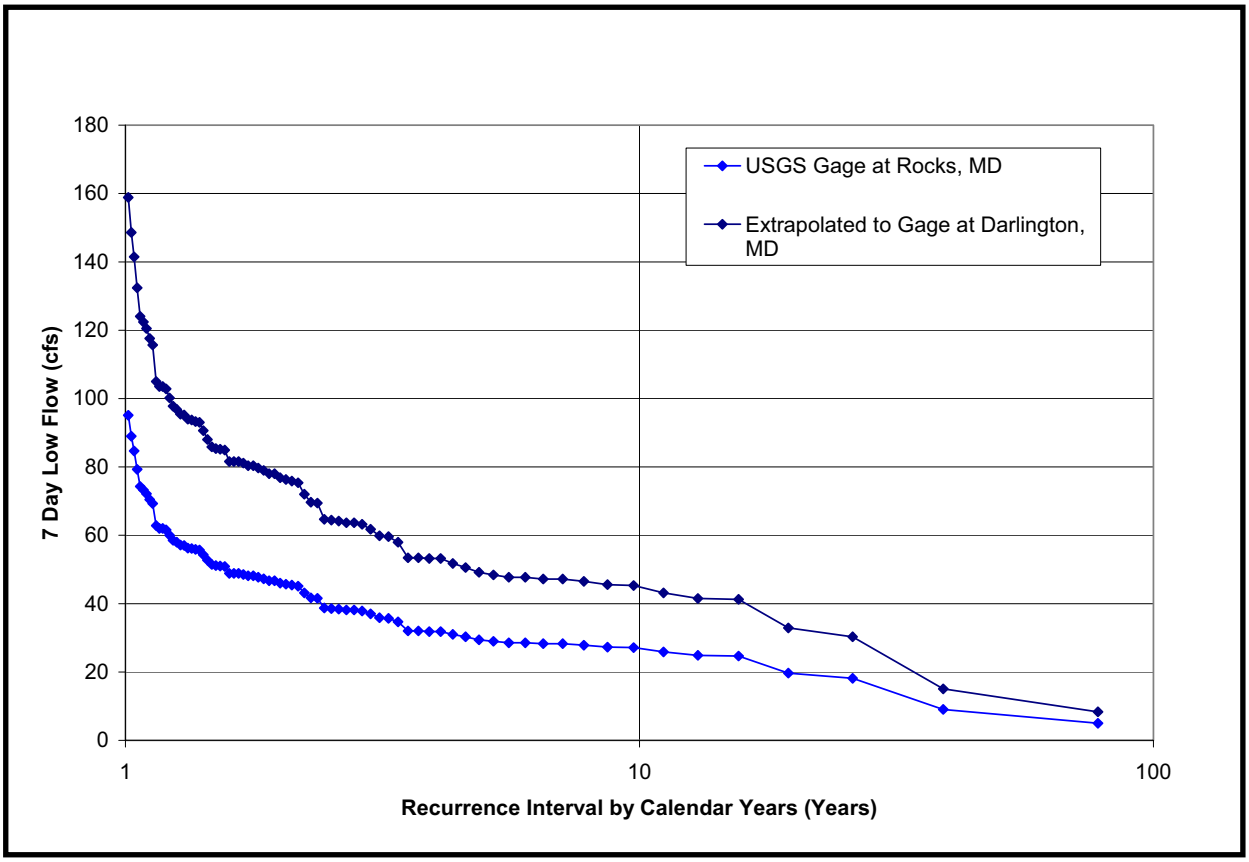

Figure 21. 7Q10 Flow at Rocks and Darlington Gages

D. Summary of Deer Creek Hydrologic Setting

Precipitation values are fairly consistent across the watershed, with average and median values for monthly precipitation varying by 2 percent to 4 percent for the period of record. Likewise, examination of the record shows that there is little change in the long-term trend of precipitation amount. The climate normal average precipitation of 45.78 inches is about an inch greater than the long-term average, and contributes just over 577 cfs to the watershed on an annual average basis.

The median streamflow value (50 percent exceedence) derived from the flow duration curve at Rocks is 94 cfs, and statistics indicate that the watershed is groundwater-dominated, with base flow being a large component of total flow. Averaged over the period of record, base flow represents 67 percent of the total flow at Rocks and 66 percent and 67 percent at Kalmia and Darlington, respectively. It can reasonably be concluded that the amount of precipitation contributing to groundwater recharge is fairly uniform throughout the watershed. In general, a comparison of the ratio of drainage areas to the ratio of base flows demonstrates that contribution of base flow per unit of drainage area is fairly uniform along the main stem of Deer Creek.

Existing gage data shows that recharge and discharge are fairly uniform across the watershed on the main stem of Deer Creek on a large-scale average basis while, on a smaller scale, local variations are likely responsible for the difference in the ratios between base flow and drainage at Darlington and Rocks. In general, there is a geographic variation between lower values associated with watersheds developed on the Baltimore Gabbro and Port Deposit Gneiss (lower Deer Creek Watershed) and higher values on the other bedrock units. These local variations are likely to be important in the analysis of water availability to meet projected demands.