DEER CREEK WATER AVAILABILITY STUDY

Publication No. 256 *May 2008*

SUSQUEHANNA RIVER BASIN COMMISSION

Paul O. Swartz, Executive Director

The Susquehanna River Basin Commission was created as an independent agency by a federal-interstate compact* among the states of Maryland, New York, Commonwealth of Pennsylvania, and the federal government. In creating the Commission, the Congress and state legislatures formally recognized the water resources of the Susquehanna River Basin as a regional asset vested with local, state, and national interests for which all the parties share responsibility. As the single federal-interstate water resources agency with basinwide authority, the Commission's goal is to coordinate the planning, conservation, management, utilization, development and control of basin water resources among the public and private sectors.

**Statutory Citations: Federal - Pub. L. 91-575, 84 Stat. 1509 (December 1970); Maryland - Natural Resources Sec. 8-301 (Michie 1974); New York - ECL Sec. 21-1301 (McKinney 1973); and Pennsylvania - 32 P.S. 820.1 (Supp. 1976).*

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DEER CREEK WATER AVAILABILITY STUDY

EXECUTIVE SUMMARY

The objectives of the Water Availability Study are to inventory and assess key water resources of the Deer Creek Watershed, establish an estimated sustainable yield from the watershed, describe and inventory current water uses, project demands for different use sectors, and evaluate potential issues and problems related to future water availability through the year 2025.

The Deer Creek Watershed is situated within a rapidly developing area of Maryland and Pennsylvania, occupying approximately 171 square miles. The predominant land use within the Deer Creek Watershed, representing roughly 60 percent of the total land area, is associated with agricultural operations. Forested regions cover about 34 percent of the watershed and developed areas, primarily low density residential areas, comprise roughly 5 percent of the watershed. Major population centers include portions of the towns of Shrewsbury and Stewartstown in Pennsylvania, with substantial growth and development in the area of Bel Air, Maryland, in the past decade.

The Deer Creek Watershed is located within the Piedmont physiographic province, and the underlying bedrock is mantled with weathered bedrock called saprolite. This mantle is typical of the Piedmont region in the Mid-Atlantic states and has a porosity that is orders of magnitude higher than in the underlying fractured bedrock. As a result, the relative amount of extractable water is much higher in the saprolite than in the unweathered bedrock. Hydrologic statistics indicate that the watershed is groundwater-dominated, and that base flow is a large component of the total flow in Deer Creek. An examination of hydrologic records showed the months that most typically exhibit the lowest flows are July through October.

During the study, stream gaging data were collected within subwatersheds of Deer Creek over a period of 6 months under varying base flow conditions for the purpose of characterizing recharge rates within the watershed. On average, there is a geographic variation in recharge; the recharge per unit area in the upper portion of the watershed is 1.02 cubic feet per second per square mile (cfs/mi^2), and the recharge in the lower portion of the watershed is 0.76 cfs/mi^2.

Water budget exercises were conducted to assess the disposition of available water in the watershed. Results of these exercises showed that, in average years, about 60 percent of precipitation to the watershed is lost to evaporation and plant transpiration; the remainder is discharged to Deer Creek either as direct surface runoff or as base flow via groundwater. A base flow separation exercise on Deer Creek flow records showed that, on average, 67 percent of the total flow in Deer Creek is base flow, and the remaining third is surface runoff. Once these natural components are understood, the potential impacts of projected water demands can be assessed.

Water use in the Deer Creek Watershed is comprised of commercial, industrial, agricultural, and residential uses. For water users in these categories that hold permits from Maryland, Pennsylvania, or the Susquehanna River Basin Commission (SRBC), there were available data to estimate current and future uses. For water users not subject to regulation, it was necessary to make assumptions about land use, population density, and population projections in order to estimate current and future water use. Based on the data and estimates, less than 1 percent of the total available water is consumptively used under current conditions, although for drought years, that amount may rise to 3 percent.

The greatest challenges for water supply in and adjacent to the Deer Creek Watershed are population growth and urbanization, including the Base Realignment and Closure (BRAC) plan for Aberdeen Proving Ground. Possible conflicts with future availability were evaluated using tables of water supply and demand to estimate timing and location of potential impacts. Under existing conditions, water demand exceeds available flow during some summer months in moderate drought years. In years with average hydrologic conditions, approximately 40 cfs remain available at the lower end of the watershed during the lowest flow months of August and September.

Projections for future water demand are based on the expected 25-year population increase of approximately 24 percent in the Deer Creek Watershed. Under drought conditions, a number of subwatersheds show the potential for resource deficits. The deficits are concentrated in the lower watershed and the Pennsylvania headwaters, which reflect both lower recharge values and higher growth in projected water use.

Based on analyses of the hydrologic setting, anticipated water demands, and riparian and aquatic needs of Deer Creek, existing reliability problems are expected to be more severe under increased demand scenarios. The results of a numerical model of groundwater and surface water interaction suggest that the conjunctive use of wells and surface water intakes could offer a reasonable solution to the problem of an interrupted supply. The SRBC plans to use the findings of this study to guide future regulatory and planning decisions affecting the Deer Creek Watershed.

As the demand for Deer Creek water grows, the following recommendations will help ensure the protection of current uses, aquatic and riparian needs, and the prevention of adverse impacts or degradation to the resources of the Deer Creek Watershed:

- Continue the collection of reported water use data;
- Monitor tributary flows and groundwater levels in high demand and sensitive areas;
- Implement stormwater management to maintain aquifer recharge and base flows;
- Encourage water conservation;
- Recognize and plan for the various hydrology, activities, and demands of the watershed;
- Conduct an evaluation of the specific passby flow needs of each subwatershed; and
- Compile information on critical seasons and hydrologic conditions associated with recreational needs.

I. INTRODUCTION

In 2005, the Susquehanna River Basin Commission (SRBC) initiated the Water Availability Study of the Deer Creek Watershed. SRBC identified the need to assess the water resource availability of the Deer Creek Watershed, located in the lower portion of the Susquehanna River Basin in southern Pennsylvania and northern Maryland, based on potential conflicts between various water uses in the watershed during low flow periods when the issue of water supply sustainability was becoming critical.

The objectives of the study are to inventory and assess key water resources of the Deer Creek Watershed, establish an estimated sustainable yield from the watershed, describe and inventory current water uses, project demands for different use sectors, and evaluate potential issues and problems related to future water availability.

The assessment includes a characterization of existing water resources, as well as the ability of the watershed to reliably meet anticipated water demands through the year 2025. The SRBC plans to use the findings of this study, within the framework of the Susquehanna River Basin Compact (Compact) and in cooperation with the State of Maryland and Commonwealth of Pennsylvania, to guide future regulatory and planning decisions affecting the Deer Creek Watershed.

SRBC contracted S.S. Papadopulos & Associates (SSP&A) to prepare the study, with the assistance of Chesapeake Environmental Management. Draft text and figures were prepared by SSP&A and incorporated into this final report by SRBC staff with assistance from the contractors.

II. GEOGRAPHY AND CLIMATE

The Deer Creek Watershed occupies approximately 171 square miles (109,521 acres) in Maryland and Pennsylvania (Figure 1). About 85 percent of the watershed is situated in Harford and Baltimore Counties, Maryland, with 15 percent in York County, Pennsylvania. The Deer Creek Watershed is the largest watershed in Harford County, Maryland, covering 38 percent of the county's land area. The watershed is elongate, extending approximately 30 miles southeasterly from York County to its confluence with the Susquehanna River about 2 miles south of the Conowingo Dam. The width of the watershed varies from about 3.5 to 9 miles. The watershed's main waterway is Deer Creek. It was named a State Scenic River in 1973, and many streams in the watershed are designated trout waters.

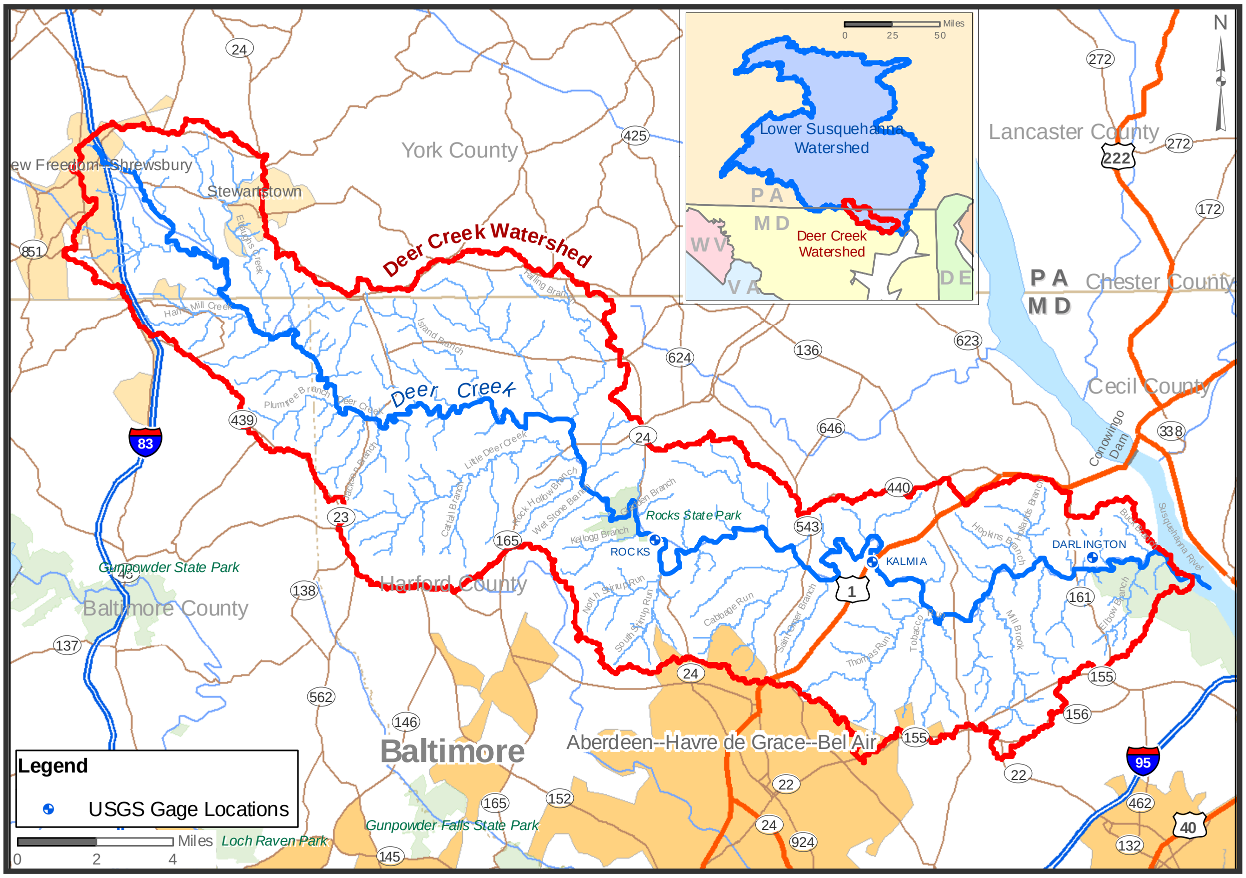

Figure 1. *Location Map*

The Deer Creek Watershed is located entirely within the Piedmont physiographic province, with a landscape that is gently rolling to hilly. The surface elevation within the watershed ranges from about 50 feet to more than 1,060 feet above sea level (Figure 2). Upland elevations in the York County portion of the watershed are typically about 900 feet. Upland elevations in Harford County, near Deer Creek's confluence with the Susquehanna River, are about 150 feet to 300 feet.

The predominant land use within the Deer Creek Watershed is agricultural, with subsidiary amounts of forested and developed land. The area retains its agricultural heritage through preservation programs, and the watershed lies outside Harford County's "development envelope." Major population centers include portions of the towns of Shrewsbury and Stewartstown, Pennsylvania (Figure 1), located near the headwaters of the watershed. The past decade has seen substantial growth and development in the area of Bel Air, Maryland. Although the Town of Bel Air is situated south of the watershed's boundary, significant development in the area has extended into the lower watershed. In addition, the proposed Base Realignment and Closure (BRAC) plan for Aberdeen Proving Ground (APG) in Maryland, located near the watershed area, could result in 30,000 people moving to Harford County as a result of BRAC's moving jobs from Fort Monmouth, New Jersey, to Aberdeen.

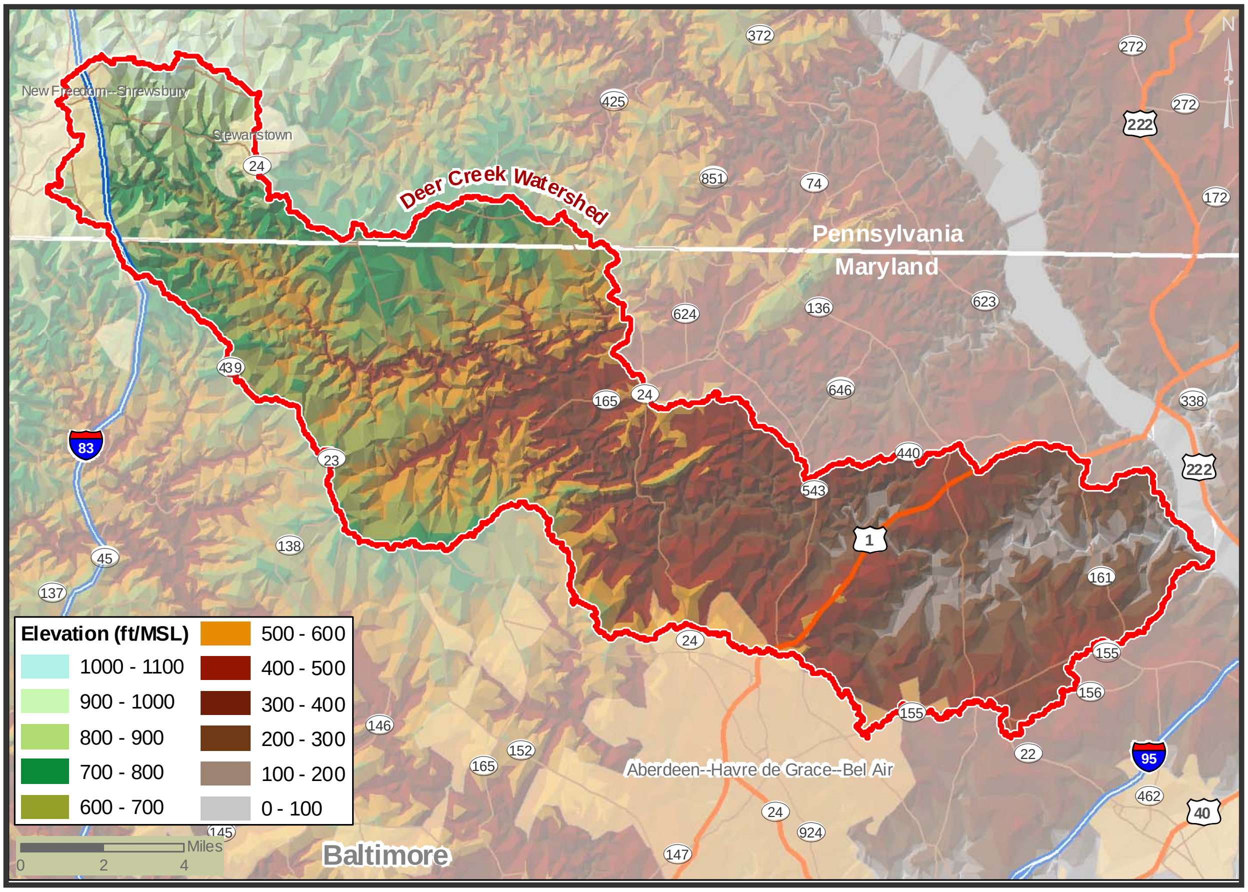

Figure 2. *Shaded Relief Map*

The climate in the Deer Creek Watershed is temperate and moderately humid. The average temperature is about 56 degrees Fahrenheit, with a mean annual precipitation of 45 inches. There are no well-defined wet and dry seasons – rainfall is distributed rather evenly throughout the year. The average low temperatures (Figure 3) for the winter months are similar near Bel Air and Shrewsbury. Nonetheless, due to the higher elevations in York County, the Pennsylvania portion of the watershed tends to see more significant snow accumulations and snowmelt runoff during the winter months than areas further south. Additional information on precipitation and recharge to the basin is presented in the following section.

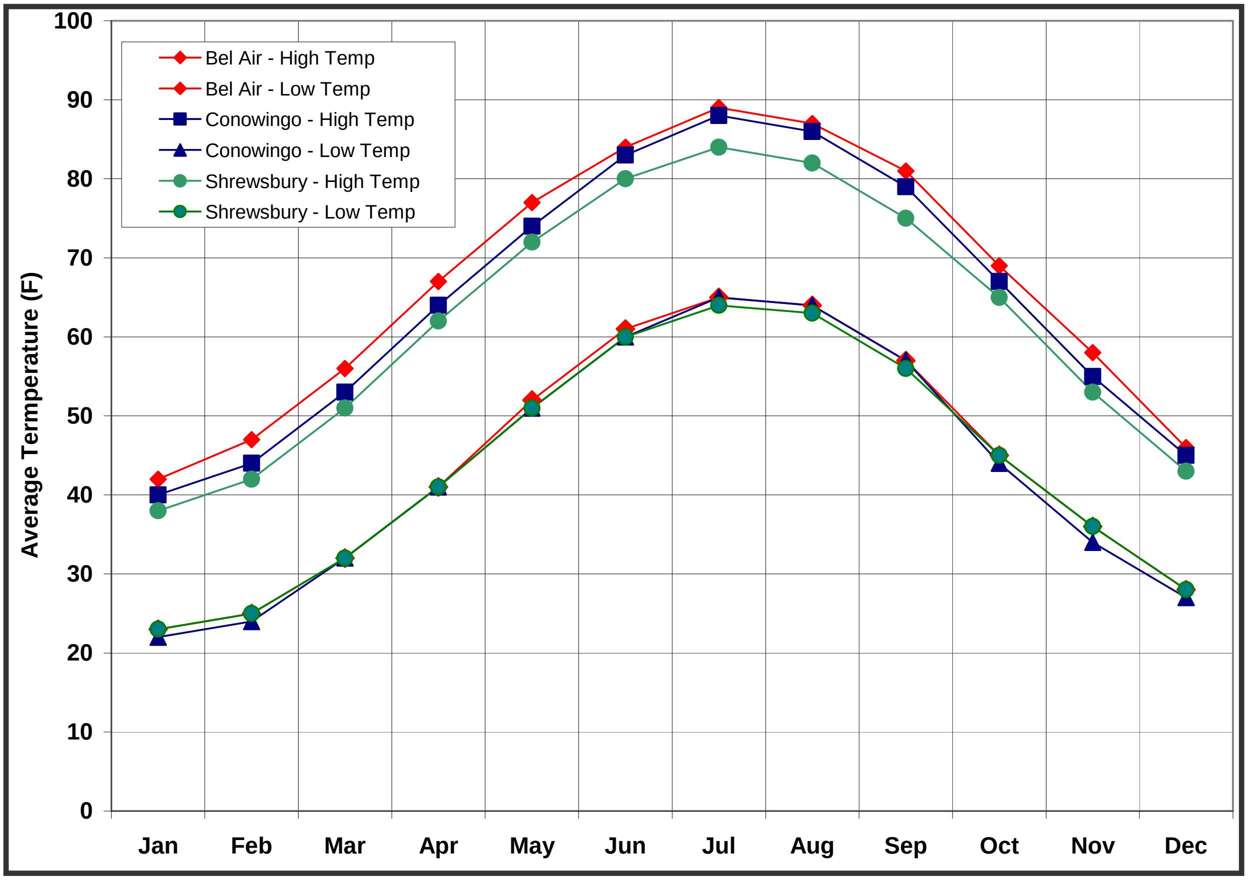

Figure 3. Average Temperatures

III. HYDROLOGIC CHARACTERISTICS

The hydrologic setting of a watershed incorporates aspects of geology, hydrogeology, topography, and other factors. These are addressed below in separate sections.

A. Geology

The Deer Creek Watershed is located within the Piedmont physiographic province and is underlain by a complex sequence of Precambrian to lower Paleozoic crystalline rocks (Stose, 1939; Maryland Geological Survey, 1969; Otton, 1964; Kuchinski, 1977; VanOlden, 1977; Pennsylvania Geological Survey, 2006). A geologic map of the Deer Creek Watershed and surrounding area is presented on Figure 4. The rock sequence consists of intensely deformed metamorphic and igneous rocks (Table 1), including the Metagraywacke, Pelitic Schist, Metaconglomerate, and Boulder Gneiss members of the Wissahickon Formation; the Baltimore Gabbro Complex; the James River Gneiss; the Port Deposit Gneiss; muscovite quartz monzonite gneiss; gabbro/quartz diorite gneiss; metagabbro/amphibolite; and ultramafic and gabbroic rocks. The portion of the Deer Creek Watershed that is located in York County, Pennsylvania, is underlain by the Octoraro Formation, which is equivalent to the albite-chlorite schist facies of Wissahickon Formation (Low et al., 2002).

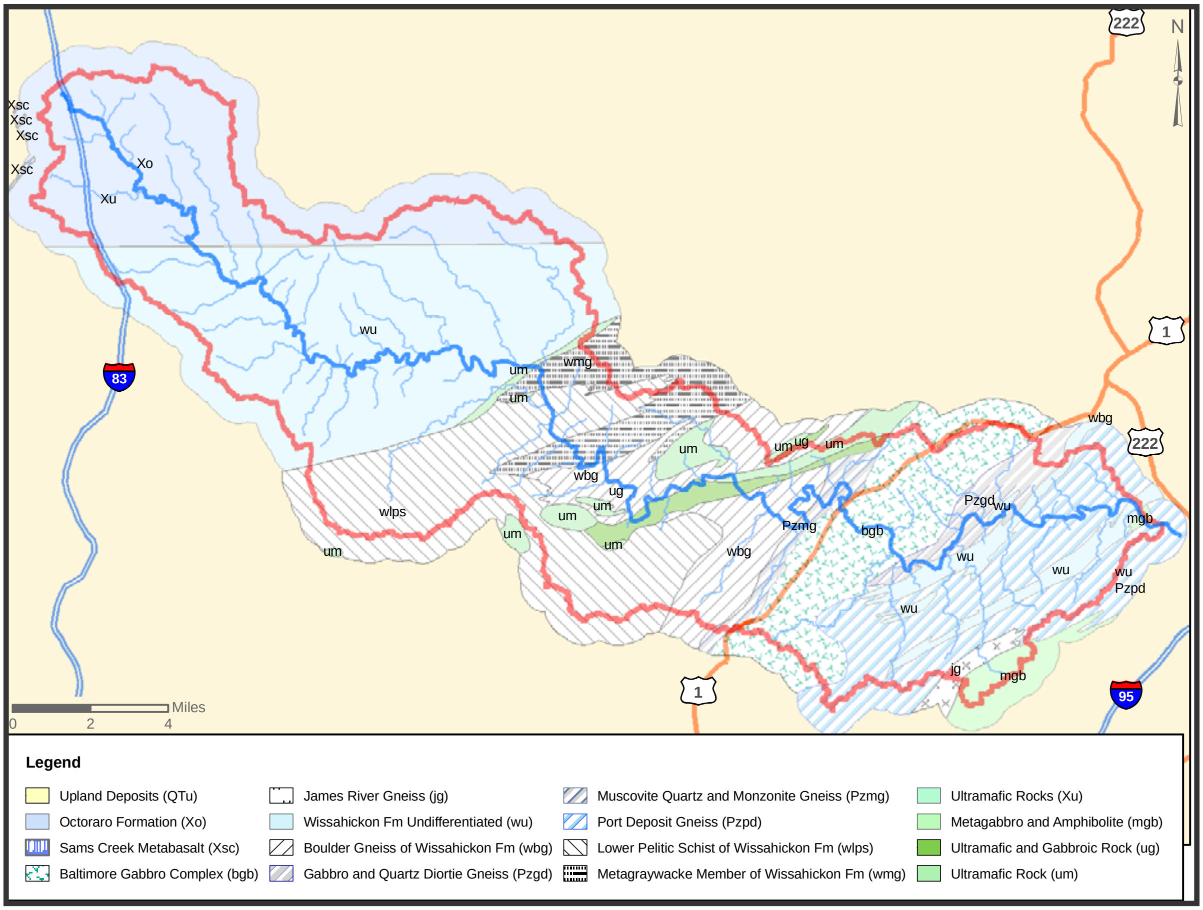

Figure 4. Geologic Map

Table 1. Description of Geologic Units

Geologic Unit	Description
Baltimore Gabbro Complex	Hypersthene gabbro with subordinate amounts of olivine gabbro, norite, anorthositic gabbro, and pyroxenite; igneous minerals and textures well preserved in some rocks, other rocks exhibit varying degrees of alteration and recrystallization, and still others are completely recrystallized with a new metamorphic mineral assemblage.
James Run Gneiss	Well-layered gneiss with a nearly continuous range of compositions between amphibolite and biotite-poor quartz-oligoclase gneiss. Quartz-amphibolite gneiss and biotite-quartz-plagioclase gneiss predominate
Metagabbro and Amphibolite	Weakly to strongly lineated metagabbro and epidote amphibolite.
Muscovite Quartz Monzonite Gneiss	Well foliated to nearly massive quartz monzonite gneiss, generally medium-grained and even textured but locally porphyritic and pegmatitic.
Octoraro Formation	Albite-chlorite schist, phyllite, and hornblende gneiss
Port Deposit Gneiss	Moderately to strongly deformed intrusive complex composed of gneissic biotite quartz diorite, hornblende-biotite quartz diorite, and biotite granodiorite; all rocks foliated and some strongly sheared.
Quartz Gabbro and Quartz Diorite Gneiss	Mixed rock zone of greenish-black, uralitized, quartz-bearing gabbro to dark gray, weakly gneissic, pyroxene-hornblende-biotite quartz diorite.
Sams Creek Metabasalt	Grayish-green, massive to schistose, amygdaloidal metabasalt.
Ultramafic and Gabbroic Rocks	Mixed metagabbro, serpentinite, metapyroxenite, and actinolite-, chlorite-, and epidote-bearing schists.
Ultramafic Rocks	Chiefly serpentine with partly to completely altered dunite, peridotite, pyroxenite; and massive to schistose soapstone; talc-carbonate rock and altered gabbro are common in some bodies.
Wissahickon Formation– Lower Pelitic Schist	Medium to coarse-grained biotite-oligoclase-muscovite-quartz schist with garnet, staurolite, and kyanite; fine- to medium-grained semipelitic schist; and fine-grained granular to weakly schistose psammitic granulite (formerly mapped as oligoclase facies of Wissahickon Formation).
Wissahickon Formation – Boulder Gneiss	Thick-bedded to massive pebble and boulder-bearing arenaceous to pelitic metamorphic rock, typically a medium-grained garnet-oligoclase-mica-quartz gneiss (formerly mapped as Sykesville and Laurel Formations). Locally intensely foliated gneiss or schist.
Wissahickon Formation (undivided)	Muscovite-chlorite-albite schist, muscovite-chlorite schist, chloritoid schist, and quartzite, intensely folded and cleaved.
Wissahickon Formation-Metaconglomerate	Well-foliated micaceous quartz-pebble metaconglomerate and quartzite. Thickness about 1,200 feet at Deer Creek, Harford County
Wissahickon Formation-Metagraywacke	Interbedded chlorite-muscovite metagraywacke and fine-grained chlorite-muscovite schist (formerly mapped as Peters Creek Formation). Graded bedding preserved locally.
Wissahickon Formation– Upper Pelitic Schist	Albite-chlorite-muscovite-quartz schist with thin beds of laminated micaceous quartzite (formerly mapped as albite facies of the Wissahickon Formation). Coarsens from west to east, primary sedimentary structures include normal bedding, graded bedding and soft-sediment deformational structures.

After Dingman et al. (1956), Nutter and Otton (1969), and Pennsylvania Geological Survey (2006).

As can be seen on Figure 4, the northwestern half of the watershed is underlain by low-grade schist of the Wissahickon and Octoraro Formations. In contrast, the southeastern portion of the watershed is primarily underlain by gneisses and gabbro, with subordinate schist. Ultramafic and gabbroic rocks occur within relatively restricted bands in the center and southeast portion of the watershed. In the center of the watershed, these units are expressed as distinctive topographic ridges that form the characteristic landforms at Rocks State Park (Figures 1 and 2). The course of Deer Creek clearly follows the northern edge of the gabbroic rocks between Routes 24 and 543 in Harford County.

The bedrock is mantled with saprolite (a layer of weathered, decomposed bedrock with pores and fracture features), typical of the Piedmont region of the Mid-Atlantic states. The lithology, texture, and structure of the parent rock govern the characteristics of the saprolite, as many features of the parent rock are preserved in the saprolite. There is a general tendency for the gneiss and quartzose schist to weather to a sandy, fairly permeable saprolite, whereas the gabbro, metabasalt, and ultramafic rocks weather to saprolite with a higher clay content and lower permeability (Nutter and Otton, 1969).

The thickness of the saprolite at any location depends on the parent rock type, the topography, and the degree of fracturing (Table 2). Saprolite thickness can be approximated by the depth of the casing installed in water supply wells. In Harford County, the saprolite thickness is reported to range from 0 to 100 feet, with an average thickness of 42 feet (Nutter, 1969). Saprolite thickness is generally highest in upland areas and along hilltops, and lower or absent in stream valleys where it has been eroded. The degree of fracturing in the parent rock contributes to the development of saprolite, as more highly fractured parent rocks tend to produce a thicker, better developed saprolite mantle.

Table 2. Saprolite Thickness and Parent Rock in Harford County

Parent Rock	Average Saprolite Thickness (feet)
Gabbro	50
Lower Pelitic Schist (Wissahickon)	48
Metagraywacks (Wissahickon)	49
Baltimore Gneiss	38
Upper Pelitic Schist (Wissahickon)	33

Post-settlement sediment deposits are frequently present within the valleys of Deer Creek and its tributaries. These fine-grained materials document the increase in sediment erosion and transport associated with deforestation and agricultural development in the eighteenth to early twentieth centuries (Jacobson and Coleman, 1986). Under current conditions, the streams tend to be incised into these sediment units. The bed of Deer Creek and its tributaries varies from exposed bedrock to sandy and gravelly depending upon local conditions (Figure 5).

Figure 5. Photographs of Deer Creek
A) Deer Creek and USGS Gage in Rocks State Park; B) Deer Creek, South of Stewartstown, Pennsylvania.; C) Deer Creek near Aberdeen Proving Ground Churchville Site; D) Deer Creek above Ebaugh's Creek

B. Hydrogeology

Within the Deer Creek Watershed, groundwater occurs under unconfined water table conditions in the crystalline rock aquifer of the Piedmont province. Groundwater generally moves downward and laterally away from upland areas to topographically lower areas of groundwater discharge (Figure 6). Groundwater occurs in fractures in the unweathered crystalline rock and in pores and relict fractures in the weathered, decomposed bedrock (saprolite). Porosity in the saprolite is orders of magnitude higher than in the fractured bedrock. As a result, the relative amount of extractable water is much higher in the saprolite than in the unweathered bedrock. The thickness, porosity, and permeability of the saprolite are key characteristics for understanding the occurrence and availability of groundwater in the region (Nutter and Otton, 1969; Richardson, 1982).

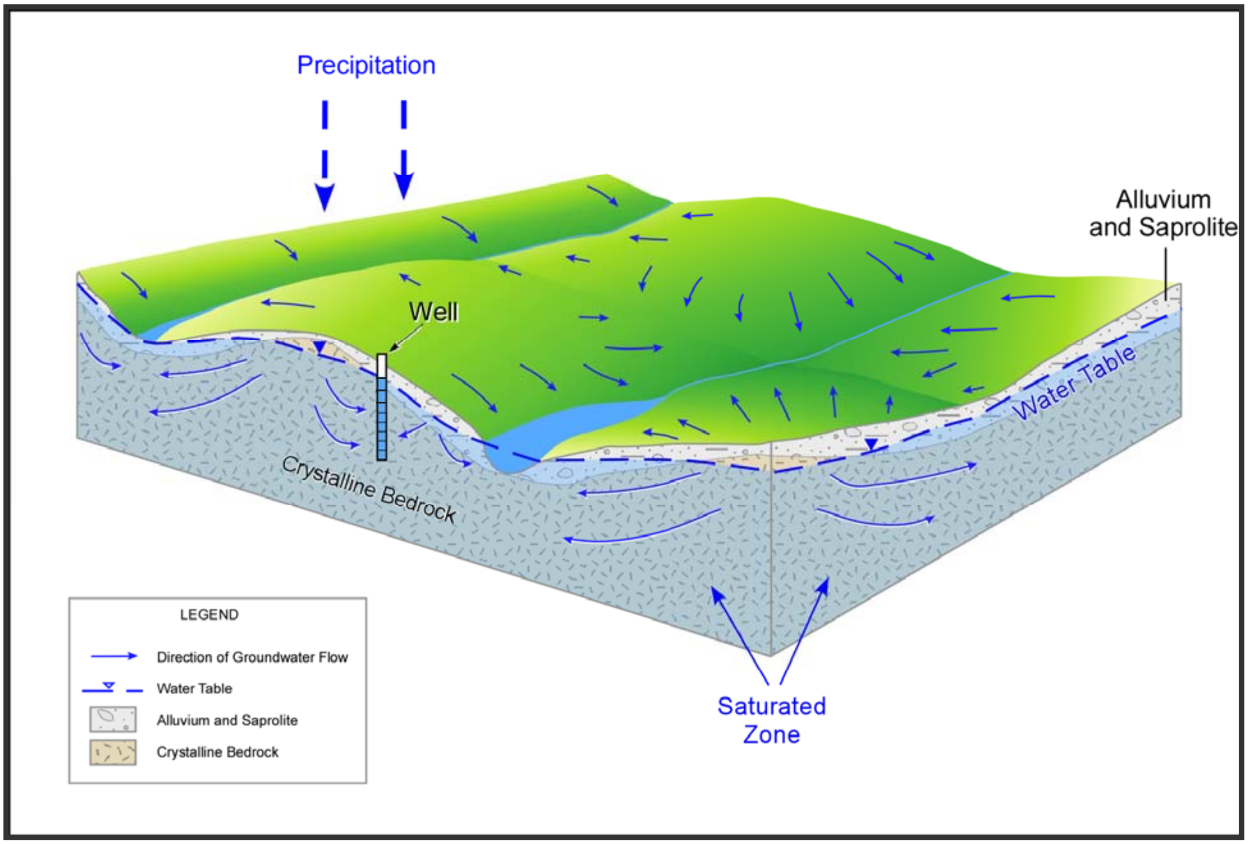

Figure 6. Schematic Hydrogeologic Conditions

Dingman and others (1956) found the porosity of saprolite developed from crystalline rocks of Harford County, Maryland, to range from 34 to 56 percent. The average porosity of saprolite developed from rocks of the Wissahickon Formation was about 48 percent, with measured porosity values ranging from 45.7 to 51.9 percent. The effective porosity, or that porosity which contributes to transmission of groundwater, will, however, be somewhat lower than these values. Estimates of the specific yield of saturated regolith in parts in the Piedmont of Pennsylvania ranged from about 8 percent to 10 percent (Low et al., 2002). Regolith is the mantle or blanket of unconsolidated or loose rock material that overlies the intact bedrock and nearly everywhere forms the land surface.

Because most wells in the Deer Creek area tend to be screened across the saprolite/bedrock interface, it is difficult to find independent estimates of the transmissivity of bedrock and saprolite. Undoubtedly, the transmissivity of the bedrock is highly variable, depending upon lithology and degree of fracturing, as well as fracture orientation. The transmissivity results of aquifer tests from wells in crystalline rock aquifers of the Maryland Piedmont vary from 4 to 4,700 square feet per day (ft^2/day), with the majority of the values between 270 and 900 ft^2/day (Nutter and Otton, 1969). Estimates of transmissivity from Baltimore and Harford County (Dingman et al., 1956), and the albite-chlorite facies of the Wissahickon (Octoraro) Formation (Low et al., 2002) are found in Table 3.

Table 3. Transmissivities and Well Yields in the Maryland and Pennsylvania Piedmont

	Baltimore and Harford Counties (Dingman et al., 1956)		**Piedmont Province of Pa. (Low et al., 2002)**		**Transmissivity from Aquifer Tests in Pa. and Md.**
Unit	**Range of Well Yield (gpm)**	**Average Well Yield (gpm)**	**Range of Well Yield (gpm)**	**Median Well Yield (gpm)**	**(ft^2/day)**
Schist (Wissahickon)	0 to 200	10.5	0 to 300	10	80 *(median for albite chlorite facies, Low et al., 2002)* 400 to 1,300 * *(Dingman et al., 1956)*
Gneiss and granitic rocks	0.5 to 55	10.8	0 to 650	15	300 to 700 (Baltimore Gneiss)
Gabbro and serpentine	0.5 to 80	10.3	2.0 to 80	12	

* The coefficient of storage for the Wissahickon wells ranged from 0.002 to 0.01.
ft^2/day – square feet per day

Well yield for supply wells in the Piedmont varies significantly, depending on the degree of weathering, topography, type of parent rock, well depth, and degree of fracturing and jointing encountered by the well. In Maryland, well yields overall range from 0 to 200 gallons per minute (gpm); however, greater than 70 percent of the wells have a yield of 10 gpm or less, and only 2 percent have a yield of 50 gpm or greater (Dingman et al., 1956). In Pennsylvania, wells from the albite-chlorite schist are reported to have a median yield of 10 gpm, and a seventy-fifth percentile yield of 25 gpm. Wells installed in areas with thicker saprolite development generally have a higher well yield. Dingman et al. (1956) found that for wells in Baltimore and Harford Counties, wells located at ridge tops generally have a reduced yield compared to wells installed in draws and valleys primarily due to the configuration of the water table. Data in Nutter (1975) confirm that the highest yields and specific capacities occur in wells that have the shortest surface casings or are the shallowest.

The type of parent rock influences the development of secondary porosity in the aquifer, in particular the presence of joints, solution features, and fractures. Since the primary porosity of the crystalline rocks is very low, groundwater is transmitted through fractures, joints, and other openings in the rock formation, and wells installed in formations that are more highly fractured will have more water available. Because the presence of open fractures tends to decrease at depth, well yield tends to decrease at depths greater than about 200 feet. About 25 percent of the wells greater than 350 feet deep in the crystalline rock aquifer of Baltimore and Harford County yielded less than a gallon a minute (Dingman et al., 1956). A summary of well yield according to rock type in the Maryland Piedmont is provided in Table 3.

Nutter (1977) compiled well data for Harford County. Based upon specific capacity data for wells screened in different formations, he subdivided the rocks of Harford County into five hydrogeologic units, three of which (Units 3, 4 and 5) occur within the Deer Creek Watershed. The specific capacities of Unit 3 were reported to be higher than those for Unit 4, and Unit 4 higher than those in Unit 5. These units are represented on Figure 7.

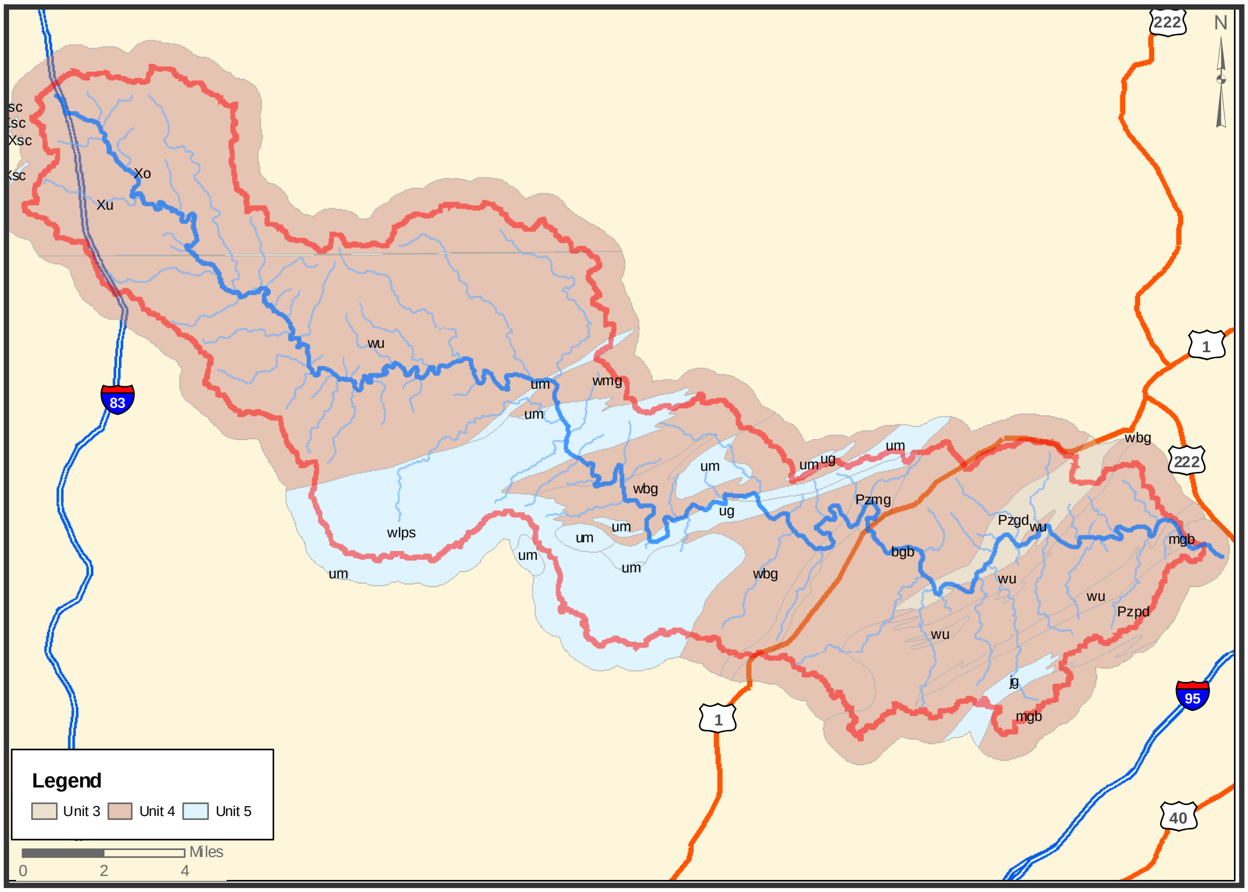

Figure 7. Hydrogeologic Units

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.

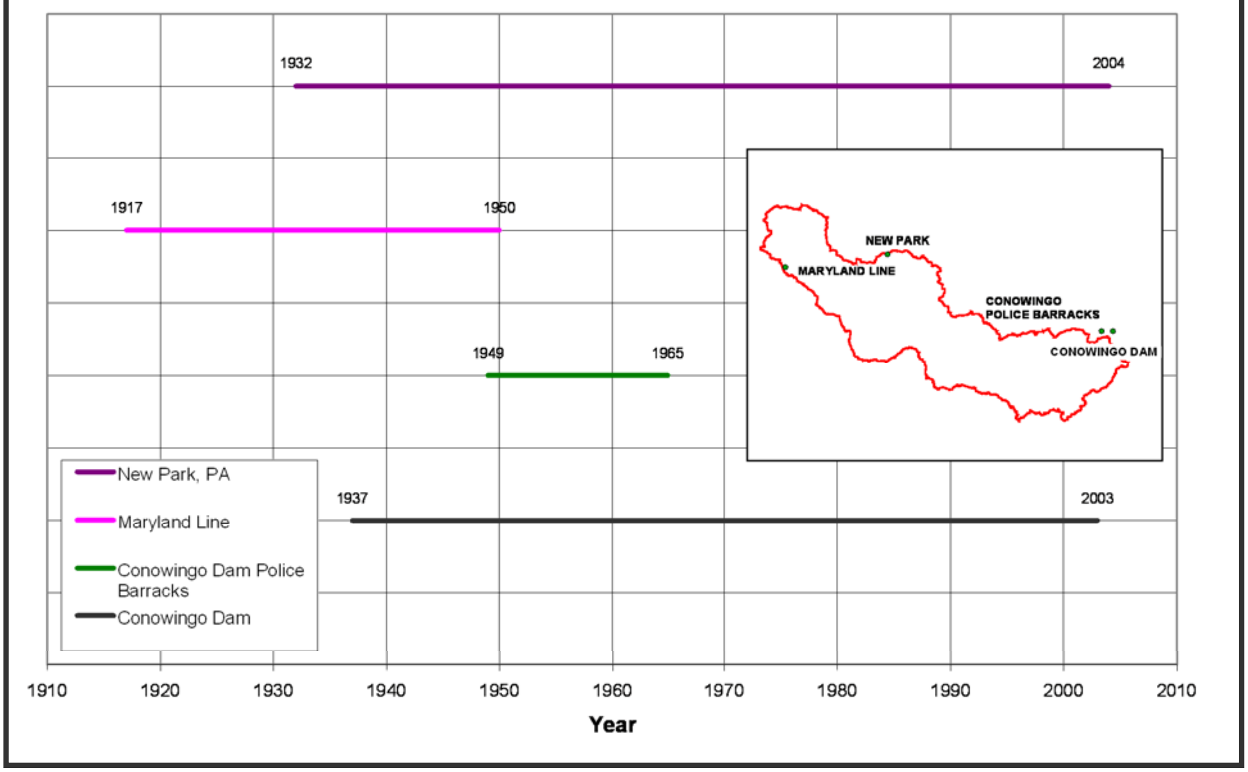

Figure 8. Precipitation Stations and Periods of Record

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.

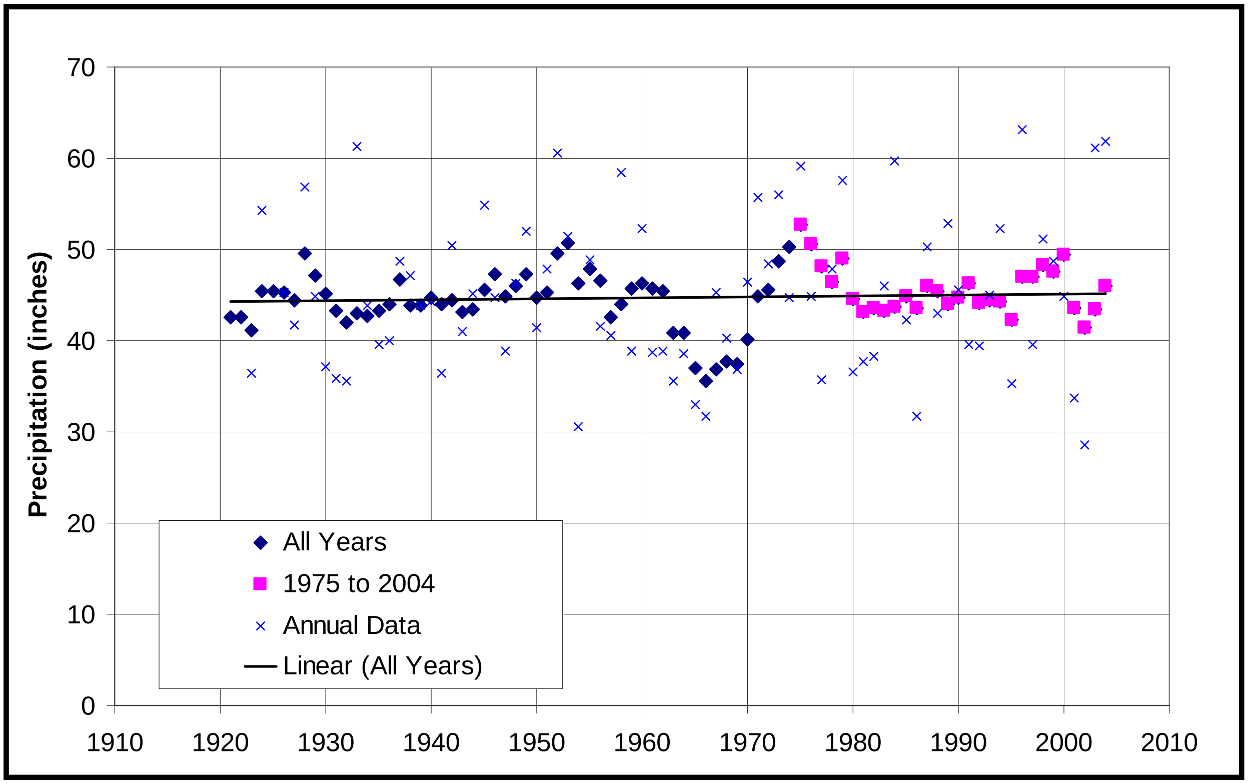

Figure 9. Long-Term Precipitation Record

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.

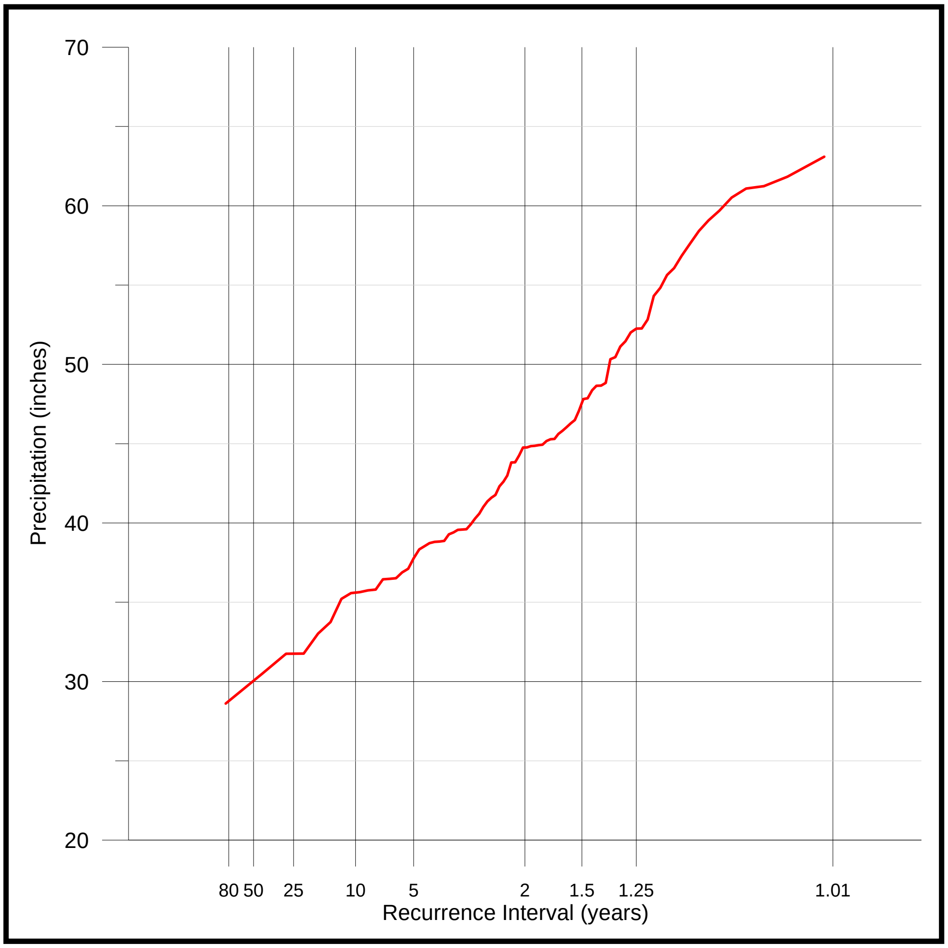

Figure 10. Recurrence Intervals for Annual Precipitation

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

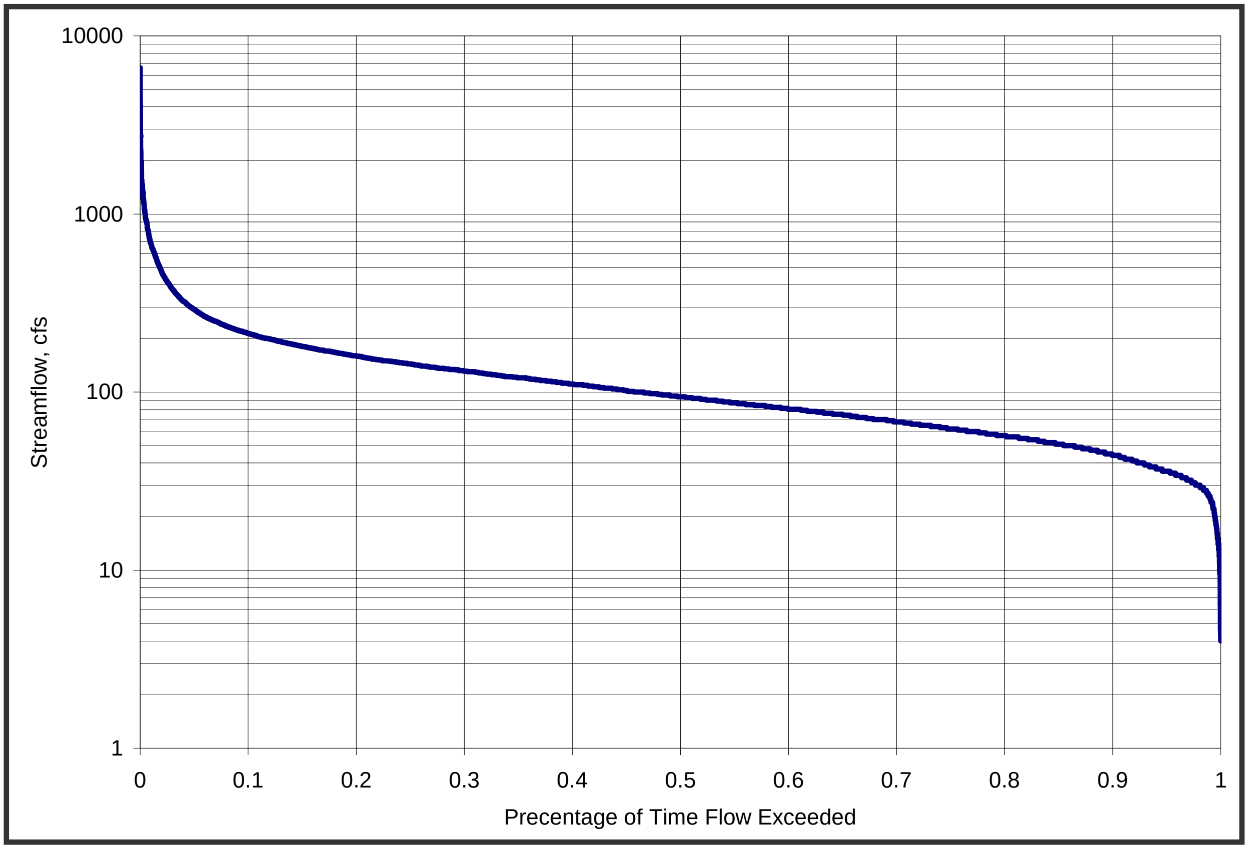

Figure 11. Flow Duration Curve for Rocks Gage

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.

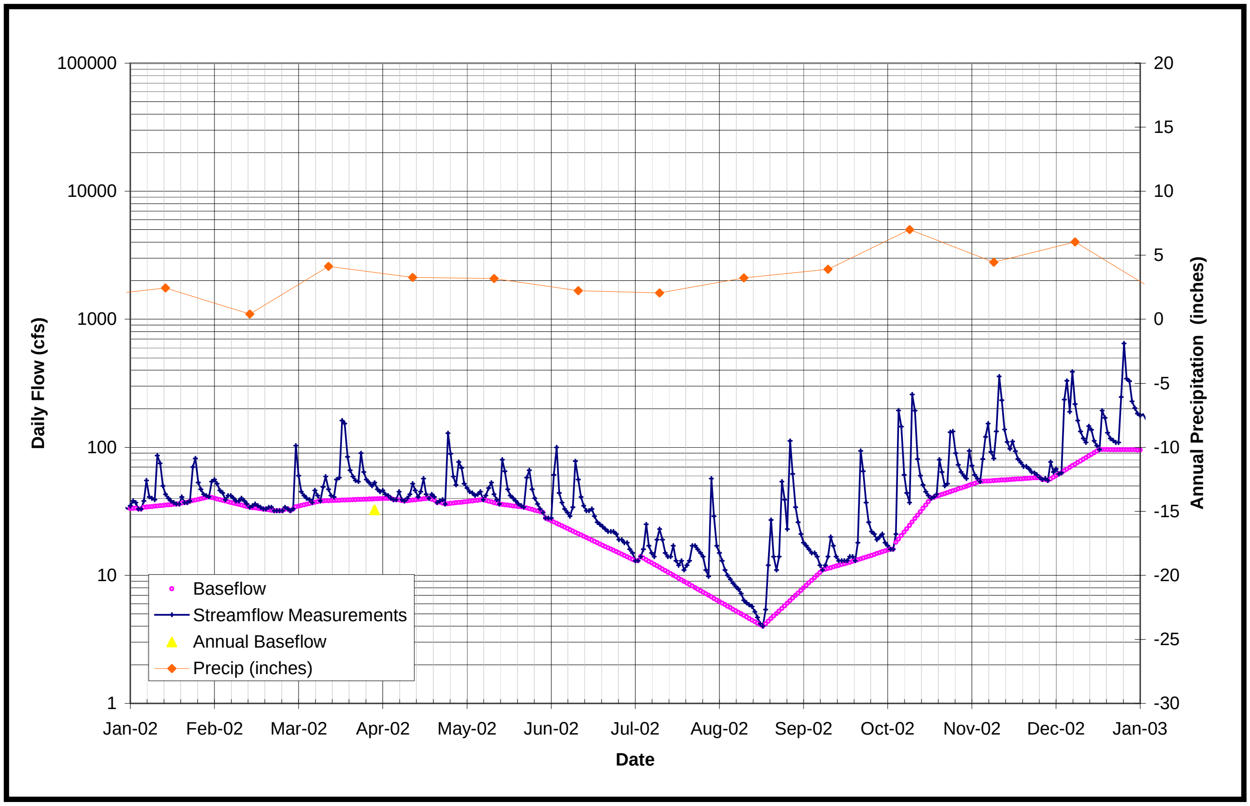

Figure 12. Base Flow Separation for 2002 at Rocks Gage

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.

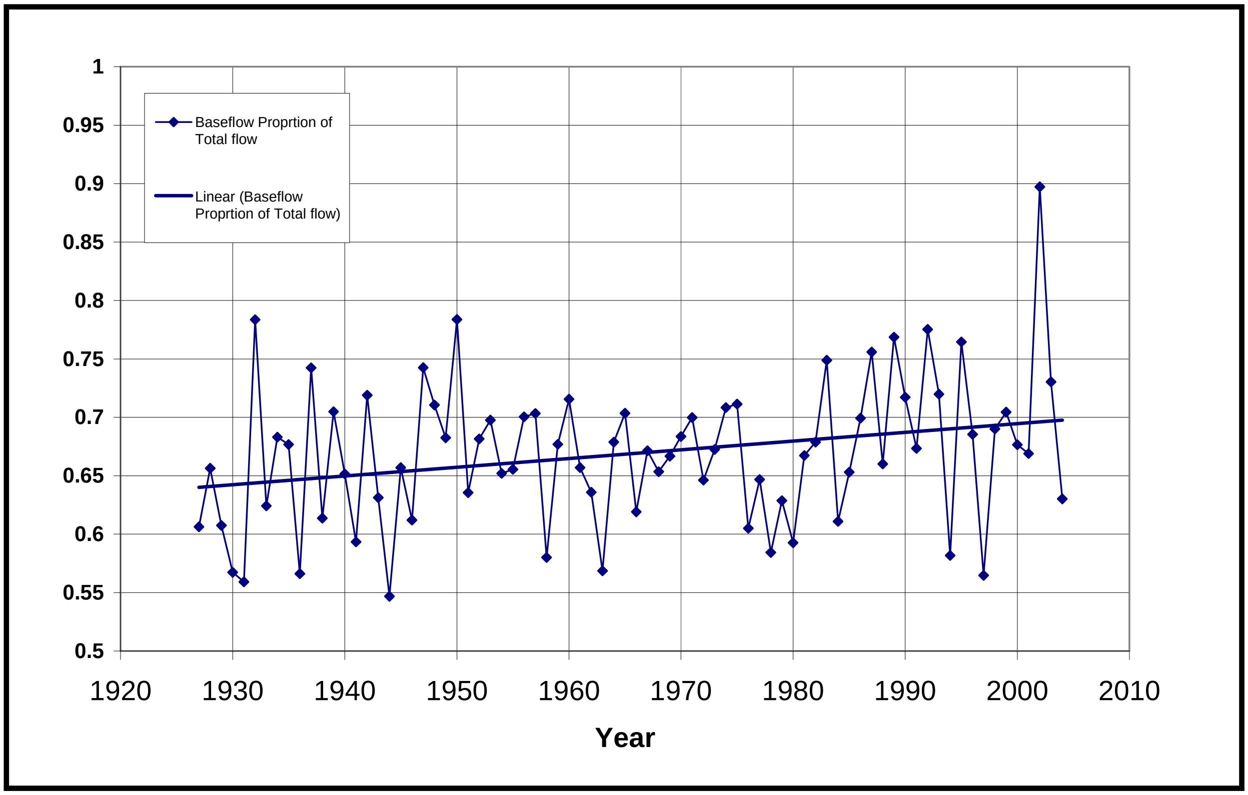

Figure 13. Ratio of Annual Base Flow to Total Flow

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.

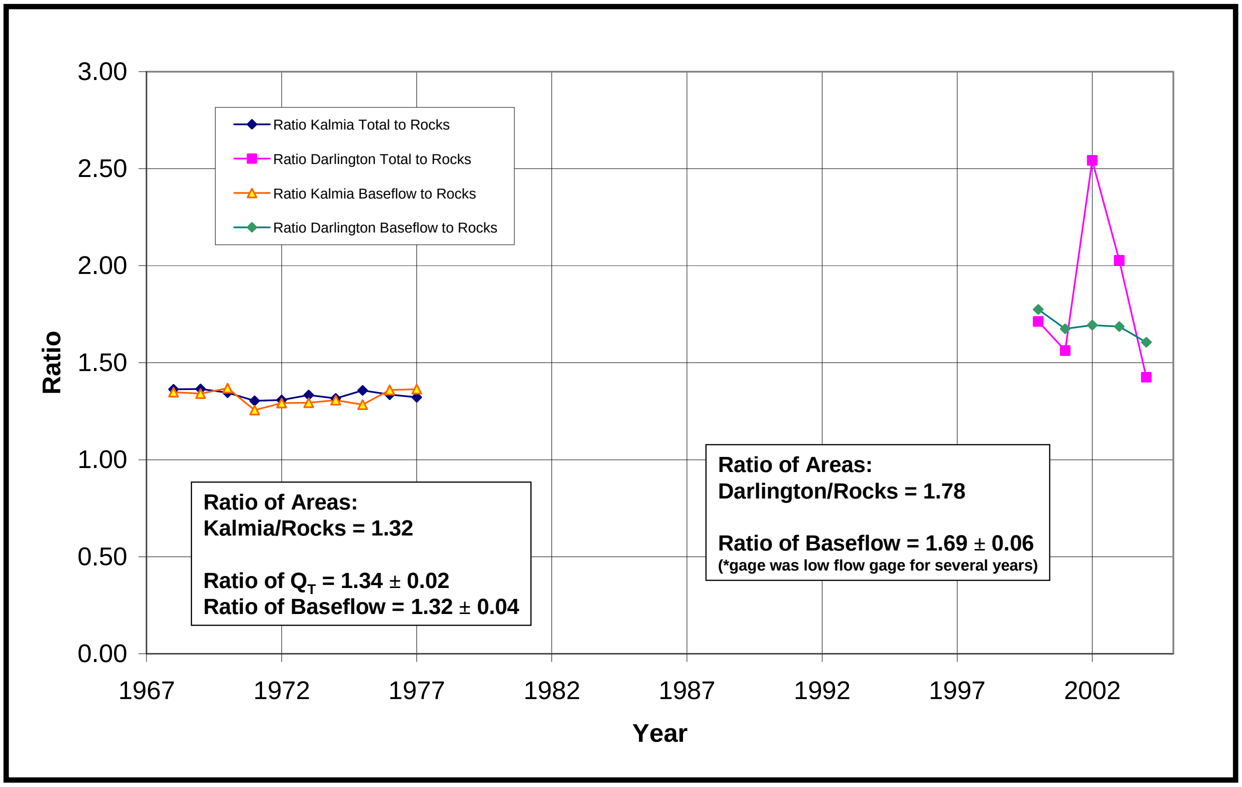

Figure 14. Ratio of Total Flow to Base Flow at Rocks Gage

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.

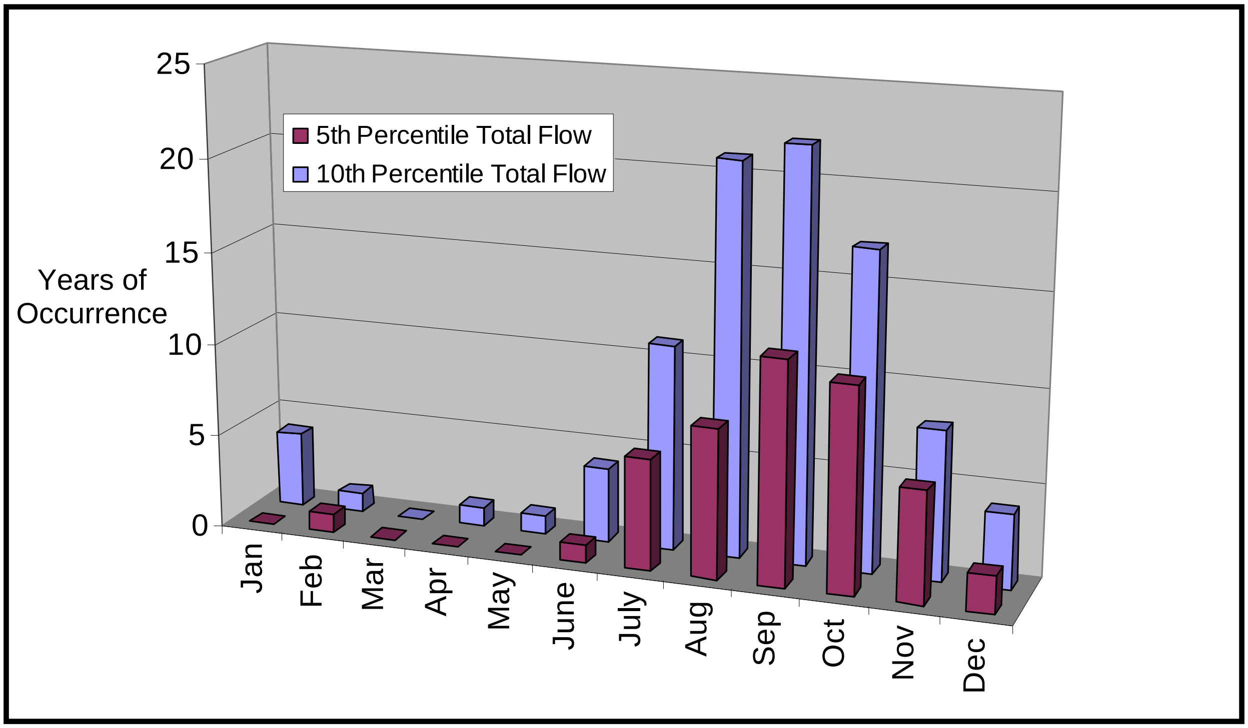

Figure 15. Frequency in Years that Average Monthly Flow Occurs Within 5th or 10th Percentile of Flow at Rocks Gage

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

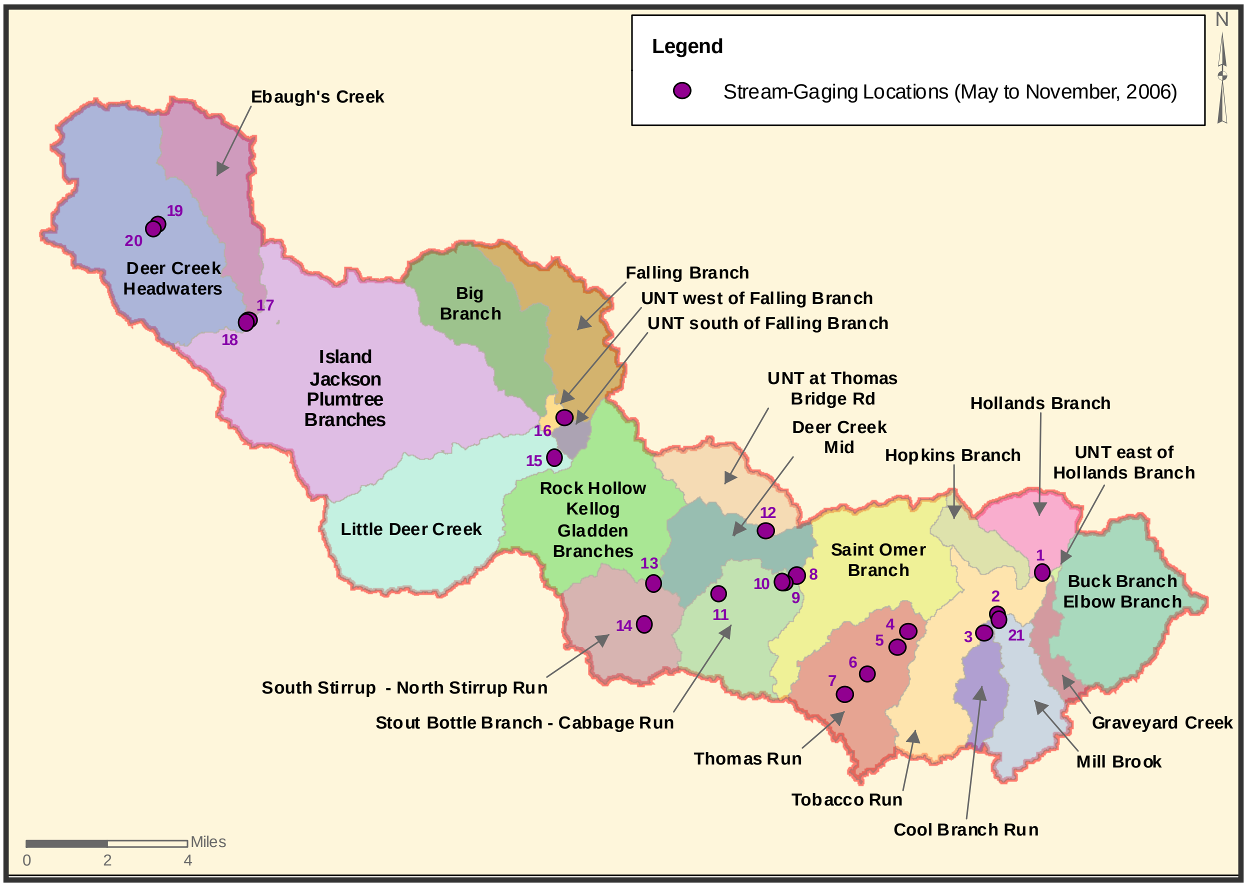

Figure 16. Subwatersheds

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	

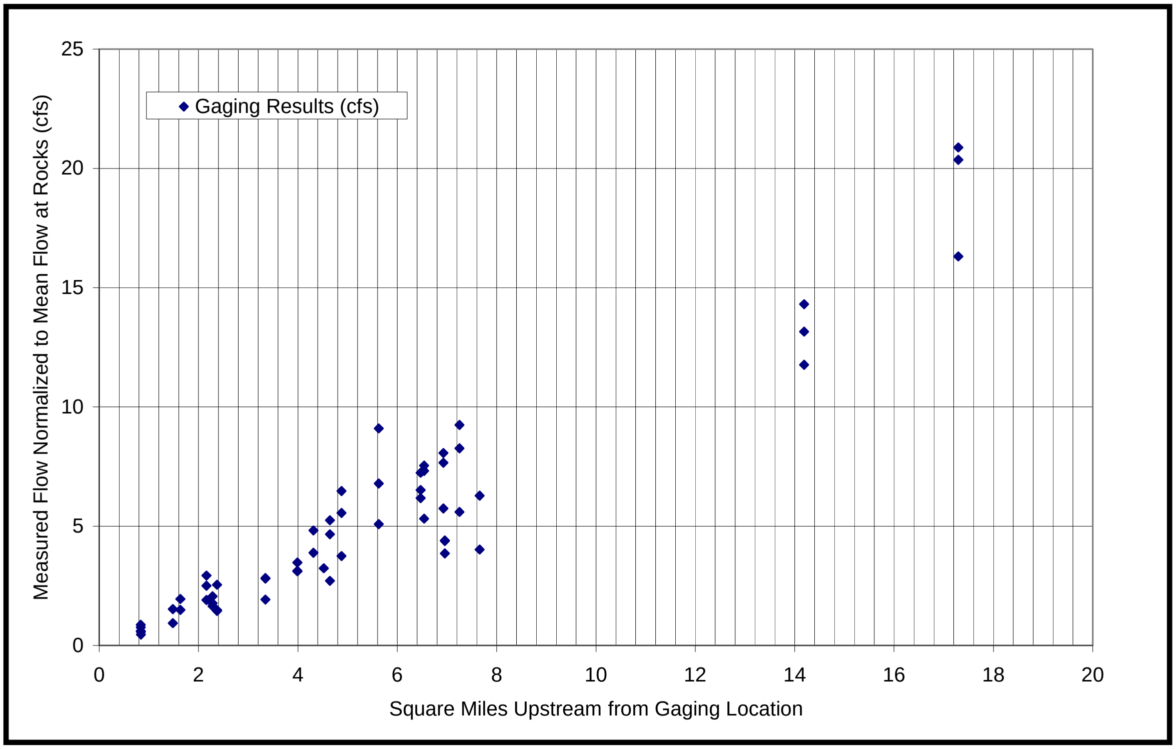

Figure 17. ***Subwatershed Stream Gaging Results***

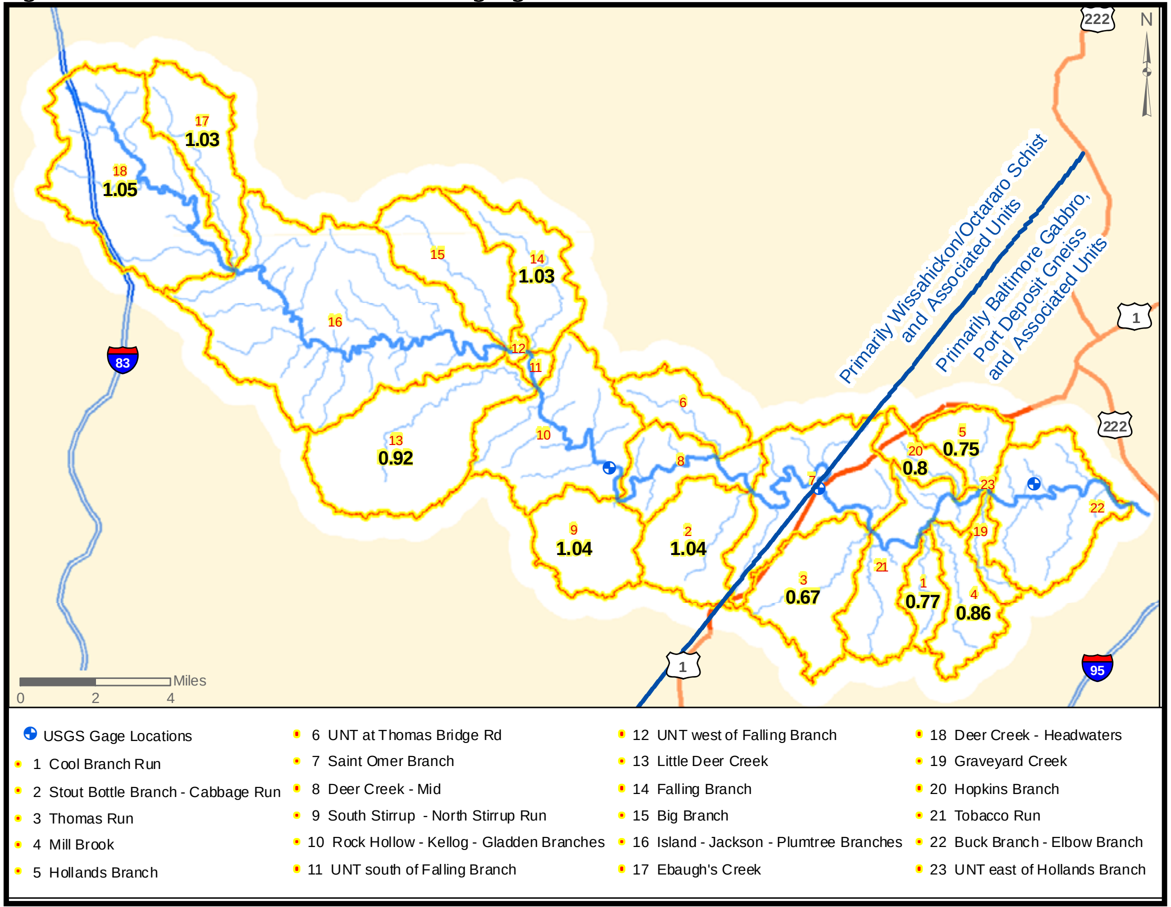

Figure 18. ***Mapped Subwatershed Flows per Recharge Area (cfs/mi^2)***

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.

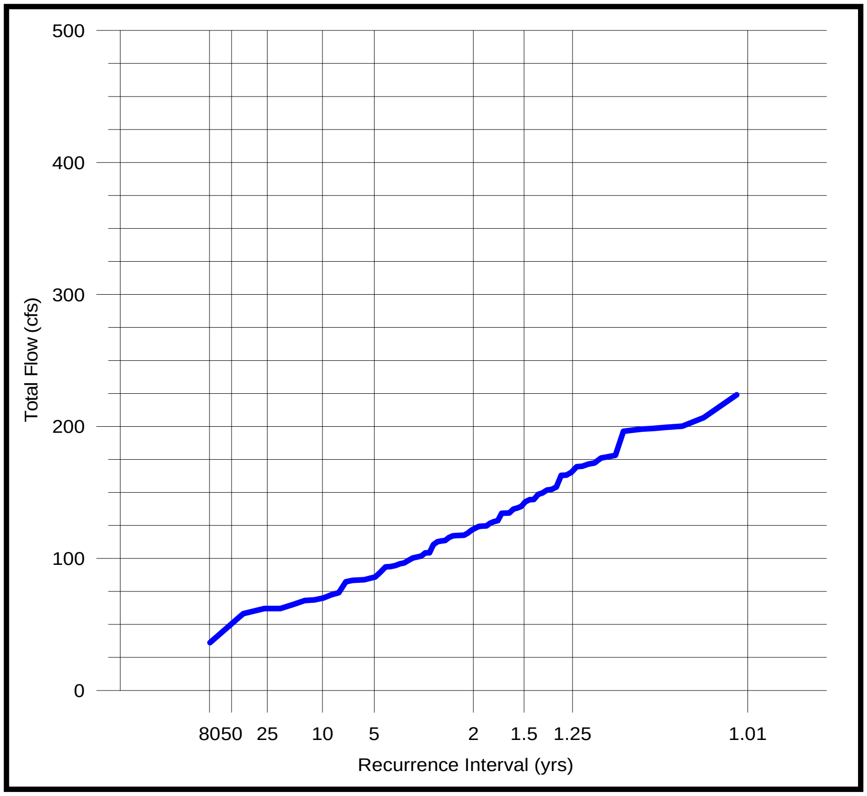

Figure 19. ***Total Flow at Rocks Gage***

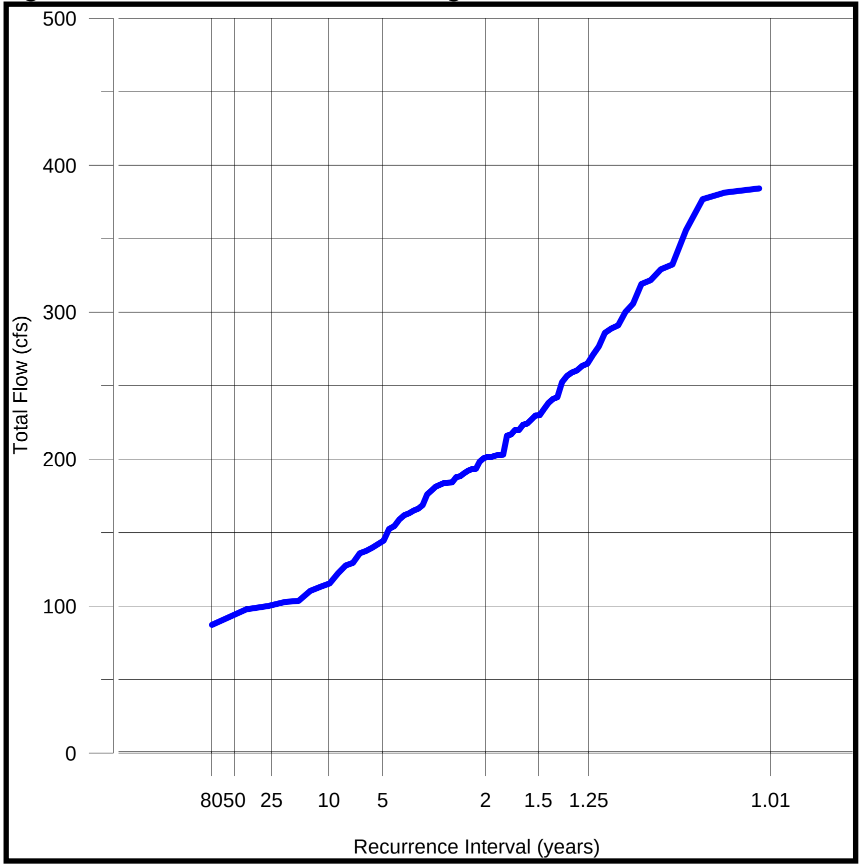

Figure 20. ***Total Flow at Darlington Gage***

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.

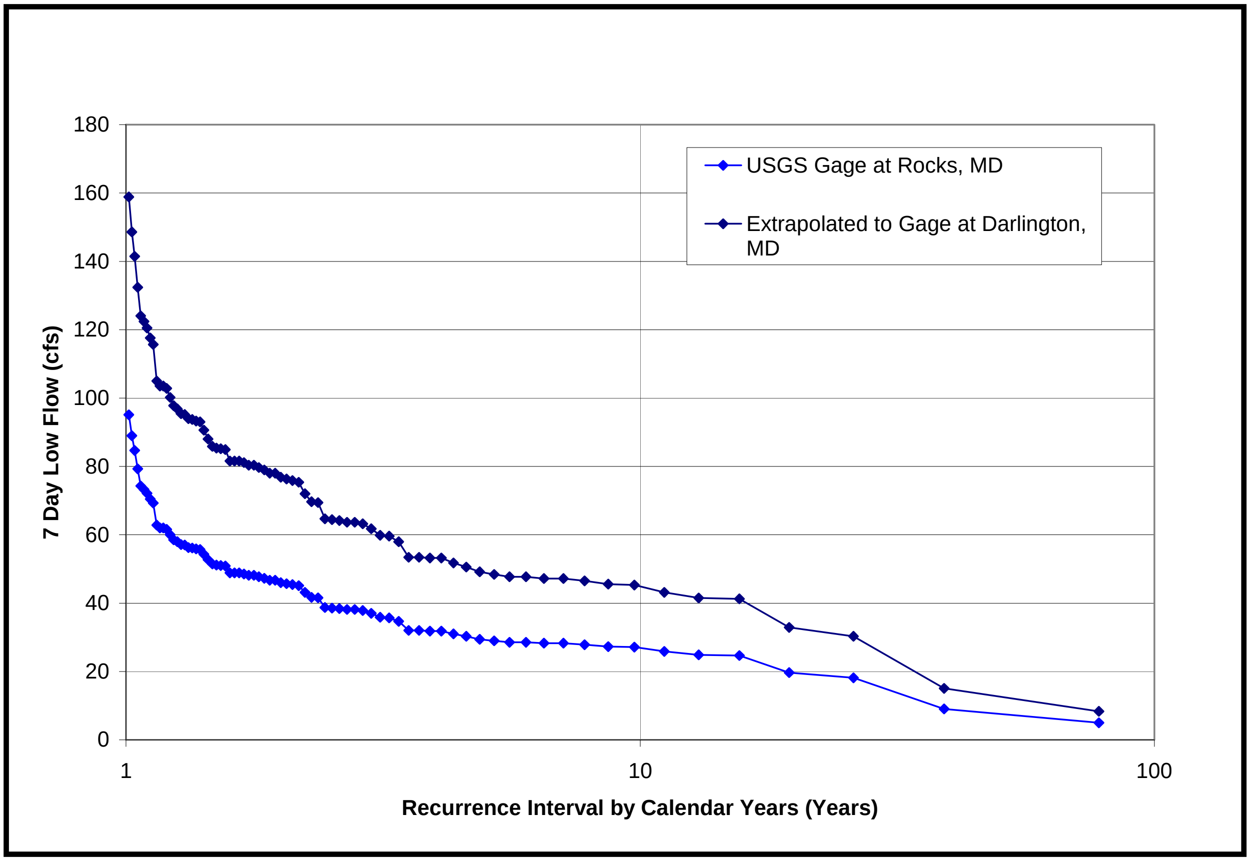

Figure 21. 7Q10 Flow at Rocks and Darlington Gages

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.

V. WATER USES/NEEDS

The uses and needs for water in the Deer Creek Watershed depend upon both land use within the watershed, and that in surrounding communities. In the following sections, the current uses and needs for water are discussed, and a water budget is developed for the watershed as a whole.

A. Land Use

Land use in the Deer Creek Watershed is largely agricultural and forested, with subsidiary amounts of developed land. The Deer Creek Watershed is the largest agricultural area in Harford County (MDE, 2006). The primary sources of quantitative information used in this analysis were:

- 1992 and 2001 Land Use Geographic Information System (GIS) coverages from the Multi-Resolution Land Characteristics Consortium (MRLC)/National Land Cover Database (NLCD);
- 2002 Harford County and Baltimore County Land Use coverage developed by the Maryland Department of Planning;
- U.S. Department of Agriculture Cropland Data Layer, 2002;
- Pennsylvania Land Use Coverage (based upon 1992 MRLC data, plus 1990s and 2002 Thematic Mapper data); and
- Deer Creek Watershed Characterization (MDE, 2006).

The percentages of land attributed to each use vary between these different sources, in part due to differing resolution of the data, and to different sources and methods. Table 11 presents an analysis of the 2001 and 2002 data sets. The data are presented graphically on Figure 22. In general, the agricultural portion of the watershed represented 58 to 63 percent of the total land area in 2001-2002. This proportion is slightly lower in Harford County than other portions of the watershed. Forested regions comprised about 34 percent of the watershed. Developed areas, primarily low density residential areas, comprised between 3 percent and 8 percent of the watershed.

Table 11. Land Use Composition

Land Use	Deer Creek 2001 MRLC/ NLCD Data	Deer Creek 2002 USDA Cropland Data	Harford County Section SSP&A Analysis (2002 data)	Harford County Section MDE Analysis (2002 data)	Baltimore County Section MDE Analysis (2002 data)	York County Section MDE Analysis (2002 data)
Agricultural	62.6%	57.9%	53.7%	54.0%	57.0%	57.0%
Forested	33.6%	33.4%	31.4%	31.0%	33.0%	23.0%
Developed	3.0%	8.2%	14.7%	15.0%	10.0%	20.0%
Other	0.8%	0.5%	0.2%	---	---	---

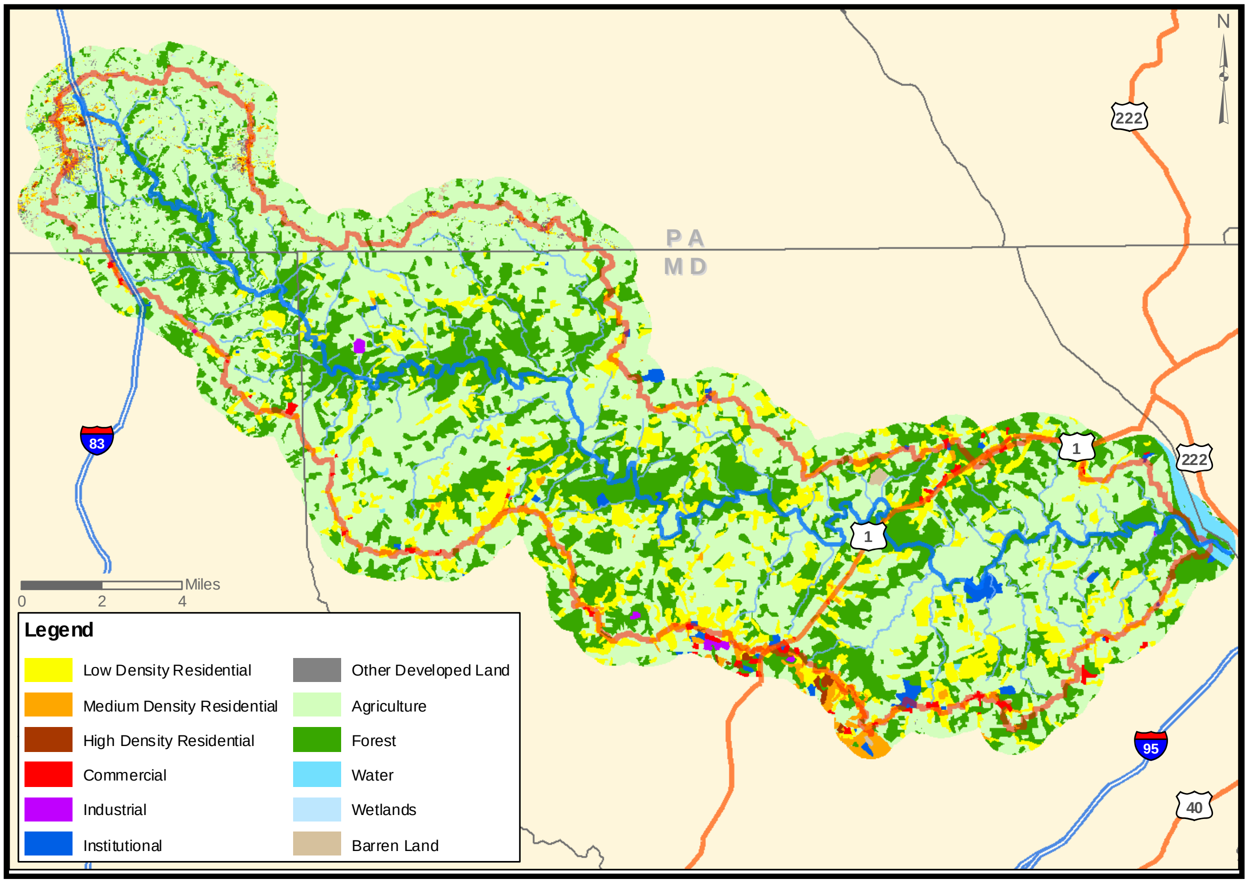

Figure 22. Land Use Map

B. Recreational Use

The water resources within the Deer Creek Watershed support a variety of recreational activities. In Harford County, the section of Deer Creek from Bond Road to the Susquehanna River is a 43.5-mile-long Class I-III section of whitewater according to American Whitewater, a boating advocacy group. The reach is typically utilized by paddlers of medium experience, as well as beginners that are accompanied by more experienced paddlers. Harford County's Eden Mill Nature Center and Park provides canoe launching, canoe trips, and offers canoe certification courses throughout the year. The section of Deer Creek within Rocks State Park is also very popular for canoeing, kayaking, tubing, and swimming. In a typical year, Deer Creek can be canoed from March to July, after which time flows typically become too low, and then again from September to November, after which time water temperatures typically become unsafe.

Upper Deer Creek, within Rocks State Park – Hidden Valley Natural Area and Eden Mill, is stocked with hatchery trout and is a very popular put-and-take trout fishery in the spring. Rainbow trout raised at the Albert Powell State Fish Hatchery in Hagerstown are stocked within the put-and-take trout management areas. Brown trout from private hatcheries also are occasionally stocked to provide another species of trout for anglers to catch. Fall stockings of hatchery trout extend the angling season for trout from October into early June. Deer Creek typically becomes too warm during the summer months to support year-round trout survival. Smallmouth bass are also found throughout Deer Creek in low numbers.

Historically, Deer Creek supported spawning runs of anadromous fish such as hickory shad, white perch, yellow perch, alewife, and blueback herring. A private dam built on Deer Creek at Wilson's Mill blocked approximately 25 miles of spawning habitat from these anadromous fishes. A Denil fish ladder was built and reopened historic anadromous fish spawning habitat in Deer Creek in 2000. Since the opening of the fish ladder, all of the historical species of anadromous fishes that ascended Deer Creek to spawn have been documented passing through the fish ladder. From late March through early May, the lower Deer Creek within the Susquehanna State Park is a popular fishing destination for anglers to catch and release hickory shad. Thousands of river herring and hickory shad run up Deer Creek to spawn. The Stafford Road Bridge area is a very popular destination for fly anglers. Due to the popularity of the spring shad run, the lower Deer Creek can be quite crowded and experience limited parking during the spring months.

C. Existing Water Demands

Water users in the Deer Creek Watershed include:

- Large permitted users in excess of 20,000 gallons per day (gpd) consumptive use and/or 100,000 gpd total use.
- Permitted and un-permitted users of less than 20,000 gpd, including small community and non-community water systems.

For this study, sources of data included:

- SRBC – users in excess of 20,000 gpd consumptive use and/or 100,000 gpd total use.
- MDE – permits for small community and non-community water systems, with exemptions for agricultural use.
- Pennsylvania Department of Environmental Protection (PADEP), York District Office – information on regulated water supply systems in York County.
- Population data from the U.S. Census Bureau.

Figure 23 and Table 12 show the major permitted users of water within the Deer Creek Watershed, and the permitted amounts.

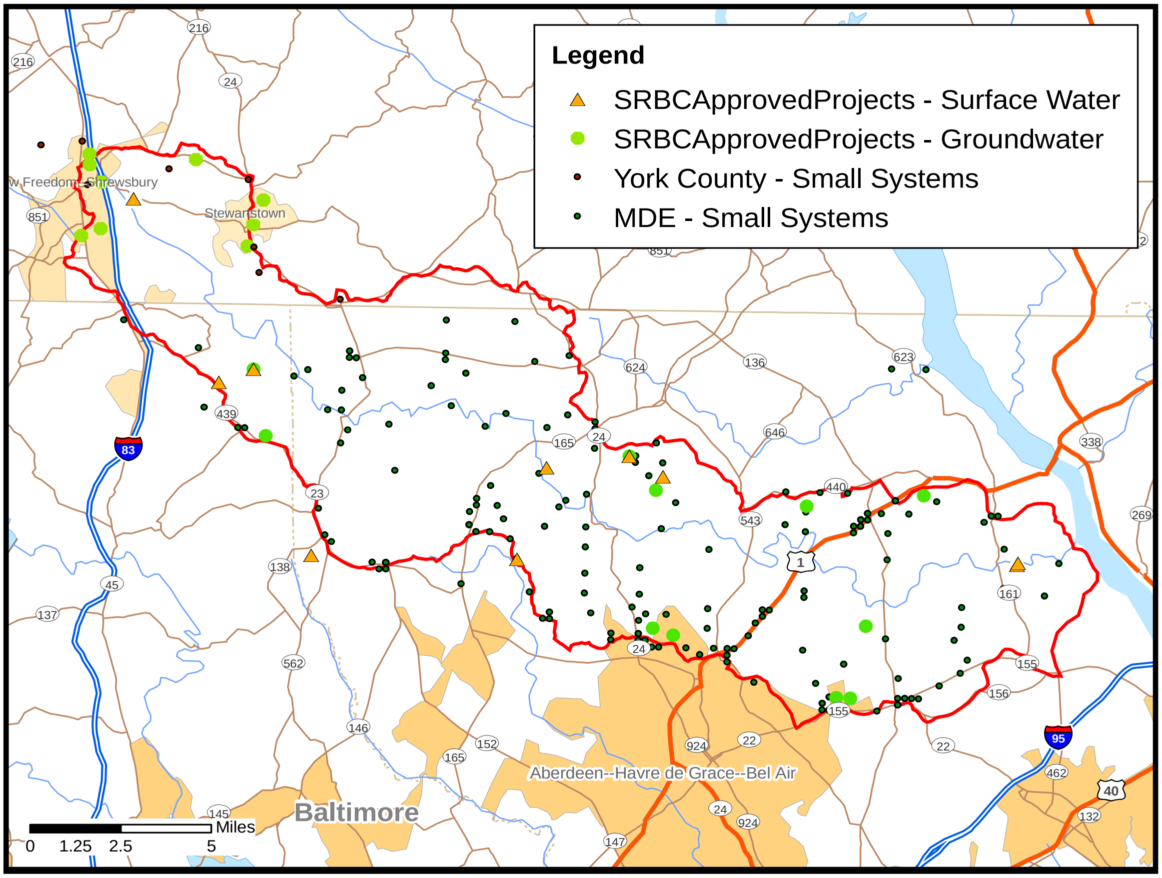

Figure 23. Major Water Users

Quantification of the water use in the basin cannot be exact with the available data. While permitted amounts are recorded by the states and SRBC, water users generally do not report detailed information on actual water use. The state of Pennsylvania recently enacted the Water Resources Planning Act of 2002 (Act 220), by which permitted users are required to report actual usage. In addition, domestic household uses are not reported or recorded by the state. Consequently, we chose to quantify the water use with the following steps:

- Assume that permitted users are withdrawing the permitted amount. Although most users typically withdraw less, it is conservative to assume they withdraw their full permitted amounts. This assumption is particularly valid considering the growth of use over time and the tendency of uses to peak during extreme conditions such as droughts.
- Assume domestic use based upon an average population density and typical volumes used in domestic settings, consistent with planning standards used in the state and local jurisdictions.
- Assume that consumptive use represents 10 percent of total use, which is consistent with the percentage demonstrated from usage records on an average annual basis.
- For farms, nurseries, and golf courses, assume consumptive use is 100 percent. Although a portion of irrigation water could potentially return to the groundwater system, it is unlikely to be significant or quantifiable, and operators are not apt to apply more water to the ground than can be uptaken by the plants.

Table 12. Summary of Major Water Users

	Annual Water Use (cfs)							
Water User	**Reported Use 2004 (PADEP)**	**SRBC Reported Use *(years)***	**SRBC Approved**	**MDE Permitted**	**Percentage from Deer Creek Watershed**	**Estimated Consumptive Use/Export (cfs)**	**Comments**	**Sources**
Shrewsbury Boro, Pa. (including Forest Lakes Water System)	0.55	0.3 - 0.42 *(1999 to 2004)*	1.07		~ 50%	0.53	consumptive use: exports to WWTP	SRBC-approved projects PADEP projects
Stewartstown Boro Authority, Pa. (excluding imports from York Water Co.)	0.34	.01 - 0.2 *(2001 to 2004)*	0.43		~ 50%	0.02		SRBC-approved projects PADEP projects
Stewartstown Boro Authority, Pa. (imports from York Water Co.)	0.11	---	---		0%	-0.10	Estimate based upon discussions with Stewartstown personnel	SRBC-approved projects
York County Solid Waste Authority Golf Course (Consumptive Use)	---	---	0.31		100%	0.31		SRBC-approved projects
Geneva Farm Golf Club (Consumptive Use)	---	.02 - 0.18 *(1992 to 2005)*	0.04		100%	0.04	Assume all use is consumptive	SRBC-approved projects MDE Files
City of Aberdeen Deer Creek Use Chapel Hill Intake	---	2.7 - 3.7 *(2003 to 2005)*	4.6	5.1	100%	5.10	Use max permitted amount all water exported	SRBC-approved projects MDE Files
Small Permitted Users of >10,000 gpd in Maryland (16 permits)	---	---	---	0.78	100%	0.53		SRBC-approved projects MDE Files
Small Permitted Users of <10,000 gpd in Maryland (179 permits)	---	---	---	0.479	100%	0.05		MDE Files
Small Permitted Users in Pa. (3 users, no use data)	---	---	---	0.24	100%	0.10		PADEP Files
Remaining Small Users - Residential (Total Use ~ 10.6 cfs)	---	---	---	---	100%	1.06	Population Density of 0.89 People/Acre (Assume 70 gpd/person)	Census Data

D. Water Budget

The summary water budget is shown in Table 13. The budget was developed for three periods: an average rainfall year, the year 2002 (the driest year in the period of record), and a relatively wet year (2004). There are several components of this budget that were estimated using the best available data. These include the estimated quantities of consumptive use that were developed from the PADEP, MDE, and SRBC databases, as described above. Although these components are not known with great precision, it is clear that they represent only a small percentage of the total water budget. They are shown in italics in Table 13. *Because this study is assessing water availability at Darlington, the APG use is not included.*

Similarly, there is a relatively small, but still significant amount of water that is being exported from the watershed in the vicinity of Shrewsbury. Groundwater pumped from the Shrewsbury well field is distributed to homes and businesses with private disposal systems, some of which are outside of the Deer Creek Watershed boundaries. This volume of water has not been quantified. In addition, Shrewsbury's municipal wastewater is all discharged to the New Freedom wastewater treatment plant, and ultimately the Codorus Creek Watershed.

The water budget begins with the amount of water provided by precipitation as the total available water in the watershed. The stream gage records provide an estimate of the quantity of water that is drained from the watershed to the Susquehanna River. Other inputs and removals (through water purveyors and consumptive uses) are added and subtracted to adjust the total. The quantity remaining – that amount of water that does not flow into the river and is not withdrawn for use – can only leave the watershed through one remaining route. It is the quantity of water that evaporates from the surface or is transpired by vegetation during the growing season. As shown in Table 13, evapotranspiration accounts for the bulk of the water budget in normal, dry, and wet years.

Table 13. Summary Water Budget

Parameter		Average (cfs)	2004 (cfs)	2002 (cfs)
Precipitation		577.42	779.86	360.92
Adjustments	Imports [1]	*0.10*	*0.10*	*0.10*
	Exports [2]	*-0.27*	*-0.27*	*-0.27*
	Streamflow [3]	-221.3	-321.7	-87.3
	Subtotal	-221.47	-321.87	-87.47
Percentage of Precipitation		38.3%	41.2%	24.2%
Water Use (estimated consumptive use Upstream of Darlington Gage)		*-2.63*	*-2.63*	*-2.63*
Percentage of Precipitation		0.3%	0.3%	0.6%
Evapotranspiration		-354.1	-456.1	-271.6
Percentage of Precipitation		61.3%	58.5%	75.3%

Estimated values shown in italics.

1 Stewartstown imports from York Water Co. (estimated to be 70,000 gpd).

2 Exports from public use outside DC watershed, and exports to New Freedom wastewater treatment plant – Shrewsbury area.

3 Flows based upon Rocks, Maryland, gage, scaled to area of watershed upstream of Darlington (ratio of 1.67).

VI. REGULATORY ENVIRONMENT

The Deer Creek Watershed is situated within two states – Maryland and Pennsylvania, and within three counties – Harford and Baltimore in Maryland, and York in Pennsylvania. As a result, the water resources of the Deer Creek Watershed are subject to a variety of state and local regulations, in addition to federal regulations. SRBC – an interstate Compact commission – also regulates water use in the watershed.

The Codes of Regulations of Maryland, Pennsylvania, the federal government, and the relevant counties and towns were reviewed. Regulations that impact water supply are summarized in Appendix A. Regulations that address solely water quality were not included. For the purposes of this evaluation, the most important regulations are those that address appropriation of groundwater and surface water:

- Maryland COMAR 26.17.06 (Water Appropriation or Use)
- Pennsylvania Code Title 25, Section 109
- Federal Regulations Establishing the SRBC (CFR 18.803, Conservation of Power and Water Resources)

The Deer Creek Watershed is subject to several special state and local programs. These programs primarily address water quality, although some aspects of water quality are inseparable from quantity of water supply.

A. Deer Creek Scenic River

Deer Creek was designated a Scenic River by the Maryland legislature in 1973. In 1978, the Deer Creek Scenic River district was established in the Harford County Code to preserve Deer Creek as a free-flowing stream and to preserve and protect its natural and cultural values for present and future generations. The Deer Creek Scenic River Advisory Board reviews proposals for new development within 150 feet of the banks of the creek, and makes recommendations concerning management and preservation of Deer Creek (MDE and Harford County, 2006).

B. Lower Deer Creek Valley Rural Legacy Area (Maryland)

The Lower Deer Creek Valley Rural Legacy Area was established in 1999. The goal of the Maryland Rural Legacy Area program is to preserve the historic rural character of the watersheds while helping to protect their water quality. The focus of the Lower Deer Creek Valley Rural Legacy Area is on acquiring perpetual easements on properties that adjoin Deer Creek, its tributaries, and properties that are adjacent to other protected properties (MDE and Harford County, 2006).

C. Agricultural Section 319 Targeted Watershed

The Deer Creek Watershed has received Section 319 funds as a Maryland Agricultural Water Quality Priority Watershed due to its potential for nutrient loading. The Harford County

Soil Conservation District has been the recipient of Section 319 funds to support the preparation of soil conservation and water quality plans on farms within the watershed.

Other special management areas within the Deer Creek Watershed include state parks (Rocks State Park, Palmer State Park, Susquehanna State Park), county parks (Eden Mill Park, Parker Conservation Area), and the APG Churchville test site.

VII. STAKEHOLDERS FOR THE DEER CREEK WATERSHED

Stakeholders for the Deer Creek Watershed include state and local agencies, community organizations, and environmental groups. The stakeholders invited to participate during the course of this project are:

- Aberdeen Proving Ground
- Baltimore County Department of Environmental Protection and Resource Management
- Baltimore County Office of Planning
- City of Aberdeen, Maryland
- Deer Creek Valley Rural Legacy Board
- Deer Creek Scenic River Advisory Board
- Deer Creek Watershed Association
- Dublin/Darlington Community Council
- Dublin/Darlington Recreation Council
- Eden Mill Nature Center
- Forest Conservancy District Board for Harford County
- Harford Community College
- Harford County Agricultural Marketing Cooperative
- Harford County Agriculture Preservation Board
- Harford County Chamber of Commerce
- Harford County Department of Planning and Zoning
- Harford County Department of Public Works
- Harford County Economic Development Council, Agricultural Advisory Board
- Harford County Farm Bureau
- Harford County Legislative Delegation
- Harford County Soil Conservation District
- Harford Land Trust
- Homebuilders Association of Maryland
- Hopewell Township
- Izaak Walton League (Bel Air, Maryland)
- Izaak Walton League (Churchville, Maryland)
- Jarrettsville/Norrisville Community Council
- Lower Susquehanna Heritage Greenway
- Maryland Department of Agriculture
- Maryland Department of the Environment
- Maryland Department of Natural Resources
- Maryland Department of Planning
- Maryland Nursery and Landscape Association
- Mid-Atlantic Environmental Law Center
- Pennsylvania Department of Environmental Protection, Southcentral Region Office
- Pennsylvania Fish and Boat Commission
- Rocks State Park
- Shrewsbury Borough Public Works

- Shrewsbury Township Board of Supervisors
- Stewartstown Borough Department of Sewer and Water
- Susquehanna State Park
- Trout Unlimited – Chapter 167, Maryland
- U.S. Army Corps of Engineers – Baltimore District
- U.S. Fish & Wildlife Service
- Upper Western Shore Tributary Team
- Watershed Alliance of York
- Whiteford/Cardiff/Pylesville/Street (Maryland) Community Council
- York County Conservation District
- York County Planning Commission
- York Water Company

VIII. WATER AVAILABILITY ISSUES

The greatest challenges for water supply issues in the Deer Creek Watershed are population growth and urbanization within and adjacent to the watershed, as well as the potential impact of such growth on the ability of the resource to meet long-term needs for agricultural operations. In the following sections, population growth and water use projections are developed for the Deer Creek Watershed.

At the current time, a primary issue of concern is the BRAC plan for APG. Harford County is undertaking significant planning steps to address potential population growth associated with this BRAC (Harford County, 2007). Surface water and groundwater resources in the Deer Creek Watershed may be appropriate resources to support this future development outside the watershed. Similarly, the towns of Bel Air and portions of Stewartstown and Shrewsbury lie outside of and adjacent to the Deer Creek Watershed. As future population growth is anticipated to nucleate around existing communities and roads, these areas are also of concern. Other demands for water use outside of the Deer Creek Watershed are not specifically addressed in this report, however.

A natural water budget for the Deer Creek Watershed was presented previously in this report. In this section, we present additional evaluations of water availability, taking into account existing and future (projected) water uses and losses. Two primary tools are used to evaluate possible conflicts related to future availability: (1) tables of water supply and demand are used to estimate the timing and locations of potential conflicts; and (2) a numerical model that simulates groundwater and surface water interactions is used to evaluate the timing of impacts on the watershed for hypothetical new appropriations.

A. Establishing Available Water Resources

To assess the availability of water resources in the Deer Creek Watershed for future allocation, water balance analyses for both average and drought years were developed. The analyses followed water allocation techniques of the SRBC and MDE Water Supply Program. These calculations are conservative and designed to assist regulators in assessing water availability rather than reflect the "natural" water budget. The assumptions used in the analyses include:

- Water use values are based upon the quantities of water permitted for each user rather than the amounts actually withdrawn. Most permit holders do not typically use their full allocation on a routine basis.
- The water use values represent the quantities of water withdrawn, not the quantity of water consumptively used (see Section I). Much of the water withdrawn is eventually returned through wastewater discharges or via on-lot septic systems. However, there is not good information available for the quantity returned, particularly for un-permitted uses, and there is little information on the quantity of Deer Creek water that is returned to watersheds outside Deer Creek, although a portion of it certainly is.
- The total available water supply is derived solely from base flow rather than total flow. Even during prolonged droughts, sporadic rainfall will temporarily boost

streamflows. That additional water is not significant and is not taken into account in this analysis.

- Because the base flow values used here are derived from the stream field measurements completed in 2006 and the historical gaged streamflow data, they are impacted by the consumptive use of water occurring in the watershed. As a result, these derived base flow values are slightly less than the natural base flow values. The quantity of consumptive use is a small percentage of the total available water (Table 13), so use of the derived base flow values should be an acceptable and conservative proxy for total natural base flow.

For the purposes of the water balance analyses, the maximum amount of water available for future use in the watershed is calculated to be the portion of base flow remaining after existing allocations and uses are taken into account. The most obvious of these are permitted users (such as industries and municipal water suppliers) and other generally un-permitted uses such as small agricultural operations and domestic wells. Estimated totals for these uses were developed previously in this report and are deducted from the base flow quantity for these water balance analyses.

There is also a less obvious use of the base flow in Deer Creek that must be considered; commonly referred to as the passby or flowby, it is the amount of water deemed necessary for preserving riparian and habitat needs. It is the policy of MDE and SRBC in approving water uses that a withdrawal cannot continue if flow conditions on the stream decline below the passby. In a sense, this policy is an allocation of water for riparian/aquatic needs; thus the passby is also deducted from the base flow when performing a water balance.

SRBC Policy No. 2003-01, dated November 8, 2002, offers guidelines on the determination of passby flows for the protection of aquatic resources and other uses, and the prevention of water quality degradation and adverse lowering of streamflow levels downstream from the point of a withdrawal. The passby determination is based on the location, drainage, state-designated stream classification, published species and habitat condition information, and state fishery management classification of the stream. In no case is the recommended passby less than the 7Q10 flow, and conditions usually dictate that a more protective level be imposed. Such was the case on Deer Creek at the site of the intake near Darlington used to service APG; local fishery needs suggested that a seasonal passby was appropriate. The passby during March, April, May, and June was determined to be the flow equal to 30 percent of the calculated average daily flow (ADF) at the site of the intake (69 cfs) and 20 percent of the ADF (46 cfs) the remainder of the year. At this particular site, 20 percent of ADF was approximately equal to the calculated 7Q10 value. It is these passby flows that were used in the water balance analysis.

Using the procedure described in the paragraphs above, Table 14 presents water balances for the watershed at a point located approximately at Darlington, subdivided by month of use. The average water balance is based upon the 30-year normal total flow at the USGS gage at Rocks, Maryland, adjusted to the Darlington gage site using techniques discussed earlier in this report. The 1-in-10-year drought flow is based upon the three lowest flow years (or tenth percentile; 1981, 2001, and 2002) for the same period. For the drought year calculation, the un-permitted water use amount was multiplied by a factor of 1.4 to account for the increase in water use typically seen during droughts.

Table 14. Monthly Comparison of Available and Allocated Water in Average and Drought Years, Using the SRBC Passby Flow at Darlington

	Total Flow at Rocks (cfs)	Base Flow at Rocks [1] (cfs)	Base Flow at Darlington [2] (cfs)	Seasonal Passby Amount [3] (cfs)	Permitted Use Upstream of Darlington (cfs)	Un-permitted Use Upstream of Darlington [4] (cfs)	Permitted Use for APG (cfs)	Undedicated Resource (cfs)
Average – 30-Year Normal (1974 to 2005)								
Jan	161.9	108.5	181.1	-46	-3.64	-3.09	-4.62	123.76
Feb	166.6	111.6	186.4	-46	-3.64	-3.09	-4.62	129.05
Mar	187.1	125.4	209.4	-69	-3.64	-3.09	-4.62	129.04
Apr	173.8	116.4	194.4	-69	-3.64	-3.09	-4.62	114.06
May	159.4	106.8	178.3	-69	-3.64	-3.09	-4.62	97.95
Jun	128.4	86.0	143.7	-69	-3.64	-3.09	-4.62	63.32
Jul	105.0	70.3	117.4	-46	-3.64	-3.09	-4.62	60.09
Aug	78.8	52.8	88.2	-46	-3.64	-3.09	-4.62	30.85
Sep	93.9	62.9	105.1	-46	-3.64	-3.09	-4.62	47.70
Oct	91.7	61.4	102.6	-46	-3.64	-3.09	-4.62	45.21
Nov	106.1	71.1	118.7	-46	-3.64	-3.09	-4.62	61.39
Dec	131.3	88.0	146.9	-46	-3.64	-3.09	-4.62	89.53
1-in-10-Year Drought of 30-Year Normal (1974 to 2005)								
Jan	57.9	38.8	64.8	-46	-3.64	-4.33	-4.62	6.21
Feb	89.5	60.0	100.2	-46	-3.64	-4.33	-4.62	41.59
Mar	92.4	61.9	103.4	-69	-3.64	-4.33	-4.62	21.80
Apr	92.1	61.7	103.1	-69	-3.64	-4.33	-4.62	21.46
May	73.9	49.5	82.7	-69	-3.64	-4.33	-4.62	1.15
Jun	62.9	42.1	70.3	-69	-3.64	-4.33	-4.62	-11.25
Jul	41.1	27.5	46.0	-46	-3.64	-4.33	-4.62	-12.63
Aug	35.0	23.5	39.2	-46	-3.64	-4.33	-4.62	-19.41
Sep	32.1	21.5	35.9	-46	-3.64	-4.33	-4.62	-22.71
Oct	45.1	30.2	50.4	-46	-3.64	-4.33	-4.62	-8.15
Nov	56.6	37.9	63.4	-46	-3.64	-4.33	-4.62	4.76
Dec	73.3	49.1	82.0	-46	-3.64	-4.33	-4.62	23.38

[1] Calculated as 67 percent of total flow.
[2] Calculated as 1.67 times the base flow at Rocks.
[3] Using the SRBC passby condition for the intake at Darlington serving APG.
[4] Based upon estimated population of 25,000 not connected to public water.

As can be seen from Table 14 and Figure 24, under existing conditions, the cumulative demand at Darlington currently exceeds the available flow during the period June through October in the 1-in-10 drought years. Under average conditions, supply exceeds demand by approximately 30 cfs during the lowest flow month of August.

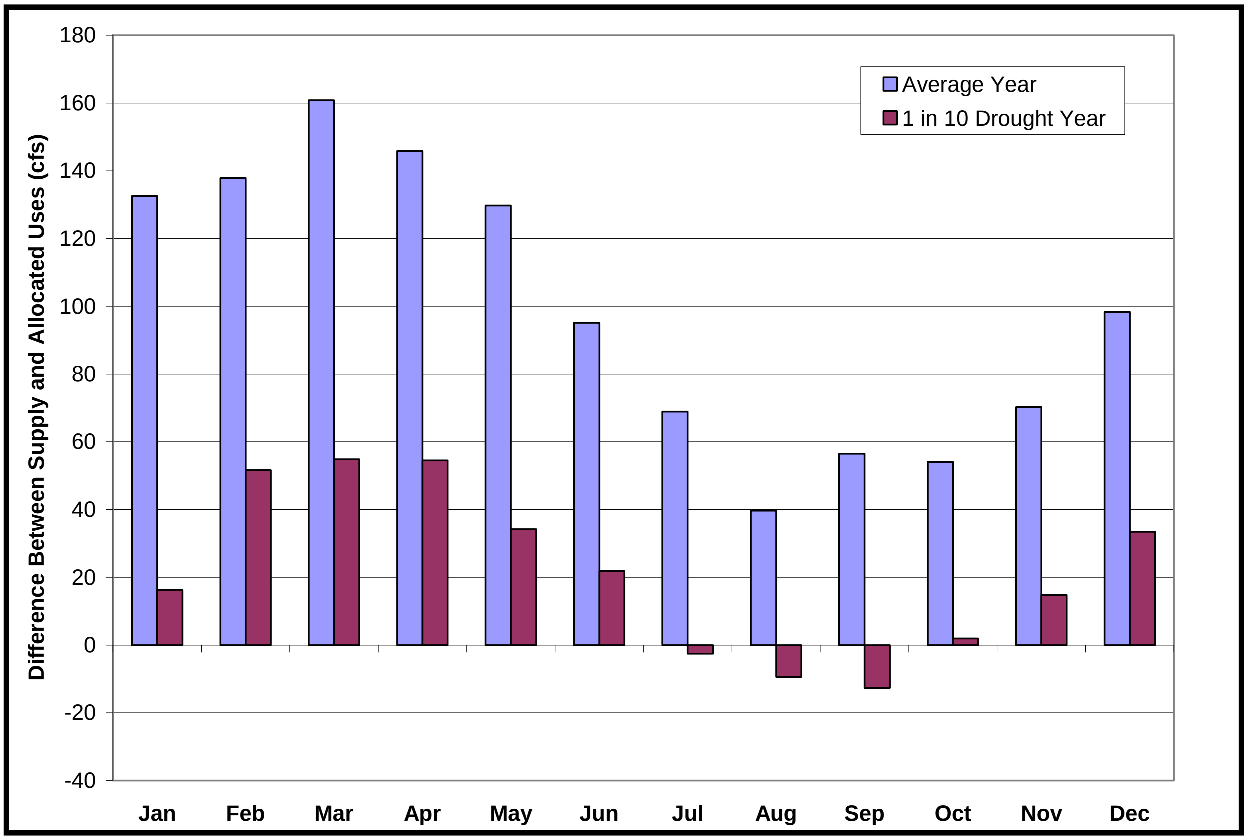

Figure 24. Monthly Comparison of Available and Allocated Water – Average and Drought Years

To demonstrate the importance of the passby flow in water allocations, the same analysis was performed using another standard, the Maryland Method. Unlike the 7Q10 calculation, which uses an analysis of annual data, the Maryland Method uses statistics based on monthly flow data, which recognizes that each month of the year has its own natural flow pattern that can differ significantly from other months. As a result, the method is more responsive to instream needs through the course of the year and is thus theoretically better at protecting aquatic habitat than the 7Q10. Also, the 7Q10 was never intended as a habitat protection measure, and actually has its origins in designs for the assimilation of wastewater discharges.

To implement an example of the Maryland Method, the monthly flow data at the Rocks gage were analyzed to extract the 85 percent exceedence value for each month over the period of record. The method then entails grouping months into seasons based on similarity of flow patterns, and deriving another exceedence value for the season. The method yielded a winter/spring passby of 89 cfs and a summer/fall passby of 57 cfs; both limits are considerably greater than the 7Q10 value at Darlington and the passby enforced by SRBC and MDE for the intake serving APG. Correspondingly, the comparison of available and allocated water in Table 15 shows greater deficits in more months.

Table 15. Monthly Comparison of Available and Allocated Water in Average and Drought Years, Using the Maryland Method for Passby Flow

	Total Flow at Rocks (cfs)	Base Flow at Rocks [1] (cfs)	Base Flow at Darlington [2] (cfs)	Seasonal Passby Amount [3] (cfs)	Permitted Use Upstream of Darlington (cfs)	Un-permitted Use Upstream of Darlington [4] (cfs)	Permitted Use for APG (cfs)	Undedicated Resource (cfs)
Average – 30-Year Normal (1974 to 2005)								
Jan	161.9	108.5	181.1	-89	-3.64	-3.09	-4.62	80.76
Feb	166.6	111.6	186.4	-89	-3.64	-3.09	-4.62	86.05
Mar	187.1	125.4	209.4	-89	-3.64	-3.09	-4.62	109.04
Apr	173.8	116.4	194.4	-89	-3.64	-3.09	-4.62	94.06
May	159.4	106.8	178.3	-89	-3.64	-3.09	-4.62	77.95
Jun	128.4	86.0	143.7	-89	-3.64	-3.09	-4.62	43.32
Jul	105.0	70.3	117.4	-57	-3.64	-3.09	-4.62	49.09
Aug	78.8	52.8	88.2	-57	-3.64	-3.09	-4.62	19.85
Sep	93.9	62.9	105.1	-57	-3.64	-3.09	-4.62	36.70
Oct	91.7	61.4	102.6	-57	-3.64	-3.09	-4.62	34.21
Nov	106.1	71.1	118.7	-57	-3.64	-3.09	-4.62	50.39
Dec	131.3	88.0	146.9	-89	-3.64	-3.09	-4.62	46.53
1-in-10-Year Drought of 30-Year Normal (1974 to 2005)								
Jan	57.9	38.8	64.8	-89	-3.64	-4.33	-4.62	-36.79
Feb	89.5	60.0	100.2	-89	-3.64	-4.33	-4.62	-1.41
Mar	92.4	61.9	103.4	-89	-3.64	-4.33	-4.62	1.80
Apr	92.1	61.7	103.1	-89	-3.64	-4.33	-4.62	1.46
May	73.9	49.5	82.7	-89	-3.64	-4.33	-4.62	-18.85
Jun	62.9	42.1	70.3	-89	-3.64	-4.33	-4.62	-31.25
Jul	41.1	27.5	46.0	-57	-3.64	-4.33	-4.62	-23.63
Aug	35.0	23.5	39.2	-57	-3.64	-4.33	-4.62	-30.41
Sep	32.1	21.5	35.9	-57	-3.64	-4.33	-4.62	-33.71
Oct	45.1	30.2	50.4	-57	-3.64	-4.33	-4.62	-19.15
Nov	56.6	37.9	63.4	-57	-3.64	-4.33	-4.62	-6.24
Dec	73.3	49.1	82.0	-89	-3.64	-4.33	-4.62	-19.62

[1] Calculated as 67 percent of total flow.
[2] Calculated as 1.67 times the base flow at Rocks.
[3] Using the Maryland Method.
[4] Based upon estimated population of 25,000 not connected to public water.

Another way to assess water availability is to perform an analysis of the frequency of occurrence of the passby flow designated for a stream reach. To illustrate this technique, the flow record developed for the Darlington gage was subjected to the seasonal passby imposed on the intake that serves APG. Tabulation was made of days exhibiting a flow below the appropriate seasonal passby, and the number of days was totaled for each year. The results are shown on Figure 25. Although the occurrence of flows less than the passby is not that frequent – in only 13 of 82 years, or 16 percent – the implication is that the source is unavailable on average about once every 6 years. The duration of the unavailability is also worth noting; in 4 years, it is for a month or more, and in 2 additional years, it is for a period of 2 to 3 weeks. An interruption of that frequency and/or duration is sufficient to render a water supply unreliable.

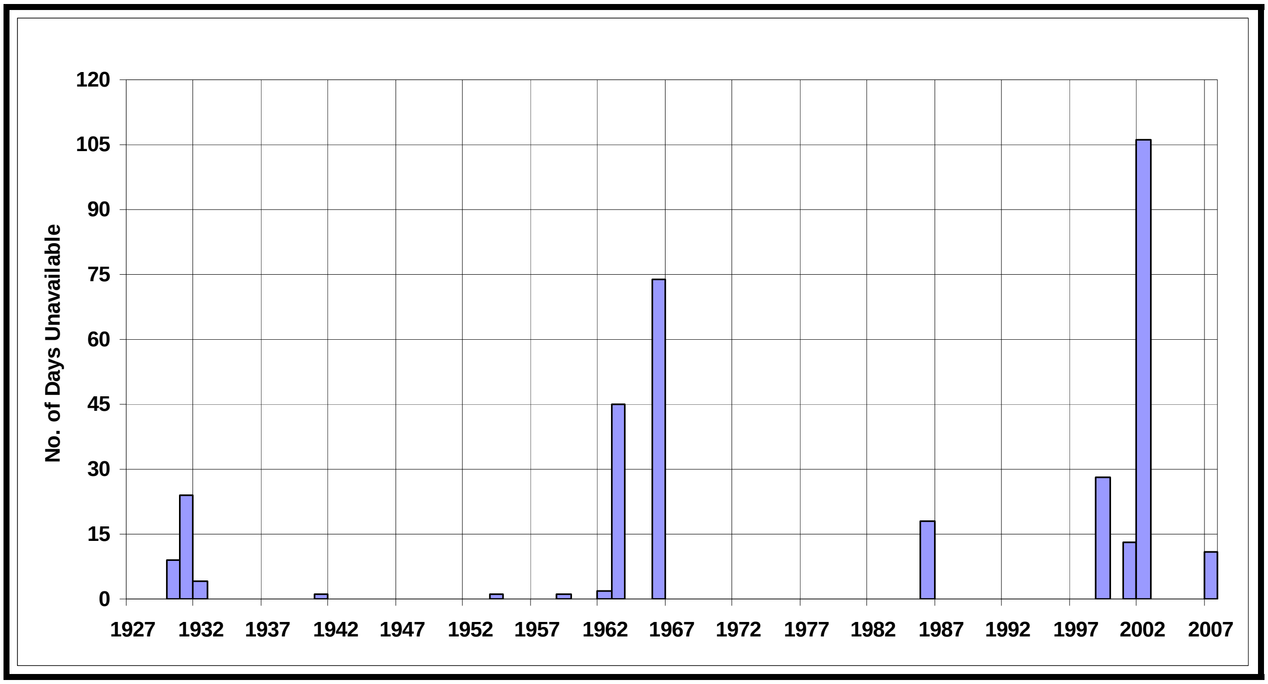

Figure 25. Occurrences of Passby Flow at Darlington

To better consider the geographic impact of water demands across the watershed, the availability of water for allocation was also evaluated by subwatersheds. Table 16 lists water availability for average year conditions, and Table 17 lists water availability for drought year conditions. Existing permitted user demands were allocated to the subwatershed in which the permitted source is located. Un-permitted residential use was incorporated using a general population density of 0.27 persons per acre (173 persons per square mile), applied evenly across the watershed. This population density is estimated from the watershed population, excluding those York County residents assumed to be receiving public water supply. Public water systems in these areas provide a substantial portion of the supply and are already accounted for under the permitted amounts. Therefore, no additional un-permitted demand was incorporated for the Deer Creek Headwaters or Ebaugh's Creek subwatersheds. The total available water for each subwatershed was estimated as base flow originating as recharge within the subwatershed. This is, of course, not an entirely accurate assumption, as water available for use within a subwatershed may originate from upstream in the main stem of Deer Creek. Nonetheless, this approach provides some insight into the impact of permitting for groundwater use and surface water use from Deer Creek tributaries.

Table 16. Average Year Allocation of Water Resources

	Sub-watershed	Basin Area (mi^2)	Base Flow [2] (cfs/mi^2)	Base Flow in Watershed [2] (cfs)	Permitted Water Use [3] (cfs)	Un-permitted Residential Use (cfs @ 0.27 person/acre)	7Q10 Passby Allowance (cfs)	Undedicated Base Flow (cfs)	Percentage of Base Flow Undedicated
Cool Branch Run	1	2.47	0.77	1.91	-0.01	-0.05	-0.65	1.19	63%
Stout Bottle Branch - Cabbage Run	2	7.25	1.02	7.39	-0.12	-0.16	-1.90	5.21	71%
Thomas Run	3	8.13	0.77	6.26	-0.05	-0.17	-2.14	3.90	62%
Mill Brook	4	4.67	0.77	3.60	-0.03	-0.10	-1.23	2.24	62%
Hollands Branch	5	3.38	0.77	2.60	-0.03	-0.07	-0.89	1.61	62%
UNT at Thomas Bridge Rd	6	4.36	1.02	4.45	-0.28	-0.09	-1.15	2.93	66%
Saint Omer Branch [1]	7	11.25	0.90	10.07	-0.06	-0.24	-2.95	6.81	68%
Deer Creek – Mid	8	5.29	1.02	5.40	-0.01	-0.11	-1.39	3.89	72%
South Stirrup - North Stirrup Run	9	6.55	1.02	6.68	-0.01	-0.14	-1.72	4.81	72%
Rock Hollow - Kellogg - Gladden Branches	10	12.50	1.02	12.75	-0.23	-0.27	-3.28	8.97	70%
UNT south of Falling Branch	11	0.63	1.02	0.64	-0.01	-0.01	-0.16	0.45	71%
UNT west of Falling Branch	12	0.38	1.02	0.39	0.00	-0.01	-0.10	0.28	72%
Little Deer Creek	13	14.36	1.02	14.64	-0.02	-0.31	-3.77	10.54	72%
Falling Branch	14	6.47	1.02	6.60	-0.01	-0.14	-1.70	4.75	72%
Big Branch	15	7.99	1.02	8.15	-0.00	-0.17	-2.10	5.88	72%
Island - Jackson - Plumtree Branches	16	29.01	1.02	29.59	-0.18	-0.62	-7.62	21.17	72%
Ebaugh’s Creek	17	6.91	1.02	7.05	-0.65	0	-1.81	4.58	65%
Deer Creek Headwaters	18	17.33	1.02	17.68	-0.55	0	-4.55	12.58	71%
Graveyard Creek	19	1.62	0.77	1.24	-0.01	-0.03	-0.42	0.78	62%
Hopkins Branch	20	2.28	0.77	1.76	-0.01	-0.05	-0.60	1.10	63%
Tobacco Run	21	7.99	0.77	6.15	-0.16	-0.17	-2.10	3.72	61%
Buck Branch - Elbow Branch [3]	22	10.26	0.77	7.90	-0.01	-0.22	-2.69	4.98	63%
UNT east of Hollands Branch	23	0.05	0.77	0.04	0.00	-0.00	-0.01	0.03	63%
Entire Watershed		**171.13**		**162.93**	**-2.44**	**-3.14**	**-44.93**	**112.42**	**69%**

[1] Half of this watershed subject to 1.02 cfs/mi^2 recharge, and half subject to 0.77 cfs/mi^2 recharge.

[2] Value includes current consumptive use.

[3] Excluding APG permitted amount of 4.6 cfs.

Table 17. Drought Year Allocation of Water Resources

	Sub-watershed	Base Flow in Watershed [2] (cfs)	Drought Year Base Flow [3] (cfs)	Permitted Water Use (cfs)	Un-permitted Residential Use [4] (@ 0.27 person/acre)	Permitted and Un-permitted Water Use - Drought Year	7Q10 Passby Allowance (cfs)	Undedicated Base Flow (cfs)	Percentage of Base Flow Undedicated
Cool Branch Run	1	1.91	0.94	-0.01	-0.07	-0.08	-0.65	0.21	22%
Stout Bottle Branch - Cabbage Run	2	7.39	3.66	-0.12	-0.22	-0.34	-1.90	1.42	39%
Thomas Run	3	6.26	3.10	-0.05	-0.24	-0.29	-2.14	0.68	22%
Mill Brook	4	3.60	1.78	-0.03	-0.14	-0.17	-1.23	0.39	22%
Hollands Branch	5	2.60	1.29	-0.03	-0.10	-0.13	-0.89	0.27	21%
UNT at Thomas Bridge Rd	6	4.45	2.21	-0.28	-0.13	-0.41	-1.15	0.65	29%
Saint Omer Branch [1]	7	10.07	4.99	-0.06	-0.34	-0.40	-2.95	1.64	33%
Deer Creek – Mid	8	5.40	2.68	-0.01	-0.16	-0.17	-1.39	1.12	42%
South Stirrup - North Stirrup Run	9	6.68	3.31	-0.01	-0.20	-0.21	-1.72	1.38	42%
Rock Hollow - Kellogg - Gladden Branches	10	12.75	6.32	-0.23	-0.37	-0.61	-3.28	2.43	38%
UNT south of Falling Branch	11	0.64	0.32	-0.01	-0.02	-0.03	-0.16	0.13	40%
UNT west of Falling Branch	12	0.39	0.19	0.00	-0.01	-0.01	-0.10	0.08	42%
Little Deer Creek	13	14.64	7.26	-0.02	-0.43	-0.45	-3.77	3.04	42%
Falling Branch	14	6.60	3.27	-0.01	-0.19	-0.20	-1.70	1.37	42%
Big Branch	15	8.15	4.04	-0.00	-0.24	-0.24	-2.10	1.70	42%
Island - Jackson - Plumtree Branches	16	29.59	14.67	-0.18	-0.87	-1.04	-7.62	6.01	41%
Ebaugh's Creek	17	7.05	3.49	-0.65	0	-0.65	-1.81	1.03	29%
Deer Creek Headwaters	18	17.68	8.76	-0.55	0	-0.55	-4.55	3.66	42%
Graveyard Creek	19	1.24	0.62	-0.01	-0.05	-0.06	-0.42	0.13	22%
Hopkins Branch	20	1.76	0.87	-0.01	-0.07	-0.08	-0.60	0.19	22%
Tobacco Run	21	6.15	3.05	-0.16	-0.24	-0.40	-2.10	0.55	18%
Buck Branch - Elbow Branch [3]	22	7.90	3.91	-0.01	-0.31	-0.32	-2.69	0.91	23%
UNT east of Hollands Branch	23	0.042	0.021	0.00	-0.002	-0.002	-0.01	0.005	23%
Entire Watershed		**163**	**80.76**	**-2.44**	**-4.40**	**-6.84**	**-44.93**	**29.00**	**36%**

[1] Half of this watershed subject to 1.02 cfs/mi^2 recharge, and half subject to 0.77 cfs/mi^2 recharge.

[2] Value includes current consumptive use.

[3] Excluding APG permitted amount of 4.6 cfs.

[4] Residential use increased by 40 percent in drought year.

Comparison of Tables 16 and 17 indicates that during average and drought years, the total amount of allocated water on an *annual* basis is less than the total available resource on an *annual* basis. To further investigate the geographic and temporal impact of water demands across the watershed, the availability of water for allocation was evaluated at three subwatersheds, subdivided by month of use. The three watersheds selected for analysis were Ebaugh's Creek, Deer Creek Headwaters, and Hopkins Branch subwatersheds. Tables 18, 19, and 20 list water availability for average 30-year normal and 1-in-10-year drought conditions at the selected subwatersheds. Figures 26, 27, and 28 depict cumulative demand compared to available flow, on a monthly basis, under average and drought year conditions at the selected subwatersheds.

As can be seen from Tables 18, 19, and 20 and Figures 26, 27, and 28, under existing conditions, the cumulative demand at each of the selected subwatersheds currently exceeds the available flow during August and September in the 1-in-10 drought years. In addition, cumulative demand also currently exceeds the available flow during July at Ebaugh's Creek subwatershed, and during June, July, and October at Hopkins Branch subwatershed, in drought years. Under average conditions for each of the selected subwatersheds, supply exceeds demand by an approximate minimum of 46 percent during the lowest flow month of September.

Table 18. Monthly Comparison of Available and Allocated Water at Ebaugh's Creek Subwatershed – Average and Drought Years

	Base Flow at Ebaugh's Creek (cfs)	Permitted Water Use (cfs)	Un-permitted Residential Use (cfs @ 0.27 person/acre)	Transferred Passby Allowance (cfs)	Undedicated Base Flow (cfs)	Percentage of Base Flow Undedicated
Average – 30-Year Normal (1974 to 2005)						
Jan	8.64	-0.65	0.00	-1.86	6.13	71%
Feb	8.89	-0.65	0.00	-1.86	6.39	72%
Mar	9.99	-0.65	0.00	-2.78	6.55	66%
Apr	9.27	-0.65	0.00	-2.78	5.84	63%
May	8.51	-0..65	0.00	-2.78	5.07	60%
Jun	6.85	-0.65	0.00	-2.78	3.42	50%
Jul	5.60	-0.65	0.00	-1.86	3.10	55%
Aug	4.21	-0.65	0.00	-1.86	1.70	40%
Sep	5.01	-0.65	0.00	-1.86	2.51	50%
Oct	4.89	-0.65	0.00	-1.86	2.39	49%
Nov	5.66	-0.65	0.00	-1.86	3.16	56%
Dec	7.01	-0.65	0.00	-1.86	4.50	64%
1-in-10-Year Drought of 30-Year Normal (1974 to 2005)						
Jan	3.23	-0.65	0.00	-1.86	0.72	22%
Feb	4.99	-0.65	0.00	-1.86	2.48	50%
Mar	5.15	-0.65	0.00	-2.78	1.72	33%
Apr	5.13	-0.65	0.00	-2.78	1.70	33%
May	4.12	-0..65	0.00	-2.78	0.69	17%
Jun	3.50	-0.65	0.00	-2.78	0.07	2%
Jul	2.29	-0.65	0.00	-1.86	-0.22	-9%
Aug	1.95	-0.65	0.00	-1.86	-0.55	-28%
Sep	1.79	-0.65	0.00	-1.86	-0.72	-40%
Oct	2.51	-0.65	0.00	-1.86	0.01	0%
Nov	3.16	-0.65	0.00	-1.86	0.65	21%
Dec	4.08	-0.65	0.00	-1.86	1.58	39%

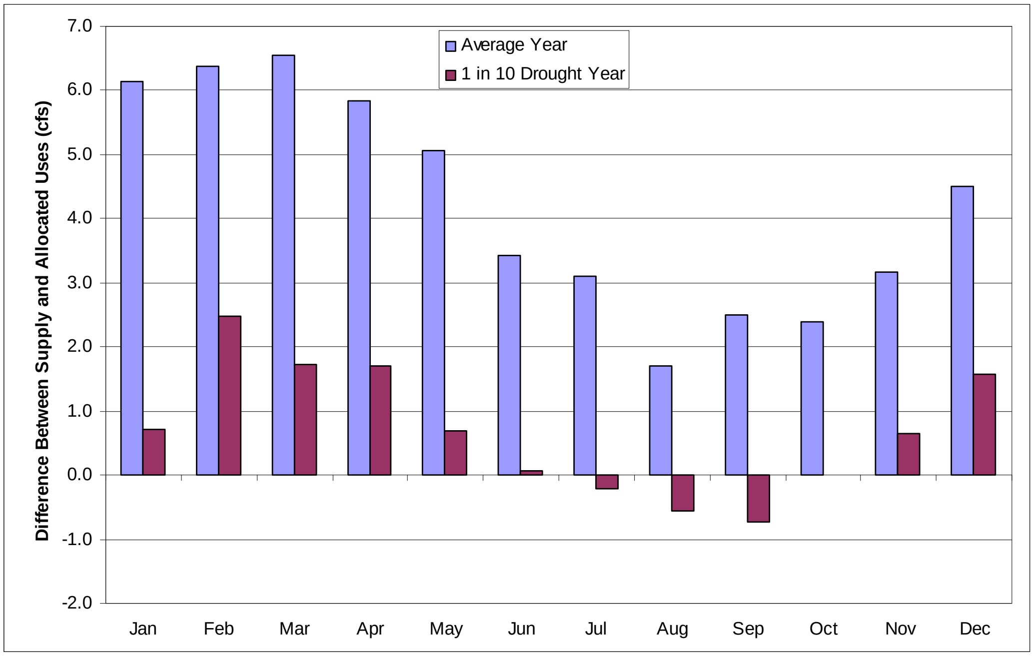

Figure 26. Monthly Comparison of Available and Allocated Water at Ebaugh's Creek Subwatershed – Average and Drought Years

Table 19. Monthly Comparison of Available and Allocated Water at Deer Creek Headwaters Subwatershed – Average and Drought Years

	Base Flow at Deer Creek Headwaters (cfs)	Permitted Water Use (cfs)	Un-permitted Residential Use (cfs @ 0.27 person/acre)	Transferred Passby Allowance (cfs)	Undedicated Base Flow (cfs)	Percentage of Base Flow Undedicated
Average – 30-Year Normal (1974 to 2005)						
Jan	21.68	-0.55	0.00	-4.66	16.47	76%
Feb	22.32	-0.55	0.00	-4.66	17.11	77%
Mar	25.07	-0.55	0.00	-6.99	17.53	70%
Apr	23.28	-0.55	0.00	-6.99	15.74	68%
May	21.35	-0.55	0.00	-6.99	13.81	65%
Jun	17.20	-0.55	0.00	-6.99	9.66	56%
Jul	14.06	-0.55	0.00	-4.66	8.85	63%
Aug	10.56	-0.55	0.00	-4.66	5.35	51%
Sep	12.58	-0.55	0.00	-4.66	7.37	59%
Oct	12.28	-0.55	0.00	-4.66	7.07	58%
Nov	14.22	-0.55	0.00	-4.66	9.01	63%
Dec	17.58	-0.55	0.00	-4.66	12.38	70%
1-in-10-Year Drought of 30-Year Normal (1974 to 2005)						
Jan	8.10	-0.55	0.00	-4.66	2.89	36%
Feb	12.52	-0.55	0.00	-4.66	7.31	58%
Mar	12.93	-0.55	0.00	-6.99	5.39	42%
Apr	12.88	-0.55	0.00	-6.99	5.34	41%
May	10.34	-0.55	0.00	-6.99	2.80	27%
Jun	8.79	-0.55	0.00	-6.99	1.25	14%
Jul	5.75	-0.55	0.00	-4.66	0.54	9%
Aug	4.90	-0.55	0.00	-4.66	-0.31	-6%
Sep	4.49	-0.55	0.00	-4.66	-0.72	-16%
Oct	6.31	-0.55	0.00	-4.66	1.10	17%
Nov	7.92	-0.55	0.00	-4.66	2.71	34%
Dec	10.25	-0.55	0.00	-4.66	5.04	49%

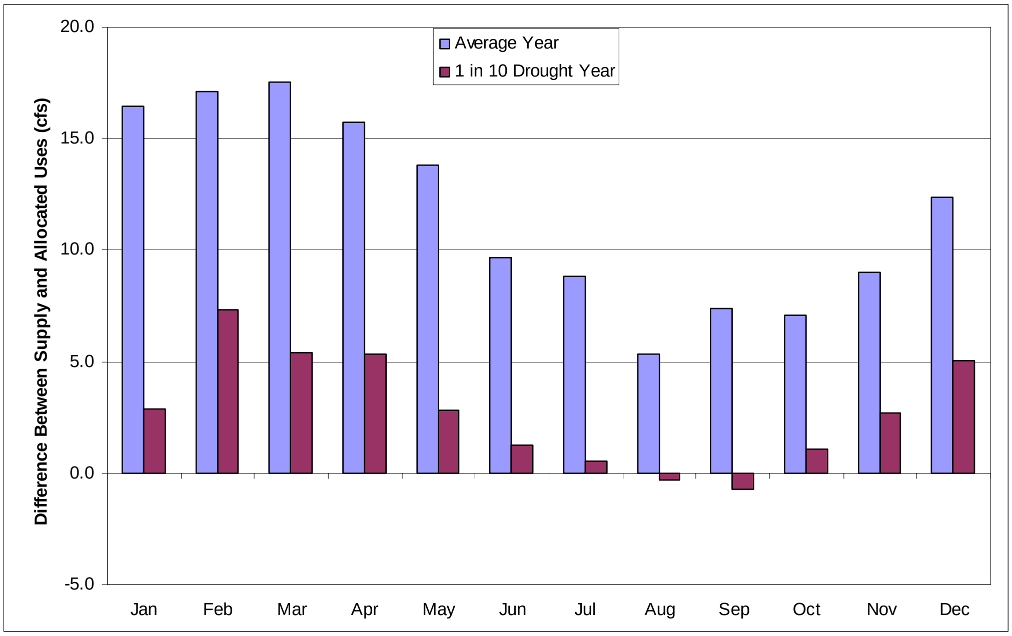

Figure 27. Monthly Comparison of Available and Allocated Water at Deer Creek Headwaters Subwatershed – Average and Drought Years

Table 20. Monthly Comparison of Available and Allocated Water at Hopkins Branch Subwatershed – Average and Drought Years

	Base Flow at Hopkins Branch (cfs)	**Permitted Water Use (cfs)**	**Un-permitted Residential Use (cfs @ 0.27 person/acre)**	**Transferred Passby Allowance (cfs)**	**Undedicated Base Flow (cfs)**	**Percentage of Base Flow Undedicated**
Average – 30-Year Normal (1974 to 2005)						
Jan	2.16	-0.01	-0.05	-0.61	1.48	69%
Feb	2.22	-0.01	-0.05	-0.61	1.55	70%
Mar	2.49	-0.01	-0.05	-0.61	1.51	61%
Apr	2.31	-0.01	-0.05	-0.61	1.34	58%
May	2.12	-0.01	-0.05	-0.61	1.14	54%
Jun	1.71	-0.01	-0.05	-0.61	0.73	43%
Jul	1.40	-0.01	-0.05	-0.61	0.73	52%
Aug	1.05	-0.01	-0.05	-0.61	0.38	36%
Sep	1.25	-0.01	-0.05	-0.61	0.58	46%
Oct	1.22	-0.01	-0.05	-0.61	0.55	45%
Nov	1.41	-0.01	-0.05	-0.61	0.74	52%
Dec	1.75	-0.01	-0.05	-0.61	1.08	62%
1-in-10-Year Drought of 30-Year Normal (1974 to 2005)						
Jan	0.81	-0.01	-0.07	-0.61	0.11	14%
Feb	1.24	-0.01	-0.07	-0.61	0.55	44%
Mar	1.28	-0.01	-0.07	-0.61	0.29	22%
Apr	1.28	-0.01	-0.07	-0.61	0.28	22%
May	1.03	-0.01	-0.07	-0.61	0.03	3%
Jun	0.87	-0.01	-0.07	-0.61	-0.12	-14%
Jul	0.57	-0.01	-0.07	-0.61	-0.12	-21%
Aug	0.49	-0.01	-0.07	-0.61	-0.20	-42%
Sep	0.45	-0.01	-0.07	-0.61	-0.25	-55%
Oct	0.63	-0.01	-0.07	-0.61	-0.06	-10%
Nov	0.79	-0.01	-0.07	-0.61	0.10	12%
Dec	1.02	-0.01	-0.07	-0.61	0.33	32%

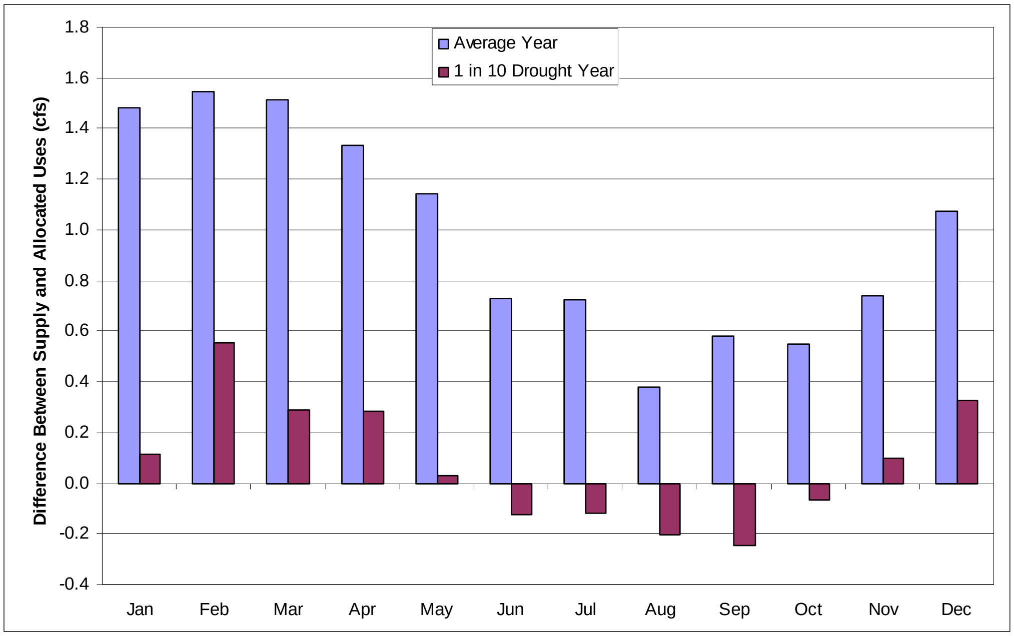

Figure 28. Monthly Comparison of Available and Allocated Water at Hopkins Branch Subwatershed – Average and Drought Years

Table 21 summarizes base flow, water uses, and available water for the entire watershed for an average year, a drought year, and a month within the drought year that is subject to the maximum groundwater use (typically August, September, or October). For consistency with the tables that follow, Table 21 is presented in terms of total gallons of use per year (or month), rather than cfs, and is expressed in billion-gallons. The available (or unavailable) gallons are then used to estimate the population that the water can serve. The yearly flow required to meet Aberdeen's permit conditions reflects 8 months at 46 cfs and 4 months at 69 cfs.

Table 21. Average Year, Drought Year, and Maximum Month Allocation of Water Resources

	Average Year		**1-in-10 Drought Year**		**Maximum Month Aug, Sept, or Oct**	
Available Base Flow						
Average Base Flow Infiltration to the Watershed	38.44	BGallons	19.05	BGallons	0.72	BGallons
Current Use						
Permitted Groundwater Withdrawals	-0.58	BGallons	-0.58	BGallons	-0.05	BGallons
Estimated Un-permitted Groundwater Withdrawals	-0.74	BGallons	-1.04	BGallons	-0.09	BGallons
Total Groundwater Consumption	-1.32	BGallons	-1.61	BGallons	-0.14	BGallons
Currently Available Base Flow						
	37.12	BGallons	17.44	BGallons	0.58	BGallons
Required Flow Passby						
Aberdeen Permit Conditions	-12.66	BGallons	-12.66	BGallons	-0.90	BGallons
Residual Groundwater Resources						
	24.46	BGallons	4.78	BGallons	-0.32	BGallons
Surplus/Deficit Population Supported						
(Represented as Residential Users @ 80, 112, and 134 gpd)	837,671	People	116,927	People	-69,879	People

B. Ten- and Twenty-Five-Year Population Projections

To assess the future demand for water within the Deer Creek Watershed, population and water demand estimates were developed. The primary sources of information were Year 2000 U.S. Census Bureau data, and population data and projections provided by Harford, Baltimore, and York Counties. All three counties provided tabulated and graphic population projections organized by Transportation Zone (TZ). Using GIS methods, the subwatershed delineation was overlain onto the TZ data. Where TZ data overlapped multiple subwatersheds or the periphery of the Deer Creek Watershed, the TZ was subdivided on the basis of area falling within each subwatershed.

The most densely populated portion of the Deer Creek Watershed is in York County, Pennsylvania. The York County Planning Commission provided current and projected population estimates for the Boroughs of Shrewsbury and Stewartstown and the Townships of Hopewell and Shrewsbury. This dataset was presented based on the County's methodology, which integrates a population trend analysis, 1930-forward, using standard projection techniques.

For comparison purposes, the GIS-compatible 2000 TZ data for York County were obtained and adjusted based on the watershed boundary to account for TZ populations within the watershed. A comparison with the tabular municipality data provided by the county showed that the GIS methodology produced population estimates for York County that were approximately 50 percent lower than data produced using standard projection techniques. The cause for the discrepancy is the assumption that the populations in the TZs are evenly distributed throughout, instead of clustered in and near the Boroughs of Shrewsbury and Stewartstown. Further, clipping the data to the limits of the watershed immediately discounted those people who utilize municipal water from the watershed but reside outside of the watershed boundary. To be conservative, the higher population projections from the County's method were incorporated instead of using the results generated from the GIS data method.

Harford County, in conjunction with MDE, has recently developed population and demand projections for its portion of the Deer Creek Watershed (Deer Creek Watershed Characterization, March 2006). The Harford County Planning Department provided the TZ data that was used for its study. The data was then divided by subwatershed to calculate populations. The Harford County Planning Department estimated that 24,750 persons resided in the Harford County portion of the watershed. The method of breaking the TZ data into percentages by subwatershed calculated a total population for the same Harford County area equaling 24,331. The difference of 1.7 percent suggests that the subwatershed breakdown is reasonably accurate.

Population projections in 5-year increments for each subwatershed can be seen in Table 22. The total 25-year projected population increase for the Deer Creek Watershed (2000 to 2025) is approximately 24 percent, as can be seen on Figure 29 and Table 22. Projected increases for individual subwatersheds range from about 5 percent to 35 percent. Population growth is generally tied to the existing road network. The lowest projected growth value corresponds to a subwatershed (Little Deer Creek), with no major roads within the watershed boundaries. The greatest projected growth is in the Deer Creek Headwaters, near Shrewsbury.

The report entitled *Aberdeen Proving Ground BRAC Impacts on Seven Jurisdictions*, prepared by the Sage Policy Group, Inc. (Sage Policy Group, 2007), was also consulted during the development of population projections. The APG-BRAC document presents estimated phasing of BRAC-related population impacts, including baseline conditions and three BRAC projection scenarios, for seven area jurisdictions. Appendix B1 provides a discussion of how the information presented in the APG BRAC plan was incorporated into the population projections and includes supporting tables and figures. Interpretation of the report suggests that BRAC will increase population growth through the study period by an additional 4 percent.

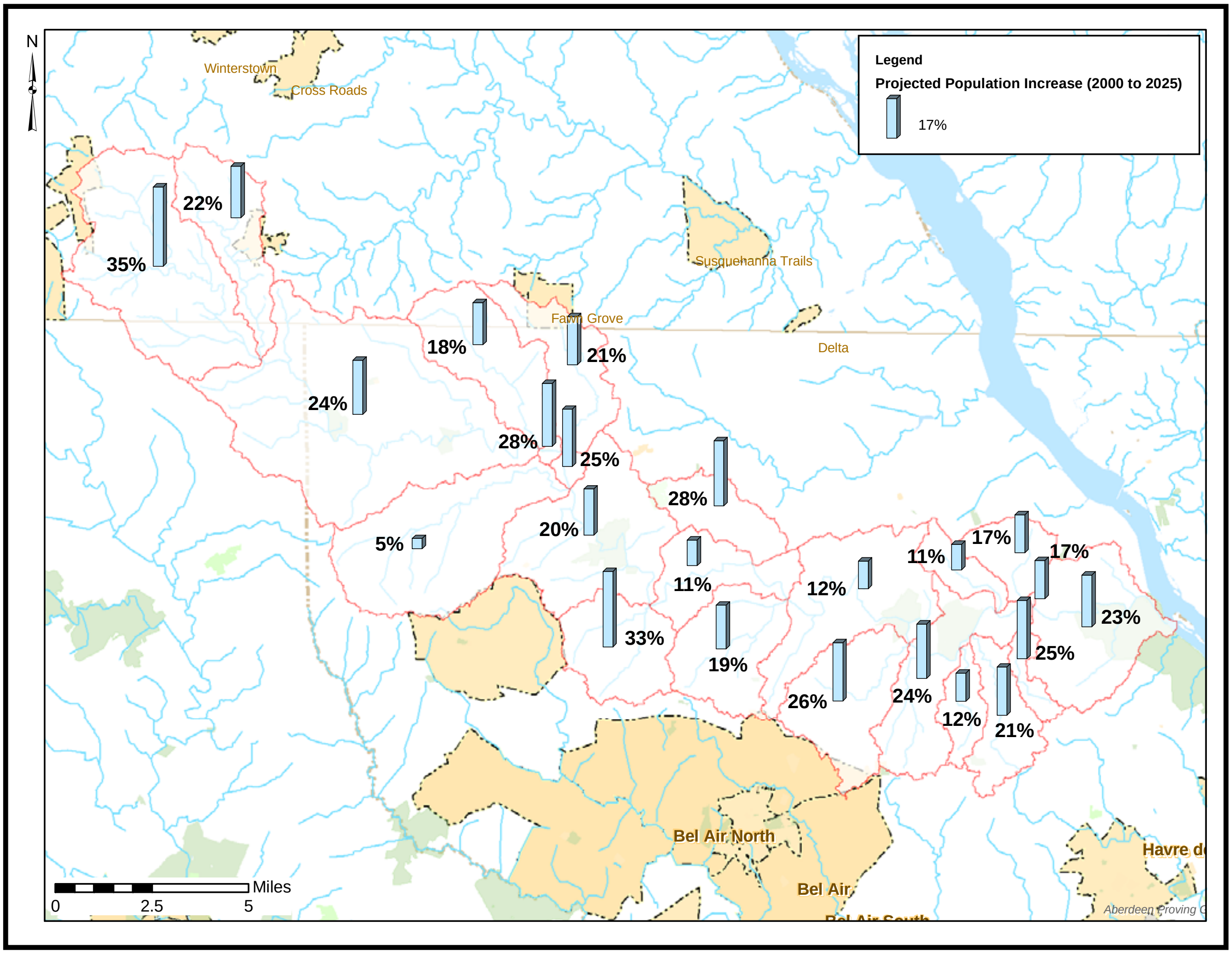

Figure 29. *Twenty-Five-Year Population Projections by Subwatershed*

Table 22. Population Projections

ID	Location	2000*	2005	2010	2015	2020	2025	10-Year Growth*	25-Year Growth*	2000 to 2025 Percentage Growth
	By County Harford County	24,332	25,421	27,130	28,160	28,729	29,129	2,799	4,798	19.7%
	York County	16,139	17,476	17,225	18,240	19,147	20,947	1,086	4,808	29.8%
	Baltimore County	1,170	1,323	1,394	1,407	1,416	1,428	224	258	22.1%
	By Subwatershed									
1	Cool Branch Run	472	477	501	516	523	530	29	58	12.3%
2	Stout Bottle Branch - Cabbage Run	1980	2102	2260	2321	2383	2358	280	378	19.1%
3	Thomas Run	3113	3407	3668	3817	3877	3907	555	794	25.5%
4	Mill Brook	736	749	801	839	865	891	65	155	21.0%
5	Hollands Branch	397	421	441	453	459	464	44	66	16.7%
6	UNT at Thomas Bridge Rd	588	620	675	712	735	755	87	167	28.4%
7	Saint Omer Branch	2238	2304	2408	2465	2487	2507	171	269	12.0%
8	Deer Creek - Mid	772	790	827	847	850	858	54	86	11.2%
9	South Stirrup - North Stirrup Run	1808	1931	2122	2253	2336	2405	314	597	33.0%
10	Rock Hollow - Kellogg - Gladden Branches	2306	2373	2543	2653	2716	2770	237	464	20.1%
11	UNT south of Falling Branch	76	80	86	90	93	95	10	19	24.7%
12	UNT west of Falling Branch	40	42	46	48	50	51	6	11	26.8%
13	Little Deer Creek	2531	2500	2583	2624	2632	2644	52	113	4.5%
14	Falling Branch	547	572	611	636	649	662	64	115	21.0%
15	Big Branch	648	676	717	742	755	767	68	119	18.3%
16	Island - Jackson - Plumtree Branches	2821	3021	3233	3351	3423	3485	412	665	23.6%
17	Ebaugh's Creek	6859	7566	6890	7300	7666	8397	32	1539	22.4%
18	Deer Creek Headwaters	9708	10394	10845	11455	11999	13072	1137	3364	34.6%
19	Graveyard Creek	177	187	201	211	216	221	25	45	25.3%
20	Hopkins Branch	413	424	441	451	455	459	29	46	11.2%
21	Tobacco Run	2276	2378	2563	2685	2757	2816	287	540	23.7%
22	Buck Branch - Elbow Branch	1130	1199	1280	1331	1360	1385	150	255	22.6%
23	UNT east of Hollands Branch	6	6	7	7	7	7	1	1	17.9%
	Deer Creek Watershed Total	41,640	44,220	45,750	47,807	49,292	51,504	4,109	9,864	23.7%

* From 2000 Census Data.

C. Water Demand Projections

The final step in completing of the groundwater balance was to forecast the projected demand for new permits and increased use in each subwatershed. Projections for three main uses were developed for future average and drought conditions:

- Commercial/Industrial Permit Demand
- Municipal Permit Demand
- Subdivision/Residential (un-permitted) Demand

Commercial/Industrial demand was estimated using zoning information provided by the counties and counting the number of commercially zoned areas within each subwatershed. The 10-year normal projections are based on an assumed development scenario requiring 50,000 gpd per commercially zoned area. The assumption is based on one retail space (e.g., 5,000 gpd for a retail convenience store), one small commercial/institutional facility (e.g., 10,000 gpd for a school, care facility, or small commercial agribusiness,) and one larger industrial facility (e.g., 35,000 gpd for food processing or industrial/building materials preparation plant). The 25-year scenario assumption is based on additional build-out of the zoned areas, resulting in the demand doubling to 100,000 gpd use. Any acreage zoned commercial/industrial, but also identified as under permanent agricultural easement in Harford County, was excluded from this estimate based on the assumption that the land will remain devoted to agriculture.

Municipal demand was based on government agency reports, and is confined to subwatersheds where the Pennsylvania municipalities of Forest Lakes, Shrewsbury, and Stewartstown have developed well fields. Subdivision/Residential demand was estimated using 10- and 25-year population projections based on the population projections described in a previous section. A demand of 80 gpd per person, based on historical records maintained for average households by MDE, was used for the normal year projections. A drought demand of 112 gpd (1.4 times normal) was assumed for drought conditions to account for the increase in water use typically seen during times of drought. The same factor was also applied to drought demands for the other two categories.

Agricultural water demand increase is not projected. Acreage of land dedicated to agricultural operations is not likely to increase, but there is potential for existing agricultural land to become more water-use intensive over the next 20 years. There is no reliable methodology for predicting such increases. However, it is important to note that the assumptions made in this study are conservatively skewed regarding agricultural water use. Permitted operations are included in current use totals, and all uses are incorporated by default due to their impacts on actual flows in the Deer Creek Watershed, which are the basis for the water balances performed. The flow measurements reflect the actual consumptive use of operations, which is often lower than the full permitted quantity. By also including the permitted use, the estimates do a better job of capturing potential increases, as well as current use. Nevertheless, approximate potential agricultural water use estimates were made for conversion to more water-intensive uses; the results are shown in Appendix B2.

The 2010 and 2025 water resource values were also adjusted for changes in impervious area for the 2010 and 2025 periods. Future impervious conditions were based on the future land use layer derived for the Watershed Restoration Action Strategy (KCI, 2007). The method involved applying a full build-out condition to the land use layers based on their current zoning classifications. The impervious factors were applied to the future land use layer to derive future imperviousness following the same methods used to generate existing imperviousness.

The future imperviousness estimate for the entire Deer Creek Watershed is 5.3 percent, an increase in 1,120 acres. The results for each subwatershed are listed in Tables 23, 24, 25, and 26 as the change in percent future impervious area. The majority of the subwatersheds are estimated to remain under 5 percent impervious. The two subwatersheds that increased to more than 5 percent are Big Branch and Falling Branch. These subwatersheds also experienced the highest percent acreage increases as a result of existing agricultural areas that are zoned in York County for residential use. The largest increases in impervious acres are estimated to be in the Deer Creek Headwaters subwatershed, with the potential for 354.72 additional acres of impervious surface and a future imperviousness of 16.70 percent. Although local and state stormwater management policies require that post-development recharge rates mimic predevelopment conditions, there are exemptions and inefficiencies in management practices; thus the conservative approach is to assume that development will result in impacts to groundwater recharge. As with agricultural water demand, the effect of permanent easements in Harford County was employed for estimates of impervious cover by excluding those acres zoned for development but conserved under easements.

Tables 23, 24, 25, and 26 are groundwater balances for average year conditions and drought year conditions for the years 2010 and 2025. These results are illustrated graphically on Figure 30. As expected, the number of subwatersheds with an allocation deficit is greater for drought years than for average years. The number also increases from 2010 to 2025, reflecting increases in demand. Under average conditions, the allocated water resources do not indicate any deficits during 2010 and a deficit only for the Hopkins Branch subwatershed in 2025.

More significantly, under 2010 and 2025 drought conditions, several of the subwatersheds show an allocation deficit. The allocation deficits are concentrated in the lower portion of the watershed and in the headwaters. This primarily reflects: (1) growth in an area having aquifers with relatively low recharge rates; and (2) growth in an area having minimal upgradient contributing recharge area. Under drought conditions in 2010, it is expected that five subwatersheds will show allocation deficits of as much as 150 million gallons over the year (0.63 cfs), which equates to the quantity of water used by more than 3,600 people. Although presented as an annual analysis, the deficits are likely to manifest during the summer months, as they did over the watershed as a whole (Table 14, Figure 24) and for the three subwatersheds selected for additional analyses (Tables 18, 19, and 20; Figures 26, 27, and 28). Under drought conditions in 2025, eight subwatersheds show deficits in the range of 18 to 314 million gallons over the year (0.08 cfs to 1.33 cfs).

The BRAC-related population projections included in the APG-BRAC document (Sage Policy Group, 2007) mentioned previously also were incorporated into the water demand projection analyses. Appendix B1 provides a discussion of how the information presented in the APG BRAC plan was incorporated into the water demand projections and includes supporting tables and figures.

Table 23. Water Allocation, 2010 Population, Average Precipitation

ID	Subwatershed	Average Base Flow (cfs)	Existing Permitted Ground-water Withdrawals (cfs)	Existing Un-permitted Ground-water Withdrawals (cfs)	Aberdeen Permit Passby (cfs)	Change in Percent Future Impervious Area (%)	Reduction for Future Impervious Area (cfs)	Reduction for Municipal/ Commercial (cfs)	Additional Residential Population[1] (cfs)	Residual Ground-water Resources (cfs)	Surplus/ Deficit Population Supported (people)
1	Cool Branch Run	1.91	-0.01	-0.05	-0.78	1.08	-0.02	-0.31	0.00	0.73	5,918
2	Stout Bottle Branch - Cabbage Run	7.39	-0.12	-0.16	-2.27	1.73	-0.13	-0.39	-0.03	4.29	34,692
3	Thomas Run	6.26	-0.05	-0.17	-2.55	0.47	-0.03	-0.39	-0.07	3.00	24,274
4	Mill Brook	3.60	-0.03	-0.10	-1.47	0.47	-0.02	-0.31	-0.01	1.67	13,495
5	Hollands Branch	2.60	-0.03	-0.07	-1.06	0.47	-0.01	-0.08	-0.01	1.35	10,872
6	UNT at Thomas Bridge Rd	4.45	-0.28	-0.09	-1.37	0.33	-0.01	-0.08	-0.01	2.61	21,046
7	Saint Omer Branch	10.07	-0.06	-0.24	-3.53	0.74	-0.07	-0.39	-0.02	5.75	46,491
8	Deer Creek – Mid	5.40	-0.01	-0.11	-1.66	0.33	-0.02	0.00	-0.01	3.59	29,014
9	South Stirrup - North Stirrup Run	6.68	-0.01	-0.14	-2.05	0.54	-0.04	-0.15	-0.04	4.25	34,302
10	Rock Hollow - Kellogg - Gladden Branches	12.75	-0.23	-0.27	-3.92	0.21	-0.03	-0.31	-0.03	7.97	64,346
11	UNT south of Falling Branch	0.64	-0.01	-0.01	-0.20	2.80	-0.02	0.00	0.00	0.40	3,254
12	UNT west of Falling Branch	0.39	0.00	-0.01	-0.12	2.80	-0.01	0.00	0.00	0.25	2,006
13	Little Deer Creek	14.65	-0.02	-0.31	-4.50	0.20	-0.03	-0.23	-0.01	9.54	77,103
14	Falling Branch	6.60	-0.01	-0.14	-2.03	2.80	-0.18	-0.39	-0.01	3.84	31,035
15	Big Branch	8.15	0.00	-0.17	-2.51	2.62	-0.21	-0.23	-0.01	5.02	40,559
16	Island - Jackson - Plumtree Branches	29.59	-0.18	-0.62	-9.10	0.22	-0.07	-0.23	-0.05	19.35	156,286
17	Ebaugh's Creek	7.05	-0.65	0.00	-2.17	2.42	-0.17	-0.39	0.00	3.67	29,633
18	Deer Creek Headwaters	17.68	-0.55	0.00	-5.44	4.06	-0.72	-0.77	-0.14	10.06	81,294
19	Graveyard Creek	1.24	-0.01	-0.03	-0.51	0.47	-0.01	0.00	0.00	0.68	5,532
20	Hopkins Branch	1.76	-0.01	-0.05	-0.72	0.47	-0.01	-0.70	0.00	0.28	2,226
21	Tobacco Run	6.15	-0.16	-0.17	-2.51	1.08	-0.07	-0.08	-0.04	3.14	25,337
22	Buck Branch - Elbow Branch	7.90	-0.01	-0.22	-3.22	0.05	0.00	0.00	-0.02	4.43	35,795
23	UNT east of Hollands Branch	0.04	0.00	0.00	-0.02	0.47	0.00	0.00	0.00	0.02	188
	Entire Watershed	**162.94**	**-2.44**	**-3.14**	**-53.67**	**1.00**	**-1.63**	**-5.42**	**-0.51**	**95.90**	**774,699**

[1] Calculated at 80 gpd per person.

Table 24. Water Allocation, 2010 Population, Drought Conditions

ID	Subwatershed	Average Base Flow (cfs)	Existing Permitted Ground-water Withdrawals (cfs)	Existing Un-permitted Ground-water Withdrawals (cfs)	Aberdeen Permit Passby (cfs)	Change in Percent Future Impervious Area (%)	Reduction for Future Impervious Area (cfs)	Reduction for Municipal/ Commercial (cfs)	Additional Residential Population[1] (cfs)	Residual Ground-water Resources (cfs)	Surplus/ Deficit Population Supported (people)
1	Cool Branch Run	0.94	-0.01	-0.07	-0.78	1.08	-0.02	-0.31	-0.01	-0.25	-1,448
2	Stout Bottle Branch - Cabbage Run	3.67	-0.12	-0.22	-2.27	1.73	-0.13	-0.39	-0.05	0.49	2,827
3	Thomas Run	3.10	-0.05	-0.24	-2.55	0.47	-0.03	-0.39	-0.10	-0.25	-1,442
4	Mill Brook	1.78	-0.03	-0.14	-1.47	0.47	-0.02	-0.31	-0.01	-0.19	-1,081
5	Hollands Branch	1.29	-0.03	-0.10	-1.06	0.47	-0.01	-0.08	-0.01	0.00	22
6	UNT at Thomas Bridge Rd	2.21	-0.28	-0.13	-1.37	0.33	-0.01	-0.08	-0.02	0.32	1,845
7	Saint Omer Branch	4.99	-0.06	-0.34	-3.53	0.74	-0.07	-0.39	-0.03	0.57	3,299
8	Deer Creek - Mid	2.68	-0.01	-0.16	-1.66	0.33	-0.02	0.00	-0.01	0.82	4,735
9	South Stirrup - North Stirrup Run	3.31	-0.01	-0.20	-2.05	0.54	-0.04	-0.15	-0.05	0.81	4,646
10	Rock Hollow - Kellogg - Gladden Branches	6.32	-0.23	-0.37	-3.92	0.21	-0.03	-0.31	-0.04	1.42	8,171
11	UNT south of Falling Branch	0.32	-0.01	-0.02	-0.20	2.80	-0.02	0.00	0.00	0.07	431
12	UNT west of Falling Branch	0.19	0.00	-0.01	-0.12	2.80	-0.01	0.00	0.00	0.05	287
13	Little Deer Creek	7.26	-0.02	-0.43	-4.50	0.20	-0.03	-0.23	-0.01	2.03	11,732
14	Falling Branch	3.27	-0.01	-0.19	-2.03	2.80	-0.18	-0.39	-0.01	0.46	2,633
15	Big Branch	4.04	0.00	-0.24	-2.51	2.62	-0.21	-0.23	-0.01	0.84	4,829
16	Island - Jackson - Plumtree Branches	14.67	-0.18	-0.87	-9.10	0.22	-0.07	-0.23	-0.07	4.16	23,985
17	Ebaugh's Creek	3.49	-0.65	0.00	-2.17	2.42	-0.17	-0.39	-0.01	0.11	655
18	Deer Creek Headwaters	8.76	-0.55	0.00	-5.44	4.06	-0.72	-0.77	-0.20	1.09	6,290
19	Graveyard Creek	0.62	-0.01	-0.05	-0.51	0.47	-0.01	0.00	0.00	0.04	245
20	Hopkins Branch	0.87	-0.01	-0.07	-0.72	0.47	-0.01	-0.70	0.00	-0.63	-3,646
21	Tobacco Run	3.05	-0.16	-0.24	-2.51	1.08	-0.07	-0.08	-0.05	-0.05	-283
22	Buck Branch - Elbow Branch	3.91	-0.01	-0.31	-3.22	0.05	0.00	0.00	-0.03	0.35	2,037
23	UNT east of Hollands Branch	0.02	0.00	0.00	-0.02	0.47	0.00	0.00	0.00	0.00	11
	Entire Watershed	**80.77**	**-2.44**	**-4.40**	**-53.67**	**1.00**	**-1.63**	**-5.42**	**-0.71**	**12.27**	**70,782**

[1] Calculated at 112 gpd per person.

Table 25. Water Allocation, 2025 Population, Average Precipitation

ID	**Subwatershed**	**Average Base Flow (cfs)**	**Existing Permitted Ground-water Withdrawals (cfs)**	**Existing Un-permitted Ground-water Withdrawals (cfs)**	**Aberdeen Permit Passby (cfs)**	**Change in Percent Future Impervious Area (%)**	**Reduction for Future Impervious Area (cfs)**	**Reduction for Municipal/ Commercial (cfs)**	**Additional Residential Population[1] (cfs)**	**Residual Ground-water Resources (cfs)**	**Surplus/ Deficit Population Supported (people)**
1	Cool Branch Run	1.91	-0.01	-0.05	-0.78	1.08	-0.02	-0.62	-0.01	0.42	3,390
2	Stout Bottle Branch - Cabbage Run	7.39	-0.12	-0.16	-2.27	1.73	-0.13	-0.77	-0.05	3.90	31,470
3	Thomas Run	6.26	-0.05	-0.17	-2.55	0.47	-0.03	-0.77	-0.10	2.59	20,910
4	Mill Brook	3.60	-0.03	-0.10	-1.47	0.47	-0.02	-0.62	-0.02	1.35	10,906
5	Hollands Branch	2.60	-0.03	-0.07	-1.06	0.47	-0.01	-0.15	-0.01	1.27	10,224
6	UNT at Thomas Bridge Rd	4.45	-0.28	-0.09	-1.37	0.33	-0.01	-0.15	-0.02	2.52	20,342
7	Saint Omer Branch	10.07	-0.06	-0.24	-3.53	0.74	-0.07	-0.77	-0.03	5.36	43,267
8	Deer Creek – Mid	5.40	-0.01	-0.11	-1.66	0.33	-0.02	0.00	-0.01	3.59	28,982
9	South Stirrup - North Stirrup Run	6.68	-0.01	-0.14	-2.05	0.54	-0.04	-0.31	-0.07	4.06	32,769
10	Rock Hollow - Kellogg - Gladden Branches	12.75	-0.23	-0.27	-3.92	0.21	-0.03	-0.62	-0.06	7.63	61,618
11	UNT south of Falling Branch	0.64	-0.01	-0.01	-0.20	2.80	-0.02	0.00	0.00	0.40	3,246
12	UNT west of Falling Branch	0.39	0.00	-0.01	-0.12	2.80	-0.01	0.00	0.00	0.25	2,001
13	Little Deer Creek	14.65	-0.02	-0.31	-4.50	0.20	-0.03	-0.46	-0.01	9.30	75,168
14	Falling Branch	6.60	-0.01	-0.14	-2.03	2.80	-0.18	-0.77	-0.01	3.45	27,860
15	Big Branch	8.15	0.00	-0.17	-2.51	2.62	-0.21	-0.46	-0.01	4.78	38,634
16	Island - Jackson - Plumtree Branches	29.59	-0.18	-0.62	-9.10	0.22	-0.07	-0.46	-0.08	19.08	154,159
17	Ebaugh's Creek	7.05	-0.65	0.00	-2.17	2.42	-0.17	-0.77	-0.19	3.09	25,001
18	Deer Creek Headwaters	17.68	-0.55	0.00	-5.44	4.06	-0.72	-1.55	-0.42	9.01	72,817
19	Graveyard Creek	1.24	-0.01	-0.03	-0.51	0.47	-0.01	0.00	-0.01	0.68	5,512
20	Hopkins Branch	1.76	-0.01	-0.05	-0.72	0.47	-0.01	-1.39	-0.01	-0.42	-3,417
21	Tobacco Run	6.15	-0.16	-0.17	-2.51	1.08	-0.07	-0.15	-0.07	3.03	24,459
22	Buck Branch - Elbow Branch	7.90	-0.01	-0.22	-3.22	0.05	0.00	0.00	-0.03	4.42	35,689
23	UNT east of Hollands Branch	0.04	0.00	0.00	-0.02	0.47	0.00	0.00	0.00	0.02	187
	Entire Watershed	**162.94**	**-2.44**	**-3.14**	**-53.67**	**1.00**	**-1.63**	**-10.83**	**-1.22**	**89.77**	**725,195**

[1] Calculated at 80 gpd per person.

Table 26. Water Allocation, 2025 Population, Drought Precipitation

ID	Subwatershed	Average Base Flow (cfs)	Existing Permitted Ground-water Withdrawals (cfs)	Existing Un-permitted Ground-water Withdrawals (cfs)	Aberdeen Permit Passby (cfs)	Change in Percent Future Impervious Area (%)	Reduction for Future Impervious Area (cfs)	Reduction for Municipal/ Commercial (cfs)	Additional Residential Population[1] (cfs)	Residual Ground-water Resources (cfs)	Surplus/ Deficit Population Supported (people)
1	Cool Branch Run	0.94	-0.01	-0.07	-0.78	1.08	-0.02	-0.62	-0.01	-0.57	-3,261
2	Stout Bottle Branch - Cabbage Run	3.67	-0.12	-0.22	-2.27	1.73	-0.13	-0.77	-0.07	0.09	498
3	Thomas Run	3.10	-0.05	-0.24	-2.55	0.47	-0.03	-0.77	-0.14	-0.68	-3,913
4	Mill Brook	1.78	-0.03	-0.14	-1.47	0.47	-0.02	-0.62	-0.03	-0.51	-2,955
5	Hollands Branch	1.29	-0.03	-0.10	-1.06	0.47	-0.01	-0.15	-0.01	-0.08	-447
6	UNT at Thomas Bridge Rd	2.21	-0.28	-0.13	-1.37	0.33	-0.01	-0.15	-0.03	0.23	1,320
7	Saint Omer Branch	4.99	-0.06	-0.34	-3.53	0.74	-0.07	-0.77	-0.05	0.17	968
8	Deer Creek - Mid	2.68	-0.01	-0.16	-1.66	0.33	-0.02	0.00	-0.01	0.82	4,703
9	South Stirrup - North Stirrup Run	3.31	-0.01	-0.20	-2.05	0.54	-0.04	-0.31	-0.10	0.60	3,470
10	Rock Hollow - Kellogg - Gladden Branches	6.32	-0.23	-0.37	-3.92	0.21	-0.03	-0.62	-0.08	1.07	6,157
11	UNT south of Falling Branch	0.32	-0.01	-0.02	-0.20	2.80	-0.02	0.00	0.00	0.07	423
12	UNT west of Falling Branch	0.19	0.00	-0.01	-0.12	2.80	-0.01	0.00	0.00	0.05	282
13	Little Deer Creek	7.26	-0.02	-0.43	-4.50	0.20	-0.03	-0.46	-0.02	1.79	10,333
14	Falling Branch	3.27	-0.01	-0.19	-2.03	2.80	-0.18	-0.77	-0.02	0.06	351
15	Big Branch	4.04	0.00	-0.24	-2.51	2.62	-0.21	-0.46	-0.02	0.60	3,439
16	Island - Jackson - Plumtree Branches	14.67	-0.18	-0.87	-9.10	0.22	-0.07	-0.46	-0.12	3.88	22,393
17	Ebaugh's Creek	3.49	-0.65	0.00	-2.17	2.42	-0.17	-0.77	-0.27	-0.53	-3,084
18	Deer Creek Headwaters	8.76	-0.55	0.00	-5.44	4.06	-0.72	-1.55	-0.58	-0.07	-401
19	Graveyard Creek	0.62	-0.01	-0.05	-0.51	0.47	-0.01	0.00	-0.01	0.04	225
20	Hopkins Branch	0.87	-0.01	-0.07	-0.72	0.47	-0.01	-1.39	-0.01	-1.33	-7,681
21	Tobacco Run	3.05	-0.16	-0.24	-2.51	1.08	-0.07	-0.15	-0.09	-0.17	-983
22	Buck Branch - Elbow Branch	3.91	-0.01	-0.31	-3.22	0.05	0.00	0.00	-0.04	0.33	1,931
23	UNT east of Hollands Branch	0.02	0.00	0.00	-0.02	0.47	0.00	0.00	0.00	0.00	10
	Entire Watershed	**80.77**	**-2.44**	**-4.40**	**-53.67**	**1.00**	**-1.63**	**-10.83**	**-1.71**	**5.85**	**33,778**

[1] Calculated at 112 gpd per person.

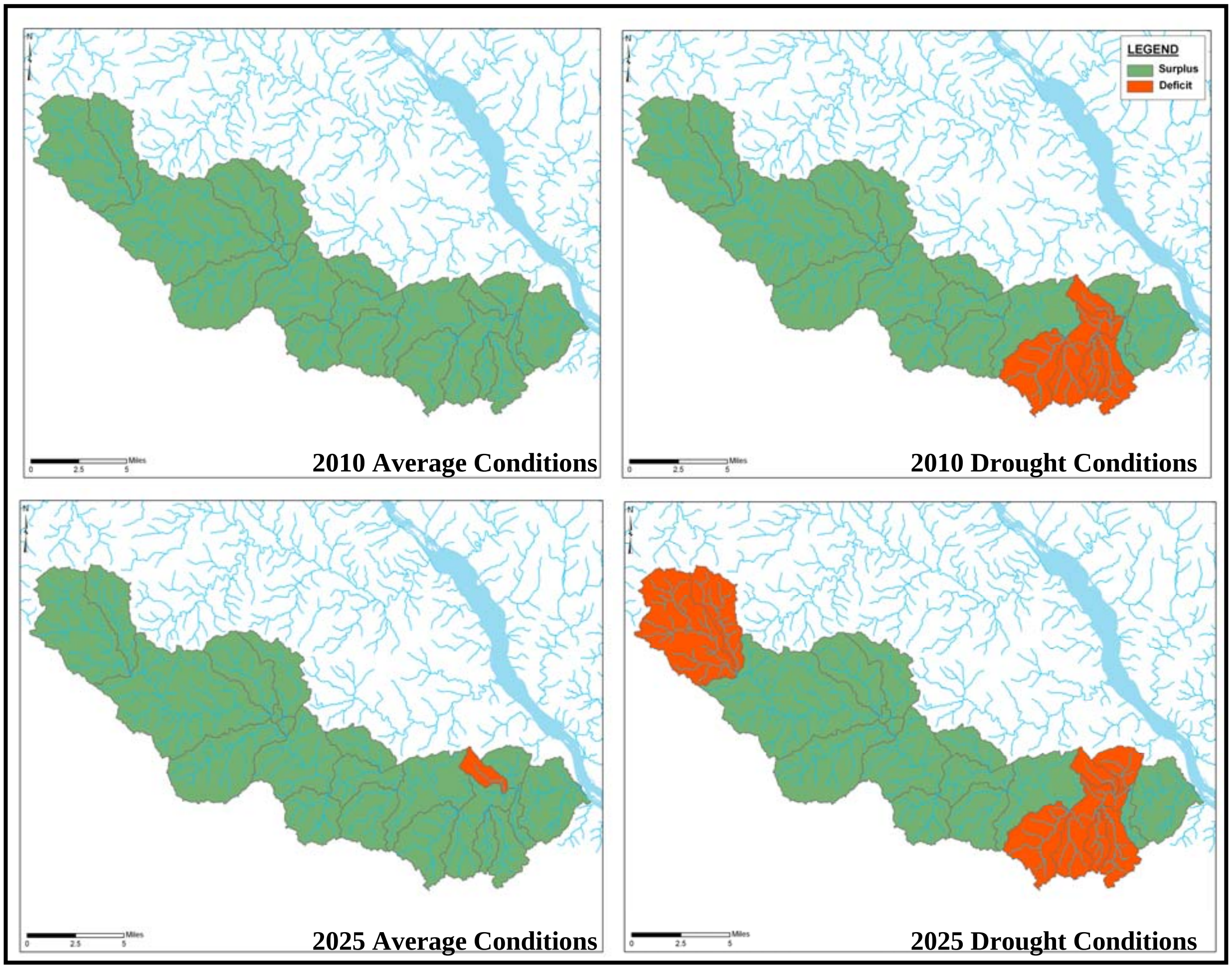

Figure 30. Twenty-Five-Year Projected Water Allocation Surplus/Deficit by Subwatershed

To assess the effect of future water demand in terms of the availability of water from Deer Creek during a drought, the number of days below the passby flow threshold at Darlington was examined using the 2002 as a reference point. In that drought, the flow at Darlington was below the passby threshold for a duration of 130 days in the time period March 1 through October 10. If the projected increase in water demand is assumed to directly reduce the flow in Deer Creek on a gallon-for-gallon basis, the impacted flow at Darlington during a repeat of the 2002 drought in the year 2025 would result in the creek being below the passby threshold for an additional 43 days, and extend the time period 1 week sooner and 2 weeks later. A graphical depiction of the change to streamflow at Darlington is shown on Figures 31 and 32. Of the projected 14.2 cfs increase in water demand during future droughts, three-quarters are attributable to commercial and municipal demand, and the remainder is about even attributable to self-supplied residential use and loss of base flow due to increase in impervious cover.

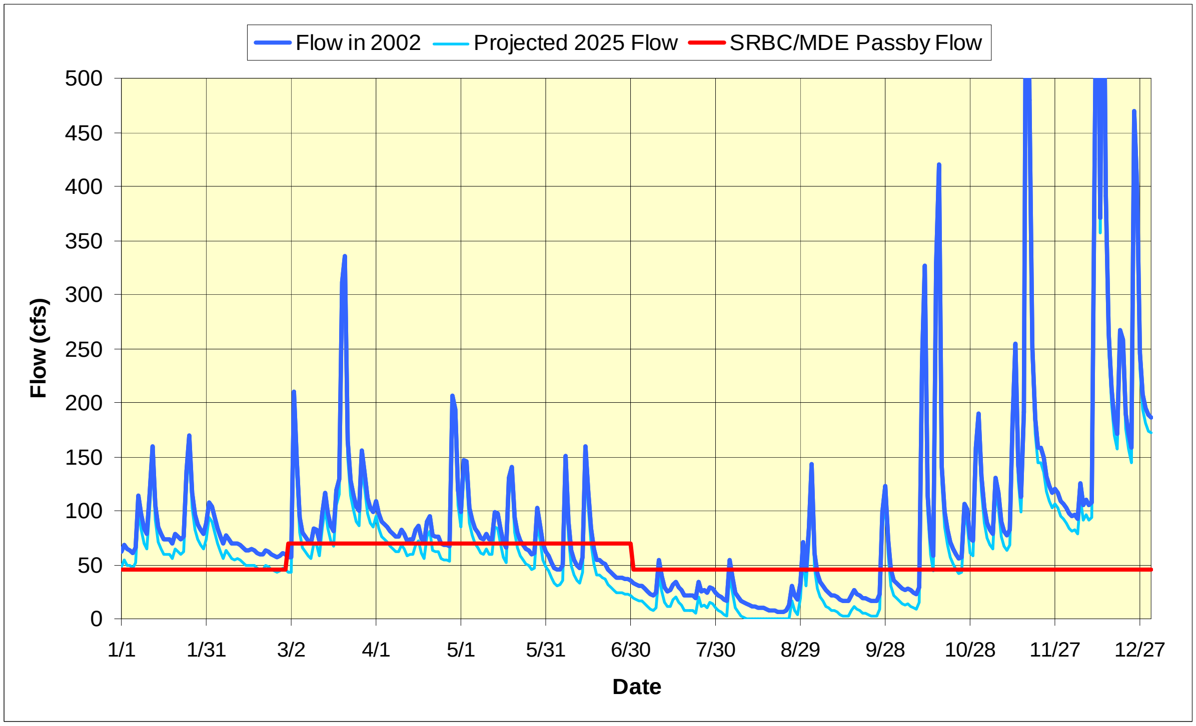

Figure 31. Actual and Reduced 2002 Drought Flow at Darlington Compared to Passby Threshold

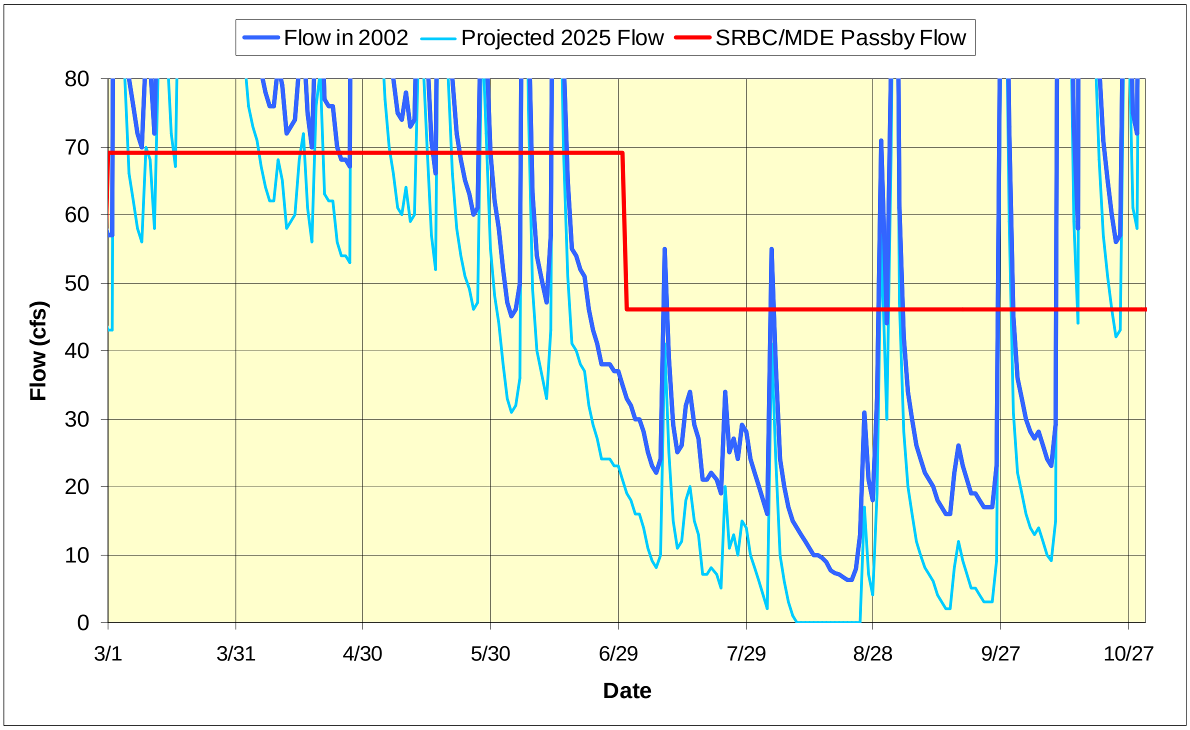

Figure 32. Close View; Actual and Reduced 2002 Drought Flow at Darlington Compared to Passby Threshold

IX. NUMERICAL MODEL OF DEER CREEK WATERSHED

The natural water budget and allocation tables displayed in this report present an accounting of the water balance of the Deer Creek Watershed, but do not present the response of the watershed to stresses such as increases in pumping or surface water withdrawal. To better understand the natural response of the watershed to such changes, and how these changes might be observed, a numerical model of groundwater and surface water flow in the watershed was developed.

The groundwater flow model was assembled using MODFLOW-2000, a finite difference flow simulation code developed by the USGS (Harbaugh et al., 2000). The input data sets for the model were prepared using Groundwater Vistas (Rumbaugh, 2003). The model tracks and moves groundwater in the Deer Creek drainage, and simulates the response of groundwater to withdrawals from wells or streams and the impact of such movement to the base flow in Deer Creek and its tributaries.

The model grid consists of 95 rows and 159 columns. Row and column spacing is 1,000 feet uniformly (Figure 33). The model domain is approximately 18 miles long and 30 miles wide, and the basin boundaries are represented by no-flow boundary conditions, meaning that groundwater available for discharge into Deer Creek is limited to what infiltrates from precipitation in the topographically delineated watershed. Once it is in the aquifer, the groundwater cannot move to adjacent watersheds. The numerical model consists of two layers representing the saprolite/alluvial aquifer and the underlying fractured bedrock. Both of the model layers have a uniform thickness. The thickness of top and second layer is 50 feet and 350 feet, respectively. No horizontal anisotropy was incorporated in the layers, meaning that the resistance to groundwater flow is the same in all directions within the horizontal plane of the model. Incorporating this simplifying assumption into the model greatly reduces model complexity while allowing achievement of the goals for which the model was intended.

MODFLOW's stream package was used to simulate both Deer Creek, as well as its major tributaries. Overall, the stream network was simulated by 1,427 reaches and 338 segments. Monthly recharge was specified as a percentage of monthly precipitation, with the percentage varying with the amount of precipitation according to the relationship shown on Figure 32. The recharge rate to model grid cells with stream segments was adjusted to account for increased recharge relative to upland areas during wet periods and evapotranspiration during summer months using the relationship shown on Figure 34. Both of the recharge relationships shown on Figure 34 were defined during the model calibration process.

The basic hydrologic parameters used in the model are summarized in Table 27. Values of transmissivity and storage for the bedrock and saprolite/alluvium layers were based upon aquifer test data and previous hydrologic analyses (see Reference list). Final values were attained through model calibration. Similarly, the recharge function was developed based upon values typical for the Piedmont geology in Baltimore County.

The model was calibrated to groundwater levels and base flows in the main stream of Deer Creek for the period 1961 to 2004. The primary target of the calibration was to match gaged flow at the USGS stream gages; appropriate recharge rates were assigned to achieve that match as closely as possible. The comparison between observed and calculated monthly base flows is illustrated on Figure 33, and the comparison between observed and calculated annual base flows is shown on Figure 34.

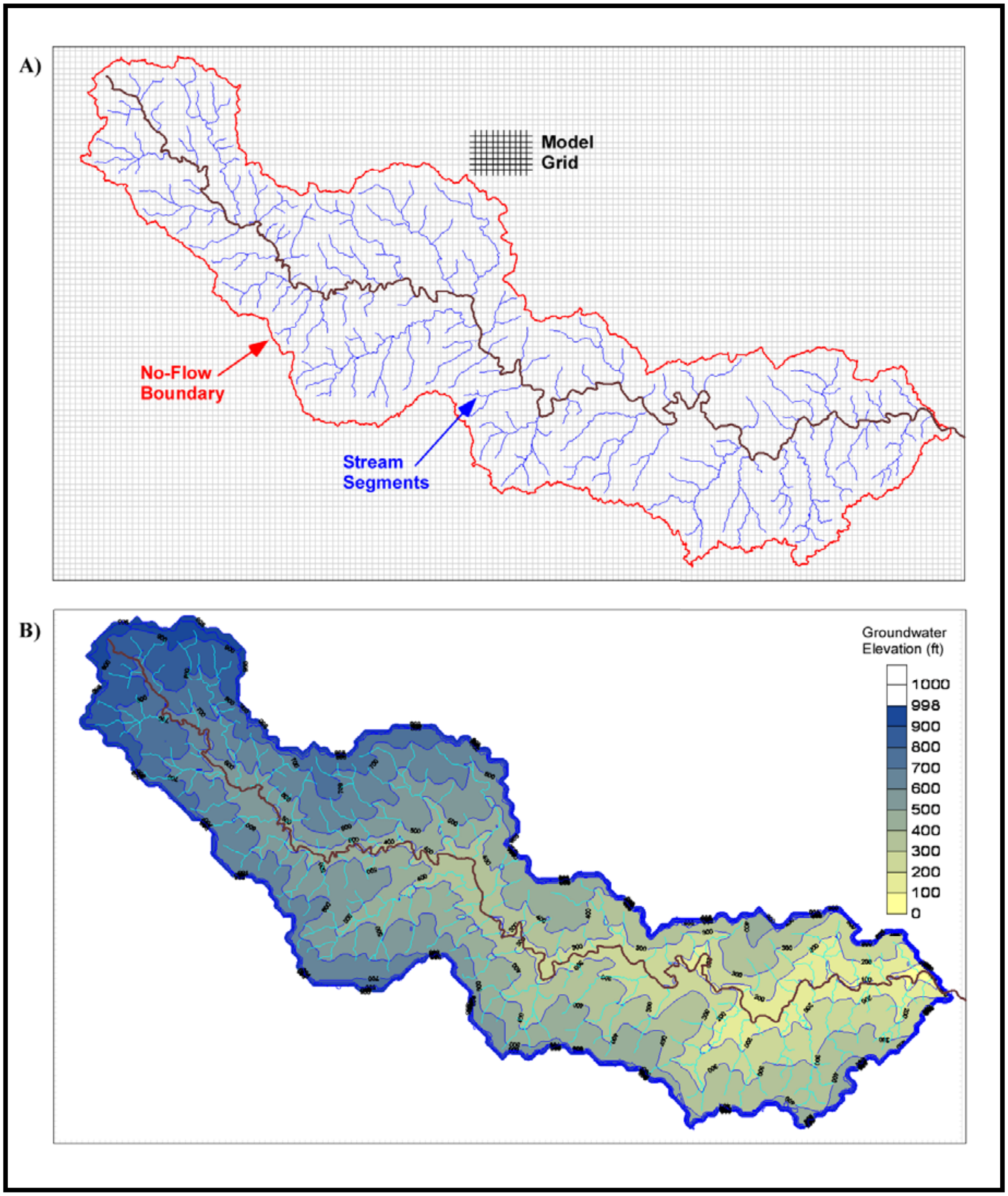

Figure 33. ***Grid Spacing, Boundary Conditions, and Stream Segments; (A) in MODFLOW Model; and (B) Groundwater Elevations in Layer 1 (Water Table)***

Table 27. Hydrologic Parameters for MODFLOW Model

	Layer 1		**Layer 2**	
	Zone A (upstream)	**Zone B (downstream)**	**Zone A (upstream)**	**Zone B (downstream)**
Horizontal Hydraulic Conductivity (Kh) (feet/day)	5	5	2.2	2.2
Vertical Hydraulic Conductivity (Kv) (feet/day)	0.05	0.05	0.05	0.05
Specific Yield (Sy)	2.00E-06	1.00E-05	2.00E-06	1.00E-05
Storage Coefficient (Sc)	0.05	0.05	0.004	0.004

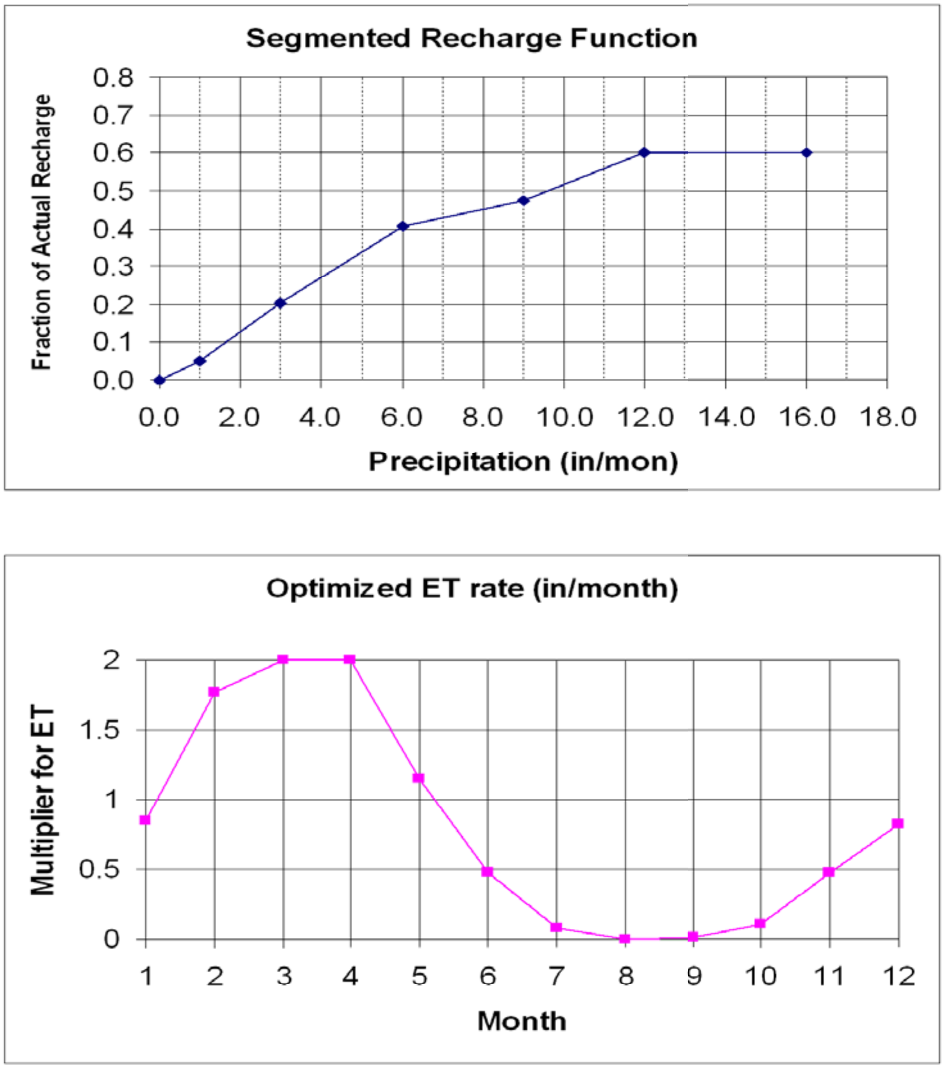

Figure 34. Recharge and Evapotranspiration (ET) Functions Used in MODFLOW Model

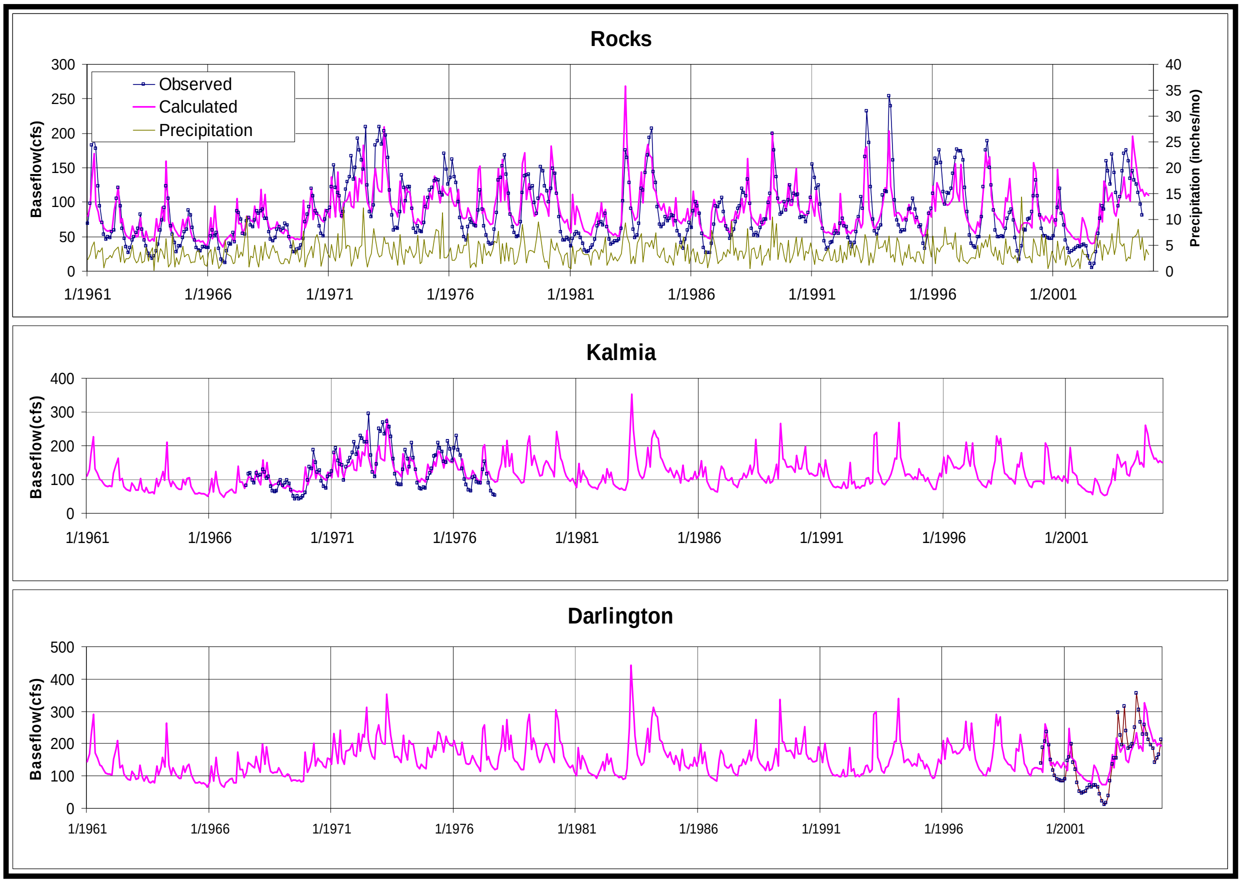

Figure 35. Observed and Calculated Base Flows for 1961 to 2004 – MODFLOW Model

On Figure 35, the plots of the calculated base flows at the three gage locations (red line) mimic very well the plots of the observed base flows (blue line), indicating successful modeling of the watershed's monthly base flows.

On Figure 36, the calculated and observed base flow values for each year of available record at the three gage locations are plotted against each other and shown relative to a line representing equivalence. The closer the plotted points fall to the red equivalence line, the better the calculated base flow values compare to the observed values. There are not a significant number of records available at Kalmia and Darlington, but the many years of record at the Rocks gage span the spectrum of hydrologic conditions from very dry to very wet. As shown by the proximity of the blue dotes to the red line, the model was successful at predicting base flow values at both extremes.

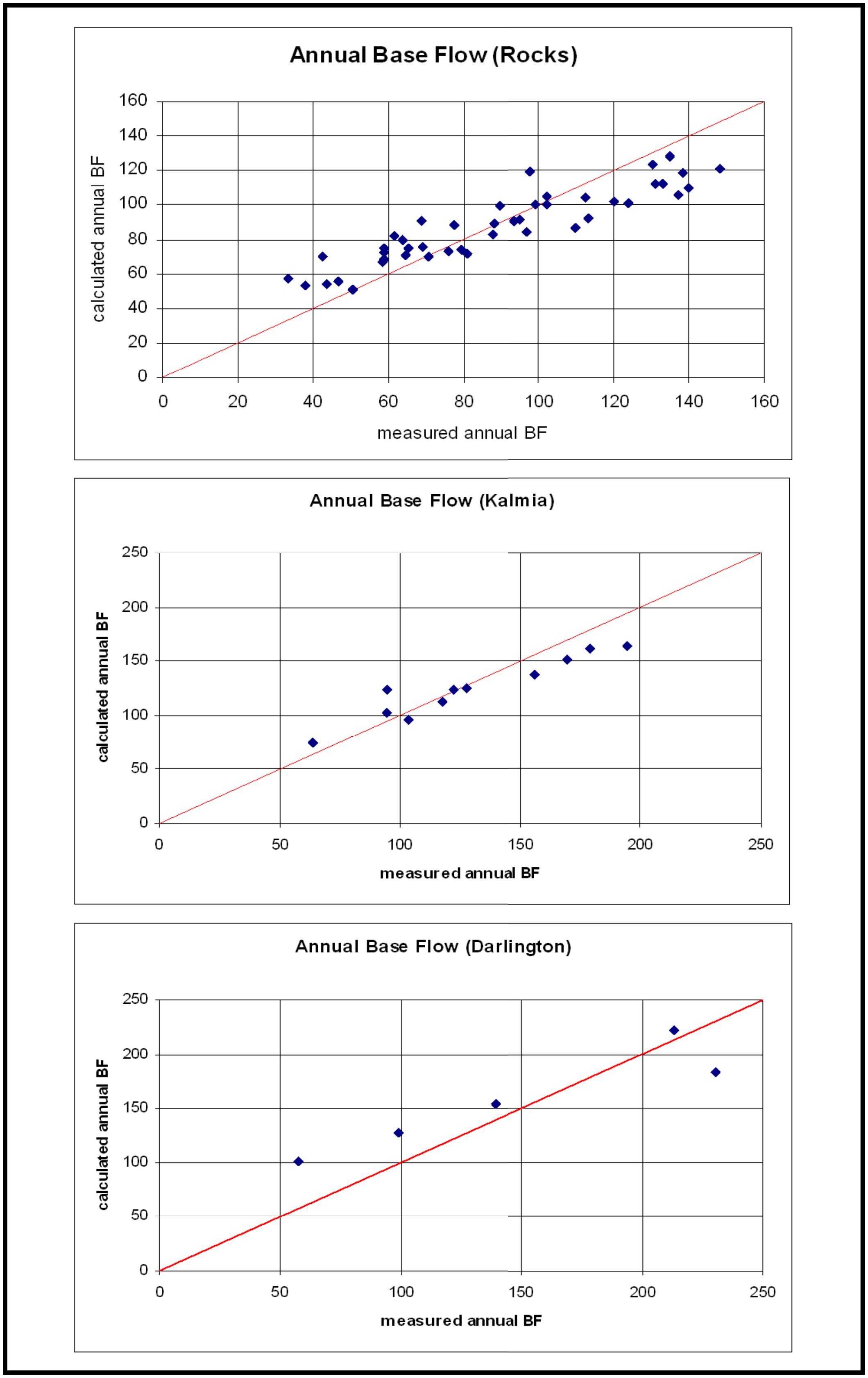

Figure 36. Scatter Diagrams for Annual Base Flow at U.S. Geological Survey Gages

As per the conceptual hydrologic model for the Maryland and Pennsylvania Piedmont (Figure 6), groundwater flow in the model is generally local and closely linked to local recharge/discharge areas. In contrast, depletions of base flow due to groundwater use can impact the base flow in all stream segments downstream of the pumping. The total base flow in each stream segment is the sum of base flow accumulated in that segment, as well as base flow from any upstream tributaries. Groundwater withdrawn from the bedrock is initially replaced by release of groundwater from storage. As the area of groundwater depletion expands over time, the depletion from storage is replaced by depletion of flow from the nearest stream segment. For a non-first-order stream segment, the total base flow depletion may include base flow derived from upstream tributaries. Any base flow depletion due to pumping is therefore unavailable downstream as well.

As noted above, the model was developed using regional calibration parameters, and a cell size of 1,000 feet. Although the model parameters are appropriate for analyses at the scale discussed here, there are local variations in geological and hydrogeologic conditions that are not incorporated into the model. These may include local variations in layer thickness, hydraulic conductivity, storage coefficients, or recharge. Use of the model for larger-scale (smaller area) evaluations should consider potential impacts of the cell size and local conditions on the results.

A. Results – Impact of Pumping on Streamflows

The primary use of the groundwater flow model is to evaluate the interaction between groundwater use and discharge to surface water (base flows) in the streams of the watershed. To evaluate this in a general way, we considered hypothetical water use scenarios in which new “well fields” were developed, and the response in the streamflow was observed.

Figure 37 illustrates the locations of the hypothetical well fields with respect to the watershed and stream segments. The well fields were situated so as to simulate the effects of pumping at varying distances from the main stem of Deer Creek. At each well field, unit pumping rates of 100 and 200 gpm were simulated for a period of 3 years. The results are shown on Figure 38.

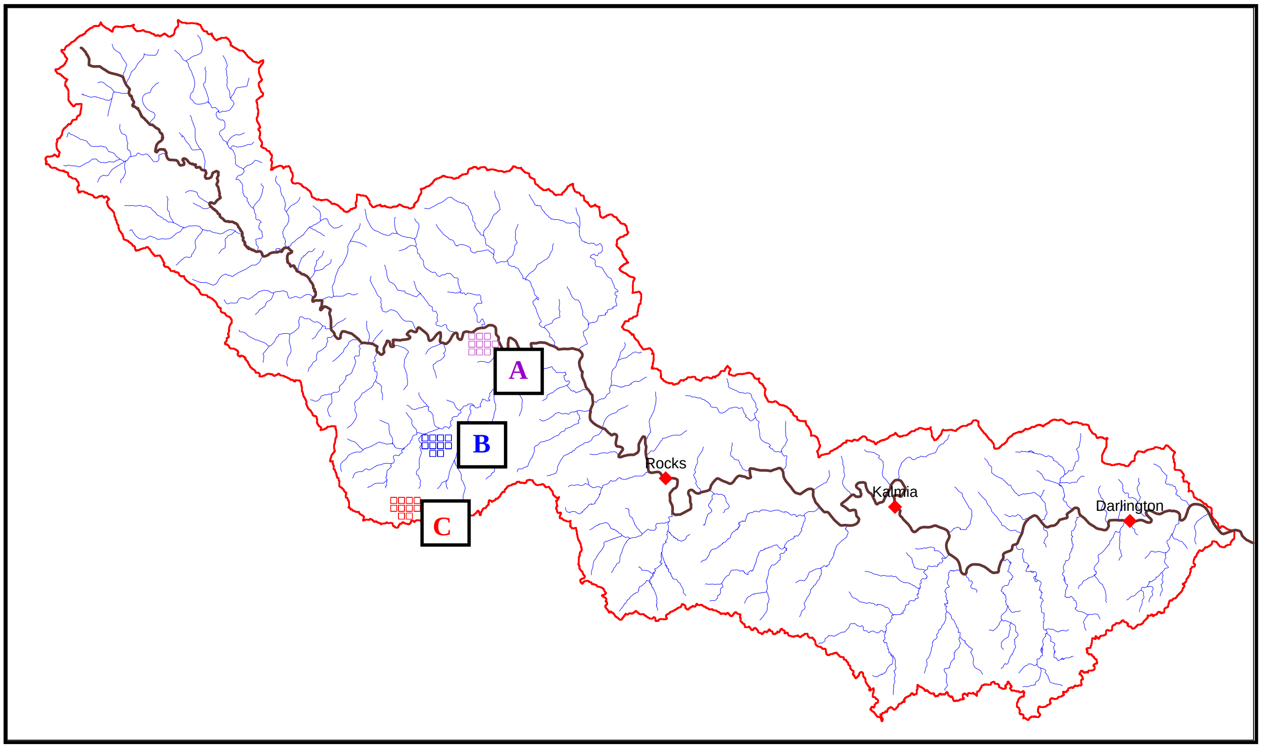

Figure 37. Locations of Hypothetical Well Fields (A, B, and C) in Modeling Domain

Under any scenario, the total volume of groundwater extracted by pumping will be compensated by a reduced volume of base flow in Deer Creek exactly equal to the amount pumped. If a well is operated for a short period of time, the change in base flow will not equal the pump rate, as some of the water that is pumped comes from a change in amount of water stored in the subsurface. When pumping from the well ceases, though, changes in base flow continue to occur until the water that was removed from storage is replenished. If a well is operated for a long period of time, after some period of pumping, all water will be derived from water that otherwise would discharge to the stream, and the change in base flow will equal the pumping rate. A pumping rate of 100 gpm is equivalent to a flow of 0.228 cfs. As can be seen from Figure 38, under all three modeled scenarios, the maximum impact of the 100 gpm pumping is about 0.23 cfs. The irregularities in the shape of the curves are artifacts of the numerical methods used to calculate the flows and their differences.

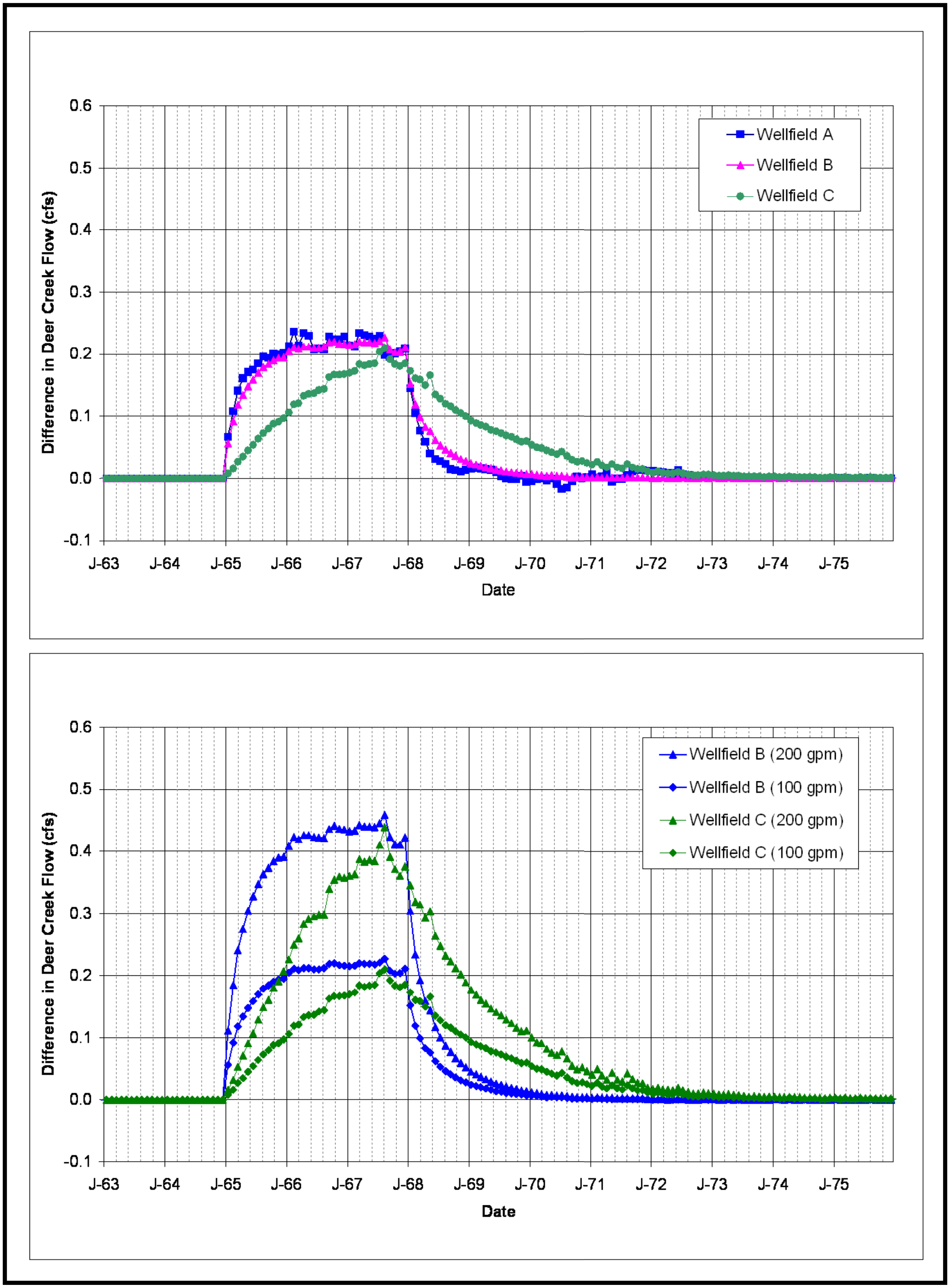

Figure 38. Difference in Base Flow in Deer Creek due to: (A) 100 gpm Pumping in Each Well Field; and B) Pumping at 100 or 200 gpm

The key differences between the three well field scenarios are the times until the maximum impact is observed in base flows. In the Deer Creek Watershed, there is a mature and extensive network of tributaries, all of which are gaining or discharging base flow from groundwater. Consequently, the primary indicator of how quickly a well field will impact the total flow in Deer Creek is its proximity to a tributary. Well fields A and B, while situated at different distances from the main stem of Deer Creek, have nearly identical curves for impact versus time on the Deer Creek base flow. The maximum impact on Deer Creek base flow is felt within about one year of pumping. While well field B is located miles from Deer Creek, it is adjacent to Little Deer Creek and its tributaries. Consequently, the base flow from the Little Deer Creek is diminished, ultimately reducing the total base flow for the Deer Creek main stem in about the same period of time as well field A situated immediately adjacent to Deer Creek.

Well field C was situated to be as far from Deer Creek or its tributaries as possible within the model domain. As can be seen, the maximum base flow impact (~0.21 cfs) is attained in about 2.75 years. We estimate that 2.75 years would be the maximum time until complete impact of a new pumping project would be observed on base flow in Deer Creek. For comparison, the same model was run, but using a total pumping rate of 200 gpm. As can be seen from Figure 38, the timing of impacts from well fields B and C are nearly identical, regardless of the pumping rate. The total impact is, however, twice as large for the 200 gpm scenario as for the 100 gpm scenario.

Although model results showing the direct impact of groundwater withdrawals on the availability of Deer Creek water resources would seem to suggest that such withdrawals conflict with desirable resource management, which is not necessarily the case. Because some water initially comes from storage when pumping begins, the use of wells as an alternative to surface water withdrawals during times of drought has the potential to avoid undue adverse impacts. Depending on the proximity of the well to the affected stream reach, a well could supplement a surface water intake for between 1 and 2.75 years before the impact is fully realized. In watersheds like Deer Creek with interrupted availability, the conjunctive use of surface and groundwater supplies is often a successful strategy.

X. CONCLUSIONS AND RECOMMENDATIONS

Several data sources are critical to conducting a study such as the one contained in this report. In terms of water resource information, there is good data available on historical and regional information on Deer Creek and its hydrology, geology, and climate. This information was supplemented by gaging studies completed in Deer Creek and its tributaries, and the usefulness of the data was enhanced by the development of a numerical groundwater model.

In addition to water data, other information is vital to a water availability analysis, including the current and projected uses of the land within the watershed, data on permitted and un-permitted water uses, and current and projected population figures for the surrounding area. Much of this information was available from county and state agencies, although some estimation of un-permitted uses was necessary.

A. Hydrologic Findings

The flow records available for the three gaging stations on Deer Creek, supplemented by gaging studies in 2006, were used to analyze the quantity and distribution of water in the watershed. The process of base flow separation is used in hydrologic studies to discern the portions of streamflow attributable to surface runoff versus contributions from groundwater (base flow). The result of the base flow separation on Deer Creek flow records was that, on average, 67 percent of the total flow in Deer Creek is base flow, and the remaining third is surface runoff. The rates of recharge to the groundwater systems that support base flow in various subwatersheds of Deer Creek were found to be fairly homogenous within two regions. Recharge averages approximately 1.02 cfs/mi^2 in the area of the watershed lying to the north and west of a line approximately following U.S. Route 1, whereas the recharge in the lower third of the watershed is approximately 0.76 cfs/mi^2. Determination of these regional values was instrumental in extrapolating the long-term record at the Rocks gage to other areas of the watershed.

A water budget developed for the watershed indicates that in average years about 60 percent of precipitation to the watershed is lost as evapotranspiration, and about 40 percent is discharged to Deer Creek either as direct surface runoff or as base flow via groundwater. Slight increases in precipitation and in the proportion of base flow to total flow were detected over the period of record. Whether these changes are related to each other or are attributable to natural variations, climate change or changes within the watershed are not known and would require further study.

B. Water Use Findings

Major water users include the towns of Stewartstown and Shrewsbury in Pennsylvania, both of which have municipal well fields situated within the watershed. Currently, Stewartstown imports some additional water from elsewhere in York County, and Shrewsbury exports an un-quantified amount of Deer Creek water to a treatment plant in New Freedom. In Maryland, the City of Aberdeen operates a surface water intake on the creek’s mainstem near Darlington to provide water supply to APG.

Other, non-permitted water use was estimated based on land use and population. Land use in the Deer Creek Watershed is predominantly agricultural (~58 percent) and forested (~33 percent), with limited amounts of developed land. Population projections compiled from Harford, Baltimore, and York Counties indicate an average of 24 percent population growth within the watershed between 2000 and 2025. This growth is concentrated along currently existing transportation corridors. In areas without major transportation corridors, growth is projected at much lower rates. The variation in projected growth in different subwatersheds is from under 5 percent growth to over 35 percent growth. The use of water for un-permitted commercial, industrial, and agricultural operations and for domestic wells was included in estimates, but was found to not be a substantial quantity. Less than 1 percent of the total available water is consumed (consumptive use) under current conditions, although for drought years, that amount may rise to 3 percent.

C. Water Availability Findings

Comparisons of water use and water supply, as depicted in Tables 14 and 15, showed that even without expected growth, the summer months currently exhibit a supply shortage at the Darlington gage under mild drought conditions, which pose an interruption of supply for APG. More severe droughts will present more serious deficits, and increased water demand upstream in the watershed will make downstream sources less reliable.

The total water use included in the budget analyses included a component for riparian needs – the passby flow. Allocation of this water for resource protection has the effect of making withdrawals from the watershed unreliable by rendering surface water unavailable for use during low flows. Although conditions do not decline to passby flow levels many – or even most – years, it is a reality that must be taken into consideration for long-term water resource planning.

Tables 23 through 26 show similar analyses for the subwatersheds, but on an annual basis and considering projected water use in 2010 and 2025. Under such conditions, certain subwatersheds, particularly those subject to development pressures, demonstrate water shortages in future drought scenarios. Figure 30 displays the subwatersheds with projected shortages.

Numerical modeling of the interactions with groundwater and surface water suggests that for any additional groundwater extraction, the full impact (equivalent to the total rate of pumping) will be observable within the base flow of Deer Creek within no more than 2.75 years, depending upon distance from surface water bodies. While this finding may limit the amount of groundwater that may be withdrawn, it does suggest that the short-term conjunctive use of wells during droughts to supplement unavailable surface water supplies may be an option.

In summary, the primary challenges for water supply in the watershed are population growth and urbanization within and adjacent to the watershed, and a supply that is already unreliable during moderate and severe droughts. State and federal governments have taken substantive steps to monitor and control water use within the watershed. These frameworks range from oversight and permitting functions of the SRBC to Maryland’s designation of the watershed as a “Scenic River.” These functions will become increasingly important as demand for water in the Deer Creek Watershed grows. The following recommendations primarily address methods for monitoring future growth and planning for increased water use within the watershed so that water management decisions can be made with all the necessary information.

D. Recommendations

The best tool in long-term water resource management is accurate and complete data. The two most important aspects of data collection are water use and hydrology.

- Maryland and Pennsylvania should continue collection of reported water use data for all water users. Under existing programs, some of this information is provided on a voluntary basis. More comprehensive and periodic evaluations of actual water use would be helpful to monitoring water use.
- The importance of maintaining existing streamflow gaging on Deer Creek cannot be overstated. The data provided by the two USGS gaging stations is critical for water resource planning and drought management. However, there is no regular or periodic monitoring of flow in tributaries. As noted in this report, groundwater and surface water withdrawals may first impact tributaries closet to the user; they will also represent a larger, and therefore potentially more significant, proportion of the total flow. A systematic program of flow monitoring in tributaries, particularly those potentially impacted by major users or those hosting especially sensitive features, is recommended. The use of monitoring wells to track groundwater levels could also prove valuable.

It will be the goal of water resource managers to minimize and monitor the potential impacts of land development and increased water use in the Deer Creek Watershed. Some mechanisms currently exist for such efforts, but others may also be beneficial.

- As noted previously, land use in the Deer Creek Watershed is already an issue of concern, and is addressed by such programs as Maryland’s Rural Legacy program, as well as zoning ordinances. Nonetheless, it is recommended that existing or more stringent (as adopted) guidelines for stormwater management during development be enforced by local governments so that future development within the watershed has as small an adverse impact as practicable on recharge to groundwater and base flow.
- During MDE, PADEP, or SRBC permitting activities for large users that involve surface water monitoring, it is recommended that streamflows be monitored both before and after the onset of extraction for a sufficient period of time to evaluate any potential impact on the stream. Depending upon a site’s distance from a tributary, there may be delayed response in the stream, and this should be considered during planning.
- Permitting activities and drought management efforts should include water conservation as a means to avoid adverse impacts to the resources of the watershed.

Finally, the multiple and varied uses of the water resources of the Deer Creek Watershed – both natural and human – are an important part of its character, and it is important to recognize when planning for future water use that there are different regions of the watershed with different hydrology, activities, and water demand.

- It may be desirable to conduct a more rigorous evaluation of the specific passby flow needs of each subwatershed for long-term planning purposes. Several methods are available for assessing the need, which may be driven by different uses (or a combination of uses) in each subwatershed, including aquatic habitat, recreation, fish migration, or protection of water supplies. At the time of this study’s publication, both MDE and SRBC are considering review of appropriate passby flows; efforts should be coordinated between the agencies.
- Recreational opportunities are an important but often overlooked component of the varied uses of Deer Creek. Recreational interests should compile information on critical seasons and conditions for the maintenance of recreation, such as suitable levels for boating, and make that information available to water managers.
- The contents and findings of this study should be periodically updated with new data. SRBC is likely unable to commit resources to perpetual oversight of the study, but could serve in a guidance or advisory role. Updates or reviews of the study could be facilitated by linking it to an existing and ongoing effort, such as Harford County’s Deer Creek Watershed Restoration Action Strategy.

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APPENDIX A

Federal, State, and Local Regulations that Apply to Water Supply in the Deer Creek Watershed

	Government Entity	Department / Section	Subtitle / Article	Regulation	Reference to State and Local Codes	Description	Application to Deer Creek Watershed
1	Federal	Corps of Engineers	Navigation and Navigable Waters	Water Resource Policies & Authorities: Corps of Engineers Participation in Improvements for Environmental Quality	CFR 33.236	The 1105–2–200 series of Engineer Regulations describe the procedures to be followed in developing water resource plans. These procedures require the establishment of planning objectives (generally encompassing a combination of National Economic Development (NED) and EQ outputs), and evaluation of alternative plans to meet those objectives to differing degrees.	Provides a brief summary of the Army Corps of Engineers' involvement in regulating water resources. Their policies affect both water quality and supply.
2	Federal	Corps of Engineers	Navigation and Navigable Waters	General Regulatory Policies	CFR 33.320	Identifies the various federal statutes which require that DA permits be issued before these activities can be lawfully undertaken, and related federal laws and the general policies applicable to the review of those activities. Parts 321 through 324 and 330 address special policies and procedures applicable to the following: 1) dams or dikes in navigable waters of the United States (Part 321); 2) other structures or work including excavation, dredging, and/or disposal activities, in navigable waters of the United States (Part 322); 3) activities that alter or modify the course, condition, location, or capacity of a navigable water of the United States (Part 322); 4) construction of artificial islands, installations, and other devices on the outer continental shelf (Part 322); 5) discharges of dredged or fill material into waters of the United States (Part 323); 6) activities involving the transportation of dredged material for the purpose of disposal in ocean waters (Part 324); and 7) nationwide general perm	The regulation under which wetlands and U.S. waterways are protected in the United States. In the state of Maryland, a joint permit process between MDE and the ACOE is in effect. Although originally created for the protection of navigable waters, these regulations also protect water quality and supply by reviewing development projects near our nation's water resources.
3	Federal	EPA		Clean Water Act	Federal Water Pollution Control Act [As Amended Through P.L. 107–303, November 27, 2002]	The Clean Water Act is a result of a 1972 water quality law which was revamped in 1977. The major programs that make up the CWA are: 1) water quality standards, 2) anti-degradation policy, 3) water body monitoring and assessment, 4) reports on condition of the nation's waters, 5) total maximum daily loads (TMDLs), 6) NPDES permit program for point sources, 7) Section 319 program for non-point sources, 8) Section 404 program regulating filling of wetlands and other waters; 9) Section 401 state water quality certification; 10) state revolving loan fund (SRF).	Affects both quality and supply. The leading federal regulation that protects water resources.
4	Federal	NRCS	Agriculture	Watershed Projects	CFR 7.622	Outlines the policies for planning and executing watershed and flood prevention projects. To help sponsors prepare and execute watershed plans, the Natural Resources Conservation Service (NRCS) and other federal agencies will conduct investigations and surveys. Results will be used to determine the extent of watershed problems and needs, and to propose solutions consistent with local, regional, and national objectives. Proposals will consist of land treatment and/or nonstructural or structural measures. Authorized proposals include: watershed protection, conservation and proper land use, flood prevention, agricultural water management, public recreation, public fish and wildlife, municipal and industrial water supply, hydropower, water quality management, groundwater supply, agricultural pollution control, and other water management. When NRCS and the sponsors agree upon a final plan, NRCS will provide technical and financial assistance to install the project.	Allows local governments to obtain funding and technical aid to help manage their local water resources.
5	Federal	NRCS, Forest Service	Agriculture	Emergency Watershed Protection	CFR 7.624	Describes the requirements and procedures for federal assistance administered by the NRCS under the Emergency Watershed Protection (EWP) program. The EWP Program is designed for emergency recovery after a sudden impairment of a watershed due to a natural disaster; its objective is to relieve imminent hazards to life and property by assisting sponsors, landowners, and operators in the implementation of measures to slow runoff and prevent erosion. The NRCS and United States Forest Service (FS) are responsible for the EWP program. The Secretary of Agriculture has delegated its administration to the chief of NRCS for state and private land. Technical and financial assistance may be made available when a federal emergency is declared by the President or when a local emergency is declared by the NRCS state Conservationist.	Funding and technical aid is available during flood emergencies.
6	Federal	SRBC	Conservation of Power and Water Resources	Susquehanna River Basin Commission - General Policies	CFR 18.801	The SRBC is a regional governmental agency whose purpose is to effect comprehensive planning for the conservation, utilization, development, management, and control of the water and related natural resources of the Susquehanna River basin. The governors of the states of New York, Pennsylvania, and Maryland, and a representative of the President of the U.S. are members. The objectives of the SRBC are to: 1) develop coordinated federal, state, local, and private water and related natural resources planning in the basin; 2) formulate, adopt, effectuate, and keep current a comprehensive plan and a water resources program for the immediate and long-range use and development of the water resources of the basin; 3) provide orderly collection and evaluation of data, and continuing research related to water resources problems; 4) establish priorities for planning, financing, development and use of projects and facilities essential to effectively meet identified water resource needs; and 5) maintain these resources in a viable state.	Defines the purpose of the SRBC and lists its general policies for regulation of the Susquehanna River Basin.

	Government Entity	**Department / Section**	**Subtitle / Article**	**Regulation**	**Reference to State and Local Codes**	**Description**	**Application to Deer Creek Watershed**
7	Federal	SRBC	Conservation of Power and Water Resources	Susquehanna River Basin Commission - Review and Approval of Projects	CFR 18.803	(a) This part establishes the scope and procedures for review and approval of projects under Section 3.10 of the Susquehanna River Basin Compact, Public Law 91–575, 84 Stat. 1509 et seq., (the compact) and establishes special standards under Section 3.4 (2) of the compact governing water withdrawals and the consumptive use of water. The special standards established pursuant to Section 3.4 (2) shall be applicable to all water withdrawals and consumptive uses in accordance with the terms of those standards, irrespective of whether such withdrawals and uses are also subject to project review under Section 3.10.	Lists the procedures for project approvals in the SRBC. There are specific requirements for water withdrawals written into this section which are specifically pertinent to the project.
8	Federal	SRBC	Conservation of Power and Water Resources	Susquehanna River Basin Commission - Special Regulations and Standards	CFR 18.804	In addition to any other requirements of commission regulations, and subject to the consent of the affected signatory state to this requirement, all persons withdrawing or diverting in excess of an average of 10,000 gpd for any consecutive thirty-day period, from surface or ground-water sources, as defined in Part 803 of this chapter, shall register the amount of this withdrawal with the commission and provide such other information as requested on forms prescribed by the commission.	SRBC's key regulation affecting water use in the watershed.
9	Federal	SRBC		Susquehanna River Basin Compact	Public Law 91-575, 84 Stat. 1509 et seq.) Maryland Act of 1967, Chapter No. 391 New York Act o f 1967, Chapter No. 785 Pennsylvania Act of 1968, Act No. 181	Sets the guidelines for the creation of the SRBC and defines its authority over water resource issues in the Susquehanna River basin.	The charter of SRBC. Delegates the authority to regulate land/water resource management in the Susquehanna River basin.
10	Federal	SRBC		Emergency Water Withdrawal /Consumptive Use Procedures	Policy No. 2003-03	Provides guidelines for processing applications for the emergency withdrawal of surface or groundwater in the Susquehanna River basin.	Affects water supply during emergency situations in the river basin.
11	Federal	SRBC		Procedural Guidelines for Addressing Compliance with Docket Conditions	Policy No. 2003-02	Provides general guidance and procedures for non-compliance/violations of the conditions set forth in approved dockets.	Enforcement policies for the river basin.
12	Federal	SRBC		Guidelines for Using and Determining Passby Flows and Conservation Releases for Surface-Water and Ground-Water Withdrawal Approvals	Policy No. 2003-01	Sets limits for surface water flow-bys and groundwater withdrawals in the basin.	Affects water supply in the river basin.
13	Federal	SRBC		Policy Limiting the Transferability of the Exemption from Consumptive Use Regulation	Policy No. 98-06	Allows pre-SRBC (1971) consumptive water users an exemption from the consumptive water regulations set by the SRBC.	Affects water supply in the river basin.
14	Federal	SRBC		Policy Regarding Discontinuance as a Method of Compliance with SRBC Regulation 803.42 – Consumptive Use of Water	Policy No. 98-02	The following SRBC regulations are enforced in the basin: 1) 18 CFR 803.42--Consumptive Use of Water (This requirement is currently suspended for agriculture) more than 20,000 gpd from any ground or surface water sources as of January 23, 1971. This regulation does not apply to projects that existed before January 23, 1971, unless they increased their consumptive water use by more than 20,000 gpd after that date; 2) 18 CFR 803.43--Groundwater Withdrawals more than 100,000 gpd as of July 13, 1978. This regulation does not apply to projects that existed before July 13, 1978, unless they increased their groundwater withdrawals by more than 100,000 gpd after that date; 3) 18 CFR 803.44--Surface Water Withdrawals more than 100,000 gpd as of November 11, 1995. This regulation does not apply to projects that existed before November 11, 1995 unless they increased their groundwater withdrawals by more than 100,000 gpd after that date.	Establishes discontinuance as an option for compliance with SRBC Consumptive Use Regulation 803.42.
15	Federal	SRBC		Policy Regarding Diversions of Water from the Susquehanna River Basin	Policy No. 98-01	Issues guidelines for applicants wishing to divert water from the Susquehanna River Basin.	Affects water supply in the river basin.

	Government Entity	**Department / Section**	**Subtitle / Article**	**Regulation**	**Reference to State and Local Codes**	**Description**	**Application to Deer Creek Watershed**
16	Federal	SRBC		Clarification of Current Consumptive Use Regulation	Policy No. 92-01	Clarifies the Consumptive Use Regulation and the types of compensation required if the stream is adversely affected by consumptive use. Applies basin wide.	Affects water supply in the river basin.
17	Federal	US Dept of the Interior	National Park Service	Rivers, Trails, and Conservation Assistance Program		The Rivers, Trails and Conservation Assistance Program, also known as Rivers & Trails or RTCA, works with community groups and local, State, and federal government agencies to conserve rivers, preserve open space, and develop trails and greenways. The RTCA program implements the natural resource conservation and outdoor recreation mission of the National Park Service in communities across America.	Offers assistance in developing trails and recreational uses within the Susquehanna Greenway Trail and in local and state parks within the watershed.
18	Federal	USDA	Agriculture	River Basin Investigations and Surveys	CFR 7.621	Describes policies, requirements, and procedures governing the Department of Agriculture's (USDA's) investigations and surveys of river watersheds and other waterways. Used as a basis to develop: a) cooperative river basin surveys in coordination with federal, state, and local agencies; b) floodplain management assistance in coordination with the responsible state agency and involved local governments; c) joint investigations and reports with the Department of the Army; and d) interagency coordination of water resources activities. Delegated authority is the Natural Resources Conservation Service (NRCS).	Land use and watershed management tool.
19	Federal	USDA	Agriculture	Water Bank Program	CFR 7.752	Describes the terms and conditions for the Water Bank Program. The objective of the program is to preserve, restore, and improve wetlands, and thereby: 1) conserve surface waters, 2) preserve and improve habitat for migratory waterfowl and other wildlife resources, 3) reduce runoff, soil and wind erosion, 4) contribute to flood control, 5) contribute to improved water quality and reduce stream sedimentation, 6) contribute to improved subsurface moisture, 7) reduce acres of new land coming into production and to retire lands now in agricultural production, 8) enhance the natural beauty of the landscape, and 9) promote comprehensive and total water management planning. Under the Water Bank program, wetlands identified for the conservation of water or related uses on a conservation plan shall be developed in cooperation with the Soil and Water Conservation District in which the lands are located. The Secretary of Agriculture is authorized to make agreements and payments to eligible persons in important migratory waterfowl nesting and breeding areas.	Promotes better water quality, but can also improve land use and water supply in the watershed.
20	Federal	USDA, Forest Service	Parks, Forests, and Public Property	Wild and Scenic Rivers	CFR 36.297	(a) No license, permit, or other authorization can be issued for a Federally assisted water resources project on any portion of a Wild and Scenic River or Study River nor can appropriations be requested to begin construction of such projects, without prior notice to the Secretary of Agriculture, and a determination in accordance with section 7 of the Act. (b) As soon as practicable, but no less than 60 days prior to the date of proposed action, the Federal agency shall provide a notice of intent to issue such license, permit, or other authorization to the Chief, Forest Service, U.S. Department of Agriculture, P.O. Box 2417, Washington, DC 20013.	Deer Creek is recognized as a Wild and Scenic River; therefore land development within the watershed must follow additional regulations. This affects both water quality and supply issues.
21	Federal	Water Resources Council	Conservation of Power and Water Resources	State Water Management Planning Program	CFR 18.740	Funds made available under the State Water Management Planning Program may be used by participating states to establish, develop or enhance existing or proposed state water resource management and planning programs. Programs should be focused on pertinent state and national goals and the objectives of Title III of the Water Resources Planning Act, and should address: 1) coordination of the program authorized by the Act and those related programs of other Federal agencies; 2) integration of water conservation with state water management planning; 3) integration of water quantity and water quality planning; 4) integration of ground and surface water planning; 5) planning for protection and management of groundwater supplies; 6) planning for protection and management of instream values; and 7) enhanced cooperation and coordination between federal, state and local governments involved in water and related land resources planning and management.	Financial assistance is available to local and state agencies for developing and implementing water management plans. The goals of this program benefit water quality and quantity.
22	Federal			Water Resource Planning Act	Act 220 42 U.S.C. §§ 1962 - 1962d-3	Establishes a council which: a) maintains a continuing study and prepare an assessment biennially, or at such less frequent intervals as the council determines, of the adequacy of supplies of water necessary to meet the water requirements in each water resource region in the United States and the national interest therein; and b) maintains a continuing study of the relation of regional or river basin plans and programs to the requirements of larger regions of the nation and of the adequacy of administrative and statutory means for the coordination of the water and related land resources policies and programs of the several federal agencies. The council shall appraise the adequacy of existing and proposed policies and programs to meet such requirements; and it shall make recommendations to the President with respect to federal policies and programs.	Involves land use planning affecting both water quality and supply. Helps SRBC adopt water resource plans for their area. Sets standards by which these plans will be reviewed by congress & the President. These standards are: 1) the efficacy of such plan or revision in achieving optimum use of the water and related land resources in the area involved; 2) the effect of the plan on the achievement of other programs for the development of agricultural, urban, energy, industrial, recreational, fish and wildlife, and other resources of the entire nation; and 3) the contributions which such plan or revision will make in obtaining the nation's economic and social goals.

	Government Entity	Department / Section	Subtitle / Article	Regulation	Reference to State and Local Codes	Description	Application to Deer Creek Watershed
23	Maryland	Dept of Natural Resources	RURAL LEGACY PROGRAM	Rural Legacy Program – General	COMAR 05.09A.01	The Rural Legacy Program was enacted by the 1997 Maryland General Assembly. The program encourages local governments and private land trusts to identify Rural Legacy Areas and to competitively apply for funds to complement existing land preservation efforts or to develop new ones. Easements or fee estate purchases are sought from willing landowners in order to protect areas vulnerable to sprawl development that can weaken an area's natural resources, thereby jeopardizing the economic value of farming, forestry, recreation and tourism.	Deer Creek is a part of this program and Harford County receives money to preserve rural lands.
24	Maryland	Dept of Natural Resources		Scenic and Wild Rivers Program	Maryland Annotated Code 8-401…	Establishes and defines the purpose of the Maryland Scenic and Wild Rivers Program.	Deer Creek is included in this program.
25	Maryland	Dept of Natural Resources	Wildlife and Heritage Service	Maryland Darter Recovery Plan	Maryland Darter Recovery Plan	A program developed to protect the Maryland Darter (an extremely rare fish found only in Maryland).	Deer Creek has a population of Maryland Darter. This program is promoting alternative ways to develop the watershed in an effort to safeguard the Maryland Darters habitat, which is being degraded as development increases in the watershed.
26	Maryland	Dept of Natural Resources	Forest Service	Maryland Forest Legacy Program	Maryland Forest Legacy Program	A program developed to protect environmentally important forest lands that are threatened by present or future conversion to non-forest use.	Some areas in the watershed are apart of this program.
27	Maryland	Dept of Natural Resources		Maryland Forest Conservation Act	Maryland Annotated Code, Natural Resources Article, Section 5-1601 through 5-1613	The Forest Conservation Act of 1991 requires units of local government with planning and zoning authority to establish and implement local forest conservation programs, and provides for the Department's administration of forest conservation requirements, in the absence of a local forest conservation program. The Forest Conservation Act of 1991 also provides that this subtitle include a model ordinance and guidance manual to: 1) establish standards of performance required in forest stand delineations and forest conservation plans; and 2) assist persons in developing the required forest stand delineations and forest conservation plans. The forest stand delineation and forest conservation plans implement forest conservation, reforestation, and afforestation requirements for certain land use categories and certain regulated activities established in Natural Resources Article, § 5-1601--5-1612, Annotated Code of Maryland.	Forest resources in the watershed are protected under the Forest Conservation Act of 1991. Directly impacts water quality/availability and watershed management.
28	Maryland	Dept. of the Environment	Regulation of Water Supply, Sewage Disposal & Solid Waste	Quality of Drinking Water in Maryland	COMAR 26.04.01	Regulates the quality of water associated with water supply, sewage disposal and solid waste.	Applies to all public water systems in the state, except for cases in which all the following conditions apply: a) the system consists only of distribution and storage facilities, and does not have any collection and treatment facilities; b) the system obtains all of its water from, but is not owned or operated by, a supplier of water to which this regulation applies; c) the system does not sell water to any person; and d) the system is not a carrier which conveys passengers in interstate commerce.
29	Maryland	Dept. of the Environment	Water Management	Construction on Non-tidal Waters and Floodplains	COMAR 26.17.04	Governs construction, reconstruction, repair, or alteration of a dam, reservoir, or waterway obstruction or any change of the course, current, or cross section of a stream or body of water within the state, including any changes to the 100-year frequency floodplain of free-flowing waters. Free-flowing waters do not include state or private wetlands or areas subject to tidal flooding. For purposes of these regulations, the landward boundaries of any tidal waters shall be deemed coterminous with the wetlands boundary maps adopted pursuant to Environment Article, § 16-301, Annotated Code of Maryland.	Protects against net loss of wetlands/waterways. Water availability is preserved by safeguarding water storage from development in the Deer Creek Watershed.
30	Maryland	Dept. of the Environment	Water Management	Flood Management Grant Program	COMAR 26.17.05	Designates funds to subdivisions for capital projects which are included in Flood Management Plans.	Impacts watershed management and indirectly impacts the water quality.
31	Maryland	Dept. of the Environment	Water Management	Water Appropriation or Use	COMAR 26.17.06	Outlines the Water Appropriations program purpose and permitting procedures. The state's water supply resources include watercourses, lakes, aquifers, tidal areas, and other bodies of water in the state. Private property owners have the right to make reasonable use of the waters of the state which cross or are adjacent to their land. A groundwater appropriation or use permit or a surface water appropriation or use permit issued by the department authorizes the permittee to make reasonable use of the waters of the state without unreasonable interference with other persons also attempting to make reasonable use of water. The permittee may not unreasonably harm the water resources of the state.	The principal state regulation limiting water consumption in the watershed.
32	Maryland	Dept. of the Environment	Susquehanna River Basin Commission	SRBC - Procedures for Review of Projects	COMAR 26.18.01	Explains the purpose of SRBC.	SRBC and MDE regulate land development, water use and quality in the Deer Creek Watershed.
33	Maryland	Dept. of the Environment	Coastal Facilities Review	Coastal Facilities Review	COMAR 26.22.01	Regulates oil and gas facilities constructed in the coastal area, delineated by county. Harford County is included.	If an oil/gas industrial facility is constructed in the watershed, the applicant must follow the regulations and permit process detailed in this document.

	Government Entity	Department / Section	Subtitle / Article	Regulation	Reference to State and Local Codes	Description	Application to Deer Creek Watershed
34	Maryland	Dept. of the Environment	Nontidal Wetlands	Nontidal Wetlands – General	COMAR 26.23.01	Explains general permit regulations for non-tidal wetlands.	Wetlands loss affects water availability/storage for the Deer Creek Watershed. Loss of wetlands also affects water quality because wetlands act as natural filters to maintain cleaner water.
35	Maryland	Dept. of the Environment	Nontidal Wetlands	Nontidal Wetlands - Permit Application and Processing	COMAR 26.23.02	Explains the MDE permit and processing guidelines for nontidal wetlands.	Wetlands loss affects water availability/storage for the Deer Creek Watershed. Loss of wetlands also affects water quality because wetlands act as natural filters to maintain cleaner water.
36	Maryland	Dept. of the Environment	Nontidal Wetlands	Nontidal Wetlands - Letter of Exemption	COMAR 26.23.03	Discusses letters of exemption awarded by MDE to specific applicants.	
37	Maryland	Dept. of the Environment	Nontidal Wetlands	Nontidal Wetlands – Mitigation	COMAR 26.23.04	Outlines process for nontidal wetland mitigation for cases in which impact is above the threshold.	Ensures no net loss of wetlands in the state of Maryland. Affects water quality and availability in the watershed.
38	Maryland	Dept. of the Environment	Nontidal Wetlands	Nontidal Wetlands - Agricultural & Forestry Activities	COMAR 26.23.05	Explains permit exemptions for agricultural and forestry activities if outlined requirements are met.	Directly impacts water quality and availability in the watershed.
39	Maryland	Dept. of the Environment	Nontidal Wetlands	Nontidal Wetlands of Special State Concern	COMAR 26.23.06	Establishes further protection for specific wetlands in the state.	Deer Creek Serpentine Barren, located near the delta in the Deer Creek Watershed, is covered by this provision.
40	Pennsylvania	Dept. of Conservation & Natural Resources	Conservation and Natural Resources	Conservation Areas	17.44 Pennsylvania Code	Discusses the management of Conservation Areas. Describes how to donate land, and how the land is maintained.	Affects land use in watershed.
41	Pennsylvania	Dept. of Env. Protection	Protection of Natural Resources - Water Resources	General Provisions	25.91 Pennsylvania Code	General Provisions for Water Resources	Governs general management of water resources
42	Pennsylvania	Dept. of Env. Protection	Water Resources Planning Act	Water Withdrawal and Use Registration & Documentation	Act 220 Pennsylvania Code	Requires the Pennsylvania Department of Environmental Protection (DEP) to update Pennsylvania's State Water Plan to determine how much water is used and how much will be available in the future. Act 220 requires any commercial, industrial, agricultural or individual activity that withdraws or uses 10,000 or more gallons of water per day, averaged over any 30-day period, to register and periodically report their water use to DEP. Those activities that use less than 10,000 gallons per day may choose to register voluntarily to help DEP get a more complete picture of water use.	Tracks water use within Pennsylvania for purposes of developing state-wide water use plan
43	York County	York Co. Planning Commission		Subdivision and Land Development Ordinance	Subdivision and Land Development Ordinance	Provides design standards for subdivisions and land development. Discusses the protection of critical environmental areas, water service analysis and feasibility report, sewer feasibility, protection of groundwater resources, and storm drainage.	Affects water quality and water supply.
44	Baltimore County	Dept. of Env. Protection & Resource Mgmt.	Dept. of Env. Protection & Resource Mgmt.	Protection of Water Quality, Streams, Wetlands & Floodplains	33.3 Baltimore County Code	Outlines regulations dealing with the protection of water quality, streams, wetlands, and floodplains. Discusses buffers for construction within sensitive areas (Chesapeake Bay Critical Area).	Applies to all wetlands, streams, and floodplains of the watershed within Baltimore County. Affects predominantly water quality, but by protecting these areas water storage within the watershed increases.
45	Baltimore County	Dept. of Env. Protection & Resource Mgmt.	Dept. of Env. Protection & Resource Mgmt.	Stormwater Management	33.4 Baltimore County Code	Discusses the regulations dealing with storm water management for developments or new subdivisions. Identifies the requirements for construction plans and permits.	Affects water quality and reduces flashiness of streams during storm events within the watershed.
46	Baltimore County	Dept. of Env. Protection & Resource Mgmt.	Groundwater Management	Wells and Drinking Water	COBAR 1.03.02	Discusses the regulations that apply to the location and approval of private water supplies for new development (e.g. water quality monitoring, hydrofracturing, well construction).	Affects both water quality and availability of groundwater resources within the watershed.
47	Baltimore County	Dept. of Env. Protection & Resource Mgmt.		Env. Guidelines for the Design & Maint. Of Golf Courses	Env. Guidelines for the Design & Maint. of Golf Courses	Discusses the permitting process for new golf courses. Includes a description of a monitoring program for golf courses.	Predominantly regulates water quality issues. Water supply is regulated by state (WAP)
48	Baltimore County	Dept. of Planning, Zoning & Subdivision Control		Zoning	32.3 Baltimore County Code	Discusses general zoning provisions for developments and new subdivisions; also addresses the need for certain public facilities (schools, parks, water, sewerage, etc.)	Affects land use in watershed.

	Government Entity	**Department / Section**	**Subtitle / Article**	**Regulation**	**Reference to State and Local Codes**	**Description**	**Application to Deer Creek Watershed**
49	Baltimore County	Dept. of Planning, Zoning & Subdivision Control		Development	32.4 Baltimore County Code	Outlines general zoning provisions for developments and new subdivisions and identifies required information for permitting and plans. Discusses development in floodplains and wetlands.	Affects land use in watershed.
50	Baltimore County	Dept. of Planning, Zoning & Subdivision Control		Floodplain Management	32.8 Baltimore County Code	Discusses special provisions and requirements for building within floodplains, including permits and required plans.	Affects land use and water quality and indirectly, water storage in the watershed.
51	Harford County	Ag. & Hist. Preservation Section		Agricultural Land Preservation		Discusses Harford County Land Preservation program and all the programs contained therein. Includes description of the Land Preservation Program, the Maryland Agricultural Land Preservation district, Maryland Agricultural Land Preservation Easements, and the Maryland Rural Legacy Program.	Discusses preservation of lands in areas like the Deer Creek Watershed. Deals mainly with land use.
52	Harford County	Dept of Planning & Zoning		Zoning	Chapter 267 of the Harford County Code	Discusses basic zoning requirements and provides requirements for sanitary landfills. Mentions special overlay areas as well as general zoning, special overlay districts (historic district, agricultural land preservation district, the floodplain district, and the natural resources district), Deer Creek Scenic River district, and growth management for public facilities.	Explains the purpose of Deer Creek Scenic River district.
53	Harford County	Dept of Planning & Zoning		Subdivision Regulations		Discusses the various regulations for subdivision zoning, and the permitting process for development.	Affects permitting issues for development in the watershed.
54	Shrewsbury Boro., York County, Pa.			Zoning Ordinance	Ordinance No. 1984-1	Discusses zoning ordinances dealing with drainage and grading provisions for construction.	Affects land use.
55	Shrewsbury Boro., York County, Pa.			Subdivision and Land Development Ordinance	Subdivision and Land Development Ordinance	Outlines the requirements for sewage disposal, water supply, storm drainage, and watercourses/drainage ways.	Affects water supply and quality.
56	Shrewsbury Twp., York County, Pa.		Zoning Ordinance	Designation of Districts	Article III, Zoning Ordinance	Discusses the districts located within the Shrewsbury Township. Outlines the types and extents of land use permitted. Summaries of the districts are included, but no specific data.	Affects land use.
57	Shrewsbury Twp., York County, Pa.		Zoning Ordinance	Environmental Regulations	Article XII, Zoning Ordinance	Describes the general environmental regulations for the Town of Shrewsbury. Discusses floodplains, critical environmental areas, wellhead protection zones, drainage, grading, etc.	Maps of wellhead protection zones are included.
58	Shrewsbury Twp., York County, Pa.			Subdivision and Land Development Ordinance	Subdivision and Land Development Ordinance	Outlines design standards for subdivisions and land development. Discusses the protection of critical environmental areas, water service analysis and feasibility report, sewer feasibility, protection of groundwater resources, and storm drainage.	Affects water quality and water supply.

APPENDIX B

Alternative Scenarios for Increased Water Demand in the Deer Creek Watershed

APPENDIX B

Alternative Scenarios for Increased Water Demand in the Deer Creek Watershed

The water demand projections presented in the main body of this study are based on population growth gleaned from county census estimates and from increases in commercial and industrial water use derived from an analysis of potential changes in land use to meet zoning. While useful for estimating increases in water demand given the current character and composition of the watershed, the analyses do not account for the potential increase in water use associated with emerging trends that are not immediately evident from census and zoning data.

The most influential of these trends are: (1) growth of Aberdeen Proving Ground (APG) in conjunction with the federal Base Realignment and Closure (BRAC) effort, and the military and civilian population growth it entails; (2) conversion of agricultural land from uses with lower-intensity water use to land uses with relatively higher-intensity water use, such as nurseries; and (3) development of commercially zoned land to relatively high water use purposes, such as golf courses. The potential increase in water demand in the Deer Creek Watershed associated with these three trends are assessed in the next three sections, and assessed cumulatively in a fourth section.

APPENDIX B1

Population and Water Demand Projections Associated with BRAC

The report entitled *Aberdeen Proving Ground BRAC Impacts on Seven Jurisdictions* (Sage Policy Group, 2007) uses estimates of jobs per household and household size to project increases in households and population attributable to BRAC changes at APG. The APG BRAC report provides baseline (without BRAC), low-, mid-, and high-case population projections for 2007, 2012, and 2017 for seven jurisdictions (including York, Harford, and Baltimore Counties), as well as a total for all seven. To incorporate estimated BRAC impacts on population, as reported in the APG BRAC document, the differences between the percent population increases under the baseline condition and the BRAC mid-case projection scenario were calculated for Harford, York, and Baltimore Counties for the 2007, 2012, and 2017 populations. The BRAC-related percent increases were then added to the percent increases extracted from the data provided by the respective counties for 2010, 2015, 2020, and 2025. Since the population projection years did not match up exactly between the two data sources, the BRAC-related percent increases for 2012 were added to the county percent increases for 2010. The BRAC-related percent increases for 2017 were added to the county percent increases for 2020. The median values of the BRAC-related percent increases between 2012 and 2017 were added to the county percent increases for 2015. The BRAC-related percent increases for 2017 also were added to the county percent increases for 2025, since the APG BRAC document did not contain projections beyond 2017.

Using the 2005 county-derived populations as a benchmark, the sum of the appropriate BRAC-related and county-projected percent population increases were applied to calculate population projections for 2010, 2015, 2020, and 2025 that reflect both county projections and APG BRAC report estimates. To apply the sum of the appropriate BRAC-related and county-projected percent increases, reported in the APG BRAC document by county, to each subwatershed, the subwatersheds were broken out by percent composition of each county and assigned percent increases accordingly.

Population projections associated with BRAC, in 5-year increments for each subwatershed, can be seen in Table B-1. The total 25-year projected population increase for the Deer Creek Watershed (2000 to 2025) is approximately 28 percent, as compared to 24 percent without including BRAC-related impacts (Table 22). Projected increases for individual subwatersheds range from about 12 percent to 41 percent when BRAC population projections are incorporated, as opposed to 5 percent to 35 percent without including BRAC projections. The lowest projected growth value corresponds to the Little Deer Creek subwatershed, as is also the case when BRAC population projections are not included in the analysis. The greatest projected growth is in the South Stirrup - North Stirrup subwatershed, near the northwestern extent of Bel Air, while the greatest projected growth without consideration of BRAC-related impacts is in the Deer Creek headwaters, near Shrewsbury. As compared to the population projections in Table 20 of this report, the population projections that incorporate BRAC impacts presented below are larger at the watershed, county, and subwatershed scales. The most substantial population increases are projected to occur in the Harford County portion of the watershed, which constitutes more than 80 percent of the total watershed area. The period of time between 2005 and 2010 is when the most pronounced increase in population growth is projected to occur as a result of BRAC impacts.

Table B-1. Population Projections (with BRAC Population Projections)

ID	Location	2000*	2005	2010	2015	2020	2025	10-Year Growth*	25-Year Growth*	2000 to 2025 Percentage Growth
	By County									
	Harford County	24,332	25,421	28,681	29,876	30,610	31,011	4,349	6,679	27.4%
	York County	16,139	17,476	17,295	18,319	19,234	21,034	1,156	4,895	30.3%
	Baltimore County	1,170	1,323	1,413	1,427	1,437	1,449	243	279	23.9%
	By Subwatershed									
1	Cool Branch Run	472	477	530	548	558	565	59	93	19.8%
2	Stout Bottle Branch - Cabbage Run	1,980	2,102	2,389	2,463	2,538	2,513	409	533	26.9%
3	Thomas Run	3,113	3,407	3,876	4,046	4,129	4,159	763	1,046	33.6%
4	Mill Brook	736	749	847	889	920	946	111	210	28.6%
5	Hollands Branch	397	421	467	482	490	495	69	97	24.5%
6	UNT at Thomas Bridge Rd	588	620	713	754	781	801	125	213	36.2%
7	Saint Omer Branch	2,238	2,304	2,549	2,621	2,658	2,677	311	439	19.6%
8	Deer Creek – Mid	772	790	875	900	908	917	103	145	18.7%
9	South Stirrup - North Stirrup Run	1,808	1,931	2,240	2,383	2,479	2,548	432	740	40.9%
10	Rock Hollow - Kellogg - Gladden Branches	2,306	2,373	2,687	2,813	2,891	2,946	381	640	27.7%
11	UNT south of Falling Branch	76	80	91	96	99	101	15	25	32.5%
12	UNT west of Falling Branch	40	42	48	51	53	54	8	14	34.6%
13	Little Deer Creek	2,531	2,500	2,736	2,792	2,817	2,829	205	298	11.8%
14	Falling Branch	547	572	638	666	683	695	92	148	27.1%
15	Big Branch	648	676	747	775	792	804	99	156	24.0%
16	Island - Jackson - Plumtree Branches	2,821	3,021	3,374	3,507	3,594	3,656	554	836	29.6%
17	Ebaugh's Creek	6,859	7,566	6,926	7,339	7,710	8,441	67	1,582	23.1%
18	Deer Creek Headwaters	9,708	10,394	10,910	11,526	12,076	13,149	1,201	3,441	35.4%
19	Graveyard Creek	177	187	213	223	230	235	36	58	33.1%
20	Hopkins Branch	413	424	467	480	486	490	55	78	18.8%
21	Tobacco Run	2,276	2,378	2,708	2,846	2,933	2,992	432	716	31.5%
22	Buck Branch - Elbow Branch	1,130	1,199	1,353	1,412	1,449	1,474	223	344	30.4%
23	UNT east of Hollands Branch	6	6	7	7	8	8	1	2	25.7%
	Deer Creek Watershed Total	**41,640**	**44,220**	**47,390**	**49,622**	**51,282**	**53,494**	**5,750**	**11,853**	**27.6%**

** From 2000 Census Data.*

The 10- and 25-year population growth projections that include BRAC-related impacts were incorporated into the analyses presented in Tables B-2 through B-5 as additional, residential population demands. The tables represent groundwater balances for average year conditions and drought year conditions for the years 2010 and 2025. These results are also illustrated graphically on Figure B-1. Many of the trends evident in the water demand projection data that does not incorporate BRAC population projections (Tables 23-26) are also evident when BRAC-related impacts are included. As expected, the number of subwatersheds with an allocation deficit is greater for drought years than for average years. The number also increases from 2010 to 2025, reflecting increases in demand. Under average conditions, the allocated water resources do not indicate any deficits during 2010 and a deficit only for the Hopkins Branch subwatershed in 2025.

More significantly, under 2010 and 2025 drought conditions, several of the subwatersheds show an allocation deficit. The allocation deficits are concentrated in the lower portion of the watershed and in the headwaters. This primarily reflects: (1) growth in an area having aquifers with relatively low recharge rates; and (2) growth in an area having minimal upgradient contributing recharge area. Under drought conditions in 2010, it is expected that five subwatersheds will show allocation deficits of as much as 150 million gallons over the year (0.64 cubic feet per second [cfs]), which equates to the quantity of water used by more than 3,600 people. Although presented as an annual analysis, the deficits are likely to manifest during the summer months, as they did over the watershed as a whole (Table 14, Figure 24) and for the three test subwatersheds (Tables 18, 19, and 20; Figures 26, 27, and 28). Under drought conditions in 2025, eight subwatersheds show deficits in the range of 18 to 316 million gallons over the year (0.08 cfs to 1.34 cfs).

As compared to the water demand projections (without BRAC impacts) incorporated into the analyses presented in Tables 23, 24, 25, and 26, and Figure 30, the water demand analyses (with BRAC impacts) reflected in Tables B-2 through B-5 and Figure B-1 are not dramatically different. The values for population supported do, however, decrease for 2010 and 2025 average and drought years, as a result of the incorporation of BRAC population projections, but not by more than 1,650 people under average conditions and 2,000 people under drought conditions for the entire watershed. On a subwatershed scale, decreases in population served as a result of BRAC-related impacts are more pronounced in subwatersheds located within Harford County since, according to the APG BRAC document, it is the county in which population projections are predicted to increase the most as a result of BRAC. The number of subwatersheds with an allocation deficit, during both average and drought years, is the same for the water demand projections with and without BRAC-related impacts, with the exception of the Hollands Branch subwatershed, which is projected to experience a deficit of four people served under drought conditions in 2010 as a result of BRAC.

With regard to the unavailability of Deer Creek at Darlington during a repeat of the 2002 drought, the increased water demand projected to accompany BRAC by 2025 would increase the duration of the time the flow is below the passby threshold by an additional 3 days to 176 days.

Table B-2. Water Allocation, 2010 Population, Average Precipitation (with BRAC Population Projections)

ID	Subwatershed	Average Base Flow (cfs)	Existing Permitted Ground-water Withdrawals (cfs)	Existing Un-permitted Ground-water Withdrawals (cfs)	Aberdeen Permit Passby (cfs)	Change in Percent Future Impervious Area (%)	Reduction for Future Impervious Area (cfs)	Reduction for Municipal/ Commercial (cfs)	Additional Residential Population[1] (cfs)	Residual Ground-water Resources (cfs)	Surplus/ Deficit Population Supported (people)
1	Cool Branch Run	1.91	-0.01	-0.05	-0.78	1.08	-0.02	-0.31	-0.01	0.73	5,889
2	Stout Bottle Branch - Cabbage Run	7.39	-0.12	-0.16	-2.27	1.73	-0.13	-0.39	-0.05	4.28	34,564
3	Thomas Run	6.26	-0.05	-0.17	-2.55	0.47	-0.03	-0.39	-0.09	2.98	24,066
4	Mill Brook	3.60	-0.03	-0.10	-1.47	0.47	-0.02	-0.31	-0.01	1.66	13,450
5	Hollands Branch	2.60	-0.03	-0.07	-1.06	0.47	-0.01	-0.08	-0.01	1.34	10,846
6	UNT at Thomas Bridge Rd	4.45	-0.28	-0.09	-1.37	0.33	-0.01	-0.08	-0.02	2.60	21,008
7	Saint Omer Branch	10.07	-0.06	-0.24	-3.53	0.74	-0.07	-0.39	-0.04	5.74	46,350
8	Deer Creek - Mid	5.40	-0.01	-0.11	-1.66	0.33	-0.02	0.00	-0.01	3.59	28,966
9	South Stirrup - North Stirrup Run	6.68	-0.01	-0.14	-2.05	0.54	-0.04	-0.15	-0.05	4.23	34,184
10	Rock Hollow - Kellogg - Gladden Branches	12.75	-0.23	-0.27	-3.92	0.21	-0.03	-0.31	-0.05	7.95	64,201
11	UNT south of Falling Branch	0.64	-0.01	-0.01	-0.20	2.80	-0.02	0.00	0.00	0.40	3,250
12	UNT west of Falling Branch	0.39	0.00	-0.01	-0.12	2.80	-0.01	0.00	0.00	0.25	2,003
13	Little Deer Creek	14.65	-0.02	-0.31	-4.50	0.20	-0.03	-0.23	-0.03	9.53	76,951
14	Falling Branch	6.60	-0.01	-0.14	-2.03	2.80	-0.18	-0.39	-0.01	3.84	31,008
15	Big Branch	8.15	0.00	-0.17	-2.51	2.62	-0.21	-0.23	-0.01	5.02	40,529
16	Island - Jackson - Plumtree Branches	29.59	-0.18	-0.62	-9.10	0.22	-0.07	-0.23	-0.07	19.33	156,145
17	Ebaugh's Creek	7.05	-0.65	0.00	-2.17	2.42	-0.17	-0.39	-0.01	3.66	29,597
18	Deer Creek Headwaters	17.68	-0.55	0.00	-5.44	4.06	-0.72	-0.77	-0.15	10.06	81,229
19	Graveyard Creek	1.24	-0.01	-0.03	-0.51	0.47	-0.01	0.00	0.00	0.68	5,520
20	Hopkins Branch	1.76	-0.01	-0.05	-0.72	0.47	-0.01	-0.70	-0.01	0.27	2,200
21	Tobacco Run	6.15	-0.16	-0.17	-2.51	1.08	-0.07	-0.08	-0.05	3.12	25,191
22	Buck Branch - Elbow Branch	7.90	-0.01	-0.22	-3.22	0.05	0.00	0.00	-0.03	4.42	35,722
23	UNT east of Hollands Branch	0.04	0.00	0.00	-0.02	0.47	0.00	0.00	0.00	0.02	187
	Entire Watershed	**162.94**	**-2.44**	**-3.14**	**-53.67**	**1.00**	**-1.63**	**-5.42**	**-0.71**	**95.69**	**773,057**

[1] Calculated at 80 gpd per person.

Table B-3. Water Allocation, 2010 Population, Drought Conditions (with BRAC Population Projections)

ID	Subwatershed	Average Base Flow (cfs)	Existing Permitted Ground-water Withdrawals (cfs)	Existing Un-permitted Ground-water Withdrawals (cfs)	Aberdeen Permit Passby (cfs)	Change in Percent Future Impervious Area (%)	Reduction for Future Impervious Area (cfs)	Reduction for Municipal/ Commercial (cfs)	Additional Residential Population[1] (cfs)	Residual Ground-water Resources (cfs)	Surplus/ Deficit Population Supported (people)
1	Cool Branch Run	0.94	-0.01	-0.07	-0.78	1.08	-0.02	-0.31	-0.01	-0.26	-1,477
2	Stout Bottle Branch - Cabbage Run	3.67	-0.12	-0.22	-2.27	1.73	-0.13	-0.39	-0.07	0.47	2,699
3	Thomas Run	3.10	-0.05	-0.24	-2.55	0.47	-0.03	-0.39	-0.13	-0.29	-1,650
4	Mill Brook	1.78	-0.03	-0.14	-1.47	0.47	-0.02	-0.31	-0.02	-0.20	-1,126
5	Hollands Branch	1.29	-0.03	-0.10	-1.06	0.47	-0.01	-0.08	-0.01	0.00	-4
6	UNT at Thomas Bridge Rd	2.21	-0.28	-0.13	-1.37	0.33	-0.01	-0.08	-0.02	0.31	1,807
7	Saint Omer Branch	4.99	-0.06	-0.34	-3.53	0.74	-0.07	-0.39	-0.05	0.55	3,158
8	Deer Creek - Mid	2.68	-0.01	-0.16	-1.66	0.33	-0.02	0.00	-0.02	0.81	4,687
9	South Stirrup - North Stirrup Run	3.31	-0.01	-0.20	-2.05	0.54	-0.04	-0.15	-0.07	0.78	4,528
10	Rock Hollow - Kellogg - Gladden Branches	6.32	-0.23	-0.37	-3.92	0.21	-0.03	-0.31	-0.07	1.39	8,026
11	UNT south of Falling Branch	0.32	-0.01	-0.02	-0.20	2.80	-0.02	0.00	0.00	0.07	427
12	UNT west of Falling Branch	0.19	0.00	-0.01	-0.12	2.80	-0.01	0.00	0.00	0.05	284
13	Little Deer Creek	7.26	-0.02	-0.43	-4.50	0.20	-0.03	-0.23	-0.04	2.01	11,580
14	Falling Branch	3.27	-0.01	-0.19	-2.03	2.80	-0.18	-0.39	-0.02	0.45	2,606
15	Big Branch	4.04	0.00	-0.24	-2.51	2.62	-0.21	-0.23	-0.02	0.83	4,799
16	Island - Jackson - Plumtree Branches	14.67	-0.18	-0.87	-9.10	0.22	-0.07	-0.23	-0.10	4.13	23,844
17	Ebaugh's Creek	3.49	-0.65	0.00	-2.17	2.42	-0.17	-0.39	-0.01	0.11	619
18	Deer Creek Headwaters	8.76	-0.55	0.00	-5.44	4.06	-0.72	-0.77	-0.21	1.08	6,225
19	Graveyard Creek	0.62	-0.01	-0.05	-0.51	0.47	-0.01	0.00	-0.01	0.04	233
20	Hopkins Branch	0.87	-0.01	-0.07	-0.72	0.47	-0.01	-0.70	-0.01	-0.64	-3,672
21	Tobacco Run	3.05	-0.16	-0.24	-2.51	1.08	-0.07	-0.08	-0.07	-0.07	-429
22	Buck Branch - Elbow Branch	3.91	-0.01	-0.31	-3.22	0.05	0.00	0.00	-0.04	0.34	1,964
23	UNT east of Hollands Branch	0.02	0.00	0.00	-0.02	0.47	0.00	0.00	0.00	0.00	10
	Entire Watershed	**80.77**	**-2.44**	**-4.40**	**-53.67**	**1.00**	**-1.63**	**-5.42**	**-0.99**	**11.98**	**69,140**

[1] Calculated at 112 gpd per person.

Table B-4. Water Allocation, 2025 Population, Average Precipitation (with BRAC Population Projections)

ID	Subwatershed	Average Base Flow (cfs)	Existing Permitted Ground-water Withdrawals (cfs)	Existing Un-permitted Ground-water Withdrawals (cfs)	Aberdeen Permit Passby (cfs)	Change in Percent Future Impervious Area (%)	Reduction for Future Impervious Area (cfs)	Reduction for Municipal/ Commercial (cfs)	Additional Residential Population[1] (cfs)	Residual Ground-water Resources (cfs)	Surplus/ Deficit Population Supported (people)
1	Cool Branch Run	1.91	-0.01	-0.05	-0.78	1.08	-0.02	-0.62	-0.01	0.42	3,354
2	Stout Bottle Branch - Cabbage Run	7.39	-0.12	-0.16	-2.27	1.73	-0.13	-0.77	-0.07	3.88	31,314
3	Thomas Run	6.26	-0.05	-0.17	-2.55	0.47	-0.03	-0.77	-0.13	2.56	20,658
4	Mill Brook	3.60	-0.03	-0.10	-1.47	0.47	-0.02	-0.62	-0.03	1.34	10,850
5	Hollands Branch	2.60	-0.03	-0.07	-1.06	0.47	-0.01	-0.15	-0.01	1.26	10,193
6	UNT at Thomas Bridge Rd	4.45	-0.28	-0.09	-1.37	0.33	-0.01	-0.15	-0.03	2.51	20,296
7	Saint Omer Branch	10.07	-0.06	-0.24	-3.53	0.74	-0.07	-0.77	-0.05	5.33	43,097
8	Deer Creek - Mid	5.40	-0.01	-0.11	-1.66	0.33	-0.02	0.00	-0.02	3.58	28,924
9	South Stirrup - North Stirrup Run	6.68	-0.01	-0.14	-2.05	0.54	-0.04	-0.31	-0.09	4.04	32,626
10	Rock Hollow - Kellogg - Gladden Branches	12.75	-0.23	-0.27	-3.92	0.21	-0.03	-0.62	-0.08	7.61	61,443
11	UNT south of Falling Branch	0.64	-0.01	-0.01	-0.20	2.80	-0.02	0.00	0.00	0.40	3,240
12	UNT west of Falling Branch	0.39	0.00	-0.01	-0.12	2.80	-0.01	0.00	0.00	0.25	1,998
13	Little Deer Creek	14.65	-0.02	-0.31	-4.50	0.20	-0.03	-0.46	-0.04	9.28	74,983
14	Falling Branch	6.60	-0.01	-0.14	-2.03	2.80	-0.18	-0.77	-0.02	3.44	27,826
15	Big Branch	8.15	0.00	-0.17	-2.51	2.62	-0.21	-0.46	-0.02	4.78	38,597
16	Island - Jackson - Plumtree Branches	29.59	-0.18	-0.62	-9.10	0.22	-0.07	-0.46	-0.10	19.06	153,988
17	Ebaugh's Creek	7.05	-0.65	0.00	-2.17	2.42	-0.17	-0.77	-0.20	3.09	24,957
18	Deer Creek Headwaters	17.68	-0.55	0.00	-5.44	4.06	-0.72	-1.55	-0.43	9.00	72,740
19	Graveyard Creek	1.24	-0.01	-0.03	-0.51	0.47	-0.01	0.00	-0.01	0.68	5,498
20	Hopkins Branch	1.76	-0.01	-0.05	-0.72	0.47	-0.01	-1.39	-0.01	-0.43	-3,448
21	Tobacco Run	6.15	-0.16	-0.17	-2.51	1.08	-0.07	-0.15	-0.09	3.01	24,283
22	Buck Branch - Elbow Branch	7.90	-0.01	-0.22	-3.22	0.05	0.00	0.00	-0.04	4.41	35,601
23	UNT east of Hollands Branch	0.04	0.00	0.00	-0.02	0.47	0.00	0.00	0.00	0.02	187
	Entire Watershed	**162.94**	**-2.44**	**-3.14**	**-53.67**	**1.00**	**-1.63**	**-10.83**	**-1.47**	**89.52**	**723,206**

[1] Calculated at 80 gpd per person.

Table B-5. Water Allocation, 2025 Population, Drought Precipitation (with BRAC Population Projections)

ID	Subwatershed	Average Base Flow (cfs)	Existing Permitted Ground-water Withdrawals (cfs)	Existing Un-permitted Ground-water Withdrawals (cfs)	Aberdeen Permit Passby (cfs)	Change in Percent Future Impervious Area (%)	Reduction for Future Impervious Area (cfs)	Reduction for Municipal/ Commercial (cfs)	Additional Residential Population[1] (cfs)	Residual Ground-water Resources (cfs)	Surplus/ Deficit Population Supported (people)
1	Cool Branch Run	0.94	-0.01	-0.07	-0.78	1.08	-0.02	-0.62	-0.02	-0.57	-3,297
2	Stout Bottle Branch - Cabbage Run	3.67	-0.12	-0.22	-2.27	1.73	-0.13	-0.77	-0.09	0.06	342
3	Thomas Run	3.10	-0.05	-0.24	-2.55	0.47	-0.03	-0.77	-0.18	-0.72	-4,165
4	Mill Brook	1.78	-0.03	-0.14	-1.47	0.47	-0.02	-0.62	-0.04	-0.52	-3,011
5	Hollands Branch	1.29	-0.03	-0.10	-1.06	0.47	-0.01	-0.15	-0.02	-0.08	-478
6	UNT at Thomas Bridge Rd	2.21	-0.28	-0.13	-1.37	0.33	-0.01	-0.15	-0.04	0.22	1,274
7	Saint Omer Branch	4.99	-0.06	-0.34	-3.53	0.74	-0.07	-0.77	-0.08	0.14	798
8	Deer Creek - Mid	2.68	-0.01	-0.16	-1.66	0.33	-0.02	0.00	-0.02	0.81	4,645
9	South Stirrup - North Stirrup Run	3.31	-0.01	-0.20	-2.05	0.54	-0.04	-0.31	-0.13	0.58	3,327
10	Rock Hollow - Kellogg - Gladden Branches	6.32	-0.23	-0.37	-3.92	0.21	-0.03	-0.62	-0.11	1.04	5,982
11	UNT south of Falling Branch	0.32	-0.01	-0.02	-0.20	2.80	-0.02	0.00	0.00	0.07	417
12	UNT west of Falling Branch	0.19	0.00	-0.01	-0.12	2.80	-0.01	0.00	0.00	0.05	279
13	Little Deer Creek	7.26	-0.02	-0.43	-4.50	0.20	-0.03	-0.46	-0.05	1.76	10,148
14	Falling Branch	3.27	-0.01	-0.19	-2.03	2.80	-0.18	-0.77	-0.03	0.05	317
15	Big Branch	4.04	0.00	-0.24	-2.51	2.62	-0.21	-0.46	-0.03	0.59	3,402
16	Island - Jackson - Plumtree Branches	14.67	-0.18	-0.87	-9.10	0.22	-0.07	-0.46	-0.14	3.85	22,222
17	Ebaugh's Creek	3.49	-0.65	0.00	-2.17	2.42	-0.17	-0.77	-0.27	-0.54	-3,128
18	Deer Creek Headwaters	8.76	-0.55	0.00	-5.44	4.06	-0.72	-1.55	-0.60	-0.08	-478
19	Graveyard Creek	0.62	-0.01	-0.05	-0.51	0.47	-0.01	0.00	-0.01	0.04	211
20	Hopkins Branch	0.87	-0.01	-0.07	-0.72	0.47	-0.01	-1.39	-0.01	-1.34	-7,712
21	Tobacco Run	3.05	-0.16	-0.24	-2.51	1.08	-0.07	-0.15	-0.12	-0.20	-1,159
22	Buck Branch - Elbow Branch	3.91	-0.01	-0.31	-3.22	0.05	0.00	0.00	-0.06	0.32	1,843
23	UNT east of Hollands Branch	0.02	0.00	0.00	-0.02	0.47	0.00	0.00	0.00	0.00	10
	Entire Watershed	**80.77**	**-2.44**	**-4.40**	**-53.67**	**1.00**	**-1.63**	**-10.83**	**-2.05**	**5.51**	**31,789**

[1] Calculated at 112 gpd per person.

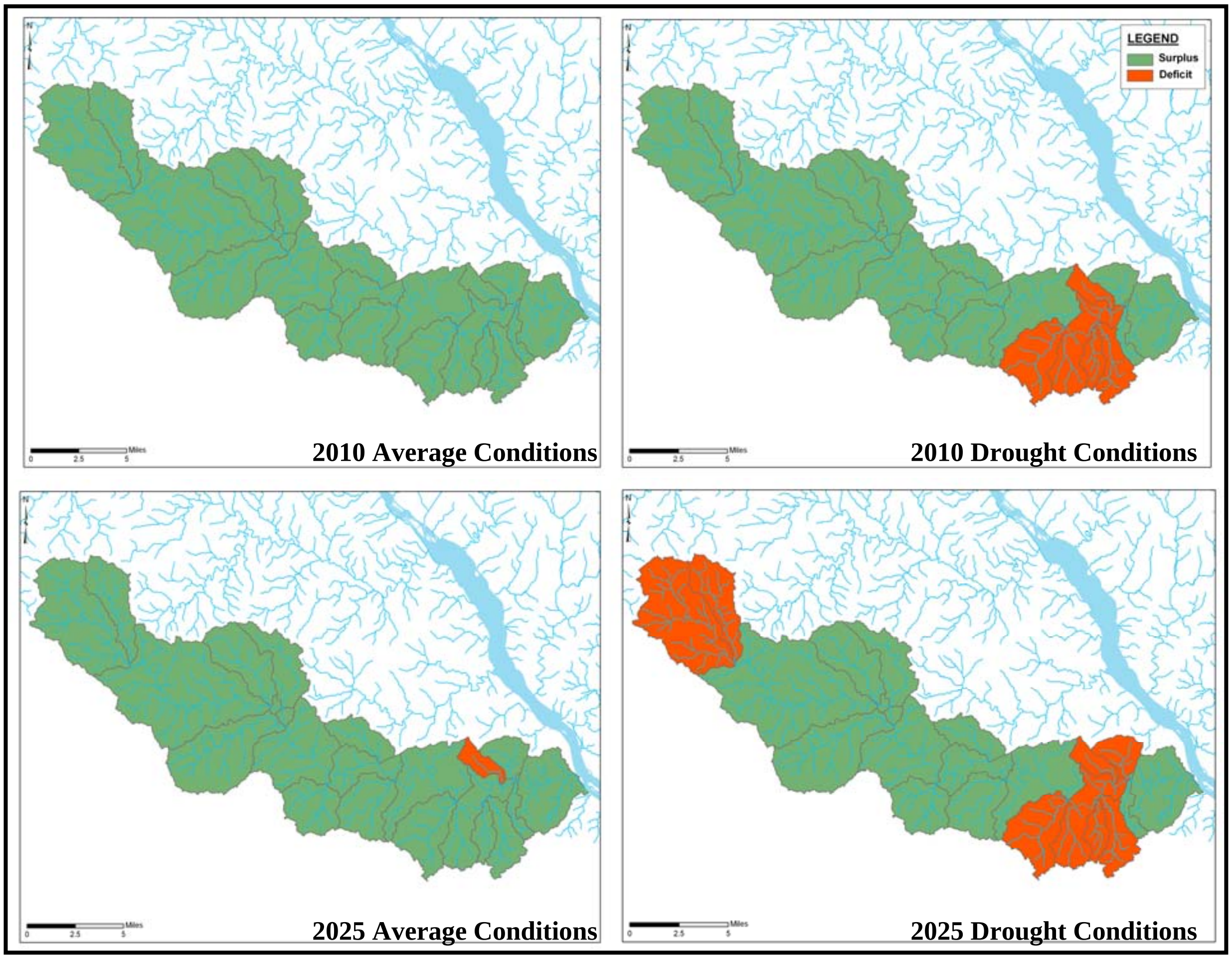

Figure B-1. Twenty-Five-Year Projected Water Allocation Surplus/Deficit by Subwatershed (with BRAC Population Projections)

APPENDIX B2

Agricultural Land Use Conversion Projections

Agricultural activities are the predominant type of land use in the Deer Creek Watershed, occupying roughly 60 percent of the total land area. However, several areas of the watershed are undergoing (or expected to undergo) rapid growth and development, most of which will consume land currently used for agricultural purposes. The analysis performed for this study incorporated estimates for the change in water use associated with the conversion of land to commercial and residential use. Excluded from the analysis were areas in the watershed designated as under permanent agricultural easement. Each of the jurisdictions in the watershed has agricultural preservation programs, and the program in Harford County has been particularly successful, with more than 40,500 acres under permanent easement. While such areas were excluded from the analysis of conversion to commercial or residential uses and the associated increases in water use, no consideration was given to conversion from one agricultural use to another. Conversions of this nature can be important because new uses can be much more water-intensive than current uses. For example, the conversion of pasture land to a vineyard is likely to require processing water and may demonstrate increased use of groundwater by the deep roots of grapevines, as compared to field grasses. Another example is the conversion of livestock lands to horticultural uses such as nurseries.

Consultation with stakeholders in the watershed revealed that certain trends within the agricultural community may be worth investigation. Specifically, horse-related activities seem likely to decline with the diminished importance of horseracing in Maryland, while growth is apparent in the nursery industry. Conversion of a preserved agricultural tract from horse farming to nursery activities is likely to result in an increase in water use. Based on research, SRBC staff estimates that typical horse-related operations require 12 gallons per animal per day, while nurseries may use up to 27,000 gallons per acre per day.

Data are available on the nature of the agricultural land under permanent easement and on the nature of horse farms in Harford County, which is the predominant horse-related area in the Deer Creek Watershed and the area where conversion from horsing to nursery is most likely to occur.

<u>Agricultural Preservation</u>: The table below shows the acres of agricultural land that under permanent easement, by jurisdiction, in the Deer Creek Watershed. The map on Figure B-2 shows the agricultural land in Harford County and the location of permanent easements on that land; the easements are located predominantly in the Deer Creek Watershed. About 40 percent of the agricultural land in the watershed is under permanent easement, representing about 24 percent of the total land area in the watershed.

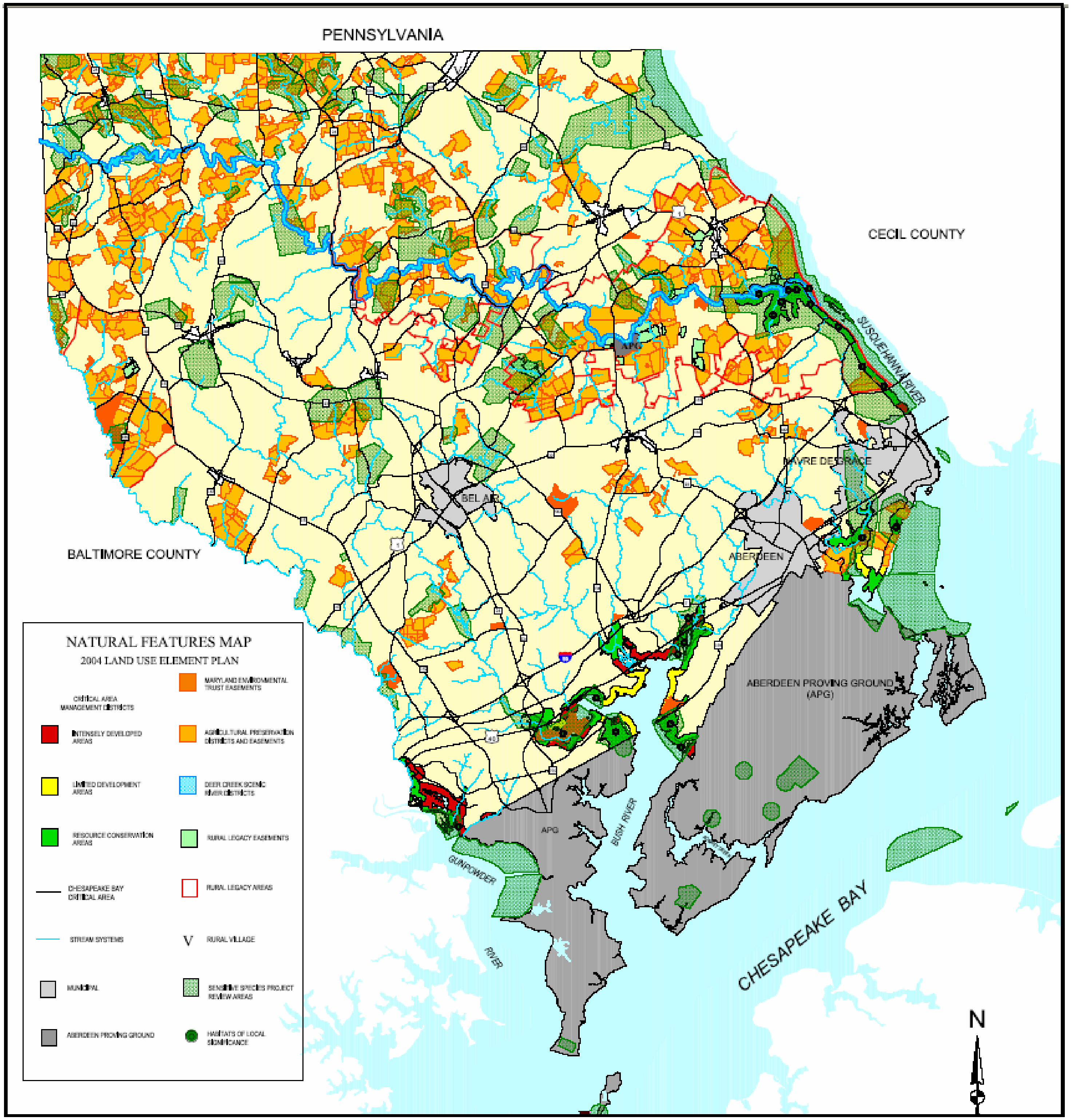

Figure B-2. ***Natural Land Features of Harford County, Maryland (Harford County, 2004)***

Horse Husbandry: Data from the 2002 Maryland Equine Census on the horse industry in Maryland indicate that Harford County ranks in the top five counties in Maryland in terms of number of horses, number of equine facilities, and in acreage devoted to horse-related activities. Statewide, approximately 41 percent of horses are associated with the racing industry. Data were not reported for the number of horses associated with racing on a county-by-county basis; however, the average value per horse in Harford County is substantially higher than the statewide average, which suggests that higher-valued racing breeds likely account for a greater portion of the horse population in Harford County than in the state as a whole. For the purposes of this exercise, 50 percent of the horse population in Harford County is assumed to be associated with racing, for a total of 3,484 animals. Using the county average of 2.5 acres per horse, 8,710 acres in the county are estimated to be associated with horseracing. This is important information because, as a result of a suspected decline in Maryland's racing industry, some of that acreage may convert from horseracing to other uses, such as nursery operations, and water demand would change accordingly. It is assumed that draft and recreational horse husbandry will not be affected by trends in racing, and that the number of such horses will remain unchanged.

Nursery Operations: Horticulture is a significant industry in Maryland, and particularly so in the central region comprised of Baltimore, Carroll, Frederick, Harford, Howard, Montgomery, and Washington Counties. According to the 2003 Maryland Horticulture Industry Economic Profile, nearly 40 percent of the state's horticulture acreage is located in the central region. The seven counties contained 6,123 acres in horticulture, for an average of 875 acres in each county. Based on the results of the profile, the industry is expected to show growth. Over the course of this study's time frame, it was assumed that 20 percent growth (an added 175 acres) could occur, given that agricultural land is expected to be available as a result of the decrease in horse operations.

Conclusion: The potential increase in water use as a result of conversion of agricultural land from horse operations to nurseries is the difference between the current estimated water use for horses and the projected water need for nursery operations.

At 12 gallons per horse, operations related to horse racing use an estimated 41,808 gallons per day (gpd) in the Deer Creek Watershed. If it is assumed that the population of horses in racing operations diminishes by half, water use would decline by 20,904 gpd, and an estimated 4,355 acres would become available for other agricultural purposes. If it is assumed that one-quarter of the acreage stays in horsing as draft or recreational operations, there would be no net change in water use, and 5,226 gpd usage will still occur on those acres. If the projected horticulture growth of 175 acres occurs on the converted acreage, a new water demand of 4,725,000 gallons will be created on that land. Finally, it is assumed that the remaining 3,091 acres formerly involved in the horse racing industry would revert to pasture, be developed into vineyards, or be put to another agricultural use that does not require more water than what is delivered by nature in the form of precipitation. Thus, the net change in water demand for agricultural lands used in horse husbandry is an additional 4,709,322 gpd. Such an increase, equivalent to 7.25 cfs, would increase the duration that Deer Creek is unavailable at Darlington by an additional 31 days, to 204 total days, should 2002 drought conditions recur in 2025 with the projected change in horse and nursery operations.

APPENDIX B3

Water Demand Projections Associated with Commercial Development

Estimates for commercial water use and growth were made for the basic analysis of this study, as presented in the main body of this report. The estimates were consistent with generally accepted standard rates of water use for commercial development, which are based on the water used for purposes such as retail, light industrial facilities, and other small business enterprises or institutions. Water use associated with these commercial facilities was assumed to total up to 100,000 gpd for the purposes of the water use projections in this study. However, it is possible that more water-intensive uses also may develop in the watershed, golf courses being of particular interest.

Anecdotal evidence suggests that many residents of Maryland travel to southern Pennsylvania for golfing due to lack of golf courses in northern Maryland. An inventory of golfing facilities in Harford County, Maryland, and York County, Pennsylvania, confirms that of about a dozen golf courses in Harford County, all but one are located in the southeast part of the county near the population centers of Bel Air, Havre de Grace, and Aberdeen. To compete with the several courses in southern York County for the patronage of residents of northern Harford County, it is conceivable that one or more additional golf courses will develop in the Deer Creek Watershed. To demonstrate the impact such development could have on the availability of water resources along Deer Creek, SRBC staff assessed the water use of two new 18-hole courses.

To estimate the potential water use by two new golf courses in the Deer Creek Watershed, SRBC staff accessed records of the courses already existing in the Susquehanna River Basin. SRBC regulates more than 200 golf courses, and their water use – particularly for newer courses – usually greatly exceeds the 100,000 gpd assumed for typical commercial development in this study's basic analysis. Most newer courses irrigate not only tees and greens, but also fairways, which dramatically increases water use. Based on monitoring reports from such courses, SRBC staff assumed that two new courses in Harford County would use 300,000 gpd each when irrigating. Thus, an additional 600,000 gpd, or nearly 1 cfs, would be withdrawn from the waters of Deer Creek and consumed. That amount of additional water use by itself is not sufficient to impact Deer Creek, but when combined with current and projected water use, has the potential to accelerate and prolong the period of time that Deer Creek is unavailable to meet withdrawals. Using the 2002 drought conditions as a reference, the additional water use for golf course irrigation would increase the unavailability at Darlington by 3 additional days, for a total of 176 days.

APPENDIX B4

Cumulative Impact of Projected Water Demand Increases

The main body of this report showed the estimated impact of expected population and water use growth in the Deer Creek Watershed, and the previous sections in this appendix presented estimates for the impacts of growth in the residential (due to BRAC), agricultural, and commercial sectors. Each sector has the potential to realize significant impacts to the water resources of Deer Creek, and although they are based only on assumptions, all the associated increase in water demand could reasonably occur. It is useful to estimate the cumulative impact of all these developments should they all happen to occur through the 2025 time frame of this study. The additional water demand would be nearly 23 cfs; Figure B-3 below shows the affect on Deer Creek at Darlington, assuming a direct gallon-for-gallon reduction to streamflow during a repeat of conditions seen during the 2002 drought. The duration of days below the passby threshold would increase from the 130 days actually experienced in 2002 to 207 days considering the increased demand in 2025.

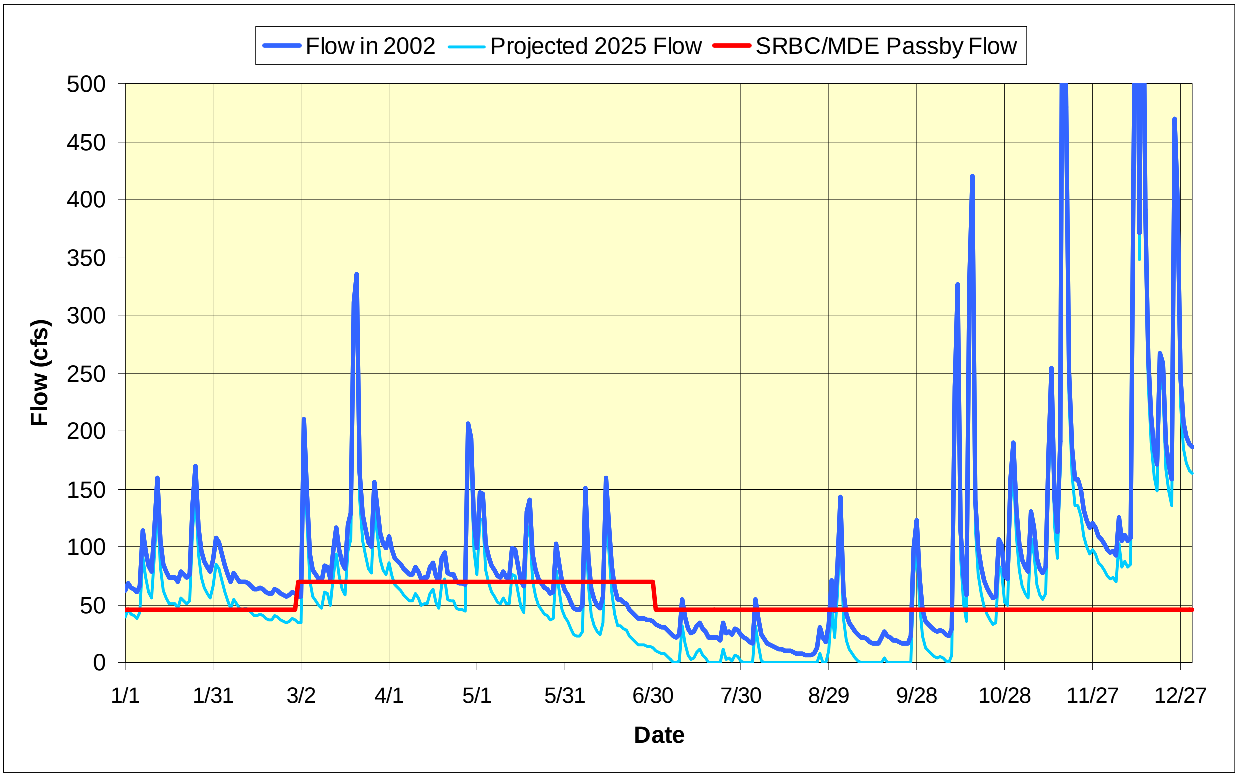

Figure B-3. Cumulative Impact of Potential Increases in Water Demand