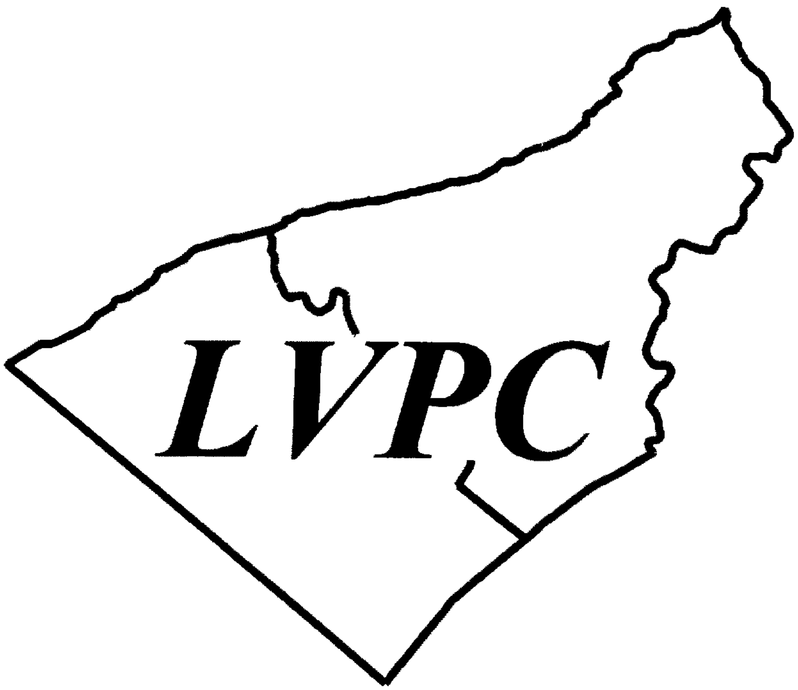
Monocacy Creek Watershed Preliminary Hydrologic Budget



Prepared by the Lehigh Valley Planning Commission
for the Wildlands Conservancy

January 1998

MONOCACY CREEK WATERSHED PRELIMINARY HYDROLOGIC BUDGET

EXECUTIVE SUMMARY

The Monocacy Creek's most unique characteristic is its ability to support a naturally reproducing trout population within the urbanized area of the City of Bethlehem. Watershed geology is the key to this unique characteristic as it guides precipitation into both surface and underground flows through the watershed. Urbanization may pose a threat to the Monocacy Creek's trout capabilities if it results in diminished groundwater supplies. A hydrologic budget is the accounting of the fate of precipitation as surface runoff, soil moisture, groundwater flow and return of atmospheric moisture.

This preliminary hydrologic budget relies on existing published water budget data and a review of available precipitation and streamflow data to identify any significant trends affecting the watershed. A rigorous hydrologic budget requires long-term surface and subsurface flow monitoring and sophisticated analyses. The surface flow monitoring is available for the Monocacy Creek from 1949 to the present. Very little groundwater flow data is available. Sophisticated water budget analyses are beyond the scope of this preliminary evaluation.

Data obtained for the period 1949 to 1996 for annual precipitation, annual streamflow, annual baseflow and annual baseflow as a percentage of streamflow were analyzed to identify any significant trends. Baseflow is that portion of streamflow which is fed from groundwater. Key findings and recommendations are listed below.

Key Findings

- Precipitation, streamflow and baseflow appear to follow cyclical patterns throughout the period of record.
- Trend analyses indicate a fairly constant level of precipitation with only a very slight increasing trend from 1949 to 1996.
- Trend analyses indicate that the portion of precipitation that becomes streamflow is increasing over time.
- Trend analyses indicate that, within the limitations of the method used to quantify baseflow, the portion of precipitation that becomes baseflow is also increasing over time.
- Trend analyses indicate that baseflow represents a fairly constant proportion of streamflow over time.
- No evidence is provided by this evaluation to suggest that baseflow levels or groundwater levels in the watershed are decreasing over time, however, more rigorous trend analyses would be required to verify these preliminary findings, especially the unexpected trend of increasing baseflows.

Key Recommendations

- The baseflow separation technique used herein should be evaluated to ensure that the methodology is providing reasonable results for the Monocacy Creek situation.
- A more rigorous water budget and trend analysis should be prepared to verify the preliminary trends identified.

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Monocacy Creek Watershed
Preliminary Hydrologic Budget

The Monocacy Creek's most unique characteristic is its ability to support a naturally reproducing trout population within the urbanized area of the City of Bethlehem. Watershed geology is the key to this unique characteristic as it guides precipitation into both surface and underground flows through the watershed for eventual discharge to the Lehigh River. Urbanization may pose a threat to the Monocacy Creek's trout capabilities for reasons of both water quality and water quantity. Water quality issues of land development are explored in a separate part of this report. Water quantity issues are explored here through the preparation of a preliminary hydrologic budget for the watershed. A hydrologic budget is the accounting of the fate of precipitation as surface runoff, soil moisture, groundwater flow and return of atmospheric moisture. A rigorous hydrologic budget requires long-term surface and subsurface flow monitoring and sophisticated analyses. The surface flow monitoring is available for the Monocacy Creek from 1949 to the present. Very little groundwater flow data is available. Sophisticated water budget analyses are beyond the scope of this preliminary evaluation. This preliminary hydrologic budget will rely on existing published water budget data and a review of available precipitation and streamflow data to identify any significant trends affecting the watershed.

Monocacy Creek Background Hydrology

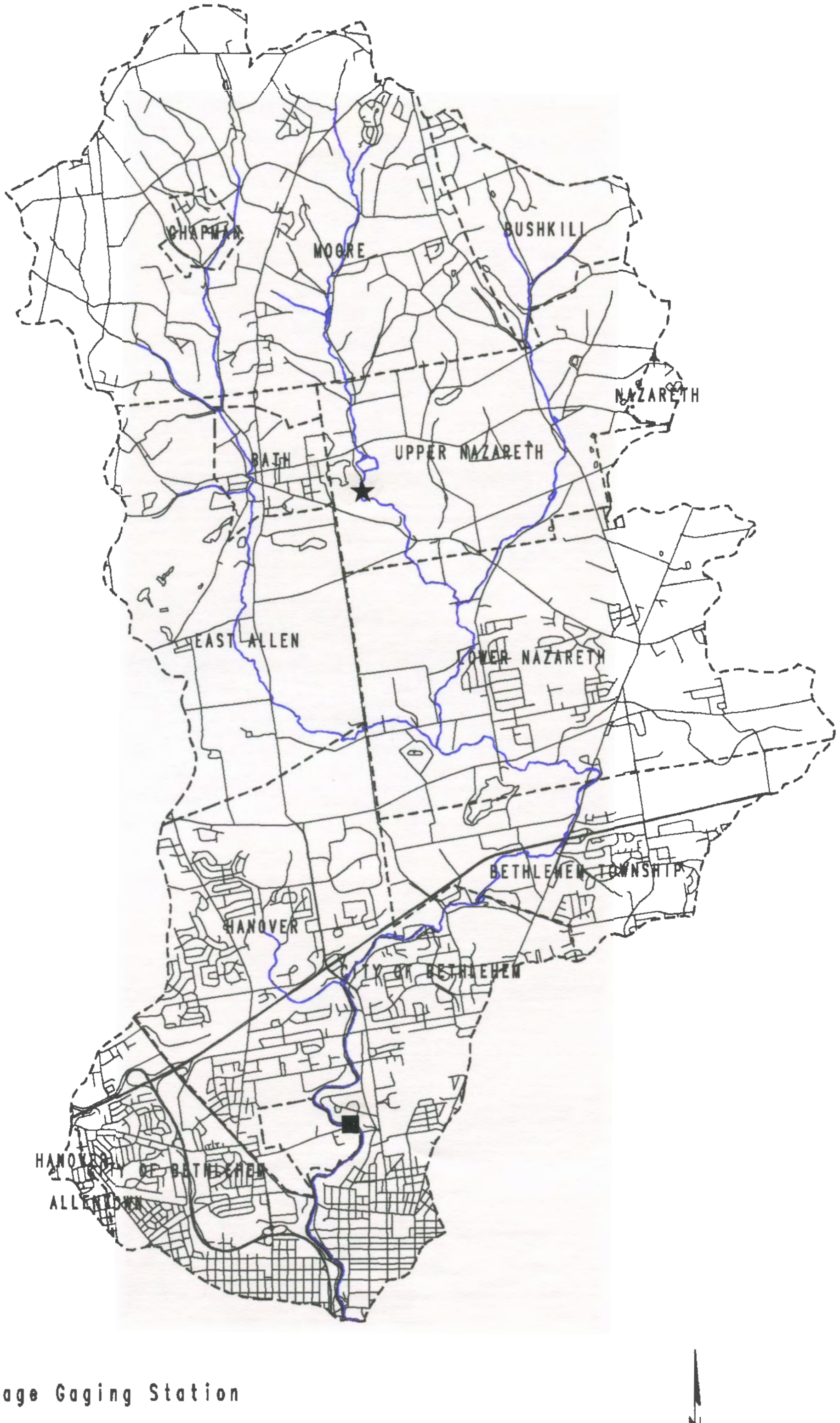
The Lehigh Valley Planning Commission prepared a stormwater management plan for the Monocacy Creek Watershed dated March 1989. As part of that plan, an assessment was prepared regarding the Monocacy Creek Watershed characteristics and hydrologic response. Although the purpose of that plan was limited to storm runoff, much of the information has direct bearing on the preliminary water budget preparation and further groundwater assessments. The remainder of this section is adapted from the *Monocacy Creek Act 167 Stormwater Management Plan.*

The Monocacy Creek is a tributary of the Lehigh River located predominantly within Northampton County with a small area located in Lehigh County. The creek drains a watershed area that includes portions of eleven municipalities. A location map is shown in Figure 1. The creek has a drainage area of 49.3 square miles. The watershed is comprised of the mainstem Monocacy Creek and the East Branch Monocacy Creek.

Figure 2 is a map of the Monocacy Creek geology. The headwaters of the creek (upper one-third of the watershed) are underlain by two members of the Martinsburg shale formation. Uppermost in the watershed the geology is the Ramseyburg member which is primarily beds of siltstone although some slaty beds are also present. The Bushkill member which makes up the lower shale region contains banded clay slate with siltstone. Below the Martinsburg shale formation in the watershed lies a vast area of predominantly limestone. Jacksonburg, Beekmantown and Allentown limestone make up approximately ninety percent (90%) of the geology of the lower two-thirds of the Monocacy Creek watershed. The three limestone formations are part of the Great Valley Section of the Valley and Ridge Physiographic Province. The remaining areas of the lower watershed are two outcrops of quartzite and gneiss associated with the Reading Prong formation.

FIGURE 1

MONOCACY CREEK WATERSHED LOCATION MAP



★ USGS Crest-stage Gaging Station

■ USGS Continuous Record Gaging Station

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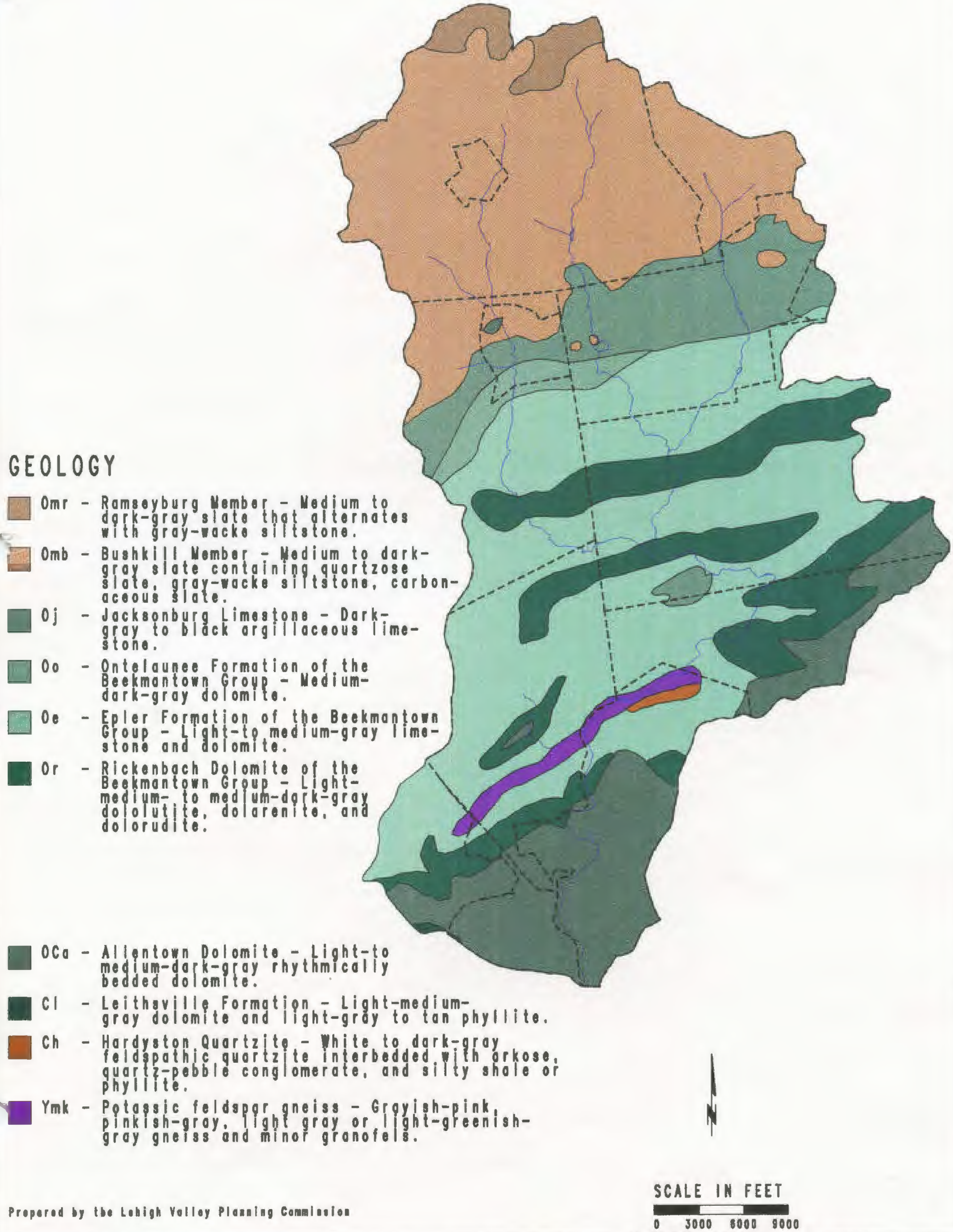
FIGURE 2

MONOCACY CREEK GEOLOGY



GEOLOGY

🟫 **Omr** - Ramseyburg Member - Medium to dark-gray slate that alternates with gray-wacke siltstone.

🟫 **Omb** - Bushkill Member - Medium to dark-gray slate containing quartzose slate, gray-wacke siltstone, carbonaceous slate.

🟩 **Oj** - Jacksonburg Limestone - Dark-gray to black argillaceous limestone.

🟩 **Oo** - Ontelaunee Formation of the Beekmantown Group - Medium-dark-gray dolomite.

🟩 **Oe** - Epler Formation of the Beekmantown Group - Light-to medium-gray limestone and dolomite.

🟩 **Or** - Rickenbach Dolomite of the Beekmantown Group - Light-medium- to medium-dark-gray dololutite, dolarenite, and dolorudite.

🟩 **OCa** - Allentown Dolomite - Light-to medium-dark-gray rhythmically bedded dolomite.

🟩 **Cl** - Leithsville Formation - Light-medium-gray dolomite and light-gray to tan phyllite.

🟧 **Ch** - Hardyston Quartzite - White to dark-gray feldspathic quartzite interbedded with arkose, quartz-pebble conglomerate, and silty shale or phyllite.

🟪 **Ymk** - Potassic feldspar gneiss - Grayish-pink, pinkish-gray, light gray or light-greenish-gray gneiss and minor granofels.

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The topography of the slate areas of the watershed is characterized by low, flat-topped hills dissected by the creek producing steep-sided valleys. There are numerous quarries throughout the slate areas, some of which are partially filled with water creating small lakes. The topography of the limestone portion of the watershed is very flat with gently sloping valleys. Sinkholes and closed depressions occur frequently. During drier months, certain stretches of the creek will disappear to groundwater only to reappear from springs further downstream. Groundwater in the limestone region flows mainly in well-defined channels formed by solution of limestone along joints. Springs emerge throughout the lower portion of the limestone region, especially at contact between consolidated and porous or less compact material. An area of concentrated springs occurs as far upstream as Camel's Hump, a quartz/gneiss outcrop near the northern boundary of the City of Bethlehem between State Routes 191 and 512 (orange and purple colors on the Monocacy Creek Geology map, Figure 2). There are nine (9) documented springs in the vicinity of Camel's Hump and a total of sixty-four (64) springs located within the twelve (12) mile stretch of creek between Camel's Hump and the Lehigh River. The springs are known to substantially increase the Monocacy Creek's flow and their cooler temperature relative to surface flows in the warmer months helps to maintain the natural trout habitat.

The basic reason for spring formation near Camel's Hump is the junction of the broad band of Beekmantown limestone to the north with granitic gneiss underlying Camel's Hump and the region immediately to the west. The metamorphic gneiss restricts the passage of groundwater flowing from the limestone region causing it to exit in a series of springs in the immediate vicinity of the Monocacy Creek, which turns west, parallel to the topographic barrier at this point.

The Department of Environmental Protection (DEP) has designated water quality criteria which are designed to protect the water uses within a given watershed. The Monocacy Creek has two water uses that are protected. One is the cold water fishes (CWF) category. This category helps to protect aquatic life in that it deals with the maintenance and/or propagation of fish species and flora and fauna which are native to cold water habitats. The other use deals with the special protection of high quality waters (HQW). High quality waters are considered as a stream or watershed with excellent quality water and environment features that require special protection.

The Monocacy Creek is used primarily for aesthetic and recreational purposes. It is known for its excellent fishing. In fact, the Monocacy Creek has been designated as a Trophy Trout stream in the area between the dam at Illicks Mill Road upstream to Bella Vista Road. The stream had to meet three requirements set by the State Fish Commission in order to be designated as such. The requirements are that the permission of the adjacent land owners must be granted; the stream must be able to reproduce trout naturally; and it must be controlled environmentally. The stream will not be stocked with trout because stocking the stream causes pressure on the stream and the stream would not longer be able to support the trout naturally. Fishermen will be permitted to use a fly, or any artificial lures, but no worms or other live bait. This designation was in effect at the beginning of trout season in 1988.

Land use within the basin varies from predominantly urban land uses at the lower portion of the watershed (City of Bethlehem, near the mouth of the Monocacy) to more suburban/rural land uses in the northern, upstream portion of Moore and Bushkill Townships). An exception to this is the Borough of Bath, located near the top of the watershed, which is predominantly urbanized although it is relatively small.

The United States Geological Survey (USGS) has maintained a continuous record gaging station on the Monocacy Creek Mainstem within Monocacy Park since 1949. The station is located 2.1 miles upstream from the mouth of the Lehigh River just downstream of Illicks Mill Road as shown in Figure 1. The drainage area monitored at the gage location is 44.5 square miles. The gaging station records the depth of water in the creek at one-hour intervals. U.S.G.S. has prepared a "rating curve" for the gage location which relates water depth to actual flow in cubic feet per second (CFS). Water depth information can therefore readily be translated into flow rate data.

The U.S.G.S. maintains another gaging station on the Monocacy Creek located on the East Branch immediately south of Newburg Road. This gage, however, is not a continuous record gage and it only records the peak depth of a given storm event and not the entire hydrograph. The drainage area monitored by the East Branch gage is 5.35 square miles, which is almost entirely underlain by slate geology, and the period of record is 1963 to the present.

In reviewing the historical data for the Monocacy Park continuous record gage station, a definite pattern was readily apparent. The largest streamflows of record occurred predominantly during the winter months. In fact, sixteen (16) of the highest twenty (20) recorded runoff events occurred between January 21st and March 14th throughout the period of record (1949 to 1987 was the period of record analyzed for the Monocacy Creek Act 167 Plan. Further analysis of the gage data through 1996 is included later in this report for groundwater flow purposes.). This phenomenon is somewhat understandable because the ground could be frozen during the winter months and produce more runoff. A compensating factor, however, is that the most intensive rainfall events tend to occur in the warmer months as thunderstorms or perhaps associated with hurricanes. The Monocacy Creek data is not typical in that it is so heavily skewed to the winter events. Presented in Table 1 is a listing of the highest twenty recorded runoff events at the downstream gage. The four non-winter events are marked with asterisks by the date.

Table 1
Monocacy Creek Mainstem U.S.G.S. Gaging Station
Historical Peak Flow Data

Rank of Peak	Peak Flow cfs	Date of Storm
1	3,490	January 25, 1979
2	2,340	February 28, 1958
3	2,320	January 26, 1978
4	2,180	February 26, 1979
5	2,150	January 26, 1976
6	1,500	February 13, 1971
7	1,409	September 8, 1987*
8	1,340	February 26, 1962
9	1,310	February 25, 1979
10	1,310	May 30, 1984*
11	1,290	February 8, 1965
12	1,170	March 6, 1963
13	1,160	January 21, 1979
14	1,150	January 22, 1958
15	1,010	February 25, 1977
16	923	September 27, 1985*
17	915	January 21, 1959
18	811	August 8, 1982*
19	776	February 21, 1986
20	755	March 14, 1978

*Indicates non-winter event.

Two additional interesting things to note from Table 1 are that the largest flow associated with any non-winter storm (September 8, 1987) was only a six (6) year return period event (based on probability analyses it would be expected to occur once every six years, on average) and that all four of the non-winter events listed are in the decade of the 1980s. In another example of the non-winter response, the September 27, 1985 peak flow was produced by a rainfall depth of 7.85 inches. This rainfall is larger than that generally accepted to be the 100-year rainfall event! Stated otherwise, a storm considered so severe that it may only occur once every 100 years produced a Monocacy Creek streamflow which you would expect to have once every three and one-half years on the average. Conversely, the wintertime storm which produced the most severe flood of record of 3,490 cfs had a total rainfall of 1.51 inches, or less than that which would be expected every two years. It is clear, therefore, that the warm weather Monocacy Creek Watershed can act like a 45 square mile sponge, but, when frozen, the watershed can produce high amounts of runoff from relatively small rainfall events.

Regarding the latter point mentioned above, the non-winter events have begun to get more severe resulting in 1980's data creeping into the record of highest flows. The fact that four summer events of the 1980's have become among those most severe would appear to indicate that new development is having an adverse impact on storm runoff peaks and that proper runoff controls on future development are important.

For stormwater planning purposes, the Monocacy Creek hydrologic response needed to be simulated through the use of a computerized model. This simulation required modeling the non-frozen watershed by including diversion of surface runoff to groundwater based on documented changes in channel capacities. As such, the stormwater model documented the known condition of high groundwater recharge in the limestone areas which eventually results in the important springs feeding the lower portion of the stream. The model was also used to document the apparent impact of land development on increasing peak runoff rates and the potential problem of future land development creating greater flow increases. The companion problem of concern here is the adverse impact that land development could have on groundwater resources. Specifically, new impervious surfaces could prevent groundwater recharge and perhaps over time diminish the groundwater supplies needed to support the existing springs and the trout habitat.

Components of a Hydrologic Budget

In *Water Resources of Lehigh County, Pennsylvania* prepared by the United States Geological Survey (USGS) and published in 1972 by the Pennsylvania Geological Survey, the various components of a watershed hydrologic budget are presented. The primary investigator for USGS was Mr. Charles Wood and the report became known as the "Wood Study" and will be referred to as such herein. The Wood Study used the term "water budget" interchangeably with hydrologic budget and described it as presented below:

> "A water budget is a quantitative statement of the balance, for a period of time, between gains and losses of water in an area. Thus, a water budget is a material balance for the water that moves through the various elements of the hydrologic cycle.... All water that enters the area is equated to that leaving the area, plus or minus changes in storage."

The water balance referred to above can be expressed numerically by equating the amount of precipitation with the amounts of water from surface runoff, soil moisture storage, groundwater flow and return of atmospheric moisture. Stated otherwise, the total amount of precipitation can be accounted for based on where it went within the watershed or atmosphere. The following water budget equation was adapted from the Wood Study with a simplification of certain terms used for changes in water storage.

$$P = R + ET + U \pm SMS \pm GWS \pm D$$

where,

P is Precipitation expressed in inches of water
R is surface Runoff or streamflow
ET is EvapoTranspoation or water re-entering the atmosphere either directly through evaporation or indirectly through plant uptake
U is groundwater Underflow
SMS is the ***change*** in Soil Moisture Storage during the time period
GWS is the ***change*** in Ground Water Storage during the time period
D is Diversions of water in or out of the watershed by man

Precipitation (P) and runoff (R) are commonly measured through use of rain gages and stream gages, respectively. Any manmade diversions (D) of water can also be measured directly. Other factors in the equation can be determined under certain hydrologic conditions when the remaining factors are either known or can be closely approximated. Note that the last three factors in the equation — Soil Moisture Storage, Ground Water Storage and Diversions — can be either positive or negative meaning net increases or decreases within the time period. An example would be for a water budget beginning in a very dry period but with significantly above-average precipitation within the time period such that increases in soil moisture storage and groundwater storage would be expected.

Monocacy Creek 1946-1962 Water Budget

Within the Wood Study, water budgets were prepared for several watersheds for the period of 1946 to 1962. Use of this time period allowed for simplification of the water budget equation to eliminate the soil moisture and groundwater storage factors. This was possible because the 1946, 1962 and average precipitation for the time period were all near normal meaning that no significant changes in the storage factors were expected (i.e. these factors would be zeros in the equation). Evapotranspiration (ET) for the time period was calculated to be 26.4 inches by a combination of empirical methods and field measurements. For the Monocacy Creek Watershed, average precipitation was 45.72 inches annually while runoff measured at the stream gage was 15.60 inches. There were no known diversions of flow in or out of the basin during the time period. Although stream gage records were only available beginning in 1949, review of the rainfall data indicated that the 1946 to 1949 period could be closely approximated using the available data. The water budget equation could be simplified for the Monocacy Creek Watershed as follows

$$P = R + ET + U \quad \text{and}$$

$$45.72 \text{ inches} = 15.60 \text{ inches} + 26.4 \text{ inches} + U \quad \text{and}$$

$$U = 3.72 \text{ inches}$$

Physically, this means that an annual average of about 3.7 inches of water applied to the whole watershed as rainfall would bypass the stream gage as groundwater flow. This component of groundwater is termed underflow. The stream gage monitors about 45 of the 49 square mile watershed area with about 2 miles of stream below the gage. According to the Wood Study, this underflow probably re-enters the creek by the mouth of the creek at the Lehigh River. The 1946 to 1962 data indicates that approximately three-tenths (34%) of precipitation becomes surface runoff, approximately six-tenths (58%) becomes evapotranspiration and approximately one-tenth (8%) is underflow.

The above simplified water budget represents the Monocacy Creek Watershed at a time of near "equilibrium". Annual precipitation amounts hovered near normal and over a short duration of 16 years the impacts of land development wouldn't be expected to be very significant on watershed hydrology. The concern is that the watershed will not stay in this equilibrium because of land development activities. The 1946 to 1962 water budget provides a baseline to look at updated data through 1996 for significant trends. Further, since the data required for preparing water budgets for non-equilibrium periods is not readily available (i.e. soil moisture changes and groundwater storage changes), the best assessment of land development impacts on watershed hydrology for the Monocacy Creek involves a closer evaluation of stream gage data.

Monocacy Creek Hydrologic Trends

The water budget prepared within the Wood Study is not detailed enough to provide insight to the trout sustaining capabilities of the Monocacy Creek. In fact, it probably gives the misimpression that groundwater flow is only a small component of the water budget. The Wood Study does document the high groundwater flow component of the Monocacy Creek in other portions of the report. Cold water springs throughout the lower portion of the creek help to maintain a habitat conducive to a trout population. Springs entering the creek above the stream gage are recorded as Runoff within the Wood Study water budget. At times of low precipitation, the streamflow may be entirely made up of groundwater flow, including springs. Springs entering the creek downstream of the gage are part of Underflow in the above water budget. With the springs (and groundwater flow in general) being the keys to maintaining the trout habitat, it's important to get a better sense of the distinction between surface runoff from storm events as measured at the gage versus the spring and the groundwater flow components as measured at the gage. The groundwater component of flow measured at the stream gage is called ***baseflow***. The methodology used to distinguish between groundwater flow and storm runoff at the gage is called ***baseflow separation***. Each watershed will be somewhat different in how precipitation events are transformed into surface versus groundwater flow components. Also, baseflow separation is not an exact science because determining the "end" of the storm runoff event is subjective, especially with closely spaced events. Various methods exist for performing baseflow separation ranging from very simplistic to very sophisticated. For our purposes of looking for long-term trends, the uniform application of a given method across the period of record is probably more important than the particular method used. USGS was able to provide a baseflow separation of the Monocacy Creek gaging station data from 1949 to 1996 using a technique called the 5-day fixed interval method. Details of the methodology are documented in USGS Water Resources Investigations Report 96-4040 and will not be further discussed here. Presented in Table 2 is a listing of total precipitation, total streamflow, baseflow and baseflow as a percentage of streamflow for the Monocacy Creek Watershed from 1949 to 1996.

TABLE 2
Monocacy Creek Precipitation, Streamflow and
Baseflow Characteristics, 1949 - 1996*

Year Ending	Precipitation (inches)	Streamflow (inches)	Baseflow** (inches)	% Baseflow***
1949	39.71	13.57	11.71	86.30
1950	40.77	11.54	9.61	83.27
1951	54.58	18.17	14.76	81.22
1952	67.69	27.29	21.96	80.45
1953	54.90	24.98	21.22	84.98
1954	38.33	12.74	10.72	84.10
1955	42.45	10.15	7.62	75.07
1956	46.42	14.30	10.64	74.40

TABLE 2(cont'd)
Monocacy Creek Precipitation, Streamflow and
Baseflow Characteristics, 1949 - 1996*

Year Ending	Precipitation (inches)	Streamflow (inches)	Baseflow** (inches)	% Baseflow***
1957	35.21	13.16	10.63	80.80
1958	44.64	16.08	11.74	72.97
1959	41.62	11.02	8.45	76.67
1960	46.81	16.65	12.92	77.62
1961	39.27	16.67	13.82	82.95
1962	41.58	12.13	9.60	79.09
1963	35.04	11.86	9.53	80.37
1964	34.74	9.28	8.18	88.19
1965	30.55	5.21	4.47	85.81
1966	38.28	4.73	4.05	85.55
1967	43.79	9.32	8.18	87.76
1968	38.43	13.20	11.86	89.91
1969	41.89	10.23	9.10	88.93
1970	41.59	12.07	10.69	88.56
1971	48.50	19.42	16.44	84.66
1972	55.85	25.37	21.71	85.56
1973	48.17	27.19	23.21	85.36
1974	48.19	22.02	18.84	85.56
1975	55.54	21.68	17.56	80.97
1976	39.90	21.74	17.15	78.89
1977	49.60	15.68	11.91	75.96
1978	45.99	27.22	20.88	76.71
1979	49.71	25.59	18.40	71.88
1980	29.82	17.53	15.38	87.70
1981	35.08	7.94	6.64	83.55
1982	43.40	12.60	9.63	76.44
1983	52.70	18.62	15.60	83.81
1984	52.41	27.45	21.92	79.86
1985	47.03	10.60	8.71	82.14
1986	43.20	19.77	16.01	80.99
1987	46.70	16.87	13.90	82.36
1988	39.42	17.89	15.32	85.60
1989	45.01	14.99	12.52	83.54
1990	44.27	18.60	15.41	82.84
1991	34.38	15.62	13.56	86.79
1992	N/A	8.13	6.96	85.65
1993	52.96	18.23	14.96	82.05
1994	48.82	26.43	21.39	80.93
1995	38.46	14.24	12.07	84.79
1996	56.87	20.59	16.15	78.42
AVERAGE	44.47	16.73	13.69	84.00

* Data interpreted from USGS streamgage 01452500 located in Monocacy Park at Bethlehem, PA.
** Baseflow separation by 5-day fixed interval technique.
*** Baseflow as a percentage of streamflow.
N/A Data not available.

From Table 2, annual precipitation for the period averaged 44.47 inches. Streamflow measured at the gage averaged 16.73 inches or about 38% of precipitation. (Note that this streamflow is about one inch higher than the 1946-1962 average found in the Wood Study even though the average precipitation is about one inch lower.) Baseflow averaged 13.69 inches for the 48 year record and baseflow as a percent of streamflow averaged 84% (this data closely corresponds with Wood Study baseflow separation data at 86% of streamflow).

Also from Table 2 there are fairly dramatic variations in the data year to year. Certainly, precipitation will vary from low periods (drought), such as the period from 1963 to 1965, to very high periods such as 1952 with approximately 50% higher precipitation than the average. Streamflow has variations from less than 5 inches per year (1966) to more than five times that value at 27 inches (1952). Baseflow variations are similar from about 4 inches per year to over 23 inches. Baseflow as a percentage of streamflow is relatively stable at between about 72% and 90%.

Of primary concern is whether the 48 years of record provides any discernable trends important for the Monocacy Creek Watershed and its preservation. Maintaining groundwater flows at historical levels would seem to be most central for preserving the springs which sustain the trout habitat. A common water resources concern with land development is the possible long-term depletion of groundwater supplies through elimination of pervious areas important for recharge. The long-term data regarding precipitation, streamflow, baseflow and baseflow as a percent of streamflow have been graphed to try to observe any trends. Graphing of the data has also included creation of a "best fit" straight line through the data representing a long-term trend line. As discussed previously, all the data has significant variation by year. Further, the best fit lines are based on mathematical equations which consider the data variations such that a best fit line is possible even if the data by eye doesn't correspond to a straight line very well. The graphs and trend lines must be used cautiously to avoid misinterpretation. Only strong trends in the data which can be conceptually explained will be considered valid.

Figure 3 is a graph of the annual precipitation data for the period of 1949 to 1996. The best fit line shows a very slight trend increase in annual precipitation (the line slopes slightly upward from 1949 to 1996). The significant variability above and below the best fit line, or trend line, is evident. From Figure 3, it appears that average precipitation has varied somewhat cyclically but as a trend has remained fairly constant throughout the period. This is important because any evaluation of other data such as streamflow or baseflow would naturally be affected if the precipitation data showed any significant upward or downward trend.

Figure 4 is a graph of the annual streamflow data for the period of 1949-1996. The best fit line shows a significant upward trend. Again, the data is quite variable above and below the trend line and varies somewhat cyclically. It is noteworthy, however, that through 1973, the midpoint of the period of record, there were only four years with more than 20 inches of streamflow. After 1973, there were eight years where streamflow exceeded 20 inches. Conversely, through 1973 there were 16 years with less than 15 inches of streamflow with only 6 years thereafter. Therefore, there is some evidence to support an annual increase in streamflow for the Monocacy Creek. This would seem reasonable because more impervious surfaces with development should increase the storm runoff component of stream flow.

FIGURE 3
ANNUAL PRECIPITATION

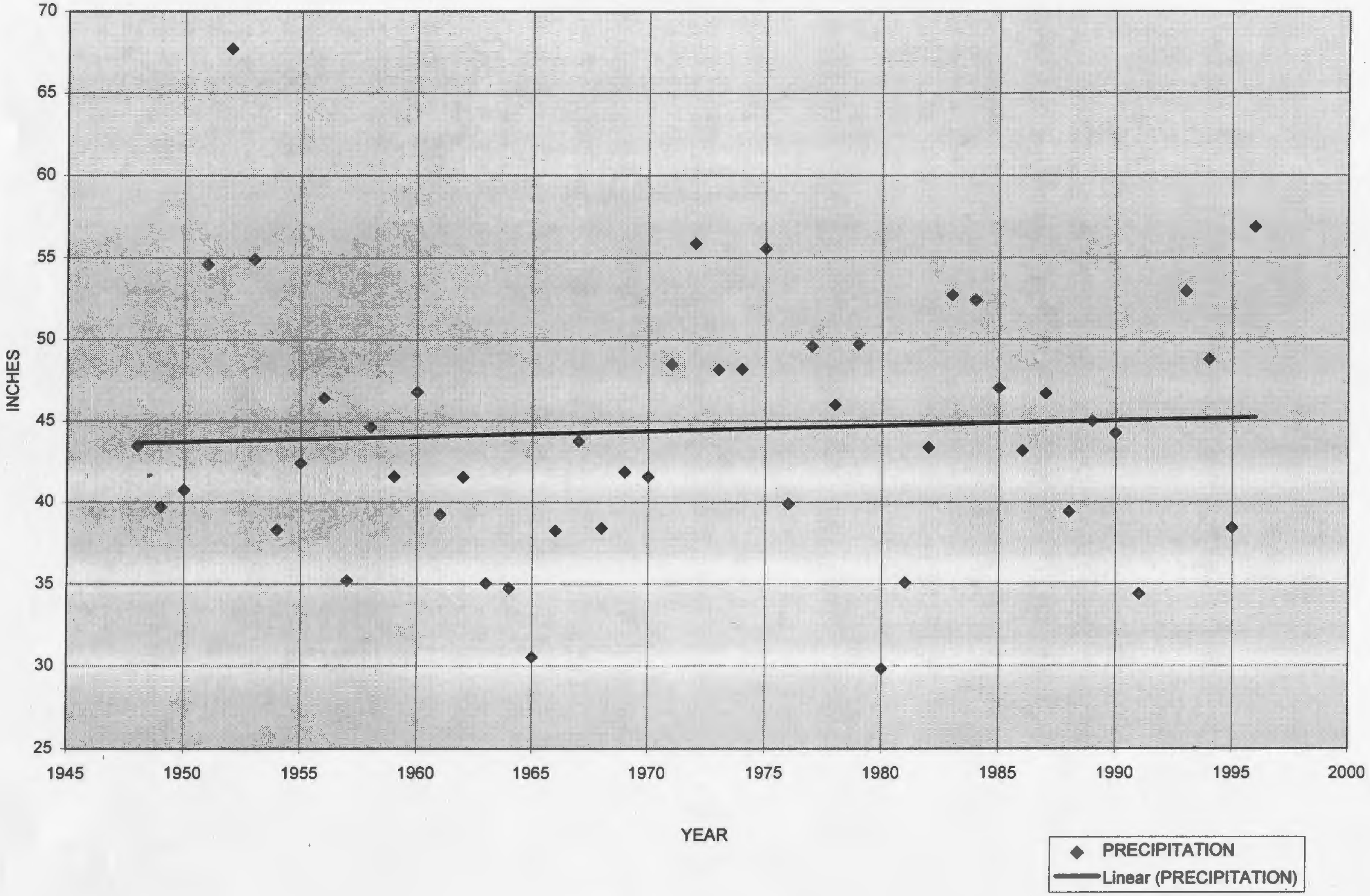

FIGURE 4
ANNUAL STREAMFLOW

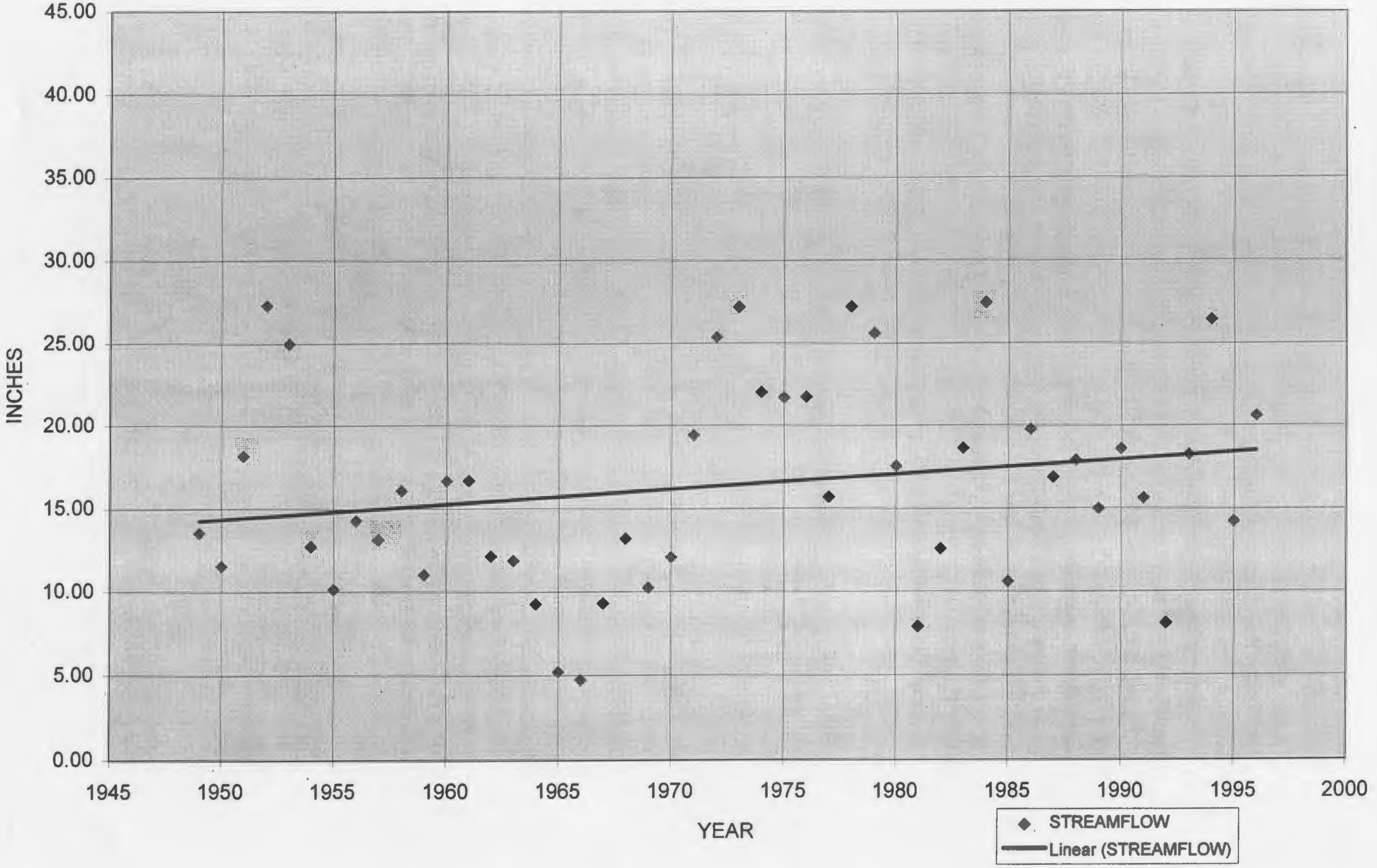

Figure 5 is a graph of annual baseflow for the period of 1949 to 1996. This best fit line also shows a significant upward trend as did annual streamflow. As with Figures 3 and 4, there is significant variability above and below the trend line which follows a somewhat cyclical pattern. Similar to Figure 4, there are far more years with baseflow above 15 inches in the second half of the period of record (after 1973) than before 1973. The reverse trend is true for events lower than 10 inches per year. The trend line and data appear to support the conclusion that baseflow is also increasing over the period of record. This conclusion does not seem very reasonable in that loss of recharge areas should mean loss of some groundwater flows over time with development. One possible explanation is that the baseflow separation technique applied to the data may not be very appropriate to the Monocacy Creek Watershed. A second possible explanation, and one that is consistent with the stormwater plan modeling of the Monocacy Creek, is that the stream channels in the upper reaches of the limestone geology are responsible for much of the discharge to groundwater through sinkholes or other means. In this case, greater storm runoff created by land development which discharges to the stream network provides greater opportunity for groundwater recharge. This enhanced groundwater recharge may be measured at the gage downstream as baseflow. It is not possible to determine from the available data and limited analyses whether either of these explanations is accurate.

Figure 6 is a graph of annual baseflow as a percentage of streamflow for the period of 1949 to 1996. The best fit line shows only a very slight upward trend. This apparent small upward trend does not seem to be significant enough to draw any clear conclusions. For all practical purposes, the annual baseflow appears to be a relatively constant percentage of streamflow over time.

The above trend analyses appear to indicate that for a period of fairly constant annual precipitation (Figure 3), the amount of precipitation which becomes streamflow is increasing over time (Figure 4), that within the limitations of the baseflow separation methodology that annual baseflows are also increasing over time (Figure 5), and that baseflow and streamflow maintain a fairly constant proportion (Figure 6). Prior to drawing any final conclusions, the baseflow separation technique should be evaluated to ensure that the methodology is providing reasonable results for the Monocacy Creek situation. A more rigorous water budget and trend analysis should be prepared to verify the preliminary trends identified. However, there is not evidence provided by this evaluation to suggest that baseflow levels or groundwater levels in the watershed are decreasing over time. Pending more detailed evaluations, this is an important preliminary observation.

FIGURE 5
ANNUAL BASE FLOW

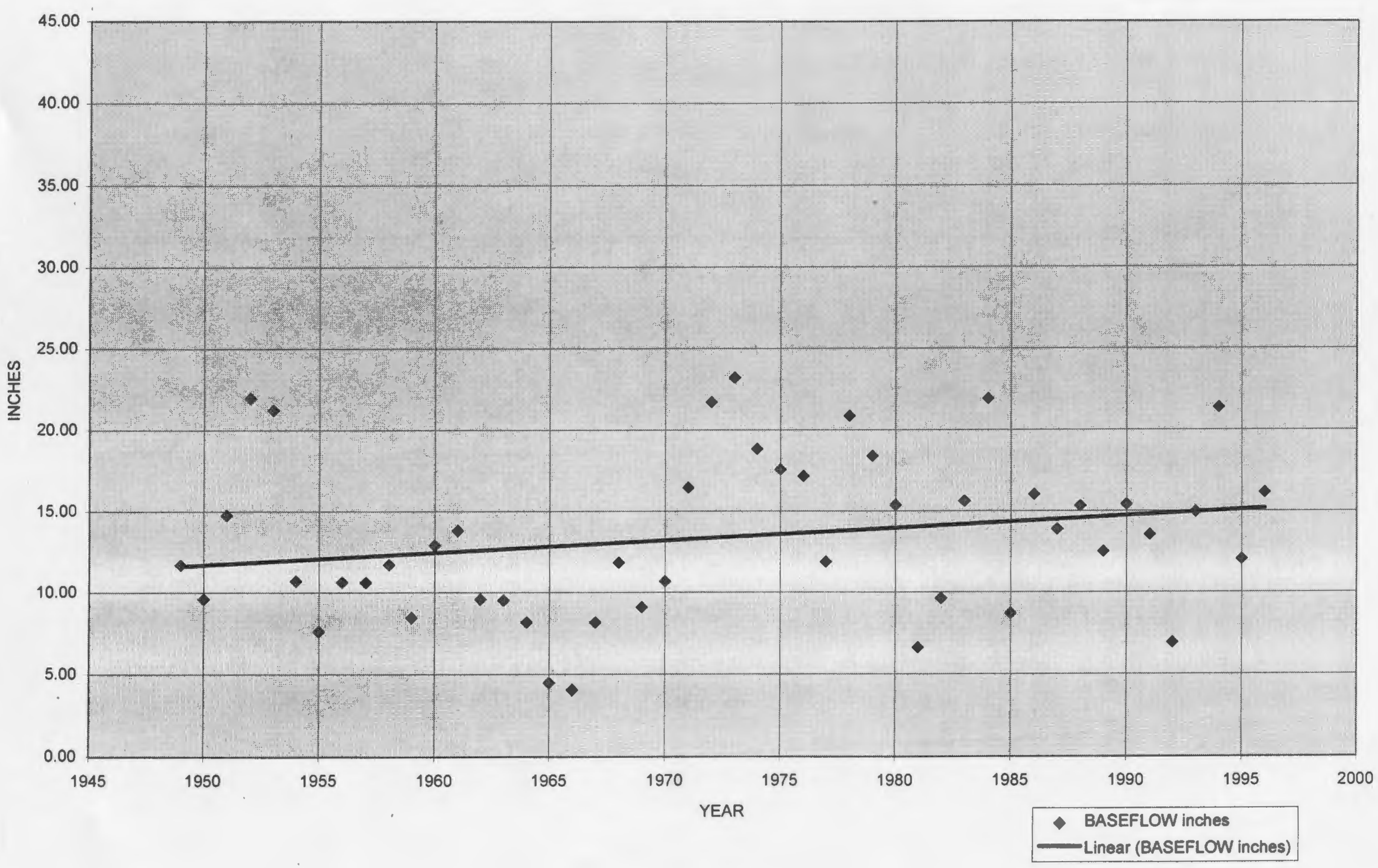

FIGURE 6
ANNUAL BASEFLOW AS A PERCENTAGE OF STREAMFLOW