ABSTRACT

Title of thesis: DEVELOPMENT AND APPLICATION OF A STREAM FLASHINESS INDEX BASED ON IMPERVIOUSNESS AND CLIMATE USING GIS

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Civil and Environmental Engineering

This work examines the relationship between imperviousness, climate, and the Richards-Baker (R-B) index, a measure of flow variability. Regression equations to predict the R-B index are developed for annual, cool, and warm seasons. The regression equations developed, are calibrated using stream flow data from 1970-2000 for 29 USGS streamgages throughout Maryland. Regression equations for the R-B flashiness index are developed as a function of imperviousness, precipitation characteristics, and drainage area. The relationship is used to estimate stream quality conditions throughout Maryland for present and future land use and climate. The regression equations are used to calculate the future streamflow variability by projecting the R-B index predictors to reflect the following conditions: (1) Increasing imperviousness only, (2) Climate change only, and (3) Jointly changing imperviousness and climate. Finally, the relationship between R-B index and stream quality is studied.

DEVELOPMENT AND APPLICATION OF A STREAM FLASHINESS INDEX BASED ON IMPERVIOUSNESS AND CLIMATE USING GIS

By

Karthik Ravirajan

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Dedication

To my Parents, Sister and all Teachers.

Acknowledgments

First and foremost, I would like to thank Dr. Glenn E. Moglen (Professor, University of Maryland) for rendering valuable guidance and giving me an opportunity to work on an interesting problem. I also thank Dr. Richard H. McCuen (Professor, University of Maryland) and Dr. Kaye L. Brubaker (Professor, University of Maryland) for serving on the thesis committee. In particular, I thank Dr. Stephen D. Prince (Professor, University of Maryland) for his help. I cannot thank Jyoteshwar Nagol and my colleagues enough for the countless times for their motivation and help during our discussions have assisted in the progress of this research.

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Chapter 1

Introduction

1.1 Background: Imperviousness and Flow variability

Streams are dynamic physical, chemical and biological systems that are influenced by their natural setting as well as by human activities, including urban development. There are several important discharge characteristics that regulate ecological processes in rivers and streams. These are magnitude of discharge, frequency of occurrence, the duration of occurrence, and the rate of change or flashiness of the stream discharge. This research involves modeling flashiness as a function of several predictors, especially imperviousness.

Flashiness refers to how quickly flow changes from one magnitude to another. Flashy streams have rapid rates of change of discharge and hydrologically stable streams have slow rates of change of discharge. Flashiness is one of the important five critical components of the flow regime (Poff and Allan, 1995). Hydrologic variability can be ecologically harmful (Archer and Newson, 2002). The two main causes of changes in flow variability are increases in imperviousness resulting from urbanization of the landscape and climatic variability.

Imperviousness refers to the surface coverage through which water cannot penetrate. Imperviousness can have profound effects on stream health. Imperviousness has a direct relation with stream temperature, runoff volumes, and peak flows (Beighley and Moglen, 2003). As the imperviousness increases, runoff volumes and peak flows increase. This makes imperviousness an important parameter in modeling rainfall-runoff relations. Also imperviousness causes sedimentation and pollutant loads to increase (Moglen et al., 2004). Imperviousness is simple to calculate and an effective index of urbanization. There are several models that give imperviousness from the land use and land cover (e.g., SCS 1986). Imperviousness can also be modeled based on the population (Stankowski, 1972; Moglen and Shivers, 2006).

Imperviousness has shown a strong correlation with stream health. Studies show that imperviousness has negative impacts when it exceeds a threshold value which is in the range of 10 to 15 percent (Carlson and Arthur, 2000; Bird et. al, 2002). Imperviousness thresholds have been implemented in policies to limit land development and to protect water resources (Kauffman and Brant, 2000).

Urbanization within a watershed increases the area of impervious surfaces which decreases infiltration of precipitation and increases surface runoff. Runoff increase is proportional to the amount of impervious surface cover(Arnold and Gibbons, 1996). Increased impervious surface area can alter the streamflow generating process, affecting the movement of water above and below the land surface, changing the frequency, magnitude, duration and timing of extreme low flow and high flow events (Poff and Allan, 1995). Urbanization has a generally positive association with overall variability in streamflow conditions and with stream flashiness (Jennings and Jarnagin, 2002). This increased flashiness results in a shorter duration of high stage conditions and a longer duration of low stage conditions.

All river flow derives ultimately from precipitation, so precipitation is one of the main factors that affects the flow variability of the stream. Flow variability is affected by the amount of rainfall and also by the time period between rainfall events. It is necessary to assess the rainfall pattern in a region in order to model the resulting flow variability or flashiness.

One of the indices that quantifies flow variability is the Richards-Baker Flashiness Index (R-B index) developed by Baker et al.(2004). This index measures the variability in flow between daily average discharges on successive days.

1.2 Motivation

The motivation for this study is to study how urbanization affects stream flashiness because of the effects of flashiness on stream ecology. Flashiness of streamflow influences species persistence and coexistence. Non-native fishes lack the behavioral adaptations to avoid being displaced downstream due to sudden heavy storms (Poff et. al, 1997). Many small fish species which seek refuge in shallow waters are negatively affected by frequent flow fluctuations.

Imperviousness is caused by the human alterations of the natural environment. These changes are as a result of increasing population or population density. It is important to understand the impact of human alterations of the landscape which add impervious surfaces which in turn leads to higher flow variability.

Human alterations also change climatic conditions. Such change is likely to affect precipitation magnitude and frequency. Since streamflow is sensitive to these quantities it is likely to be affected by climate change. This study can potentially address whether land use change or climate change will have a greater affect on streamflow variability.

1.3 Objectives

The aim of this research is to address the following questions:

1. Can flow variability be modeled as a function of imperviousness (urbanization)?

   This research addresses this question using a regression equation approach. The equations developed predict the R-B index.

2. How does the R-B index vary throughout Maryland?

   With the regression equation developed in Objective 1, we can use GIS to address this question in both tabular and spatial contexts.

3. Is flow variability a function of the spatial pattern of development?

   The spatial distribution of developed land will be characterized similarly to the previous work of Beighley and Moglen (2003). Development patterns will be quantified using an index to be called the spatial impervious index.

4. Is it possible to assess the impacts of future conditions on flow variability?

   The regression equations developed in this study can be used to assess the impacts of future urbanization on flow variability. They also provide quantification of the effects of changing climatic conditions on flow variability. We will be able to spatially assess possible future changes in the R-B value of Maryland streams using the equations developed in the earlier objectives.

1.4 Summary

Flow variability is an important flow characteristic that is affected by urbanization and climate. The R-B index will be used to quantify flow variability in this study. We will develop a relationship that quantifies how the R-B index varies with imperviousness, among other predictors. With this relationship we will assess the impacts of urbanization on flow variability on all streams across Maryland. The effects of possible future changes in imperviousness and climatic conditions on streamflow variability will be studied in both tabular and spatial formats.

Chapter 2

Literature Review

This chapter summarizes the work of others related to flashiness, urbanization and its impacts on stream ecology. The first section discusses the effects of urbanization. The second section discusses various works related to streamflow flashiness. The third section gives a brief overview of the R-B index.

2.1 Urbanization and Ecology

Freshwater systems are vulnerable to land use change, especially urbanization. Imperviousness is a useful indicator with which to measure the impacts of land development on aquatic systems. Urbanization contributes to the degradation of aquatic community structure and stream biota.

Flood flows and low flows have dramatic effects on the biotic communities and ecological processes (Poff et al., 1997). Currently two-thirds of the nation's freshwater mussels are at risk of extinction and half of all crayfish species are in jeopardy. This is because of increased imperviousness from urbanization(Snyder et al., 2005). In the Chesapeake Bay watershed, many studies have demonstrated the association between land use changes and their impacts on the biological, physical and chemical quality of streams (e.g., Palmer et al., 2002). Land use influences hydrologic, sediment and nutrient regimes which in turn influence aquatic biota and ecological processes in fresh waters. In the state of Maryland about 46 percent of the streams are in poor condition (Snyder et al., 2005). Healthy freshwater ecosystems are those in which the ecological structure and function is sufficiently unperturbed so that biotic assemblages thrive and ecological processes continue unimpeded. Poor conditions are quantified based on fish Index of Biological Integrity (IBI) values (Karr, 1981).

Poff and Allan(1995) specifically related disturbance from streamflow variability to significant changes in aquatic habitat structure . The instream changes in species composition noted in urban studies are primarily due to changes in the variability of frequency and magnitude of stream flow disturbance brought about by impervious surfaces.

The effects on stream ecology are categorized into two orders by Palmer et al. (2002): first order and the second order. The first order effects mainly include the influence on biota that is caused by the changes in the riparian vegetation. Landscape changes in the amount of and arrangement of riparian and floodplain habitat have influences on running-water ecosystems. Stream and riparian zones not only serve as habitat but act as corridors for movement of biota. Land use changes that magnify the influx of nutrients or contaminants may have lethal effects on biota.

Second order factors include changes in flow variability which are mediated by the hydrologic and geomorphic changes. Numerous studies have been developed associating land cover information with stream health (Kennen, 1999; Basnyat et al., 2000; Meador and Goldstein, 2003). This gives feasibility to associate stream health with land cover information.

Klein (1979) was one of the first to note that macro-invertebrate diversity drops sharply at 10 to 15 percent of imperviousness. Jones and Clark (1987) concluded that aquatic insect diversity composition changed markedly after watershed population density exceeded four or more individuals per acre. Booth (1991) found that channel stability and fish habitat quality declined rapidly after 10 percent imperviousness. Schueler(1994) observed that the imperviousness of a watershed can be used as a predictor of stream ecosystem health and hypothesized that a threshold for urban stream stability and habitat quality exists at approximately 10 to 20 percent impervious surface area.

Urban development tends to have impacts on the stream and on the water table. Urban development reduces infiltration rates and lowers the water table. Infiltration rates will be higher in areas of low density cluster development than in the highly urbanized centers (Tourbier, 1994; Paul and Meyer, 2001). With infiltration rates reduced groundwater recharge is proportionately reduced.

Increasing imperviousness leads to higher peak flows and lower base flows. The direct hydrologic effect of impervious surfaces occurs as a change in the magnitude and variability of velocity and volume of surface flow (Jennings and Jarnagin, 2002). In landscapes under the influence of impervious surfaces, precipitation that would normally infiltrate, instead falls on and flows over impervious surfaces. Henshaw and Booth(2001) observed that increasing urbanization was related to decreases in the frequency of flows above the mean. The increase in imperviousness results in more flashy streams (Hirsch et al., 1990; Poff and Allan, 1995). Urbanization has a generally positive association with overall variability in streamflow conditions and with stream flashiness (Jennings and Jarnagin, 2002).

The addition of impervious surface to a watershed can lead to increased channel area and possibly incision. Floods affect the stream channel by increasing their channel cross section either by widening the stream banks, down-cutting the stream bed or both. This in turn causes channel instability and habitat degradation. Watershed development beyond 10 percent imperviousness consistently resulted in unstable and eroding channels (Hammer, 1972). The rate and severity of channel is a function of sub-bankfull floods, whose frequency can increase by a factor of 10 even at relatively low levels of imperviousness (Hollis, 1975; Macrae and Marsalek, 1992; Schueler, 1987)

Urbanization increases thermal pollution generated by runoff from hot paved surfaces and organic and heavy metal pollution largely from roads and parking lots (Palmer et al., 2002). During storm events these pollutants are quickly washed off and rapidly delivered to aquatic systems. Studies have consistently indicated that urban pollutant loads are directly proportional to the amount of impervious surface (Schueler, 1987).

2.2 Flashiness Indices

Figure 2.1 shows an example of a stream that becomes flashier after land use change or development of impervious area in the stream's watershed.

The hydrograph with the higher peak flow, lower baseflow, and sharp increase

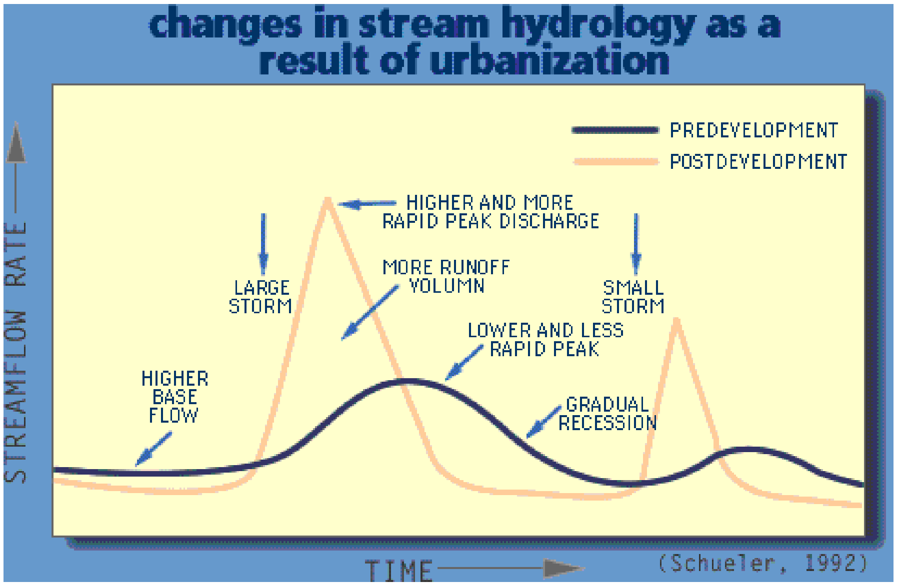

Figure 2.1: Comparison of discharge hydrographs from a stable and flashy stream. (adapted from Schueler, 1992)

in the flow rate with time is characteristic of a flashier stream, while the hydrograph with the smaller peak flow, higher base flow, and gradual recession is characteristic of a stable stream.

There are various flashiness indices developed by many researchers. We will look at the definitions of few of these indices.

R-B Index (R-B) : Richards-Baker Flashiness Index developed by Baker et al. (2004) measures variability in flow between daily average discharges on successive days. They defined this index as shown in equation 2.1.

$$R - B = \frac{\sum_{i=1}^{n} |Q_i - Q_{i-1}|}{\sum_{i=1}^{n} Q_i} \tag{2.1}$$

where Q_i is the mean daily flow in cfs for a given day, i, and n is the number of days of recorded data at a given gaging station.

Coefficient of Variation (CV): The coefficient of variation measures relative variability of streamflow by dividing the standard deviation of the daily mean flows by the average of the observed daily average discharges.

$$CV = \frac{\sqrt{\frac{\sum_{i=1}^{n}[Q_i^2 - \frac{\left(\sum_{i=1}^{n} Q_i\right)^2}{n}]}{n}}}{\frac{\sum_{i=1}^{n} Q_i}{n}} \tag{2.2}$$

where Q_i is the mean daily flow in cfs for a given day, i, and n is the number of days of recorded data at a given gaging station.

Lag-one autocorrelation (R_{L1}): The lag-one auto correlation measures the degree of correlation between values separated by one time interval.

$$R_{L1} = \frac{\sum_{i=1}^{n-1} Q - \frac{1}{n-1}\left(\sum_{i=1}^{n-1} Q_i\right)\left(\sum_{i=2}^{n} Q_i\right)}{\left[\sum_{i=1}^{n-1} Q_i^2 - \frac{1}{n-1}\left(\sum_{i=1}^{n-1} Q_i\right)^2\right]^{0.5}\left[\sum_{i=2}^{n} Q_i^2 - \frac{1}{n-1}\left(\sum_{i=2}^{n} Q_i\right)^2\right]^{0.5}} \tag{2.3}$$

where Q_i is the mean daily flow in cfs for a given day, i, and n equals number of days of recorded data at a given gaging station

Ratio of Discharges(R_{Q10-90}): The R_{Q10-90} is the ratio of the discharge which is equaled or exceeded 10 percent of the time (Q_{10}) to the discharge which is equaled or exceeded 90 percent of the time (Q_{90}) (Baker et al. 2004). The higher the value is, the greater the flow variability.

$$R_{Q10-90} = \frac{Q_{10}}{Q_{90}} \tag{2.4}$$

McMahon et al.(2003) used stage data to characterize an index for flow variability. In their discussion about the flow variability index, they point out that flow variability has a strong dependence on the spatial arrangement of the impervious surfaces. They further characterized other variables such as LPI and MPS (LPI, the percentage of the basin area composed of the largest patch of developed land, and MPS, mean developed patch size)in order to define the spatial variables. Moglen and Beighley (2003), concluded that a upstream oriented development pattern within a watershed can cause larger peak discharges compared to a downstream oriented development pattern. Ritcher et al.(1996) developed a set of 33 indices that are relevant to the aquatic communities which are called IHA(Indicators of Hydrologic Alteration) parameters. The term "flashiness" is not used for any of the IHA parameters, however several parameters such as the average rate of flow increase or decrease, frequency and duration of high pulses, and number of flow reversals reflect stream flashiness. Burges et al.(1999) correlated increased flashiness with increased magnitude of flood peaks relative to wet season baseflow, increased rate of storm flow recession, and decreased duration of time that the mean discharge rate is exceeded.

The research presented in this thesis extracts ideas from the above works to develop a predictive equation for the R-B flashiness index based on watershed and climate characteristics.

2.3 R-B Index

The R-B index measures fluctuations in flow relative to total flow (or discharge), and provides a useful characterization of the stream flow variability. This index can be used to classify a stream as stable and flashy. The R-B index ranges from 0 to 2. Urbanized watersheds tend to have higher R-B index values than less developed watersheds. The R-B index integrates several flow regime characteristics associated with the concept of stream flashiness. This index is positively correlated with the increasing frequency and magnitude of the storm events and negatively correlated to the watershed area. Baker et al.(2004), found that there is a strong correlation between the R-B index and imperviousness, however this correlation was not further quantified. The R-B index may be useful as a tool for assessing the effectiveness of programs aimed at restoring more natural streamflow regimes, particularly where modified regimes are a consequence of land use/ land management practices (Baker et al., 2004). R-B index is typically calculated on an annual basis. The R-B index has lower interannual variability than the other flow regime indicators, making it well suited for detecting gradual changes in flow regimes associated with changes in land use and in land management practices (Baker et al., 2004).

Chapter 3

Methodology

This chapter presents the data and methods used and developed in this study. The first section discusses the data that are required for modeling the R-B index and lists the sources from which they are acquired. The second section deals with the calculation of R-B index from the raw streamflow data. The third section discusses the method in which the watershed boundaries are delineated. The fourth section describes the method for calculating the imperviousness for the various time periods. The fifth section deals with the calculation of the precipitation factor from the rainfall data. Precipitation factor is given by the variance of precipitatin over its mean for a given time period. The sixth section presents the method for calculating the spatial impervious index. The seventh section presents the trend analysis for the R-B index. The eighth section deals with the calibration of the R-B index equations for various seasons of the year. The final section shows how these equations can be applied to future conditions/scenarios.

3.1 Data Collection

Data were collected in order to calculate the R-B index, precipitation factor, and imperviousness. The R-B index was calculated from daily streamflow data obtained from the USGS. Data for 29 USGS stream gages were collected for thirty years from 1970 to 2000. Imperviousness was calculated from population density. Population density data were collected using U.S. census data. The precipitation factor was calculated from the daily precipitation data which were obtained from the NCDC (National Climate Data Center website, http://www.ncdc.noaa.gov). The drainage area and physical boundaries of the watersheds were determined using GIS methods.

Calculation of R-B index was performed for three time periods : Annual, cool and warm seasons. We defined the cool season of the year as the period from October to May and the warm season as June to September.

Census tract data in digital format were available for the years 1970, 1980, 1990 and 2000. The availability of digital census data controlled the selection of the precipitation and the stream flow gages.

Daily precipitation data were collected for the years 1970-2000. Missing data were managed by censoring the entire year of data in which data were missing.

3.2 Calculation of R-B index

The R-B index was calculated using the streamflow data for all study watersheds across Maryland for the thirty years from 1970 to 2000. The streamflow data were obtained from the USGS and the watersheds draining to these gages were delineated using GISHydro. The watersheds delineated are shown in Figure 3.1. Streamflow data were collected for years 1970-2000. Missing streamflow data were managed by censoring the entire year of data in which data were missing. Gage selection was based on having more than 20 years of record between the years 1970 and 2000. Streamflow data were obtained in tabular form from the USGS. These data were then processed using equation 2.1 to determine the R-B index. The values of R-B index for the years from 1970 to 2000 are calculated and tabulated in Appendix A. Similarly the R-B indices for the cool and warm periods were calculated and are tabulated in Appendix A. Figure 3.1 shows the spatial distribution of the study watersheds.

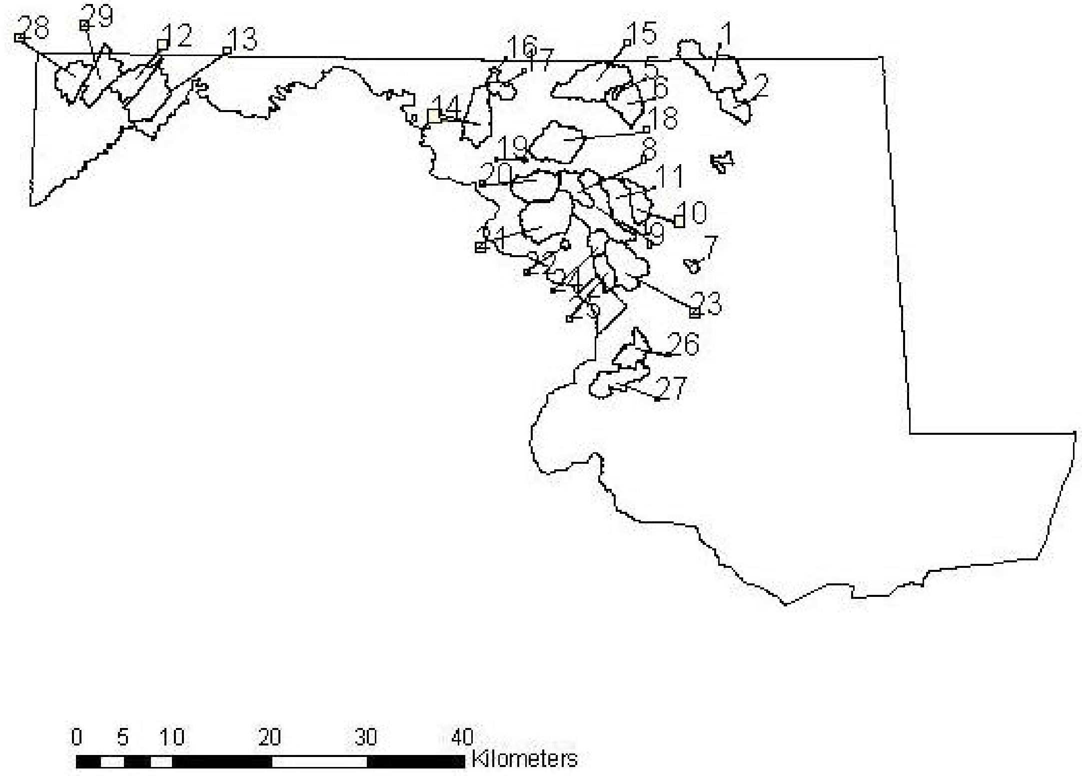

Figure 3.1: Spatial distribution of study watersheds in Maryland.

3.3 Calculation of Watershed Area and Boundaries

GIS was used to calculate the watershed area and boundaries for the streamflow gages listed in Table 3.1. DEM data are required to calculate the watershed area and delineate the watershed boundaries. With the help of flow direction and flow accumulation functions in GIS the watershed boundary was delineated for each streamflow gage. These watershed boundaries were then used to calculate the other predictors (e.g imperviousness and precipitation).

3.4 Calculation of Imperviousness

Imperviousness is a characteristic that has a strong influence on flood magnitude. Unfortunately, there is a poor record of spatial and temporal distribution of imperviousness derived from satellite data or land use maps. This study required imperviousness data for the period from 1970 to 2000. Therefore, imperviousness derived from census-derived population density was used in this study.

Census data are readily available in digital format for the period from 1970 through 2000 in 10-year increments. Assuming linear changes in population density between census snapshots, it is possible to develop space-time estimates of population density at any location within the U.S. at the spatial resolution of a census tract. Census tracts vary considerably in scale depending upon the population density. The nature of this study was to focus on urban areas which plays to the strength of the census data since urban areas tend to have smaller scale census tracts.

Moglen and Shivers(2006) developed a simple power model for calculating imperviousness from population density (for the state of Maryland). The calibrated equation determined was:

$$IA = 12.1953.(PD)^{0.5195} \tag{3.1}$$

where IA is imperviousness in percent and PD is population density in thousands of persons per square mile. Imperviousness was obtained from the 2001 NLCD. Imperviousness were present at 30 meter resolution. This equation was determined for $0.0002 < PD < 176.4$ and $0.08 < IA < 96.66$. The median PD and IA values were 3.87 and 21.8, respectively. The regression was performed using data from 998 census tracts. The ratio of the standard error, Se, of equation 26 to the standard deviation, Sd of observed imperviousness was: Se/Sd=0.6163 with an explained variance of 62.1 percent.

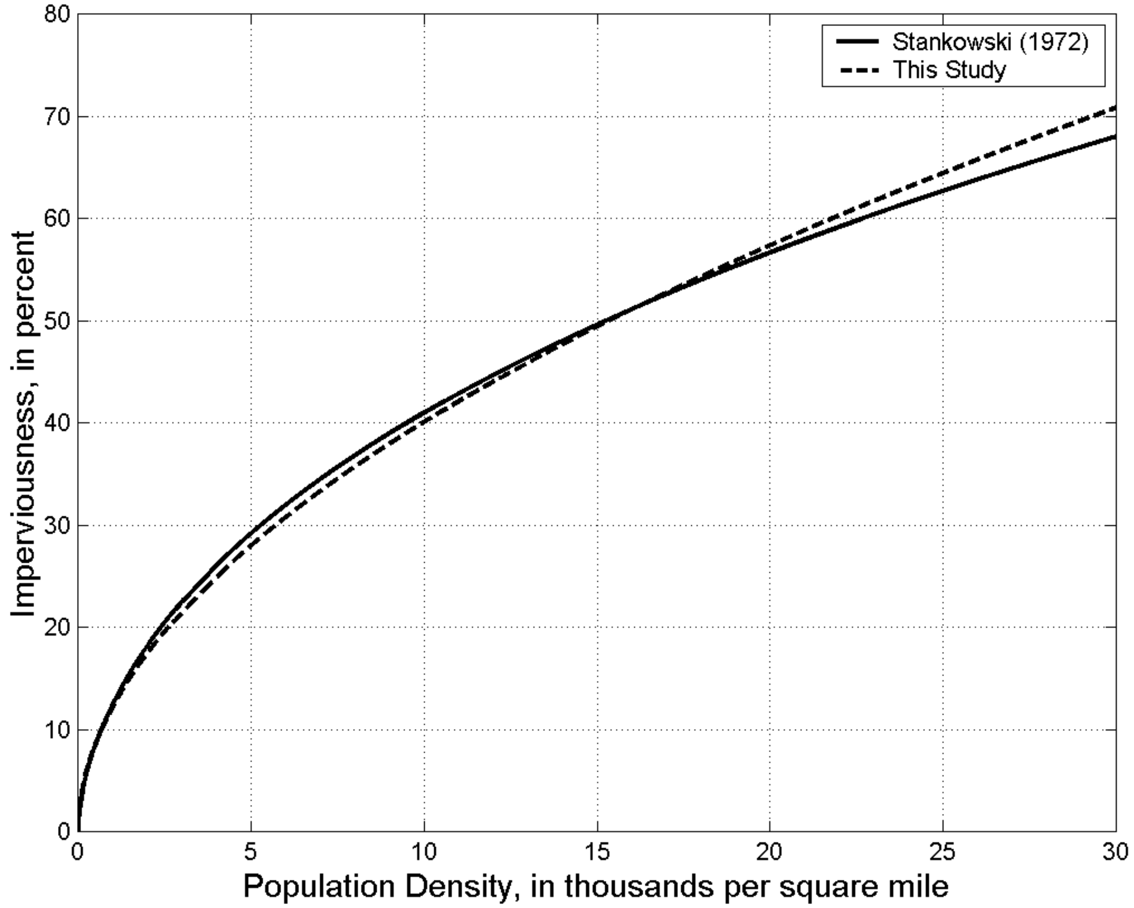

Figure 3.2: Comparison of relationships developed by Stankowski (1972) and Moglen and Shivers(2006). Figure is taken from Moglen and Shivers (2006).

Equation 3.1 was used to calculate imperviousness from the census tracts for a watershed. Similarly the same equation was further used for the different watersheds that are considered in this study. The average imperviousness across a watershed for the years 1970, 1980, 1990 and 2000 are linearly interpolated in order to get the imperviousness for the period of 30 years. These values were used for calibrating the equation to predict the R-B index. Similarly an imperviousness raster layer was created using the census tracts data for the years 1970, 1980, 1990 and 2000 across Maryland.

3.5 Calculation of Precipitation Factor

As streamflow derives from precipitation, it is important to consider precipitation in modeling the flashiness index. Daily precipitation data were collected from the NCDC. The precipitation factor was calculated as the variance of precipitation over the mean in units of inches for the annual, cool and warm periods. The coefficient of variation was also considered for the precipitation factor, however variance over the mean turned out to be a stronger predictive variable in our analyses. The precipitation factor was calculated using the daily rainfall data from 1970 to 2000. This factor was calculated and is shown in Appendix A for the selected stream gages. The list of the precipitation gages and their corresponding stream gages is shown in Table 3.1.

The precipitation factor was calculated for three periods: annual, cool and warm periods. The warm period is the months June to September and October to May was considered as the cool period of the year. The value of variance over the mean precipitation was calculated for these periods using the daily precipitation data. Periods were chosen to roughly correspond to convective dominated (warm period) weather and frontal dominated (cool period) weather.

In order to calibrate the R-B index predictive equation, we required a continuous time series of daily values of precipitation. Precipitation gages were selected within twenty miles of the stream gages. Wherever missing data were encountered the following approach was used to fill in the missing values. The nearest four precipitation gages to the streamflow gages were determined and were tabulated in Table 3.1. Of the four gages chosen, the best gage in terms of data availability was chosen and variance over the mean for every year was calculated for that precipitation gage.

A GIS layer of precipitation factor was created throughout Maryland for annual, warm and cool months of the year using the average precipitation factor calculated for the years 1970 through 2000. Since each precipitation gage is a point, we needed to create a continuous spatial layer of precipitation factor. Theissen polygons of data were created. These Theissen polygons show the precipitation factor across Maryland. Figures 3.3, 3.4, 3.5 and 3.6 represent the precipitation gages and the Theissen layers of the precipitation factor for the annual, cool and warm months, respectively.

Table 3.1: Watersheds used in R-B index regression analyses.

Study Id.	Gage Id.	Area (sq. miles)	Nearest Precipitation Gages			
			1	2	3	4
1	01580000	94.41	186844	181960	185934	182060
2	01581700	34.59	181960	186844	182060	180015
3	01585100	7.53	182308	180470	181960	187015
4	01585300	4.50	182308	180470	187015	181960
5	01585500	3.25	189440	185934	186844	189030
6	01586000	56.03	189440	185934	186844	181960
7	01590500	6.96	180193	180700	180193	180185
8	01591000	34.93	181125	181862	189030	181032
9	01592500	132.56	181125	181862	187705	189502
10	01593500	38.19	181862	189750	189314	181125
11	01594000	98.14	181862	181125	189750	189314
12	01596500	49.13	185894	186408	186410	183795
13	01599000	72.72	185894	186408	186410	182285
14	01637500	67.35	184780	181530	182770	183350
15	01639500	102.97	189440	182906	185934	189030
16	01640500	6.13	181530	182770	182906	183980

Study Id.	Gage Id.	Area (sq. miles)	Nearest Precipitation Gages			
			1	2	3	4
17	01641000	18.63	181530	182770	182906	183350
18	01642500	82.18	189030	183355	183348	183350
19	01643000	1.23	183355	183348	183350	189030
20	01643500	62.83	183355	183348	183350	181032
21	01645000	102.03	181032	187705	187272	181125
22	01645200	3.70	187705	187272	189502	183645
23	01649500	73.36	180705	180714	185111	181995
24	01650500	21.29	189502	181125	180714	187705
25	01651000	49.42	189502	180714	180705	181995
26	01653600	39.75	188289	189195	189070	186350
27	01658000	55.78	189195	185080	188289	
28	03076600	49.02	185832	188315	186410	183795
29	03078000	63.77	186410	183795	186408	185894

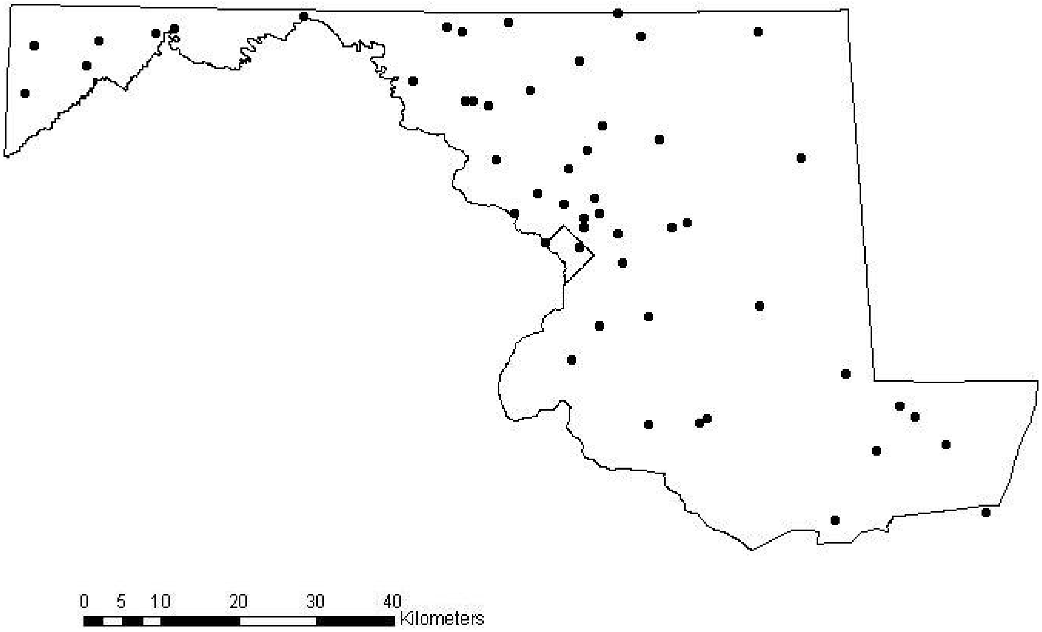

Figure 3.3: Spatial distribution of precipitation gages in Maryland.

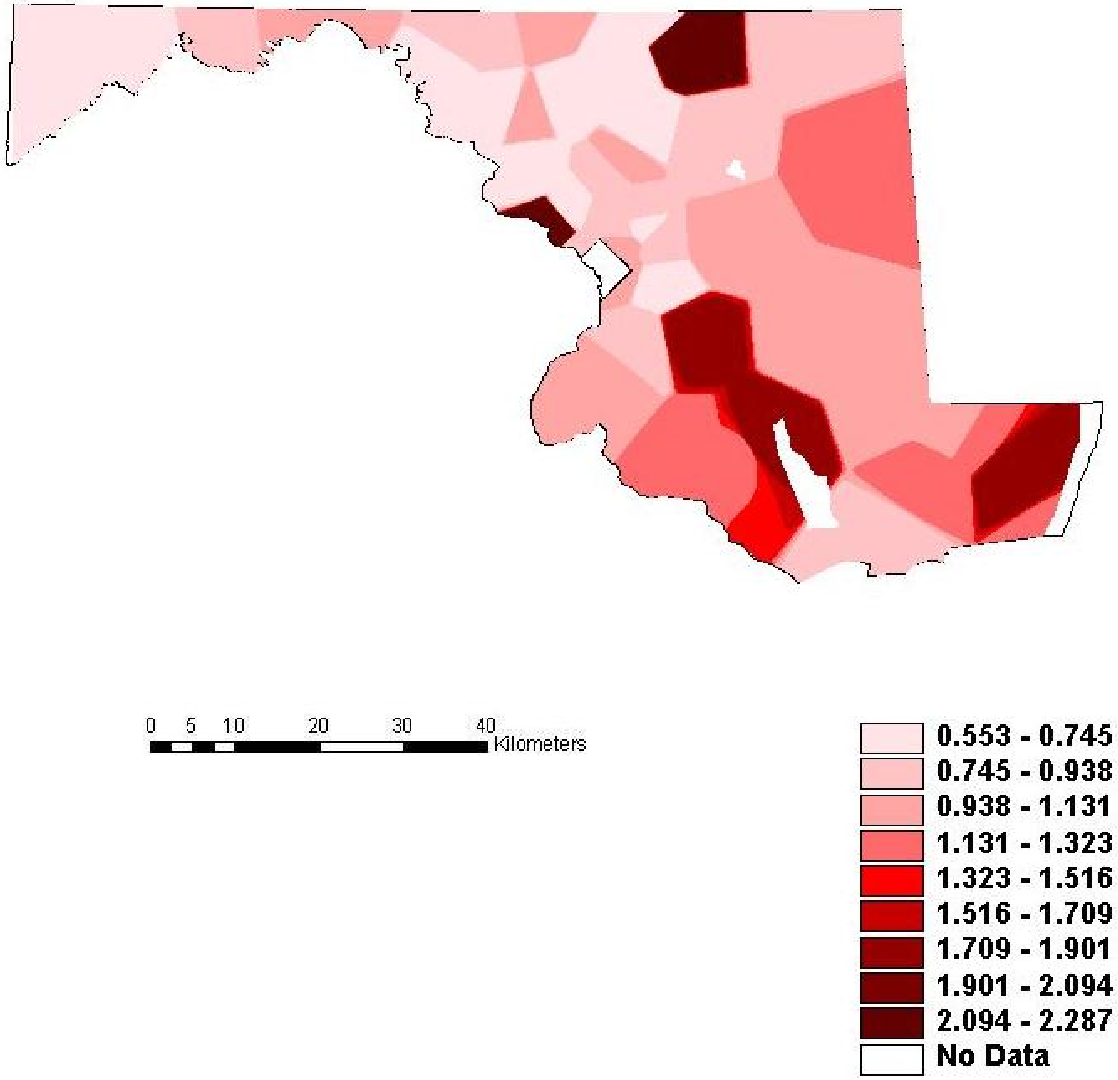

Figure 3.4: Raster representation of annual precipitation factor (in inches) in Maryland.

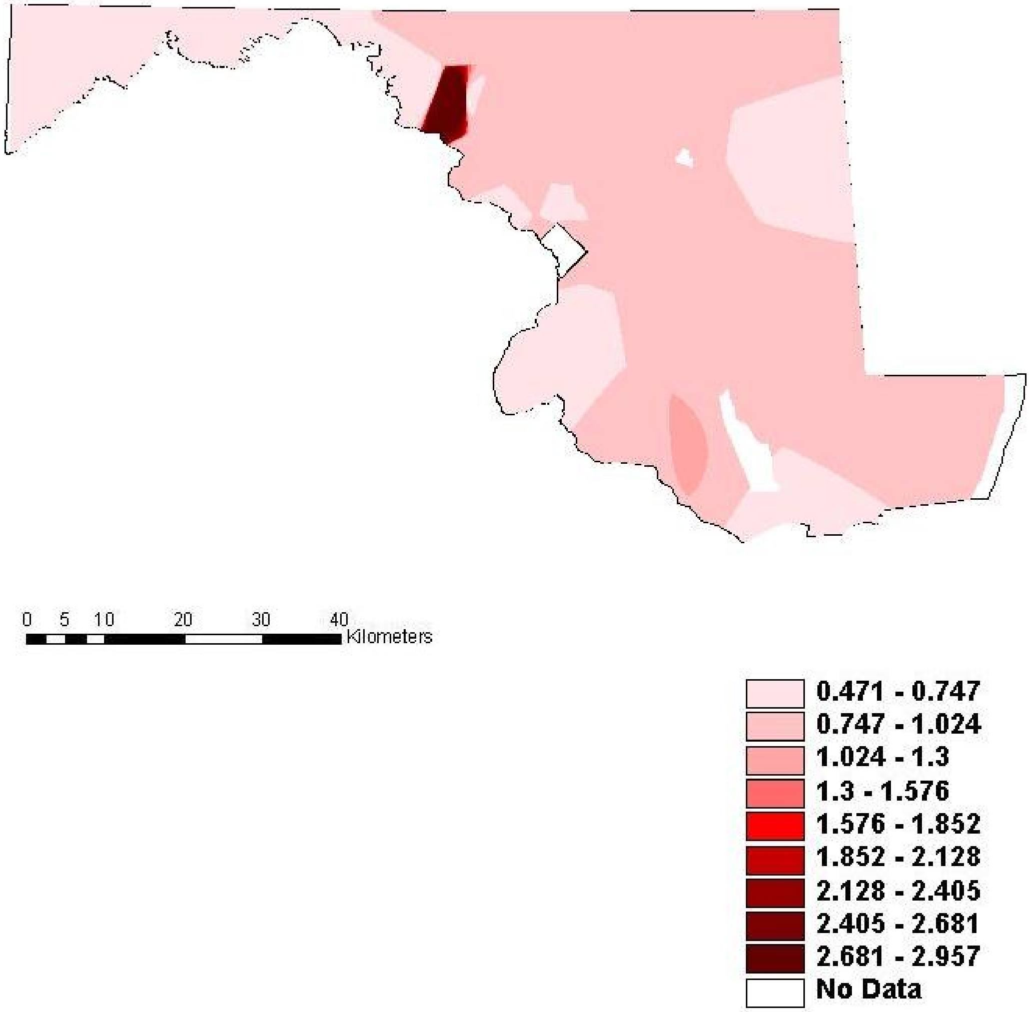

Figure 3.5: Raster representation of cool period precipitation factor (in inches) in Maryland.

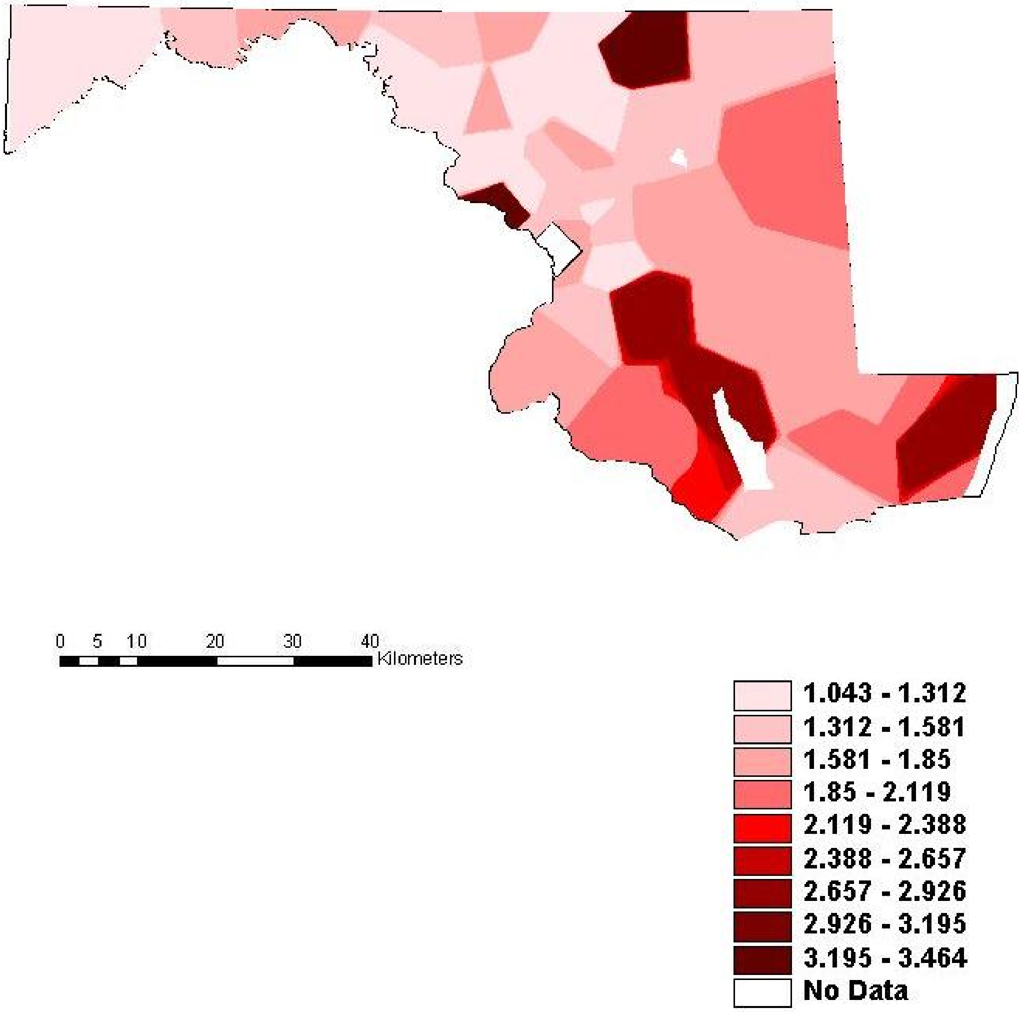

Figure 3.6: Raster representation of warm period precipitation factor (in inches) in Maryland.

3.6 Calculating Spatial Impervious Index

The spatial impervious index is calculated to examine the effect of spatial arrangement of development on the flow variability. McMahon et al. (2003) showed the correspondence of spatial arrangement of imperviousness to the flow variability. The spatial development pattern within a watershed is a function of the percentage of total development that occurs relative to the line that separates 50 percent of the longest drainage path length from the watershed outlet (i.e., gage location). The watershed is divided into two parts along the longest path and the ratio of the imperviousness weighted with area, that is,

$$SII = \frac{UI \times UA}{DI \times DA} \tag{3.2}$$

where SII is the spatial impervious index, UI is the upstream imperviousness of the watershed measured in percent, UA is the upstream area measured in square miles, DI is the downstream imperviousness in percent and DA is the downstream area in square miles. This parameter is defined as the spatial impervious index.

An example calculation of this index is shown in Figure 3.7. The figure shows the Deer Creek at Rocks, MD watershed divided into halves based on drainage distance to the watershed outlet. Imperviousness is then calculated using the procedure described in Section 3.4. Then the calculated imperviousness is used to calculate the spatial impervious index using equation 3.2. The list of watersheds and their spatial impervious index through the years 1970 to 2000 is given in Appendix A.

The spatial impervious index is used to quantify the spatial development pattern, which is classified, qualitatively, as upstream-oriented or downstream-oriented.

The watershed is divided across the longest flow path. The part which contains the outlet point is the downstream part and the other is called the upstream. Typically, the upstream-oriented development pattern results in larger peak discharges compared with the downstream pattern (Moglen and Beighley, 2003). When $SII > 1$ then the watershed is considered upstream-oriented and when $SII < 1$ then the watershed is considered downstream-oriented. The SII for the Deer creek watershed was found to be 1.01 (for the year 2000). This value is greater than 1 which implies that Deer Creek watershed is (very slightly) upstream oriented. The imperviousness for the upstream region was found to be 5.33 % and for the downstream region was found to be 4.15 %. The area of the upstream region was found to be 41.51 square miles and the area of the downstream region was found to be 52.82 square miles.

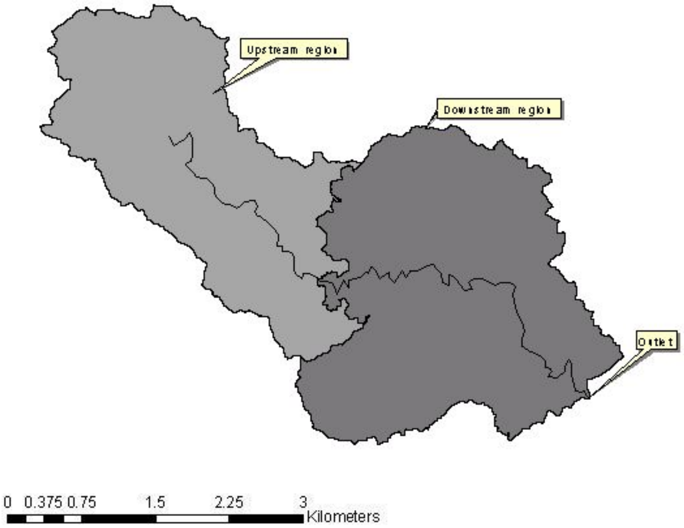

Figure 3.7: Deer Creek at Rocks, MD.

3.7 Hypothesis Test for Temporal Trends in the R-B Index

Hypothesis tests were performed between the R-B index and time in order to test for trends of increasing R-B index with time. A one-tailed Mann-Kendall test was performed as the hypothesis test, with the null hypothesis being no trend and the alternate hypothesis stating that there is an increasing trend in the R-B index. A one-tailed test was chosen so that we could evaluate the conditions for an increasing R-B index. The test was performed for the selected watersheds across Maryland shown in Figure 3.1 and tabulated in Table 3.2.

Figure 3.8 shows an example of the trend analyses for the White Marsh Run (USGS gage 01585100) watershed. Data were collected for 24 years for the White Marsh Run watershed. A Mann-Kendall test was performed for this watershed with the null hypothesis stating that there is no trend in the R-B index values with respect to time. The calculated τ statistic was found to be 0.87, while the critical t statistic at 10% probability was found to be 0.196. Hence we reject the null hypothesis and this shows that there is a significant trend in the R-B index at 10% probability.

The results for the study watersheds for the annual period are shown in Table 3.2. There were 16 USGS watersheds with a significant trend in the R-B index values and there were 13 watersheds with no significant trend. Watersheds with a significant trend were found near the Washington D.C. area. The significant trend in R-B index is assumed to be due to the change in imperviousness. When the change in imperviousness is greater than 3.5% then a significant trend in R-B index was generally found. However, 8 of the 16 watersheds had a change in imperviousness less than 3.5% but still showed a significant trend in increasing R-B index (USGS watersheds were: 01583000, 01585500, 01586000, 01599000, 01637500, 01639500, 01640500 and 03076600). While the change in imperviousness for 2 other watersheds was greater than 3.5% but there was no significant trend in the R-B index (USGS watersheds were: 01643000, and 01645000). Overall, the 3.5% threshold correctly predicts the presence or absence of a significant trend in 19 of 29 watersheds for the annual period.

For the cool period, 20 USGS watersheds were found to have a significant trend in the R-B index values and there were 9 watersheds with no significant trend. There was no threshold value of imperviousness found for the cool periods.

For the warm period, there were 10 USGS watersheds with a significant trend in the R-B index values and there were 19 watersheds with no significant trend. A value of 2% was found as the threshold for the warm periods. However, 3 of the 10 watersheds had a change in imperviousness less than 2% but still showed a significant trend in increasing R-B index (USGS watersheds were: 01585300, 01586000 and 03076600). While the change in imperviousness for 6 other watersheds was greater than 2% but there was no significant trend in the R-B index (USGS watersheds were: 01581700, 01643000, 01645000, 01650500, 01653600 and 01658000). Overall, the 2% threshold correctly predicts the presence or absence of a significant trend in 20 of 29 watersheds for the warm period. The results of the cool (Table B.1) and warm (Table B.2) periods are presented in Appendix B.

Table 3.2: Hypothesis test for the selected USGS watersheds for the annual period with rejection probability 10%.

Study Id.	Gage Id.	Statistics	Decision / Result
1	01580000	n = 29 ΔImp = 1.48% $\tau_{critical}$= 0.172 $\tau_{calculated}$ = -0.1182	Accept
2	01581700	n = 29 ΔImp = 3.82% $\tau_{critical}$ = 0.172 $\tau_{calculated}$ = 0.2167	Reject
3	01585100	n =24 ΔImp = 9.29% $\tau_{critical}$ = 0.196 $\tau_{calculated}$ = 0.8696	Reject
4	01585300	n =19 ΔImp = 0.05% $\tau_{critical}$ = 0.228 $\tau_{calculated}$ = 0.4795	Reject
5	01585500	n =19 ΔImp = 2.31%	Reject

Study Id.	Gage Id.	Statistics	Decision / Result
		$\tau_{critical}$ = 0.228 $\tau_{calculated}$ = 0.9474	
6	01586000	n = 19 ΔImp = 1.24% $\tau_{critical}$ = 0.228 $\tau_{calculated}$ = 0.4561	Reject
7	01590500	n = 14 ΔImp = 5.24% $\tau_{critical}$ = 0.275 $\tau_{calculated}$ = 0.9011	Reject
8	01591000	n =21 ΔImp =1.16% $\tau_{critical}$ = 0.21 $\tau_{calculated}$ = -0.0571	Accept
9	01592500	n = 21 ΔImp = 1.70% $\tau_{critical}$ = 0.21 $\tau_{calculated}$ = -0.2286	Accept
10	01593500	n =28 ΔImp = 9.39%	Reject

Study Id.	Gage Id.	Statistics	Decision / Result
		$\tau_{critical}$ = 0.18 $\tau_{calculated}$ = 0.3492	
11	01594000	n = 12 ΔImp = 5.50% $\tau_{critical}$ = 0.303 $\tau_{calculated}$ = 1.0303	Reject
12	01596500	n = 25 ΔImp = 1.64% $\tau_{critical}$ = 0.193 $\tau_{calculated}$ = -0.4	Accept
13	01599000	n =25 ΔImp = 0.23% $\tau_{critical}$ = 0.193 $\tau_{calculated}$ = 0.3067	Reject
14	01637500	n = 29 ΔImp = 0.3% $\tau_{critical}$ = 0.172 $\tau_{calculated}$ = 0.2956	Reject
15	01639500	n = 19 ΔImp = 0.88%	Reject

Study Id.	Gage Id.	Statistics	Decision / Result
		$\tau_{critical}$ = 0.228 $\tau_{calculated}$ = 0.4795	
16	01640500	n = 15 ΔImp = 0.14% $\tau_{critical}$ = 0.276 $\tau_{calculated}$ = 0.4381	Reject
17	01641000	n =22 ΔImp 0.36% $\tau_{critical}$ = 0.203 $\tau_{calculated}$ = 0.0286	Accept
18	01642500	n = 13 ΔImp = 0.17% $\tau_{critical}$ = 0.308 $\tau_{calculated}$ = 0	Accept
19	01643000	n = 26 ΔImp 5.94% $\tau_{critical}$ = 0.188 $\tau_{calculated}$ = -0.1662	Accept
20	01643500	n =26 ΔImp 0.57%	Accept

Study Id.	Gage Id.	Statistics	Decision / Result
		$\tau_{critical}$ = 0.188 $\tau_{calculated}$ = 0.0677	
21	01645000	n = 21 ΔImp = 6.61% $\tau_{critical}$ = 0.21 $\tau_{calculated}$ = -0.1524	Accept
22	01645200	n =17 ΔImp = 4.00% $\tau_{critical}$ = 0.25 $\tau_{calculated}$ = 0.3235	Reject
23	01649500	n =30 ΔImp = 5.79% $\tau_{critical}$ = 0.172 $\tau_{calculated}$ = 0.8414	Reject
24	01650500	n = 14 ΔImp = 3.05% $\tau_{critical}$ = 0.275 $\tau_{calculated}$ = 0.022	Accept
25	01651000	n =24 ΔImp = 1.21%	Accept

Study Id.	Gage Id.	Statistics	Decision / Result
		$\tau_{critical}$ = 0.196 $\tau_{calculated}$ = -0.1449	
26	01653600	n = 30 ΔImp = 3.09% $\tau_{critical}$ = 0.172 $\tau_{calculated}$ = -0.023	Accept
27	01658000	n =26 ΔImp = 3.39% $\tau_{critical}$ = 0.188 $\tau_{calculated}$ = -0.1169	Accept
28	03076600	n =19 ΔImp = 0.1% $\tau_{critical}$ = 0.228 $\tau_{calculated}$ = 0.8304	Reject
29	03078000	n = 25 ΔImp = 0.31% $\tau_{critical}$ = 0.193 $\tau_{calculated}$ = -0.1867	Accept

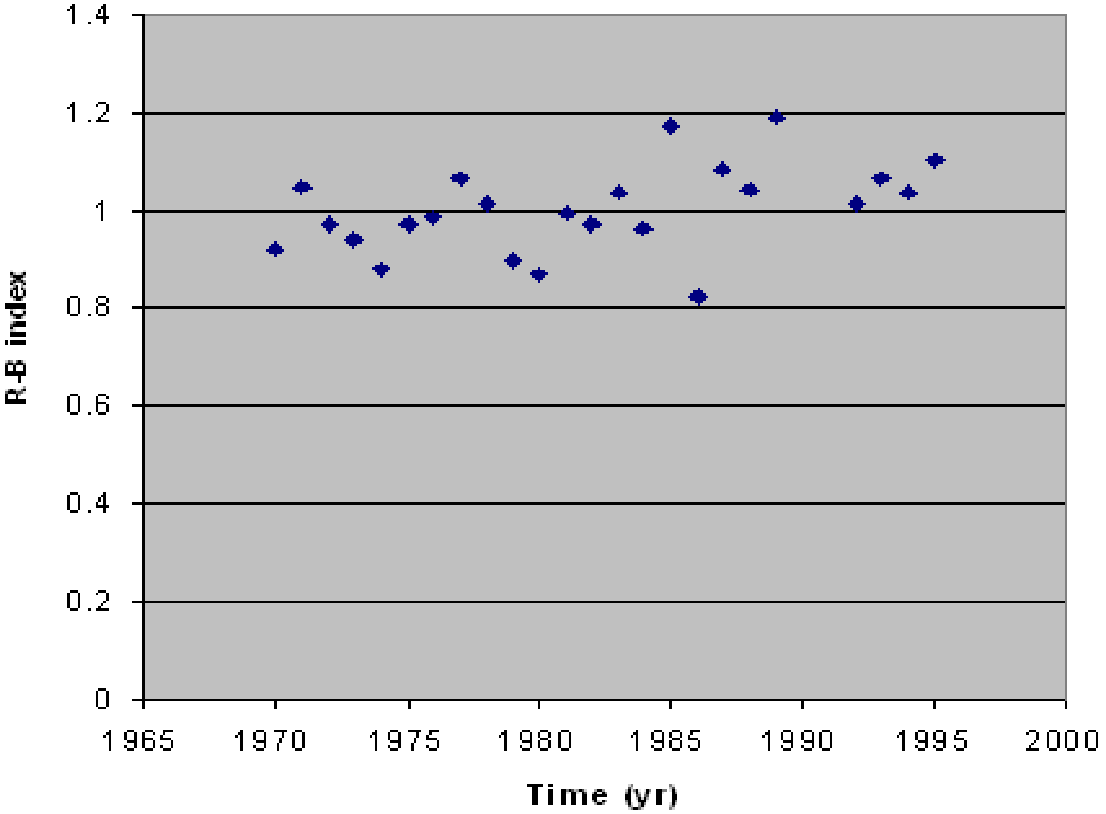

Figure 3.8: Trend analysis for White Marsh Run watershed annual period, USGS gage 01585100.

3.8 Calibrating a Predictive Equation for the R-B Index

3.8.1 Linear Model to Predict R-B Index

In this section, the goal is to develop a predictive equation for the R-B index as a function of imperviousness, precipitation factor, and watershed area. A simple linear model was evaluated for the relation between R-B index, imperviousness, precipitation factor, and the drainage area. The calibrated equation determined was:

$$R - B_{(Annual)} = 0.1361 + 0.0304 * (I) + 0.1622 * (P_f) - 0.00068 * (DA) \tag{3.3}$$

The R^2 value for the predicted annual R-B index was found to be 0.74 (S_e/S_y = 0.51). I represents the imperviousness in percent, P_f is the precipitation factor in inches. DA is the drainage area in square miles. The range of the predictor variables was $2.14 < I < 22.98, 0.37 < P_f < 2.26, 1.23 < DA < 132.56$

$$R - B_{(cool)} = 0.1501 + 0.0279 * (I) + 0.1642 * (P_f) - 0.00069 * (DA) \tag{3.4}$$

Equation 3.4 is calibrated for the cool periods of the year with a R^2 value of 0.72 ($S_e/S_y = 0.53$). The range of the predictor variables were $2.15 < I < 22.98, 0.30 < P_f < 1.41, 2.15, 1.23 < DA < 132.56$.

$$R - B_{(warm)} = 0.2 + 0.0362 * (I) + 0.0758 * (P_f) - 0.0011 * (DA) \tag{3.5}$$

Equation 3.5 is calibrated for the warm periods of the year with a R^2 value of 0.58 ($S_e/S_y = 0.65$). The range of the predictor variables for the above equation were $2.15 < I < 22.98, 0.001 < P_f < 4.70, 1.23 < DA < 132.56$.

3.8.2 Linear Model with Spatial Impervious Index to Predict R-B Index

In this section, our goal is to develop a predictive equation for the R-B index as a function of imperviousness, precipitation factor, watershed area, and spatial impervious index.

$$R - B_{(Annual)} = 0.07070 + (0.0304) * I + 0.1696 * P_f - (0.00043) * (DA) + 0.0446 * SII \tag{3.6}$$

Equation 3.6 is for the annual R-B index calculated, the R^2 value was found to be $0.75 (S_e/S_y = 0.50)$. I represents the imperviousness in percent, P_f represents the precipitation factor in inches. DA is the drainage area in square miles. SII is the spatial impervious index calculated using equation 3.1. The range of the predictor variables were $2.14 < I < 22.98, 0.37 < P_f < 2.26, 1.23 < DA < 132.56, 0.36 < SII < 2.53$

$$R - B_{(cool)} = 0.0942 + (0.0287) * (I) + (0.1682) * P_f - (0.000748) * (DA) + (0.0434) * (SII) \tag{3.7}$$

Equation 3.8 is calibrated for the cool periods of the year with a R^2 value of

Table 3.3: Comparison of R^2 and standard error for the predictive equations of the R-B index.

season	Model w/o SII		Model with SII	
	R^2	S_e/S_y	R^2	S_e/S_y
Annual	0.74	0.51	0.75	0.5
Cool	0.72	0.53	0.74	0.51
Warm	0.58	0.65	0.59	0.65

$0.74(S_e/S_y = 0.51)$. The range of the predictor variables for the above equation were $0.30 < P_f < 1.41, 2.15 < I < 22.98, 1.23 < DA < 132.56, 0.36 < SII < 2.53$.

$$R{-}B_{(warm)} = 0.16416 + (0.03665)*(I) + (0.07781)*P_f - (0.00113962)*(DA) + (0.02774)*(SII) \tag{3.8}$$

Equation 3.7 is calibrated for the warm periods of the year with a R^2 value of $0.59(S_e/S_y = 0.65)$. The range of the predictor variables for the above equation were $0.001 < P_f < 4.70, 2.14 < I < 22.98, 1.23 < DA < 132.56, 0.36 < SII < 2.53$.

Table 3.3 gives the comparison between the two models, that is the model for R-B index without the spatial impervious index and the model with the spatial impervious index. The linear model without spatial impervious index was chosen because of its simplicity and because there was not any meaningful difference in R^2 value (The difference is less than 3 percent).

3.9 Predicting the R-B Index Throughout Maryland

The impact of imperviousness on streams in Maryland is analyzed by applying the equations 3.3 to 3.5 for stream locations having drainage area greater than 0.5 sq. miles. Using GIS techniques, the methods and data described in Sections 3.4 and 3.5, spatially-varied imperviousness, precipitation factor, and drainage area were used to calculate the R-B index.

A sample application is shown in the following figures. A detailed analysis of these results is presented in the next chapter. Figure 3.8 shows the region in which Figures 3.9, 3.10, 3.11 are featured.

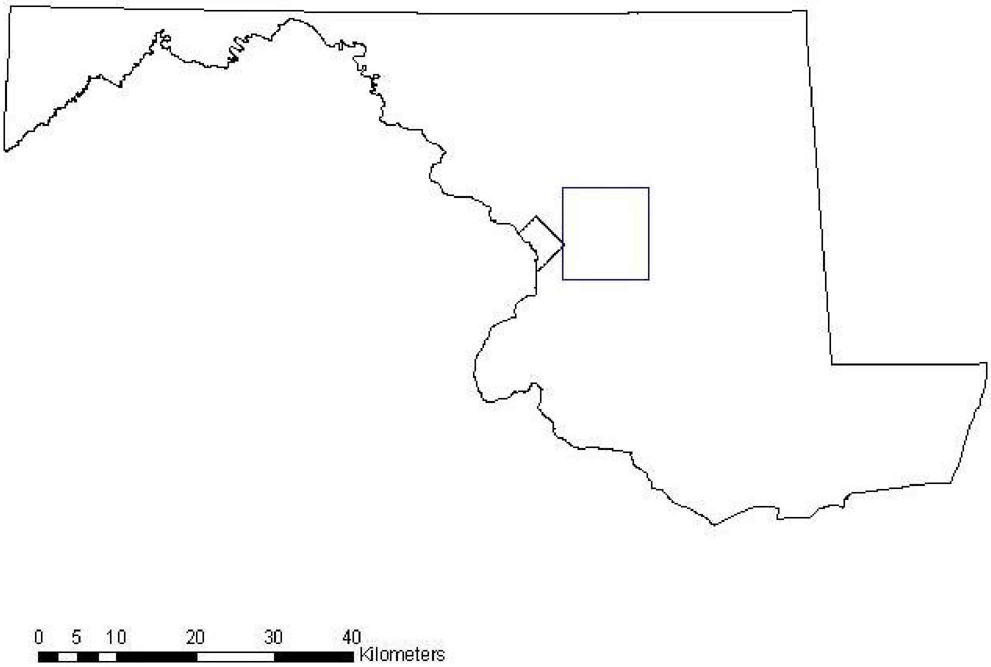

Figure 3.9: Sample results for part of Maryland, marked in blue box, and provided in this section.

Figure 3.10 shows the result that is obtained by applying equation 3.3 for the annual period for the year 2000, census-derived imperviousness, and weather conditions.

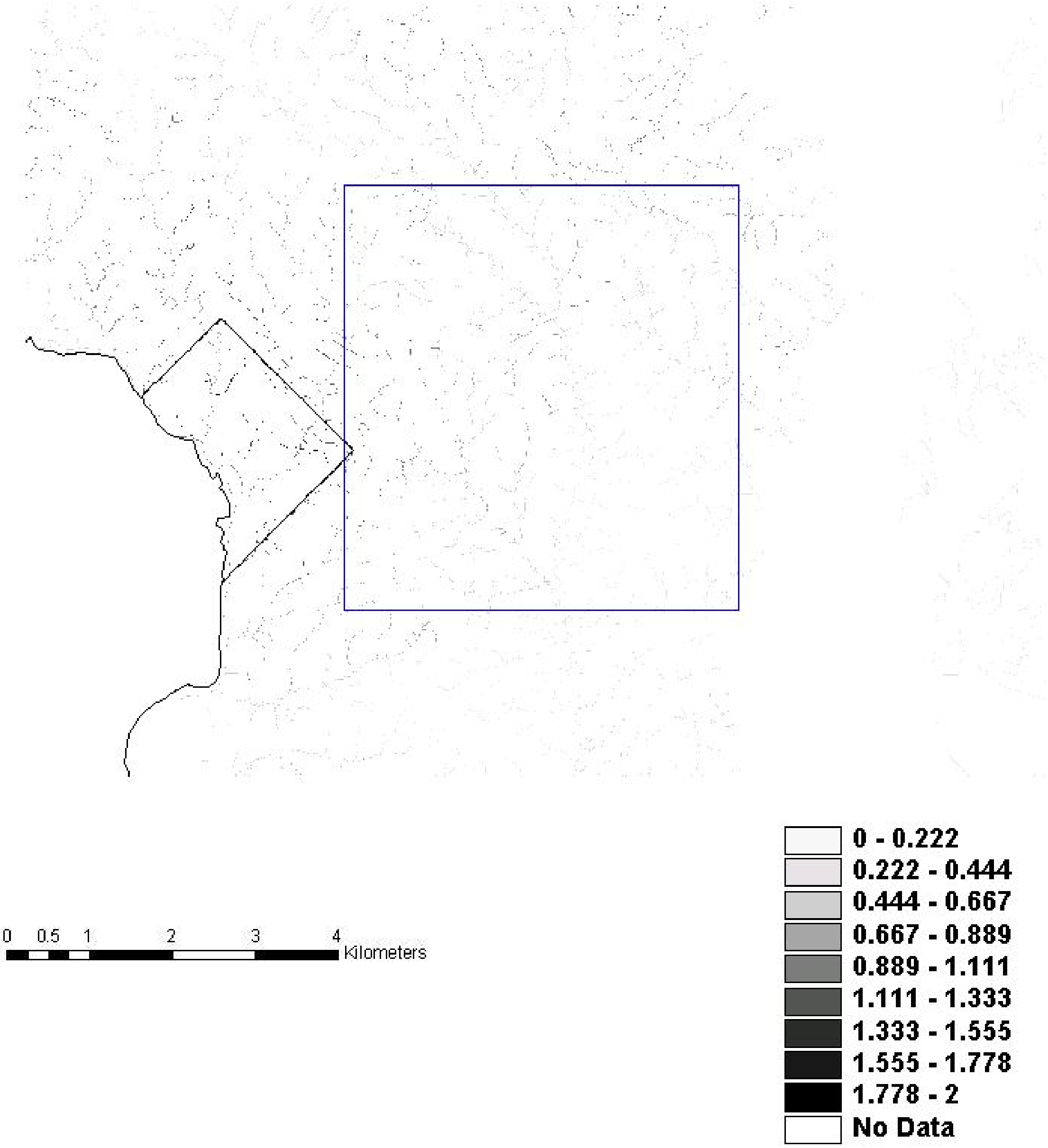

Figure 3.10: Spatial distribution of the R-B index along the stream network for the annual period in year 2000 for the box indicated in Figure 3.9.

Figure 3.11 shows the result that is obtained by applying equation 3.4 for the cool period for the year 2000, census-derived imperviousness, and weather conditions.

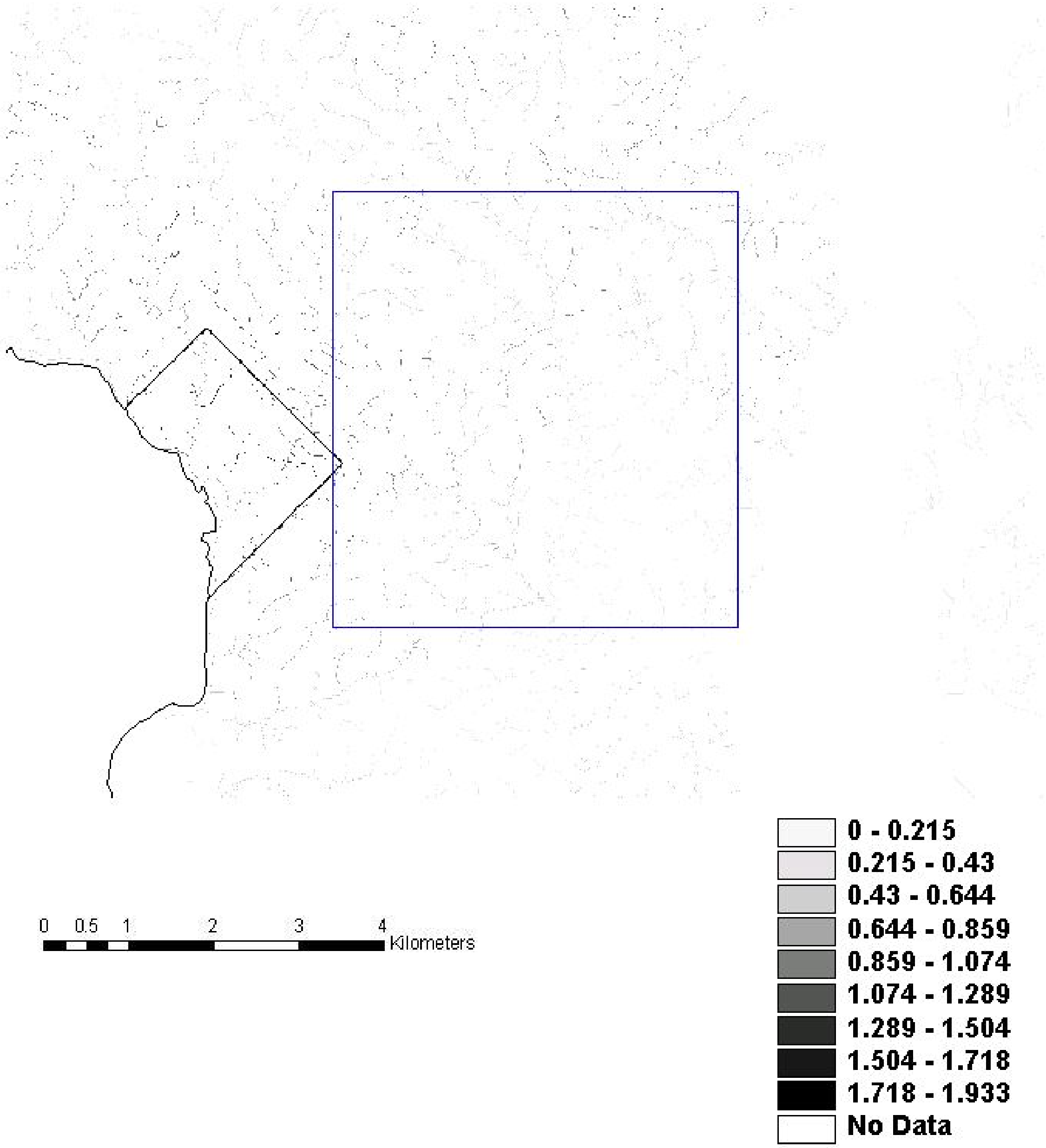

Figure 3.11: Spatial distribution of R-B index along the stream network for the cool period in year 2000 for the box indicated in Figure 3.9.

Figure 3.12 shows the result that is obtained by applying equation 3.5 for the warm period for the year 2000 census-derived imperviousness, and weather conditions.

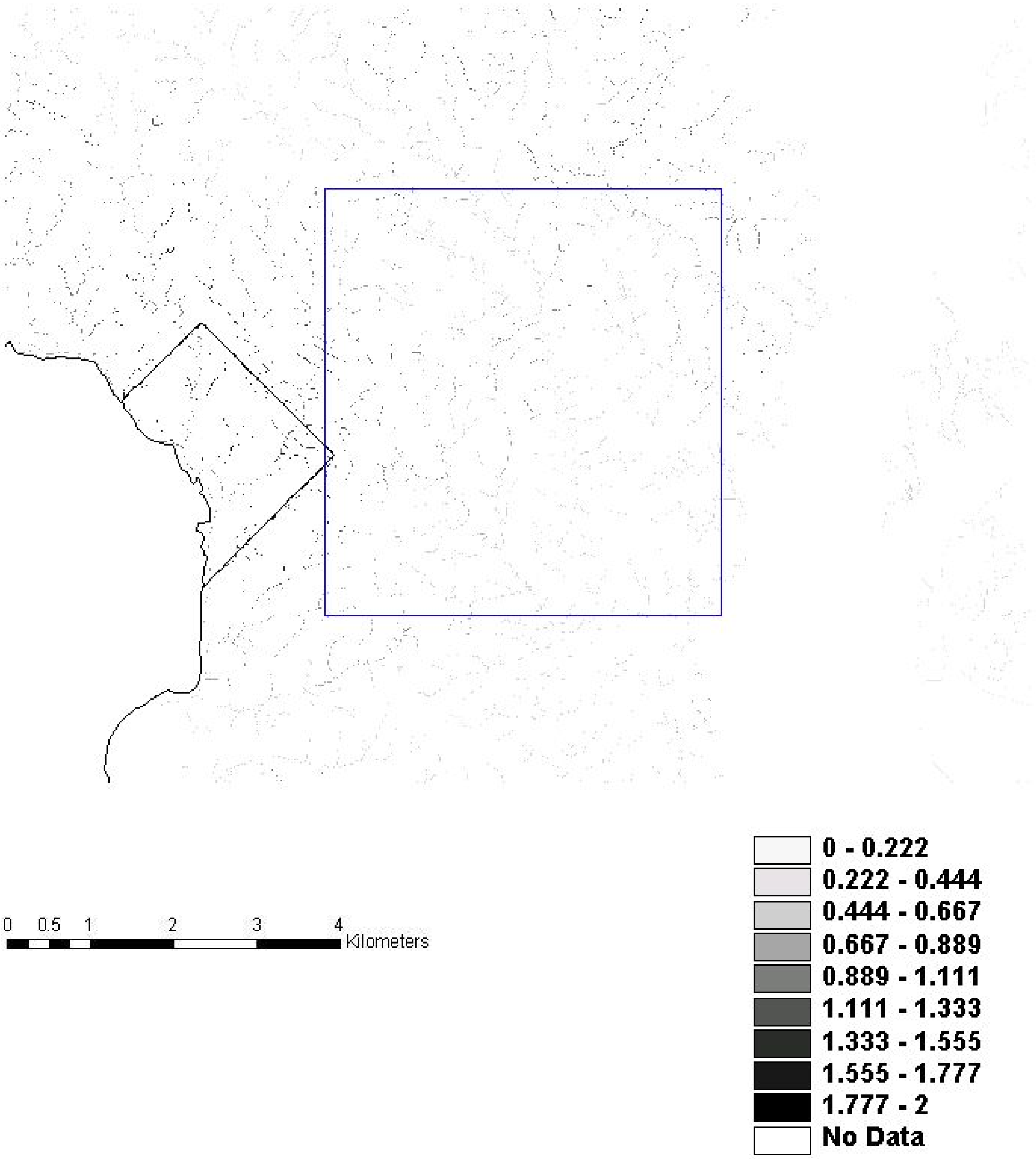

Figure 3.12: Spatial distribution of the R-B index along the stream network for the warm period in year 2000 for the box indicated in Figure 3.9.

Figures 3.10 to 3.12 show that the values of R-B indices are higher at the west end of the box, since this area is closest to Washington D.C. The value of imperviousness is higher near D.C area, causing the R-B index to be higher than in geographic locations more removed from large cities.

3.10 Prediction of Future R-B Index

In this section we apply equations 3.3 to 3.5 to a hypothetical future degree of imperviousness and future climate for the year 2050. The intent of these future predictions is to generate an approximate estimate of future streamflow variability. This estimate also provides some insight into the relative importance of future changes in both imperviousness and climate. The future population density was assumed to increase using the following equation:

$$PD_{future} = max(PD_{current} + 0.5(25 - PD_{current}), PD_{current}) \tag{3.9}$$

where PD is the population density measured in thousands per square mile. Imperviousness was then determined based on this future distribution of population density.

A value of 25 (thousands per sq. mile) was chosen for the threshold population density because this represents a general upper-bound to population density in the majority of census tracts analyzed in the development of equation 3.1.

The precipitation factor for future conditions was predicted using a GCM model. Climate data for the year 2050 were obtained for Rockville, MD which lies in Middle Potomac-Catoctin watershed. The Hadley GCM (Johns et al. (1997) B2 scenario data downscaled to the Rockville Co-Op gage (ID: 187705) using the methods of Pandey et al. (2000). The B2 scenario is a more moderate potential future condition in terms of population growth, economic development, and technological gains relative to the A1, A2, and B1 scenario families. The precipitation factor for the annual period of 2050 was 1.71 inches, cool period 1.04 inches, Warm period 2.45 inches while the average precipitation factor for the annual period was 0.96 inches, cool period was 0.80 inches and for warm period was 1.76 inches for the three decades from 1970 to 2000. The result of the increase in imperviousness and the climate change is shown in the Figures 3.13 and 3.14. The impacts of the increasing imperviousness are discussed detail in the next chapter, but are briefly discussed here.

The values of R-B index for the impervious and weather conditions for the year 2000 vary from 0.35 to 1.39, while for the predicted future conditions for the year 2050 vary from 1.295 to 1.65.

The effect of change in imperviousness is more profound than the change in precipitation factor on R-B index. The average value of imperviousness and precipitation factor for the years 1970-2000 were 9.14% and 0.97 inches respectively. While the average imperviousness and the precipitation factor for the year 2050 were 33.31% and 1.72 inches respectively. The average R-B index for the changing imperviousness condition holding precipitation factor constant at year 2000 conditions was 1.20 while that for changing precipitation factor holding imperviousness constant at year 2000 was 0.63. This shows that the changing imperviousness has a greater effect on the R-B index than the changing precipitation factor. A more detailed discussion is presented in Chapter 4.

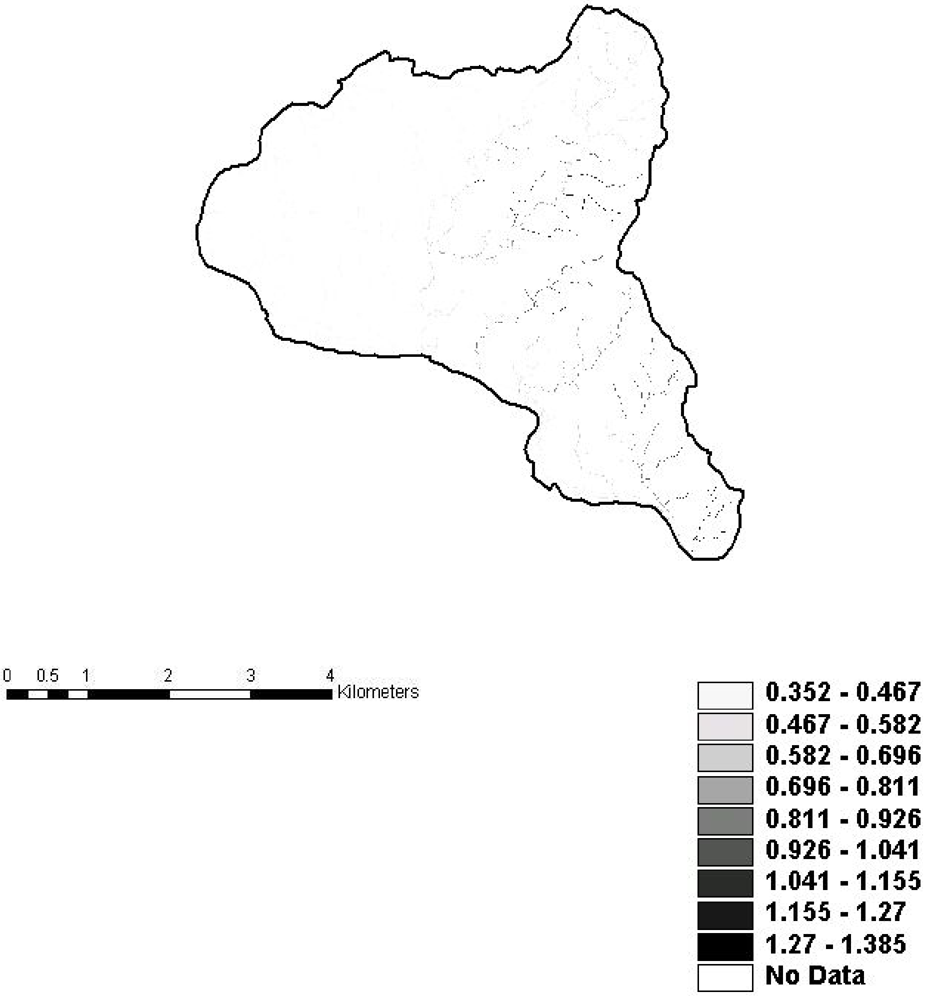

Figure 3.13: Spatial distribution of R-B index along the stream network for the annual period 2000, Middle Potomac-Catoctin.

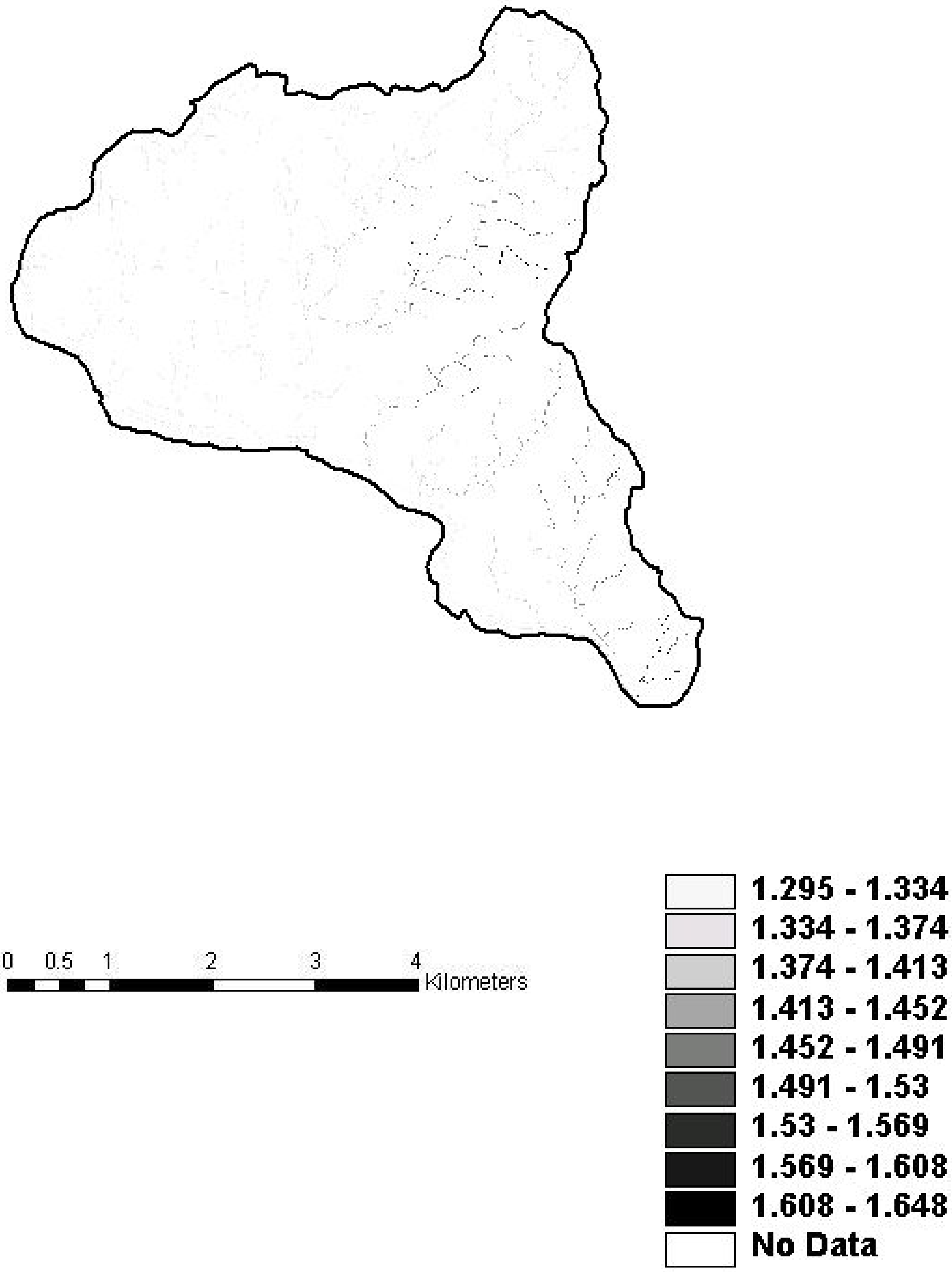

Figure 3.14: Spatial distribution of R-B index along the stream network for the annual period 2050, Middle Potomac-Catoctin.

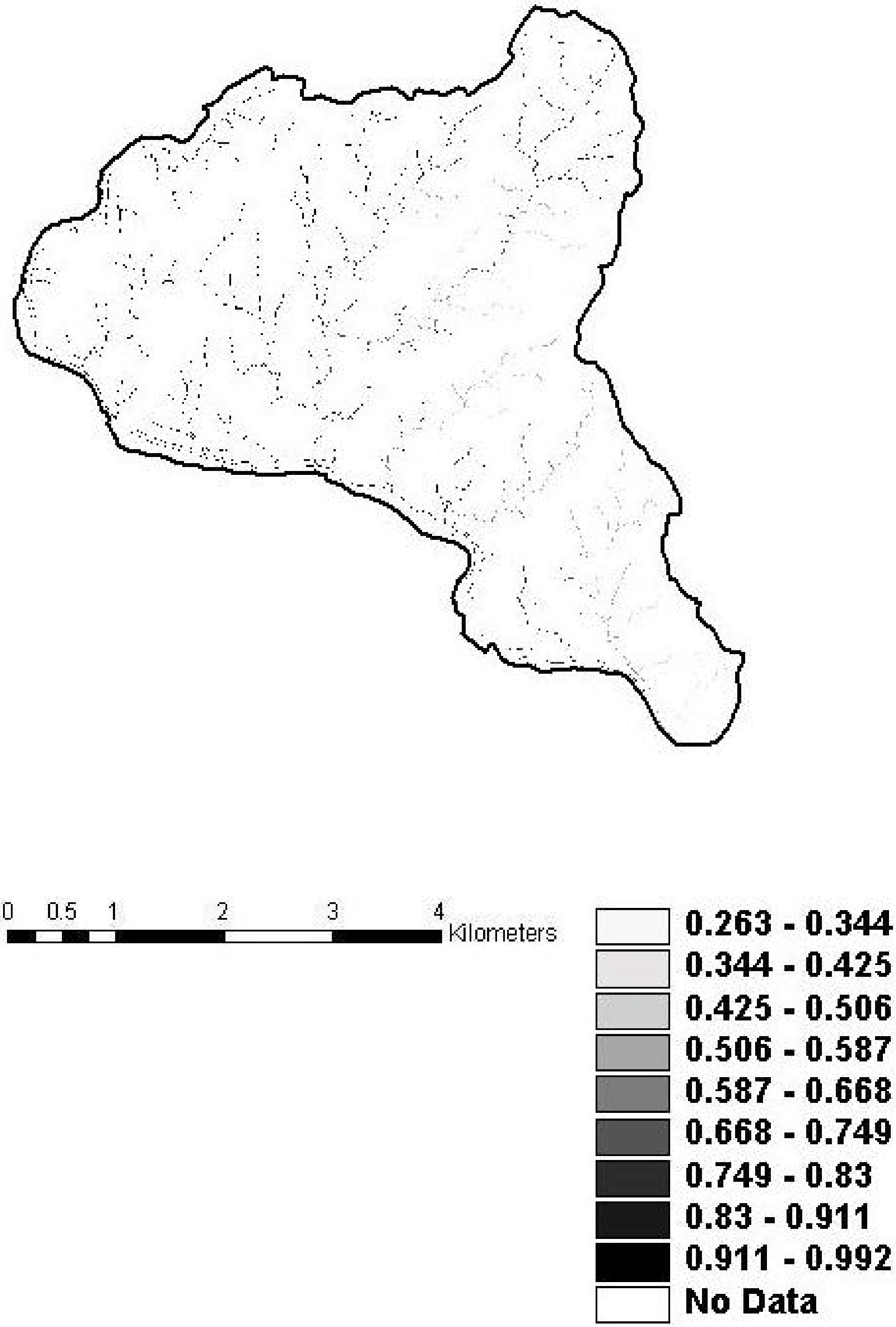

Figure 3.15: Difference in spatial distribution of R-B index along the streams for the annual period between the years 2050 and 2000, Middle Potomac-Catoctin.

The R-B index has increased for the year 2050 from the year 2000 and also the variability in R-B index has decreased. This is due to the increased imperviousness and the climate change. Comparing figures 3.13 and 3.14 shows that the values of R-B index have increased in the year 2050 compared to the year 2050. Chapter 4 gives a detailed analyses of the R-B indices for these two years.

Figure 3.15 shows the difference between the spatial distribution of R-B index between the annual periods for year 2050 and 2000. This figure shows that the R-B index values have increased for the 2050 when compared with the R-B values for the year 2000. The differences are found in the areas where imperviousness increased for the year 2050 relative to year 2000.

There are values of both future imperviousness and drainage area that exceed the range of these predictor variables while applying the regression equations for the future scenario for the streams in Maryland. However to calculate a complete assessment of Maryland, the regression equations were applied to all locations where the predictor variables were out of observed bounds. The values that were out of bounds are shown in italics in Table 3.3.

Table 3.4: Range of the predictor variables(present) used in this study.

8-digit watershed name	Imperviousness (%) (High/low)	Drainage Area (mi^2) (High/low)	Precipitation Factor(in)		
			Annual (High/low)	Warm (High/low)	Cool(High/low)
Blackwater	*29.296/0.52*	117.2/*1.0*	1.322/0.91	2.916/1.52	1.034/0.732
Broadkill-Smyrna	*23.831/0.863*	168.91/*1.0*	1.019/0.918	2.265/1.538	0.864/0.734
Brandywine	*78.803/0.357*	152.99/*1.0*	0.845/0.95	3.301/1.094	0.857/0.775
Cacapon	11.873/*1.581*	*178.577/1.00*	0.799/0.699	1.766/1.325	0.739/0.628
Chester	21.186/*1.315*	*309.86/1.00*	1.018/.814	3.301/1.095	0.857/0.743
Choptank	22.877/*0.775*	*915.97/1.00*	1.352/0.91	2.916/1.444	1.049/0.723
Conococheague	*46.466/1.912*	*409.27/1.00*	2.287/0.711	1.852/1.079	2.957/0.642
Lower Potomac	*31.571/1.573*	*751.33/1.00*	1.352/0.873	3.28/1.239	1.049/0.721
Middle Potomac-Anacostia	*88.434/0.684*	*392.58/1.00*	0.992/0.853	3.464/1.201	0.857/0.657
Middle Potomac-Catoctin	*90.252/0.381*	*360.16/1.00*	1.092/0.892	3.644/1.181	0.967/0.757
Monocacy	*46.366*/2.733	*958.73/1.00*	2.287/0.756	3.301/1.079	*2.957*/0.7

8-digit watershed name	Imperviousness (%) (High/low)	Drainage Area (mi^2) (High/low)	Precipitation Factor(in)		
			Annual (High/low)	Warm (High/low)	Cool(High/low)
Nanticoke	11.923/*0.775*	*793.382/1.00*	1.085/0.91	2.904/1.52	0.9/0.723
North Branch Potomac	*32.839/1.581*	*251.42/1.00*	0.799/0.553	1.766/1.043	0.739/0.471
Patapsco	*78.834/0.782*	*505.834/1.00*	2.287/0.756	3.464/1.079	2.957/0.657
Patuxent	*54.348/2.12*	*910.191/1.00*	1.352/0.756	3.464/1.079	1.308/0.657
Pocomoke	10.26/*1.019*	*420.55/1.00*	1.087/0.91	2.907/1.52	0.911/0.723
Severn	*33.511/1.769*	64.841/*1.00*	1.352/0.873	3.464/1.199	1.049/0.657
Susquehanna	18.34/3.426	*264.298/1.00*	0.989/.814	3.301/1.094	0.847/0.748
Youghiogheny	3.208/*1.581*	*301.766/1.00*	0.71/0.553	1.34/1.043	0.661/0.471

3.11 Summary

Equations for the R-B index for the various periods of the year were developed and calibrated as a function of imperviousness, precipitation factor and drainage area. The trend analyses performed with the R-B index showed that the trend was significant in regions near major cities like Washington D.C., and Baltimore. A threshold of 5% imperviousness was found, that is when the change in imperviousness is greater than 5%, a significant trend was found. A spatial impervious index was also developed to study the impact of the spatial distribution of imperviousness on the R-B index. However the model with the spatial impervious index did not meaningfully improve upon the model without the spatial impervious index, hence the simple model was selected. A population density model was developed to predict the population density for future conditions. The impacts of imperviousness, precipitation factor were also estimated for the future conditions with the help of the population density model and the GCM model, respectively. Chapter 4 will present the results of the R-B index equation applied throughout Maryland.

Chapter 4

Results and Discussion

Overview

This chapter contains six sections that present results and interpretations of the R-B index model developed and applied in this study. The first section discusses the goodness of fit statistics for the equations developed for the model. The second section deals with calculation of the R-B index in terms of stream length for the various 8-digit watersheds located across the state of Maryland. The third section compares the R-B index of the 8-digit watersheds for various years in order to study the effect of development in these watersheds. The fourth section analyzes the impacts of the imperviousness and the precipitation factor on the R-B index under different scenarios. In the fifth section R-B indices are compared for various 8-digit watersheds across Maryland. The final section shows the streams that exceed a threshold value of the R-B index, indicating a level of flashiness that is ecologically unhealthy.

4.1 Regression equations for predicting the R-B index

Regression equations were developed for various models and a simple linear model was selected as providing the best compromise between goodness of fit and model rationality. The equation for the annual R-B index is:

$$R - B_{(Annual)} = 0.1361 + 0.1622 * (P_f) + 0.0304 * (I) - 0.00068 * (DA) \qquad (4.1)$$

The above equation was developed for the Annual period in section 3.8.1, where P_f is the precipitation factor measured in inches, I is the imperviousness measured in percent, and DA is the drainage area measured in square miles. The R^2 value for this equation is 0.74 for a sample size of 668. The value of S_e/S_y was found to be 0.51. The largest value of the absolute error was found to be 0.49. Overall the model is unbiased as the model is linear. A plot of observed versus the predicted values of R-B index is shown below. Figure 4.1 shows relatively good and unbiased agreement between observed and predicted values for the annual period except at very high observed R-B index where the model tends to underpredict systematically. These underpredictions correspond to exclusively three watersheds (USGS watersheds: 01585100, 01585300 and 01645200) watersheds with high imperviousness (I between 13.69% and 22.98%) and small drainage areas (DA between 3.71 mi^2 and 7.53 mi^2).

The equation for the cool period R-B index is:

$$R - B_{(Cool)} = 0.1501 + 0.1642 * (P_f) + 0.0279 * (I) - 0.00069 * (DA) \qquad (4.2)$$

The R^2 value for this equation is 0.72. The value of Se/Sy is 0.53. The lower the value of Se/Sy better the model. The largest value of the absolute error was found to be 0.42. A plot of observed versus the predicted values of R-B index is shown below. Figure 4.2 shows relatively good and unbiased agreement between observed and predicted values for the cool period except at very high observed R-B

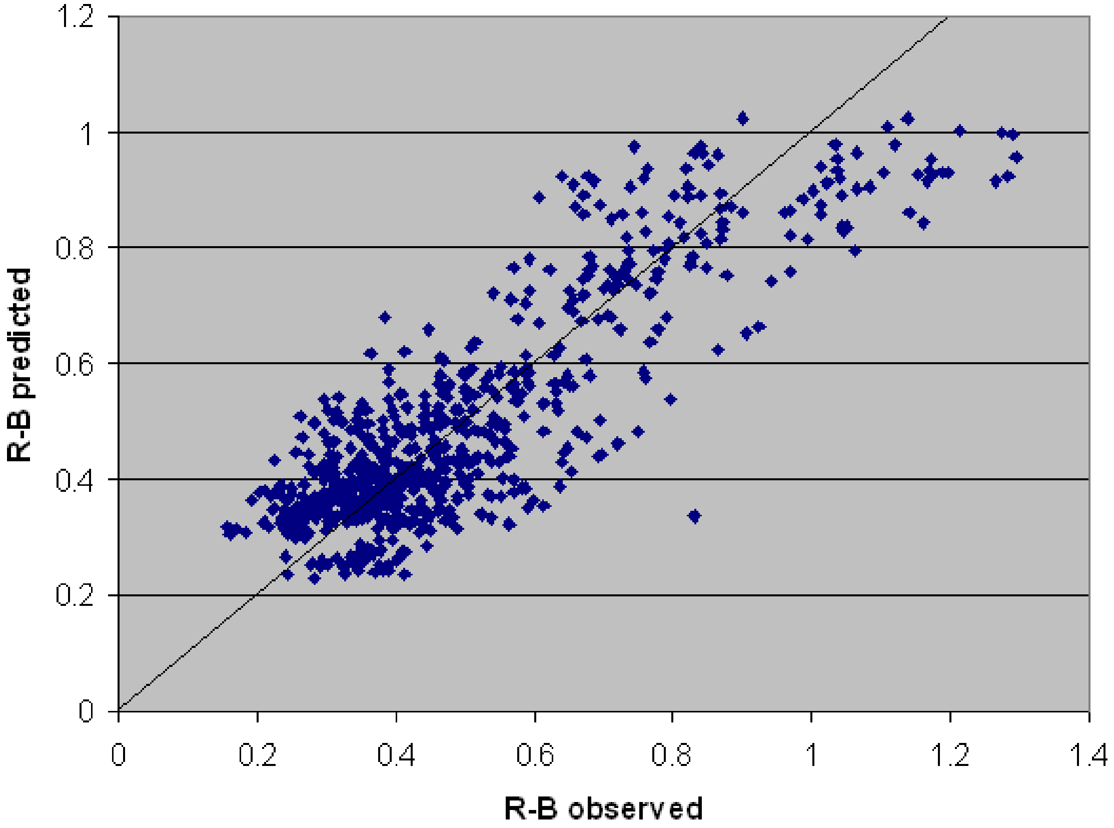

Figure 4.1: Predicted versus observed values of R-B index for the annual period

index where the model tends to underpredict systematically. These underpredictions correspond to exclusively three watersheds (USGS watersheds: 01585100, 01585300 and 01645200) watersheds with high imperviousness (I between 13.69% and 22.98%) and small drainage areas (DA between 3.71 mi^2 and 7.53 mi^2).

The equation for the warm period R-B index is:

$$R - B_{(Warm)} = 0.2 + 0.0758 * (P_f) + 0.0362 * (I) - 0.0011 * (DA) \tag{4.3}$$

The R^2 value for this equation is 0.58. The value of Se/Sy is 0.65. The largest value of the absolute error was found to be 0.83. A plot of observed versus the predicted values of R-B index is shown below.

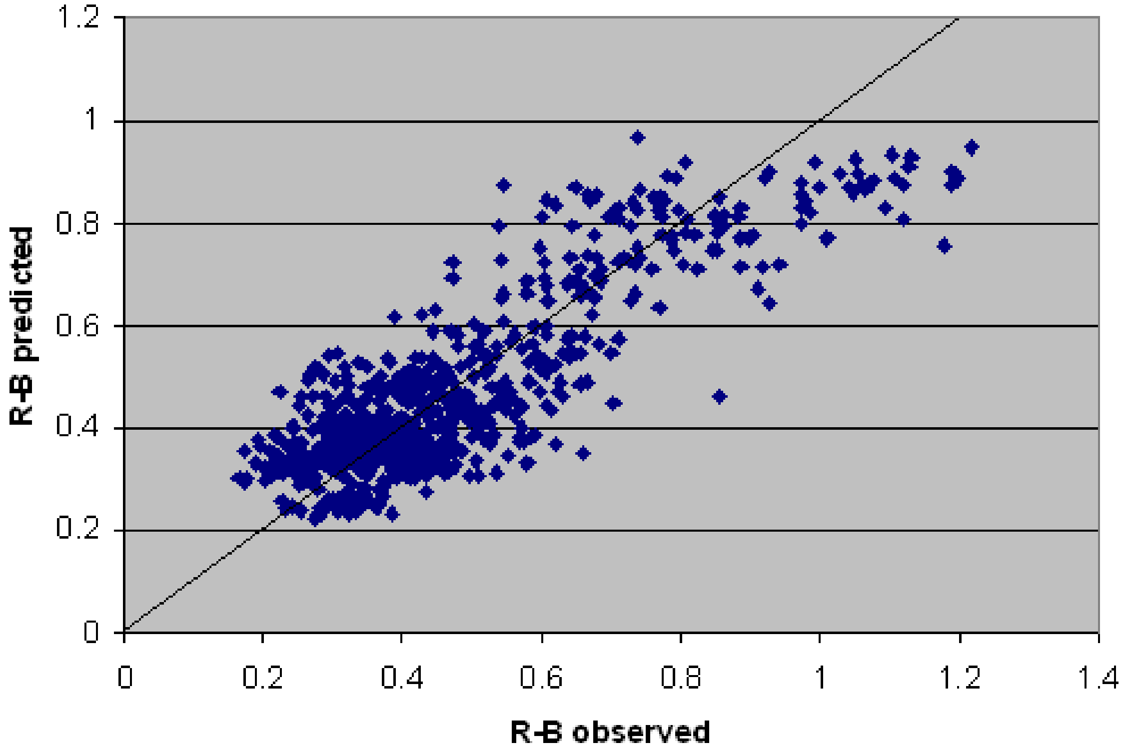

Figure 4.2: Predicted versus observed values of R-B index for the cool period.

The calibrated models for the annual and cool periods have a good R^2 value greater than 0.7. The R^2 value for the warm period is comparatively smaller due to the erratic rainfall pattern during the summer. The coefficients of the equations are rational, R-B index increases with the precipitation factor and imperviousness, and decreases with increasing drainage area of the watershed.

4.2 Value of R-B index in 8-digit Maryland Watersheds

The primary boundaries for analysis were defined by the large watersheds identified as the 8-digit Hydrologic Unit Codes (HUCs). Overall 19, 8-digit HUCs cover the state of Maryland. The 8-digit HUCs across Maryland are shown in Figure

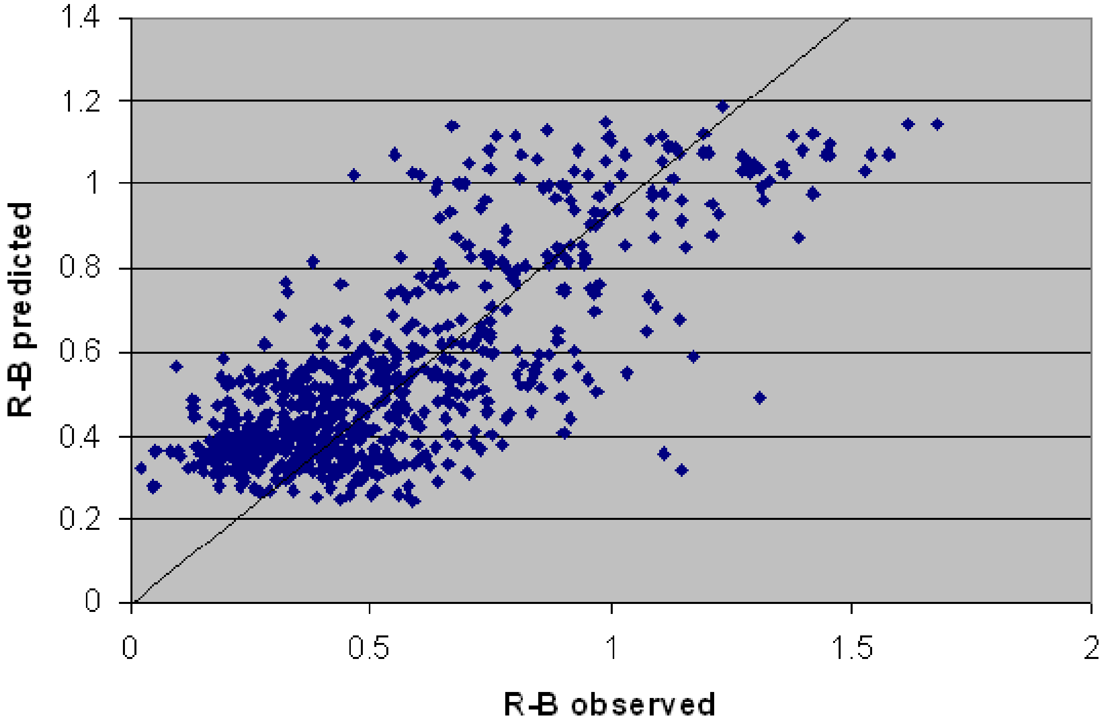

Figure 4.3: Predicted versus observed values of R-B index for the warm period

4.4. The regression equations were applied to all streams in Maryland using GIS. An imperviousness layer was created using the census tract population density data for the years 1970, 1980, 1990 and 2000. An average precipitation factor layer was also created for the annual, cool, and warm periods of the year.

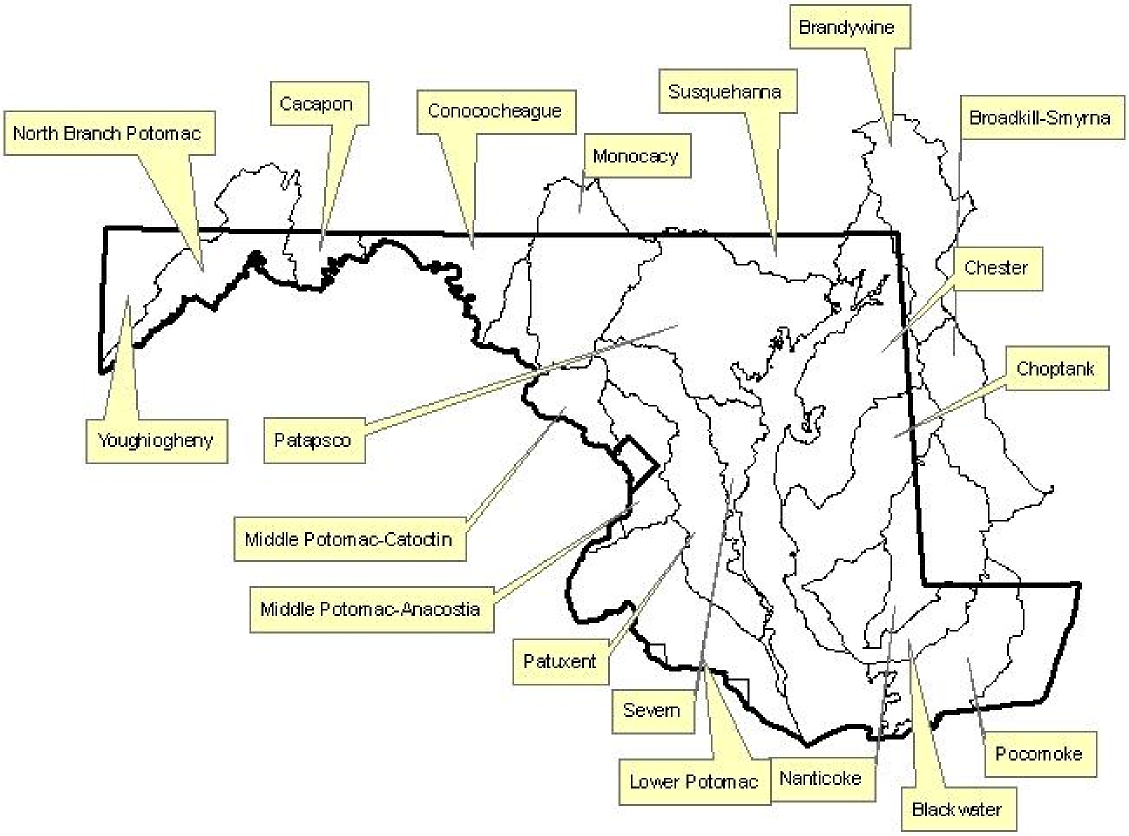

Figure 4.4: Figure showing the spatial distribution of Maryland's 8-digit watersheds.

4.2.1 Script for calculating R-B index on a watershed basis

The first script shown in Appendix C is used for calculating the R-B index, imperviousness and the drainage area on a watershed basis. The script was written in ArcView 3.2 using the Avenue scripting language. The inputs for the script are the flow direction grid, imperviousness grid and precipitation grid. The output from the script is the R-B index grid. This output is further used as the input for the script to calculate the distribution of stream lengths as a function of R-B index. This output is written to a text file for further analysis.

4.2.2 Script for calculating the stream length

The second script shown in Appendix C is used for calculating the R-B index in the streams. Input for this script is the R-B index and the drainage area grid resulting from the script in section 4.2.1 and the flow direction grid which was used as the input for the previous script. All streams draining an area greater than 0.3861 square miles (1 square kilometer) are determined. These are the streams for which R-B index estimates will be determined. The R-B index is calculated at all stream locations and then grouped into intervals of the R-B index between 0 and 2 in increments of 0.1. The total length of streams in each increment is written to a text file.

4.3 Quantifying the effects of Imperviousness and Climate on the R-B index

The results are analyzed to quantify the impacts of imperviousness and climate on the flow variability in Maryland streams. The scripts described in the previous sections were applied to the 8-digit watersheds for the years 1970, 1980, 1990 and 2000 for the annual, cool, and warm periods. The results are presented graphically in this section.

Table 4.1 presents the mean and range of imperviousness for the 8-digit watersheds and Table 4.2 presents the mean and the range of precipitation factors.

Table 4.1: Mean imperviousness and range of imperviousness for 8-digit watersheds.

Watershed	Year	Mean Imp. (Percent)	Range Imp. (Percent) (max/min)
Blackwater	1970	2.55	27.32/0.81
(02060007)	1980	2.67	26.87/0.81
	1990	2.82	26.87/0.81
	2000	2.96	29.30 / 0.78
Brandywine	1970	7.67	57.82/0.02
(02040205)	1980	8.31	59.56/0.02
	1990	8.97	59.56/0.02
	2000	9.88	60.82/0.02
Broadkill-Smyrna	1970	3.91	23.41/0.55
(02040207)	1980	3.97	23.41/0.55
	1990	3.97	23.41/0.55
	2000	4.38	23.83/0.86
Cacapon	1970	1.57	2.98/1.43
(02070003)	1980	1.57	2.98/1.43
	1990	1.65	3.01/1.51
	2000	1.72	3.02/1.58
Chester	1970	3.02	21.17/1.30
(02060002)	1980	3.15	22.46/1.30
	1990	3.25	20.96/1.30
	2000	3.57	21.19/3.19
Choptank	1970	2.71	24.83/0.12
(02060005)	1980	2.71	24.83/0.12
	1990	2.74	24.83/0.12
	2000	2.89	22.87/0.78
Conococheague	1970	4.65	36.97/2.57
(02070004)	1980	4.98	36.33/2.56
	1990	5.12	54.07/2.67
	2000	5.36	46.47/1.91
Lower Potomac	1970	3.54	11.57/0.39
(02070011)	1980	3.54	11.57/0.39
	1990	3.53	29.39/0.39
	2000	3.78	31.57/1.57
Middle Potomac-Anacostia	1970	19.05	85.64/2.52
(02070010)	1980	19.29	85.64/2.52
	1990	19.88	82.45/2.52
	2000	20.27	89.57/2.52
Middle Potomac-Catoctin	1970	6.53	45.43/1.85
(02070008)	1980	8.41	54.78/1.93
	1990	10.22	53.29/2.65
	2000	11.38	50.32/2.75

Watershed	Year	Mean Imp. (%)	Range Imp. (%) (max/min)
Monocacy	1970	4.17	46.37/1.85
(02070009)	1980	4.22	54.15/2.29
	1990	4.70	47.48/2.69
	2000	5.23	46.37/2.64
Nanticoke	1970	3.14	10.22/0.82
(02060008)	1980	3.18	11.59/0.91
	1990	3.26	11.63/0.81
	2000	3.48	11.92/0.78
North Branch Potomac	1970	3.09	38.00/4.18
(02070002)	1980	3.09	38.01/4.18
	1990	3.11	38.01/1.51
	2000	3.15	31.05/1.58
Patapsco	1970	9.66	85.74/2.34
(02070003)	1980	10.24	87.39/2.34
	1990	10.56	88.11/2.34
	2000	11.05	78.83/2.34
Patuxent	1970	5.50	45.68/2.12
(02060006)	1980	6.39	46.90/2.12
	1990	7.07	49.29/2.12
	2000	8.07	54.35/2.12
Pocomoke	1970	2.35	24.83/1.04
(02060009)	1980	2.45	24.83/1.04
	1990	2.49	22.83/1.04
	2000	2.68	10.26/1.02
Severn	1970	7.03	43.99/1.72
(02060004)	1980	7.18	40.32/3.17
	1990	7.90	33.91/1.72
	2000	8.63	33.51/1.77
Susquehanna	1970	4.22	28.89/2.81
(02050306)	1980	4.57	27.23/3.49
	1990	4.82	19.39/3.85
	2000	5.23	18.34/3.43
Youghiogheny	1970	2.48	3.15/1.45
(05020006)	1980	2.49	3.15/1.55
	1990	2.49	3.15/1.55
	2000	2.58	2.31/1.58

Table 4.2: Mean precipitation factor and range of precipitation factor for 8-digit watersheds.

Watershed	Period of Precip.	Mean Precip. Factor(inches)	Range Precip. Factor (inches)(max/min)
Blackwater	Annual	1.00	1.32/0.91
(02060007)	Cool	0.84	1.03/0.72
	Warm	2.02	2.92/1.52
Brandywine	Annual	0.85	1.53/0.77
(02040205)	Cool	0.78	0.86/0.77
	Warm	1.57	3.30/1.09
Broadkill- Smyrna	Annual	0.94	1.02/0.91
(02040207)	Cool	0.78	0.86/0.74
	Warm	1.89	2.26/1.54
Cacapon	Annual	0.75	0.80/0.70
(02070003)	Cool	0.68	0.74/0.63
	Warm	1.55	1.77/1.33
Chester	Annual	0.94	0.98/0.92
(02060002)	Cool	0.79	0.83/0.74
	Warm	1.82	1.97/1.54
Choptank	Annual	0.94	1.01/0.92
(02060005)	Cool	0.81	0.87/0.74
	Warm	1.94	2.92/1.61
Conococheague	Annual	0.85	1.00/0.80
(02070004)	Cool	0.74	0.93/0.70
	Warm	1.44	1.77/1.23
Lower Potomac	Annual	1.12	1.35/0.89
(02070011)	Cool	0.79	1.05/0.72
	Warm	1.83	2.51/1.49
Middle Potomac-Anacostia	Annual	0.91	0.99/0.85
(02070010)	Cool	0.75	0.83/0.66
	Warm	1.52	1.81/1.24
Middle Potomac-Catoctin	Annual	0.90	0.98/0.87
(02070008)	Cool	0.77	0.81/0.74
	Warm	1.80	3.46/1.28
Monocacy	Annual	0.94	2.29/0.76
(02070009)	Cool	0.88	2.96/0.72
	Warm	1.48	1.85/1.08
Nanticoke	Annual	1.01	1.09/0.92
(02060008)	Cool	0.82	0.89/0.74
	Warm	1.73	2.05/1.69
North Branch Potomac	Annual	0.67	0.71/0.58
(02070002)	Cool	0.61	0.66/0.50

Watershed	Period of Precip.	Mean Precip. Factor (inches)	Range Precip. Factor (inches)(max/min)
	Warm	1.26	1.34/1.11
Patapsco (02070003)	Annual	0.94	0.99/0.81
	Cool	0.81	0.86/0.74
	Warm	1.74	3.30/1.09
Patuxent (02060006)	Annual	0.98	1.35/0.88
	Cool	0.81	1.05/0.72
	Warm	1.85	2.92/1.20
Pocomoke (02060009)	Annual	1.02	1.09/0.91
	Cool	0.85	0.89/0.72
	Warm	2.12	2.73/1.52
Severn (02060004)	Annual	0.99	1.35/0.90
	Cool	0.83	1.05/0.79
	Warm	1.93	2.92/1.3
Susquehanna (02050306)	Annual	0.97	0.97/0.97
	Cool	0.78	0.80/0.78
	Warm	1.91	3.30/1.54
Youghiogheny (05020006)	Annual	0.58	0.71/0.55
	Cool	0.50	0.66/0.47
	Warm	1.09	1.26/1.04

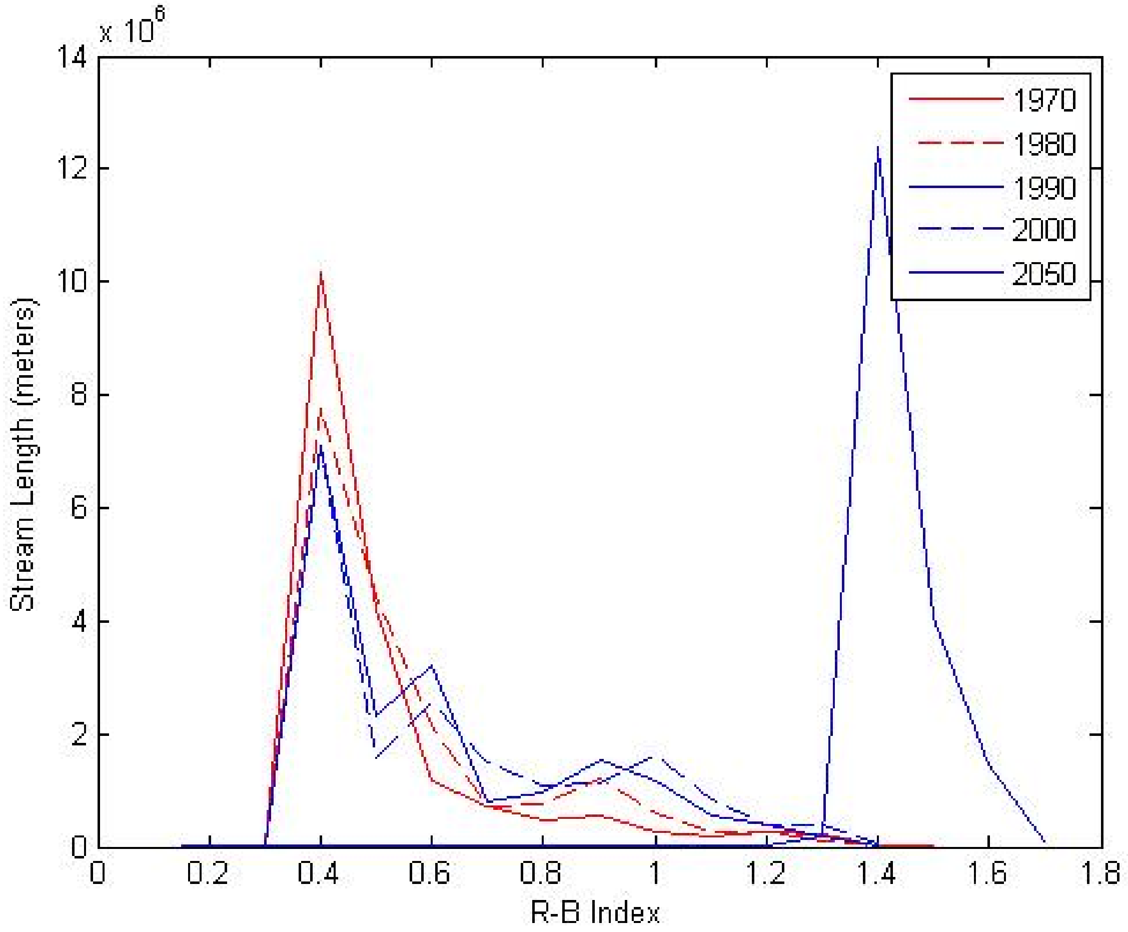

Figure 4.5: Stream length versus R-B index (Annual), for the years 1970, 1980, 1990, 2000 and 2050 for the Middle Potomac-Catoctin watershed

Figure 4.5 shows stream length graphed against the R-B index for the years 1970, 1980, 1990, 2000 and 2050. It can be seen that the modal value of the R-B index is 0.4 during the year 1970 while the R-B index value increases for the streams in the subsequent time periods. This is caused by increasing imperviousness with time. The effect of flow variability is pronounced in the year 2050 as 12,000 kilometers of stream have R-B equal to 1.4, which characterizes high flow variability and is harmful to stream ecology. Imperviousness predicted for future conditions is a projected value and it is, likely that the model given in Chapter 3 is overpredicting imperviousness in 2050.

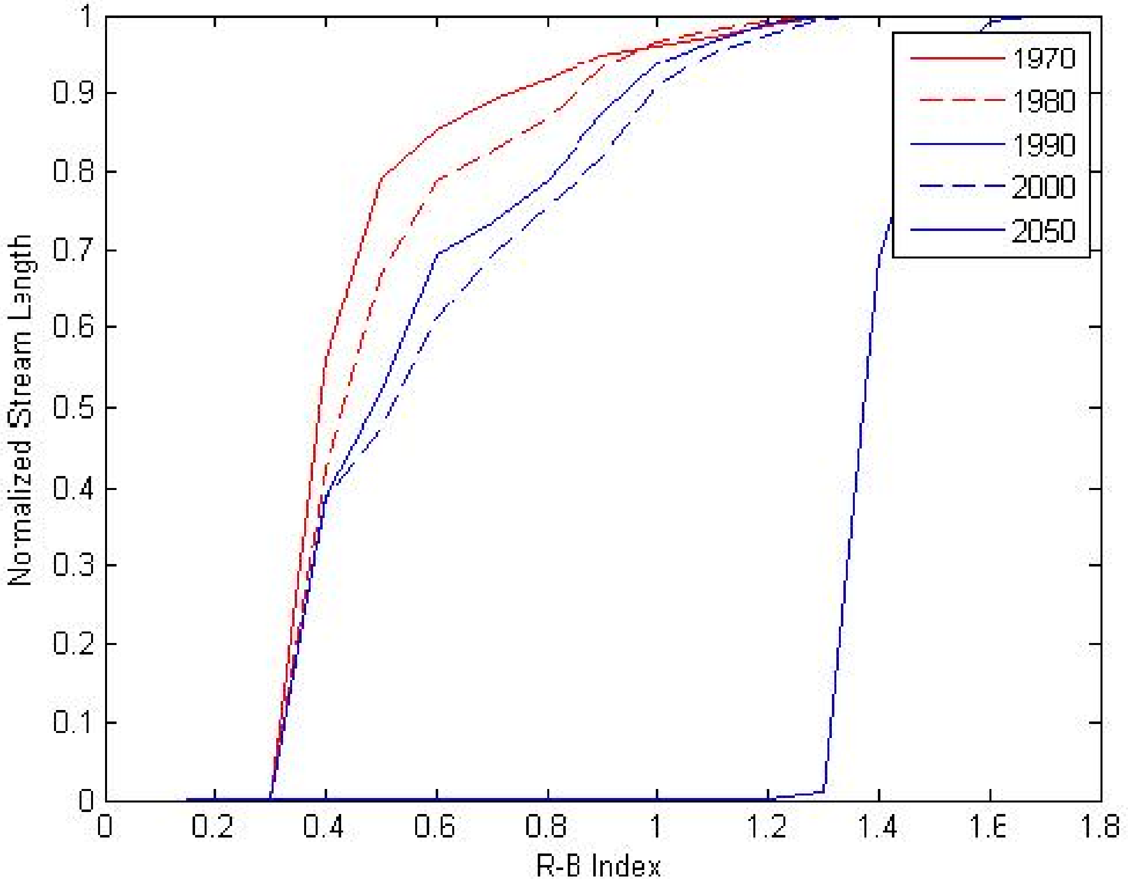

Figure 4.6: Normalized stream length versus R-B index (Annual), for the years 1970, 1980, 1990, 2000 and 2050 for the Middle Potomac-Catoctin watershed

Another perspective on R-B distribution is provided in Figure 4.6 which shows the normalized stream length versus the R-B index.

Box plots are plotted for year versus the R-B index. The box represents the spread which is the 25th to 75th percentile of the data. The '+' represents the outliers that is, the values that are outside the whiskers which represent the most extreme data values within one-half times the interquartile range beyond the box.

The line within the box represents the median of the data.

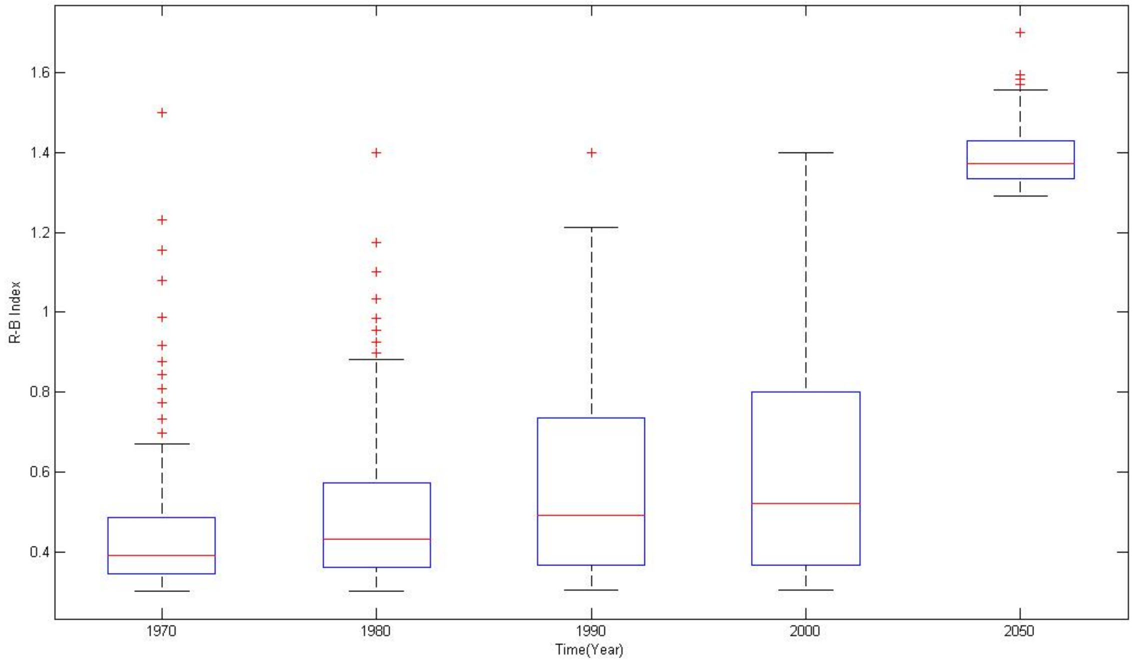

Figure 4.7: The R-B index(Annual) versus time (year), for the years 1970, 1980, 1990, 2000 and 2050 for the Middle Potomac-Catoctin watershed

The box plot shows the impact of imperviousness on the stream flow variability. The median value for the year 1970 was 0.39, for 1980 it was 0.43, for 1990 it was 0.49, for the year 2000 it was 0.52 and for the year 2050 it is expected to be 1.37. There is an increasing trend in the values of R-B index. The increase in R-B index can be attributed to the increase in imperviousness. The spread of the data also increases with time. If imperviousness is going to increase as the function assumed for the future scenario then it can be seen that the R-B index has less variability than the present condition. The lowest value of R-B index for the year 2050 is 1.29.

Similar trends can be seen for the warm and cool periods of the year (graphs shown in Figures 4.8 and 4.9, respectively). The median of the warm period is

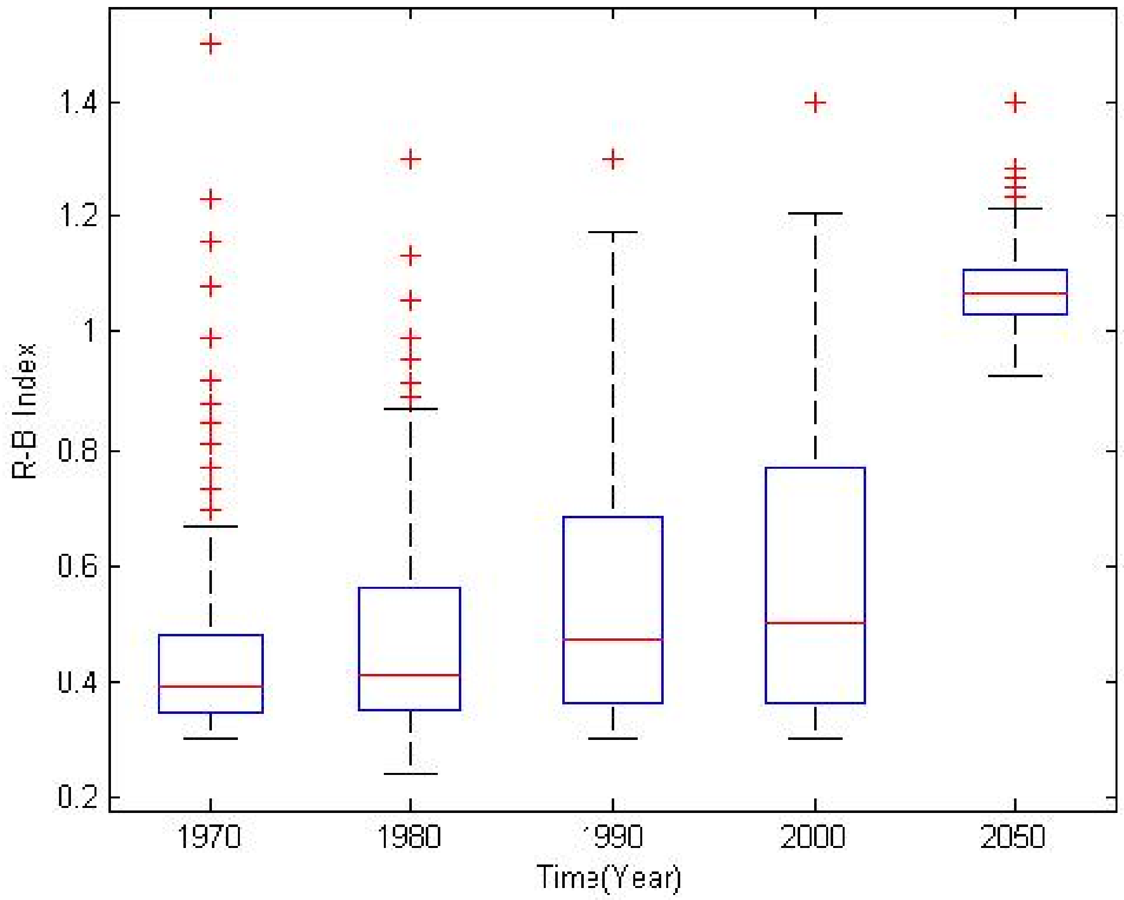

Figure 4.8: Figure showing R-B index(Cool) vs Time (year), for the years 1970, 1980, 1990, 2000 and 2050 for the Middle Potomac-Catoctin watershed

higher than the median of the annual and cool periods of the year. This is because the precipitation factor is larger for the(Annual period: 0.96 inches, Cool period: 0.80 inches and Warm period 1.76: inches) warm period of the year than the annual and cool periods of the year. Figure 4.7 shows the general trend of increasing R-B index with imperviousness.

The future scenario was evaluated only for Middle Potomac-Catoctin 8-digit watershed due to the exclusive availability of the rainfall data in this location. For

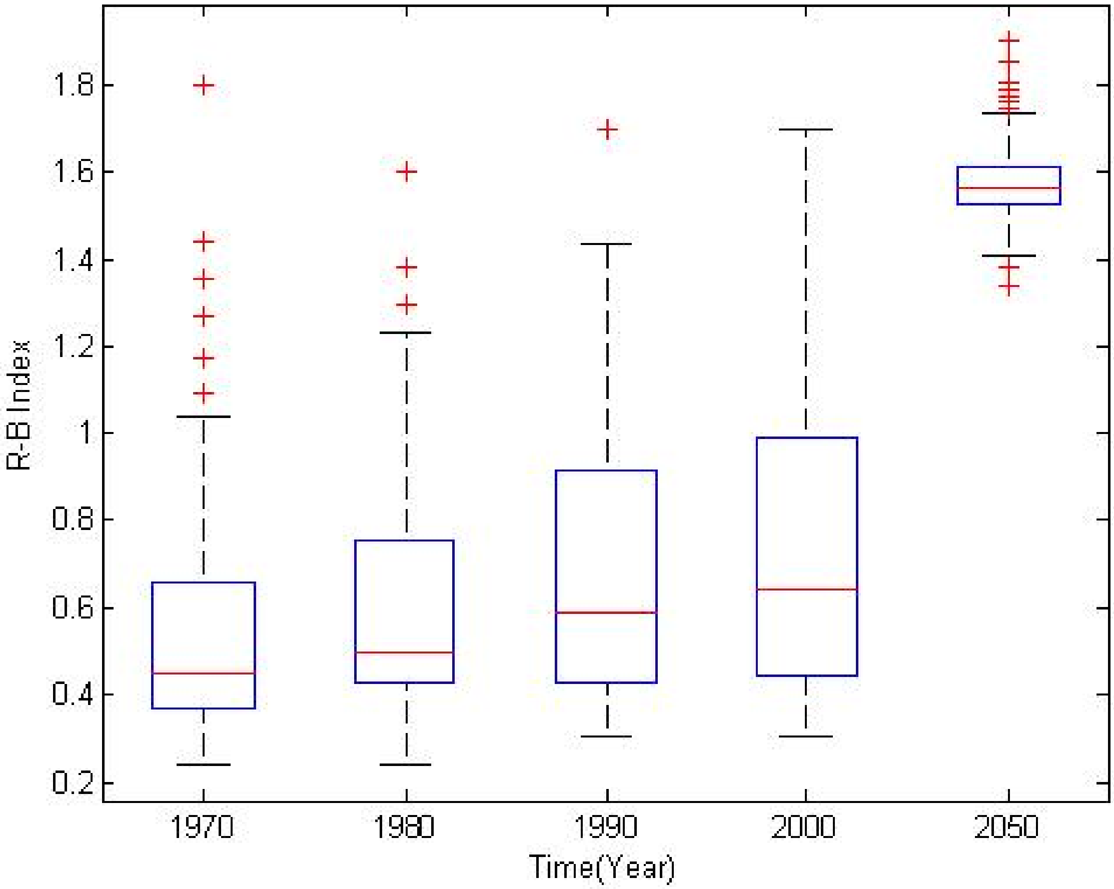

Figure 4.9: The R-B index(Warm) versus time (year), for the years 1970, 1980, 1990, 2000 and 2050 for the Middle Potomac-Catoctin watershed

the other 8-digit watersheds, analyses are performed only for the years 1970, 1980, 1990 and 2000 for the annual, cool and warm periods.

4.4 Evaluating the impact of imperviousness and climate in the future

The impacts of imperviousness and climate change in the future are evaluated separately in order to determine the effects of the parameters individually. Con-

Table 4.3: Table listing different scenarios(conditions) discussed

Scenario	Imperviousness	Precipitation factor
Scenario 1	Imperviousness prevailing in 2000	Average precipitation factor from 1970 to 2000
Scenario 2	Imperviousness prevailing in 2050	Average precipitation factor from 1970 to 2000
Scenario 3	Imperviousness prevailing in 2000	Average precipitation factor in 2050
Scenario 4	Imperviousness prevailing in 2050	Average precipitation factor in 2050

sider the Middle Potomac-Catoctin watershed. Values of R-B index are plotted for different scenarios. The first scenario corresponds to the base condition, the second scenario correspond to changing land use, the third scenario corresponds to changing climatic conditions and the fourth scenario corresponds to jointly changing land use and changing climatic conditions. Table 4.3 summarizes the different scenarios that are considered.

It can be seen that the effect of changing imperviousness is greater than the effect of changing precipitation factor. The increased imperviousness causes an increase of the median value from 0.52 in the year 2000 to a value of 1.26 for the changed imperviousness conditions in the year 2050. The annual precipitation factor is estimated to increase from 0.97 to 1.72 for years 2000 to 2050, respectively, but the impacts are not as great when the imperviousness does not change. The median

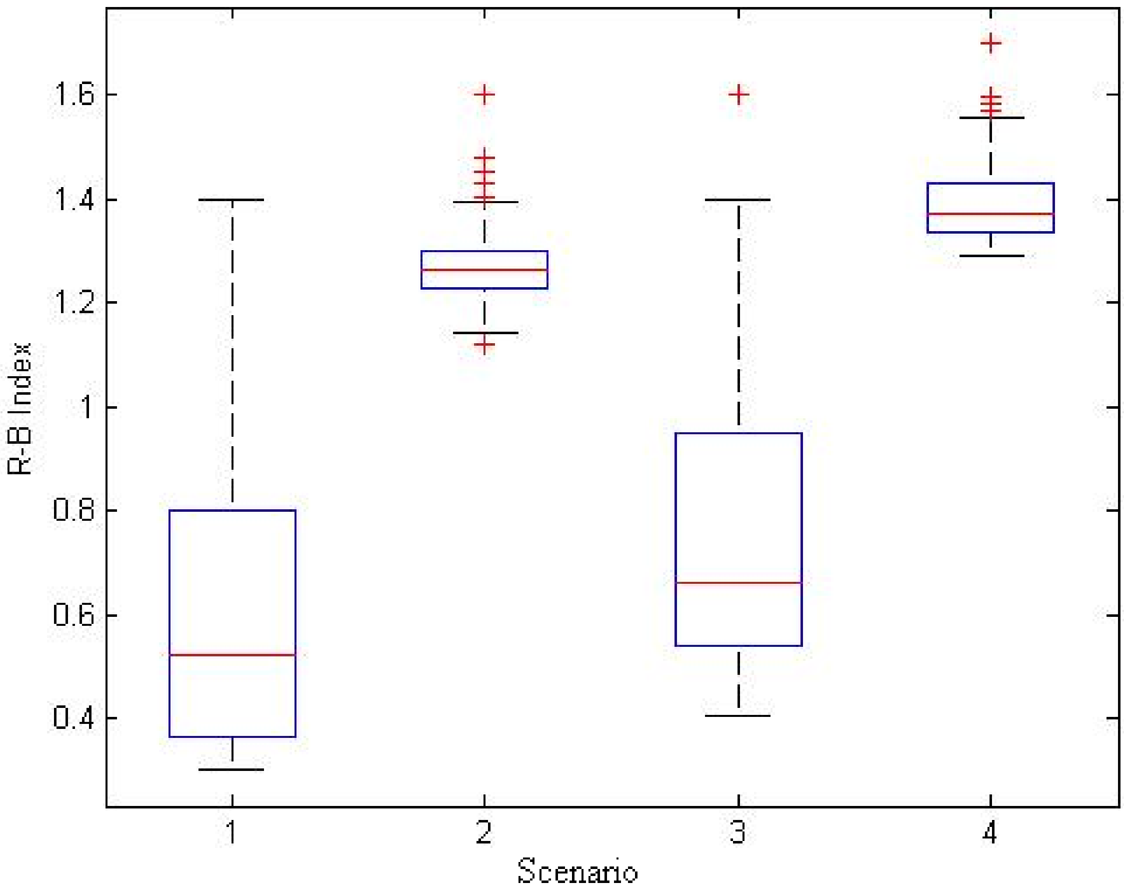

Figure 4.10: The R-B index(Annual) versus different scenarios for the Middle Potomac-Catoctin watershed. Scenarios are defined in Table 4.3.

R-B index value is projected to increase from 0.52 to a value of 0.66. However when both imperviousness and precipitation factor change, the median value increases to 1.41 and the spread of R-B index are in the ranges of 1.34 and 1.43 with the median being 1.37.

The effect of the cool period on the R-B index shows a slight deviation from the findings for the annual and warm periods. The R-B index decreases for the changing climatic conditions. This is expected as the rainfall decreases for the

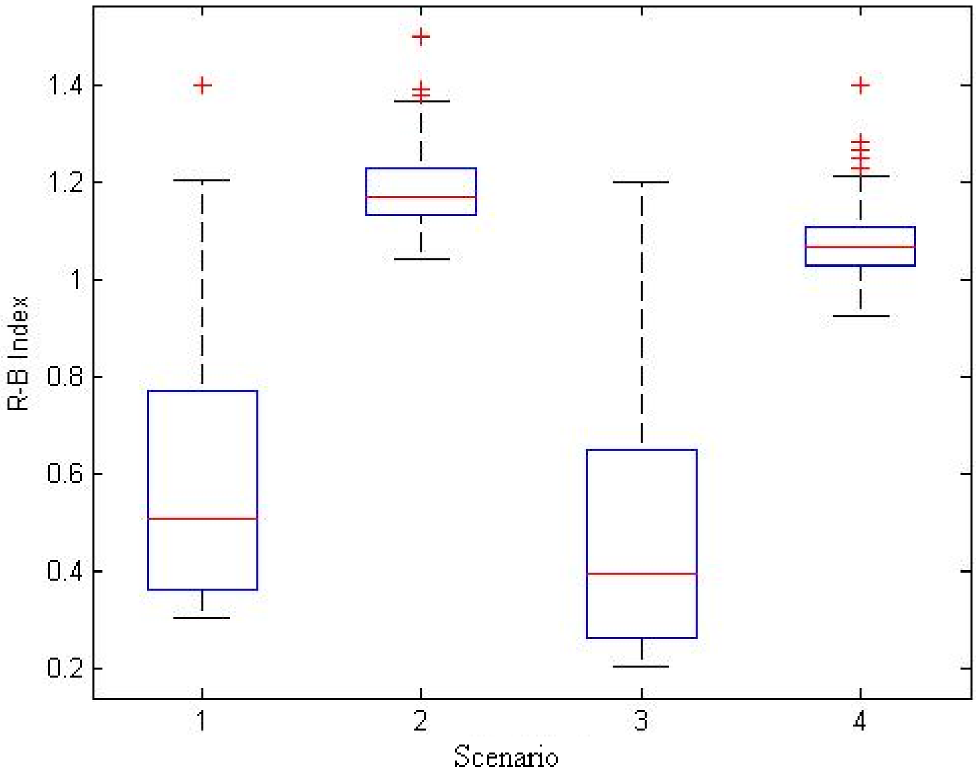

Figure 4.11: The R-B index(Cool) versus different scenarios for the Middle Potomac-Catoctin watershed. Scenarios are defined in Table 4.3.

future conditions for the cool periods This has the effect of reducing the predicted R-B index for Scenarios 3 and 4 relative to Scenario 1 and 2 due to the positive relationship of precipitation factor on R-B index indicated in equation 4.2.

The results for different scenarios of changing imperviousness and climate are given in tabular format in Table 4.3.

Table 4.4: The R-B index for various time periods for different scenarios

season		Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual	Median	0.51	1.26	0.98	1.40
	25^{th}	0.38	1.22	0.57	1.38
	75^{th}	0.80	1.32	0.64	1.43
Cool	Median	0.48	1.19	0.4	1.08
	25^{th}	0.38	1.13	0.27	1.05
	75^{th}	0.78	1.22	0.62	1.10
Warm	Median	0.63	1.25	1.02	1.61
	25^{th}	0.42	1.21	0.52	1.56
	75^{th}	0.99	1.30	0.68	1.68

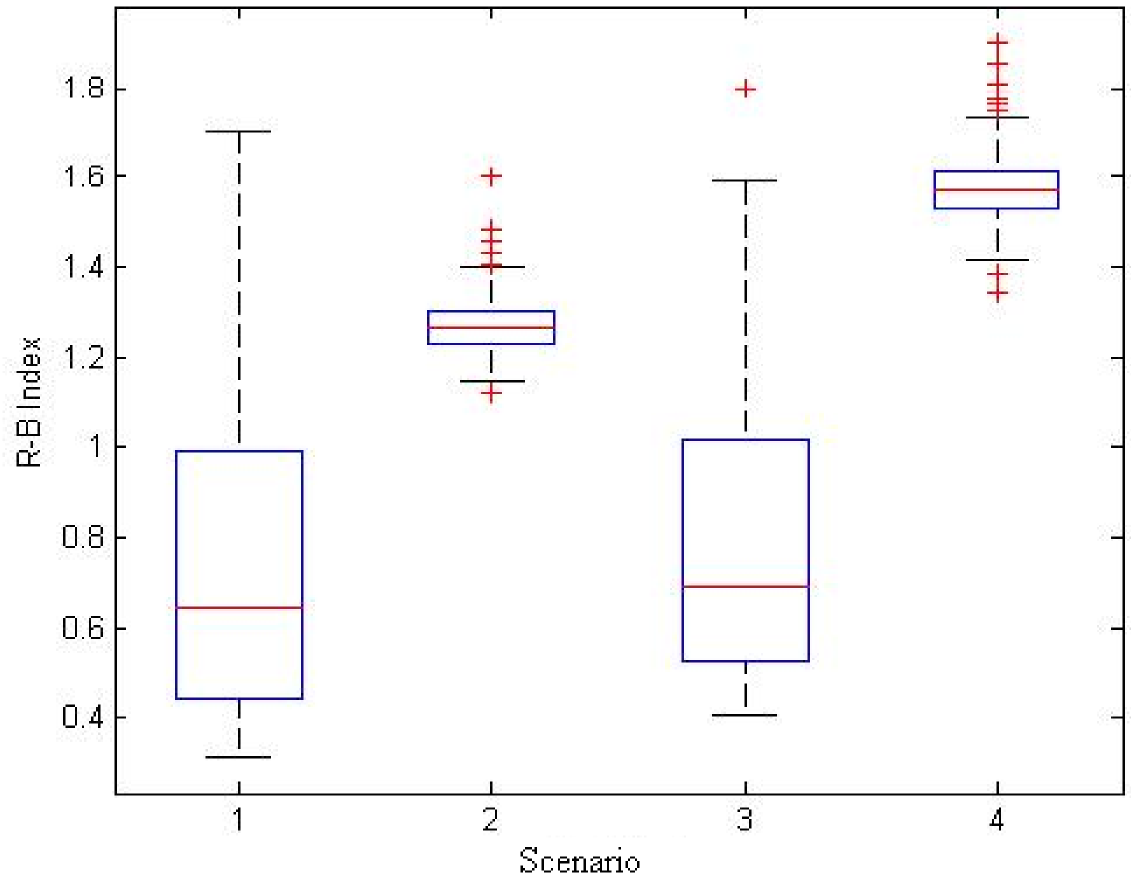

Figure 4.12: R-B index(Warm) versus different scenarios for the Middle Potomac-Catoctin watershed. Scenarios are defined in Table 4.3.

4.5 Spatial variation of R-B index across Maryland

In this section the spatial variation of R-B index is quantified across the 19 8-digit watersheds that cover Maryland. Table 4.4 gives the watershed identifications for the 19 watersheds. The watersheds are arranged in west to east direction across Maryland. The urbanized streams are predicted to have larger values of the R-B index than the less urbanized streams. This trend is consistent across annual, cool, and warm periods for the year. The R-B index is predicted from the equations 3.3, 3.4, and 3.5 for the annual, cool, and warm periods respectively. Similar graphs are shown in Figures 4.13, 4.14 and 4.15 for year 2000 conditions.

Table 4.5: Listing of all study watersheds. The indicated watershed ID is used in Figures 4.13 - 4.15.

Watershed ID	8-digit Watershed Name	Watershed Area in Maryland (mi^2))
1	Youghiogheny	301.77
2	North Branch Potomac	251.42
3	Cacapon	178.58
4	Conococheague	409.27
5	Monocacy	958.73
6	Middle Potomac- Catoctin	352.32
7	Middle Potomac- Anacostia	392.58
8	Lower Potomac	751.33
9	Patuxent	910.19
10	Susquehanna	264.3
11	Patapsco	505.83
12	Severn	64.841
13	Chester	309.86
14	Choptank	915.97
15	Blackwater	117.2
16	Nanticoke	793.38
17	Pocomoke	420.55
18	Broadkill- Smyrna	168.91
19	Brandywine	152.99

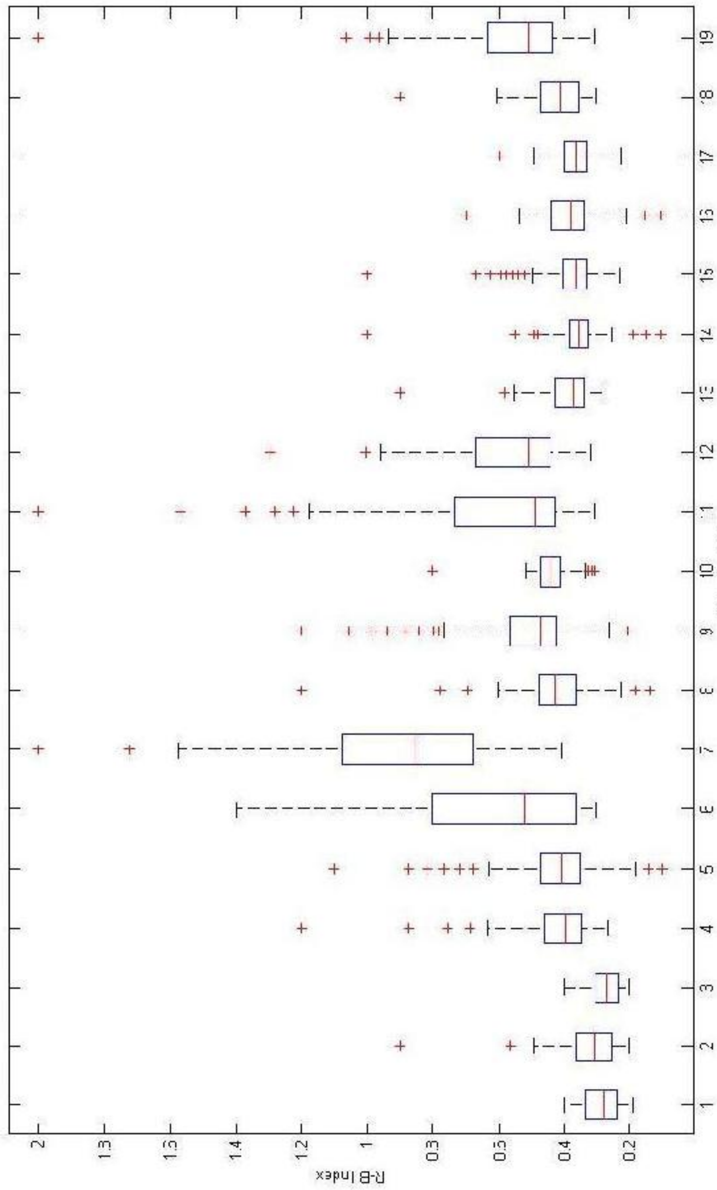

Figure 4.13: The distribution of R-B index(Annual), for the 8-digit watersheds across Maryland for year 2000.

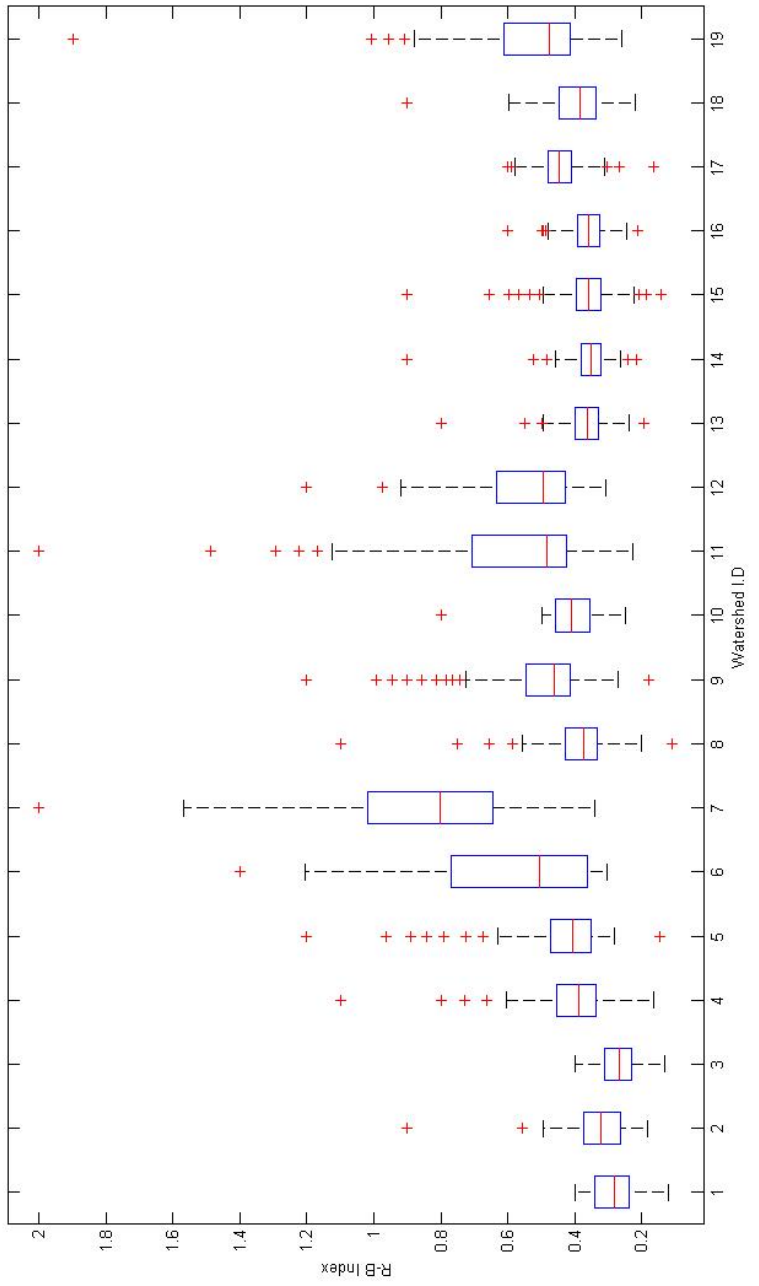

Figure 4.14: The distribution of R-B index(Cool), for the 8-digit watersheds across Maryland for year 2000.

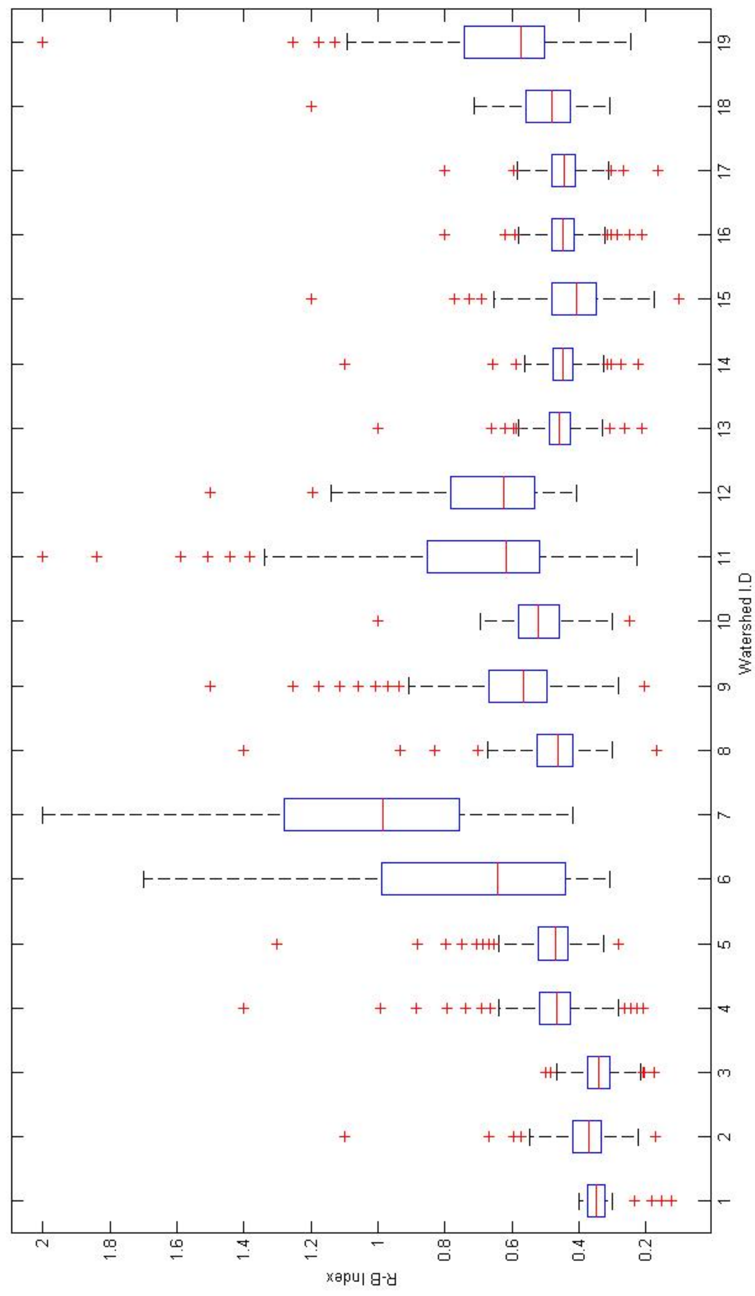

Figure 4.15: The distribution of R-B index(Warm), for 8-digit watersheds across Maryland

4.6 Stream Quality and R-B index

An analysis for the correlation between stream quality and the R-B index was performed based on the water quality results from Montgomery County, Maryland for the years 1994 to 2000. Based on a report by Montgomery County Department of Environmental Protection, Montgomery County (Maryland Department of Environmental Protection, 2003)was divided into watersheds based on the water quality. These were divided into Excellent, Good, Fair and Poor. The majority of the urbanized watersheds were found to be in fair condition. Out of the 13 main urbanized watersheds in Montgomery County, 9 were found to be in fair condition, 2 were found to be in poor condition, and 2 were found to be in good condition. There were 9 rural watersheds of which 8 were found to be in good condition and 1 was in fair condition. These watersheds were taken as references in order to develop a relation between stream quality and R-B index.

Figure 4.17 shows the watersheds (marked in red) that were considered to develop a relationship between the water quality and the R-B index. The results and the ranges of R-B index were tabulated. Four watersheds of each category was chosen to establish a relationship between R-B index and water quality for the year 2000. The water quality was then attributed to the ranges of R-B index. Based on the relationship between R-B index and water quality, stream lengths for Maryland 8-digit watersheds were classified as Excellent, Good, Fair and Poor. The results are shown in Table 4.5.

Table 4.6: Relationship between estimated annual R-B indices and Montgomery County stream quality conditions

Watershed Quality	min	max	avg
Excellent	0.36	0.364	0.362
	0.38	0.384	0.379
	0.427	0.43	0.428
	0.377	0.393	0.39
Good	0.361	0.614	0.428
	0.479	0.747	0.567
	0.434	0.438	0.436
	0.548	0.549	0.549
Fair	0.669	1.23	0.917
	0.503	0.939	0.739
	0.504	0.838	0.742
	0.95	1.026	0.995
Poor	1.178	1.503	1.264
	0.869	1.021	0.989
	1.017	1.385	1.192
	0.919	1.12	0.999

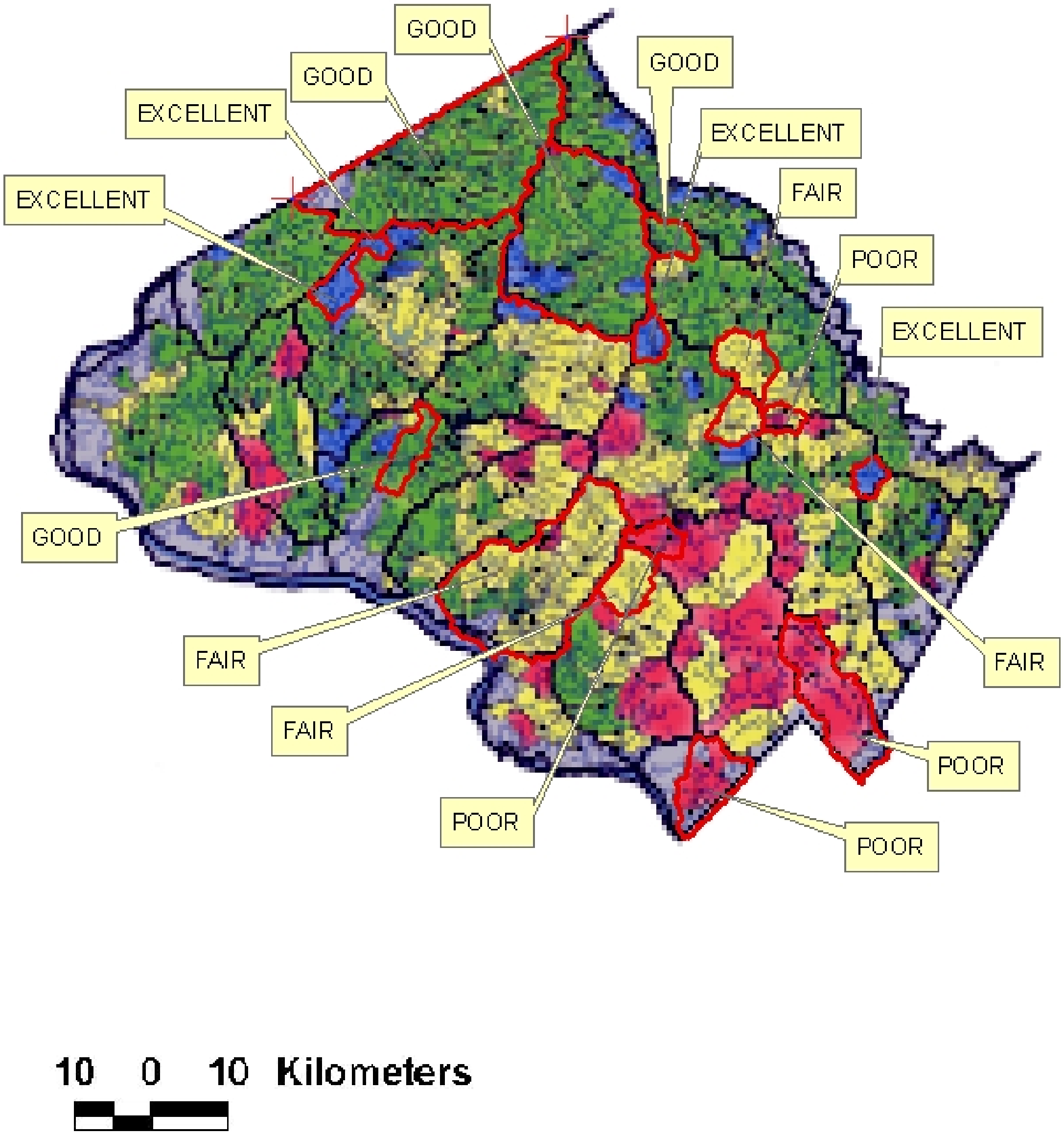

Figure 4.16: Watersheds considered for developing a relationship between water quality and R-B index, Montgomery County, Maryland. Figure is taken from Montgomery County DEP.

Table 4.7: Water quality and R-B index range based on Montgomery County, Maryland study.

Watershed Condition	R-B index
Excellent	0.0-0.4
Good	0.4-0.6
Fair	0.6-0.9
Poor	0.9-2.0

This relationship was further extended to all streams across the 8-digit watersheds. The streams were studied and were classified based on this relationship. The stream length for each category was calculated for all streams across the 8-digit watersheds. The total stream length across all the 8-digit watersheds was found to be just greater than 726,000 kilometers. The stream length for each category is expressed as a percentage of this total stream length in Table 4.8.

Table 4.8: Change in distribution of stream quality classification in all study watersheds over time.

Stream condition	1970(% stream length)	1980(% stream length)	1990(% stream length)	2000(% stream length)
Excellent	61.19	55.08	44.32	47.71
Good	31.57	36.3	47.11	40.41
Fair	4.77	5.56	5.71	7.79
Poor	2.47	2.86	3.06	4.09

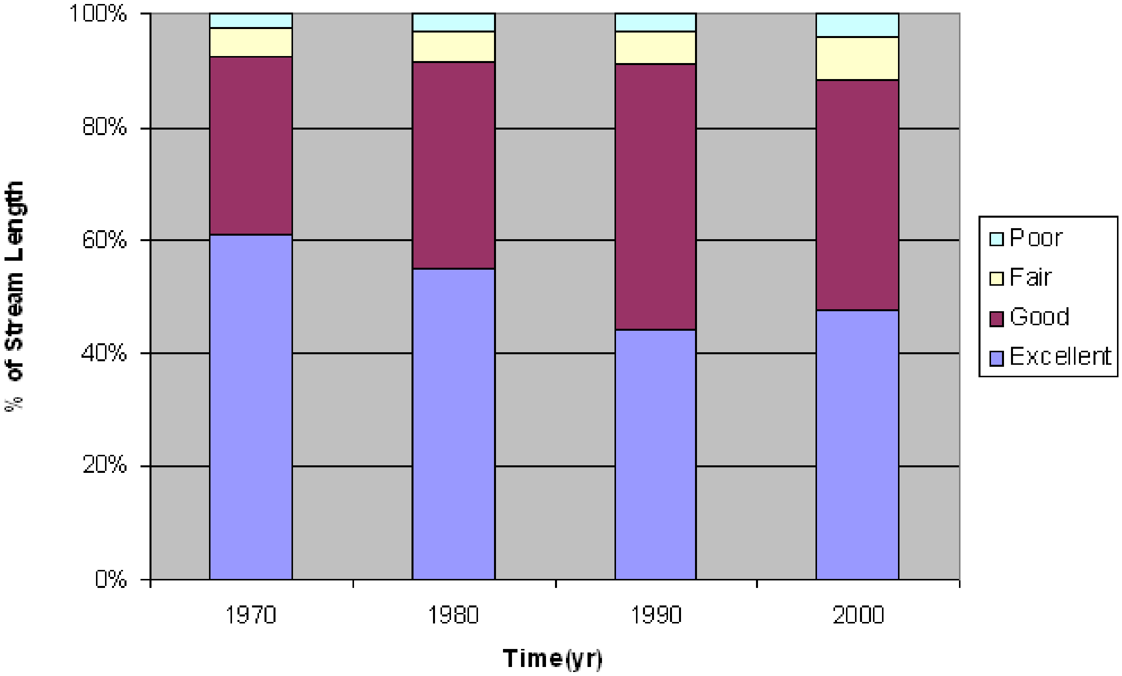

Figure 4.17: Change in distribution of stream quality classification in all study watersheds over time.

Figure 4.17 shows a graphical depiction of the information in Table 4.8. The percentage of streams in fair and poor conditions increases with time. The total stream length of streams in excellent condition generally is trending downward. These results indicate that over time there is a trend for the total amount of stream length in poor or fair condition to increase at the expense of good and excellent stream conditions. Such a trend is indicative of the negative consequences of urbanization and climate change on the streams in Maryland.

Table 4.9 shows the change in distribution of stream quality for the individual 8-digit watersheds. It can be seen that the most urbanized watershed do not have streams in excellent condition. For instance, the Middle Potomac-Anacostia does not have any streams in excellent condition as predicted by this analyses, while there is a high percentage of other urbanized watersheds like Middle Potomac-Catoctin with streams in a poor condition. These findings can be mainly related to the amount of imperviousness in those regions.

Table 4.9: Distribution of Stream Conditions in 8-digit watersheds.

Watershed Name	Total Stream Length (Km)	Stream Condition	2000 (%)	1990 (%)	1980 (%)	1970 (%)
Blackwater	30725	Excellent	74.51	72.01	74.78	81.1
(02060007)		Good	22.79	25.23	23.28	17.56
		Fair	2.57	2.57	1.91	1.34
		Poor	0.12	0.19	0.02	0
Brandywine	41743	Excellent	11.99	19.8	21.51	30.53
(02040205)		Good	58.7	57.71	60.33	57.58
		Fair	24.11	18.29	13.43	7.58
		Poor	5.21	4.2	4.73	4.31
Broadkill-Smyrna	37287	Excellent	44.44	60.71	50.49	61.03
(02040207)		Good	54.52	37.86	48.11	37.54
		Fair	1.04	1.43	1.4	1.43
		Poor	0	0	0	0
Cacapon	11204	Excellent	100	100	100	100
(02070003)		Fair	0	0	0	0
		Good	0	0	0	0
		Poor	0	0	0	0
Chester	64586	Excellent	66.79	75.79	77.04	83.03
(02060002)		Fair	32.69	24.1	22.87	16.88
		Good	0.52	0.11	0.09	0.09
		Poor	0	0	0	0
Choptank	51502	Excellent	87.81	90.95	93.43	93.43
(02060005)		Good	11.58	8.46	5.93	5.93
		Fair	0.61	0.54	0.59	0.59
		Poor	0	0.05	0.05	0.05
Conococheague	28590	Excellent	52.66	53.27	54.92	63.78

Watershed Name	Total Stream Length (Km)	Stream Condition	2000(%)	1990 (%)	1980 (%)	1970 (%)
(02070004)		Good	42.93	42.89	41.22	32.27
		Fair	3.83	3.21	3.11	3.14
		Poor	0.58	0.64	0.75	0.81
Lower Potomac	56635	Excellent	36.08	41.85	39.36	39.17
(02070011)		Good	60.9	55.21	59.96	60.15
		Fair	2.92	2.87	0.68	0.68
		Poor	0.11	0.08	0	0
Midpotomac-catoctin	18200	Excellent	38.85	39.05	42.54	55.9
(02070008)		Good	22.55	30.3	36.25	29.41
		Fair	20.33	17.85	14.43	9.44
		Poor	18.28	12.8	6.78	5.25
Midpotomac-Anacostia	21078	Excellent	0	0	0	0
(02070010)		Good	17.29	18.25	25.39	27.17
		Fair	40.17	42.57	38.93	42.57
		Poor	42.54	39.18	35.67	30.26
Nanticoke	49194	Excellent	60.27	17.66	68.07	73.26
(02060008)		Good	39.49	82.34	31.9	26.74
		Fair	0.24	0.01	0.03	0
		Poor	0	0	0	0
North Branch Potomac	43650	Excellent	89.27	89.26	85.24	84.91
(02070002)		Good	10.11	10.18	14.14	14.47
		Fair	0.62	0.52	0.42	0.43
		Poor	0	0.04	0.2	0.19
Patapsco	73317	Excellent	13.43	14.57	17.25	34.19
(02070003)		Good	54.52	56.2	55.87	42.48
		Fair	16.27	15.51	13.88	13.09
		Poor	15.78	13.71	13	10.24

Watershed Name	Total Stream Length (Km)	Stream Condition	2000(%)	1990 (%)	1980 (%)	1970 (%)
Patuxent (02060006)	52026	Excellent	12.43	18.2	24.55	38.55
		Good	68.29	67	65.49	55.85
		Fair	15.58	12.42	8.26	5.01
		Poor	3.7	2.38	1.7	0.59
Pocomoke (02060009)	37666	Excellent	75.4	84.22	87.4	89.36
		Good	24.6	15.76	12.58	10.62
		Fair	0	0.02	0.02	0.02
		Poor	0	0	0	0
Monacacy (02070009)	54810	Excellent	45.85	55.01	65.87	64.4
		Good	47.39	39.88	29.18	29.35
		Fair	6.16	4.77	4.89	5.66
		Poor	0.6	0.34	0.05	0.6
Severn (02060004)	17064	Excellent	5.6	15.21	18.24	11.12
		Good	60.18	57.78	60.13	72.28
		Fair	30.72	25.09	19.87	14.98
		Poor	3.5	1.91	1.76	1.62
Susquehanna (02050306)	15375	Excellent	11.5	15.77	41.25	63.85
		Good	88.19	84.07	58.61	35.22
		Fair	0.3	0.16	0.14	0.93
		Poor	0	0	0	0
Youghigheny (05020006)	21487	Excellent	100	100	100	100
		Good	0	0	0	0
		Fair	0	0	0	0
		Poor	0	0	0	0

4.7 Stream Quality in Maryland Inferred from R-B Index

A threshold value was chosen for R-B index so that stream quality conditions could be separated based on this R-B index. A value of 0.6 was chosen as threshold as it separates Excellent and Good streams from the Fair and Poor streams according to the analysis in section 4.6. According to this analysis, that 11.9 percent of the stream length across all of Maryland have a R-B value of 0.6 or greater (mostly in urbanized areas). Figure 4.18 shows the streams in Washington, D.C metropolitan area that have a value greater than the threshold value.

The streams near major cities like Washington, D.C. and Baltimore are found to have greater amount of stream length in Fair and Poor conditions as compared to other places. This is because of the direct impact of imperviousness on the R-B index. Equations 3.2, 3.3, and 3.4 could be revisited with the threshold value of R-B equal to 0.6 specifically. These equations could be re-arranged to suggest a maximum imperviousness value such that R-B greater than 0.6 does not result. The corresponding imperviousness is suggestive of maximum allowable amount of development such that fair or poor stream conditions do not occur.

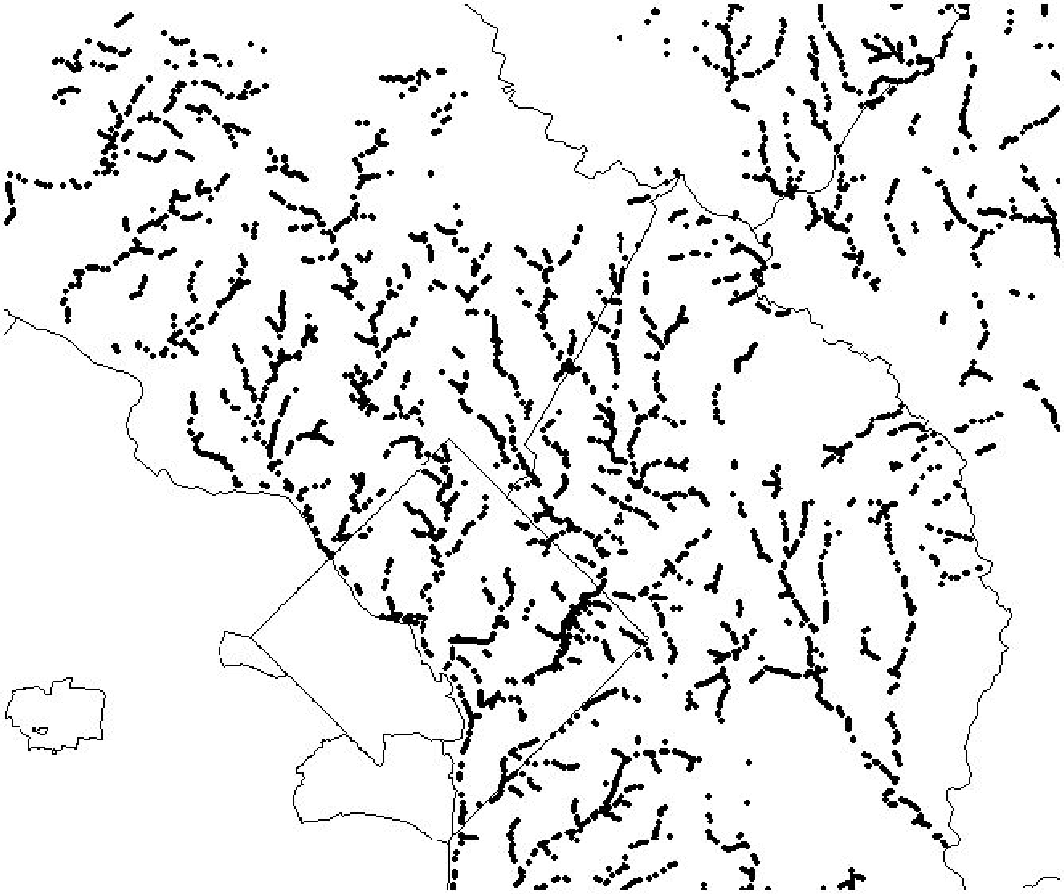

Figure 4.18: Streams with R-B index greater than 0.6 in the Washington D.C metropolitan area.

4.8 Summary

The impacts of imperviousness and precipitation factor on the R-B Index were analyzed using the developed regression equations. The spatial variation of the R-B index was observed by dividing Maryland into 8-digit watersheds. It was found that the R-B index increases from the east to the central part of Maryland and decreases to the west. This pattern is because of urbanization and development found near the major cities.

Imperviousness was found to have more impact than the precipitation factor. This was found by projecting both of these quantities to the year 2050. Also the impacts of imperviousness and precipitation factor on Maryland streams were analyzed based on these predicted values.

Relationships between stream conditions and the R-B index were developed. The relationship was developed using a report from the Montgomery County Department of Environmental Protection. A value of 0.6 was chosen as a threshold value of R-B index as it separated the streams in Excellent and Good conditions from these in Fair and Poor conditions. Using this criterion, 11.9% of all streams in Maryland were in Fair and Poor conditions. Also the change in distribution of stream quality was analyzed across Maryland for the years 1970, 1980, 1990, and 2000.

Chapter 5

Conclusions and Recommendations

5.1 Overview

The main goal was of this thesis to develop an equation for R-B index as a function of imperviousness, precipitation factor, and watershed characteristics and employ this equation to quantify the R-B index across Maryland. Based on this goal specific objectives were developed, as follows:

1. To develop an equation that estimates R-B index as a function of imperviousness.
2. To model the spatial distribution of the R-B index across Maryland using the developed equations.
3. To analyze whether flow variability is a function of the spatial pattern of development.
4. To analyze the impacts of future conditions on flow variability in Maryland.

This chapter will present conclusions regarding these objectives and identify future research that might be undertaken based on the study presented in this thesis.

5.2 Conclusions

The first objective was to develop equations that model R-B index as a function of imperviousness, precipitation factor, and watershed characteristics. Regression equations were developed for this purpose. Equations 3.3, 3.4, and 3.5 for the annual, cool and warm periods, respectively, were chosen to model R-B index.

The second objective was to model the spatial distribution of the R-B index. This was accomplished by dividing Maryland into the USGS-defined, 8-digit watersheds and the developed equations were applied to all streams within each such watershed. Figures 4.13, 4.14 and 4.15 show how flow variability increases from eastern to central Maryland, then again decreases from central Maryland to the west. This pattern is generally observed because more urbanization was found near major cities like Washington, D.C. and Baltimore, located in central Maryland.

The third objective was to analyze whether the R-B index is a function of the spatial pattern of development. A second set of equations incorporating the spatial impervious index were developed. Equations 3.6, 3.7, and 3.8 represent the models incorporating the spatial impervious index for the annual, cool and warm periods, respectively. However the simple linear models without the spatial impervious index (i.e, equations 3.3, 3.4, and 3.5) were chosen to characterize R-B index for the annual, cool, and warm periods. This is because the change in goodness of fit statistics for models incorporating the spatial impervious index were not meaningful.

The fourth objective was to model the impacts of future conditions on flow variability. For this, the imperviousness and precipitation data were projected for the future year 2050 in the Middle Potomac-Catoctin 8-digit watershed. Imperviousness was predicted using the equation 3.9 which forecasts future population density in this watershed. Precipitation data was predicted using the Hadley GCM model (Johns et al., 1997) focusing on the B2 scenario. Using these two time series we were able to project the imperviousness and precipitation factor for the future conditions and hence calculate the R-B index for future conditions. Chapter 4 discusses various scenarios that are used to analyze the impact of future conditions. Figures 4.6 to 4.11 illustrate the impacts of the future conditions on flow variability. From these analyses, the R-B index was found to increase from a average value of 0.6 in the year 2000 to a value of 1.6 in the year 2050. Also the variability of R-B index decreases in the year 2050. From these analyses we also found that imperviousness had a greater impact on the flow variability than the precipitation factor.

A relationship was developed between the stream quality and the R-B index using stream condition monitoring in Montgomery County, conditions were divided into ”Excellent”, ”Good”, ”Fair”, and ”Poor” based on this study by the Montgomery County Department of Environmental Protection.

Ranges of the R-B index and corresponding stream quality are given in Table 4.6. A value of 0.6 was chosen as a threshold value of the R-B index as it separates the streams in Excellent and Good condition from the streams in Fair and Poor condition. About 11.9% of all studied streams by length were found to have a R-B index greater than 0.6. Figure 4.8 shows the streams that have R-B index greater than 0.6 near Washington, D.C. In general, streams near the urban centers have a greater R-B index than the streams that are in more rural settings. This is because of the prevalence of impervious cover in more urban areas.

5.3 Limitations and Future Study

There were a few limitations in this study. First, data available for calibrating the R-B index equation(i.e., equations 3.3, 3.4, and 3.5) was less as compared to the whole state of Maryland. There were only 29 USGS gaging stations and precipitation gages available for the analyses. The imperviousness data was also limited, as the census tract data was only available for four points in time: 1970, 1980, 1990 and 2000.

Regression equations were applied globally to the region with site specific conditions occasionally outside the bounds of the developed equations. The applicability range of the regression equations provided in Table 3.4. However, to quantify the impact of imperviousness and the precipitation factor, the equations were applied throughout Maryland.

The relationship developed for predicting imperviousness for future conditions was simplistic and probably tended to overpredict the degree of imperviousness for the year 2050.

The relationship between stream conditions and R-B index was developed only using conditions in Montgomery County. However, these results were spatially extrapolated throughout Maryland.

A strong relationship between the stream quality and the R-B index can be developed as a part of future study. Various spatial imperviousness indices like mean nearest neighbor(MNN) and nearest neighbor coefficient of variation(NNCV) can be used to analyze the impact of the spatial distribution of imperviousness on the R-B index.

Appendix A

Data for the development of regression equations 3.3, 3.4, 3.5, 3.6, 3.7 and 3.8

Table A.1: Data for Deer Creek at Rocks, MD (USGS Gage ID: 01580000) for the annual period.

YEAR	$R - B_{Annual}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
YEAR	$R - B_{Annual}$	P_f	I	DA	SII
1970	0.34	0.95	2.90	73.42	0.59
1971	0.36	1.30	2.98	73.42	0.62
1972	0.32	1.11	3.06	73.42	0.64
1973	0.26	0.73	3.14	73.42	0.66
1974	0.25	0.81	3.22	73.42	0.68
1975	0.33	1.18	3.29	73.42	0.70
1976	0.25	0.78	3.37	73.42	0.72
1977	0.29	1.00	3.45	73.42	0.73
1978	0.40	1.06	3.53	73.42	0.75
1979	0.49	1.08	3.61	73.42	0.77
1980	0.24	0.73	3.68	73.42	0.78

YEAR	$R - B_{Annual}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1981	0.24	0.66	3.73	73.42	0.80
1982	0.37	0.71	3.77	73.42	0.81
1983	0.29	1.02	3.82	73.42	0.83
1984	0.34	0.94	3.87	73.42	0.84
1985	0.38	1.38	3.91	73.42	0.85
1986	0.16	0.60	3.96	73.42	0.87
1987	0.30	1.35	4.00	73.42	0.88
1988	0.26	0.86	4.05	73.42	0.89
1989	0.28	0.86	4.09	73.42	0.91
1990	0.25	0.74	4.14	73.42	0.92
1991	0.21	0.65	4.16	73.42	0.93
1993	0.26	0.70	4.22	73.42	0.95
1994	0.37	0.96	4.24	73.42	0.96
1995	0.24	0.80	4.27	73.42	0.97
1996	0.44	0.80	4.30	73.42	0.97
1997	0.23	1.03	4.32	73.42	0.98
1998	0.29	0.83	4.35	73.42	0.99
1999	0.36	1.85	4.38	73.42	1.00

Table A.2: Data for Deer Creek at Rocks, MD (USGS Gage ID: 01580000) for the cool period.

YEAR	$R - B_{Cool}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1970	0.25	0.67	2.90	73.42	0.59
1971	0.34	0.81	2.98	73.42	0.62
1972	0.19	0.90	3.06	73.42	0.64
1973	0.28	0.57	3.14	73.42	0.66
1974	0.25	0.83	3.22	73.42	0.68
1975	0.26	0.90	3.29	73.42	0.70
1976	0.23	0.72	3.37	73.42	0.72
1977	0.29	1.04	3.45	73.42	0.73
1978	0.45	0.88	3.53	73.42	0.75
1979	0.46	0.71	3.61	73.42	0.77
1980	0.25	0.73	3.68	73.42	0.78
1981	0.25	0.67	3.73	73.42	0.80
1982	0.41	0.70	3.77	73.42	0.81
1983	0.32	0.86	3.82	73.42	0.83
1984	0.33	0.88	3.87	73.42	0.84
1985	0.37	0.88	3.91	73.42	0.85
1986	0.17	0.50	3.96	73.42	0.87
1987	0.24	0.77	4.00	73.42	0.88

YEAR	$R - B_{Cool}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1988	0.29	0.83	4.05	73.42	0.89
1989	0.33	0.69	4.09	73.42	0.91
1990	0.24	0.60	4.14	73.42	0.92
1991	0.21	0.55	4.16	73.42	0.93
1993	0.28	0.66	4.22	73.42	0.95
1994	0.39	1.05	4.24	73.42	0.96
1995	0.25	0.76	4.27	73.42	0.97
1996	0.45	0.67	4.30	73.42	0.97
1997	0.25	1.12	4.32	73.42	0.98
1998	0.31	0.69	4.35	73.42	0.99
1999	0.31	0.61	4.38	73.42	1.00

Table A.3: Data for Deer Creek at Rocks, MD (USGS Gage ID: 01580000) for the warm period.

YEAR	$R - B_{Warm}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1970	0.50	1.47	2.90	73.42	0.59
1971	0.38	2.20	2.98	73.42	0.62
1972	0.51	1.62	3.06	73.42	0.64
1973	0.17	1.03	3.14	73.42	0.66
1974	0.27	1.44	3.22	73.42	0.68
1975	0.41	1.70	3.29	73.42	0.70
1976	0.33	1.07	3.37	73.42	0.72
1977	0.27	1.11	3.45	73.42	0.73
1978	0.17	1.44	3.53	73.42	0.75
1979	0.54	1.80	3.61	73.42	0.77
1980	0.20	0.87	3.68	73.42	0.78
1981	0.22	0.75	3.73	73.42	0.80
1982	0.30	0.85	3.77	73.42	0.81
1983	0.20	1.48	3.82	73.42	0.83
1984	0.37	1.22	3.87	73.42	0.84
1985	0.42	2.08	3.91	73.42	0.85
1986	0.10	3.99	3.96	73.42	0.87
1987	0.42	2.33	4.00	73.42	0.88

YEAR	$R - B_{Warm}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1988	0.15	1.02	4.05	73.42	0.89
1989	0.19	1.26	4.09	73.42	0.91
1990	0.25	1.10	4.14	73.42	0.92
1991	0.23	0.91	4.16	73.42	0.93
1993	0.22	0.97	4.22	73.42	0.95
1994	0.26	0.68	4.24	73.42	0.96
1995	0.19	0.97	4.27	73.42	0.97
1996	0.43	1.18	4.30	73.42	0.97
1997	0.12	0.67	4.32	73.42	0.98
1998	0.20	1.28	4.35	73.42	0.99
1999	0.51	3.37	4.38	73.42	1.00

Table A.4: Data for Winters Run Near Benson, MD (USGS Gage ID: 01581700) for the annual period.

YEAR	$R - B_{Annual}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1970	0.42	0.95	4.85	34.60	0.63
1971	0.50	1.30	5.08	34.60	0.63
1972	0.47	1.11	5.31	34.60	0.62
1973	0.31	0.73	5.53	34.60	0.62
1974	0.29	0.81	5.76	34.60	0.62
1975	0.44	1.18	5.99	34.60	0.62
1976	0.40	0.78	6.22	34.60	0.61
1977	0.36	1.00	6.45	34.60	0.61
1978	0.51	1.06	6.67	34.60	0.61
1979	0.54	1.08	6.90	34.60	0.61
1980	0.25	0.73	7.13	34.60	0.61
1981	0.31	0.66	7.22	34.60	0.61
1982	0.49	0.71	7.31	34.60	0.61
1983	0.34	1.02	7.40	34.60	0.61
1984	0.40	0.94	7.49	34.60	0.62
1985	0.63	1.38	7.58	34.60	0.62
1986	0.27	0.60	7.66	34.60	0.62
1987	0.48	1.35	7.75	34.60	0.62

YEAR	$R-B_{Annual}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1988	0.42	0.86	7.84	34.60	0.62
1989	0.47	0.86	7.93	34.60	0.63
1990	0.35	0.74	8.02	34.60	0.63
1991	0.30	0.65	8.09	34.60	0.62
1993	0.42	0.70	8.24	34.60	0.61
1994	0.49	0.96	8.31	34.60	0.60
1995	0.36	0.80	8.39	34.60	0.59
1996	0.55	0.80	8.46	34.60	0.59
1997	0.30	1.03	8.53	34.60	0.58
1998	0.40	0.83	8.60	34.60	0.58
1999	0.57	1.85	8.68	34.60	0.57

Table A.5: Data for Winters Run Near Benson, MD (USGS Gage ID: 01581700) for the cool period.

YEAR	$R - B_{Cool}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1970	0.35	0.67	4.85	34.60	0.63
1971	0.46	0.81	5.08	34.60	0.63
1972	0.34	0.90	5.31	34.60	0.62
1973	0.34	0.57	5.53	34.60	0.62
1974	0.32	0.83	5.76	34.60	0.62
1975	0.34	0.90	5.99	34.60	0.62
1976	0.31	0.72	6.22	34.60	0.61
1977	0.36	1.04	6.45	34.60	0.61
1978	0.56	0.88	6.67	34.60	0.61
1979	0.51	0.71	6.90	34.60	0.61
1980	0.25	0.73	7.13	34.60	0.61
1981	0.30	0.67	7.22	34.60	0.61
1982	0.53	0.70	7.31	34.60	0.61
1983	0.39	0.86	7.40	34.60	0.61
1984	0.38	0.88	7.49	34.60	0.62
1985	0.54	0.88	7.58	34.60	0.62
1986	0.26	0.50	7.66	34.60	0.62
1987	0.39	0.77	7.75	34.60	0.62

YEAR	$R - B_{Cool}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1988	0.43	0.83	7.84	34.60	0.62
1989	0.46	0.69	7.93	34.60	0.63
1990	0.29	0.60	8.02	34.60	0.63
1991	0.30	0.55	8.09	34.60	0.62
1993	0.44	0.66	8.24	34.60	0.61
1994	0.50	1.05	8.31	34.60	0.60
1995	0.36	0.76	8.39	34.60	0.59
1996	0.56	0.67	8.46	34.60	0.59
1997	0.31	1.12	8.53	34.60	0.58
1998	0.42	0.69	8.60	34.60	0.58
1999	0.32	0.61	8.68	34.60	0.57

Table A.6: Data for Winters Run Near Benson, MD (USGS Gage ID: 01581700) for the warm period.

YEAR	$R - B_{Warm}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1970	0.54	1.47	4.85	34.60	0.63
1971	0.56	2.20	5.08	34.60	0.63
1972	0.67	1.62	5.31	34.60	0.62
1973	0.22	1.03	5.53	34.60	0.62
1974	0.20	1.44	5.76	34.60	0.62
1975	0.53	1.70	5.99	34.60	0.62
1976	0.69	1.07	6.22	34.60	0.61
1977	0.37	1.11	6.45	34.60	0.61
1978	0.34	1.44	6.67	34.60	0.61
1979	0.59	1.80	6.90	34.60	0.61
1980	0.27	0.87	7.13	34.60	0.61
1981	0.36	0.75	7.22	34.60	0.61
1982	0.40	0.85	7.31	34.60	0.61
1983	0.19	1.48	7.40	34.60	0.61
1984	0.48	1.22	7.49	34.60	0.62
1985	0.87	2.08	7.58	34.60	0.62
1986	0.33	3.99	7.66	34.60	0.62
1987	0.69	2.33	7.75	34.60	0.62

YEAR	$R - B_{Warm}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1988	0.38	1.02	7.84	34.60	0.62
1989	0.48	1.26	7.93	34.60	0.63
1990	0.44	1.10	8.02	34.60	0.63
1991	0.34	0.91	8.09	34.60	0.62
1993	0.35	0.97	8.24	34.60	0.61
1994	0.44	0.68	8.31	34.60	0.60
1995	0.37	0.97	8.39	34.60	0.59
1996	0.53	1.18	8.46	34.60	0.59
1997	0.21	0.67	8.53	34.60	0.58
1998	0.32	1.28	8.60	34.60	0.58
1999	1.08	3.37	8.68	34.60	0.57

Table A.7: Data for Whitemarsh Run at Whitemarsh, MD (USGS Gage ID: 01585100) for the annual period.

YEAR	$R - B_{Annual}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1970	0.92	0.72	13.69	7.53	1.44
1971	1.05	1.64	14.18	7.53	1.42
1972	0.97	1.13	14.68	7.53	1.40
1973	0.94	0.92	15.17	7.53	1.39
1974	0.88	0.89	15.66	7.53	1.37
1975	0.97	1.50	16.16	7.53	1.36
1976	0.99	1.53	16.65	7.53	1.35
1977	1.06	0.87	17.14	7.53	1.34
1978	1.01	1.17	17.64	7.53	1.33
1979	0.90	1.10	18.13	7.53	1.32
1980	0.87	0.72	18.62	7.53	1.31
1981	0.99	0.67	18.95	7.53	1.28
1982	0.97	0.65	19.28	7.53	1.26
1983	1.04	1.19	19.61	7.53	1.24
1984	0.96	0.76	19.94	7.53	1.22
1985	1.17	1.14	20.28	7.53	1.20
1986	0.82	0.91	20.61	7.53	1.18
1987	1.08	0.86	20.94	7.53	1.16

YEAR	$R - B_{Annual}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1988	1.04	0.71	21.27	7.53	1.14
1989	1.19	0.87	21.60	7.53	1.13
1992	1.01	0.79	22.35	7.53	1.10
1993	1.06	0.91	22.56	7.53	1.09
1994	1.04	0.80	22.77	7.53	1.09
1995	1.10	0.62	22.98	7.53	1.08

Table A.8: Data for Whitemarsh Run at Whitemarsh, MD (USGS Gage ID: 01585100) for the cool period.

YEAR	$R - B_{Cool}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1970	0.93	0.70	13.69	7.53	1.44
1971	0.91	0.80	14.18	7.53	1.42
1972	0.89	0.97	14.68	7.53	1.40
1973	0.94	0.92	15.17	7.53	1.39
1974	0.82	0.76	15.66	7.53	1.37
1975	0.97	1.22	16.16	7.53	1.36
1976	0.79	1.01	16.65	7.53	1.35
1977	1.01	0.89	17.14	7.53	1.34
1978	0.99	1.13	17.64	7.53	1.33
1979	0.86	0.85	18.13	7.53	1.32
1980	0.89	0.64	18.62	7.53	1.31
1981	0.81	0.65	18.95	7.53	1.28
1982	0.90	0.56	19.28	7.53	1.26
1983	1.04	1.08	19.61	7.53	1.24
1984	0.97	0.78	19.94	7.53	1.22
1985	0.86	0.65	20.28	7.53	1.20
1986	0.70	0.55	20.61	7.53	1.18
1987	1.00	0.84	20.94	7.53	1.16

YEAR	$R - B_{Cool}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1988	0.97	0.69	21.27	7.53	1.14
1989	1.12	0.77	21.60	7.53	1.13
1992	0.92	0.72	22.35	7.53	1.10
1993	1.05	0.92	22.56	7.53	1.09
1994	0.99	0.86	22.77	7.53	1.09
1995	1.07	0.58	22.98	7.53	1.08

Table A.9: Data for Whitemarsh Run at Whitemarsh, MD (USGS Gage ID: 01585100) for the warm period.

YEAR	$R - B_{Warm}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
YEAR	$R - B_{Warm}$	P_f	I	A	SII
1970	0.90	0.84	13.69	7.53	1.44
1971	1.15	2.76	14.18	7.53	1.42
1972	1.16	1.65	14.68	7.53	1.40
1973	0.95	1.06	15.17	7.53	1.39
1974	1.03	1.28	15.66	7.53	1.37
1975	0.97	2.07	16.16	7.53	1.36
1976	1.42	2.43	16.65	7.53	1.35
1977	1.21	0.86	17.14	7.53	1.34
1978	1.09	1.32	17.64	7.53	1.33
1979	0.98	1.62	18.13	7.53	1.32
1980	0.73	1.01	18.62	7.53	1.31
1981	1.21	0.98	18.95	7.53	1.28
1982	1.15	0.94	19.28	7.53	1.26
1983	1.03	1.60	19.61	7.53	1.24
1984	0.89	0.74	19.94	7.53	1.22
1985	1.58	1.90	20.28	7.53	1.20
1986	1.29	1.48	20.61	7.53	1.18

YEAR	$R - B_{Warm}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1987	1.36	1.02	20.94	7.53	1.16
1988	1.29	0.84	21.27	7.53	1.14
1989	1.28	1.19	21.60	7.53	1.13
1992	1.14	1.01	22.35	7.53	1.10
1993	1.13	1.00	22.56	7.53	1.09
1994	1.20	0.78	22.77	7.53	1.09
1995	1.23	2.13	22.98	7.53	1.08

Table A.10: Data for Stemmers Run at Rossville, MD (USGS Gage ID: 01585300) for the annual period.

YEAR	$R - B_{Annual}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1970	1.16	0.72	19.49	4.50	1.97
1971	1.28	1.64	19.76	4.50	1.91
1972	1.15	1.13	20.02	4.50	1.85
1974	1.07	0.89	20.55	4.50	1.75
1975	1.11	1.50	20.81	4.50	1.70
1976	1.14	1.53	21.08	4.50	1.66
1977	1.28	0.87	21.34	4.50	1.61
1978	1.12	1.17	21.61	4.50	1.57
1979	1.03	1.10	21.87	4.50	1.53
1980	1.17	0.72	22.13	4.50	1.50
1981	1.27	0.67	22.17	4.50	1.49
1982	1.17	0.65	22.20	4.50	1.48
1983	1.22	1.19	22.23	4.50	1.47
1984	1.04	0.76	22.27	4.50	1.46
1985	1.29	1.14	22.30	4.50	1.45
1986	0.87	0.91	22.34	4.50	1.45
1987	1.17	0.86	22.37	4.50	1.44
1988	1.20	0.71	22.40	4.50	1.43

YEAR	$R-B_{Annual}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1989	1.30	0.87	22.44	4.50	1.42

Table A.11: Data for Stemmers Run at Rossville, MD (USGS Gage ID: 01585300) for the cool period.

YEAR	$R - B_{Cool}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1970	1.12	0.70	19.49	4.50	1.97
1971	1.09	0.80	19.76	4.50	1.91
1972	1.07	0.97	20.02	4.50	1.85
1974	0.98	0.76	20.55	4.50	1.75
1975	1.13	1.22	20.81	4.50	1.70
1976	0.93	1.01	21.08	4.50	1.66
1977	1.20	0.89	21.34	4.50	1.61
1978	1.10	1.13	21.61	4.50	1.57
1979	1.05	0.85	21.87	4.50	1.53
1980	1.19	0.64	22.13	4.50	1.50
1981	1.06	0.65	22.17	4.50	1.49
1982	1.05	0.56	22.20	4.50	1.48
1983	1.22	1.08	22.23	4.50	1.47
1984	1.03	0.78	22.27	4.50	1.46
1985	0.97	0.65	22.30	4.50	1.45
1986	0.74	0.55	22.34	4.50	1.45
1987	1.13	0.84	22.37	4.50	1.44
1988	1.11	0.69	22.40	4.50	1.43

YEAR	$R - B_{Cool}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1989	1.19	0.77	22.44	4.50	1.42

Table A.12: Data for Stemmers Run at Rossville, MD (USGS Gage ID: 01585300) for the warm period.

YEAR	$R - B_{Warm}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1970	1.32	0.84	19.49	4.50	1.97
1971	1.42	2.76	19.76	4.50	1.91
1972	1.36	1.65	20.02	4.50	1.85
1974	1.31	1.28	20.55	4.50	1.75
1975	1.08	2.07	20.81	4.50	1.70
1976	1.62	2.43	21.08	4.50	1.66
1977	1.53	0.86	21.34	4.50	1.61
1978	1.19	1.32	21.61	4.50	1.57
1979	1.00	1.62	21.87	4.50	1.53
1980	1.03	1.01	22.13	4.50	1.50
1981	1.45	0.98	22.17	4.50	1.49
1982	1.46	0.94	22.20	4.50	1.48
1983	1.19	1.60	22.23	4.50	1.47
1984	1.11	0.74	22.27	4.50	1.46
1985	1.68	1.90	22.30	4.50	1.45
1986	1.38	1.48	22.34	4.50	1.45
1987	1.40	1.02	22.37	4.50	1.44
1988	1.54	0.84	22.40	4.50	1.43

YEAR	$R - B_{Warm}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1989	1.45	1.19	22.44	4.50	1.42

Table A.13: Data for Cranberry Branch Near Westminster, MD (USGS Gage ID: 01585500) for the annual period.

YEAR	$R-B_{Annual}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1980	0.49	0.94	4.84	3.25	1.13
1981	0.51	0.88	5.04	3.25	1.09
1982	0.50	0.61	5.25	3.25	1.05
1983	0.45	0.68	5.45	3.25	1.02
1984	0.46	0.78	5.65	3.25	0.99
1985	0.66	1.06	5.86	3.25	0.96
1986	0.35	0.61	6.06	3.25	0.93
1987	0.52	0.97	6.26	3.25	0.91
1988	0.45	0.95	6.47	3.25	0.89
1989	0.50	0.65	6.67	3.25	0.87
1990	0.56	0.74	6.88	3.25	0.85
1991	0.63	1.27	6.91	3.25	0.85
1992	0.70	0.62	6.94	3.25	0.85
1993	0.53	0.84	6.98	3.25	0.84
1994	0.58	1.23	7.01	3.25	0.84
1995	0.56	0.91	7.05	3.25	0.84
1996	0.75	0.83	7.08	3.25	0.83
1997	0.46	0.91	7.12	3.25	0.83

YEAR	$R - B_{Annual}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1998	0.67	0.75	7.15	3.25	0.83

Table A.14: Data for Cranberry Branch Near Westminster, MD (USGS Gage ID: 01585500) for the cool period.

YEAR	$R-B_{Cool}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1980	0.54	0.99	4.84	3.25	1.13
1981	0.56	0.84	5.04	3.25	1.09
1982	0.52	0.52	5.25	3.25	1.05
1983	0.51	0.69	5.45	3.25	1.02
1984	0.48	0.70	5.65	3.25	0.99
1985	0.66	1.05	5.86	3.25	0.96
1986	0.34	0.49	6.06	3.25	0.93
1987	0.50	0.74	6.26	3.25	0.91
1988	0.49	0.73	6.47	3.25	0.89
1989	0.55	0.71	6.67	3.25	0.87
1990	0.60	0.79	6.88	3.25	0.85
1991	0.62	0.57	6.91	3.25	0.85
1992	0.70	0.65	6.94	3.25	0.85
1993	0.50	0.71	6.98	3.25	0.84
1994	0.59	1.34	7.01	3.25	0.84
1995	0.43	0.58	7.05	3.25	0.84
1996	0.86	0.70	7.08	3.25	0.83
1997	0.46	0.94	7.12	3.25	0.83

YEAR	$R - B_{Cool}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1998	0.62	0.76	7.15	3.25	0.83

Table A.15: Data for Cranberry Branch Near Westminster, MD (USGS Gage ID: 01585500) for the annual period.

YEAR	$R - B_{Warm}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1980	0.33	0.86	4.84	3.25	1.13
1981	0.43	1.05	5.04	3.25	1.09
1982	0.44	0.86	5.25	3.25	1.05
1983	0.28	0.69	5.45	3.25	1.02
1984	0.41	1.06	5.65	3.25	0.99
1985	0.70	1.18	5.86	3.25	0.96
1986	0.37	0.92	6.06	3.25	0.93
1987	0.56	1.53	6.26	3.25	0.91
1988	0.25	0.91	6.47	3.25	0.89
1989	0.38	0.65	6.67	3.25	0.87
1990	0.41	0.72	6.88	3.25	0.85
1991	0.75	2.61	6.91	3.25	0.85
1992	0.68	0.68	6.94	3.25	0.85
1993	0.66	1.21	6.98	3.25	0.84
1994	0.55	1.11	7.01	3.25	0.84
1995	0.84	1.37	7.05	3.25	0.84
1996	0.53	1.16	7.08	3.25	0.83
1997	0.45	0.88	7.12	3.25	0.83

YEAR	$R-B_{Warm}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1998	0.83	0.84	7.15	3.25	0.83

Table A.16: Data for North Branch Patapsco River at Cedarhurst, MD (USGS Gage ID: 01586000) for the annual period.

YEAR	$R - B_{Annual}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1976	0.32	0.77	8.02	6.97	1.16
1977	0.28	0.77	8.39	6.97	1.16
1978	0.44	0.83	8.77	6.97	1.16
1979	0.50	1.13	9.14	6.97	1.16
1980	0.27	0.60	9.52	6.97	1.16
1981	0.35	0.88	9.89	6.97	1.17
1982	0.40	0.70	10.27	6.97	1.19
1983	0.44	0.93	10.64	6.97	1.20
1984	0.39	1.00	11.02	6.97	1.21
1985	0.38	1.88	11.39	6.97	1.23
1986	0.31	0.88	11.77	6.97	1.24
1987	0.54	0.64	12.14	6.97	1.26
1988	0.44	0.74	12.52	6.97	1.27
1989	0.49	0.89	13.26	6.97	1.28

Table A.17: Data for North Branch Patapsco River at Cedarhurst, MD (USGS Gage ID: 01586000) for the cool period.

YEAR	$R - B_{Cool}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1976	0.29	0.57	8.02	6.97	1.16
1977	0.27	0.81	8.39	6.97	1.16
1978	0.46	0.82	8.77	6.97	1.16
1979	0.39	0.77	9.14	6.97	1.16
1980	0.26	0.57	9.52	6.97	1.16
1981	0.27	0.58	9.89	6.97	1.17
1982	0.35	0.64	10.27	6.97	1.19
1983	0.44	0.88	10.64	6.97	1.20
1984	0.38	0.96	11.02	6.97	1.21
1985	0.32	0.78	11.39	6.97	1.23
1986	0.27	0.78	11.77	6.97	1.24
1987	0.53	0.68	12.14	6.97	1.26
1988	0.41	0.66	12.52	6.97	1.27
1989	0.44	0.72	13.26	6.97	1.28

Table A.18: Data for North Branch Patapsco River at Cedarhurst, MD (USGS Gage ID: 01586000) for the warm period.

YEAR	$R - B_{Warm}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1976	0.45	0.89	8.02	6.97	1.16
1977	0.35	0.77	8.39	6.97	1.16
1978	0.36	0.96	8.77	6.97	1.16
1979	0.71	1.81	9.14	6.97	1.16
1980	0.32	0.89	9.52	6.97	1.16
1981	0.56	1.53	9.89	6.97	1.17
1982	0.53	0.98	10.27	6.97	1.19
1983	0.45	1.30	10.64	6.97	1.20
1984	0.41	1.22	11.02	6.97	1.21
1985	0.64	3.56	11.39	6.97	1.23
1986	0.55	1.14	11.77	6.97	1.24
1987	0.58	0.62	12.14	6.97	1.26
1988	0.63	0.98	12.52	6.97	1.27
1989	0.56	1.32	13.26	6.97	1.28

Table A.19: Data for Bacon Ridge Branch at Chesterfield, MD (USGS Gage ID: 01590500) for the annual period.

YEAR	$R - B_{Annual}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1976	0.32	0.77	8.02	6.97	1.16
1977	0.28	0.77	8.39	6.97	1.16
1978	0.44	0.83	8.77	6.97	1.16
1979	0.50	1.13	9.14	6.97	1.16
1980	0.27	0.60	9.52	6.97	1.16
1981	0.35	0.88	9.89	6.97	1.17
1982	0.40	0.70	10.27	6.97	1.19
1983	0.44	0.93	10.64	6.97	1.20
1984	0.39	1.00	11.02	6.97	1.21
1985	0.38	1.88	11.39	6.97	1.23
1986	0.31	0.88	11.77	6.97	1.24
1987	0.54	0.64	12.14	6.97	1.26
1988	0.44	0.74	12.52	6.97	1.27
1989	0.49	0.89	13.26	6.97	1.28

Table A.20: Data for Bacon Ridge Branch at Chesterfield, MD (USGS Gage ID: 01590500) for the cool period.

YEAR	$R - B_{Cool}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1976	0.29	0.57	8.02	6.97	1.16
1977	0.27	0.81	8.39	6.97	1.16
1978	0.46	0.82	8.77	6.97	1.16
1979	0.39	0.77	9.14	6.97	1.16
1980	0.26	0.57	9.52	6.97	1.16
1981	0.27	0.58	9.89	6.97	1.17
1982	0.35	0.64	10.27	6.97	1.19
1983	0.44	0.88	10.64	6.97	1.20
1984	0.38	0.96	11.02	6.97	1.21
1985	0.32	0.78	11.39	6.97	1.23
1986	0.27	0.78	11.77	6.97	1.24
1987	0.53	0.68	12.14	6.97	1.26
1988	0.41	0.66	12.52	6.97	1.27
1989	0.44	0.72	13.26	6.97	1.28

Table A.21: Data for Bacon Ridge Branch at Chesterfield, MD (USGS Gage ID: 01590500) for the warm period.

YEAR	$R - B_{Warm}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1976	0.45	0.89	8.02	6.97	1.16
1977	0.35	0.77	8.39	6.97	1.16
1978	0.36	0.96	8.77	6.97	1.16
1979	0.71	1.81	9.14	6.97	1.16
1980	0.32	0.89	9.52	6.97	1.16
1981	0.56	1.53	9.89	6.97	1.17
1982	0.53	0.98	10.27	6.97	1.19
1983	0.45	1.30	10.64	6.97	1.20
1984	0.41	1.22	11.02	6.97	1.21
1985	0.64	3.56	11.39	6.97	1.23
1986	0.55	1.14	11.77	6.97	1.24
1987	0.58	0.62	12.14	6.97	1.26
1988	0.63	0.98	12.52	6.97	1.27
1989	0.56	1.32	13.26	6.97	1.28

Table A.22: Data for Patuxent River Near Unity, MD (USGS Gage ID: 01591000) for the annual period.

YEAR	$R - B_{Annual}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1970	0.34	0.93	3.54	34.94	1.72
1971	0.59	1.00	3.61	34.94	1.71
1972	0.39	2.24	3.68	34.94	1.70
1973	0.33	0.78	3.74	34.94	1.69
1974	0.33	0.83	3.81	34.94	1.68
1975	0.55	1.24	3.87	34.94	1.67
1976	0.33	0.78	3.94	34.94	1.66
1977	0.34	0.76	4.00	34.94	1.65
1978	0.46	1.03	4.07	34.94	1.64
1979	0.49	1.23	4.14	34.94	1.63
1980	0.31	0.57	4.20	34.94	1.62
1981	0.30	0.74	4.25	34.94	1.64
1982	0.34	0.64	4.30	34.94	1.66
1983	0.38	1.05	4.35	34.94	1.68
1984	0.37	0.89	4.40	34.94	1.70
1985	0.42	0.93	4.45	34.94	1.72
1986	0.22	0.62	4.50	34.94	1.74
1987	0.44	0.96	4.55	34.94	1.76

YEAR	$R-B_{Annual}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1988	0.35	0.91	4.60	34.94	1.78
1989	0.41	0.84	4.65	34.94	1.79
1990	0.28	0.70	4.70	34.94	1.81

Table A.23: Data for Patuxent River Near Unity, MD (USGS Gage ID: 01591000) for the annual period.

YEAR	$R - B_{Cool}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1970	0.31	0.86	3.54	34.94	1.72
1971	0.41	0.79	3.61	34.94	1.71
1972	0.29	0.87	3.68	34.94	1.70
1973	0.34	0.73	3.74	34.94	1.69
1974	0.33	0.89	3.81	34.94	1.68
1975	0.39	0.82	3.87	34.94	1.67
1976	0.33	0.69	3.94	34.94	1.66
1977	0.35	0.82	4.00	34.94	1.65
1978	0.47	1.09	4.07	34.94	1.64
1979	0.46	0.70	4.14	34.94	1.63
1980	0.34	0.62	4.20	34.94	1.62
1981	0.30	0.79	4.25	34.94	1.64
1982	0.33	0.54	4.30	34.94	1.66
1983	0.39	1.03	4.35	34.94	1.68
1984	0.39	0.87	4.40	34.94	1.70
1985	0.43	0.69	4.45	34.94	1.72
1986	0.23	0.53	4.50	34.94	1.74
1987	0.39	0.76	4.55	34.94	1.76

YEAR	$R - B_{Cool}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1988	0.39	0.76	4.60	34.94	1.78
1989	0.47	0.73	4.65	34.94	1.79
1990	0.30	0.67	4.70	34.94	1.81

Table A.24: Data for Patuxent River Near Unity, MD (USGS Gage ID: 01591000) for the warm period.

YEAR	$R - B_{Warm}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1970	0.41	1.17	3.54	34.94	1.72
1971	0.75	1.48	3.61	34.94	1.71
1972	0.58	4.70	3.68	34.94	1.70
1973	0.27	1.13	3.74	34.94	1.69
1974	0.33	0.82	3.81	34.94	1.68
1975	0.78	1.84	3.87	34.94	1.67
1976	0.30	1.06	3.94	34.94	1.66
1977	0.29	0.71	4.00	34.94	1.65
1978	0.39	1.02	4.07	34.94	1.64
1979	0.56	2.14	4.14	34.94	1.63
1980	0.16	0.52	4.20	34.94	1.62
1981	0.31	0.79	4.25	34.94	1.64
1982	0.37	0.93	4.30	34.94	1.66
1983	0.34	1.17	4.35	34.94	1.68
1984	0.28	1.07	4.40	34.94	1.70
1985	0.36	1.50	4.45	34.94	1.72
1986	0.22	0.92	4.50	34.94	1.74
1987	0.56	1.46	4.55	34.94	1.76

YEAR	$R - B_{Warm}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1988	0.18	1.36	4.60	34.94	1.78
1989	0.25	1.19	4.65	34.94	1.79
1990	0.19	0.88	4.70	34.94	1.81

Table A.25: Data for Patuxent River Near Laurel, MD (USGS Gage ID: 01592500) for the annual period.

YEAR	$R - B_{Annual}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1970	0.56	0.93	4.11	132.56	1.97
1971	0.83	1.00	4.21	132.56	1.99
1972	0.55	2.24	4.31	132.56	2.01
1973	0.18	0.78	4.41	132.56	2.03
1974	0.26	0.83	4.51	132.56	2.05
1975	0.64	1.24	4.61	132.56	2.07
1976	0.39	0.78	4.70	132.56	2.09
1977	0.24	0.76	4.80	132.56	2.11
1978	0.60	1.03	4.90	132.56	2.13
1979	0.44	1.23	5.00	132.56	2.15
1980	0.38	0.57	5.10	132.56	2.17
1981	0.40	0.74	5.17	132.56	2.11
1982	0.26	0.64	5.24	132.56	2.05
1983	0.57	1.05	5.31	132.56	2.00
1984	0.61	0.89	5.39	132.56	1.95
1985	0.35	0.93	5.46	132.56	1.91
1986	0.17	0.62	5.53	132.56	1.87
1987	0.24	0.96	5.60	132.56	1.83

YEAR	$R - B_{Annual}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1988	0.31	0.91	5.67	132.56	1.79
1989	0.40	0.84	5.74	132.56	1.76
1990	0.36	0.70	5.81	132.56	1.72

Table A.26: Data for Patuxent River Near Laurel, MD (USGS Gage ID: 01592500) for the cool period.

YEAR	$R - B_{Cool}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1970	0.53	0.86	4.11	132.56	1.97
1971	0.50	0.79	4.21	132.56	1.99
1972	0.30	0.87	4.31	132.56	2.01
1973	0.18	0.73	4.41	132.56	2.03
1974	0.27	0.89	4.51	132.56	2.05
1975	0.20	0.82	4.61	132.56	2.07
1976	0.42	0.69	4.70	132.56	2.09
1977	0.29	0.82	4.80	132.56	2.11
1978	0.58	1.09	4.90	132.56	2.13
1979	0.44	0.70	5.00	132.56	2.15
1980	0.39	0.62	5.10	132.56	2.17
1981	0.40	0.79	5.17	132.56	2.11
1982	0.26	0.54	5.24	132.56	2.05
1983	0.57	1.03	5.31	132.56	2.00
1984	0.66	0.87	5.39	132.56	1.95
1985	0.45	0.69	5.46	132.56	1.91
1986	0.20	0.53	5.53	132.56	1.87
1987	0.26	0.76	5.60	132.56	1.83

YEAR	$R - B_{Cool}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1988	0.34	0.76	5.67	132.56	1.79
1989	0.44	0.73	5.74	132.56	1.76
1990	0.39	0.67	5.81	132.56	1.72

Table A.27: Data for Patuxent River Near Laurel, MD (USGS Gage ID: 01592500) for the warm period.

YEAR	$R - B_{Warm}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1970	0.64	1.17	4.11	132.56	1.97
1971	1.15	1.48	4.21	132.56	1.99
1972	0.93	4.70	4.31	132.56	2.01
1973	0.23	1.13	4.41	132.56	2.03
1974	0.19	0.82	4.51	132.56	2.05
1975	1.11	1.84	4.61	132.56	2.07
1976	0.19	1.06	4.70	132.56	2.09
1977	0.05	0.71	4.80	132.56	2.11
1978	0.70	1.02	4.90	132.56	2.13
1979	0.44	2.14	5.00	132.56	2.15
1980	0.23	0.52	5.10	132.56	2.17
1981	0.40	0.79	5.17	132.56	2.11
1982	0.27	0.93	5.24	132.56	2.05
1983	0.57	1.17	5.31	132.56	2.00
1984	0.35	1.07	5.39	132.56	1.95
1985	0.06	1.50	5.46	132.56	1.91
1986	0.02	0.92	5.53	132.56	1.87
1987	0.19	1.46	5.60	132.56	1.83

YEAR	$R - B_{Warm}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1988	0.09	1.36	5.67	132.56	1.79
1989	0.35	1.19	5.74	132.56	1.76
1990	0.23	0.88	5.81	132.56	1.72

Table A.28: Data for Little Patuxent River at Guilford, MD (USGS Gage ID: 01593500) for the annual period.

YEAR	$R - B_{Annual}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1970	0.54	0.72	8.14	38.19	0.60
1971	0.76	1.24	8.66	38.19	0.56
1972	0.75	2.14	9.18	38.19	0.52
1973	0.58	0.79	9.71	38.19	0.49
1974	0.54	0.83	10.23	38.19	0.47
1975	0.78	1.36	10.76	38.19	0.44
1976	0.51	0.85	11.28	38.19	0.42
1977	0.47	0.68	11.81	38.19	0.41
1978	0.64	0.88	12.33	38.19	0.39
1979	0.72	0.98	12.85	38.19	0.38
1980	0.41	0.64	13.38	38.19	0.36
1981	0.51	0.64	13.68	38.19	0.37
1982	0.51	0.65	13.98	38.19	0.37
1983	0.71	0.84	14.28	38.19	0.38
1984	0.65	0.88	14.59	38.19	0.38
1985	0.65	0.99	14.89	38.19	0.38
1986	0.45	0.54	15.19	38.19	0.39
1987	0.70	0.95	15.49	38.19	0.39

YEAR	$R - B_{Annual}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1988	0.66	0.75	15.80	38.19	0.39
1989	0.85	1.03	16.10	38.19	0.40
1990	0.59	0.71	16.40	38.19	0.40
1991	0.68	0.86	16.51	38.19	0.40
1992	0.71	0.68	16.62	38.19	0.40
1996	0.78	0.81	17.07	38.19	0.39
1997	0.59	0.90	17.19	38.19	0.39
1998	0.68	0.83	17.30	38.19	0.38
1999	0.68	0.90	17.41	38.19	0.38
2000	0.57	0.76	17.52	38.19	0.38

Table A.29: Data for Little Patuxent River at Guilford, MD (USGS Gage ID: 01593500) for the cool period.

YEAR	$R - B_{Cool}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1970	0.54	0.64	8.14	38.19	0.60
1971	0.67	0.76	8.66	38.19	0.56
1972	0.64	0.96	9.18	38.19	0.52
1973	0.60	0.71	9.71	38.19	0.49
1974	0.52	0.84	10.23	38.19	0.47
1975	0.61	0.97	10.76	38.19	0.44
1976	0.48	0.73	11.28	38.19	0.42
1977	0.47	0.81	11.81	38.19	0.41
1978	0.67	0.92	12.33	38.19	0.39
1979	0.61	0.71	12.85	38.19	0.38
1980	0.43	0.75	13.38	38.19	0.36
1981	0.39	0.66	13.68	38.19	0.37
1982	0.50	0.53	13.98	38.19	0.37
1983	0.73	0.78	14.28	38.19	0.38
1984	0.61	0.72	14.59	38.19	0.38
1985	0.58	0.75	14.89	38.19	0.38
1986	0.45	0.51	15.19	38.19	0.39
1987	0.61	0.73	15.49	38.19	0.39

YEAR	$R - B_{Cool}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1988	0.66	0.65	15.80	38.19	0.39
1989	0.92	0.87	16.10	38.19	0.40
1990	0.60	0.67	16.40	38.19	0.40
1991	0.68	0.68	16.51	38.19	0.40
1992	0.64	0.61	16.62	38.19	0.40
1996	0.71	0.74	17.07	38.19	0.39
1997	0.60	0.91	17.19	38.19	0.39
1998	0.72	0.77	17.30	38.19	0.38
1999	0.47	0.69	17.41	38.19	0.38
2000	0.54	0.69	17.52	38.19	0.38

Table A.30: Data for Little Patuxent River at Guilford, MD (USGS Gage ID: 01593500) for the warm period.

YEAR	$R - B_{Warm}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1970	0.53	1.00	8.14	38.19	0.60
1971	0.89	2.06	8.66	38.19	0.56
1972	0.95	4.22	9.18	38.19	0.52
1973	0.47	1.11	9.71	38.19	0.49
1974	0.61	0.97	10.23	38.19	0.47
1975	0.97	1.98	10.76	38.19	0.44
1976	0.64	1.16	11.28	38.19	0.42
1977	0.45	0.52	11.81	38.19	0.41
1978	0.45	0.88	12.33	38.19	0.39
1979	0.91	1.54	12.85	38.19	0.38
1980	0.31	0.58	13.38	38.19	0.36
1981	0.75	0.71	13.68	38.19	0.37
1982	0.54	0.97	13.98	38.19	0.37
1983	0.67	1.10	14.28	38.19	0.38
1984	0.79	1.44	14.59	38.19	0.38
1985	0.87	1.50	14.89	38.19	0.38
1986	0.44	0.69	15.19	38.19	0.39
1987	0.95	1.48	15.49	38.19	0.39

YEAR	$R - B_{Warm}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1988	0.64	1.07	15.80	38.19	0.39
1989	0.71	1.50	16.10	38.19	0.40
1990	0.56	0.95	16.40	38.19	0.40
1991	0.69	1.31	16.51	38.19	0.40
1992	0.88	0.76	16.62	38.19	0.40
1996	0.89	1.00	17.07	38.19	0.39
1997	0.55	3.81	17.19	38.19	0.39
1998	0.46	3.12	17.30	38.19	0.38
1999	1.00	2.69	17.41	38.19	0.38
2000	0.64	2.78	17.52	38.19	0.38

Table A.31: Data for Little Patuxent River at Savage, MD (USGS Gage ID: 01594000) for the annual period.

YEAR	$R - B_{Annual}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1986	0.31	0.54	10.09	98.15	0.60
1987	0.50	0.95	10.59	98.15	0.59
1988	0.44	0.75	11.09	98.15	0.58
1989	0.57	1.03	11.59	98.15	0.58
1990	0.41	0.71	12.09	98.15	0.57
1991	0.47	0.86	12.59	98.15	0.58
1992	0.46	0.68	13.09	98.15	0.58
1996	0.66	0.81	13.59	98.15	0.58
1997	0.50	0.90	14.09	98.15	0.58
1998	0.59	0.83	14.59	98.15	0.58
1999	0.59	0.90	15.09	98.15	0.58
2000	0.46	0.76	15.59	98.15	0.58

Table A.32: Data for Little Patuxent River at Savage, MD (USGS Gage ID: 01594000) for the cool period.

YEAR	$R - B_{Cool}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1986	0.31	0.69	10.09	98.15	0.60
1987	0.45	1.48	10.59	98.15	0.59
1988	0.45	1.07	11.09	98.15	0.58
1989	0.58	1.50	11.59	98.15	0.58
1990	0.43	0.95	12.09	98.15	0.57
1991	0.46	1.31	12.59	98.15	0.58
1992	0.40	0.76	13.09	98.15	0.58
1996	0.60	1.00	13.59	98.15	0.58
1997	0.51	3.81	14.09	98.15	0.58
1998	0.63	3.12	14.59	98.15	0.58
1999	0.38	2.69	15.09	98.15	0.58
2000	0.43	2.78	15.59	98.15	0.58

Table A.33: Data for Little Patuxent River at Savage, MD (USGS Gage ID: 01594000) for the warm period.

YEAR	$R - B_{Annual}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1986	0.35	0.69	10.09	98.15	0.60
1987	0.67	1.48	10.59	98.15	0.59
1988	0.42	1.07	11.09	98.15	0.58
1989	0.55	1.50	11.59	98.15	0.58
1990	0.37	0.95	12.09	98.15	0.57
1991	0.50	1.31	12.59	98.15	0.58
1992	0.61	0.76	13.09	98.15	0.58
1996	0.75	1.00	13.59	98.15	0.58
1997	0.38	3.81	14.09	98.15	0.58
1998	0.33	3.12	14.59	98.15	0.58
1999	0.97	2.69	15.09	98.15	0.58
2000	0.56	2.78	15.59	98.15	0.58

Table A.34: Data for Savage River Near Barton, MD (USGS Gage ID: 01596500) for the annual period.

YEAR	$R - B_{Annual}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1970	0.37	0.47	5.55	49.13	1.82
1971	0.35	0.53	5.71	49.13	1.81
1972	0.37	0.53	5.87	49.13	1.81
1973	0.36	0.60	6.04	49.13	1.80
1974	0.35	0.49	6.20	49.13	1.80
1975	0.43	0.70	6.37	49.13	1.79
1976	0.31	0.49	6.53	49.13	1.79
1977	0.39	0.56	6.70	49.13	1.78
1978	0.34	0.72	6.86	49.13	1.78
1980	0.37	0.61	7.19	49.13	1.77
1981	0.30	0.56	7.19	49.13	1.76
1982	0.30	0.48	7.19	49.13	1.76
1983	0.32	0.44	7.19	49.13	1.75
1984	0.36	0.53	7.19	49.13	1.75
1985	0.30	0.58	7.19	49.13	1.74
1986	0.47	0.68	7.19	49.13	1.74
1987	0.31	0.54	7.19	49.13	1.73
1988	0.39	0.72	7.19	49.13	1.73

YEAR	$R - B_{Annual}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1989	0.31	0.62	7.19	49.13	1.73
1990	0.27	0.64	7.19	49.13	1.72
1991	0.36	0.58	7.19	49.13	1.77
1992	0.28	0.54	7.19	49.13	1.81
1993	0.30	0.75	7.19	49.13	1.86
1994	0.35	0.70	7.19	49.13	1.90
1995	0.33	1.00	7.19	49.13	1.95

Table A.35: Data for Savage River Near Barton, MD (USGS Gage ID: 01645000) for the cool period.

YEAR	$R - B_{Cool}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1970	0.35	0.40	5.55	49.13	1.82
1971	0.35	0.53	5.71	49.13	1.81
1972	0.36	0.54	5.87	49.13	1.81
1973	0.37	0.52	6.04	49.13	1.80
1974	0.35	0.51	6.20	49.13	1.80
1975	0.43	0.85	6.37	49.13	1.79
1976	0.31	0.43	6.53	49.13	1.79
1977	0.39	0.66	6.70	49.13	1.78
1978	0.32	0.53	6.86	49.13	1.78
1980	0.37	0.60	7.19	49.13	1.77
1981	0.30	0.51	7.19	49.13	1.76
1982	0.29	0.41	7.19	49.13	1.76
1983	0.33	0.41	7.19	49.13	1.75
1984	0.35	0.46	7.19	49.13	1.75
1985	0.30	0.63	7.19	49.13	1.74
1986	0.48	0.81	7.19	49.13	1.74
1987	0.31	0.49	7.19	49.13	1.73
1988	0.37	0.61	7.19	49.13	1.73

YEAR	$R - B_{Cool}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1989	0.29	0.55	7.19	49.13	1.73
1990	0.24	0.50	7.19	49.13	1.72
1991	0.36	0.60	7.19	49.13	1.77
1992	0.28	0.54	7.19	49.13	1.81
1993	0.30	0.74	7.19	49.13	1.86
1994	0.35	0.67	7.19	49.13	1.90
1995	0.30	0.43	7.19	49.13	1.95

Table A.36: Data for Savage River Near Barton, MD (USGS Gage ID: 01596500) for the warm period.

YEAR	$R - B_{Warm}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1970	0.57	0.70	5.55	49.13	1.82
1971	0.41	0.66	5.71	49.13	1.81
1972	0.46	0.62	5.87	49.13	1.81
1973	0.33	0.88	6.04	49.13	1.80
1974	0.38	0.62	6.20	49.13	1.80
1975	0.43	0.54	6.37	49.13	1.79
1976	0.28	0.67	6.53	49.13	1.79
1977	0.35	0.44	6.70	49.13	1.78
1978	0.44	0.93	6.86	49.13	1.78
1980	0.38	0.77	7.19	49.13	1.77
1981	0.32	1.21	7.19	49.13	1.76
1982	0.33	1.45	7.19	49.13	1.76
1983	0.25	1.68	7.19	49.13	1.75
1984	0.36	1.37	7.19	49.13	1.75
1985	0.34	1.43	7.19	49.13	1.74
1986	0.30	1.43	7.19	49.13	1.74
1987	0.33	1.47	7.19	49.13	1.73
1988	0.53	1.58	7.19	49.13	1.73

YEAR	$R - B_{Warm}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1989	0.37	1.28	7.19	49.13	1.73
1990	0.41	1.42	7.19	49.13	1.72
1991	0.25	1.98	7.19	49.13	1.77
1992	0.27	1.40	7.19	49.13	1.81
1993	0.43	1.48	7.19	49.13	1.86
1994	0.34	1.45	7.19	49.13	1.90
1995	0.46	2.21	7.19	49.13	1.95

Table A.37: Data for Georges Creek at Franklin, MD (USGS Gage ID: 01599000) for the annual period.

YEAR	$R - B_{Annual}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1970	0.30	0.47	5.48	72.73	1.63
1971	0.24	0.53	5.49	72.73	1.62
1972	0.27	0.53	5.50	72.73	1.62
1973	0.27	0.60	5.51	72.73	1.61
1974	0.23	0.49	5.52	72.73	1.61
1975	0.31	0.70	5.53	72.73	1.61
1976	0.25	0.49	5.54	72.73	1.60
1977	0.34	0.56	5.55	72.73	1.60
1978	0.28	0.72	5.56	72.73	1.60
1980	0.34	0.61	5.57	72.73	1.59
1981	0.29	0.56	5.58	72.73	1.55
1982	0.28	0.48	5.59	72.73	1.51
1983	0.33	0.44	5.60	72.73	1.47
1984	0.37	0.53	5.61	72.73	1.43
1985	0.29	0.58	5.62	72.73	1.40
1986	0.34	0.68	5.63	72.73	1.37
1987	0.25	0.54	5.64	72.73	1.34
1988	0.32	0.72	5.65	72.73	1.32

YEAR	$R - B_{Annual}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1989	0.29	0.62	5.66	72.73	1.29
1990	0.27	0.64	5.67	72.73	1.27
1991	0.28	0.58	5.68	72.73	1.26
1992	0.27	0.54	5.69	72.73	1.26
1993	0.25	0.75	5.70	72.73	1.26
1994	0.30	0.70	5.71	72.73	1.25
1995	0.29	1.00	5.72	72.73	1.25

Table A.38: Data for Georges Creek at Franklin, MD (USGS Gage ID: 01599000) for the cool period.

YEAR	$R - B_{Cool}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1970	0.31	0.40	5.48	72.73	1.63
1971	0.24	0.53	5.49	72.73	1.62
1972	0.24	0.54	5.50	72.73	1.62
1973	0.26	0.52	5.51	72.73	1.61
1974	0.22	0.51	5.52	72.73	1.61
1975	0.29	0.85	5.53	72.73	1.61
1976	0.25	0.43	5.54	72.73	1.60
1977	0.34	0.66	5.55	72.73	1.60
1978	0.25	0.53	5.56	72.73	1.60
1980	0.35	0.60	5.57	72.73	1.59
1981	0.30	0.51	5.58	72.73	1.55
1982	0.26	0.41	5.59	72.73	1.51
1983	0.34	0.41	5.60	72.73	1.47
1984	0.36	0.46	5.61	72.73	1.43
1985	0.29	0.63	5.62	72.73	1.40
1986	0.34	0.81	5.63	72.73	1.37
1987	0.26	0.49	5.64	72.73	1.34
1988	0.31	0.61	5.65	72.73	1.32

YEAR	$R - B_{Cool}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1989	0.28	0.55	5.66	72.73	1.29
1990	0.23	0.50	5.67	72.73	1.27
1991	0.29	0.60	5.68	72.73	1.26
1992	0.27	0.54	5.69	72.73	1.26
1993	0.24	0.74	5.70	72.73	1.26
1994	0.30	0.67	5.71	72.73	1.25
1995	0.25	0.43	5.72	72.73	1.25

Table A.39: Data for Georges Creek at Franklin, MD (USGS Gage ID: 01599000) for the warm period.

YEAR	$R - B_{Warm}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1970	0.23	0.70	5.48	72.73	1.63
1971	0.27	0.66	5.49	72.73	1.62
1972	0.40	0.62	5.50	72.73	1.62
1973	0.37	0.88	5.51	72.73	1.61
1974	0.28	0.62	5.52	72.73	1.61
1975	0.42	0.54	5.53	72.73	1.61
1976	0.29	0.67	5.54	72.73	1.60
1977	0.22	0.44	5.55	72.73	1.60
1978	0.43	0.93	5.56	72.73	1.60
1980	0.31	0.77	5.57	72.73	1.59
1981	0.25	1.21	5.58	72.73	1.55
1982	0.39	1.45	5.59	72.73	1.51
1983	0.25	1.68	5.60	72.73	1.47
1984	0.47	1.37	5.61	72.73	1.43
1985	0.25	1.43	5.62	72.73	1.40
1986	0.28	1.43	5.63	72.73	1.37
1987	0.18	1.47	5.64	72.73	1.34
1988	0.37	1.58	5.65	72.73	1.32

YEAR	$R - B_{Warm}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1989	0.34	1.28	5.66	72.73	1.29
1990	0.41	1.42	5.67	72.73	1.27
1991	0.13	1.98	5.68	72.73	1.26
1992	0.27	1.40	5.69	72.73	1.26
1993	0.35	1.48	5.70	72.73	1.26
1994	0.22	1.45	5.71	72.73	1.25
1995	0.37	2.21	5.72	72.73	1.25

Table A.40: Data for Catoctin Creek Near Middletown, MD (USGS Gage ID: 01637500) for the annual period.

YEAR	$R - B_{Annual}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1970	0.34	1.04	4.04	67.35	0.98
1971	0.30	0.79	4.04	67.35	0.98
1972	0.37	1.50	4.04	67.35	0.99
1973	0.32	0.98	4.04	67.35	0.99
1974	0.32	0.78	4.04	67.35	0.99
1975	0.42	1.29	4.04	67.35	0.99
1976	0.31	0.90	4.04	67.35	0.99
1977	0.58	1.06	4.04	67.35	0.99
1978	0.40	0.93	4.04	67.35	0.99
1979	0.50	1.46	4.04	67.35	0.99
1980	0.30	0.76	4.04	67.35	0.99
1981	0.37	1.14	4.04	67.35	0.98
1982	0.29	0.83	4.04	67.35	0.97
1983	0.31	0.76	4.04	67.35	0.96
1984	0.38	1.42	4.04	67.35	0.94
1985	0.40	0.74	4.04	67.35	0.93
1986	0.27	0.86	4.04	67.35	0.92
1987	0.33	1.10	4.04	67.35	0.91

YEAR	$R - B_{Annual}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1988	0.41	1.22	4.04	67.35	0.90
1989	0.32	1.04	4.04	67.35	0.89
1990	0.27	0.59	4.04	67.35	0.88
1992	0.42	0.80	4.10	67.35	0.87
1993	0.38	1.09	4.13	67.35	0.87
1994	0.37	0.98	4.16	67.35	0.86
1996	0.54	0.94	4.22	67.35	0.85
1997	0.30	0.80	4.25	67.35	0.85
1998	0.46	0.96	4.28	67.35	0.84
1999	0.40	0.91	4.31	67.35	0.84
2000	0.34	0.70	4.34	67.35	0.83

Table A.41: Data for Catoctin Creek Near Middletown, MD (USGS Gage ID: 01637500) for the cool period.

YEAR	$R - B_{Cool}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1970	0.29	1.06	4.04	67.35	0.98
1971	0.30	0.75	4.04	67.35	0.98
1972	0.28	0.91	4.04	67.35	0.99
1973	0.32	0.73	4.04	67.35	0.99
1974	0.32	0.91	4.04	67.35	0.99
1975	0.35	1.04	4.04	67.35	0.99
1976	0.30	0.77	4.04	67.35	0.99
1977	0.57	1.34	4.04	67.35	0.99
1978	0.40	0.92	4.04	67.35	0.99
1979	0.44	0.79	4.04	67.35	0.99
1980	0.30	0.82	4.04	67.35	0.99
1981	0.36	1.18	4.04	67.35	0.98
1982	0.25	0.62	4.04	67.35	0.97
1983	0.31	0.81	4.04	67.35	0.96
1984	0.38	1.32	4.04	67.35	0.94
1985	0.39	0.61	4.04	67.35	0.93
1986	0.27	0.73	4.04	67.35	0.92
1987	0.32	1.28	4.04	67.35	0.91

YEAR	$R - B_{Cool}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1988	0.43	1.41	4.04	67.35	0.90
1989	0.33	0.85	4.04	67.35	0.89
1990	0.27	0.56	4.04	67.35	0.88
1992	0.38	0.86	4.10	67.35	0.87
1993	0.38	1.05	4.13	67.35	0.87
1994	0.37	0.99	4.16	67.35	0.86
1996	0.45	0.90	4.22	67.35	0.85
1997	0.29	0.75	4.25	67.35	0.85
1998	0.47	1.01	4.28	67.35	0.84
1999	0.33	0.77	4.31	67.35	0.84
2000	0.33	0.69	4.34	67.35	0.83

Table A.42: Data for Catoctin Creek Near Middletown, MD (USGS Gage ID: 01637500) for the warm period.

YEAR	$R - B_{Warm}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1970	0.53	1.13	4.04	67.35	0.98
1971	0.34	1.01	4.04	67.35	0.98
1972	0.57	2.72	4.04	67.35	0.99
1973	0.33	1.74	4.04	67.35	0.99
1974	0.32	0.63	4.04	67.35	0.99
1975	0.55	1.78	4.04	67.35	0.99
1976	0.39	1.24	4.04	67.35	0.99
1977	0.70	0.58	4.04	67.35	0.99
1978	0.39	1.09	4.04	67.35	0.99
1979	0.74	2.44	4.04	67.35	0.99
1980	0.27	0.63	4.04	67.35	0.99
1981	0.41	1.23	4.04	67.35	0.98
1982	0.43	1.30	4.04	67.35	0.97
1983	0.31	0.67	4.04	67.35	0.96
1984	0.41	1.83	4.04	67.35	0.94
1985	0.46	1.06	4.04	67.35	0.93
1986	0.37	1.30	4.04	67.35	0.92
1987	0.49	0.74	4.04	67.35	0.91

YEAR	$R-B_{Warm}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1988	0.23	0.74	4.04	67.35	0.90
1989	0.25	1.50	4.04	67.35	0.89
1990	0.24	0.77	4.04	67.35	0.88
1992	0.53	0.83	4.10	67.35	0.87
1993	0.51	1.89	4.13	67.35	0.87
1994	0.30	1.65	4.16	67.35	0.86
1996	0.64	1.25	4.22	67.35	0.85
1997	0.38	2.71	4.25	67.35	0.85
1998	0.32	2.66	4.28	67.35	0.84
1999	0.69	2.40	4.31	67.35	0.84
2000	0.38	1.89	4.34	67.35	0.83

Table A.43: Data for Big Pipe Creek at Bruceville, MD (USGS Gage ID: 01639500) for the annual period.

YEAR	$R - B_{Annual}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1980	0.44	0.94	4.14	102.97	1.73
1981	0.45	0.88	4.20	102.97	1.75
1982	0.40	0.61	4.26	102.97	1.77
1983	0.43	0.68	4.33	102.97	1.79
1984	0.48	0.78	4.39	102.97	1.80
1985	0.50	1.06	4.45	102.97	1.82
1986	0.27	0.61	4.51	102.97	1.84
1987	0.40	0.97	4.57	102.97	1.86
1988	0.39	0.95	4.64	102.97	1.88
1989	0.49	0.65	4.70	102.97	1.89
1990	0.35	0.74	4.76	102.97	1.91
1991	0.42	1.27	4.79	102.97	1.91
1992	0.45	0.62	4.83	102.97	1.91
1993	0.46	0.84	4.86	102.97	1.91
1994	0.47	1.23	4.90	102.97	1.91
1995	0.44	0.91	4.93	102.97	1.91
1996	0.59	0.83	4.96	102.97	1.92
1997	0.39	0.91	5.00	102.97	1.92

YEAR	$R - B_{Annual}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1998	0.52	0.75	5.03	102.97	1.92

Table A.44: Data for Big Pipe Creek at Bruceville, MD (USGS Gage ID: 01639500) for the cool period.

YEAR	$R - B_{Cool}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1980	0.47	0.99	4.14	102.97	1.73
1981	0.41	0.84	4.20	102.97	1.75
1982	0.37	0.52	4.26	102.97	1.77
1983	0.46	0.69	4.33	102.97	1.79
1984	0.47	0.70	4.39	102.97	1.80
1985	0.52	1.05	4.45	102.97	1.82
1986	0.27	0.49	4.51	102.97	1.84
1987	0.38	0.74	4.57	102.97	1.86
1988	0.42	0.73	4.64	102.97	1.88
1989	0.47	0.71	4.70	102.97	1.89
1990	0.38	0.79	4.76	102.97	1.91
1991	0.41	0.57	4.79	102.97	1.91
1992	0.43	0.65	4.83	102.97	1.91
1993	0.46	0.71	4.86	102.97	1.91
1994	0.47	1.34	4.90	102.97	1.91
1995	0.42	0.58	4.93	102.97	1.91
1996	0.58	0.70	4.96	102.97	1.92
1997	0.40	0.94	5.00	102.97	1.92

YEAR	$R - B_{Cool}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1998	0.55	0.76	5.03	102.97	1.92

Table A.45: Data for Big Pipe Creek at Bruceville, MD (USGS Gage ID: 01639500) for the warm period.

YEAR	$R - B_{Warm}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1980	0.24	0.86	4.14	102.97	1.73
1981	0.54	1.05	4.20	102.97	1.75
1982	0.47	0.86	4.26	102.97	1.77
1983	0.30	0.69	4.33	102.97	1.79
1984	0.53	1.06	4.39	102.97	1.80
1985	0.40	1.18	4.45	102.97	1.82
1986	0.22	0.92	4.51	102.97	1.84
1987	0.45	1.53	4.57	102.97	1.86
1988	0.19	0.91	4.64	102.97	1.88
1989	0.51	0.65	4.70	102.97	1.89
1990	0.23	0.72	4.76	102.97	1.91
1991	0.49	2.61	4.79	102.97	1.91
1992	0.51	0.68	4.83	102.97	1.91
1993	0.48	1.21	4.86	102.97	1.91
1994	0.44	1.11	4.90	102.97	1.91
1995	0.51	1.37	4.93	102.97	1.91
1996	0.61	1.16	4.96	102.97	1.92
1997	0.15	0.88	5.00	102.97	1.92

YEAR	$R - B_{Warm}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1998	0.37	0.84	5.03	102.97	1.92

Table A.46: Data for Owens Creek at Lantz, MD (USGS Gage ID: 01640500) for the annual period.

YEAR	$R - B_{Annual}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1970	0.32	1.04	7.94	6.14	1.10
1971	0.31	0.79	7.95	6.14	1.10
1972	0.36	1.50	7.96	6.14	1.10
1973	0.35	0.98	7.97	6.14	1.10
1974	0.32	0.78	7.98	6.14	1.10
1975	0.50	1.29	7.99	6.14	1.10
1976	0.30	0.90	8.00	6.14	1.10
1977	0.44	1.06	8.01	6.14	1.10
1978	0.35	0.93	8.02	6.14	1.10
1979	0.46	1.46	8.03	6.14	1.10
1980	0.28	0.76	8.04	6.14	1.10
1981	0.47	1.14	8.05	6.14	1.10
1982	0.26	0.83	8.06	6.14	1.10
1983	0.35	0.76	8.07	6.14	1.10
1984	0.47	1.42	8.08	6.14	1.10

Table A.47: Data for Owens Creek at Lantz, MD (USGS Gage ID: 01640500) for the cool period.

YEAR	$R - B_{Cool}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1970	0.29	1.06	7.94	6.14	1.10
1971	0.30	0.75	7.95	6.14	1.10
1972	0.28	0.91	7.96	6.14	1.10
1973	0.32	0.73	7.97	6.14	1.10
1974	0.32	0.91	7.98	6.14	1.10
1975	0.44	1.04	7.99	6.14	1.10
1976	0.26	0.77	8.00	6.14	1.10
1977	0.45	1.34	8.01	6.14	1.10
1978	0.35	0.92	8.02	6.14	1.10
1979	0.42	0.79	8.03	6.14	1.10
1980	0.29	0.82	8.04	6.14	1.10
1981	0.50	1.18	8.05	6.14	1.10
1982	0.22	0.62	8.06	6.14	1.10
1983	0.37	0.81	8.07	6.14	1.10
1984	0.48	1.32	8.08	6.14	1.10

Table A.48: Data for Owens Creek at Lantz, MD (USGS Gage ID: 01640500) for the warm period.

YEAR	$R - B_{Warm}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1970	0.42	1.13	7.94	6.14	1.10
1971	0.37	1.01	7.95	6.14	1.10
1972	0.55	2.72	7.96	6.14	1.10
1973	0.49	1.74	7.97	6.14	1.10
1974	0.35	0.63	7.98	6.14	1.10
1975	0.59	1.78	7.99	6.14	1.10
1976	0.51	1.24	8.00	6.14	1.10
1977	0.34	0.58	8.01	6.14	1.10
1978	0.38	1.09	8.02	6.14	1.10
1979	0.59	2.44	8.03	6.14	1.10
1980	0.21	0.63	8.04	6.14	1.10
1981	0.40	1.23	8.05	6.14	1.10
1982	0.38	1.30	8.06	6.14	1.10
1983	0.23	0.67	8.07	6.14	1.10
1984	0.40	1.83	8.08	6.14	1.10

Table A.49: Data for Hunting Creek at Jimtown, MD (USGS Gage ID: 01641000) for the annual period.

YEAR	$R - B_{Annual}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1970	0.29	1.04	3.94	18.63	0.37
1971	0.26	0.79	3.96	18.63	0.37
1972	0.34	1.50	3.97	18.63	0.37
1973	0.39	0.98	3.99	18.63	0.37
1974	0.29	0.78	4.00	18.63	0.38
1975	0.46	1.29	4.02	18.63	0.38
1976	0.27	0.90	4.03	18.63	0.38
1977	0.47	1.06	4.05	18.63	0.38
1978	0.34	0.93	4.06	18.63	0.38
1979	0.50	1.46	4.08	18.63	0.38
1980	0.30	0.76	4.09	18.63	0.38
1981	0.46	1.14	4.11	18.63	0.38
1982	0.25	0.83	4.12	18.63	0.38
1983	0.39	0.76	4.14	18.63	0.38
1984	0.41	1.42	4.15	18.63	0.38
1985	0.22	0.74	4.17	18.63	0.38
1986	0.23	0.86	4.19	18.63	0.38
1987	0.35	1.10	4.20	18.63	0.38

YEAR	$R-B_{Annual}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1988	0.39	1.22	4.22	18.63	0.38
1989	0.37	1.04	4.23	18.63	0.38
1990	0.25	0.59	4.25	18.63	0.38
1991	0.31	0.80	4.30	18.63	0.37

Table A.50: Data for Hunting Creek at Jimtown, MD (USGS Gage ID: 01641000) for the cool period.

YEAR	$R - B_{Cool}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1970	0.29	1.06	3.94	18.63	0.37
1971	0.25	0.75	3.96	18.63	0.37
1972	0.27	0.91	3.97	18.63	0.37
1973	0.37	0.73	3.99	18.63	0.37
1974	0.30	0.91	4.00	18.63	0.38
1975	0.40	1.04	4.02	18.63	0.38
1976	0.26	0.77	4.03	18.63	0.38
1977	0.48	1.34	4.05	18.63	0.38
1978	0.34	0.92	4.06	18.63	0.38
1979	0.41	0.79	4.08	18.63	0.38
1980	0.31	0.82	4.09	18.63	0.38
1981	0.50	1.18	4.11	18.63	0.38
1982	0.17	0.62	4.12	18.63	0.38
1983	0.41	0.81	4.14	18.63	0.38
1984	0.37	1.32	4.15	18.63	0.38
1985	0.21	0.61	4.17	18.63	0.38
1986	0.23	0.73	4.19	18.63	0.38
1987	0.32	1.28	4.20	18.63	0.38

YEAR	$R - B_{Cool}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1988	0.41	1.41	4.22	18.63	0.38
1989	0.38	0.85	4.23	18.63	0.38
1990	0.25	0.56	4.25	18.63	0.38
1991	0.31	0.86	4.30	18.63	0.37

Table A.51: Data for Hunting Creek at Jimtown, MD (USGS Gage ID: 01641000) for the warm period.

YEAR	$R - B_{Warm}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1970	0.31	1.04	3.94	18.63	0.37
1971	0.33	0.79	3.96	18.63	0.37
1972	0.53	1.50	3.97	18.63	0.37
1973	0.50	0.98	3.99	18.63	0.37
1974	0.20	0.78	4.00	18.63	0.38
1975	0.57	1.29	4.02	18.63	0.38
1976	0.34	0.90	4.03	18.63	0.38
1977	0.26	1.06	4.05	18.63	0.38
1978	0.33	0.93	4.06	18.63	0.38
1979	0.73	1.46	4.08	18.63	0.38
1980	0.14	0.76	4.09	18.63	0.38
1981	0.37	1.14	4.11	18.63	0.38
1982	0.44	0.83	4.12	18.63	0.38
1983	0.23	0.76	4.14	18.63	0.38
1984	0.55	1.42	4.15	18.63	0.38
1985	0.26	0.74	4.17	18.63	0.38
1986	0.32	0.86	4.19	18.63	0.38
1987	0.53	1.10	4.20	18.63	0.38

YEAR	$R - B_{Warm}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1988	0.17	1.22	4.22	18.63	0.38
1989	0.32	1.04	4.23	18.63	0.38
1990	0.27	0.59	4.25	18.63	0.38
1991	0.34	0.80	4.30	18.63	0.37

Table A.52: Data for Linganore Creek Near Frederick, MD (USGS Gage ID: 01642500) for the annual period.

YEAR	$R - B_{Annual}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1970	0.39	0.78	3.86	82.19	2.53
1971	0.47	0.82	3.86	82.19	2.49
1972	0.57	2.23	3.86	82.19	2.46
1973	0.27	0.69	3.87	82.19	2.42
1974	0.31	0.84	3.87	82.19	2.39
1975	0.49	1.03	3.88	82.19	2.36
1976	0.40	0.75	3.88	82.19	2.33
1977	0.43	0.81	3.89	82.19	2.30
1978	0.44	0.76	3.89	82.19	2.27
1979	0.54	0.84	3.89	82.19	2.24
1980	0.34	0.97	3.90	82.19	2.21
1981	0.31	0.76	3.96	82.19	2.21
1982	0.39	0.81	4.02	82.19	2.22

Table A.53: Data for Linganore Creek Near Frederick, MD (USGS Gage ID: 01642500) for the cool period.

YEAR	$R - B_{Cool}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1970	0.38	0.61	3.86	82.19	2.53
1971	0.43	0.65	3.86	82.19	2.49
1972	0.35	0.99	3.86	82.19	2.46
1973	0.26	0.63	3.87	82.19	2.42
1974	0.27	0.87	3.87	82.19	2.39
1975	0.31	0.66	3.88	82.19	2.36
1976	0.40	0.75	3.88	82.19	2.33
1977	0.43	0.76	3.89	82.19	2.30
1978	0.45	0.73	3.89	82.19	2.27
1979	0.51	0.66	3.89	82.19	2.24
1980	0.37	1.05	3.90	82.19	2.21
1981	0.29	0.77	3.96	82.19	2.21
1982	0.35	0.64	4.02	82.19	2.22

Table A.54: Data for Linganore Creek Near Frederick, MD (USGS Gage ID: 01642500) for the warm period.

YEAR	$R - B_{Warm}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1970	0.44	1.12	3.86	82.19	2.53
1971	0.55	1.20	3.86	82.19	2.49
1972	0.85	4.21	3.86	82.19	2.46
1973	0.33	0.98	3.87	82.19	2.42
1974	0.44	0.95	3.87	82.19	2.39
1975	0.73	1.54	3.88	82.19	2.36
1976	0.40	0.91	3.88	82.19	2.33
1977	0.41	1.02	3.89	82.19	2.30
1978	0.35	0.94	3.89	82.19	2.27
1979	0.61	1.30	3.89	82.19	2.24
1980	0.16	0.82	3.90	82.19	2.21
1981	0.35	0.85	3.96	82.19	2.21
1982	0.46	1.17	4.02	82.19	2.22

Table A.55: Data for Monacacy River at Jug Bridge Near Frederick, MD (USGS Gage ID: 01643000) for the annual period.

YEAR	$R - B_{Annual}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1973	0.41	1.05	3.85	1.24	2.07
1974	0.45	0.84	3.95	1.24	2.07
1975	0.50	0.86	4.06	1.24	2.07
1976	0.41	0.64	4.17	1.24	2.07
1977	0.56	1.08	4.27	1.24	2.07
1978	0.45	0.68	4.38	1.24	2.07
1980	0.37	0.83	4.59	1.24	2.07
1981	0.46	0.67	4.69	1.24	2.07
1982	0.38	0.59	4.80	1.24	2.07
1983	0.49	0.76	4.90	1.24	2.07
1984	0.52	0.75	5.01	1.24	2.07
1985	0.44	0.71	5.11	1.24	2.07
1986	0.34	0.40	5.22	1.24	2.07
1987	0.42	0.70	5.32	1.24	2.07
1988	0.45	0.92	5.43	1.24	2.07
1989	0.41	0.60	5.54	1.24	2.07
1990	0.39	0.73	5.64	1.24	2.07
1991	0.43	0.72	6.06	1.24	2.07

YEAR	$R-B_{Annual}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1992	0.45	0.67	6.47	1.24	2.07
1993	0.47	0.69	6.89	1.24	2.07
1994	0.36	0.66	7.30	1.24	2.07
1995	0.40	0.59	7.72	1.24	2.07
1997	0.39	0.78	8.55	1.24	2.07
1998	0.51	0.84	8.96	1.24	2.07
1999	0.39	0.92	9.38	1.24	2.07
2000	0.41	0.71	9.79	1.24	2.07

Table A.56: Data for Monacacy River at Jug Bridge Near Frederick, MD (USGS Gage ID: 01643000) for the cool period.

YEAR	$R-B_{Cool}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1973	0.41	0.54	3.85	1.24	2.07
1974	0.46	0.89	3.95	1.24	2.07
1975	0.42	0.71	4.06	1.24	2.07
1976	0.42	0.63	4.17	1.24	2.07
1977	0.58	1.34	4.27	1.24	2.07
1978	0.47	0.66	4.38	1.24	2.07
1980	0.39	0.75	4.59	1.24	2.07
1981	0.45	0.74	4.69	1.24	2.07
1982	0.35	0.47	4.80	1.24	2.07
1983	0.51	0.74	4.90	1.24	2.07
1984	0.52	0.76	5.01	1.24	2.07
1985	0.44	0.66	5.11	1.24	2.07
1986	0.36	0.43	5.22	1.24	2.07
1987	0.41	0.59	5.32	1.24	2.07
1988	0.49	0.97	5.43	1.24	2.07
1989	0.40	0.67	5.54	1.24	2.07
1990	0.42	0.62	5.64	1.24	2.07
1991	0.44	0.77	6.06	1.24	2.07

YEAR	$R - B_{Cool}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1992	0.45	0.64	6.47	1.24	2.07
1993	0.48	0.77	6.89	1.24	2.07
1994	0.37	0.70	7.30	1.24	2.07
1995	0.40	0.58	7.72	1.24	2.07
1997	0.41	0.72	8.55	1.24	2.07
1998	0.54	0.87	8.96	1.24	2.07
1999	0.34	0.72	9.38	1.24	2.07
2000	0.41	0.54	9.79	1.24	2.07

Table A.57: Data for Monacacy River at Jug Bridge Near Frederick, MD (USGS Gage ID: 01643000) for the warm period.

YEAR	$R - B_{Warm}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1973	0.42	0.60	3.85	1.24	2.07
1974	0.33	0.86	3.95	1.24	2.07
1975	0.59	1.19	4.06	1.24	2.07
1976	0.33	0.79	4.17	1.24	2.07
1977	0.23	0.62	4.27	1.24	2.07
1978	0.35	0.84	4.38	1.24	2.07
1980	0.13	1.11	4.59	1.24	2.07
1981	0.47	0.92	4.69	1.24	2.07
1982	0.47	1.30	4.80	1.24	2.07
1983	0.34	1.32	4.90	1.24	2.07
1984	0.48	1.09	5.01	1.24	2.07
1985	0.44	1.19	5.11	1.24	2.07
1986	0.19	1.12	5.22	1.24	2.07
1987	0.46	1.12	5.32	1.24	2.07
1988	0.13	1.20	5.43	1.24	2.07
1989	0.43	0.97	5.54	1.24	2.07
1990	0.27	1.31	5.64	1.24	2.07
1991	0.40	1.26	6.06	1.24	2.07

YEAR	$R - B_{Warm}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1992	0.46	1.09	6.47	1.24	2.07
1993	0.32	0.89	6.89	1.24	2.07
1994	0.28	0.95	7.30	1.24	2.07
1995	0.41	1.10	7.72	1.24	2.07
1997	0.20	1.00	8.55	1.24	2.07
1998	0.28	1.28	8.96	1.24	2.07
1999	0.61	1.44	9.38	1.24	2.07
2000	0.39	1.34	9.79	1.24	2.07

Table A.58: Data for Bennett Creek at Park Mills, MD (USGS Gage ID: 01643500) for the annual period.

YEAR	$R-B_{Annual}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1973	0.40	1.05	4.27	62.84	1.05
1974	0.38	0.84	4.28	62.84	1.04
1975	0.47	0.86	4.29	62.84	1.02
1976	0.38	0.64	4.30	62.84	1.01
1977	0.40	1.08	4.31	62.84	1.00
1978	0.48	0.68	4.32	62.84	0.98
1980	0.32	0.83	4.33	62.84	0.96
1981	0.41	0.67	4.37	62.84	0.98
1982	0.42	0.59	4.40	62.84	1.00
1983	0.40	0.76	4.44	62.84	1.01
1984	0.40	0.75	4.47	62.84	1.02
1985	0.43	0.71	4.51	62.84	1.03
1986	0.27	0.40	4.54	62.84	1.04
1987	0.48	0.70	4.58	62.84	1.05
1988	0.42	0.92	4.61	62.84	1.06
1989	0.41	0.60	4.65	62.84	1.07
1990	0.33	0.73	4.68	62.84	1.08
1991	0.39	0.72	4.70	62.84	1.08

YEAR	$R - B_{Annual}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1992	0.36	0.67	4.71	62.84	1.08
1993	0.43	0.69	4.73	62.84	1.07
1994	0.46	0.66	4.75	62.84	1.07
1995	0.34	0.59	4.76	62.84	1.07
1997	0.38	0.78	4.79	62.84	1.06
1998	0.53	0.84	4.81	62.84	1.06
1999	0.39	0.92	4.82	62.84	1.06
2000	0.37	0.71	4.84	62.84	1.06

Table A.59: Data for Bennett Creek at Park Mills, MD (USGS Gage ID: 01643500) for the cool period.

YEAR	$R - B_{Cool}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1973	0.41	0.54	4.27	62.84	1.05
1974	0.38	0.89	4.28	62.84	1.04
1975	0.35	0.71	4.29	62.84	1.02
1976	0.38	0.63	4.30	62.84	1.01
1977	0.41	1.34	4.31	62.84	1.00
1978	0.51	0.66	4.32	62.84	0.98
1980	0.35	0.75	4.33	62.84	0.96
1981	0.42	0.74	4.37	62.84	0.98
1982	0.41	0.47	4.40	62.84	1.00
1983	0.43	0.74	4.44	62.84	1.01
1984	0.41	0.76	4.47	62.84	1.02
1985	0.43	0.66	4.51	62.84	1.03
1986	0.27	0.43	4.54	62.84	1.04
1987	0.34	0.59	4.58	62.84	1.05
1988	0.47	0.97	4.61	62.84	1.06
1989	0.46	0.67	4.65	62.84	1.07
1990	0.36	0.62	4.68	62.84	1.08
1991	0.39	0.77	4.70	62.84	1.08

YEAR	$R - B_{Cool}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1992	0.34	0.64	4.71	62.84	1.08
1993	0.44	0.77	4.73	62.84	1.07
1994	0.49	0.70	4.75	62.84	1.07
1995	0.30	0.58	4.76	62.84	1.07
1997	0.39	0.72	4.79	62.84	1.06
1998	0.57	0.87	4.81	62.84	1.06
1999	0.29	0.72	4.82	62.84	1.06
2000	0.34	0.54	4.84	62.84	1.06

Table A.60: Data for Bennett Creek at Park Mills, MD (USGS Gage ID: 01643500) for the warm period.

YEAR	$R - B_{Warm}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1973	0.35	0.60	4.27	62.84	1.05
1974	0.37	0.86	4.28	62.84	1.04
1975	0.68	1.19	4.29	62.84	1.02
1976	0.36	0.79	4.30	62.84	1.01
1977	0.31	0.62	4.31	62.84	1.00
1978	0.34	0.84	4.32	62.84	0.98
1980	0.14	1.11	4.33	62.84	0.96
1981	0.38	0.92	4.37	62.84	0.98
1982	0.43	1.30	4.40	62.84	1.00
1983	0.26	1.32	4.44	62.84	1.01
1984	0.30	1.09	4.47	62.84	1.02
1985	0.46	1.19	4.51	62.84	1.03
1986	0.23	1.12	4.54	62.84	1.04
1987	0.71	1.12	4.58	62.84	1.05
1988	0.20	1.20	4.61	62.84	1.06
1989	0.18	0.97	4.65	62.84	1.07
1990	0.21	1.31	4.68	62.84	1.08
1991	0.29	1.26	4.70	62.84	1.08

YEAR	$R - B_{Warm}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1992	0.42	1.09	4.71	62.84	1.08
1993	0.32	0.89	4.73	62.84	1.07
1994	0.33	0.95	4.75	62.84	1.07
1995	0.48	1.10	4.76	62.84	1.07
1997	0.20	1.00	4.79	62.84	1.06
1998	0.23	1.28	4.81	62.84	1.06
1999	0.71	1.44	4.82	62.84	1.06
2000	0.46	1.34	4.84	62.84	1.06

Table A.61: Data for Seneca Creek at Dawsonville, MD (USGS Gage ID: 01645000) for the annual period.

YEAR	$R - B_{Annual}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1970	0.45	0.74	4.91	102.04	1.14
1971	0.69	1.33	5.18	102.04	1.11
1972	0.47	1.91	5.44	102.04	1.09
1973	0.47	0.93	5.71	102.04	1.07
1974	0.39	0.75	5.98	102.04	1.05
1975	0.65	0.96	6.25	102.04	1.04
1976	0.43	0.75	6.52	102.04	1.02
1977	0.41	0.79	6.78	102.04	1.01
1978	0.57	0.72	7.05	102.04	1.00
1979	0.65	1.03	7.32	102.04	0.99
1980	0.43	0.78	7.59	102.04	0.98
1981	0.38	0.66	7.98	102.04	1.00
1982	0.48	0.70	8.37	102.04	1.01
1983	0.46	0.84	8.77	102.04	1.02
1984	0.39	0.74	9.16	102.04	1.04
1985	0.38	0.71	9.55	102.04	1.05
1986	0.30	0.68	9.94	102.04	1.06
1987	0.50	1.06	10.34	102.04	1.07

YEAR	$R - B_{Annual}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1988	0.47	0.69	10.73	102.04	1.08
1989	0.51	0.90	11.12	102.04	1.09
1990	0.41	0.79	11.51	102.04	1.10

Table A.62: Data for Seneca Creek at Dawsonville, MD (USGS Gage ID: 01645000) for the cool period.

YEAR	$R - B_{(Cool)}$	$P_f(inches)$	I(%)	DA(mi^2)	SII
1970	0.36	0.70	4.91	102.04	1.14
1971	0.46	0.80	5.18	102.04	1.11
1972	0.34	0.79	5.44	102.04	1.09
1973	0.47	0.68	5.71	102.04	1.07
1974	0.40	0.82	5.98	102.04	1.05
1975	0.43	0.84	6.25	102.04	1.04
1976	0.43	0.73	6.52	102.04	1.02
1977	0.42	0.87	6.78	102.04	1.01
1978	0.59	0.69	7.05	102.04	1.00
1979	0.55	0.93	7.32	102.04	0.99
1980	0.47	0.78	7.59	102.04	0.98
1981	0.37	0.64	7.98	102.04	1.00
1982	0.44	0.65	8.37	102.04	1.01
1983	0.49	0.87	8.77	102.04	1.02
1984	0.42	0.79	9.16	102.04	1.04
1985	0.37	0.64	9.55	102.04	1.05
1986	0.30	0.49	9.94	102.04	1.06
1987	0.42	0.76	10.34	102.04	1.07

YEAR	$R - B_{(Cool)}$	$P_f(inches)$	I(%)	DA(mi^2)	SII
1988	0.50	0.73	10.73	102.04	1.08
1989	0.57	1.02	11.12	102.04	1.09
1990	0.42	0.83	11.51	102.04	1.10

Table A.63: Data for Seneca Creek at Dawsonville , MD (USGS Gage ID: 01645000) for the warm period.

YEAR	$R-B_{(Warm)}$	P_f (inches)	I(%)	DA(mi^2)	SII
1970	0.66	0.91	4.91	102.04	1.14
1971	0.92	2.19	5.18	102.04	1.11
1972	0.69	3.79	5.44	102.04	1.09
1973	0.46	1.65	5.71	102.04	1.07
1974	0.35	0.85	5.98	102.04	1.05
1975	0.91	1.26	6.25	102.04	1.04
1976	0.40	0.92	6.52	102.04	1.02
1977	0.36	0.78	6.78	102.04	1.01
1978	0.50	0.93	7.05	102.04	1.00
1979	0.83	1.35	7.32	102.04	0.99
1980	0.20	0.59	7.59	102.04	0.98
1981	0.42	0.80	7.98	102.04	1.00
1982	0.55	0.89	8.37	102.04	1.01
1983	0.34	0.85	8.77	102.04	1.02
1984	0.21	0.57	9.16	102.04	1.04
1985	0.43	1.00	9.55	102.04	1.05
1986	0.30	1.31	9.94	102.04	1.06
1987	0.65	1.59	10.34	102.04	1.07

YEAR	$R - B_{(Warm)}$	P_f (inches)	I(%)	DA(mi^2)	SII
1988	0.32	0.69	10.73	102.04	1.08
1989	0.29	0.57	11.12	102.04	1.09
1990	0.38	0.81	11.51	102.04	1.10

Table A.64: Data for Watts Branch at Rockville, MD (USGS Gage ID: 01645200) for the Annual period.

YEAR	$R - B_{(Annual)}$	P_f (inches)	I(%)	DA(mi^2)	SII
1970	1.05	1.26	16.33	3.71	0.94
1971	0.83	0.88	16.67	3.71	0.94
1972	0.85	1.80	17.02	3.71	0.94
1973	0.85	0.91	17.37	3.71	0.95
1974	0.82	0.91	17.71	3.71	0.95
1975	1.14	1.08	18.06	3.71	0.95
1976	0.73	0.76	18.41	3.71	0.95
1977	0.81	0.87	18.76	3.71	0.95
1978	0.87	1.10	19.10	3.71	0.95
1979	1.00	1.08	19.45	3.71	0.95
1980	0.71	0.70	19.80	3.71	0.95
1981	0.87	0.65	19.87	3.71	0.96
1982	1.04	0.59	19.95	3.71	0.97
1984	0.87	0.76	20.10	3.71	0.99
1985	1.01	0.79	20.17	3.71	1.00
1986	0.79	0.64	20.25	3.71	1.00
1987	1.02	1.00	20.33	3.71	1.01

Table A.65: Data for Watts Branch at Rockville, MD (USGS Gage ID: 01645200) for the cool period.

YEAR	$R - B_{(Cool)}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1970	0.85	1.18	16.33	3.71	0.94
1971	0.85	0.80	16.67	3.71	0.94
1972	0.85	0.95	17.02	3.71	0.94
1973	0.79	0.68	17.37	3.71	0.95
1974	0.77	0.81	17.71	3.71	0.95
1975	1.18	0.63	18.06	3.71	0.95
1976	0.68	0.68	18.41	3.71	0.95
1977	0.73	0.74	18.76	3.71	0.95
1978	0.85	0.78	19.10	3.71	0.95
1979	0.81	0.70	19.45	3.71	0.95
1980	0.71	0.74	19.80	3.71	0.95
1981	0.85	0.70	19.87	3.71	0.96
1982	0.90	0.39	19.95	3.71	0.97
1984	0.88	0.64	20.10	3.71	0.99
1985	0.85	0.66	20.17	3.71	1.00
1986	0.74	0.68	20.25	3.71	1.00
1987	0.89	0.69	20.33	3.71	1.01

Table A.66: Data for Watts Branch at Rockville, MD (USGS Gage ID: 01645200) for the warm period.

YEAR	$R - B_{(Warm)}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1970	1.39	1.18	16.33	3.71	0.94
1971	0.78	1.18	16.67	3.71	0.94
1972	0.85	3.30	17.02	3.71	0.94
1973	1.01	1.51	17.37	3.71	0.95
1974	0.98	1.17	17.71	3.71	0.95
1975	1.09	1.72	18.06	3.71	0.95
1976	0.93	1.00	18.41	3.71	0.95
1977	1.23	0.71	18.76	3.71	0.95
1978	0.93	1.90	19.10	3.71	0.95
1979	1.28	1.71	19.45	3.71	0.95
1980	0.74	0.69	19.80	3.71	0.95
1981	0.92	0.64	19.87	3.71	0.96
1982	1.31	0.98	19.95	3.71	0.97
1984	0.81	1.14	20.10	3.71	0.99
1985	1.33	1.10	20.17	3.71	1.00
1986	1.09	0.57	20.25	3.71	1.00
1987	1.29	1.57	20.33	3.71	1.01

Table A.67: Data for North East Branch Anacostia River at Riverdale, MD (USGS Gage ID: 01649500) for the annual period.

YEAR	$R-B_{(Annual)}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1970	0.57	0.87	15.95	73.36	0.68
1971	0.70	0.97	15.95	73.36	0.68
1972	0.71	1.19	15.95	73.36	0.68
1973	0.67	0.90	15.95	73.36	0.68
1974	0.69	0.66	15.95	73.36	0.68
1975	0.79	1.29	15.95	73.36	0.68
1976	0.67	1.07	15.95	73.36	0.68
1977	0.59	0.83	15.95	73.36	0.68
1978	0.77	0.93	15.95	73.36	0.68
1979	0.74	1.08	15.95	73.36	0.68
1980	0.61	0.60	15.95	73.36	0.69
1981	0.67	0.60	16.12	73.36	0.71
1982	0.66	0.67	16.29	73.36	0.73
1983	0.73	1.07	16.46	73.36	0.75
1984	0.72	0.89	16.63	73.36	0.77
1985	0.77	1.22	16.80	73.36	0.79
1986	0.54	0.73	16.97	73.36	0.81
1987	0.74	1.15	17.14	73.36	0.83

YEAR	$R-B_{(Annual)}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1988	0.68	0.94	17.31	73.36	0.85
1989	0.78	0.79	17.48	73.36	0.87
1990	0.72	0.78	17.65	73.36	0.89
1991	0.72	0.78	17.75	73.36	0.89
1992	0.73	0.88	18.24	73.36	0.89
1993	0.74	0.87	18.74	73.36	0.89
1994	0.79	1.07	19.24	73.36	0.90
1996	0.84	1.14	19.74	73.36	0.90
1997	0.76	1.14	20.24	73.36	0.90
1998	0.83	0.77	20.74	73.36	0.90
1999	0.87	1.14	21.24	73.36	0.90
2000	0.62	0.68	21.74	73.36	0.90

Table A.68: Data for North East Branch Anacostia River at Riverdale, MD (USGS Gage ID: 01649500) for the cool period.

YEAR	$R - B_{(Cool)}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1970	0.54	0.71	15.95	73.36	0.68
1971	0.65	0.86	15.95	73.36	0.68
1972	0.68	0.70	15.95	73.36	0.68
1973	0.69	0.86	15.95	73.36	0.68
1974	0.67	0.65	15.95	73.36	0.68
1975	0.61	0.63	15.95	73.36	0.68
1976	0.64	0.83	15.95	73.36	0.68
1977	0.58	0.86	15.95	73.36	0.68
1978	0.76	1.00	15.95	73.36	0.68
1979	0.66	0.68	15.95	73.36	0.68
1980	0.61	0.62	15.95	73.36	0.69
1981	0.54	0.64	16.12	73.36	0.71
1982	0.61	0.58	16.29	73.36	0.73
1983	0.72	1.02	16.46	73.36	0.75
1984	0.73	0.94	16.63	73.36	0.77
1985	0.66	0.85	16.80	73.36	0.79
1986	0.47	0.70	16.97	73.36	0.81
1987	0.69	0.79	17.14	73.36	0.83

YEAR	$R - B_{(Cool)}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1988	0.67	0.93	17.31	73.36	0.85
1989	0.80	0.79	17.48	73.36	0.87
1990	0.74	0.85	17.65	73.36	0.89
1991	0.68	0.83	17.75	73.36	0.89
1992	0.64	0.82	18.24	73.36	0.89
1993	0.74	0.93	18.74	73.36	0.89
1994	0.82	1.04	19.24	73.36	0.90
1996	0.79	0.96	19.74	73.36	0.90
1997	0.77	1.23	20.24	73.36	0.90
1998	0.85	0.81	20.74	73.36	0.90
1999	0.65	0.58	21.24	73.36	0.90
2000	0.61	0.65	21.74	73.36	0.90

Table A.69: Data for North East Branch Anacostia River at Riverdale, MD (USGS Gage ID: 01649500) for the warm period.

YEAR	$R - B_{(Warm)}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1970	0.65	1.26	15.95	73.36	0.68
1971	0.80	1.30	15.95	73.36	0.68
1972	0.78	2.22	15.95	73.36	0.68
1973	0.61	1.12	15.95	73.36	0.68
1974	0.74	0.81	15.95	73.36	0.68
1975	0.94	2.05	15.95	73.36	0.68
1976	0.77	1.55	15.95	73.36	0.68
1977	0.62	0.88	15.95	73.36	0.68
1978	0.81	0.83	15.95	73.36	0.68
1979	0.87	1.76	15.95	73.36	0.68
1980	0.60	0.61	15.95	73.36	0.69
1981	0.96	0.67	16.12	73.36	0.71
1982	0.79	0.92	16.29	73.36	0.73
1983	0.75	1.28	16.46	73.36	0.75
1984	0.63	0.78	16.63	73.36	0.77
1985	1.09	1.95	16.80	73.36	0.79
1986	0.82	0.92	16.97	73.36	0.81
1987	0.90	1.16	17.14	73.36	0.83

YEAR	$R - B_{(Warm)}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1988	0.75	1.07	17.31	73.36	0.85
1989	0.71	0.95	17.48	73.36	0.87
1990	0.65	2.12	17.65	73.36	0.89
1991	0.91	0.74	17.75	73.36	0.89
1992	0.92	1.20	18.24	73.36	0.89
1993	0.74	0.80	18.74	73.36	0.89
1994	0.68	1.35	19.24	73.36	0.90
1996	0.97	1.67	19.74	73.36	0.90
1997	0.68	2.92	20.24	73.36	0.90
1998	0.59	3.18	20.74	73.36	0.90
1999	1.11	2.52	21.24	73.36	0.90
2000	0.67	1.86	21.74	73.36	0.90

Table A.70: Data for North West Branch Anacostia River Near Colesville, MD (USGS Gage ID: 01650500) for the annual period.

YEAR	$R - B_{(Annual)}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1970	0.64	0.93	9.79	21.30	0.79
1971	0.76	1.00	10.00	21.30	0.78
1972	0.79	2.24	10.22	21.30	0.78
1973	0.63	0.78	10.44	21.30	0.78
1974	0.65	0.83	10.65	21.30	0.78
1975	0.91	1.24	10.87	21.30	0.78
1976	0.57	0.78	11.08	21.30	0.78
1977	0.58	0.76	11.30	21.30	0.78
1978	0.77	1.03	11.52	21.30	0.77
1979	0.79	1.23	11.73	21.30	0.77
1980	0.53	0.57	11.95	21.30	0.77
1981	0.59	0.74	12.25	21.30	0.77
1982	0.67	0.64	12.55	21.30	0.76
1983	0.71	1.05	12.85	21.30	0.76

Table A.71: Data for North West Branch Anacostia River Near Colesville, MD (USGS Gage ID: 01650500) for the cool period.

YEAR	$R - B_{(Cool)}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1970	0.64	0.86	9.79	21.30	0.79
1971	0.70	0.79	10.00	21.30	0.78
1972	0.68	0.87	10.22	21.30	0.78
1973	0.66	0.73	10.44	21.30	0.78
1974	0.64	0.89	10.65	21.30	0.78
1975	0.71	0.82	10.87	21.30	0.78
1976	0.53	0.69	11.08	21.30	0.78
1977	0.56	0.82	11.30	21.30	0.78
1978	0.77	1.09	11.52	21.30	0.77
1979	0.66	0.70	11.73	21.30	0.77
1980	0.55	0.62	11.95	21.30	0.77
1981	0.54	0.79	12.25	21.30	0.77
1982	0.64	0.54	12.55	21.30	0.76
1983	0.73	1.03	12.85	21.30	0.76

Table A.72: Data for North West Branch Anacostia River Near Colesville, MD (USGS Gage ID: 01650500) for the warm period.

YEAR	$R - B_{(Warm)}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1970	0.65	1.17	9.79	21.30	0.79
1971	0.89	1.48	10.00	21.30	0.78
1972	0.96	4.70	10.22	21.30	0.78
1973	0.51	1.13	10.44	21.30	0.78
1974	0.67	0.82	10.65	21.30	0.78
1975	1.10	1.84	10.87	21.30	0.78
1976	0.73	1.06	11.08	21.30	0.78
1977	0.73	0.71	11.30	21.30	0.78
1978	0.75	1.02	11.52	21.30	0.77
1979	0.97	2.14	11.73	21.30	0.77
1980	0.41	0.52	11.95	21.30	0.77
1981	0.69	0.79	12.25	21.30	0.77
1982	0.78	0.93	12.55	21.30	0.76
1983	0.58	1.17	12.85	21.30	0.76

Table A.73: Data for North West Branch Anacostia River Near Hyattsville, MD (USGS Gage ID: 01651000) for the annual period.

YEAR	$R - B_{Annual}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1970	0.76	1.01	21.45	49.42	0.38
1971	0.84	1.28	21.45	49.42	0.39
1972	0.84	1.35	21.45	49.42	0.39
1973	0.67	0.85	21.45	49.42	0.40
1974	0.80	0.84	21.45	49.42	0.40
1975	0.90	1.66	21.45	49.42	0.41
1976	0.64	1.04	21.45	49.42	0.41
1977	0.66	0.72	21.45	49.42	0.42
1978	0.82	1.13	21.45	49.42	0.42
1979	0.83	1.30	21.45	49.42	0.43
1980	0.61	0.82	21.45	49.42	0.43
1981	0.73	0.63	21.45	49.42	0.44
1982	0.76	0.65	21.46	49.42	0.45
1983	0.74	0.93	21.46	49.42	0.46
1985	0.84	0.85	21.47	49.42	0.47
1986	0.67	0.62	21.47	49.42	0.48
1987	0.88	0.71	21.47	49.42	0.49
1988	0.69	0.74	21.47	49.42	0.50

YEAR	$R - B_{Annual}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1989	0.82	0.82	21.48	49.42	0.50
1990	0.68	1.03	21.48	49.42	0.51
1991	0.76	1.06	21.78	49.42	0.51
1992	0.68	0.87	22.07	49.42	0.51
1993	0.66	0.77	22.37	49.42	0.51
1994	0.74	1.14	22.66	49.42	0.52

Table A.74: Data for North West Branch Anacostia River Near Hyattsville, MD (USGS Gage ID: 01651000) for the cool period.

YEAR	$R - B_{Cool}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1970	0.76	0.81	21.45	49.42	0.38
1971	0.78	1.08	21.45	49.42	0.39
1972	0.79	1.04	21.45	49.42	0.39
1973	0.66	0.84	21.45	49.42	0.40
1974	0.77	0.82	21.45	49.42	0.40
1975	0.77	0.66	21.45	49.42	0.41
1976	0.55	0.95	21.45	49.42	0.41
1977	0.62	0.73	21.45	49.42	0.42
1978	0.81	1.24	21.45	49.42	0.42
1979	0.70	0.59	21.45	49.42	0.43
1980	0.60	0.59	21.45	49.42	0.43
1981	0.64	0.49	21.45	49.42	0.44
1982	0.71	0.56	21.46	49.42	0.45
1983	0.78	0.79	21.46	49.42	0.46
1985	0.73	0.76	21.47	49.42	0.47
1986	0.54	0.48	21.47	49.42	0.48
1987	0.80	0.68	21.47	49.42	0.49
1988	0.67	0.78	21.47	49.42	0.50

YEAR	$R - B_{Cool}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1989	0.85	0.81	21.48	49.42	0.50
1990	0.68	0.84	21.48	49.42	0.51
1991	0.71	0.66	21.78	49.42	0.51
1992	0.61	0.67	22.07	49.42	0.51
1993	0.65	0.79	22.37	49.42	0.51
1994	0.74	1.32	22.66	49.42	0.52

Table A.75: Data for North West Branch Anacostia River Near Hyattsville, MD (USGS Gage ID: 01651000) for the warm period.

YEAR	$R - B_{Warm}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1970	0.75	1.52	21.45	49.42	0.38
1971	0.99	1.78	21.45	49.42	0.39
1972	0.93	2.10	21.45	49.42	0.39
1973	0.70	1.04	21.45	49.42	0.40
1974	0.90	1.01	21.45	49.42	0.40
1975	1.00	2.56	21.45	49.42	0.41
1976	0.95	1.31	21.45	49.42	0.41
1977	0.82	1.97	21.45	49.42	0.42
1978	0.88	0.97	21.45	49.42	0.42
1979	1.00	2.33	21.45	49.42	0.43
1980	0.64	0.85	21.45	49.42	0.43
1981	0.91	0.94	21.45	49.42	0.44
1982	0.86	0.90	21.46	49.42	0.45
1983	0.60	1.34	21.46	49.42	0.46
1985	1.13	1.20	21.47	49.42	0.47
1986	1.11	2.55	21.47	49.42	0.48
1987	1.12	2.18	21.47	49.42	0.49
1988	0.80	2.50	21.47	49.42	0.50

YEAR	$R-B_{Warm}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1989	0.75	2.11	21.48	49.42	0.50
1990	0.67	2.84	21.48	49.42	0.51
1991	0.99	2.82	21.78	49.42	0.51
1992	0.87	2.46	22.07	49.42	0.51
1993	0.70	1.30	22.37	49.42	0.51
1994	0.76	1.98	22.66	49.42	0.52

Table A.76: Data for Piscataway Creek at Piscataway, MD (USGS Gage ID: 01653600) for the Annual period.

YEAR	$R-B_{Annual}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1970	0.56	0.66	7.35	39.75	0.93
1971	0.69	1.02	7.48	39.75	0.94
1972	0.61	1.17	7.60	39.75	0.95
1973	0.64	0.64	7.73	39.75	0.96
1974	0.55	0.90	7.86	39.75	0.97
1975	0.65	1.29	7.98	39.75	0.98
1976	0.49	0.88	8.11	39.75	0.99
1977	0.45	0.59	8.24	39.75	1.00
1978	0.63	1.02	8.36	39.75	1.00
1979	0.80	1.06	8.49	39.75	1.01
1980	0.37	0.51	8.62	39.75	1.02
1981	0.61	0.67	8.69	39.75	1.02
1982	0.51	0.90	8.76	39.75	1.02
1983	0.58	0.82	8.84	39.75	1.02
1984	0.50	0.75	8.91	39.75	1.03
1985	0.55	1.25	8.98	39.75	1.03
1986	0.38	0.62	9.05	39.75	1.03
1987	0.50	0.69	9.12	39.75	1.03

YEAR	$R - B_{Annual}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1988	0.44	0.69	9.20	39.75	1.03
1989	0.59	1.04	9.27	39.75	1.03
1990	0.53	1.02	9.34	39.75	1.03
1991	0.42	0.54	9.45	39.75	1.03
1992	0.57	0.83	9.56	39.75	1.03
1993	0.46	0.68	9.67	39.75	1.03
1995	0.68	1.05	9.89	39.75	1.03
1996	0.57	0.83	10.00	39.75	1.02
1997	0.55	1.08	10.11	39.75	1.02
1998	0.59	1.05	10.22	39.75	1.02
1999	0.87	1.24	10.33	39.75	1.02
2000	0.53	0.89	10.44	39.75	1.02

Table A.77: Data for Piscataway Creek at Piscataway, MD (USGS Gage ID: 01653600) for the cool period.

YEAR	$R - B_{Cool}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1970	0.55	0.64	7.35	39.75	0.93
1971	0.63	0.81	7.48	39.75	0.94
1972	0.55	0.94	7.60	39.75	0.95
1973	0.61	0.64	7.73	39.75	0.96
1974	0.52	1.02	7.86	39.75	0.97
1975	0.47	0.56	7.98	39.75	0.98
1976	0.45	0.91	8.11	39.75	0.99
1977	0.42	0.58	8.24	39.75	1.00
1978	0.62	1.02	8.36	39.75	1.00
1979	0.55	0.66	8.49	39.75	1.01
1980	0.37	0.56	8.62	39.75	1.02
1981	0.49	0.44	8.69	39.75	1.02
1982	0.44	1.01	8.76	39.75	1.02
1983	0.52	0.89	8.84	39.75	1.02
1984	0.47	0.74	8.91	39.75	1.03
1985	0.45	0.63	8.98	39.75	1.03
1986	0.35	0.65	9.05	39.75	1.03
1987	0.46	0.69	9.12	39.75	1.03

YEAR	$R - B_{Cool}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1988	0.43	0.74	9.20	39.75	1.03
1989	0.59	0.97	9.27	39.75	1.03
1990	0.46	0.81	9.34	39.75	1.03
1991	0.41	0.59	9.45	39.75	1.03
1992	0.50	0.84	9.56	39.75	1.03
1993	0.46	0.65	9.67	39.75	1.03
1995	0.63	0.56	9.89	39.75	1.03
1996	0.52	0.82	10.00	39.75	1.02
1997	0.52	1.11	10.11	39.75	1.02
1998	0.59	1.15	10.22	39.75	1.02
1999	0.61	0.60	10.33	39.75	1.02
2000	0.46	0.63	10.44	39.75	1.02

Table A.78: Data for Piscataway Creek at Piscataway, MD (USGS Gage ID: 01653600) for the warm period.

YEAR	$R - B_{Warm}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1970	0.74	0.81	7.35	39.75	0.93
1971	0.90	1.53	7.48	39.75	0.94
1972	0.82	1.84	7.60	39.75	0.95
1973	0.90	0.75	7.73	39.75	0.96
1974	0.71	0.81	7.86	39.75	0.97
1975	0.81	2.08	7.98	39.75	0.98
1976	0.81	0.95	8.11	39.75	0.99
1977	0.97	0.68	8.24	39.75	1.00
1978	0.73	1.17	8.36	39.75	1.00
1979	1.17	1.68	8.49	39.75	1.01
1980	0.45	0.46	8.62	39.75	1.02
1981	1.04	1.07	8.69	39.75	1.02
1982	0.69	0.84	8.76	39.75	1.02
1983	0.84	0.70	8.84	39.75	1.02
1984	0.64	0.90	8.91	39.75	1.03
1985	1.07	2.21	8.98	39.75	1.03
1986	0.96	0.69	9.05	39.75	1.03
1987	0.80	0.78	9.12	39.75	1.03

YEAR	$R - B_{Warm}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1988	0.66	0.63	9.20	39.75	1.03
1989	0.59	1.27	9.27	39.75	1.03
1990	0.75	1.38	9.34	39.75	1.03
1991	0.67	0.52	9.45	39.75	1.03
1992	0.73	1.37	9.56	39.75	1.03
1993	0.54	1.50	9.67	39.75	1.03
1995	0.86	0.00	9.89	39.75	1.03
1996	0.85	0.98	10.00	39.75	1.02
1997	0.92	1.09	10.11	39.75	1.02
1998	0.52	0.71	10.22	39.75	1.02
1999	1.14	1.96	10.33	39.75	1.02
2000	0.75	1.34	10.44	39.75	1.02

Table A.79: Data for Mattawoman Creek Near Pomonkey, MD (USGS Gage ID: 01658000) for the annual period.

YEAR	$R - B_{Annual}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1970	0.46	0.84	4.91	55.78	1.29
1971	0.63	2.26	4.95	55.78	1.26
1972	0.63	1.68	4.98	55.78	1.23
1973	0.47	0.89	5.02	55.78	1.21
1974	0.55	0.75	5.05	55.78	1.18
1975	0.52	1.16	5.09	55.78	1.16
1976	0.45	1.22	5.12	55.78	1.14
1977	0.40	0.79	5.16	55.78	1.11
1978	0.50	0.82	5.19	55.78	1.09
1979	0.64	1.06	5.23	55.78	1.07
1980	0.37	0.58	5.26	55.78	1.05
1981	0.40	0.77	5.47	55.78	1.10
1982	0.50	0.79	5.68	55.78	1.14
1983	0.51	0.93	5.89	55.78	1.18
1984	0.56	0.74	6.10	55.78	1.22
1985	0.72	1.05	6.31	55.78	1.25
1986	0.35	0.91	6.52	55.78	1.29
1987	0.49	1.15	6.72	55.78	1.33

YEAR	$R-B_{Annual}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1988	0.49	0.70	6.93	55.78	1.36
1989	0.54	1.20	7.14	55.78	1.39
1990	0.57	0.82	7.35	55.78	1.43
1991	0.54	0.64	7.49	55.78	1.42
1992	0.54	0.84	7.62	55.78	1.42
1993	0.43	0.75	7.76	55.78	1.42
1996	0.56	0.86	8.17	55.78	1.42
1997	0.46	0.62	8.30	55.78	1.42

Table A.80: Data for Mattawoman Creek Near Pomonkey, MD (USGS Gage ID: 01658000) for the cool period.

YEAR	$R - B_{Cool}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1970	0.46	0.72	4.91	55.78	1.29
1971	0.62	0.73	4.95	55.78	1.26
1972	0.53	0.84	4.98	55.78	1.23
1973	0.48	0.66	5.02	55.78	1.21
1974	0.50	0.80	5.05	55.78	1.18
1975	0.48	0.61	5.09	55.78	1.16
1976	0.43	0.77	5.12	55.78	1.14
1977	0.37	0.70	5.16	55.78	1.11
1978	0.51	0.82	5.19	55.78	1.09
1979	0.52	0.68	5.23	55.78	1.07
1980	0.35	0.61	5.26	55.78	1.05
1981	0.34	0.57	5.47	55.78	1.10
1982	0.44	0.54	5.68	55.78	1.14
1983	0.52	0.82	5.89	55.78	1.18
1984	0.57	0.72	6.10	55.78	1.22
1985	0.35	0.68	6.31	55.78	1.25
1986	0.34	0.79	6.52	55.78	1.29
1987	0.49	0.74	6.72	55.78	1.33

YEAR	$R - B_{Cool}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1988	0.50	0.67	6.93	55.78	1.36
1989	0.52	0.73	7.14	55.78	1.39
1990	0.57	0.76	7.35	55.78	1.43
1991	0.50	0.68	7.49	55.78	1.42
1992	0.51	0.65	7.62	55.78	1.42
1993	0.41	0.77	7.76	55.78	1.42
1996	0.48	0.81	8.17	55.78	1.42
1997	0.43	0.51	8.30	55.78	1.42

Table A.81: Data for Mattawoman Creek Near Pomonkey, MD (USGS Gage ID: 01658000) for the warm period.

YEAR	$R-B_{Warm}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1970	0.48	1.17	4.91	55.78	1.29
1971	0.66	4.55	4.95	55.78	1.26
1972	0.84	3.03	4.98	55.78	1.23
1973	0.38	1.50	5.02	55.78	1.21
1974	0.77	0.75	5.05	55.78	1.18
1975	0.61	1.79	5.09	55.78	1.16
1976	0.64	2.07	5.12	55.78	1.14
1977	0.66	1.05	5.16	55.78	1.11
1978	0.47	0.91	5.19	55.78	1.09
1979	0.79	1.65	5.23	55.78	1.07
1980	0.60	0.66	5.26	55.78	1.05
1981	0.60	1.15	5.47	55.78	1.10
1982	0.66	1.28	5.68	55.78	1.14
1983	0.29	1.33	5.89	55.78	1.18
1984	0.42	1.37	6.10	55.78	1.22
1985	1.31	1.63	6.31	55.78	1.25
1986	0.48	1.20	6.52	55.78	1.29
1987	0.43	2.11	6.72	55.78	1.33

YEAR	$R - B_{Warm}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1988	0.43	0.89	6.93	55.78	1.36
1989	0.63	1.95	7.14	55.78	1.39
1990	0.53	1.07	7.35	55.78	1.43
1991	0.69	0.69	7.49	55.78	1.42
1992	0.57	1.18	7.62	55.78	1.42
1993	0.56	1.06	7.76	55.78	1.42
1996	0.72	1.36	8.17	55.78	1.42
1997	0.67	0.93	8.30	55.78	1.42

Table A.82: Data for Bear Creek at Friendsville, MD (USGS Gage ID: 03076600) for the annual period.

YEAR	$R - B_{Annual}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1972	0.28	0.54	2.15	49.03	0.52
1973	0.24	0.61	2.16	49.03	0.53
1974	0.25	0.42	2.16	49.03	0.53
1975	0.36	0.66	2.17	49.03	0.53
1976	0.28	0.37	2.18	49.03	0.53
1977	0.34	0.53	2.18	49.03	0.54
1978	0.31	0.59	2.19	49.03	0.54
1979	0.35	0.59	2.19	49.03	0.54
1980	0.36	0.60	2.20	49.03	0.54
1981	0.29	0.49	2.20	49.03	0.54
1982	0.32	0.49	2.21	49.03	0.55
1983	0.28	0.51	2.22	49.03	0.55
1985	0.34	0.61	2.23	49.03	0.55
1986	0.44	0.71	2.23	49.03	0.56
1987	0.29	0.54	2.24	49.03	0.56
1988	0.37	0.51	2.24	49.03	0.56
1989	0.35	0.50	2.25	49.03	0.56
1990	0.34	0.60	2.26	49.03	0.56

YEAR	$R-B_{Annual}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1991	0.33	0.52	2.26	49.03	0.57

Table A.83: Data for Bear Creek at Friendsville, MD (USGS Gage ID: 03076600) for the cool period.

YEAR	$R - B_{Cool}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1972	0.23	0.40	2.15	49.03	0.52
1973	0.23	0.49	2.16	49.03	0.53
1974	0.24	0.43	2.16	49.03	0.53
1975	0.37	0.74	2.17	49.03	0.53
1976	0.28	0.30	2.18	49.03	0.53
1977	0.32	0.48	2.18	49.03	0.54
1978	0.29	0.37	2.19	49.03	0.54
1979	0.36	0.61	2.19	49.03	0.54
1980	0.33	0.48	2.20	49.03	0.54
1981	0.29	0.38	2.20	49.03	0.54
1982	0.32	0.34	2.21	49.03	0.55
1983	0.28	0.38	2.22	49.03	0.55
1985	0.31	0.51	2.23	49.03	0.55
1986	0.43	0.60	2.23	49.03	0.56
1987	0.29	0.50	2.24	49.03	0.56
1988	0.36	0.42	2.24	49.03	0.56
1989	0.34	0.48	2.25	49.03	0.56
1990	0.25	0.35	2.26	49.03	0.56

YEAR	$R - B_{Cool}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1991	0.33	0.51	2.26	49.03	0.57

Table A.84: Data for Bear Creek at Friendsville, MD (USGS Gage ID: 03076600) for the warm period.

YEAR	$R - B_{Warm}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1972	0.48	0.94	2.15	49.03	0.52
1973	0.33	1.00	2.16	49.03	0.53
1974	0.27	0.53	2.16	49.03	0.53
1975	0.29	0.63	2.17	49.03	0.53
1976	0.34	0.62	2.18	49.03	0.53
1977	0.46	0.75	2.18	49.03	0.54
1978	0.43	1.07	2.19	49.03	0.54
1979	0.26	0.66	2.19	49.03	0.54
1980	0.48	0.91	2.20	49.03	0.54
1981	0.31	0.81	2.20	49.03	0.54
1982	0.32	0.88	2.21	49.03	0.55
1983	0.24	0.86	2.22	49.03	0.55
1985	0.41	0.93	2.23	49.03	0.55
1986	0.52	1.62	2.23	49.03	0.56
1987	0.29	1.57	2.24	49.03	0.56
1988	0.46	1.42	2.24	49.03	0.56
1989	0.38	1.18	2.25	49.03	0.56
1990	0.51	1.54	2.26	49.03	0.56

YEAR	$R - B_{Warm}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1991	0.30	2.09	2.26	49.03	0.57

Table A.85: Data for Casselman River at Grantsville, MD (USGS Gage ID: 03078000) for the annual period.

YEAR	$R - B_{Annual}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1970	0.41	0.47	2.15	63.78	0.83
1971	0.38	0.53	2.16	63.78	0.83
1972	0.39	0.53	2.17	63.78	0.84
1973	0.35	0.60	2.18	63.78	0.84
1974	0.37	0.49	2.20	63.78	0.84
1975	0.41	0.70	2.21	63.78	0.84
1976	0.32	0.49	2.22	63.78	0.84
1977	0.39	0.56	2.24	63.78	0.84
1978	0.38	0.72	2.25	63.78	0.85
1980	0.40	0.61	2.27	63.78	0.85
1981	0.34	0.56	2.29	63.78	0.85
1982	0.35	0.48	2.30	63.78	0.85
1983	0.32	0.44	2.31	63.78	0.85
1984	0.38	0.53	2.32	63.78	0.86
1985	0.34	0.58	2.34	63.78	0.86
1986	0.41	0.68	2.35	63.78	0.86
1987	0.32	0.54	2.36	63.78	0.86
1988	0.36	0.72	2.38	63.78	0.86

YEAR	$R-B_{Annual}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1989	0.36	0.62	2.39	63.78	0.86
1990	0.36	0.64	2.40	63.78	0.87
1991	0.34	0.58	2.41	63.78	0.86
1992	0.30	0.54	2.43	63.78	0.86
1993	0.35	0.75	2.44	63.78	0.85
1994	0.35	0.70	2.45	63.78	0.85
1995	0.30	1.00	2.46	63.78	0.85

Table A.86: Data for Casselman River at Grantsville, MD (USGS Gage ID: 03078000) for the cool period.

YEAR	$R - B_{Cool}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1970	0.39	0.40	2.15	63.78	0.83
1971	0.35	0.53	2.16	63.78	0.83
1972	0.35	0.54	2.17	63.78	0.84
1973	0.35	0.52	2.18	63.78	0.84
1974	0.37	0.51	2.20	63.78	0.84
1975	0.40	0.85	2.21	63.78	0.84
1976	0.31	0.43	2.22	63.78	0.84
1977	0.37	0.66	2.24	63.78	0.84
1978	0.34	0.53	2.25	63.78	0.85
1980	0.37	0.60	2.27	63.78	0.85
1981	0.30	0.51	2.29	63.78	0.85
1982	0.33	0.41	2.30	63.78	0.85
1983	0.32	0.41	2.31	63.78	0.85
1984	0.37	0.46	2.32	63.78	0.86
1985	0.32	0.63	2.34	63.78	0.86
1986	0.41	0.81	2.35	63.78	0.86
1987	0.32	0.49	2.36	63.78	0.86
1988	0.33	0.61	2.38	63.78	0.86

YEAR	$R - B_{Cool}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1989	0.35	0.55	2.39	63.78	0.86
1990	0.30	0.50	2.40	63.78	0.87
1991	0.34	0.60	2.41	63.78	0.86
1992	0.30	0.54	2.43	63.78	0.86
1993	0.33	0.74	2.44	63.78	0.85
1994	0.34	0.67	2.45	63.78	0.85
1995	0.29	0.43	2.46	63.78	0.85

Table A.87: Data for Casselman River at Grantsville, MD (USGS Gage ID: 03078000) for the warm period.

YEAR	$R - B_{Warm}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1970	0.56	0.70	2.15	63.78	0.83
1971	0.50	0.66	2.16	63.78	0.83
1972	0.58	0.62	2.17	63.78	0.84
1973	0.42	0.88	2.18	63.78	0.84
1974	0.39	0.62	2.20	63.78	0.84
1975	0.44	0.54	2.21	63.78	0.84
1976	0.46	0.67	2.22	63.78	0.84
1977	0.59	0.44	2.24	63.78	0.84
1978	0.58	0.93	2.25	63.78	0.85
1980	0.51	0.77	2.27	63.78	0.85
1981	0.49	1.21	2.29	63.78	0.85
1982	0.43	1.45	2.30	63.78	0.85
1983	0.34	1.68	2.31	63.78	0.85
1984	0.50	1.37	2.32	63.78	0.86
1985	0.45	1.43	2.34	63.78	0.86
1986	0.41	1.43	2.35	63.78	0.86
1987	0.37	1.47	2.36	63.78	0.86
1988	0.59	1.58	2.38	63.78	0.86

YEAR	$R - B_{Warm}$	P_f (inches)	$I(\%)$	$DA(mi^2)$	SII
1989	0.42	1.28	2.39	63.78	0.86
1990	0.56	1.42	2.40	63.78	0.87
1991	0.29	1.98	2.41	63.78	0.86
1992	0.32	1.40	2.43	63.78	0.86
1993	0.62	1.48	2.44	63.78	0.85
1994	0.45	1.45	2.45	63.78	0.85
1995	0.41	2.21	2.46	63.78	0.85

Appendix B

Hypothesis Test for Temporal Trends in the R-B Index for the cool and warm periods

Table B.1: Hypothesis test for the selected USGS watersheds for the cool period with rejection probability 10%.

Study Id.	Gage Id.	Statistics	Decision / Result
1	01580000	n = 29 ΔImp = 1.48% $\tau_{critical}$= 0.172 $\tau_{calculated}$ = 0.2167	Reject
2	01581700	n = 29 ΔImp = 3.82% $\tau_{critical}$ = 0.172 $\tau_{calculated}$ = 0.2365	Reject
3	01585100	n =24 ΔImp = 9.29% $\tau_{critical}$ = 0.196 $\tau_{calculated}$ = 0.7536	Reject

Study Id.	Gage Id.	Statistics	Decision / Result
4	01585300	n =19 ΔImp = 0.05% $\tau_{critical}$ = 0.228 $\tau_{calculated}$ = 0.1988	Reject
5	01585500	n =19 ΔImp = 2.31% $\tau_{critical}$ = 0.228 $\tau_{calculated}$ = 0.4094	Reject
6	01586000	n = 19 ΔImp = 1.24% $\tau_{critical}$ = 0.228 $\tau_{calculated}$ = 0.2456	Reject
7	01590500	n = 14 ΔImp = 5.24% $\tau_{critical}$ = 0.275 $\tau_{calculated}$ = 0.8132	Reject
8	01591000	n =21 ΔImp =1.16% $\tau_{critical}$ = 0.21 $\tau_{calculated}$ = 0.3238	Reject

Study Id.	Gage Id.	Statistics	Decision / Result
9	01592500	n = 21 ΔImp = 1.70% $\tau_{critical}$ = 0.21 $\tau_{calculated}$ = 0.20	Accept
10	01593500	n =28 ΔImp = 9.39% $\tau_{critical}$ = 0.18 $\tau_{calculated}$ = 0.4021	Reject
11	01594000	n = 12 ΔImp = 5.50% $\tau_{critical}$ = 0.303 $\tau_{calculated}$ = 0.6061	Reject
12	01596500	n = 25 ΔImp = 1.64% $\tau_{critical}$ = 0.193 $\tau_{calculated}$ = -0.3733	Accept
13	01599000	n =25 ΔImp = 0.23% $\tau_{critical}$ = 0.193 $\tau_{calculated}$ = 0.24	Reject

Study Id.	Gage Id.	Statistics	Decision / Result
14	01637500	n = 29 ΔImp = 0.3% $\tau_{critical} = 0.172$ $\tau_{calculated} = 0.5123$	Reject
15	01639500	n = 19 ΔImp = 0.88% $\tau_{critical} = 0.228$ $\tau_{calculated} = 0.5263$	Reject
16	01640500	n = 15 ΔImp = 0.14% $\tau_{critical} = 0.276$ $\tau_{calculated} = 0.781$	Reject
17	01641000	n =22 ΔImp = 0.36% $\tau_{critical} = 0.203$ $\tau_{calculated} = 0.2684$	Reject
18	01642500	n = 13 ΔImp = 0.17% $\tau_{critical} = 0.308$ $\tau_{calculated} = 0.359$	Reject

Study Id.	Gage Id.	Statistics	Decision / Result
19	01643000	n = 26 ΔImp 5.94% $\tau_{critical}$ = 0.188 $\tau_{calculated}$ = -0.1292	Accept
20	01643500	n =26 ΔImp 0.57% $\tau_{critical}$ = 0.188 $\tau_{calculated}$ = 0.0677	Accept
21	01645000	n = 21 ΔImp = 6.61% $\tau_{critical}$ = 0.21 $\tau_{calculated}$ = 0.3619	Reject
22	01645200	n =17 ΔImp = 4.00% $\tau_{critical}$ = 0.25 $\tau_{calculated}$ = 0.3529	Reject
23	01649500	n =30 ΔImp = 5.79% $\tau_{critical}$ = 0.172 $\tau_{calculated}$ = 0.7218	Reject

Study Id.	Gage Id.	Statistics	Decision / Result
24	01650500	n = 14 ΔImp = 3.05% $\tau_{critical}$ = 0.275 $\tau_{calculated}$ = 0.1099	Accept
25	01651000	n =24 ΔImp = 1.21% $\tau_{critical}$ = 0.196 $\tau_{calculated}$ = -0.058	Accept
26	01653600	n = 30 ΔImp = 3.09% $\tau_{critical}$ = 0.172 $\tau_{calculated}$ = -0.0138	Accept
27	01658000	n =26 ΔImp = 3.39% $\tau_{critical}$ = 0.188 $\tau_{calculated}$ = 0.0062	Accept
28	03076600	n =19 ΔImp = 0.1% $\tau_{critical}$ = 0.228 $\tau_{calculated}$ = 0.7602	Reject

Study Id.	Gage Id.	Statistics	Decision / Result
29	03078000	n = 25 ΔImp = 0.31% $\tau_{critical}$ = 0.193 $\tau_{calculated}$ = -0.5467	Accept

Table B.2: Hypothesis test for the selected USGS watersheds for the warm period with rejection probability 10%.

Study Id.	Gage Id.	Statistics	Decision / Result
1	01580000	n = 29 ΔImp = 1.48% $\tau_{critical}$= 0.172 $\tau_{calculated}$ = -0.2069	Accept
2	01581700	n = 29 ΔImp = 3.82% $\tau_{critical}$ = 0.172 $\tau_{calculated}$ = 0.0	Accept
3	01585100	n =24 ΔImp = 9.29% $\tau_{critical}$ = 0.196 $\tau_{calculated}$ = 0.6812	Reject
4	01585300	n =19 ΔImp = 0.05% $\tau_{critical}$ = 0.228 $\tau_{calculated}$ = 0.5497	Reject
5	01585500	n =19 ΔImp = 2.31%	Reject

Study Id.	Gage Id.	Statistics	Decision / Result
		$\tau_{critical}$ = 0.228 $\tau_{calculated}$ = 0.9474	
6	01586000	n = 19 ΔImp = 1.24% $\tau_{critical}$ = 0.228 $\tau_{calculated}$ = 0.4094	Reject
7	01590500	n = 14 ΔImp = 5.24% $\tau_{critical}$ = 0.275 $\tau_{calculated}$ = 1.033	Reject
8	01591000	n =21 ΔImp =1.16% $\tau_{critical}$ = 0.21 $\tau_{calculated}$ = -0.5524	Accept
9	01592500	n = 21 ΔImp = 1.70% $\tau_{critical}$ = 0.21 $\tau_{calculated}$ = -0.4571	Accept
10	01593500	n =28 ΔImp = 9.39%	Reject

Study Id.	Gage Id.	Statistics	Decision / Result
		$\tau_{critical}$ = 0.18 $\tau_{calculated}$ = 0.2328	
11	01594000	n = 12 ΔImp = 5.50% $\tau_{critical}$ = 0.303 $\tau_{calculated}$ = 0.6667	Reject
12	01596500	n = 25 ΔImp = 1.64% $\tau_{critical}$ = 0.193 $\tau_{calculated}$ = -0.16	Accept
13	01599000	n =25 ΔImp = 0.23% $\tau_{critical}$ = 0.193 $\tau_{calculated}$ = 0.04	Accept
14	01637500	n = 29 ΔImp = 0.3% $\tau_{critical}$ = 0.172 $\tau_{calculated}$ = 0.0197	Accept
15	01639500	n = 19 ΔImp = 0.88%	Accept

Study Id.	Gage Id.	Statistics	Decision / Result
		$\tau_{critical}$ = 0.228 $\tau_{calculated}$ = 0.20	
16	01640500	n = 15 ΔImp = 0.14% $\tau_{critical}$ = 0.276 $\tau_{calculated}$ = -0.0952	Accept
17	01641000	n =22 ΔImp 0.36% $\tau_{critical}$ = 0.203 $\tau_{calculated}$ = 0.0086	Accept
18	01642500	n = 13 ΔImp = 0.17% $\tau_{critical}$ = 0.308 $\tau_{calculated}$ = -0.3077	Accept
19	01643000	n = 26 ΔImp 5.94% $\tau_{critical}$ = 0.188 $\tau_{calculated}$ = 0.0554	Accept
20	01643500	n =26 ΔImp= 0.57%	Accept

Study Id.	Gage Id.	Statistics	Decision / Result
		$\tau_{critical}$ = 0.188 $\tau_{calculated}$ = 0.1046	
21	01645000	n = 21 ΔImp = 6.61% $\tau_{critical}$ = 0.21 $\tau_{calculated}$ = -0.5333	Accept
22	01645200	n =17 ΔImp = 4.00% $\tau_{critical}$ = 0.25 $\tau_{calculated}$ = 0.5588	Reject
23	01649500	n =30 ΔImp = 5.79% $\tau_{critical}$ = 0.172 $\tau_{calculated}$ = 0.2437	Reject
24	01650500	n = 14 ΔImp = 3.05% $\tau_{critical}$ = 0.275 $\tau_{calculated}$ = 0.1099	Accept
25	01651000	n =24 ΔImp = 1.21%	Accept

Study Id.	Gage Id.	Statistics	Decision / Result
		$\tau_{critical}$ = 0.196 $\tau_{calculated}$ = -0.0145	
26	01653600	n = 30 ΔImp = 3.09% $\tau_{critical}$ = 0.172 $\tau_{calculated}$ = -0.0414	Accept
27	01658000	n =26 ΔImp = 3.39% $\tau_{critical}$ = 0.188 $\tau_{calculated}$ = 0.0923	Accept
28	03076600	n =19 ΔImp = 0.1% $\tau_{critical}$ = 0.228 $\tau_{calculated}$ = 0.3626	Reject
29	03078000	n = 25 ΔImp = 0.31% $\tau_{critical}$ = 0.193 $\tau_{calculated}$ = -0.1867	Accept

Appendix C

Script for calculating R-B index

```
’Script for the RB index, imperviousness, area
theView = av.finddoc(”view1”)
theTheme = theView.findtheme(”Flow direction grid”)
theGrid = theTheme.GetGrid
flodirgrid = theview.findtheme(”flodir”).getGrid ’ looks for theme called ”DEM” to set extent
varprcpgrid = theview.findtheme(”Precipitation grid”).getgrid
tempimpgrid = theview.findtheme(”impervious grid”).getgrid
floaccgrid = flodirgrid.flowaccumulation(tempimpgrid)+tempimpgrid
areagrid = (flodirgrid.flowaccumulation(nil)+1.asgrid)
impgrid = floaccgrid/areagrid
varprcpgrid = flodirgrid.flowaccumulation(varprcpgrid)+varprcpgrid
varprcpgrid = varprcpgrid/areagrid
areagrid = areagrid * (0.000347.asgrid) ’ area is in square miles
rbgrid = 0.12752.asgrid+ ((0.16798.asgrid)*(varprcpgrid)) + ((0.0296.asgrid)*(impgrid)) - ((0.000391394.asgrid) * (areagrid))
areagrid = areagrid * (2.5899.asgrid)
’End of Script
```

```
’Program to calculate the stream length and write the output to txt file
theView = av.finddoc(”view1”)
flodirgrid = theview.findtheme(”flodir”).getGrid
rbidxgrid = theview.findtheme(”Resulting grid file from the previous script”).getGrid
areagrid = theview.findtheme(”Area”).getGrid
areagrid = (areagrid ≥ 1.0.asgrid)
rbgrid = (areagrid/areagrid)*rbidxgrid
’rbgrid = theview.findtheme(”Rbindex70”).getgrid
distlist= list.make
pixelcntlist = list.make
pixelcnt1list = list.make cntlist = list.make
for each i in 0..5 by 0.1
checkgrid = (rbgrid ≥ (i).asgrid) and (rbgrid≥(i+0.1).asgrid)
pixelcnt = 0 pixelcnt1 = 0
checktab = checkgrid.getvtab
cheknumrecds = checktab.getnumrecords
if(cheknumrecds = 2) then
maskedflodir = (checkgrid/checkgrid)*flodirgrid
tempflodir = (maskedflodir.log2)%(2.asgrid)
temp1flodir = 1.asgrid - tempflodir
dirtab = tempflodir.getvtab if(dirtab¡¿NIL) then
dirval = dirtab.findfield(”value”)
dircnt = dirtab.findfield(”Count”)
```

```
numrecords = dirtab.getnumrecords
if(pixelvalue = 1) then
pixelcnt = dirtab.returnvalue(dircnt,j-1)
pixelcntlist.add(pixelcnt) cntlist.add(i)
else (pixelvalue = 0)
pixelcnt1 = dirtab.returnvalue(dircnt,j-1) pixelcnt1list.add(pixelcnt1)
end
end
end
end ’if statement check grid end ’for statement
pixelcounts = pixelcntlist.count
reccounts = cntlist.count
if (pixelcounts ≤ 60) then
for each m in 1..pixelcounts
totalpixcnt = (((pixelcntlist.get(m-1))*(2.sqrt)) + (pixelcnt1list.get(m-1)))*900
distlist.add(totalpixcnt)
end end
listcnt = distlist.count
datastring = ”Stream Length” + ” ” + ”Range” + NL
datafilename = filename.make(”Path of your choice”)
datafile.writeELT(datastring)
if(reccounts = listcnt) then
for each i in 1..listcnt
```

```
    dist = distlist.get(i-1) reccountno = cntlist.get(i-1)

    datastring = dist.asstring + ” ” + reccountno.asstring + ”-” + (reccountno+0.1).asstring+NL

datafile.writeELT(datastring)

    end

    end
```

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