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LONG-TERM EFFECTS OF FORESTRY BEST MANAGEMENT PRACTICES ON HYDROLOGY AND WATER CHEMISTRY IN THREE APPALCHIAN HEADWATER CATCHMENTS

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LONG-TERM EFFECTS OF FORESTRY BEST MANAGEMENT PRACTICES ON HYDROLOGY AND WATER CHEMISTRY IN THREE APPALACHIAN HEADWATER CATCHMENTS

THESIS

A thesis submitted in partial fulfillment of the
requirements for the degree of Master of Science in Biosystems and Agricultural
Engineering in the College of Engineering at the University of Kentucky

By

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Lexington, Kentucky

2016

ABSTRACT OF THESIS

LONG-TERM EFFECTS OF FORESTRY BEST MANAGEMENT PRACTICES ON HYDROLOGY AND WATER CHEMISTRY IN THREE APPALACHIAN HEADWATER CATCHMENTS

In 1982, a study was initiated in the Field Branch watershed, in the University of Kentucky's Robinson Forest, to evaluate forestry best management practice (BMP) effectiveness after intensive harvesting. The study utilized a paired watershed approach on three adjacent Field Branch subcatchments. One subcatchment was left as the control, one had BMPs implemented (including a 50-ft undisturbed buffer along the stream), and one was clear-cut to the stream's banks without the use of BMPs (i.e. logger's choice). Prior research has shown that logging can negatively impact watershed functions by altering stream hydrology, geomorphology, water quality, and instream habitat. Thus, the goal of forestry BMPs is to mitigate these impacts; however, information on their effectiveness, especially on the long-term, is limited. Monitoring of three streams, one in each subcatchment, has continued since 1982. In 1985, two years after harvest, results indicated a significant increase in stormflow, baseflow, storm volume as a percentage of rainfall, and curve number in the BMP implemented subcatchment. Conversely, in the clear-cut subcatchment these same parameters were significantly increased in 1984, 1985, 2006, and 2007. Water quality results were mixed and forestry BMPs seemingly added little to no benefit over the clear-cut subcatchment for most monitored constituents.

KEYWORDS: Storm hydrology, best management practices, water quality, headwater streams, forest harvesting.

Kameryn Isaiah Wright

July 29, 2016

LONG-TERM EFFECTS OF FORESTRY BEST MANAGEMENT PRACTICES ON HYDROLOGY AND WATER CHEMISTRY IN THREE APPALACHIAN HEADWATER CATCHMENTS

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July 29, 2016

For my children Elyja William, Elyse Mae, and Hadley Jane

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Finally, I would like to thank my parents Kent and Trina Wright for their unwavering support, and to my mother and father-in-law Lisa and Dennis Barker for letting me stay with them while I spent many long hours writing this.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1: INTRODUCTION

1.1 INTRODUCTION

Riparian zones, also known as streamside zones, provide a buffer between upland management scenarios and the stream. The importance of riparian zones in maintaining hydrologic function, filtering upland derived sediments, utilizing upland derived nutrients, maintaining in-stream and near-stream temperature profiles, and providing habitat and corridors for aquatic and terrestrial fauna has been identified but not well quantified, particularly for headwater stream systems (NCASI, 1999a). Because of their small size, headwater streams are quite sensitive to anthropogenic disturbances such as harvesting which can cause larger runoff volumes, higher peak flows, and decreased water quality (Richardson and Danehy, 2007; Reeves, 2012). Most forestry best management practices (BMPs) are designed to decrease sediment transport resulting from soil erosion. Soil erosion and subsequent suspended sediment in surface waters was considered by many as one of the largest environmental concerns in the U.S. during the 1980's and is still a major concern today (USEPA, 1992). Erosion of organic and nutrient rich surface soils also decreases forest productivity (Pritchett and Fisher, 1987). Transport of sediment to streams and subsequent sedimentation leads to loss of stream habitat and altered steam hydrology (NCASI, 1999a; 1999b). Although sediment transport is a main concern associated with forest harvesting, nutrient transport and impacts on stream temperature and carbon distribution are also important (Hornbeck and Edwards, 1990; Arthur et al., 1998). While research has examined the short term effectiveness of forestry BMPs (Arthur et al., 1998; McClure et al., 2004; Witt et al., 2011), research on the long-term effects on these BMPs is quite limited (Burt et al., 2015). As such, a thorough investigation into the long-term effectiveness of forestry BMP use is needed, particularly with respect to riparian buffers, to provide a framework of understanding of how such BMPs can protect headwater streams systems thus leading to better forestry management practices.

In 1982, a study was initiated to evaluate BMP effectiveness on three headwater catchments following logging. The headwater catchments are located in the Field Branch watershed in the University of Kentucky's Robinson Forest, which is a teaching, research and extension experimental forest located in the Cumberland Plateau of eastern Kentucky. Treatments included a control or reference catchment (WSA), a catchment with BMPs implemented including a 15.2 m buffer along the perennial stream segment and others pertaining to road and trail development and retirement (WSB), and a catchment that was harvested completely to the stream's banks without the use of BMPs (i.e. logger's choice) (WSC). An overview of initial results by Arthur et al. (1998) concluded that the harvested sites recovered within approximately four years after harvest and that WSB performed marginally better than WSC at reducing water yield. With regards to water quality, the streamside buffer in WSB limited NO_3 export but the benefits of forestry BMPs at limiting the other nutrient fluxes in WSB was marginal. The results regarding sediment loading that were found in the Arthur et al. (1998) study concluded that WSB and WSC were significantly higher than WSA from 1984-1986, WSC was significantly higher than WSA in 1988, and in 1990 all three watersheds were significantly different from each other with WSC being the highest and WSA being the lowest. Although the preliminary conclusions were intriguing from a BMP effectiveness standpoint, little is known about the long-term significance that BMP implementation may have on water yield and quality.

1.2 OBJECTIVES

The main goal of this project was to evaluate the effectiveness of forestry BMPs on long-term hydrology and water quality characteristics by comparing three forested Appalachian headwater catchments before and after logging. Three treatments were implemented and include: control (WSA), BMPs implemented during and after harvest (WSB), and clear-cut to the stream (i.e., loggers' choice) with no BMPs (WSC). The objectives of the study were:

1. Evaluate yearly, growing, and non-growing season baseflow volume, stormflow volume, peak flow, stormflow volume as a percentage of rainfall, time to peak, and curve number on the paired watersheds to determine significant pairwise differences and long-term trends for the monitored time periods (Chapter 2).
2. Analyze the monitored pollutants on the paired watersheds by comparing yearly, growing, and non-growing season concentrations to determine significant pairwise differences and long-term trends for the monitored time periods (Chapter 3).

1.3 ORGANIZATION OF THESIS

Chapter 1 contains an overview of the research problems and objectives. Chapters 2 and 3 present detailed descriptions of the work performed to satisfy the research objectives. Chapter 4 discusses the conclusions of the research while Chapter 5 looks into opportunities for future work.

CHAPTER 2: EFFECT OF BEST MANAGEMENT PRACTICES ON THE HYDROLOGY OF THREE APPALACHIAN HEADWATER CATCHMENTS

2.1 INTRODUCTION

Harvesting has the potential to significantly alter the hydrologic response of a watershed. Reduced vegetative cover often means reduced evapotranspiration (ET) rates, higher peak flows, quicker response times, and greater storm runoff volumes. A review of 94 catchment experiments found that every experiment except one observed significant increases in water yield and decreases in ET rates with decreased vegetative cover (Bosch and Hewlett 1982). An experiment detailing the hydrologic changes following clear-cutting on a southern Appalachian catchment noted similar results as well as a significant increase in stormflow volumes and higher peak flows (Swank et al., 2001). One means of reducing the impacts of harvesting on watershed hydrology is through the use of best management practices (BMPs).

Forestry BMPs are employed primarily to reduce erosion and subsequent suspended sediment from reaching streams but other goals may include: preserving wildlife and stand characteristics, aesthetics, recreation, and promoting water quality. Although the primary goal of forestry BMPs is to reduce erosion, studies have shown that altered forest hydrology due to harvesting may play a significant role in determining sediment transport rates (Troendle and Olsen, 1993; Arthur et al., 1998). The USDA Forest Service has a complete guide on designing and implementing BMPs on national forested lands while Kentucky's Division of Forestry has their own region specific guide (Stringer, 2001; USDA Forest Service, 2012). Common forestry BMPs that are detailed in these guides include: the use of streamside management zones (SMZs), access road construction and subsequent seeding, stream crossing improvements, and reestablishing vegetation on disturbed sites.

A number of studies throughout the United States have examined the role of BMPs in mitigating the negative impacts of harvesting a forested watershed. However, much of this work has focused on water chemistry and less on the effectiveness of forestry BMPs for minimizing changes in watershed hydrology. A review of 81 different BMP effectiveness studies revealed that only five examined impacts to watershed hydrology (Patric, 1980; Keppeler and Ziemer, 1990; Lynch and Corbett, 1990; Arthur et al., 1998; Keppeler et al., 2008; Stednic, 2008; Cristan et al., 2016). Of those five studies, only two, Patric (1980) and Arthur et al. (1998) are located in the Appalachian Plateaus physiographic province.

In an eastern Kentucky study, Arthur et al. (1998) concluded that forestry BMPs provided some marginal benefit over an adjacent clear-cut watershed in reducing water yield post-harvest, but neither watershed had returned to pre-harvest conditions at the conclusion of the study eight years post-harvest. In a West Virginia study, results indicated that the use of a 20 m SMZ was effective at limiting significant increases in water yield following clear-cutting and that water yield nearly returned to pre-harvest conditions five years post-harvest (Patric, 1980). One additional study, located in the Allegheny Mountains, found that annual peak flows and total annual stormflow volumes were unchanged from pre-harvest to post-harvest with BMP implementation, but significant increases in peak flow and stormflow volumes were observed during the growing season for six years post-harvest (Kochenderfer et al., 1997). Barring the initial study by Arthur et al. (1998), neither Patric (1980) nor Kochenderfer et al. (1997) utilized a paired watershed approach to determine the performance of BMPs on watershed hydrology as compared to a clear-cut watershed and a control. This is important because a secondary conclusion that was reached by Bosch and Hewlett (1982) was that the most reliable results from catchment experiments were developed on studies that utilized the paired watershed approach.

The Wagon Wheel Gap Study, initiated in Colorado in 1909, is widely recognized as the first paired watershed study in the U.S. where separate treatment and control watersheds were used to examine the hydrologic effects of forest cutting (Hewlett et al., 1969; Bosch and Hewlett, 1982; Stednick, 1996; Ice and Stednick, 2004). The paired watershed approach to hydrologic study involves the use of a control watershed and one or more treatment watersheds (Cherry, 2006; Brooks et al., 2012; Witt, 2012). Initially, before treatments are implemented, each watershed is monitored for a specific period of time during which data for all desired parameters are collected. This is referred to as the calibration period. These data are then used to develop a regression relationship between the control watershed and each individual treatment watershed through a mass balance approach. Once a suitable relationship has been developed, treatments are carried out and monitoring continues. Data from this post treatment period are then used to develop post treatment regression relationships among control and treatment watersheds. Treatment effects and their magnitude are detected by examining differences in slopes and y-intercepts between calibration and post treatment regressions. In order for this method to be effective, it is important that control and treatment watersheds are as similar as possible in terms of watershed area, location, aspect, vegetative cover, soil types, geologic composition and topography, and that there are no deep seepages into or out of any of the watersheds so that differences detected throughout the post-treatment period are confidently attributed to the treatments alone (Borman and Likens, 1979; Cherry, 2006; Witt, 2012).

As the relationship between forest cutting, water yield, and evapotranspiration became accepted amongst forest scientists, it became apparent that large variability in results from hydrologic studies were observed from one site to another (Hibbert, 1967; Bosch and Hewlett, 1982; Witt, 2012). While it was known that forest removal could generate increases in water yield, it was unclear as to what the threshold level of removal was. Stednick (1996) reported that the threshold of harvested area needed to generate a streamflow response in various regions of the United States was between 15 – 50% (Stednick, 1996; Wei and Zhang, 2010). In the Appalachian Mountains, the minimum harvested area necessary to produce a measureable streamflow response was found to be 20% (Stednick, 1996). However, these suggested levels were shown not to hold true in all instances. For example, Adams et al. (2004) reported that at least 25% of stand basal area must be removed in order to elicit a hydrologic response at the Fernow Experimental Forest in West Virginia. Moreover, the minimum threshold has been reported to be as low as

10% at the Coweeta Hydrologic Laboratory in North Carolina (Stednick, 1996; Swank and Crossley, 2012).

This level of variability within the Appalachian region is primarily a reflection of the complexity of climatic, geographic and biotic factors it presents. The mixed mesophytic forest that covers much of Appalachia and most of eastern Kentucky is a complex mixture of different forest types and is considered by many to be one of the most diverse (in terms of flora) ecosystems in the United States (Moore et al., 2005). This mosaic of forest types is controlled by numerous factors including elevation, aspect, geology, land use history, and the species composition of the surroundings. The effect that forest management/manipulation may have on hydrology is directly tied to interactions among all of these factors. For example, Douglas (1983) showed that first year hydrologic response to forest cutting in Appalachian forests is determined mainly by the amount of basal area removed and the amount of solar radiation received at the site, which is a function of catchment aspect. Hewlett and Hibbert (1967) observed an almost three-fold difference in water yield between north and south facing catchments after harvest at the Coweeta Hydrologic Laboratory, with north facing catchments being the greater of the two (Douglas, 1983). Further, it has been shown that management actions that result in changes in species composition and tree ecophysiology may alter hydrologic processes and evapotranspiration through changes in canopy interception and transpiration (Stoy et al., 2006; Ford et al., 2011; Vose et al., 2011). Lu et al. (2003) found that the spatial variability of regional actual evapotranspiration in the southeastern U.S. was best explained by a multivariate linear regression model using precipitation, latitude, elevation, and percentage of forest cover as independent variables. However, over the long term, Zhang et al. (2004) found that under the same climatic conditions average annual evapotranspiration was determined mainly by the vegetative characteristics of a watershed and how the species present use available soil water.

Another important aspect of forest hydrology is recovery time. That is, the time needed for a watershed to resume a hydrologic regime which is statistically similar to that observed prior to disturbance (Hibbert and Gottfried, 1987; Stednick and Kern, 1992; Hornbeck et al., 1993; Stednick, 1996; Stednick, 2008). In a meta-analysis of various hydrologic databases from throughout the southeastern U.S., Sun et al. (2005) found that forest removal in the southeast will increase water yield, with the greatest increases occurring in areas with greater precipitation. Furthermore, Appalachian watersheds could experience the greatest water yield increases after harvest due to their high precipitation input, low temperatures, and forest cover characteristics. Sun et al. (2005) also stated that hydrologic recovery time for hilly upland systems is expected to be significantly longer than for other systems in the Southeast. Long-term data from Coweeta Hydrologic Laboratory in North Carolina showed that the longest recovery times were observed in high elevation and north facing watersheds, where either stand species conversion or coppicing treatments have been repeatedly implemented (Ford et al., 2011). As of 2008, neither of two species conversion watersheds or the coppicing watershed had fully recovered since their latest treatment in 1956-57 and 1962, respectively. Ford et al. (2011) proposed that the unexpected level of streamflow increase from the coppicing treatment at Coweeta may be due to increased competition among individual stems reducing leaf area index, thereby reducing evapotranspiration.

Species conversions resulting in changes to leaf area index can significantly increase or decrease streamflow over the long term, depending on the direction of change in leaf area index (Ford et al., 2011). Higher leaf areas indices are associated with decreased streamflow while lower leaf areas indices are associated with increased streamflow. Wullschleger et al. (2001) found that diffuse porous hardwood species generally contain a larger sapwood area within their stems than ring porous hardwoods of similar stem diameter. A number of studies have observed that differences in stomatal conductance between xylem functional groups (i.e. ring porous vs. diffuse porous) in Appalachian forests may be great (Wallace, 1988; Wullschleger et al., 2001; Vose, 2007; Ford et al., 2010; Ford et al., 2011). The implications of these findings were stated eloquently by Wullschleger et al. (2001):

> *"Whenever a forest is composed of both ring porous and diffuse porous species, total transpiration is likely to be dominated not by the species with the largest basal area, nor by the species present in the greatest number, but rather by the species with the largest sapwood area."*

The hydrologic recovery time of disturbed watersheds in Appalachia is dictated by numerous parameters. Douglas and Swank (1972) produced a regression model relating first year water yield increases to percentage of basal area cut using data from all known forest harvesting experiments in the Appalachian Highland Physiographic Division (Douglas, 1983). The results of this regression model indicated that hydrologic recovery time in this region is 1.57 years for each inch of water yield recorded in the first year after harvest. In light of the limited amount of research on the long-term effects of forestry BMPs on watershed hydrology, the objective of this study was to evaluate yearly, growing, and non-growing season baseflow volume, stormflow volume, peak flow, stormflow volume as a percentage of rainfall, time to peak, and curve number on the paired watersheds to examine significant pairwise differences and long-term trends for the monitored time periods

2.2 METHODS

2.2.1 Study Site

The research was conducted at the University of Kentucky's Robinson Forest, which is located in southeastern Kentucky in the Cumberland Plateau section of the Appalachian Plateaus province of the Appalachian Highlands (latitude 37˚ 27.01 N; longitude 83˚ 11.43 W) (Figure 2.1). Robinson Forest is approximately 6,000 ha in size with eight discontinuous properties: the main block where this research takes place is 4,200 ha. Robinson Forest is situated in the Appalachian mixed mesophytic forest region, which is characterized by high hills and low valleys with elevations ranging from 385 to 610 m (1,270 to 2,000 ft).

Figure 2.1: Location of University of Kentucky's Robinson Forest labeled in green.

These mixed mesophytic forests occur on moist and topographically protected areas within highly dissected hills and mountains. These forests are a part of a transition zone from oak-hickory forest to the northern hardwood forest and are among the most diverse in the United States with more than 30 canopy tree species (Moore et al., 2005). Robinson Forest is characterized by steep side-slopes (μ=45%) and a hydrologically restrictive geologic substrate consisting of interbedded sandstone, siltstone, shale, and coal (McDowell et al., 1981). Robinson Forest was clear-cut in the early 1900's then donated by the Mowbray-Robinson lumber company to the University of Kentucky as a teaching, research, and extension experimental forest (Figure 2.2).

The study site where this research takes place is just a small portion of Robinson Forest and consists of three adjacent subcatchments (WSA, WSB, and WSC) all located in the Field Branch watershed (Figures 2.3 and 2.4). The drainage areas of WSA, WSB and WSC are 16.1, 11.2, and 10.5 ha, respectively. At the start of the study in 1982, the overstory of WSB and WSC was dominated by oaks (*Quercus spp*.; 39%), hickories (*Carya spp*.; 17%), and yellow poplar (*Liriodendron tulipifera L*.; 15%) while WSA's overstory consisted predominately of yellow poplar (Overstreet, 1984).

Figure 2.2: Mowbray-Robinson logging operations at Robinson station in Quicksand Kentucky.

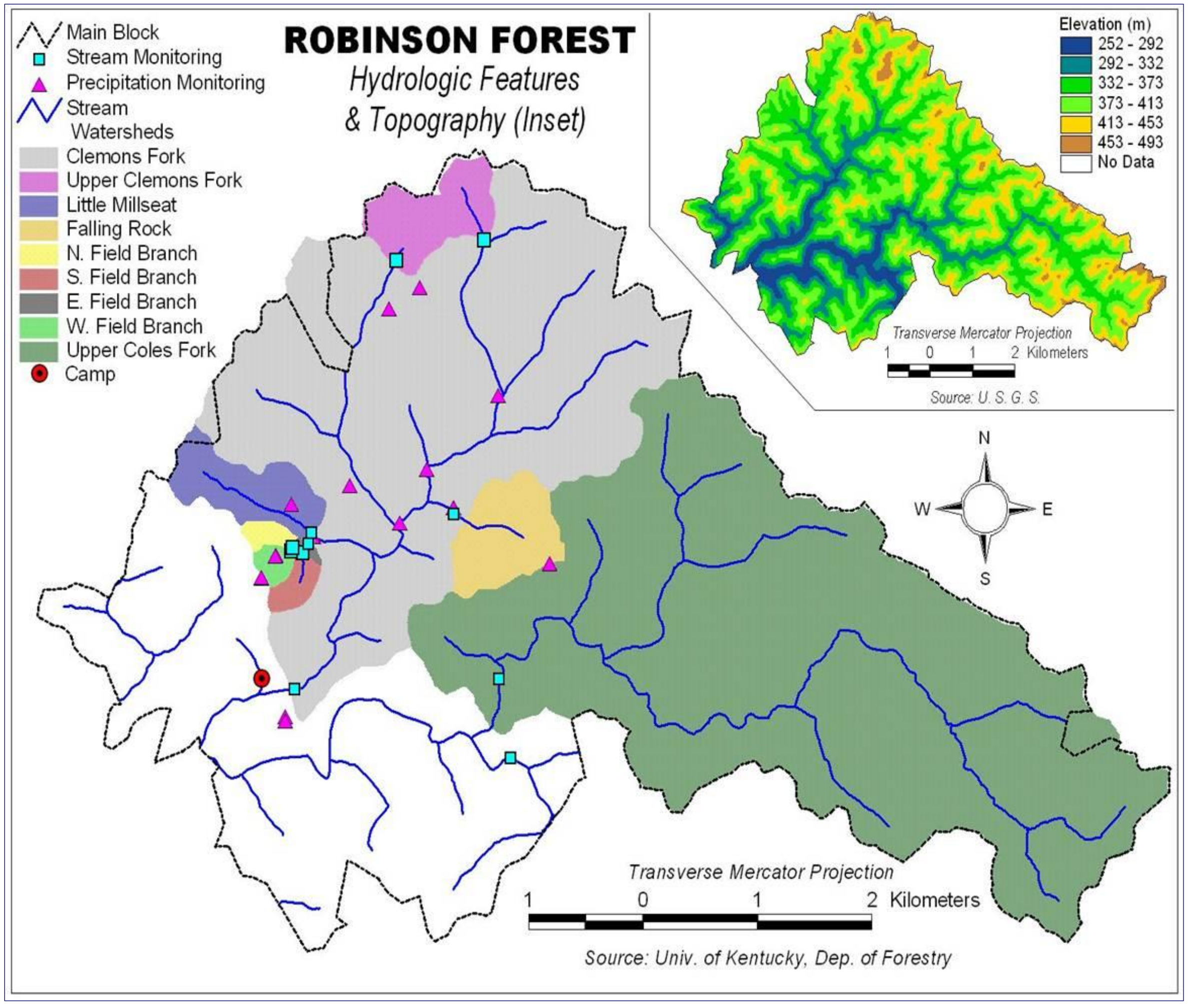

Figure 2.3: Robinson Forest hydrologic features and topography. The study area is N. Field Branch (WSA); W. Field Branch (WSB); and S. Field Branch (WSC).

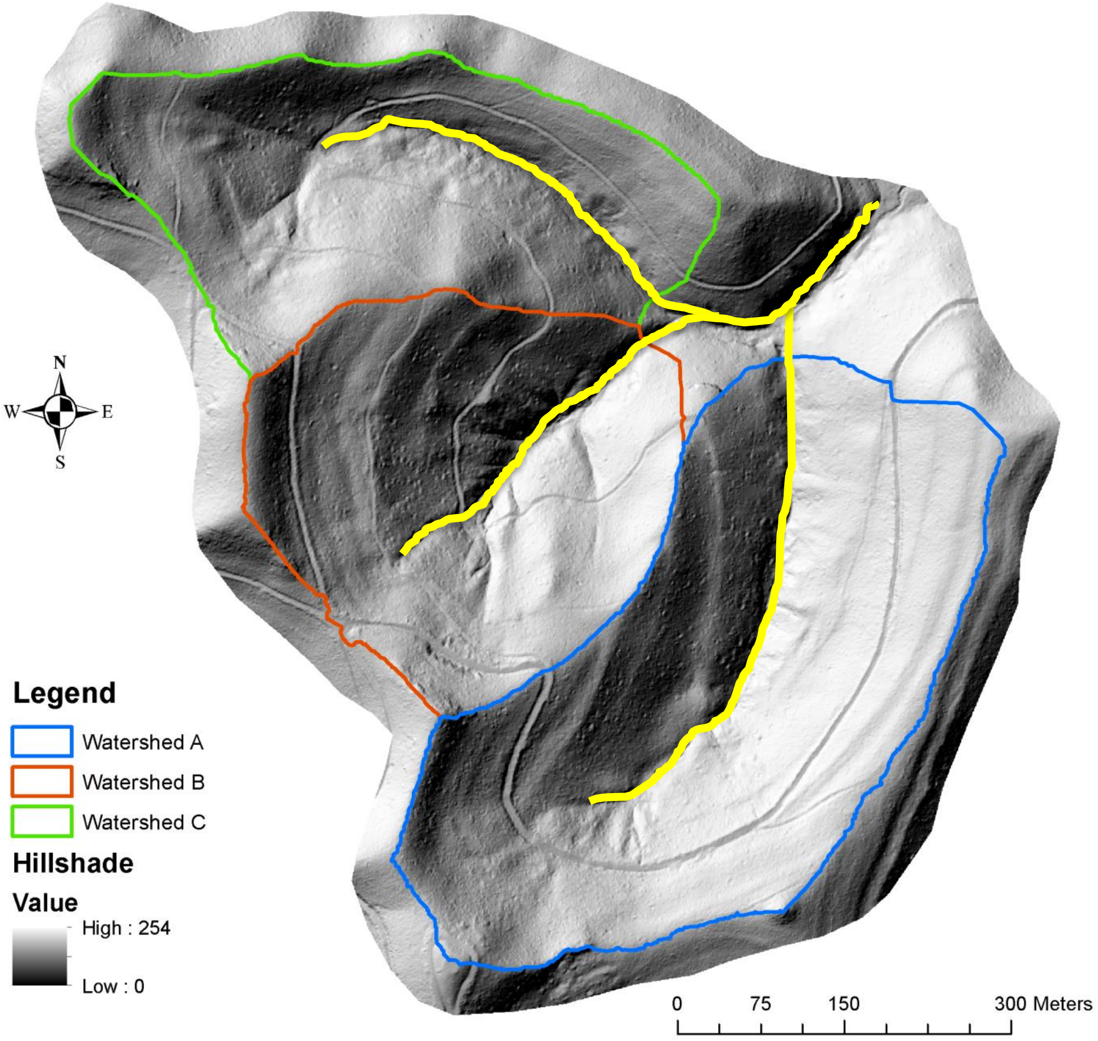

Figure 2.4: Digital elevation model of study site with stream network shown in yellow, WSA shown in blue, WSB in red, and WSC in green.

For this study, a paired watershed approach was used with WSA serving as the uncut control, WSB was clear-cut with BMP implementation, and WSC was clear-cut to the stream with no BMP implementation.

The BMPs that were implemented in WSB included:

1. 15.2 m (50 ft) undisturbed riparian buffer on both sides of the perennial stream
2. Logging roads seeded with fescue after logging was complete
3. Logging roads constructed on less than 10% grade
4. Log skidder kept on roads
5. Broad-based dips used as water control structures on logging roads
6. Logging debris was kept out of the stream

The management strategies that were implemented at WSC include:

1. No intact riparian buffer on either side of the perennial stream
2. Roads left bare after logging was complete
3. Logging roads constructed on more than 10% grade
4. Logs repeatedly skidded downhill
5. No water control structures were used on logging roads
6. Trees felled into and across the stream

Hydrologic monitoring for the three subcatchments began in February of 1982, and following a 19-month calibration period, WSB and WSC were harvested (Figure 2.5). Harvesting at both sites resulted in a complete silvicultural clear-cut with commercial timbers (> 35.5 cm diameter at breast heigh (dbh)) being removed from the site and all stems < 5 cm dbh cut and left on site (Arthur et al., 1998). Since harvest, the subcatchments have experienced no further harvesting or modifications and visibly larger trees surround the riparian buffer in WSB compared to WSC in 2005, 22 years post-harvest (Figure 2.6). Hydrologic monitoring has continued post-harvest until the present day.

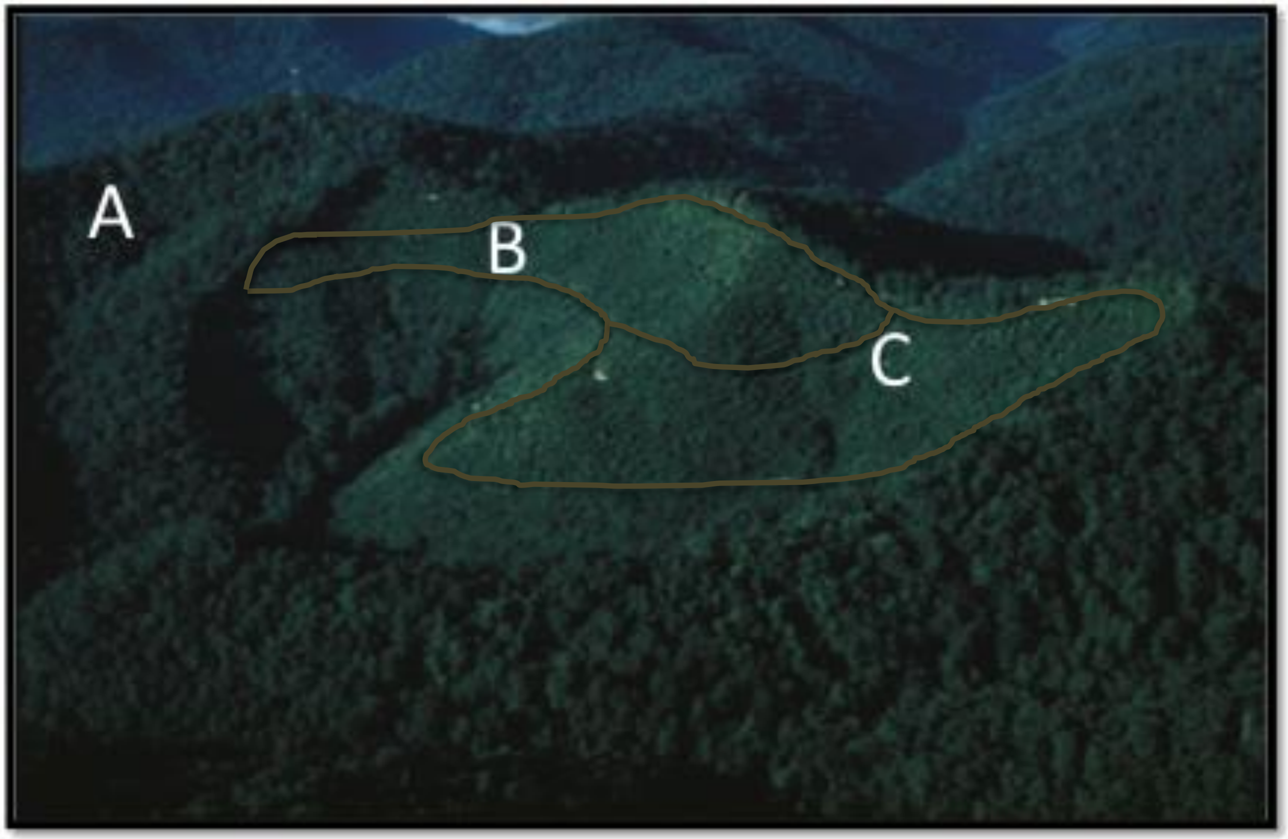

Figure 2.5: Study site post-harvest (1984) with logging roads shown in brown: WSA is on the far left, WSB is in the middle along with the riparian buffer that was left along the stream, and WSC is on the right.

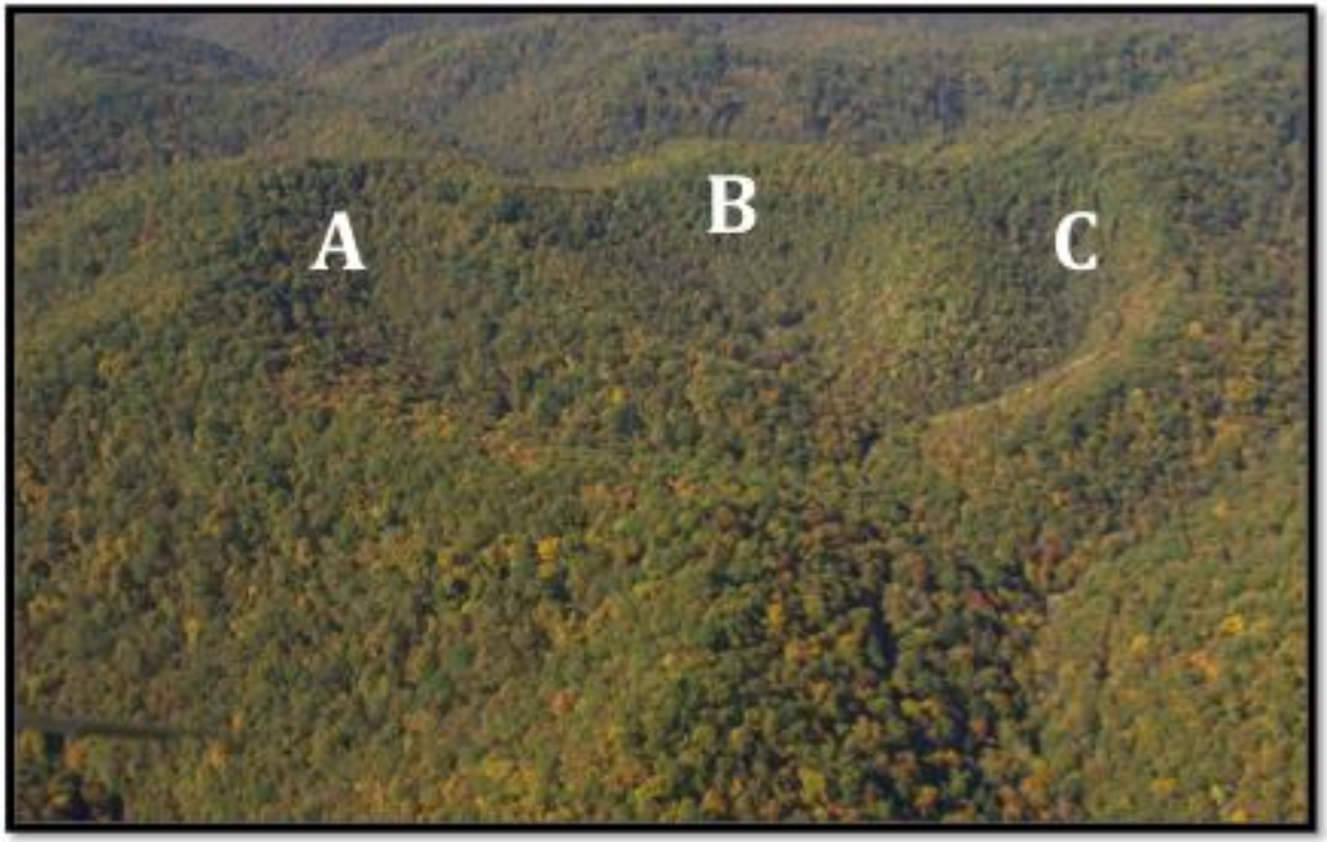

Figure 2.6: Study site 22 years after harvest (2005) with WSA on the far left, WSB in the middle, and WSC on the right.

2.2.2 Precipitation Data

Precipitation data (P) were collected by weather stations located in Little Millseat and at Camp (Figure 2.3). The Little Millseat weather station is located below the confluence of the three watersheds (latitude 37˚ 28.53 N; longitude 83˚ 09.63 W) and the Camp weather station is located in a nearby hollow (latitude 37˚ 27.01 N; longitude 83˚ 11.43 W). Daily cumulative precipitation data at the weather stations were collected using tipping bucket recording gauges and weighing gauges. At the Camp site, a Campbell Scientific weather station was installed in 2000 which allowed for the collection of 15-minute cumulative precipitation data as well as relative humidity, temperature, wind speed and direction, and solar radiation. During the first half of the study (1982-1993), precipitation data from the Little Millseat weather station were used in the hydrologic analyses. The Camp weather station data was used during the second half of the study (2002-2008) because of its ability to record 15-min precipitation data. The Camp weather station is located about 3 km south of the Little Millseat weather station. Data from both weather stations were unavailable in 1999 and 2000 and were substituted with data from nearby (≈ 20 Km) Jackson County Airport (latitude 37˚ 59.36 N; longitude 83˚ 31.73 W). These data were only used to help determine the 27-year study period average annual precipitation characteristics.

Storms events were characterized by cumulative precipitation (rainfall) depths greater than or equal to 11 mm. The 11 mm value was chosen in accordance with the Revised Universal Soil Loss Equation (RUSLE), which specifies that erosion does not occur during rainfall events less than 12.7 mm (½ in). Reducing this value to 11 mm increased overall sample size and was utilized in previous storm characteristic and hydrograph studies in eastern Kentucky (Warner et al., 2010b; Blackburn-Lynch, 2015). Storm events were considered single if the time gap between recorded rainfall exceeded three hours (Warner et al., 2010b; Blackburn-Lynch, 2015). For instances when only daily cumulative precipitation data were available, unit runoff depths and durations were computed for each hydrograph and compared to daily precipitation depths to determine if a storm event occurred over multiple days. Consecutive days with precipitation that fell during the course of the hydrograph response were included in the total storm depth. The only time this was not the case was if a spike in daily precipitation occurred past the time of peak hydrograph flow. Hydrograph response would dictate whether this spike in precipitation was two separate storm events (multiple peaks) or a single storm event (single peak) (Figures 2.7 and 2.8). If possible, hydrographs were separated into their respective storm events; otherwise, they were placed into the unsuitable hydrograph category (Figure 2.8). Each storm depth was compared against each respective unit hydrograph depth to confirm that flow out was not greater than flow in and to ensure all attributable precipitation was recorded with storm depth.

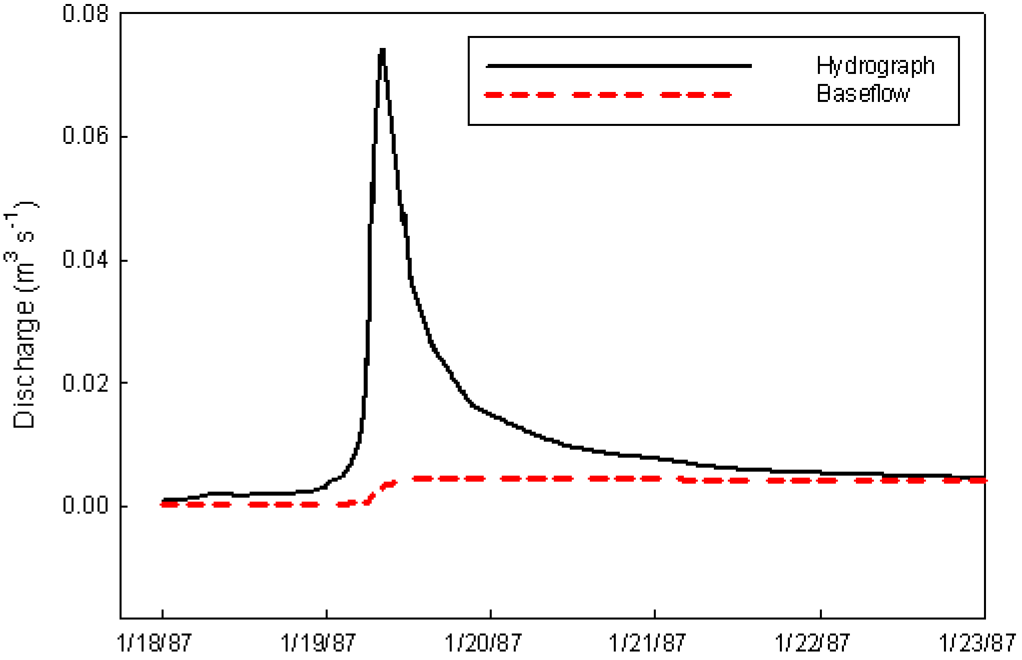

Figure 2.7: Example of baseflow separation and a suitable (single peak) hydrograph for analysis

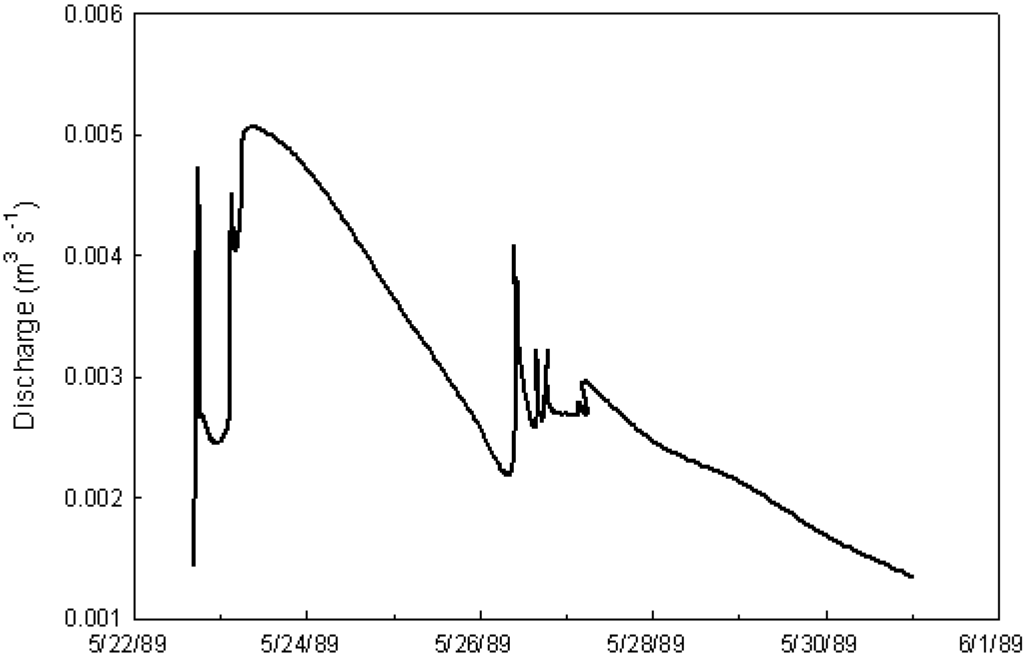

Figure 2.8: Example of an unsuitable hydrograph (multiple peaks).

2.2.3 Hydrograph Data

Stage data for WSA, WSB and WSC were each recorded using an H-flume equipped with a stage-height recorder. WSA was equipped with a .91 m (3 ft) tall H-flume while WSB and WSC were both equipped with a .76 m (2.5 ft) tall H-flume. Equations were then formulated to detail the stage-discharge relationship for the flumes. To ensure accuracy for all flow regimes, the stage-discharge relationships for the flumes were subdivided into a low-flow regime and a high-flow regime. Low-flows were defined as follows: flows that occurred during a stage less than 0.28 m in the 0.91 m tall flume and 0.20 m in the 0.76 m tall flume. High-flows were defined as everything above the low-flow stages up to the tops of the flumes. The resulting stage-discharge equations are as follows (stage denoted as h (m), discharge denoted as Q (m^3 s^{-1})):

$$Q = 0.6h^2 + 0.02h \qquad \text{Equation 2.1}$$

$$Q = 1.16h^2 - 0.14h \qquad \text{Equation 2.2}$$

$$Q = 0.6h^2 + 0.01h \qquad \text{Equation 2.3}$$

$$Q = 1.06h^2 - 0.1h \qquad \text{Equation 2.4}$$

The low-flow and high-flow stage-discharge relationships for WSA are shown in equations 2.1 and 2.2, respectively. The low-flow and high-flow stage-discharge relationships for both WSB and WSC are shown in equations 2.3 and 2.4, respectively. The coefficients of determination (R^2) for equations 2.1-2.4 were all R^2=0.99 or greater, indicating a very good fit between stage and discharge. From the stage-discharge relationship, it was determined that the maximum flow that the flume in WSA could accommodate was 0.83 m^3 s^{-1} (29.4 ft^3 s^{-1}) and in WSB and WSC it was 0.52 m^3 s^{-1} (18.5 ft^3 s^{-1}). During the analyzation periods, the respective flume stage-discharge relationships were used to check that overtopping of the flumes did not occur. Data were collected on a flow-weighted basis with a minimum recording increment of 15 minutes during rapidly varied flow and a maximum recording increment of 1 day during minimally varied flow. Periodic equipment failure at the three flumes resulted in data gaps from 1994-

2001 for WSA and WSB and from 1994-2004 for WSC. Equipment failure was largely an effect of periodic flooding, which resulted in broken stilling wells and displaced and damaged stream-gauging equipment. High sediment loads associated with the floods also periodically filled the flumes and, on occasion, cracked flume foundations resulting in leakage (Figures 3.2 and 3.3).

Storm hydrographs were separated into base flow and storm flow using Purdue's Web-based Hydrograph Analysis Tool (WHAT) (Figure 2.7). WHAT is a recursive digital filter which uses hydrogeological specific constants and a filter algorithm to partition streamflow into baseflow and stormflow (Eckhardt, 2005). As noted by Eckhardt (2005), this type of filter helps reduce subjectivity by limiting the influence of human judgment, is easily reproducible, and can be automated for large data sets. The one subjective element in this technique is the maximum baseflow index (BFI_{max}) parameter, which is the ratio of baseflow to total flow used by the algorithm. The BFI_{max} parameter varies by hydrogeologic region. A study of the United States by Santhi et al. (2008) recommended a baseflow index of 0.2-0.4 for the hydrogeologic region in which this study is located. WHAT recommended a BFI_{max} of 0.25 for catchments with a perennial stream and hard rock aquifers, which fits the study area, and thus this was the value used. Currently, the only way that the BFI_{max} parameter can be accurately selected is through tracer-based experiments. However, a sensitivity analysis was conducted on the BFI_{max} parameter, and it was found that an incorrectly selected BFI_{max} value led to little relative error as long as the hydrogeologic condition was accurately selected (Eckhardt, 2012).

Over the study period (1982-1993 and 2002-2008), approximately 555 hydrographs from each subcatchment (WSA, WSB, and WSC) were recorded. All hydrographs, including multiple peak hydrographs, were used to calculate annual, annual growing, and annual non-growing season baseflow volumes; storm flow volumes; and total flow (baseflow + stormflow) volumes (Figure 2.8). The growing season dates were defined by the Natural Resource Conservation Service (NRCS) soil survey for Breathitt county and ran from April 20-October 26 (Hayes, 1998). For suitable (e.g. single peak) hydrographs (Figure 2.7), the following characteristics were computed and statistically analyzed: stormflow volume, baseflow volume, peak flow (Q_p), stormflow volume as a percentage of rainfall ([S/P] %), time to peak (T_p) (only if 15-min rainfall data were available), and curve number (CN). Time to peak was defined as the time difference between peak hydrograph discharge and the start of rainfall. Subcatchment hydrograph characteristics that were suitable for analysis across all watersheds, 190 hydrographs from the first time period and 104 hydrographs from the second, were evaluated on an annual, annual growing season, and annual non-growing season basis (Table 2.1).

Table 2.1: Total, growing, and non-growing season suitable hydrographs 1982-1993 and 2002-2008.

Period	Year	Total	Growing	Non-growing
Pre-harvest	1982	15	7	8
Pre-harvest	1983	16	11	5
Post-harvest	1984	19	9	10
Post-harvest	1985	15	11	4
Post-harvest	1986	11	6	5
Post-harvest	1987	17	8	9
Post-harvest	1988	11	5	6
Post-harvest	1989	18	11	7
Post-harvest	1990	20	10	10
Post-harvest	1991	22	11	11
Post-harvest	1992	15	12	3
Post-harvest	1993	11	10	1
Post-harvest	2002[1]	15	8	7
Post-harvest	2003[1]	16	8	8
Post-harvest	2004[1]	26	16	10
Post-harvest	2005	15	13	2
Post-harvest	2006	11	8	3
Post-harvest	2007	12	6	6
Post-harvest	2008	9	3	6

[1] WSC was excluded from analysis from 2002-2004

2.2.3.1 Curve Number Method

The CN method was developed by the United States Soil Conservation Service (SCS), presently NRCS, to determine runoff depth and peak flow for different size storm events (USDA-SCS, 1972; USDA-NRCS 2004). The CN method is primarily a planning and design tool that enables professionals to determine peak flows and runoff depths for selected storm sizes at a specific site. In this capacity, CN is selected based on land-use, hydrologic condition, and hydrologic soil group, and ranges from 30 to 100. Higher CNs indicates higher runoff potential while lower CNs indicates lower runoff potential. In this study, however, runoff depth along with precipitation depth were known allowing for direct calculation of CN through equation 2.8 and 2.9 (Hawkins, 1973). Results from Hawkins (1993) found a CN of 85 for Little Millseat watershed in Robinson forest; Little Millseat is located directly north and adjacent to WSA (Figure 2.3).

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S} \qquad \text{Equation 2.5}$$

$$I_a = \lambda S \qquad \text{Equation 2.6}$$

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \qquad \text{Equation 2.7}$$

$$S = \frac{1000}{CN} - 10 \qquad \text{Equation 2.8}$$

$$S = 5[P + 2Q - (4Q^2 + 5PQ)^{0.5}] \qquad \text{Equation 2.9}$$

The variable Q is the runoff depth (in), P is the precipitation depth (in), S is the potential maximum retention after runoff begins, λ is the initial abstraction ratio, and I_a is the initial abstraction. Initial abstraction represents all the losses (i.e. water retained by surface depressions, interception, evaporation, and infiltration) before runoff occurs. The initial abstraction ratio is commonly chosen to be $\lambda=0.2$ although Hawkins et al. (2002) has shown that this provides an over-approximation of the CN and that $\lambda=0.05$ is more suitable. CNs in this study were computed using initial abstraction ratios of $\lambda=0.2$ and $\lambda=0.05$. Rainfall events with a cumulative depth less than 25.4 mm (1 in) have also been shown to over approximate the CN (Hawkins et al., 2002; Warner et al., 2010b). Because of this, CN analysis was separated into all suitable hydrograph events (Table 2.1), and all suitable hydrograph events with a cumulative depth equal to or greater than 25.4 mm (Table 2.2). For the latter, analysis was broken into a pre-harvest period (1982 and 1983) and four post-harvest periods (1984-1988, 1989-1993, 2002-2004, and 2005-2008). This was due to the limited number of suitable events associated with a cumulative depth equal to or greater than 25.4 mm. Statistical analysis of CN was only completed for all suitable events (Table 2.1) to allow for larger yearly sample sizes and to provide a more robust analysis.

Table 2.2: Total, growing, and non-growing season suitable hydrographs with a cumulative storm depth equal to or greater than 25.4 mm 1982-1993 and 2002-2008.

Period	Year	Total	Growing	Non-growing
Pre-harvest	1982-1983	16	11	5
Post-harvest	1984-1988	48	14	24
Post-harvest	1989-1993	55	26	29
Post-harvest	2002-2004[1]	26	15	11
Post-harvest	2005-2008	12	7	5

[1] WSC was excluded from analysis from 2002-2004

2.2.4 Forest Stand Analysis

A stand survey was performed in the fall of 2010 to determine the species composition and stand density of the study area. Using ArcMap® software, a systematic random plot distribution was created which resulted in 25 plots per watershed all of which were greater than 20 m apart. Inventory plots were 10 m x 10 m with one ground cover plot in each plot corner measuring 1 m x 1 m. In each inventory plot, all trees with dbh ≥5 cm were recorded by species, diameter and total height. Tree heights were measured using a Suunto® clinometer. Tree diameters were measured using a Forestry Suppliers diameter measuring tape. Each ground cover plot was assigned a ground cover percentage using a 1 m x 1 m grid placed within each corner of inventory plots. Throughout the inventory process, any invasive species were noted.

Light detection and ranging (LiDAR) technology was used to further evaluate stand structure. Three LiDAR datasets were used in the analysis. One dataset was low density (~ 1 pt m^{-2}) collected in the spring of 2013 during the leaf-off season for the purpose of acquiring terrain information, as a part of a statewide elevation data acquiring program from the Kentucky Division of Geographic Information. The second dataset was high density (~ 40 pt m^{-2}) collected in the summer of 2013 during the leaf-on season for the purpose of collecting detailed vegetation information. Raw LiDAR datasets were processed using the TerraScan software (Terrasolid Ltd., 2012) to classify LiDAR points into ground and non-ground points. A third dataset was also created by combining both low-density and high-density points. For each of the three LiDAR datasets (low-density, high-density, and combined), the “Create LAS Dataset” tool in ArcMap 10.2 was used to create a LAS dataset file. The LAS dataset was then filtered to include ground points only, and the “LAS dataset to Raster” tool in ArcMap was used to create a 1 m resolution DEM using the natural neighbor as a fill void method. Four DEMs for each dataset were created considering different interpolation methods: average, inverse distance weighted, minimum, and nearest neighbor. As a result, a total of 12 DEMs covering the study areas were created: three LiDAR datasets and four interpolation methods.

2.2.5 Statistical Analysis

Due to periodic data gaps related to equipment failure, the study’s post-harvest phase was separated into two different time periods: 1984-1993 and 2002-2008. In the second time period, WSC was analyzed from (2005-2008) due to complications with the stage-height recorder from 2002-2004. Massive flooding in May of 2009 compromised flume integrity at all three subcatchments, and in 2010 pressure transducers were installed all three site thereby replacing the stage-height recorders. Large inaccuracies were observed in the data recorded by the pressure transducers from 2010-present and inclusion of these data in this study were unfeasible. The reason for these inaccuracies was thought to be a result of sediment accumulating in the stilling wells.

One-way analyses of variance (ANOVAs) were used to evaluate annual, pre-harvest and post-harvest storm characteristic differences. Differences were assessed on an annual basis so comparisons could be made between yearly storm characteristics and hydrograph characteristics. Differences in storm characteristics were assessed on a pre-harvest and post-harvest basis to test if statistically significant differences between the two periods existed. Significant differences ($p \leq 0.05$) between annual storm characteristics and the study period average storm characteristic were evaluated using Dunn's multiple comparison tests. Significant differences ($p \leq 0.05$) between pre-harvest and post-harvest storm characteristics were also evaluated using Dunn's multiple comparison tests. Storm characteristics evaluated were storm depth (mm), 5-day antecedent moisture (mm) (1982-1993 and 2002-2008), and in the second time period average storm intensity (mm hr^{-1}), and max storm intensity (mm hr^{-1}) (2002-2008).

One-way analyses of covariance (ANCOVAs) were used to evaluate differences in baseflow volume, stormflow volume, peak flow, stormflow volume as a percentage of rainfall, time to peak, and curve number between the subcatchments. Precipitation depth and growing season served as covariates. Differences were assessed on an annual basis to limit the temporal variability of subcatchment hydrology due to regrowth and to determine the year when treatment watersheds reached pre-harvest conditions. Additionally, a three-year post-harvest period was assessed to determine differences in treatment effects directly after harvest. Significant pairwise differences ($p \leq 0.05$) between subcatchments were evaluated using Holm-Sidak multiple comparison tests. In one instance, the underlying assumptions of an ANCOVA were not met (e.g. linearity of regression, homogeneity of error variances, independence of error terms, normality of error terms, and homogeneity of regression slopes). For this instance, a one-way analysis of variance (ANOVA) was used and significant pairwise differences ($p \leq 0.05$) were evaluated using Tukey comparison tests.

ANCOVA was preferred to ANOVA because the inclusion of the covariates, precipitation depth and growing season, reduced the amount of unexplained variance in the hydrograph parameters allowing for a more accurate assessment of treatment effects. Hydrograph parameters that were statistically analyzed included baseflow volume (m^3 ha^{-1}), stormflow volume (m^3 ha^{-1}), peak flow (m^3 s^{-1} ha^{-1}), stormflow volume as a percentage of rainfall (%), time to peak (hr), and curve number (CN). Baseflow volume, stormflow volume, and peak flow were normalized by drainage area. This was achieved by dividing baseflow volume, stormflow volume, and peak flow by the respective drainage areas in each subcatchment. By design, stormflow volume as a percentage of rainfall is already normalized by drainage area. These measures were taken to reduce the differences in evaluated characteristics due to differences in subcatchment size. Statistical analyses were performed in SigmaPlot 13 (Systat Software, Inc., 2015).

2.3 RESULTS AND DISCUSSION

2.3.1 Precipitation Characteristics

Table 2.3 contains storm event characteristics for the first time period (1982-1993) while Table 2.4 contains storm event characteristics for the second time period (2002-2008). The pre-harvest period had an average of 33 storms per year, comparatively; post-harvest averaged 34 storms per year. Average storm events for the entire analyzation period (1982-1993 and 2002-2008) equaled 34. The yearly cumulative precipitation for the study site from 1982-2008 is shown in Figure 2.9; the average yearly cumulative precipitation for this time period was 1120 mm. The year 2004 had the highest cumulative rainfall at 1490 mm while 2007 had the lowest at 850 mm. The maximum and minimum storm depths in the first study period were 80.0 mm and 11.2 mm, respectively, and in the second time period they were 105.7 mm and 10.4 mm, respectively. Additionally, the maximum and minimum storm depths during pre-harvest were 48.5 mm and 11.2 mm, respectively while post-harvest values were 105.7 mm and 10.4 mm, respectively. The average storm depth in the first time period was

Table 2.3: Storm event characteristics 1982-1993.

Date	Precipitation (mm)	Total 5-day antecedent rainfall (mm)	Season[1]
February 8, 1982	49.3	7.4	NG
February 16, 1982	29.5	12.7	NG
March 15, 1982	36.1	22.4	NG
March 31, 1982	23.4	1.0	NG
May 21, 1982	31.0	11.4	G
May 28, 1982	16.5	9.1	G
June 4, 1982	16.3	20.3	G
July 28, 1982	36.8	3.0	G
August 5, 1982	38.1	4.3	G
September 13, 1982	62.2	0.0	G
September 25, 1982	15.7	10.9	G
November 20, 1982	21.3	3.0	NG
November 30, 1982	13.2	24.6	NG
December 5, 1982	15.2	13.2	NG
December 15, 1982	14.5	21.6	NG
January 21, 1983	26.9	1.0	NG
February 10, 1983	22.1	9.1	NG
April 14, 1983	23.6	7.4	NG
May 3, 1983	34.3	12.2	G
May 13, 1983	93.5	17.3	G
May 22, 1983	41.9	19.8	G
June 3, 1983	27.9	2.3	G
June 4, 1983	15.0	29.5	G
July 3, 1983	33.3	0.0	G
July 5, 1983	13.2	33.3	G
July 18, 1983	12.2	8.9	G
August 2, 1983	25.4	0.0	G
August 11, 1983	32.5	0.5	G
August 27, 1983[2]	14.0	0.0	G
November 14, 1983	30.2	12.7	NG
December 27, 1983	16.3	5.8	NG
February 27, 1984	41.4	5.6	NG
March 20, 1984	27.9	16.0	NG
March 28, 1984	24.1	2.8	NG
April 4, 1984	27.7	1.0	NG
April 9, 1984	41.4	27.7	NG

Table 2.3: Continued

Date	Precipitation (mm)	Total 5-day antecedent rainfall (mm)	Season[1]
April 21, 1984	44.7	18.3	G
May 4, 1984	23.6	23.6	G
May 6, 1984	136.1	42.4	G
May 23, 1984	11.4	0.0	G
May 28, 1984	22.1	21.6	G
July 26, 1984	21.3	17.3	G
July 27, 1984	16.3	33.5	G
July 30, 1984	11.4	49.8	G
August 22, 1984	38.9	7.1	G
November 4, 1984	20.1	9.4	NG
November 18, 1984	64.8	3.3	NG
November 28, 1984	27.4	0.0	NG
December 20, 1984	22.1	12.2	NG
December 24, 1984	21.8	31.0	NG
January 3, 1985	27.4	26.2	NG
February 11, 1985	44.7	0.0	NG
May 15, 1985	18.5	1.0	G
June 5, 1985	18.3	13.0	G
June 10, 1985	22.6	23.1	G
June 11, 1985	28.7	27.4	G
July 10, 1985	27.9	0.0	G
July 30, 1985	27.7	2.5	G
August 1, 1985	38.1	27.7	G
August 17, 1985	14.5	25.4	G
August 25, 1985	13.2	10.9	G
August 30, 1985	39.4	13.2	G
September 26, 1985	14.7	1.8	G
November 2, 1985	62.5	5.8	NG
December 12, 1985	27.9	0.0	NG
February 2, 1986	48.0	2.0	NG
April 28, 1986	13.7	0.0	G
May 11, 1986	26.2	4.1	G
July 2, 1986	19.1	8.9	G
July 20, 1986	16.5	0.0	G
July 26, 1986	18.3	5.1	G
October 1, 1986	16.5	0.8	G
November 5, 1986	30.0	3.3	NG

Table 2.3: Continued

Date	Precipitation (mm)	Total 5-day antecedent rainfall (mm)	Season[1]
November 8, 1986	82.0	40.9	NG
November 10, 1986	23.4	122.9	NG
December 8, 1986	33.8	0.8	NG
January 18, 1987	35.8	5.1	NG
February 22, 1987	23.6	5.6	NG
February 26, 1987	41.1	23.6	NG
March 18, 1987	12.7	13.0	NG
March 30, 1987	72.4	0.0	NG
May 12, 1987	14.0	0.0	G
May 21, 1987	18.5	4.3	G
May 25, 1987	15.2	19.3	G
June 16, 1987	14.0	5.1	G
June 25, 1987	37.1	16.8	G
July 11, 1987	28.7	7.6	G
August 22, 1987	19.1	16.5	G
September 12, 1987	17.0	13.2	G
November 9, 1987	39.9	0.0	NG
November 16, 1987	15.7	0.0	NG
December 14, 1987	13.7	0.0	NG
December 24, 1987	79.0	7.1	NG
January 18, 1988	37.8	6.4	NG
April 6, 1988	36.1	5.8	NG
May 4, 1988	50.3	0.0	G
June 2, 1988	12.2	0.8	G
June 9, 1988	13.2	0.0	G
August 23, 1988	44.7	5.1	G
September 16, 1988	50.8	0.0	G
November 4, 1988	33.0	0.0	NG
November 27, 1988	15.2	2.5	NG
December 21, 1988	30.0	0.0	NG
December 24, 1988	32.0	38.6	NG
January 11, 1989	51.3	20.3	NG
February 3, 1989	31.0	9.1	NG
February 13, 1989	60.7	0.0	NG
February 20, 1989	50.5	30.0	NG
March 20, 1989	43.4	1.3	NG

Table 2.3: Continued

Date	Precipitation (mm)	Total 5-day antecedent rainfall (mm)	Season[1]
April 3, 1989	24.4	18.5	NG
May 19, 1989	14.5	9.4	G
June 12, 1989	104.6	8.9	G
June 22, 1989	14.7	10.7	G
July 23, 1989	25.1	26.9	G
July 27, 1989	20.3	26.9	G
July 31, 1989	26.2	29.0	G
August 5, 1989	31.0	26.2	G
August 18, 1989	37.3	6.1	G
September 22, 1989	56.4	0.0	G
September 30, 1989	36.8	11.4	G
October 16, 1989	102.4	0.0	G
November 14, 1989	35.6	1.8	NG
January 29, 1990	26.2	4.8	NG
February 3, 1990	36.1	26.2	NG
February 9, 1990	35.3	2.5	NG
February 15, 1990	31.0	13.7	NG
March 16, 1990	38.6	0.0	NG
April 6, 1990	25.9	0.0	NG
May 26, 1990	14.5	8.1	G
May 28, 1990	29.2	15.7	G
June 2, 1990	33.8	29.2	G
June 21, 1990	19.8	4.3	G
July 30, 1990	11.4	1.3	G
August 8, 1990	19.1	15.2	G
August 29, 1990	16.8	0.0	G
September 9, 1990	16.5	0.0	G
September 12, 1990	11.4	16.5	G
October 4, 1990	27.9	0.0	G
December 2, 1990	33.8	4.6	NG
December 20, 1990	51.1	61.7	NG
December 27, 1990	38.1	38.4	NG
December 30, 1990	31.0	38.1	NG
January 6, 1991	32.3	0.0	NG
February 6, 1991	23.6	1.3	NG
February 13, 1991	29.7	0.0	NG

Table 2.3: Continued

Date	Precipitation (mm)	Total 5-day antecedent rainfall (mm)	Season[1]
February 17, 1991	62.2	31.0	NG
March 22, 1991	34.0	12.7	NG
March 29, 1991	34.3	9.4	NG
April 15, 1991	26.7	11.4	NG
April 19, 1991	29.2	26.7	NG
May 9, 1991	17.8	6.9	G
May 18, 1991	18.5	0.0	G
May 27, 1991	16.5	0.0	G
May 29, 1991	29.2	16.5	G
June 22, 1991	30.5	32.3	G
June 25, 1991	35.6	39.9	G
July 10, 1991	17.3	7.6	G
July 12, 1991	30.5	23.6	G
August 7, 1991	31.0	0.0	G
October 5, 1991	38.1	0.0	G
October 15, 1991	21.6	0.0	G
November 21, 1991	59.7	2.0	NG
December 13, 1991	24.1	20.8	NG
December 28, 1991	40.9	10.2	NG
February 24, 1992	40.1	7.4	NG
March 30, 1992	34.8	5.6	NG
May 28, 1992	38.9	0.8	G
June 17, 1992	15.2	7.4	G
June 24, 1992	28.4	0.8	G
July 1, 1992	80.8	14.5	G
July 14, 1992	24.6	0.3	G
July 17, 1992	11.2	24.6	G
July 22, 1992	17.5	12.4	G
July 24, 1992	57.9	18.8	G
August 8, 1992	22.9	6.4	G
August 27, 1992	49.8	5.3	G
September 4, 1992	11.7	0.0	G
September 18, 1992	25.1	0.0	G
December 20, 1992	29.2	22.1	NG
March 29, 1993	40.6	15.0	NG

Table 2.3: Continued

Date	Precipitation (mm)	Total 5-day antecedent rainfall (mm)	Season[1]
April 25, 1993	21.6	17.3	G
May 9, 1993	23.9	0.0	G
June 9, 1993	21.6	11.4	G
June 21, 1993	21.6	0.0	G
July 13, 1993	58.4	25.4	G
July 15, 1993	17.0	75.4	G
July 26, 1993	36.8	0.0	G
September 2, 1993	30.7	4.1	G
September 15, 1993	57.9	0.0	G
October 18, 1993	36.6	9.1	G

🟦 Hydrograph was plotted for storm event.

[1] G-Growing season runs from April 20 - October 26.
NG-Non-Growing season runs from October 27 - April 19.

[2] Final storm before harvest.

Table 2.4: Storm Event Characteristics 2002-2008.

Start Date	End Date	Duration (hr)	Depth (mm)	5 Day Prior (mm)	Avg. Int. (mm/hr)	Max Int. (mm/hr)	Season[1]
1/9/02 13:00	1/9/02 17:45	4.7	11.2	3.3	2.6	6.1	NG
1/22/02 22:15	1/23/02 8:15	10.0	14.0	21.8	2.2	6.1	NG
1/24/02 5:45	1/24/02 19:15	13.5	22.9	31.0	2.4	6.1	NG
2/7/02 11:30	2/7/02 16:00	4.5	11.9	0.3	2.6	4.1	NG
3/16/02 3:45	3/16/02 8:15	4.5	16.8	2.5	5.6	22.4	NG
3/17/02 19:15	3/18/02 6:15	11.0	23.4	27.2	2.2	6.1	NG
3/19/02 6:15	3/19/02 14:00	7.7	13.2	50.0	1.9	5.1	NG
3/20/02 7:15	3/20/02 12:15	5.0	19.1	64.8	3.6	7.1	NG
3/26/02 3:45	3/26/02 13:30	9.7	16.3	0.0	3.0	15.2	NG
3/29/02 19:15	3/30/02 3:00	7.7	16.5	16.5	3.9	16.3	NG
3/31/02 1:45	3/31/02 15:45	14.0	23.1	36.8	2.3	8.1	NG
4/14/02 14:45	4/14/02 18:30	3.7	14.7	7.9	8.4	30.5	NG
4/21/02 23:00	4/25/02 1:15	74.2	50.8	5.3	7.5	25.4	G
4/28/02 6:30	4/28/02 9:45	3.2	15.5	31.2	5.2	16.3	G
5/2/02 12:00	5/2/02 22:00	10.0	59.4	27.7	9.5	41.7	G
5/8/02 11:00	5/9/02 13:15	26.2	11.7	18.0	5.2	18.3	G
5/13/02 3:30	5/13/02 10:45	7.2	42.2	12.7	6.0	30.5	G
5/17/02 19:30	5/18/02 6:30	11.0	29.5	43.4	4.7	23.4	G
6/6/02 2:30	6/6/02 14:30	12.0	27.7	12.4	4.8	19.3	G
6/12/02 19:45	6/12/02 23:15	3.5	13.7	3.8	4.6	18.3	G
7/12/02 18:30	7/13/02 17:30	23.0	61.2	0.3	4.5	24.4	G
7/19/02 14:00	7/20/02 5:00	15.0	18.3	13.0	8.1	32.5	G
8/15/02 16:30	8/15/02 17:00	0.5	18.5	1.8	24.7	43.7	G
9/21/02 1:00	9/21/02 12:45	11.7	17.5	0.5	3.0	12.2	G
9/22/02 12:45	9/22/02 15:15	2.5	15.2	29.0	6.1	34.5	G
9/25/02 18:15	9/26/02 23:45	29.5	37.3	43.7	1.8	5.1	G
10/10/02 1:15	10/11/02 5:45	28.5	29.7	4.6	1.9	6.1	G
10/15/02 17:15	10/16/02 10:45	17.5	15.7	15.2	1.4	3.0	G
10/28/02 6:15	10/28/02 11:45	5.5	22.1	6.6	3.8	10.2	NG
10/29/02 4:30	10/29/02 9:30	5.0	14.2	28.7	3.8	14.2	NG
11/5/02 9:00	11/6/02 2:00	17.0	17.8	4.8	1.7	5.1	NG
11/10/02 23:30	11/11/02 4:15	4.7	16.0	2.8	3.8	15.2	NG
11/15/02 13:30	11/16/02 0:30	11.0	11.7	16.0	1.4	2.0	NG
12/5/02 1:15	12/5/02 6:45	5.5	11.2	0.8	2.2	12.2	NG
12/10/02 20:15	12/11/02 8:15	12.0	15.7	12.7	1.7	4.1	NG
12/13/02 8:30	12/14/02 9:00	24.5	25.9	27.9	2.3	10.2	NG
12/19/02 19:45	12/20/02 4:00	8.2	14.7	0.5	2.8	8.1	NG
1/1/03 6:30	1/1/03 9:00	2.5	11.2	3.3	4.5	9.1	NG
1/29/03 0:45	1/29/03 16:15	15.5	15.2	3.3	1.5	4.1	NG

Table 2.4: Continued

Start Date	End Date	Duration (hr)	Depth (mm)	5 Day Prior (mm)	Avg. Int. (mm/hr)	Max Int. (mm/hr)	Season[1]
2/3/03 21:15	2/4/03 4:00	6.7	14.0	2.3	2.8	10.2	NG
2/15/03 10:30	2/18/03 5:30	67.0	105.7	4.8	2.2	10.2	NG
2/23/03 1:45	2/23/03 8:30	6.7	25.7	7.4	4.3	10.2	NG
2/23/03 16:45	2/23/03 19:30	2.7	16.3	31.2	8.1	20.3	NG
3/30/03 6:15	3/30/03 10:30	4.2	13.0	5.6	3.0	8.1	NG
4/7/03 16:00	4/8/03 6:15	14.2	27.9	11.9	2.1	5.1	NG
4/9/03 11:30	4/9/03 20:45	9.2	19.8	40.4	2.9	9.1	NG
4/10/03 0:45	4/10/03 22:00	21.2	17.0	60.2	1.8	8.1	NG
4/17/03 13:30	4/18/03 2:00	12.5	25.7	0.0	2.6	8.1	NG
5/8/03 23:15	5/9/03 2:15	3.0	20.1	14.5	10.0	51.8	G
5/15/03 16:15	5/15/03 18:00	1.7	13.0	16.8	8.6	42.7	G
5/29/03 8:30	5/29/03 16:15	7.7	11.4	7.1	2.5	9.1	G
6/6/03 20:30	6/7/03 9:30	13.0	30.2	14.2	4.2	17.3	G
6/11/03 13:45	6/11/03 18:30	4.7	12.2	33.8	5.4	33.5	G
6/16/03 15:00	6/16/03 17:30	2.5	13.2	38.6	4.8	15.2	G
7/10/03 17:15	7/10/03 21:15	4.0	22.6	15.7	6.5	25.4	G
7/28/03 9:45	7/28/03 15:45	6.0	25.1	3.0	9.1	36.6	G
8/3/03 21:45	8/3/03 22:30	0.7	16.0	21.3	16.0	26.4	G
8/4/03 6:15	8/4/03 8:45	2.5	12.7	37.3	4.6	18.3	G
8/17/03 15:30	8/17/03 17:30	2.0	16.5	0.0	13.2	30.5	G
9/3/03 21:30	9/4/03 8:00	10.5	63.8	36.8	10.5	34.5	G
9/22/03 3:15	9/22/03 18:00	14.7	31.0	0.0	3.2	13.2	G
9/27/03 9:00	9/27/03 15:15	6.2	11.4	26.4	4.2	10.2	G
10/14/03 12:00	10/14/03 16:00	4.0	23.6	0.3	5.6	17.3	G
10/26/03 11:45	10/27/03 11:00	23.2	21.1	0.0	2.1	7.1	G
11/5/03 11:15	11/5/03 17:30	6.2	11.4	10.4	3.0	13.2	NG
11/12/03 17:30	11/12/03 19:00	1.5	15.2	2.3	8.7	45.7	NG
11/18/03 18:45	11/19/03 13:00	18.2	46.2	14.2	3.3	13.2	NG
11/28/03 5:45	11/28/03 15:45	10.0	15.5	12.7	2.1	16.3	NG
12/10/03 12:00	12/10/03 21:45	9.7	14.0	6.9	3.1	17.3	NG
12/14/03 3:45	12/14/03 18:30	14.7	13.0	16.3	1.3	3.0	NG
12/16/03 20:00	12/17/03 4:15	8.2	11.2	13.2	1.9	3.0	NG
12/29/03 21:00	12/30/03 2:45	5.7	12.2	0.0	2.6	15.2	NG
1/1/04 23:45	1/2/04 16:15	16.5	45.5	12.4	3.4	23.4	NG
1/5/04 1:00	1/5/04 8:30	7.5	20.1	46.7	3.0	13.2	NG
1/17/04 17:45	1/18/04 13:30	19.7	27.2	2.5	1.9	5.1	NG
2/2/04 18:00	2/3/04 10:15	16.2	15.5	6.9	2.1	6.1	NG
2/5/04 11:45	2/5/04 17:45	6.0	34.0	22.4	5.4	10.2	NG
2/5/04 20:30	2/6/04 7:30	11.0	31.2	55.1	2.8	5.1	NG

Table 2.4: Continued

Start Date	End Date	Duration (hr)	Depth (mm)	5 Day Prior (mm)	Avg. Int. (mm/hr)	Max Int. (mm/hr)	Season[1]
3/5/04 19:45	3/6/04 3:30	7.8	45.0	6.1	5.6	18.3	NG
3/16/04 1:30	3/16/04 9:15	7.7	16.0	0.5	2.6	7.1	NG
3/30/04 1:45	3/30/04 9:00	7.3	16.0	0.5	2.6	9.1	NG
4/12/04 7:15	4/12/04 19:30	12.3	27.2	2.5	2.5	9.1	NG
4/13/04 1:45	4/13/04 10:15	8.5	28.4	29.7	4.1	11.2	NG
5/2/04 5:30	5/2/04 13:15	7.7	14.7	0.5	2.5	9.1	G
5/16/04 5:15	5/16/04 10:30	5.3	14.0	5.1	3.5	8.1	G
5/24/04 21:15	5/24/04 23:15	2.0	24.9	0.0	11.1	26.4	G
5/26/04 23:00	5/27/04 6:00	7.0	38.6	40.4	7.0	40.6	G
5/27/04 23:45	5/28/04 1:15	1.5	19.3	79.0	12.9	39.6	G
5/28/04 2:45	5/28/04 6:30	3.8	11.9	98.3	4.3	23.4	G
5/30/04 11:00	5/30/04 15:15	4.2	49.5	90.2	19.8	64.0	G
5/31/04 1:30	5/31/04 5:00	3.5	16.5	140.7	5.5	44.7	G
6/4/04 12:45	6/4/04 16:30	3.8	14.0	37.6	4.0	10.2	G
6/11/04 17:45	6/11/04 18:15	0.5	11.4	2.8	15.2	43.7	G
6/15/04 20:15	6/15/04 23:15	3.0	37.3	26.4	12.4	25.4	G
6/22/04 18:45	6/22/04 20:00	1.3	10.7	3.0	7.1	17.3	G
6/25/04 7:30	6/25/04 18:30	11.0	23.9	17.3	2.7	10.2	G
7/6/04 21:15	7/6/04 22:45	1.5	13.7	18.3	7.8	26.4	G
7/22/04 7:45	7/22/04 10:30	2.8	13.0	4.3	5.2	18.3	G
7/26/04 15:45	7/26/04 22:15	6.5	25.7	16.8	6.0	28.4	G
7/27/04 2:00	7/27/04 5:00	3.0	13.0	42.4	4.3	16.3	G
7/31/04 8:30	7/31/04 14:15	5.7	13.0	39.9	3.2	22.4	G
8/5/04 4:30	8/5/04 8:30	4.0	22.4	19.6	6.0	29.5	G
8/12/04 7:15	8/12/04 13:15	6.0	20.3	1.8	3.4	11.2	G
9/7/04 9:45	9/9/04 1:15	39.5	92.7	0.8	3.1	10.2	G
9/16/04 18:15	9/17/04 17:15	23.0	78.7	3.0	4.3	17.3	G
10/2/04 7:15	10/2/04 12:00	4.8	10.4	0.0	2.3	7.1	G
10/13/04 9:15	10/13/04 10:30	1.3	14.2	7.9	9.5	38.6	G
10/18/04 22:15	10/19/04 4:00	5.8	34.0	12.4	6.8	19.3	G
10/27/04 1:30	10/27/04 7:30	6.0	30.7	8.6	5.9	15.2	NG
11/4/04 1:30	11/4/04 10:00	8.5	38.4	0.5	6.7	32.5	NG
11/11/04 23:00	11/12/04 7:15	8.2	15.7	0.0	2.4	6.1	NG
11/30/04 6:30	12/1/04 3:15	20.7	42.4	5.3	2.5	11.2	NG
12/6/04 0:30	12/6/04 4:45	4.2	10.7	7.1	3.6	13.2	NG
12/6/04 21:00	12/7/04 9:00	12.0	13.0	11.2	1.6	4.1	NG
12/9/04 5:30	12/9/04 16:45	11.2	32.8	24.1	3.5	8.1	NG
12/23/04 3:30	12/23/04 8:15	4.7	14.0	1.3	3.1	7.1	NG
1/4/05 13:45	1/4/05 21:45	8.0	12.2	10.2	2.0	4.1	NG

Table 2.4: Continued

Start Date	End Date	Duration (hr)	Depth (mm)	5 Day Prior (mm)	Avg. Int. (mm/hr)	Max Int. (mm/hr)	Season[1]
1/7/05 14:30	1/8/05 2:15	11.7	25.9	26.4	3.0	10.2	NG
1/13/05 17:30	1/14/05 0:30	7.0	13.2	5.1	1.9	4.1	NG
1/29/05 6:15	1/30/05 0:30	18.3	22.9	3.3	1.8	7.1	NG
2/20/05 11:15	2/20/05 23:00	11.8	17.5	4.3	2.3	14.2	NG
2/28/05 0:30	2/28/05 8:00	7.5	14.2	0.8	2.0	4.1	NG
3/7/05 21:15	3/8/05 4:15	7.0	13.5	6.6	1.9	6.1	NG
3/28/05 2:30	3/28/05 6:15	3.7	18.5	10.7	4.9	12.2	NG
4/1/05 19:15	4/2/05 3:15	8.0	18.5	36.1	3.7	15.2	NG
4/2/05 13:00	4/2/05 19:45	6.8	12.2	43.4	2.1	7.1	NG
4/29/05 16:15	4/30/05 5:30	13.3	49.8	19.3	5.4	14.2	G
5/19/05 18:30	5/20/05 1:15	6.7	30.5	3.0	5.8	28.4	G
5/22/05 23:30	5/23/05 1:00	1.5	13.5	31.8	7.7	17.3	G
6/3/05 13:45	6/3/05 16:00	2.3	13.5	7.6	6.7	29.5	G
6/20/05 18:15	6/20/05 20:45	2.5	30.2	0.0	11.0	37.6	G
7/1/05 14:15	7/1/05 18:00	3.8	23.9	12.4	9.6	19.3	G
7/7/05 7:15	7/7/05 16:00	8.8	14.5	0.8	2.1	5.1	G
7/13/05 5:15	7/13/05 13:30	8.3	14.5	2.8	2.1	6.1	G
7/27/05 14:30	7/27/05 17:30	3.0	13.7	0.5	7.8	42.7	G
8/5/05 18:30	8/5/05 19:45	1.2	18.5	0.0	12.4	47.8	G
8/16/05 13:30	8/16/05 14:30	1.0	14.7	0.0	11.8	26.4	G
8/19/05 19:45	8/19/05 20:30	0.8	16.5	22.4	16.5	52.8	G
9/26/05 3:30	9/26/05 10:30	7.0	11.9	0.0	1.8	4.1	G
11/16/05 0:00	11/16/05 5:45	5.8	27.9	14.5	5.1	25.4	NG
11/28/05 23:30	11/29/05 7:30	8.0	21.6	0.0	3.3	12.2	NG
12/3/05 21:45	12/4/05 2:15	4.5	11.9	24.4	3.4	7.1	NG
12/8/05 14:45	12/9/05 0:00	9.2	12.7	14.5	1.7	4.1	NG
12/15/05 1:15	12/15/05 15:15	14.0	20.3	3.3	1.8	4.1	NG
1/17/06 14:15	1/18/06 1:30	11.3	25.1	18.3	2.6	7.1	NG
1/23/06 0:15	1/23/06 11:00	10.8	31.5	17.3	3.8	12.2	NG
3/13/06 16:45	3/13/06 21:45	5.0	17.5	15.5	5.4	23.4	NG
4/2/06 18:45	4/3/06 5:30	10.8	17.3	7.9	3.8	15.2	NG
4/7/06 16:15	4/7/06 17:45	1.5	18.5	22.1	10.6	43.7	NG
4/19/06 6:00	4/19/06 9:00	3.0	13.0	13.2	4.0	20.3	NG
4/21/06 20:00	4/22/06 5:15	9.2	17.3	27.9	2.6	9.1	G
5/2/06 17:30	5/2/06 18:15	0.7	12.7	5.1	12.7	25.4	G
5/25/06 22:45	5/26/06 3:00	4.3	22.9	2.5	5.7	26.4	G
5/31/06 15:45	5/31/06 19:30	3.8	17.8	0.0	7.9	43.7	G
6/11/06 0:15	6/11/06 3:15	3.0	12.7	0.0	5.6	23.4	G
6/23/06 1:45	6/23/06 6:30	4.8	25.1	5.6	5.3	35.6	G

Table 2.4: Continued

Start Date	End Date	Duration (hr)	Depth (mm)	5 Day Prior (mm)	Avg. Int. (mm/hr)	Max Int. (mm/hr)	Season[1]
6/25/06 12:15	6/25/06 19:00	6.8	14.0	37.3	3.7	15.2	G
7/4/06 18:15	7/4/06 19:30	1.3	13.2	1.5	10.6	25.4	G
7/5/06 10:45	7/5/06 17:15	6.5	30.5	23.4	7.6	28.4	G
7/20/06 16:00	7/20/06 16:15	0.2	11.4	0.0	22.9	44.7	G
8/11/06 17:45	8/11/06 20:00	2.3	13.2	8.6	7.5	29.5	G
8/28/06 13:45	8/28/06 15:30	1.8	14.5	0.3	8.3	17.3	G
9/18/06 18:00	9/18/06 19:30	1.5	12.4	0.0	7.1	16.3	G
9/23/06 5:30	9/23/06 10:15	4.7	24.1	19.6	4.8	15.2	G
9/23/06 19:00	9/23/06 22:30	3.5	13.0	34.5	4.0	21.3	G
9/30/06 16:45	9/30/06 23:00	6.3	12.4	14.2	2.8	14.2	G
10/16/06 17:30	10/17/06 5:00	11.5	21.3	4.3	2.1	6.1	G
10/26/06 21:30	10/27/06 23:00	25.5	61.7	0.3	3.1	15.2	G
11/1/06 18:00	11/1/06 21:30	3.5	14.7	16.5	5.4	19.3	NG
11/7/06 17:45	11/8/06 12:45	19.0	17.5	2.8	1.5	3.0	NG
11/16/06 3:30	11/16/06 6:15	2.7	12.7	16.3	4.2	12.2	NG
12/22/06 6:45	12/22/06 12:30	5.8	18.8	9.1	3.3	11.2	NG
1/4/07 22:30	1/5/07 6:00	7.5	16.0	12.2	2.2	10.2	NG
1/7/07 11:45	1/7/07 19:45	8.0	16.8	16.5	2.5	9.1	NG
1/21/07 7:45	1/21/07 14:45	7.0	17.8	0.0	2.5	6.1	NG
3/1/07 9:45	3/1/07 23:15	13.5	35.6	7.4	3.2	7.1	NG
3/28/07 10:30	3/28/07 13:00	2.5	12.7	0.0	5.1	11.2	NG
4/3/07 20:30	4/4/07 0:45	4.2	15.5	1.8	4.8	14.2	NG
4/11/07 12:15	4/11/07 23:00	10.7	20.8	1.0	3.3	14.2	NG
4/14/07 0:30	4/15/07 4:00	27.5	39.9	20.8	2.2	15.2	NG
5/16/07 11:15	5/16/07 14:00	2.7	19.1	0.0	6.9	30.5	G
6/1/07 18:15	6/1/07 19:15	1.0	33.3	0.0	26.6	99.6	G
6/5/07 13:15	6/5/07 21:00	7.7	20.1	40.9	5.7	30.5	G
6/18/07 18:00	6/18/07 18:30	0.5	17.8	0.0	23.7	36.6	G
6/25/07 17:45	6/25/07 19:00	1.2	11.9	6.1	15.9	39.6	G
6/29/07 16:15	6/29/07 20:00	3.7	13.5	24.1	5.4	21.3	G
7/19/07 21:00	7/19/07 23:45	2.7	15.7	7.4	5.2	18.3	G
7/27/07 11:00	7/27/07 12:30	1.5	13.5	3.8	9.0	24.4	G
7/27/07 20:45	7/28/07 15:15	18.5	20.1	17.3	2.1	11.2	G
8/3/07 15:00	8/3/07 15:30	0.5	15.0	0.0	20.0	53.8	G
9/11/07 4:00	9/11/07 10:15	6.2	18.3	2.5	3.9	11.2	G
10/19/07 4:00	10/19/07 5:15	1.2	13.7	3.3	9.1	21.3	G
10/23/07 11:15	10/24/07 20:00	32.7	47.8	15.2	2.4	14.2	G
11/5/07 20:00	11/5/07 23:00	3.0	14.7	0.0	5.4	15.2	NG
11/14/07 17:30	11/15/07 2:45	9.2	33.3	5.8	4.8	15.2	NG

Table 2.4: Continued

Start Date	End Date	Duration (hr)	Depth (mm)	5 Day Prior (mm)	Avg. Int. (mm/hr)	Max Int. (mm/hr)	Season[1]
11/25/07 23:00	11/26/07 10:15	11.2	14.0	5.8	1.9	7.1	NG
11/26/07 17:45	11/26/07 19:30	1.7	12.2	19.8	7.0	19.3	NG
12/10/07 2:00	12/10/07 18:30	16.5	27.2	21.3	2.6	10.2	NG
12/13/07 8:30	12/13/07 14:15	5.7	14.7	42.9	2.9	16.3	NG
12/20/07 22:00	12/21/07 5:45	7.7	15.0	4.1	2.3	4.1	NG
12/28/07 11:15	12/28/07 20:45	9.5	15.0	1.0	2.5	7.1	NG
1/29/08 14:00	1/29/08 23:30	9.5	26.4	0.5	3.8	8.1	NG
2/6/08 4:00	2/6/08 15:15	11.3	14.7	11.7	2.8	10.2	NG
3/4/08 4:30	3/4/08 9:00	4.5	11.2	5.8	2.5	4.1	NG
3/7/08 7:45	3/7/08 17:15	9.5	23.1	22.1	2.6	5.1	NG
3/9/08 10:00	3/9/08 11:45	1.8	11.7	34.5	5.8	13.2	NG
3/15/08 13:15	3/15/08 22:15	9.0	11.9	6.9	2.3	7.1	NG
4/3/08 9:15	4/3/08 19:00	9.8	18.3	5.6	2.9	9.1	NG
4/11/08 16:00	4/11/08 23:45	7.8	16.5	1.0	4.1	22.4	NG
4/27/08 21:00	4/28/08 8:15	11.3	25.7	0.3	3.8	19.3	G
5/11/08 15:00	5/12/08 3:30	12.5	14.0	24.1	1.4	3.0	G
6/3/08 8:30	6/3/08 13:45	5.2	12.4	27.2	3.6	18.3	G
7/28/08 15:15	7/28/08 17:00	1.8	10.9	0.0	6.2	18.3	G
7/30/08 13:45	7/30/08 15:30	1.8	16.8	10.9	9.6	35.6	G
7/31/08 5:45	7/31/08 12:00	6.2	19.1	27.7	4.2	14.2	G
8/26/08 14:30	8/27/08 2:00	11.5	29.5	0.0	3.1	10.2	G
10/8/08 6:30	10/8/08 13:30	7.0	13.0	0.0	2.6	6.1	G
10/24/08 13:45	10/25/08 3:00	13.3	19.3	0.0	1.9	5.1	G
11/13/08 2:30	11/13/08 7:30	5.0	18.3	0.5	4.9	29.5	NG
11/14/08 23:15	11/15/08 9:00	9.8	23.6	18.5	2.7	8.1	NG
11/24/08 11:00	11/24/08 21:15	10.2	12.2	2.0	1.5	5.1	NG
11/30/08 9:15	11/30/08 19:30	10.3	15.7	0.8	2.0	6.1	NG
12/10/08 0:30	12/10/08 8:00	7.5	33.3	0.8	4.3	9.1	NG
12/10/08 23:45	12/11/08 16:30	16.7	22.9	35.8	2.1	5.1	NG
12/15/08 13:15	12/15/08 21:00	7.8	13.2	39.9	1.8	4.1	NG
12/16/08 14:00	12/16/08 18:45	4.7	13.0	40.6	2.9	6.1	NG

🟦	Hydrograph was plotted for storm event.
⬜	Missing precipitation data was filled in from Little Millseat weather station.

[1] G-Growing season runs from April 20 - October 26.
NG-Non-Growing season runs from October 27 - April 19.

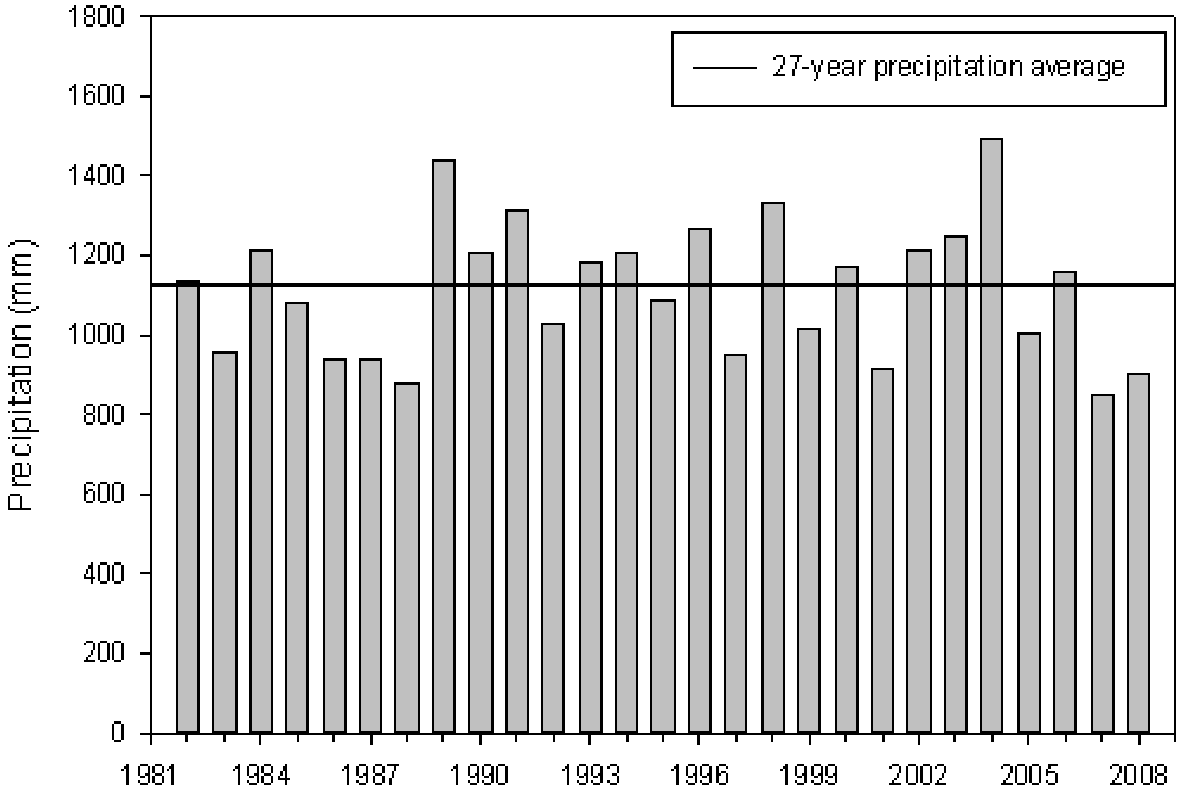

Figure 2.9: Yearly precipitation sums and 27-year precipitation average. Data were taken from nearby Jackson County Airport for 1999 and 2000.

21.2 mm and in the second time period it was 21.3 mm. Average storm depths pre-harvest and post-harvest were 19.6 mm and 21.4 mm, respectively. Table 2.5 provides a summary of the yearly, pre-harvest and post-harvest average storm depths, maximum storm depths, cumulative storm depths, and storm events per period. For the years when storm intensity was evaluated (2002-2008), the years 2006 and 2007 had the highest average intensities at 6.0 mm hr^{-1} and 6.6 mm hr^{-1}, respectively, 2008 had the lowest at 3.4 mm hr^{-1}. The years 2006 and 2007 also had the highest average maximum intensity at 20.7 mm hr^{-1} and 20.5 mm hr^{-1}, respectively, and 2008 was again the lowest at 11.3 mm hr^{-1}. Table 2.6 provides a summary of the yearly, pre-harvest and post-harvest average storm intensities, maximum storm intensities, and storm events per period. No statistical significance was found between periods for the storm characteristics of depth, 5-day antecedent moisture, average storm intensity, and maximum storm intensity.

Table 2.5: Average storm depth ± Std. dev. (mm), average 5-day antecedent depth ± std. dev. (mm), maximum storm depth (mm), cumulative storm depth (mm), and sample size 1982-1993 and 2002-2008.

Year	Avg. Storm Depth ± Std. Dev.	Avg. 5-day antecedent rainfall ± Std. Dev.	Max Storm Depth	Annual Cumulative Storm Depth	Sample size
1982	19.7±9.4	14.7±11.4	41.4	710.9	36
1983	19.5±8.8	13.2±15.1	48.5	585.7	30
1984	22.4±13.6	17.6±19.8	66.0	850.4	38
1985	21.8±9.2	16.3±13.5	51.3	720.6	33
1986	18.4±10.3	16.4±25.0	66.8	607.1	33
1987	18.8±5.4	13.3±13.5	35.1	639.3	34
1988	21.4±10.5	10.1±13.8	47.5	576.6	27
1989	22.9±11.3	19.7±17.4	66.5	1029.2	45
1990	22.4±12.4	16.3±21.6	80.0	872.2	39
1991	23.3±11.3	18.3±22.1	73.2	1001.8	43
1992	20.4±12.4	10.0±9.5	65.3	613.2	30
1993	21.5±11.6	13.1±15.6	57.9	796.5	37
2002	22.1±12.8	16.9±16.3	61.2	816.4	37
2003	22.1±18.1	14.6±14.9	105.7	773.9	35
2004	25.9±17.2	21.6±30.4	92.7	1141.5	44
2005	18.9±8.3	10.9±12.2	49.8	528.8	28
2006	19.2±10.0	11.6±10.8	61.7	537.0	28
2007	20.0±9.2	9.7±11.8	47.8	580.6	29
2008	17.9±6.2	12.7±14.4	33.3	446.5	25
Pre-harvest	19.6±9.1	14.0±13.1	48.5	1296.67	63
Post-harvest	21.4±11.9	15.2±18.2	105.7	12531.598	588

Table 2.6: Average storm intensity ± standard deviation (mm/hr), average maximum intensity ± standard deviation (mm/hr), and sample size 2002-2008.

Year	Avg. Storm Intensity ± Std. Dev.	Avg. Max Storm Intensity ± Std. Dev.	Sample size
2002	4.4±4.0	15.4±11.2	37
2003	4.9±3.5	17.7±12.7	35
2004	5.3±3.8	18.7±13.3	44
2005	5.1±4.0	16.7±14.3	28
2006	6.0±4.3	20.7±11.1	28
2007	6.6±6.6	20.5±18.9	29
2008	3.4±1.8	11.3±8.3	25

2.3.2 Hydrograph Characteristics

From 1982-1993, 345 hydrographs were identified of which 190 (55.1%) were deemed acceptable for use in the analysis of hydrograph characteristics. For the period of 2002-2008, 210 hydrographs were identified of which 104 (49.5%) were acceptable. Hydrographs with similar storm depths (26.4 mm-49.8 mm) from each year of the study period are shown in Figures 2.10-2.28. The purpose of the following hydrographs is to show the discharge relationship between the study subcatchments and how that relationship varies from pre-harvest to post-harvest as well as its variability with regards to seasonality, storm intensity, and antecedent moisture conditions. Tables 2.2 and 2.3 detail all of these variables for all storms that occurred during the study period, including from which the storms the hydrographs plotted below represent. Due to this large amount of variability, statistical analyses of hydrograph characteristics were only performed on those hydrographs that were matched to a storm event across all watersheds.

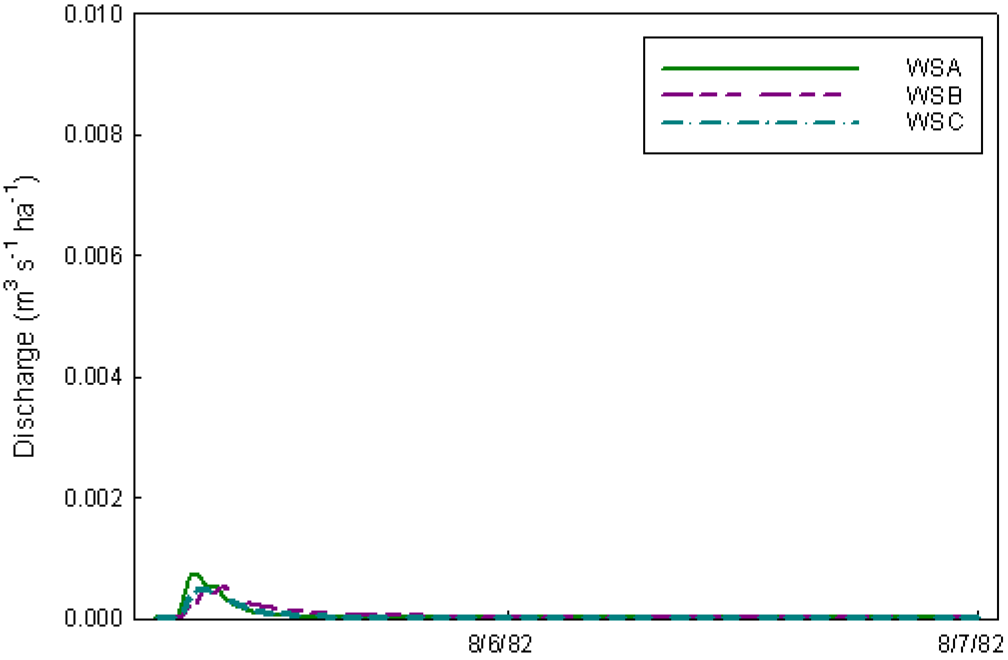

Figure 2.10: Pre-harvest hydrographs for WSA, WSB, and WSC for a storm event (38.1 mm) on August 5, 1982 (G). WSA=control, WSB=BMP, and WSC=no BMPs.

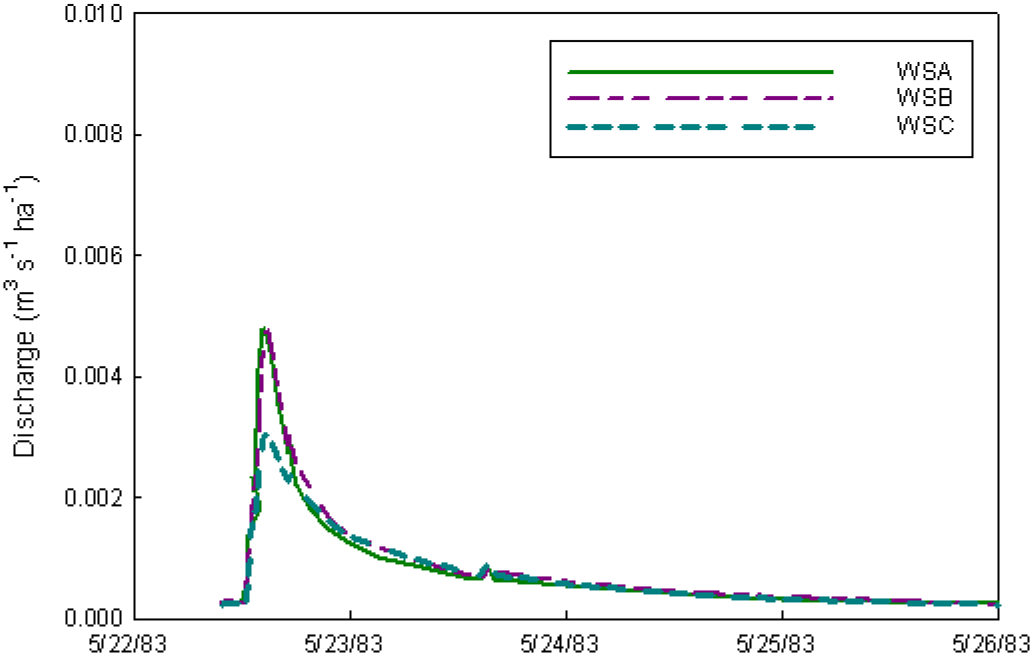

Figure 2.11: Pre-harvest hydrographs for WSA, WSB, and WSC for a storm event (41.9 mm) on May 22, 1983 (G). WSA=control, WSB=BMP, and WSC=no BMPs.

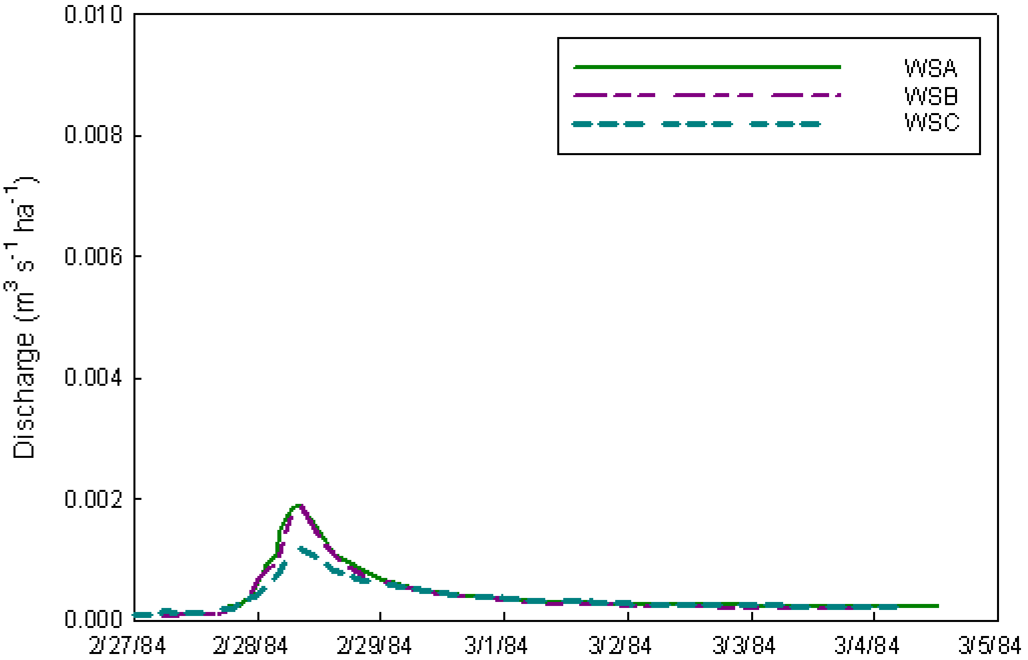

Figure 2.12: Post-harvest hydrographs for WSA, WSB, and WSC for a storm event (41.4 mm) on February 27, 1984 (NG). WSA=control, WSB=BMP, and WSC=no BMPs.

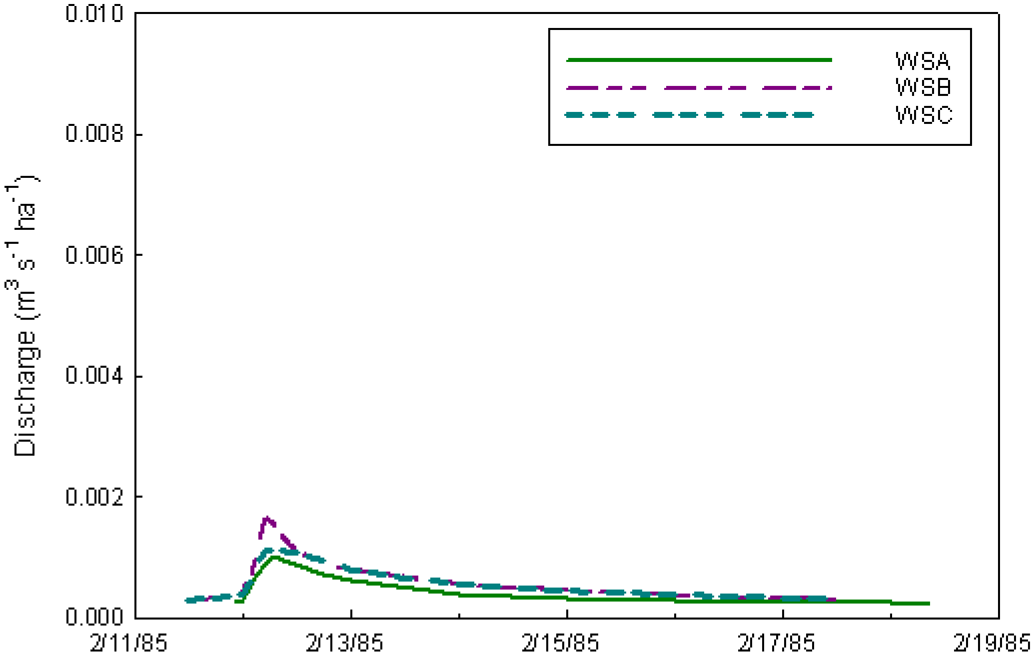

Figure 2.13: Post-harvest hydrographs for WSA, WSB, and WSC for a storm event (44.7 mm) on February 11, 1985 (NG). WSA=control, WSB=BMP, and WSC=no BMPs.

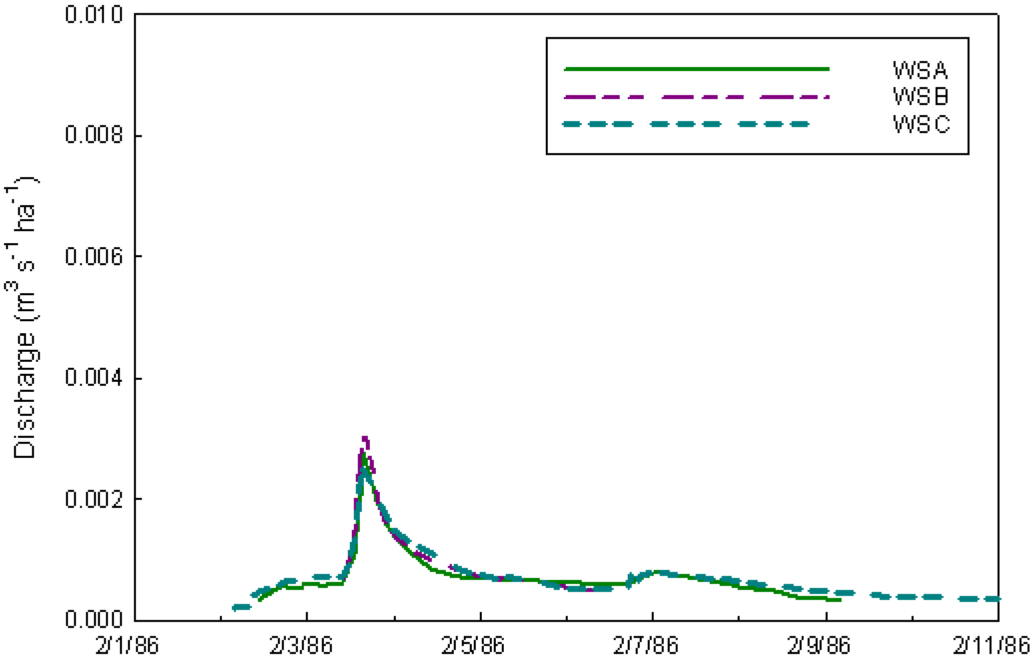

Figure 2.14: Post-harvest hydrographs for WSA, WSB, and WSC for a storm event (48.0 mm) on February 2, 1986 (NG). WSA=control, WSB=BMP, and WSC=no BMPs.

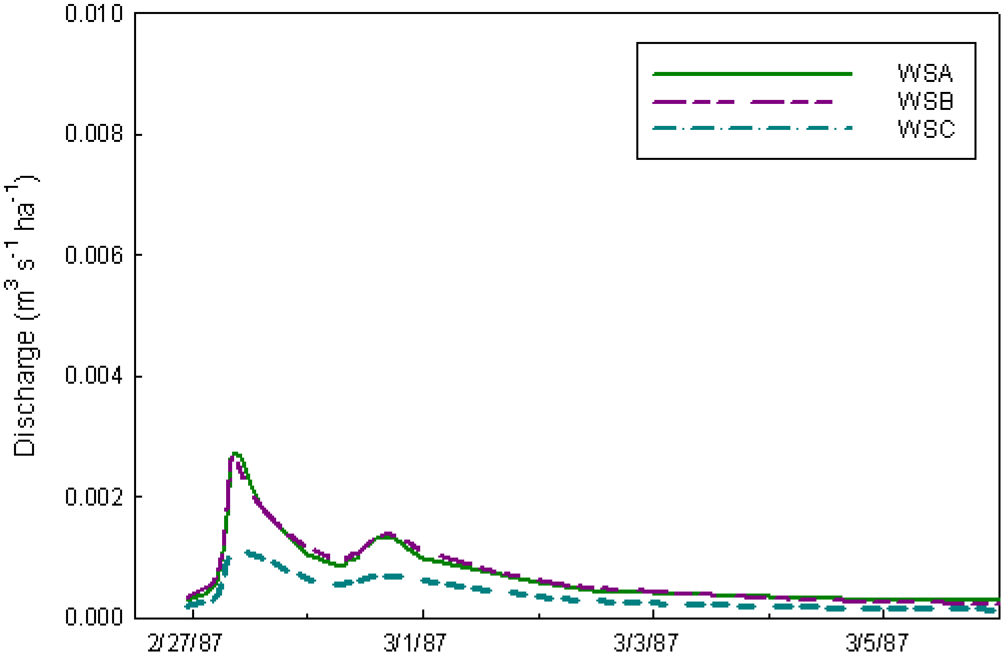

Figure 2.15: Post-harvest hydrographs for WSA, WSB, and WSC for a storm event (41.1 mm) on February 26, 1987 (NG). WSA=control, WSB=BMP, and WSC=no BMPs.

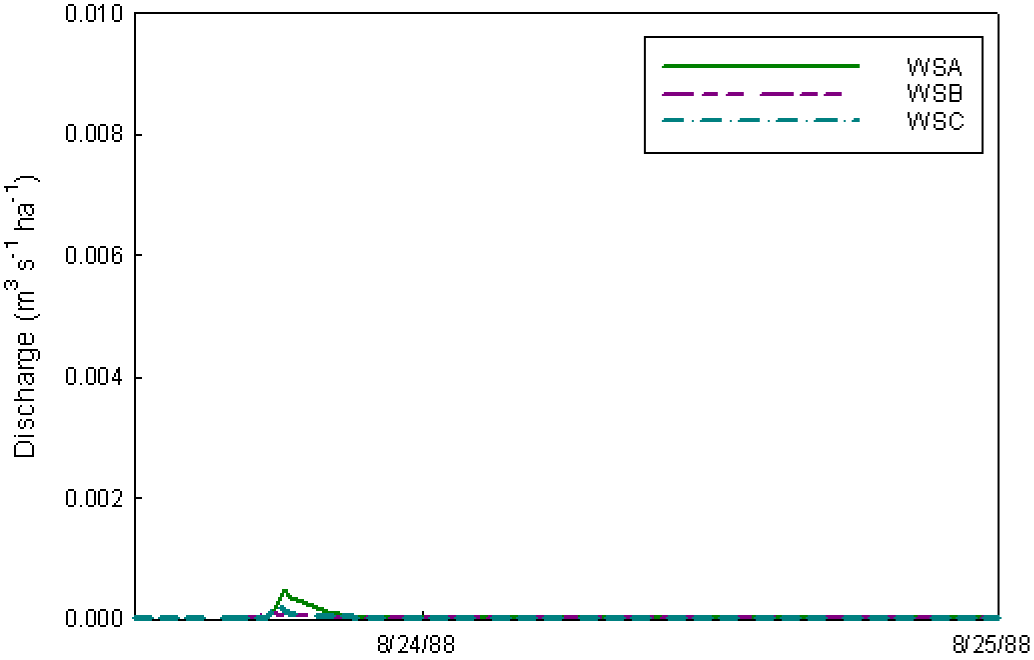

Figure 2.16: Post-harvest hydrographs for WSA, WSB, and WSC for a storm event (44.7 mm) on August 23, 1988 (G). WSA=control, WSB=BMP, and WSC=no BMPs.

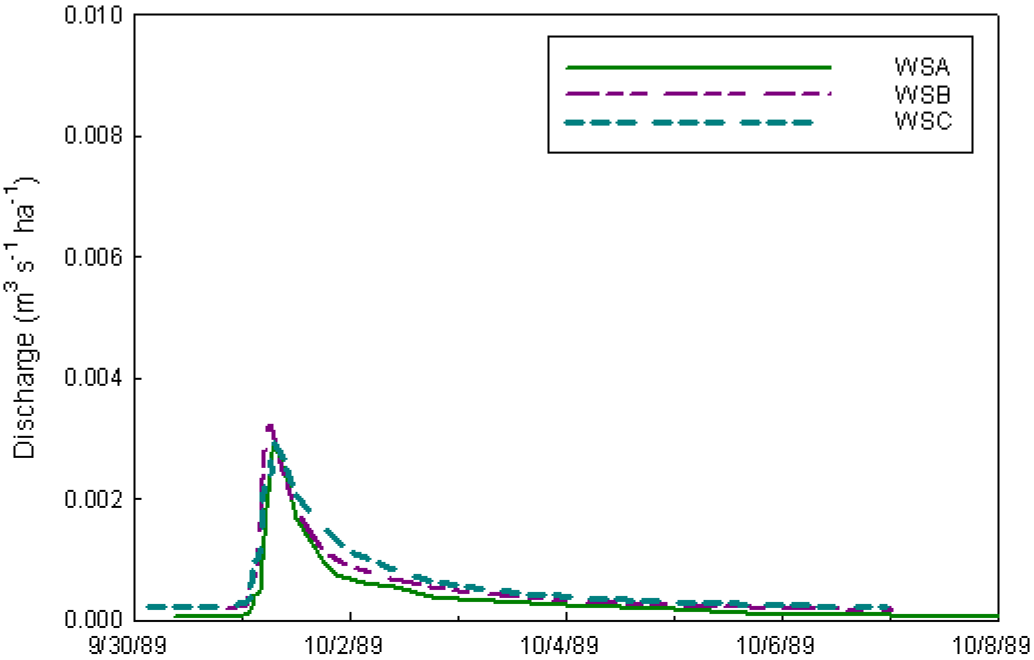

Figure 2.17: Post-harvest hydrographs for WSA, WSB, and WSC for a storm event (36.8 mm) on September 30, 1989 (G). WSA=control, WSB=BMP, and WSC=no BMPs.

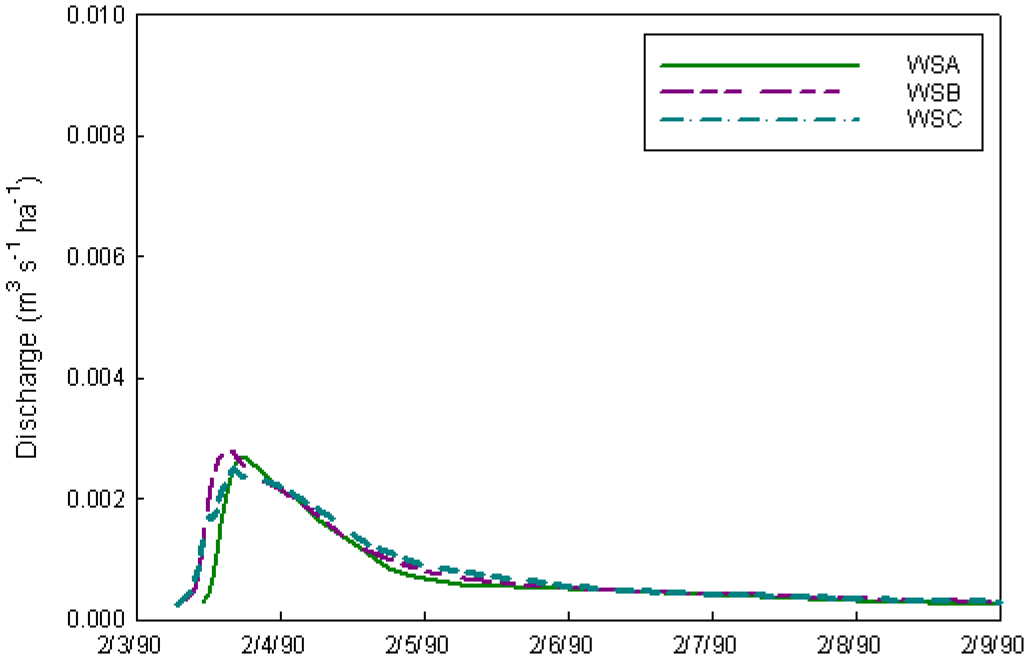

Figure 2.18: Post-harvest hydrographs for WSA, WSB, and WSC for a storm event (36.1 mm) on February 3, 1990 (NG). WSA=control, WSB=BMP, and WSC=no BMPs.

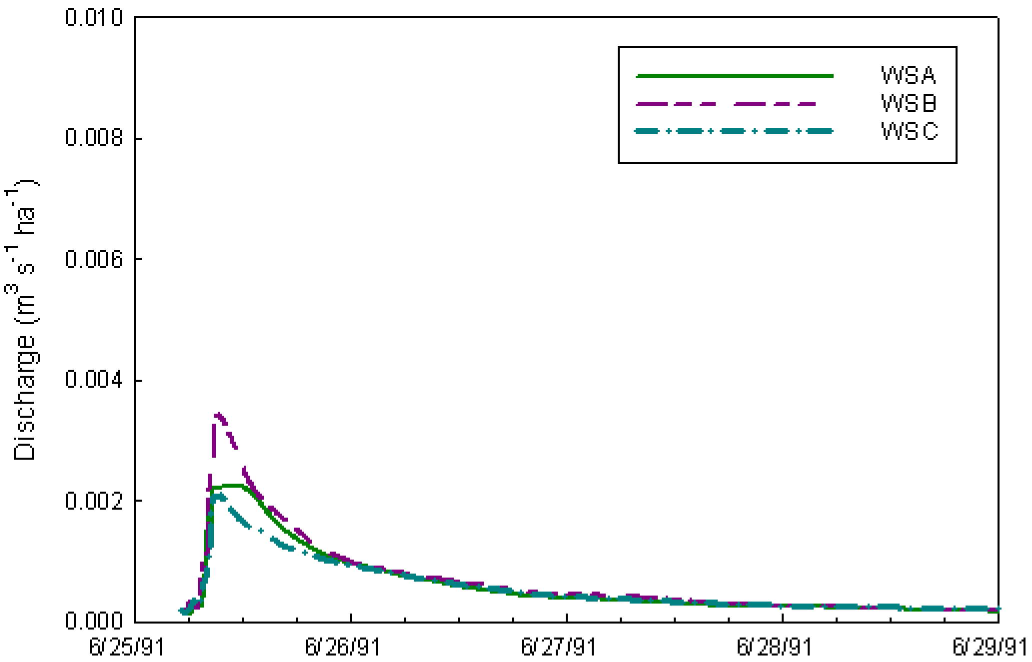

Figure 2.1: Post-harvest hydrographs for WSA, WSB, and WSC for a storm event (35.6 mm) on June 25, 1991 (G). WSA=control, WSB=BMP, and WSC=no BMPs.

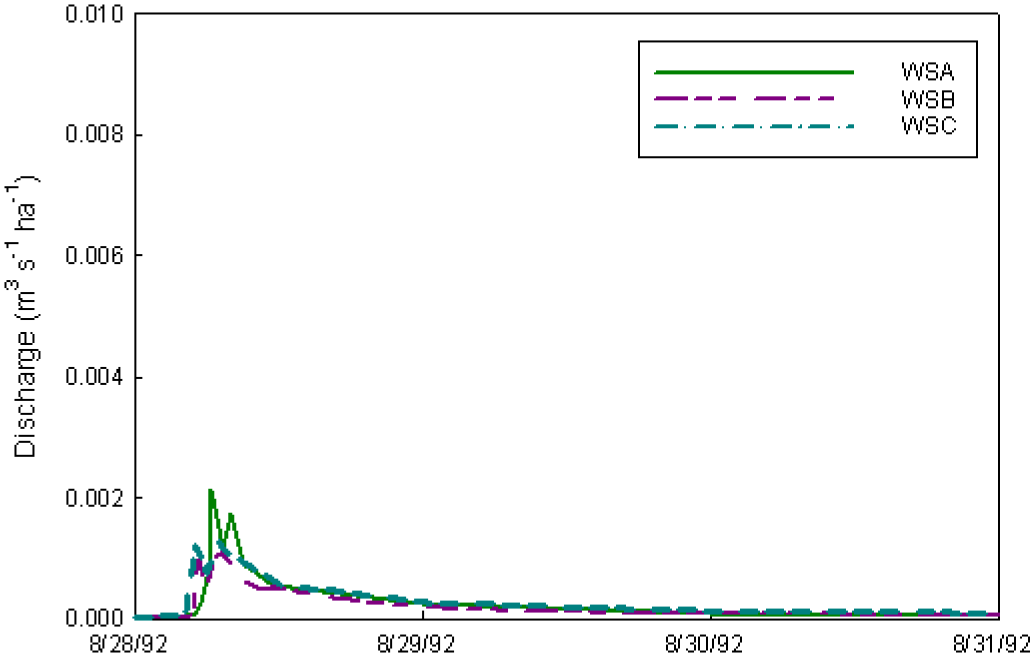

Figure 2.20: Post-harvest hydrographs for WSA, WSB, and WSC for a storm event (49.8 mm) on August 27, 1992 (G). WSA=control, WSB=BMP, and WSC=no BMPs.

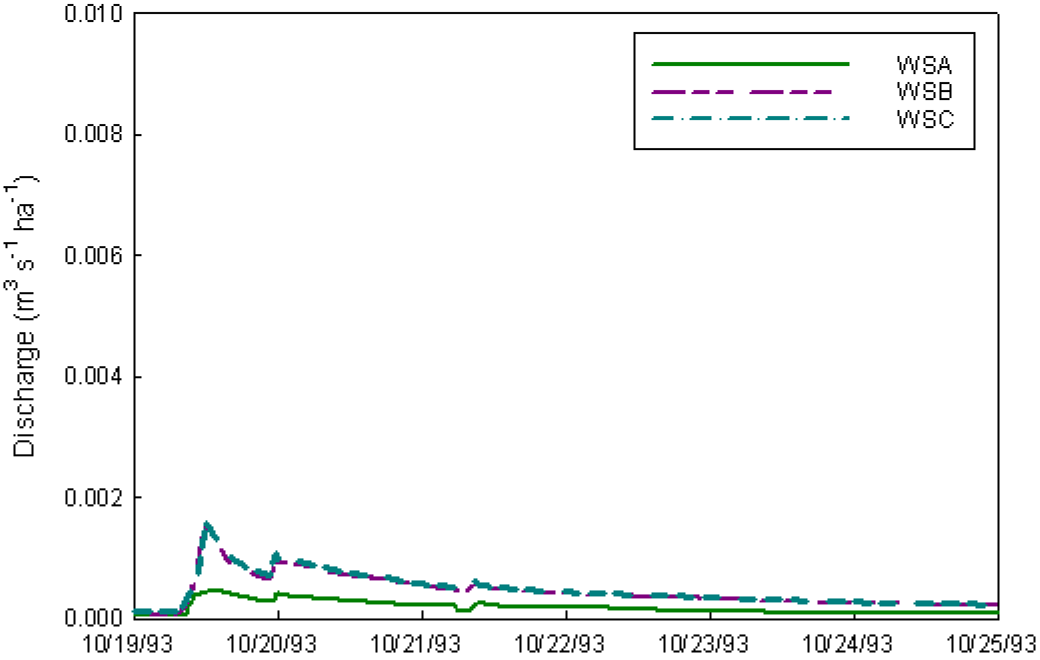

Figure 2.21: Post-harvest hydrographs for WSA, WSB, and WSC for a storm event (36.6 mm) on October 18, 1993 (G). WSA=control, WSB=BMP, and WSC=no BMPs.

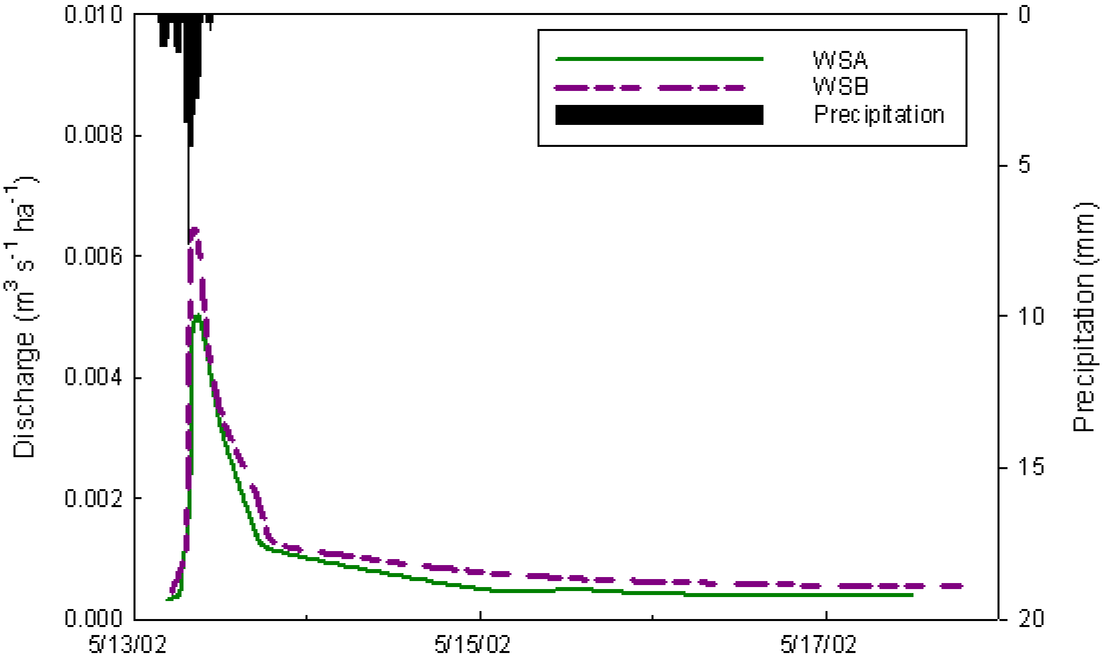

Figure 2.22: Post-harvest hydrographs for WSA, WSB, and WSC for a storm event (42.2 mm, 7.2 hr) on May 13, 2002 (G). WSA=control, WSB=BMP, and WSC=no BMPs.

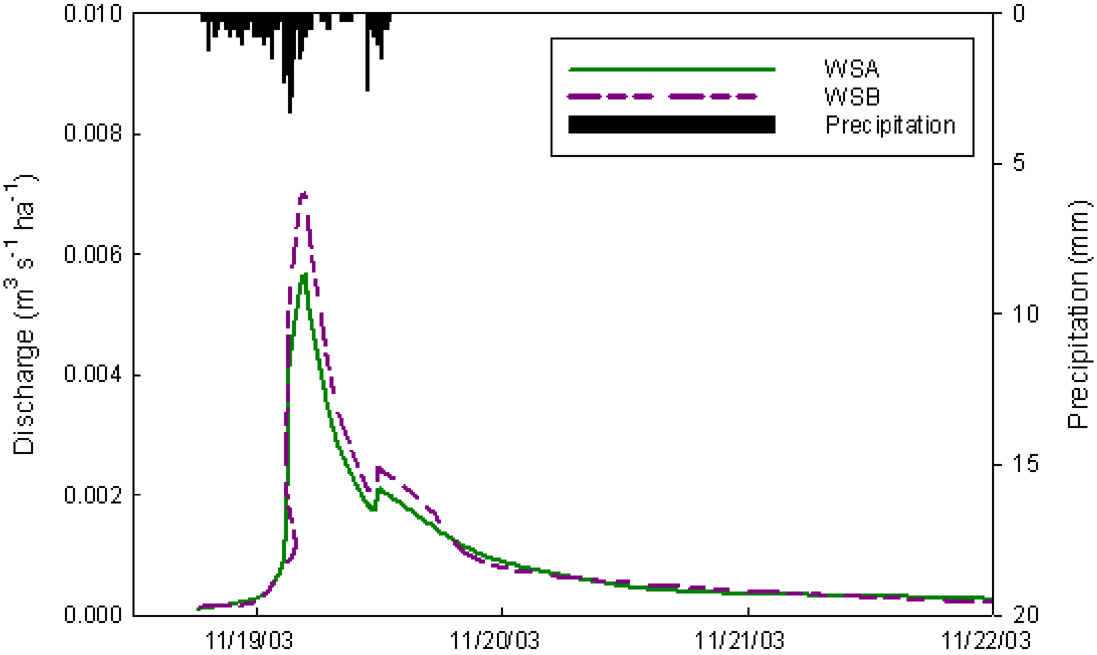

Figure 2.23: Post-harvest hydrographs for WSA, WSB, and WSC for a storm event (46.2 mm, 18.2 hr) on November 18, 2003 (NG). WSA=control, WSB=BMP, and WSC=no BMPs.

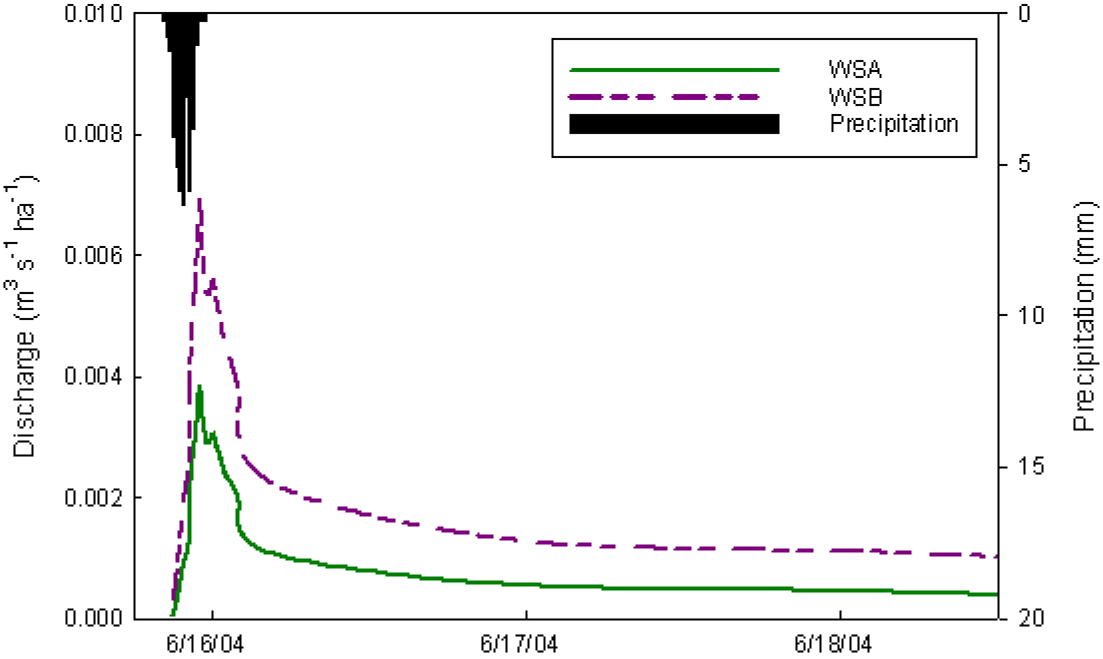

Figure 2.24: Post-harvest hydrographs for WSA, WSB, and WSC for a storm event (37.3 mm, 3 hr) on June 15, 2004 (G). WSA=control, WSB=BMP, and WSC=no BMPs.

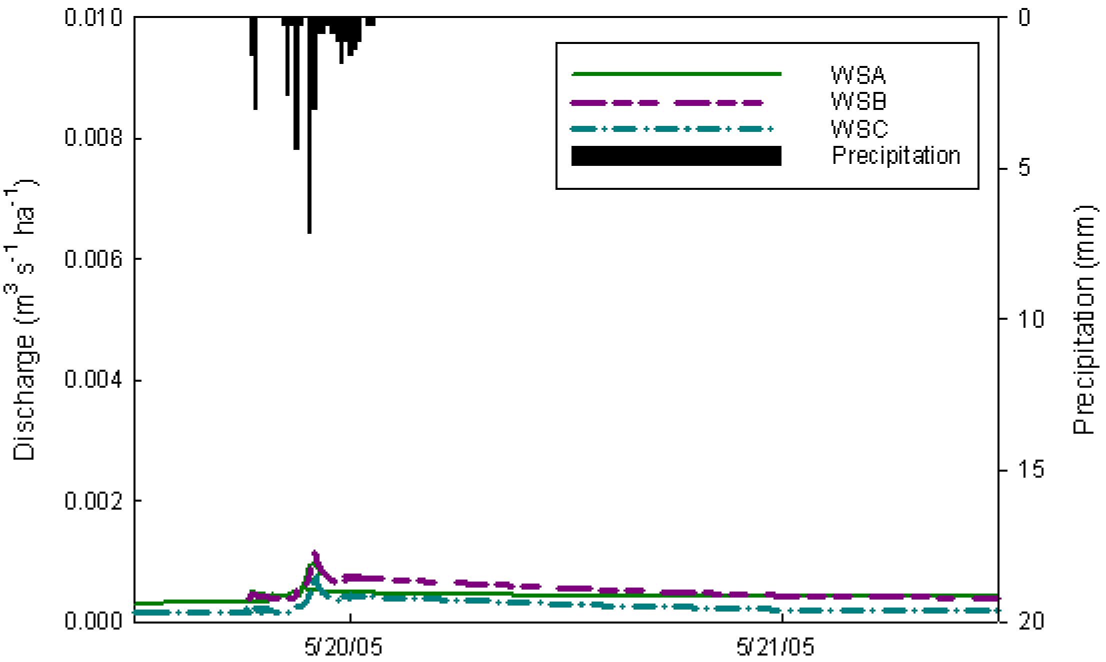

Figure 2.25: Post-harvest hydrographs for WSA, WSB, and WSC for a storm event (30.5 mm, 6.7 hr) on May 19, 2005 (G). WSA=control, WSB=BMP, and WSC=no BMPs.

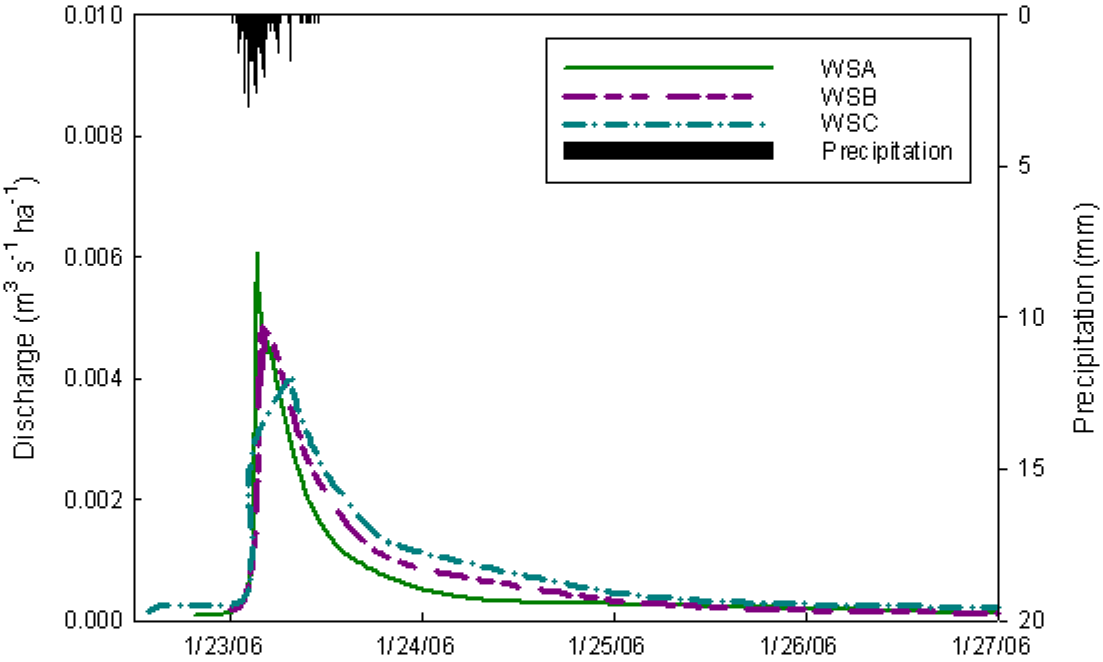

Figure 2.26: Post-harvest hydrographs for WSA, WSB, and WSC for a storm event (31.5 mm, 10.8 hr) on January 23, 2006 (NG). WSA=control, WSB=BMP, and WSC=no BMPs.

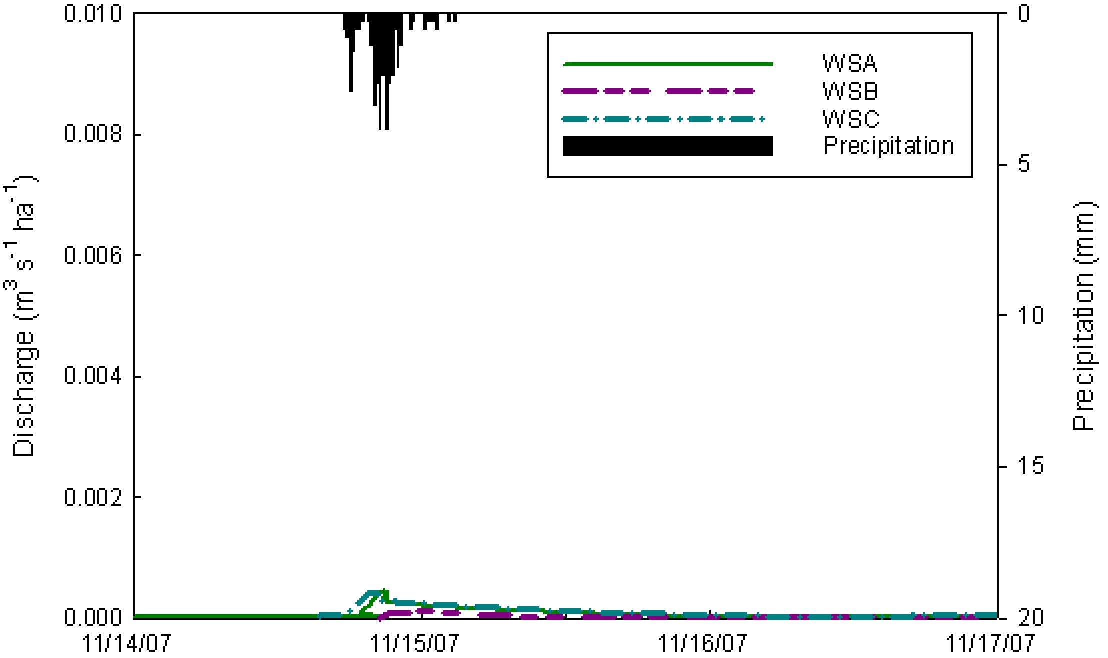

Figure2.27: Post-harvest hydrographs for WSA, WSB, and WSC for a storm event (33.3 mm, 9.2 hr) on November 14, 2007 (NG). WSA=control, WSB=BMP, and WSC=no BMPs

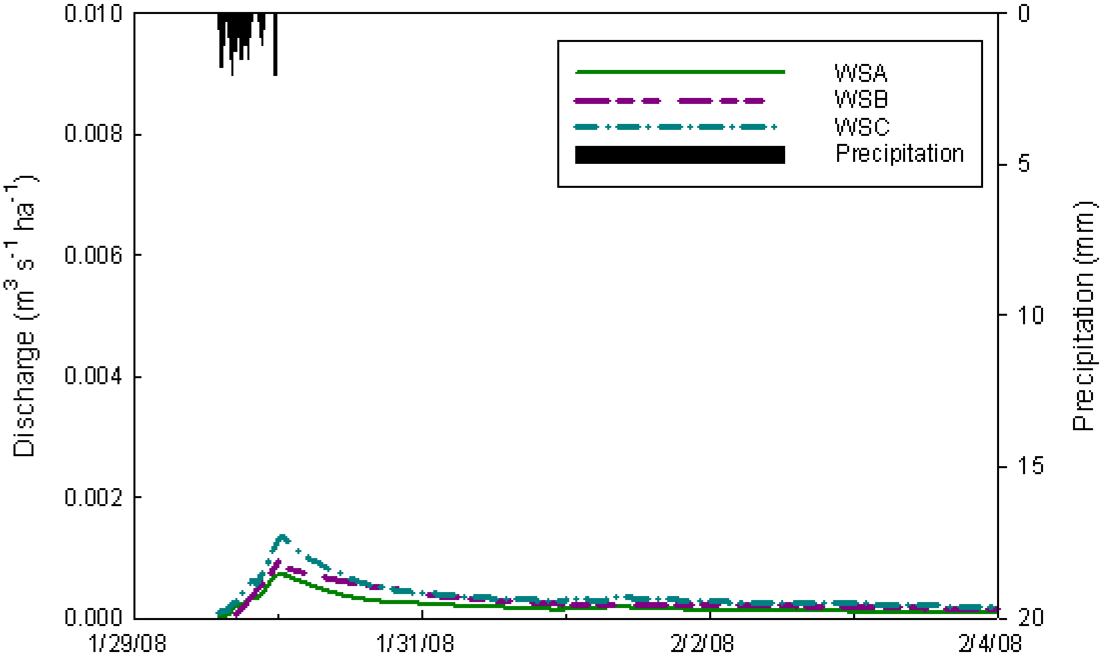

Figure 2.28: Post-harvest hydrographs for WSA, WSB, and WSC for a storm event (26.4 mm, 9.5 hr) on January 29, 2008 (NG). WSA=control, WSB=BMP, and WSC=no BMPs.

Results from the statistical analyses performed on the hydrograph parameters are shown in Tables 2.7-2.11. Table 2.7 details the results from the baseflow volume and stormflow volume statistical analyses. Results from the baseflow volume statistical analyses found significant differences between WSA and WSC in 1985 and 2007. The total yearly baseflow volume was 1.3 times as much in WSC in 1985 and 1.6 times as much in 2007. Significant statistical differences were also found between WSA and WSB in 1985; total yearly baseflow was 1.4 times greater than WSA. Finally, statistically significant differences were observed between WSB and WSC in 2007. Total yearly baseflow volume was 1.3 times higher in WSC compared to WSB.

More significant variations were seen in stormflow volume between the subcatchments throughout the study. Statistically significant differences in stormflow volume were seen between WSA and WSC in 1984, 1985, 2006 and 2007 with total yearly stormflow volume in WSC being greater by 2.3, 2.5, 3.1, and 1.4 times, respectively. Statistically significant differences were also seen in stormflow between WSA and WSB in 1985 where WSB was 2.2 times higher than WSA. Finally, statistically significant differences in stormflow were observed between WSB and WSC in 2007. Results indicated that WSC was statistically elevated over WSB; however, the total annual stormflow volume in WSB was slightly larger than WSC in 2007 (2,019.7 m^3 ha^{-1} vs. 1,862.7 m^3 ha^{-1}) (Table 2.11). This may indicate that the suitable hydrographs in 2007 did not accurately represent the stormflow volume relationship between WSB and WSC.

Table 2.8 details the results from the peak flow statistical analysis. No statistical significance differences were found between the subcatchments for peak flow during the study period.

Table 2.9 details the results from the storm volume as a percentage of rainfall statistical analysis. Significant statistical differences between WSA and WSC were observed in 1984, 1985, 1989, 2006, and 2007. Average [S/P]% for WSC during those years were 56%, 25%, 47%, 38%, and 14%, respectively, compared to average [S/P]% in WSA being 35%, 12%, 28%, 19%, and 7%. Statistical differences between WSA and WSB were only present in 1985;

Table 2.7: ANCOVA baseflow volume and stormflow volume results for WSA, WSB, and WSC 1982-1993 and 2002-2008. [1]

	Baseflow Volume (m^3 ha^{-1})			Stormflow Volume (m^3 ha^{-1})		
Year	WSA	WSB	WSC	WSA	WSB	WSC
1982	420.5	283.6	531.1	1161.2	817.3	1155.6
1983	470.3	466.1	425.2	1198.1	1214.1	1164.9
1984	1212.5	1174.2	1175.0	2713.6b	2759.4ab	3138.5a
1985	208.2b	526.6a	579.6a	608.8b	1212.3a	1286.1a
1986	339.6	273.1	603.5	878.6	788.9	1450.2
1987	659.9	707.8	811.2	1395.1	1533.2	1789.5
1988	499.6	704.3	625.4	1130.5	923.1	1237.8
1989	1444.5	1766.3	2265.4	3205.7	3221.8	4234.5
1990	936.5	1287.9	1064.4	1828.1	2280.2	2342.0
1991	1142.7	1550.1	1234.1	2270.6	2867.6	2856.9
1992	806.7	595.6	655.4	1160.3	1182.9	1239.8
1993	254.0	379.3	345.2	624.6	827.6	822.8
2002	835.5	920.2	- -[2]	1444.3	1820.9	- -
2003	482.4	568.9	- -	1037.2	1176.9	- -
2004	1706.1	1715.3	- -	2898.0	3282.1	- -
2005	578.1	1271.6	574.2	620.6	774.3	758.4
2006	251.0	243.5	332.3	549.5b	835.1ab	1116.5a
2007	58.5b	56.0b	113.6a	131.6b	142.5b	305.8a
2008	54.6	80.3	114.7	223.4	452.3	449.4

[1] Within each row, constituents with different letters (a,b,c) indicate statistical differences between watersheds, while constituents with the same letter denote statistical similarity between watersheds. Constituents with no letters indicate no statistical significance.

[2] No data available.

Table 2.8: ANCOVA peak flow (Qp) (m^3 s^{-1} ha^{-1} x 10^{-2}) results for WSA, WSB, and WSC 1982-1993 and 2002-2008. [1]

	Average Peak Flow		
Year	WSA	WSB	WSC
1982	0.23	0.16	0.16
1983	0.14	0.12	0.11
1984	0.35	0.26	0.22
1985	0.07	0.09	0.09
1986	0.16	0.15	0.20
1987	0.10	0.09	0.09
1988	0.21	0.17	0.17
1989	0.34	0.26	0.29
1990	0.14	0.14	0.12
1991	0.16	0.15	0.13
1992	0.17	0.15	0.15
1993	0.12	0.15	0.42
2002	0.12	0.15	- -[2]
2003	0.13	0.15	- -
2004	0.37	0.33	- -
2005	0.02	0.01	0.03
2006	0.34	0.24	0.20
2007	0.03	0.03	0.05
2008	0.05	0.07	0.08

[1] Within each row, constituents with different letters (a,b,c) indicate statistical differences between watersheds, while constituents with the same letter denote statistical similarity between watersheds. Constituents with no letters indicate no statistical significance.

[2] No data available.

Table 2.9: ANCOVA storm volume as a (%) of rainfall results for WSA, WSB, and WSC 1982-1993 and 2002-2008. [1]

	Average [(S/P)%]		
Year	WSA	WSB	WSC
1982	25.9	19.2	27.6
1983	21.5	23.5	22.5
1984	34.9b	48.5ab	56.2a
1985	11.8b	23.0a	24.9a
1986	18.9	25.9	32.7
1987	22.7	25.2	28.1
1988	28.2	25.4	32.6
1989	35.4b	41.1ab	47.2a
1990	26.7	32.9	34.4
1991	34.2	38.5	37.3
1992	18.0	20.4	20.7
1993	18.8	22.5	21.6
2002	35.6	45.8	- -[2]
2003	29.7	33.4	- -
2004	32.9	37.2	- -
2005	17.8	21.1	17.9
2006	18.7b	28.9ab	38.6a
2007	6.6b	6.9b	14.0a
2008	13.5	26.1	26.9

[1] Within each row, constituents with different letters (a,b,c) indicate statistical differences between watersheds, while constituents with the same letter denote statistical similarity between watersheds. Constituents with no letters indicate no statistical significance.

[2] No data available.

average [S/P]% for WSB was 23% compared to WSA’s 12%. Finally, statistically significant differences between WSB and WSC were observed in 2007 with average [S/P]% for WSC being 14% compared to 7% in WSB.

Table 2.10 details the results from the time to peak statistical analysis. No statistical significance differences were found between the subcatchments for time to peak during the study period.

Table 2.11 details the results from the CN statistical analysis. Statistically significant differences between WSA and WSC were observed in 1984, 1985, 2006, and 2007 with average CNs (λ=0.05) in WSC of 91, 79, 88, and 81 respectively; average CNs in WSA were 82, 70, 80, and 75, respectively. Statistically significant differences between WSA and WSB only occurred in 1985 with WSB having an average CN of 78 while WSA’s was 70. Finally, statistically significant differences between WSB and WSC were observed in 2007; the average CN for WSC in 2007 was 81 while WSB’s was 74.

Table 2.10: ANCOVA time to peak (Tp) results for WSA, WSB, and WSC 2002-2008. [1]

	Average Time to Peak (hr)		
Year	WSA	WSB	WSC
2002	14.4	12.1	
2003	10.1	12.9	
2004	10.5	10.1	
2005	6.0	6.1	8.9
2006	11.2	9.8	10.7
2007	4.9	9.8	6.5
2008	10.5	7.3	8.9

[1] Within each row, constituents with different letters (a,b,c) indicate statistical differences between watersheds, while constituents with the same letter denote statistical similarity between watersheds.

[2] No data available.

Table 2.11: ANCOVA CN (λ=0.2 & λ=0.05) results for WSA, WSB, and WSC 1982-1993 and 2002-2008. [1]

	Average CN (λ=0.2)			Average CN (λ=0.05)		
Year	WSA	WSB	WSC	WSA	WSB	WSC
1982	83	81	82	77	75	76
1983	82	83	83	76	77	76
1984	86b	91ab	93a	81b	88ab	91a
1985	78b	84a	84a	70b	78a	79a
1986	82	86	88	76	80	84
1987	82	84	86	76	78	81
1988	82	82	85	76	76	80
1989	85	87	89	80	82	85
1990	86	87	88	81	83	84
1991	86	87	86	80	83	81
1992	80	82	82	73	75	76
1993	77	80	80	68	73	73
2002	89	91	- -[2]	85	88	- -
2003	87	88	- -	82	84	- -
2004	87	88	- -	83	84	- -
2005	85	85	86	80	80	81
2006	85b	88ab	91a	80b	84ab	88a
2007	81b	81b	86a	75b	74b	81a
2008	83	87	86	76	82	82

[1] Within each row, constituents with different letters (a,b,c) indicate statistical differences between watersheds, while constituents with the same letter denote statistical similarity between watersheds. Constituents with no letters indicate no statistical significance.

[2] No data available.

2.3.2.1 Baseflow, Storm Flow and Total Flow Volumes

Figures 2.29-2.34 and Tables 2.12-2.14 show annual, annual growing, and annual non-growing season baseflow, stormflow, and total flow (sum of baseflow and stormflow) volumes for WSA, WSB, and WSC. The year 2004 had the highest cumulative baseflow volume, stormflow volume, and total flow volume for WSA and WSB with WSA having volumes of 4,312 m^3 ha^{-1}, 6,030 m^3 ha^{-1}, and 10,342 m^3 ha^{-1}, respectively; WSB had volumes of 4,547 m^3 ha^{-1}, 6,989 m^3 ha^{-1}, and 11,536 m^3 ha^{-1}, respectively. Note that 2004 was the year with the highest cumulative precipitation during the study period; WSC was not analyzed in 2004. The year with the highest baseflow volume for WSC was 1985 with a volume of 3,516 m^3 ha^{-1}, and the highest stormflow volume and total flow volume in WSC occurred in 1989 with volumes of 8,652 m^3 ha^{-1} and 10,789 m^3 ha^{-1}, respectively. During the study period, 1989 was the year with the second highest cumulative precipitation. The lowest baseflow volume, stormflow volume, and total flow volume for WSA occurred in 2008 with volumes of 490 m^3 ha^{-1}, 1192 m^3 ha^{-1}, and 1,682 m^3 ha^{-1}, respectively. The lowest baseflow volume and total flow volume for WSB also occurred in 2008 with volumes of 819 m^3 ha^{-1} and 2,769 m^3 ha^{-1}, respectively. The lowest stormflow volume in WSB occurred in 1982 with a volume of 1,717 m^3 ha^{-1}. The lowest baseflow volume, stormflow volume, and total flow volume in WSC occurred in 1983 with volumes of 1,064 m^3 ha^{-1}, 1,776 m^3 ha^{-1}, and 2,840 m^3 ha^{-1}, respectively. The years 1982, 1983 and 2008 were all periods with below average cumulative precipitation.

Results from the statistical analysis found large significant differences in baseflow volume between WSA and WSC two years post-harvest in 1985 and 24 years post-harvest in 2007. Statistically significant differences in stormflow volume were observed between WSA and WSC in 1984, 1985, 2006, and 2007. Results from the precipitation analysis showed that 2006 and 2007 were years with high average storm intensity and high average maximum storm intensity (Table 2.4-2.6). Although these years were found not to be statistically higher than the period average intensity and average maximum intensity, they were found to be statistically higher than the period minimum occurring in 2008.

Table 2.12: Yearly WSA, WSB, and WSC stormflow, baseflow, and total flow normalized by drainage area[1] 1982-1993 and 2002-2008.

Year	WSA			WSB			WSC		
	Baseflow (m^3 ha^{-1})	Stormflow (m^3 ha^{-1})	Total Q (m^3 ha^{-1})	Baseflow (m^3 ha^{-1})	Stormflow (m^3 ha^{-1})	Total Q (m^3 ha^{-1})	Baseflow (m^3 ha^{-1})	Stormflow (m^3 ha^{-1})	Total Q (m^3 ha^{-1})
1982	1928.8	1598.5	3527.2	1510.2	1716.7	3226.9	1116.8	2426.3	3543.1
1983	1374.1	1596.1	2970.2	950.5	2013.9	2964.4	1064.4	1776.3	2840.7
1984	2445.1	2923.5	5368.6	1903.0	5640.4	7543.4	2212.2	6607.3	8819.6
1985	2705.2	1596.7	4301.9	3766.7	3473.7	7240.4	3516.4	3969.3	7485.7
1986	1953.1	1705.1	3658.1	1791.4	3245.3	5036.6	1919.5	3541.8	5461.3
1987	1896.1	1786.5	3682.6	1502.7	2636.4	4139.1	1270.1	3635.5	4905.6
1988	1743.3	1610.5	3353.9	1107.5	2381.8	3489.3	1507.5	2800.8	4308.4
1989	4052.4	4352.7	8405.1	1533.5	7759.4	9292.9	2136.8	8652.4	10789.3
1990	2469.8	2928.2	5398.0	1371.7	5097.2	6468.9	1798.4	5088.9	6887.3
1991	4163.4	3643.4	7806.8	1855.6	6578.3	8433.9	1879.3	6180.6	8059.9
1992	2994.2	2117.8	5112.0	1520.6	3745.7	5266.3	1852.5	4103.3	5955.8
1993	2880.9	1726.8	4607.7	2062.8	3355.6	5418.4	1758.2	3634.2	5392.5
2002	2163.3	3216.8	5380.1	2587.0	4308.8	6895.8	- -[2]	- -	- -
2003	2457.3	3828.9	6286.2	3713.0	6090.9	9803.9	- -	- -	- -
2004	4312.3	6030.1	10342.4	4546.8	6989.1	11535.9	- -	- -	- -
2005	2572.9	2698.0	5270.9	2621.6	2650.6	5272.2	3069.2	4741.9	7811.1
2006	824.4	1502.3	2326.7	1183.3	2459.5	3642.7	2219.4	4649.0	6868.4
2007	651.6	1345.0	1996.5	823.4	2019.7	2843.2	1032.0	1862.7	2894.7
2008	490.4	1191.8	1682.3	819.1	1950.3	2769.3	1033.2	2076.5	3109.7

[1] Drainage areas: WSA (16.1 ha), WSB (11.2 ha), and WSC (10.5 ha).

[2] No data available.

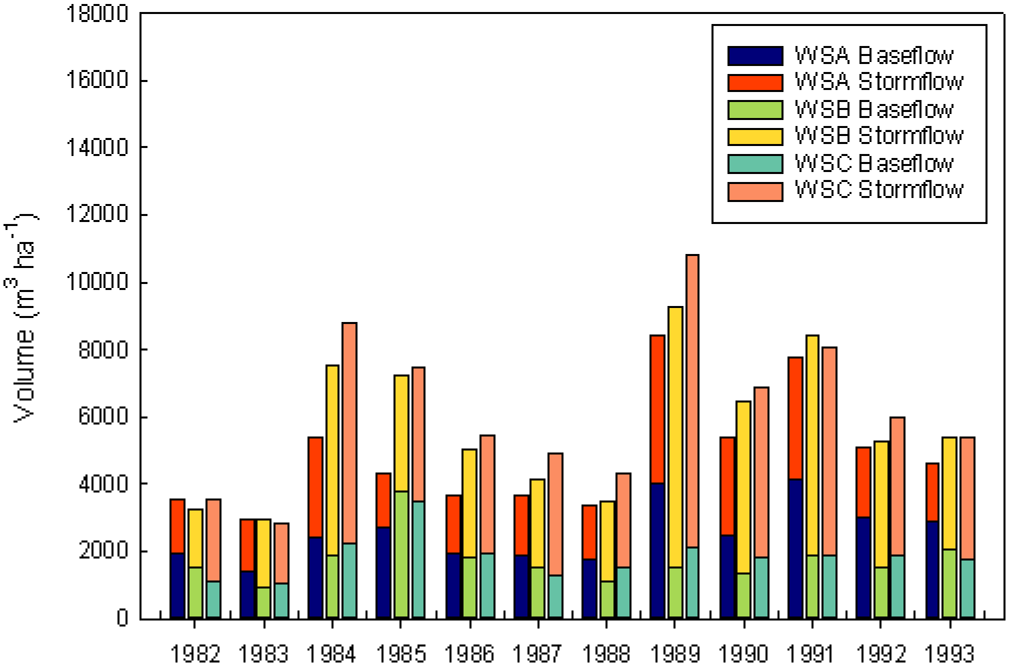

Figure 2.29: Yearly baseflow and stormflow WSA, WSB, and WSC (1982-1993).

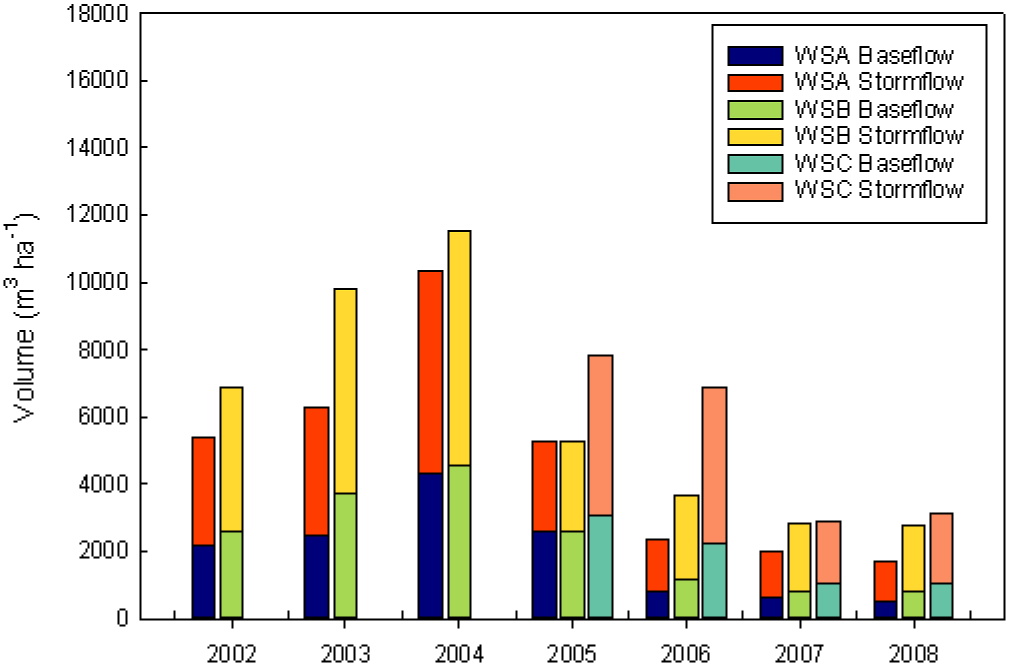

Figure 2.30: Yearly baseflow and stormflow WSA, WSB, and WSC (2002-2008).

Table 2.13: Growing season WSA, WSB, and WSC stormflow, baseflow, and total flow normalized by drainage area[1] 1982-1993 and 2002-2008.

Year	WSA			WSB			WSC		
	Baseflow (m^3 ha^{-1})	Stormflow (m^3 ha^{-1})	Total Q (m^3 ha^{-1})	Baseflow (m^3 ha^{-1})	Stormflow (m^3 ha^{-1})	Total Q (m^3 ha^{-1})	Baseflow (m^3 ha^{-1})	Stormflow (m^3 ha^{-1})	Total Q (m^3 ha^{-1})
1982	267.2	115.9	383.2	276.7	163.9	440.6	423.9	132.0	555.9
1983	683.8	1011.5	1695.2	345.9	1274.1	1620.0	379.8	1196.5	1576.4
1984	1067.6	1374.4	2442.0	631.4	2758.9	3390.3	908.4	3469.3	4377.8
1985	277.3	140.4	417.6	747.2	805.0	1552.3	975.5	837.8	1813.3
1986	292.4	71.6	363.9	375.0	343.9	718.9	546.0	358.1	904.1
1987	601.5	75.3	676.8	505.0	243.1	748.1	743.6	410.4	1153.9
1988	705.1	339.9	1045.0	400.0	393.0	793.0	529.0	600.6	1129.5
1989	1708.9	2047.2	3756.1	697.0	3682.8	4379.9	901.9	4557.3	5459.2
1990	835.4	454.4	1289.8	552.6	939.1	1491.7	759.6	1265.1	2024.7
1991	952.5	776.0	1728.5	692.0	1528.9	2220.9	719.5	1255.5	1975.0
1992	1073.4	734.3	1807.7	525.0	1153.6	1678.5	759.7	1266.0	2025.7
1993	795.7	471.0	1266.7	854.5	949.1	1803.5	807.7	843.0	1650.7
2002	1431.2	1660.7	3091.9	1759.4	2102.6	3862.0	- -[2]	- -	- -
2003	893.3	1333.3	2226.6	843.8	1280.0	2123.9	- -	- -	- -
2004	2086.2	2470.9	4557.1	2768.8	3892.4	6661.1	- -	- -	- -
2005	1883.8	1384.7	3268.6	605.3	1201.5	1806.8	1295.1	1165.8	2460.8
2006	404.2	627.2	1031.4	1002.6	1935.9	2938.5	792.4	1591.5	2383.9
2007	302.7	562.0	864.7	576.0	1143.6	1719.7	277.4	303.7	581.0
2008	251.5	367.0	618.6	40.8	320.3	361.0	282.8	287.5	570.3

[1] Drainage areas: WSA (16.1 ha), WSB (11.2 ha), and WSC (10.5 ha).

[2] No data available.

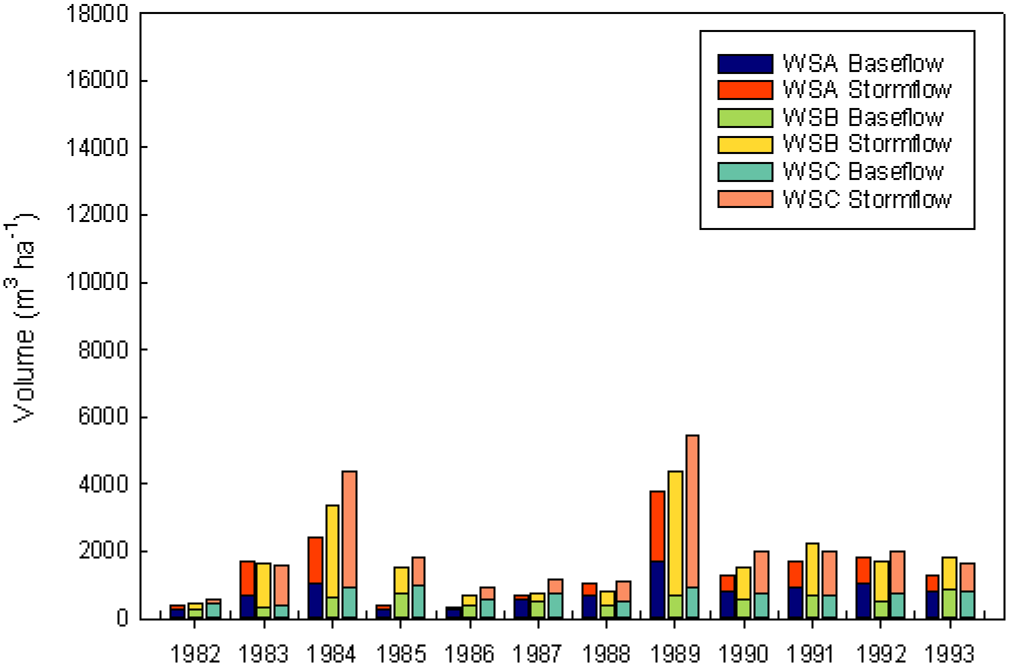

Figure 2.31: Growing season stormflow and baseflow WSA, WSB, and WSC (1982-1993).

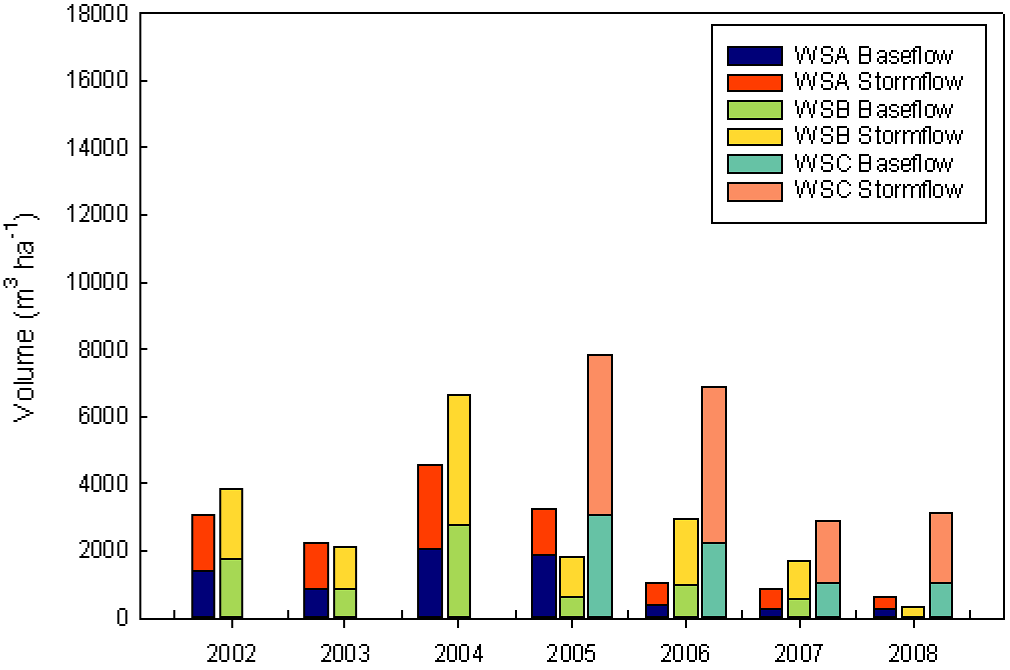

Figure 2.32: Growing Season baseflow and stormflow WSA, WSB, and WSC (2002-2008).

Table 2.14: Non-growing season WSA, WSB, and WSC stormflow, baseflow, and total flow normalized by drainage area[1] 1982-1993 and 2002-2008.

Year	WSA			WSB			WSC		
	Baseflow (m^3 ha^{-1})	Stormflow (m^3 ha^{-1})	Total Q (m^3 ha^{-1})	Baseflow (m^3 ha^{-1})	Stormflow (m^3 ha^{-1})	Total Q (m^3 ha^{-1})	Baseflow (m^3 ha^{-1})	Stormflow (m^3 ha^{-1})	Total Q (m^3 ha^{-1})
1982	1661.5	1482.5	3144.1	1233.5	1552.8	2786.3	692.9	2294.3	2987.2
1983	690.3	584.7	1275.0	604.6	739.8	1344.4	684.5	579.8	1264.3
1984	1377.5	1549.1	2926.6	1271.6	2881.6	4153.2	1303.8	3138.0	4441.8
1985	2428.0	1456.4	3884.3	3019.4	2668.7	5688.1	2540.9	3131.5	5672.4
1986	1660.7	1633.5	3294.2	1416.4	2901.3	4317.7	1373.5	3183.7	4557.2
1987	1294.6	1711.3	3005.9	997.7	2393.3	3391.0	526.5	3225.2	3751.7
1988	1038.2	1270.7	2308.9	707.5	1988.9	2696.3	978.5	2200.3	3178.8
1989	2343.5	2305.4	4648.9	836.5	4076.5	4913.0	1235.0	4095.1	5330.1
1990	1634.4	2473.8	4108.3	819.1	4158.1	4977.2	1038.7	3823.8	4862.5
1991	3210.9	2867.4	6078.3	1163.6	5049.4	6213.0	1159.8	4925.2	6084.9
1992	1920.8	1383.6	3304.4	995.6	2592.2	3587.8	1092.8	2837.2	3930.0
1993	2085.2	1255.8	3341.1	1208.3	2406.6	3614.9	950.5	2791.3	3741.8
2002	732.1	1556.1	2288.2	827.6	2206.2	3033.8	- -[2]	- -	- -
2003	1564.0	2495.6	4059.6	2869.2	4810.9	7680.1	- -	- -	- -
2004	2226.1	3559.2	5785.3	1778.1	3096.7	4874.8	- -	- -	- -
2005	689.1	1313.3	2002.3	2016.4	1449.0	3465.4	1774.2	3576.1	5350.3
2006	420.2	875.1	1295.2	180.6	523.5	704.2	1427.0	3057.5	4484.5
2007	348.9	783.0	1131.9	247.4	876.1	1123.5	754.6	1559.1	2313.6
2008	212.1	740.1	952.3	778.3	1630.0	2408.3	750.4	1789.0	2539.4

[1] Drainage areas: WSA (16.1 ha), WSB (11.2 ha), and WSC (10.5 ha).

[2] No data available.

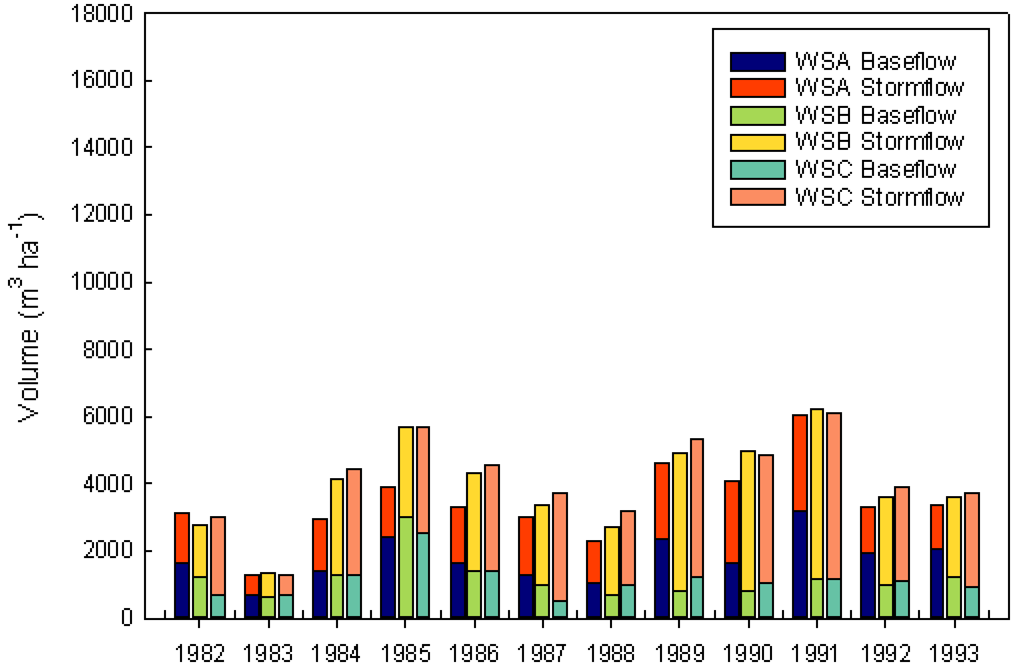

Figure 2.33: Non-growing season baseflow and stormflow WSA, WSB, and WSC (1982-1993).

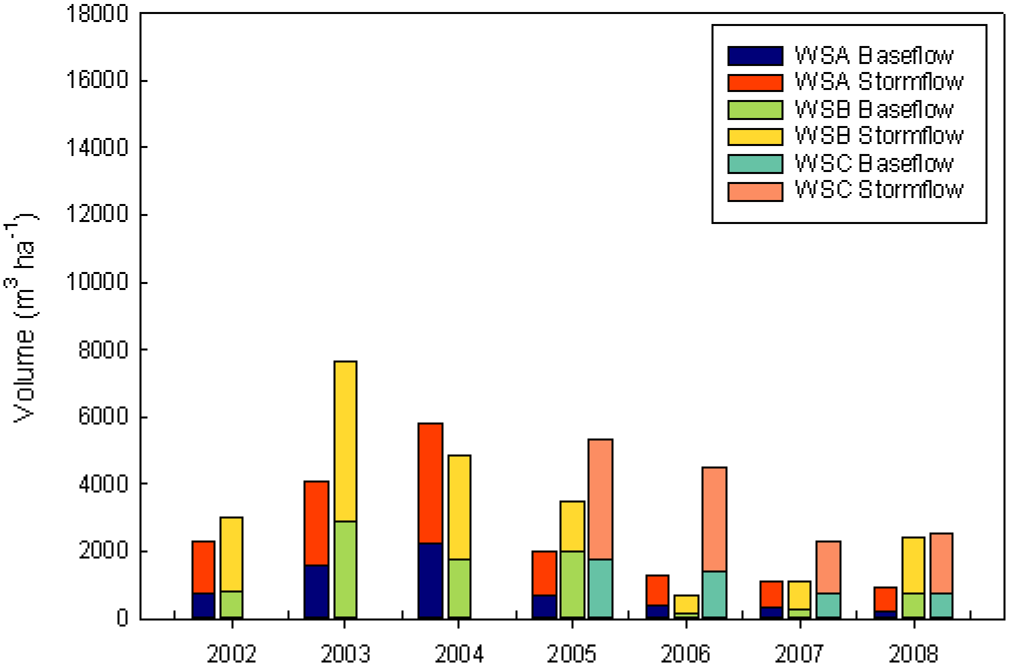

Figure 2.2: Non-growing season baseflow and stormflow WSA, WSB, and WSC (2002-2008).

This could explain the large statistical differences in baseflow volume and stormflow volume between WSA and WSC 23 and 24 years post-harvest following a large time gap of no statistical differences. In contrast, statistically significant differences in baseflow volume and stormflow volume between WSA and WSB only occurred in 1985.

Pre-harvest WSC had a yearly baseflow volume that was on average 0.7 times as much as WSA and a yearly stormflow volume that was 1.3 times higher. Similar values were observed in WSB with a yearly baseflow volume that was on average 0.7 times as much as WSA and a yearly stormflow volume that was 1.2 times higher. The post-harvest (1984-1993 and 2005-2008) yearly baseflow volume in WSC was on average 1.1 times higher than WSA and yearly stormflow volume was 2.0 times higher. For the same post-harvest time period the yearly baseflow volume in WSB was on average 0.9 times as much and yearly stormflow volume was 1.7 times higher.

During the growing season, the differences that were previously explored were even larger (Figure 2.31 and 2.32; Table 2.13). Pre-harvest WSC had a growing season baseflow volume that was on average 0.7 times as much as WSA and a yearly stormflow volume that was 1.8 times higher. Similar values were observed in WSB with a growing season baseflow volume that was on average 0.6 times as much as WSA and a yearly stormflow volume that was 1.6 times higher. The yearly baseflow volume and stormflow volume in WSC for the same post-harvest time period during the growing season was on average 1.2 and 2.5 times respectively, higher than WSA. The baseflow volume and stormflow volume for WSB during the same time period and growing period were 1.0 and 2.4 times respectively, higher than WSA.

Differences in baseflow volume and stormflow volume were also observed during the non-growing season (Figure 2.33 and 2.34; Table 2.14). Pre-harvest WSC had a non-growing season baseflow volume that was on average 0.7 times as much as WSA and a yearly stormflow volume that was 1.3 times higher. Similar values were observed in WSB with a growing season baseflow volume that was on average 0.8 times as much as WSA and a yearly stormflow volume that was 1.2 times higher. The yearly baseflow volume and stormflow volume in WSC for the same post-harvest time period during the non-growing season was 1.3 and 2.1 times, respectively higher than WSA. The baseflow volume and stormflow volume for WSB during the same time period and growing period were 1.0 and 1.6 times, respectively higher than WSA.

These results show that the stormflow volume in WSB is on average more aligned with the control during the non-growing season than during the growing-season but has not quite reached pre-harvest conditions. A similar study conducted in the Allegheny Mountains observed seasonality effects with statistically significant elevated peak flows and stormflow volumes six years post-harvest during the growing season (Kochenderfer et al., 1997). Seasonality had very little effect on WSC; stormflow volumes were somewhat more aligned with the control during the non-growing season while baseflow volume experienced no change. This would indicate that even though the watersheds have been allowed to regrow for 25 years, the role of vegetation in the hydrologic cycle still does not match the control watershed. Another important result from this analysis was that the stormflow volumes in WSB and WSC remained elevated at the conclusion of the study in 2008. Variations in temporal rainfall distribution have been shown to play a major role in determining storm runoff volumes. Results from (Warner et al., 2010) found that rainfall events with a temporal distribution classified as intense (μ=14.8 mm/hr) produced larger storm runoff volumes and subsequently elevated CNs in the Appalachian region of Kentucky compared to rainfall events with lower intensities. Similar results were found during this study with the highest amount of variability in runoff volumes between the harvested watersheds and the control occurring during years with the highest storm intensities: 2006 and 2007 average storm intensity was 6 and 6.6 mm hr^{-1}, respectively, and average maximum intensity was 20.7 and 20.5 mm hr^{-1}, respectively. Comparatively, 2008 had the lowest average storm intensity at 3.4 mm hr^{-1} and lowest average maximum storm intensity at 11.3 mm hr^{-1} (Table 2.6). Finally, baseflow volumes were less impacted by treatment than stormflow volumes; nonetheless, statistical variation was present two years after harvest for both WSB and WSC and again in 2007 for WSC, a year with high intensity storms.

2.3.2.2 Peak Discharge

Figures 2.35-2.40 and Table 2.15 show annual, growing season, and non-growing season average peak flow for WSA, WSB, and WSC.

No statistical differences were recorded during the study period. Graphically, there only seems to be marginal differences between the watersheds and no discernible trends in the data. The main difference that can be seen from the graph is in 1993 when the average storm peak flow for WSC was much higher. This difference mainly came from one event (July 13, 1993) when the peak flow in WSC was 15 times higher than WSA and 16 times higher than WSB. In the second time period, these differences become even less noticeable and the watersheds have nearly identical results for most years.

These results are surprising because higher peak flows were expected to accompany higher stormflows but that was hardly the case. For comparison, the pre-harvest average peak flow for WSA, WSB, and WSC was 1.9, 1.4, and 1.3 (m^3 s^{-1} ha^{-1}), respectively. Due to their respective areas, these values seem reasonable. Average peak flow post-harvest for WSA, WSB, and WSC was 1.8, 1.6, and 1.7 (m^3 s^{-1} ha^{-1}), respectively. These differences seem pretty insignificant, and it would seem that harvest might have had some small effect on peak flow. With limited pre-harvest data, not much emphasis should be placed on this result. Witness accounts from the first time period (1982-1993) noted logging debris left in the stream in WSC following harvest was trapping large amounts of sediment. This effectively increased frictional effects in the stream channel, which in turn would have decreased stream velocity. This may explain why increases to stream velocity were not observed in WSC as expected. It was also observed that a large storm event, perhaps the event on July 13, 1993, washed out all of this debris and sediment and stripped the channel in WSC to bedrock. This may explain the large elevated peak flow in WSC during the event on July 13, 1993. Differences between the watersheds in Q_p due to seasonality were not observed during the analyzed time periods.

Table 2.15: WSA, WSB, and WSC average yearly, growing, and non-growing season peak flow (Q_p) ± standard deviation (m^3 ha^{-1} s^{-1} x 10^{-2}) normalized by drainage area[1] 1982-1993 and 2002-2008.

	WSA			WSB			WSC		
Year	Qp Year	QP Growing	Qp Non-Growing	Qp Year	QP Growing	Qp Non-Growing	Qp Year	QP Growing	Qp Non-Growing
1982	0.23±0.46	0.09±0.14	0.36±0.61	0.16±0.25	0.06±0.09	0.24±0.32	0.16±0.29	0.06±0.06	0.25±0.37
1983	0.14±0.22	0.18±0.26	0.06±0.04	0.12±0.16	0.15±0.19	0.06±0.04	0.11±0.16	0.14±0.18	0.04±0.02
1984	0.35±0.79	0.55±1.14	0.17±0.13	0.26±0.30	0.28±0.39	0.24±0.21	0.22±0.26	0.24±0.31	0.21±0.21
1985	0.07±0.04	0.06±0.05	0.09±0.01	0.09±0.06	0.07±0.05	0.15±0.05	0.09±0.06	0.07±0.05	0.14±0.07
1986	0.16±0.20	0.05±0.03	0.29±0.24	0.15±0.19	0.03±0.01	0.30±0.21	0.20±0.30	0.04±0.02	0.38±0.39
1987	0.10±0.12	0.06±0.06	0.13±0.15	0.09±0.12	0.03±0.02	0.13±0.14	0.09±0.10	0.05±0.03	0.13±0.12
1988	0.21±0.28	0.10±0.15	0.31±0.34	0.17±0.23	0.10±0.19	0.23±0.26	0.17±0.20	0.13±0.21	0.20±0.20
1989	0.34±0.44	0.38±0.54	0.28±0.22	0.26±0.29	0.26±0.35	0.25±0.17	0.29±0.33	0.33±0.41	0.23±0.16
1990	0.14±0.11	0.07±0.06	0.21±0.09	0.14±0.13	0.04±0.03	0.24±0.10	0.12±0.09	0.05±0.04	0.19±0.08
1991	0.16±0.10	0.13±0.09	0.18±0.12	0.15±0.12	0.11±0.11	0.20±0.13	0.13±0.09	0.11±0.09	0.14±0.09
1992	0.17±0.23	0.18±0.25	0.15±0.06	0.15±0.21	0.14±0.23	0.15±0.07	0.15±0.23	0.16±0.26	0.12±0.05
1993	0.12±0.09	0.11±0.09	0.22[2]	0.15±0.12	0.13±0.11	0.36[2]	0.42±0.69	0.39±0.72	0.74[2]
2002	0.24±0.45	0.35±0.60	0.12±0.11	0.24±0.41	0.33±0.55	0.15±0.15	- -[3]	- -	- -
2003	0.12±0.16	0.11±0.15	0.13±0.19	0.13±0.20	0.11±0.19	0.15±0.23	- -	- -	- -
2004	0.31±0.31	0.27±0.32	0.37±0.32	0.31±0.32	0.30±0.37	0.33±0.23	- -	- -	- -
2005	0.25±0.48	0.29±0.51	0.02±0.02	0.22±0.45	0.26±0.47	0.01±0.01	0.24±0.53	0.27±0.56	0.03±0.00
2006	0.18±0.24	0.12±0.13	0.34±0.41	0.13±0.15	0.10±0.11	0.24±0.22	0.15±0.15	0.13±0.14	0.20±0.17
2007	0.05±0.06	0.08±0.07	0.03±0.02	0.03±0.02	0.03±0.03	0.03±0.02	0.07±0.06	0.10±0.07	0.05±0.02
2008	0.04±0.03	0.02±0.02	0.05±0.03	0.05±0.04	0.01±0.01	0.07±0.02	0.07±0.05	0.04±0.04	0.08±0.05

[1] Drainage areas: WSA (16.1 ha), WSB (11.2 ha), and WSC (10.5 ha).

[2] One storm suitable for analysis.

[3] No data available.

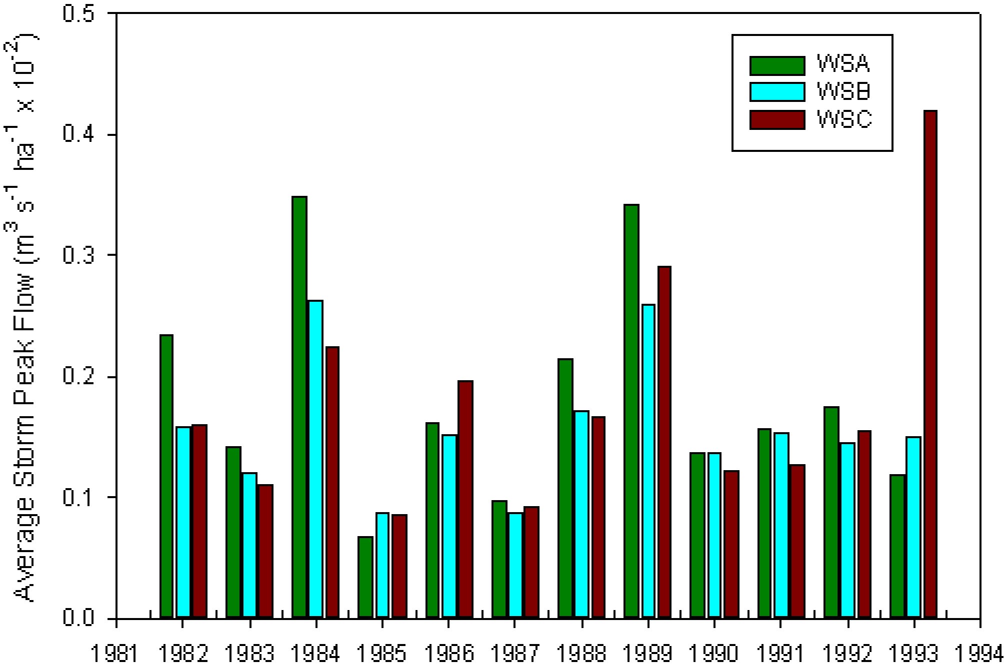

Figure 2.35: Average Storm Peak Flow WSA, WSB, WSC (1982-1993).

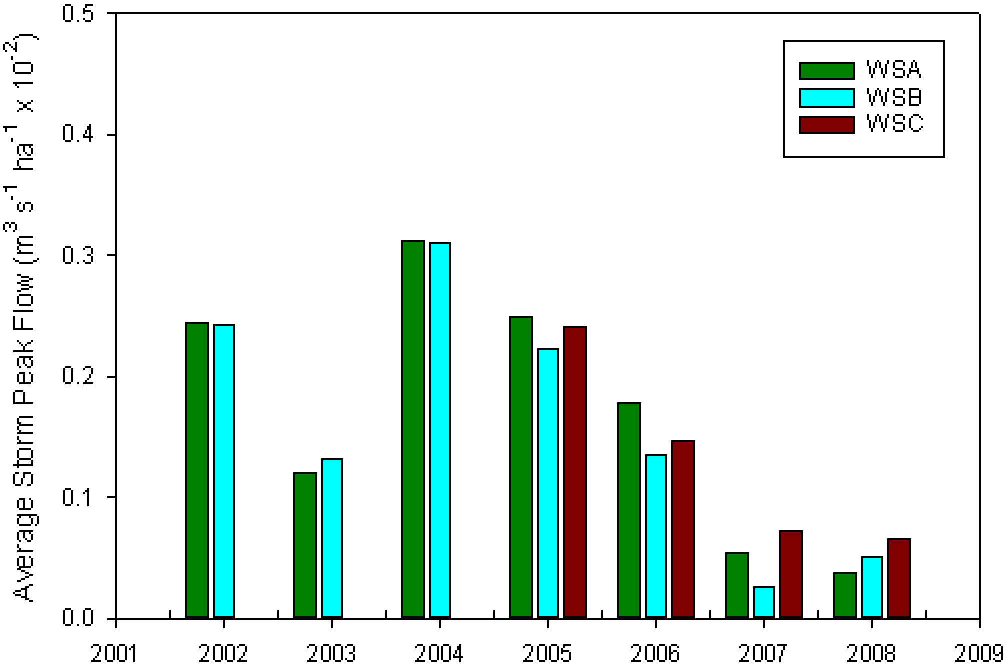

Figure 2.36: Average Storm Peak Flow WSA, WSB, WSC (2002-2008).

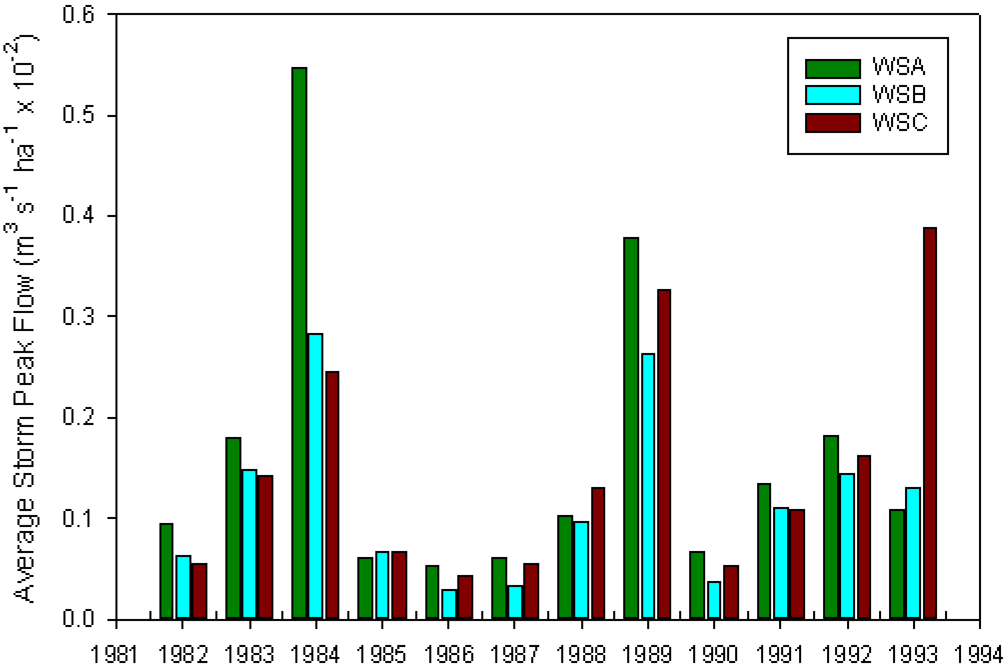

Figure 2.37: Growing Season Average Storm Peak Flow WSA, WSB, WSC (1982-1993).

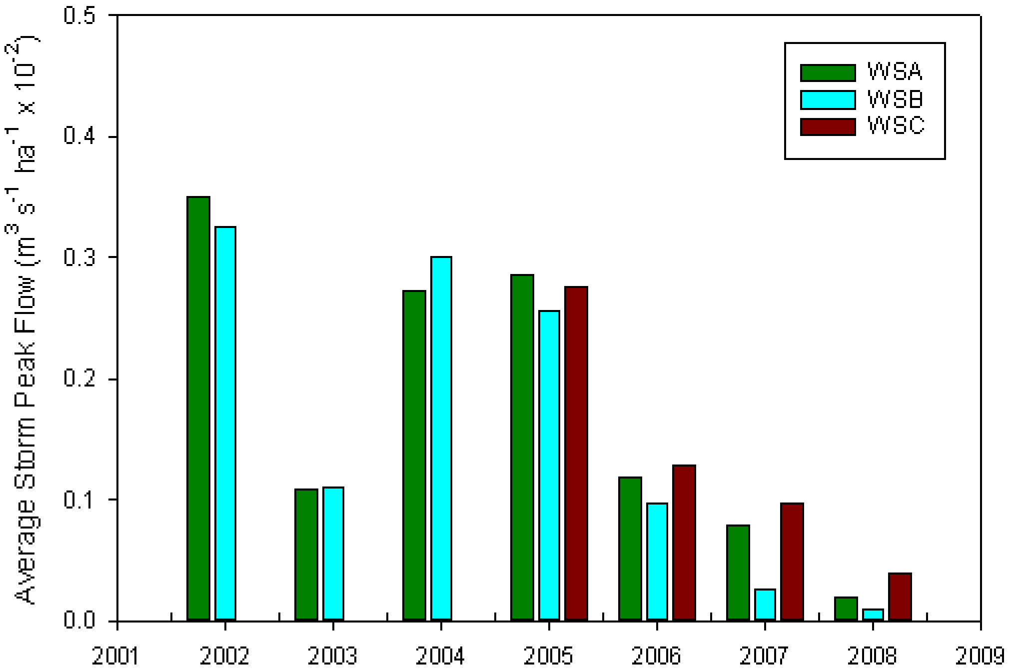

Figure 2.38: Growing Season Average Storm Peak Flow WSA, WSB, WSC (2002-2008).

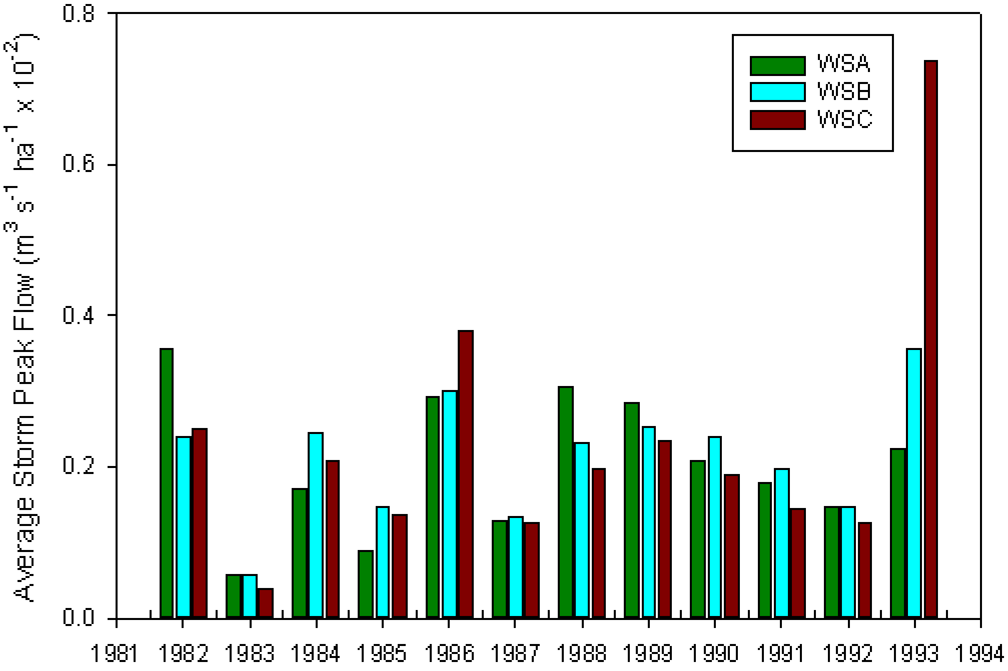

Figure 2.39: Non-Growing Season Average Storm Peak Flow WSA, WSB, WSC (1982-1993).

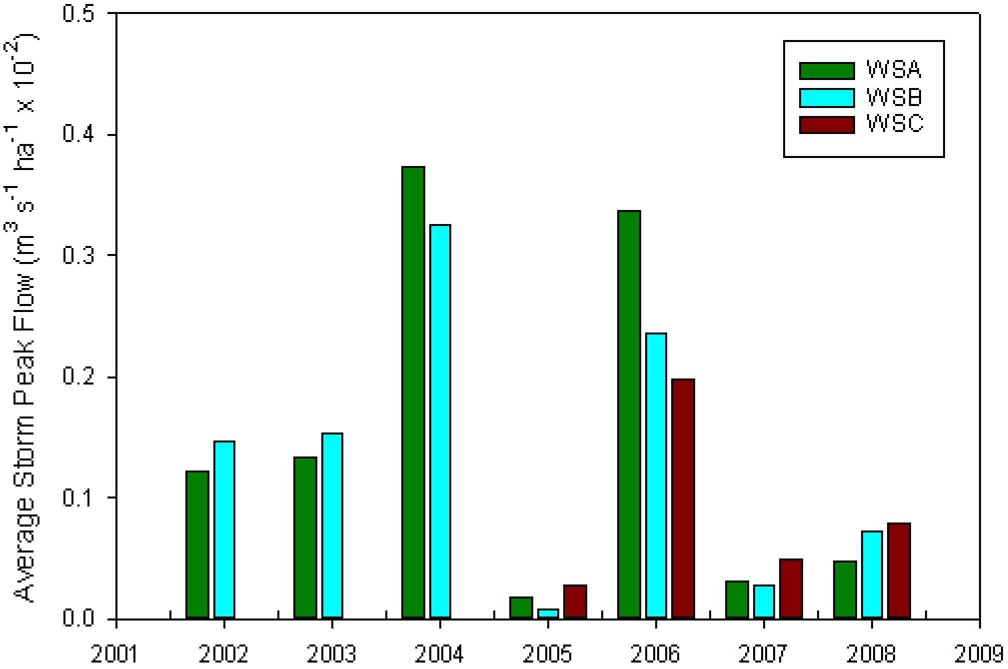

Figure 2.40: Non-Growing Season Average Storm Peak Flow WSA, WSB, WSC (2002-2008).

2.3.2.3 Stormflow Volume as a Percentage of Rainfall

Results from comparisons of the average storm volume as a percentage of rainfall ([S/P]%) across watersheds are presented in Figures 2.41-2.46 and Tables 2.16-2.18. The yearly maximum average [S/P]% for WSA occurred in 1989 with a value of 35.4% and the yearly maximum average [S/P]% for WSB and WSC occurred directly after harvest in 1984 with values of 48.5% and 65.2%, respectively.

Significant statistical differences between WSA and WSC were observed in 1984, 1985, 1989, 2006, and 2007. Average [S/P]% for WSC was 56%, 25%, 47%, 38%, and 14%, respectively, compared to average [S/P]% in WSA being 35%, 12%, 28%, 19%, and 7%. Statistical differences between WSA and WSB were only present in 1985; average [S/P]% for WSB was 23% compared to WSA's 12%. Finally, statistically significant differences between WSB and WSC were only observed in 2007 with average [S/P]% for WSC being 14% compared to 7% in WSB.

These results, along with the stormflow results, show that WSB and WSC became more responsive to precipitation following harvest, which in turn led to larger stormflow volumes. The largest of these effects were seen in the first few years following harvest. By the end of the first time period, hardly any variation existed. Oddly enough, when monitoring was resumed in WSC (2005), large spikes in storm volumes were observed from 2006-2008. This again was most likely caused by high intensity rainfall events. Seasonal variations followed a similar pattern as the baseflow and stormflow volume results already explored. Larger variations between the harvested watersheds and WSA were present during the growing season when vegetation plays an active role in the hydrologic cycle. Less variation was present during the non-growing season when vegetation was dormant.

Table 2.16: Yearly average storm volume as a (%) of rainfall ± standard deviation for WSA, WSB, and WSC 1982-1993 and 2002-2008.

Year	WSA	WSB	WSC
1982	25.9±30.2	19.2±20.6	27.6±33.7
1983	21.5±22.3	23.5±24.6	22.5±24.4
1984	34.9±28.9	48.5±26.9	56.2±29.9
1985	11.8±16.8	23.0±25.9	24.9±26.8
1986	18.9±25.9	25.9±29.7	32.7±34.2
1987	22.7±30.8	25.2±30.8	28.1±31.3
1988	28.2±31.4	25.4±24.3	32.6±30.1
1989	35.4±25.9	41.1±26.3	47.2±30.0
1990	26.7±25.5	32.9±31.1	34.4±31.1
1991	34.2±30.7	38.5±32.0	37.3±34.2
1992	18.0±22.5	20.4±24.8	20.7±23.0
1993	18.8±29.5	22.5±27.9	21.6±26.5
2002	35.6±28.2	45.8±33.5	- -[1]
2003	29.7±27.7	33.4±27.1	- -
2004	32.9±25.3	37.2±29.8	- -
2005	17.8±23.8	21.1±30.9	17.9±24.8
2006	18.7±17.5	28.9±24.1	38.6±27.8
2007	6.6±8.2	7.0±8.6	14.0±9.3
2008	13.5±16.8	26.1±28.0	26.9±30.9

[1] No data available.

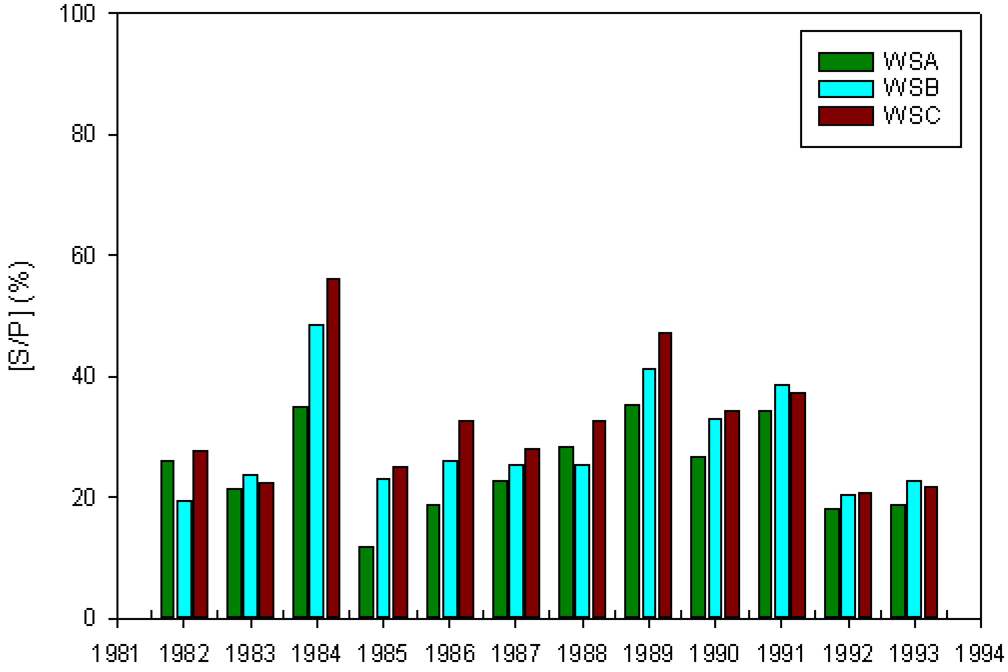

Figure 2.3: Average storm volume as a percentage of rainfall WSA, WSB, WSC (1982-1993).

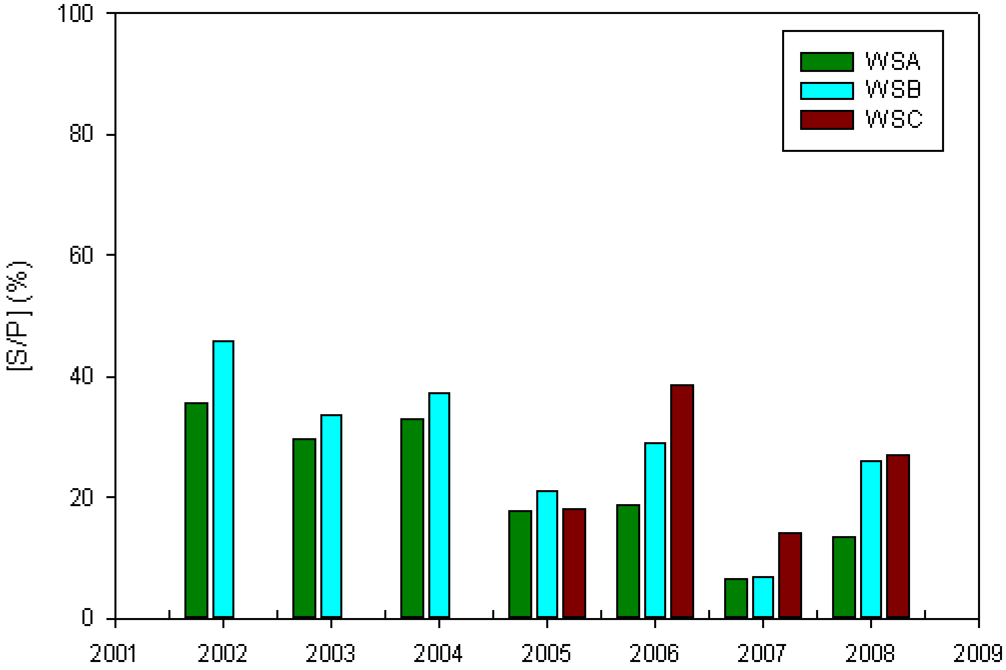

Figure 2.42: Average storm volume as a percentage of rainfall WSA, WSB, WSC (2002-2008).

Table 2.17: Growing season average storm volume as a (%) of rainfall ± standard deviation for WSA, WSB, and WSC 1982-1993 and 2002-2008.

Year	WSA	WSB	WSC
1982	2.0±1.0	2.1±1.3	2.4±2.2
1983	15.9±20.8	18.2±24.2	17.9±24.0
1984	23.7±32.7	36.4±33.0	42.9±35.6
1985	3.0±4.5	10.5±16.1	11.7±14.3
1986	2.9±1.9	5.0±3.2	8.3±3.8
1987	3.1±1.7	5.3±4.3	7.7±6.8
1988	12.6±25.5	6.7±11.8	13.3±20.3
1989	19.5±18.1	24.5±19.1	29.7±25.3
1990	4.1±5.6	4.7±5.8	6.0±6.7
1991	8.2±11.0	11.7±12.3	8.2±10.9
1992	8.8±12.0	9.8±9.2	11.5±9.4
1993	14.5±27.2	16.8±21.5	15.9±19.4
2002	29.4±31.2	36.6±37.8	- -[1]
2003	8.1±8.5	13.3±14.3	- -
2004	20.3±18.1	25.6±26.3	- -
2005	19.4±25.2	23.7±32.6	18.3±26.8
2006	10.6±7.6	17.8±12.4	28.5±17.9
2007	2.9±2.2	2.3±2.2	8.8±4.8
2008	3.2±1.8	5.5±4.3	7.0±4.8

[1] No data available.

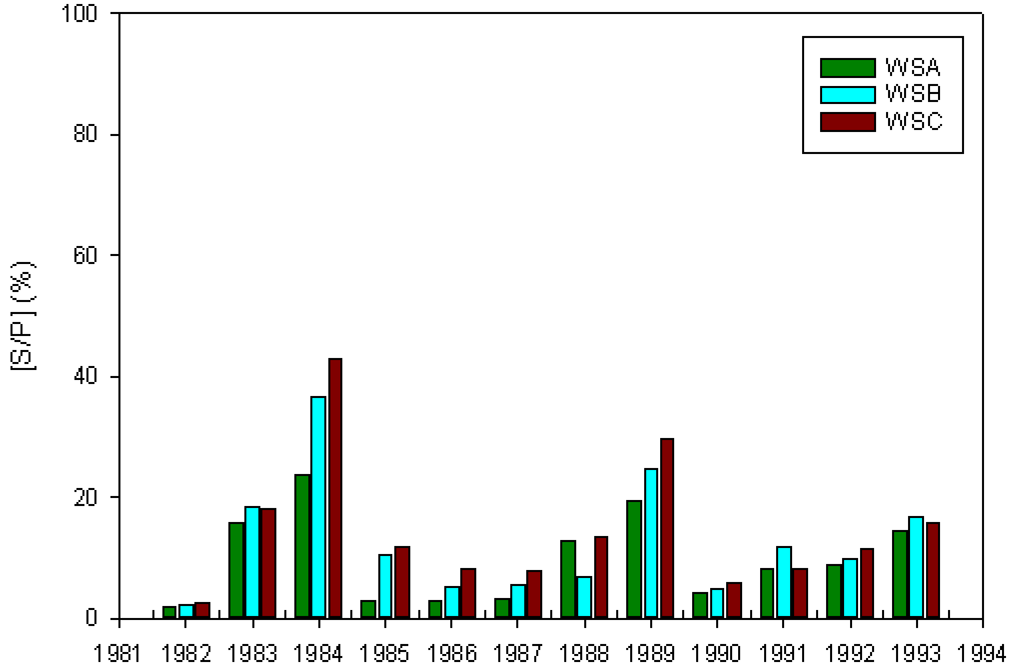

Figure 2.43: Growing season average storm volume as a percentage of rainfall WSA, WSB, WSC (1982-1993).

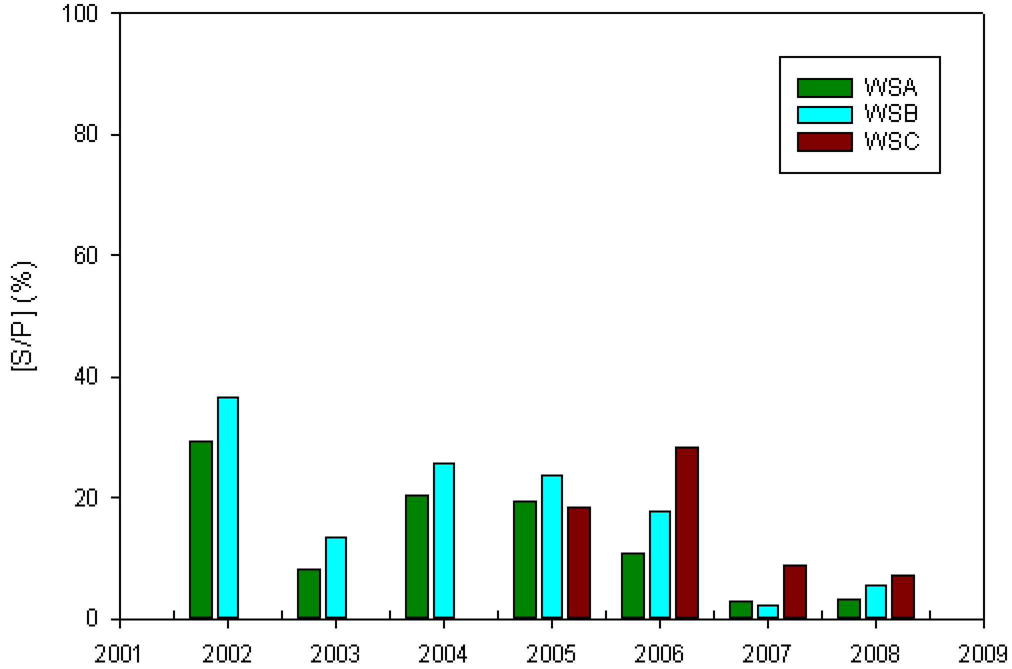

Figure 2.4: Growing season average storm volume as a percentage of rainfall WSA, WSB, WSC (2002-2008).

Table 2.18: Non-growing season average storm volume as a (%) of rainfall ± standard deviation for WSA, WSB, and WSC 1982-1993 and 2002-2008.

Year	WSA	WSB	WSC
1982	46.7±27.5	34.2±17.4	49.6±32.8
1983	33.8±22.5	35.2±23.6	32.6±24.4
1984	45.0±21.8	59.3±14.0	68.2±18.0
1985	36.2±13.2	57.4±11.2	61.3±16.5
1986	38.0±28.8	50.9±27.5	62.1±30.5
1987	40.1±34.3	43.0±33.6	46.2±33.7
1988	41.2±31.7	41.0±20.7	48.7±28.2
1989	60.2±12.9	67.2±7.1	74.8±6.2
1990	49.3±14.6	61.1±15.8	62.9±14.2
1991	60.3±19.0	65.3±20.6	66.4±21.8
1992	54.7±14.7	62.8±22.1	57.5±26.1
1993[1]	62.1	79.7	78.9
2002	42.7±24.7	56.2±26.5	- -[2]
2003	51.2±22.6	53.6±21.1	- -
2004	53.2±22.2	55.8±26.1	- -
2005	7.4±6.6	4.5±2.7	15.5±3.8
2006	40.3±19.1	58.4±23.9	65.6±35.0
2007	10.2±10.5	11.6±10.3	19.2±10.2
2008	18.7±18.8	36.4±29.3	36.8±34.2

[1] One storm suitable for analysis.

[2] No data available.

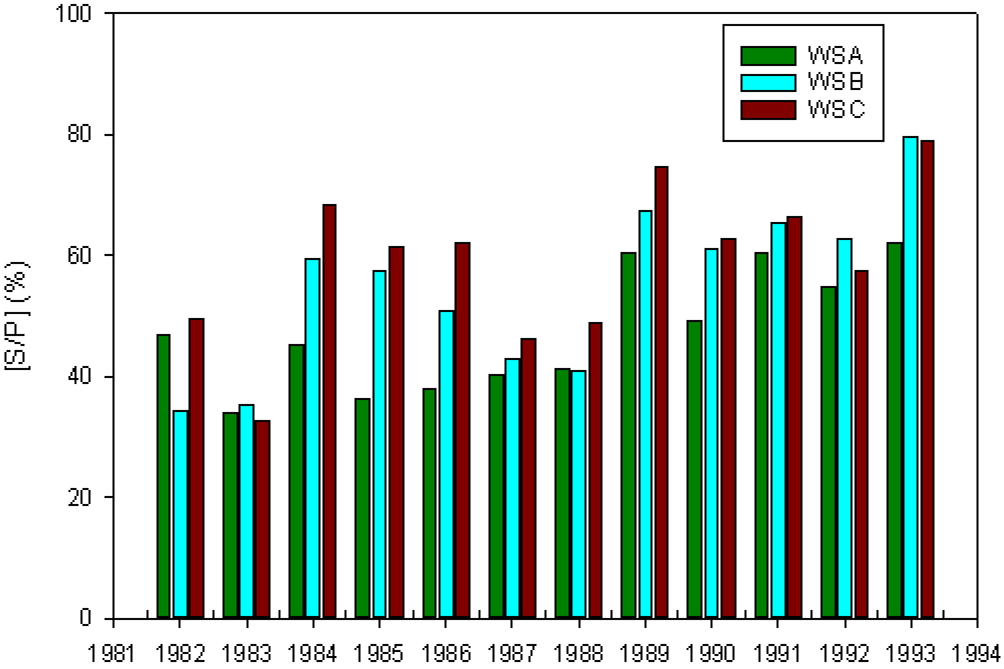

Figure 2.45: Non-growing season average storm volume as a percentage of rainfall WSA, WSB, WSC (1982-1993).

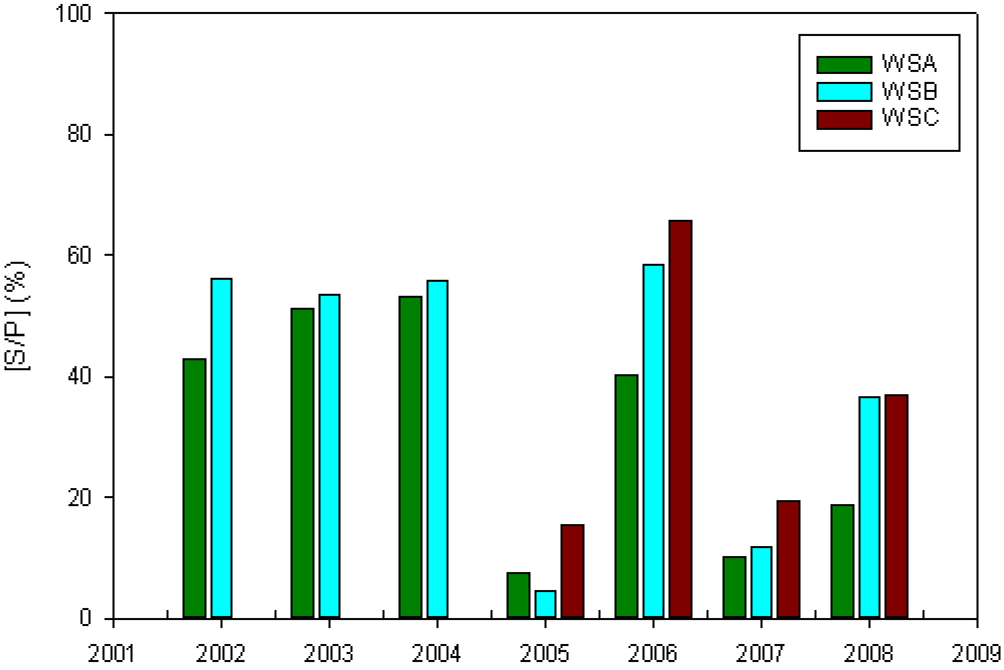

Figure 2.46: Non-growing season average storm volume as a percentage of rainfall WSA, WSB, WSC (2002-2008).

2.3.2.4 Time to Peak

Differences in the T_p for the three watersheds were analyzed (Figures 2.47-2.49; Table 2.19). Unfortunately, the T_p was only analyzed in the second time period due to 15-minute rainfall data only becoming available in 2000. No statistical differences were found during the analyzed period. Interestingly, average annual time to peak across all subcatchments was 6.6 hours. This value may seem large due to the size of the subcatchments and the steep sideslopes but may be explained by the site-specific geologic conditions and forest hydrology. The flow path of rain before it reaches the stream may look something like the following. Rain falls through the canopy where a fraction is intercepted by leaves. The rain that makes it through the canopy then has to travel down past leaf litter and infiltrates down into a layer of organic material and soil (no overland flow occurs). After, the water will reach a tightly woven layer of interbedded sandstone, siltstone, or shale, where a fraction travels towards the stream as subsurface flow and the other fraction infiltrates further. The portion that infiltrates further then may reach a coal seam where again a fraction travels toward the stream as subsurface flow and the other fraction infiltrates. Eventually, the water that is remaining will reach a layer of bedrock where it has to travel toward the stream as subsurface flow. A final portion of the water will get tied up into soil pore spaces where it will be utilized by flora and fauna. Moving through all of these layers, especially the layers of sandstone, siltstone, shale, and coal, dampen the movement of water towards the stream and prolong the time to peak.

An observation on the effect of seasonality indicated an average longer time to peak during the non-growing season compared to the growing season during all analyzed years. Temporal rainfall distribution is expected to have played a role in the longer average time to peak during the non-growing season. Convective storms mainly occur during the warm season months and produce large intense rainfall events. From June 1990 to September 1991, 42 rainfall events were separated by temporal rainfall distribution into classifications of intense, steady, multi-interval intense, and multi-interval steady in the work by

Table 2.19: WSA, WSB, and WSC average time to peak (Tp) ± standard deviation (hr) 2002-2008.

	WSA			WSB			WSC		
Year	Tp Year	Tp Growing	Tp Non-Growing	Tp Year	Tp Growing	Tp Non-Growing	Tp Year	Tp Growing	Tp Non-Growing
2002	9.4±7.5	5.0±5.2	14.4±6.8	9.4±6.5	7.0±5.0	12.1±7.1	- -[1]	- -	- -
2003	6.5±6.9	2.9±2.6	10.1±8.1	8.6±6.5	4.4±3.7	12.9±6.0	- -	- -	- -
2004	7.2±8.2	5.0±7.4	10.5±8.7	6.5±6.4	4.3±4.7	10.1±7.5	- -	- -	- -
2005	4.4±6.1	4.1±6.6	6.0±0.4	4.7±6.6	4.5±7.1	6.1±1.6	5.1±6.6	4.6±6.8	8.9±4.1
2006	6.0±6.3	4.0±5.7	11.2±5.3	7.7±6.9	6.9±7.4	9.8±6.4	7.4±5.8	6.2±5.4	10.7±6.7
2007	3.0±4.9	1.1±0.9	4.9±6.5	5.2±6.6	0.7±0.4	9.8±6.9	3.6±4.7	0.6±0.3	6.5±5.2
2008	7.9±8.2	2.6±3.4	10.5±8.9	7.1±3.3	6.9±5.6	7.3±2.2	8.2±6.1	6.8±10.8	8.9±3.5

[1] No data available.

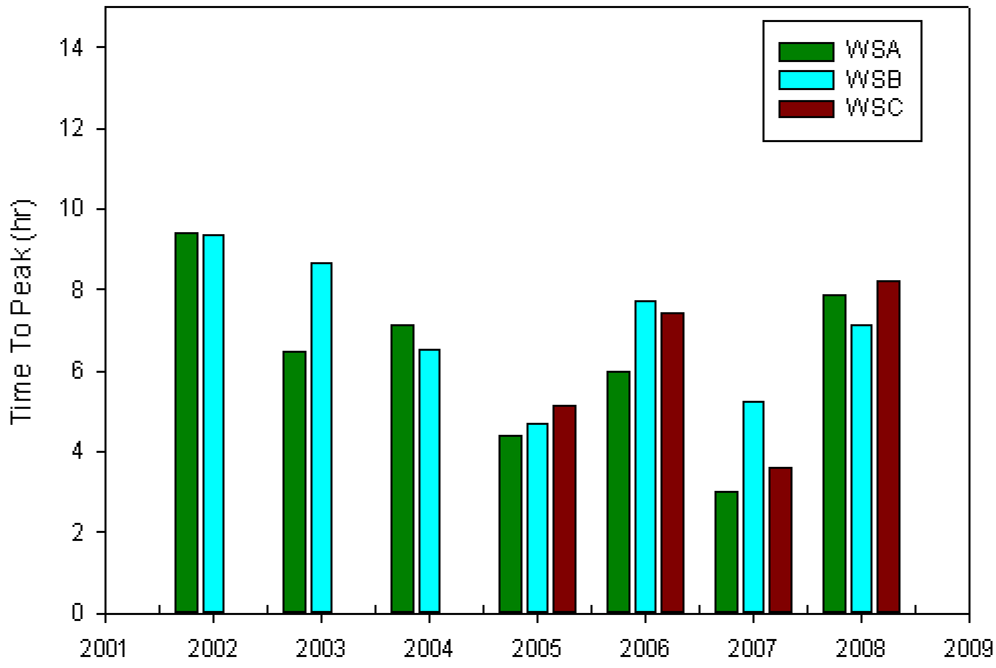

Figure 2.47: Average Time to Peak WSA, WSB, WSC (2002-2008).

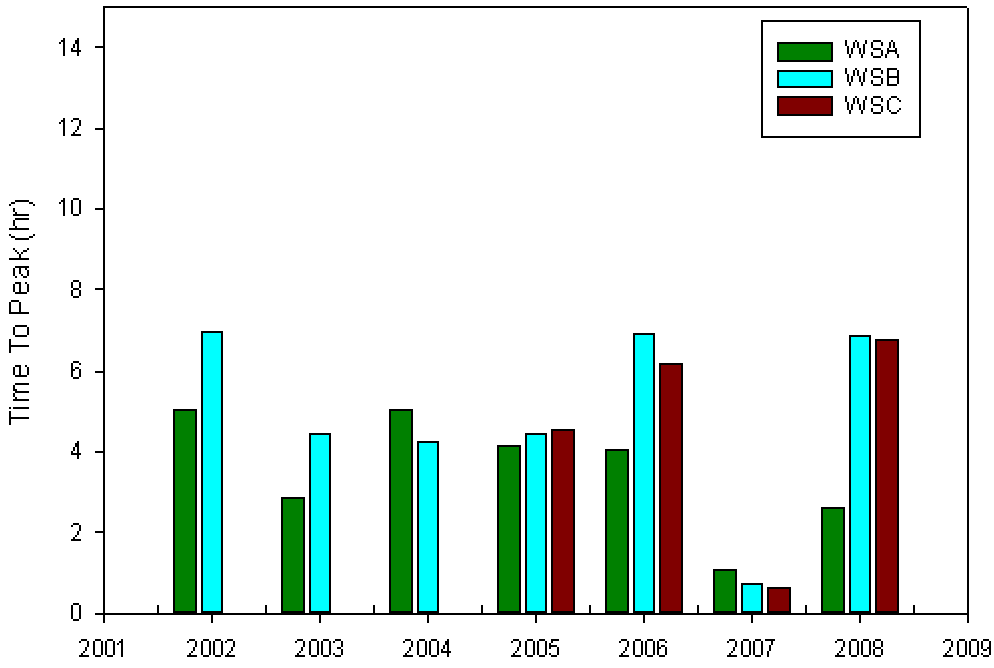

Figure 2.48: Growing season average Time to Peak WSA, WSB, WSC (2002-2008).

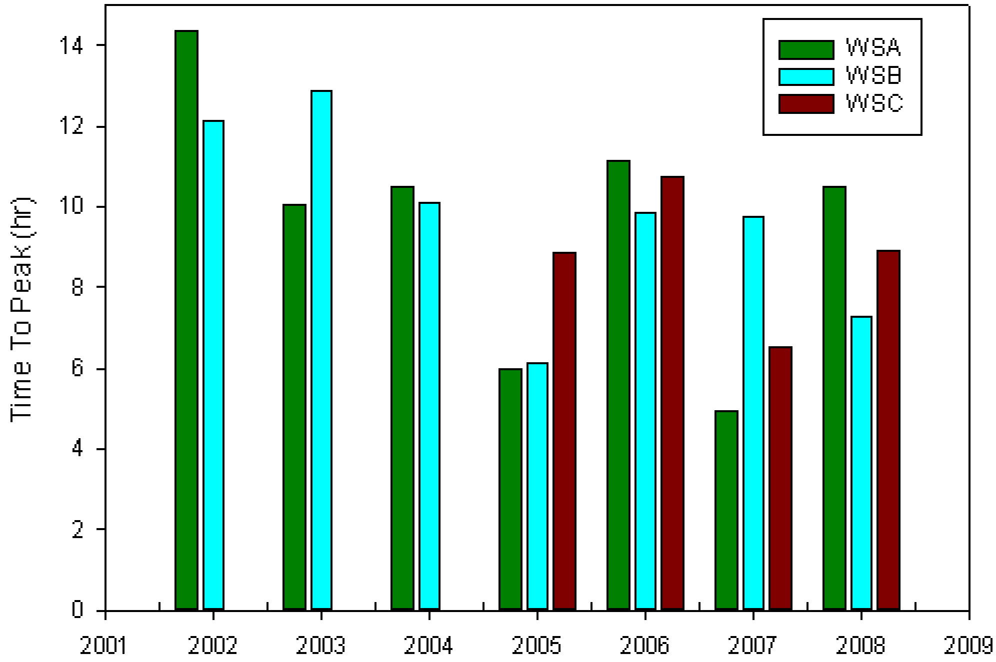

Figure 2.49: Non-growing season average Time to Peak WSA, WSB, WSC (2002-2008).

Warner et al., (2010b). Of these 42 events, seven occurred during the non-growing season and only one was classified as intense. However, it should be noted that this one storm had the lowest rainfall intensity of the 14 storms classified as intense and occurred during a month that experienced 3 times as much precipitation as the long-term monthly average. As noted by Bauer (1974), infiltration rates exhibit a period of recovery when rainfall intensities are less than infiltration capacities, or during periods with absent rainfall. This would indicate that multi-interval and less intense rainfall events would allow soil infiltration rates and depressional storage to rebound and subsequently prolong the time it takes for rainfall to reach the stream, inherently increasing the time to peak.

2.3.2.5 Curve Number

Results of the CN are presented in Figures 2.50-2.67 and Tables 2.20-2.25. Statistically significant differences between WSA and WSC were observed in 1984, 1985, 2006, and 2007 with average CNs (λ=0.05) in WSC of 91, 79, 88, and 81, respectively; average CNs in WSA were 82, 70, 80, and 75, respectively. Statistically significant differences between WSA and WSB only occurred in 1985 with WSB having an average CN of 78 while WSA's was 70. Finally, statistical differences between WSB and WSC were observed in 2007. The average CN for WSC in 2007 was 81 while WSB's was 74. The maximum CN (λ=0.05) for WSA occurred in 2004 with a value of 87 while the maximum CNs in WSB and WSC occurred directly after harvest in 1984 with values of 88 and 91, respectively. The average pre-harvest CN of WSA, WSB, and WSC were all 76 while post-harvest WSA had an average CN of 78, WSB's was 81, and WSC's was 82.

It was observed that the yearly CN in WSB became elevated directly following harvest and aligned back with WSA around 1987. WSC behaved similarly and was the most elevated from 1984-1987 but remained elevated or somewhat elevated throughout the study. As expected, CNs were the highest during the non-growing season when vegetation was dormant. With the exception of the first few years after harvest, minimal differences were observed between CNs during the non-growing season. Conversely, throughout much of

Table 2.20: Yearly curve numbers (CNs) ± standard deviation for WSA, WSB, and WSC 1982-1993 and 2002-2008.

Year	CN (λ=0.2)			CN (λ=0.05)		
	WSA	WSB	WSC	WSA	WSB	WSC
1982	83±14	81±13	82±15	77±20	75±18	76±20
1983	82±10	83±11	83±10	76±15	77±15	76±15
1984	86±10	91±7	93±7	82±14	88±10	91±10
1985	78±9	84±9	84±9	70±13	78±13	79±13
1986	82±8	86±7	88±7	76±12	80±10	84±10
1987	82±11	84±11	86±9	76±15	78±15	81±13
1988	82±14	82±13	85±13	76±19	76±18	80±17
1989	85±9	87±8	89±8	80±12	82±12	85±12
1990	86±7	87±8	88±7	81±10	83±11	84±10
1991	86±10	87±10	86±11	80±14	83±14	81±15
1992	80±9	82±9	82±9	73±13	75±13	76±12
1993	77±14	80±13	80±12	68±19	73±18	73±17
2002	89±9	91±10	- -[1]	85±12	88±14	- -
2003	87±10	88±10	- -	82±14	84±14	- -
2004	87±9	88±10	- -	83±13	84±13	- -
2005	85±8	85±8	86±8	80±11	80±11	81±12
2006	85±7	88±7	91±7	80±10	84±10	88±9
2007	81±8	81±8	86±6	75±11	74±12	81±9
2008	83±10	87±10	86±10	76±14	82±14	82±15

[1] No data available.

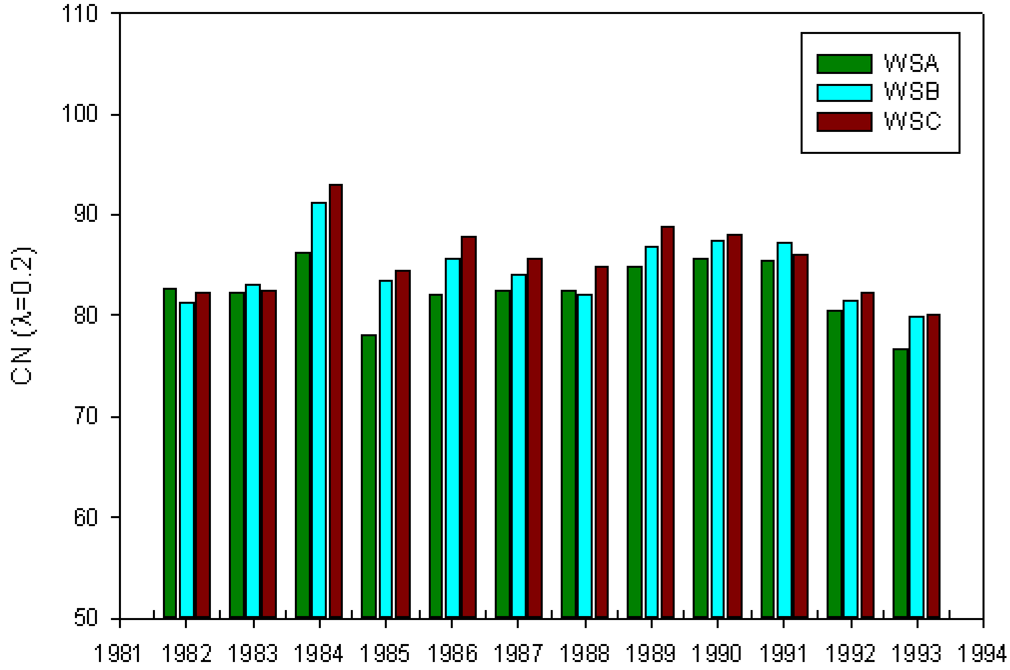

Figure 2.50: Average curve number (λ=0.2) WSA, WSB, WSC (1982-1993).

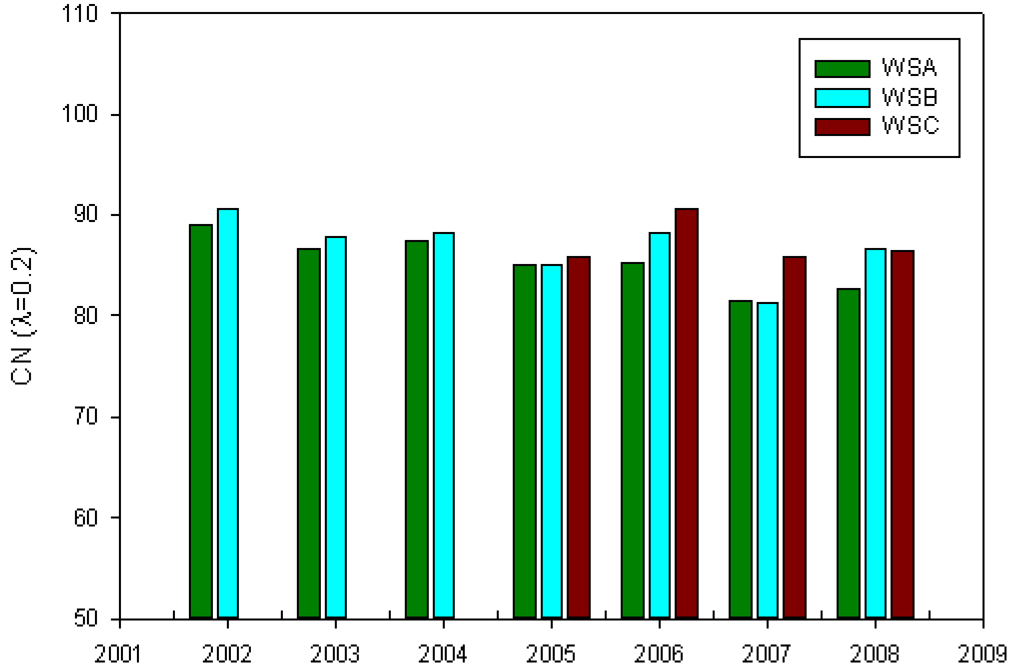

Figure 2.51: Average curve number (λ=0.2) WSA, WSB, WSC (2002-2008).

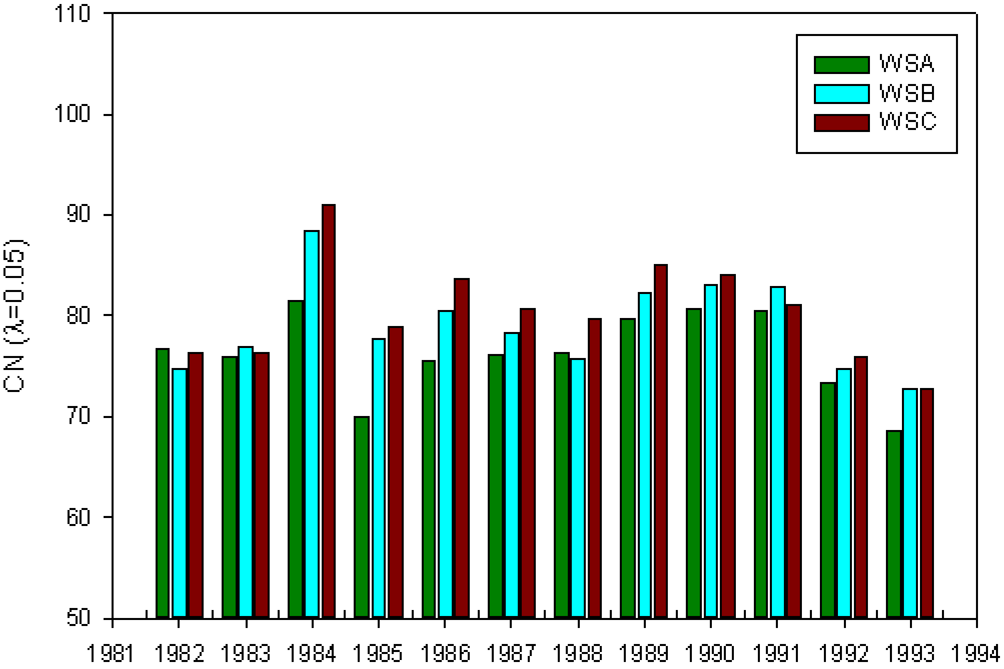

Figure 2.52: Average curve number (λ=0.05) WSA, WSB, WSC (1982-1993).

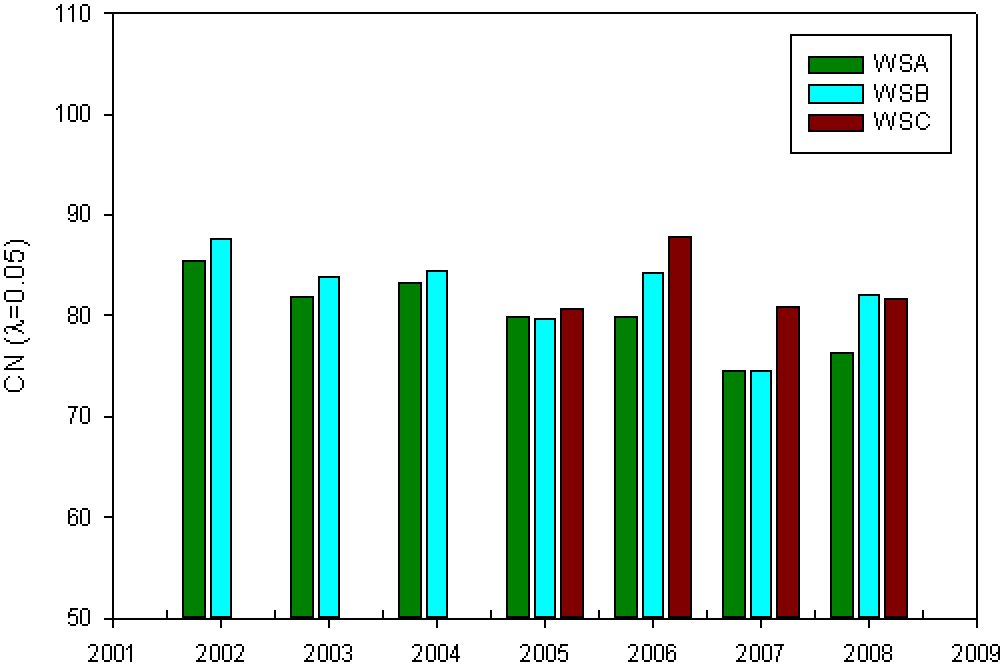

Figure 2.53: Average curve number (λ=0.05) WSA, WSB, WSC (2002-2008).

Table 2.21: Growing season curve numbers (CNs) ± standard deviation for WSA, WSB, and WSC 1982-1993 and 2002-2008.

Year	CN (λ=0.2)			CN (λ=0.05)		
	WSA	WSB	WSC	WSA	WSB	WSC
1982	71±12	71±12	71±13	60±15	60±16	60±17
1983	79±10	80±10	80±10	72±14	73±15	72±15
1984	82±10	88±9	91±9	76±14	84±13	88±12
1985	76±7	81±8	82±8	66±10	73±11	75±11
1986	80±4	82±3	84±4	73±6	76±4	79±6
1987	79±6	81±5	83±6	71±8	74±7	76±8
1988	75±16	73±13	77±14	66±21	63±18	69±19
1989	80±7	82±7	84±8	72±10	76±10	79±11
1990	80±4	81±3	82±3	72±6	74±5	75±5
1991	79±6	81±6	78±6	70±9	74±9	70±9
1992	77±7	78±7	80±7	69±10	70±11	72±10
1993	75±14	78±13	78±11	66±18	70±18	70±16
2002	85±10	86±11	- -[1]	79±14	81±16	- -
2003	79±7	81±9	- -	71±10	74±13	- -
2004	84±10	85±10	- -	78±14	80±14	- -
2005	85±8	85±9	85±9	80±12	80±12	80±12
2006	83±6	86±6	89±6	77±9	81±9	85±9
2007	79±6	78±6	84±4	71±9	70±8	78±6
2008	80±10	81±12	83±11	73±14	75±17	76±16

[1] No data available.

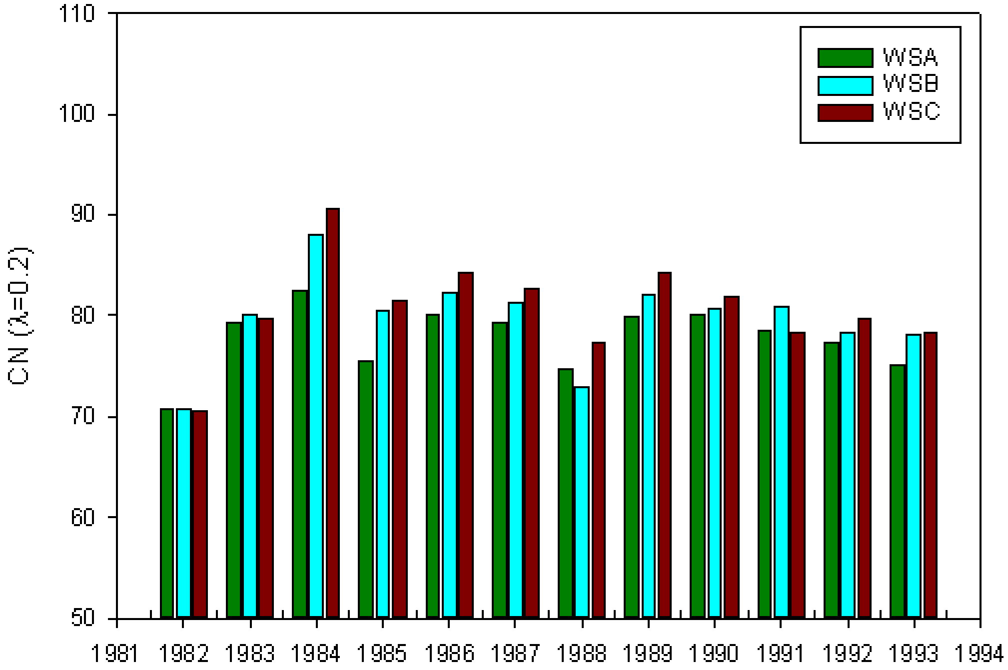

Figure 2.54: Growing season average curve number (λ=0.2) WSA, WSB, WSC (1982-1993).

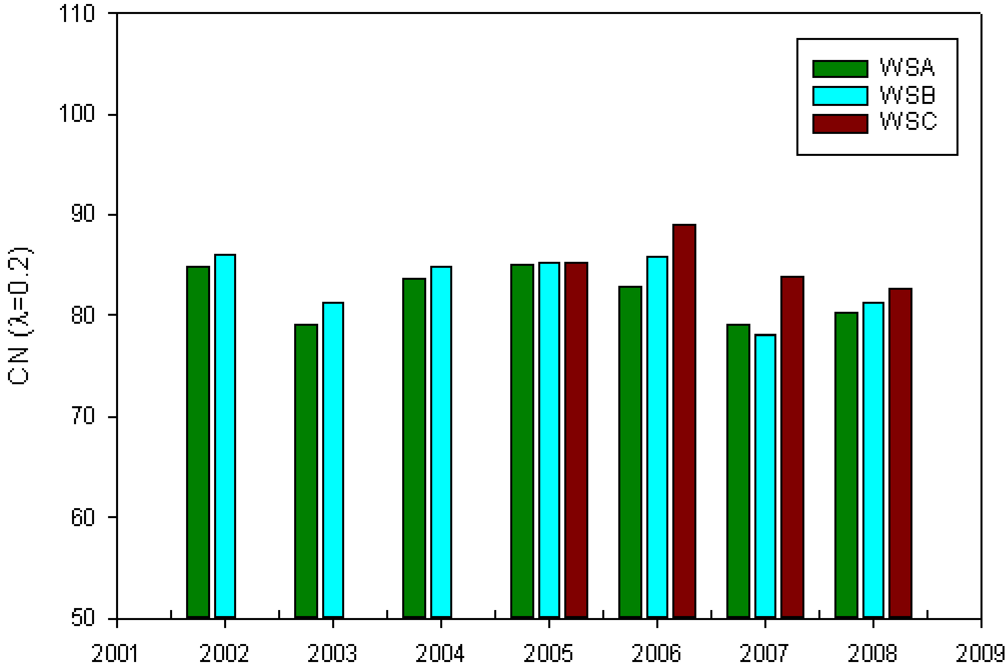

Figure 2.55: Growing season average curve number (λ=0.2) WSA, WSB, WSC (2002-2008).

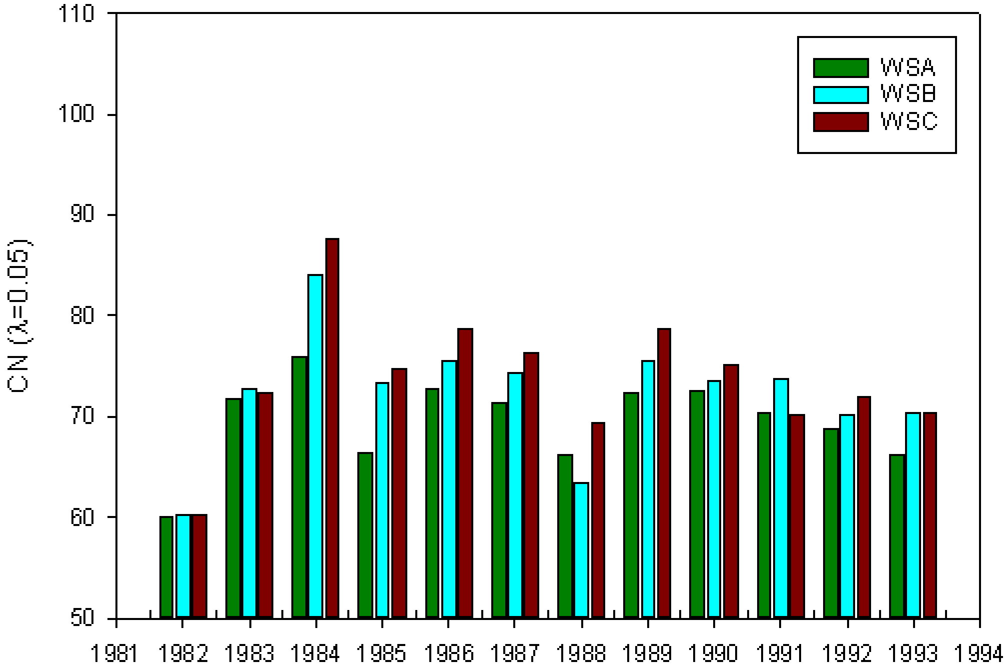

Figure 2.56: Growing season average curve number (λ=0.05) WSA, WSB, WSC (1982-1993).

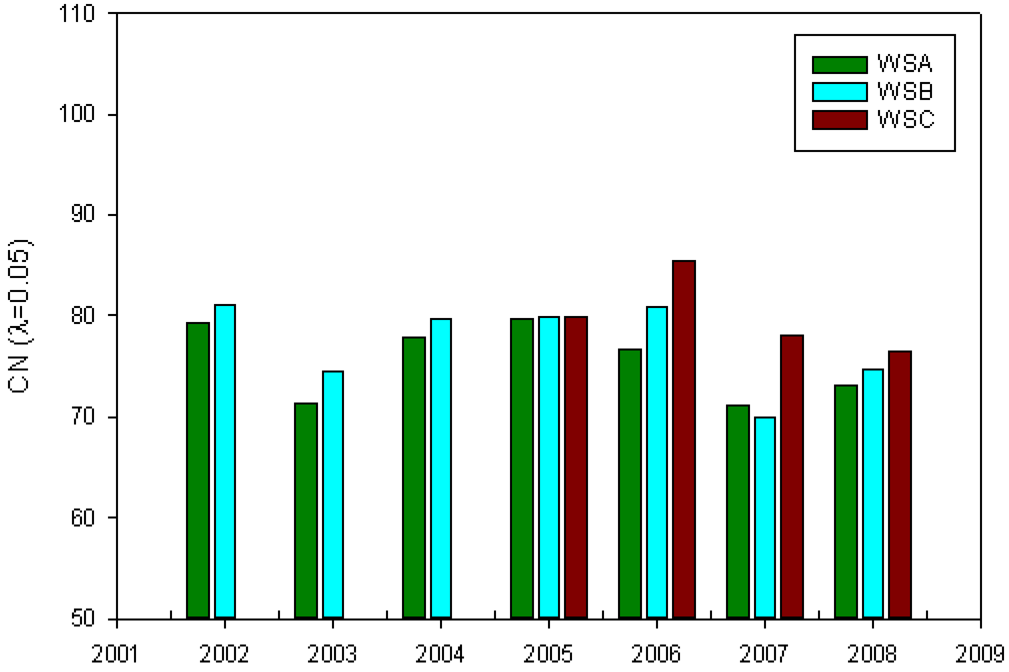

Figure 2.57: Growing season average curve number (λ=0.05) WSA, WSB, WSC (2002-2008).

Table 2.22: Non-growing season curve numbers (CNs) ± standard deviation for WSA, WSB, and WSC 1982-1993 and 2002-2008.

Year	CN (λ=0.2)			CN (λ=0.05)		
	WSA	WSB	WSC	WSA	WSB	WSC
1982	93±5	90±5	93±7	91±7	88±7	90±9
1983	89±9	90±8	89±9	85±13	86±11	85±12
1984	90±8	94±4	95±4	87±12	92±6	94±5
1985	85±10	92±5	93±5	80±15	90±7	90±7
1986	85±11	90±8	92±8	79±16	86±11	90±11
1987	85±14	87±14	88±12	80±19	82±19	84±16
1988	89±9	89±8	91±8	85±13	86±11	88±11
1989	93±3	94±2	96±2	91±4	93±3	95±2
1990	91±4	94±3	94±3	89±6	93±5	93±4
1991	93±8	94±8	94±9	91±11	92±11	92±12
1992	93±2	94±4	93±5	91±3	93±5	91±7
1993[1]	94	97	97	92	97	96
2002	94±4	96±3	- -[2]	92±5	95±4	- -
2003	94±4	95±4	- -	92±6	93±6	- -
2004	94±4	94±5	- -	92±5	92±7	- -
2005	86±1	84±3	89±5	81±1	78±4	86±7
2006	91±5	95±4	95±6	89±7	93±5	94±8
2007	84±9	85±9	88±8	78±12	79±13	84±12
2008	84±11	89±9	88±10	78±15	86±12	84±14

[1] One suitable storm for analysis.

[2] No data available.

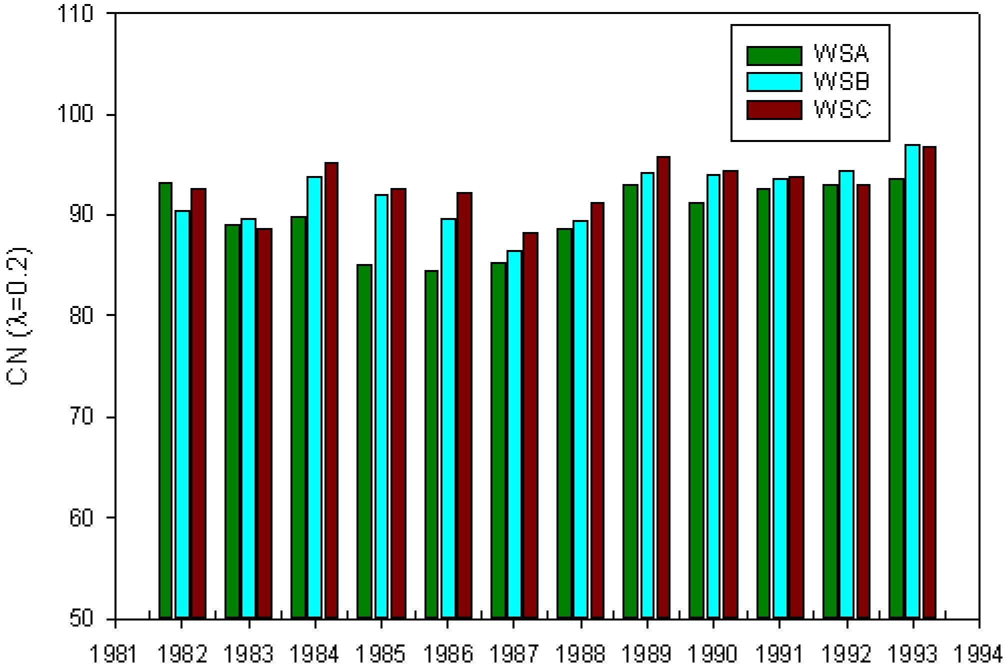

Figure 2.58: Non-growing season average curve number (λ=0.2) WSA, WSB, WSC (1982-1993).

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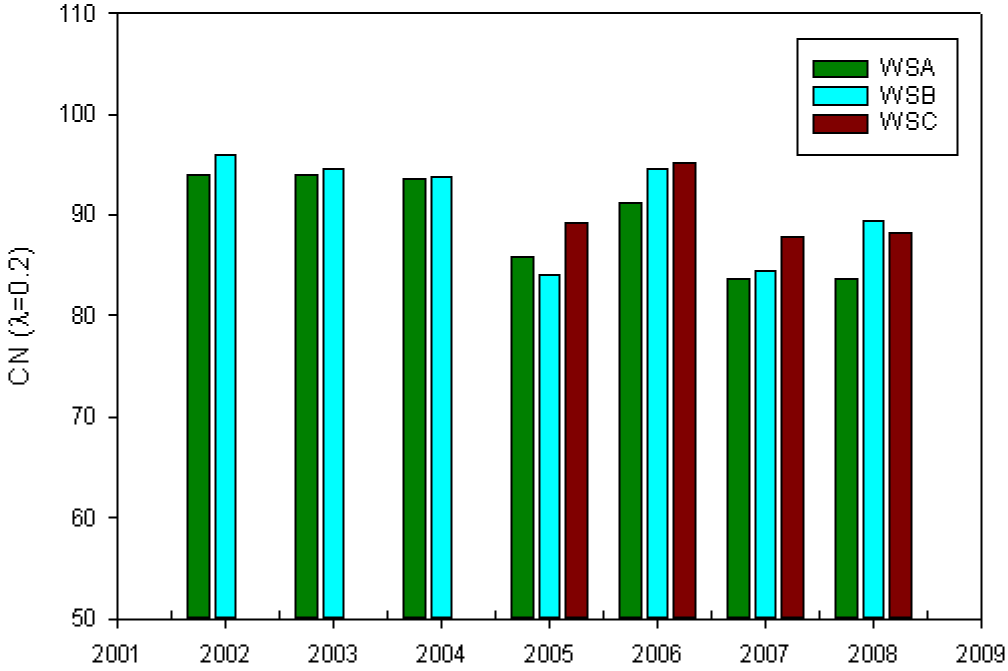


Figure 2.59: Non-growing season average curve number (λ=0.2) WSA, WSB, WSC (2002-2008)

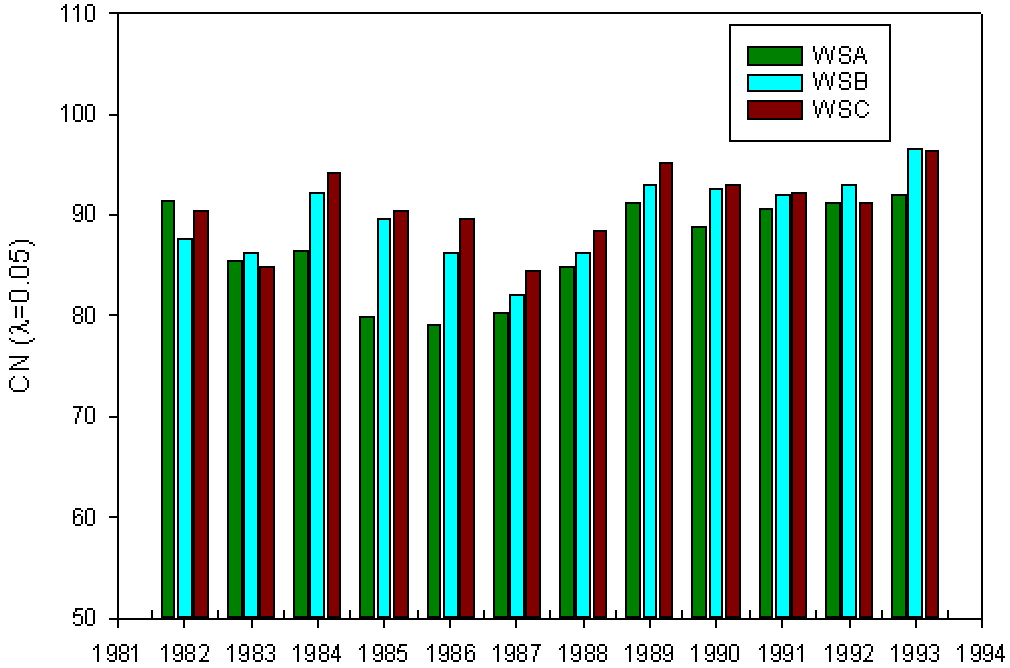


Figure 2.60: Non-growing season average curve number (λ=0.05) WSA, WSB, WSC (1982-1993).

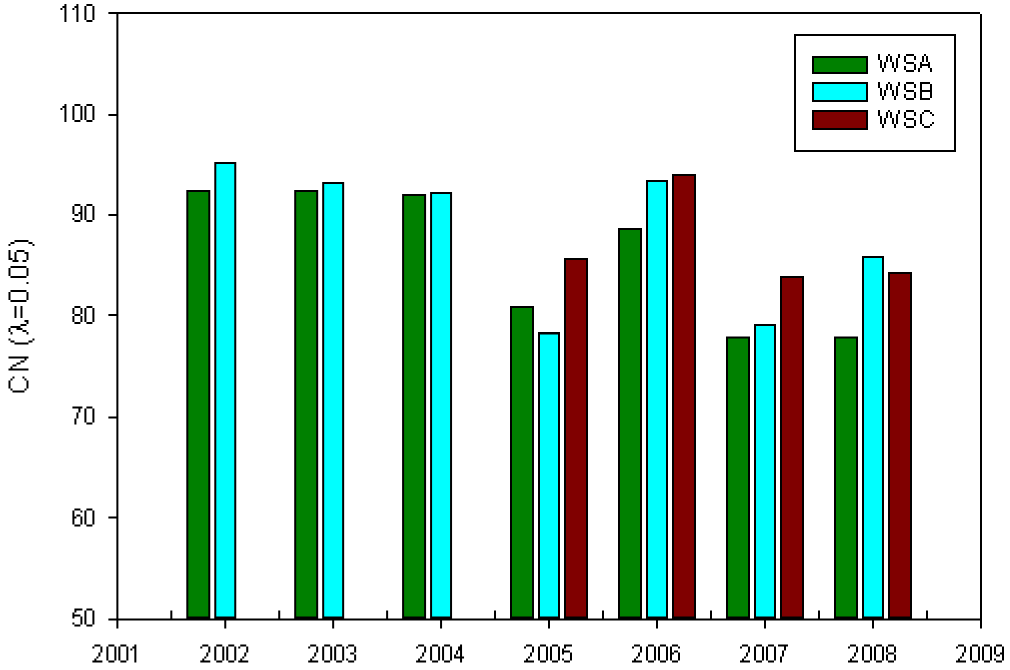


Figure 2.61: Non-growing season average curve number (λ=0.05) WSA, WSB, WSC (2002-2008).

Table 2.23: Average curve numbers (CNs) ± standard deviation for storms with cumulative depth equal to or greater than 25.4 mm in WSA, WSB, and WSC for the periods of 1982-1983, 1984-1988, 1989-1993 and 2002-2008.

Period	CN (λ=0.2)			CN (λ=0.05)		
	WSA	WSB	WSC	WSA	WSB	WSC
1982-1983	77±14	77±13	77±14	69±19	68±18	69±20
1984-1988	81±13	84±12	86±11	74±18	79±16	82±16
1989-1993	83±11	86±11	87±11	78±16	81±16	82±16
2002-2004	85±11	87±12	- -[1]	80±15	82±16	- -
2005-2008	77±9	81±10	83±11	69±13	74±15	77±15

[1] No data available.

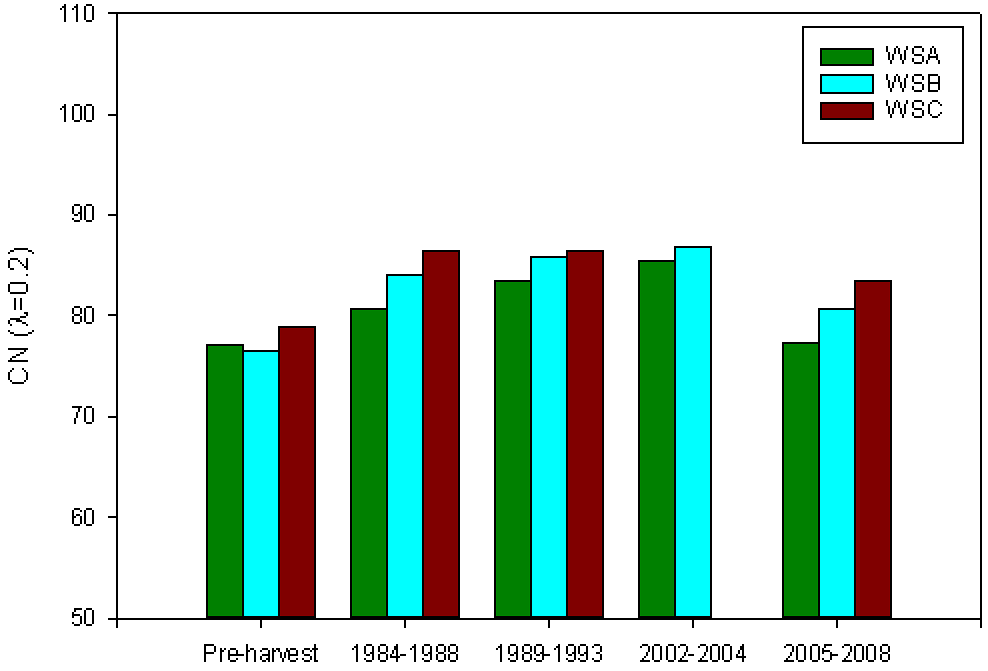


Figure 2.62: Average curve number (λ=0.2) for storms with cumulative depth equal to or greater than 25.4 mm in WSA, WSB, and WSC for the periods of 1982-1983, 1984-1988, 1989-1993 and 2002-2008.

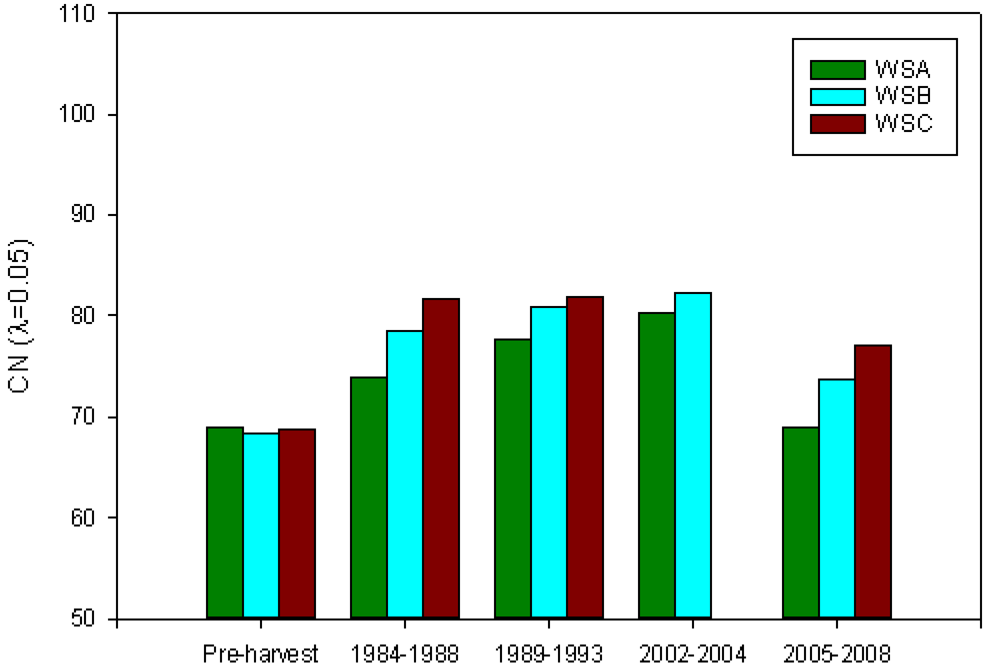


Figure 2.63: Average curve number (λ=0.05) for storms with cumulative depth equal to or greater than 25.4 mm in WSA, WSB, and WSC for the periods of 1982-1983, 1984-1988, 1989-1993 and 2002-2008.

Table 2.24: Growing season curve numbers (CNs) ± standard deviation for storms with cumulative depth equal to or greater than 25.4 mm in WSA, WSB, and WSC for the periods of 1982-1983, 1984-1988, 1989-1993 and 2002-2008.

Period	CN (λ=0.2)			CN (λ=0.05)		
	WSA	WSB	WSC	WSA	WSB	WSC
1982-1983	71±11	71±12	71±12	60±15	61±16	61±16
1984-1988	72±11	76±11	79±12	62±16	67±16	71±17
1989-1993	74±9	77±9	78±9	64±11	68±13	70±13
2002-2004	80±11	82±13	- -[1]	72±15	75±18	- -
2005-2008	76±9	80±11	82±10	67±13	72±15	76±15

[1] No data available.

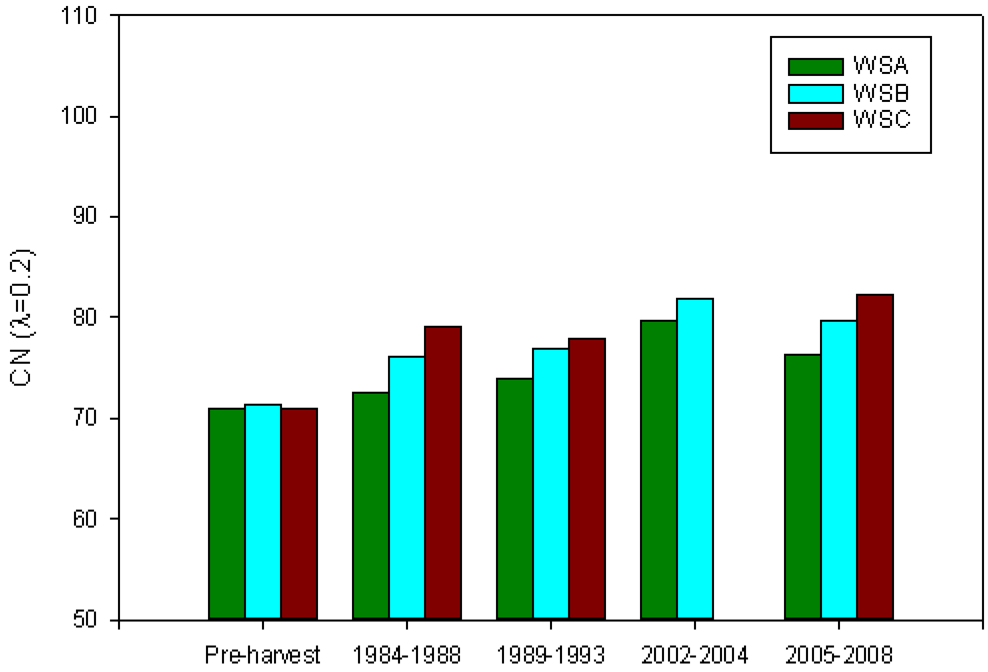


Figure 2.64: Growing season curve number (λ=0.2) for storms with cumulative depth equal to or greater than 25.4 mm in WSA, WSB, and WSC for the periods of 1982-1983, 1984-1988, 1989-1993 and 2002-2008.

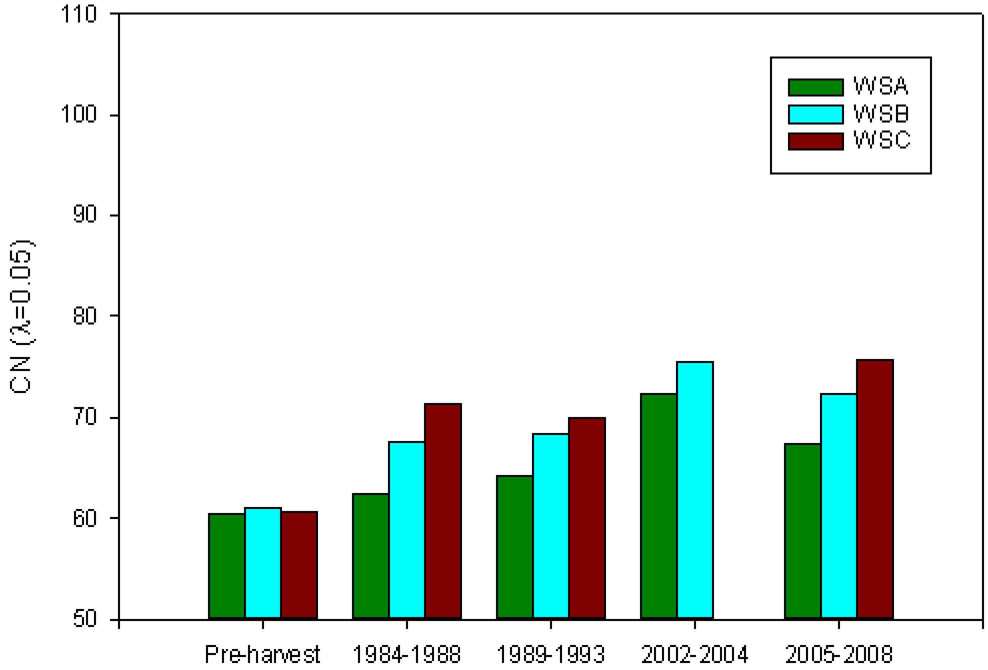


Figure 2.65: Growing season curve number (λ=0.05) for storms with cumulative depth equal to or greater than 25.4 mm in WSA, WSB, and WSC for the periods of 1982-1983, 1984-1988, 1989-1993 and 2002-2008.

Table 2.25: Non-growing season curve numbers (CNs) ± standard deviation for storms with cumulative depth equal to or greater than 25.4 mm in WSA, WSB, and WSC for the periods of 1982-1983, 1984-1988, 1989-1993 and 2002-2008.

Period	CN (λ=0.2)			CN (λ=0.05)		
	WSA	WSB	WSC	WSA	WSB	WSC
1982-1983	91±10	88±7	90±10	88±14	84±10	87±14
1984-1988	86±12	89±9	91±9	81±16	85±13	88±12
1989-1993	92±5	94±5	94±6	90±8	92±7	93±8
2002-2004	93±4	93±5	- -[1]	91±5	92±7	- -
2005-2008	79±10	82±11	85±12	71±14	76±16	79±16

[1] No data available.

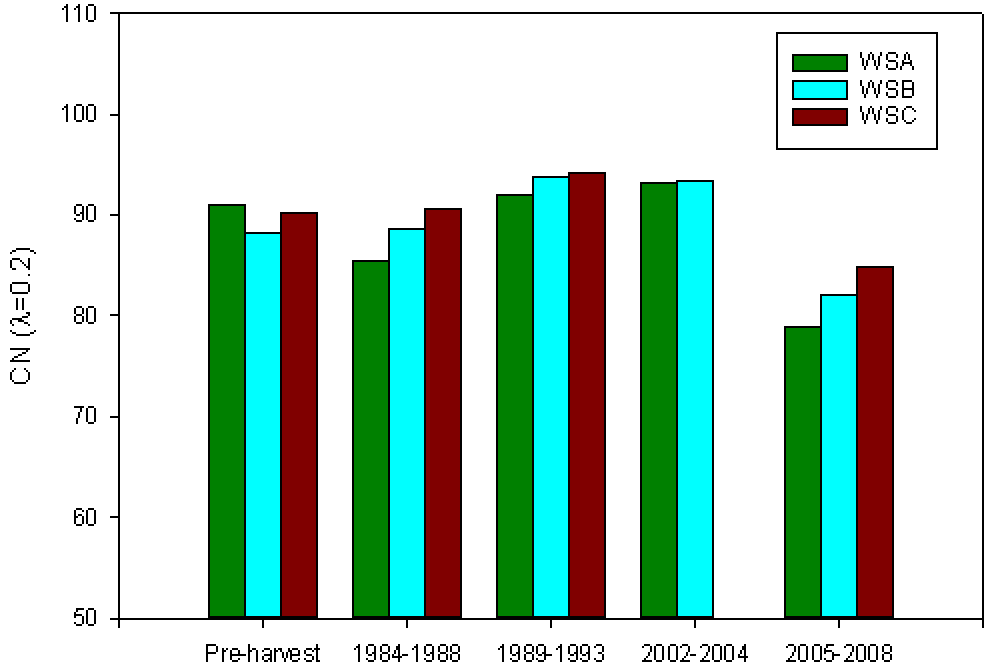


Figure 2.66: Non-growing season curve number (λ=0.2) for storms with cumulative depth equal to or greater than 25.4 mm in WSA, WSB, and WSC for the periods of 1982-1983, 1984-1988, 1989-1993 and 2002-2008.

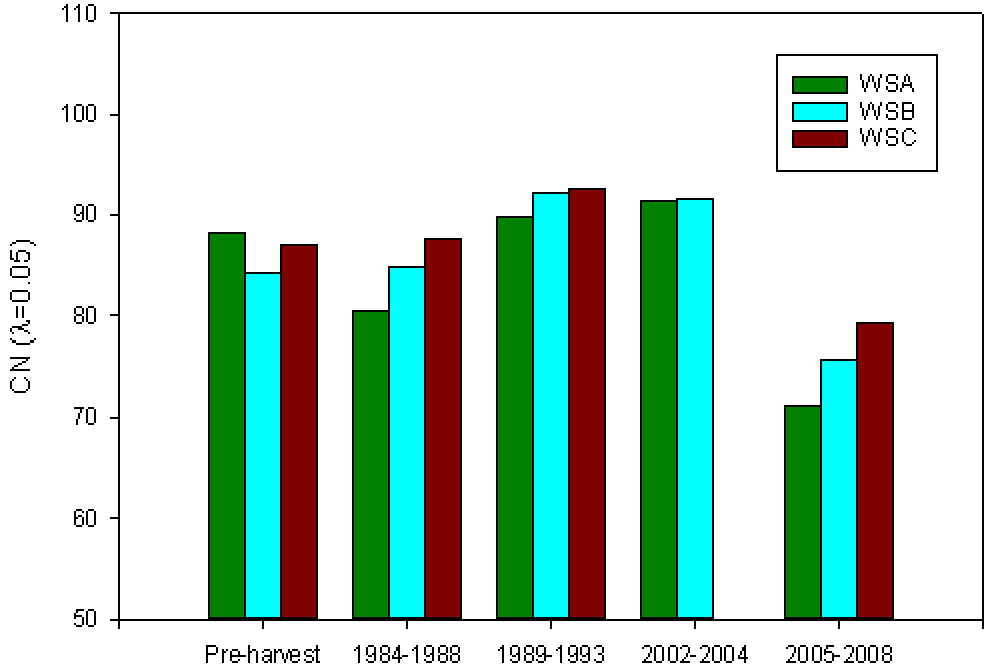
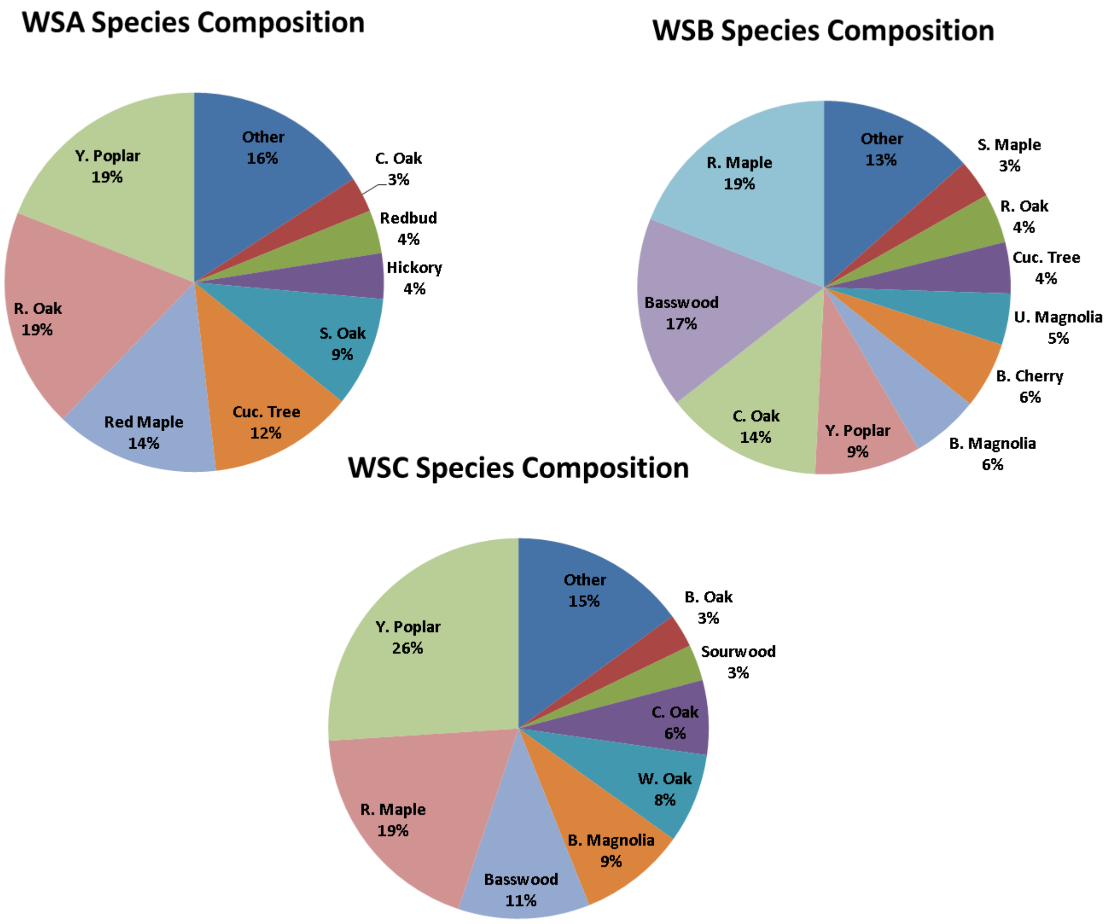


Figure 2.67: Non-growing season curve number (λ=0.05) for storms with cumulative depth equal to or greater than 25.4 mm in WSA, WSB, and WSC for the periods of 1982-1983, 1984-1988, 1989-1993 and 2002-2008.

the study, large differences in CN were observed between the watersheds during the growing season.

2.3.3 Forest Stand Characteristics

In 2010, species composition in WSA (Figure 2.68) was dominated by 19% each of *Liriodendron tulipifera L.* (Figure 2.69) and *Quercus rubra* (Figure 2.70) followed by *Acer rubrum* (Figure 2.71) at 14% and *Magnolia acuminate* (Figure 2.72) at 12%. Species composition in WSB (Figure 2.68) was dominated by 19% *A. rubrum*, 17% *Tilia Americana* (Figure 2.73)*,* 14% *Q. Montana* (Figure 2.74), and 9% *L. tulipifera L.* Species composition in WSC (Figure 2.68) was dominated by 26% *L. tulipifera L.*, 19% *A. rubrum*, 11%, *T. americana,* and 9% *Magnolia macrophylla* (Figure 2.75). Arthur et al. (1998) noted that before the harvest began, *Quercus spp.* accounted for 39% of canopy tree density with *Carya spp.* and *L. tulipifera L.* comprising 17% and 15%, respectively. Over a 27-year period, density of *Quercus spp.* decreased throughout all three watersheds with the largest reductions in WSB and WSC, which now contain 18% and 17% *Quercus spp*., respectively. Density of *Carya spp.* also decreased and is now at 4% in WSA and slightly over 2% each in WSB and WSC. Interestingly, *L. tulipifera L.* density increased to 19% in WSA, decreased to 9% in WSB, and increased in WSC to 26%.


WSA Species Composition

WSB Species Composition

WSC Species Composition

Figure 2.68 Percent stand composition in WSA, WSB, and WSC in 2010.

Figure 2.69: Leaf of *Liriodendron tulipifera L.*-Yellow Poplar (Mohlenbrock, 1995).

Figure 2.70: Leaf of *Quercus rubra*-Red Oak (Seiberling et al., 2006).

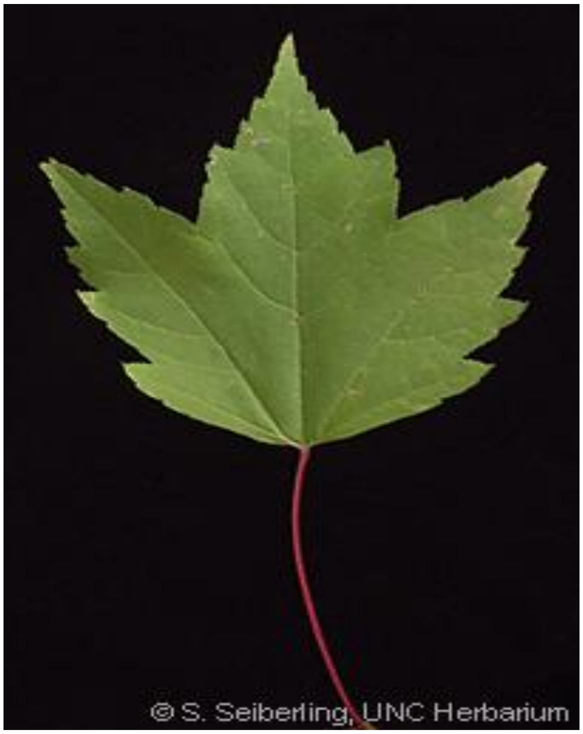


Figure 2.71: Leaf of *Acer rubrum*-Red Maple (Seiberling et al., 2006).

Figure 2.72: Leaf of *Magnolia accuminata*-Cucumber Tree (Chamuris, 2016).

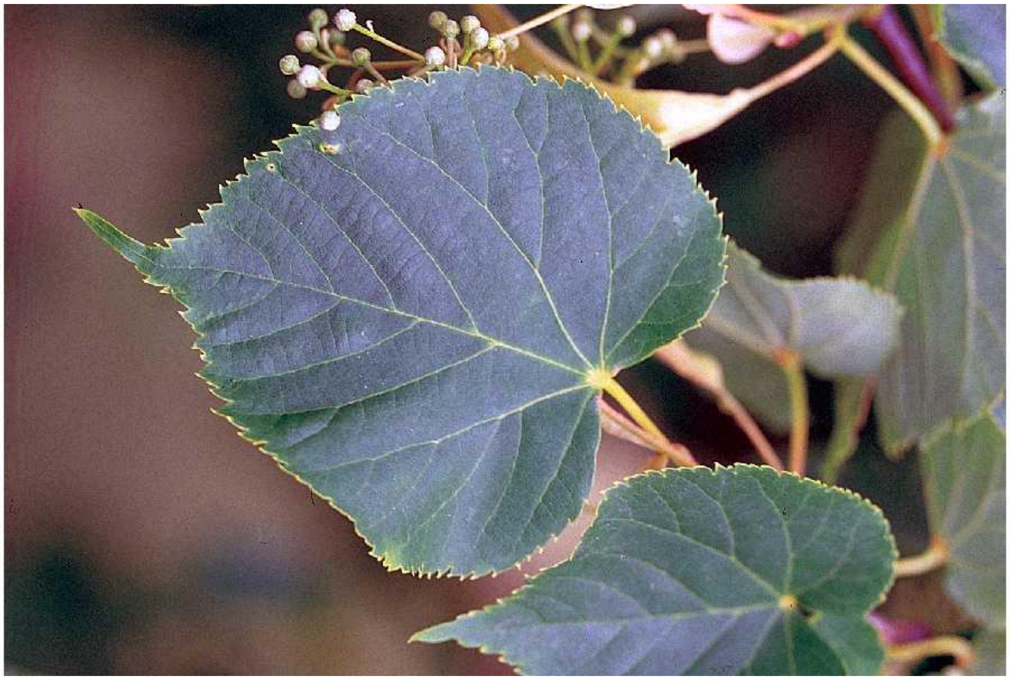


Figure 2.73: Leaf of *Tilia americana*-Basswood (Herman, D.E., et al., 1996).

Figure 2.74: Leaf of *Q. montana*-Chestnut Oak (Mohlenbrock, 1995).

Figure 2.75: Leaves of *Magnolia macrophylla*-Bigleaf Magnolia (Profant, 2010).

The differences in tree species composition among the three watersheds could have an impact on watershed hydrology due to differences in transpiration demand and leaf area. A shift to species with lower leaf area could result in decreased canopy interception and ET and increased water yield (or vice versa). Shifts in species composition from ring-porous species (*Quercus*) to diffuse porous species (*Acer, Liriodendron, and Betula*) have been shown to effectively increase total stand transpiration (Wulschleger et al., 2001), thereby decreasing water yield. As demonstrated by Ford et al. (2011), for a given tree diameter, yellow-poplar (*Liriodendron tulipifera*) transpiration rates were nearly two-fold greater than hickory (*Carya* spp.) and four-fold greater than oaks (*Quercus* spp.). However, the mechanism by which this hydrologic alteration occurs is related to the proportional increase in diffuse porous sapwood area.

Ground cover percentages for WSA, WSB and WSC were found to average 17%, 13% and 11%, respectively. Of the total groundcover, average herbaceous cover comprised 11%, 7% and 9% for WSA, WSB and WSC, respectively. In both WSB and WSC, the exotic grass *Microstegium sp.* (Figure 2.76) was encountered. In WSB, *Microstegium sp.* was found only as large patches on logging roads whereas in WSC it was found in two separate plots away from any roads. The invasive *Lonicera maackii* (Figure 2.77) was encountered at one plot in WSB and was roughly at shoulder height and had produced numerous stems. The only other invasive plant species encountered throughout the surveying process was *Ailanthus altissima* (Figure 2.78), which was found in the upper rear reaches of WSC near an active forest road, and had produced two separate canopy sized stems.

Figure 2.76: Invasive grass *Microstegium sp*.-Nepalese browntop (Mohlenbrock, 1991).

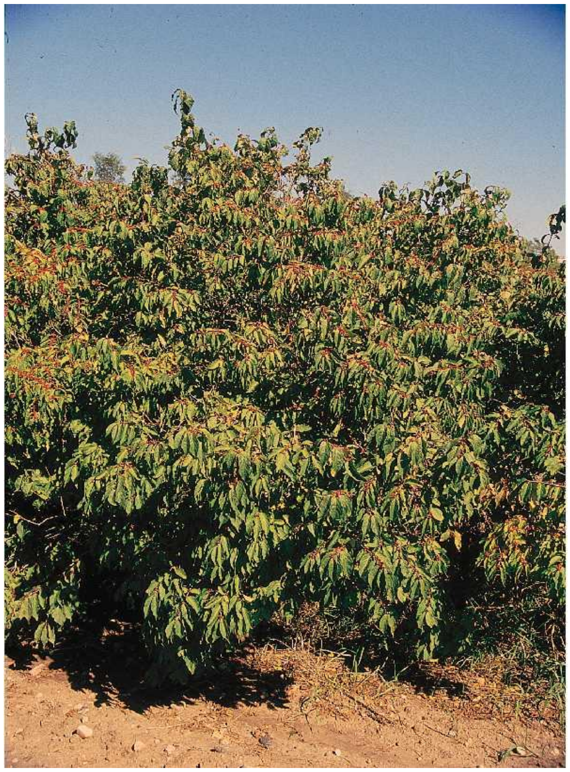


Figure 2.77: Invasive *Lonicera maackii*-Honeysuckle (Herman, D.E., et al., 1996).

Figure 2.78: Ailanthus altissima-Tree of heaven (Goldman, 2012).

Stand data for WSA were found to have an average basal area of 22.5 m^2 ha^{-1} and an average diameter of 11.2 cm in the 2010 survey. WSB was found to have an average basal area of 22.9 m^2 ha^{-1} and average diameter of 12.6 cm. WSC was found to have an average basal area of 21.3 m^2 ha^{-1} and average diameter of 12.1 cm. Overall, these three parameters are fairly similar among the three catchments. However, stand density does vary substantially from one catchment to the other. Stand densities in WSA, WSB and WSC were 1,144 trees ha^{-1}, 1,392 trees ha^{-1}, and 1,479 trees ha^{-1}, respectively. That is a 17.8% and 22.7% lower density in WSA than WSB and WSC, respectively.

The lower stand density in WSA may be an attribute of its age (approximately 90 years; see Cotton et al., 2013), which would be reflected by taller trees and more canopy cover. Use of LiDAR data in 2013 confirmed this relationship (Figure 2.79). Average tree height was 22.8, 18.5 and 16.5 m for WSA, WSB and WSC, respectively (Table 2.26). Moreover, the distribution of trees in the 22 to 40 m height class was much greater for WSA than WSB or WSC (Figure 2.80). The retention of trees within the SMZ also contributed to an overall increase in stand height in WSB over WSC.

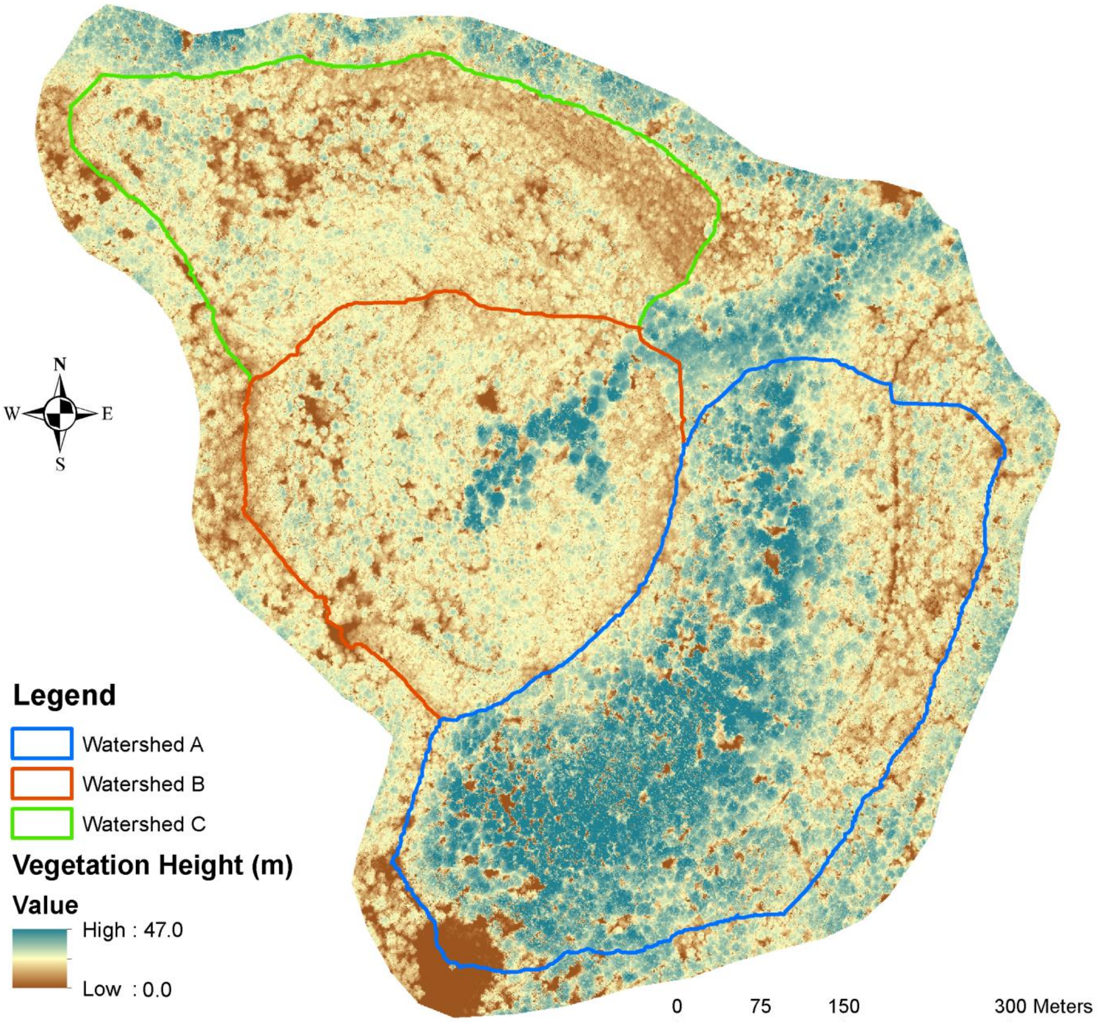


Figure 2.79: Vegetation height collected by LiDAR in 2013 for WSA, WSB, and WSC.

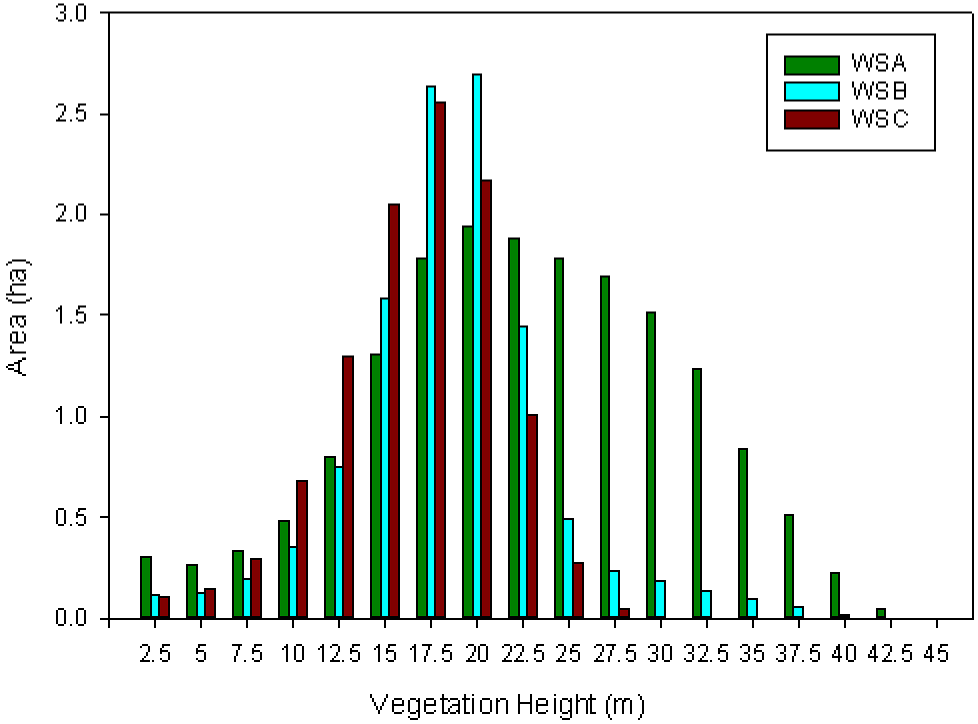


Figure 2.80: Vegetation height distributions in 2013 in WSA, WSB, and WSC.

Table 2.26: Vegetation height distribution in WSA, WSB, and WSC.

Vegetation attributes (m)	Watershed		
	A	B	C
Minimum	0.00	0.00	0.00
25th percentile	17.37	15.83	13.95
Median value	22.91	18.58	17.00
75th percentile	28.97	21.12	19.59
Maximum	45.74	44.26	31.80
Average	22.88	18.56	16.55

Structurally speaking, all three watersheds exhibited similar mean basal area and stem diameters in 2010, but mean stand density was lowest in WSA and highest in WSC. Figures 2.81-2.83 depict the stand density in 2015 along the stream and into the riparian areas. The greater stand density in WSB and especially in WSC over WSA may be large enough to affect competition among individual stems, which could result in greater than expected streamflow over the long-term (Ford et al., 2011). Experience has shown that changes in stand density and composition can influence the water budget. As a result of reduced ET, annual water yield has been shown to increase after forest harvesting (Hibbert 1987; Bosch 1982; Arthur et al. 1998). The magnitude and duration of the increase is related to the percentage of vegetation cover removed, climate, and forest type (Bosch 1982; Stednick 1996). Regardless, ET has been repeatedly identified as a major regulator of streamflow, soil moisture, and groundwater recharge in forested ecosystems and is mainly controlled by solar radiation, air temperature, precipitation, and vegetation characteristics including amount of leaf biomass (Sun et al. 2011). Even after nearly 30 years, mean tree heights in WSA remain higher than that observed in WSB or WSC. Given the relationship of height to biomass, it seems likely that WSA would have higher water demand and subsequently lower water yield (Pflugmacher et al., 2008).

Figure 2.81: Stand density in WSA (2015).

Figure 2.82: Stand density and regrowth in WSB (2015).

Figure 2.83: Stand density and regrowth in WSC (2015).

2.4 CONCLUSIONS

Harvesting has resulted in long-term impacts to the hydrologic regime of the treated areas. The implementation of BMPs in WSB has led to less severe long-term harvesting effects on streamflow than those observed in WSC. A similar observation was made by Arthur et al. (1998) who attributed these differences among treatments mainly to the retirement of haul roads and the use of a riparian buffer within WSB. Elevated stormflow and altered storm responses are the main mechanisms by which observed streamflow increases have occurred. It has been shown at Coweeta hydrologic laboratory in North Carolina that storm hydrograph response and baseflow are sensitive to logging intensity and road disturbance (Swank et al., 2001). This observation is further supported by another study performed at Coweeta, where 65% removal of stand basal area by commercial logging and tractor skidding with high road density led to roughly double the stormflow volume and peak flow rate produced by cable logging (Douglas and Swank, 1976; Swank et al., 2001).

The magnitude of streamflow increase in WSC when compared to WSA and WSB is further evidence that greater harvest intensity and greater road disturbance in logging operations leads to greater hydrologic response. In addition, changes in stand density and structure also appear to have had a significant effect on watershed hydrology, likely through increased ET that is related to the size of trees and their respective biomass. The hydrologic recovery in the treatment watersheds may depend on the long-term regrowth in WSB and WSC and the transformation of logging roads into the forest habitat. Presently, elevated stormflows at the treatment sites, especially following intense rainfall events, suggest that there may still be direct flow paths from the old logging operations to the stream. However, changes in species composition and subsequently sapwood area may alter the hydrologic function of these subcatchments and streamflow response may not reach pre-harvest conditions.

Nonetheless, there are some indications that hydrologic recovery in WSB has occurred or nearly occurred while WSC continues to show some impacts from the harvest. The use of BMPs in WSB, most notably the retirement of haul roads and use of a riparian buffer, has effectively decreased the severity of harvesting impacts to overall hydrology. Although water yield within WSB has attenuated to a level that is no longer significantly different than the control, complete hydrologic recovery under all rainfall intensities in either watershed has yet to be observed. The true mechanisms by which such long-term hydrologic response has occurred remain unclear, although several hypotheses exist. 1) The intensity of cutting coupled with the design and placement of haul roads has significantly increased stormflow as well as hydrologic sensitivity to high precipitation events. These effects are greatest in WSC, which experienced a greater intensity of treatment. 2) Shifts in belowground flow and storage processes have resulted in significantly greater hydrologic input to the stream channels. These treatment effects have been greatest in WCS. 3) Increased stand density in treatment watersheds has been sufficient to affect an increase in competition, thereby reducing leaf area index and stand transpiration. This reduction in stand transpiration has caused a significant switch in streamflow from baseflow to stormflow throughout the growing season in the treatment watersheds. These three hypotheses are not mutually exclusive, and it is certainly possible that each are contributing to some extent to the observations made within the treatment watersheds B and C.

CHAPTER 3: LONG-TERM EFFECTS OF BEST MANAGEMENT PRACTICES ON WATER CHEMISTRY FOR THREE APPALACHIAN HEADWATER CATCHMENTS

3.1 INTRODUCTION

Headwater streams are generally 1st-3rd order ephemeral, intermittent, and perennial reaches (Vannote et al., 1980) and relatively small in stature; however, cumulatively they contribute 60 to 85% of the total stream length in a river network, and drain 70 to 90% of the total drainage basin area (Leopold et al., 1964; Benda et al., 2005; MacDonald and Coe, 2007). Various definitions exist for what constitutes ephemeral, intermittent, and perennial reaches but the following has been chosen for this study. Ephemeral reaches are defined as streams that only flow in direct response to precipitation. Intermittent reaches are defined as streams that only flow for a portion of the year, usually the wet season, and when the water table is above the streambed. Perennial reaches are the streams that flow continuously under normal precipitation conditions (USEPA, 2013). These headwater stream systems and their riparian zones provide valuable habitat to sensitive flora and fauna as well as macroinvertebrate populations (Meyer et al., 2007; Richardson and Danehy, 2007) and serve as significant contributors to down-gradient stream and river health by filtering upland derived sediment, processing and cycling nutrients, and providing energy inputs for larger downstream organisms (Pritchett and Fisher, 1987; Kaplan et al., 2008).

Average annual concentrations for common constituents in forested systems are; NO_3 (0.01-1.7 mg L^{-1}), total suspended solids are generally less than 10 mg L^{-1} but can range from 100-1000 mg L^{-1} during stormflows, and PO_4 (μ=.08 mg L^{-1}) (Binkley and Brown, 1993; Ice and Binkley, 2003). Water quality of forested systems is usually considered superior compared to other land uses but factors such as: season, geology and soil chemistry, past land use, severity of erosion, air pollution inputs, streamflow levels and sources, and types and age of vegetation present can significantly alter stream quality (Stuart and Edwards, 2006). Forest harvesting is another factor that has been shown to significantly impact stream water quality as well. Studies done in the northeastern United States on stream water quality following harvest have found that harvesting a forested watershed leads to an increase in NO_3 concentration as well as an increase in base cations (Mg, Ca, K, Na), aluminum, and acidity (Martin et al., 2000; Wang et al., 2005).

Nitrogen is a key nutrient for sustaining plant health and is often the limiting nutrient in forested systems. However, removal of vegetation from a site reduces the amount of nitrogen taken up by plants and can lead to excess nitrogen leaching through the soil and into the stream. Multiple studies have confirmed this and shown that forest harvesting resulted in a change in soil processes such as N-mineralization and nitrification which then lead to an excess of nutrients that leached through the soil and into the streams (Hornbeck and Leak, 1992; Pierce et al., 1993; Burns and Murdoch, 2005). The primary inputs of nitrogen into forested systems are via long-term inputs of small amounts of nitrogen in precipitation, particulates, dry deposition, and nitrogen fixation (Binkley et al., 2000). The nitrogen cycle consists of mineralization of soluble or insoluble organic nitrogen to NH_4, followed by either immobilization via microbial uptake or nitrification to NO_3. Nitrate may be leached from the soil, immobilized by microbial uptake, taken up by plants, or lost via denitrification (Binkley and Fisher, 2012).

Phosphorous is another key nutrient vital for plant growth. The primary pathway that phosphorous enters into forested systems is through weathering of minerals. Phosphate ions bind tightly to soil molecules and are highly insoluble, this means very little leaches out with water runoff. From there, phosphate can either be taken up by vegetation or erode into the stream via sediment transport. The phosphorus cycle is unique in that it does not have a gas phase. Therefore, the amount of phosphate at a site is dictated by the rate of mineral weathering, the amount of phosphate in soil suspension, and the amount of phosphate in biological pools (Binkley and Fisher, 2012). Forest harvesting removes phosphate from the available phosphate in biological pools but, surprisingly, does not usually result in phosphate increases in the stream (Aubertin and Patric, 1974; Stuart and Dunshie, 1976; Hornbeck et al., 1987; Richardson, 1988; Jewett et al., 1995; Clark et al., 2000). One paired watershed study, similar in design to this research (control watershed, BMP watershed, no BMP watershed), done in the coastal plain physiographic province in Virginia did record significant increases in phosphate concentration in the stream for the no BMP watershed following clear-cutting (Wynn et al., 2000).

Another factor that can impact stream quality in forested systems is the effects from atmospheric deposition. This is especially important in Kentucky where a large fraction of energy production is produced from coal-fired power plants. Kentucky is home to 21 coal-fired power plants with 45 more plants in the surrounding states of Indiana, Ohio, Tennessee, Virginia, and West Virginia. As of 2012 Kentucky ranked 6th for the top states that rely on coal-fired power production (USEIA, 2012). Coal-fired power plants produce large amounts of SO_2 and NO_x that enter into the atmosphere and subsequently fall back as acidic precipitation otherwise known as acid rain. Several experiments that were conducted on small forested headwater catchments found that sites that suffer from soil acidification due to atmospheric deposition experience large changes in stream water alkalinity or stream buffering capacity from small changes in ionic inputs that leach through the soil column (Lange et al., 1996).

The Clean Air Act was enacted in 1970 by the United States Environmental Protection Agency (USEPA) to combat air pollution. Later in 1990 an amendment was made to the Clean Air Act to specifically address the issue of acid rain by limiting the amount of SO_2 and NO_x that entered into the atmosphere. From 1984 to 2013, decreases of 62% and 34% in the wet deposition of SO_4 and NO_3, respectively, were recorded at the Lilley Cornett Woods National Atmospheric Deposition Program (NAPD) monitoring site in Letcher County, Kentucky. Studies have shown that a reduction in acid deposition leads to an increase in alkalinity and subsequently increases a stream's buffering capacity (Chen and Lin 2009; Neal et al., 2010;). Although reductions in SO_2 and NO_x

emissions have been recorded, recent studies conducted at the Daniel Boone National Forest have shown that the effects from atmospheric deposition on forest soils are still prevalent and noted that inputs from SO_2 and NO_x can lead to a loss of base cations that leach into the stream, increase soil acidity, mobilize Al on exchange complexes, increase the weathering of clay minerals, and leach heavy metals and pollutants into solution (Reuss, 1983; Barton et al., 2002; Sanderson, 2014). While coal-fired power plant emissions have been reduced through emission controlling technology, such as scrubbers, production increases in other sectors, such as aerosols and livestock, have increased the amount of NH_4 in precipitation. A study that was conducted close to the study site in Rowan county Kentucky from 1990-1998 found that the concentration of NH_4 in precipitation had significantly increased from an initial concentration of 0.2 mg L^{-1} in 1990 to a value of 0.35 mg L^{-1} by 1998 (Aneja, 2003).

Best management practices (BMPs) are employed all over the United States to reduce soil erosion and subsequent suspended sediment from land use changes. The problems that arise from soil erosion are numerous and are not centralized to the location they originate. Once vegetation is removed from a site, the soil becomes more vulnerable to transport (Aust et al., 2011). Storm events collect this soil and transport it into nearby streams and rivers; this can decrease water quality, negatively impact aquatic biota, reshape streams and rivers, and lower soil fertility (Stuart and Edwards, 2006; Frady et al., 2007; Boggs et al., 2016). Headwater catchments such as the ones being studied here are especially vulnerable to erosion because of their steep gradient and the fact that they serve as sediment traps until large precipitation events periodically flush this sediment downstream (Benda et al., 2005). From visual observations and from Arthur et al., (1998), it would seem that harvesting exacerbates this phenomenon and sediment transport events occur more readily and are in general larger. The focus of this research is to assess the nutrient transport that takes place post-harvest due to erosional processes as well as inputs from atmospheric deposition by comparing yearly, growing, and non-growing season concentrations of $SO_{4,}$ Mg, Ca, K, Na, total alkalinity, $NO_{3,}$ PO_4, Cl, $NH_{4,}$ and total organic carbon to determine significant pairwise differences and long-term trends for the monitored time period. Due to the long-term nature of this study, it is hypothesized that some of the monitored constituents that enter through atmospheric deposition may gradually decline due to more stringent air quality regulations imposed by the 1990 amendments made to the Clean Air Act.

3.2 METHODS

3.2.1 Water Quality Data

Grab samples for the three watersheds were collected on a weekly basis starting in February 1982 and have continued until present. Constituents and their analyzation method from 1982-1993 were: SO_4 (Bausch-Lomb mass spectrophotometer); Mg, Ca, K, Na (Perkin Elmer Atomic Absorption Spectrophotometer); total alkalinity (titration to methyl orange endpoint); NO_3 (nitrate reductase method; 1982-1990); and PO_4 (Bausch-Lomb mass spectrophotometer). For 2002-2008 samples, SO_4 and Cl concentrations were determined using a quantitative ion chromatography procedure on a Dionex Ion Chromatograph (IC) 2000. Measurement of Mg, Ca, K, and Na concentrations were made with a GBC SDS 270 Atomic Adsorption Spectrophometer. Total alkalinity was determined using an Orion pH meter and auto titrator with a titrant endpoint pH of 4.6. Analysis of NO_3 and NH_4 were performed using a Bran-Luebbe Autoanalyzer (continuous-flow multi-test methods; MT7/MT8 (EPA 353.2) and MT15/16 (EPA 350.1), respectively). Total organic carbon was measured on samples of ≤ 2mL with a Shimadzu TOC 5000A Analyzer (Shimadzu Corporation).

The constituents were summarized into yearly, growing, and non-growing season flow-weighted mean concentrations (FWMC) (Equation 3.1).

$$\bar{c} \cong \frac{\sum_{i=1}^{n}(\frac{c_i + c_{i+1}}{2})(\frac{Q_i + Q_{i+1}}{2})}{\sum_{i=1}^{n}(\frac{Q_i + Q_{i+1}}{2})} \qquad \text{Equation 3.1}$$

In the equation above, $\bar{c}$ represents the FWMC, c_i is the concentration at time *i*, and Q_i is the discharge at time *i*. This method is advantageous because it summarizes all of the weekly concentrations for a specified time period into a single concentration, thus making comparison easier. It also takes into account the effects from variable flow. According to Rickert (1985), constituent concentrations from metals, nutrients, and suspended sediments increase with increasing flow. The FWMC achieves this by placing more weight on constituent concentrations that occur with higher flows and less weight on concentrations that occur under lower flows. The one negative to using the FWMC is that it is flow dependent, meaning flow data are required for analysis. Suspended sediment samples were also collected and analyzed using a filtration technique (1982-1986 and 1988-1990). Due to extended equipment failure (ISCO Model 1680), suspended sediment data were limited. The data available were analyzed by a previous study (Arthur et al., 1998), and because of this, no further analysis was conducted as part of this study.

3.2.2 Statistical Analysis

Significant temporal differences in water quality constituents due to treatment were analyzed by a before-after-control-impact (BACI) statistical design. Data were categorized into before (pre-harvest) and after (post-harvest) and then a one-way analysis of variance (ANOVA) was conducted to test for significant ($p \leq 0.5$) time and treatment interactions. If significant differences were found in treatment only, then that would suggest that the watersheds were weakly paired for that constituent. If significant differences were found for time only, then that would suggest there is an independent background time effect not related to treatment. Finally, if significant differences were found for treatment*time, then that would suggest that treatment has an effect compared to the control and that the before and after trends vary among treatments. In addition to the above analyses, a linear regression was conducted in order to determine the long-term trends in the data and to assess whether the trends were significantly different from zero. Statistical analyses were performed in SAS version 9.4 (SAS Institute, Inc., 2015).

3.3 RESULTS AND DISCUSSION

3.3.1 Time and Treatment Effects

The results regarding sediment loading found in the Arthur et al. (1998) study concluded that WSB and WSC were significantly higher than WSA from 1984-1986, WSC was significantly higher than WSA in 1988, and in 1990 all three watersheds were significantly different from each other with WSC being the highest and WSA being the lowest. Another interesting result from the study was that:

> *Ninety-five percent of the sediment flux from Watershed B in that year (1987) occurred during a single early November 7.5-cm rain event that produced 733 kg/ha of suspended sediment. It is likely that Watershed C had a similarly large sediment discharge during that single storm because the two clear-cut watersheds generally paralleled each other in sediment production during this period. Watershed A produced only 9.7 kg/ha suspended sediment during the same rainfall event*. -Arthur et al. (1998).

Steep gradient headwater catchments, such as the ones being studied here, are susceptible to mass wasting and serve as sediment traps, large precipitation events periodically flush this sediment downstream (Benda et al., 2005). From visual observations and from Arthur et al. (1998), it would seem that harvesting exacerbates this phenomenon and sediment transport events occur more readily and are in general larger (Arthur et al., 1998). A more recent study (2001) on coarse woody debris (CWD) was conducted on these watersheds and found that the watersheds differed in the type of CWD and in the recruitment of CWD. Based on their findings, the authors suggested that WSB may be more prone to windthrow or slumping, which in turn would affect its capacity to buffer sediment from reaching the stream on the long-term (McClure et al., 2004). Although sediment data were no longer collected after 1990, it seems that sediment buildup is still presently an issue. Figures 3.1-3.3 depict the sediment buildup that was present behind the flumes during a site visit in July 2016. During the visit, it was noted that considerable amounts of sediment were trapped behind the flumes in WSB and WSC even though sediment is removed every 2-3 months and as needed after large storm events.

Figure 3.1: Sediment and debris buildup behind WSA flume (2016).

Figure 3.2: Sediment and debris buildup behind WSB flume (2016).

Figure 3.3: Sediment and debris buildup behind WSC flume (2016).

Results from the statistical analysis on the significant time interactions on constituent concentrations across the watersheds are presented in Table 3.1. From the analysis, it was found that SO_4, Ca (WSB), K (WSC), Na (WSB), ALK, NO_3, and PO_4 were statistically different from pre-harvest to post-harvest. Results also showed statistically similar results from pre-harvest to post-harvest for Ca (WSA, WSC), K (WSA, WSB), and Na (WSA, WSC) while Mg was deemed not statistically significant for any of the watersheds. Constituents whose monitoring period began in 2002 (Cl, NH_4, TOC) were not analyzed in this section because no pre-harvest data were available.

Table 3.1: ANOVA time interaction results, pre- and post-harvest concentration (mg L^{-1}) plus sample size (pre)x(post).[1]

	WSA			WSB			WSC		
Constituent	Pre-harvest	Post-harvest	Sample Size	Pre-harvest	Post-harvest	Sample Size	Pre-harvest	Post-harvest	Sample Size
SO_4	12.7a	9.3b	(75)x(791)	13.4a	9.9b	(72)x(738)	11.4a	8.6b	(68)x(769)
Mg	1.8	1.7	(75)x(791)	2.0	1.9	(72)x(774)	1.7	2.1	(68)x(770)
Ca	2.2a	2.3a	(75)x(791)	2.6a	2.3b	(72)x(774)	2.5a	2.5a	(68)x(770)
K	1.3a	1.4a	(75)x(791)	1.6a	1.6a	(72)x(774)	1.5b	1.8a	(68)x(770)
Na	1.0a	1.0a	(75)x(791)	1.2a	1.1b	(72)x(774)	0.9a	1.0a	(68)x(770)
ALK	12.2b	23.5a	(75)x(791)	12.9b	23a	(69)x(772)	13.4b	27.9a	(66)x(770)
NO_3	0.13b	0.38a	(75)x(778)	0.17b	0.49a	(72)x(760)	0.1b	0.5a	(68)x(770)
PO_4	0.07b	0.1a	(75)x(484)	0.06b	0.1a	(72)x(472)	0.04b	0.1a	(68)x(465)

Constituents with different letters (a,b) from pre to post-harvest indicate statistical differences within watershed between time periods, while constituents with the same letter denote statistical similarity between time periods

Constituents with no letters indicate no statistical significance

Significant statistical differences between treatments were observed for SO_4, Ca, K, Na, and TOC. Slightly less significant differences ($p \leq 0.10$) were also observed for NO_3 and Cl. Magnesium, ALK, PO_4, and NH_4 exhibited no statistical significance during the study period. Results from the analysis showed all watersheds were statistically different for SO_4 with WSB having the highest concentration and WSC having the lowest. WSB and WSC had nearly identical Ca concentrations and were statistically higher than WSA for the study period. Next, all three watersheds had statistically different concentrations for K with WSC being the highest and WSA being the lowest. Sodium was the next constituent to be analyzed with WSB having a statistically higher concentration than both WSA and WSC. Furthermore, results from NO_3 showed WSB having the highest concentration and WSA having the lowest with WSC having a statistically similar concentration to both WSA and WSB. Next, Cl was analyzed and the results showed WSA and WSB had a statistically higher concentration than WSC. Finally, results from TOC displayed statistical similarity for WSA and WSC and they had a statistically higher concentration than WSB.

Table 3.2: ANOVA treatment interaction results, concentration (mg L^{-1}) plus sample.[1]

	WSA		WSB		WSC	
Constituent	Concentration	Sample Size	Concentration	Sample Size	Concentration	Sample Size
SO_4	11.0b	877	11.6a	821	10.0c	844
Mg	1.8	877	1.9	857	1.9	846
Ca	2.2b	877	2.5a	857	2.5a	846
K	1.38c	877	1.57b	857	1.63a	846
Na	0.97b	877	1.17a	857	0.97b	846
ALK	17.8	877	18.0	852	20.6	844
NO_3*	0.26b	864	0.33a	843	0.28ab	836
PO_4	0.08	570	0.08	555	0.08	541
Cl*	0.82a	307	0.83a	301	0.78b	305
NH_4	0.04	184	0.0	173	0.1	184
TOC	4.5a	275	4.0b	268	4.6a	269

* Significance level of $\alpha \leq 0.10$

Constituents with different letters (a,b,c) indicate statistical differences between watersheds, while constituents with the same letter denote statistical similarity between watersheds

Constituents with no letters indicate no statistical significance

Significant statistical differences were observed for SO_4, Ca, K, and Na while no statistical significance differences were found for Mg, ALK, NO_3, and PO_4; this was true for both pre- and post-harvest. During pre-harvest, all three watersheds were statistically different for SO_4 (WSB, WSA, WSC), Ca (WSB, WSC, WSA), and K (WSB, WSC, WSA); watersheds are listed in order of highest to lowest concentration. Watershed B had a statistically higher concentration for Na pre-harvest while the concentrations in WSA and WSC were lower and statistically similar. Post-harvest statistical differences were exhibited across all three watersheds for SO_4 (WSB, WSA, WSC) and Ca (WSC, WSB, WSA). Watershed B and WSC had a statistically similar and higher concentration for K post-harvest compared to WSA. Similar to the pre-harvest result, WSB had a statistically higher concentration for Na while the concentration in WSA and WSC was lower and statistically similar.

Table 3.3: ANOVA time*treatment interaction results, pre and post-harvest concentration (mg L^{-1}) plus sample size (pre)x(post).[1]

	Pre-harvest			Post-harvest			Sample Size		
Constituent	WSA	WSB	WSC	WSA	WSB	WSC	WSA	WSB	WSC
SO_4	12.8b	13.4a	11.4c	9.3b	9.9a	8.6c	(75)x(791)	(72)x(738)	(68)x(769)
Mg	1.8	2.0	1.7	1.7	1.9	2.1	(75)x(791)	(72)x(774)	(68)x(770)
Ca	2.2c	2.6a	2.5b	2.3c	2.6a	2.5b	(75)x(791)	(72)x(774)	(68)x(770)
K	1.3c	1.6a	1.5b	1.4b	1.6a	1.8a	(75)x(791)	(72)x(774)	(68)x(770)
Na	1.0b	1.2a	1.0b	1.0b	1.1a	1.0b	(75)x(791)	(72)x(774)	(68)x(770)
ALK	12.2	12.9	13.4	23.5	23.0	27.9	(75)x(791)	(69)x(772)	(66)x(770)
NO_3	0.13	0.17	0.1	0.39	0.49	0.47	(75)x(778)	(72)x(760)	(68)x(770)
PO_4	0.07	0.06	0.04	0.10	0.10	0.11	(75)x(484)	(72)x(472)	(68)x(465)

Constituents with different letters (a,b,c) indicate statistical differences within time period and between the watersheds, while constituents with the same letter denote statistical similarity between watersheds within the time period

Constituents with no letters indicate no statistical significance

The final set of results to be analyzed was the long-term regression analysis that was run on the constituent concentrations (Table 3.4). The goal of the regression analysis was to determine if there were any long-term trends in the data and to assess whether constituent concentrations had increased or decreased throughout the study period and whether that change was significantly different from zero. Constituents that showed a statistically significant long-term decrease in concentration were SO_4, Mg (WSA, WSB), Ca, K (WSB, WSC), NO_3, PO_4, and TOC. Constituents that showed a statistically significant long-term increase in concentration were Na, ALK (WSA), Cl (WSA, WSC), and NH_4.

Table 3.4: Water quality regression analysis, slope (mg L^{-1} d^{-1} x 10^{-4}), *p*-value, and sample size.[1]

	Slope			p-value			Sample Size		
Constituent	WSA	WSB	WSC	WSA	WSB	WSC	WSA	WSB	WSC
SO_4	-2.0	-2.2	-1.7	*	*	*	877	821	844
Mg	-0.28	-0.48	-0.06	*	*	0.9	877	857	846
Ca	-1.1	-1.4	-1.8	*	*	*	877	857	846
K	0.03	-0.20	-0.24	0.6	*	0.006	877	857	846
Na	0.27	0.09	0.10	*	0.02	*	877	857	846
ALK	3.4	0.8	7.5	0.02	0.6	0.2	877	852	844
NO_3	-0.10	-0.30	-0.40	0.05	*	*	864	843	836
PO_4	-0.07	-0.07	-0.10	0.02	0.06	0.005	570	555	541
Cl	0.66	0.18	1.1	0.05	0.7	0.002	307	301	305
NH_4	0.37	0.18	0.25	*	*	*	184	173	184
TOC	-4.6	-4.8	-7.3	0.06	0.02	0.003	275	268	269

* $p < 0.001$

Results from the statistical analyses showed some very interesting time and treatment effects. One of the main aspects of this analysis was to assess the combined contribution of time and treatments interactions (Table 3.3) on constituent concentrations during the study period. If the statistical relationship varied from pre-harvest to post-harvest, then we could confidently say that treatment had an effect on constituent concentration. This was the case for the base cations Ca and K which are shown in Figures 3.4-3.6 and 3.7-3.9, respectively. For Ca, all three watersheds were significantly different from each other pre-harvest with WSB having the highest concentration and WSA having the lowest. Post-harvest, all three watersheds remained significantly different but WSC had the highest Ca concentration while WSA remained the lowest. When looking at the time only interaction for Ca, it can be seen that the concentration for Ca remained statistically similar in WSA and WSC throughout the study while following treatment, Ca concentrations in WSB declined. For K, all three watersheds were significantly different pre-harvest with WSB having the highest concentration and WSA having the lowest. Post-harvest, WSB and WSC were statistically similar and also had a statistically higher concentration compared to WSA. When looking at the time interaction as well, it can be seen that the K concentration in WSA and WSB remained statistically similar from pre-harvest to post-harvest while the K concentration in WSC was statistically higher following harvest. These results indicate that the BMPs in WSB helped retain the base cations of Ca and K compared with WSC.

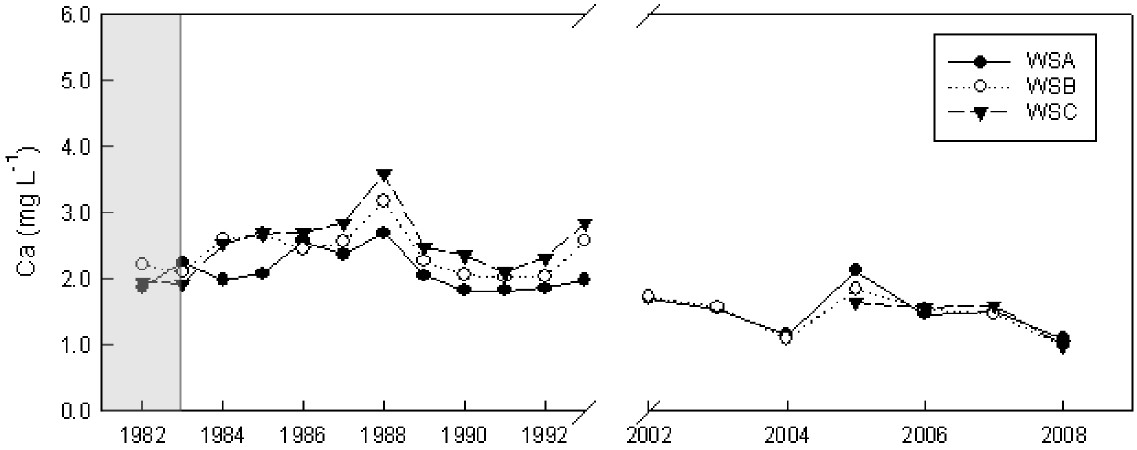


Figure 3.4: Yearly calcium FWMC (1982-1993) and (2002-2008).

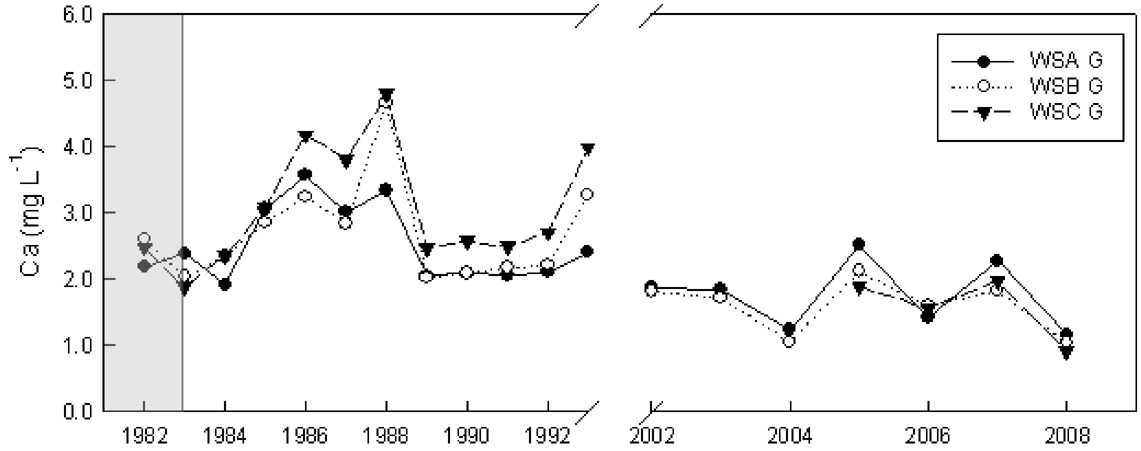


Figure 3.5: Growing season calcium FWMC (1982-1993) and (2002-2008).

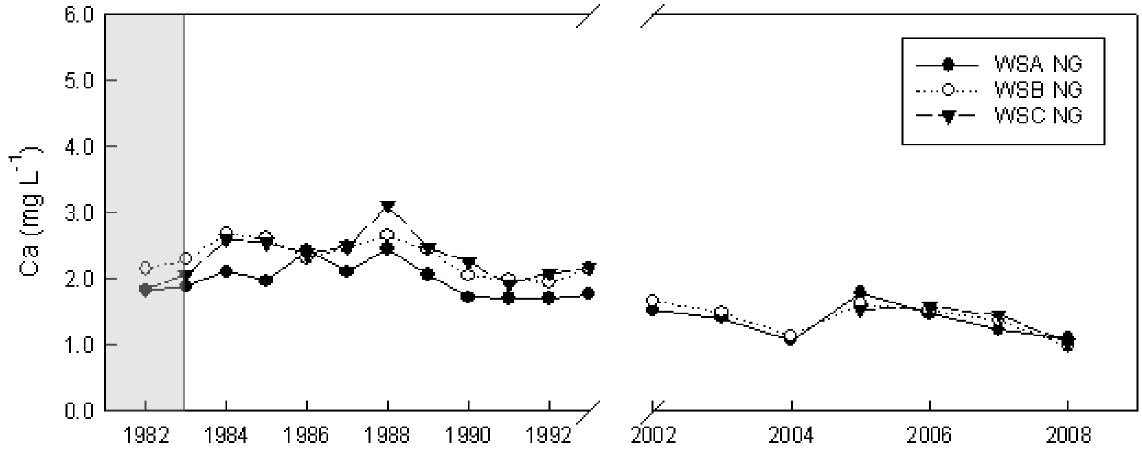


Figure 3.6: Non-growing season calcium FWMC (1982-1993) and (2002-2008).

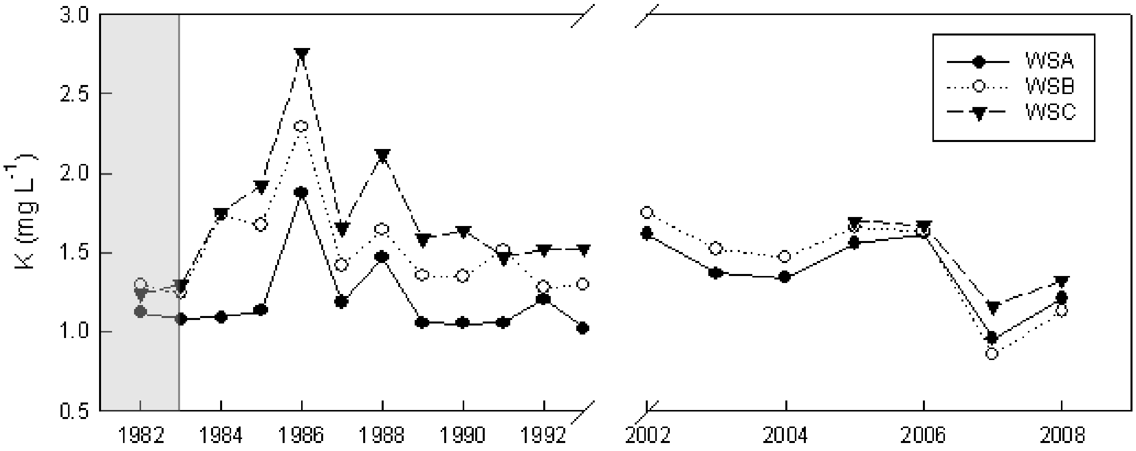


Figure 3.7: Yearly potassium FWMC (1982-1993) and (2002-2008).

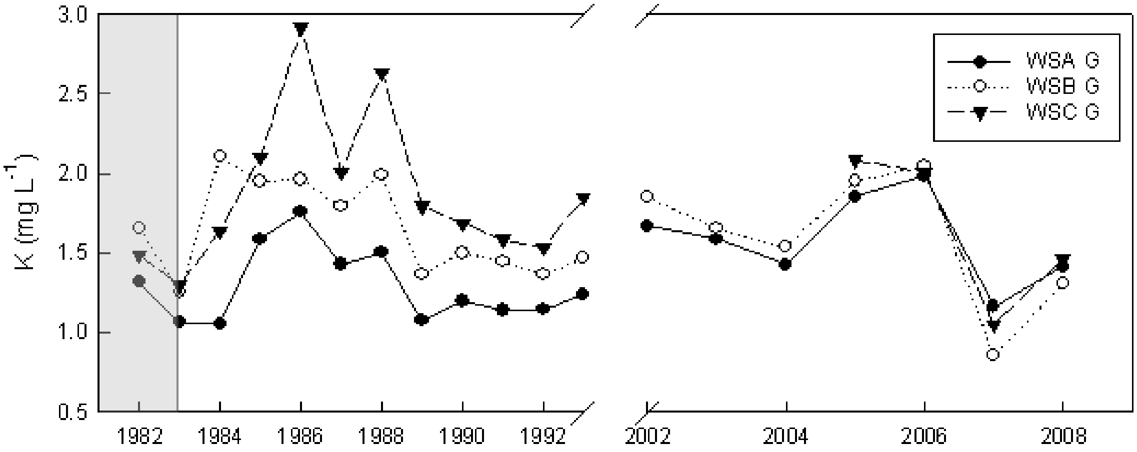


Figure 3.8: Growing season potassium FWMC (1982-1993) and (2002-2008).

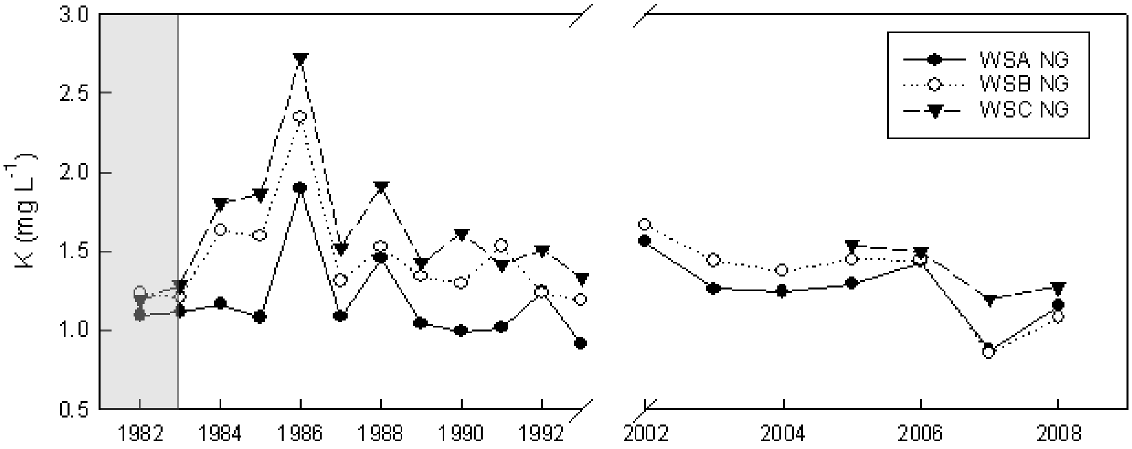


Figure 3.9: Non-growing season potassium FWMC (1982-1993) and (2002-2008).

The base cations that did not have significant time*treatment interactions (Mg, Na) exhibited some mixed results in this study. Magnesium concentration was deemed not statistically significant for all three interactions (time, treatment, and time*treatment), and from the regression analysis, WSA and WSB showed a statistically significant decline in Mg concentration over the study period (Figures 3.10-3.12). Although it was deemed not statistically significant, spikes in Mg concentration can be seen graphically in WSB and WSC post-harvest. As for Na, a significant time interaction was observed in WSB where Na concentration was statistically higher pre-harvest compared to post-harvest. However, results from the regression analysis showed a statistically significant increase in Na concentration for all three watersheds throughout the study period (Figures 3.13-3.15). These results may be explained by some recent studies that were conducted at the Daniel Boone National Forest. The studies examined the effects of atmospheric deposition on forest soils and noted that inputs from SO_4 and NO_x can lead to a loss of base cations that leach into the stream (Barton et al., 2002; Reuss, 1983; Sanderson, 2014). Interestingly, large spikes in Mg, Ca, and Na concentrations were observed around 1988, five years post-harvest. These spikes may have been caused by deposition from dust produced by surface mining operations that took place next to Clemons Fork around that time (Figure 2.3).

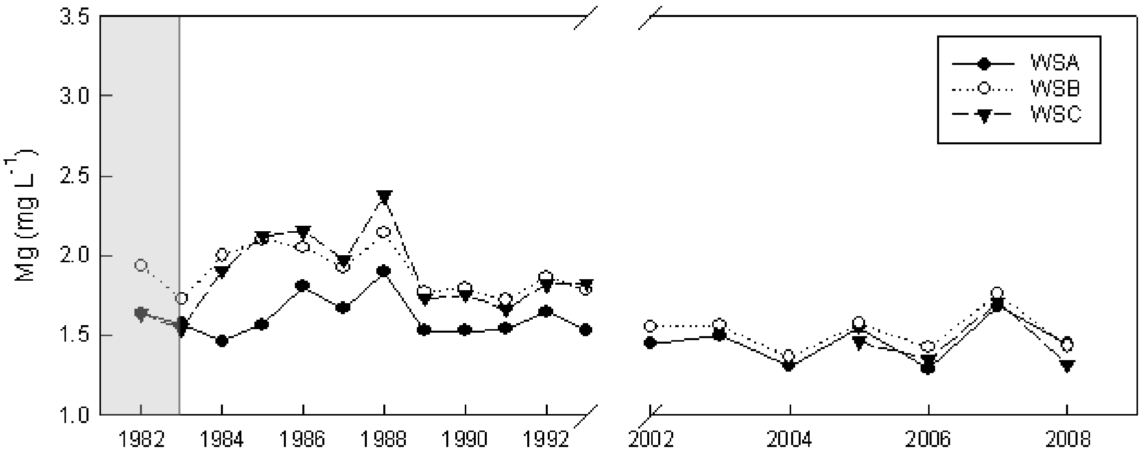


Figure 3.10: Yearly magnesium FWMC (1982-1993) and (2002-2008).

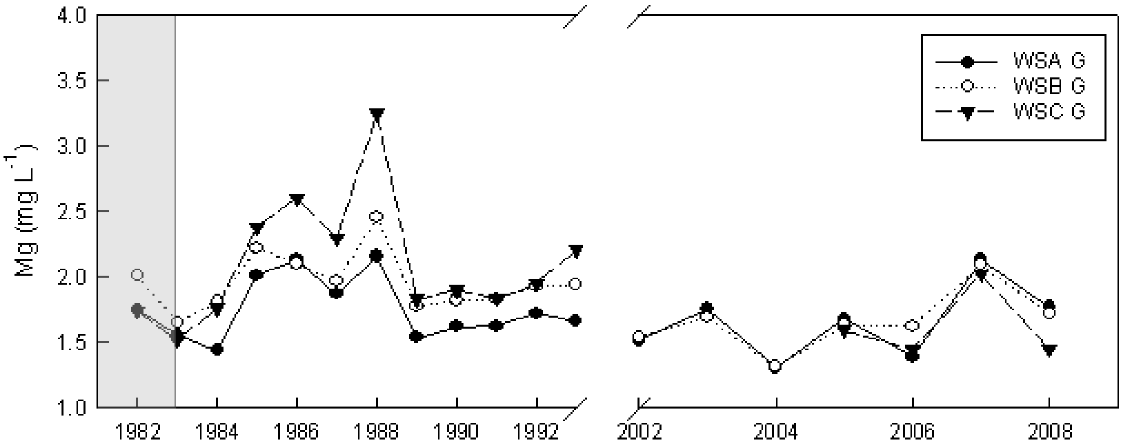


Figure 3.11: Growing season magnesium FWMC (1982-1993) and (2002-2008).

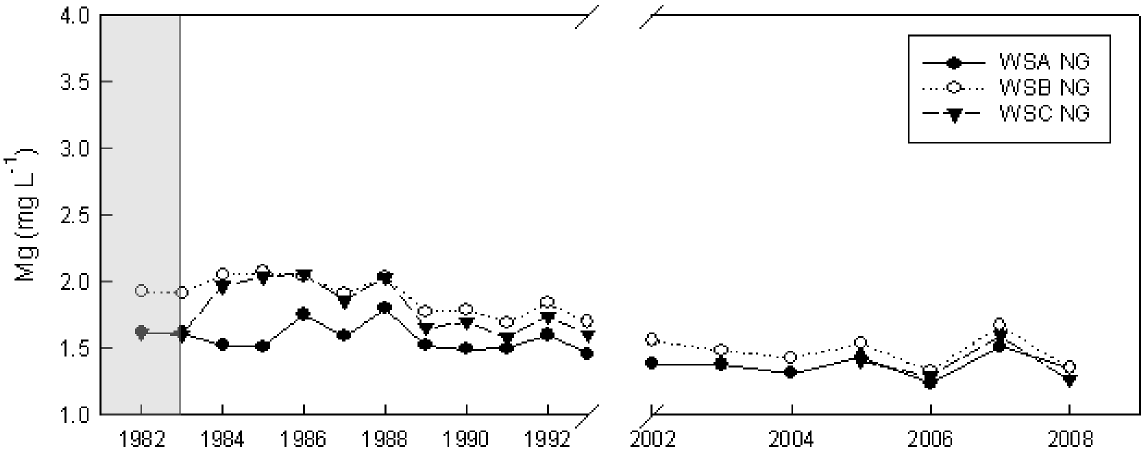


Figure 3.12: Non-growing season magnesium FWMC (1982-1993) and (2002-2008).

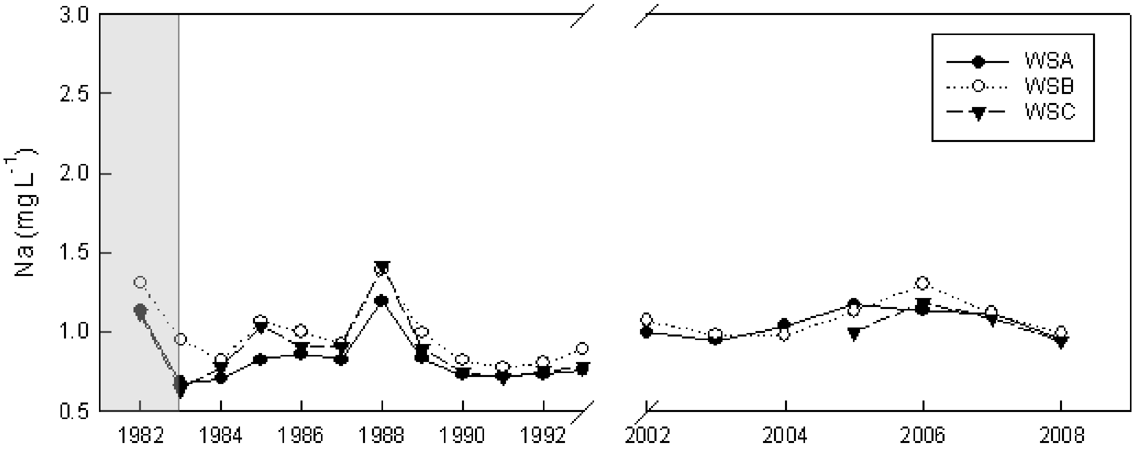


Figure 3.13: Yearly sodium FWMC (1982-1993) and (2002-2008).

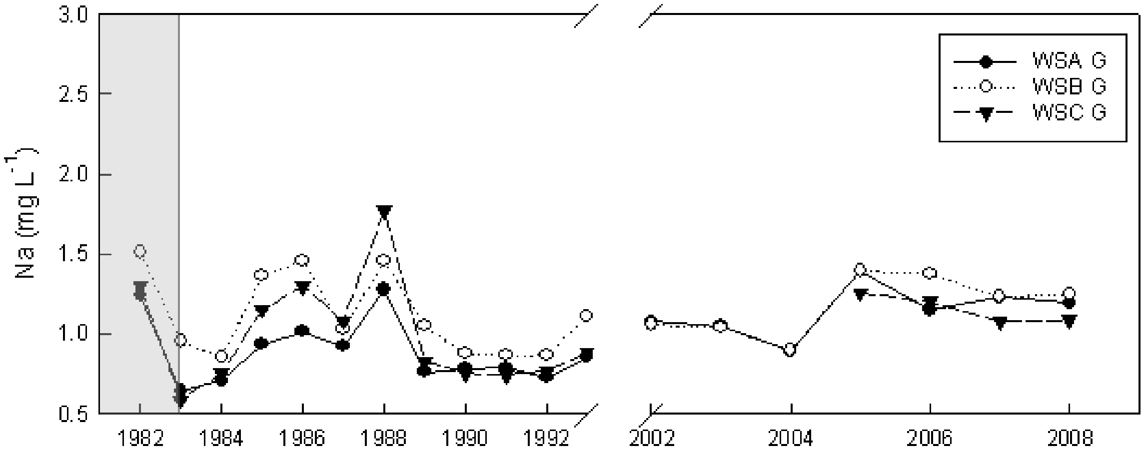


Figure 3.14: Growing season sodium FWMC (1982-1993) and (2002-2008).

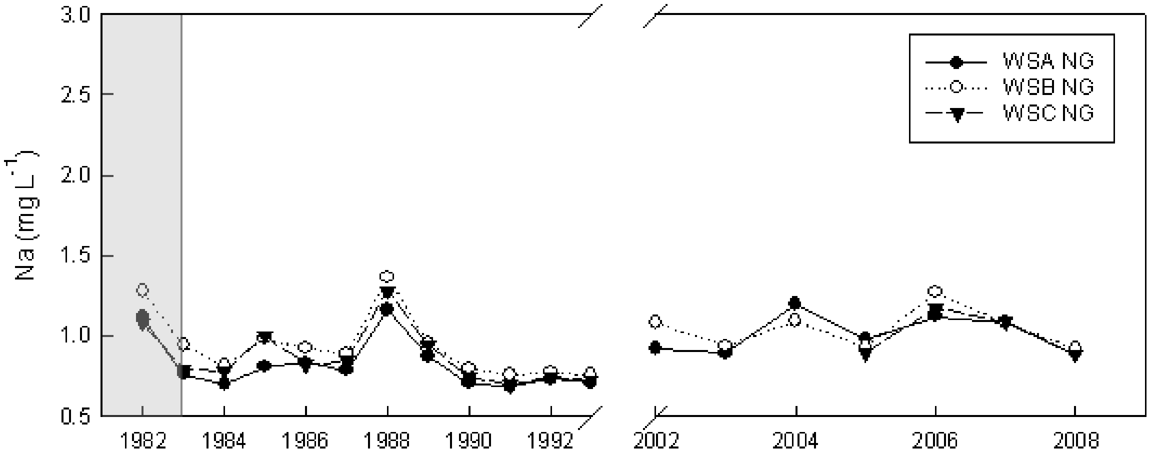


Figure 3.15: Non-growing season sodium FWMC (1982-1993) and (2002-2008).

Some other interesting results were seen for those constituents that enter through atmospheric deposition. Looking at the time interaction, the SO_4 concentration in all three watersheds was significantly reduced following harvest (Figures 3.16-3.18). This was also seen in the results from the regression analysis where the concentration of SO_4 had significantly declined throughout the study period across all watersheds. This outcome is most likely the result of more stringent air quality regulations imposed by a 1990 amendment to the Clean Air Act, which affected many nearby coal-fired power plants (Sanderson, 2014). Nitrate, another constituent affected by the Clean Air Act's regulations also saw an overall significant decrease in concentration over the study period across all watersheds (Figures 3.19-3.21). However, it should be noted that NO_3 concentration spiked for both harvested watersheds directly after treatment and remained elevated for roughly five years. This effect is largely a result of a cumulative reduction in plant NO_3 uptake due to removed vegetation. This resulted in a change in soil processes such as N-mineralization and nitrification which then lead to an excess of nutrients that leached through the soil and into the streams (Hornbeck and Leak, 1992; Pierce et al., 1993; Burns and Murdoch, 2005). A statistically significant increase in NH_4 concentration was also exhibited from 2002-2008 across all watersheds (Figures 3.22-3.24). This result is interesting because NH_4 is usually pretty immobile in soil because it binds to cation exchange sites. Also, NH_4 that is in soil solution usually gets converted to NO_3 through nitrification; NO_3 does not bind to cation exchange sites and is therefore easily leachable. This would indicate that the increase in NH_4 concentration is likely an input from precipitation. A study conducted in nearby Rowan county Kentucky from 1990-1998 confirmed that the concentration of NH_4 had significantly increased in precipitation and nearly doubled during the study period (Aneja, 2003).

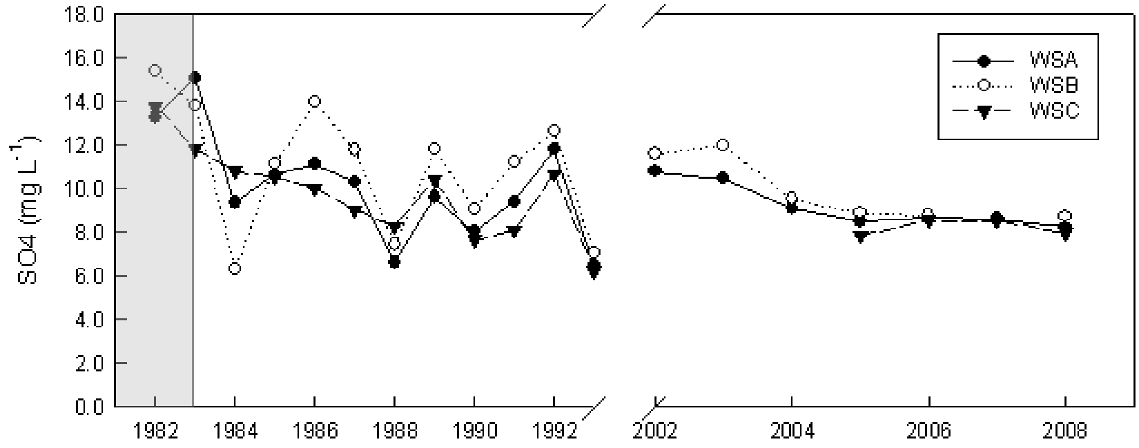


Figure 3.16: Yearly sulfate FWMC (1982-1993) and (2002-2008).

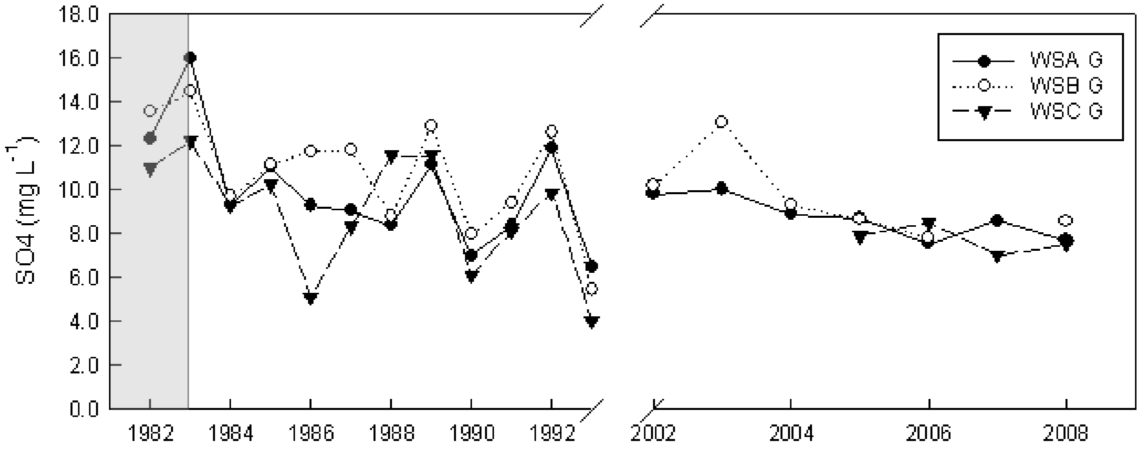


Figure 3.17: Growing season sulfate FWMC (1982-1993) and (2002-2008).

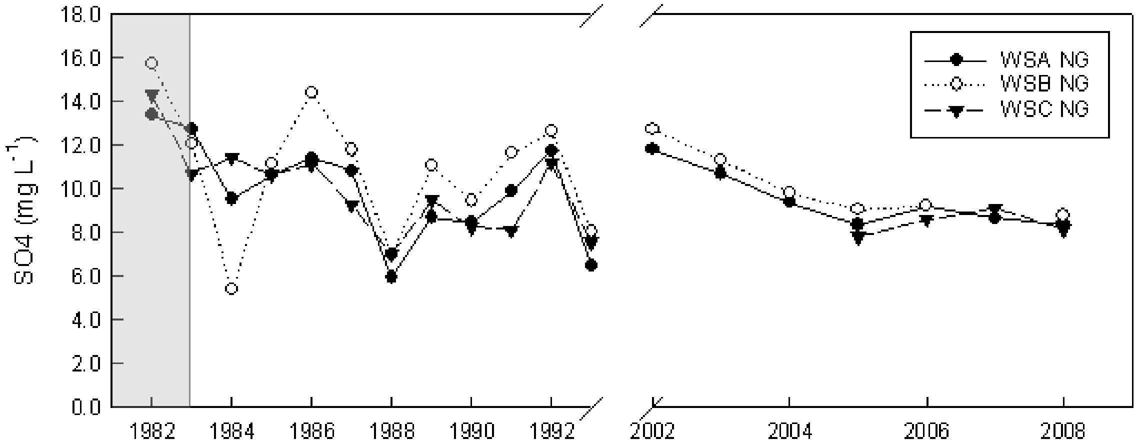


Figure 3.18: Non-growing season sulfate FWMC (1982-1993) and (2002-2008).

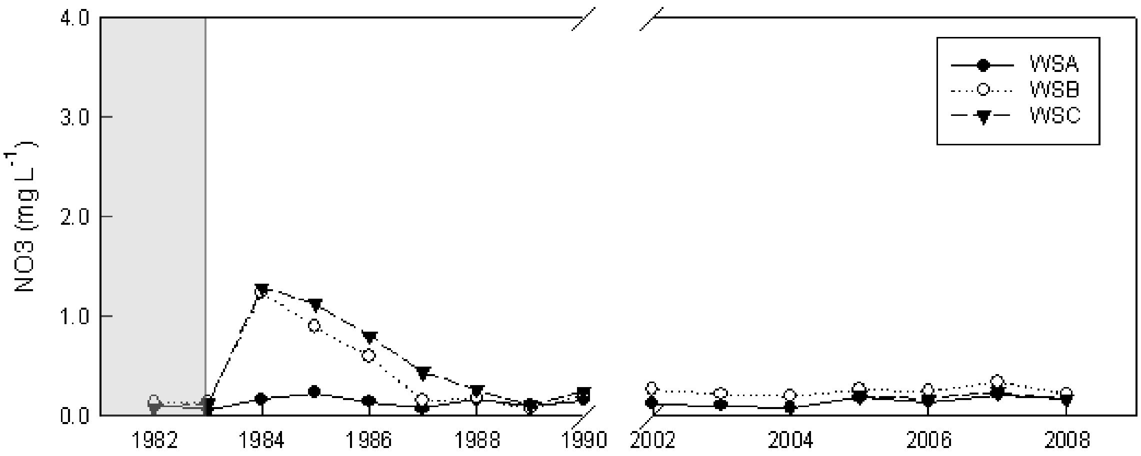


Figure 3.19: Yearly nitrate FWMC (1982-1990) and (2002-2008).

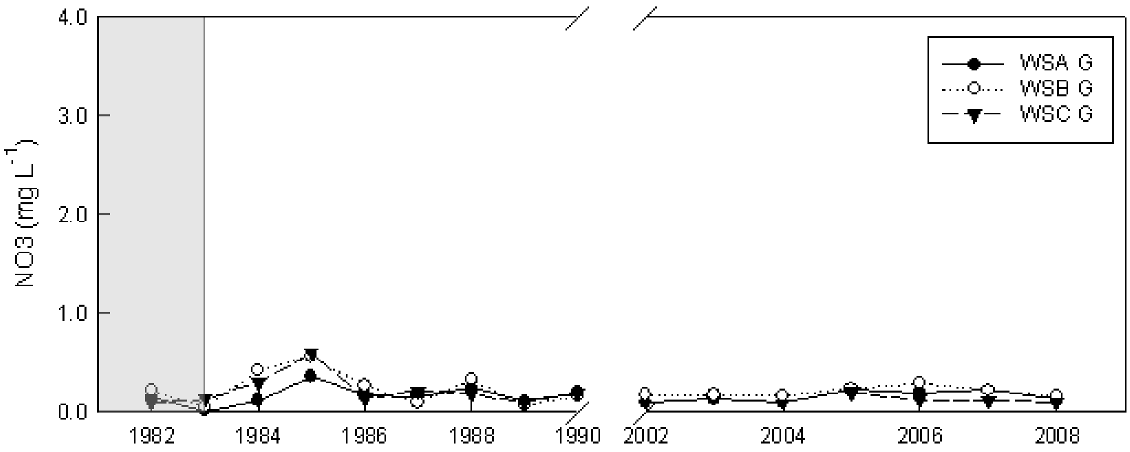


Figure 3.20: Growing season nitrate FWMC (1982-1990) and (2002-2008).

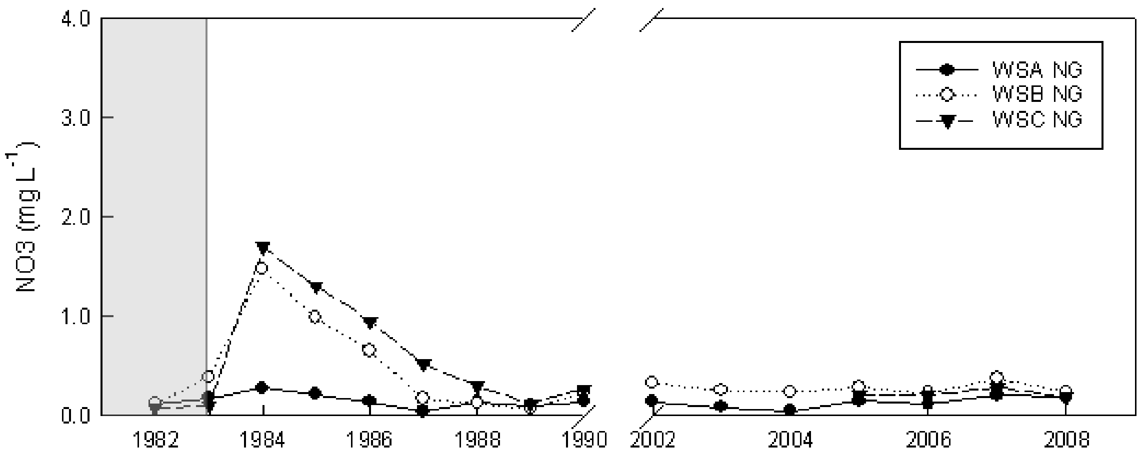


Figure 3.21: Non-growing season nitrate FWMC (1982-1990) and (2002-2008).

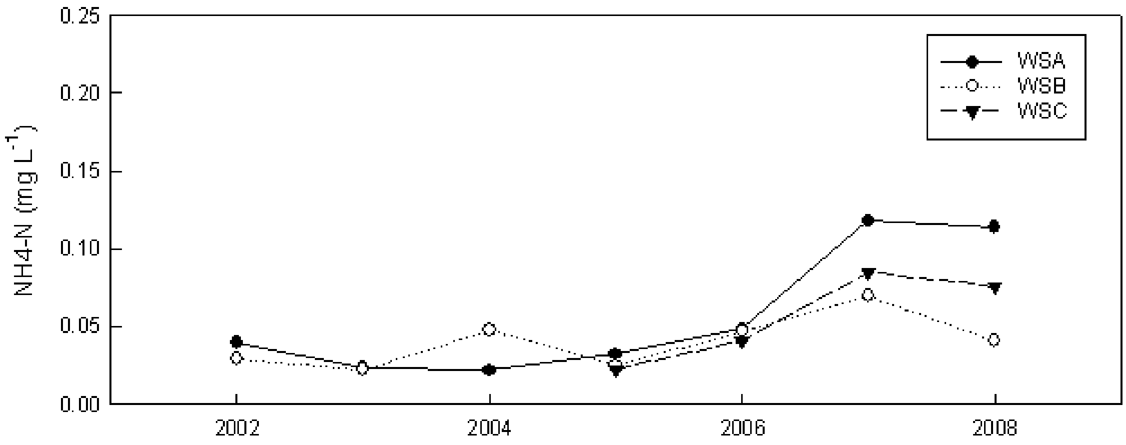


Figure 3.22: Yearly ammonium FWMC (2002-2008).

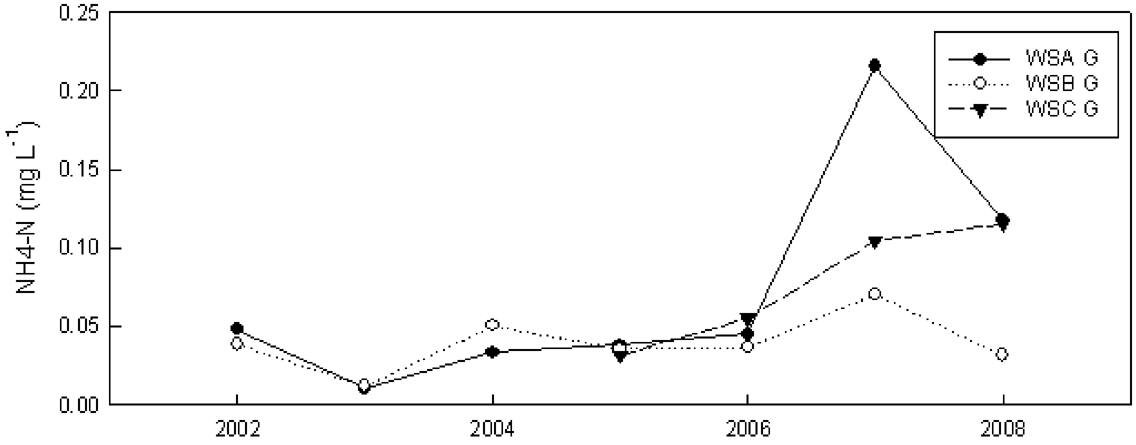


Figure 3.23: Growing season ammonium FWMC (2002-2008).

Figure 3.24: Non-growing season ammonium FWMC (2002-2008).

Total alkalinity was another constituent that was affected by soil acidity and subsequently affected by changes to the Clean Air Act in 1990. Several experiments that were conducted on small forested headwater catchments found that sites that suffer from soil acidification due to atmospheric deposition experience large changes in stream water alkalinity from small changes in ionic inputs that leach through the soil column (Lange et al., 1996). Changes such as this were exhibited in this study and can be seen from the figures for SO_4 (Figures 3.16-3.18) and (Figures 3.25-3.27). ALK where changes in SO_4 concentration had large inverse effects on ALK concentration. During the second time period, following the 1990 amendment to the Clean Air Act, SO_4 concentration significantly declined and was much less variable year to year. This correlated into less variability for ALK as well and results from the time interaction showed a statistical increase in ALK concentration throughout the study period.

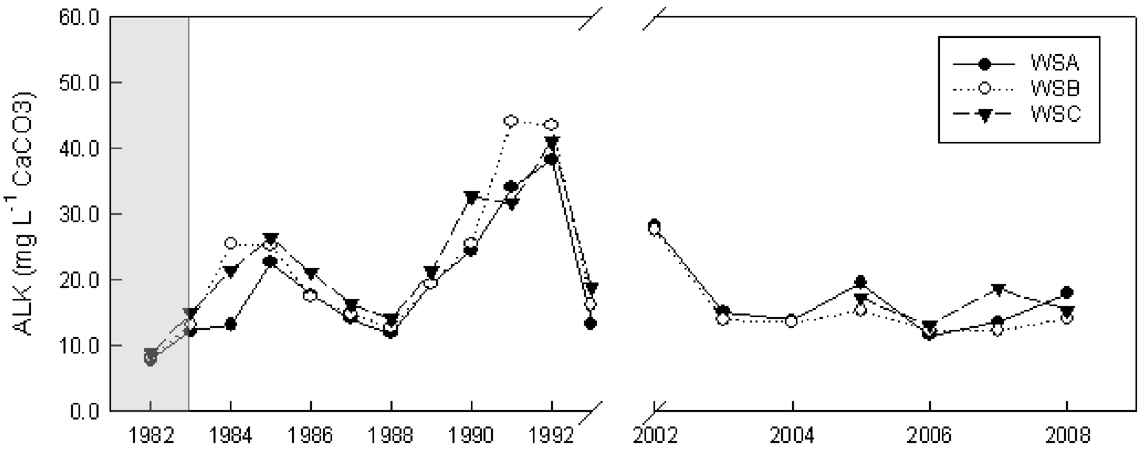


Figure 3.25: Yearly alkalinity FWMC (1982-1993) and (2002-2008).

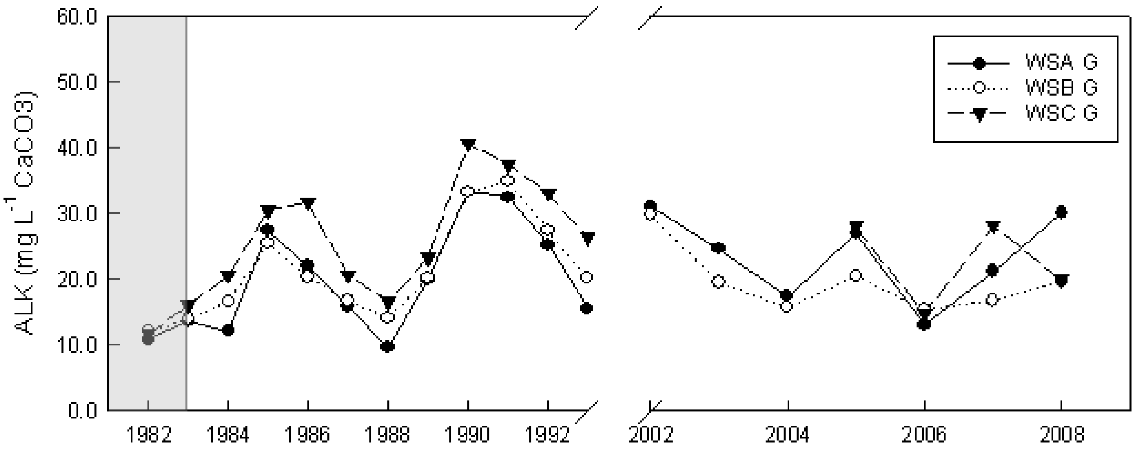


Figure 3.26: Growing season alkalinity FWMC (1982-1993) and (2002-2008).

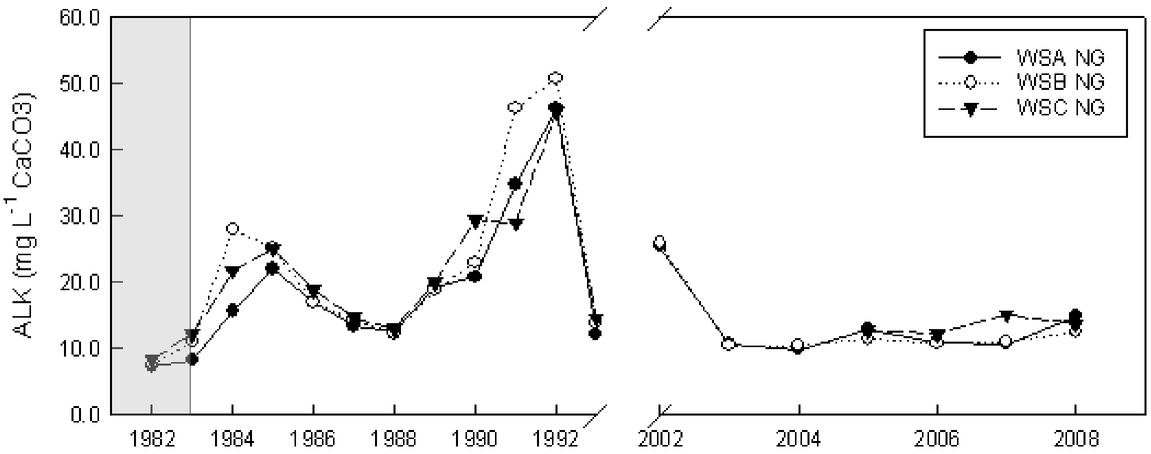


Figure 3.27: Non-growing season alkalinity FWMC (1982-1993) and (2002-2008).

Results from the time interaction exhibited a statistical increase in PO_4 concentrations across all watersheds from pre-harvest to post-harvest (Figures 3.28-3.30). Increases in PO_4 concentrations in WSB and WSC were observed for two years post-harvest and then realign with WSA in 1986. Afterwards, all three watersheds experience a large increase in phosphate concentration around 1988. This increase in PO_4 may be linked to the surface mining operations that took place next to Clemons Fork, as increases were seen around the same time as Mg, Ca, and Na.

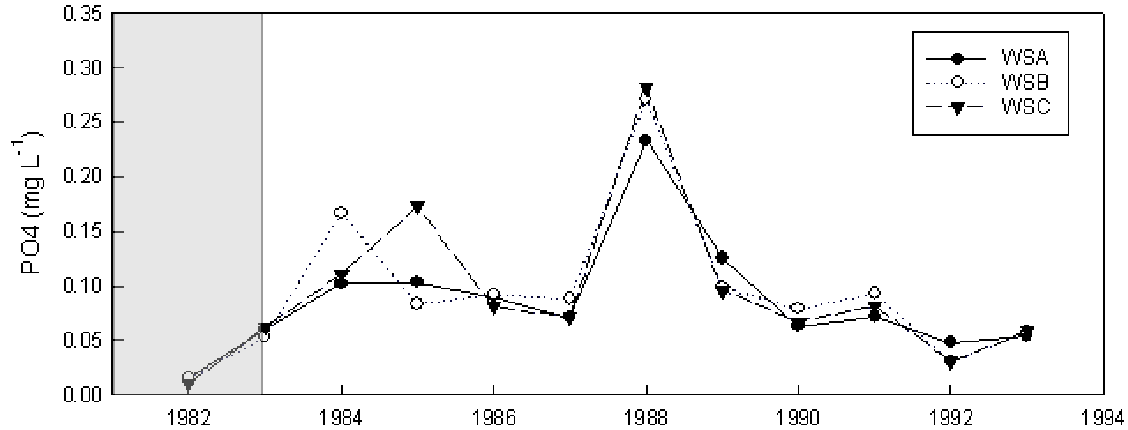


Figure 3.28: Yearly phosphate FWMC (1982-1993).

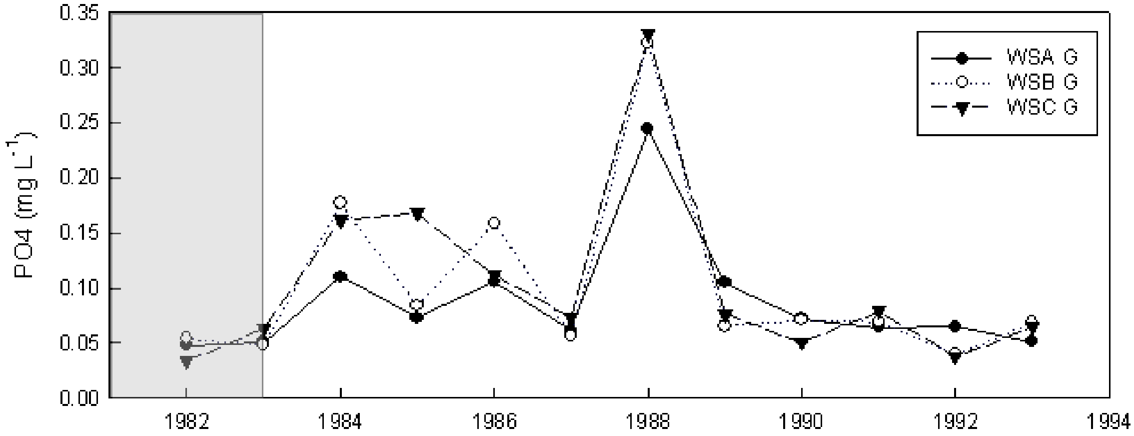


Figure 3.29: Growing season phosphate FWMC (1982-1993).

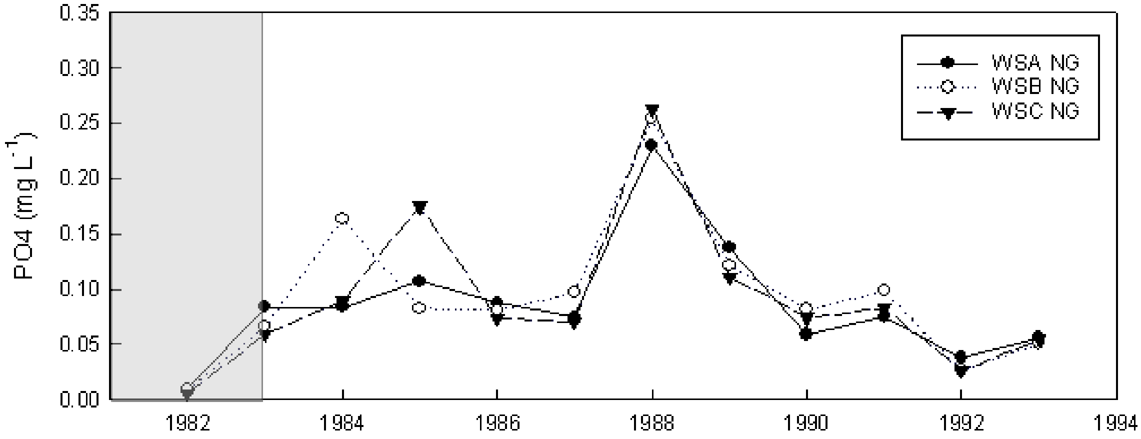


Figure 3.30: Non-growing season phosphate FWMC (1982-1993).

Figures 3.31-3.33 and 3.34-3.36 depict the Cl and TOC concentrations from 2002-2008. Since no pre-harvest data were available for these constituents, a regression analysis was only used to assess long-term trends. The Cl concentration in both WSA and WSC exhibited a significant statistical increase in concentration from 2002-2008. The reason behind this increase in concentration is unclear. Results from the regression analysis for TOC showed a significant decrease in TOC concentration from 2002-2008 across all watersheds. A large decrease can be seen in TOC in 2008; this year TOC data were scarce and mainly came from the non-growing season. Looking at the TOC data, it is apparent that TOC concentration is season dependent with high concentrations occurring during the growing season and low concentrations occurring in the non-growing season. The data from 2008 may have skewed the results, as the trend from the previous years is seemingly linear.

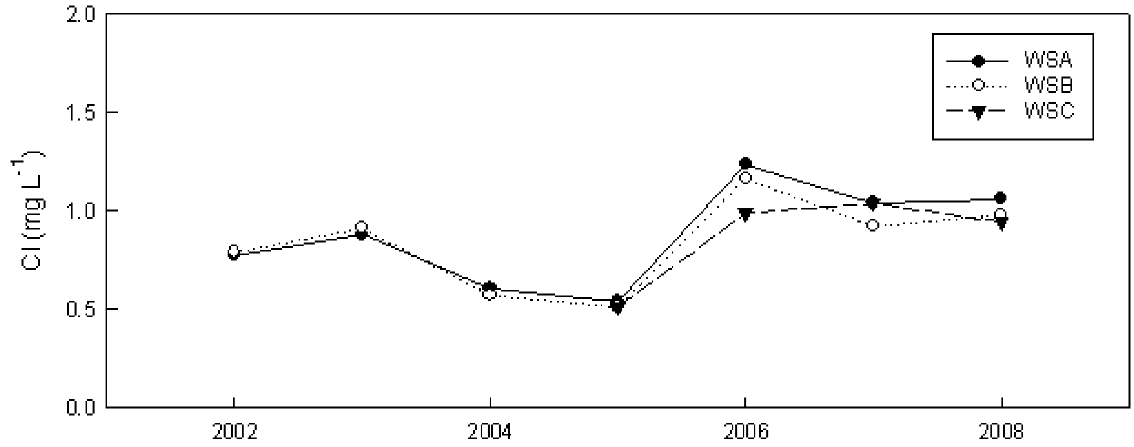


Figure 3.31: Yearly chloride FWMC (2002-2008).

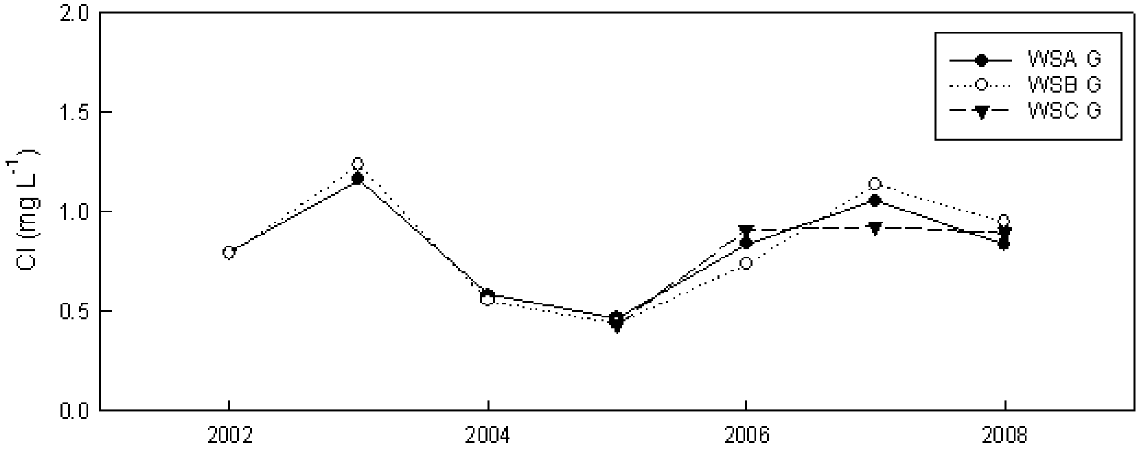


Figure 3.32: Growing season chloride FWMC (2002-2008).

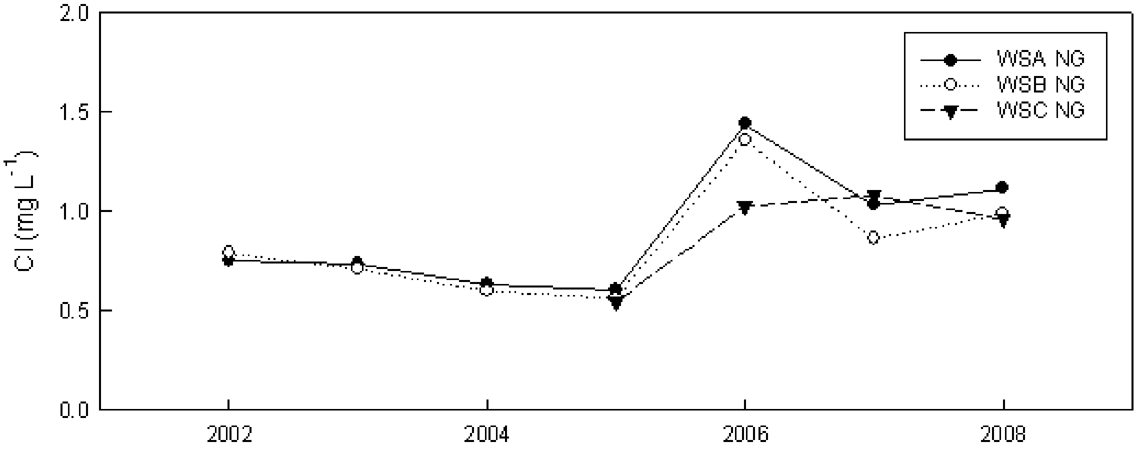


Figure 3.33: Non-growing season chloride FWMC (2002-2008).

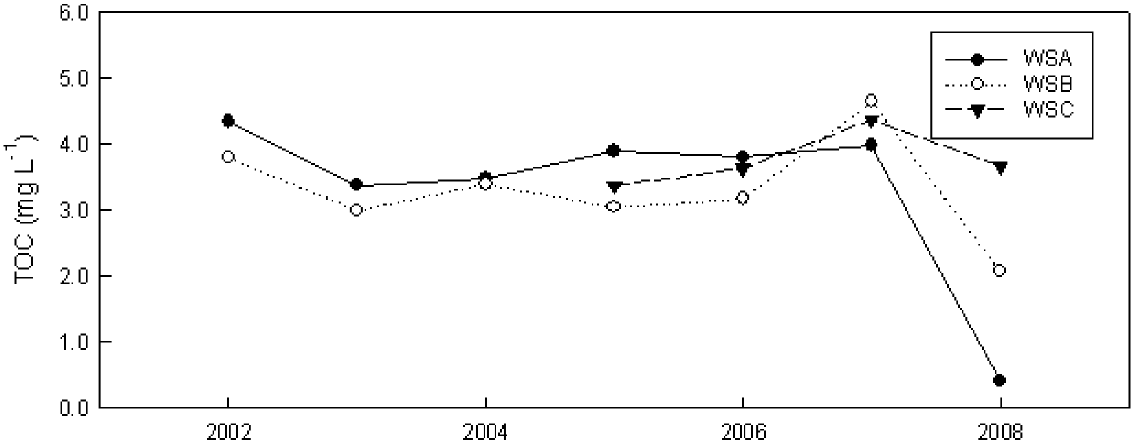


Figure 3.34: Yearly total organic carbon FWMC (2002-2008).

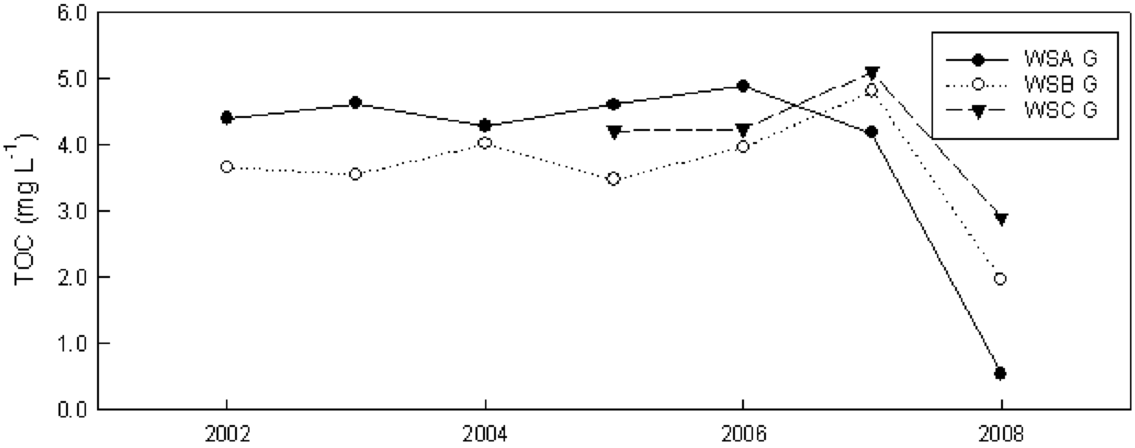


Figure 3.35: Growing season total organic carbon FWMC (2002-2008).

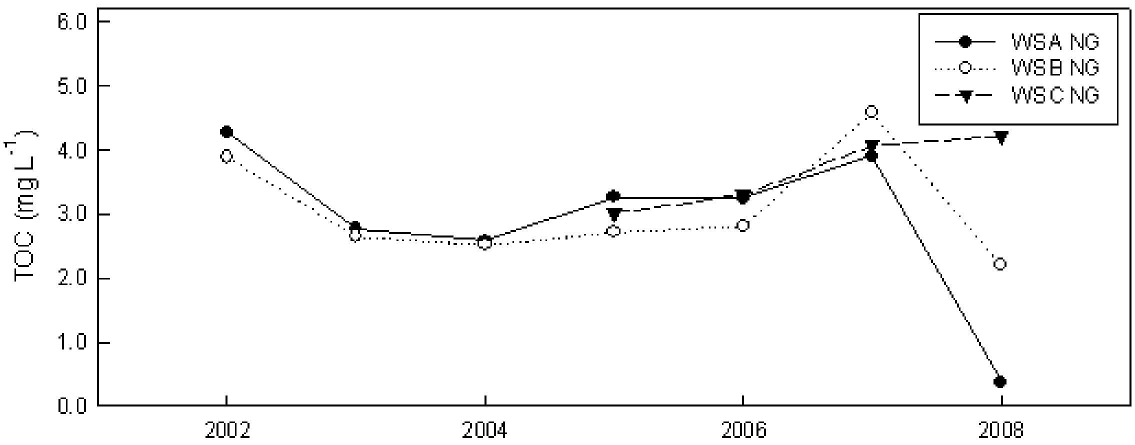


Figure 3.36: Non-growing season total organic carbon FWMC (2002-2008).

3.4 CONCLUSIONS

Harvesting the two treatment watersheds resulted in increased sediment loads, and leaching of base cations, NO_3, and PO_4 into the stream. From the results it would seem that the most notable contribution of BMP implementation was that it limited the depletion of base cations and reduced sediment transport compared to the clear-cut watershed. When looking at NO_3, BMPs seemingly added no benefit and WSB remained elevated alongside WSC for five years after harvest.

Interestingly, some of the largest changes to stream water chemistry in these watersheds came from atmospheric deposition and not forest harvesting. During the study period NO_3 and SO_4 significantly declined across all watersheds. This significant reduction across all watersheds is attributed to regulations imposed by the 1990 amendment to the Clean Air Act that affected many nearby coal-fired power plants. Unlike NO_3 and SO_4, however, NH_4 significantly increased during its' monitoring period and was likely the result of increasing NH_4 precipitation inputs due to increases to livestock production and aerosol emissions. Other significant changes to stream water chemistry came in the form of deposition from nearby surface mining activities which is thought to have caused the observed spikes in Mg, Ca, Na, and PO_4 concentrations in 1988. Although significant increases in constituent concentrations were observed in the treatment watersheds, WSB and WSC are still considered to have excellent stream water quality compared to eastern Kentucky standards.

CHAPTER 4: CONCLUSIONS

This study evaluated the long-term impacts of harvest and the effectiveness of BMPs at mitigating those impacts. The research was conducted at the University of Kentucky's Robinson Forest in eastern Kentucky and consisted of three adjacent headwater catchments. A paired watershed approach was used and yearly hydrograph characteristics plus water quality constituents were analyzed and compared across the watersheds. Results from this study affirm that implementing BMPs are an effective way to limit the damaging impacts of harvest and simply clear-cutting a watershed has significant long-term consequences. However, BMP effectiveness on promoting water quality was less certain and seemed to only add some benefit for some of the monitored constituents. Regardless, with this knowledge and knowing that headwater catchments make up a large majority of stream length and drainage area in a river network, it doesn't make sense that these first and second order streams should continue to go unregulated or under regulated.

Chapter One detailed the background of BMPs and their significance as well as the research objectives.

Chapter Two evaluated the storm hydrograph characteristics of baseflow, stormflow, peak discharge, storm volume as a percentage of rainfall, time to peak (2002-2008), and curve number of the paired watersheds. No differences in the analyzed characteristics were observed between the watersheds pre-harvest indicating the watersheds were strongly paired from a hydrologic standpoint. However, it should be noted that pre-harvest data were quite limited. Considering this was a long-term study, it cannot be definitively said that these watersheds would have behaved in the future as similarly as they did in the 19 pre-harvest months. Following treatment, large hydrologic differences were observed in both harvested watersheds.

Watershed B was statistically different from WSA in 1985 for all calculated hydrograph parameters besides peak discharge. By 1988, all of the evaluated hydrograph parameters besides stormflow in WSB had returned or nearly returned to control conditions. The stormflow in WSB remained elevated throughout the first time period, and by the beginning of the second time period (2002), was realigned with the control. Watershed C was statistically different from WSA for all hydrograph parameters besides peak discharge and time to peak in 1984, 1985, 2006, and 2007 and was statistically different from WSA in 1989 for storm volume as a percentage of rainfall. Large differences in hydrograph parameters were observed throughout the study period even though massive regrowth is present at the site. The findings here indicate that BMP implementation was very effective at limiting the negative hydrologic effects due to harvest and clear-cutting a watershed can have significant long-term consequences.

Chapter Three compared water quality constituents of SO_4, Mg, Ca, K, Na, ALK (1982-2008), NO_3 (1982-1990 & 2002-2008), PO_4 (1982-1993), Cl, NH_4-N, and TOC (2002-2008) to assess significant differences between the watersheds due to harvest. Another goal of this study was to determine if the monitored constituents showed any long-term increasing or decreasing trends. The most notable contribution of BMP implementation was that it seemed to limit the depletion of base cations compared with the clear-cut watershed and reduced erosional effects. When looking at NO_3, the BMPs seemingly added no benefit and WSB remained elevated alongside WSC for roughly five years after harvest. Nitrate concentration significantly declined after this across all watersheds. This reduction in NO_3 is attributed to regulations imposed by the Clean Air Act and is also responsible for the significant decline in SO_4 that was observed across the watersheds. Unlike NO_3 and SO_4, however, NH_4 significantly increased during its' monitoring period and this was likely the result of increasing NH_4 precipitation inputs.

CHAPTER 5: FUTURE WORK

Future research should continue at the sites to assess correlations between storm characteristics (max intensity, average intensity, duration, and antecedent moisture conditions) and hydrograph responses across the watersheds. It would be interesting to see what kinds of storms illicit different responses in the watersheds and how they vary temporally. Further research should also be conducted at similar sites to assess the performance of a wider riparian buffer but with a percentage of the buffer being harvested. This will allow the same amount of timber to be harvested but may help limit sediment transport and stormflow directly after harvest. Finally, research on time-based hydrograph characteristics such as lag time and time of concentration should be conducted at similar sites. The headwater catchments studied here were extremely responsive to precipitation, and with the advancement of monitoring equipment, a smaller time-step could be used which would allow an accurate comparison to be made.

Further research should also be done to measure the performance of BMPs on limiting sediment transport in headwater catchments. A previous study at the site found significant differences in sediment loading across the watersheds, but due to extended equipment failure, monitoring was discontinued in 1990 (Arthur et al., 1998). From recent observation, it would seem that sediment transport may still be an issue in both harvested watersheds. Erosion control is one of the main goals of implementing BMPs, and as such, monitoring of suspended sediment should resume so an analysis can be done.

APPENDIX A: INDIVIDUAL HYDROGRAPH CHARACTERISTICS

Table A.1: WSA, WSB, and WSC Stormflow and Baseflow (1982-1993).

Date	WSA		WSB		WSC	
	Stormflow ($m^3 ha^{-1}$)	Baseflow ($m^3 ha^{-1}$)	Stormflow ($m^3 ha^{-1}$)	Baseflow ($m^3 ha^{-1}$)	Stormflow ($m^3 ha^{-1}$)	Baseflow ($m^3 ha^{-1}$)
February 8, 1982	376.2	139.8	257.3	130.8	270.4	191.7
February 16, 1982	213.5	79.6	155.0	39.9	266.3	110.2
March 15, 1982	281.1	81.3	145.9	24.4	272.7	83.1
March 31, 1982	87.8	56.5	83.1	35.6	133.7	74.1
May 21, 1982	7.3	4.7	7.1	6.1	9.1	10.3
May 28, 1982	3.3	2.9	4.6	2.7	6.9	5.6
June 4, 1982	6.3	4.7	7.5	4.3	10.5	7.4
July 28, 1982	1.9	0.3	1.9	1.4	1.3	0.4
August 5, 1982	6.1	2.0	6.6	2.4	4.8	2.2
September 13, 1982	13.2	3.9	9.7	2.6	5.3	1.1
September 25, 1982	2.4	1.1	2.1	1.1	1.7	0.9
November 20, 1982	15.9	3.6	12.0	2.1	7.0	0.9
November 30, 1982	35.5	10.5	28.9	6.8	24.7	4.3
December 5, 1982	31.5	13.0	27.0	11.9	25.4	8.9
December 15, 1982	79.1	16.8	68.6	11.5	115.9	30.1
January 21, 1983	114.4	24.8	118.8	34.2	100.5	23.4
February 10, 1983	125.6	33.7	123.9	29.6	132.0	37.4
April 14, 1983	116.3	23.6	131.9	34.7	120.9	32.5
May 3, 1983	176.6	54.6	173.7	54.4	173.7	54.8
May 13, 1983	412.4	200.2	375.7	173.2	371.4	169.7
May 22, 1983	138.2	96.4	163.4	100.7	149.1	72.3
June 3, 1983	10.8	1.9	7.7	1.7	7.7	1.2
June 4, 1983	55.7	18.4	66.6	21.3	69.3	18.9
July 3, 1983	0.6	0.2	1.7	0.1	1.8	0.2
July 5, 1983	2.1	2.0	3.1	2.0	1.9	1.6
July 18, 1983	1.0	0.5	0.8	0.3	0.8	0.5
August 2, 1983	1.2	0.5	0.7	0.2	0.8	0.2
August 11, 1983	3.3	0.7	3.4	1.2	3.1	1.0
August 27, 1983[1]	0.2	0.02	0.3	0.04	0.1	0.02
November 14, 1983	13.7	4.3	22.6	5.2	16.1	5.2
December 27, 1983	26.0	8.5	20.0	7.3	15.6	6.3
February 27, 1984	181.5	51.7	155.5	46.5	162.3	37.7
March 20, 1984	211.8	63.9	199.2	71.0	235.4	68.7
March 28, 1984	141.5	55.7	127.8	60.4	154.1	54.8
April 4, 1984	159.8	51.9	156.7	47.4	167.9	46.8
April 9, 1984	238.5	110.9	233.3	103.8	307.0	104.3
April 21, 1984	288.4	179.4	309.6	188.1	335.6	201.0
May 4, 1984	174.9	28.1	187.3	43.2	179.8	31.5
May 6, 1984	851.5	515.5	225.3	30.1	235.2	26.6
May 23, 1984	2.6	7.0	4.2	16.9	3.5	11.9
May 28, 1984	12.1	5.2	117.5	52.5	139.3	78.1

Table A.1: Continued

Date	WSA		WSB		WSC	
	Stormflow ($m^3 ha^{-1}$)	Baseflow ($m^3 ha^{-1}$)	Stormflow ($m^3 ha^{-1}$)	Baseflow ($m^3 ha^{-1}$)	Stormflow ($m^3 ha^{-1}$)	Baseflow ($m^3 ha^{-1}$)
July 26, 1984	1.5	0.21	2.6	0.37	5.2	1.67
July 27, 1984	2.6	2.00	49.0	9.44	64.6	16.34
July 30, 1984	0.6	0.76	9.9	6.55	19.4	8.25
August 22, 1984	4.1	0.25	26.4	16.50	52.4	38.27
November 4, 1984	8.5	2.87	99.7	19.85	113.1	24.06
November 18, 1984	128.3	42.01	357.2	266.85	403.6	233.03
November 28, 1984	69.4	25.23	144.6	97.83	148.1	88.68
December 20, 1984	121.3	30.74	187.5	42.08	199.9	35.04
December 24, 1984	114.5	39.04	166.3	54.76	212.0	68.36
January 3, 1985	117.9	32.87	189.3	56.16	225.2	58.87
February 11, 1985	154.8	66.42	192.3	87.70	188.0	86.58
May 15, 1985	2.2	1.14	5.0	3.42	10.2	5.90
June 5, 1985	5.6	3.88	20.5	6.86	19.7	7.93
June 10, 1985	3.1	1.24	9.3	3.16	8.5	3.93
June 11, 1985	47.1	10.07	163.9	45.65	149.6	70.13
July 10, 1985	3.4	1.04	8.3	14.89	12.1	18.76
July 30, 1985	1.4	0.12	1.9	1.23	2.0	1.58
August 1, 1985	6.9	2.73	21.9	14.48	21.3	15.71
August 17, 1985	3.3	0.78	14.7	6.09	12.8	6.24
August 25, 1985	2.4	1.35	3.6	1.27	16.9	9.89
August 30, 1985	9.1	4.52	58.1	46.61	74.4	42.13
September 26, 1985	0.8	0.07	4.9	9.78	8.0	9.80
November 2, 1985	115.0	35.72	343.7	142.47	360.8	131.10
December 12, 1985	135.9	46.26	174.9	86.88	176.5	111.00
February 2, 1986	347.5	74.94	223.8	34.20	454.6	96.87
April 28, 1986	8.4	4.71	10.5	11.03	21.4	21.15
May 11, 1986	8.2	4.27	25.6	18.10	18.6	11.36
July 2, 1986	3.2	1.26	9.5	2.01	9.9	9.74
July 20, 1986	2.4	1.33	3.0	0.81	13.2	11.26
July 26, 1986	1.9	0.61	3.3	1.05	11.0	12.44
October 1, 1986	6.3	2.64	6.9	2.92	12.5	7.47
November 5, 1986	17.7	4.18	45.1	5.26	64.7	7.10
November 8, 1986	215.8	78.71	135.6	8.89	414.5	140.20
November 10, 1986	49.6	50.07	89.5	82.43	124.3	131.59
December 8, 1986	217.4	116.84	236.1	106.37	305.4	154.28
January 18, 1987	185.9	186.25	207.8	141.95	267.3	140.65
February 22, 1987	146.3	36.88	163.4	38.99	163.6	38.65
February 26, 1987	308.2	127.11	302.2	177.45	334.3	154.83
March 18, 1987	108.3	78.54	105.6	81.91	88.1	96.71
March 30, 1987	473.3	147.49	501.0	158.93	544.6	193.83
May 12, 1987	2.2	5.16	4.2	11.79	8.1	19.57

Table A.1: Continued

Date	WSA		WSB		WSC	
	Stormflow ($m^3 ha^{-1}$)	Baseflow ($m^3 ha^{-1}$)	Stormflow ($m^3 ha^{-1}$)	Baseflow ($m^3 ha^{-1}$)	Stormflow ($m^3 ha^{-1}$)	Baseflow ($m^3 ha^{-1}$)
May 21, 1987	4.7	5.4	8.6	10.8	9.0	16.6
May 25, 1987	5.5	7.3	8.9	7.2	12.3	11.4
June 16, 1987	4.6	4.8	4.9	5.4	7.1	7.4
June 25, 1987	12.3	2.3	16.9	12.4	19.8	20.1
July 11, 1987	18.9	12.6	45.0	18.3	69.0	38.2
August 22, 1987	2.1	0.4	4.4	1.6	6.4	5.6
September 12, 1987	4.4	1.1	5.2	0.5	8.0	2.4
November 9, 1987	11.2	7.1	10.0	2.5	19.5	8.0
November 16, 1987	3.6	4.8	9.8	3.9	7.7	4.8
December 14, 1987	5.6	2.8	13.0	4.6	12.9	4.9
December 24, 1987	98.3	29.8	122.4	29.7	211.8	47.5
January 18, 1988	208.4	121.0	163.4	194.9	233.3	112.9
April 6, 1988	292.3	113.9	229.3	183.3	315.9	142.5
May 4, 1988	293.3	135.3	134.3	155.9	248.9	175.5
June 2, 1988	1.5	2.3	1.5	14.4	8.7	22.3
June 9, 1988	1.8	2.9	2.1	4.1	2.8	4.9
August 23, 1988	3.7	2.1	6.0	2.3	20.1	6.1
September 16, 1988	7.4	6.9	8.1	4.9	16.3	15.3
November 4, 1988	17.4	3.7	25.9	5.4	32.6	9.6
November 27, 1988	27.1	10.9	55.3	33.1	54.4	52.3
December 21, 1988	53.1	6.7	99.3	16.0	93.0	15.6
December 24, 1988	224.6	94.1	198.0	90.1	212.0	68.5
January 11, 1989	332.1	139.7	346.1	181.1	418.6	167.7
February 3, 1989	151.1	90.0	182.4	87.6	227.3	97.9
February 13, 1989	373.2	114.5	400.6	105.9	444.8	109.0
February 20, 1989	436.5	277.8	349.8	341.5	378.3	290.4
March 20, 1989	213.6	85.4	254.2	158.6	272.5	143.9
April 3, 1989	139.3	75.2	191.7	140.3	194.3	87.1
May 19, 1989	8.5	9.0	8.6	17.2	7.9	17.1
June 12, 1989	533.7	239.0	495.9	242.4	547.1	315.4
June 22, 1989	24.5	36.5	33.4	65.7	31.8	49.6
July 23, 1989	18.2	14.6	16.3	10.5	15.6	17.9
July 27, 1989	3.0	2.2	4.4	2.7	3.8	4.3
July 31, 1989	21.1	13.7	56.7	23.5	79.1	36.3
August 5, 1989	3.4	1.3	70.6	55.1	65.9	39.5
August 18, 1989	5.8	5.1	8.9	8.8	13.6	16.9
September 22, 1989	136.7	57.2	224.9	100.0	325.8	161.9
September 30, 1989	149.3	90.6	182.0	102.1	201.4	144.0
October 16, 1989	463.2	117.3	139.9	14.9	729.0	424.2
November 14, 1989	192.5	75.5	255.6	108.5	277.8	142.4
January 29, 1990	147.7	36.1	184.3	42.3	173.7	34.1

Table A.1: Continued

Date	WSA		WSB		WSC	
	Stormflow (m^3 ha^{-1})	Baseflow (m^3 ha^{-1})	Stormflow (m^3 ha^{-1})	Baseflow (m^3 ha^{-1})	Stormflow (m^3 ha^{-1})	Baseflow (m^3 ha^{-1})
February 3, 1990	265.4	105.5	291.7	98.5	317.1	84.9
February 9, 1990	197.2	119.9	259.5	128.1	274.0	115.5
February 15, 1990	173.5	109.5	183.5	204.3	197.9	153.8
March 16, 1990	212.1	76.8	275.6	122.5	213.5	78.3
April 6, 1990	129.5	48.9	127.1	51.8	142.6	55.8
May 26, 1990	2.3	2.0	2.5	2.2	2.5	7.2
May 28, 1990	36.4	16.6	41.5	13.8	46.9	24.2
June 2, 1990	55.1	26.6	56.6	19.0	70.0	26.0
June 21, 1990	6.5	9.7	4.0	6.1	7.3	7.5
July 30, 1990	0.6	1.2	1.5	3.5	3.0	5.3
August 8, 1990	1.8	0.4	4.5	8.9	6.6	5.5
August 29, 1990	1.9	2.6	2.3	4.4	4.0	5.7
September 9, 1990	4.9	1.6	2.3	3.8	3.8	3.7
September 12, 1990	1.0	1.8	1.9	3.6	2.5	3.8
October 4, 1990	3.4	3.0	12.1	8.4	12.6	10.6
December 2, 1990	117.5	70.3	186.7	107.0	230.1	105.7
December 20, 1990	278.8	103.2	384.4	202.1	330.0	111.9
December 27, 1990	94.1	65.5	128.3	76.9	136.1	71.2
December 30, 1990	98.5	135.5	130.1	180.7	168.0	153.6
January 6, 1991	276.9	170.7	311.2	173.2	293.7	166.5
February 6, 1991	173.4	50.0	189.5	48.6	161.4	47.7
February 13, 1991	138.2	40.9	152.6	38.6	157.1	36.4
February 17, 1991	108.5	13.0	477.9	219.6	607.2	230.2
March 22, 1991	189.4	63.6	204.8	76.8	200.6	68.4
March 29, 1991	277.7	105.7	262.0	95.6	257.2	88.2
April 15, 1991	178.5	72.5	209.9	72.0	204.5	59.0
April 19, 1991	185.8	194.7	183.9	205.7	175.5	113.8
May 9, 1991	12.5	8.8	9.6	16.4	3.3	2.9
May 18, 1991	4.1	4.1	14.5	20.7	4.2	5.2
May 27, 1991	4.5	5.0	6.6	7.3	4.9	3.9
May 29, 1991	20.8	13.4	25.7	11.9	16.5	10.1
June 22, 1991	32.5	3.9	77.3	38.5	58.2	26.1
June 25, 1991	143.0	61.9	152.3	82.9	132.7	68.3
July 10, 1991	3.2	1.8	2.9	3.2	2.4	3.1
July 12, 1991	16.8	19.3	28.2	23.4	27.4	13.5
August 7, 1991	14.2	10.9	16.9	9.2	12.5	11.0
October 5, 1991	8.8	1.7	12.6	6.8	7.3	1.8
October 15, 1991	11.9	14.2	31.0	24.3	10.1	11.3
November 21, 1991	94.2	48.1	108.2	69.1	88.4	63.7
December 13, 1991	121.3	109.1	128.4	149.5	172.3	80.5
December 28, 1991	254.4	129.4	261.7	156.7	259.6	122.5

Table A.1: Continued

Date	WSA		WSB		WSC	
	Stormflow (m^{3} ha^{-1})	Baseflow (m^{3} ha^{-1})	Stormflow (m^{3} ha^{-1})	Baseflow (m^{3} ha^{-1})	Stormflow (m^{3} ha^{-1})	Baseflow (m^{3} ha^{-1})
February 24, 1992	261.2	121.0	306.4	110.1	298.4	99.1
March 30, 1992	212.7	96.1	259.9	118.5	246.2	104.8
May 28, 1992	2.4	0.6	4.7	2.7	25.8	15.0
June 17, 1992	12.4	8.3	20.2	10.1	14.3	6.2
June 24, 1992	5.3	0.7	14.7	5.9	10.7	4.3
July 1, 1992	375.9	344.6	253.2	166.8	261.1	188.9
July 14, 1992	2.0	2.3	2.0	5.3	6.7	15.2
July 17, 1992	2.9	5.4	5.4	21.2	3.7	6.9
July 22, 1992	4.7	4.0	6.0	5.1	4.8	3.9
July 24, 1992	87.9	143.2	119.6	68.3	141.0	83.5
August 8, 1992	23.7	24.0	25.1	22.2	33.0	26.0
August 27, 1992	47.3	26.2	43.1	17.9	57.9	35.1
September 4, 1992	2.7	4.7	5.9	12.1	9.6	22.5
September 18, 1992	8.5	8.1	7.1	3.7	46.4	18.5
December 20, 1992	110.7	17.6	109.6	25.6	80.3	25.5
March 29, 1993	252.2	89.3	323.9	160.7	320.6	132.2
April 25, 1993	193.3	58.1	115.3	40.3	34.2	6.9
May 9, 1993	22.5	15.8	24.0	17.4	9.4	7.4
June 9, 1993	3.9	5.2	7.2	5.4	9.4	1.0
June 21, 1993	4.8	5.2	8.2	5.4	7.2	3.9
July 13, 1993	9.0	3.0	15.5	3.6	51.5	37.6
July 15, 1993	14.1	11.4	19.7	16.9	58.7	40.3
July 26, 1993	7.2	10.2	10.2	13.5	9.6	5.2
September 2, 1993	9.6	9.1	37.3	6.1	39.8	6.5
September 15, 1993	21.2	12.2	45.1	29.3	47.8	23.6
October 18, 1993	86.8	34.5	221.2	80.6	234.6	80.5
Mean ± Std. Dev. (Pre)	80.0±113.9	30.3±48.1	68.6±92.2	25.4±41.9	78.9±104.9	32.6±50.7
Mean ± Std. Dev. (Post)	98.5±130.5	46.7±69.1	109.6±118.6	55.8±66.2	126.9±142.8	58.2±68.4

[1] Final storm before treatment.

Table A.2: WSA, WSB, and WSC Stormflow and Baseflow (2002-2008).

Date	WSA		WSB		WSC	
	Stormflow ($m^3\ ha^{-1}$)	Baseflow ($m^3\ ha^{-1}$)	Stormflow ($m^3\ ha^{-1}$)	Baseflow ($m^3\ ha^{-1}$)	Stormflow ($m^3\ ha^{-1}$)	Baseflow ($m^3\ ha^{-1}$)
March 17, 2002	161.0	18.5	201.2	30.3	- -[1]	- -[1]
April 28, 2002	117.2	53.4	140.7	48.4	- -	- -
May 2, 2002	451.2	359.3	513.0	353.5	- -	- -
May 13, 2002	169.5	127.8	231.7	172.3	- -	- -
May 17, 2002	67.6	98.3	130.5	163.4	- -	- -
June 6, 2002	11.7	13.5	19.3	18.0	- -	- -
July 19, 2002	13.4	9.1	9.5	6.3	- -	- -
September 25, 2002	14.9	8.9	8.6	1.5	- -	- -
October 15, 2002	8.1	5.6	3.5	1.7	- -	- -
October 29, 2002	32.9	13.4	38.8	7.0	- -	- -
November 5, 2002	31.3	16.2	40.9	9.6	- -	- -
November 10, 2002	27.8	18.2	105.3	23.3	- -	- -
December 10, 2002	105.4	10.7	119.5	10.6	- -	- -
December 13, 2002	178.8	46.8	204.7	35.1	- -	- -
December 19, 2002	53.3	35.9	53.7	39.0	- -	- -
January 1, 2003	85.7	53.0	77.4	55.4	- -	- -
February 3, 2003	121.0	46.1	121.3	42.3	- -	- -
April 6, 2003	131.1	11.9	147.3	13.1	- -	- -
April 17, 2003	106.9	56.9	112.8	112.0	- -	- -
May 8, 2003	40.7	12.4	81.1	53.4	- -	- -
June 6, 2003	54.2	24.3	84.1	29.9	- -	- -
June 11, 2003	2.2	1.9	8.4	6.6	- -	- -
July 10, 2003	4.3	7.3	5.3	9.0	- -	- -
August 3, 2003	2.2	0.6	4.0	1.3	- -	- -
August 17, 2003	4.2	6.5	13.1	9.5	- -	- -
September 3, 2003	107.3	88.1	113.9	76.0	- -	- -
September 22, 2003	7.4	8.6	2.8	2.7	- -	- -
November 12, 2003	19.1	6.1	23.5	7.8	- -	- -
November 18, 2003	201.6	91.8	215.8	85.2	- -	- -
November 28, 2003	75.3	43.5	74.3	41.2	- -	- -
December 10, 2003	74.0	23.2	91.7	23.6	- -	- -
January 17, 2004	158.2	68.3	177.3	96.3	- -	- -
February 2, 2004	80.3	17.2	101.5	25.7	- -	- -
February 5, 2004	120.8	6.1	71.2	4.8	- -	- -
March 5, 2004	212.1	173.7	256.0	157.5	- -	- -
May 16, 2004	4.6	6.6	3.1	5.6	- -	- -
May 24, 2004	4.4	4.8	6.5	3.5	- -	- -
May 26, 2004	90.1	14.9	88.2	12.9	- -	- -
May 27, 2004	180.1	90.0	221.8	60.2	- -	- -

Table A.2: Continued

Date	WSA		WSB		WSC	
	Stormflow (m^3 ha^{-1})	Baseflow (m^3 ha^{-1})	Stormflow (m^3 ha^{-1})	Baseflow (m^3 ha^{-1})	Stormflow (m^3 ha^{-1})	Baseflow (m^3 ha^{-1})
June 15, 2004	148.8	118.0	290.3	226.8	- -	- -
June 22, 2004	27.7	25.7	35.9	35.1	- -	- -
June 25, 2004	93.5	47.1	128.9	73.2	- -	- -
July 6, 2004	7.6	3.6	9.0	6.1	- -	- -
July 26, 2004	1.6	0.2	3.8	0.8	- -	- -
July 27, 2004	20.8	11.8	13.1	5.3	- -	- -
July 31, 2004	7.6	7.0	2.9	3.8	- -	- -
August 5, 2004	9.2	16.2	11.6	15.0	- -	- -
September 7, 2004	128.1	57.6	128.3	53.2	- -	- -
September 16, 2004	346.5	295.1	409.7	225.7	- -	- -
October 13, 2004	9.7	6.9	12.6	4.8	- -	- -
October 18, 2004	123.1	110.3	152.2	81.4	- -	- -
October 27, 2004	191.3	107.0	188.8	111.1	- -	- -
November 4, 2004	231.8	172.5	208.3	120.6	- -	- -
November 11, 2004	52.6	52.2	38.1	50.9	- -	- -
November 30, 2004	328.2	91.1	363.8	116.6	- -	- -
December 9, 2004	299.0	185.0	324.1	149.2	- -	- -
December 23, 2004	20.2	16.8	34.9	69.3	- -	- -
April 29, 2005	307.7	206.3	399.4	825.5	495.9	364.5
May 19, 2005	31.6	73.3	51.4	105.9	28.5	31.7
May 22, 2005	49.6	60.6	87.2	115.0	26.2	29.9
June 3, 2005	104.4	133.5	121.2	141.5	42.2	47.4
June 20, 2005	6.4	3.3	29.6	30.9	17.4	12.2
July 1, 2005	7.3	10.5	4.6	4.4	4.1	4.3
July 7, 2005	8.8	13.6	1.0	2.8	30.6	4.1
July 17, 2005	26.9	6.5	29.4	7.2	17.4	8.5
July 18, 2005	33.4	28.9	28.4	29.2	32.9	32.2
July 27, 2005	4.6	9.9	1.1	2.3	8.9	14.6
August 5, 2005	4.4	10.1	2.4	2.2	2.4	4.4
August 16, 2005	2.5	4.6	0.7	1.3	0.9	2.0
August 19, 2005	5.3	10.6	1.7	1.2	3.1	4.4
December 3, 2005	3.3	0.6	3.1	0.3	21.7	4.2
December 15, 2005	24.6	5.8	13.0	1.8	26.0	9.9
January 17, 2006	53.8	11.8	86.0	15.4	63.3	6.8
January 23, 2006	126.0	99.3	185.8	72.1	271.3	70.9
March 13, 2006	104.3	24.5	143.6	17.0	149.8	37.8
May 2, 2006	7.5	19.7	13.0	29.0	53.6	29.3
May 25, 2006	18.1	12.8	14.5	8.1	45.6	13.4

Table A.2: Continued

Date	WSA		WSB		WSC	
	Stormflow (m^3 ha^{-1})	Baseflow (m^3 ha^{-1})	Stormflow (m^3 ha^{-1})	Baseflow (m^3 ha^{-1})	Stormflow (m^3 ha^{-1})	Baseflow (m^3 ha^{-1})
May 31, 2006	29.5	15.7	57.5	10.4	82.9	11.4
July 5, 2006	63.0	21.6	98.1	35.3	139.2	43.5
September 23, 2006	5.1	0.4	8.8	0.6	9.4	0.6
September 23, 2006	10.0	1.8	22.9	6.1	23.3	4.9
September 30, 2006	4.3	2.3	10.4	4.6	9.8	3.4
October 26, 2006	128.0	40.9	194.4	44.7	268.5	110.6
March 28, 2007	37.0	16.4	8.1	9.6	18.4	6.9
May 16, 2007	4.1	2.1	8.7	8.6	26.7	11.1
June 1, 2007	6.8	2.7	6.0	2.6	42.1	8.6
June 5, 2007	12.1	5.2	11.1	5.3	22.8	15.3
June 18, 2007	1.0	0.3	0.1	0.3	2.4	1.3
June 29, 2007	7.0	13.1	1.9	2.4	9.2	9.0
August 3, 2007	2.3	1.5	0.7	0.5	9.8	3.8
November 14, 2007	15.8	4.8	7.7	1.4	21.7	4.4
November 26, 2007	4.2	1.7	7.3	1.0	22.1	9.5
December 10, 2007	12.4	2.7	20.0	2.2	38.0	6.1
December 13, 2007	24.0	4.9	43.9	11.6	50.9	15.7
December 20, 2007	4.8	3.1	26.8	10.8	41.5	21.9
January 29, 2008	79.6	14.6	133.5	16.4	157.1	31.5
February 6, 2008	73.5	21.1	128.7	21.9	135.3	32.7
May 11, 2008	5.4	3.5	12.0	11.0	13.9	5.9
June 3, 2008	5.6	4.1	8.9	5.3	11.9	20.9
August 26, 2008	3.5	0.7	1.8	0.1	4.4	0.9
November 14, 2008	5.8	1.5	25.0	2.7	13.7	2.4
December 10, 2008	6.9	1.0	29.7	1.4	23.1	1.4
December 10, 2008	17.6	4.6	77.0	9.8	37.1	7.9
December 16, 2008	25.5	3.5	35.8	11.7	52.7	11.1
Mean ± Std. Dev. (02-04)	94.4±98.5	53.1±70.8	110.2±113.2	56.2±69.8		
Mean ± Std. Dev. (05-08)	32.4±53.0	20.0±38.1	46.9±73.0	35.1±121.7	56.0±89.5	24.1±54.6

[1] No data available.

TableA.3: WSA, WSB, and WSC peak flow (m^3 s^{-1} ha^{-1} $x10^{-2}$) (1982-1993).

Date	WSA	WSB	WSC
February 8, 1982	1.81	0.94	1.10
February 16, 1982	0.30	0.27	0.25
March 15, 1982	0.46	0.45	0.45
March 31, 1982	0.12	0.13	0.08
May 21, 1982	0.09	0.05	0.07
May 28, 1982	0.02	0.03	0.02
June 4, 1982	0.03	0.01	0.02
July 28, 1982	0.04	0.02	0.04
August 5, 1982	0.07	0.05	0.05
September 13, 1982	0.40	0.27	0.18
September 25, 1982	0.01	0.00	0.01
November 20, 1982	0.01	0.01	0.01
November 30, 1982	0.03	0.03	0.02
December 5, 1982	0.03	0.02	0.02
December 15, 1982	0.09	0.07	0.07
January 21, 1983	0.06	0.08	0.05
February 10, 1983	0.09	0.09	0.06
April 14, 1983	0.10	0.09	0.06
May 3, 1983	0.18	0.21	0.18
May 13, 1983	0.82	0.55	0.61
May 22, 1983	0.49	0.47	0.30
June 3, 1983	0.14	0.09	0.14
June 4, 1983	0.16	0.13	0.15
July 3, 1983	0.00	0.04	0.05
July 5, 1983	0.02	0.01	0.01
July 18, 1983	0.01	0.01	0.02
August 2, 1983	0.03	0.02	0.02
August 11, 1983	0.10	0.10	0.07
August 27, 1983[1]	0.01	0.00	0.01
November 14, 1983	0.02	0.02	0.02
December 27, 1983	0.01	0.01	0.01
February 27, 1984	0.19	0.19	0.12
March 20, 1984	0.20	0.22	0.13
March 28, 1984	0.07	0.06	0.06
April 4, 1984	0.08	0.09	0.08
April 9, 1984	0.49	0.57	0.49
April 21, 1984	0.82	0.92	0.69
May 4, 1984	0.37	0.38	0.29
May 6, 1984	3.50	0.98	0.86
May 23, 1984	0.02	0.02	0.02
May 28, 1984	0.02	0.05	0.04

Table A.3: Continued

Date	WSA	WSB	WSC
July 26, 1984	0.04	0.04	0.06
July 27, 1984	0.03	0.05	0.06
July 30, 1984	0.00	0.02	0.04
August 22, 1984	0.11	0.08	0.15
November 4, 1984	0.03	0.07	0.07
November 18, 1984	0.27	0.68	0.70
November 28, 1984	0.07	0.14	0.10
December 20, 1984	0.14	0.19	0.13
December 24, 1984	0.16	0.22	0.17
January 3, 1985	0.09	0.11	0.10
February 11, 1985	0.10	0.16	0.11
May 15, 1985	0.04	0.04	0.05
June 5, 1985	0.08	0.08	0.12
June 10, 1985	0.03	0.04	0.05
June 11, 1985	0.10	0.19	0.18
July 10, 1985	0.09	0.08	0.07
July 30, 1985	0.01	0.01	0.01
August 1, 1985	0.08	0.08	0.07
August 17, 1985	0.03	0.03	0.02
August 25, 1985	0.02	0.03	0.05
August 30, 1985	0.17	0.12	0.08
September 26, 1985	0.01	0.02	0.02
November 2, 1985	0.07	0.21	0.25
December 12, 1985	0.09	0.11	0.08
February 2, 1986	0.28	0.30	0.25
April 28, 1986	0.02	0.02	0.02
May 11, 1986	0.09	0.05	0.05
July 2, 1986	0.04	0.03	0.04
July 20, 1986	0.07	0.04	0.06
July 26, 1986	0.07	0.03	0.05
October 1, 1986	0.03	0.01	0.03
November 5, 1986	0.05	0.06	0.06
November 8, 1986	0.67	0.61	1.04
November 10, 1986	0.13	0.17	0.18
December 8, 1986	0.34	0.35	0.37
January 18, 1987	0.46	0.41	0.35
February 22, 1987	0.08	0.07	0.08
February 26, 1987	0.27	0.27	0.22
March 18, 1987	0.03	0.03	0.03
March 30, 1987	0.20	0.24	0.26
May 12, 1987	0.03	0.02	0.02
May 21, 1987	0.03	0.03	0.04

Table A.3: Continued

Date	WSA	WSB	WSC
May 25, 1987	0.04	0.03	0.05
June 16, 1987	0.05	0.03	0.07
June 25, 1987	0.21	0.07	0.09
July 11, 1987	0.08	0.05	0.10
August 22, 1987	0.02	0.02	0.05
September 12, 1987	0.02	0.01	0.02
November 9, 1987	0.03	0.02	0.03
November 16, 1987	0.01	0.01	0.01
December 14, 1987	0.01	0.01	0.02
December 24, 1987	0.08	0.15	0.14
January 18, 1988	0.54	0.33	0.33
April 6, 1988	0.28	0.20	0.19
May 4, 1988	0.36	0.43	0.51
June 2, 1988	0.01	0.01	0.02
June 9, 1988	0.01	0.01	0.01
August 23, 1988	0.05	0.01	0.02
September 16, 1988	0.08	0.03	0.09
November 4, 1988	0.02	0.01	0.02
November 27, 1988	0.01	0.02	0.02
December 21, 1988	0.10	0.13	0.08
December 24, 1988	0.88	0.70	0.54
January 11, 1989	0.35	0.32	0.32
February 3, 1989	0.15	0.14	0.13
February 13, 1989	0.20	0.21	0.22
February 20, 1989	0.73	0.60	0.54
March 20, 1989	0.27	0.22	0.19
April 3, 1989	0.07	0.07	0.06
May 19, 1989	0.02	0.02	0.03
June 12, 1989	1.53	1.07	1.36
June 22, 1989	0.12	0.07	0.09
July 23, 1989	0.33	0.10	0.21
July 27, 1989	0.03	0.03	0.04
July 31, 1989	0.09	0.14	0.30
August 5, 1989	0.03	0.07	0.06
August 18, 1989	0.17	0.09	0.15
September 22, 1989	0.16	0.20	0.21
September 30, 1989	0.29	0.32	0.30
October 16, 1989	1.39	0.80	0.83
November 14, 1989	0.21	0.21	0.18
January 29, 1990	0.15	0.18	0.11
February 3, 1990	0.27	0.28	0.25
February 9, 1990	0.34	0.33	0.30

Table A.3: Continued

Date	WSA	WSB	WSC
February 15, 1990	0.30	0.29	0.21
March 16, 1990	0.21	0.20	0.14
April 6, 1990	0.04	0.04	0.04
May 26, 1990	0.02	0.01	0.02
May 28, 1990	0.07	0.05	0.11
June 2, 1990	0.20	0.09	0.13
June 21, 1990	0.08	0.05	0.06
July 30, 1990	0.01	0.01	0.02
August 8, 1990	0.02	0.01	0.02
August 29, 1990	0.02	0.01	0.01
September 9, 1990	0.11	0.05	0.08
September 12, 1990	0.01	0.01	0.01
October 4, 1990	0.11	0.07	0.08
December 2, 1990	0.10	0.16	0.13
December 20, 1990	0.28	0.39	0.26
December 27, 1990	0.21	0.29	0.24
December 30, 1990	0.18	0.23	0.22
January 6, 1991	0.13	0.13	0.10
February 6, 1991	0.08	0.08	0.07
February 13, 1991	0.09	0.11	0.10
February 17, 1991	0.23	0.45	0.38
March 22, 1991	0.12	0.12	0.10
March 29, 1991	0.13	0.13	0.11
April 15, 1991	0.27	0.26	0.21
April 19, 1991	0.49	0.41	0.16
May 9, 1991	0.04	0.03	0.03
May 18, 1991	0.03	0.02	0.03
May 27, 1991	0.04	0.03	0.04
May 29, 1991	0.16	0.09	0.08
June 22, 1991	0.22	0.29	0.26
June 25, 1991	0.22	0.34	0.22
July 10, 1991	0.10	0.06	0.06
July 12, 1991	0.22	0.12	0.11
August 7, 1991	0.22	0.13	0.21
October 5, 1991	0.19	0.09	0.14
October 15, 1991	0.02	0.02	0.03
November 21, 1991	0.17	0.21	0.15
December 13, 1991	0.10	0.11	0.10
December 28, 1991	0.15	0.16	0.12
February 24, 1992	0.21	0.22	0.17
March 30, 1992	0.10	0.10	0.08
May 28, 1992	0.02	0.01	0.03

Table A.3: Continued

Date	WSA	WSB	WSC
June 17, 1992	0.04	0.03	0.03
June 24, 1992	0.11	0.05	0.06
July 1, 1992	0.88	0.38	0.62
July 14, 1992	0.05	0.05	0.06
July 17, 1992	0.02	0.02	0.02
July 22, 1992	0.06	0.07	0.04
July 24, 1992	0.45	0.80	0.81
August 8, 1992	0.25	0.18	0.09
August 27, 1992	0.21	0.11	0.13
September 4, 1992	0.04	0.02	0.03
September 18, 1992	0.05	0.02	0.03
December 20, 1992	0.13	0.13	0.12
March 29, 1993	0.22	0.36	0.74
April 25, 1993	0.07	0.05	0.02
May 9, 1993	0.21	0.14	0.18
June 9, 1993	0.11	0.05	0.15
June 21, 1993	0.14	0.05	0.15
July 13, 1993	0.10	0.14	2.42
July 15, 1993	0.02	0.03	0.11
July 26, 1993	0.30	0.40	0.38
September 2, 1993	0.05	0.14	0.15
September 15, 1993	0.05	0.14	0.15
October 18, 1993	0.05	0.15	0.16
Mean ± Std. Dev. (Pre)	0.20±0.36	0.15±0.21	0.14±0.23
Mean ± Std. Dev. (Post)	0.18±0.34	0.16±0.20	0.18±0.27

[1] Final storm before treatment.

Table A.4: WSA, WSB, and WSC peak flow ($m^3 s^{-1} ha^{-1} x 10^{-2}$) (2002-2008).

Date	WSA	WSB	WSC
March 17, 2002	0.34	0.46	- -[1]
April 28, 2002	0.15	0.15	- -
May 2, 2002	1.78	1.59	- -
May 13, 2002	0.50	0.64	- -
May 17, 2002	0.11	0.11	- -
June 6, 2002	0.03	0.03	- -
July 19, 2002	0.20	0.07	- -
September 25, 2002	0.03	0.01	- -
October 15, 2002	0.01	0.00	- -
October 29, 2002	0.10	0.09	- -
November 5, 2002	0.03	0.04	- -
November 10, 2002	0.05	0.09	- -
December 10, 2002	0.13	0.13	- -
December 13, 2002	0.17	0.19	- -
December 19, 2002	0.03	0.04	- -
January 1, 2003	0.03	0.03	- -
February 3, 2003	0.05	0.06	- -
April 6, 2003	0.21	0.25	- -
April 17, 2003	0.06	0.08	- -
May 8, 2003	0.11	0.09	- -
June 6, 2003	0.12	0.14	- -
June 11, 2003	0.05	0.03	- -
July 10, 2003	0.02	0.02	- -
August 3, 2003	0.02	0.01	- -
August 17, 2003	0.07	0.03	- -
September 3, 2003	0.46	0.56	- -
September 22, 2003	0.03	0.01	- -
November 12, 2003	0.04	0.02	- -
November 18, 2003	0.57	0.69	- -
November 28, 2003	0.04	0.04	- -
December 10, 2003	0.05	0.05	- -
January 17, 2004	0.17	0.15	- -
February 2, 2004	0.06	0.08	- -
February 5, 2004	0.59	0.53	- -
March 5, 2004	0.72	0.58	- -
May 16, 2004	0.02	0.01	- -
May 24, 2004	0.06	0.02	- -
May 26, 2004	0.40	0.30	- -
May 27, 2004	0.99	0.83	- -
June 15, 2004	0.40	0.69	- -
June 22, 2004	0.21	0.30	- -

Table A.4: Continued

Date	WSA	WSB	WSC
June 25, 2004	0.06	0.08	- -
July 6, 2004	0.05	0.05	- -
July 26, 2004	0.04	0.05	- -
July 27, 2004	0.07	0.09	- -
July 31, 2004	0.03	0.02	- -
August 5, 2004	0.11	0.08	- -
September 7, 2004	0.26	0.29	- -
September 16, 2004	0.97	1.28	- -
October 13, 2004	0.17	0.09	- -
October 18, 2004	0.54	0.61	- -
October 27, 2004	0.33	0.40	- -
November 4, 2004	0.98	0.42	- -
November 11, 2004	0.03	0.03	- -
November 30, 2004	0.36	0.51	- -
December 9, 2004	0.48	0.52	- -
December 23, 2004	0.03	0.03	- -
April 29, 2005	1.87	1.67	1.94
May 19, 2005	0.09	0.12	0.08
May 22, 2005	0.07	0.11	0.07
June 3, 2005	0.34	0.22	0.08
June 20, 2005	0.10	0.11	0.08
July 1, 2005	0.07	0.05	0.04
July 7, 2005	0.01	0.00	0.02
July 17, 2005	0.72	0.81	0.96
July 18, 2005	0.20	0.14	0.19
July 27, 2005	0.05	0.01	0.03
August 5, 2005	0.11	0.06	0.07
August 16, 2005	0.02	0.003	0.005
August 19, 2005	0.05	0.01	0.01
December 3, 2005	0.01	0.004	0.02
December 15, 2005	0.03	0.01	0.03
January 17, 2006	0.09	0.10	0.10
January 23, 2006	0.81	0.49	0.40
March 13, 2006	0.11	0.12	0.10
May 2, 2006	0.04	0.02	0.07
May 25, 2006	0.03	0.02	0.06
May 31, 2006	0.33	0.15	0.17
July 5, 2006	0.16	0.17	0.21
September 23, 2006	0.04	0.03	0.04
September 23, 2006	0.03	0.03	0.04
September 30, 2006	0.02	0.01	0.01
October 26, 2006	0.31	0.33	0.44

Table A.4: Continued

Date	WSA	WSB	WSC
March 28, 2007	0.02	0.01	0.03
May 16, 2007	0.04	0.02	0.08
June 1, 2007	0.20	0.06	0.10
June 5, 2007	0.14	0.06	0.24
June 18, 2007	0.03	0.004	0.05
June 29, 2007	0.03	0.01	0.06
August 3, 2007	0.03	0.00	0.05
November 14, 2007	0.04	0.01	0.04
November 26, 2007	0.03	0.01	0.06
December 10, 2007	0.03	0.04	0.05
December 13, 2007	0.05	0.07	0.09
December 20, 2007	0.01	0.01	0.02
January 29, 2008	0.07	0.09	0.13
February 6, 2008	0.08	0.10	0.13
May 11, 2008	0.01	0.01	0.03
June 3, 2008	0.05	0.02	0.08
August 26, 2008	0.01	0.00	0.01
November 14, 2008	0.01	0.03	0.02
December 10, 2008	0.03	0.06	0.06
December 10, 2008	0.04	0.08	0.07
December 16, 2008	0.05	0.07	0.06
Mean ± Std. Dev. (02-04)	0.24±0.33	0.24±0.32	- -
Mean ± Std. Dev. (05-08)	0.14±0.30	0.12±0.27	0.14±0.31

[1] No data available.

Table A.5: WSA, WSB, and WSC discharge volume as % of rainfall (1982-1993).

Date	WSA	WSB	WSC
February 8, 1982	76.4	52.2	54.9
February 16, 1982	72.5	52.6	90.4
March 15, 1982	77.9	40.4	75.6
March 31, 1982	37.6	35.6	57.2
May 21, 1982	2.4	2.3	2.9
May 28, 1982	2.0	2.8	4.2
June 4, 1982	3.9	4.6	6.4
July 28, 1982	0.5	0.5	0.3
August 5, 1982	1.6	1.7	1.3
September 13, 1982	2.1	1.6	0.8
September 25, 1982	1.5	1.3	1.1
November 20, 1982	7.5	5.6	3.3
November 30, 1982	26.9	21.9	18.7
December 5, 1982	20.6	17.7	16.7
December 15, 1982	54.6	47.4	80.1
January 21, 1983	42.5	44.1	37.3
February 10, 1983	56.8	56.1	59.7
April 14, 1983	49.2	55.8	51.2
May 3, 1983	51.5	50.6	50.6
May 13, 1983	44.1	58.7	57.6
May 22, 1983	33.0	39.0	35.6
June 3, 1983	3.9	2.7	2.8
June 4, 1983	37.2	44.4	46.2
July 3, 1983	0.8	0.5	0.6
July 5, 1983	1.6	2.3	1.5
July 18, 1983	0.8	0.7	0.6
August 2, 1983	0.5	0.3	0.3
August 11, 1983	1.0	1.1	1.0
August 27, 1983[1]	0.1	0.2	0.1
November 14, 1983	4.5	7.5	5.3
December 27, 1983	16.0	12.3	9.6
February 27, 1984	43.8	37.6	39.2
March 20, 1984	75.8	71.3	84.3
March 28, 1984	58.6	53.0	63.9
April 4, 1984	57.7	56.6	60.6
April 9, 1984	57.6	56.4	74.2
April 21, 1984	64.5	69.2	75.1
May 4, 1984	74.1	79.3	76.1
May 6, 1984	62.5	75.6	96.0
May 23, 1984	2.3	3.6	3.0
May 28, 1984	5.5	53.2	63.1

Table A.5: Continued

Date	WSA	WSB	WSC
July 26, 1984	0.7	1.2	2.4
July 27, 1984	1.6	30.1	39.8
July 30, 1984	0.5	8.6	17.0
August 22, 1984	1.7	6.8	13.5
November 4, 1984	4.2	49.7	56.4
November 18, 1984	19.8	55.1	62.3
November 28, 1984	25.3	52.7	54.0
December 20, 1984	54.9	84.8	90.4
December 24, 1984	52.4	76.1	97.0
January 3, 1985	43.0	69.0	82.1
February 11, 1985	34.6	43.0	42.1
May 15, 1985	1.2	2.7	5.5
June 5, 1985	3.1	11.2	10.8
June 10, 1985	1.4	4.1	3.7
June 11, 1985	16.4	57.1	52.1
July 10, 1985	1.2	3.0	4.3
July 30, 1985	0.5	0.7	0.7
August 1, 1985	1.8	5.7	5.6
August 17, 1985	2.3	10.2	8.9
August 25, 1985	1.8	2.7	12.8
August 30, 1985	2.3	14.8	18.9
September 26, 1985	0.5	3.3	5.4
November 2, 1985	18.4	55.0	57.7
December 12, 1985	48.6	62.6	63.2
February 2, 1986	72.4	85.4	94.7
April 28, 1986	6.1	7.6	15.6
May 11, 1986	3.2	9.8	7.1
July 2, 1986	1.7	5.0	5.2
July 20, 1986	1.5	1.8	8.0
July 26, 1986	1.1	1.8	6.0
October 1, 1986	3.8	4.2	7.6
November 5, 1986	5.9	15.0	21.6
November 8, 1986	26.3	45.7	50.5
November 10, 1986	21.2	38.3	53.2
December 8, 1986	64.4	69.9	90.4
January 18, 1987	51.9	58.0	74.6
February 22, 1987	61.9	69.2	69.3
February 26, 1987	74.9	73.4	81.3
March 18, 1987	85.3	83.1	69.4
March 30, 1987	65.4	69.2	75.2
May 12, 1987	1.6	3.0	5.8
May 21, 1987	2.5	4.6	4.8

Table A.5: Continued

Date	WSA	WSB	WSC
May 25, 1987	3.6	5.9	8.1
June 16, 1987	3.3	3.5	5.1
June 25, 1987	3.3	4.6	5.3
July 11, 1987	6.6	15.7	24.1
August 22, 1987	1.1	2.3	3.4
September 12, 1987	2.6	3.0	4.7
November 9, 1987	2.8	2.5	4.9
November 16, 1987	2.3	6.2	4.9
December 14, 1987	4.1	9.5	9.4
December 24, 1987	12.4	15.5	26.8
January 18, 1988	55.1	43.2	61.6
April 6, 1988	81.1	63.6	87.6
May 4, 1988	58.3	27.8	49.5
June 2, 1988	1.2	1.3	7.1
June 9, 1988	1.4	1.6	2.1
August 23, 1988	0.8	1.3	4.5
September 16, 1988	1.5	1.6	3.2
November 4, 1988	5.3	7.8	9.9
November 27, 1988	17.8	36.3	35.7
December 21, 1988	17.7	33.1	31.0
December 24, 1988	70.2	61.9	66.2
January 11, 1989	64.7	67.5	81.6
February 3, 1989	48.7	58.8	73.3
February 13, 1989	61.5	66.0	73.3
February 20, 1989	86.4	69.2	74.8
March 20, 1989	49.2	58.5	62.7
April 3, 1989	57.1	78.6	79.7
May 19, 1989	5.9	5.9	5.4
June 12, 1989	51.0	47.4	52.3
June 22, 1989	16.7	22.6	21.6
July 23, 1989	7.2	6.5	6.2
July 27, 1989	1.5	2.2	1.9
July 31, 1989	8.1	21.7	30.2
August 5, 1989	13.0	22.8	21.3
August 18, 1989	1.5	2.4	3.6
September 22, 1989	24.2	39.9	57.8
September 30, 1989	40.5	49.4	54.7
October 16, 1989	45.3	49.0	71.2
November 14, 1989	54.1	71.9	78.1
January 29, 1990	56.4	70.4	66.4
February 3, 1990	73.6	80.9	87.9
February 9, 1990	55.8	73.5	77.6

Table A.5: Continued

Date	WSA	WSB	WSC
February 15, 1990	56.0	59.2	63.9
March 16, 1990	54.9	71.4	55.3
April 6, 1990	50.0	49.1	55.0
May 26, 1990	1.6	1.7	1.8
May 28, 1990	12.5	14.2	16.1
June 2, 1990	16.3	16.7	20.7
June 21, 1990	3.3	2.0	3.7
July 30, 1990	0.6	1.3	2.6
August 8, 1990	1.0	2.3	3.4
August 29, 1990	1.1	1.4	2.4
September 9, 1990	3.0	1.4	2.3
September 12, 1990	0.9	1.6	2.1
October 4, 1990	1.2	4.3	4.5
December 2, 1990	34.8	55.3	68.1
December 20, 1990	54.6	75.3	64.6
December 27, 1990	24.7	33.7	35.7
December 30, 1990	31.8	42.0	54.2
January 6, 1991	85.8	96.5	91.1
February 6, 1991	73.4	80.2	68.3
February 13, 1991	46.5	51.3	52.9
February 17, 1991	61.9	76.8	97.6
March 22, 1991	55.6	60.2	58.9
March 29, 1991	81.0	76.4	75.0
April 15, 1991	66.9	78.7	76.7
April 19, 1991	63.6	62.9	60.1
May 9, 1991	7.0	5.4	1.8
May 18, 1991	2.2	7.8	2.3
May 27, 1991	2.7	4.0	3.0
May 29, 1991	7.1	8.8	5.7
June 22, 1991	10.7	25.4	19.1
June 25, 1991	40.2	42.8	37.3
July 10, 1991	1.9	1.7	1.4
July 12, 1991	5.5	9.2	9.0
August 7, 1991	4.6	5.5	4.0
October 5, 1991	2.3	3.3	1.9
October 15, 1991	5.5	14.4	4.7
November 21, 1991	15.8	18.1	14.8
December 13, 1991	50.3	53.2	71.4
December 28, 1991	62.2	64.0	63.5
February 24, 1992	65.1	76.4	74.3
March 30, 1992	61.1	74.7	70.8
May 28, 1992	4.6	7.0	6.6

Table A.5: Continued

Date	WSA	WSB	WSC
June 17, 1992	8.1	13.2	9.4
June 24, 1992	1.9	5.2	3.8
July 1, 1992	44.3	31.3	32.3
July 14, 1992	0.8	0.8	2.7
July 17, 1992	2.6	4.9	3.3
July 22, 1992	2.7	3.4	2.7
July 24, 1992	15.2	24.1	24.3
August 8, 1992	10.4	11.0	14.5
August 27, 1992	9.5	8.6	11.6
September 4, 1992	2.3	5.0	8.2
September 18, 1992	3.4	2.8	18.5
December 20, 1992	37.9	37.3	27.5
March 29, 1993	62.1	79.7	78.9
April 25, 1993	89.5	53.4	15.8
May 9, 1993	9.4	10.1	3.9
June 9, 1993	1.8	3.3	4.4
June 21, 1993	2.2	3.8	3.3
July 13, 1993	1.5	2.7	8.8
July 15, 1993	8.3	11.6	34.5
July 26, 1993	1.9	2.8	2.6
September 2, 1993	3.1	12.1	13.0
September 15, 1993	3.7	7.8	8.3
October 18, 1993	23.7	60.5	64.2
Mean ± Std. Dev. (Pre)	23.9±26.5	21.7±22.8	25.5±29.2
Mean ± Std. Dev. (Post)	26.0±27.5	31.7±29.1	34.7±31.2

[1] Final storm before treatment.

Table A.6: WSA, WSB, and WSC discharge volume as % of rainfall (2002-2008).

Date	WSA	WSB	WSC
March 17, 2002	68.9	86.1	- -[1]
April 28, 2002	75.7	90.8	- -
May 2, 2002	75.9	86.3	- -
May 13, 2002	40.2	54.9	- -
May 17, 2002	23.0	44.3	- -
June 6, 2002	4.2	7.0	- -
July 19, 2002	7.4	5.2	- -
September 25, 2002	4.0	2.3	- -
October 15, 2002	5.1	2.2	- -
October 29, 2002	23.1	27.3	- -
November 5, 2002	17.6	23.0	- -
November 10, 2002	17.4	65.8	- -
December 10, 2002	67.0	75.9	- -
December 13, 2002	69.0	79.0	- -
December 19, 2002	36.2	36.5	- -
January 1, 2003	76.7	69.3	- -
February 3, 2003	86.6	86.8	- -
April 6, 2003	46.9	52.7	- -
April 17, 2003	41.7	44.0	- -
May 8, 2003	20.3	40.4	- -
June 6, 2003	17.9	27.8	- -
June 11, 2003	1.8	6.9	- -
July 10, 2003	1.9	2.4	- -
August 3, 2003	1.3	2.5	- -
August 17, 2003	2.6	7.9	- -
September 3, 2003	16.8	17.9	- -
September 22, 2003	2.4	0.9	- -
November 12, 2003	12.6	15.4	- -
November 18, 2003	43.6	46.7	- -
November 28, 2003	48.6	47.9	- -
December 10, 2003	53.0	65.6	- -
January 17, 2004	58.2	65.2	- -
February 2, 2004	51.8	65.5	- -
February 5, 2004	35.5	20.9	- -
March 5, 2004	47.2	56.9	- -
May 16, 2004	3.3	2.2	- -
May 24, 2004	1.8	2.6	- -
May 26, 2004	23.3	22.9	- -
May 27, 2004	57.7	71.0	- -
June 15, 2004	39.9	77.8	- -
June 22, 2004	25.9	33.7	- -

Table A.6: Continued

Date	WSA	WSB	WSC
June 25, 2004	39.1	54.0	- -
July 6, 2004	5.5	6.5	- -
July 26, 2004	0.6	1.5	- -
July 27, 2004	16.1	10.1	- -
July 31, 2004	5.8	2.2	- -
August 5, 2004	4.1	5.2	- -
September 7, 2004	13.8	13.8	- -
September 16, 2004	44.0	52.0	- -
October 13, 2004	6.9	8.8	- -
October 18, 2004	36.2	44.7	- -
October 27, 2004	62.2	61.4	- -
November 4, 2004	60.4	54.3	- -
November 11, 2004	33.4	24.2	- -
November 30, 2004	77.4	85.8	- -
December 9, 2004	91.3	98.9	- -
December 23, 2004	14.5	25.0	- -
April 29, 2005	61.8	80.2	99.6
May 19, 2005	10.4	16.8	9.4
May 22, 2005	36.8	64.8	19.5
June 3, 2005	77.5	90.0	31.3
June 20, 2005	2.1	9.8	5.8
July 1, 2005	3.1	1.9	1.7
July 7, 2005	6.0	0.7	21.2
July 17, 2005	11.6	12.7	7.5
July 18, 2005	32.1	27.3	31.6
July 27, 2005	3.4	0.8	6.5
August 5, 2005	2.4	1.3	1.3
August 16, 2005	1.7	0.5	0.6
August 19, 2005	3.2	1.0	1.9
December 3, 2005	2.7	2.6	18.2
December 15, 2005	12.1	6.4	12.8
January 17, 2006	21.4	34.2	25.2
January 23, 2006	40.0	59.0	86.1
March 13, 2006	59.5	81.9	85.4
May 2, 2006	5.9	10.3	42.2
May 25, 2006	7.9	6.3	19.9
May 31, 2006	16.6	32.4	46.6
July 5, 2006	20.7	32.2	45.7
September 23, 2006	2.1	3.6	3.9
September 23, 2006	7.7	17.7	18.0
September 30, 2006	3.4	8.3	7.9
October 26, 2006	20.7	31.5	43.5

Table A.6: Continued

Date	WSA	WSB	WSC
March 28, 2007	29.1	6.4	14.5
May 16, 2007	2.2	4.6	14.0
June 1, 2007	2.1	1.8	12.7
June 5, 2007	6.0	5.5	11.3
June 18, 2007	0.6	0.1	1.4
June 29, 2007	5.2	1.4	6.8
August 3, 2007	1.6	0.5	6.5
November 14, 2007	4.7	2.3	6.5
November 26, 2007	3.5	6.0	18.2
December 10, 2007	4.6	7.4	14.0
December 13, 2007	16.3	29.8	34.6
December 20, 2007	3.2	17.9	27.7
January 29, 2008	30.1	50.5	59.5
February 6, 2008	49.9	87.4	91.9
May 11, 2008	3.9	8.6	10.0
June 3, 2008	4.5	7.2	9.5
August 26, 2008	1.2	0.6	1.5
November 14, 2008	2.5	10.6	5.8
December 10, 2008	2.1	8.9	7.0
December 10, 2008	7.7	33.7	16.2
December 16, 2008	19.6	27.6	40.7
Mean ± Std. Dev. (02-04)	32.7±26.4	38.4±29.9	- -
Mean ± Std. Dev. (05-08)	14.3±18.1	20.3±25.3	23.5±25.2

[1] No data available.

Table A.7: WSA, WSB, and WSC time to peak (2002-2008).

Date	WSA	WSB	WSC
March 17, 2002	8.3	6.9	- -[1]
April 28, 2002	1.7	4.6	- -
May 2, 2002	3.9	5.4	- -
May 13, 2002	4.3	3.2	- -
May 17, 2002	1.3	3.3	- -
June 6, 2002	9.0	2.5	- -
July 19, 2002	2.3	7.6	- -
September 25, 2002	16.3	16.1	- -
October 15, 2002	1.5	13.0	- -
October 29, 2002	2.5	2.3	- -
November 5, 2002	17.0	12.2	- -
November 10, 2002	17.0	23.5	- -
December 10, 2002	20.5	17.4	- -
December 13, 2002	14.0	14.7	- -
December 19, 2002	21.2	8.0	- -
January 1, 2003	2.8	18.5	- -
February 3, 2003	10.0	6.2	- -
April 6, 2003	15.5	17.7	- -
April 17, 2003	17.0	6.0	- -
May 8, 2003	2.1	2.5	- -
June 6, 2003	6.4	6.5	- -
June 11, 2003	0.5	0.5	- -
July 10, 2003	1.0	1.9	- -
August 3, 2003	1.0	9.5	- -
August 17, 2003	2.0	0.5	- -
September 3, 2003	7.5	9.6	- -
September 22, 2003	2.5	4.5	- -
November 12, 2003	0.8	7.3	- -
November 18, 2003	10.0	9.9	- -
November 28, 2003	23.0	17.5	- -
December 10, 2003	1.5	19.7	- -
January 17, 2004	21.5	14.8	- -
February 2, 2004	13.8	14.8	- -
February 5, 2004	8.4	6.0	- -
March 5, 2004	6.5	7.0	- -
May 16, 2004	2.4	4.1	- -
May 24, 2004	0.8	1.5	- -
May 26, 2004	1.9	6.0	- -
May 27, 2004	1.1	3.0	- -
June 15, 2004	2.3	2.0	- -
June 22, 2004	0.5	0.5	- -

Table A.7: Continued

Date	WSA	WSB	WSC
June 25, 2004	8.5	8.5	- -
July 6, 2004	0.8	0.6	- -
July 26, 2004	1.0	1.0	- -
July 27, 2004	1.5	2.0	- -
July 31, 2004	0.5	0.4	- -
August 5, 2004	3.5	3.3	- -
September 7, 2004	14.7	14.7	- -
September 16, 2004	14.6	14.9	- -
October 13, 2004	0.6	1.0	- -
October 18, 2004	26.3	4.8	- -
October 27, 2004	4.8	4.3	- -
November 4, 2004	6.8	11.0	- -
November 11, 2004	3.8	3.9	- -
November 30, 2004	29.8	27.9	- -
December 9, 2004	6.2	7.4	- -
December 23, 2004	3.8	4.1	- -
April 29, 2005	9.9	12.2	12.4
May 19, 2005	21.8	22.0	22.0
May 22, 2005	1.3	1.4	1.4
June 3, 2005	0.6	0.7	0.5
June 20, 2005	0.9	0.8	1.4
July 1, 2005	2.8	1.0	3.0
July 7, 2005	12.5	14.5	13.1
July 17, 2005	0.6	0.5	0.8
July 18, 2005	0.8	2.6	2.4
July 27, 2005	0.6	0.4	0.5
August 5, 2005	1.0	1.0	0.8
August 16, 2005	0.8	0.8	0.8
August 19, 2005	0.4	0.2	0.2
December 3, 2005	5.7	5.0	6.0
December 15, 2005	6.3	7.2	11.8
January 17, 2006	17.2	16.7	18.4
January 23, 2006	8.0	4.1	7.9
March 13, 2006	8.3	8.6	6.0
May 2, 2006	0.8	0.9	0.6
May 25, 2006	1.5	2.3	1.6
May 31, 2006	0.5	0.8	1.5
July 5, 2006	7.6	6.6	7.7
September 23, 2006	2.6	9.8	9.8
September 23, 2006	1.2	3.6	3.6
September 30, 2006	1.2	8.5	8.3
October 26, 2006	16.9	23.1	16.4

Table A.7: Continued

Date	WSA	WSB	WSC
March 28, 2007	1.6	13.5	0.6
May 16, 2007	1.3	1.3	0.6
June 1, 2007	0.5	0.8	0.6
June 5, 2007	2.6	0.9	1.3
June 18, 2007	0.5	0.1	0.5
June 29, 2007	1.4	0.5	0.6
August 3, 2007	0.2	0.8	0.2
November 14, 2007	1.5	3.3	4.2
November 26, 2007	1.5	3.0	7.1
December 10, 2007	18.0	16.3	16.0
December 13, 2007	4.8	4.5	4.8
December 20, 2007	2.3	18.0	6.5
January 29, 2008	10.0	6.8	10.0
February 6, 2008	11.6	11.3	15.0
May 11, 2008	6.5	11.0	19.2
June 3, 2008	0.5	0.5	0.5
August 26, 2008	0.9	9.1	0.6
November 14, 2008	27.1	6.5	6.5
December 10, 2008	2.1	8.0	6.8
December 10, 2008	4.3	6.3	9.6
December 16, 2008	7.7	4.9	5.6
Mean ± Std. Dev. (02-04)	7.5±7.6	7.9±6.5	- -
Mean ± Std. Dev. (05-08)	5.1±6.3	6.0±6.1	5.9±6.0

[1] No data available.

Table A.8: Curve numbers for WSA, WSB, and WSC (1982-1993).[1]

Date	CN (λ=0.2)			CN (λ=0.05)		
	WSA	WSB	WSC	WSA	WSB	WSC
February 8, 1982	96	90	90	95	86	87
February 16, 1982	97	94	99	96	92	99
March 15, 1982	97	89	97	97	86	96
March 31, 1982	92	92	96	90	89	95
May 21, 1982	70	70	71	59	58	60
May 28, 1982	81	82	83	74	75	77
June 4, 1982	83	84	85	77	78	80
July 28, 1982	62	62	61	48	48	47
August 5, 1982	64	64	63	51	51	50
September 13, 1982	53	52	50	38	37	35
September 25, 1982	81	81	80	74	74	73
November 20, 1982	82	81	78	75	73	70
November 30, 1982	94	93	92	92	91	90
December 5, 1982	91	91	90	89	88	87
December 15, 1982	97	96	99	97	96	99
January 21, 1983	92	92	91	90	90	88
February 10, 1983	96	96	96	95	95	95
April 14, 1983	94	95	95	93	94	93
May 3, 1983	92	92	92	90	90	90
May 13, 1983	78	85	84	69	79	79
May 22, 1983	85	87	86	79	83	81
June 3, 1983	74	73	73	64	62	62
June 4, 1983	95	96	96	94	95	95
July 3, 1983	65	64	64	52	51	51
July 5, 1983	84	85	84	78	79	78
July 18, 1983	84	83	83	78	77	77
August 2, 1983	70	69	69	59	58	58
August 11, 1983	66	66	66	54	54	54
August 27, 1983[2]	80	80	80	72	73	72
November 14, 1983	74	76	74	63	67	64
December 27, 1983	89	88	87	86	84	82
February 27, 1984	89	87	87	85	82	83
March 20, 1984	97	97	98	97	96	98
March 28, 1984	96	95	96	95	94	96
April 4, 1984	95	95	95	94	94	94
April 9, 1984	92	92	96	90	90	95
April 21, 1984	94	95	96	92	93	95
May 4, 1984	98	98	98	97	98	98
May 6, 1984	81	88	98	75	85	98
May 23, 1984	86	87	87	82	83	83
May 28, 1984	80	95	97	72	94	96

Table A.8: Continued

Date	CN (λ=0.2)			CN (λ=0.05)		
	WSA	WSB	WSC	WSA	WSB	WSC
July 26, 1984	74	75	77	64	66	69
July 27, 1984	81	93	95	73	91	94
July 30, 1984	84	90	93	78	87	91
August 22, 1984	64	71	76	50	60	67
November 4, 1984	80	95	96	73	94	95
November 18, 1984	71	88	90	59	84	87
November 28, 1984	87	94	94	83	93	93
December 20, 1984	95	99	99	95	99	99
December 24, 1984	95	98	100	94	98	100
January 3, 1985	92	97	98	90	96	98
February 11, 1985	85	88	87	79	84	83
May 15, 1985	78	80	83	69	72	76
June 5, 1985	81	86	86	73	81	81
June 10, 1985	75	78	78	65	70	69
June 11, 1985	83	95	94	77	93	92
July 10, 1985	70	73	75	59	63	65
July 30, 1985	68	69	69	56	57	57
August 1, 1985	65	70	70	51	59	59
August 17, 1985	83	88	88	77	85	84
August 25, 1985	84	85	90	78	80	87
August 30, 1985	65	77	79	52	68	71
September 26, 1985	80	84	86	73	78	81
November 2, 1985	70	88	89	59	84	86
December 12, 1985	93	96	96	91	95	95
February 2, 1986	95	98	99	94	97	99
April 28, 1986	87	88	91	82	84	88
May 11, 1986	75	81	79	65	73	70
July 2, 1986	78	82	82	70	75	75
July 20, 1986	80	81	86	73	73	81
July 26, 1986	78	79	83	69	71	77
October 1, 1986	83	83	86	77	77	81
November 5, 1986	75	82	85	65	75	79
November 8, 1986	70	81	83	59	73	77
November 10, 1986	88	92	95	83	90	94
December 8, 1986	95	96	99	94	95	99
January 18, 1987	92	93	97	90	92	96
February 22, 1987	96	97	97	96	97	97
February 26, 1987	96	96	97	95	95	97
March 18, 1987	99	99	98	99	99	98
March 30, 1987	90	91	93	87	89	92
May 12, 1987	83	85	87	77	79	82
May 21, 1987	80	82	82	72	75	75

Table A.8: Continued

Date	CN (λ=0.2)			CN (λ=0.05)		
	WSA	WSB	WSC	WSA	WSB	WSC
May 25, 1987	84	86	87	78	80	82
June 16, 1987	85	85	86	79	80	81
June 25, 1987	68	69	70	55	58	59
July 11, 1987	77	83	86	67	76	81
August 22, 1987	77	79	80	68	71	73
September 12, 1987	81	82	83	74	75	77
November 9, 1987	65	65	68	52	52	56
November 16, 1987	82	85	84	75	80	79
December 14, 1987	86	89	89	81	85	85
December 24, 1987	60	63	71	46	50	60
January 18, 1988	92	89	94	90	86	92
April 6, 1988	97	95	98	97	93	98
May 4, 1988	91	80	88	89	72	85
June 2, 1988	84	84	89	79	79	85
June 9, 1988	83	84	84	77	78	79
August 23, 1988	58	60	65	44	46	52
September 16, 1988	57	57	60	42	43	46
November 4, 1988	73	75	77	62	65	68
November 27, 1988	91	94	94	88	93	93
December 21, 1988	83	89	88	77	85	84
December 24, 1988	96	95	96	96	94	95
January 11, 1989	93	93	97	91	92	96
February 3, 1989	92	94	97	90	93	96
February 13, 1989	90	92	94	88	90	92
February 20, 1989	98	94	95	97	92	94
March 20, 1989	90	92	93	87	90	92
April 3, 1989	95	98	98	94	98	98
May 19, 1989	86	86	86	81	81	81
June 12, 1989	80	78	80	72	69	73
June 22, 1989	91	92	92	88	90	90
July 23, 1989	79	79	78	71	71	70
July 27, 1989	77	78	77	68	69	69
July 31, 1989	79	86	89	71	82	86
August 5, 1989	80	85	84	72	79	78
August 18, 1989	64	66	68	51	53	56
September 22, 1989	76	84	90	67	78	87
September 30, 1989	89	91	93	85	89	91
October 16, 1989	77	79	89	68	71	86
November 14, 1989	93	96	97	91	95	97
January 29, 1990	95	97	96	94	97	96
February 3, 1990	96	97	98	96	97	98
February 9, 1990	93	96	97	91	96	97

Table A.8: Continued

Date	CN (λ=0.2)			CN (λ=0.05)		
	WSA	WSB	WSC	WSA	WSB	WSC
February 15, 1990	94	95	95	93	93	94
March 16, 1990	92	96	92	90	95	90
April 6, 1990	94	94	95	92	92	94
May 26, 1990	82	83	83	76	76	76
May 28, 1990	81	82	82	73	75	76
June 2, 1990	80	81	83	73	73	76
June 21, 1990	80	78	80	72	70	72
July 30, 1990	84	85	87	78	80	82
August 8, 1990	77	79	80	68	71	73
August 29, 1990	79	80	81	72	72	74
September 9, 1990	82	80	81	75	73	74
September 12, 1990	85	86	86	79	81	81
October 4, 1990	70	75	75	59	65	65
December 2, 1990	88	93	96	84	92	95
December 20, 1990	90	95	93	87	94	91
December 27, 1990	83	86	87	76	82	83
December 30, 1990	88	91	94	84	88	92
January 6, 1991	98	100	99	98	100	99
February 6, 1991	98	98	97	97	98	97
February 13, 1991	92	93	94	90	92	92
February 17, 1991	90	95	99	88	94	100
March 22, 1991	93	94	94	92	93	93
March 29, 1991	98	97	97	97	97	96
April 15, 1991	96	98	98	96	98	97
April 19, 1991	96	95	95	95	95	94
May 9, 1991	84	83	80	79	77	72
May 18, 1991	79	84	80	72	79	72
May 27, 1991	82	83	82	75	77	75
May 29, 1991	77	78	75	68	70	66
June 22, 1991	79	86	83	70	81	77
June 25, 1991	89	90	88	86	87	84
July 10, 1991	80	80	79	73	72	72
July 12, 1991	74	78	77	64	69	69
August 7, 1991	73	74	72	63	64	62
October 5, 1991	65	67	65	53	55	52
October 15, 1991	80	86	80	73	81	72
November 21, 1991	70	71	69	58	60	57
December 13, 1991	94	95	97	93	94	97
December 28, 1991	94	94	94	92	93	92
February 24, 1992	94	96	96	93	96	95
March 30, 1992	94	97	96	93	96	95
May 28, 1992	68	71	71	56	60	59

Table A.8: Continued

Date	CN (λ=0.2)			CN (λ=0.05)		
	WSA	WSB	WSC	WSA	WSB	WSC
June 17, 1992	87	89	87	82	86	83
June 24, 1992	71	75	74	60	66	64
July 1, 1992	80	73	74	73	63	64
July 14, 1992	72	72	75	61	61	66
July 17, 1992	87	88	87	82	85	83
July 22, 1992	81	82	81	74	75	74
July 24, 1992	70	76	76	58	66	66
August 8, 1992	83	83	85	77	77	80
August 27, 1992	68	67	70	56	55	59
September 4, 1992	86	88	90	81	84	86
September 18, 1992	76	75	86	66	65	81
December 20, 1992	90	90	87	87	87	83
March 29, 1993	94	97	97	92	97	96
April 25, 1993	99	95	86	99	94	82
May 9, 1993	82	82	77	75	75	68
June 9, 1993	76	78	79	67	70	71
June 21, 1993	77	79	78	68	71	70
July 13, 1993	54	56	64	39	41	51
July 15, 1993	86	87	94	81	83	92
July 26, 1993	66	67	67	53	55	54
September 2, 1993	71	79	80	60	72	72
September 15, 1993	58	63	64	43	50	50
October 18, 1993	83	94	95	77	92	93
Mean ± Std. Dev. (Pre)	82 ± 12	82 ± 12	82 ± 13	76 ± 17	76 ± 17	76 ± 18
Mean ± Std. Dev. (Post)	83±10	85±10	87±9	77±14	80±14	82±13

[1] AMC II

[2] Final storm before treatment.

Table A.9: Curve numbers for WSA, WSB, and WSC (2002-2008).[1]

Date	CN (λ=0.2)			CN (λ=0.05)		
	WSA	WSB	WSC	WSA	WSB	WSC
March 17, 2002	97	99	- -[2]	97	99	- -[2]
April 28, 2002	99	100	- -	99	100	- -
May 2, 2002	95	97	- -	94	97	- -
May 13, 2002	87	92	- -	83	89	- -
May 17, 2002	85	92	- -	80	90	- -
June 6, 2002	75	78	- -	65	69	- -
July 19, 2002	84	83	- -	78	76	- -
September 25, 2002	69	66	- -	57	53	- -
October 15, 2002	85	82	- -	79	75	- -
October 29, 2002	92	93	- -	90	92	- -
November 5, 2002	89	91	- -	86	88	- -
November 10, 2002	90	98	- -	87	98	- -
December 10, 2002	98	99	- -	98	99	- -
December 13, 2002	97	98	- -	96	98	- -
December 19, 2002	95	95	- -	93	94	- -
January 1, 2003	99	99	- -	99	99	- -
February 3, 2003	99	99	- -	99	99	- -
April 6, 2003	93	94	- -	91	92	- -
April 17, 2003	92	93	- -	90	91	- -
May 8, 2003	89	94	- -	85	92	- -
June 6, 2003	83	87	- -	77	82	- -
June 11, 2003	85	89	- -	80	85	- -
July 10, 2003	76	76	- -	66	67	- -
August 3, 2003	81	82	- -	73	75	- -
August 17, 2003	82	86	- -	75	81	- -
September 3, 2003	69	70	- -	57	58	- -
September 22, 2003	70	67	- -	59	55	- -
November 12, 2003	89	90	- -	85	87	- -
November 18, 2003	87	88	- -	83	85	- -
November 28, 2003	96	96	- -	95	95	- -
December 10, 2003	97	98	- -	96	98	- -
January 17, 2004	95	96	- -	94	95	- -
February 2, 2004	96	98	- -	96	98	- -
February 5, 2004	88	83	- -	84	76	- -
March 5, 2004	89	92	- -	85	89	- -
May 16, 2004	85	84	- -	79	78	- -
May 24, 2004	74	75	- -	63	65	- -
May 26, 2004	82	82	- -	75	75	- -
May 27, 2004	94	96	- -	93	96	- -
June 15, 2004	89	97	- -	85	97	- -
June 22, 2004	95	96	- -	94	95	- -
June 25, 2004	92	95	- -	90	94	- -

Table A.9: Continued

Date	CN ($\lambda=0.2$)			CN ($\lambda=0.05$)		
	WSA	WSB	WSC	WSA	WSB	WSC
July 6, 2004	87	87	- -	82	83	- -
July 26, 2004	70	72	- -	59	62	- -
July 27, 2004	91	89	- -	89	86	- -
July 31, 2004	87	85	- -	83	79	- -
August 5, 2004	79	80	- -	70	72	- -
September 7, 2004	58	58	- -	43	43	- -
September 16, 2004	81	84	- -	73	78	- -
October 13, 2004	87	88	- -	82	84	- -
October 18, 2004	88	91	- -	85	88	- -
October 27, 2004	95	95	- -	94	94	- -
November 4, 2004	94	92	- -	92	90	- -
November 11, 2004	94	92	- -	92	90	- -
November 30, 2004	96	98	- -	96	98	- -
December 9, 2004	99	100	- -	99	100	- -
December 23, 2004	90	93	- -	87	91	- -
April 29, 2005	92	96	100	90	96	100
May 19, 2005	78	82	78	70	76	69
May 22, 2005	95	98	92	94	98	90
June 3, 2005	99	100	94	99	100	93
June 20, 2005	70	78	75	59	70	65
July 1, 2005	76	75	74	67	65	64
July 7, 2005	86	81	92	82	74	90
July 17, 2005	83	84	81	77	78	74
July 18, 2005	96	95	96	95	94	95
July 27, 2005	85	82	87	80	75	83
August 5, 2005	80	78	78	72	70	70
August 16, 2005	82	80	80	76	73	73
August 19, 2005	82	80	81	76	72	74
December 3, 2005	86	86	93	81	81	91
December 15, 2005	85	82	86	80	75	81
January 17, 2006	87	91	88	82	88	84
January 23, 2006	90	94	98	87	93	98
March 13, 2006	97	99	99	96	99	99
May 2, 2006	88	84	90	86	96	95
May 25, 2006	81	74	80	73	87	83
May 31, 2006	89	85	93	91	95	94
July 5, 2006	84	78	88	84	92	90
September 23, 2006	75	65	77	68	77	68
September 23, 2006	88	85	92	90	92	90
September 30, 2006	86	82	89	86	89	85
October 26, 2006	72	62	78	70	84	78
March 28, 2007	94	93	88	84	91	89

Table A.9: Continued

Date	CN (λ=0.2)			CN (λ=0.05)		
	WSA	WSB	WSC	WSA	WSB	WSC
May 16, 2007	79	71	82	75	87	83
June 1, 2007	68	56	68	55	78	70
June 5, 2007	82	75	82	75	85	80
June 18, 2007	77	68	75	66	79	71
June 29, 2007	87	82	83	77	88	83
August 3, 2007	82	75	80	72	86	81
November 14, 2007	72	61	68	57	74	64
November 26, 2007	87	82	88	84	92	90
December 10, 2007	76	66	78	70	82	76
December 13, 2007	90	88	94	92	94	93
December 20, 2007	84	78	91	88	93	91
January 29, 2008	89	86	94	92	95	94
February 6, 2008	96	96	99	99	100	100
May 11, 2008	85	80	88	84	89	85
June 3, 2008	87	83	89	85	90	86
August 26, 2008	69	57	67	55	70	58
November 14, 2008	76	66	83	76	79	71
December 10, 2008	68	56	76	66	74	64
December 10, 2008	81	74	91	89	86	81
December 16, 2008	92	90	94	93	96	95
Mean ± Std. Dev. (02-04)	88±9	83±13	89±10	85±13	- -	- -
Mean ± Std. Dev. (05-08)	84±8	78±11	85±8	80±12	87±8	83±11

[1] AMC II

[2] No data available.

APPENDIX B: FWMC TABLES

Table B.1: Growing, non-growing, and yearly Sulfate FWMC ± Std. Dev. (1982-1993).

	SO_4 (mg L^{-1})			Sample Size (n)		
	Year	Growing	Non-Growing	Year	Growing	Non-Growing
WSA	13.3±1.7	12.3±1.5	13.4±1.0	44	25	19
WSB 1982	15.4±2.6	13.6±1.4	15.7±3.4	45	25	20
WSC	13.8±2.4	11.0±2.0	14.3±2.0	42	22	20
WSA	15.1±2.7	16.0±2.6	12.7±2.6	47	22	25
WSB 1983	13.8±3.8	14.5±3.4	12.1±4.0	48	23	25
WSC	11.8±3.7	12.2±4.2	10.7±3.3	42	17	25
WSA	9.4±2.0	9.3±2.4	9.5±1.5	52	26	26
WSB 1984	6.3±2.9	9.7±1.8	5.4±3.5	52	26	26
WSC	10.8±2.0	9.3±1.9	11.4±2.0	52	26	26
WSA	10.7±1.3	11.1±1.4	10.6±1.3	48	23	25
WSB 1985	11.1±1.2	11.1±1.4	11.1±0.8	52	27	25
WSC	10.5±1.5	10.2±1.3	10.6±1.7	52	27	25
WSA	11.1±2.6	9.3±2.0	11.4±1.6	48	24	24
WSB 1986	14.0±2.3	11.8±1.6	14.4±2.5	43	19	24
WSC	10.0±4.4	5.1±3.7	11.1±2.3	50	25	25
WSA	10.3±1.6	9.0±1.7	10.8±1.2	44	21	23
WSB 1987	11.8±2.1	11.8±2.5	11.8±1.6	42	20	22
WSC	9.0±3.1	8.3±3.8	9.3±1.9	46	24	22
WSA	6.6±2.7	8.4±2.8	5.9±1.3	41	16	25
WSB 1988	7.4±2.7	8.8±2.4	7.0±2.1	38	14	24
WSC	8.3±5.1	11.6±6.2	7.0±2.9	43	18	25
WSA	9.6±2.4	11.1±1.3	8.7±2.8	52	27	25
WSB 1989	11.8±2.8	12.9±2.3	11.0±3.0	50	27	23
WSC	10.4±2.8	11.6±2.9	9.5±2.1	51	27	24
WSA	8.0±1.4	7.0±1.1	8.5±0.7	52	27	25
WSB 1990	9.1±1.3	8.0±1.0	9.4±1.3	51	27	24
WSC	7.6±2.2	6.1±1.9	8.3±1.4	51	27	24
WSA	9.4±1.8	8.4±0.6	9.9±2.1	52	27	25
WSB 1991	11.2±2.0	9.4±1.4	11.6±1.8	53	27	26
WSC	8.1±1.0	8.1±0.9	8.1±1.0	34	18	16
WSA	11.8±1.2	11.9±1.2	11.7±1.1	52	27	25
WSB 1992	12.6±0.9	12.6±0.7	12.6±1.1	51	28	23
WSC	10.7±2.2	9.9±2.5	11.2±1.5	51	28	23
WSA	6.5±2.0	6.5±2.2	6.5±1.6	44	27	17
WSB 1993	7.0±2.4	5.4±2.6	8.0±1.9	43	27	16
WSC	6.2±2.7	4.0±2.2	7.6±2.7	43	27	16

Table B.2: Growing, non-growing, and yearly Sulfate FWMC ± Std. Dev. (2002-2008).

	SO_4 (mg L^{-1})			Sample Size (n)		
	Year	Growing	Non-Growing	Year	Growing	Non-Growing
WSA	10.8±1.9	9.8±1.4	11.8±1.8	47	23	24
WSB 2002	11.6±1.8	10.2±1.3	12.7±1.6	46	21	25
WSC	10.3±2.5	9.4±2.7	10.8±1.3	48	24	24
WSA	10.5±1.8	10.0±2.0	10.7±1.5	49	25	24
WSB 2003	12.0±1.8	13.1±2.2	11.3±1.3	49	25	24
WSC	10.0±2.2	9.9±2.4	10.1±1.7	49	25	24
WSA	9.1±0.8	8.9±0.8	9.4±0.7	51	28	23
WSB 2004	9.5±0.9	9.3±0.8	9.8±0.7	51	28	23
WSC	8.3±0.9	8.1±1.0	8.5±0.6	51	28	23
WSA	8.5±1.0	8.7±1.0	8.4±1.0	43	22	21
WSB 2005	8.9±0.8	8.6±0.4	9.0±0.9	41	20	21
WSC	7.8±1.7	7.9±1.6	7.8±1.7	40	19	21
WSA	8.7±2.0	7.6±2.4	9.2±1.5	48	24	24
WSB 2006	8.8±1.7	7.8±1.7	9.2±1.7	47	23	24
WSC	8.6±2.1	8.5±2.3	8.6±1.6	49	25	24
WSA	8.6±1.1	8.6±1.6	8.7±0.7	35	14	21
WSB 2007	0.0±0.8			0	0	0
WSC	8.5±4.9	7.0±1.7	9.1±5.4	36	14	22
WSA	8.2±1.8	7.7±0.7	8.4±2.1	35	13	22
WSB 2008	8.7±0.0	8.5±0.5	8.8±0.9	35	13	22
WSC	8.0±1.3	7.5±0.5	8.1±1.5	36	14	22

Table B.3: Growing, Non-Growing, and Yearly Magnesium FWMC ± Std. Dev. (1982-1993).

		Mg (mg L^{-1})			Sample Size (n)		
		Year	Growing	Non-Growing	Year	Growing	Non-Growing
WSA	1982	1.6±0.5	1.7±0.4	1.6±0.4	45	25	20
WSB		1.9±0.4	2.0±0.3	1.9±0.5	45	25	20
WSC		1.6±0.3	1.7±0.3	1.6±0.2	42	22	20
WSA	1983	1.6±0.4	1.6±0.5	1.6±0.2	47	22	25
WSB		1.7±0.4	1.7±0.4	1.9±0.2	48	23	25
WSC		1.5±1.0	1.5±1.6	1.6±0.2	42	17	25
WSA	1984	1.5±0.4	1.4±0.4	1.5±0.1	52	26	26
WSB		2.0±0.1	1.8±0.2	2.1±0.1	52	26	26
WSC		1.9±0.3	1.8±0.3	2.0±0.3	52	26	26
WSA	1985	1.6±0.4	2.0±0.3	1.5±0.2	48	23	25
WSB		2.1±0.2	2.2±0.3	2.1±0.1	52	27	25
WSC		2.1±0.5	2.4±0.6	2.0±0.1	52	27	25
WSA	1986	1.8±0.3	2.1±0.3	1.8±0.1	48	24	24
WSB		2.1±0.1	2.1±0.1	2.0±0.1	43	19	24
WSC		2.2±0.5	2.6±0.5	2.1±0.3	50	25	25
WSA	1987	1.7±0.5	1.9±0.4	1.6±0.5	44	21	23
WSB		1.9±0.3	2.0±0.2	1.9±0.4	42	20	22
WSC		2.0±0.6	2.3±0.6	1.9±0.5	46	24	22
WSA	1988	1.9±0.8	2.2±1.0	1.8±0.3	41	16	25
WSB		2.1±0.7	2.5±1.0	2.0±0.2	38	14	24
WSC		2.4±1.1	3.2±1.3	2.0±0.3	43	18	25
WSA	1989	1.5±0.1	1.5±0.2	1.5±0.1	52	27	25
WSB		1.8±0.1	1.8±0.1	1.8±0.2	50	27	23
WSC		1.7±0.2	1.8±0.3	1.7±0.1	51	27	24
WSA	1990	1.5±0.2	1.6±0.2	1.5±0.1	52	27	25
WSB		1.8±0.1	1.8±0.1	1.8±0.1	51	27	24
WSC		1.8±0.4	1.9±0.4	1.7±0.1	51	27	24
WSA	1991	1.5±0.3	1.6±0.3	1.5±0.3	52	27	25
WSB		1.7±0.1	1.8±0.1	1.7±0.1	53	27	26
WSC		1.7±0.3	1.8±0.3	1.6±0.1	35	19	16
WSA	1992	1.6±0.1	1.7±0.1	1.6±0.2	52	27	25
WSB		1.9±0.1	1.9±0.1	1.8±0.1	51	28	23
WSC		1.8±0.2	2.0±0.1	1.7±0.2	51	28	23
WSA	1993	1.5±0.2	1.7±0.1	1.5±0.1	44	27	17
WSB		1.8±0.1	1.9±0.1	1.7±0.1	43	27	16
WSC		1.8±0.3	2.2±0.3	1.6±0.1	43	27	16

Table B.4: Growing, non-growing, and yearly Magnesium FWMC ± Std. Dev. (2002-2008).

		Mg (mg L^{-1})			Sample Size (n)		
		Year	Growing	Non-Growing	Year	Growing	Non-Growing
WSA	2002	1.4±0.2	1.7±1.1	1.9±1.2	47	23	24
WSB		1.6±0.2	1.7±1.1	1.8±1.3	46	21	25
WSC		1.5±0.2	1.9±0.7	1.9±0.8	48	24	24
WSA	2003	1.4±0.2	1.5±0.5	1.8±0.6	51	27	24
WSB		1.5±0.1	1.6±0.5	1.7±0.6	51	27	24
WSC		1.4±0.3	1.5±0.3	1.6±0.4	51	27	24
WSA	2004	1.3±0.1	1.2±0.7	1.2±0.8	51	28	23
WSB		1.4±0.1	1.1±0.3	1.1±0.3	51	28	23
WSC		1.4±0.1	1.2±0.2	1.2±0.2	51	28	23
WSA	2005	1.4±0.2	2.1±1.2	2.5±1.2	43	22	21
WSB		1.5±0.2	1.8±0.7	2.1±0.3	41	20	21
WSC		1.4±0.2	1.6±0.5	1.9±0.2	40	19	21
WSA	2006	1.2±0.2	1.5±0.5	1.4±0.6	48	24	24
WSB		1.3±0.1	1.5±0.4	1.6±0.5	47	23	24
WSC		1.3±0.2	1.6±0.3	1.6±0.4	49	25	24
WSA	2007	1.5±0.3	1.5±1.2	2.3±1.3	35	14	21
WSB		1.7±0.3	1.5±1.1	1.8±1.3	33	13	20
WSC		1.6±0.4	1.6±0.9	2.0±1.0	36	14	22
WSA	2008	1.4±0.5	1.1±0.6	1.2±0.5	35	13	22
WSB		1.4±0.4	1.0±0.6	1.0±0.4	35	13	22
WSC		1.3±0.4	1.0±0.6	0.9±0.2	36	14	22

Table B.5: Growing, non-growing, and yearly Calcium FWMC ± Std. Dev. (1982-1993).

		Ca (mg L^{-1})			Sample Size (n)		
		Year	Growing	Non-Growing	Year	Growing	Non-Growing
WSA	1982	1.9±0.6	2.2±0.5	1.8±0.5	45	25	20
WSB		2.2±1.1	2.6±1.1	2.1±0.8	45	25	20
WSC		2.0±1.3	2.5±1.4	1.8±0.7	42	22	20
WSA	1983	2.2±0.6	2.4±0.6	1.9±0.4	47	22	25
WSB		2.1±0.7	2.0±0.8	2.3±0.5	48	23	25
WSC		1.9±0.9	1.9±1.2	2.1±0.6	42	17	25
WSA	1984	2.0±0.7	1.9±0.7	2.1±0.5	52	26	26
WSB		2.6±0.4	2.3±0.2	2.7±0.4	52	26	26
WSC		2.5±0.4	2.4±0.3	2.6±0.4	52	26	26
WSA	1985	2.1±0.9	3.1±0.9	2.0±0.5	48	23	25
WSB		2.7±0.4	2.9±0.5	2.6±0.3	52	27	25
WSC		2.7±0.7	3.1±0.7	2.6±0.4	52	27	25
WSA	1986	2.6±0.9	3.6±0.7	2.4±0.4	48	24	24
WSB		2.4±0.6	3.2±0.6	2.3±0.3	43	19	24
WSC		2.7±1.2	4.2±1.1	2.4±0.6	50	25	25
WSA	1987	2.4±1.4	3.0±1.3	2.1±1.4	44	21	23
WSB		2.6±1.3	2.8±1.0	2.5±1.5	42	20	22
WSC		2.8±1.8	3.8±1.8	2.5±1.5	46	24	22
WSA	1988	2.7±1.5	3.3±1.7	2.5±0.6	41	16	25
WSB		3.2±2.2	4.7±2.9	2.7±0.3	38	14	24
WSC		3.6±2.2	4.8±2.5	3.1±0.7	43	18	25
WSA	1989	2.1±0.4	2.1±0.4	2.1±0.4	52	27	25
WSB		2.3±0.4	2.0±0.2	2.4±0.5	50	27	23
WSC		2.5±0.5	2.5±0.6	2.5±0.3	51	27	24
WSA	1990	1.8±0.4	2.1±0.4	1.7±0.2	52	27	25
WSB		2.1±0.3	2.1±0.4	2.0±0.2	51	27	24
WSC		2.4±0.9	2.6±0.9	2.3±0.4	51	27	24
WSA	1991	1.8±1.0	2.1±1.0	1.7±0.7	52	27	25
WSB		2.0±0.4	2.2±0.4	2.0±0.4	53	27	26
WSC		2.1±0.6	2.5±0.6	1.9±0.1	35	19	16
WSA	1992	1.9±0.4	2.1±0.3	1.7±0.4	52	27	25
WSB		2.0±0.3	2.2±0.2	2.0±0.3	51	28	23
WSC		2.3±0.6	2.7±0.4	2.1±0.6	51	28	23
WSA	1993	2.0±0.8	2.4±0.7	1.8±0.2	44	27	17
WSB		2.6±0.7	3.3±0.6	2.1±0.2	43	27	16
WSC		2.8±1.0	4.0±0.8	2.2±0.2	43	27	16

Table B.6: Growing, non-growing, and yearly Calcium FWMC ± Std. Dev. (2002-2008).

		Ca (mg L^{-1})			Sample Size (n)		
		Year	Growing	Non-Growing	Year	Growing	Non-Growing
WSA	2002	1.7±1.1	1.9±1.2	1.5±0.3	47	23	24
WSB		1.7±1.1	1.8±1.3	1.7±0.3	46	21	25
WSC		1.9±0.7	1.9±0.8	1.8±0.3	48	24	24
WSA	2003	1.5±0.5	1.8±0.6	1.4±0.2	51	27	24
WSB		1.6±0.5	1.7±0.6	1.5±0.1	51	27	24
WSC		1.5±0.3	1.6±0.4	1.5±0.2	51	27	24
WSA	2004	1.2±0.7	1.2±0.8	1.1±0.1	51	28	23
WSB		1.1±0.3	1.1±0.3	1.1±0.2	51	28	23
WSC		1.2±0.2	1.2±0.2	1.2±0.2	51	28	23
WSA	2005	2.1±1.2	2.5±1.2	1.8±1.0	43	22	21
WSB		1.8±0.7	2.1±0.3	1.6±1.0	41	20	21
WSC		1.6±0.5	1.9±0.2	1.5±0.7	40	19	21
WSA	2006	1.5±0.5	1.4±0.6	1.5±0.2	48	24	24
WSB		1.5±0.4	1.6±0.5	1.5±0.2	47	23	24
WSC		1.6±0.3	1.6±0.4	1.6±0.2	49	25	24
WSA	2007	1.5±1.2	2.3±1.3	1.2±0.4	35	14	21
WSB		1.5±1.1	1.8±1.3	1.4±0.3	33	13	20
WSC		1.6±0.9	2.0±1.0	1.5±0.7	36	14	22
WSA	2008	1.1±0.6	1.2±0.5	1.1±0.7	35	13	22
WSB		1.0±0.6	1.0±0.4	1.0±0.7	35	13	22
WSC		1.0±0.6	0.9±0.2	1.0±0.8	36	14	22

Table B.7: Growing, non-growing, and yearly Potassium FWMC ± Std. Dev. (1982-1993).

		K (mg L^{-1})			Sample Size (n)		
		Year	Growing	Non-Growing	Year	Growing	Non-Growing
WSA	1982	1.1±0.4	1.3±0.4	1.1±0.4	44	25	19
WSB		1.3±0.7	1.7±0.7	1.2±0.4	45	25	20
WSC		1.2±0.6	1.5±0.6	1.2±0.3	42	22	20
WSA	1983	1.1±0.6	1.1±0.7	1.1±0.5	47	22	25
WSB		1.2±0.8	1.3±1.0	1.2±0.5	48	23	25
WSC		1.3±3.0	1.3±4.4	1.3±0.1	42	17	25
WSA	1984	1.1±0.8	1.1±0.8	1.2±0.6	52	26	26
WSB		1.7±0.5	2.1±0.5	1.6±0.4	52	26	26
WSC		1.8±0.5	1.6±0.4	1.8±0.1	52	26	26
WSA	1985	1.1±0.5	1.6±0.5	1.1±0.4	48	23	25
WSB		1.7±0.7	2.0±0.9	1.6±0.4	52	27	25
WSC		1.9±0.6	2.1±0.6	1.9±0.2	52	27	25
WSA	1986	1.9±0.6	1.8±0.6	1.9±0.6	48	24	24
WSB		2.3±0.9	2.0±0.6	2.3±1.0	43	19	24
WSC		2.8±1.1	2.9±1.2	2.7±0.1	50	25	25
WSA	1987	1.2±0.7	1.4±0.3	1.1±0.9	44	21	23
WSB		1.4±0.5	1.8±0.2	1.3±0.6	42	20	22
WSC		1.7±0.8	2.0±0.6	1.5±0.3	46	24	22
WSA	1988	1.5±0.7	1.5±0.9	1.5±0.4	41	16	25
WSB		1.6±0.9	2.0±1.2	1.5±0.3	38	14	24
WSC		2.1±1.1	2.6±1.3	1.9±0.4	43	18	25
WSA	1989	1.1±0.3	1.1±0.2	1.0±0.3	52	27	25
WSB		1.3±0.5	1.4±0.2	1.3±0.7	50	27	23
WSC		1.6±0.5	1.8±0.5	1.4±0.2	51	27	24
WSA	1990	1.1±0.4	1.2±0.3	1.0±0.5	52	27	25
WSB		1.3±0.3	1.5±0.3	1.3±0.3	51	27	24
WSC		1.6±0.5	1.7±0.5	1.6±0.1	51	27	24
WSA	1991	1.1±0.4	1.1±0.2	1.0±0.5	52	27	25
WSB		1.5±0.2	1.4±0.1	1.5±0.2	53	27	26
WSC		1.5±0.2	1.6±0.2	1.4±0.0	35	19	16
WSA	1992	1.2±0.4	1.1±0.3	1.2±0.5	52	27	25
WSB		1.3±0.3	1.4±0.3	1.2±0.2	51	28	23
WSC		1.5±0.3	1.5±0.3	1.5±0.1	51	28	23
WSA	1993	1.0±0.4	1.2±0.4	0.9±0.2	44	27	17
WSB		1.3±0.3	1.5±0.4	1.2±0.2	43	27	16
WSC		1.5±0.4	1.8±0.4	1.3±0.1	43	27	16

Table B.8: Growing, non-growing, and yearly Potassium FWMC ± Std. Dev. (2002-2008).

		K (mg L^{-1})			Sample Size (n)		
		Year	Growing	Non-Growing	Year	Growing	Non-Growing
WSA	2002	1.6±0.7	1.7±0.7	1.6±0.4	47	23	24
WSB		1.7±0.6	1.9±0.6	1.7±0.4	46	21	25
WSC		2.0±0.8	2.1±0.9	1.8±0.1	48	24	24
WSA	2003	1.4±0.5	1.6±0.4	1.3±0.4	51	27	24
WSB		1.5±0.3	1.7±0.3	1.4±0.3	51	27	24
WSC		1.7±0.5	1.8±0.5	1.6±0.2	51	27	24
WSA	2004	1.3±0.2	1.4±0.2	1.2±0.1	51	28	23
WSB		1.5±0.2	1.5±0.2	1.4±0.1	51	28	23
WSC		1.6±0.2	1.6±0.2	1.5±0.3	51	28	23
WSA	2005	1.6±0.5	1.9±0.4	1.3±0.4	43	22	21
WSB		1.7±0.4	2.0±0.4	1.4±0.3	41	20	21
WSC		1.7±0.6	2.1±0.5	1.5±0.2	40	19	21
WSA	2006	1.6±0.4	2.0±0.3	1.4±0.4	48	24	24
WSB		1.6±0.4	2.0±0.3	1.4±0.4	47	23	24
WSC		1.7±0.4	2.0±0.3	1.5±0.2	49	25	24
WSA	2007	1.0±0.6	1.2±0.5	0.9±0.6	35	14	21
WSB		0.9±0.3	0.9±0.3	0.9±0.3	33	13	20
WSC		1.2±0.8	1.0±0.4	1.2±0.1	36	14	22
WSA	2008	1.2±0.6	1.4±0.5	1.2±0.6	35	13	22
WSB		1.1±0.4	1.3±0.4	1.1±0.3	35	13	22
WSC		1.3±0.4	1.5±0.4	1.3±0.3	36	14	22

Table B.9: Growing, non-growing, and yearly Sodium FWMC ± Std. Dev. (1982-1993).

		Na (mg L^{-1})			Sample Size (n)		
		Year	Growing	Non-Growing	Year	Growing	Non-Growing
WSA	1982	1.1±0.3	1.2±0.2	1.1±0.3	44	25	19
WSB		1.3±0.4	1.5±0.3	1.3±0.5	45	25	20
WSC		1.1±0.3	1.3±0.3	1.1±0.3	42	22	20
WSA	1983	0.7±0.1	0.6±0.1	0.8±0.1	47	22	25
WSB		1.0±0.2	1.0±0.2	0.9±0.3	48	23	25
WSC		0.6±0.2	0.6±0.4	0.8±0.1	42	17	25
WSA	1984	0.7±0.1	0.7±0.1	0.7±0.1	52	26	26
WSB		0.8±0.2	0.9±0.2	0.8±0.2	52	26	26
WSC		0.8±0.1	0.8±0.2	0.8±0.1	52	26	26
WSA	1985	0.8±0.2	0.9±0.1	0.8±0.2	48	23	25
WSB		1.1±0.4	1.4±0.3	1.0±0.2	52	27	25
WSC		1.0±0.2	1.1±0.1	1.0±0.2	52	27	25
WSA	1986	0.9±0.1	1.0±0.1	0.8±0.1	48	24	24
WSB		1.0±0.4	1.5±0.3	0.9±0.3	43	19	24
WSC		0.9±0.3	1.3±0.3	0.8±0.1	50	25	25
WSA	1987	0.8±0.2	0.9±0.2	0.8±0.2	44	21	23
WSB		0.9±0.4	1.0±0.3	0.9±0.4	42	20	22
WSC		0.9±0.3	1.1±0.4	0.8±0.3	46	24	22
WSA	1988	1.2±0.4	1.3±0.4	1.2±0.3	41	16	25
WSB		1.4±0.5	1.5±0.5	1.4±0.6	38	14	24
WSC		1.4±0.5	1.8±0.5	1.3±0.4	43	18	25
WSA	1989	0.8±0.2	0.8±0.2	0.9±0.2	52	27	25
WSB		1.0±0.5	1.1±0.6	1.0±0.4	50	27	23
WSC		0.9±0.2	0.8±0.2	0.9±0.2	51	27	24
WSA	1990	0.7±0.1	0.8±0.1	0.7±0.1	52	27	25
WSB		0.8±0.2	0.9±0.2	0.8±0.2	51	27	24
WSC		0.7±0.1	0.8±0.1	0.7±0.1	51	27	24
WSA	1991	0.7±0.1	0.8±0.1	0.7±0.1	52	27	25
WSB		0.8±0.2	0.9±0.2	0.8±0.2	53	27	26
WSC		0.7±0.1	0.7±0.1	0.7±0.0	35	19	16
WSA	1992	0.7±0.1	0.7±0.2	0.7±0.1	52	27	25
WSB		0.8±0.2	0.9±0.2	0.8±0.2	51	28	23
WSC		0.8±0.2	0.8±0.2	0.7±0.1	51	28	23
WSA	1993	0.8±0.1	0.9±0.1	0.7±0.1	44	27	17
WSB		0.9±0.2	1.1±0.2	0.8±0.1	43	27	16
WSC		0.8±0.1	0.9±0.1	0.7±0.1	43	27	16

Table B.10: Growing, non-growing, and yearly Sodium FWMC ± Std. Dev. (2002-2008).

		Na (mg L^{-1})			Sample Size (n)		
		Year	Growing	Non-Growing	Year	Growing	Non-Growing
WSA	2002	1.0±0.2	1.1±0.2	0.9±0.1	47	23	24
WSB		1.1±0.3	1.1±0.3	1.1±0.2	46	21	25
WSC		1.0±0.1	1.0±0.1	1.0±0.1	48	24	24
WSA	2003	0.9±0.2	1.1±0.1	0.9±0.2	51	27	24
WSB		1.0±0.3	1.0±0.2	0.9±0.3	51	27	24
WSC		0.9±0.2	1.0±0.1	0.9±0.2	49	27	24
WSA	2004	1.0±0.2	0.9±0.1	1.2±0.3	51	28	23
WSB		1.0±0.2	0.9±0.2	1.1±0.3	51	28	23
WSC		1.1±0.2	1.0±0.1	1.2±0.3	51	28	23
WSA	2005	1.2±0.4	1.4±0.4	1.0±0.2	43	22	21
WSB		1.1±0.3	1.4±0.2	0.9±0.3	41	20	21
WSC		1.0±0.3	1.3±0.1	0.9±0.2	40	19	21
WSA	2006	1.1±0.2	1.2±0.2	1.1±0.2	48	24	24
WSB		1.3±0.2	1.4±0.2	1.3±0.2	47	23	24
WSC		1.2±0.1	1.2±0.1	1.2±0.2	49	25	24
WSA	2007	1.1±0.3	1.2±0.3	1.1±0.2	35	14	21
WSB		1.1±0.3	1.2±0.3	1.1±0.2	33	13	20
WSC		1.1±0.2	1.1±0.2	1.1±0.1	36	14	22
WSA	2008	1.0±0.3	1.2±0.1	0.9±0.2	35	13	22
WSB		1.0±0.3	1.2±0.2	0.9±0.3	35	13	22
WSC		0.9±0.3	1.1±0.2	0.9±0.3	36	14	22

Table B.11: Growing, non-growing, and yearly Alkalinity FWMC ± Std. Dev. (1982-1993).

		ALK (mg $L^{-1}CaCO_3$)			Sample Size (n)		
		Year	Growing	Non-Growing	Year	Growing	Non-Growing
WSA	1982	7.7±4.5	10.8±3.6	7.3±2.0	44	25	19
WSB		8.2±6.2	12.1±5.6	7.5±4.0	43	25	18
WSC		8.8±5.6	11.6±5.9	8.3±2.4	41	22	19
WSA	1983	12.2±10.4	13.7±10.1	8.2±6.0	47	22	25
WSB		13.2±11.3	14.0±12.7	11.0±6.4	47	23	24
WSC		15.0±26.4	16.1±37.1	12.1±7.9	41	17	24
WSA	1984	13.2±9.9	12.1±10.5	15.6±4.6	52	26	26
WSB		25.5±8.0	16.7±7.4	28.0±8.1	52	26	26
WSC		21.4±7.9	20.7±7.7	21.8±6.2	52	26	26
WSA	1985	22.6±6.9	27.4±7.7	22.1±5.0	48	23	25
WSB		25.2±5.3	25.4±6.2	25.1±4.0	52	27	25
WSC		26.4±8.4	30.5±8.7	25.1±5.9	52	27	25
WSA	1986	17.7±4.9	22.0±4.0	17.1±3.9	48	24	24
WSB		17.5±5.7	20.3±5.2	17.0±5.4	43	19	24
WSC		21.2±10.5	31.8±9.8	18.8±5.3	50	25	25
WSA	1987	14.1±4.1	15.9±4.4	13.4±1.2	44	21	23
WSB		14.8±3.9	16.7±4.5	14.3±2.2	42	20	22
WSC		16.3±5.5	20.6±5.3	14.7±2.2	46	24	22
WSA	1988	11.9±6.3	9.6±5.3	12.7±6.9	41	16	25
WSB		12.8±6.8	14.2±6.8	12.3±6.8	38	14	24
WSC		14.1±8.9	16.6±10.4	13.1±6.6	43	18	25
WSA	1989	19.5±3.4	20.0±4.1	19.1±2.4	52	27	25
WSB		19.4±3.1	20.1±3.2	18.8±2.8	50	27	23
WSC		21.4±4.9	23.3±5.0	19.9±3.5	51	27	24
WSA	1990	24.5±10.6	33.3±8.6	20.8±7.0	52	27	25
WSB		25.5±11.0	33.2±8.2	23.0±7.5	51	27	24
WSC		32.7±19.1	40.6±17.7	29.5±12.0	51	27	24
WSA	1991	34.1±10.3	32.5±8.6	34.8±11.8	52	27	25
WSB		44.1±11.7	34.9±8.1	46.2±14.5	53	27	26
WSC		31.8±8.0	37.5±6.0	29.0±5.9	35	19	16
WSA	1992	38.3±21.9	25.3±3.9	46.3±29.2	52	27	25
WSB		43.6±20.8	27.4±3.8	50.8±27.4	51	28	23
WSC		41.1±17.9	33.1±5.9	45.7±24.3	51	28	23
WSA	1993	13.3±4.6	15.5±4.2	12.2±1.6	44	27	17
WSB		16.2±4.2	20.1±4.6	13.8±1.6	42	26	16
WSC		18.9±7.3	26.3±6.7	14.5±2.9	43	27	16

Table B.12: Growing, non-growing, and yearly Alkalinity FWMC ± Std. Dev. (2002-2008).

		ALK (mg $L^{-1}CaCO_3$)			Sample Size (n)		
		Year	Growing	Non-Growing	Year	Growing	Non-Growing
WSA	2002	28.3±16.1	31.1±16.2	25.5±9.7	47	23	24
WSB		27.6±16.4	29.7±16.9	25.9±9.1	46	21	25
WSC		32.5±15.6	35.6±15.3	30.4±11.7	48	24	24
WSA	2003	15.2±14.6	24.6±15.3	10.6±6.2	51	27	24
WSB		13.9±12.1	19.5±12.2	10.4±5.6	51	27	24
WSC		17.7±14.8	24.6±15.2	13.9±9.7	49	27	24
WSA	2004	13.8±13.7	17.4±15.3	9.9±1.6	51	28	23
WSB		13.5±8.6	15.7±9.0	10.5±1.6	51	28	23
WSC		34.0±191.9	22.3±7.7	46.7±280.1	51	28	23
WSA	2005	19.5±23.8	27.0±26.5	12.9±10.2	43	22	21
WSB		15.3±12.3	20.6±11.0	11.5±9.2	41	20	21
WSC		17.3±14.5	28.0±14.9	12.8±5.4	40	19	21
WSA	2006	11.6±5.2	13.0±5.9	10.9±2.4	48	24	24
WSB		12.2±5.4	15.4±6.1	10.8±2.0	47	23	24
WSC		13.1±6.9	14.9±8.0	12.2±3.1	49	25	24
WSA	2007	13.6±18.6	21.2±23.0	10.8±5.5	35	14	21
WSB		12.3±20.1	16.7±25.4	11.1±3.4	33	13	20
WSC		18.6±18.0	28.1±21.2	15.1±10.4	36	14	22
WSA	2008	18.0±15.5	30.1±16.3	14.9±9.4	35	13	22
WSB		14.0±16.7	19.7±16.7	12.5±14.3	35	13	22
WSC		15.4±12.8	19.9±9.8	13.7±13.3	36	14	22

Table B.13: Growing, non-growing, and yearly Nitrate FWMC ± Std. Dev. (1982-1993).

		NO_3 (mg L^{-1})			Sample Size (n)		
		Year	Growing	Non-Growing	Year	Growing	Non-Growing
WSA	1982	0.1±0.1	0.2±0.1	0.1±0.1	44	25	19
WSB		0.1±0.2	0.2±0.2	0.1±0.1	45	25	20
WSC		0.1±0.04	0.1±0.1	0.1±0.0	42	22	20
WSA	1983	0.1±0.2	0.0±0.2	0.2±0.2	47	22	25
WSB		0.1±1.7	0.0±1.8	0.4±1.5	48	23	25
WSC		0.1±0.1	0.1±0.1	0.1±0.1	42	17	25
WSA	1984	0.2±0.2	0.1±0.3	0.3±0.2	52	26	26
WSB		1.2±0.6	0.4±0.4	1.5±0.6	52	26	26
WSC		1.3±0.8	0.3±0.4	1.7±0.9	52	26	26
WSA	1985	0.2±0.1	0.4±0.1	0.2±0.1	48	23	25
WSB		0.9±0.3	0.6±0.2	1.0±0.2	52	27	25
WSC		1.1±0.4	0.6±0.3	1.3±0.2	52	27	25
WSA	1986	0.1±0.1	0.2±0.2	0.1±0.1	48	24	24
WSB		0.6±0.2	0.3±0.1	0.7±0.3	43	19	24
WSC		0.8±0.4	0.1±0.1	1.0±0.3	50	25	25
WSA	1987	0.1±0.1	0.2±0.1	0.0±0.1	44	21	23
WSB		0.2±0.1	0.1±0.1	0.2±0.1	42	20	22
WSC		0.4±0.2	0.2±0.1	0.5±0.2	46	24	22
WSA	1988	0.2±0.3	0.2±0.4	0.1±0.1	41	16	25
WSB		0.2±0.3	0.3±0.4	0.1±0.1	38	14	24
WSC		0.3±0.2	0.2±0.1	0.3±0.2	43	18	25
WSA	1989	0.1±0.1	0.1±0.1	0.1±0.0	52	27	25
WSB		0.1±0.0	0.1±0.03	0.1±0.04	50	27	23
WSC		0.1±0.05	0.1±0.03	0.1±0.0	51	27	24
WSA	1990	0.2±0.1	0.2±0.1	0.1±0.1	52	27	25
WSB		0.2±0.1	0.2±0.1	0.2±0.1	50	27	23
WSC		0.2±0.1	0.2±0.1	0.3±0.1	51	27	24
WSA	1991	1.0±1.0	1.2±0.7	1.0±1.2	52	27	25
WSB		3.0±1.0	1.3±0.4	3.4±1.4	53	27	26
WSC		1.6±0.8	1.5±0.6	1.7±0.9	35	19	16
WSA	1992	1.3±0.6	1.6±0.5	1.1±0.5	48	27	21
WSB		2.0±0.8	1.3±0.5	2.4±0.8	47	27	20
WSC		2.2±1.2	1.3±0.7	2.8±1.4	50	28	22
WSA	1993	0.2±0.4	0.3±0.4	0.2±0.2	35	18	17
WSB		0.4±0.2	0.5±0.3	0.3±0.1	34	18	16
WSC		0.5±0.2	0.5±0.1	0.5±0.2	34	18	16

Table B.14: Growing, non-growing, and yearly Nitrate FWMC ± Std. Dev. (2002-2008).

		NO_3 (mg L^{-1})			Sample Size (n)		
		Year	Growing	Non-Growing	Year	Growing	Non-Growing
WSA	2002	0.1±0.1	0.1±0.1	0.1±0.1	47	23	24
WSB		0.3±0.2	0.2±0.1	0.3±0.2	46	21	25
WSC		0.3±0.1	0.2±0.1	0.3±0.1	48	24	24
WSA	2003	0.1±0.1	0.1±0.1	0.1±0.1	51	27	24
WSB		0.2±0.1	0.2±0.1	0.3±0.1	51	27	24
WSC		0.2±0.1	0.2±0.1	0.3±0.1	49	25	24
WSA	2004	0.1±0.1	0.1±0.1	0.1±0.0	51	28	23
WSB		0.2±0.1	0.2±0.1	0.2±0.1	51	28	23
WSC		0.2±0.1	0.1±0.0	0.2±0.1	51	28	23
WSA	2005	0.2±0.3	0.2±0.2	0.1±0.3	43	22	21
WSB		0.3±0.2	0.2±0.1	0.3±0.3	41	20	21
WSC		0.2±0.1	0.2±0.1	0.2±0.1	40	19	21
WSA	2006	0.1±0.2	0.2±0.2	0.1±0.1	48	24	24
WSB		0.2±0.1	0.3±0.1	0.2±0.2	47	23	24
WSC		0.2±0.1	0.1±0.1	0.2±0.1	49	25	24
WSA	2007	0.2±0.2	0.2±0.2	0.2±0.2	35	14	21
WSB		0.3±0.2	0.2±0.1	0.4±0.2	33	13	20
WSC		0.2±0.1	0.1±0.1	0.3±0.2	36	14	22
WSA	2008	0.2±0.4	0.1±0.1	0.2±0.5	35	13	22
WSB		0.2±0.5	0.2±0.1	0.2±0.5	35	13	22
WSC		0.2±0.1	0.1±0.05	0.2±0.1	36	14	22

Table B.15: Growing, non-growing, and yearly Phosphate FWMC ± Std. Dev. (1982-1993).

		PO_4 (mg L^{-1})			Sample Size (n)		
		Year	Growing	Non-Growing	Year	Growing	Non-Growing
WSA	1982	0.0±0.1	0.05±0.1	0.01±0.03	44	25	19
WSB		0.0±0.1	0.1±0.1	0.01±0.04	45	25	20
WSC		0.0±0.1	0.03±0.2	0.01±0.1	43	22	21
WSA	1983	0.1±0.0	0.1±0.02	0.1±0.04	47	22	25
WSB		0.1±0.0	0.05±0.02	0.07±0.02	48	23	25
WSC		0.1±0.0	0.1±0.03	0.1±0.03	42	17	25
WSA	1984	0.1±0.1	0.1±0.1	0.1±0.02	52	26	26
WSB		0.2±0.1	0.2±0.1	0.2±0.05	52	26	26
WSC		0.1±0.1	0.2±0.1	0.1±0.1	52	26	26
WSA	1985	0.1±0.0	0.1±0.02	0.1±0.05	48	23	25
WSB		0.1±0.0	0.1±0.04	0.1±0.05	52	27	25
WSC		0.2±0.1	0.2±0.1	0.2±0.1	52	27	25
WSA	1986	0.1±0.1	0.1±0.1	0.1±0.05	48	24	24
WSB		0.1±0.1	0.2±0.1	0.1±0.1	43	19	24
WSC		0.1±0.1	0.1±0.1	0.1±0.1	50	25	25
WSA	1987	0.1±0.1	0.1±0.02	0.1±0.08	44	21	23
WSB		0.1±0.0	0.1±0.1	0.1±0.05	42	20	22
WSC		0.1±0.1	0.1±0.04	0.1±0.1	46	24	22
WSA	1988	0.2±0.2	0.2±0.2	0.2±0.2	41	16	25
WSB		0.3±0.3	0.3±0.4	0.3±0.3	38	14	24
WSC		0.3±0.2	0.3±0.2	0.3±0.2	43	18	25
WSA	1989	0.1±0.1	0.1±0.1	0.1±0.1	52	27	25
WSB		0.1±0.1	0.1±0.1	0.1±0.1	50	27	23
WSC		0.1±0.1	0.1±0.1	0.1±0.1	51	27	24
WSA	1990	0.1±0.0	0.1±0.03	0.1±0.04	52	27	25
WSB		0.1±0.0	0.1±0.03	0.1±0.06	51	27	24
WSC		0.1±0.04	0.1±0.03	0.1±0.04	51	27	24
WSA	1991	0.1±0.0	0.1±0.02	0.1±0.03	52	27	25
WSB		0.1±0.1	0.1±0.02	0.1±0.08	53	27	26
WSC		0.1±0.1	0.1±0.1	0.1±0.03	35	19	16
WSA	1992	0.0±0.1	0.1±0.1	0.04±0.02	52	27	25
WSB		0.0±0.0	0.04±0.01	0.03±0.01	51	28	23
WSC		0.0±0.01	0.04±0.01	0.03±0.01	51	28	23
WSA	1993	0.1±0.0	0.1±0.03	0.1±0.02	44	27	17
WSB		0.1±0.0	0.1±0.03	0.1±0.02	42	26	16
WSC		0.1±0.03	0.1±0.04	0.1±0.02	43	27	16

Table B.16: Growing, non-growing, and yearly Chlorine FWMC Std. Dev. (2002-2008).

		Cl (mg L^{-1})			Sample Size (n)		
		Year	Growing	Non-Growing	Year	Growing	Non-Growing
WSA	2002	0.8±0.1	0.8±0.1	0.8±0.1	47	23	24
WSB		0.8±0.1	0.8±0.1	0.8±0.1	46	21	25
WSC		0.7±0.1	0.8±0.1	0.7±0.1	48	24	24
WSA	2003	0.9±0.6	1.2±0.7	0.7±0.2	51	25	24
WSB		0.9±0.8	1.2±1.0	0.7±0.2	51	25	24
WSC		0.8±0.5	1.1±0.6	0.7±0.1	49	25	24
WSA	2004	0.6±0.1	0.6±0.1	0.6±0.1	51	28	23
WSB		0.6±0.5	0.6±0.7	0.6±0.1	51	28	23
WSC		0.6±0.1	0.6±0.1	0.6±0.1	51	28	23
WSA	2005	0.5±0.1	0.5±0.1	0.6±0.1	43	22	21
WSB		0.5±0.1	0.4±0.1	0.6±0.1	41	20	21
WSC		0.5±0.2	0.4±0.1	0.5±0.2	40	19	21
WSA	2006	1.2±0.5	0.8±0.5	1.4±0.5	48	24	24
WSB		1.2±0.6	0.7±0.5	1.4±0.6	47	23	24
WSC		1.0±0.5	0.9±0.5	1.0±0.6	49	25	24
WSA	2007	1.0±0.4	1.1±0.4	1.0±0.3	35	14	21
WSB		0.9±0.4	1.1±0.5	0.9±0.3	33	13	20
WSC		1.0±0.7	0.9±0.4	1.1±0.8	36	14	22
WSA	2008	1.1±0.4	0.8±0.3	1.1±0.4	35	13	22
WSB		1.0±0.3	0.9±0.2	1.0±0.3	35	13	22
WSC		0.9±0.3	0.9±0.27	1.0±0.3	36	14	22

Table B.17: Growing, non-growing, and yearly Ammonia FWMC ± Std. Dev. (2002-2008).

		NH_4-N (mg L^{-1})			Sample Size (n)		
		Year	Growing	Non-Growing	Year	Growing	Non-Growing
WSA	2002	0.04±0.04	0.05±0.05	0.03±0.02	37	23	14
WSB		0.03±0.05	0.04±0.05	0.02±0.03	36	21	15
WSC		0.03±0.05	0.04±0.05	0.02±0.03	38	24	14
WSA	2003	0.02±0.02	0.01±0.01	0.03±0.02	51	27	24
WSB		0.02±0.02	0.01±0.03	0.03±0.02	51	27	24
WSC		0.02±0.02	0.02±0.02	0.03±0.02	51	27	24
WSA	2004	0.02±0.02	0.03±0.02	0.01±0.02	38	20	18
WSB		0.05±0.02	0.1±0.02	0.04±0.02	28	17	11
WSC		0.03±0.04	0.03±0.04	0.02±0.02	32	21	11
WSA	2005	0.03±0.02	0.04±0.02	0.03±0.01	14	7	7
WSB		0.03±0.01	0.04±0.01	0.02±0.01	16	9	7
WSC		0.02±0.01	0.03±0.01	0.02±0.02	14	6	8
WSA	2006	0.05±0.1	0.04±0.1	0.05±0.04	20	10	10
WSB		0.05±0.03	0.04±0.04	0.05±0.02	20	9	11
WSC		0.04±0.03	0.1±0.03	0.04±0.01	20	10	10
WSA	2007	0.1±0.1	0.2±0.1	0.1±0.1	19	6	13
WSB		0.1±0.04	0.1±0.02	0.1±0.04	18	6	12
WSC		0.1±0.1	0.1±0.04	0.1±0.1	23	6	17
WSA	2008	0.1±0.04	0.1±0.05	0.1±0.02	7	2	5
WSB		0.04±0.1	0.03±0.0	0.07±0.1	6	2	4
WSC		0.1±0.04	0.1±0.0	0.1±0.04	11	1	10

Table B.18: Growing, non-growing, and yearly TOC FWMC ± Std. Dev. (2002-2008).

		TOC (mg L^{-1})			Sample Size (n)		
		Year	Growing	Non-Growing	Year	Growing	Non-Growing
WSA	2002	4.3±3.7	4.4±4.4	4.3±1.2	47	23	24
WSB		3.8±2.8	3.7±3.3	3.9±1.1	46	21	25
WSC		5.2±4.1	5.3±5.0	5.2±1.4	48	24	24
WSA	2003	3.4±2.1	4.6±2.1	2.8±1.0	51	27	24
WSB		3.0±1.4	3.6±1.5	2.7±0.6	51	27	24
WSC		3.8±2.3	4.7±2.5	3.3±1.3	51	27	24
WSA	2004	3.5±1.6	4.3±1.6	2.6±0.5	51	28	23
WSB		3.4±1.4	4.0±1.3	2.5±0.7	51	28	23
WSC		3.9±1.6	4.8±1.6	2.9±0.7	51	28	23
WSA	2005	3.9±2.9	4.6±3.1	3.3±2.1	43	22	21
WSB		3.0±1.6	3.5±1.4	2.7±1.4	41	20	21
WSC		3.4±2.4	4.2±1.8	3.0±2.7	40	19	21
WSA	2006	3.8±1.6	4.9±1.3	3.2±1.7	46	24	22
WSB		3.2±1.3	4.0±1.1	2.8±1.5	45	23	22
WSC		3.6±1.4	4.2±1.4	3.3±1.2	47	25	22
WSA	2007	4.0±2.9	4.2±2.1	3.9±3.4	35	14	21
WSB		4.6±2.5	4.8±1.7	4.6±2.8	29	12	17
WSC		4.4±2.2	5.1±1.6	4.1±2.6	30	14	16
WSA	2008	0.4±1.3	0.5±1.6	0.4±1.0	35	13	22
WSB		2.1±0.7	2.0±0.4	2.2±0.8	8	5	3
WSC		3.7±0.6	2.9±0.31	4.2±0.01	7	5	2

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