# WATER YIELD, PEAK FLOW AND HIGH FLOW RESPONSE OF A LARGE FORESTED WATERSHED IN CENTRAL ARKANSAS TO SUSTAINED FOREST HARVEST OPERATIONS

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# CHAPTER I

# INTRODUCTION

Streams provide a wide range of beneficial uses to humans and are a habitat for fish and other aquatic fauna. Streams afford opportunities for recreation, are a source of water for industrial, municipal, and agricultural users, and can act as a reservoir for diluting liquid waste discharges. These uses are affected by the quantity and quality of the stream water. The magnitude, rate, and quality of water delivered from the forested watershed is influenced by vegetation, climate, soils, geology, solar energy, and other watershed characteristics. Of these, vegetation, its density, type and age, is most affected by forest management practices. By reducing the volume of evapotranspiring material, forest harvesting increases soil moisture, and, consequently, enables a greater proportion of precipitation to contribute to streamflow. Watershed-scale research on the effects of natural and man-made changes in forest vegetation on water yield, low-flows, stormflow volume, and peak flow rate have helped us to better understand the water yield impact of forest management alternatives. Annual water yield increases as much as 400 mm after clearcutting experimental watersheds.

Of special interest to watershed managers is the timing of these increases during the year. Augmentation of streamflow during the growing season as a consequence of forest clearing is often welcome. High evapotranspiration and low summer rainfall can result in low streamflows that may be detrimental to those humans and fauna alike which utilize the stream. The unfavorable consequences of forest clearing are the possible increase in stormflow volume and peak flow rates. Most of the research has shown, however, that cutting the forest has more of an impact on smaller stormflows than on the major flood events which cause structure damage and channel erosion.

The results of small watersheds research is often extrapolated to larger basins under the scenario of sustained yield timber harvesting in order to understand the practical implications of the research. Researchers have estimated that the potential for water yield augmentation from forested drainages in the east, southwest, and northwest United States is between one and six percent of total annual water yield. Adding to this body of research are historical studies of the impact of gradual, long-term changes in forest vegetation on large areas, such as what occurs when abandoned farmlands revert to forest. Although these types of studies are rare, they often confirm the results of small watershed research, and provide direct measurement of the downstream impact of large area-based forest management practices.

The 545 square kilometer drainage area of the South Fourche LaFave River in the Arkansas portion of the Ouachita Mountain Province is over 95 percent forested with shortleaf/loblolly pine and mixed hardwoods. Timber harvesting from the 1940's to the mid-1960's was largely by the selection method in which individual trees within a stand were cut. Since then, however, the predominant commercial harvesting technique has been the clearcut, and over 40 percent of the watershed has been logged in the past 20 years. This represents a fundamental and abrupt change in the magnitude and intensity of the logging activity on the watershed. Consequently, it may be possible, to determine what impact this activity has had on the flow of the river draining the South Fourche LaFave watershed.

## Objectives

This study examines the impact that nearly twenty years of even-aged forest management has had on the streamflow response of the South Fourche LaFave River in central Arkansas. Daily stream discharge and precipitation records that have been collected by various federal agencies since 1942 were used in the analysis. Forest plantation age records from the U.S. Forest Service and Weyerhaeuser Company were also used.

The primary objectives of the study were:

1) To determine if a significant change in annual or seasonal water yields has occurred as a result of forest harvest activity during the past 20 years.

2) To determine if a significant change in the annual series of maximum instantaneous peak discharges has occurred as a result of the harvesting activities.

3) To determine if the high-flow characteristics of the stream have significantly changed as a result of the harvesting activities.

## Definitions

The following definitions are from Hewlett's (1982) <u>Principles of Forest Hydrology</u>, Univ. of Georgia Press, Athens, Georgia:

Baseflow - generally defined as the outflow from extensive ground water aquifers which are recharged by water percolating vertically through the soil mantle to the water table. It is also sustained by the slow drainage of unsaturated soil, particularly in steep areas. Baseflow is normally thought to be the sole component of streamflow between storm or snowmelt periods.

Peak flow rate - The maximum discharge rate that occurs during a storm or other runoff-causing event, such as snowmelt.

Stormflow - the sum of surface and subsurface stormflow. It is the combination of channel precipitation, that part of streamflow which fails to infiltrate and runs over the surface of the soil to the stream, and that part of streamflow that is derived from subsurface source, but arrives at the stream channel so quickly that it becomes part of the storm hydrograph. Also referred to as "quickflow" and "stormflow volume".

Streamflow - The flow of water past any point in a natural channel above the bottoms and sides of the channel. The sum of stormflow and baseflow from groundwater and subsurface flow.

Water yield - A drainage basin's total yield of liquid water during some period of time. It is the sum of streamflow, underflow (which refers to ungaged water moving past a stream channel section), and deep seepage (which is either a loss or a gain of water from a basin by deep pathways that do not discharge into the channel above the gaging station). In this study and in the research reviewed here, underflow and deep seepage are assumed to be either constant or negligible. Yield is then the sum of the daily discharges for the time period of interest.

# CHAPTER II

# LITERATURE REVIEW

## Forest Hydrologic Processes

Part of the rain that enters the tree canopy is intercepted by plant surfaces. The amount of intercepted water that evaporates is called interception loss. The amount of the total precipitation actually reaching the ground is the sum of throughfall and stemflow. Throughfall is that quantity that falls directly through the canopy to the ground plus that part of intercepted water that drips from the foliage and branches. Stemflow is that part of intercepted water that flows down the trunks of trees. Lawson (1967) examined these processes in a shortleaf pine overstory-hardwood understory stand at the Alum Creek Experimental Forest in the Ouachita Mountains of Arkansas. The average annual interception loss was 12.7 percent of average annual rainfall. Stemflow was 2.4 percent, making total throughfall 84.9 percent of total precipitation. Thus, with a mean annual rainfall of 1078 mm (millimeters) for the 5-year study period, about 137 mm was intercepted and evaporated yearly. Regression analysis of throughfall for 53 storms showed that the relative amount of storm precipitation that is intercepted and evaporated decreases as storm size increases. This relationship reflects the fact that a fixed amount of water is required to wet the foliage. Therefore, with respect to the timber harvest, the relative impact of reducing crown cover on interception would be greatest during smaller storms.

The amount of rainfall intercepted and stored in the canopy changes with vegetation type, as demonstrated by the differences in interception between eastern white pine and mature hardwoods (Helvey and Patric, 1965; Helvey, 1967). A white pine stand 10 years old intercepted 4.3 mm from a 50 mm rainfall, whereas hardwoods in full leaf intercepted only 3.8 mm, and in the dormant season only 1.8 mm. As pine stand age increases, larger interception differences between pines and hardwoods occur in both seasons.

Infiltration capacity is the rate at which water can enter the soil surface. For undisturbed forest land, infiltration capacities nearly always exceed rainfall intensities (Anderson et al., 1976). Thus, overland flow is virtually absent in the forest and subsurface flow is the dominant process. When forest soil is exposed or becomes compacted by road construction or logging activity, infiltration capacities may be impaired and overland flow may occur. Surface flow also occurs when the cut slopes of roads intersect the transmission lines of subsurface water. Ditches and culverts may then deliver this water to the stream more rapidly than the subsurface system (Harr et al., 1975).

Infiltrated water that is stored in the soil eventually leaves to go to groundwater, to streamflow or other surface waters, or is evaporated to the atmosphere. The maximum volume of plant-available water stored in a forest soil is found by taking the difference between field capacity and wilting point moisture contents throughout the rooting depth (Anderson et al., 1976). Rogerson (1985) examined soil water contents for a 2-year period on three small pine-hardwood watersheds at Alum Creek in central Arkansas. The soils are shallow (.76 to .91 meters deep) and moderately permeable. The maximum amount of water available for plant use (i.e. the maximum soil water deficit generated by the forest at any one time) was 142 mm. Rogerson also examined the variability of soil water deficits during a year. In the growing season, transpiration removes soil water, creating large soil water deficits which are replenished during the dormant season, when lower transpiration rates and increased rainfall contribute to recharging the soil water reservoir. In Rogerson's study, soil water deficits were in the 0 to 55 mm range for most of the dormant season (November-April), and increased in May as forest transpiration demands increased. The largest growing season deficits were between 75 mm and 150 mm and occurred during the high evapotranspiration period between June and October. Growing season rainfall temporarily reduced deficits, but transpiration losses quickly returned the deficits to usual growing season levels. Nash (1963) examined soil water deficits on different slopes and aspects in a southern Missouri watershed. Slope and aspect have a major effect on the amount of solar radiation received by an area, and, therefore, affect evapotranspiration and soil moisture content. The calculated deficit on a horizontal surface for a normal year was 99 mm. A 40 degree north slope had a deficit of 48 mm, and a 40 degree southwest slope had a deficit of 150 mm.

When vegetation is cleared, interception and transpiration losses are greatly reduced, while surface evaporation may increase (Anderson et al., 1976). The result is that soil on a cutover area may have a greater water content at any time during the growing season than it would have had with forest cover. Some of this increase in soil water may augment streamflows, as a relatively smaller amount of storm precipitation is required to recharge the soil. The duration of any soil water, transpirational, or streamflow changes depends upon the magnitude of the initial response to cutting and on the rapidity with which the forest canopy and root network become re-established. In Rogerson's (1985) study one watershed was clearcut and another was thinned (43 percent of the basal area removed). Dormant season soil water deficits were unaffected by the treatments and remained relatively low (0-25 mm). The first year after the treatments, growing season deficits were reduced 50 to 75 mm on the thinned watershed and 75 to

100 mm on the clearcut watershed. The effect of the timber harvest on soil water deficits continued for several years. After thinning, the expansion of the crowns and root systems of the remaining pines resulted in the return to pretreatment soil water deficit values within 7 years. On the cleared watershed the rapid establishment of a dense grass cover produced a similar outcome. The increase in soil moisture after forest cutting resulted in increases in annual water yield from both the treated watersheds. The year after thinning, annual water yield increased 109 mm above the predicted value based on the flow from the uncut (control) watershed. Similarly, the first year yield increase on the clearcut watershed was 259 mm. As the cutover areas on both watersheds revegetated, annual water yields declined toward pretreatment levels.

## Introduction to Watershed Research

Results from watershed experiments that examine the effects of vegetation changes on water yields and stormflows are routinely used to evaluate the impact of forest management on hydrologic processes. Research on the effect of vegetation changes on water yield and stormflow is reviewed in the following sections. The discussion is in two major parts; the first pertains to designed forest cutting experiments on small watersheds, and the second to field investigations involving natural forest disturbances, forest regeneration on abandoned lands, and long-term timber harvest activities. Typically, field studies involve large drainage areas with a variety of soil, geologic, topographic, and vegetation conditions. The relation between forest vegetation and streamflow in regions that are very dry, such as the southwest United States, and where precipitation falls primarily as snow, are not covered specificallly in this review, as these climates are dissimilar to the region being studied.

## Small Watershed Research

Experiments designed to determine the effects of vegetation changes on water yields and stormflows often use the control watershed approach (Wilm, 1944). The control watershed serves as a climatic standard to correct the experimental results for climate. During a calibration period, flow relationships are developed between two similar watersheds. A treatment, such as a clearcut, is applied to the treatment watershed. Then, for the years following the treatment, the flow from the control watershed is used to predict the size of the flow that would have come from the treated watershed had it remained forested. The difference between observed and predicted flows is then attributed to the removal of the forest vegetation. Reviewing the data from the best controlled catchment experiments in the eastern United States, Hewlett (1971) observed that annual yield can be predicted "to an accuracy of plus or minus 50 mm of streamflow at the 95 percent level of confidence, or about 5 to 10 percent of the average annual streamflow". He also emphasized the need to consider the magnitude of the standard error of the estimate in deciding whether to rely on the control watershed method or to find another approach.

Hewlett (1971) cautioned that vegetation regrowth after the treatment, changing climate, and periods of zero-flow in the stream bed can partly confound the effect of the treatment. When the treatment watershed is cut and no steps are taken to suppress the regrowth, the posttreatment relationship between the control and treatment watersheds is not constant. Rapid forest regeneration diminishes the hydrologic impact of the treatment and shortens the posttreatment analysis period. In addition, the range in climate during the calibration period may not be the same as that occurring during the short period when the treatment effect is measurable. Hewlett also cautioned that periods of zero flow in the experimental basins may confuse the analysis: "As long as flow is above the stream bed, we may assume that the great majority of effect of treatment is quantitatively included in measured streamflow, and that subsurface leaks (underflow) or diversions elsewhere in the basin are constant or are accounted for in the calibration relationship."

When streamflow from the potential control watershed is poorly correlated to the treatment watershed, the treatment watershed may be calibrated using climatological data. This is the single watershed approach. Reinhart (1967) suggests that the best alternative may be to combine the control watershed and climatic calibration techniques. For example, using the control watershed streamflow and the difference in precipitation falling on the two watersheds to predict streamflow from the treatment watershed.

The small watershed research studies reviewed in this paper used the control watershed approach. In field investigations, both the control and single watershed methods were used to analyze the effects of forest change.

## Water Yield Changes After Forest Clearing

The water yield of an area is dependent on the type, age, density, and health of vegetation; soil and geologic factors; precipitation and other climatic factors; and slope, aspect and lattitude of the area, which influence the amount of incident solar radiation. Of these factors, vegetation conditions are most effected by forest management practices. Forest cutting reduces evapotranspiration, increases soil moisture content, and makes more precipitation available for streamflow. The magnitude of this contribution is generally proportional to the relative change in vegetation. The variability of the water yield response between similar watersheds is often related to local differences in soil depth and the energy available for evapotranspiration. Fluctuations in water yield response from year to year may be the result of short-term fluctuations in the pattern and/or magnitude of annual precipitation.

Magnitude and Timing of Water Yield Increases. Much of the watershed research on the effects of forest cutting on streamflow has been conducted in the Appalacian hardwood forests at the Coweeta Hydrologic Laboratory in North Carolina. The watersheds have deep (8 meters average), permeable soils. Average annual precipitation is 2000 millimeters (mm), almost all falling as rain, and is distributed uniformly throughout the year. Dormant season precipitation produces high winter and spring streamflows. Summer flows are greatly reduced even though rainfall does not decrease (Douglass and Swank, 1975). One of the earliest studies at Coweeta involved clearcutting a 14 hectare north-facing watershed (WS 17). The cut vegetation was left on the site to minimize soil disturbance, and annual regrowth was cut periodically for the next 12 years (Hewlett and Hibbert, 1961; Swank and Miner, 1968). The first year increase in annual water yield (May-April water year) on WS 17 was 408 mm, with 71 percent of the increase occurring between August and January. During the 7 years in which tree regrowth was annually cut back, the average annual yield increase was 235 mm. The decline was attributed to the establishment of a close cover of herbaceous and low shrubby growth during this period.

In the research cited here, annual yield analysis is usually based on either May-April or October-September water years because of the stability from year to year of soil water storage at the start of these periods. Selecting a water year which minimizes the storage (S) term in the annual water balance: $P = Q + ET +/- S$ (neglecting deep percolatation out of the watershed) improves the correlation between Q (measured streamflow) and P (precipitation). This leads "to a degree of improvement in a regression line which would be difficult to equal by the addition of other independent variables ... [allowing] ... additional analyses [to] start at a more precise level" (Brakensiek, 1957). In the humid east, the Forest Service has found that the maximum storage value, using a May-April water year, is more stable from year to year. For several large watersheds in Ohio, Brakensiek (1957) selected the March-February water year, which corresponded to the average maximum soil water content. Because soil moisture data is seldom available for use in determining the optimum water year, some researchers have used regression analysis to determine the optimum water year (Brakensiek, 1959; Mustonen, 1967; Reigner, 1964; Schneider and Ayer, 1961; Sharp et al., 1960). Annual water yield and annual precipitation are determined for the calibration period using water years starting on the first day of different months of the year. The water year chosen is that one which the regression of water yield against precipitation gives the highest correlation coefficient and/or the lowest standard error. Seasonal water yield changes cited in this paper were usually based on 6-month growing or dormant season periods. The assumption being that soil water storage at the beginning and end of each season is usually stable from year to year. Analysis by 3-month periods, caution Hewlett and Hibbert (1961), is only meaningful when streamflows from the paired watersheds are highly correlated and when corrections are made for the differences in soil moisture storage at the start and end of each period for each year of the study.

Simultaneous to the WS 17 experiment, another north-facing watershed (WS 13) was clearcut, also without removal of wood products, but in this case regrowth was not suppressed (Swift and Swank, 1981). The first year water yield increase was 362 mm. Forty-six percent of this increase occurred between the months of January and April, and was attributed to a lag relationship between evapotranspiration and streamflow within the soil reservoir, in part due to the deep soils of the region. The treatment was repeated 23 years later and resulted in a nearly identically first year yield increase of 375 mm.

The response to clearcutting Coweeta WS 37, a high-elevation, north-facing watershed, was an unexpected low annual water yield increase of 255 mm (Swift and Swank, 1981). The researchers theorized that this was due to lower overall potential evapotranspiration associated with the shallow soils and shorter growing season of the high-elevation watershed, which limited the effect that removing vegetation had on water yield.

Partial cutting studies on north-facing slopes at Coweeta support the principle that first year yield increases are proportional to the percent of stand removed (Hewlett and Hibbert, 1961). Strip clearcuts removing 50 percent of the basal area on WS 22 resulted in a first year increase about half as large (189 mm) as those observed from clearcutting WS 17 and WS 13. Cutting the mountain laurel and rhododendron understory of WS 19 reduced basal area by 22 percent and increased the annual yield by 71 mm, about one-fifth the response from the cleared watersheds. Cutting studies involving removal of smaller percentages of basal area produced nonsignificant changes in annual yield, suggesting that the increases, if they occurred, were less than than the experimental error of the flow measurements.

Clearcutting vegetation on south-facing watersheds at Coweeta produced first year yield increases smaller than those observed on the northern exposures. The difference has been attributed to the higher amount of incident radiant energy on the exposed southerly slopes during the growing season (Swift, 1960; 1972). Here, more of the available soil water increase after forest cutting goes towards evaporation rather than to increases in streamflow. The first year increase after clearcutting a 16 hectare south-facing watershed (WS 1) (without tree removal) was only 150 mm (Swank and Miner, 1968). A commercial clearcut on WS 7 that involved product removal resulted in an increase of only 260 mm (Swank et al., 1982).

The early Coweeta research (Hewlett and Hibbert, 1961) was reinforced by research at the Fernow Experimental Forest in West Virginia (Reinhart et al., 1963). Together, these studies were the first to provide evidence that the magnitude of first year water yield increases is proportional to the amount of forest cut. Soils on the Fernow watersheds are not as deep as the Coweeta soils (only 0.9 to 1.5 meters). Annual precipitation averages 1450 mm and is well-distributed during most years. Like Coweeta, dormant season streamflows on small streams are relatively high, but decline in the summer because of high evapotranspiration losses (Patric, 1973). A commercial clearcut removing 85 percent of basal area from one watershed, and a 36 percent diameter-limit cut on another, produced statistically significant first year (May-April water year) annual yield increases of 130 mm and 64 mm, respectively (Reinhart et al., 1963). In the same study, lighter treatments removing 20 percent and 13 percent of basal area from two experimental watersheds produced smaller, but not statistically significant increases in yield. On two other Fernow watersheds, where the timber on half the watershed areas was clearcut and removed, Patric and Reinhart (1971) reported that the average annual yield increase for the 3 years in which regrowth was suppressed was 145 mm. When the remaining vegetation on both watersheds was cut, the average yield increase was 255 mm.

Hibbert (1967) explained the difficulty in detecting water yield increases from small cuts: (1) a border effect can exist when cutting is confined to scattered individual trees or small groups of trees - neighboring trees absorb the radiant energy and soil moisture that would have gone to the cut trees, especially in dry climates or during dry years when evapotranspiration is primarily limited by the water supply; and (2) no statistical significance can be attributed to measured yield response when the expected response is smaller than the experimental error associated with the measurement.

In contrast to the 2000 mm and 1450 mm average annual rainfalls at Coweeta and Fernow, annual precipitation at the Hubbard Brook Experimental Forest in New Hampshire is only 1220 mm, with one-fourth to one-third falling as snow. Soils average about 1.5 meters in depth and are permeable throughout the year. Hubbard Brook researchers conducted a cutting study similar to the Coweeta WS 17 experiment (Hornbeck et al., 1970). All vegetation was cut and the material left on the site. Seedling regeneration and stump sprouts were chemically suppressed for the next three years. Yield response functions were developed for streamflow between the treated and control watersheds for individual months, for growing and dormant seasons, and for the water year (June-May). Annual yield increases for the three years of vegetation suppression were 343 mm, 274 mm, and 240 mm. To determine seasonal response, years were divided into a 4-month growing season (June-September) and an 8-month dormant season (October-May). A major portion of the annual increases occurred in the growing season. For these three years, growing season yield increases were 315 mm, 236 mm, and 124 mm, respectively.

The timing of yield increases observed in the Fernow studies occurred through December, whereas yield increases were measured well into the dormant season for most of the Coweeta experiments. On the cleared watershed at Fernow, 86 percent of the total increase occurred in the growing season (Reinhart et al., 1963). When half the area of two Fernow watersheds was cut and removed, 65 percent of the total 3-year yield increase happened during the growing season (Patric and Reinhart, 1971). After the remaining vegetation was cut, 80 percent of the 255 mm yield increase occurred in the growing season. When Coweeta WS 17 was 100 percent clearcut, 71 percent of the 408 mm first year yield increase came between August and January (Hewlett and Hibbert, 1961). Similarly, 46 percent of the 362 mm increase after clearcutting WS 13 occurred between January and April. The difference in the timing of yield increases between Coweeta and Fernow has been partially attributed to the differences in soil depth of the two regions. During the fall-winter soil recharge period, the shallow soils at Fernow recharge sooner then the deep Coweeta soils. Wherever the location, once the soils on cut and uncut areas are completely recharged, any difference in soil moisture deficits between the cut and uncut areas becomes negligible and water yield differences due to cutting cease. At Hubbard Brook, 91 and 87 percent of the annual yield increase the first two years after clearcutting a watershed occurred in the 4-month growing season (June-September) (Hornbeck et al., 1970). This was attributed to the fact that soil moisture recharge at Hubbard Brook usually occurs early in the dormant season. Dormant season yield increases these two years were not statistically significant. In the third posttreatment year, however, 48 percent of the annual increase of 240 mm came during the dormant season. Growing season rainfall was exceptionally low this year, and soil recharge was delayed into the dormant season.

In an effort to develop a predictive model for estimating the magnitude of first year yield increases after forest removal, Douglass and Swank (1975) examined the results from 23 cutting experiments in the Appalacian Highland physiographic division. These included 13 experiments at Coweeta, 8 at Fernow, and one each at the Leading Ridge watersheds in Pennsylvania and at Hubbard Brook. They developed a regression model that related the variability of first year water yield increases (Y) after treatment to the percent reduction in basal area (BA) (or land area if basal area is well-distributed over the watershed), and an energy term (PI) to account for any disparity in yield increases between cutting north- vs south-facing watersheds. The model was

$$Y = 0.00224\ (BA/PI)^{1.4462}$$

where PI is the annual potential insolation in langleys (times $10^{-6}$) for the watershed. This model explained 89 percent of the variation in first year yield increases as a result of treatment. In cautioning wise use of the model Douglass (1983) advised that such models are best evaluated over the long run, where positive and negative deviations for individual years have a chance to cancel out.

In Arkansas Lawson (1976) and Rogerson (1985) examined the impact on annual water yield of removing a shortleaf pine overstory from two small, 0.6 hectare watersheds at Alum Creek in the Ouachita Mountains. Soils on the Alum Creek watershed are shallow (.75 to .92 meters deep) and moderately permeable. Annual precipitation averages 1325 mm and is fairly evenly distributed throughout the year. In both watersheds the hardwood understory was injected and the hardwood regrowth chemically suppressed for three years. Cutting all the pine on one watershed resulted in a first year increase of 259 mm. Sixty-one percent of the cumulative streamflow increase for the first seven years after the cut occurred in the growing season. The pine stand on the second watershed was thinned to 13.8 $m^2$/hectare, a 43 percent reduction in basal area. The first year yield increase was 109 mm. The cumulative streamflow increase for the 7-year posttreatment period was divided evenly between the growing and dormant seasons, and was attributed to lower year-round transpiration and interception losses.

Cutting studies in western Oregon support the general principles formulated from the studies east of the Rocky Mountains. The regional climate is characterized by dry summers and wet winters. About 80 percent of annual precipitation and streamflow occurs between October 1 and March 31. Lower elevation precipitation occurs as rain in low intensity, long duration storms. Harr (1976, 1983) reviewed the changes in water yield after cutting in this region. Annual yields increased 360-540 mm after 100 percent clearcut logging and 100-300 mm after partial cutting. These increases occurred immediately after logging and diminished as the sites revegetated. The largest relative increases occurred during the low-flow months in the summer. The greatest portion of the yield increases occurred during the October-March rainy season. Rothacher (1970) examined the effects of forest clearing at the H.J. Andrews Experimental Forest in the Cascade Range of western Oregon. He observed that 50 percent of the first year yield increase after clearcutting a 96 hectare watershed occurred at the start of the rainy season (October-December), and that an additional 30 percent took place between January and March. Harr (1976) attributed the fall water yield increase to less rainfall required for soil moisture recharge, making more water available for streamflow. The winter yield increases were attributed to differences in interception between cut and uncut areas.

Streamflow response to cutting also varies greatly according to the type of vegetation cut. In their summary of worldwide catchment experiments, Bosch and Hewlett (1982) separated the watershed experiments by vegetative type (conifer, deciduous hardwood and scrub) and fitted regression lines to the results in an attempt to better understand the treatment responses that Hibbert (1967) had referred to as unpredictable. In general, the analysis showed that conifer forests are more consumptive of water and reduce total streamflow more than other vegetation types. Annual water yield changed 40 mm on average per ten percent change in conifer cover, and 25 and 10 mm per ten percent change in hardwood and scrub cover, respectively. The difference in evapotranspiration between white pine and mature eastern hardwoods was examined at Coweeta on a north- (WS 17) and a south-facing (WS 1) watershed (Swank and Miner, 1968; Swank and Douglass, 1974; Swift et al., 1986). The hardwood forest on both watersheds was clearcut and planted with pine. Within 10 years after planting, water yields on both watersheds had declined to the level predicted for the mature hardwood stand. By age 17, annual yield was almost 200 mm less than expected from the original stand. The largest monthly reductions in yield occurred between November and May (Swank and Douglass, 1974; Swift et al., 1986). These results were expected because of the differences in evapotranspiration between cover types, especially during the dormant season. Simulation studies using data from the Coweeta watersheds have shown that transpiration losses are 120-160 mm greater for pine than hardwood in the dormant season while they are about equal during the growing season (Swift et al., 1975). Interception by pine is about 50 mm greater than the interception by an oak-hickory forest in both seasons. Therefore, all other factors being the same, we can expect larger increases in water yield after cutting a pine forest than a hardwood forest. Anderson et al., (1976) point out that these increases may not decline as rapidly as those resulting from cutting hardwoods due to the absence of hardwood sprouting, and that, consequently, the duration of yield increases may be longer after cutting pines than it is for hardwoods.

Because precipitation has a fundamental influence on the hydrologic cycle, changes in water yield from a basin are highly dependent on the magnitude of annual and seasonal precipitation. Bosch and Hewlett (1982), in their review of 94 worldwide catchment experiments, attributed some of the variability in the first year yield increases between studies of like vegetation to both the mean annual precipitation of the study area - changes in flow are smallest in regions with low average annual rainfall - and the magnitude of the precipitation for the year of the treatment. Patric (1973) observed that the 255 mm mean yield increase after completely deforesting a pair of

Fernow watersheds may have been larger had it not been for below-average annual precipitation. Likewise, Hornbeck et al. (1970) observed a relationship between growing season precipitation and growing season yield increases following a clearcut at Hubbard Brook. Regrowth was suppressed for three years, but yield increases declined from 343 mm the first year to 240 mm the third year. They concluded that the change was caused by a decline in the growing season precipitation during the three years, the third year being so dry that soil moisture recharge was delayed until well into the dormant season. Conversely, in the Oregon Cascades, Rothacher (1970) attributed an extremely high (540 mm) first year yield increase after a 100 percent clearcut to an unusually high rainfall that year. Examining yield increases for several years after forest removal, both Harr (1983) and Swift and Swank (1981) attributed deviations of the annual yield increase from a smooth, declining time-trend curve to the variability of annual precipitation. These experiments are discussed in the next section.

Duration of Yield Increases. In rainfall dominated climates, yield increases after forest clearing are primarily the result of reduced evapotranspiration. Consequently, the duration of yield increases is directly related to the length of time required for the evapotranspiring potential of the regrowth stand to reach predisturbance levels. In turn, this depends on the magnitude of the initial disturbance, and the rate, density and type of regrowth. Where snow is a major portion of precipitation, the amount of snow reaching the ground and the rate of snowmelt also influence the duration of yield increases. The time required for annual yield to decline to pretreatment levels has been estimated to be from 10 to 49 years in rainfall-dominated climates and as much as 80 years in snow-dominated climates.

Coweeta WS 13 was clearcut twice, first in 1940 and again in 1963. In both cases, annual flow increases (Y) attributed to the cutting declined logarithmically as the forest regrew according to the formula: $Y = a + b(\log \text{time})$. By 1962, when the first regrowth stand was 22 years old and the second cut was to be made, basal area was 73 percent of that of the original forest and annual flow increases had declined 80 percent to 70 mm. The estimated termination of yield increases was 49 years (Kovner, 1956; Swift and Swank, 1981). After the second cut, the estimated time of recovery was 18 years sooner (Swift and Swank, 1981). The more rapid decline in water yield was partially attributed to a more rapid recovery of stand density and leaf area (Swank and Helvey, 1970). The first cut turned a mature, uneven-aged stand containing 2600 stems per hectare into an even-aged stand having a stem density of 4200 stems per hectare just prior to the second cut. This higher density of trees provided more sites for sprouting after the second cut and resulted in the rapid revegetation of the site and the rapid decline in flow increases.

Swift and Swank (1981) fitted logarithmic functions to the recovery of annual yield after cutting on WS's 37 and 28 at Coweeta, two higher elevation watersheds that were treated simultaneous to the second cut on WS 13. The slope of the trend lines are the same for all three watersheds but the initial flow response on the higher elevation watersheds was smaller - only a 255 mm increase in response to clearcutting WS 37, and a 220 mm increase after removing 65 percent of the basal area from WS 28. The lower first-year increases shortened the estimated recovery period for both watersheds to only 12 years.

Fluctuations in yield increases away from the smooth logarithmic trend line occurred for all three watersheds cut in 1963 (WS 13, 28, and 37). Swift and Swank (1981) attributed this variability to changes in rainfall, and, by including a rainfall function in the regression model, reduced the standard error of the regression 26 percent below that obtained when using logarithm of years alone. The researchers commented that this use of precipitation data to explain yield changes was unusual because the high, evenly distributed annual precipitation in the region is generally higher than potential evapotranspiration rates: When the evapotranspirational demands of the forested control catchment are met, the relationship between the flow from the treated and the control watershed maintains a predictable relationship. However, during soil drought evapotranspiration demands are limited by the water supply and may not be met. Consequently, the predictive relationship between the watersheds may change and can produce unexpected results.

Kochenderfer and Wendel (1983) made extensive vegetation measurements on a Fernow watershed to attempt to relate the decline in annual flow increase after a clearcut to the regrowth of the stand. The recovery of streamflow to original levels was rapid and only slight increases were observed 10 years after the treatment. Yield increases declined logarithmically as either aboveground biomass or average vegetation height increased.

Harr (1983) analyzed the time trend of yield increases after clearcutting a 96 hectare watershed at H.J. Andrews and determined that the size of the increases (Y) was primarily related to the time since logging ($X_1$) by the equation: $Y = 513.2 - 19.1*X_1$. The model explained 75 percent of the total variance in yield increases. Using this model, predicted streamflow would decline to calibration period levels after 27 years. The addition of annual precipitation ($X_2$) to the model accounted for a statistically significant portion of the total variance of yields. The full model: $Y = 308.4 - 18.1*X_1 + 0.87*X_2$ explained 89 percent of the total variance in yield after the clearcut.

Although the recovery periods are relatively short for regions where rainfall is the dominant precipitation form, the recovery period in areas of high snowfall can be much greater. After a 40 percent strip clearcut at Fool Creek in Colorado, annual water yields were not expected to return to pretreatment levels for 80 years (Troendle and King, 1985). The increases in yield were related more to depth of the snowpack than to evapotranspiration savings from cutting. Lowered interception and redistribution of snowfall resulted in a greater amount of snow on the ground in the cleared or still-open canopy compared to adjacent forest. Given the short growing season, the low year-round temperatures, and the inability of the conifers to sprout from the stump like most hardwoods, forest growth is slow and the effects of cutting persist for a very long time.

Extrapolation to Large Watersheds. Hewlett (1971) stated that conclusions from the small watershed experiments about the effect on water yield from forest cutting "will never satisfy the watershed manager, or the public, until those conclusions have been demonstrated on a scale appropriate to the management problem; i.e., on a drainage basin large enough to serve as a primary water supply to a community or industry". However, he emphasized that the preponderance of evidence from watershed research around the world points to the fact that forested lands yield less water than the same lands without forest. Historical studies that examine the effect of natural reforestation or sustained yield timber harvest practices on large basins are valuable additions to the body of research on water yield augmentation (Schneider and Ayer, 1961; Dons, 1986; Sullivan et al., 1987; Trimble et al., 1987). Most often, however, estimates for potential water yield augmentation through forest management are based on extrapolating the results from cutting in small, headwater, experimental watersheds to larger basins (Rothacher, 1970; Harr et al., 1979; Harr, 1983; Hibbert, 1983; Troendle, 1983). Douglass and Swank (1972) point out, however, that, when extending results to larger areas containing a variety of slopes, aspects, soils, and vegetation conditions, it is best to use the average streamflow response obtained from several small watersheds. In the same context, Hewlett (1971) proposed that as areal size increases, the effect on the analysis of deep seepage and differences in the surface-subsurface curvature of a watershed diminish due to the averaging effect attributed to large watersheds.

Harr et al. (1979) extrapolated the 360 mm yield increase from clearcutting the 50 hectare Coyote Creek watershed as follows: A 100-$km^2$ (square kilometer) forested watershed which yields 750 mm of water each year is managed on a 100-year rotation and equal areas are cut each year. The first year increase from such a cut is 360 mm and yield increases become negligible 30 years after cutting. The decline in yield increases is given by the equation: $Q_t = Q_1 * (0.9)^{t-1}$ where $Q_t$ is the increase in yield t years after cutting, and $Q_1 = 360$ mm. Integrating this equation between t=1 and t=30, the total water yield increase becomes 3430 mm, or about an average of 110 mm per year for 30 years. However, only 30 percent of the watershed has been cut during this period. Therefore, 30 percent of the watershed would yield 860 mm (750 mm+110 mm) and 70 percent would yield the base level of 750 mm. The total annual yield for the larger basin would be 780 mm, an increase of only 30 mm or 4 percent. Harr (1983) acknowledges that this kind of exercise assumes pristine forest conditions on the large basin and ignores the fact that portions of the forest may have been converted to other uses. The result being that the potential increase from timber harvest may be overestimated.

In a series of articles in Water Resources Bulletin, researchers extrapolated the results from small watershed experiments to larger, managed forested watersheds in the east, the southwest, the Pacific Northwest, and the Rocky Mountain Region (Douglass, 1983; Hibbert, 1983; Harr, 1983; Troendle, 1983). They concluded that yield increases on large watersheds subject to sustained yield management would range between 1 and 6 percent of unaugmented flows. While the increases may not be measurable due to the error associated with streamflow measurements, these researchers, like Hewlett (1971), believe that the extensive body of knowledge acquired from small watershed research indicates that we should accept these increases as real.

### Storm Hydrograph Changes After Forest Clearing

Stormflow response (primarily stormflow volume, or quickflow, and peak flow rate) is affected by forest clearing in the same ways that water yield is changed. The reduction in evapotranspiration increases soil moisture and makes storm precipitation directly available to streamflow during the summer and fall seasons, until such time that watershed soils become completely recharged. Roads, skid trails and landings associated with logging may also effect stormflow response. Intercepted subsurface flow and reduced infiltration rates create more opportunities for faster overland flow, thus contributing to stormflow. The effect of forest removal on individual stormflow events is often variable, however. Prior to soil recharge, differences in soil moisture deficit between cut and uncut watersheds from one storm to another affect the response of the logged watershed. Also, the timing of stormflow increases from cleared areas may be such that stormflow downstream may or may not be augmented.

In the eastern United States one of the first studies of the effect of forest removal on stormflow was begun in 1951 at Fernow (Reinhart et al., 1963). A commercial clearcut increased mean quickflow volume and the mean peak flow rate during the growing season by 24 and 21 percent, respectively. The largest increase in quickflow for an individual event was 12 mm. While most growing season runoff events were augmented by forest removal, dormant season responses were variable. Quickflow increases continued through November and were attributed to differences in soil moisture deficits between the cut watershed and the uncut control. In the same study, selection cuts that removed from 20 to 59 percent of the original stand produced no observable changes in either quickflow or peak flow.

Hewlett and Helvey (1970) examined the stormflow response to clearcutting a high elevation watershed (WS 37) at Coweeta (cut timber left on-site). An 11 percent (5.8 mm) increase in the mean quickflow for all major storms was statistically significant. Mean peak flow increased by 7 percent (0.066 $m^3/s\text{-}km^2$). The quickflow increases were positively related to the size of the event - larger increases were produced from larger storms. The largest increase in quickflow was 48 mm for a regional record storm lasting seven days, while the smallest quickflow events were not much effected by the treatment. No seasonal trends in the data were found and no relationship between the treatment effect and antecedant storage variables could be shown. The researchers concluded that the very deep soils on the watershed are never fully recharged, causing stormflow increases further into the fall and winter seasons than would normally be expected.

More recently at Coweeta, a commercial clearcut using cable logging on a lower elevation watershed (WS 7) produced significant increases in mean quickflow and peak flow for the four posttreatment years. Quickflow increased 9.8 percent (0.3 mm) and peak flow increased 14.6 percent (0.017 $m^3/s\text{-}km^2$). Another Coweeta study examined the stormflow response to commercial logging using tractor skidding (Douglass and Swank, 1976). Sixty-five percent of the basal area from a 144 hectare watershed (WS 28) was removed. For the 9-year posttreatment period, mean quickflow increased 17 percent. Mean peak flow increased 30 percent the first 2 years after logging but declined in subsequent years.

Hornbeck (1973) examined the effects of a clearcut at Hubbard Brook. The cut trees were left on the watershed and regrowth was inhibited for 3 years. The average increase in individual quickflow was 13 mm for summer storms and 8 mm for spring snowmelt events. Quickflow changes for individual events ranged from minor decreases to 37 mm for summer storms and 59 mm for spring storms. Storms occurring after soil moisture recharge in the fall and before the start of spring snowmelt were not affected. Variations in individual quickflow increases were attributed to differences in soil moisture deficits from storm to storm.

Cutting studies in the Cascade Range of western Oregon generally support many of the results of the studies in the eastern United States. Rothacher (1973) examined the peak flow response to clearcutting a 96 hectare watershed at H.J. Andrews. The average peak flow increased 25 percent after logging. The largest individual increases in peak flows were between 40 and 200 percent, and resulted from soil moisture recharge during the first large storms of the fall rainy season. Midwinter peaks were little affected by the change in forest cover.

At the Alsea Cooperative watersheds on the Oregon Coast Range, Harris (1973) evaluated the peak flow response after 82 percent of a watershed was clearcut and 5 percent of its area roaded. Using only large winter runoff events, Harris found no change in peak flows after the treatment. When Harr et al. (1975) considered an additional 30 smaller events, significant increases in both fall and winter peak flows were observed. The fall mean peak flow increased by 114 percent (0.175 $m^3/s\text{-}km^2$) and winter peaks increased an average of 23 percent (0.109 $m^3/s\text{-}km^2$). The researchers believed that the use of many small winter storms in the analysis contributed to the dormant season response of peak flow to forest clearing. When storm size is small, even small differences in soil moisture deficits between cut and uncut watersheds may be large enough to increase peak flows above predicted levels. Harr (1987) contended that this dormant season effect may also have been related to the amount of watershed compaction caused by roads and skid trails. Most of the runoff events used in the Oregon studies were small and of little consequence for flooding.

In the Alsea study only 2 of the 85 storms used by Harr et al. (1975) produced a peak flow on the control watershed greater than the $Q_{2.33}$ peak of 0.918 $m^3/s\text{-}km^2$.

## Field Investigations

Some studies of the effect of vegetation on water yield and stormflow have been based on analysis of historical data instead of designed experiments on paired watersheds. Historical studies often involve watersheds of large size, providing insight into the effects of large area-based vegetative changes that Hewlett (1971) and others regard as the necessary extension of small watershed research. Some studies are of single-event disturbances of forest vegetation, such as insect epidemics (Love, 1955; Helvey and Tiedemann, 1978; Potts, 1984). Other research has investigated the effects of gradual, long-term changes in land use, such as the annual timber harvest (Lyons and Beschta, 1983; Duncan, 1986; Sullivan et al., 1987), forest decline (Caspary, 1990), or the gradual afforestation of abandoned lands (Eschner and Satterlund, 1966; Schneider and Ayer, 1968; Dons, 1986; Trimble et al., 1987). Many analytical approaches have been used in attempts to quantify how streamflow was impacted by these events. When a control watershed is not available, climatic calibration of the study watershed is attempted. For gradual changes in vegetation, time-trend analysis is often used.

## Magnitude and Timing of Water Yield Changes After Forest Disturbance

Love (1955) investigated the effect on streamflow of an Engelmann spruce beetle epidemic on a 1974 $km^2$ (square kilometer) drainage of the White River in western Colorado. Approximately 60 percent of the trees within a 585 $km^2$ area of the basin were killed. The analysis used a 533 $km^2$ control watershed located 97 kilometers from the study watershed. A climatic variable representing the difference in April water content of the snowpack on each watershed was used in the regression model to account for climatic differences between the two watersheds. Tree mortality resulted in a 58 mm increase in the average annual water yield (about a 20 percent increase in average flow) for the first 5 years (1947-1951) after the epidemic ended. The yield increase was attributed to reduced evapotranspiration and interception of snow by the beetle-killed trees. It represented a 325 mm increase when just the affected area was considered. A later analysis by Bethlahmy (1975) indicated that runoff was greater than normal even 25 years after the attack as a result of post-epidemic mortality.

In northeastern Oregon, on the 352 $km^2$ Umatilla River watershed, an outbreak of the Douglas fir tussock moth resulted in defoliation of 25 percent of the transpiring surface area of the watershed (Helvey and Tiedemann, 1978). A control watershed analysis showed that a statistically significant 132 mm increase in annual yield occurred the year after the infestation ended. No flow increases were observed in succeeding years, possibly due to tree recovery. Two other watersheds, similar in size but less severely defoliated (16 and 13 percent reduction in transpiring surface), did not show any change in flow. More recently, Potts (1984) discussed the impact of a mountain pine beetle epidemic which killed approximately 35 percent of the trees on the 133 $km^2$ Jack Creek watershed in southwestern Montana. Potts used double-mass analysis to compare the cumulative annual flow from Jack Creek with the average cumulative flow from four other "control" watersheds within a 100 km radius of Jack Creek. Annual water yield increased by about 15 percent as a result of tree mortality. The author states, however, that the brief period of record used in the analysis (1974-1982) and the lack of adequate precipitation data weakened the analysis and the subsequent conclusions.

Eschner and Satterlund (1966) documented the change in water yields from the Sacandaga River basin during a 39-year period of forest recovery, and the impact of a sudden storm that disrupted forest stand development. The 1272 $km^2$ watershed is located in the Adirondack Mountains of New York. Basin yield was at its lowest in 1912 (average basal area was 17 $m^2$/hectare due to logging, insect attack, and fires. Protection of the area resulted in an increase in basal area to 30 $m^2$/hectare by 1950. For the recovery period multiple regression was used to relate annual yield to annual precipitation, total precipitation for the month preceding the water year, which represented antecedent moisture conditions, and the average April temperature, which represented the energy available for snowmelt. The addition of a time variable (ln T, the natural logarithm of years since start of the forest recovery) accounted for a statistically significant portion of the total variance in annual yield. The model explained 78 percent of the variation in annual flow. Using the average values for the climatic variables during the recovery period (1912-1950), and T=1 and 39, the calculated annual yield decrease for the 39-year period was 196 mm. Further analysis showed that 67 percent of the annual reduction occurred during the dormant season. After the devastating storm of 1950, it was believed that the yield relationship had changed due to destruction of forest integrity. A hypothesis was tested that there was no change in the relationship between yield, rainfall, and temperature. The post-storm rainfall and temperature data were plugged into the pre-storm regression functions. A t-test was used to evaluate the difference between the actual mean yield and the estimated mean yield. For both the annual and dormant season models the conclusion was that the yield relationship was different for the two periods.

Schneider and Ayer (1961) studied the hydrologic effect of forest recovery on three partially deforested watersheds between 181 and 808 hectares. Between 35 and 58 percent of their areas were planted with pine and spruce. Both the single watershed and control watershed methods were used. The optimum water year, determined by regressing annual yield against precipitation, was the year beginning May 1. The full model : $R = a + bP$ related annual yield or runoff (R) to annual precipitation (P). No statistically significant change with time was found. Analysis of growing season yields also showed no trend with time. However, a time trend was observed for dormant season yields. The full model: $R_d = a + bP_d + cTP_d$ related dormant season yield or runoff ($R_d$) to precipitation ($P_d$) and to the product of precipitation and time (T) in years since the first year of record. Between 1934 and 1957, the total reduction in dormant season yield for the three watersheds (based on the mean precipitation for the period of record for each area) ranged from 106 mm to 172 mm. Extrapolating these decreases from the area of the partial plantings to the entire watershed area, the relative reduction in dormant season yields ranged from 224 mm to 491 mm. Using the control watershed approach, the time variable was again significant. The new model resulted in a decrease in dormant season yield nearly identical to the decrease obtained using the single watershed approach. The large dormant season response was attributed to the increased interception of rainfall by the conifers in the reforested area. Attempts to relate the differences in response to the size of the reforested areas and the size of the basin were not successful. Efforts to relate annual and seasonal yields to an antecedent precipitation index did not produce significant correlation. The researchers believe that the generally stable ground water levels at the end of each season (April 30 and October 31) accounted for their inability to relate antecedent precipitation to yield. Nik et al. (1983) suggest that a high correlation between annual yield and annual precipitation implies similar soil water storage conditions from year to year; consequently, they reason, annual yield is influenced more by the distribution of precipitation and evaporative demands than by small differences in antecedent moisture conditions. Attempts by Schneider and Ayer (1961) to correlate monthly water yields with precipitation gave poor results because of month-to-month carryover effects of rainfall and snowmelt on soil water deficits.

Trimble et al. (1987) studied the hydrologic effect of cropland reversion to forest on ten large, populated, multiuse basins on the southern Piedmont. Basin size ranged from 2820 to 19450 km$^2$. Precipitation data was taken from U.S. Weather Bureau records and stream discharge data was obtained from U.S. Geological Survey records. Because of rapid urbanization of the area in recent decades, streamflows were adjusted for consumptive loads such as municipal use, reservoirs, farm ponds, and irrigation. Soil Conservation Service records and U.S. Census data were used to determine the approximate change in forested area for the period of analysis. Streamflow records were divided into periods, an early period (1900-1940) during which row crop agriculture flourished, and a later period (1955-1975) when forests were more widespread. The amount of forested land increased between 10 percent and 28 percent in the ten watersheds. Simple regression analysis was used to climatically calibrate annual flow with annual precipitation for each watershed for the two periods. Analysis of covariance was used to test the difference between the regression line slopes for each watershed. Eight watersheds showed a significant decrease in water yield at the 5 percent level or less. The range in streamflow reduction was between 25 and 99 mm. A double-mass analysis showed that annual water yield was reduced between 38 and 94 mm for the ten basins, and provided results similar to the regression analysis for 6 of the watersheds.

Dons (1986) studied the hydrologic effect of 18 years of planting pine on 28 percent of the Tarawera River watershed (906 km$^2$) in New Zealand. Annual yield was regressed against current and antecedent annual precipitation, and against the amount of area reforested annually. The addition of the latter variable significantly improved the model. The full model explained

82 percent of the variation in annual yield. Using a 948 km$^2$ undisturbed watershed nearby as a control watershed, Dons also developed an annual yield model based on the control watershed method. The addition of the reforested area variable significantly improved the model, which explained 89 percent of the variation in yield. For the control watershed analysis, the annual yield reduction attributed to reforestation was 157 mm, 13 percent of the average yield for the period of the study. The 157 mm decrease represented a 559 mm reduction in yield when only the area reforested was considered.

Sullivan et al. (1987) studied the changes in streamflow brought on by the annual timber harvest in the Cascade Range of western Washington. Clearcut logging on the Deschutes River basin (232 km$^2$) had been continuous since 1950, with cutover areas regenerated with Douglas fir. Fifty-five percent of the watershed area had been harvested during the past 37 years, and 44 percent of the area had a stand age of less than 15 years. Regression analysis of dormant and growing season yield against time revealed no significant time trend. However, a visible though non-significant increasing time trend in growing season yields contrasted with a declining trend in yields from an unlogged area. The Deschutes River flow increased 40 mm between 1976 and 1986 according to the regression equation. Most of this occurred in the spring and was attributed to either a change in the distribution of snow in the cutover areas or to savings of evapotranspiration losses on cleared areas.

The effect of forest decline on water yield was described by Caspary (1990). The study was conducted on the Eyach watershed in the Northern Black Forest of the Federal Republic of Germany. The study area is an uninhabited, 99 km$^2$ catchment totally covered with coniferous forest. The watershed is composed of 4 smaller subwatersheds, two in the headwater reaches and two downstream. Soil acidification from industrial air pollution resulted in forest decline measured as an average needle loss between 1983 and 1987 of 31 percent on the lower portions of the watershed, with greater losses on the upper reaches of the basin. Regression analysis for the four subwatersheds included a trend analysis of seasonal flow versus precipitation, time, and precipitation and time together, and an analysis of rainfall versus time. The two headwater catchments showed a statistically significant increase in growing season yield for the study period. No trend or correlation existed between rainfall and time. Flow from the headwater catchments increased at the rate of 17 mm per year, a total increase of 221 mm for the study period (1973-1985). The yield increases were attributed to a reduction in transpiration. Soil acidification resulted in a reduction of fine root growth and a reduction of the water conductivity of the roots. The subsequent water stress led to a reduction in transpiration and the eventual loss of foliage.

### Storm Hydrograph Changes After Forest Disturbance

Few cutting studies have addressed the cumulative effect of gradual, long-term changes in forest vegetation on stormflow. Schneider and Ayer (1968) evaluated the change in storm peak discharges of Shackham Brook during an 18-year period of forest growth after half of the 808-ha watershed was planted with conifers. Significant reductions in the average peak flows were observed for the months of November (66 percent decrease) through April (16 percent decrease) based on the correlation with peak discharges of Albright Creek, the control. The change was attributed to increased interception of precipitation, especially snow, the retarding of snowmelt in the reforested areas, and the concomitant desychronization of snowmelt runoff.

Lyons and Beschta (1983) analyzed the time trend of peak flows greater than 100 $m^3/s$ (cubic meters per second) from the 668 $km^2$ Middle Fork Willamette River drainage in western Oregon during a 22-year period of timber harvesting and road building. Single watershed analysis related peak flow to storm precipitation and revealed a time trend in the flow residuals that indicated an increase in peak flows as basin harvesting expanded. The model explained only 38 percent of the variation in peak flows. Duncan (1989) used a similar approach for the Deschutes River watershed study.

Forty-four percent of the 232 km2 forested watershed was harvested from 1965 to 1980. Storm peak flows greater than 56 m3/s were regressed against storm precipitation for the logged watershed and for a nearby watershed that had not been logged since 1951. The regression models explained 45 and 34 percent of the variation in peak flows, respectively. The plot of flow residuals showed no time trend for either watershed.

# CHAPTER III

# SITE DESCRIPTION

## Location

The South Fourche LaFave River watershed lies in the Fourche Mountain subdivision of the Ouachita physiographic province in west-central Arkansas (Figure 1). The river flows east 48 kilometers through Yell and Perry counties, then north and east 14.2 kilometers until it enters the Fourche LaFave River, approximately 4.1 kilometers from Nimrod, Arkansas (Figure 2). The U.S. Geological Survey gaging station is located 8.1 kilometers from the river's junction with the Fourche LaFave, measuring runoff from a 545.1 square kilometer area. The station was established in 1941. The nearest community to the gage is Hollis, Arkansas.

## Watershed Size and Shape

The drainage area of the watershed at the gage is 545.1 $km^2$, of which 63.9 percent is in Perry County, 28.2 percent is in Yell County, 7.6 percent is in Saline County, and 0.3 percent is in Garland County. The communities of Hollis, Steve, and Onyx are located in the watershed along the river. Approximately 50.7 percent of the watershed

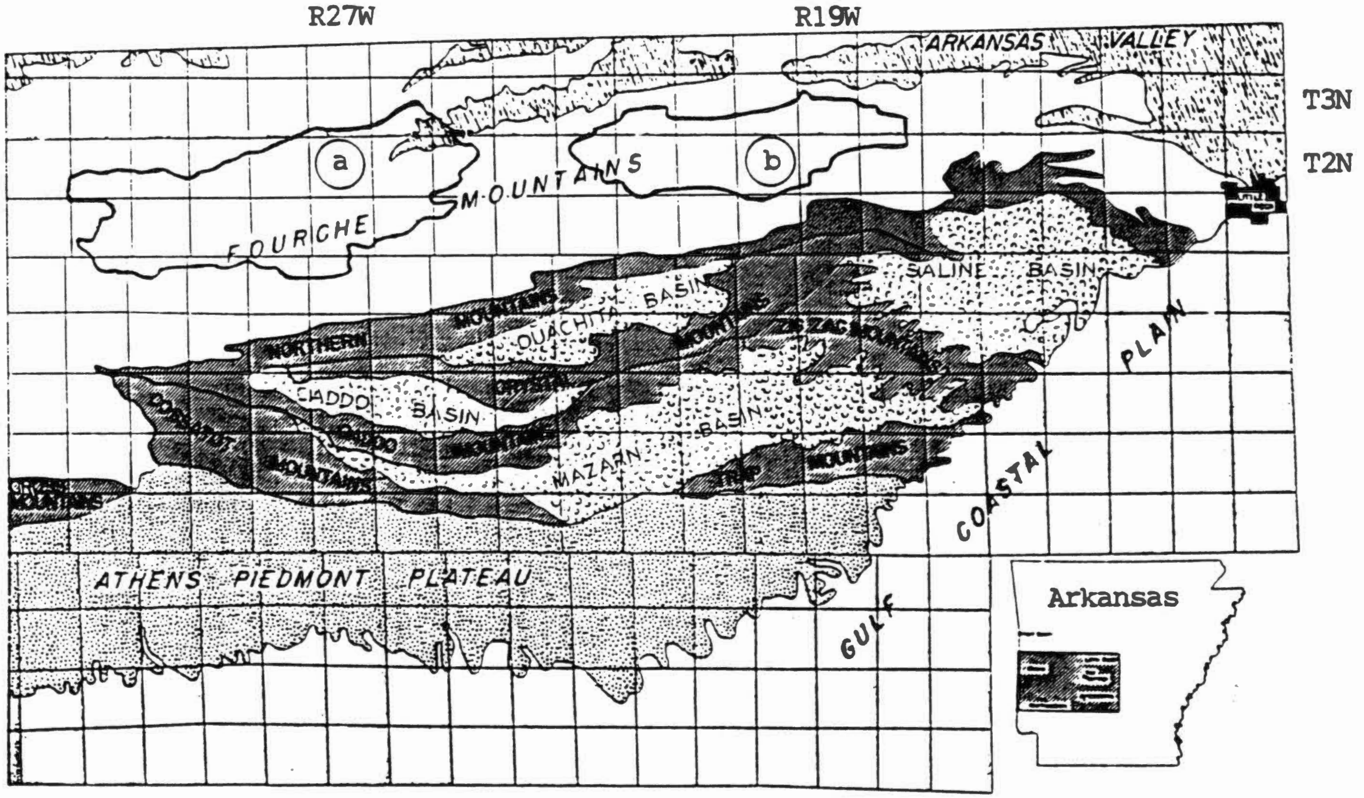

Figure 1. Map showing major physiographic features in the Ouachita Mountain region of Arkansas and the location of the study watersheds: (a)control, (b)treatment watersheds (Stone, 1986).

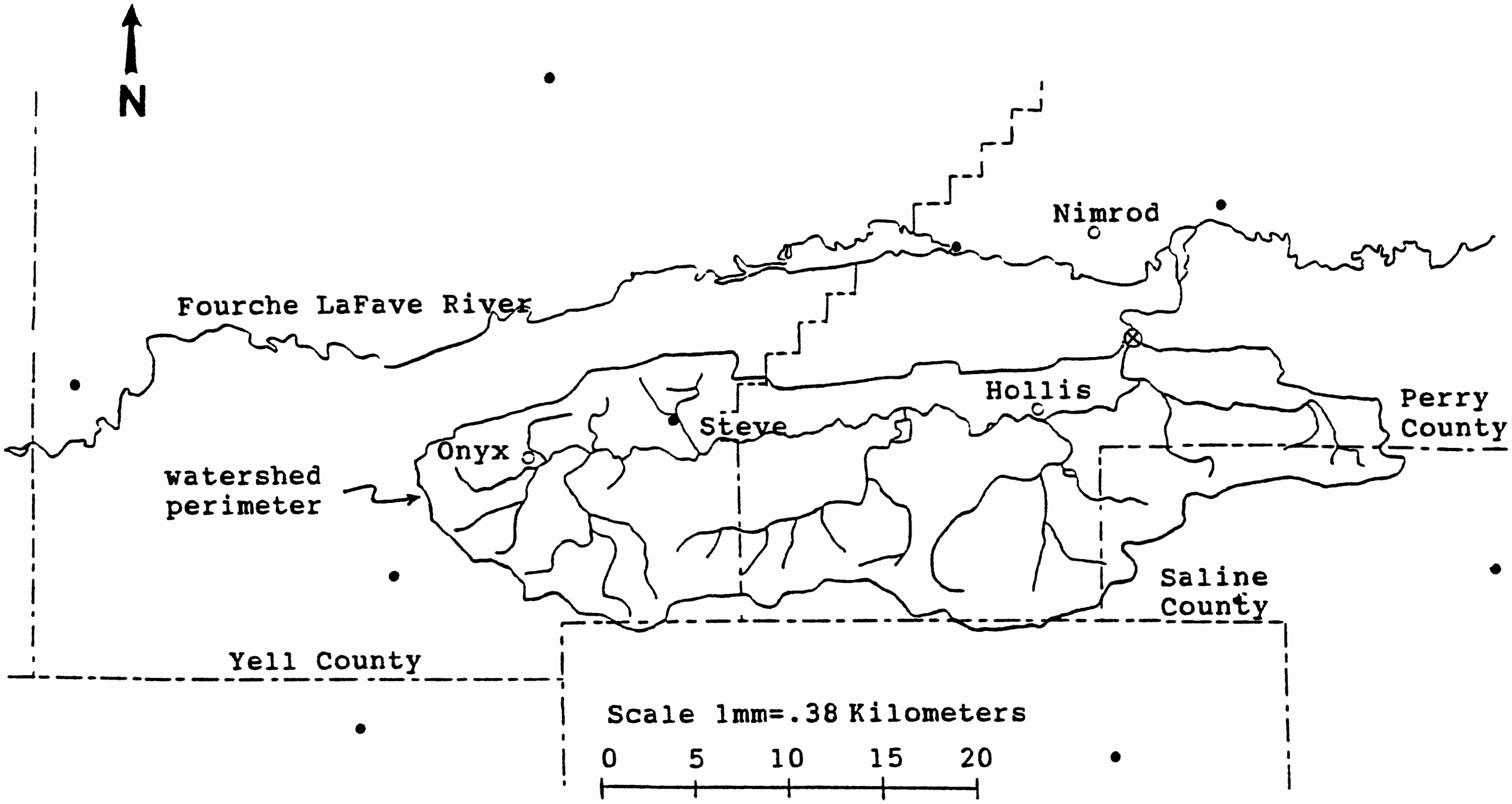

Figure 2. Drainage area for South Fourche LaFave River and its' tributaries. Map shows the location of USGS stream gaging station near Hollis (⊗) and the Weather Bureau climatic stations (●).

area is national forest land managed by the U.S. Forest Service, 41.3 percent is owned by Weyerhaeuser Company, and the remaining 8 percent consists of small, privately owned tracts (Figure 3).

The watershed is oval-shaped, approximately 14 kilometers wide (north-south), and 53 kilometers long (east -west). The largest subwatersheds are the drainage areas of Graham Creek, Dry Fork, Bear Creek, and Cedar Creek (Figure 4). Cedar Creek branches east off of the South Fourche, the rest of the large tributaries lie south of the main stem. Most of the perennial streams in the larger subwatersheds are second, third, or fourth order streams. The intermittent streams are first and second order streams (based on the stream network shown on USGS 1:24000 scale topographic maps). Most of the watershed stream network exhibits a dendritic pattern. The Cedar Creek network and the small intermittent streams which branch directly off the South Fourche have a trellis pattern, probably due to the underlying geologic fault which the river follows.

## Topography

The topography of the South Fourche watershed ranges from narrow to broad valleys, with small hills and moderately sloping to very steep east-west ridges and mountains. From its headwaters west of the Onyx community to the USGS gage, the river descends from 305 meters to 112 meters above mean sea level. This represents an average

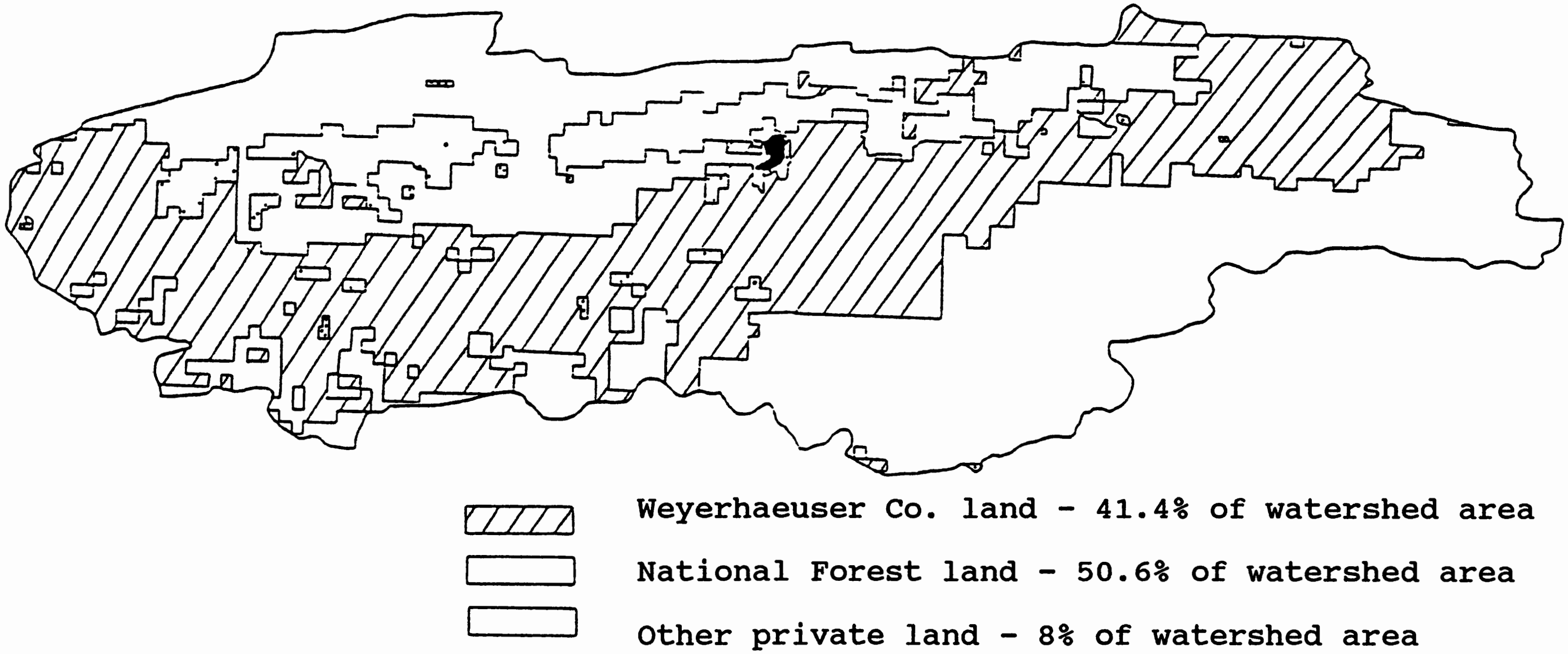

Figure 3. Land ownership of the South Fourche watershed. (Ouachita National Forest - Arkansas, USDA Forest Service map, 1984)

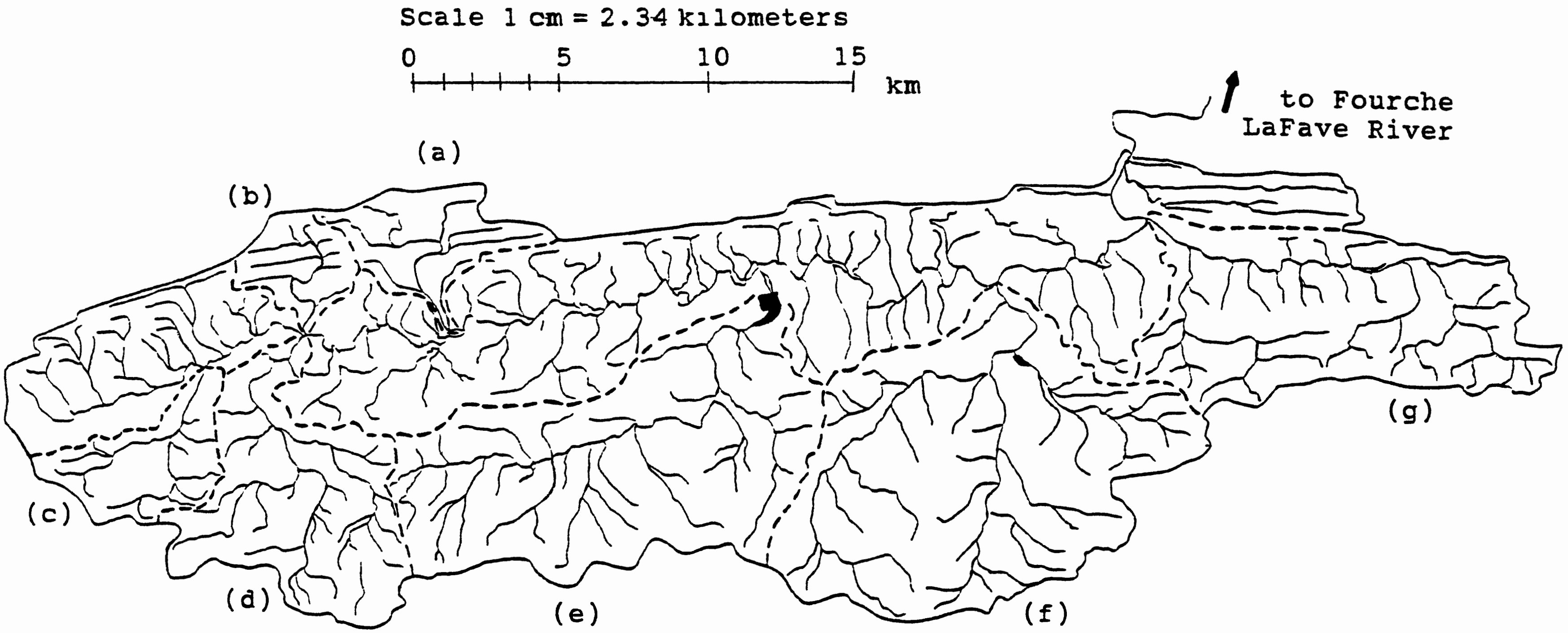

Figure 4. South Fourche watershed perennial and intermittent stream network with major subwatershed boundaries (- - -). Counter-clockwise from top: (a) Buchanan Creek, (b) Turner Branch, (c) Haw Creek, (d) Graham Creek, (e) Dry Fork, (f) Bear Creek, and (g) Cedar Creek subwatersheds.

drop in elevation of 3.6 meters per kilometer over the 54.2 kilometer river length.

Figure 5 shows the general topography of the watershed. The major ridges and mountains in the south and east part of the watershed are formed from sandstones of the Jackfork Formation. Some of the lower ridges, particularly the long east-west trending mountains along the northern border of the watershed, are formed from rocks of the Atoka Formation. Deckard Mountain, the highest point on the watershed, is 552.3 meters above mean sea level. Five other mountains have crests higher than 500 meters. The steepest parts of the watershed (40-60 percent slopes) are found in the Bear Creek and Cedar Creek drainages, and occupy 4.4 percent of the total watershed area. Level to nearly level soils (0-3 percent slopes) occupy 9.3 percent of the watershed.

## Geology

The Ouachitas is an oval shaped mountainous region about 120 kilometers wide (north-south) and 400 kilometers long (east-west). The rocks of the Ouachitas are sedimentary and were deposited within a subsiding geosyncline during the Pennsylvanian and Mississippian Periods. After the sea receded, the rocks were uplifted by northerly compressive forces, producing east-west folds and thrust faults, narrowing the rocks by as much as 320 kilometers. Since then, minor arching has occurred and

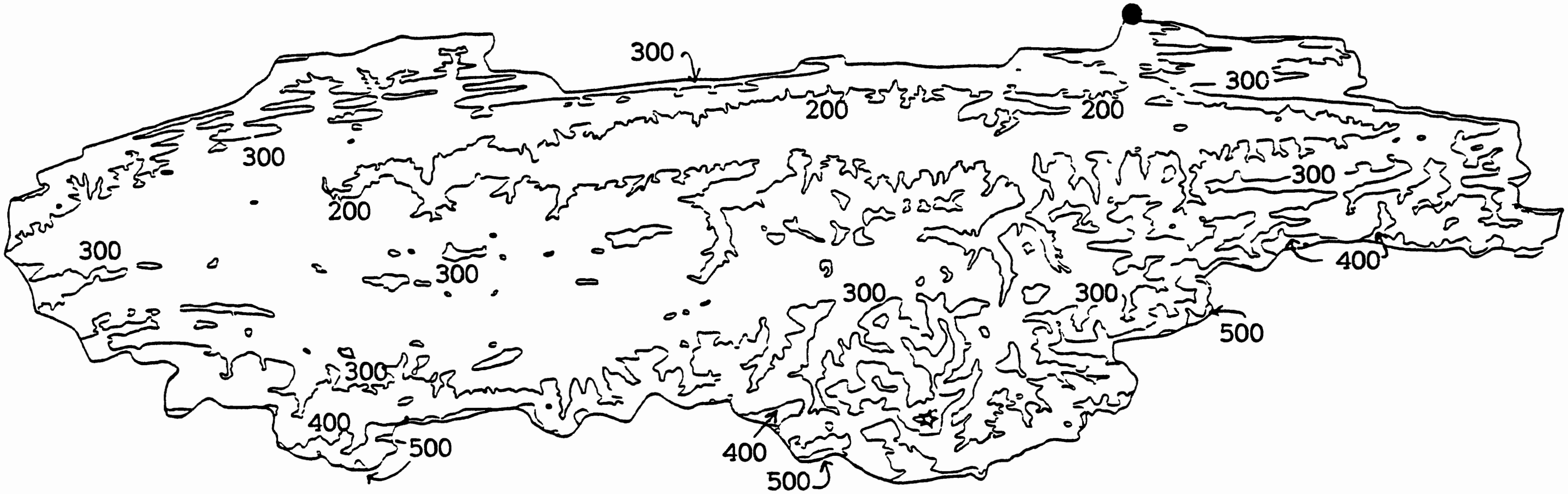

Figure 5. Topographic map of the South Fourche watershed. Contour intervals of 100 meters.
Deckard Mountain (☆) - 552.3 meters above msl.
USGS gaging station (●) - 111.6 meters above msl.

thousands of feet of rock have been eroded (Stone and Bush, 1986).

The most intense folding occurred in the Broken Bow-Benton Uplift subdivision (Morris et al., 1975). The South Fourche watershed and its control lie directly north of the Uplift, in the Fourche Mountain subdivision, also known as the frontal Ouachita Mountains. These frontal Ouachitas were thrust an estimated 30 to 80 kilometers during the Ouachita orogeny. The exposed rocks of the frontal Ouachitas belong to the Lower Atoka, Jackfork, Johns Valley, and Stanley formations. The sandstones of the Jackfork and Atoka formations form the major ridges of the watershed. Jackfork shales are often exposed along the sideslopes. The Johns Valley and Stanley formations have greater proportions of limestone, less resistant shale, and impure sandstone that form most of the basins, valley floors, and lower hills. These rocks weather into material from which Carnasaw and Sherless soils are formed. Atoka and Jackfork rocks are also the parent material for Clebit soils, and Stanley rocks weather into Bismark soils. During the orogeny, some weakly metamorphosed and slates and quartzites were formed from shales and sandstones.

The South Fourche watershed is characterized by anticlines on the north and south, and by an east-west trending syncline in the middle (Figure 6) (Morris et al., 1975). The major geologic structures are the Little Cedar Creek anticline, the Aly and White Oak Mountain synclines,

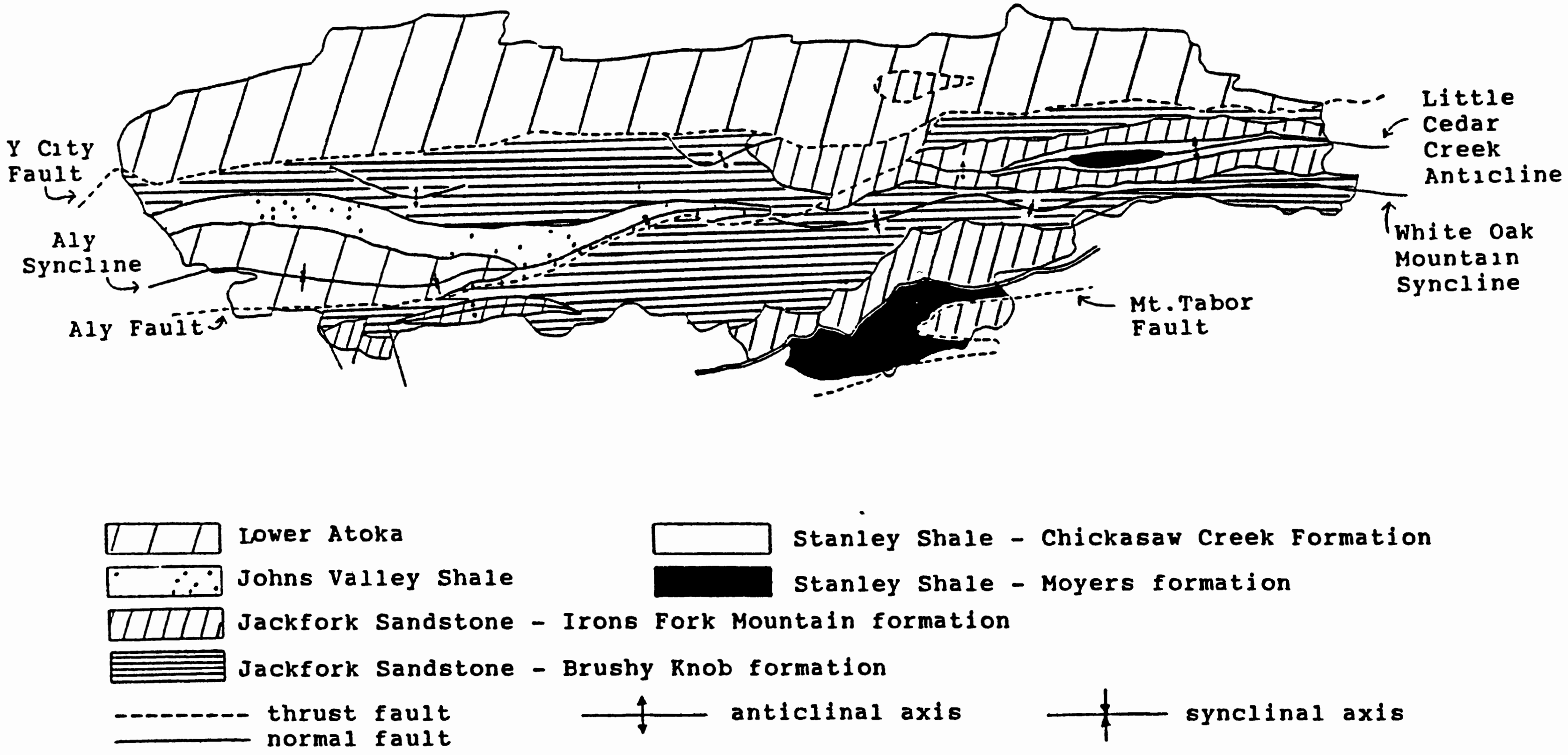

Figure 6. Geologic map of the South Fourche watershed (from Morris et al., 1975)

and the Y City and Aly faults. The Y City fault is probably the most extensive fault in the Arkansas Frontal Ouachitas. It extends 52 kilometers across the upper third of the watershed. The South Fourche LaFave River and Cedar Creek generally follow the path of the Y City Fault. Stanley, Jackfork, and Johns Valley rocks are exposed south of the fault, while Atoka rocks appear to the north. The anticlines have Stanley rocks exposed in the core, while Jackfork sandstones are found along the flanks. The proportion of exposed rocks is approximately 30 percent Lower Atoka, 10 percent Johns Valley, 50 percent Jackfork and 10 Percent Stanley. The control watershed, gaged on the Fourche LaFave River near Gravelly, Arkansas, consists of approximately 60 percent Lower Atoka, 20 percent Middle Atoka, and 20 percent Jackfork, with small outcrops of Johns Valley and Stanley rocks (Haley, 1976).

Lower Atoka rocks form many of the lower ridges in the watershed. The formation is mainly interbedded shale and sandstone tilted about 30 degrees from the horizontal. Atoka rocks may be as much as 6100 meters thick north of the Y City Fault, and are about 300 meters thick along the Aly syncline. The rocks are composed of 35 percent mostly thin-bedded silty, fine-grained, sandstone, 25 percent siltstone, and 40 percent silty shale. Sandstone beds are usually less than one meter thick. (Morris et al., 1975)

The Johns Valley Shale Formation rests on Jackfork sandstone. It is 600 to 900 meters thick within the Hollis watershed. These rocks are exposed across a belt almost a mile wide along the north flank of the Aly syncline.

The Jackfork Formation is divided into an upper part, the Brushy Knob Formation, and a lower part, the Irons Fork Mountain Formation. The Brushy Knob Formation is composed of massive beds of ridge-forming sandstones, stratified with thin-bedded sandstone and shale. The sandstone beds are fine- to medium-grained, with seams of quartz and chert granules. There are deep voids containing residues of limestone within the formation. Approximately 50 percent of the formation consists of mudstones similar to those of the Irons Fork Mountain, but with a larger volume of sandstone blocks. The Irons Fork Mountain Formation overlies the Stanley Shale Formation. It is approximately 60 percent sandstone at its base, with almost all of the upper part being shale, mudstone, and siltstone, with numerous fine- to very fine-grained sandstone blocks.

The Stanley Shale Formation consists of soft, tilted, thin layers of interbedded sandstone and shale. Chickasaw Creek and Moyers subsections of the formation are exposed on the north flank of the Mount Tabor fault and along the axis of the Little Cedar Creek anticline. The Chickasaw Creek Formation consists of shale, siliceous shale, thin-bedded chert, and large limestone blocks. It is approximately 60 meters thick within the watershed. The Moyers Formation is about 270 meters thick and consists of platy shales and thickly-bedded sandstones.

## Soils

Table 1 lists the soils found on the South Fourche watershed and gives their relative coverage, according to their general topographic position in the watershed (Townsend and Williams, 1982; Vodrazka, 1988).

### TABLE I

### EXTENT & LOCATION OF SOILS ON THE SOUTH FOURCHE WATERSHED

| Soil Name | Slope % | Percent of Watershed* | Topographic Position |
|---|---|---|---|
| Kenn-Ceda complex, occ. flooded | 0-3 | 1.590 | level flood plains along streams in narrow valleys |
| Ceda gravelly fine sandy loam, freq. flooded | 0-3 | 2.471 | narrow flood plains of small streams |
| Spadra fine sandy loam, occ. flooded | 0-3 | 1 471 | level low stream terraces along larger streams |
| Barling silt loam, occ. flooded | 0-2 | 658 | level flood plains of local streams |
| Guthrie silt loam, occ. flooded | 0-1 | 164 | low terraces of local streams |
| Taft silt loam | 0-2 | .138 | old stream terraces in broad valleys |
| Avilla silt loam | 1-3 | 1.030 | stream terraces |
| Avilla silt loam | 3-8 | .357 | stream terraces |
| Leadvale silt loam | 1-3 | 1.941 | old terraces in broad valleys |
| Leadvale silt loam | 3-8 | .382 | colluvial footslopes & old terraces in broad valleys |
| Sherless fine sandy loam | 3-8 | 2.570 | lower ridgetops and sideslopes |
| Sherless gravelly fine sandy loam | 3-8 | .575 | ridgetops and footslopes |
| Carnasaw-Sherless complex | 3-8 | 12** | gently sloping sideslopes/hilltops |
| Carnasaw-Sherless-Clebit complex | 8-20 | 30** | strong sloping to moderately steep ridges and sideslopes |
| Carnasaw-Sherless-Clebit complex | 20-40 | 40** | sideslopes of hills & mountains |
| Clebit-Carnasaw-Sherless complex | 40-60 | 4.409 | steep sides of hills/mountains |

* dot grid calculations from SCS Soil Surveys

** eyeball estimation from Soil Survey maps

The uplands of the South Fourche watershed are comprised of soils from the Carnasaw, Sherless, and Clebit series that formed in loamy and clayey residuum weathered from sandstones and shales. These soils are on the sides, tops, and footslopes of hills and ridges, and cover about 87.5 percent of the watershed area.

The steepest soil association, the Clebit-Carnasaw-Sherless complex (40 to 60 percent slope), occupies 4.4 percent of the watershed area and occurs primarily in the Bear Creek and Cedar Creek subwatersheds. North of the South Fourche LaFave River and Cedar Creek, where Atoka rocks are exposed, the dominate upland associations are strongly sloping (8 to 20 percent slope) to steep (20 to 40 percent slope) regions of long east-west trending complexes of Carnasaw, Sherless, and Clebit soils. The Carnasaw-Sherless complex (3 to 8 percent slopes) appears prominently in the southwest part of the watershed on the tops of hills around Haw Creek and Graham Creek. Elsewhere, this complex occurs along the bottom slopes of hills and along some intermittent streams.

The Carnasaw series consists of deep (100 to 150 cm), well drained, slowly permeable soils formed in clayey residuum weathered from shale with interbedded lenses of siltstone and sandstone. They are found on hillsides, mountainsides, and ridges. Slopes range from 3 to 60 percent. They have a dark grayish brown gravelly silt loam surface layer with silty clay loam and silty clay subsoil.

The control section of the Carnasaw soils has more clay than either Sherless or Clebit soils.

Sherless soils are moderately deep (50 to 100 cm), well drained, moderately permeable soils found on lower colluvial slopes of the uplands. Slopes range from 3 to 50 percent. They formed in loamy material weathered from sandstone with interbedded lenses of siltstone and shale. They have a dark grayish brown, fine sandy loam surface layer with loam, sandy clay loam and gravelly sandy clay loam subsoil horizons.

Clebit soils are shallow (25 to 50 cm), well drained, moderately rapidly permeable soils that formed in a thin layer of loamy material weathered from sandstone with interbedded lenses of siltstone and shale. They are on ridgetops and strongly sloping (8 to 60 percent) side slopes of forest uplands. They have a dark brown very fine sandy loam surface layer with a very gravelly fine sandy loam subsoil.

The Carnasaw and Sherless soils are moderately suited to not suited for cultivated crops or pasture, depending on the slope. Clebit soils are not suited for pasture or crops because of surface stones, shallow depth, and slope.

Flood plain and terrace soils comprise about 12.5 percent of the watershed. They are deep, poorly to well drained, slowly to rapidly permeable soils that formed in gravelly, silty and loamy alluvium and colluvium from local uplands. Kenn, Ceda, and Barling soils are colluvial soils found on flood plains of upland drainages that are occasionally to frequently flooded. Avilla, Leadvale, Spadra, Guthrie, and some Sherless soils are alluvial soils with well developed horizons and are located on stream terraces and footslopes.

## Climate

Precipitation in the Ouachitas is predominantly due to convective storms except for occasional periods of general cyclonic rainfall during late fall, winter, and early spring. Spring and summer have frequent thunderstorms. Precipitation falls 95 to 110 days a year, while thunderstorms occur about 50 to 60 days a year. The average annual precipitation (Theissen method) during the 1942-1989 study period (March-February water year) for the South Fourche watershed was 1262 mm. Annual precipitation ranged from a low of 791 mm in 1945, to a high of 1920 mm in 1954. Droughty periods that averaged less than 1016 mm (40 inches) of annual rainfall occurred between 1954-1956, and 1963-1964.

Rainfall is fairly evenly distributed throughout the year. During the 48-year study period, dormant season (October-February) precipitation averaged 506 mm, while the mean growing season rainfall was 781 mm. Monthly rainfall averaged 107 mm, and ranged from 84 mm in August to 144 mm in May. July through October is uniformly the dry time of the year, with the range in mean monthly rainfall between

85 mm and 98 mm. Over the study period, about half of the monthly rainfall totals between July and October were less than 50 mm. The average monthly Theissen-weighted precipitation for the treatment and control watersheds during the study period (1942-1989) is given in Table II.

The study area is subject to occasional periods with storm precipitation totals in excess of 125 mm. The largest event recorded for the treatment and control watersheds was, respectively, 306 mm and 227 mm for the storm of December 2-6, 1982. The event resulted from a nearly stationary frontal boundary across northwestern Arkansas and a strong influx of very moist, warm air from the South. Very heavy rainfall on December 2nd and 3rd produced serious flash flooding.

Most of the precipitation in the study area falls as rain, but snow does occasionally fall and will remain on the ground for a week or more. In Perry County, where much of the South Fourche watershed is located, the average annual snowfall is aproximately 75 mm, and, for an average of 1 day per year, at least 25 mm of snow is on the ground.

Average daily temperatures range from 2.8 degrees Celsius in January to 26.8 degrees Celsius in July (Table II). The first freezing temperature (0 degrees Celsius or lower) generally occurs during the third or fourth week in October. The last freezing temperature usually occurs during the second or third week in April.

# TABLE II

## MEAN MONTHLY TEMPERATURE, PRECIPITATION, STREAMFLOW, AND HYDROLOGIC RESPONSE FOR STUDY WATERSHEDS 1942-1989[a]

(Compiled from Climatological Data (US Weather Bureau) and Water Resources Data (USGS))

| Month | Average daily temperature (Celsius)[b] | South Fourche Watershed P (mm)[c] | South Fourche Watershed Q (mm) | South Fourche Watershed Streamflow as a % of Precipitation | Control Watershed P (mm)[c] | Control Watershed Q (mm) | Control Watershed Streamflow as a % of Precipitation |
|---|---|---|---|---|---|---|---|
| Mar | 9.7 | 134 | 90.5 | 68 | 123 | 79.9 | 65 |
| Apr | 16.0 | 124 | 68.3 | 55 | 125 | 66.5 | 53 |
| May | 20.3 | 144 | 59 1 | 41 | 153 | 68.5 | 45 |
| June | 24.3 | 104 | 21.3 | 20 | 106 | 28.1 | 27 |
| July | 26.8 | 97 | 6.8 | 7 | 104 | 10 0 | 10 |
| Aug | 26.1 | 84 | 5.2 | 6 | 79 | 3.0 | 4 |
| Sep | 22.6 | 95 | 8 0 | 8 | 98 | 5.9 | 6 |
| Oct | 16.4 | 94 | 13.8 | 15 | 97 | 13.4 | 14 |
| Oct[d] |  | 84 | 6.4 | 8 | 89 | 8.3 | 9 |
| Nov | 9 7 | 113 | 31.4 | 28 | 105 | 30.4 | 30 |
| Dec | 4.8 | 112 | 59 8 | 53 | 101 | 49 5 | 50 |
| Jan | 2.8 | 88 | 54.9 | 62 | 78 | 46.0 | 59 |
| Feb | 5.4 | 98 | 67.5 | 69 | 93 | 60.1 | 65 |
| Year | 15.4 | 1287 | 486.6 | 38 | 1262 | 461.3 | 37 |

[a] March-February water years. Period of record March, 1942 to February, 1990.
[b] Recorded in the period 1951-1978 at Nimrod Dam, Arkansas.
[c] Theissen-weighted values using records from climatic stations shown in Figure 2
[d] 1984 water year data omitted.

P=precipitation, Q=streamflow

## Groundwater

Groundwater in the Ouachitas occurs in relatively small reservoirs in the numerous joints, fractures, and bedding plane separations formed by the differential movement between shale and sandstone beds (Albin, 1965). These reservoirs are recharged by rapid infiltration of rainfall from local storms. Water for domestic and nonirrigation farm use is obtained from wells and water holes. Deep wells on bottom lands can supply water for irrigation. On the South Fourche watershed very few farmers irrigate their land. In Perry County no more than three farms and less than 20 hectares of land is irrigated (Herrington, 1990).

## Streamflow

The South Fourche is free-flowing with no flow regulating structures on the main stem between the headwaters and the gaging station near Hollis. The gaging station has been in operation since 1941. Two small earthern dams regulate floodwaters on two major tributaries of the river. In operation since the late seventies, they control storm runoff from 20 percent of the watershed. The watershed contains 415 km of perennial and 415 km of intermittent streams (determined from USGS 7.5 minute series topographic maps). Elevation, stream length, and drainage densities for the major subwatersheds in the South Fourche watershed are provided in Table III. The watershed contains about 3400 hectares of land on flood plains and low stream terraces which are occasionally or frequently flooded for brief periods from December to May.

During the 1942-1989 study period, the average annual (March-February water year) streamflow for the South Fourche watershed and its control was 488 mm (8.42 $m^3/s$) and 465 mm (15.7 $m^3/s$), respectively. The mean monthly

## TABLE III

## AREA, ELEVATION, STREAM LENGTH, AND DRAINAGE DENSITY FOR MAJOR SOUTH FOURCHE SUBWATERSHEDS

| | Area (ha) | Elevation Minimum (m) | Maximum (m) | Intermittent Stream Length (km) | Perennial Stream Length (km) | Drainage Density ($km/km^2$) |
|---|---|---|---|---|---|---|
| Total Watershed | 54510 | 111.6 | 552 | 415.0 | 415.0 | 1.52 |
| Subwatersheds | | | | | | |
| Bear Creek | 10360 | 149 | 552 | 80 1 | 31.8 | 1.08 |
| Dry Fork | 8960 | 182 | 480 | 39 6 | 49 9 | 1.00 |
| Cedar Creek | 6815 | 125 | 525 | 41.7 | 28 9 | 1 04 |
| Graham Creek | 4345 | 201 | 549 | 30.0 | 17 7 | 1.10 |
| Haw Creek | 1930 | 216 | 384 | 7 9 | 2.6 | 0.54 |
| Buchanan Creek | 1680 | 186 | 418 | 37 0 | 7.1 | 2.62 |
| Turner Branch | 975 | 201 | 415 | 21.0 | 4.6 | 2.62 |

[a] Determined from USGS 7.5 minute series topographic maps

streamflow gaged for both watersheds is given in Table II on page 65. November through May are the months of greatest flow, with an average monthly flow of 62 mm (13.0 $m^3/s$). Between June and October discharge is 11 mm (2.3 $m^3/s$). The correspondent flows for the control watershed are 58 mm (23.8 $m^3/s$) and 12 mm (4.9 $m^3/s$), respectively.

The average monthly hydrologic response (streamflow as a percent of precipitation) for the South Fourche watershed ranges from a low of 6.2 percent in August to a high of 69 percent in February (Table II). Approximately 38 percent of the average annual rainfall becomes streamflow.

The South Fourche can go dry for short periods during the summer. Between 1942 and 1988 (May-April water years) there were 20 years in which no flow was recorded for 7 consecutive days or longer, and the mean daily discharge was zero approximately 5.6 percent of the time. The control stream had 7 consecutive days of zero flow for 14 of those 48 years, and about 4.6 percent of the mean daily discharge values were zero. On the South Fourche a mean daily flow of 36 $m^3/s$ (0.066 $m^3/s/km^2$) is exceeded about 5 percent of the time, and the daily discharge of 1.47 $m^3/s$ (0.0027 $m^3/s/km^2$) is exceeded about one-half of the time.

## Engineering Works

### Roads

As of 1988, there were 730 kilometers of roads on the South Fourche watershed. This includes 60 kilometers of paved state highways (Routes 7, 27, and 314), and 670 kilometers of "improved, light duty" gravel roads belonging to either the counties, Weyerhaeuser Company, or the Forest Service. Eighty-seven percent (634 kilometers) of the total road length is a network of Forest Service and Weyerhaeuser roads constructed primarily to support logging activities. The road density on the watershed is 1.34 km/km$^2$. The road density on the Weyerhaeuser land within the watershed is twice that on Forest Service land (1.88 km/km$^2$ versus 0.95 km/km$^2$). Using 7.5 meters as the average road width, roads occupy 547 hectares, or 1.01 percent of the total watershed area. Table IV lists the total road length, density, and area by land ownership.

Nearly all of the Weyerhaeuser roads, and over half (169 km) of the Forest Service roads have been constructed since 1969. USFS #86 going east from Hollis and USFS #45, which runs between Onyx and Hollis, are the oldest logging roads, being built in the 1930's. Figure 7 shows the Forest Service road construction since 1971. Most roads on the watershed follow topographic contour lines, and, when crossing contour lines, a route is often chosen which traverses the most gradual slope in the immediate area.

### Dams

Two floodwater retarding structures (FRS) were constructed on the South Fourche watershed as part of a watershed protection and flood prevention program sponsored

## TABLE IV

### ROAD LENGTH, DENSITY AND AREA BY LAND OWNERSHIP: SOUTH FOURCHE WATERSHED 1988

| | All Ownerships | National Forest | Weyerhaeuser | Small Private |
|---|---|---|---|---|
| Road Length (km) | | | | |
| All Roads | 729.97 | 261.69 | 423.35 | 44.92 |
| Paved Highways | 60.16 | 21.70 | 14.69 | 23.77 |
| County Roads | 35.36 | 10.00 | 8.72 | 16.64 |
| Forest Service | 334.34 | 219.76 | 110.07 | 4.51 |
| Weyerhaeuser Co. | 300.11 | 10.24 | 289.87 | 0.00 |
| Road Density (km/km$^2$) | 1.34 | 0.95 | 1.88 | 1.03 |
| Roaded Area [a] (% of watershed) | 1.02 | 0.72 | 1.43 | 0.78 |

a - Assuming an average road width of 7.6 meters

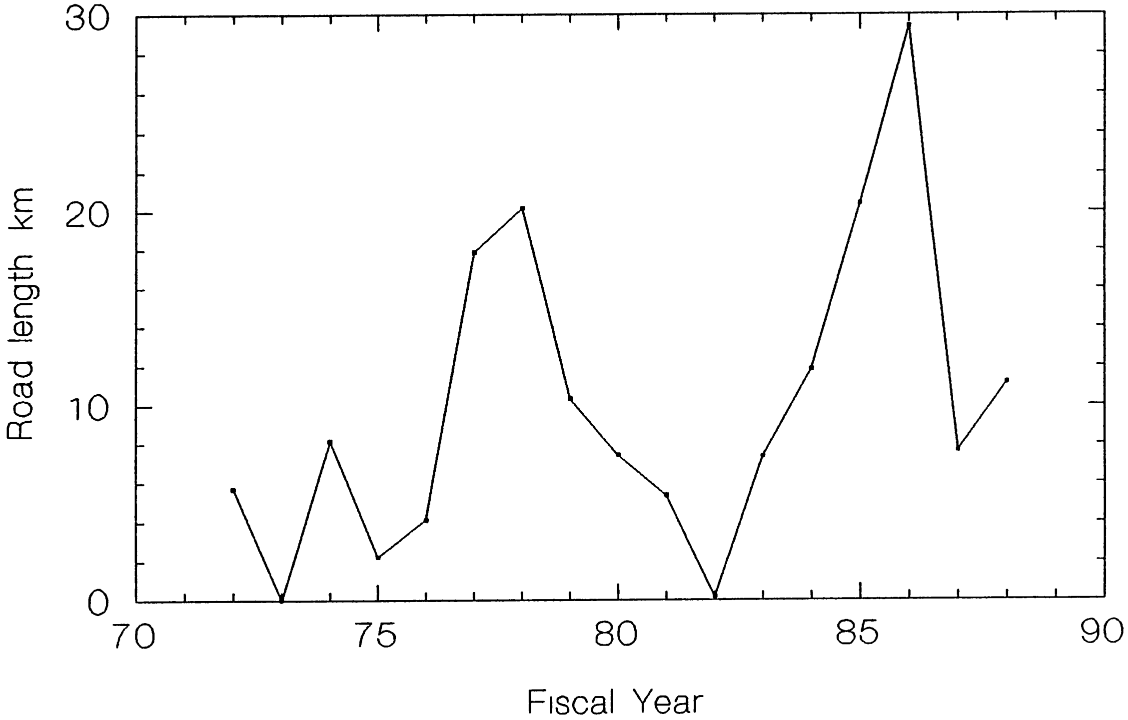

Figure 7. Forest Service road construction since 1972.

by the USDA Soil Conservation Service (SCS). The dams are designed to reduce property and crop damage due to flooding and sedimention along the Fourche LaFave River downstream of its junction with the South Fourche. They are earthen dams that have ungated drop-inlet principal spillways, and open-channel emergency spillways. The largest structure is located on Dry Fork and has a low stage inlet two feet below the principal spillway designed to release quickflow from the drainage area. Both FRSs have a small ungated mitigation or low-water release port located at the 50-year sediment pool level (3.8 mm (1.5 inch) diameter at the large dam and 8.9 mm (3.5 inch) at the small dam). The flow from the FRSs from these ports is estimated at .142 $m^3$/sec (5.0 $ft^3$/sec) for the large dam and .034 $m^3$/sec (1.2 $ft^3$/sec) for the small dam on Little Bear Creek.

Both FRSs are designed to control runoff from a 100-year storm and to release stored waters above the principal spillway within 10 days. The duration of the floodwater release depends on the magnitude of the rainfall event and the elevation of the detention pool at the start of the storm. Flow from the low-water release ports may last for months given the detention pool is near the level of the principal spillway.

The FRS on Dry Fork is located 22.6 km upstream of the Hollis gage. It became operational in March, 1977. It receives runoff from 8866 hectares and has 1396 hectare-meters of floodwater detention (the storage between the principal and emergency spillways). Floodwaters reached the level of the emergency spillway once since its construction, at 3:30 a.m., December 3, 1982 (Herrington, 1990). The dam on Little Bear Creek is 17.8 km upstream of the Hollis gage. It drains a watershed of 1997 hectares and has 380 hectare-meters of floodwater storage. Since its construction in December, 1980, no floodwaters have reached the elevation of the emergency spillway.

Floodwater retarding structures are designed to decrease main stem flood peaks and regulate the storm runoff recession (Tortorelli and Bergman, 1985). By delaying the runoff recession, FRSs also can affect the magnitude of certain high-flow indices used to characterize streamflow, such as the 3-, 7-, and 14-day high flow events. These are the highest mean consecutive-day stream discharge for a 3-day, 7-day, or 14-day period. In this study the annual and partial series of instantaneous peak flows, and the 7-, 14-, 60-, and 90-day high flow values for the study and control streams were compared during both the calibration and postcalibration periods. To account for the construction of the dams, however, the observed peak flows on the South Fourche watershed after March, 1977 (the completion of the first structure) were augmented in proportion to the drainage area controlled by the structures. The impact of the FRS on the high-flow indices was evaluated using the SWAMP program developed in the Agricultural Engineering Department at Oklahoma State

University. Storms of various sizes were routed through the FRSs to determine if the magnitude of the high-flow indices was affected by detention of floodwaters. The SWAMP program required as inputs the storm size, an average curve number (CN) for the drainage area, and the stage-storage and stage-discharge tables for the structures. Using extreme cases, with detention pool elevations at the crest of either the principal or emergency spillways at the start of the event, it was found that the high flow values were unaffected by the FRSs.

## Land Use History

The shortleaf pine (*Pinus echinata*) forest of the Ouachita Mountains was the last virgin pine forest east of the Rocky Mountains to be cut. In the late 1800's, timber speculators made their way south from the Great Lakes region, eventually entering the rugged mountains of the Ouachitas. In the first half of the twentieth century, the virgin pines were heavily logged.

The forest land on the South Fourche watershed that is today owned by Weyerhaeuser (22505 hectares or 41.3 percent of the total area) is part of a larger block of land that was originally obtained from the federal government by the Santa Fe Railroad Company in 1904 (Smith, 1986). The railroad acquired the land as part of a land exchange program after the government had put Santa Fe lands around Flagstaff, Arizona into the public reserve. Santa Fe promptly sold the land to two northern lumbermen, Paul Rust and Frank Drummond. These men formed the Yell Lumber Company but never developed a logging operation. In October, 1925, Yell sold the land (35600 hectares in Perry, Yell, and Scott counties) to Dierks Lumber and Coal Company. Nine months later, Dierks sold the west half of this land to Caddo River Lumber Co. The land retained by Dierks was located in and around the South Fourche watershed. It remained in Dierks ownership until 1969, when Weyerhaeuser acquired the property.

Dierks divided this land into two districts. The west half was called the Onyx District and the east half was called the Fourche District (Chancy, 1989). The Fourche District was largely uncut virgin timber up until 1951, although some small tracts had been logged prior to World War II. Much of the Onyx District within the watershed was also uncut virgin timber. However, the area around Steve and in the far west end of the watershed, by highway 27, was being logged up until 1928 by the Fort Smith Lumber Company (Bryant, 1991). Fort Smith owned tracts of land scattered among the original Yell Lumber Co. holdings, and was logging this land between 1908 and 1928 to support their mill at Plainview, Arkansas (Smith, 1986). Fort Smith logging practices, like most operations in this era, was a heavy "logger's choice" operation, in which all the healthy, merchantable virgin pine was cut.

Dierks was the first lumber company in the region to attempt to manage their lands on a sustained yield basis. Most companies practiced a "cut out and get out" policy, abandoning cutover lands to avoid paying taxes. In 1925 Dierks began a sustained yield management program. Trees under 12 or 14 inches in diameter were to be left standing. Trees damaged by disease, wind, or fire were to be cut to the lowest merchantable size. Stands of timber having too many small trees were to be thinned out, and loggers were to protect young trees as much as possible during the cutting and skidding operations (Smith, 1986).

Dierks spent a majority of the time during the late 1920's and early 1930's doing a timber inventory on the Fourche and Onyx districts. The land was divided into five general categories: 1) 100 percent even-aged virgin pine; 2) uneven-aged pine, anywhere from new to 300 years old, usually 95 percent pine, but at least 60 percent pine; 3) understocked pine; 4) pine-hardwood; and 5) hardwood. North and east slopes usually contained mixes of pine and hardwood. Stand volumes ranged from 2500 to 6500 board-feet Doyle per acre (750-1950 $ft^3$/acre), but usually averaged 2500 to 3000 board-feet (Chancy, 1989). The old growth of the Ouachitas was usually smaller than two feet in diameter, and many of the trees were defective with "red heart", a darkening of the heartwood that preceded decay, or were fire scarred. The largest pine that came off of Dierks' land scaled at 1325 board-feet, though the average pine log at the Forester sawmill in Scott County scaled only 69 board-feet (Smith, 1986).

The first cut on the two districts began in 1951. It was a "salvage and sanitation cut" (Chancy, 1989). The operation lasted ten years. Most of the culled timber was either dead or dying, but some trees were taken on an "age and vigor" basis in which the oldest, slowest growing trees were cut. A stand had to have a minimum of 500 board-feet Doyle per acre (150 $ft^3$/acre) to be cut. A "log-average" in the high 80's and 90's board-feet was typical for the timber removed in this first cut - a log having a volume of 100 board-feet Doyle was about 16 feet long and 16 inches in diameter. About 35 percent of the stand was removed during this operation. A second 35 percent cut was made from 1957 to 1969 on an "age and vigor" basis. Under this practice stands were divided into four age classes: 1) less than 15 years old, 2) 15 to 75 years, 3) 75 to 150 years, and 4) more than 150 years. Tree vigor was classed from "A" (fast growing) to "D" (very slow growing). All trees classified as 4-B, -C, or -D, 3-C, or -D, 2-D, and 1-D were felled. Sometimes trees rated as 3-B or 2-C were taken. Log-averages were slightly lower than the first cut, with most logs being in the 80's board-feet Doyle. Dierks also did some thinning and made some small clearcuts (one-tenth to two acres) to take advantage of favorable prices for pulp and post wood. A third cut was being planned when Dierks sold the land to Weyerhaeuser in September, 1969. At this time, shortleaf pine stands on the Dierks land ranged in year of establishment from 1870 to 1950, with the majority falling between 1890 and 1920.

Weyerhaeuser approached forest management from a different perspective than Dierks. While Dierks practiced uneven-aged management and relied on natural seeding to reestablish pine in the forest openings, Weyerhaeuser implemented an intensive style of forest management. Under this new management scheme, cleared land was planted with loblolly pine (*Pinus taeda*) seedlings from genetically improved growing stock. As the stand matured it was thinned several times, protected from disease, fire, and hardwood encroachment, and finally clearcut. The cleared site was prepared for planting of the next generation of pines. Tree growth was about one-half cubic foot per tree per year at 10 years of age (Bryant, 1988). Average stand volume after 10 years is about 500 $ft^3$/acre, and after 15 years it is about 1300 $ft^3$/acre. Weyerhaeuser clearcuts were usually limited to 350 acres. Land not managed for timber by Weyerhaeuser were areas with slopes greater than 20 percent and streamside buffer zones (Bryant, 1991).

While Weyerhaeuser began intensive forest management on the old Dierks land at the start of the 1970's, even-age forest management on the rest of the watershed had actually begun several years earlier, around 1963. The U.S. Forest Service had been managing the land of the Arkansas National Forest since 1908 (renamed the Ouachita National Forest in 1926). In the 1920's the Forest Service began a policy of uneven-aged management to upgrade the forest and to insure perpetual use of the land for timber (Smith, 1986). This policy continued until it was replaced by even-aged forest management in the early 1960's.

## Land Ownership and Classification

Early settlers in the South Fourche watershed, as in the rest of the Ouachitas, occupied most of the better drained areas along the main stem of the river. They were primarily subsistence farmers, but soon started to grow corn, wheat and other cash crops, and raised beef cattle, poultry, and hogs to provide an income. The watershed population remained fairly constant through the first half of this century, averaging approximately 860 people between 1900 and 1940 (U.S. Census). Some of these people were farmers and some were involved in the timber industry. As better job opportunities developed in other parts of the country during and after World War II, the population of the Ouachitas declined. Since 1950, the population of the South Fourche watershed has averaged only 372 people. Today, the best farmland remains with farmers, much of the better forest land has passed through Dierks' ownership to Weyerhaeuser, and the rest of the watershed, including much of the rougher topography, is administered by the Forest Service. Approximately 50.7 percent of the watershed area is national forest land, 41.3 percent is owned by Weyerhaeuser, and the remaining 8 percent is privately owned. Table V lists watershed land ownership as of 1988 by major land cover type.

Aerial photographs show that abandoned farmland commonly reverted to even-age shortleaf pine forest. The area that has remained farmland consists of cultivated fields of corn and wheat, hayland, and pasture planted with improved grasses. Common pasture and hayland vegetation includes bermudagrass, tall fescue, bahiagrass, hop clover, and annual lespedezas. Examination of aerial photographs obtained from the Forest Service shows that land use has changed little in the last 50 years (Table VI). The proportion of the watershed cleared for crops, forage, or occupied by dwellings and other buildings, has decreased

## TABLE V

### LAND OWNERSHIP BY MAJOR LAND COVER TYPE SOUTH FOURCHE WATERSHED - 1988

| | All lands | Forest land | Farm land | Water areas | Roads & right-of-ways [c] |
|---|---|---|---|---|---|
| | | (hectares) | | | |
| Nat'l Forest[a] | 27648[b] | 27209[b] | - | 127[b] | 312 |
| Weyerhaeuser | 22505[c] | 22103 | - | 35[c] | 367 |
| Small Private | 4357[c] | 2941 | 1307[d] | 72[c] | 37 |
| All Ownerships | 54510 | 52253 | 1307 | 234 | 716 |

a - 5088 hectares is reserved/deferred land.
b - Determined from Forest Service CISC II database.
c - Determined from USGS 7.5 minute maps which show national forest boundries. Roads assumed to be 7.5 meters wide, utility corridors 45 meters, pipeline corridors 16 meters.
d - Determined from color aerial photographs 1:24000 scale.

## TABLE VI

## WATERSHED AREA IN PASTURE AND FARMLAND

| Year | South Fourche Watershed | | Control Watershed | |
|---|---|---|---|---|
| | (hectares) | (watershed percent) | (hectares) | (watershed percent) |
| 1934[a] | 2100 | 3.86 | 12600 | 11.86 |
| 1972[b] | 1250 | 2.29 | - | - |
| 1988[c] | 1307 | 2.40 | 10130 | 9.54 |
| Total Area(ha) | 54510 | | 106192 | |

a - Determined using dot grid on aerial photos, 1:34700.
b - Determined using dot grid on aerial photos, 1:24000.
c - Determined using dot grid on aerial photos, 1:24000.

from a high of 3.86 percent (2100 hectares) in 1934 to a low of 2.29 percent (1250 hectares) in 1972. Most of the farmland that reverted to forest was along the main stem of the river in the west half of the watershed. Thus, excluding the area of the watershed in roads, surface waters, or recently logged land, the watershed has remained about 97 percent forested since the 1930's.

### Forest Type and Age

The shortleaf pine - oak - hickory forest type is the most common type in the watershed, as it is throughout the northern Ouachitas. In young stands (40 years), understory species include redbud, persimmon, eastern redcedar, yellow-poplar, and sweetgum. Various oaks (post, blackjack, white, black, and southern red), hickories (mockernut, bitternut, black, shagbark, and pignut), and blackgum make up the understory in older stands. Flowering dogwood and red maple are found in nearly all pine stands.

The extent and type of hardwoods that are codominant with pine are determined by site characteristics such as soil, slope, and aspect (Eyre, 1980). A shade intolerant species, shortleaf pine is generally the dominant species on the high, dry sites typical of narrow ridgetops and south- to west-facing slopes. Hardwoods become codominant with pines on moister, more fertile sites characteristic of northern or eastern exposures, lower slopes, or narrow stream valleys. On drier sites the hardwoods tend to be post, blackjack, and southern red oak. On moister sites the common oaks are white, southern red, and black oak. Blackgum, winged elm, red maple, and various hickories are common on both dry and moist sites.

In mixed stands, the pine is generally even-aged and much older than the hardwoods, which are comprised of several broad age classes. Pine and hardwood are near the same age in stands regenerated in old abandoned fields or where fire and grazing were controlled in cut-over stands. Because hardwood species are generally less resistant to fire damage than are pine species, fire can assist in maintaining the dominance of the pine vegetation over hardwoods (Alcock, 1989). With the advent of fire protection programs in the 1930's, the hardwood component of pine stands has probably increased.

Loblolly pine does not occur naturally to any great extent in the northern Ouachitas. The western extent of its natural range is southern Arkansas and eastern Texas on the Coastal Plain (Eyre, 1980). However, extensive planting has extended its range to eastern Oklahoma and northwestern Arkansas. Loblolly pine seedlings selected from genetically improved nursery stock have been planted on much of the Weyerhaeuser land on the South Fourche watershed. The Forest Service plants primarily shortleaf pine seedlings originating from seed collected at their seed orchard. Approximately 70.2 percent of Weyerhaeuser land on the watershed (15804 hectares) was logged and planted with pine from 1970 to 1989. Only 3606 hectares of national forest land was clearcut during this time. Thus, a total 19410 hectares of forest (35.6%) of the watershed, was clearcut during this 20 year period. In contrast, only 8.9 percent of the control watershed was harvested.

Shortleaf and loblolly pine stands comprise a large part of the watershed. As of 1990 there were 36136 hectares of pine stands, which is nearly 70 percent of the forested area and 66 percent of the total watershed area. Of this, 17762 hectares is on National Forest land, and 18374 hectares is on Weyerhaeuser land. Sixty-six percent (11802 hectares) of the pine stands on the National Forest are 51 years and older, while 86 percent (15804 hectares) of the Weyerhaeuser pine stands are less than 20 years old. Table VII shows the age distribution of various forest ecotypes on both Weyerhaeuser and National Forest lands in the South Fourche watershed.

On National Forest land within the South Fourche watershed, the current distribution of stands of different age classes is heavily weighted toward the older age classes (Figure 8). Approximately 73 percent (19916

## TABLE VII

### AGE DISTRIBUTION OF FOREST STANDS BY FOREST TYPE FOR WEYERHAEUSER AND NATIONAL FOREST LANDS - 1988

(Compiled from harvest and regeneration data from
Weyerhaeuser Co. and the US Forest Service)

| Age class | Weyerhaeuser Pine plantations | Wildlife & buffer zones | National Forest Pine[b] | Pine/ hdwd[c] | Hdwd/ pine[d] | Hdwd[e] | Total | All stands |
|---|---|---|---|---|---|---|---|---|
| years | hectares | | hectares | | | | | hectares |
| 0-5[a] | 2338 | | 1600 | 32 | | 24 | 1656 | 3994 |
| 6-10 | 6748 | | 828 | 14 | | 15 | 858 | 7606 |
| 11-15 | 3162 | | 615 | 48 | 33 | 4 | 701 | 3863 |
| 16-20 | 3556 | | 290 | 63 | | 38 | 391 | 3947 |
| 21-25 | | | 1262 | | 30 | 72 | 1364 | 1364 |
| 26-30 | | | 540 | 8 | | 148 | 696 | 696 |
| 31-40 | | | 407 | 117 | 14 | 26 | 564 | 564 |
| 41-50 | | | 418 | 184 | 176 | 285 | 1064 | 1064 |
| 51-60 | | | 2020 | 598 | 301 | 1563 | 4482 | 4482 |
| 61-70 | ( 2570 ) | ( 3729 ) | 2677 | 698 | 652 | 1444 | 5470 | 5470 |
| 71-80 | age unknown | | 3794 | 375 | 379 | 689 | 5238 | 5238 |
| 81-90 | | | 1737 | 335 | 124 | 480 | 2676 | 2676 |
| 91-10 | | | 983 | 177 | 104 | | 1263 | 1263 |
| 100+ | | | 591 | 83 | 23 | 90 | 787 | 787 |
| All ages | 18374 | 3729 | 17762 | 2734 | 1836 | 4877 | 27209 | 49312 |

[a] Birth year for stands age 1 is 1989. Stands age "0" have been cut but not planted

[b] pine type. at least 70 % of the dominant and co-dominant crowns are softwoods.

[c] pine-hardwood type: 51 to 69 % of the dominant and codominant crowns are softwoods

[d] hardwood-pine type. 51 to 69 % of the dominant and codominant crowns are hardwoods

[e] hardwood type: at least 70 % of the dominant and co-dominant crowns are hdwds.

hectares) of all forest types on National Forest land is 51 years and older, and 56 percent (15190 hectares) is between 51 and 80 years old. Seventeen percent (4650 hectares) of National Forest land on the watershed has been clearcut and planted since the Forest Service began even-age management in the early sixties. Figure 8 also shows the age distribution of the Weyerhaeuser plantations. In all, Figure 8 reflects the age class distribution of 89 percent of the timberlands on the watershed. The forest land not included in this figure is 2570 hectares of Weyerhaeuser

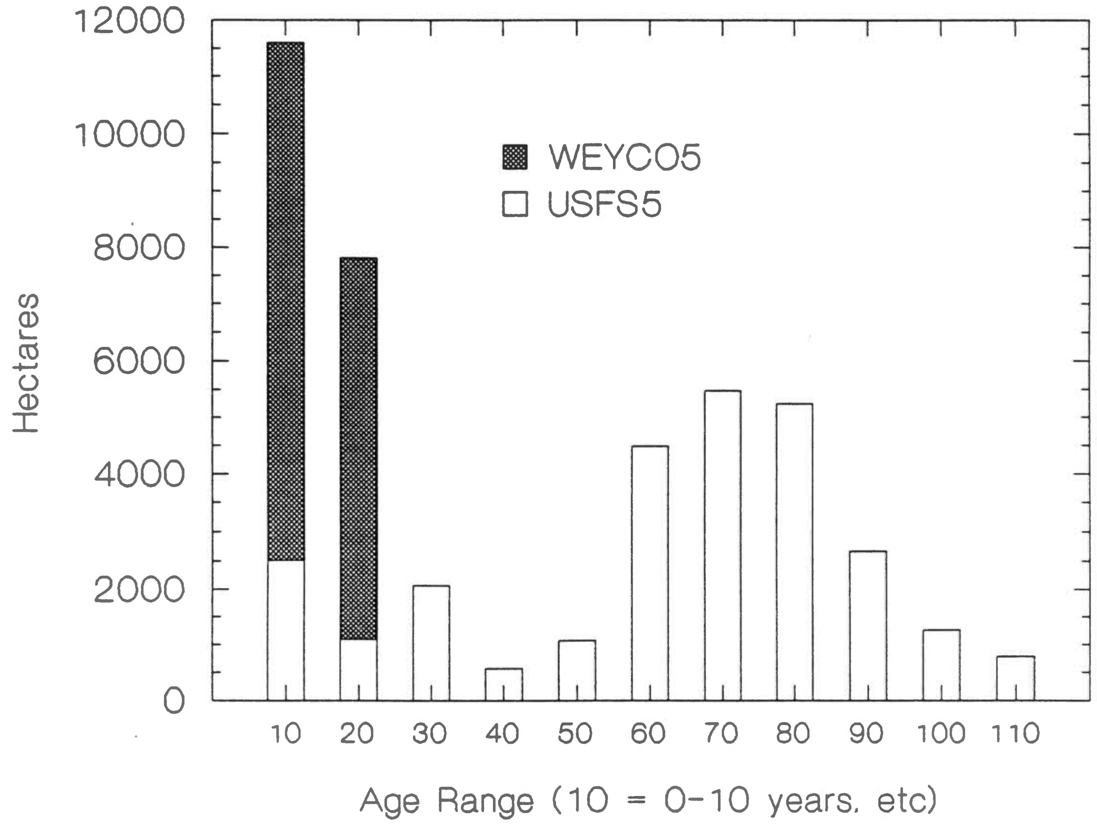

Figure 8. Distribution of age classes of forest stands by area for the South Fourche watershed.

land and 2941 hectares of forest owned by individual land owners. The Weyerhaeuser land is either plantations that have not been cut yet, streamside zones that will not be cut, or land that has greater than 20 percent slopes.

## Fish and Wildlife

The Arkansas Game and Fish Commission rates the South Fourche, Cedar Creek, and Bear Creek as "fair sport fish habitat" and the other perennial streams as "in need of improvement" (Spears, 1976). The largest streams support an estimated 250 pounds/acre of fish, smaller streams about 150. Sport fish in the larger streams include largemouth and smallmouth bass, spotted bass, bluegill, and channel catfish. The Kiamichi shiner and the southern brook lamprey, both recently found in the watershed, are listed as threatened native fish by the Arkansas Game and Fish Commission. Table VIII lists the estimated fall population densities of selected game species by major cover type.

## TABLE VIII

## WILDLIFE GAME SPECIES BY LAND CLASSIFICATION (Spears, 1976)

| Species | Forest | Grassland | Cropland |
|---|---|---|---|
| | (acres per animal) | | |
| Whitetail deer | 80 | - | - |
| Turkey | 30 | - | - |
| Gray squirrel | 6 | - | - |
| Cottontail rabbit | 20 | 7 | 5 |
| Bobwhite quail | 50 | 17 | 8 |
| Mourning dove | - | 8 | 4 |

# CHAPTER IV

# DATA ACQUISITION

## Forest Harvest

For the U.S. Forest Service (USFS) and Weyerhaeuser Company harvesting operations, plantation age was used to establish the year of the harvest. This data was obtained from the USFS CISC II database and from Weyerhaeuser Lotus 123 data files. In both organizations, plantation age was determined by the birth year of the seedlings at the time of planting. Plantation age accurately reflected the harvest year when the time between the harvest and the planting was equal to the age of the seedlings at the time of planting. (For example, the plantation age indicates the year of the harvest when a two year-old seedling is planted two years after the harvest operations.) However, plantation age may not always correspond to the actual year of the harvest. Also, a harvest operation may sometimes overlap water years (a March to February water year was used in the yield analysis). To account for this discrepancy in the regression analysis, a three-year moving average of plantation age (as a percent of basin area) was used to reflect the harvest activity. Three other harvest variables were used in the analysis: (1) actual plantation age, (2) plantation age less than five years old, and (3) plantation age less than ten years old, each expressed as a percentage of watershed area (Figure 9).

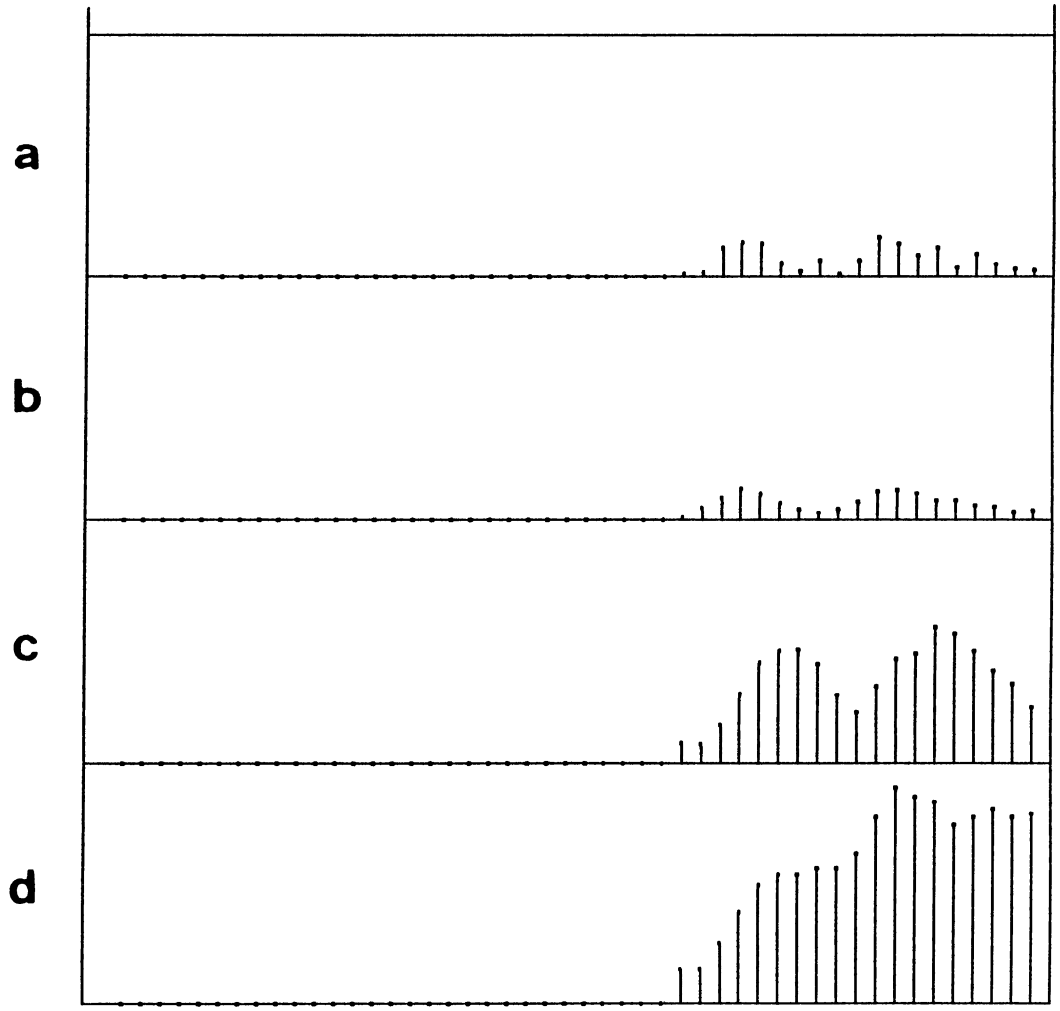

Figure 9. Harvest activity on the South Fourche watershed. Computed using plantation age: (a) actual annual harvest, (b) three-year moving average of harvest, (c) percent of watershed 0-5 years old, (d) percent of watershed 0-10 years old. The period reflected in the plots is 1942 to 1989. The scale is 0 to 25 percent of watershed area.

## Streamflow

Streamflow data from water years 1942-1990 was obtained from the Surface Water Records of Arkansas. The U.S. Geological Survey's (USGS) streamgaging stations recording the streamflow were on the South Fourche LaFave River near Hollis, Arkansas (study watershed), and on the Fourche LaFave River near Gravelly, Arkansas ("control" watershed). Annual and seasonal yields, and high flows are volumes of flow computed for a water year or season and are expressed as a uniform depth (centimeters) over a watershed. The high flows of the study watershed are the highest total discharge for 7, 14, 60, and 90 consecutive days in each year of record. The annual series of instantaneous peak flows are expressed as a volume rate of flow ($m^3/s$). The USGS rated the accuracy of the streamflow data from both gages as "good", which is interpreted to mean that about 95 percent of the daily discharges are within ten percent of their reported values.

## Precipitation

Precipitation data was compiled from "Climatological Data" for Arkansas published by the National Weather Service (NWS). For both study watersheds, precipitation for the area was determined by the Theissen method and was expressed as a uniform depth (centimeters) over the watershed. The Theissen method consists of locating on a map the network of NWS stations in and around the watershed, then drawing the perpendicular bisectors of the lines joining adjacent stations. The polygons formed around the stations represent the area of influence of each gage. The average rainfall for the watershed is the sum of the rainfall at each gage weighted in proportion to its area of influence. For this study, Theissen-weighted precipitation was computed for each day of the study period. Daily values were then summed for the requisite time period for the yield, high flow, and peak flow analyses. Missing rainfall data was not estimated. Instead, a gage was removed from the Theissen network for any month in which a part or all of its daily rainfall record was missing. A new network was constructed and a new Theissen formula was determined.

The rain gage network for the South Fourche watershed during the study period (1942-1989) consisted of three to six operational NWS nonrecording rain gages for any particular month. Five to seven stations were operational on the Fourche LaFave watershed. Appendix A contains the location, elevation and recording times for each station, a summary of operational gages for each month during the period of record, and the Theissen formulas used to calculate precipitation. The rain gage network on the South Fourche watershed that was utilized most often (15 years, 4 months) for the Theissen calculations consisted of the NWS stations at Alum Fork, Aly, Aplin, Jessieville, and Nimrod Dam (Figure 10).

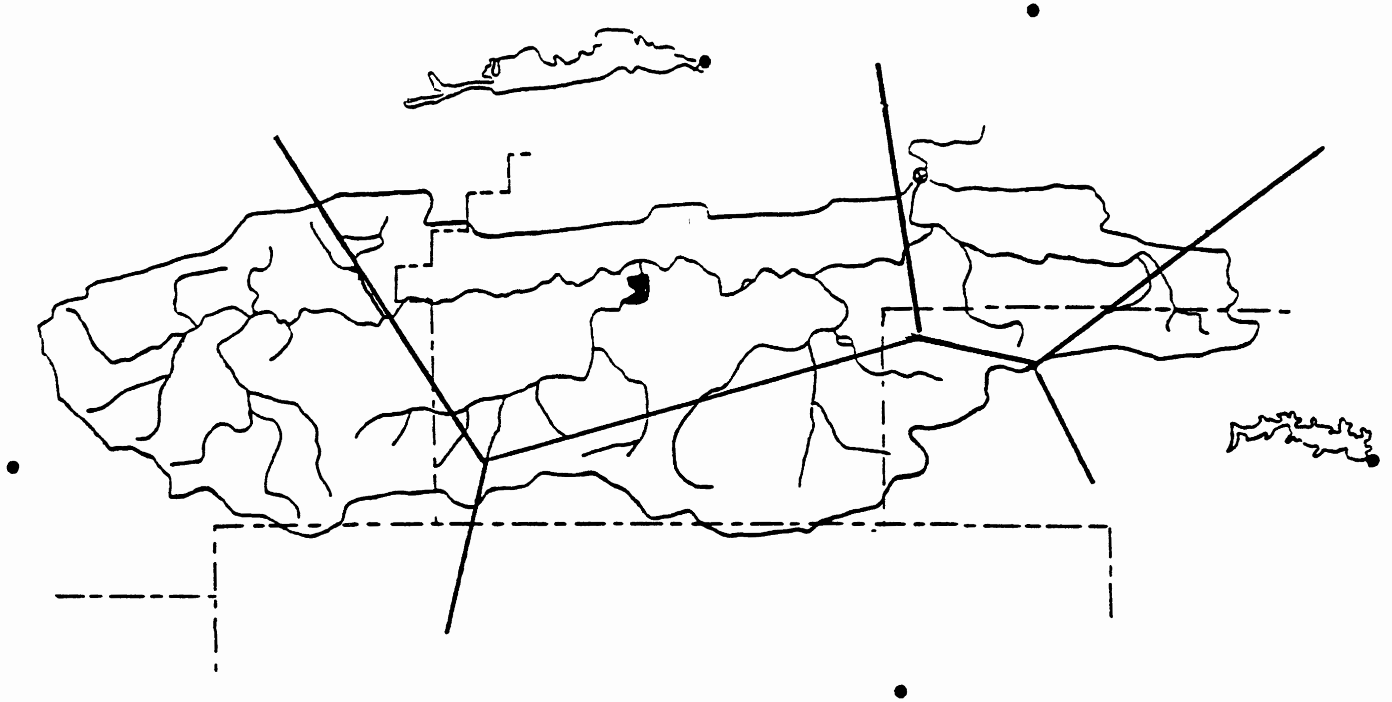

Figure 10. South Fourche LaFave watershed Theissen polygons. Constructed around NWS rainfall measuring stations at Alum Fork, Aly, Aplin, Jessieville, and Nimrod Dam.

# CHAPTER V

# ANALYSIS METHODS

## Regression Analysis

The period of study (1942-1989) was separated into a calibration period (1942-1970) and a postcalibration period (1971-1989). The latter represents the change in land ownership and the concurrent increase in forest management and road building activity. Least squares multiple regression analysis was used to develop prediction equations for several streamflow variables: annual and seasonal water yield, peak flow rate and high-flow volume.

Both the control watershed and single watershed calibration methods were used in this analysis, which was based on the indicator, or dummy variable technique. An indicator variable, T, was used to determine if the regression of the streamflow variable, hereafter referred to just as streamflow, on the independent variables followed a particular linear relation during the calibration period, but a different linear relation in the postcalibration period. A significant change in the relationship may indicate that changes in land management affected streamflow.

Two approaches were taken to determine the hydrologic impact of Weyerhaeuser forest management. First, a multiple regression was performed to determine if the forest harvest was significantly related to streamflow. Second, a time trend analysis was made to determine if streamflow was related to time, and if this relationship had changed during the postcalibration period.

## Forest Harvest and Streamflow

The general model for this analysis contained these generalized variables:

$$Y_t = f(X_c \text{ or } X_t\text{, CUT, and T})$$

where $Y_t$ represents a streamflow variable (yield, high flow, or peak flow rate) from the treatment basin; $X_c$ and $X_t$ respectively represent one or more independent variables using the control ($X_c$) and single ($X_t$) watershed calibration methods; and CUT represents the three-year moving average of the pine plantation age on the study watershed, expressed as a percent of the basin area. The indicator variable T was assigned the code 0 during the calibration period and the code 1 during the postcalibration phase.

A significant change in streamflow between the calibration and postcalibration periods could be due either to higher levels of forest harvesting during the last two decades (CUT), or to a change in the relationship between streamflow and another variable in the prediction model ($X_c$ or $X_t$), or to a change in a factor not used in the model.

For example, using the single watershed approach, rainfall during the two time periods may be different in magnitude or distributed differently during the water year, and this may affect streamflow. The result could be that the coefficient(s) of the variable(s) representing rainfall in the regression model is a different value for the calibration and postcalibration periods.

An example of the full prediction model using the single watershed method and two climatic variables ($X_{t1}$ and $X_{t2}$) may be written:

$$Y_t = b_0 + b_1T + (b_2+b_3T)X_{t1} + (b_4+b_5T)X_{t2} + (b_6T)CUT$$

where T=0 for the calibration period
T=1 for the postcalibration period

The indicator variable T let us use one model statement to analyze the impact of the independent variables on streamflow for both periods. Note that the harvest variable was expressed in the model only as part of the postcalibration period. For the calibration period, T equals zero and the harvest variable drops from the analysis.

Evaluation of the example model required two steps. First, the hypothesis that a change in streamflow has occurred was tested. If a change was found, a second step determined which independent variable(s) was responsible for the change. In the first step, the hypothesis that a change in streamflow has occurred was tested by the F-statistic for the hypothesis ($b_1=b_3=b_5=b_6=0$). If the hypothesis could not be rejected (or, put another way, if we "accepted" the hypothesis), then we could conclude that Weyerhaeuser forest management had no significant effect on streamflow. If the F-test resulted in a rejection of the hypothesis, the conclusion would be that at least one of the variables ($b_1$, $b_3$, $b_5$, or $b_6$) was not zero, and that streamflow had changed. It then would be necessary to determine which of the postcalibration period coefficients was not zero.

## Time Trends and Streamflow

The analysis just described is the most direct method of evaluating the effect of forest management on streamflow. A second but less conclusive test is to determine whether streamflow changes over time. The general model for this approach was

$$Y_t = f(X_c \text{ or } X_t, \text{TIME, and T})$$

where Yt, Xc, Xt, and T are as described earlier, and TIME represents the date of occurrence for the event of interest. For water yields TIME was the last two digits of the water year (i.e. TIME=42 for 1942, 43 for 1943, etc.). For peak flows and high flows, TIME represented the day that the annual peak occurred, or the day that the high flow period began, in any given water year. Thus, the time variable was initialized (TIME=1) for the date January 1, 1900, and was stepped by one for each day thereafter, until the end of the study period (i.e. TIME=15250 for October 1, 1941; TIME=33146 for September 30, 1990).

An example of the full regression model for predicting water yields using two climatic variables ($X_{t1}$ and $X_{t2}$) and TIME may be written:

$$Y_t = b_0 + b_1T + (b_2+b_3T)X_{t1} + (b_4+b_5T)X_{t2} + b_6\mathrm{TIME} + b_7T(\mathrm{TIME}-70)$$

where T=0 for the calibration period
T=1 for the postcalibration period

As the model shows, two time trend variables are required for this analysis. The first, TIME, represents the time trend of yields during the calibration period. The second variable, "TIME-70", is used in conjunction with the first to represent the time trend of yields for the postcalibration period. It must reflect the fact that this is a new period; therefore, since TIME=71 at the start of the postcalibration period, 70 must be subtracted from TIME in order for the variable to equal one for the first year of the new period.

The time trend model above is an example of "discontinuous piecewise linear regression" (Netter, et al, 1989). The objective of this analysis was to determine if there was a significant difference in the time trend of streamflow between the calibration and postcalibration periods. A "difference" can mean a change in the slope of the time trend at the junction of the two time periods ("piecewise"), or a jump in the regression function at the junction ("discontinuous"), or both. Figure 11 is an illustration of this when the streamflow response in the above model is plotted versus time, using the average values for $X_{t1}$ and $X_{t2}$.

The change in the response function is tested for significance by testing the hypothesis: $b_1=b_3=b_5=b_7=0$. If we reject this hypothesis, the regression function is evaluated to determine which of the coefficients is significantly different from zero. If we cannot reject the hypothesis, then we may conclude Weyerhaeuser forest management had no significant on water yields.

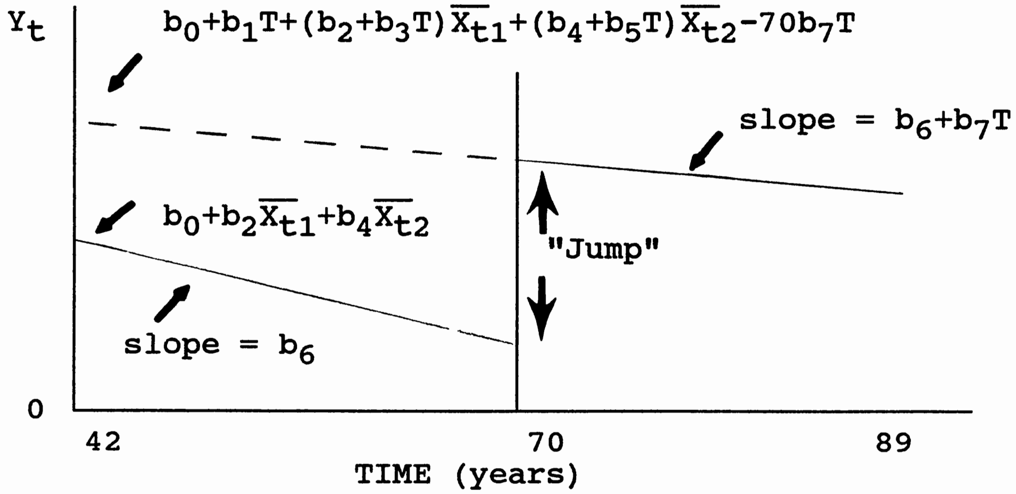

Figure 11. Illustration of response function for discontinuous piecewise linear regression.

## Hypothesis Test F Statistic, Regression Assumptions and Other Information

The test to determine if a variable or group of variables significantly improves a flow model is

$$F = \frac{(SS1-SS2)/(df1-df2)}{EMS} \quad > \quad F(p-k,\ n-p,\ a)$$

where SS1 = Regression sum of squares for the full regression model (T=1)
SS2 = Regression sum of squares for the reduced model (T=0)
df1 = degrees of freedom for the full model
df2 = degrees of freedom for the reduced model
EMS = Error mean square of the full model
p = Number of parameters of the full model
k = Number of parameters of the reduced model
n = Number of observations
F( ) = F statistic at the confidence level (a)

The confidence level ("a" or alpha) chosen for these significance tests was 0.05. For any single variable in a regression model, a p-value smaller than 0.05 indicated a significant variable. Unless otherwise indicated, the p-values for the variables in the models presented in this study were less than 0.01.

Regression analysis does not require any assumptions to be made concerning the model. However, to perform reliable hypothesis testing, the residuals need to be independent and normally distributed with constant variance and a mean of zero. The Durbin-Watson test statistic was used to test for the serial correlation (dependence) of residuals. For this data set, a large D-statistic (about 1.65 or higher) implied that the residuals of the regression were not serially correlated. The assumption of normality of the residuals is not critical and will hold unless there are major departures from the normal form (Netter, et al, 1989). An informal test for normality is to prepare a normal probability plot of the residuals. A plot that departs substantially from linearity suggests that the error distribution is not normal. The residuals for all models presented in this study passed the requirements for independence and normality. Finally, the least squares regression method insures a mean of zero and a constant variance.

In the annual and dormant season water yield analysis the 1984 year was omitted from the analysis because of an extremely high October rainfall. This data exhibited extremely large leverage on the analysis. An unusually large leverage has a value greater than approximately 2p/n, where p is the number of estimated parameters (including the constant) and n is the number of observations (Velleman and Welsch, 1981). The October, 1984 rainfall of 56.0 centimeters was the highest monthly rainfall (by 14 centimeters) recorded during the 48 year study period. It was 20 centimeters greater than the next highest October rainfall. Although this rainfall caused significant streamflow, it did not produce the quantity of streamflow that would have been expected had it occurred in subsequent months, when high rainfall periods were most common, and when the soil water reservoirs had become replenished. Instead, the October, 1984 rainfall occurred after growing season evapotranspiration demands had depleted the soil water reservoirs and watershed hydrologic response was low. As a result, the high precipitation caused the model to overpredict the yield, resulting in an extremely large and negative prediction error (residual) for the annual and dormant season regression models.

## Frequency Analysis

Frequency analysis was used to determine if there was a difference in the frequency distribution of South Fourche annual peak flow rates and high flow volumes between the calibration and postcalibration periods.

A frequency curve relates magnitude of a variable to frequency of occurrence. The frequency curves in this study were computed and plotted using the OSU Agricultural Engineering department's SWAMP software program. The program uses the Weibull plotting position formula (m/(n+1), where m is the rank of the events from largest (m=1) to smallest, and n is the number of events) to compute the plotting position for all streamflow variables. The plotting positions for the calibration period values were determined, and different known frequency distributions were fitted to these points. In all cases the Log Pearson Type III distribution best fit the plotted points. Then, the 95 percent confidence limits for the data were calculated according to the US Geological Survey Bulletin #17B ("Guidelines for Determining Flood Flow

Frequency"). The confidence limits have the property that, "if the data belong to the fitted distribution, a known percentage [95 percent] of the data points should fall between the two curves." (Riggs, 1972). After the frequency curve and confidence limits were established for the calibration period, the frequency distribution of the postcalibration period flows was determined, then superimposed on the fitted distribution for the calibration period. If most of the postcalibration period points fell outside the confidence limits, the two distributions were judged to be significantly different from each other. As a check the same procedure was applied to the rainfall which produced these flows and to the control watershed flows.

## Terms

### Annual and Seasonal Yield Analysis Terms

The water yield prediction models developed from the single watershed calibration method have, as independent variables, a precipitation variable(s) and an antecedent precipitation variable. The latter term was used to account for year-to-year differences in soil moisture conditions at the start of each year or season being studied. The prediction models developed from the control watershed method have, as independent variables, the yield from the control watershed and the difference in precipitation between the two watersheds. The latter term was needed to account for the large geographic separation between the study and the control watersheds (ten kilometers). All models initially contained a cultural variable, either forest harvest (CUT) or time (TIME), which was used to determine if a change in streamflow had occurred between the calibration and postcalibration periods. Watershed yield and precipitation are expressed as a uniform depth (centimeters) over the watershed. The forest harvest is expressed on an annual basis as a percent of watershed area. The time variable represents the last two digits of the water year. The terms used in the regression analysis of water yields are listed in Table IX.

## TABLE IX

## VARIABLES USED IN WATER YIELD ANALYSIS[a]

| Symbol | Variable (Yield and precipitation units are cm.) |
|---|---|
| Q | Yield from study watershed |
| QC | Yield from control watershed |
| P | Gross precipitation for study watershed |
| PE | Effective precipitation for study watershed |
| PD | Gross precipitation difference between the two watersheds (study - control) |
| P2 | Total rainfall 2 months before season of interest |
| P3 | Total rainfall 3 months before season of interest |
| API30 | Antecedent precipitation index for 30-day period before season of interest |
| CUT | 3-year moving average of plantation age, (% area) |
| TIME | last 2 digits of year number (i.e. 42 = yr 1942) |
| T | Indicator (dummy) variable<br>T=0 for calibration period (1942-1970)<br>T=1 for post-calibration period (1971-1989) |

[a] Yield and precipitation variables apply to a given hydrologic period: water year; growing and dormant seasons; spring, summer, fall, and winter.

Annual, seasonal and monthly yield and precipitation variables were used in the regression models. Subscripts were used to indicate the time period. A, G, and D indicate annual, growing, and dormant seasons. S, SM, F, and W indicate spring, summer, fall, and winter. Monthly totals were indicated by the number of the month with respect to a calendar year: 1 for January, 2 for February, and so on.

In Table IX, the effective precipitation term, PE, reflects the fact that a portion of the daily rainfall is intercepted by the forest canopy and does not have an opportunity to contribute to streamflow. One-half (0.5) centimeters was deducted from the daily gross precipitation, and the remaining positive values were summed for the month, season, or year, as required. Effective precipitation variables using 1.0, 1.5, and 2.0 centimeter deductions from daily rainfall were also evaluated, but were either not significant, or not as significant as the 0.5 cm variable in the regressions. This matches well with Lawson's (1967) finding that first-day-of-storm interception by a shortleaf pine overstory-hardwood understory (Alum Creek watersheds) was about 0.5 centimeters.

Also in Table IX, the variables P2, P3, and API30 are antecedent precipitation indices (API) used to express watershed soil moisture conditions at the start of the hydrologic season. The variable API30 was computed using the formula

$$API30 = P_1 + (1/2)P_2 + (1/3)P_3 +...+ (1/30)P_{30}$$

where $P_1$ is the gross daily precipitation the day before the start of the period in question, $P_2$ is the daily rainfall 2 days before the start of the period, and so on. An API60 (60-day index) and API90 (90-day index) were also evaluated, but only the 30-day index provided statistically significant improvements in the prediction models.

The mean, range and standard deviation for the independent and dependent variables used in this analysis are provided in Table X. The values for annual and dormant season variables were based on 1942 to 1989 data. Growing season values were based on 1942 to 1990 data. The annual and dormant season calculations do not include data for 1984, a year often excluded from the analyses due to high statistical leverage.

Water yield calculations and analyses were based on a March-February water year because the start of this period reflected the most stable soil water storage conditions from year to year (discussed in more detail on page 109).

## Annual Peak Flow Analysis Terms

The peak flow prediction models (only the control watershed method was used) have, as independent variables, the peak flow from the control watershed and the difference in peak flow precipitation between the two watersheds. The

## TABLE X

## MEAN, RANGE AND STANDARD DEVIATION OF VARIABLES USED IN THE YIELD REGRESSION MODELS[a]

| Symbol | Unit | Mean | Range | Standard Deviation |
|---|---|---|---|---|
| $Q_A$ | cm | 47.68 | 13.30 - 97.86 | 19.32 |
| $Q_G$ | cm | 26.24 | 4.83 - 65.57 | 14.38 |
| $Q_D$ | cm | 21.73 | 1.69 - 53.35 | 11.95 |
| $Q_S$ | cm | 12.55 | 4.39 - 51.99 | 12.55 |
| $Q_{SM}$ | cm | 4.05 | 0.07 - 17.27 | 4.44 |
| $Q_F$ | cm | 3.61 | 0.00 - 17.27 | 4.36 |
| $Q_W$ | cm | 18.12 | 0.96 - 47.10 | 10.44 |
| Control watershed variables | | | | |
| $QC_S$ | cm | 22.22 | 5.88 - 57.23 | 13.35 |
| $QC_{SM}$ | cm | 4.75 | 0.11 - 22.56 | 5.64 |
| $QC_F$ | cm | 3.68 | 0.00 - 22.29 | 4.64 |
| $QC_W$ | cm | 15.36 | 0.21 - 43.75 | 9.69 |
| $PD_S$ | cm | -0.13 | -11.75 - 11.97 | 5.37 |
| $PD_{SM}$ | cm | -0.84 | -26.45 - 17.33 | 8.21 |
| $PD_F$ | cm | 0.12 | -10.95 - 8.44 | 3.81 |
| $PD_W$ | cm | 2.67 | -7.88 - 11.25 | 4.40 |
| Single watershed variables | | | | |
| $P_S$ | cm | 40.76 | 16.36 - 72.23 | 13.72 |
| $P_{SM}$ | cm | 37.61 | 13.73 - 73.07 | 12.58 |
| $P_F$ | cm | 19.56 | 4.83 - 36.32 | 7.49 |
| $P_W$ | cm | 29.73 | 7.56 - 58.56 | 11.18 |
| $PE_{SM}$ | cm | 23.23 | 4.95 - 53.41 | 9.62 |
| $PE_F$ | cm | 13.50 | 2.61 - 28.02 | 6.32 |
| $P2_{A,G}$ | cm | 18.58 | 4.19 - 45.51 | 9.63 |
| $P3_D$ | cm | 27.23 | 10.29 - 47.92 | 9.17 |

[a] The values are based on 1942 to 1989 data. The calculations do not include 1984 data.

peak flow precipitation was defined as the amount of precipitation the day of and the day before the peak, as this formula produced models with the highest $R^2$ and lowest standard error. Other variables used in the regression analysis were the same two cultural variables, CUT and

TIME, that were used in the water yield analysis. The time variable was put in units of days rather than years, as the annual peak could occur at any time during the water year. The water year was the October 1 - September 30 year used by the USGS. This division was used so that the hydrologic "wet" season between December and May would not be split into different water years. The terms used in the regression analysis of annual peak flow rates are listed in Table XI.

TABLE XI

VARIABLES USED IN PEAK FLOW ANALYSIS

| Symbol | Variable |
|---|---|
| $Q_{Pt}$ | Annual peak flow, study watershed, ($m^3$/sec) |
| $Q_{Pc}$ | Annual peak flow, control watershed, ($m^3$/sec) |
| PD | Peak flow precipitation difference between the two watersheds (study - control), (cm) |
| CUT | 3-year moving average of annual forest harvest, (% of watershed area) |
| TIME | day the annual peak occurred<br>TIME=1 for January 1, 1900<br>TIME=15250 for October 1, 1942<br>TIME=33146 for September 30, 1990 |
| T | Indicator (dummy) variable<br>T=0 for calibration period (1942-1970)<br>T=1 for post-calibration period (1971-1990) |

## High Flow Analysis Terms

The high flow prediction models (only the control watershed method was used) have, as independent variables, the respective 7-, 14-, 60-, and 90-day high flows from the control watershed, the difference in precipitation between the watersheds for these periods, and the same two cultural variables, CUT and TIME. High flow was defined as the total maximum consecutive-day discharge in any given water year. That is, for each year of the study, the high flow is the highest total volume discharge over a 7, 14, 60, and 90 consecutive day period during each of those years. The high flow precipitation was the cumulative precipitation for the corresponding period. Both high flow and high flow precipitation were expressed as a uniform depth (centimeters) over the watershed. As in the peak flow analysis, the time variable (TIME) was put in units of days rather than years. The values for TIME corresponded to the start of the respective high flow periods each year. The water year used for the analysis was the October 1 - September 30 year, because, like peak flows, the desire was to maintain the continuity of the hydrologic "wet" season between December and May. The terms used in the regression analysis of high flows are listed in Table XII.

## TABLE XII

## VARIABLES USED IN HIGH FLOW ANALYSIS

| Symbol | Variable |
|---|---|
| $Q_{7t}$ | Maximum 7-day flow, study watershed, (cm) |
| $Q_{14t}$ | Maximum 14-day flow, study watershed, (cm) |
| $Q_{60t}$ | Maximum 60-day flow, study watershed, (cm) |
| $Q_{90t}$ | Maximum 90-day flow, study watershed, (cm) |
| $Q_{7c}$ | Maximum 7-day flow, control watershed, (cm) |
| $Q_{14c}$ | Maximum 14-day flow, control watershed, (cm) |
| $Q_{60c}$ | Maximum 60-day flow, control watershed, (cm) |
| $Q_{90c}$ | Maximum 90-day flow, control watershed, (cm) |
| $PD_7$ | Precipitation difference between the watersheds (study-control) for 7-day high flow period, (cm) |
| $PD_{14}$ | Precipitation difference between the watersheds (study-control) for 14-day high flow period, (cm) |
| $PD_{60}$ | Precipitation difference between the watersheds (study-control) for 60-day high flow period, (cm) |
| $PD_{90}$ | Precipitation difference between the watersheds (study-control) for 90-day high flow period, (cm) |
| CUT | 3-year moving average of annual forest harvest, (% of watershed area) |
| TIME | day that the high flow period started<br>TIME=1 for January 1, 1900<br>TIME=15250 for October 1, 1942<br>TIME=33146 for September 30, 1990 |
| T | Indicator (dummy) variable<br>T=0 for calibration period (1942-1970)<br>T=1 for post-calibration period (1971-1990) |

# CHAPTER VI

# ANNUAL AND SEASONAL YIELD ANALYSIS RESULTS AND DISCUSSION

## Water Year and Season Determination

A March-February water year was used for the analysis. Seasons were determined according to changes in mean monthly streamflow (Q), rainfall (P), and watershed hydrologic response (H), defined as streamflow divided by rainfall, keeping in mind the approximate start of the seasons (TABLE XIII). The growing season was taken as the period from March 1 to September 30, the dormant season from October 1 to February 28(29).

To determine the water year, regressions of annual yield were made for the calibration period (1942-1970) for all water year combinations (i.e. water years starting in January and ending in December, starting in February and ending the following January, etc.). Both the control and the single watershed methods were used. The optimum water year was determined to be the regression which had both the highest $R^2$ and the lowest standard error (S) (TABLE XIV).

Several researchers have used this method of "optimizing" the water year as a first step in the climatic calibration of watershed streamflow. In most cases,

## TABLE XIII

## MEAN MONTHLY PRECIPITATION, YIELD, AND HYDROLOGIC RESPONSE: SOUTH FOURCHE WATERSHED - CALIBRATION PERIOD

| Season | Month | P(cm) | Q(cm) | H(%)(=Q/P) |
|---|---|---|---|---|
| Growing Season | | | | |
| Spring | Mar | 13.3 | 9.0 | 68 |
| | Apr | 13.3 | 7.5 | 56 |
| | May | 15.0 | 6.9 | 46 |
| Summer | Jun | 9.7 | 1.8 | 19 |
| | Jul | 10.1 | .8 | 8 |
| | Aug | 8.9 | .6 | 7 |
| | Sep | 9.3 | .8 | 9 |
| Dormant Season | | | | |
| Fall | Oct | 8.0 | .5 | 7 |
| | Nov | 9.4 | 1.9 | 20 |
| Winter | Dec | 10.1 | 4.2 | 42 |
| | Jan | 10.0 | 6.5 | 65 |
| | Feb | 9.9 | 6.7 | 68 |

starting the water year in the spring after the soil has been recharged has given the optimum water year. This has been linked to the fact that soil moisture measurements during the spring are more stable than at any other time of the year. This stability implies that the "storage" term (S) of the water balance equation (Q=P-ET-S) is relatively constant from year to year at this time (Q=yield, P=precipitation, and ET=evapotranspiration). Thus, the elimination of the term from the model can be justified. At the very least, the failure to adequately model the storage term under these conditions would not significantly effect the ability of the model to predict streamflow.

## TABLE XIV

## RESULTS OF REGRESSION OF ANNUAL YIELD FOR DETERMINATION OF THE OPTIMUM WATER YEAR

| Water Year Starting | Regression Equations | | | |
|---|---|---|---|---|
| | $Q=b_0 + b_1P$ | | $Q=b_0 + b_1QC + B_2PD$ | |
| | $R^2$ | S(cm) | $R^2$ | S(cm) |
| January | .889 | 7.056 | .922 | 6.039 |
| February | .893 | 7.051 | .922 | 6.160 |
| March | *.898 | 6.737 | *.930 | 5.700 |
| April | .850 | 7.504 | .906 | 6.055 |
| May | .839 | 7.307 | .891 | 6.110 |
| June | .804 | 8.616 | .906 | 6.076 |
| July | .847 | 7.652 | .918 | 5.693 |
| August | .793 | 8.672 | .890 | 6.456 |
| September | .802 | 8.569 | .885 | 6.645 |
| October | .805 | 8.730 | .910 | 6.046 |
| November | .787 | 9.094 | .903 | 6.270 |
| December | .858 | 7.878 | .915 | 6.207 |

* Indicates the model with both the highest $R^2$ and the lowest standard error (S).

## Plots of Raw Data

The following plots contain the raw data for water yields and precipitation for the study and control watersheds. Figures 12 and 13 are the plots versus time for the annual and dormant season variables, respectively. Figures 14 and 15 are the double mass plots for annual water yields (study watershed) versus rainfall and control watershed yields, respectively. Figures 16 and 17 are the double mass plots for dormant season water yields versus rainfall and control watershed yields, respectively.

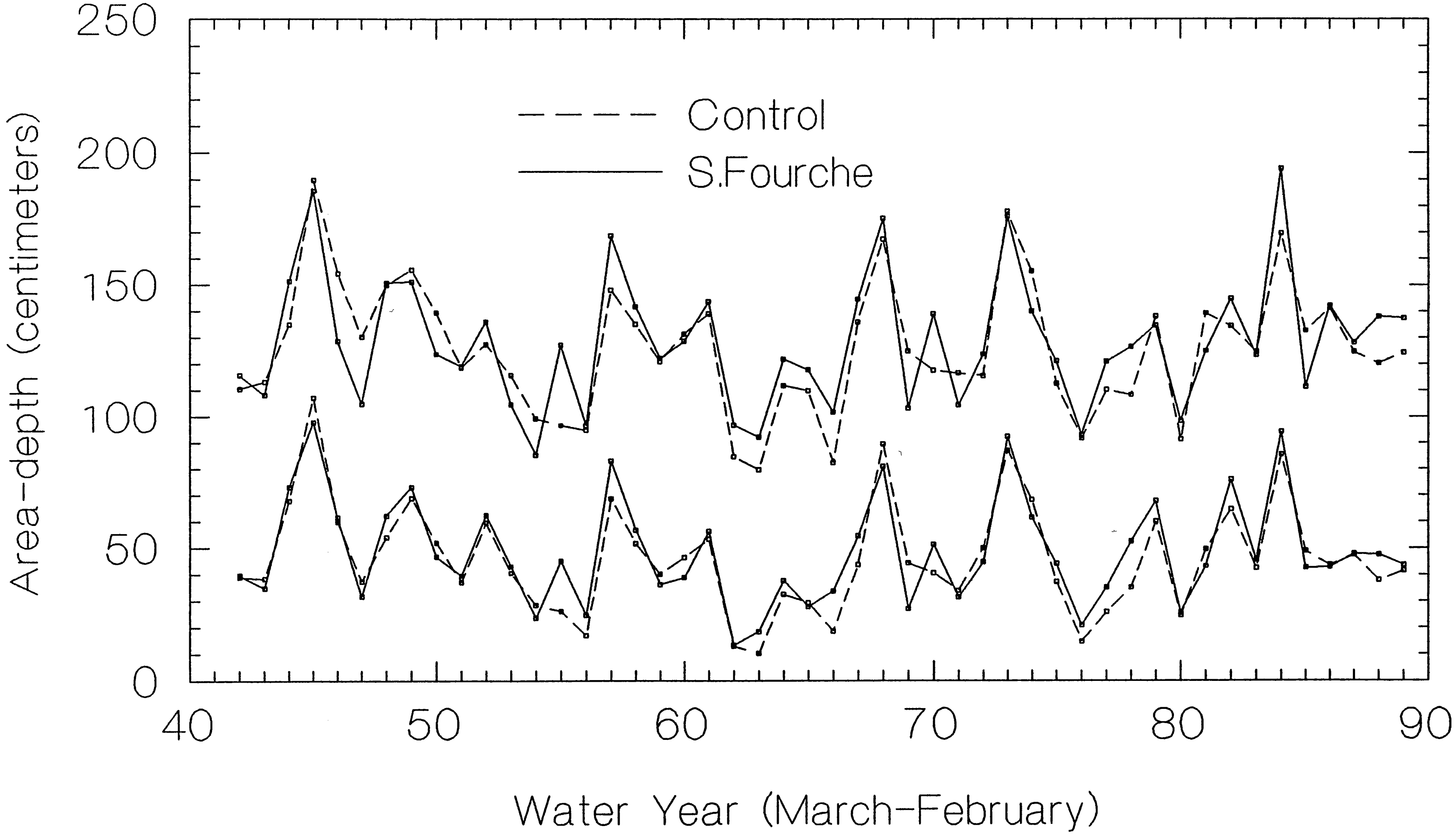

**Figure 12. Plot of annual data. Annual water yield and precipitation for the study and control watersheds versus time. Upper two plots are precipitation.**

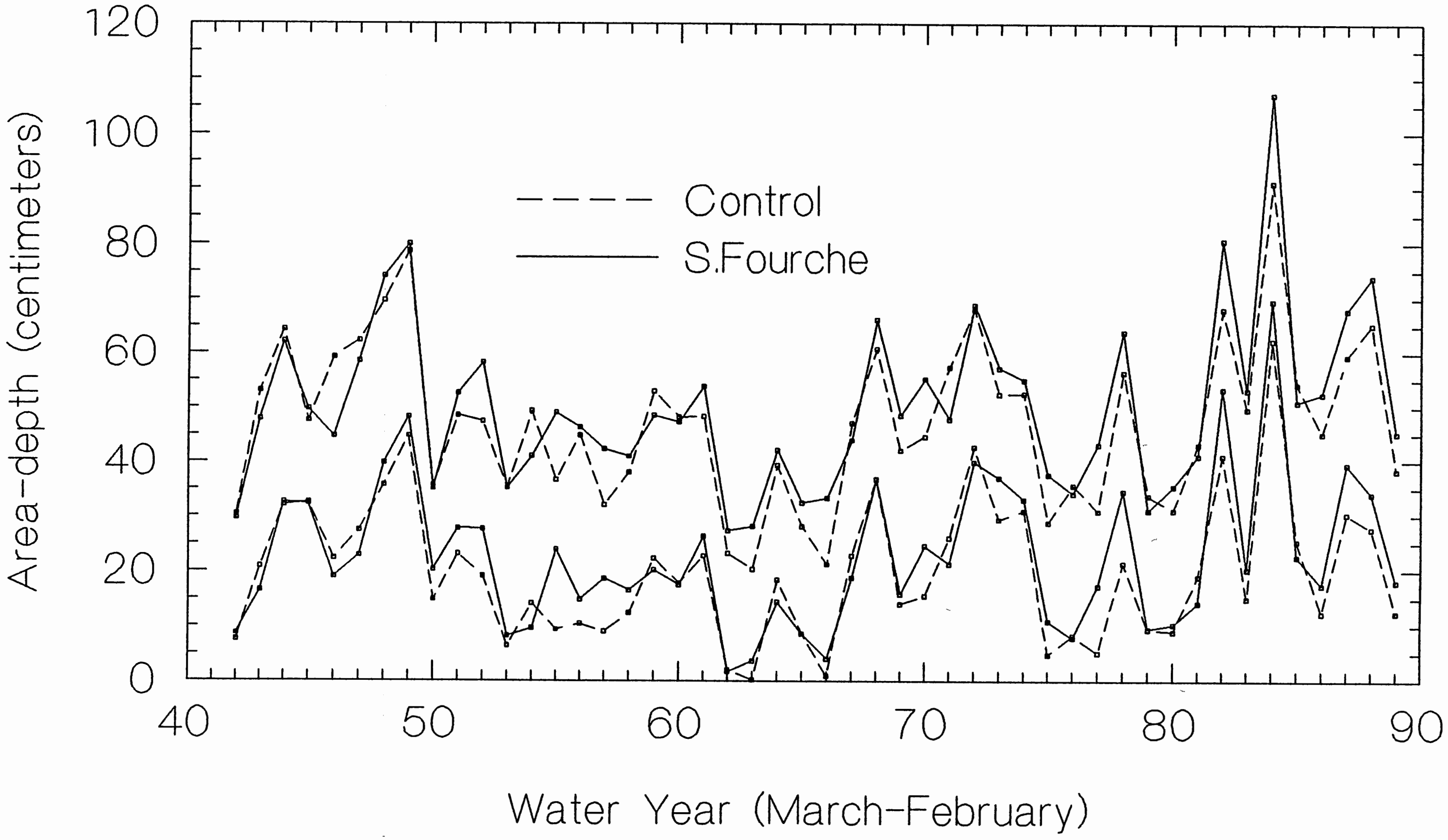

**Figure 13. Plot of dormant season data. Dormant season water yield and precipitation for the study and control watersheds versus time. Upper two plots are precipitation.**

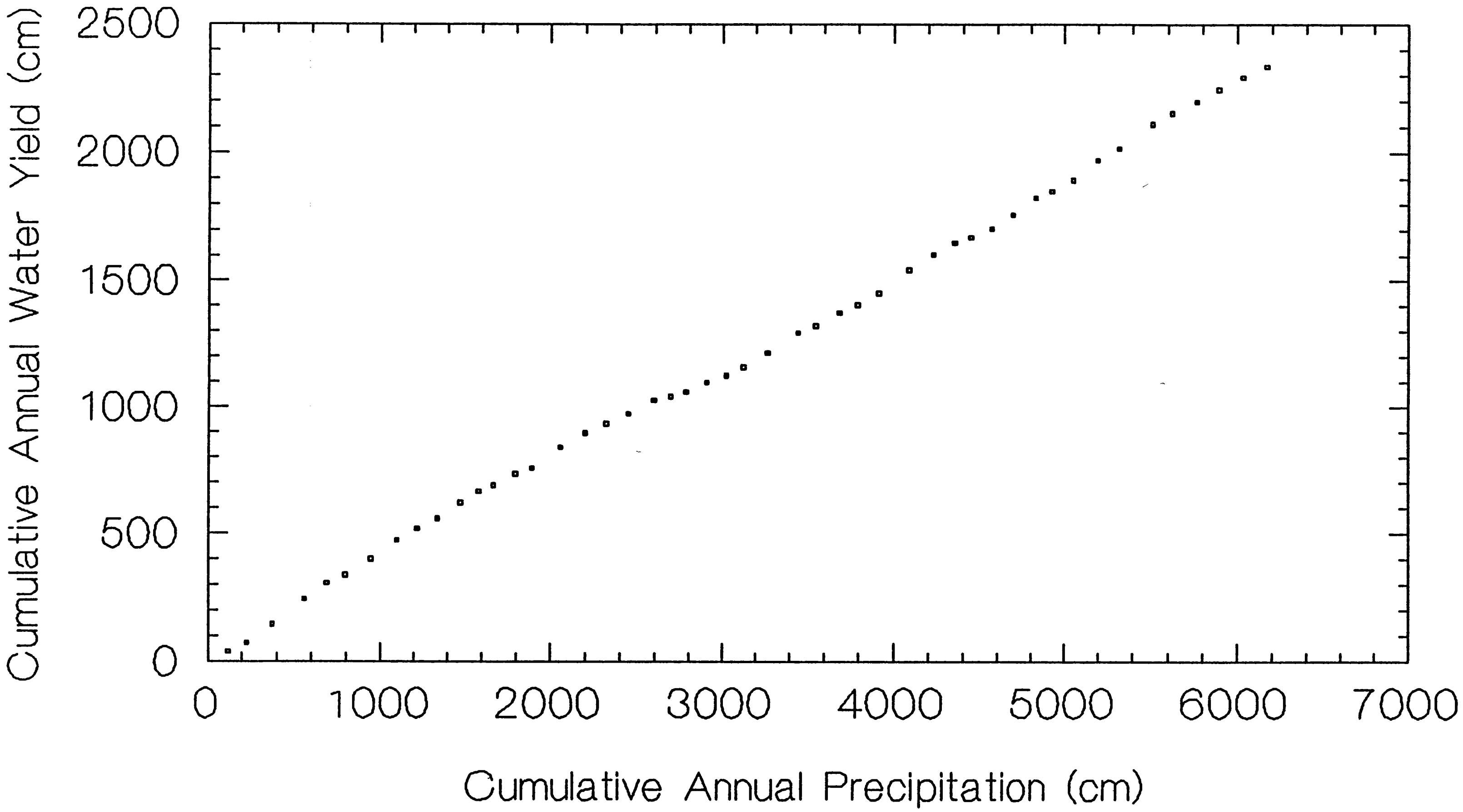

**Figure 14. Double mass plot of annual water yield versus annual precipitation for the study watershed.**

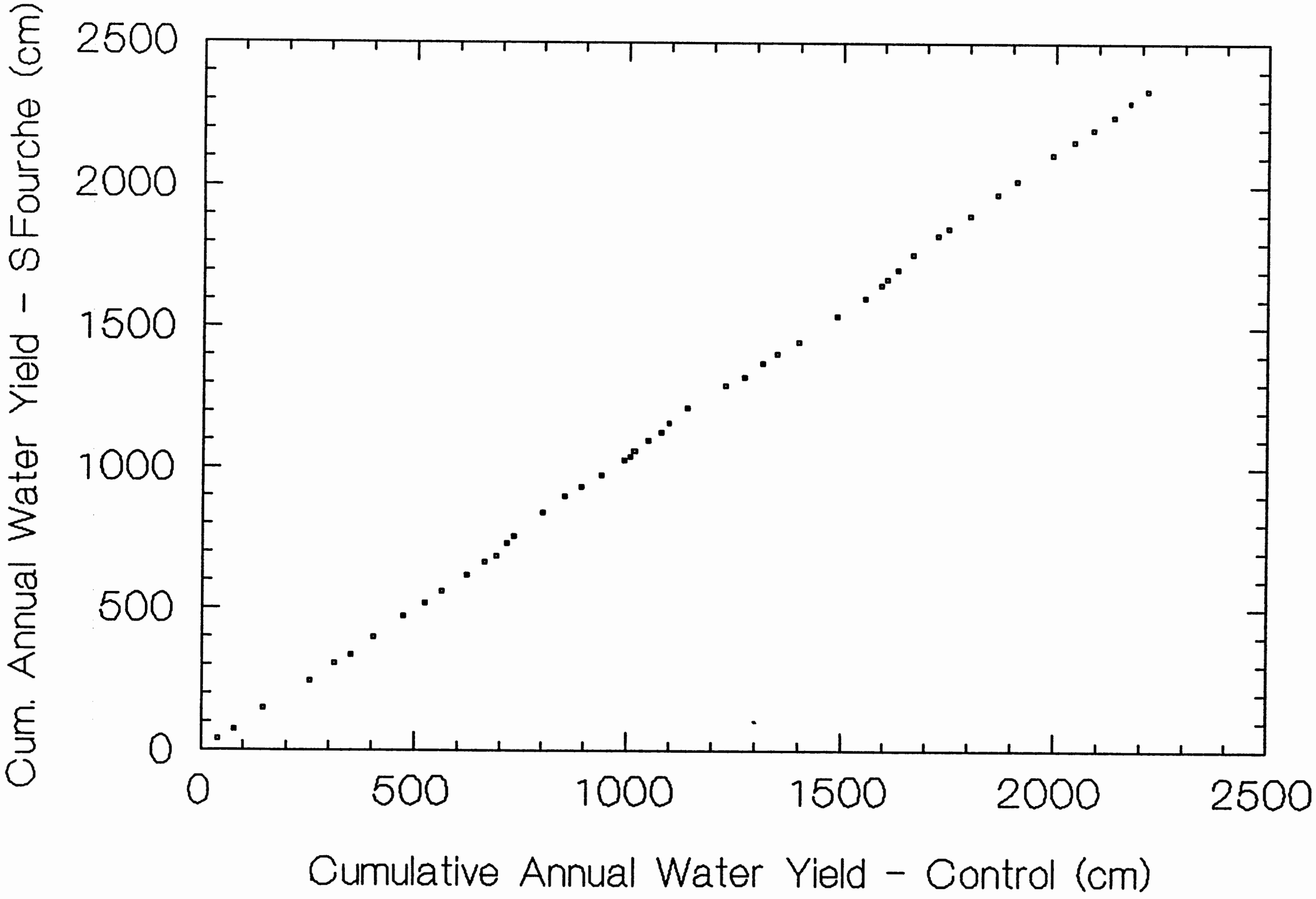

Figure 15. Double mass plot of annual water yield for the study watershed versus the annual yield for the control watershed.

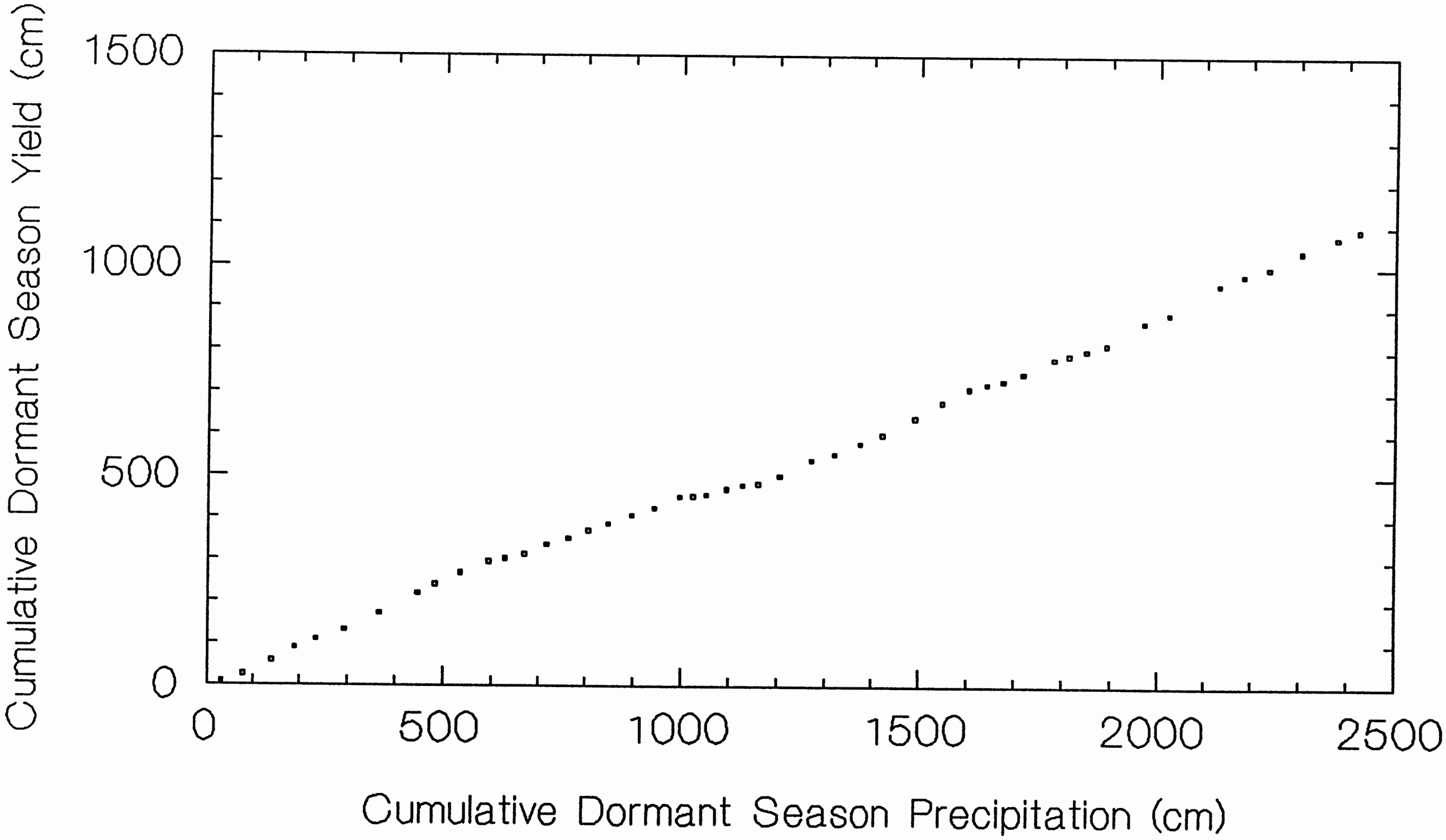

**Figure 16.** Double mass plot of dormant season water yield versus dormant season precipitation for the study watershed.

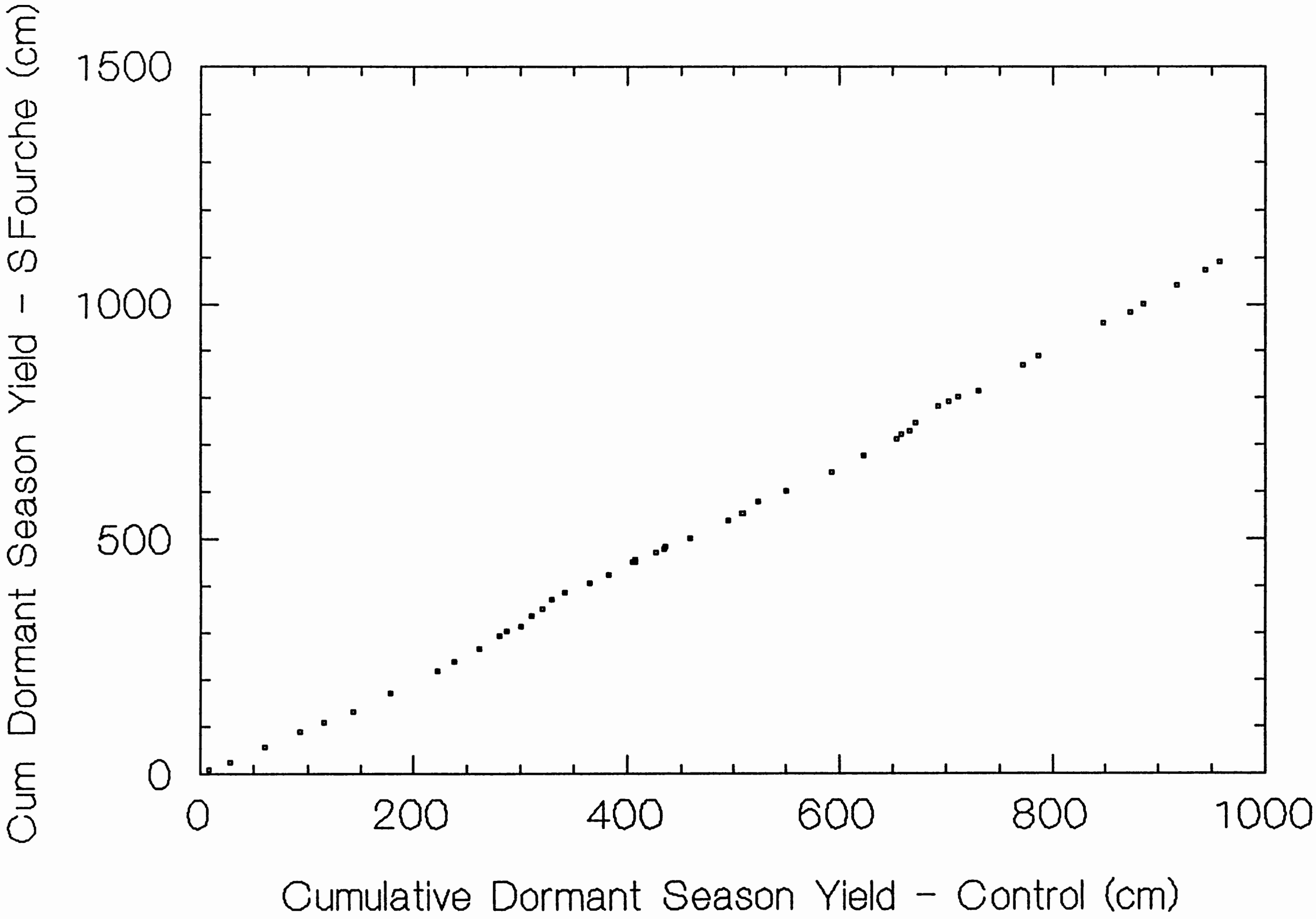

Figure 17. Double mass plot of dormant season water yield for the study watershed versus the dormant season yield for the control watershed.

## Regression of Annual Yield

Annual yield regression models developed using the control watershed and single watershed calibration methods are given in Equations 1 through 3. The coefficient of multiple determination ($R^2$), the standard error of the estimate (S), and the Durbin-Watson test statistic (D) accompany the equations.

Equation 1 is the annual yield model developed using control watershed variables. Equations 2 and 3 are the annual yield models obtained from the single watershed approach. Neither CUT nor TIME was significant in the control watershed model. When annual yields were climatically calibrated, however, TIME was significant in explaining some of the variability in water yields during the study period (Equation 3). In addition, a "jump" occurred in the yield response function as reflected by the significance of the indicator variable, T (Equation 3). (Note: subscripts indicate seasons: S-spring, SM-summer, F-fall, and W-winter.)

$$Q_A = 3.148 + 1.049*QC_S + .758*QC_{SM} + 1.015*QC_F + .965*QC_W + .533*PD_S + .39*PD_{SM} + .675*PD_F \qquad (1)$$

$$R^2 = .933 \quad S = 5.439 \text{ cm} \quad D = 1.774$$

$$Q_A = -58.673 + 1.006*P_S + .471*P_{SM} + 1.005*P_F + .779*P_W + .297*P2 \qquad (2)$$

$$R^2 = .930 \quad S = 5.409 \text{ cm} \quad D = 1.546$$

$$Q_A = -37.926 + .988*P_S + .50*P_{SM} + .996*P_F + .747*P_W + .263*P2 -.355*TIME + 9.669*T \qquad (3)$$

$$R^2 = .949 \quad S = 4.735 \text{ cm} \quad D = 1.952$$

In the control watershed model (Equation 1) the winter precipitation difference variable was not significant. The difference in winter rainfall between the watersheds was large (+2.67 centimeters) compared to the other seasons (-0.838 to 0.123 cm) (Table X, p.105). The reason for this is unknown, but it probably is an indication of why the winter variable was not significant.

In the climatically calibrated models (Equations 2 and 3), annual yield was regressed against seasonal rainfall and an antecedent precipitation index (API). The API that gave the best regression results was the 2-month cumulative precipitation prior to the start of the water year (P2). Annual precipitation was separated into spring, summer, fall and winter rainfall. For the basic model (Equation 2) the use of seasonal instead of annual rainfall improved the $R^2$ from 0.887 to 0.937, and lowered the standard error from 6.704 to 4.955 centimeters. Similar improvements occurred in the growing and dormant season yield analyses.

Climatic calibration of annual yield indicates a significant change in yield response for the post-calibration period (Equation 3). In the context of this analysis TIME is an all-inclusive variable which reflects changes in yield caused by one or more factors other than those represented in the model. The plots of the regression residuals by water year (residual plots) for the climatic calibration models are shown in Figure 18. The plot in Figure 18(a) demonstrates the time trend in yield response for the calibration and postcalibration periods.

For both periods annual yield declines at an average rate of 0.36 centimeters per year (coefficient of TIME in Equation 3). During the latter period, however, the entire response "jumps" from an intercept of -37.926 to one at -28.257 cm (the sum of the intercept and the coefficient of T).

The change in annual yield response between the two periods can be illustrated using the average values for seasonal precipitation (Table X, p.105) in Equation 3 and plotting yield as a function of time (Figure 19) in a two dimensional graph. The slope of the relationship remains constant, but the postcalibration response function is approximately 10 centimeters higher than that for the calibration period, given the same rainfall conditions.

The change in yield response remained significant even when parts of the period-of-record were deleted from the data base: The analysis was carried out after omitting from the data set those years when streamflow was low for long periods (greater than 60 days of zero flow in a year), and again after omitting those years when a major portion (more than 40 percent) of annual yield occurred in a particular month.

## Regression of Growing Season Yields

Growing season regression models developed using the control watershed and single watershed calibration methods

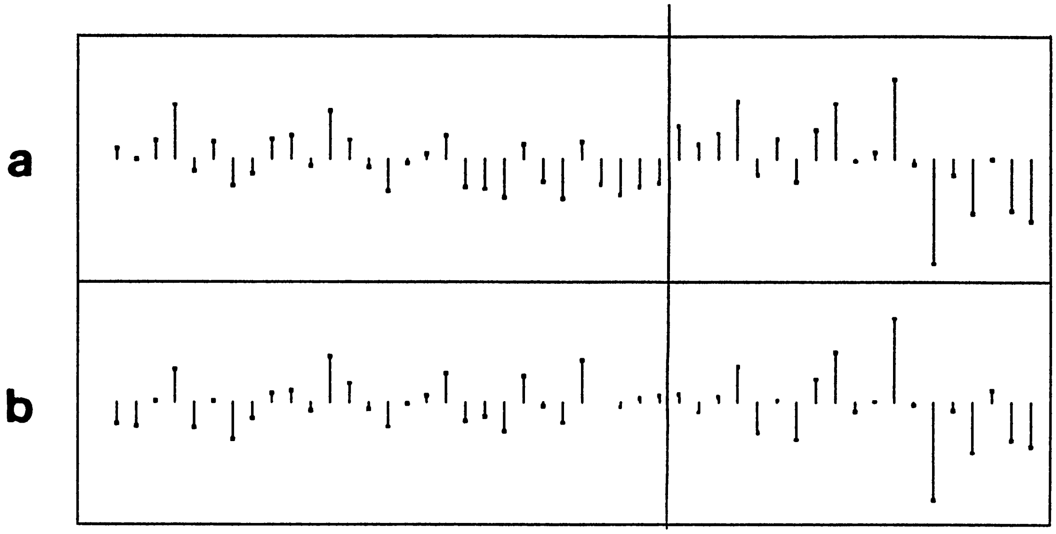

Figure 18. Residual plots for climatically calibrated annual yield models: (a) model Equation 2; (b) with TIME added, model Equation 3. Scale is +/-20 centimeters centered on Y = zero.

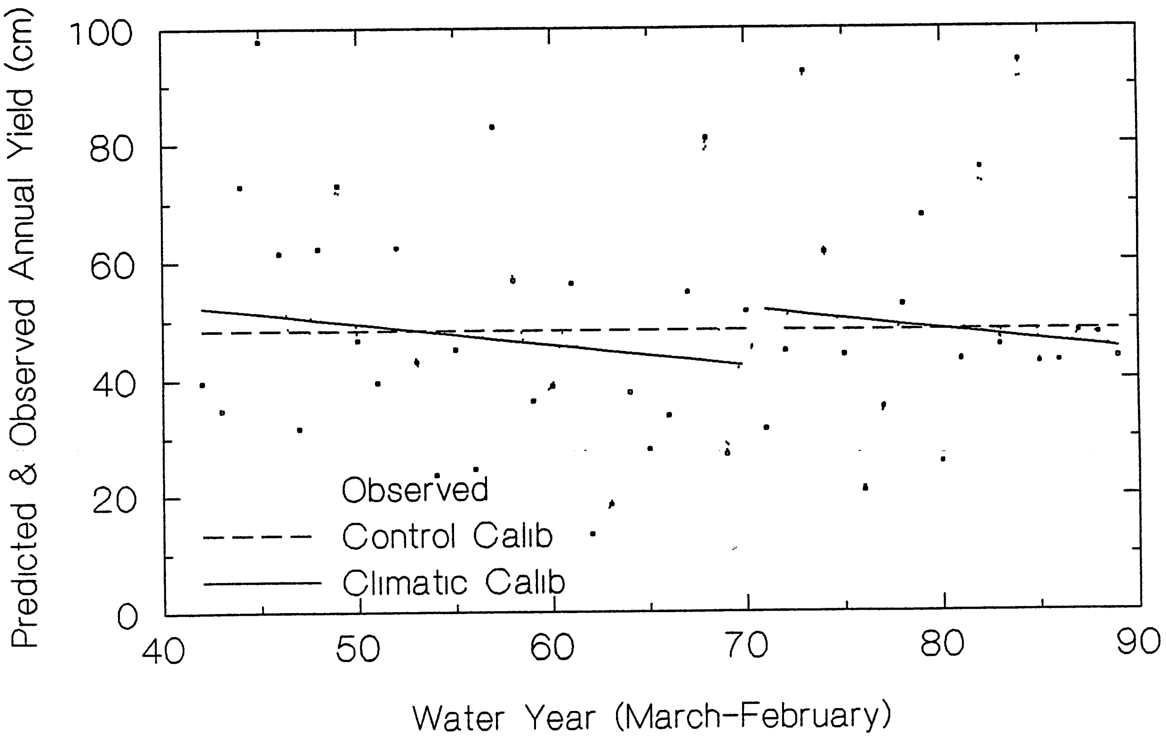

Figure 19. Annual yield v. time for the control and single watershed models (Equations 1 & 3) using the average values (1942-1989) for the climatic and control watershed variables. Observed yields for reference.

are given in Equations 4 and 5. Neither CUT nor TIME were significantly related to growing season yield.

$$Q_G = 2.29 + .926*QC_S + .766*QC_{SM} + .526*PD_S + .252*PD_{SM} \quad (4)$$

$R^2 = .895 \quad S = 4.872$ cm $\quad D = 1.646$
p-value for $PD_{SM}$ is 0.015

$$Q_G = -24.156 + .931*P_S + .414*PE_{SM} + .17*P2 \quad (5)$$

$R^2 = .923 \quad S = 4.113$ cm $\quad D = 1.924$
p-value for P2 is 0.013

The largest residual for the growing season models was in 1979 and appears to be the result of unusually high spring precipitation. The average hydrologic response of the watershed that spring was 83 percent, and of the total water yield that year, 77 percent was produced in the three spring months.

The spring and summer components of growing season yield also were regressed against control watershed and climatic variables. The analyses did not show significant response of yields either to forest harvest or time.
(Note on subscripts: 3=March, 4=April, etc)

$$Q_S = 1.767 + .828*QC_3 + 1.097*QC_4 + .82*QC_5 + .649*PD_3 + .587*PD_4 + .404*PD_5 \quad (6)$$

$R^2 = .903 \quad S = 4.178$ cm

$$Q_S = -15.142 + .807*P_3 + 1.106*P_4 + .743*P_5 + 1.246*API30_S \quad (7)$$

$R^2 = .916 \quad S = 3.751$ cm

$$Q_{SM} = .643 + .765*QC_{SM} + .206*PD_{SM} \quad (8)$$

$R^2 = .741 \quad S = 2.312$ cm

$$Q_{SM} = -5.223 + .353*PE_{SM} + .699*API30_{SM} \quad (9)$$

$$R^2 = .629 \quad S = 2.782 \text{ cm}$$

No effect on spring streamflow from the forest harvest was anticipated as this is a period when soils on both forested and harvested sites are normally saturated. Although summer streamflow may be affected by land management, in this analysis the standard errors for the summer yield models were relatively high (2.3 and 2.8 cm) and the average summer flow was low (4.05 cm, Table X, p.105). We may not, therefore, reasonably expect that these analyses would detect a significant change in yield.

## Regression of Dormant Season Yields

Dormant season regression models developed using the control watershed and single watershed calibration methods are given in Equations 10 through 14. This was the only analysis in which the control watershed calibration method indicated a significant difference between calibration and postcalibration period yields. Both CUT and TIME were found to be significant in the climatically calibrated yield models (Equations 13 and 14). As in the time trend analysis of annual yield, the response of dormant season yields jumped during the postcalibration period.

$$Q_D = .338 + .923*QC_F + 1.032*QC_W + .597*PD_F + .762*PD_W \quad (10)$$

$$R^2 = .938 \quad S = 3.117 \text{ cm} \quad D = 1.349$$

$$Q_D = 9.974 + .867*QC_F + 1.01*QC_W + .667*PD_F + .836*PD_W - .175*Time + 5.392*T \qquad (11)$$

$$R^2 = .950 \quad S = 2.868\text{ cm} \quad D = 1.728$$

$$Q_D = -25.213 + 1.062*PE_F + .87*P_W + .247*P3 \qquad (12)$$

$$R^2 = .923 \quad S = 3.425\text{ cm} \quad D = 1.696$$

$$Q_D = -25.837 + .998*PE_F + .877*P_W + .265*P3 + 1.143*T*CUT \qquad (13)$$

$$R^2 = .931 \quad S = 3.273\text{ cm} \quad D = 1.667$$

p-value for T*CUT is 0.029

$$Q_D = -12.134 + 1.073*PE_F + .848*P_W + .287*P3 - .251*Time + 7.078*T \qquad (14)$$

$$R^2 = .949 \quad S = 2.867\text{ cm} \quad D = 2.361$$

The climatically calibrated yield models (Equations 12-14) contain an "effective" precipitation variable that represented fall precipitation. Effective precipitation reflects the fact that a high proportion of October and November precipitation helps to replenish soil water reservoir depleted during the growing season. A review of the hydrologic response of the South Fourche watershed (Table XIII, p.110) illustrates this point. The average hydrologic response is 7 percent for October, rises to 20 percent in November, 42 percent in December, and stays above 60 percent from January to April. Using effective precipitation in place of gross precipitation raises the $R^2$ of the general model (Equation 12) from 0.918 to 0.923 and lowers the standard error from 3.56 to 3.42 centimeters.

The forest harvest variable was significant (p=.029) in the climatic calibration regression of dormant season yield (Equation 13). However, the fact that CUT may explain some of the variation in dormant season yields may be more of a coincidence than a cause-and-effect correlation. Much of the significance of CUT is related to the high positive residual in 1982, which corresponds to the maxima in the second peak in the CUT plot (Figure 20). If the 1982 data is dropped from the analysis, the CUT variable drops from the equation with a p-value of 0.107.

One cause of the high prediction error in 1982 may be the 41.8 centimeter rainfall that December which, next to the October, was the highest recorded monthly rainfall during the 48-year study period. The December, 1982 precipitation fell on saturated soil and was almost totally converted into streamflow. The hydrologic response of the South Fourche watershed this month was 95.8 percent. The result was that the climatically calibrated yield model greatly underestimated the observed yield, resulting in a high positive residual ($Q_{obs}-Q_{pred}$). Since much of the correlation between CUT and postcalibration period yields is the result of this high residual, the significance of the timber harvest variable may be just coincidence.

If CUT is used in the dormant season yield model, a smaller prediction error results. The cumulative effect of timber harvest on yields can be determined by comparing the residuals of Equations 12 and 13 for the postcalibration period (the 1984 residuals were computed but the 1984 data was not used in the analysis). The mean difference between the residuals obtained from the two yield models is 1.0

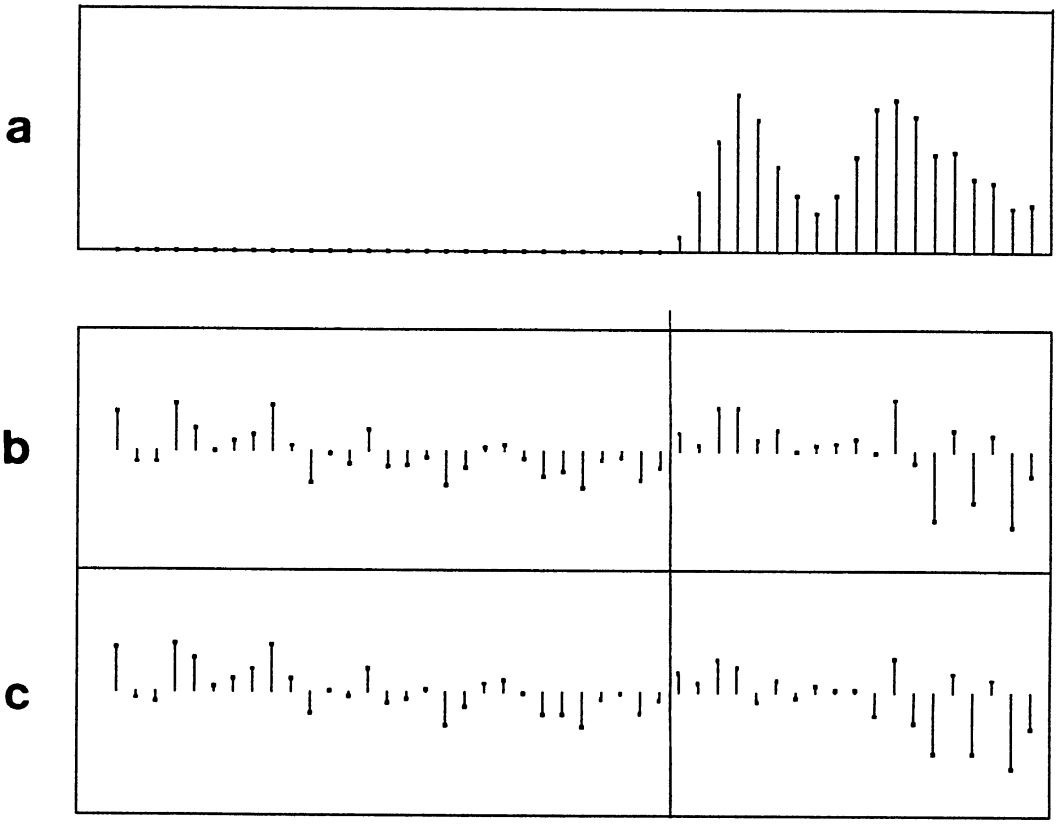

Figure 20. Residual plots for dormant season yield prediction models using single watershed calibration method: (a) Percentage of the watershed cut annually, 3-year moving average, scale = 0-5 percent; (b) Residual plot for the model Equation 12; (c) Residual plot for the same model with CUT added, Equation 13. Scale of residual plots = +/-15 centimeters centered on Y=0.

centimeters. That is, during the 19-year postcalibration period, the impact of the timber harvest is to increase total dormant season yield an average of 1.0 centimeters per year, or 19.0 centimeters total. Given the area of the South Fourche watershed, 54510 hectares, and the length of the dormant season, 151 days, this corresponds to an increase in streamflow rate of 0.42 $m^3/s$ or 14.8 cfs during the dormant season.

Both the control and single watershed calibration methods produced regression functions in which the relationship between dormant season yields and time was significant (Equations 11 and 14). The residual plots for the regression models with and without a correction for time are shown in Figure 21.

There are similarities between the prediction models Equations 11 and 14. Developed independently and based on different calibration methods, each model contains time-related variables (TIME and T) with nearly equal coefficients. Using the coefficients of the variables to explain these similarities, the control watershed model (Equation 11) reveals that during the study period the water yield response of the South Fourche watershed declined at an average rate of 0.175 centimeters (cm) per year relative to the control watershed, and the response function jumped 5.39 cm for the postcalibration period. Likewise, the single watershed model (Equation 14) shows that, for equivalent climatic conditions, yield response declined at an average rate of 0.251 cm per year, and the response function increased 7.08 cm in the postcalibration period. This is illustrated in Figure 22 (page 129).

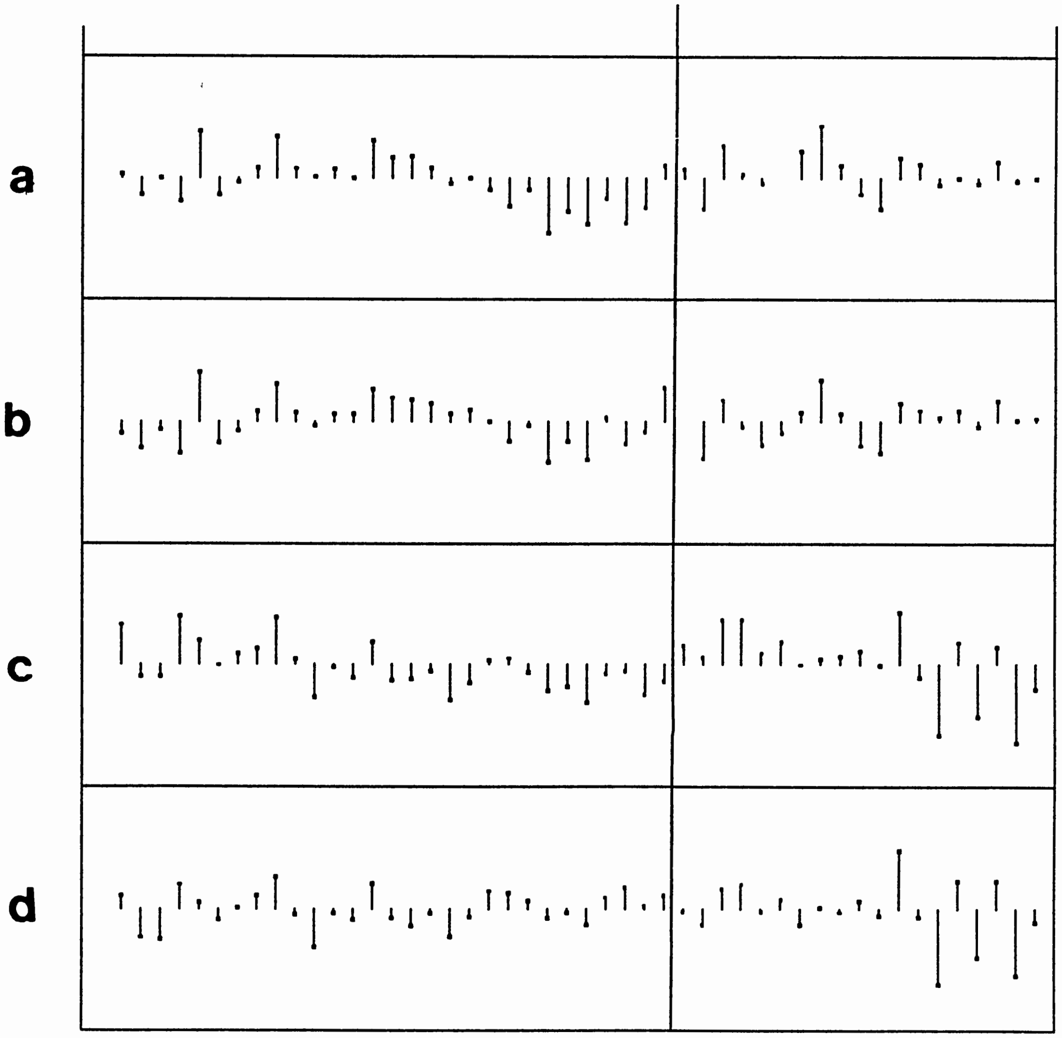

Figure 21. Residual plots for dormant season yield prediction models: (a) control watershed model, Equation 10; (b) the same model with TIME added, Equation 11; (c) single watershed model, Equation 12; (d) the same model with TIME added, Equation 14. Scale = +/- 15 centimeters centered on Y = zero.

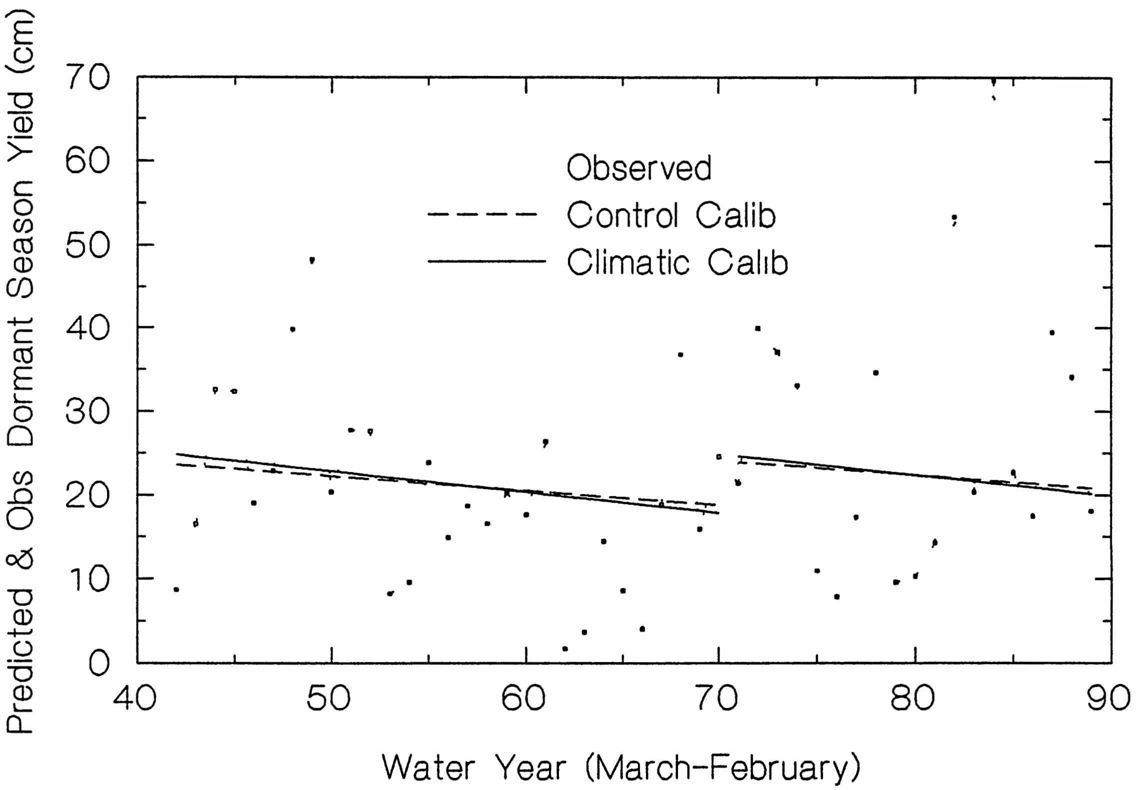

Figure 22. Dormant season yield v. time for the control and single watershed models (Equation 11 & 14) using average values (1942-1989) for the climatic and control watershed variables. Observed yields for reference.

The fall and winter components of dormant season yield also were regressed against control watershed and climatic variables.

$$Q_F = .226 + .767*QC_{10} + .94*QC_{11} + .295PD_{10} + .314PD_{11} \quad (15)$$

$$R^2 = .865 \quad S = 1.675 \text{ cm}$$

$$Q_F = -7.708 + .599*PE_{10} + .64*PE_{11} + .165*P2 \quad (16)$$

$$R^2 = .848 \quad S = 1.757 \text{ cm}$$

$$Q_W = 1.103 + .829*QC_{12} + 1.064*QC_1 + .958*QC_2 + .454*PD_{12} + .862*PD_1 + .718*PD_2 \qquad (17)$$

$R^2 = .934$   $S = 2.633$ cm
note: 1982 data not used in analysis

$$Q_W = -13.398 + .893*P_{12} + .941*P_1 + .716*P_2 + .322*P2 \qquad (18)$$

$R^2 = .924$   $S = 3.004$ cm

The analysis did not show a significant water yield response to forest harvest. However, time was significant or marginally significant ($0.05<p<0.10$) in the climatic calibration models for fall and winter yields, and in the winter yield model using control watershed variables. The p-values for the two time-related variables (TIME and T) ranged between 0.019 and 0.084 and their coefficients were of the same order of magnitude.

Finally, the fall and winter yield models, while similar to the spring and summer models, are different with respect to the form of the antecedent precipitation variable. The API30 index was the most effective in the regressions on spring and summer yields. For the fall and winter regression functions the most effective variable was the accumulated precipitation for the two months prior to the season. The reason for the different API terms may be related to the hydrologic response of the South Fourche watershed (Table XIII, p.110). On average, hydrologic response is high at the start of spring and summer seasons. Under spring conditions, the API30 variable best describes the antecedent soil moisture conditions that affect streamflow. In contrast, in the months preceding fall and winter the hydrologic response of the watershed is usually very low as rainfall does not always generate streamflow, but does replenish the soil water reservoir. Under these conditions, accumulated rainfall over a longer period is a better measure than API30 of the "wetness" of the watershed at the start of the season.

## Analyses Which Did Not Improve the Yield Models

1. Omitted from the data set those years in which the South Fourche LaFave River was dry (zero flow at the USGS gage) for more than 60 days for the annual yield analysis, and for more than 30 days for the dormant season analysis. Those years deleted for annual regressions were 1943, 1947, 1953, 1954, 1956, 1963, 1964, and 1980, and for the dormant season regressions 1947, 1953, and 1963. This did not alter or improve previous results.

2. Omitted from the data set those years in which greater than 40 percent of the annual water yield occurred in any one month during that year (Eight years).

3. An October-to-September water year was used to prevent splitting the hydrologically wet period between December and May into different years. The same independent variables were used as in the original analysis. This did not alter or improve previous results.

4. The start of the March-February water year was changed from March 1 to a variable date to account for the

occasional heavy rainstorm beginning near the end of February and continuing into March. For water years 1944, 1945, 1948, 1961, and 1962 the rainfall and yield calculations were begun on the day the storm began, before streamflow rose in reaction to the storm. This did not improve the regressions on annual or seasonal yields.

5. Monthly precipitation variables were used in the dormant season analysis to determine if separating the season into smaller periods would produce a yield model in which time was not significantly related to yield. The results were virtually identical to the analysis using fall and winter rainfall terms.

6. The control watershed itself was climatically calibrated to determine if, like the South Fourche watershed, dormant season yields were similarly time-dependent. Time was not a significant factor ($p = .9$) in the prediction equation, which had an $R^2$ and standard error comparable to the South Fourche yield model.

7. Four effective precipitation variables were used in the analysis. These were the accumulated rainfall in excess of 0.5, 1.0, 1.5, and 2.0 centimeters per day. These daily deductions eliminate many small daily rains and result in precipitation indices that perhaps more nearly reflect streamflow-producing precipitation. The index with the 0.5 centimeter deduction was useful in modeling summer and fall, and growing and dormant season streamflows. The other indices did not predict water yields as well.

## Discussion

The South Fourche and control watersheds are unique in many ways. They are large basins that have long streamflow and precipitation records, and each has a network of rain gages dispersed about its area. The watersheds are highly forested, sparsely populated, and have remained so for the length of the study period. While much of the private forest lands were cleared in the early twenties, the watersheds remained largely undisturbed since then. In 1969 a portion (41.3 percent of the area) of the South Fourche watershed was transferred from Dierks to Weyerhaeuser ownership and came under intensive forest management, which included clearcutting and road building operations. The result of these unique factors is that regression analysis to predict annual and seasonal water yields has been very successful.

Using either the control or single watershed calibration methods, prediction models were developed that explained from 90 to 95 percent of the variability in water yield on the South Fourche watershed. The objective of these analyses was to determine the affect of the recent land management activities on yields. This discussion focuses on three parts of the analysis: the climatic and control watershed variables, the forest harvest variable, and the time trend of water yields.

## Climatic and Control Watershed Variables

The first observation is that the response of yield to the climatic and control watershed independent variables was the same for both the calibration and the postcalibration periods. This result was probably due to the long length of both periods, which allowed for a wide range of values for the parameters. If the periods had been shorter, the chances are greater that the range of values of the variables would have been narrower, increasing the likelihood that the coefficients of these variables in the prediction model would have been different for the two time periods. This also confirms an initial check of the precipitation data, which found that the mean and variance of seasonal and annual precipitation falling on both watersheds was the same for both time periods. These tests were performed according to Haan (1977).

A second observation concerning these variables is that their separation into spring, summer, fall, and winter components produced the best annual, growing season and dormant season yield models. The improvement of the models using seasonal variables was probably because these seasons were generally different from each other hydrologically. Differences in rainfall, streamflow, and hydrologic response distinguish these four seasons from one another (Table XIII, p.110). The prediction equations were evaluated for correlations between the seasonal variables that would have made the models appear better than they actually were. Correlation coefficients between variable pairs were low (less than 0.30), indicating that the variables acted separately to explain yield. Mustonen (1967) also found that seasonal climatic variables were useful for predicting the water yield in his study of several basins in Finland.

Thirdly, the analysis of seasonal water yields reveals that using summer and fall "effective" precipitation (PE) rather than total precipitation results in improved yield prediction models. "Effective" precipitation was used in the regressions of summer, fall, growing season, and dormant season yields. This term represents the accumulated rainfall after deducting 0.5 centimeters from each day's total rainfall. The initial motivation for developing the variable was that some rainfall is intercepted by the forest canopy and is unavailable for either infiltration or streamflow; thus, rainfall corrected for interception might be a better predictor of yield than gross precipitation. With respect to the actual intercepted volume, however, the deduction of a half centimeter from each daily rainfall may be excessive. While the interception rate at the start of a storm may be around 0.5 centimeters (Lawson, 1967), the rate would diminish as the forest canopy becomes saturated. In addition, a short storm starting soon before and ending soon after the daily measurement of rainfall would, under this formula, have two 0.5 centimeter deductions, one from the measurement the day of the storm and one from the next day's measurement, long after the storm had ended. There is no doubt about the utility of the variable, but rather than effective precipitation being a correction for interception losses, it may instead act to compensate for the state of the soil water reservoir: during the summer and fall the reservoir is depleted due to evapotranspiration demands, and much of the total precipitation during this time replenishes the soil water reservoir and is unavailable for streamflow. These general seasonal differences in the level of the soil water reservoir may explain the fourth observation concerning the climatically calibrated water yield models. Namely, that the spring and summer yield models used a different antecedent precipitation index (API) than did the fall and winter yield models.

The API used in the regression models for spring, summer, fall, and winter yields had two forms. The API30 formula, was used for the spring and summer models; the accumulated rainfall the previous two months, P2, was used in the fall and winter models. As discussed earlier, the applicability of the API may be related to the average hydrologic response of the watershed, which itself is an indicator of the level of the soil water reservoir. In general, the hydrologic response is high during the period directly preceding the start of spring (February) and summer (May). During these periods the watershed is very responsive to rainfall. Under these conditions, the API30 term, which weights the previous 30 days rainfall according to proximity to the start of the season, is the best variable of those examined (P1, P2, P3, API30, API60, and API90) which reflects the antecedent moisture conditions that affect streamflow. In contrast, in the months preceding fall and winter, the hydrologic response of the watershed is usually very low. Rainfall does not always generate streamflow, but instead replenishes the soil water reservoir. Under these conditions, the accumulated rainfall over a longer period is a better measure than API30 of the "wetness" of the watershed at the start of individual storms.

## Forest Harvest Variable

Except for the dormant season single watershed model, the forest harvest variable, CUT, was not significant in any yield prediction model; and, for reasons given previously, it is doubtful that CUT should be included in even the dormant season model. The variable suffers from several inaccuracies. Firstly, it does not take into account road construction. More than 460 kilometers of gravel logging access roads were constructed on the watershed by Weyerhaeuser and the U.S. Forest Service since 1970. This may not be too critical, since road construction is often concomitant with forest harvesting. Secondly, the variable only reflects the first year impact of forest cutting. It does not reflect the cumulative impact that sustained forest management would have on water yields after the "first year". Thirdly, the forest harvest variable was based on plantation age, which is based on the birth year of the planted seedlings rather than the actual harvest period. In addition, the actual harvest period could have extended between water years, and between seasons within a water year. Thus, the true harvest period may not always be represented accurately by CUT, a variable based on plantation age. This is why the three-year moving average of the harvest was used in the analysis. Even so constructed, however, the term was not effective in explaining the variability of yield during the postcalibration period. The forest harvest in any one year was just too small (less than four percent of the watershed area) to impact water yields significantly. Instead, time was used as a "cultural" variable to determine if the change in forest management practices had caused a time trend or a change in a time trend of water yields.

## Time Trend of Water Yields

Regression analysis of the relation of water yields to time revealed two things: (1) dormant season and annual yields declined over time at a constant rate for the entire study period (calibration and postcalibration periods); and (2) the dormant season and annual yield response functions "jumped" seven and ten centimeters, respectively, for the postcalibration period.

Both the control and single watershed calibration methods showed that dormant season yields declined with time at the same rate for both periods, and that the response function jumped five to seven centimeters, respectively, for the postcalibration period (Equations 11 and 14). The annual yield model using the single watershed method showed a similar response, with a jump in the relationship of almost ten centimeters during the latter period (Equation 3). However, the control watershed method did not show a change in annual yield response between periods, even though it had showed a statistically significant five centimeter increase in dormant season yield response. This was probably due to the incomplete form of the annual yield model (Equation 1). The model contained only three of the four variables used to express the difference in annual precipitation between the two watersheds, $PD_S$, $PD_{SM}$, and $PD_F$, the difference in rainfall for the spring, summer, and fall seasons. But the fourth variable, $PD_W$, the winter variable, was not significant. Possibly, if the annual yield model had contained the full expression for the difference in precipitation between watersheds, the declining time trend (TIME variable) and the "jump" (indicator variable, T) in annual yield response may have been significant.

The two time trends in annual and dormant season water yields - the declining trend over time and the increase in the yield response during the postcalibration period - are believed to be caused by two different land use activities. The declining trend in yields may be the result of cutting of much of the virgin forest in the early twenties by the Fort Smith Lumber Company and others, and by selection cutting between 1950 and 1960 by the Dierks Lumber and Coal Company. Dierks' "salvage and sanitation" cut in the fifties took many of the individual dead, dying and older growth trees, and their "age and vigor" cuts in the sixties opened the stands even further. The declining time trend in yields may be a reflection of the demand for water as the forest recovered in the areas cleared in the twenties and as it flourished in the areas opened by the Dierks' operations. An even liklier scenario is that the advent of fire suppression practices in the Ouachitas in the 1930's, by both the Forest Service and by Dierks, resulted in the gradual transition of the virgin forest from pine overstory with a sparce understory, to a forest with a growing hardwood midstory and understory. The continuing declining time trend in yield response in the most recent decades may also have been the result of plantation management techniques, which strive to obtain greater quantities of wood product than the unmanaged virgin forest would have produced. Although these points are speculative, they are factors that must be considered when trying to explain the probable reasons why South Fourche water yield response has declined over time (i.e. significant TIME variable with negative coefficient in the annual and dormant season water yield models).

This type of declining time trend in water yields with forest regeneration was observed on larger watersheds by Eschner (1963) and Schneider and Ayer (1960), and was documented on smaller watersheds after clearcutting by Kovner (1956) and Swift and Swank (1981). Unlike most of these studies, however, the time trend found in this analysis was not logarithmic. Water yield did not decline rapidly and then level off to a constant rate, as might happen when a young, vigorous forest matures. This may be because on the South Fourche watershed the forest was not cut all at one time, and then allowed to regrow without disturbance. Instead, portions of the watershed were cut at several times during the century, first the removal of much of the virgin forest in the twenties, then the selection cuts by Dierks in the fifties, then the intensive forest silvicultural practices by Weyerhaeuser since 1970.

The change in forest management since the sale of the Dierks land to Weyerhaeuser in September, 1969 is the basis for the second time-related change in water yields - the jump in the yield response function for the annual and dormant season (significant indicator variable, T). For the nineteen year period between 1971 and 1989 inclusive, dormant season yield response was five to seven centimeters higher than would have been expected (given the same climatic conditions) for the calibration period, and annual yield response was ten centimeters higher. The dormant season increase appears to result primarily from changes in the winter yield response, because both the climatic and control watershed winter yield models revealed marginally significant increases in the winter yield response function, while there was no change in the fall water yield response. The conclusion that dormant season yields have increased in the postcalibration period is strengthened by the fact that both calibration methods resulted in similar increases (5 cm-Equation 11, and 7 cm-Equation 14), and by the fact that for the average values of the independent variables, the two calibration methods produced remarkably similar plots of predicted yield over time (Figure 22).

An argument can be made that, rather than being a real jump in the yield response caused by cultural changes in land use on the watershed, that the jump represents a cyclical phenomena caused by factors not accounted for in either the climatic or control watershed calibration models. Similarly, one can contend that separating the independent variables into spring, summer, fall, and winter components may not account for the year-to-year differences in the distribution of rainfall through the water year; and that changes in the monthly distribution of annual rainfall over a long period may indeed cause such cyclical patterns in yields. Several responses can be made to put this speculation in perspective:

(1) The control watershed method minimizes the influence

of other climatic factors not in the model. If we assume that the general climate on both of these large watersheds was similar, then the control watershed models would be one way to reduce the influence of factors related to evapotranspiration and soil moisture storage. The dormant season model using control watershed variables (Equation 11) shows that a significant increase in yield response of five centimeters occurred in the postcalibration period.

(2) Monthly (rather than fall and winter) variables were used to develop dormant season yield models based on both the control and single watershed methods. This was done to determine if the yield response was related to changes in the distribution of annual rainfall not adequately expressed by the seasonal variables. The results were the same as those in the initial analysis.

(3) During the 48-year study period, there were years which were very dry hydrologically and years when a large part of the annual yield occurred during a very short period of time. The annual and dormant season yield analyses were recalculated, once omitting from the data base those years when more than 60 days of zero flow occurred in a year, and again omitting those years when greater than 40 percent of the annual yield occurred in any month. Neither approach changed the basic relationship between yield and time.

The annual yield response of the South Fourche watershed to harvest activities compares well with the results of partial and complete clearcutting experiments, though the forest management practiced by Weyerhaeuser can not be directly compared to the treatments in small watershed research. In this study the annual yield increased by ten centimeters during the postcalibration period. The plantation age data reveals that, while the annual cut was never greater than four percent of the total basin area, the area of the basin under ten years of age has risen rapidly between 1970 and 1980, leveling off at about 20 percent thereafter (Figure 23).

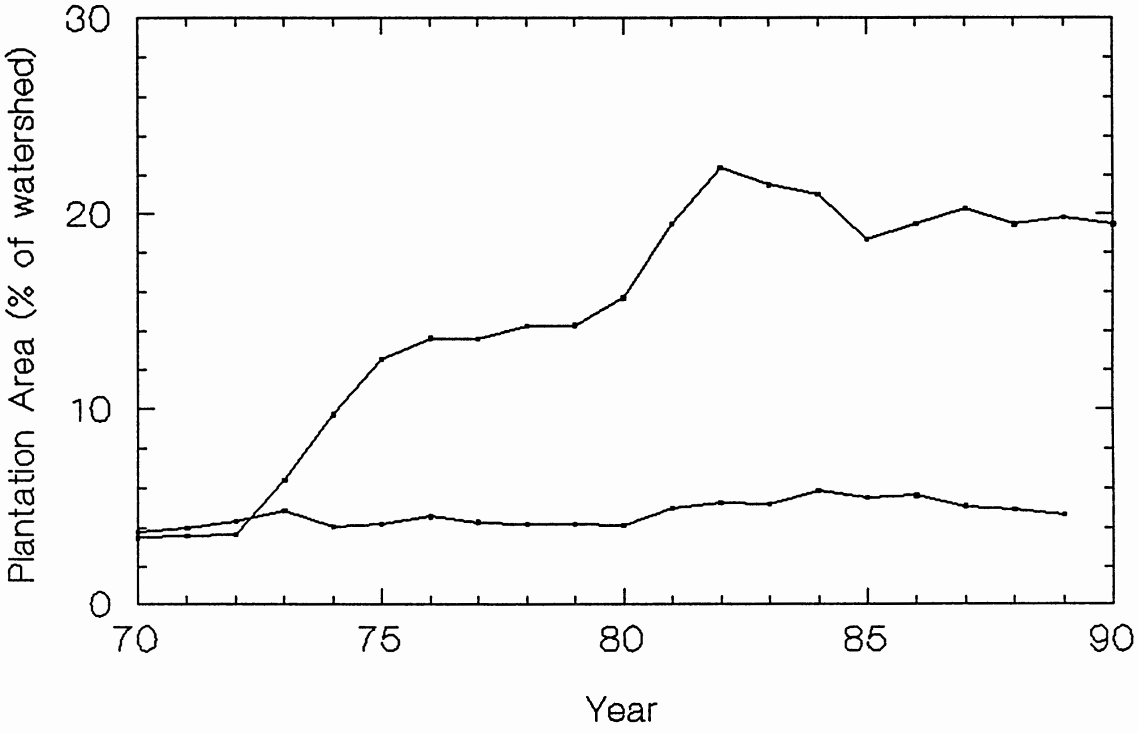

Figure 23. Area of plantations age 0-10 years for the period 1970-1989. Upper curve shows South Fourche watershed plantation area. Lower curve shows same for control watershed.

Much of the small watershed research in the southeast has shown a 25 to 40 centimeter increase in annual yield the first year after 100 percent clearcutting (Swank and Miner, 1968; Swift and Swank, 1981; Swank et al., 1982; Patric and Reinhart, 1971). In Arkansas clearcutting small watersheds has produced first year yield increases of 26 centimeters (Rogerson, 1985). Partial cuttings have demonstrated that first year increases are proportional to the portion of the watershed cleared (Hewlett and Hibbert, 1961; Reinhart et al., 1963; Rogerson, 1985). This research, however, is often conditioned on the fact that such one-time measurements are also influenced by the magnitude of the annual rainfall during that first year (Bosch and Hewlett, 1982; Patric, 1973; Hornbeck et al., 1970; Rothacher, 1970; Swift and Swank, 1981). Finally, Bosch and Hewlett (1982), in their synopsis of 94 worldwide catchement experiments, separate the body of research into conifer, hardwood and scrub-type vegetation classes. For conifers they propose that annual yield changes by 4 centimeters (cm) for every 10 percent change in cover area, and by 2.5 and 1.0 cm per 10 percent change in hardwood and scrub cover, respectively.

We cannot directly compare the gradual change in land use on the South Fourche watershed to small watershed research in which a catchement is cleared one year and first-year water yield increases are measured the next year. However, an indirect comparison may be made. In

this study, there was found to be a ten centimeter increase in the annual yield response function between the calibration and the postcalibration periods. In addition, during the latter period approximately 20 percent of the watershed land area was converted from unmanaged, uneven-aged forest to pine plantation ten years of age or less. The body of small watershed research shows that changes in yield are proportional to the change in vegetation coverage, and that yields increase about four centimeters for every 10 percent decrease in conifer cover area (Bosch and Hewlett, 1982). To compare this to the South Fourche watershed study, the magnitude of the change in annual water yield response from the South Fourche was about one-fourth of the mean first year increase found in the small watershed experiments, and, correspondingly, approximately one-fifth of the watershed was converted from an unmanaged, primarily pine forest to young (0-10 years old) pine plantations.

There have been several studies on the impact of vegetative changes on the hydrology of very large watersheds. Very few, however, have addressed the impact on water yields caused by a gradual change in watershed vegetation over many years. To end this discussion and to put the present analysis into perspective, these studies are briefly described.

Eschner and Satterlund (1966) documented the change in water yields during a 39-year period of forest recovery, and the impact of a sudden storm that disrupted forest stand development. The 1272 $km^2$ Sacandaga River watershed is located in the Adirondack Mountains of New York. Multiple regression was used to relate annual yield to annual precipitation, total precipitation for the month preceding the water year, to represent antecedent moisture conditions, and the average April temperature, to reflect the energy available for snowmelt. The addition of a time variable (ln T, the natural logarithm of years since start of the forest recovery) accounted for a statistically significant portion of the total variance in annual yield. The model explained 78 percent of the variation in annual flow. Using the average values for the climatic variables during the recovery period (1912-1950), and T = 1 and 39, the calculated annual yield decrease for the 39-year period was 19.6 centimeters. Further analysis showed that 67 percent of the annual reduction occurred during the dormant season. After the devastating storm of 1950, it was believed that the yield relationship had changed due to destruction of forest integrity. A hypothesis was tested that there was no change in the relationship between yield, rainfall, and temperature. The post-storm rainfall and temperature data were used in the pre-storm regression functions. A t-test was used to evaluate the difference between the actual mean yield and the estimated mean yield. For both the annual and dormant season models the conclusion was that the yield relationship was different for the two periods.

Schneider and Ayer (1961) studied the hydrologic effect of forest recovery on a 808 hectare New York watershed. Fifty-eight percent of the area was abandoned farmland and had been reforested with pine and spruce. Both the single watershed and control watershed methods were used to evaluate the long term hydrologic impact of these efforts. An optimum water year, beginning May 1, was found by regressing yield against precipitation. A time trend was observed for dormant season yields in which yield was related to precipitation and to the product of precipitation and time, expressed as years since the first year of record. Between 1934 and 1957, the total reduction in dormant season yield for the watershed (based on the mean precipitation for the period) was 13 centimeters. This was the equivalent of a 25.8 centimeter increase when just the reforested area was considered. Using the control watershed approach, the time variable was again significant. The new prediction equation resulted in a decrease in yield nearly identical to the change shown by the climatically calibrated model. The large dormant season response was attributed to the increased interception of rainfall by the conifers in the reforested area.

Dons (1986) studied the hydrologic effect of 18 years of planting pine on 28 percent of the Tarawera River watershed (906 km$^2$) in New Zealand. Annual yield was regressed against current and antecedent annual precipitation, and against the amount of area reforested annually. The addition of the latter variable significantly improved the model. The full model explained 82 percent of the variation in annual yield. Using a 948 $km^2$ undisturbed watershed nearby as a control watershed, Dons also developed an annual yield model using on the control watershed method. The addition of the reforested area variable significantly improved the model, which then explained 89 percent of the variation in yield. For the control watershed analysis, the annual yield reduction attributed to reforestation was 15.7 centimeters, 13 percent of the average yield for the period of the study. The 15.7 centimeter decrease represented a 55.9 centimeter reduction in yield when only the area reforested was considered.

Sullivan et al. (1987) studied the changes in streamflow brought on by the annual timber harvest in the Cascade Range of western Washington. Clearcut logging on the Deschutes River basin (232 $km^2$) was continuous since 1950, with cutover areas regenerated with Douglas fir. Fifty-five percent of the watershed area had been harvested since 1950, and 44 percent of the area was plantations under 15 years of age. Regression analysis of dormant and growing season yields against time revealed no significant change with time. However, a visible though non-significant increasing trend in growing season yields contrasted with the yields from an unlogged area, which declined over time. The Deschutes River flow increased 4 centimeters between 1976 and 1986 according to the regression equation. Most of this appeared to occur in the spring and was attributed to either a change in the distribution of snow in the cutover areas or to savings of evapotranspiration losses on cleared areas.

While different aspects of these field investigations are common to the present analysis of South Fourche water yields, the long 29-year calibration period followed by the 19-year period of increased forest harvest and road building, and the good streamflow and precipitation records for both watersheds make this study unique and adds to the body of research in this field.

# CHAPTER VII

# ANNUAL SERIES OF PEAK FLOWS: ANALYSIS RESULTS AND DISCUSSION

## Adjustments to Peak Flows

Notice must be made here of the impact of the two floodwater retarding structures (FRSs) built on the South Fourche watershed as part of a flood prevention program sponsored by the US Soil Conservation Service (SCS). The largest structure, built in March 1977, receives runoff from 8866 hectares (ha). The smaller dam was constructed in December 1980 and receives runoff from 1997 hectares. These FRSs effectively remove those parts of the watershed from contributing to the instantaneous storm peaks. It is necessary therefore to adjust the affected peaks in order to make appropriate comparisons to previous peak flow events or to peak flows on the control watershed.

One corrective action would be to offset the peaks in proportion to the area of the watershed controlled by the FRSs. This would mean augmenting the peak flows for the 1978-80 water years by 16.3 percent (8866 ha/54510 ha total area) and those after 1980 by 19.9 percent (10863 ha/54510 ha). In this study a more conservative approach was taken. In Oklahoma, the prediction formula for peak flow events of various return periods is given by the equation:

$$Qx_{(R)} = a * A^{b} * P^{c}$$

where $Qx_{(R)}$ = the peak flow with return period R
A = drainage area in square miles
P = storm precipitation
b = 0.57

We are interested in the ratio between the peak flow from the watershed when no dams are present (Qx (watershed)), and the peak flow from the watershed drainage area not affected by the dams, which is actually the measured peak flow (Qx (measured)). The ratio may be written:

$$\frac{Qx\ (\text{watershed})}{Qx\ (\text{measured})} = [A\ (\text{watershed})/A\ (\text{measured})]^{.57}$$

This ratio was 1.111 for the three years when only the first FRS was operating, and was 1.136 thereafter. Thus, the annual peak flows for these years were increased by 11.1 and 13.6 percent, respectively. The measured and adjusted peak flows are listed in Appendix C.

## Plot of Raw Data

Figure 24 is the plot versus time for the annual series of maximum instantaneous peak flows from both the study and control watersheds.

## Regression Analysis

The control watershed method was used to develop a prediction model for the annual peak flows from the South

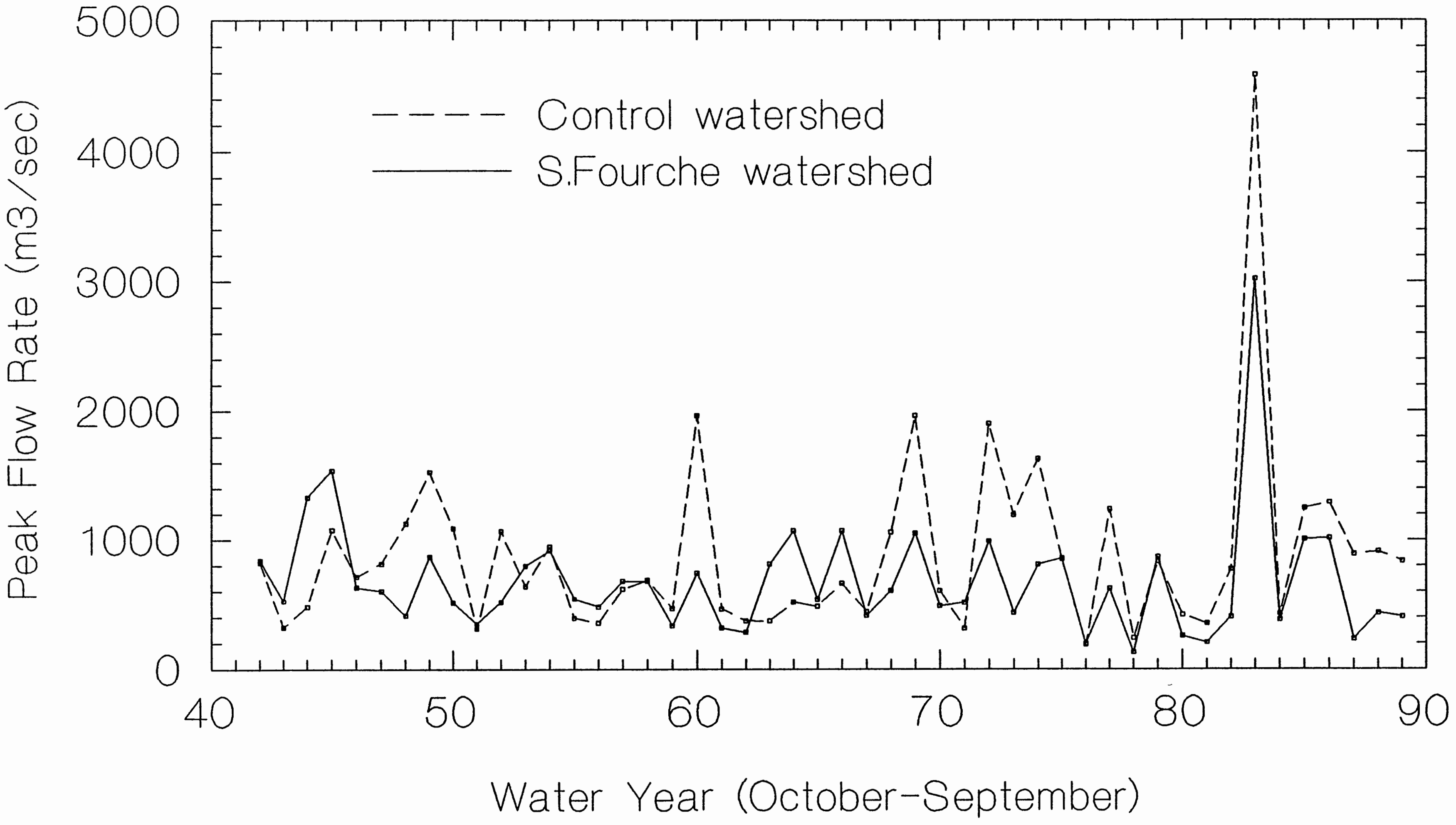

Figure 24. Plot versus time for the annual series of maximum instantaneous peak flows from the study and control watersheds.

Fourche watershed. The single watershed method was not used as no data had been compiled concerning rainfall intensity, which has been found to influence peak flows (Hewlett and Helvey, 1970). Fortunately, the yield analyses demonstrated that the control watershed approach produced models comparable to the single watershed method. Peak flow prediction equations were developed using the annual peak flow dates common to both watersheds (peak flow dates within one day of one another were accepted). The period of study (1942-1990) contained 24 common peak events from 49 possible observations, 15 for the calibration period and 9 for the postcalibration period. The peak flow event for the 1983 water year was not used as it had large leverage on the calculations. This 3024 $m^3/s$ event, occurring on December 2, 1982, was nearly twice as large as the next highest annual peak during the study period. The regression analysis showed that forest harvest was not significantly related to peak flows, however, a time trend in peak flows was found. An example of the full regression model to test for a change in peaks with time may be written

$$Qp_t = b_0 + b_1T + (b_2 + b_3T)Qp_c + (b_4 + b_5T)DP + b_6TIME + b_7T*(TIME-26206)$$

where $Qp_t$, $Qp_c$ are the peaks from the study (t) and control (c) watersheds
DP=difference in peak rainfall between the watersheds (study minus control)
T=0 for calibration period
T=1 for postcalibration period
TIME is in units of days where TIME=1 for January 1, 1900 and TIME=26206 for September 30, 1971.

The control watershed variables are used to remove the variation in peaks attributable to climatic factors. The remaining variation can be examined for temporal trends. The "TIME" variable tests for a time trend in peak flows during the calibration period, "T" tests for a step-change in the response function between the two time periods, and "(TIME-26206)" tests for a change in the slope of the time trend during the postcalibration period.

The analysis resulted in the annual peak flow prediction models given in Equations 19 and 20.

$$Qp_t = 324.74 + .442*Qp_c + 51.89*DP \tag{19}$$

$R^2 = .635$ $S = 198.8\ m^3/s$ $D = 2.174$ note: 1982 data not included; $N = 24$

$$Qp_t = 862.91 + .447*Qp_c + 51.76*DP - .023*TIME \tag{20}$$

$R^2 = .756$ $S = 166.7\ m^3/s$ $D = 2.409$
note: 1982 data not included; $N = 24$

These equations show that, like the annual and dormant season yield models, annual peak flows exhibit a declining time trend over the study period relative to the control watershed. In addition, the relationship between peak flow and the control watershed variables was the same for both time periods. However, unlike the yield models, the peak flow models do not indicate a change in peak flow response between the two periods. The temporal change in peak flows can be illustrated using the average values for the control watershed variables in Equation 20 ($Qp_c(ave)=910.52\ m^3/sec$, $DP(ave)= -1.277$ cm) and plotting peak flow as a function of time, where TIME equals 15250 at the start of the study period (October 1, 1942), and 33146 at the end of the study period (September 30, 1990) (Figure 25).

The plot shows that, for conditions of average rainfall and average peak flow on the control watershed, that the peak flows on the South Fourche watershed have declined by 412 $m^3$/sec for the 49 year study period. This represents a decline of 48 percent from the "average peak flow" of 853 $m^3$/sec at the start of the study period. This

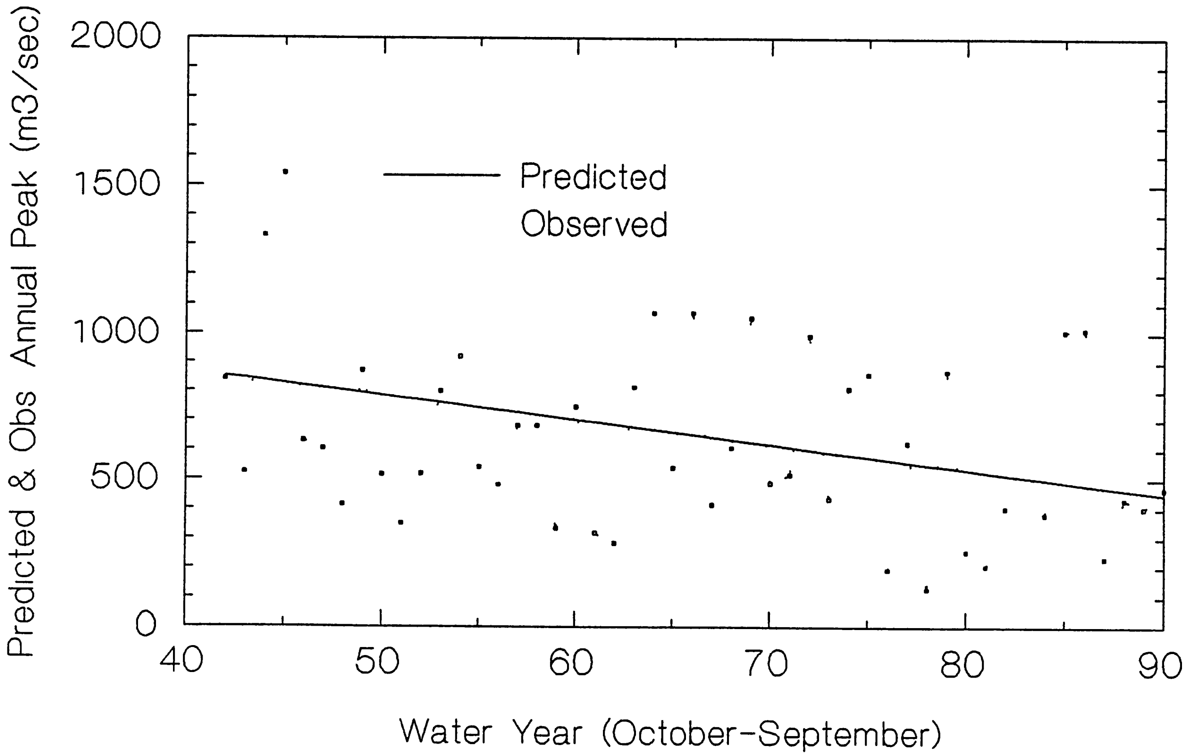

Figure 25. Annual peaks v. time for the control watershed model (Equation 20) using the average values (1942-1990) for the control watershed variables. Observed annual peaks for reference (1982 peak not shown: 3024 $m^3$/sec).

means that the annual peak flows on the South Fourche watershed, relative to those on the control watershed, have declined steadily over the past 49 years. Unfortunately, conclusions from this analysis are weakened by the fact that the regression function in equation 20 explains only 76 percent of the variation in peak flows (Equation 20) and is based only on 24 observations. At least one reason for this low $R^2$ is that the variable which represents the difference in rainfall between the watersheds, DP, is based on single daily rainfall readings that were not adjusted to account for the exact time of the storm.

## Frequency Analysis

The Weibull plotting positions for the South Fourche annual peak flows during the calibration period best fit the Log Pearson Type III distribution (Figure 26). The other distributions fitted to this data were the Lognormal and Extreme Value Type I distributions. The Log Pearson curve fit the data better than the others at the higher return intervals (low exceedance probability), which are the flows of greatest interest. The frequency distribution of calibration period peaks is shown with the fitted Log Pearson III distribution and 95-percent confidence limits, which were calculated according to the USGS Bulletin #17B (Figure 27a, page 159). The y-axis (natural log) is the peak flow in cubic meters per second. The x-axis is the exceedance probability. The plot can be read: The peak flow corresponding to any given "x"-percent exceedance probability and "y" discharge will have a "x"-percent chance of being exceeded in any given year.

To compare the peak flows for the two time periods, the postcalibration period data was superimposed on the fitted distribution for the calibration period (Figure 27b).

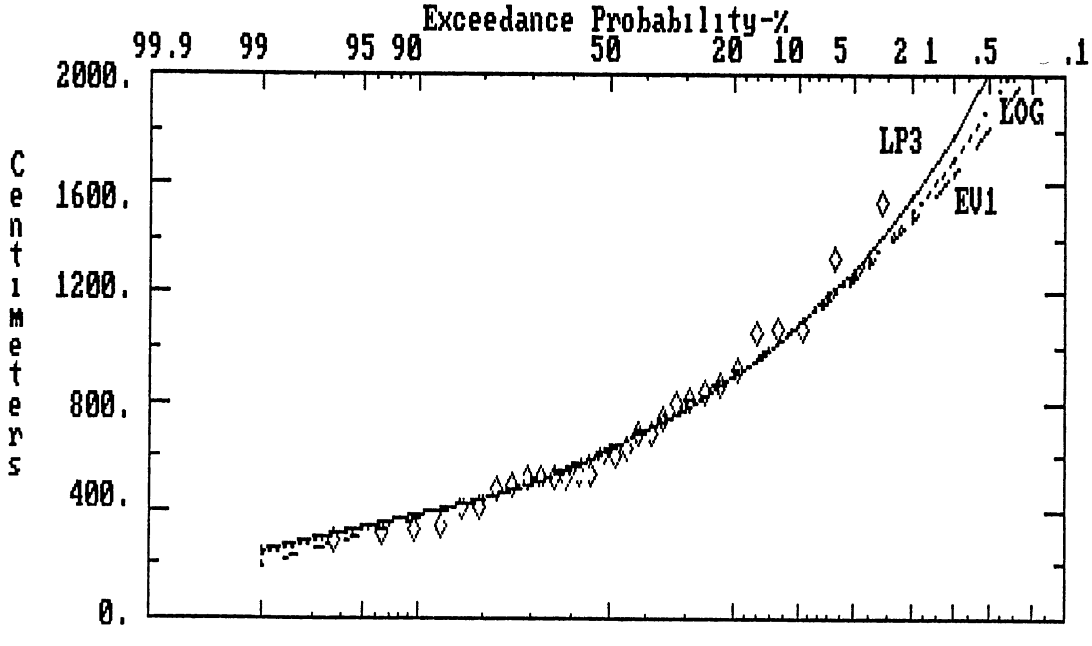

Figure 26. Comparison of three distributions (Log Pearson III, Lognormal, and Extreme Value I) fitted to calibration period annual peak flows for the South Fourche watershed, (1942-1971).

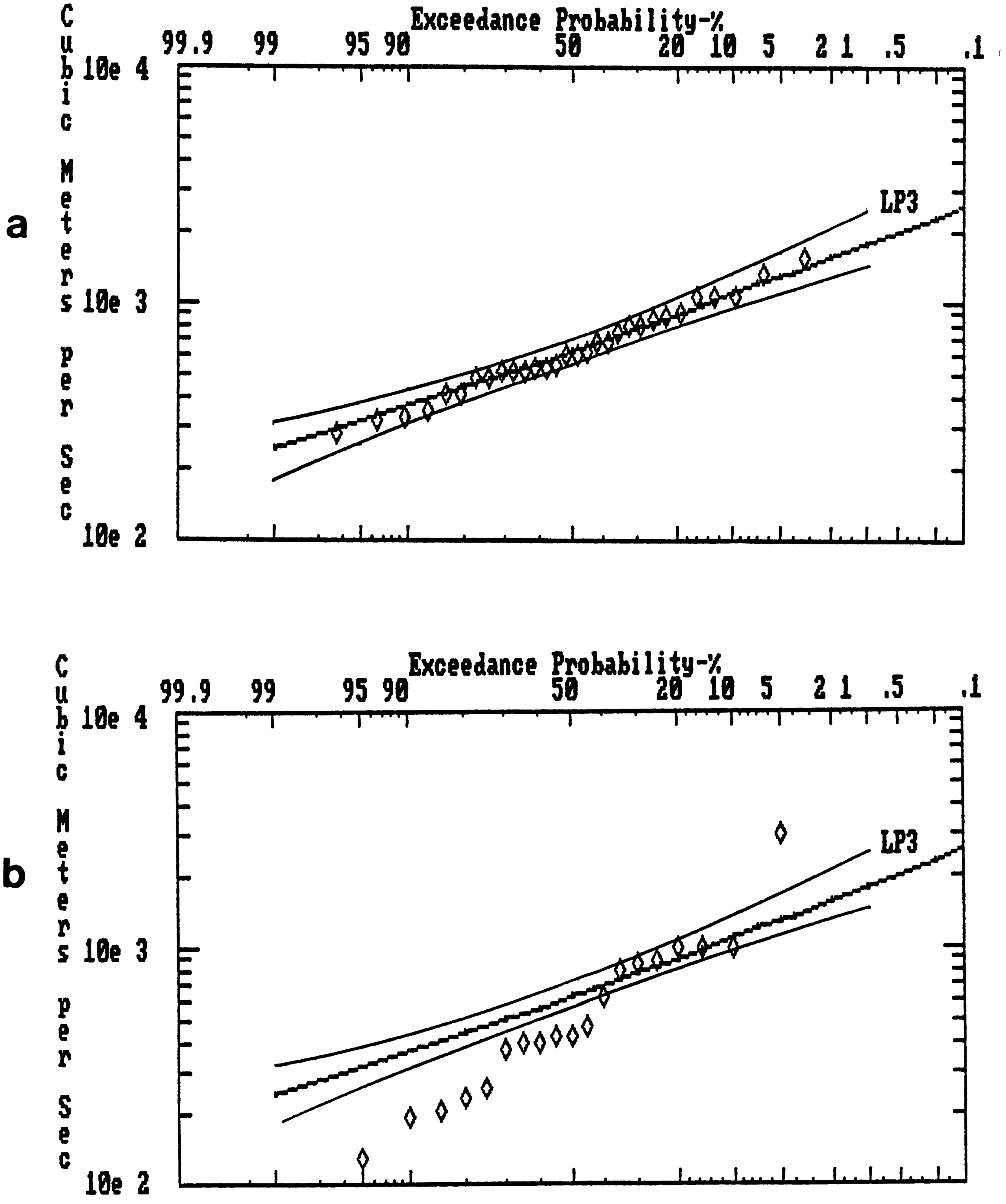

Figure 27. South Fourche watershed annual peak flow frequency plots: a) Log Pearson III plot of calibration period flows with 95 percent confidence curves; b) frequency distribution of postcalibration period peaks compared to the fitted distribution for the calibration period.

Several of the postcalibration period peaks fall below the lower confidence limit curve, whereas the peak flow from the December 1982 event is the only point greater than the higher confidence curve. The 1982 peak (3024 $m^3$/sec) was nearly twice as high as the next largest annual peak (1540 $m^3$/sec in 1945). For further comparison, plots were developed of the frequency distribution of annual peaks from the control watershed for the two time periods (Figure 28), and of the frequency distribution of the two-day rainfall corresponding to the peak flows from the South Fourche (Figure 29). For the postcalibration period, both the peak-producing rainfall and the control watershed annual peak flow frequency plots exhibit the same form as the South Fourche annual peak flow plots.

## Discussion

Three main points of discussion emerged from the regression analysis of annual peaks. First, the regression function (Equation 20) only accounted for 75 percent of the variation in annual peak flows. In comparison, the yield models explained as much as 96 percent of the variation in yields. Second, the results parallel those for the annual and dormant season yields in that the prediction equation showed that annual peak flows have declined over time relative to the those from the control watershed. Third, unlike the yield analysis, the peak flow regression analysis did not show a change in the peak flow response

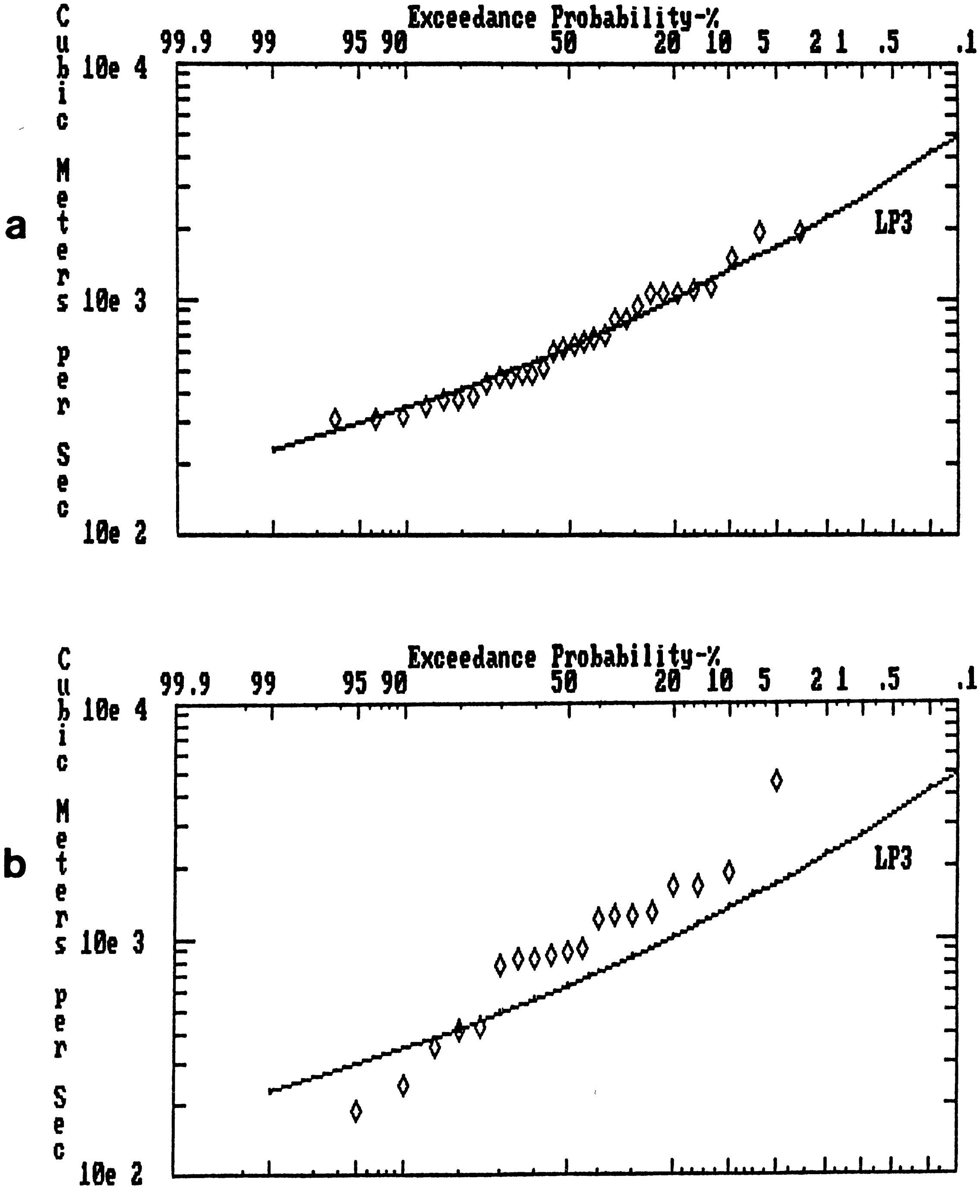

Figure 28. Control watershed annual peak flow frequency plots: a) Log Pearson III plot of calibration period flows with 95 percent confidence curves; b) frequency distribution of postcalibration period peaks compared to the fitted distribution for the calibration period.

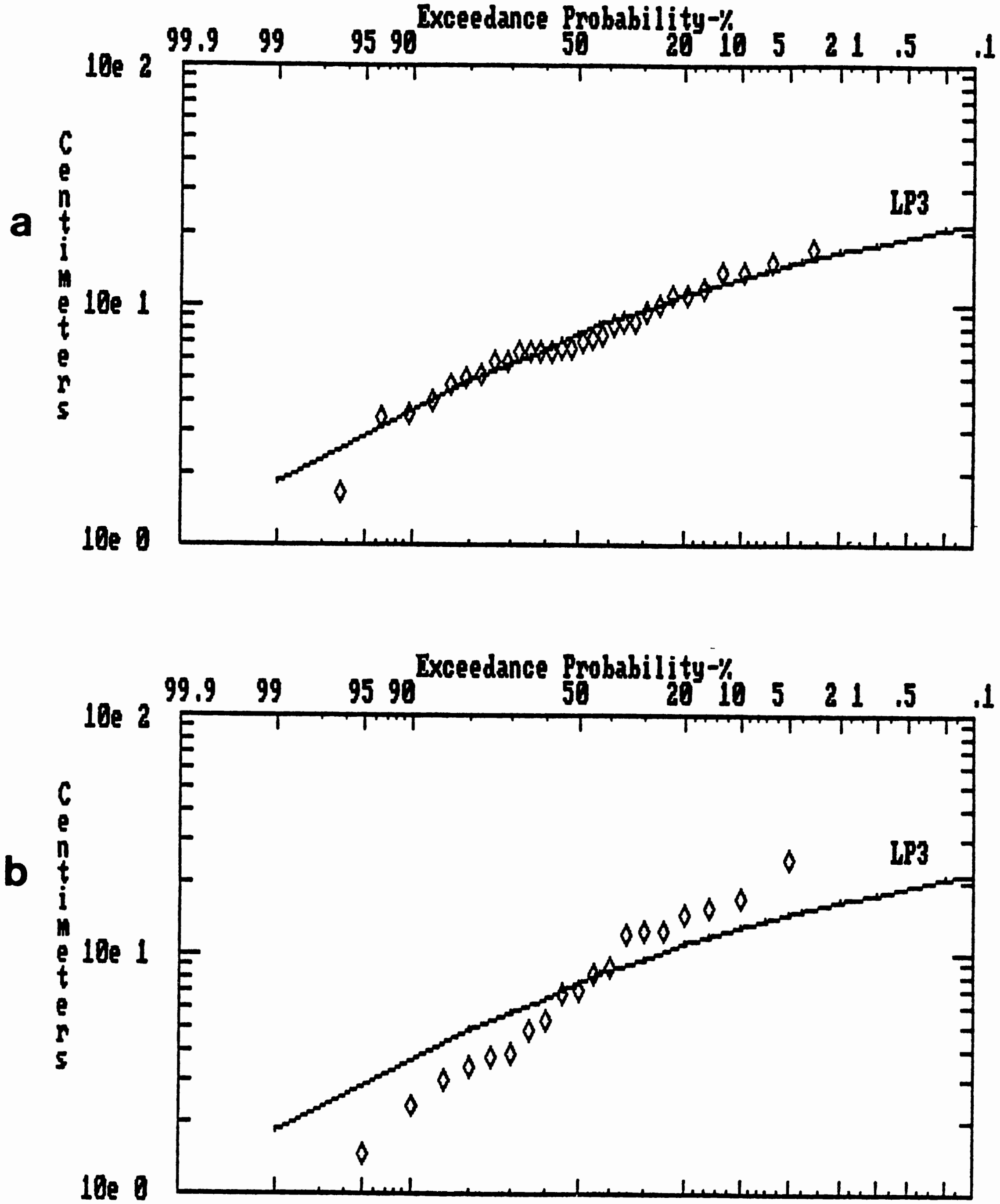

Figure 29. South Fourche annual peak-producing rainfalls: a) Log Pearson III plot of calibration period rainfalls; b) frequency distribution of postcalibration period rainfalls compared to the fitted distribution for the calibration period.

function between the calibration and the postcalibration periods.

The relatively high amount of unexplained variation in peak flows has several possible sources. One major source may be an inadequate expression for the peak-producing storm rainfall. The rain gage data used to construct the Theissen-weighted area rainfall was based on single daily measurements and was not adjusted to account for the time of the peak. The storm rainfall was defined as the rainfall on the day of the peak and the previous day. So, if a peak occurred at 1:00 am on January 3, and rainfall for January 3 was measured at 7:00 am on January 3, then the rainfall variable would include six hours of rainfall after the peak had occurred. In addition, the rainfall at the Alum Fork gage, which represented between three and twelve percent of the total rainfall in the Theissen calculations, was measured at 5:00 pm, while all the other gages on both watersheds were read at either 7:00 am or 8:00 am. These timing problems had no influence on the yield analysis, which dealt with precipitation accumulated over several months, and therefore tended to minimize the effect of discrepancies in daily rainfall measurements. The peak flow analysis, however, relied on rainfall measurements over a period of days rather than months, and thus may have been greatly affected by the timing of the daily rain gage readings. Another source of the low $R^2$ may have been that, because they are individual events which can occur any time during a year, annual peaks necessarily develop under a variety of climatic and watershed moisture conditions. The result may be that, though the control watershed approach is meant to address this problem, the wide range of conditions under which the peak can occur and the large geographic separation between the two watersheds contributed to the low $R^2$. Annual peaks occurred in all months between October and July, inclusive.

The second issue raised by the regression analysis is that annual peak flows on the South Fourche watershed, relative to those on the control watershed, declined over time during the study period. As in the time trend of water yields, this may be caused by the re-establishment and regrowth of the forest lands after logging in the early 1920's and in the 1950's. Another factor that may be at work here is that the general character of the stream channel may be changing over time. Channel storage may be increasing due to a natural widening of the stream channel. Finally, the time trend may not be real. The model without the TIME variable explains only 63 percent of the variability of peak flows (Equation 19). It is possible that if other real, measurable, climatic or basin characteristic factors were included in the model that the $R^2$ would increase considerably. If this happened, the variable TIME, more or less a term that encompasses the cumulative impact of all excluded but relevant variables, may become non-significant. This is especially a possibility when the original model has such a low predictive ability ($R^2$) as does Equation 19.

The third issue is that the analysis did not indicate that peak flows changed as a result of Weyerhaeuser forest management. There was neither a change in the slope of the time trend nor a jump in the response function for annual peak flows during the postcalibration period.

Even if we ignore the reasoning that not enough of the watershed was cut or compacted each year to significantly affect annual peaks, there remain several reasons why peak flows were not affected by the changes in forest management, and most of these are related to the large size of the watershed.

In a large watershed, all disturbed areas do not contribute equally to increasing peak flow and storm flow volume. The proximity of disturbed areas to streams is variable - some areas may be located outside of the variable source area that contributes to the stormflow peak. Flow from a disturbed area which can contribute to the peak may be interrupted by another feature of the land. Roads and ditches can direct overland flow and intercepted subsurface flow quickly into a stream. These factors change the timing of the flow elements that can produce the peak flow event. Therefore, depending on the outcome of the analysis, it can be debated that the disturbed areas caused changes in the timing of the flow elements such that peak flow was either augmented, reduced, or not significantly changed. For the circumstances of this study, four things were possible: Either the prediction model was not good enough to determine that a change in peak flows had occurred; or the forest harvest and road building activity was not enough to affect downstream peaks; or a change did occur but was masked by those factors causing the declining time trend in peak flows; or the effects on storm flow from the various clearcuts and roads were not additive to the extent that peak flows were changed.

The frequency analysis added to our understanding of this problem. Although the analysis showed that the distribution of South Fourche peak flows was different for the two periods, the same is true of the peak flows from the control watershed and for the rainfalls which generated the South Fourche peak flows (Figures 28 and 29). Much of the difference in the distributions was for low return period peaks, and was caused by five of nineteen annual peaks during the postcalibration period that were less than 283 $m^3$/sec (10000 cfs). No peaks were less than 283 $m^3$/sec during the 30-year calibration period. Because the differences in the distributions for the two periods occurred on both watersheds, the source of the differences may be related to climatic rather than land use changes.

# CHAPTER VIII

# HIGH FLOW PERIODS: ANALYSIS RESULTS AND DISCUSSION

## Plots of Raw Data

The following plots contain the raw data for the high flows for the study watershed. Figures 30 through 33 are the plots versus time for the average maximum consecutive-day flows for the 7-, 14-, 60-, and 90-day periods, respectively.

## Regression Analysis

The control watershed method was used to create a prediction model for the annual high flows from the South Fourche watershed. Prediction equations were developed using the high flow dates common to both watersheds. For the 7-, 14-, 60-, and 90-day high flow analyses, the database contained 29, 31, 35, and 36 of 48 possible observations, respectively.

The regression analysis showed that high flows were not significantly related to either forest harvest or time. As in the yield and peak flow analyses, the high flow analysis showed that the relationship between the control watershed variables and high flow was the same for both the

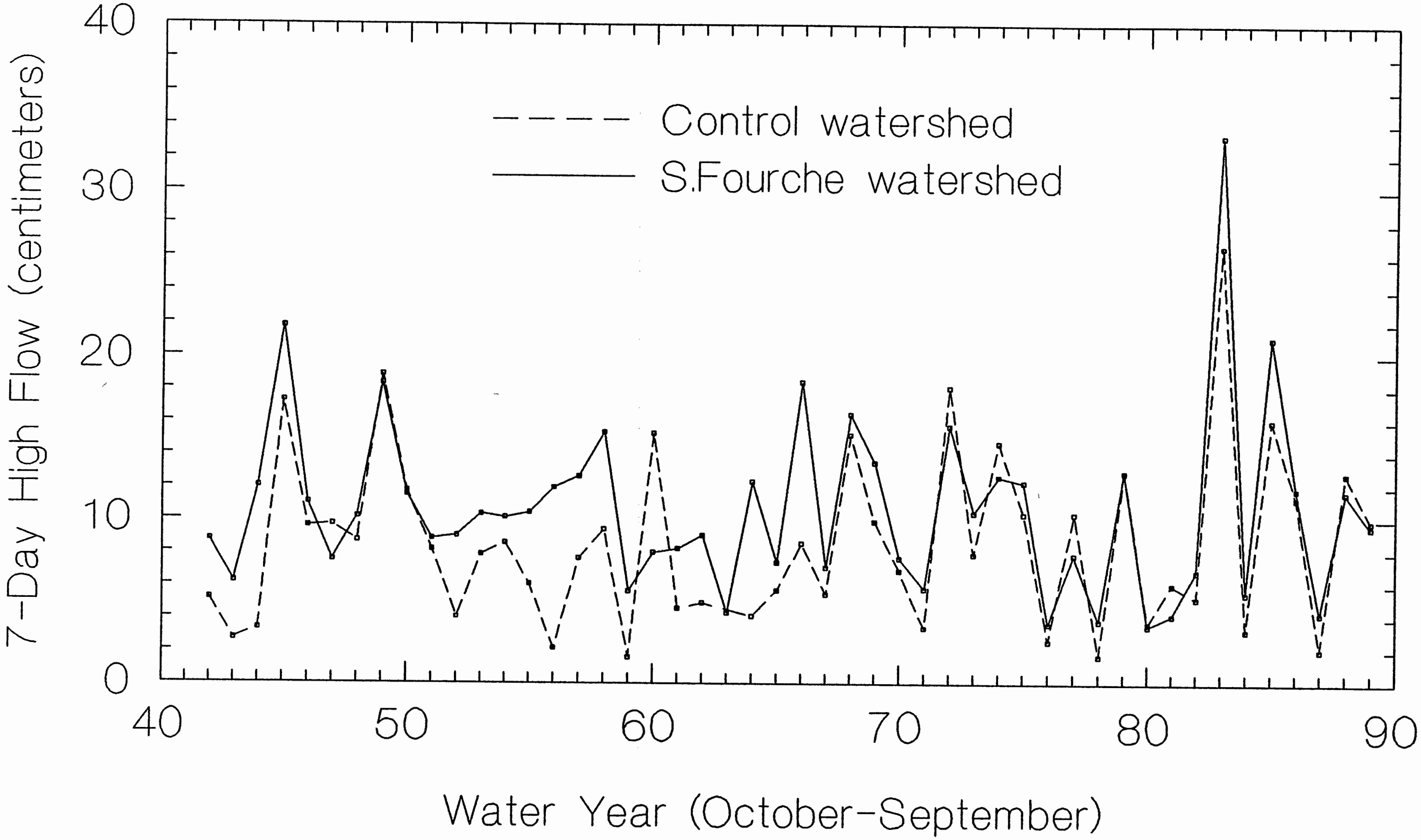

**Figure 30.** Plot versus time for the 7-day high flow volume from the study watershed. The flows from the control watershed for the corresponding 7-day period are also shown.

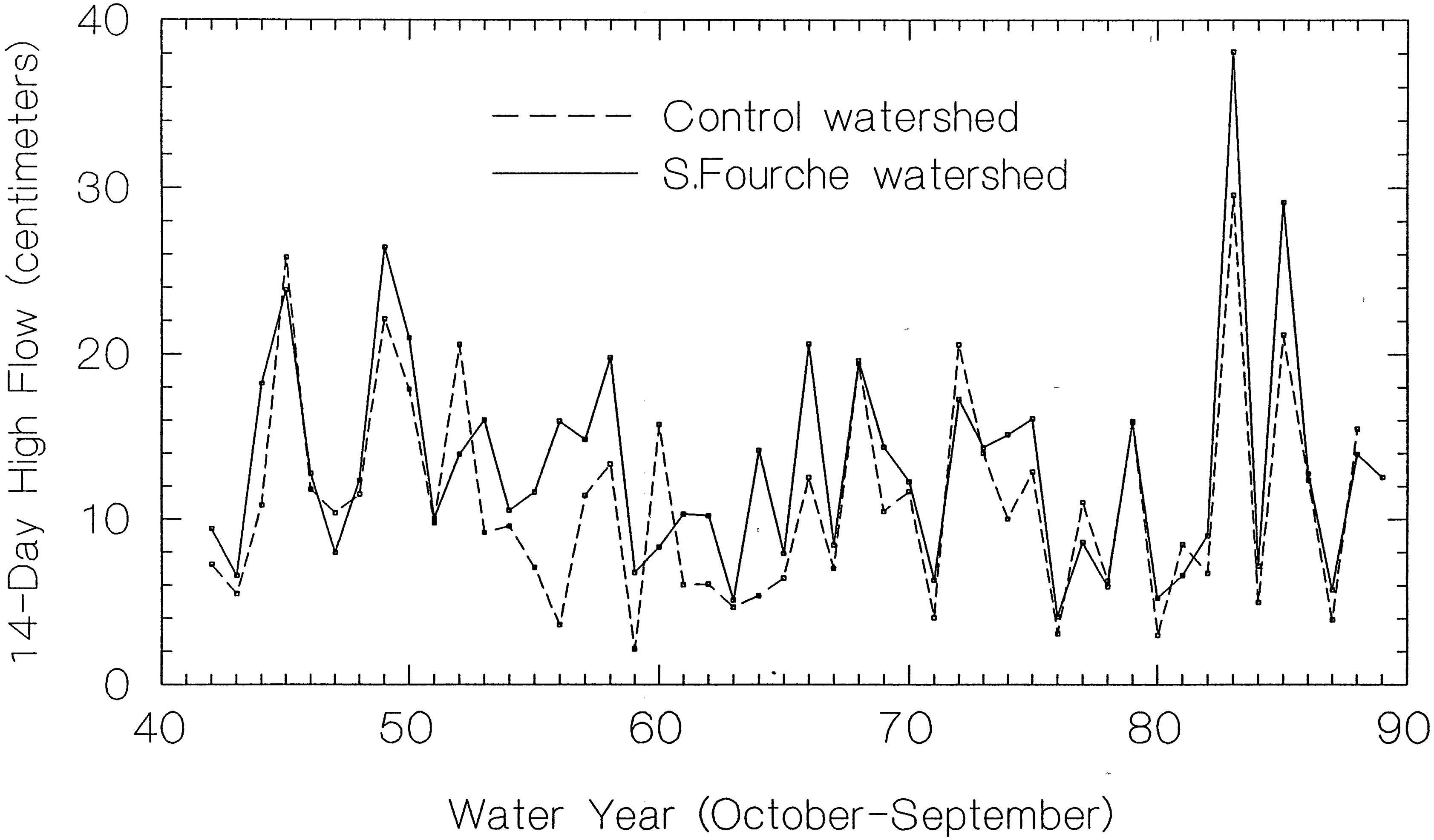

**Figure 31. Plot versus time for the 14-day high flow volume from the study watershed. The flows from the control watershed for the corresponding 14-day period are also shown.**

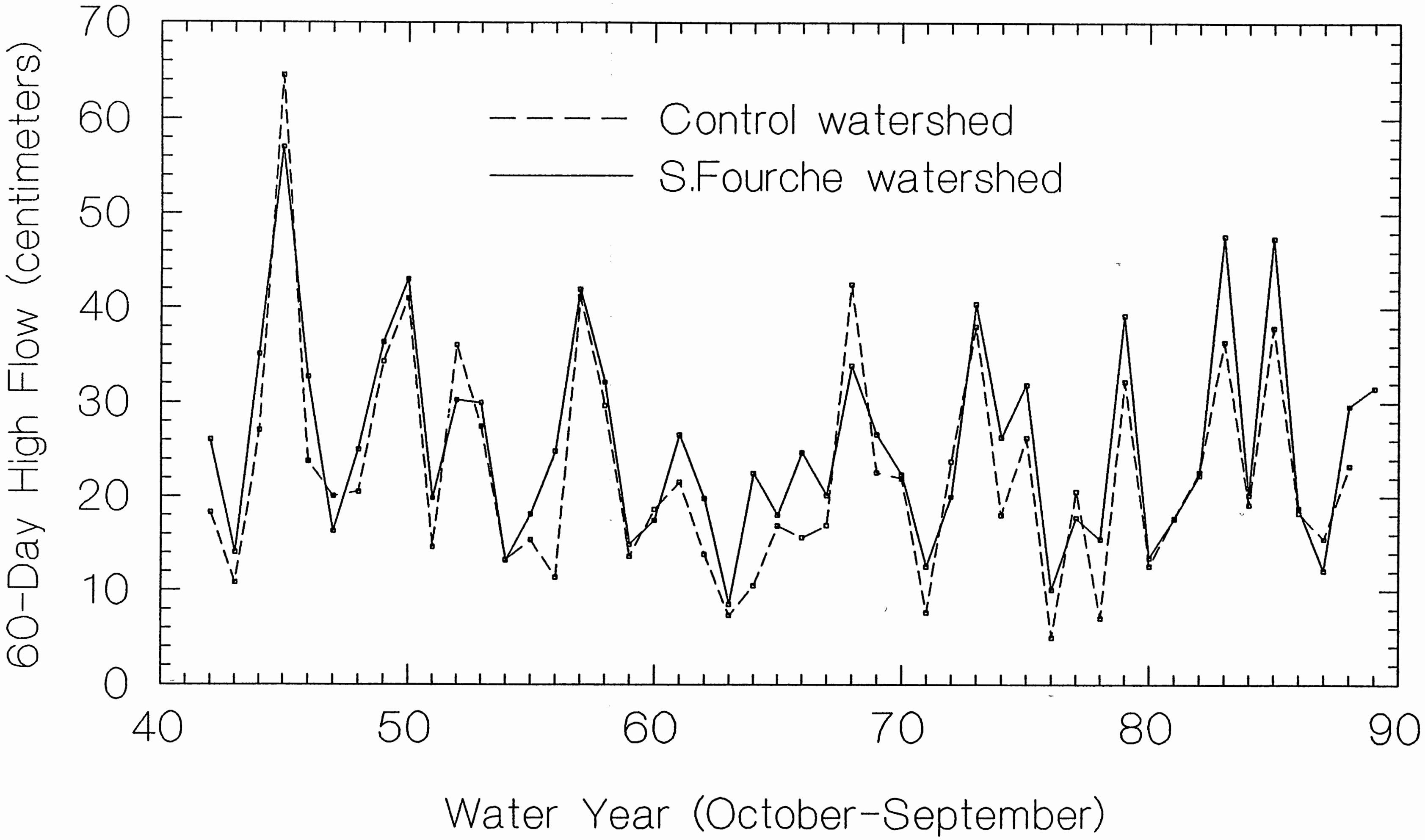

**Figure 32.** Plot versus time for the 60-day high flow volume from the study watershed. The flows from the control watershed for the corresponding 60-day period are also shown.

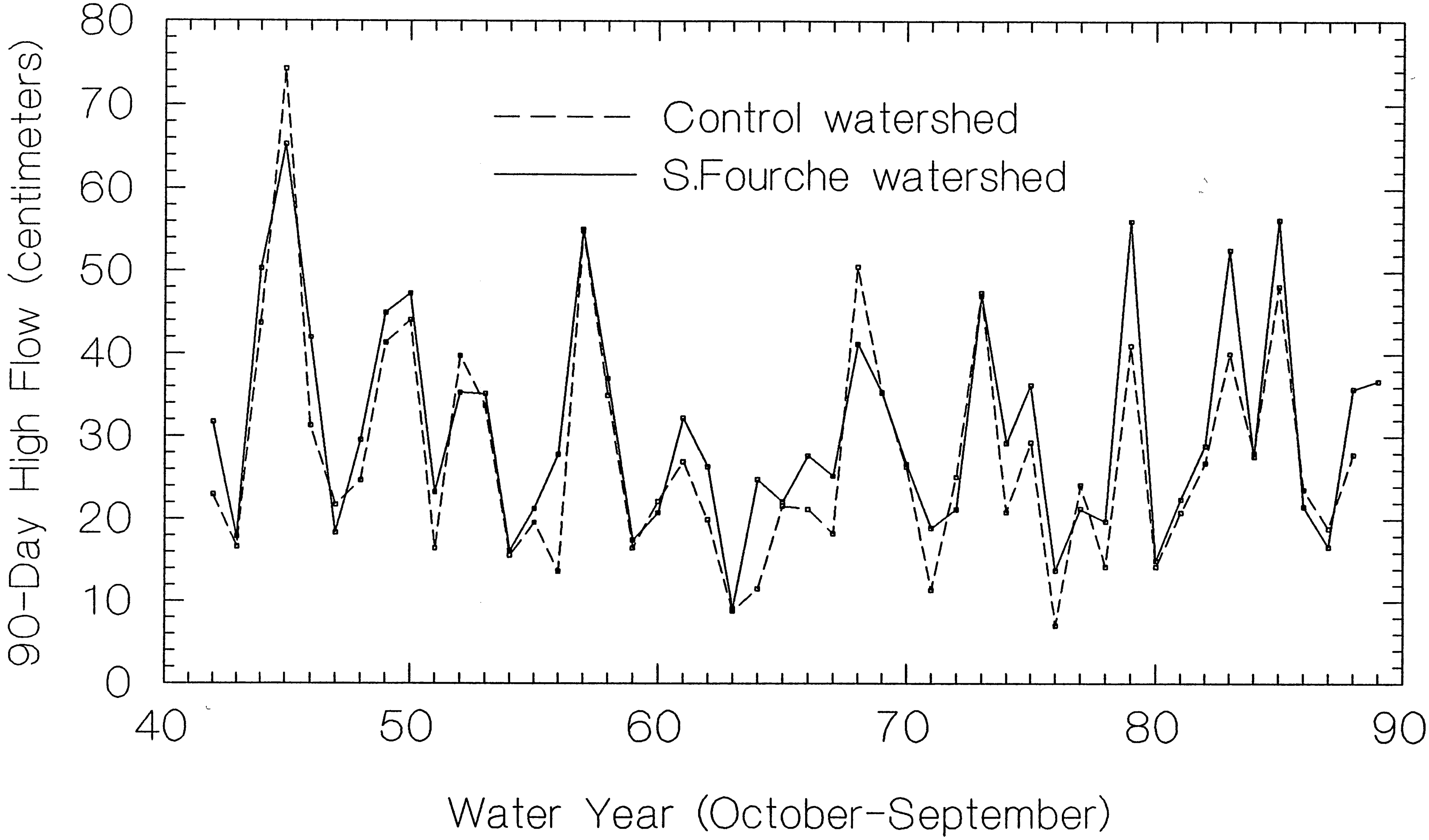

**Figure 33. Plot versus time for the 90-day high flow volume from the study watershed. The flows from the control watershed for the corresponding 90-day period are also shown.**

calibration and postcalibration periods. The analysis resulted in the high flow prediction models given in Equations 21 through 24. Based on the events common to both watersheds, the models may be written

$$Q_{7t} = .233 + 1.068*Q_{7c} + .723*DP_7 \tag{21}$$

$$R^2 = .857 \quad S = 2.436 \text{ cm} \quad D = 1.759$$

$$Q_{14t} = .85 + 1.023*Q_{14c} + .821*DP_{14} \tag{22}$$

$$R^2 = .883 \quad S = 2.712 \text{ cm} \quad D = 2.214$$

$$Q_{60t} = 4.761 + .876*Q_{60c} + .55*DP_{60} \tag{23}$$

$$R^2 = .893 \quad S = 3.789 \text{ cm} \quad D = 2.493$$

$$Q_{90t} = 4.161 + .90*Q_{90c} + .476*DP_{90} \tag{24}$$

$$R^2 = .927 \quad S = 3.907 \text{ cm} \quad D = 2.267$$

where the subscripts "t" and "c" refer to the South Fourche and the control watersheds, respectively, and the subscripts "7", "14", "60", and "90" refer to the appropriate consecutive-day period.

## Frequency Analysis

The Weibull plotting positions of the high flows from the South Fourche watershed for the calibration period fit the Log Pearson Type III distribution (Figure 34a-37a). The 95-percent confidence limits accompany the fitted distributions. To compare the high flows for the two time periods, the postcalibration period data was superimposed on the fitted distribution for the calibration period (Figures 34b-37b). The 7-day and 14-day high flow frequency distributions (Figures 34b and 35b) show that several of the postcalibration period flows fall below the lower confidence limit curve. For comparison the frequency distributions of the 7-day and 14-day high flows from the control watershed for the postcalibration period were plotted (Figure 38). They had a similar form. In addition, the frequency distribution of the rainfalls corresponding to the 7-day and 14-day high flows from the South Fourche watershed were also plotted (Figure 39). The distribution of postcalibration period rainfalls for the 7-day events had the same form as the plot of high flows.

## Discussion

The regression analysis of high flows using control watershed variables produced models which explained between 86 percent (7-day high flow model) and 93 percent (90-day high flow model) of the variability of South Fourche high flows. The predictive ability of the models improved as the consecutive-day period of interest increased. It is possible that differences in antecedent moisture conditions between the watersheds at the start of the high flow periods may limit our ability to accurately predict high flows for the shorter time periods. As the number of days in the high flow period increase, the affect of antecedent moisture differences between the watersheds on the magnitude of high flows diminishes. Also, it is possible that as the number of days increase the relationship

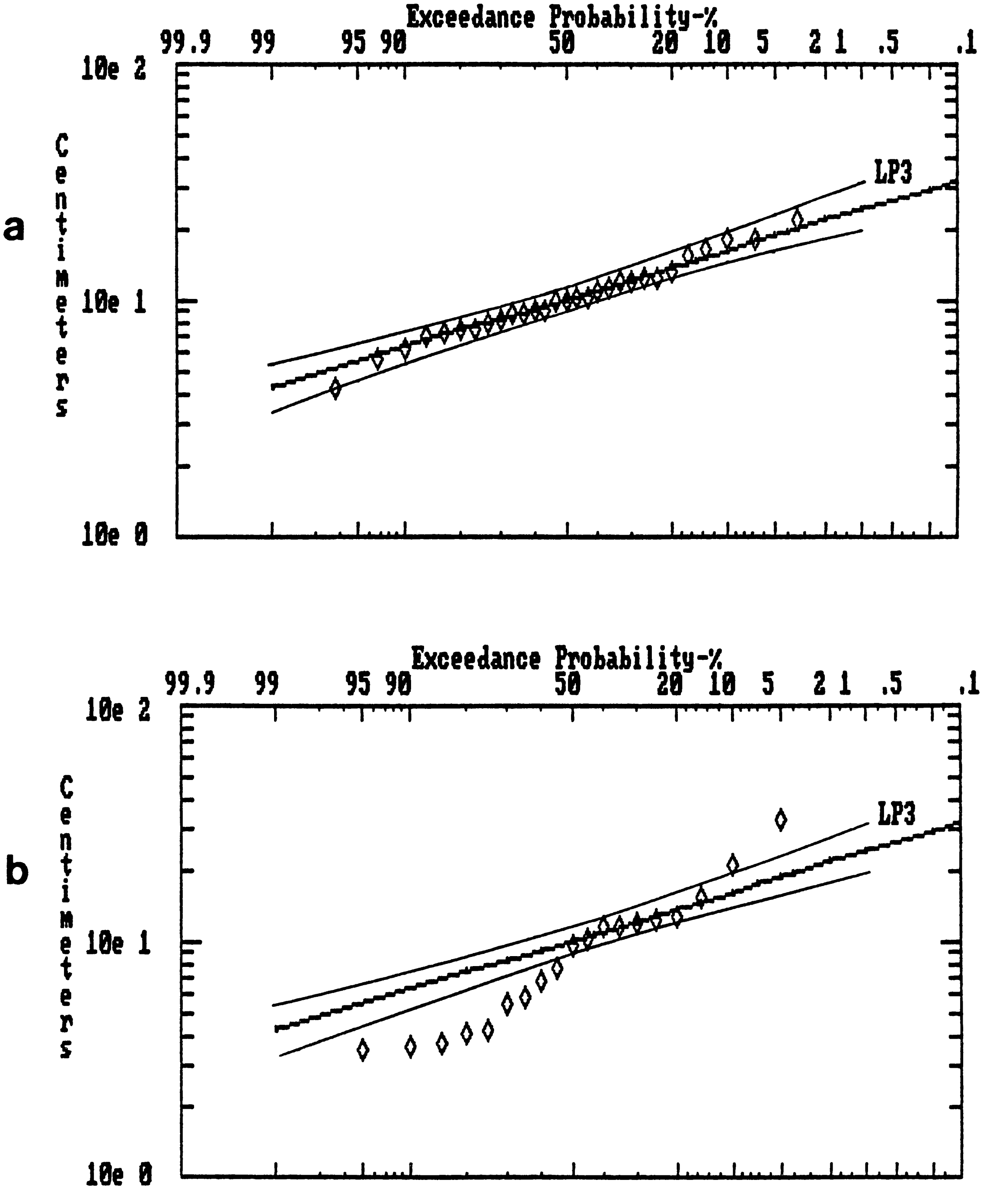

Figure 34. South Fourche 7-day high flow frequency plots: a) Log Pearson III plot of calibration period flows with 95 percent confidence curves; b) frequency distribution of postcalibration period high flows compared to the fitted distribution for the calibration period.

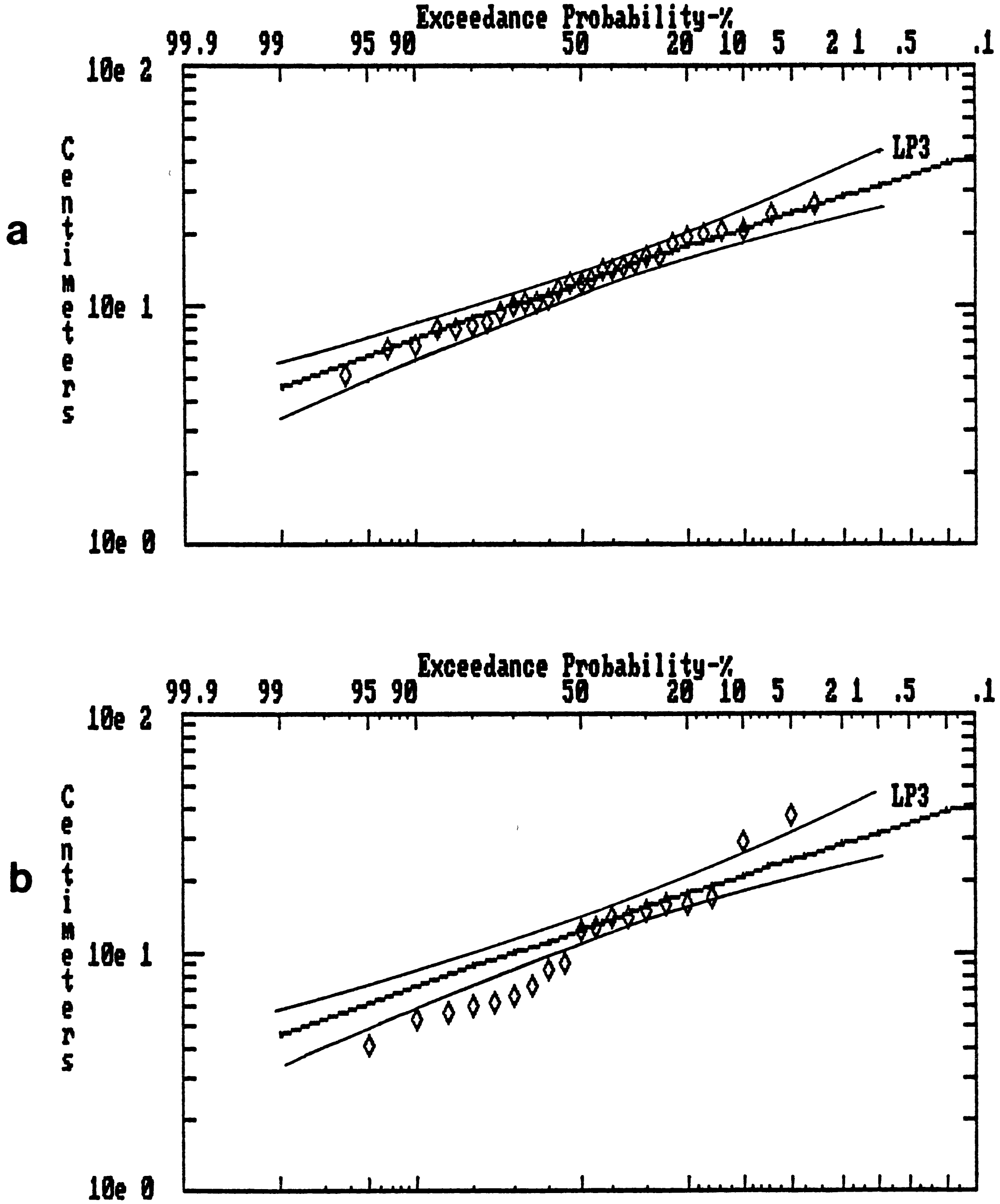

Figure 35. South Fourche 14-day high flow frequency plots: a) Log Pearson III plot of calibration period flows with 95 percent confidence curves; b) frequency distribution of postcalibration period high flows compared to the fitted distribution for the calibration period.

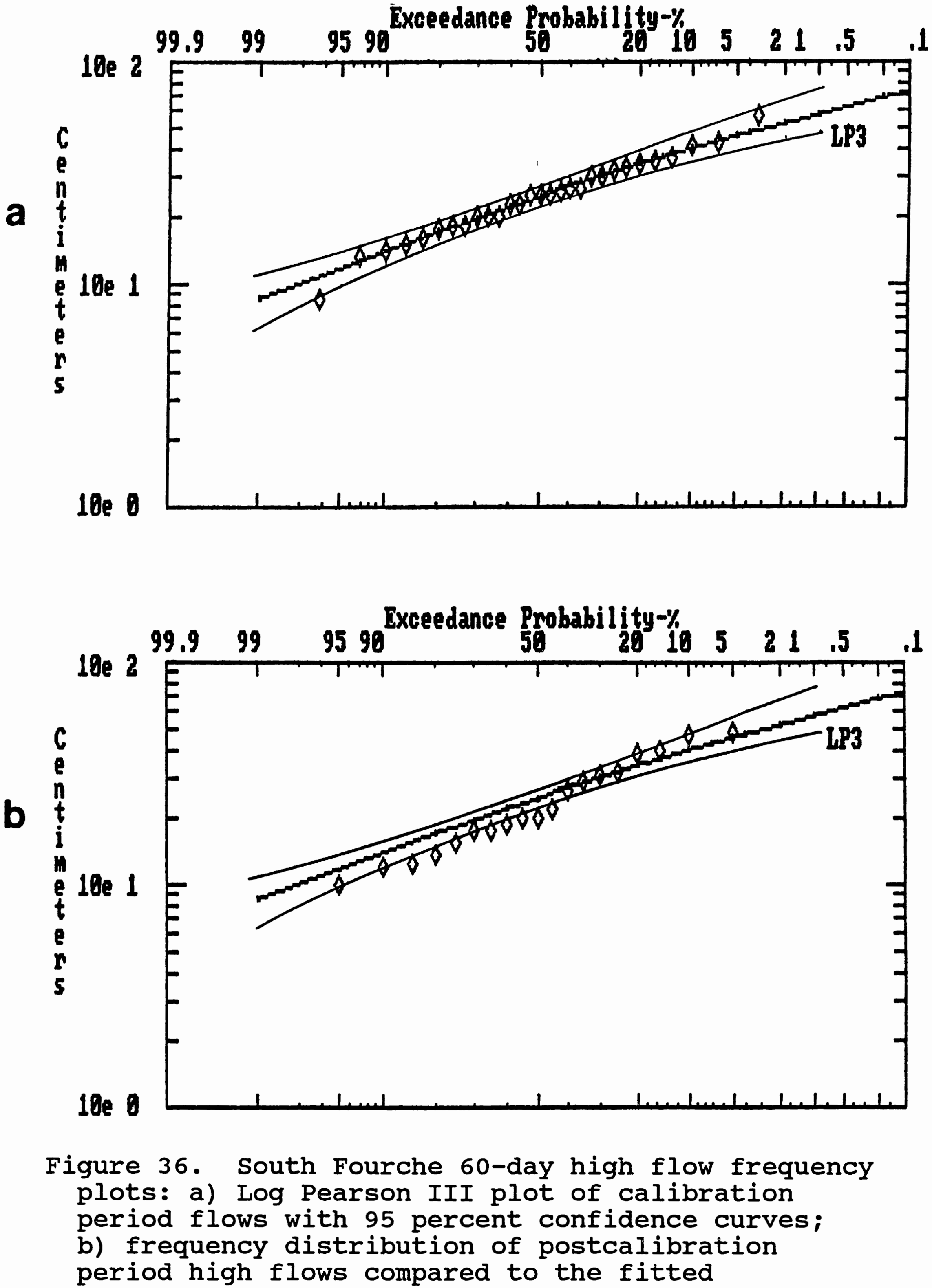

Figure 36. South Fourche 60-day high flow frequency plots: a) Log Pearson III plot of calibration period flows with 95 percent confidence curves; b) frequency distribution of postcalibration period high flows compared to the fitted distribution for the calibration period.

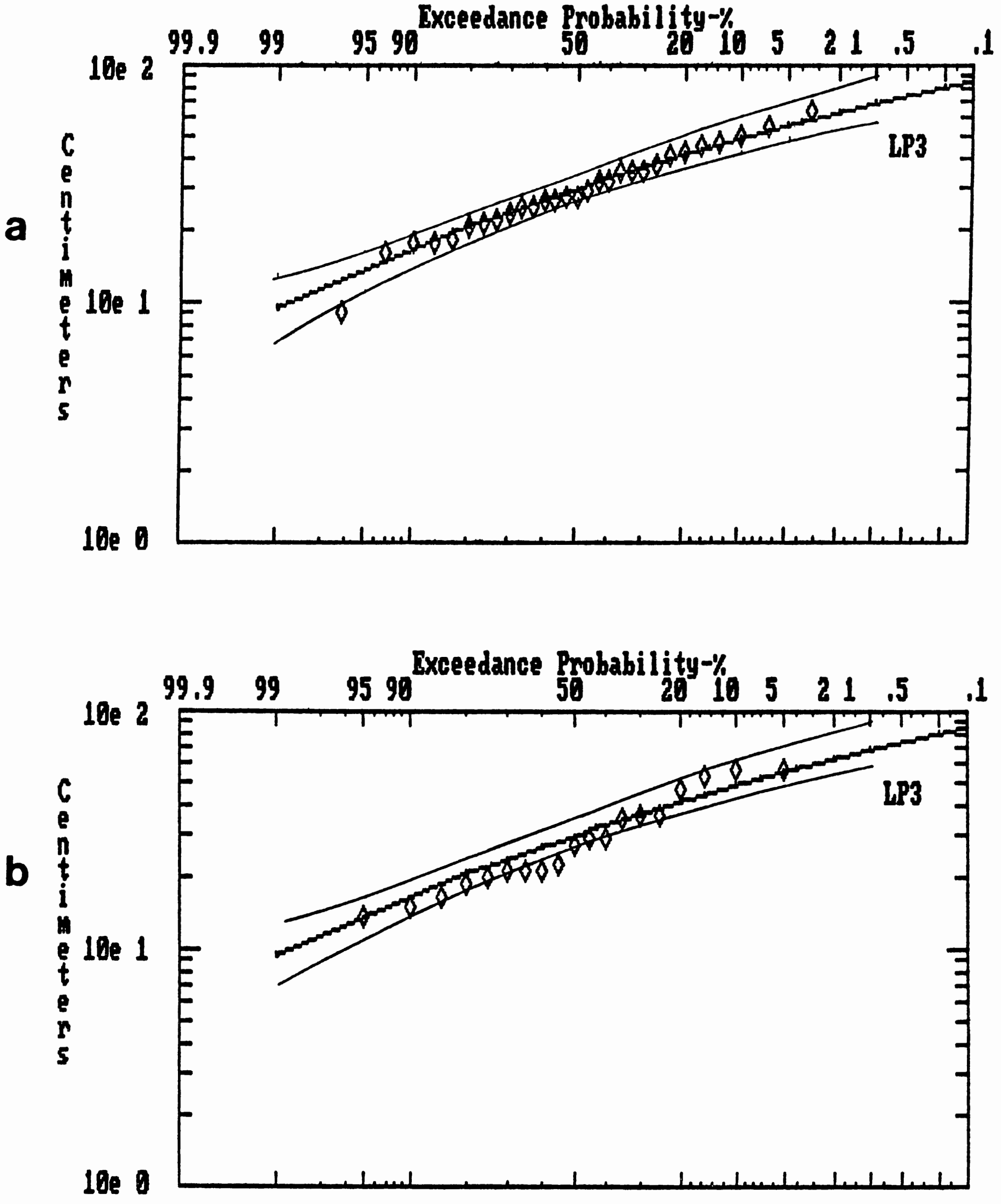

Figure 37. South Fourche 90-day high flow frequency plots: a) Log Pearson III plot of calibration period flows with 95 percent confidence curves; b) frequency distribution of postcalibration period high flows compared to the fitted distribution for the calibration period.

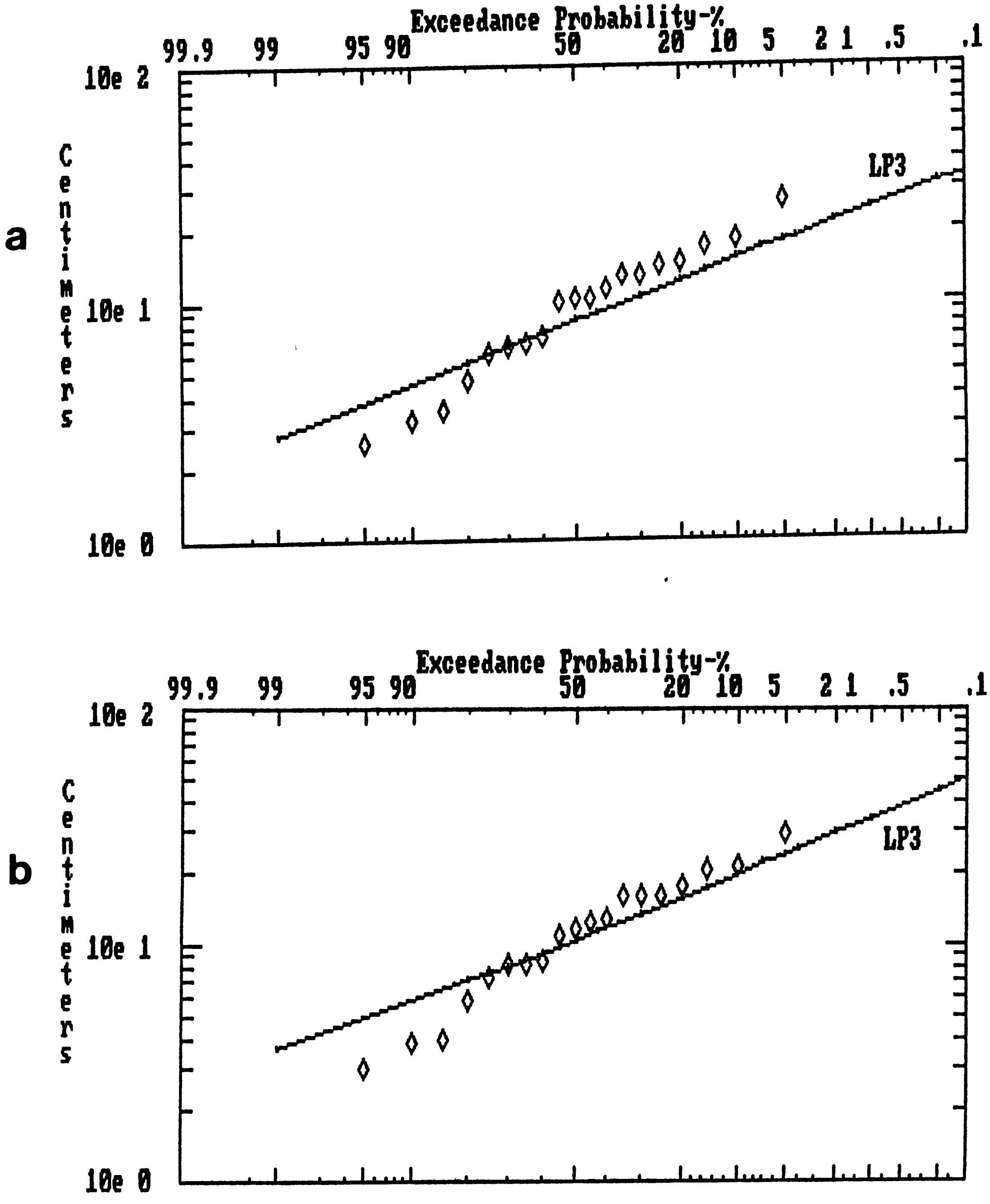

Figure 38. Control watershed high flows for the postcalibration period: a) 7-day high flows; b) 14-day high flows. The solid curve is the Log Pearson III plot of calibration period flows.

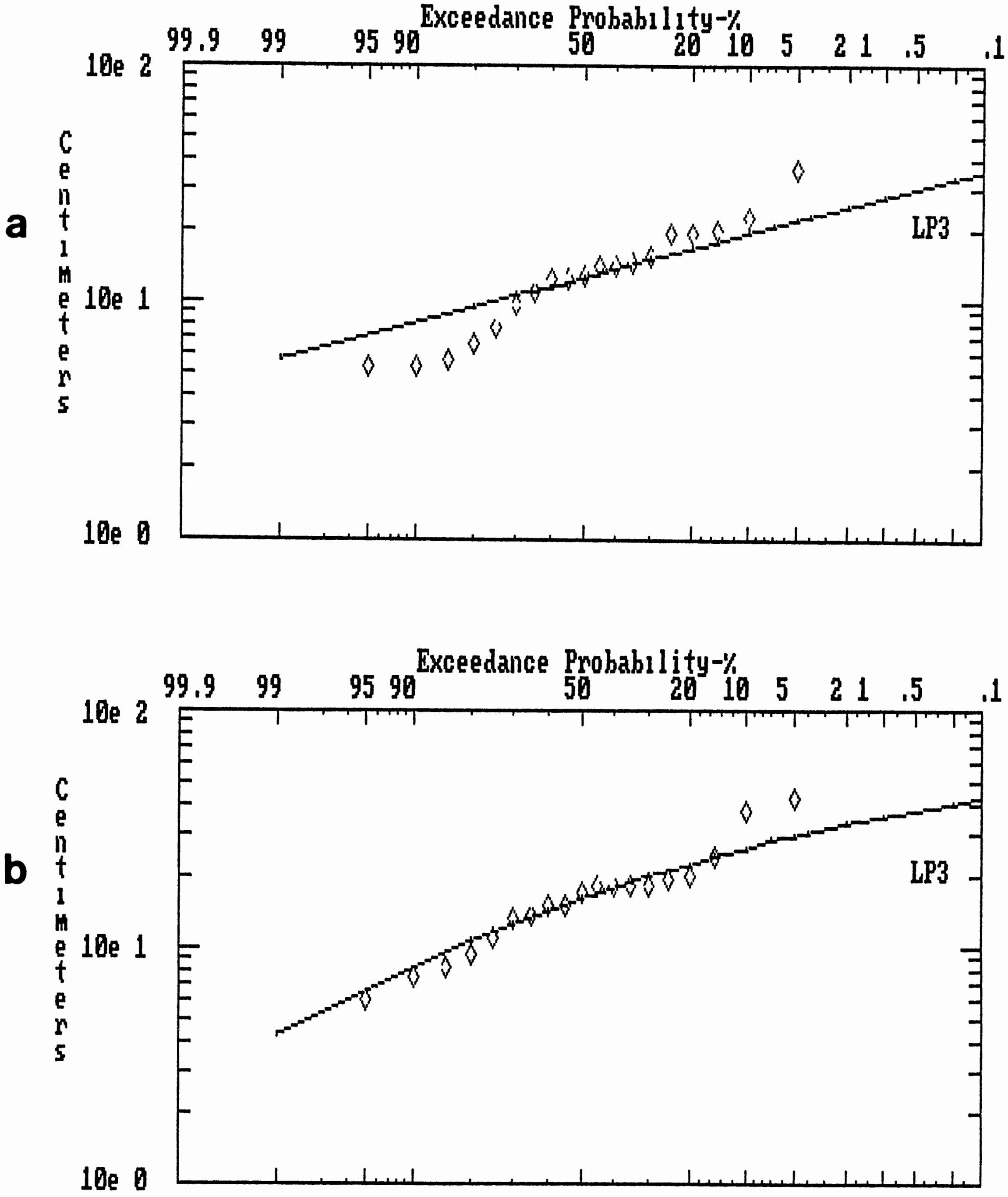

Figure 39. South Fourche rainfall frequency plots for postcalibration period: a) 7-day high flow period; b) 14-day high flow period. The solid curve is the Log Pearson III plot of calibration period rainfalls.

between streamflow and rainfall improves. Prediction variability may be caused by the fact that daily rainfall is based on measurements taken at 7:00 am, and daily streamflow is based on continuous river stage recordings from midnight-to-midnight. The most significant result of this high flow analysis was that no relationship with time was found. Not only was their no jump or change in the response of high flows between the two time periods, but there was no time trend found at all. This is in contrast to the declining time trends found in both annual and dormant season yields. The lack of a time trend is probably related to the season of the year when most of these high flows occur, which is late in the winter and during the spring. For the four high flow variables modeled, between 76 and 80 percent of all events utilized in the analysis started between the months of January and June inclusive. Thus, they occurred when the soil water reservoir was saturated, and when the differences in soil moisture between cut and uncut areas were negligible. Consequently, we can conclude that no significant jump or change would be found in the response of high flows corresponding to Weyerhaeuser's acquisition of the Dierks' land and subsequent intensive forest harvest operations.

The regression analysis also revealed that high flows were not related to time. That is, compared to the control watershed the high flows from the South Fourche did not tend to either increase or decrease during the study period. This is in contrast to the annual and dormant season yields of the South Fourche, which the prediction models showed declined steadily during the study period after adjustments were made for either climate or control watershed yields. We have speculated that this general declining trend in yields was due to the maturation of the forest following extensive logging in the early twenties. The fact is that the majority of high flow events occur between January and March inclusive, when transpiration is negligible, and thus are not affected by the general forest growth. In roundabout thinking, the lack of any time trend in high flows reinforces the belief that the declining trend in yields is due to forest maturation and fire suppression.

Although the regression analysis shows that the relationship between high flows for the South Fourche and control watersheds does not change during the study period, the frequency analysis indicates that for the 7-day and 14-day events the distribution of high flows is different for the two periods (Figure 34 and 35). The distributions diverge at the lower return intervals. However, both watersheds exhibit this change (Figure 38 shows the distribution of the control watershed high flows). Therefore, the change in the magnitude of 7-day and 14-day high flows is probably the result of climate, which affects the hydrology of both watersheds, rather than forest cutting, which has primarily occurred on the South Fourche watershed. This conclusion is supported by the frequency distribution plots of rainfall corresponding to the 7-day high flow events (Figure 39). As in the frequency plots of the high flows, the distribution of postcalibration period rainfalls diverges from the calibration period values at the lower return intervals.

# CHAPTER IX

## SUMMARY AND CONCLUSIONS

Regression analysis showed that, with respect to climatic conditions, the overall annual and dormant season water yield response of the South Fourche watershed increased during the postcalibration period, and that during both periods yield response declined at a constant rate. In addition, regression analysis showed that, relative to the control watershed, peak flow (annual series) and high flow (maximum consecutive-day) response of the study watershed remained unchanged between the two periods. However, peak flow response did exhibit a declining time trend that remained constant over the study period. Frequency analysis showed that, for lower return period events, peak flows and 7- and 14-day high flows from the South Fourche decreased in the postcalibration period.

Plantation age data revealed that the proportion of the watershed under ten years of age rose rapidly during the postcalibration period, and remained constant at about 20 percent after 1980. This was attributed to the intensive style of forest management practiced by Weyerhaeuser Co., which had acquired 41 percent of the watershed area from Dierks Lumber Co. in 1969.

Annual and seasonal water yield models were developed using both the control watershed and single watershed (climatic) calibration methods. These methods produced very similar yield response functions. The single watershed approach showed that annual yield response increased ten centimeters during the postcalibration period and that most of this increase, seven centimeters, occurred in the dormant season. The control watershed approach showed a similar five centimeter increase in dormant season yield response during the postcalibration period, though it did not show any significant change in annual yields. This latter fact was attributed to the incomplete form of the control watershed model, which, due to significance, did not contain a prediction variable representing the difference in winter precipitation between watersheds.

Few researchers (Dons, 1986; Sullivan, et al, 1987) have had the opportunity to address the impact on water yields from high intensity forestry operations on a large watershed sustained over many years, and none have had as complete a set of streamflow and rainfall data to work with as the South Fourche data. Our results cannot be compared directly to the first-year yield increases after forest cutting, which has been reported on widely in the research, nor to many of the historical studies of larger watersheds. However, a general comparison can be made. A ten centimeter increase in annual yield response resulting from a conversion of about 20 percent of the watershed from mature forest to young pine stands can be compared to the conclusions of Bosch and Hewlett (1982) who, in a review of 94 watershed yield studies, stated that there is about a four centimeter change in annual water yield per ten percent change in coniferous forest cover.

In addition to the change in water yield response between the calibration and postcalibration periods, the regression analysis showed that annual yield response declined at the rate of 0.36 centimeters per year for both periods, and that about 70 percent of this yearly decline occurred in the dormant season. This was believed to be the result of a general maturing of the watershed, which is 98 percent forested, after extensive logging in the 1920's, and to the growth of midstory and understory vegetation as a result of fire suppression practices begun in the 1930's.

Regression analysis also showed that annual peak flows and the maximum annual high flow periods were unaffected by the change in land management in the postcalibration period. This was probably because most annual peaks and high flow periods occur between January and May, when forest soils have become saturated, and the difference in soil moisture between cut and uncut areas is negligible. The peak flow analysis, however, did show that the magnitude of the annual peaks on the South Fourche, relative to those common annual peaks on the control watershed, decreased during the study period by a total of 412 $m^3$/second for the 49 year study period. This represented a decline of 48 percent from the "average peak flow" of 853 $m^3$/second at the start of the study period. However, the analysis was based on only 24 events common to both watersheds, and explained only 76 percent of the variation in annual peaks. Some reasons for the poor predictive ability of the model were that daily rainfall measurements were not adjusted to reflect only the storm rainfall at the time the peak was measured, and that variables such as storm pattern and intensity were not evaluated.

Although the relationship of peak flows and high flows between the South Fourche and control watersheds did not change during the study period, frequency analysis showed that, for lower return period events, annual peaks and 7- and 14-day high flows were smaller in the postcalibration period. Frequency analysis of the corresponding rainfalls and control watershed flows showed that these differences were due to changes in climate rather than land use. The frequency distributions of the 60- and 90-day high flows were the same for both periods.

The most significant finding of this study was that the annual and dormant season water yield response of the South Fourche watershed increased during the postcalibration period, a period during which much of the watershed had come under intensive forest management. Direct comparisons to most other water yield research cannot be made because of the differences in the treatments between small watershed research (one-time cutting) and the incremental though high level of forest harvesting and planting that characterized the postcalibration period forest management operations on the South Fourche. With this said, however, what we know about the hydrologic impact of forest cutting remains relevant and can be applied here. We know that forest cutting reduces water losses due to interception and transpiration, and that this results in cut-over areas having higher levels of soil water content than vegetated areas during the growing season and early in the dormant season, before soil recharge occurs. And we know that small watershed research is nearly uniform in demonstrating that the difference in soil water content between cut and uncut areas results in higher water yields from the treated or cut watershed. The South Fourche data shows that the response of water yields has increased about 10 centimeters during the postcalibration period. It also shows that during this period a significant portion of the forest has been cleared and planted, and that this has resulted in about 20 percent of the land base being converted from a largely unmanaged, uneven-aged forest to pine plantations 10 years old or less. This data and our knowledge of the affect that forest cutting has on hydrologic processes lead us to conclude that the change in water yield response of the South Fourche is primarily the result of the recent changes in forest management style.

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# APPENDIXES

# APPENDIX A

# RAIN GAGE AND THEISSEN AREA RAINFALL CALCULATION INFORMATION

## Rain Gage Information

| gage name | latitude | longitude | elevation above msl | recording time |
|---|---|---|---|---|
| | (degrees and minutes) | | (feet) | |
| South Fourche watershed: | | | | |
| Alum Fork | 34 48 | 92 52 | 760 | 5 pm |
| Aly | 34 47 | 93 29 | 850 | 7 am |
| Aplin | | | | |
| Danville | 35 03 | 93 24 | 370 | 7 am |
| Gravelly | 34 53 | 93 41 | 500 | 7 am |
| Jessieville | 34 42 | 93 04 | 730 | 7 am |
| Nimrod Dam | 34 57 | 93 10 | 470 | 8 am |
| Steve | 34 53 | 93 19 | 680 | 7 am |
| Story | 34 42 | 93 31 | 650 | |
| Fourche LaFave watershed: | | | | |
| Eagle Gap | 34 43 | 94 19 | 1150 | 8 am |
| Forester | 34 47 | 93 53 | 660 | 7 am/pm |
| Gravelly | 34 53 | 93 41 | 500 | 7 am |
| Mena | 34 35 | 94 15 | 1210 | 7 am |
| Oden | 34 38 | 93 48 | 800 | 7 am |
| Parks | 34 48 | 94 00 | 610 | 7 am |
| Pine Ridge | 34 35 | 93 54 | 840 | 7 am |
| Waldron | 34 54 | 94 06 | 680 | 7 am |

## Theissen Formulas for Area Rainfall for Control Watershed

1. .2308E + .398F + .1205G + .0028M +.0062O + .0623PR + .1794W
2. .2318E + .4346F + .1205G .0064M + .0245O + .1823W
3. .2308E + .2691G + .0028M + .1445O + .0919PR + .2609W
4. .2308E + .0028M + .3782O + .0919PR + .2963W
5. .398F + .1205G + .1531M + .0062O + .0623PR + .2599W
6. .2308E + .399F + .1205G + .0028M + .0667PR + .1794W
7. .2308E + .3173G + .0028M + .1821PR + .267W
8. .2318E + .4591F + .1205G + .0064M + .1823W
9. .399F + .1205G + .1531M + .0667PR + .2599W
10. .2214G + .1213M + .0764O + .4664P + .0241PR + .0906W
11. .2214G + .0764O + .5152P + .0241PR + .1631W
12. .2414G + .1213M + .5028P + .0441PR + .0906W
13. .2214G + .1213M + .0764O +.557P + .0241PR

E = Eagle Gap
F = Forester
G = Gravelly
M = Mena
O = Oden
P = Parks
PR = Pine Ridge
W = Waldron

## Theissen Formulas for Area Rainfall for South Fourche Watershed

1. .0967AF + .5283J + .2829SY + .0921D
2. .0859AF + .0128D + .1773F + .519N + .205SY
3. .0859AF + .1508J + .2442N + .519S
4. .0398AF + .1177AP + .0128D + .1682J + .4565N + .205SY
5. .0398AF + .1177AP + .1417J + .1817N + .519S
6. .0271AF + .1302AP + .2972N + .5455S
7. .0398AF + .1277AP + .0128D + .6147N + .205SY
8. .1573AP + .2972N + .5455S
9. .0398AF + .1277AP + .0897A + .287N + .4558S
10. .0398AF + .1177AP + .0897A + .1417J + .1817N + .4295S
11. .03987AF + .1177AP + .3099A + .1645J + .3681N
12. .1575AP + .0897A + .1417J + .1817N + .4295S
13. .0859AF + .0897A + .1508J + .2442N + .4295S
14. .0398AF + .1177AP + .0494D + .0698G + .1727J + .5507N
15. .0398AF + .232AP + .39A +.3382J
16. .1575AP + .3099A + .1645J + .3681N
17. .0859AF + .3099A + .1736J + .4306N
18. .3099A + .2236J + .4665N
19. .0859AF + .0494D + .0698G + .1818J + .6132N
20. .116AF + .39A + .494J
21. .116AF + .197D + .0698G + .6172J
22. .0859AF + .0792D + .1818N + .6532N

AF = Alum Fork
A = Aly
AP = Aplin
D = Danville
G = Gravelly
J = Jessieville
N = Nimrod Dam
S = Steve
SY = Story

## Monthly Chronology of Theissen Calculations for South Fourche Watershed

| Time Period | Number of months | Stations used for Theissen calculations | Theissen formula number |
|---|---|---|---|
| Oct 41 - May 42 | 8 | AF,J,D,SY | 1 |
| Jun 42 - Sep 43 | 16 | AF,J,D,SY,N | 2 |
| Oct 43 - Dec 43 | 3 | AF,J,SY,N,S | 3 |
| Jan 44 | 1 | AF,J,SY,ND,AP | 4 |
| Feb 44 - Oct 44 | 9 | AF,J,N,S,AP | 5 |
| Nov 44 - Dec 44 | 2 | AF,J,SY,ND,AP | 4 |
| Jan 45 - Jul 45 | 7 | AF,J,N,S,AP | 5 |
| Aug 45 | 1 | AF,J,SY,ND,AP | 4 |
| Sep 45 | 1 | AF,J,N,S,AP | 5 |
| Oct 45 -Dec 46 | 14 | AF,N,S,AP | 6 |
| Jan 47 | 1 | AF,SY,N,AP | 7 |
| Feb 47 - Apr 47 | 3 | AF,N,S,AP | 6 |
| Jun 47 | 1 | N,AP,ST | 8 |
| Jul 47 | 1 | AF,SY,N,AP | 7 |
| Aug 47 - Dec 47 | 5 | AF,N,S,AP | 6 |
| Jan 48 - Jun 48 | 6 | AF,N,S,AP,A | 9 |
| Jul 48 - Nov 48 | 5 | AF,J,N,S,AP,A | 10 |
| Dec 48 | 1 | AF,J,N,S,AP | 5 |
| Jan 49 - Dec 49 | 12 | AF,J,N,S,AP,A | 10 |
| Jan 50 - Feb 50 | 2 | AF,J,N,S,AP | 5 |
| Mar 50 - Feb 51 | 12 | AF,J,N,S,AP,A | 10 |
| Mar 51 | 1 | AF,J,N,AP,A | 11 |
| Apr 51 - Sep 51 | 6 | AF,J,N,S,AP,A | 10 |
| Oct 51 - Nov 51 | 2 | AF,J,N,AP,A | 11 |
| Dec 51 | 1 | J,N,S,AP,A | 12 |
| Jan 52 - Apr 53 | 16 | AF,J,N,S,AP,A | 10 |
| May 53 | 1 | AF,J,N,S,A | 13 |
| Jun 53 - Jan 54 | 8 | AF,J,N,S,AP,A | 10 |
| Feb 54 | 1 | AF,J,N,AP,D,G | 14 |
| Mar 54 - Apr 54 | 2 | AF,J,N,S,AP | 5 |
| May 54 | 1 | AF,J,N,AP,A | 11 |
| Jun 54 - Jan 59 | 56 | AF,J,N,S,AP,A | 10 |
| Feb 59 - Mar 59 | 2 | AF,J,N,S,AP | 5 |
| Apr 59 - Oct 59 | 7 | AF,J,N,S,AP,A | 10 |
| Nov 59 - Nov 66 | 85 | AF,J,N,AP,A | 11 |
| Dec 66 - Mar 67 | 4 | AF,J,AP,A | 15 |
| Apr 67 - Feb 75 | 95 | AF,J,N,AP,A | 11 |
| Mar 75 - Apr 75 | 2 | J,N,AP,A | 16 |
| May 75 - Feb 76 | 10 | AF,J,N,A | 17 |
| Mar 76 | 1 | J,N,A | 18 |
| Apr 76 | 1 | AF,J,N,A | 17 |
| May 76 | 1 | AF,J,N,D,G | 19 |
| Jun 76 - May 78 | 24 | AF,J,N,A | 17 |
| Jun 78 | 1 | AF,J,A | 20 |
| Jul 78 - Jun 80 | 24 | AF,J,N,A | 17 |
| Jul 80 | 1 | AF,J,A | 20 |

| | | | |
|---|---|---|---|
| Aug 80 - Jan 81 | 6 | AF,J,N,A | 17 |
| Feb 81 - Apr 81 | 3 | AF,J,N,D,G | 19 |
| May 81 - Dec 81 | 7 | AF,J,N,A | 17 |
| Jan 82 - Jun 82 | 6 | AF,J,N,D,G | 19 |
| Jul 82 | 1 | AF,J,D,G | 21 |
| Aug 82 | 1 | AF,J,N,D,G | 19 |
| Sep 82 | 1 | AF,J,N,D | 22 |
| Oct 82 - Jan 89 | 76 | AF,J,N,D,G | 19 |
| Feb 89 | 1 | AF,J,D,G | 21 |
| Mar 89 - present | | AF,J,N,D,G | 19 |

AF = Alum Fork
A = Aly
AP = Aplin
D = Danville
G = Gravelly
J = Jessieville
N = Nimrod Dam
S = Steve
SY = Story

## Monthly Chronology of Theissen Calculations for Control Watershed

| Time Period | Number of months | Stations used for Theissen calculations | Theissen formula number |
|---|---|---|---|
| Jan 42 - Dec 42 | 12 | E,F,G,M,O,PR,W | 1 |
| Jan 43 | 1 | E,F,G,M,O,W | 2 |
| Feb 43 - Feb 45 | 25 | E,F,G,M,O,PR,W | 1 |
| Mar 45 - Apr 45 | 2 | E,G,M,O,PR,W | 3 |
| May 45 | 1 | E,M,O,PR,W | 4 |
| Jun 45 - Jul 45 | 2 | E,G,M,O,PR,W | 3 |
| Aug 45 - Jul 47 | 24 | E,F,G,M,O,PR,W | 1 |
| Aug 47 - Sep 47 | 2 | F,G,M,O,PR,W | 5 |
| Oct 47 - Jan 48 | 4 | E,F,G,M,O,PR,W | 1 |
| Feb 48 | 1 | E,F,G,M,PR,W | 6 |
| Mar 48 - May 48 | 3 | E,F,G,M,O,PR,W | 1 |
| Jun 48 | 1 | E,G,M,PR,W | 7 |
| Jul 48 - Nov 48 | 5 | E,F,G,M,PR,W | 6 |
| Dec 48 - Jan 49 | 2 | E,F,G,M,O,W | 8 |
| Feb 49 - May 49 | 4 | E,F,G,M,O,PR,W | 1 |
| Jun 49 | 1 | E,F,G,M,PR,W | 6 |
| Jul 49 - Feb 50 | 8 | E,F,G,M,O,PR,W | 1 |
| Mar 50 - Dec 50 | 10 | E,F,G,M,PR,W | 6 |
| Jan 51 - Mar 51 | 3 | E,F,G,M,O,PR,W | 1 |
| Apr 51 | 1 | F,G,M,PR,W | 9 |
| May 51 - Dec 51 | 8 | E,F,G,M,PR,W | 6 |
| Jan 52 - Jan 55 | 37 | E,F,G,M,O,PR,W | 1 |
| Feb 55 - Jul 55 | 6 | F,G,M,O,PR,W | 5 |
| Aug 55 - Feb 56 | 7 | E,F,G,M,O,PR,W | 1 |
| Mar 56 | 1 | F,G,M,O,PR,W | 5 |
| Apr 56 - Sep 79 | 282 | G,M,O,P,PR,W | 10 |
| Oct 79 - Mar 80 | 6 | G,P,PR,O,W | 11 |
| Apr 80 - Dec 81 | 21 | G,M,O,P,PR,W | 10 |
| Jan 82 - Jun 82 | 6 | G,M,P,PR,W | 12 |
| Jul 82 - Jan 89 | 79 | G,M,O,P,PR,W | 10 |
| Feb 89 - Apr 89 | 3 | G,M,O,P,PR | 13 |
| May 89 - present |  | G,M,O,P,PR,W | 10 |

E = Eagle Gap
F = Forester
G = Gravelly
M = Mena
O = Oden
P = Parks
PR = Pine Ridge
W = Waldron

# APPENDIX B

# DATA USED TO DEVELOP WATER YIELD REGRESSION MODELS

Variables* Used to Develop Water Yield Regression Models (From files SSFW3.wk1 and SSFW3.sys)

| WT43 | T | TIME | WYEAR | SQMF (cm) | SQGROW (cm) | SQDORM (cm) | SQSPG (cm) | SQSUM (cm) | SQFALL (cm) | SQWTR (cm) | SPSPG (cm) | SPSUM (cm) | SPFALL (cm) | SPWTR (cm) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 |  | 42 | 39.58 | 30.90 | 8.68 | 27.75 | 3.15 | 0.58 | 8.09 | 47.02 | 39.04 | 13.02 | 16.59 |
| 1 | 0 |  | 43 | 34.76 | 18.28 | 16.48 | 17.11 | 1.17 | 0.26 | 16.22 | 44.75 | 15.60 | 11.34 | 36.51 |
| 1 | 0 |  | 44 | 72.90 | 40.37 | 32.52 | 39.03 | 1.34 | 0.10 | 32.42 | 51.65 | 37.52 | 12.23 | 49.91 |
| 1 | 0 |  | 45 | 97.86 | 65.57 | 32.28 | 48.30 | 17.27 | 3.82 | 28.46 | 62.86 | 73.07 | 12.36 | 37.38 |
| 1 | 0 |  | 46 | 61.48 | 42.48 | 18.99 | 40.35 | 2.14 | 6.53 | 12.46 | 60.16 | 23.73 | 25.04 | 19.69 |
| 1 | 0 |  | 47 | 31.65 | 8.77 | 22.88 | 8.60 | 0.17 | 0.34 | 22.54 | 25.99 | 20.39 | 20.29 | 38.27 |
| 1 | 0 |  | 48 | 62.24 | 22.43 | 39.80 | 20.90 | 1.54 | 0.39 | 39.41 | 37.69 | 38.89 | 20.51 | 53.71 |
| 1 | 0 |  | 49 | 73.05 | 24.76 | 48.30 | 19.72 | 5.04 | 1.32 | 46.98 | 38.89 | 32.24 | 21.48 | 58.56 |
| 1 | 0 |  | 50 | 46.68 | 26.33 | 20.34 | 13.51 | 12.82 | 0.93 | 19.41 | 32.65 | 56.00 | 9.21 | 25.88 |
| 1 | 0 |  | 51 | 39.54 | 11.79 | 27.75 | 7.63 | 4.16 | 8.34 | 19.41 | 16.37 | 50.15 | 25.56 | 27.07 |
| 1 | 0 |  | 52 | 62.43 | 34.80 | 27.63 | 34.53 | 0.27 | 7.65 | 19.98 | 51.76 | 26.02 | 28.36 | 29.86 |
| 1 | 0 |  | 53 | 43.08 | 34.87 | 8.21 | 34.62 | 0.25 | 0.00 | 8.21 | 49.43 | 20.01 | 10.78 | 24.41 |
| 1 | 0 |  | 54 | 23.56 | 13.96 | 9.61 | 13.88 | 0.07 | 0.94 | 8.67 | 30.54 | 13.73 | 19.24 | 21.80 |
| 1 | 0 |  | 55 | 45.12 | 21.23 | 23.90 | 20.14 | 1.09 | 0.65 | 23.25 | 45.24 | 32.91 | 10.26 | 38.75 |
| 1 | 0 |  | 56 | 24.55 | 9.70 | 14.85 | 9.07 | 0.63 | 0.13 | 14.71 | 26.38 | 23.91 | 14.91 | 31.43 |
| 1 | 0 |  | 57 | 82.93 | 64.28 | 18.65 | 49.30 | 14.99 | 9.92 | 8.73 | 69.15 | 57.16 | 25.20 | 17.09 |
| 1 | 0 |  | 58 | 56.81 | 40.27 | 16.54 | 36.88 | 3.39 | 5.58 | 10.96 | 49.59 | 51.23 | 23.99 | 17.00 |
| 1 | 0 |  | 59 | 36.32 | 16.12 | 20.20 | 9.85 | 6.27 | 0.65 | 19.56 | 21.61 | 51.98 | 11.87 | 36.67 |
| 1 | 0 |  | 60 | 38.93 | 21.37 | 17.56 | 18.76 | 2.61 | 0.81 | 16.76 | 34.64 | 46.69 | 15.75 | 31.56 |
| 1 | 0 |  | 61 | 56.28 | 29.90 | 26.38 | 27.50 | 2.40 | 2.88 | 23.50 | 50.71 | 39.01 | 17.87 | 36.02 |
| 1 | 0 |  | 62 | 13.30 | 11.62 | 1.68 | 11.00 | 0.62 | 0.72 | 0.96 | 23.20 | 46.21 | 19.79 | 7.56 |
| 1 | 0 |  | 63 | 18.40 | 14.75 | 3.66 | 9.08 | 5.67 | 1.09 | 2.57 | 34.33 | 29.68 | 13.49 | 14.60 |
| 1 | 0 |  | 64 | 37.77 | 23.38 | 14.40 | 23.27 | 0.10 | 1.00 | 13.40 | 44.02 | 35.66 | 14.73 | 27.41 |
| 1 | 0 |  | 65 | 27.92 | 19.35 | 8.58 | 13.56 | 5.78 | 0.18 | 8.40 | 36.16 | 49.18 | 4.83 | 27.61 |
| 1 | 0 |  | 66 | 33.81 | 29.76 | 4.05 | 26.67 | 3.09 | 0.21 | 3.84 | 40.53 | 27.83 | 12.66 | 20.65 |
| 1 | 0 |  | 67 | 54.63 | 35.79 | 18.84 | 24.35 | 11.44 | 2.97 | 15.87 | 54.05 | 46.53 | 17.67 | 26.32 |
| 1 | 0 |  | 68 | 80.91 | 44.14 | 36.77 | 41.33 | 2.81 | 3.39 | 33.38 | 63.26 | 45.80 | 23.12 | 43.12 |
| 1 | 0 |  | 69 | 27.02 | 11.17 | 15.85 | 8.11 | 3.07 | 1.82 | 14.03 | 26.16 | 28.56 | 21.34 | 27.24 |
| 1 | 0 |  | 70 | 51.41 | 26.81 | 24.60 | 23.90 | 2.91 | 8.66 | 15.94 | 40.44 | 43.33 | 28.75 | 26.54 |
| 1 | 1 | 1 | 71 | 31.43 | 10.07 | 21.35 | 7.73 | 2.34 | 0.14 | 21.22 | 23.32 | 33.27 | 13.29 | 34.57 |
| 1 | 1 | 2 | 72 | 44.78 | 4.84 | 39.94 | 4.39 | 0.45 | 17.27 | 22.67 | 20.63 | 34.11 | 36.32 | 32.69 |
| 1 | 1 | 3 | 73 | 92.34 | 55.31 | 37.03 | 44.08 | 11.23 | 13.91 | 23.11 | 63.27 | 55.60 | 30.29 | 26.99 |
| 1 | 1 | 4 | 74 | 61.51 | 28.47 | 33.04 | 12.88 | 15.58 | 12.80 | 20.25 | 31.81 | 53.15 | 29.96 | 25.10 |
| 1 | 1 | 5 | 75 | 44.16 | 33.22 | 10.94 | 31.06 | 2.16 | 0.25 | 10.69 | 51.99 | 31.48 | 14.23 | 23.43 |
| 1 | 1 | 6 | 76 | 20.81 | 12.93 | 7.88 | 8.68 | 4.25 | 0.64 | 7.24 | 27.91 | 30.99 | 16.28 | 17.86 |
| 1 | 1 | 7 | 77 | 35.25 | 17.93 | 17.33 | 17.20 | 0.73 | 3.39 | 13.94 | 35.45 | 42.27 | 20.63 | 22.49 |
| 1 | 1 | 8 | 78 | 52.56 | 18.00 | 34.56 | 17.01 | 0.98 | 3.54 | 31.02 | 33.63 | 28.88 | 20.98 | 43.01 |
| 1 | 1 | 9 | 79 | 67.73 | 58.17 | 9.56 | 51.99 | 6.17 | 1.51 | 8.05 | 62.69 | 41.07 | 14.49 | 16.51 |
| 1 | 1 | 10 | 80 | 25.70 | 15.42 | 10.28 | 15.07 | 0.36 | 1.71 | 8.57 | 39.47 | 23.65 | 17.71 | 17.69 |
| 1 | 1 | 11 | 81 | 43.29 | 29.06 | 14.22 | 20.14 | 8.92 | 1.37 | 12.86 | 39.79 | 44.16 | 19.31 | 21.75 |
| 1 | 1 | 12 | 82 | 75.82 | 22.47 | 53.35 | 19.22 | 3.26 | 6.25 | 47.10 | 29.73 | 34.50 | 28.53 | 52.10 |
| 1 | 1 | 13 | 83 | 45.66 | 25.37 | 20.30 | 21.82 | 3.55 | 1.37 | 18.93 | 42.55 | 27.77 | 21.81 | 31.30 |
| 0 | 1 | 14 | 84 | 94.17 | 24.50 | 69.67 | 21.47 | 3.03 | 47.03 | 22.64 | 43.03 | 44.02 | 76.17 | 30.96 |
| 1 | 1 | 15 | 85 | 42.75 | 20.11 | 22.64 | 19.85 | 0.25 | 12.25 | 10.39 | 41.64 | 18.80 | 35.65 | 15.31 |
| 1 | 1 | 16 | 86 | 42.98 | 25.55 | 17.43 | 14.86 | 10.69 | 2.95 | 14.48 | 36.50 | 53.32 | 23.61 | 28.87 |
| 1 | 1 | 17 | 87 | 47.91 | 8.47 | 39.44 | 7.64 | 0.83 | 10.54 | 28.91 | 24.61 | 35.59 | 27.24 | 40.73 |
| 1 | 1 | 18 | 88 | 47.57 | 13.49 | 34.07 | 13.32 | 0.18 | 7.69 | 26.39 | 27.61 | 36.50 | 34.45 | 39.53 |
| 1 | 1 | 19 | 89 | 43.60 | 25.59 | 18.01 | 19.23 | 6.36 | 0.35 | 17.67 | 42.58 | 49.63 | 6.95 | 38.30 |
|  |  | 20 | 90 |  | 42.03 |  | 40.95 | 1.08 |  |  | 72.23 | 28.59 | 21.79 |  |

| WYEAR | SPMAR (cm) | SPAPR (cm) | SPMAY (cm) | SPJUN (cm) | SPJUL (cm) | SPAUG (cm) | SPSEP (cm) | SPOCT (cm) | SPNOV (cm) | SPDEC (cm) | SPJAN (cm) | SPFEB (cm) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 42 | 12.49 | 26.43 | 8.09 | 12.33 | 2.95 | 16.61 | 7.15 | 4.61 | 8.41 | 12.39 | 1.18 | 3.02 |
| 43 | 13.04 | 8.11 | 23.59 | 4.97 | 1.69 | 1.07 | 7.87 | 9.60 | 1.73 | 10.59 | 7.25 | 18.67 |
| 44 | 15.93 | 22.37 | 13.36 | 8.63 | 11.61 | 16.38 | 0.89 | 1.20 | 11.03 | 21.52 | 4.87 | 23.52 |
| 45 | 34.84 | 14.16 | 13.86 | 25.14 | 12.20 | 11.02 | 24.71 | 5.10 | 7.25 | 4.41 | 19.23 | 13.74 |
| 46 | 18.10 | 17.24 | 24.83 | 4.78 | 11.09 | 6.23 | 1.62 | 5.32 | 19.73 | 14.72 | 3.60 | 1.37 |
| 47 | 5.39 | 11.57 | 9.03 | 5.29 | 1.45 | 5.90 | 7.75 | 7.37 | 12.92 | 16.30 | 6.77 | 15.21 |
| 48 | 11.08 | 11.75 | 14.87 | 10.07 | 15.94 | 11.37 | 1.52 | 8.71 | 11.81 | 11.51 | 33.29 | 8.91 |
| 49 | 15.34 | 6.75 | 16.80 | 14.01 | 6.54 | 6.19 | 5.50 | 20.47 | 1.01 | 13.05 | 30.50 | 15.00 |
| 50 | 6.83 | 7.15 | 18.67 | 9.19 | 17.92 | 14.83 | 14.07 | 5.64 | 3.56 | 0.82 | 12.22 | 12.84 |
| 51 | 5.83 | 7.51 | 3.02 | 14.28 | 12.21 | 10.13 | 13.53 | 13.58 | 11.98 | 6.87 | 11.21 | 8.99 |
| 52 | 16.07 | 22.78 | 12.91 | 1.00 | 10.70 | 10.23 | 4.09 | 2.43 | 25.93 | 13.31 | 11.12 | 5.42 |
| 53 | 15.10 | 19.30 | 15.02 | 0.61 | 12.08 | 3.62 | 3.69 | 4.03 | 6.74 | 5.57 | 12.82 | 6.02 |
| 54 | 4.14 | 8.02 | 18.39 | 3.44 | 1.83 | 1.98 | 6.48 | 16.37 | 2.87 | 9.84 | 2.52 | 9.43 |
| 55 | 16.08 | 9.11 | 20.04 | 6.56 | 6.79 | 7.22 | 12.34 | 6.83 | 3.43 | 1.31 | 15.35 | 22.09 |
| 56 | 6.81 | 12.87 | 6.70 | 5.58 | 11.60 | 3.42 | 3.31 | 7.75 | 7.16 | 7.32 | 16.02 | 8.08 |
| 57 | 15.54 | 30.46 | 23.15 | 14.87 | 8.83 | 22.74 | 10.72 | 7.61 | 17.59 | 6.15 | 7.61 | 3.33 |
| 58 | 13.81 | 16.53 | 19.25 | 19.60 | 11.75 | 6.20 | 13.67 | 5.19 | 18.80 | 2.46 | 3.44 | 11.10 |
| 59 | 11.84 | 5.88 | 3.90 | 16.97 | 15.31 | 6.06 | 13.64 | 8.21 | 3.66 | 20.77 | 9.63 | 6.27 |
| 60 | 7.48 | 5.10 | 22.05 | 14.25 | 10.58 | 7.55 | 14.30 | 8.50 | 7.24 | 17.01 | 2.62 | 11.93 |
| 61 | 25.86 | 7.36 | 17.50 | 10.28 | 11.03 | 7.29 | 10.41 | 3.16 | 14.71 | 11.85 | 9.13 | 15.04 |
| 62 | 11.49 | 6.55 | 5.17 | 13.69 | 8.00 | 7.13 | 17.39 | 14.22 | 5.57 | 3.17 | 1.70 | 2.69 |
| 63 | 16.92 | 8.00 | 9.41 | 6.53 | 19.63 | 0.88 | 2.65 | 0.43 | 13.06 | 5.18 | 1.29 | 8.13 |
| 64 | 22.54 | 14.67 | 6.81 | 2.51 | 5.76 | 12.20 | 15.19 | 1.10 | 13.63 | 3.37 | 12.00 | 12.04 |
| 65 | 12.61 | 6.02 | 17.52 | 10.19 | 7.76 | 9.28 | 21.96 | 1.00 | 3.82 | 4.31 | 13.47 | 9.83 |
| 66 | 2.93 | 25.54 | 12.06 | 0.42 | 6.90 | 18.41 | 2.11 | 6.49 | 6.17 | 11.63 | 4.23 | 4.79 |
| 67 | 8.91 | 16.36 | 28.78 | 5.83 | 15.00 | 14.20 | 11.50 | 13.07 | 4.60 | 15.19 | 8.47 | 2.66 |
| 68 | 17.99 | 12.81 | 32.46 | 12.01 | 16.40 | 7.41 | 9.97 | 7.85 | 15.27 | 17.03 | 18.27 | 7.82 |
| 69 | 8.01 | 5.14 | 13.02 | 12.10 | 12.31 | 2.68 | 1.47 | 13.43 | 7.91 | 16.50 | 2.28 | 8.45 |
| 70 | 13.83 | 21.21 | 5.40 | 15.13 | 7.71 | 9.24 | 11.25 | 23.26 | 5.49 | 8.61 | 8.33 | 9.61 |
| 71 | 7.59 | 4.91 | 10.82 | 8.74 | 6.29 | 15.39 | 2.85 | 5.05 | 8.24 | 26.82 | 5.25 | 2.51 |
| 72 | 4.09 | 11.03 | 5.51 | 9.07 | 5.18 | 3.15 | 16.72 | 18.86 | 17.46 | 14.18 | 10.44 | 8.07 |
| 73 | 31.70 | 21.63 | 9.94 | 16.90 | 12.42 | 4.46 | 21.81 | 16.25 | 14.04 | 13.38 | 8.10 | 5.51 |
| 74 | 7.19 | 13.57 | 11.05 | 24.06 | 3.85 | 12.42 | 12.82 | 8.07 | 21.88 | 5.97 | 6.54 | 12.59 |
| 75 | 24.47 | 7.07 | 20.44 | 12.44 | 5.42 | 6.01 | 7.62 | 4.07 | 10.16 | 12.18 | 3.40 | 7.86 |
| 76 | 10.67 | 3.88 | 13.36 | 12.47 | 5.61 | 4.89 | 8.01 | 12.53 | 3.75 | 5.37 | 5.96 | 6.53 |
| 77 | 21.47 | 9.04 | 4.95 | 8.91 | 15.23 | 5.07 | 13.06 | 4.67 | 15.96 | 7.56 | 10.16 | 4.78 |
| 78 | 10.80 | 9.58 | 13.25 | 10.73 | 4.90 | 8.39 | 4.86 | 2.34 | 18.64 | 17.96 | 8.58 | 16.47 |
| 79 | 19.69 | 17.50 | 25.50 | 8.27 | 14.70 | 4.75 | 13.35 | 9.13 | 5.36 | 8.94 | 4.80 | 2.78 |
| 80 | 10.06 | 17.15 | 12.26 | 3.19 | 3.90 | 0.59 | 15.96 | 10.73 | 6.98 | 5.61 | 2.35 | 9.72 |
| 81 | 12.89 | 7.95 | 18.95 | 15.21 | 11.11 | 10.59 | 7.26 | 14.67 | 4.64 | 1.58 | 14.12 | 6.06 |
| 82 | 8.40 | 11.09 | 10.24 | 17.51 | 12.43 | 4.01 | 0.55 | 7.14 | 21.39 | 41.84 | 2.86 | 7.41 |
| 83 | 7.06 | 14.31 | 21.19 | 11.67 | 11.14 | 2.74 | 2.22 | 7.86 | 13.95 | 14.10 | 3.27 | 13.93 |
| 84 | 12.06 | 9.02 | 21.94 | 3.58 | 11.44 | 14.85 | 14.16 | 56.00 | 20.18 | 12.69 | 6.59 | 11.68 |
| 85 | 19.52 | 14.15 | 7.98 | 7.21 | 2.45 | 4.37 | 4.78 | 10.17 | 25.47 | 7.52 | 1.20 | 6.59 |
| 86 | 9.19 | 16.62 | 10.69 | 20.54 | 2.17 | 24.79 | 5.81 | 14.36 | 9.25 | 8.64 | 6.99 | 13.23 |
| 87 | 8.11 | 2.68 | 13.82 | 10.44 | 6.40 | 7.86 | 10.90 | 4.90 | 22.34 | 26.77 | 5.20 | 8.76 |
| 88 | 12.35 | 11.83 | 3.43 | 6.84 | 13.92 | 7.40 | 8.34 | 11.07 | 23.37 | 8.70 | 9.14 | 21.69 |
| 89 | 18.39 | 4.96 | 19.23 | 10.16 | 22.34 | 4.00 | 13.13 | 2.74 | 4.21 | 2.99 | 16.15 | 19.16 |
| 90 | 21.93 | 17.65 | 32.65 | 3.52 | 6.43 | 3.91 | 14.73 | 15.31 | 6.48 | 17.34 |  |  |

| WYEAR | SPSPG2 (cm) | SPFALL2 (cm) | SPFALL3 (cm) | MAR30M (cm) | JUN30M (cm) | SPPSUM (cm) | SPPFALL (cm) | NCUT (%) | SCUTTOT (%) | SCUT (%) | SCUT5 (%) | SCUT10 (%) | SCUT3MA (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 42 | 16.33 | 23.76 | 26.71 | 1.03 | 0.50 | 20.84 | 7.50 | 0.35 | 0.04 | 0 | 0 | 0 | 0 |
| 43 | 4.19 | 8.94 | 10.63 | 0.21 | 4.34 | 6.67 | 8.19 | 0.14 | 0.16 | 0 | 0 | 0 | 0 |
| 44 | 25.92 | 17.28 | 28.88 | 4.63 | 1.46 | 24.29 | 8.08 | 0.38 | 0.23 | 0 | 0 | 0 | 0 |
| 45 | 28.39 | 35.73 | 47.92 | 7.78 | 0.75 | 53.41 | 6.75 | 0.12 | 0.40 | 0 | 0 | 0 | 0 |
| 46 | 32.97 | 7.85 | 18.94 | 0.76 | 3.51 | 15.38 | 18.37 | 0.05 | 0.16 | 0 | 0 | 0 | 0 |
| 47 | 4.97 | 13.65 | 15.10 | 0.16 | 0.68 | 10.73 | 10.48 | 0.08 | 0.03 | 0 | 0 | 0 | 0 |
| 48 | 21.98 | 12.88 | 28.82 | 3.03 | 0.90 | 21.06 | 9.31 | 0.21 | 0.01 | 0 | 0 | 0 | 0 |
| 49 | 42.20 | 11.69 | 18.23 | 1.01 | 4.14 | 15.29 | 15.14 | 0.00 | 0.07 | 0 | 0 | 0 | 0 |
| 50 | 45.51 | 28.90 | 46.81 | 1.08 | 1.29 | 36.66 | 5.35 | 0.02 | 0.25 | 0 | 0 | 0 | 0 |
| 51 | 25.06 | 23.66 | 35.87 | 1.07 | 0.13 | 33.25 | 18.70 | 0.33 | 0.06 | 0 | 0 | 0 | 0 |
| 52 | 20.20 | 14.32 | 25.02 | 0.78 | 1.16 | 15.21 | 23.24 | 0.00 | 0.14 | 0 | 0 | 0 | 0 |
| 53 | 16.55 | 7.31 | 19.40 | 0.56 | 0.67 | 11.21 | 7.29 | 0.03 | 0.03 | 0 | 0 | 0 | 0 |
| 54 | 18.84 | 8.46 | 10.29 | 0.26 | 0.53 | 4.96 | 14.04 | 0.01 | 0.00 | 0 | 0 | 0 | 0 |
| 55 | 11.95 | 19.56 | 26.36 | 0.72 | 2.35 | 18.77 | 5.85 | 0.32 | 0.00 | 0 | 0 | 0 | 0 |
| 56 | 37.44 | 6.73 | 18.33 | 1.52 | 2.13 | 18.68 | 9.51 | 0.12 | 0.10 | 0 | 0 | 0 | 0 |
| 57 | 24.10 | 33.46 | 42.29 | 1.01 | 2.49 | 33.74 | 19.16 | 0.15 | 0.17 | 0 | 0 | 0 | 0 |
| 58 | 10.94 | 19.87 | 31.62 | 0.67 | 0.73 | 33.06 | 18.76 | 0.20 | 0.18 | 0 | 0 | 0 | 0 |
| 59 | 14.54 | 19.70 | 35.02 | 1.12 | 0.37 | 34.36 | 8.66 | 0.12 | 0.12 | 0 | 0 | 0 | 0 |
| 60 | 15.90 | 21.85 | 32.43 | 0.76 | 1.61 | 30.92 | 8.93 | 0.52 | 0.51 | 0 | 0 | 0 | 0 |
| 61 | 14.55 | 17.70 | 28.73 | 2.51 | 0.97 | 24.02 | 11.97 | 0.04 | 0.02 | 0 | 0 | 0 | 0 |
| 62 | 24.16 | 24.52 | 32.52 | 4.10 | 1.55 | 25.45 | 10.86 | 0.02 | 0.37 | 0 | 0 | 0 | 0 |
| 63 | 4.39 | 3.52 | 23.15 | 0.38 | 1.06 | 17.35 | 10.74 | 0.02 | 0.25 | 0 | 0 | 0 | 0 |
| 64 | 9.42 | 27.39 | 33.15 | 0.44 | 0.73 | 23.06 | 10.17 | 1.25 | 0.13 | 0 | 0 | 0 | 0 |
| 65 | 24.04 | 31.23 | 38.99 | 0.85 | 1.94 | 32.05 | 2.61 | 0.62 | 0.50 | 0 | 0 | 0 | 0 |
| 66 | 23.30 | 20.52 | 27.42 | 1.41 | 0.57 | 14.67 | 8.63 | 0.13 | 0.30 | 0 | 0 | 0 | 0 |
| 67 | 9.03 | 25.70 | 40.70 | 0.30 | 9.12 | 32.22 | 11.55 | 0.87 | 0.53 | 0 | 0 | 0 | 0 |
| 68 | 11.13 | 17.38 | 33.78 | 1.07 | 2.29 | 28.91 | 15.95 | 0.26 | 0.92 | 0 | 0 | 0 | 0 |
| 69 | 26.09 | 4.15 | 16.46 | 1.35 | 1.95 | 15.90 | 15.98 | 0.27 | 0.26 | 0 | 0 | 0 | 0 |
| 70 | 10.73 | 20.49 | 28.20 | 1.01 | 1.41 | 29.08 | 20.60 | 0.35 | 0.25 | 0 | 0 | 0 | 0 |
| 71 | 17.93 | 18.24 | 24.53 | 0.88 | 0.77 | 17.92 | 7.67 | 0.23 | 0.23 | 0.23 | 2.07 | 3.62 | 0.30 |
| 72 | 7.75 | 19.87 | 25.05 | 0.25 | 0.65 | 17.04 | 28.02 | 0.36 | 0.41 | 0.41 | 1.95 | 3.67 | 1.21 |
| 73 | 18.51 | 26.27 | 38.69 | 0.73 | 0.86 | 35.31 | 22.34 | 0.53 | 2.97 | 2.98 | 4.01 | 6.39 | 2.28 |
| 74 | 13.61 | 25.24 | 29.10 | 0.61 | 1.65 | 34.69 | 22.41 | 0.48 | 3.45 | 3.45 | 7.21 | 9.72 | 3.25 |
| 75 | 19.13 | 13.63 | 19.04 | 0.98 | 2.41 | 15.78 | 9.12 | 0.74 | 3.33 | 3.34 | 10.41 | 12.55 | 2.73 |
| 76 | 11.26 | 12.91 | 18.52 | 0.68 | 1.68 | 15.02 | 9.70 | 0.50 | 1.39 | 1.39 | 11.57 | 13.64 | 1.75 |
| 77 | 12.49 | 18.13 | 33.36 | 0.95 | 0.61 | 23.30 | 13.94 | 0.59 | 0.51 | 0.51 | 11.67 | 13.62 | 1.16 |
| 78 | 14.93 | 13.25 | 18.15 | 1.06 | 0.78 | 16.02 | 16.16 | 0.17 | 1.57 | 1.58 | 10.27 | 14.28 | 0.79 |
| 79 | 25.06 | 18.10 | 32.80 | 2.91 | 2.56 | 28.38 | 10.63 | 0.26 | 0.29 | 0.29 | 7.10 | 14.31 | 1.14 |
| 80 | 7.58 | 16.55 | 20.45 | 0.12 | 1.11 | 15.25 | 12.66 | 0.29 | 1.55 | 1.55 | 5.32 | 15.73 | 1.95 |
| 81 | 12.07 | 17.85 | 28.95 | 1.20 | 3.37 | 28.51 | 12.74 | 1.08 | 3.99 | 4.00 | 7.92 | 19.49 | 2.96 |
| 82 | 20.17 | 4.56 | 16.99 | 1.30 | 1.44 | 22.16 | 21.28 | 0.66 | 3.32 | 3.33 | 10.74 | 22.41 | 3.14 |
| 83 | 10.27 | 4.96 | 16.10 | 0.63 | 1.28 | 17.88 | 14.92 | 0.45 | 2.09 | 2.09 | 11.26 | 21.53 | 2.80 |
| 84 | 17.20 | 29.01 | 40.44 | 3.12 | 2.16 | 27.90 | 62.72 | 1.15 | 2.96 | 2.96 | 13.94 | 21.04 | 2.01 |
| 85 | 18.26 | 9.15 | 11.60 | 1.64 | 1.63 | 7.89 | 27.33 | 0.40 | 0.97 | 0.97 | 13.36 | 18.67 | 2.05 |
| 86 | 7.79 | 30.60 | 32.78 | 0.28 | 0.65 | 38.08 | 14.97 | 0.61 | 2.22 | 2.23 | 11.59 | 19.51 | 1.49 |
| 87 | 20.23 | 18.76 | 25.15 | 5.29 | 1.95 | 19.44 | 19.75 | 0.04 | 1.28 | 1.29 | 9.54 | 20.28 | 1.42 |
| 88 | 13.96 | 15.74 | 29.66 | 0.62 | 0.33 | 21.72 | 25.54 | 0.00 | 0.76 | 0.76 | 8.21 | 19.47 | 0.90 |
| 89 | 30.83 | 17.13 | 39.47 | 2.98 | 2.01 | 31.22 | 3.00 | 0.02 | 0.64 | 0.65 | 5.89 | 19.83 | 0.96 |
| 90 | 35.31 | 18.64 | 25.07 | | | | | | 1.46 | 1.46 | 6.37 | 19.47 | |

| WYEAR | NQMAR (cm) | NQAPR (cm) | NQMAY (cm) | NQJUN (cm) | NQJUL (cm) | NQAUG (cm) | NQSEP (cm) | NQOCT (cm) | NQNOV (cm) | NQDEC (cm) | NQJAN (cm) | NQFEB (cm) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 42 | 7.61 | 10.78 | 7.78 | 1.80 | 0.41 | 0.64 | 2.45 | 0.18 | 1.94 | 3.58 | 1.32 | 0.48 |
| 43 | 4.27 | 4.18 | 7.31 | 1.58 | 0.18 | 0.00 | 0.00 | 0.01 | 0.60 | 2.36 | 4.45 | 13.38 |
| 44 | 12.21 | 10.86 | 10.04 | 2.20 | 0.19 | 0.06 | 0.15 | 0.00 | 0.75 | 8.57 | 3.46 | 19.28 |
| 45 | 40.97 | 5.87 | 10.07 | 12.16 | 1.45 | 0.79 | 3.33 | 4.48 | 1.64 | 1.02 | 13.31 | 12.06 |
| 46 | 5.72 | 8.69 | 19.36 | 3.40 | 0.26 | 0.08 | 0.01 | 0.01 | 8.45 | 11.48 | 1.84 | 0.57 |
| 47 | 1.72 | 3.62 | 4.09 | 0.32 | 0.01 | 0.00 | 0.23 | 0.11 | 0.50 | 5.47 | 10.01 | 11.30 |
| 48 | 7.39 | 6.00 | 3.44 | 0.38 | 0.48 | 0.54 | 0.05 | 0.01 | 0.47 | 2.41 | 23.37 | 9.50 |
| 49 | 8.39 | 3.15 | 7.79 | 4.38 | 0.31 | 0.05 | 0.04 | 0.68 | 0.36 | 2.41 | 23.37 | 17.97 |
| 50 | 3.39 | 3.53 | 14.70 | 1.02 | 5.70 | 3.14 | 5.61 | 0.82 | 0.49 | 0.27 | 2.16 | 11.13 |
| 51 | 3.20 | 2.41 | 2.11 | 3.06 | 2.86 | 0.20 | 0.18 | 1.51 | 7.83 | 4.76 | 5.67 | 3.39 |
| 52 | 9.61 | 26.79 | 3.43 | 0.41 | 0.02 | 0.00 | 0.00 | 0.00 | 5.88 | 4.45 | 4.80 | 4.00 |
| 53 | 9.70 | 12.99 | 10.79 | 0.19 | 0.36 | 0.11 | 0.01 | 0.00 | 0.01 | 0.02 | 3.71 | 2.68 |
| 54 | 0.71 | 2.88 | 10.39 | 0.19 | 0.01 | 0.00 | 0.00 | 2.60 | 0.73 | 2.50 | 2.46 | 5.86 |
| 55 | 8.81 | 4.88 | 2.48 | 0.58 | 0.06 | 0.01 | 0.00 | 0.00 | 0.01 | 0.01 | 0.34 | 9.01 |
| 56 | 2.37 | 2.05 | 2.01 | 0.11 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 | 0.84 | 4.42 | 5.15 |
| 57 | 7.19 | 28.20 | 13.37 | 8.82 | 0.21 | 0.97 | 0.88 | 0.26 | 3.08 | 1.29 | 2.88 | 1.48 |
| 58 | 11.66 | 9.91 | 13.26 | 3.02 | 1.11 | 0.25 | 0.10 | 0.34 | 5.71 | 1.18 | 2.49 | 2.69 |
| 59 | 8.97 | 7.11 | 0.79 | 0.59 | 0.21 | 0.14 | 0.02 | 0.84 | 0.58 | 10.48 | 6.44 | 4.04 |
| 60 | 4.81 | 1.31 | 20.01 | 0.88 | 1.35 | 0.32 | 0.04 | 0.06 | 0.18 | 8.92 | 3.40 | 5.32 |
| 61 | 12.42 | 4.96 | 5.92 | 3.91 | 2.47 | 0.49 | 0.40 | 0.59 | 3.72 | 6.41 | 5.89 | 6.18 |
| 62 | 5.99 | 3.59 | 0.71 | 0.23 | 0.08 | 0.04 | 0.23 | 0.54 | 0.46 | 0.44 | 0.41 | 0.17 |
| 63 | 6.89 | 1.15 | 1.54 | 0.37 | 0.06 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.21 |
| 64 | 5.99 | 4.54 | 1.96 | 0.08 | 0.00 | 0.16 | 1.40 | 0.48 | 3.83 | 1.48 | 5.01 | 7.59 |
| 65 | 7.95 | 2.96 | 3.91 | 3.22 | 0.36 | 0.04 | 2.32 | 0.40 | 0.19 | 0.19 | 1.20 | 6.65 |
| 66 | 1.59 | 9.10 | 6.59 | 0.23 | 0.04 | 0.09 | 0.15 | 0.02 | 0.01 | 0.07 | 0.29 | 0.49 |
| 67 | 1.59 | 7.31 | 8.52 | 1.59 | 1.08 | 0.47 | 0.50 | 2.24 | 1.76 | 9.14 | 5.04 | 4.66 |
| 68 | 15.71 | 12.53 | 22.18 | 1.33 | 0.44 | 0.30 | 0.08 | 0.08 | 5.34 | 11.57 | 10.43 | 9.43 |
| 69 | 4.41 | 2.81 | 4.93 | 3.55 | 13.96 | 0.66 | 0.06 | 0.14 | 1.93 | 5.21 | 3.24 | 3.52 |
| 70 | 9.46 | 12.21 | 2.59 | 0.57 | 0.13 | 0.06 | 0.08 | 4.21 | 1.79 | 1.66 | 3.29 | 4.56 |
| 71 | 3.42 | 2.06 | 1.80 | 0.35 | 0.06 | 0.29 | 0.03 | 0.65 | 0.28 | 21.51 | 2.09 | 1.48 |
| 72 | 0.71 | 4.72 | 1.82 | 0.04 | 0.05 | 0.00 | 0.02 | 5.41 | 16.87 | 6.06 | 8.37 | 6.02 |
| 73 | 20.52 | 17.17 | 8.14 | 8.54 | 1.07 | 0.22 | 1.98 | 6.51 | 7.66 | 8.45 | 4.67 | 2.10 |
| 74 | 6.58 | 2.30 | 5.71 | 16.70 | 0.16 | 0.14 | 5.56 | 0.85 | 12.21 | 5.40 | 2.86 | 9.64 |
| 75 | 16.27 | 3.90 | 7.30 | 4.44 | 0.34 | 0.13 | 0.21 | 0.06 | 0.06 | 2.40 | 1.26 | 1.00 |
| 76 | 3.77 | 1.33 | 0.78 | 0.34 | 0.06 | 0.04 | 0.01 | 0.21 | 0.44 | 1.55 | 3.02 | 3.10 |
| 77 | 17.03 | 2.93 | 0.36 | 0.27 | 0.07 | 0.05 | 0.10 | 0.11 | 0.32 | 0.69 | 1.50 | 2.46 |
| 78 | 6.79 | 1.89 | 4.45 | 0.62 | 0.09 | 0.01 | 0.00 | 0.00 | 1.59 | 3.53 | 5.84 | 10.46 |
| 79 | 10.98 | 15.15 | 15.08 | 6.79 | 1.63 | 0.80 | 0.13 | 0.04 | 0.40 | 4.49 | 1.87 | 2.60 |
| 80 | 2.29 | 4.82 | 7.39 | 0.44 | 0.02 | 0.00 | 0.62 | 1.92 | 0.88 | 3.65 | 0.29 | 2.29 |
| 81 | 5.94 | 2.41 | 8.27 | 8.76 | 2.85 | 1.71 | 0.55 | 1.88 | 1.67 | 1.05 | 6.04 | 8.41 |
| 82 | 9.07 | 4.22 | 5.67 | 4.03 | 0.31 | 0.39 | 0.02 | 0.00 | 9.14 | 25.79 | 1.93 | 4.15 |
| 83 | 4.01 | 6.05 | 12.52 | 1.59 | 3.21 | 0.14 | 0.02 | 0.00 | 0.73 | 5.94 | 1.39 | 7.01 |
| 84 | 10.21 | 4.19 | 8.24 | 0.30 | 0.09 | 0.05 | 0.11 | 25.05 | 12.22 | 9.66 | 5.54 | 9.88 |
| 85 | 12.07 | 8.56 | 1.85 | 0.91 | 0.11 | 0.05 | 0.01 | 0.33 | 13.30 | 5.30 | 0.76 | 5.74 |
| 86 | 1.56 | 10.58 | 6.37 | 11.56 | 0.82 | 0.17 | 0.32 | 0.59 | 1.96 | 2.70 | 3.19 | 3.90 |
| 87 | 11.21 | 1.60 | 3.14 | 1.18 | 0.07 | 0.02 | 0.00 | 0.00 | 4.11 | 18.16 | 5.18 | 2.89 |
| 88 | 3.75 | 5.99 | 0.37 | 0.06 | 0.02 | 0.10 | 0.06 | 0.01 | 4.03 | 2.94 | 5.54 | 15.12 |
| 89 | 6.71 | 3.06 | 7.60 | 7.97 | 2.95 | 0.38 | 0.35 | 0.05 | 0.05 | 0.06 | 4.84 | 7.40 |
| 90 | 8.86 | 13.14 | 35.23 | 2.29 | 0.08 | 0.07 | 0.28 |  |  |  |  |  |

| WYEAR | NQSPG (cm) | NQSUM (cm) | NQFALL (cm) | NQWTR (cm) | DSPG (cm) | DSUM (cm) | DFALL (cm) | DWTR (cm) |
|---|---|---|---|---|---|---|---|---|
| 42 | 26.17 | 5.31 | 2.11 | 5.38 | 4.59 | 1.33 | -5.35 | 4.58 |
| 43 | 15.77 | 1.76 | 0.61 | 20.18 | 1.04 | -0.93 | -4.14 | -1.07 |
| 44 | 33.11 | 2.60 | 0.76 | 31.31 | 9.53 | 9.11 | -5.07 | 2.81 |
| 45 | 56.91 | 17.73 | 6.12 | 26.39 | -2.68 | -3.49 | -1.77 | 3.91 |
| 46 | 33.77 | 3.75 | 8.46 | 13.89 | -9.23 | -1.86 | -10.95 | -3.60 |
| 47 | 9.43 | 0.57 | 0.61 | 26.78 | -4.42 | -17.20 | 4.08 | -7.88 |
| 48 | 16.82 | 1.44 | 0.48 | 35.29 | -4.79 | 1.28 | 2.44 | 2.06 |
| 49 | 19.34 | 4.79 | 1.04 | 43.75 | 0.18 | -6.11 | 3.11 | -1.80 |
| 50 | 21.61 | 15.46 | 1.31 | 13.56 | -5.12 | -9.94 | -0.67 | 0.05 |
| 51 | 7.73 | 6.30 | 9.35 | 13.82 | -1.76 | -1.73 | -1.05 | 5.11 |
| 52 | 39.83 | 0.43 | 5.88 | 13.25 | -5.66 | 3.50 | 0.83 | 9.91 |
| 53 | 33.48 | 0.68 | 0.01 | 6.41 | -2.62 | -8.40 | -0.87 | 0.82 |
| 54 | 13.99 | 0.20 | 3.33 | 10.83 | -1.53 | -4.10 | -7.70 | -0.57 |
| 55 | 16.16 | 0.64 | 0.01 | 9.36 | 11.97 | 6.17 | 1.11 | 11.25 |
| 56 | 6.44 | 0.13 | 0.00 | 10.40 | 2.20 | -1.84 | 0.07 | 1.42 |
| 57 | 48.76 | 10.88 | 3.35 | 5.65 | 0.06 | 10.19 | 7.68 | 2.62 |
| 58 | 34.83 | 4.48 | 6.05 | 6.36 | 1.11 | 2.74 | -2.50 | 5.44 |
| 59 | 16.86 | 0.96 | 1.42 | 20.96 | -11.75 | 17.33 | -4.99 | 0.62 |
| 60 | 26.14 | 2.59 | 0.24 | 17.64 | -8.10 | 6.23 | 3.22 | -4.13 |
| 61 | 23.30 | 7.26 | 4.31 | 18.47 | 9.71 | -10.70 | -0.74 | 6.29 |
| 62 | 10.29 | 0.58 | 0.99 | 1.03 | 2.54 | 5.50 | 2.39 | 1.75 |
| 63 | 9.58 | 0.45 | 0.00 | 0.21 | 0.80 | 3.84 | 8.44 | -0.71 |
| 64 | 12.49 | 1.65 | 4.31 | 14.08 | 7.54 | -0.38 | -1.75 | 4.57 |
| 65 | 14.81 | 5.95 | 0.59 | 8.04 | 6.77 | -3.12 | -1.30 | 5.59 |
| 66 | 17.27 | 0.51 | 0.03 | 0.84 | 6.45 | 0.75 | 4.16 | 7.87 |
| 67 | 17.42 | 3.64 | 3.99 | 18.83 | 5.83 | 5.90 | -1.40 | -1.71 |
| 68 | 50.42 | 2.14 | 5.41 | 31.43 | -6.47 | 8.88 | -2.58 | 8.00 |
| 69 | 12.15 | 18.23 | 2.06 | 11.97 | -1.57 | -26.45 | 0.43 | 6.06 |
| 70 | 24.27 | 0.84 | 6.00 | 9.50 | 1.85 | 8.98 | 5.32 | 5.29 |
| 71 | 7.28 | 0.72 | 0.93 | 25.07 | -0.57 | -1.90 | -2.46 | -7.14 |
| 72 | 7.26 | 0.11 | 22.29 | 20.45 | 0.85 | 6.49 | -5.96 | 6.85 |
| 73 | 45.83 | 11.82 | 14.17 | 15.22 | -1.52 | -5.18 | -0.79 | 5.60 |
| 74 | 14.59 | 22.56 | 13.06 | 17.90 | -5.77 | -12.06 | 1.86 | 0.68 |
| 75 | 27.47 | 5.12 | 0.12 | 4.67 | 6.63 | -6.87 | 3.46 | 5.40 |
| 76 | 5.88 | 0.45 | 0.65 | 7.67 | 0.24 | 2.60 | -1.29 | -0.24 |
| 77 | 20.32 | 0.50 | 0.43 | 4.65 | -1.86 | 0.25 | 5.95 | 6.29 |
| 78 | 13.14 | 0.73 | 1.59 | 19.82 | 2.13 | 8.51 | -0.09 | 7.63 |
| 79 | 41.22 | 9.35 | 0.44 | 8.96 | 0.04 | -0.75 | 0.60 | -3.31 |
| 80 | 14.50 | 1.08 | 2.81 | 6.23 | 5.48 | -2.68 | 2.76 | 1.58 |
| 81 | 16.62 | 13.88 | 3.55 | 15.50 | -0.97 | -11.29 | 0.16 | -2.26 |
| 82 | 18.96 | 4.74 | 9.14 | 31.87 | -7.22 | 5.13 | 2.52 | 10.00 |
| 83 | 22.58 | 4.96 | 0.73 | 14.34 | -1.04 | -3.64 | -0.54 | 4.02 |
| 84 | 22.64 | 0.54 | 37.27 | 25.08 | 4.88 | 3.56 | 14.83 | 1.27 |
| 85 | 22.48 | 1.09 | 13.63 | 11.80 | 1.86 | -19.89 | 0.27 | -3.56 |
| 86 | 18.51 | 12.87 | 2.55 | 9.80 | -3.43 | -2.91 | 2.68 | 4.69 |
| 87 | 15.95 | 1.26 | 4.11 | 26.23 | -10.20 | 5.16 | 2.52 | 6.03 |
| 88 | 10.11 | 0.24 | 4.04 | 23.59 | 2.60 | 6.46 | 4.32 | 4.43 |
| 89 | 17.37 | 11.65 | 0.10 | 12.30 | 5.37 | 0.96 | 2.53 | 4.35 |
| 90 | 57.23 | 2.72 |  |  | -5.47 | -4.08 | -3.04 |  |

| WYEAR | DMAR (cm) | DAPR (cm) | DMAY (cm) | DJUN (cm) | DJUL (cm) | DAUG (cm) | DSEP (cm) | DOCT (cm) | DNOV (cm) | DDEC (cm) | DJAN (cm) | DFEB (cm) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 42 | 3.11 | 6.10 | -4.62 | 3.09 | -2.86 | 1.81 | -0.72 | -1.46 | -3.89 | 3.17 | 0.92 | 0.49 |
| 43 | 2.69 | -0.63 | -1.02 | -3.50 | 1.09 | 0.75 | 0.73 | -3.90 | -0.24 | 1.98 | -2.89 | -0.16 |
| 44 | 2.38 | 6.33 | 0.82 | -0.86 | 6.17 | 4.76 | -0.97 | -0.60 | -4.47 | 3.56 | 0.06 | -0.81 |
| 45 | -6.12 | 5.96 | -2.52 | -0.94 | 3.31 | -2.66 | -3.19 | -3.05 | 1.28 | 1.40 | 1.89 | 0.62 |
| 46 | 6.06 | -1.38 | -13.91 | 0.44 | -0.57 | 0.93 | -2.66 | -1.90 | -9.05 | -3.56 | 0.31 | -0.35 |
| 47 | -0.98 | -0.04 | -3.40 | -0.20 | 0.05 | -8.04 | -9.01 | 1.02 | 3.06 | -0.74 | -4.58 | -2.56 |
| 48 | -0.07 | -0.90 | -3.82 | 1.81 | 1.08 | -0.43 | -1.18 | -2.79 | 5.23 | 1.85 | 4.21 | -4.00 |
| 49 | 2.67 | -3.45 | 0.96 | -2.61 | 2.91 | -4.31 | -2.10 | 3.13 | -0.02 | 1.89 | -2.91 | -0.77 |
| 50 | -0.28 | -3.63 | -1.22 | 0.71 | -8.63 | 4.62 | -6.65 | -0.57 | -0.10 | 0.50 | 4.19 | -4.64 |
| 51 | 0.66 | -1.28 | -1.15 | -2.92 | -3.80 | 5.13 | -0.14 | -2.95 | 1.90 | -0.24 | 3.91 | 1.43 |
| 52 | 1.33 | -6.60 | -0.39 | 0.11 | 3.62 | 3.09 | -3.31 | -0.44 | 1.27 | 6.07 | 2.48 | 1.37 |
| 53 | -2.05 | -2.18 | 1.62 | -0.15 | -8.04 | -0.92 | 0.71 | -1.15 | 0.28 | 0.26 | 0.59 | -0.02 |
| 54 | 1.06 | -4.19 | 1.60 | -0.51 | -0.64 | -3.39 | 0.44 | -8.68 | 0.98 | -0.96 | -0.55 | 0.94 |
| 55 | 3.14 | 0.13 | 8.69 | 0.54 | 1.69 | -1.88 | 5.83 | 2.81 | -1.70 | -0.03 | 7.76 | 3.52 |
| 56 | -0.32 | 2.54 | -0.01 | 0.85 | -0.35 | -4.11 | 1.76 | 2.01 | -1.94 | -0.98 | 2.73 | -0.32 |
| 57 | 0.97 | -1.86 | 0.95 | 4.45 | 1.22 | 8.82 | -4.29 | 2.89 | 4.79 | 2.01 | 1.51 | -0.90 |
| 58 | -2.02 | 0.72 | 2.41 | -0.40 | 0.61 | -2.40 | 4.92 | -4.26 | 1.77 | 0.19 | -0.70 | 5.96 |
| 59 | -3.54 | -5.15 | -3.05 | 7.80 | 0.66 | 0.55 | 8.32 | -4.92 | -0.07 | 0.05 | 2.37 | -1.80 |
| 60 | 1.18 | -1.79 | -7.49 | 1.25 | -5.39 | 1.06 | 9.30 | 2.19 | 1.03 | -6.36 | 0.40 | 1.83 |
| 61 | 4.83 | 3.16 | 1.72 | -2.14 | -7.79 | -1.05 | 0.27 | -1.34 | 0.60 | 2.54 | -0.04 | 3.79 |
| 62 | 1.44 | 0.11 | 1.00 | 1.12 | -2.10 | -0.31 | 6.78 | 1.57 | 0.82 | 0.47 | 0.32 | 0.96 |
| 63 | 4.05 | 0.49 | -3.74 | -2.23 | 11.31 | -2.66 | -2.58 | -0.21 | 8.65 | -0.17 | 0.06 | -0.60 |
| 64 | 5.17 | 2.33 | 0.05 | -0.58 | 0.98 | -3.33 | 2.55 | 0.88 | -2.62 | 0.20 | 3.25 | 1.12 |
| 65 | 4.11 | 2.13 | 0.53 | -7.07 | 1.13 | 0.46 | 2.36 | -1.36 | 0.06 | 0.84 | 7.35 | -2.60 |
| 66 | 0.11 | 6.62 | -0.29 | -0.81 | -4.16 | 6.84 | -1.11 | 3.10 | 1.05 | 5.71 | 0.92 | 1.24 |
| 67 | 1.02 | -2.64 | 7.45 | -0.81 | 0.26 | 5.85 | 0.60 | -3.71 | 2.32 | 1.11 | -1.87 | -0.96 |
| 68 | -4.90 | -5.16 | 3.59 | 1.58 | 7.58 | 0.98 | -1.28 | 1.54 | -4.11 | 2.92 | 3.87 | 1.21 |
| 69 | 0.87 | -2.34 | -0.10 | -2.15 | -20.16 | -0.89 | -3.25 | -0.31 | 0.73 | 4.18 | 0.53 | 1.35 |
| 70 | 2.64 | -0.51 | -0.29 | 4.23 | 3.74 | 3.20 | -2.18 | 4.05 | 1.27 | 2.45 | 1.30 | 1.54 |
| 71 | 0.39 | -1.79 | 0.83 | -1.14 | -4.52 | 5.46 | -1.70 | -4.52 | 2.06 | -6.08 | 0.03 | -1.08 |
| 72 | 1.18 | -0.93 | 0.60 | 5.10 | -0.34 | 0.27 | 1.45 | -3.10 | -2.86 | 5.03 | 0.98 | 0.84 |
| 73 | 2.09 | 0.72 | -4.33 | -6.68 | -1.88 | 1.86 | 1.53 | -1.94 | 1.15 | 2.65 | 0.99 | 1.96 |
| 74 | -2.54 | -0.45 | -2.78 | -0.15 | -2.27 | 0.01 | -9.64 | -0.75 | 2.61 | -0.42 | -0.57 | 1.67 |
| 75 | 3.64 | -0.38 | 3.36 | -0.46 | -2.34 | -1.62 | -2.44 | 2.09 | 1.37 | 0.83 | 1.33 | 3.24 |
| 76 | 0.22 | -2.58 | 2.59 | 3.08 | 1.48 | 0.14 | -2.09 | -1.08 | -0.22 | -0.49 | -0.06 | 0.31 |
| 77 | -3.11 | 1.78 | -0.52 | -2.07 | 5.46 | -2.85 | -0.29 | -0.33 | 6.28 | 3.70 | 4.54 | -1.94 |
| 78 | 0.26 | 1.59 | 0.28 | 4.37 | -0.32 | 2.79 | 1.67 | 0.99 | -1.08 | 4.24 | 1.72 | 1.67 |
| 79 | 3.51 | -1.30 | -2.17 | -3.27 | -1.19 | -1.69 | 5.39 | -1.02 | 1.61 | -4.22 | 0.41 | 0.50 |
| 80 | 2.45 | 6.55 | -3.52 | 0.63 | 0.13 | -0.08 | -3.36 | 0.74 | 2.03 | -0.39 | 0.02 | 1.95 |
| 81 | 2.19 | -0.32 | -2.84 | 0.15 | -12.77 | -0.73 | 2.06 | 1.27 | -1.11 | 0.14 | 0.23 | -2.64 |
| 82 | 0.44 | 0.52 | -8.18 | 5.68 | 2.18 | -2.69 | -0.04 | 1.11 | 1.41 | 10.93 | -0.72 | -0.21 |
| 83 | -0.08 | 2.38 | -3.34 | 0.19 | -1.91 | -0.48 | -1.43 | -1.06 | 0.51 | 2.70 | -0.20 | 1.52 |
| 84 | -1.34 | 3.06 | 3.16 | 0.20 | -0.59 | 4.83 | -0.88 | 11.68 | 3.15 | 0.18 | -0.51 | 1.60 |
| 85 | 3.76 | -0.58 | -1.32 | -6.40 | -3.91 | -4.61 | -4.97 | -4.17 | 4.44 | 1.53 | -0.83 | -4.26 |
| 86 | 4.29 | -3.42 | -4.30 | -10.35 | 0.43 | 11.76 | -4.75 | 4.19 | -1.51 | 0.90 | 2.05 | 1.73 |
| 87 | -5.72 | 1.37 | -5.85 | 5.54 | -1.97 | 0.14 | 1.45 | -0.26 | 2.79 | 1.52 | 0.98 | 3.52 |
| 88 | 1.98 | 1.84 | -1.22 | 1.79 | 4.63 | -1.01 | 1.05 | 3.44 | 0.87 | 0.48 | 0.44 | 3.51 |
| 89 | 7.93 | -4.39 | 1.83 | -5.46 | 4.28 | 0.75 | 1.39 | 0.33 | 2.20 | -1.45 | -0.69 | 6.48 |
| 90 | 4.95 | 0.92 | -11.34 | 0.59 | -4.12 | -0.61 | 0.06 | 0.10 | -3.14 | 3.73 |  |  |

* Variables defined:

SQ: Indicates yield (Q) from South Fourche watershed (S) for period of interest.
SP: Indicates rainfall (P) on South Fourche watershed (S) for period of interest.
NQ: Indicates yield (Q) from [North] Fourche (control) watershed (N) for period of interest.
NP: Indicates rainfall (P) on [North] Fourche (control) watershed (N) for period of interest.
D : Indicates difference in rainfall between the watersheds (S-N) for period of interest

SPSPG2: Cumulative rainfall for 2 months prior to start of spring in March.
SPFALL2: Cumulative rainfall for 2 months prior to start of fall in October.
SPFALL3: Cumulative rainfall for 3 months prior to start of fall in October.
MAR30M: Antecedent precipitation index for 30-day period prior to start of spring in March.
JUN30M: Antecedent precipitation index for 30-day period prior to start of summer in June
SPPSUM: "Effective" precipitation variable used as an alternative to SPSUM, the total summer rainfall.
SPPFALL. "Effective" precipitation variable used as an alternative to SPFALL, the total fall rainfall.
NCUT: Total annual harvest on control watershed, % of basin area (not used in the analysis)
SCUT_TOT: Total annual harvest on study watershed, % of basin area (not used in the analysis).
SCUT  Total annual harvest on study watershed, % of basin area (used in the analysis).
SCUT5: Plantation area in ages from 0 to 5 years, % of basin area (used in the analysis).
SCUT10: Plantation area in ages from 0 to 10 years, % of basin area (used in the analysis)
SCUT3MA· Three-year moving average of total annual harvest, % of basin area (used in the analysis).

T: Indicator or dummy variable: T=0 for calibration period, T=1 for postcalibration period.
WT43: A weighting variable for use in regression analysis: WT43=0 for 1982 observations, WT43=1 otherwise.
WYEAR: Water year. A stepping variable with initial value WYEAR=42 for year 1942.
TIME: A stepping variable with initial value TIME=1 for the first year of the postcalibration period.

Period of interest:
MF: Indicates annual water yield or rainfall for the March-February (MF) water year.
GROW: Growing season (March-September).
DORM: Dormant season (October-February).
SPG: Spring (March-May).
SUM· Summer (June-September).
FALL: Fall (October-November).
WTR: Winter (December-February).
JAN, FEB,..., NOV, DEC: Calender months.

# APPENDIX C

# DATA USED TO DEVELOP ANNUAL PEAK FLOW REGRESSION MODELS

Data* Used to Develop Annual Peak Flow Regression Models

| T | TQPA | DAYSA | DATESA | TIMESA | SQPA (m$^3$/s) | SQPA+ (m$^3$/s) | SPA3 (cm) | SPA2 (cm) | SPA1 (cm) | SPA (cm) |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 27-Apr-42 | 15458 | | 841.01 | 841.01 | 10.43 | 10.43 | 7.42 | 4.41 |
| 0 | 0 | 27-Dec-42 | 15702 | | 523.86 | 523.86 | 6.68 | 6.68 | 6.68 | 5.18 |
| 0 | 0 | 23-Apr-44 | 16185 | | 1330.89 | 1330.89 | 12.80 | 9.96 | 9.96 | 9.96 |
| 0 | 1 | 30-Mar-45 | 16526 | | 1540.44 | 1540.44 | 17.22 | 17.22 | 17.22 | 10.97 |
| 0 | 0 | 28-Mar-46 | 16889 | | 628.63 | 628.63 | 10.21 | 9.80 | 8.66 | 8.48 |
| 0 | 1 | 12-Dec-46 | 17148 | | 603.15 | 603.15 | 11.15 | 10.26 | 6.53 | 5.79 |
| 0 | 0 | 13-Apr-48 | 17636 | | 413.43 | 413.43 | 10.11 | 5.05 | 4.95 | 1.37 |
| 0 | 1 | 24-Jan-49 | 17922 | | 869.33 | 869.33 | 7.39 | 7.32 | 6.96 | 6.25 |
| 0 | 0 | 02-Jan-50 | 18265 | | 515.37 | 515.37 | 0.67 | 0.67 | 0.66 | 0.5 |
| 0 | 1 | 15-Feb-51 | 18674 | | 348.30 | 348.30 | 4.75 | 4.75 | 4.75 | 2.97 |
| 0 | 1 | 22-Apr-52 | 19106 | | 518.20 | 518.20 | 6.86 | 6.65 | 6.58 | 4.72 |
| 0 | 0 | 04-Dec-52 | 19332 | | 798.54 | 798.54 | 9.91 | 9.12 | 7.26 | 5.99 |
| 0 | 1 | 02-May-54 | 19846 | | 917.47 | 917.47 | 6.83 | 6.17 | 5.89 | 4.37 |
| 0 | 1 | 20-Mar-55 | 20168 | | 540.85 | 540.85 | 6.40 | 6.15 | 4.04 | 0.99 |
| 0 | 0 | 29-Jan-56 | 20483 | | 481.39 | 481.39 | 8.99 | 8.94 | 8.64 | 8.56 |
| 0 | 1 | 03-Apr-57 | 20913 | | 679.60 | 679.60 | 7.14 | 4.80 | 3.40 | 3.20 |
| 0 | 1 | 02-May-58 | 21307 | | 679.60 | 679.60 | 8.97 | 5.92 | 5.87 | 3.81 |
| 0 | 0 | 14-Feb-59 | 21595 | | 334.14 | 334.14 | 6.45 | 6.45 | 6.38 | 5.08 |
| 0 | 1 | 20-May-60 | 22056 | | 744.73 | 744.73 | 11.05 | 11.05 | 11.00 | 6.91 |
| 0 | 1 | 11-Dec-60 | 22261 | | 317.15 | 317.15 | 5.56 | 5.13 | 5.13 | 4.78 |
| 0 | 0 | 26-Feb-62 | 22703 | | 283.17 | 283.17 | 8.26 | 5.82 | 3.51 | 3.35 |
| 0 | 0 | 16-Jul-63 | 23208 | | 812.69 | 812.69 | 8.28 | 8.10 | 6.35 | 3.43 |
| 0 | 1 | 09-Mar-64 | 23445 | | 1070.38 | 1070.38 | 11.00 | 11.00 | 11.00 | 9.09 |
| 0 | 0 | 22-Sep-65 | 24007 | | 538.02 | 538.02 | 13.92 | 13.92 | 13.92 | 13.36 |
| 0 | 0 | 24-Apr-66 | 24221 | | 1070.38 | 1070.38 | 15.85 | 15.16 | 15.16 | 8.56 |
| 0 | 0 | 31-May-67 | 24623 | | 413.43 | 413.43 | 8.36 | 8.36 | 8.36 | 7.77 |
| 0 | 1 | 14-May-68 | 24972 | | 605.98 | 605.98 | 17.02 | 13.59 | 11.68 | 6.73 |
| 0 | 0 | 30-Jan-69 | 25233 | | 1053.39 | 1053.39 | 13.72 | 13.69 | 13.61 | 10.95 |
| 0 | 1 | 19-Apr-70 | 25677 | | 487.05 | 487.05 | 12.04 | 11.91 | 6.50 | 6.50 |
| 0 | 1 | 27-Oct-70 | 25868 | | 515.37 | 515.37 | 12.37 | 9.42 | 9.42 | 9.42 |
| 1 | 1 | 10-Dec-71 | 26277 | 71 | 991.09 | 991.09 | 17.65 | 15.77 | 15.77 | 10.34 |
| 1 | 0 | 02-Mar-73 | 26725 | 519 | 433.25 | 433.25 | 6.93 | 6.93 | 6.93 | 6.68 |
| 1 | 1 | 07-Jun-74 | 27187 | 981 | 809.86 | 809.86 | 12.80 | 12.80 | 8.81 | 7.57 |
| 1 | 1 | 28-Mar-75 | 27481 | 1275 | 858.00 | 858.00 | 8.46 | 8.46 | 8.38 | 6.02 |
| 1 | 0 | 29-Dec-75 | 27757 | 1551 | 192.55 | 192.55 | 5.49 | 3.86 | 3.86 | 3.84 |
| 1 | 1 | 28-Mar-77 | 28212 | 2006 | 622.97 | 560.67 | 12.14 | 11.96 | 11.96 | 8.74 |
| 1 | 0 | 01-Nov-77 | 28430 | 2224 | 128.06 | 115.25 | 2.36 | 2.36 | 2.31 | 1.68 |
| 1 | 0 | 03-Dec-78 | 28827 | 2621 | 868.38 | 781.55 | 2.97 | 2.97 | 2.97 | 2.97 |
| 1 | 1 | 24-Dec-79 | 29213 | 3007 | 254.22 | 228.80 | 6.43 | 6.43 | 5.38 | 4.78 |
| 1 | 1 | 07-Jun-81 | 29744 | 3538 | 203.37 | 178.96 | 6.76 | 5.36 | 3.71 | 1.22 |
| 1 | 0 | 14-Mar-82 | 30024 | 3818 | 402.23 | 353.96 | 4.88 | 4.88 | 4.88 | 4.88 |
| 1 | 0 | 03-Dec-82 | 30288 | 4082 | 3024.75 | 2661.78 | 24.77 | 24.77 | 24.74 | 23.93 |
| 1 | 0 | 23-Sep-84 | 30948 | 4742 | 379.70 | 334.14 | 3.40 | 3.40 | 3.40 | 2.21 |
| 1 | 0 | 20-Oct-84 | 30975 | 4769 | 1007.18 | 886.32 | 19.96 | 18.80 | 12.62 | 10.59 |
| 1 | 1 | 27-Nov-85 | 31378 | 5172 | 1013.61 | 891.98 | 17.27 | 17.27 | 17.12 | 16.87 |
| 1 | 1 | 17-Mar-87 | 31853 | 5647 | 231.04 | 203.31 | 1.45 | 1.45 | 1.45 | 1.45 |
| 1 | 1 | 26-Dec-87 | 32137 | 5931 | 431.19 | 379.45 | 12.85 | 12.85 | 12.29 | 7.42 |
| 1 | 0 | 29-Mar-89 | 32596 | 6390 | 402.23 | 353.96 | 7.97 | 7.97 | 6.89 | 6.65 |
| 1 | 0 | 02-May-90 | 32995 | 6789 | 466.58 | 410.59 | 14.92 | 14.92 | 14.78 | 4.94 |

| TQPA | DAYNA | NQPA ($m^3/s$) | NPA3 (cm) | NPA2 (cm) | NPA1 (cm) | NPA (cm) | DPA3 (cm) | DPA2 (cm) | DPA1 (cm) | DPA (cm) |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 31-Oct-41 | 824.02 | 6.07 | 6.07 | 6.07 | 2 86 | 4.36 | 4.36 | 1.35 | 1.55 |
| 0 | 20-May-43 | 319.98 | 5.85 | 5.85 | 5.85 | 5.81 | 0.83 | 0.83 | 0.83 | -0.62 |
| 0 | 02-May-44 | 481.39 | 9.14 | 9.14 | 5.95 | 2.49 | 3.66 | 0.82 | 4.00 | 7.47 |
| 1 | 29-Mar-45 | 1076.04 | 8.96 | 8.87 | 8.87 | 8.87 | 8.27 | 8.35 | 8.35 | 2 10 |
| 0 | 14-Feb-46 | 713.58 |  |  | 7.47 | 4.57 |  |  | 1.19 | 3.91 |
| 1 | 12-Dec-46 | 815.53 | 16.73 | 16.44 | 10.48 | 7.69 | -5 58 | -6.18 | -3.96 | -1.90 |
| 0 | 01-Jan-48 | 1127.01 |  |  | 7.19 | 4.26 |  |  | -2.25 | -2.90 |
| 1 | 24-Jan-49 | 1529.11 | 9.75 | 9.73 | 9 73 | 8.89 | -2.36 | -2.41 | -2.77 | -2.64 |
| 0 | 13-Feb-50 | 1087 37 | 11.28 | 11.28 | 8.10 | 1.07 | -10.61 | -10.61 | -6.43 | 0.20 |
| 1 | 15-Feb-51 | 311.49 | 5 59 | 5.59 | 5 59 | 3.78 | -0.84 | -0.84 | -0.84 | -0.81 |
| 1 | 22-Apr-52 | 1067 55 | 12.01 | 11.91 | 11.91 | 8.71 | -5 16 | -5.26 | -5.33 | -3.99 |
| 0 | 13-May-53 | 639 96 | 10.24 | 10.21 | 8.31 | 4 42 | -0 33 | -1.09 | -1.04 | 1.57 |
| 1 | 02-May-54 | 945.78 | 10.57 | 9.27 | 8.46 | 8.08 | -3.73 | -3.10 | -2.57 | -3.71 |
| 1 | 21-Mar-55 | 393 60 | 8.33 | 7.09 | 4 22 | 3.91 | -1.93 | -0.94 | -0.18 | -2.92 |
| 0 | 18-Feb-56 | 356.79 | 6.99 | 6.72 | 5.00 | 4 08 | 2 00 | 2.22 | 3.64 | 4.48 |
| 1 | 04-Apr-57 | 617.31 | 7 39 | 7.04 | 7.04 | 3.30 | -0.25 | -2.24 | -3.63 | -0.10 |
| 1 | 03-May-58 | 688.10 | 10.72 | 9.93 | 8.38 | 4.01 | -1 75 | -4.01 | -2.51 | -0.20 |
| 0 | 17-Nov-58 | 467.23 | 13.76 | 12.99 | 7.56 | 7.15 | -7.30 | -6.54 | -1.18 | -2.07 |
| 1 | 20-May-60 | 1965.19 | 18.90 | 18.90 | 18 82 | 11.68 | -7.85 | -7.85 | -7.82 | -4.78 |
| 1 | 11-Dec-60 | 464.40 | 7.54 | 7.24 | 7.24 | 6.55 | -1.98 | -2.11 | -2.11 | -1.78 |
| 0 | 23-Nov-61 | 373.78 | 8 65 | 8.62 | 8.62 | 5.52 | -0 39 | -2 80 | -5.11 | -2.17 |
| 0 | 19-Mar-63 | 370.95 | 5.13 | 4.63 | 4.54 | 1.51 | 3.16 | 3.48 | 1.81 | 1.92 |
| 1 | 09-Mar-64 | 518.20 | 8 43 | 8 43 | 7.92 | 7.32 | 2.57 | 2.57 | 3.07 | 1.78 |
| 0 | 10-Feb-65 | 484.22 | 6.88 | 6.86 | 6.55 | 1.09 | 7.04 | 7 06 | 7.37 | 12.27 |
| 0 | 10-Feb-66 | 662.61 | 8.59 | 8.59 | 8 57 | 3 39 | 7.26 | 6.58 | 6.59 | 5.17 |
| 0 | 06-May-67 | 444.57 | 6.38 | 6.38 | 5.44 | 5.44 | 1 98 | 1.98 | 2.92 | 2.34 |
| 1 | 14-May-68 | 1059.05 | 12 37 | 10.16 | 8.61 | 3.56 | 4.65 | 3.43 | 3.07 | 3.18 |
| 0 | 26-Jul-69 | 1965.19 | 23.52 | 22.57 | 20.59 | 18.88 | -9.80 | -8.88 | -6.98 | -7.93 |
| 1 | 19-Apr-70 | 605 98 | 13.92 | 11.84 | 8.59 | 8.48 | -1.88 | 0.08 | -2.08 | -1.98 |
| 1 | 27-Oct-70 | 314.32 | 7.16 | 4.93 | 4.93 | 4.93 | 5.21 | 4.50 | 4.50 | 4.50 |
| 1 | 10-Dec-71 | 1902.89 | 24.94 | 22.15 | 19.81 | 13.46 | -7 29 | -6.38 | -4.04 | -3.12 |
| 0 | 31-Oct-72 | 1192.14 | 16.28 | 16.26 | 16.03 | 15.44 | -9 35 | -9.32 | -9.09 | -8.76 |
| 1 | 07-Jun-74 | 1631.05 | 17 86 | 17 86 | 12 73 | 12.04 | -5.05 | -5.05 | -3 91 | -4.47 |
| 1 | 29-Mar-75 | 849.51 | 10.85 | 10.85 | 7.54 | 1.65 | -2.39 | -2.39 | 0.84 | 4.37 |
| 0 | 09-Mar-76 | 188.59 | 5 03 | 5.02 | 5 02 | 1.38 | 0.46 | -1.16 | -1.16 | 2.45 |
| 1 | 28-Mar-77 | 1237.45 | 14.30 | 14 20 | 14.20 | 10.11 | -2.16 | -2.24 | -2.24 | -1.37 |
| 0 | 24-Mar-78 | 240.41 | 4.58 | 3.73 | 3.73 | 3.73 | -2.22 | -1.36 | -1.41 | -2.05 |
| 0 | 01-Apr-79 | 835 35 | 14.12 | 13 56 | 7.92 | 7.01 | -11 15 | -10 59 | -4 95 | -4.04 |
| 1 | 24-Dec-79 | 419.09 | 7 21 | 7.21 | 6 58 | 4.55 | -0 79 | -0.79 | -1.19 | 0 23 |
| 1 | 07-Jun-81 | 351.13 | 8.86 | 7 54 | 4 72 | 1 14 | -2.11 | -2.18 | -1.02 | 0.08 |
| 0 | 31-Jan-82 | 770.22 | 6.81 | 6.81 | 6 81 | 5.46 | -1.93 | -1.93 | -1 93 | -0.58 |
| 0 | 03-Dec-82 | 4587.33 | 21.34 | 21.34 | 21.34 | 20.93 | 3 43 | 3.43 | 3.40 | 3.00 |
| 0 | 03-May-84 | 424.75 | 9.09 | 8 95 | 8 54 | 4 19 | -5 69 | -5.55 | -5.14 | -1.98 |
| 0 | 25-Oct-84 | 1248.77 | 11 84 | 11.48 | 10 50 | 9.86 | 8.12 | 7.32 | 2 13 | 0.74 |
| 1 | 27-Nov-85 | 1291.25 | 12.29 | 12.24 | 12.07 | 11.46 | 4 98 | 5.03 | 5.05 | 5.41 |
| 1 | 18-Mar-87 | 889.15 | 10.44 | 10.44 | 10 44 | 4.57 | -8.99 | -8 99 | -8.99 | -3.12 |
| 1 | 26-Dec-87 | 908.97 | 12.75 | 12.75 | 12 62 | 8.13 | 0 10 | 0 10 | -0.33 | -0.71 |
| 0 | 15-Feb-89 | 835.35 | 6.74 | 6.74 | 6.74 | 5.61 | 1.23 | 1.23 | 0.15 | 1.04 |
| 0 | 03-May-90 | 1656.54 | 20 62 | 20.62 | 20.62 | 11.27 | -5.70 | -5.70 | -5.84 | -6.33 |

* Variables defined:

SQPA: Indicates annual peak (QPA) from South Fourche watershed (S).

SQPA$^{+}$· Annual peak on S.Fourche before adjusting for peak retardation due to FRSs between 1977-1990

NQPA: Indicates annual peak (QPA) from [North] Fourche (control) watershed (N).

SPA: Indicates annual peak rainfall (PA) on South Fourche watershed (S) for day of the peak.

SPA1: Indicates annual peak rainfall (PA) on South Fourche watershed (S) for 1 day before and day of the peak.

SPA2 Indicates annual peak rainfall (PA) on South Fourche watershed (S) for 2 days before and day of the peak.

SPA3: Indicates annual peak rainfall (PA) on South Fourche watershed (S) for 3 days before and day of the peak.

NPA. Indicates annual peak rainfall (PA) on [North] Fourche (control) watershed (N) for day of the peak.

DPA: Indicates difference in rainfall between the watersheds (S-N).

T. Indicator or dummy variable: T=0 for calibration period, T=1 for postcalibration period.

TQPA· A variable which indentifies the annual peaks common to both watersheds, TQPA=1 for common peaks.

DATESA=date of annual peak on South Fourche watershed given that DATESA=1 for Jan 1, 1900

TIMESA=date of postcalibration peaks on South Fourche given that TIMESA=1 for Oct 1, 1971

# APPENDIX D

# DATA USED TO DEVELOP HIGH FLOW REGRESSION MODELS

Data* Used to Develop High Flow Regression Models (7-, 14-, 60-, and 90-day high flows).

| OSWY | T | T7 | SDAY7 | DATE7 | TIME7 | SQ7 (cm) | NDAY7 | NQ7 (cm) | DP7 (cm) | NDAY7$^{+}$ | NQ7$^{+}$ (cm) | DP7$^{+}$ (cm) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 42 | 0 | 0 | 4/26/1942 | 15457 |  | 8.73 | 10/30/1941 | 7.54 | 7.15 | 4/26/1942 | 5.16 | 3.58 |
| 43 | 0 | 0 | 12/27/1942 | 15702 |  | 6.18 | 5/20/1943 | 3.29 | -0.49 | 12/27/1942 | 2.68 | 1.05 |
| 44 | 0 | 0 | 4/20/1944 | 16182 |  | 12.02 | 4/30/1944 | 8.22 | 3.85 | 4/20/1944 | 3.29 | 7 44 |
| 45 | 0 | 1 | 3/29/1945 | 16525 |  | 21.79 | 3/25/1945 | 17 43 | 4.74 | 3/29/1945 | 17.27 | 4.83 |
| 46 | 0 | 1 | 1/ 5/1946 | 16807 |  | 11.01 | 1/ 5/1946 | 9.58 | -1.71 | 1/ 5/1946 | 9.58 | -1.71 |
| 47 | 0 | 1 | 12/10/1946 | 17146 |  | 7.53 | 12/10/1946 | 9.68 | -6.18 | 12/10/1946 | 9.68 | -6.18 |
| 48 | 0 | 0 | 2/25/1948 | 17588 |  | 10.15 | 12/31/1947 | 9.56 | -0.34 | 2/25/1948 | 8.68 | -0.34 |
| 49 | 0 | 1 | 1/24/1949 | 17922 |  | 18.33 | 1/24/1949 | 18.84 | -2.63 | 1/24/1949 | 18.84 | -2.63 |
| 50 | 0 | 1 | 1/10/1950 | 18273 |  | 11.51 | 1/10/1950 | 11.74 | -0.14 | 1/10/1950 | 11.74 | -0.14 |
| 51 | 0 | 1 | 2/15/1951 | 18674 |  | 8.80 | 2/15/1951 | 8.14 | -2.98 | 2/15/1951 | 8.14 | -2.98 |
| 52 | 0 | 0 | 1/ 2/1952 | 18995 |  | 8.98 | 4/21/1952 | 12.18 | 3.86 | 1/ 2/1952 | 4.02 | -4.32 |
| 53 | 0 | 1 | 5/11/1953 | 19490 |  | 10.32 | 5/12/1953 | 7.83 | 0.24 | 5/11/1953 | 7.83 | 0.24 |
| 54 | 0 | 1 | 5/ 1/1954 | 19845 |  | 10.10 | 4/30/1954 | 8.55 | 2.60 | 5/ 1/1954 | 8 55 | 2.23 |
| 55 | 0 | 1 | 3/18/1955 | 20166 |  | 10.41 | 3/19/1955 | 6.03 | 2.51 | 3/18/1955 | 6 03 | 2.51 |
| 56 | 0 | 0 | 1/29/1956 | 20483 |  | 11.93 | 2/17/1956 | 4.71 | 7.46 | 1/29/1956 | 2.13 | 0.53 |
| 57 | 0 | 0 | 5/23/1957 | 20963 |  | 12.62 | 4/23/1957 | 14 81 | 1.47 | 5/23/1957 | 7.61 | -5.37 |
| 58 | 0 | 1 | 4/27/1958 | 21302 |  | 15.32 | 4/28/1958 | 9.38 | 5.57 | 4/27/1958 | 9.38 | 5.57 |
| 59 | 0 | 0 | 2/14/1959 | 21595 |  | 5.62 | 11/15/1958 | 5.07 | 4.04 | 2/14/1959 | 1.59 | 1.57 |
| 60 | 0 | 1 | 5/19/1960 | 22055 |  | 7.97 | 5/19/1960 | 15 26 | -6.15 | 5/19/1960 | 15 26 | -6.15 |
| 61 | 0 | 0 | 3/26/1961 | 22366 |  | 8 21 | 12/ 6/1960 | 6.96 | 4.82 | 3/27/1961 | 4.57 | -6.06 |
| 62 | 0 | 1 | 2/23/1962 | 22700 |  | 9.02 | 2/23/1962 | 4.90 | 3.31 | 2/23/1962 | 4.90 | 3 31 |
| 63 | 0 | 0 | 7/14/1963 | 23206 |  | 4.31 | 3/18/1963 | 3 60 | 0.00 | 7/14/1963 |  | -1.11 |
| 64 | 0 | 0 | 3/ 4/1964 | 23440 |  | 12.30 | 3/ 9/1964 | 4.98 | 4.19 | 3/ 4/1964 | 4.12 | 3.60 |
| 65 | 0 | 1 | 2/ 9/1965 | 23782 |  | 7.37 | 2/ 9/1965 | 5.69 | 2.15 | 2/ 9/1965 | 5.69 | 2.15 |
| 66 | 0 | 1 | 4/23/1966 | 24220 |  | 18.42 | 4/24/1966 | 8.53 | 7.00 | 4/23/1966 | 8.53 | 7.00 |
| 67 | 0 | 1 | 5/ 1/1967 | 24593 |  | 7.09 | 5/ 2/1967 | 5.45 | 0.86 | 5/ 1/1967 | 5 45 | 0 86 |
| 68 | 0 | 1 | 5/ 9/1968 | 24967 |  | 16 45 | 5/11/1968 | 15.18 | 5 10 | 5/ 9/1968 | 15 18 | 5.10 |
| 69 | 0 | 0 | 1/29/1969 | 25232 |  | 13.49 | 7/26/1969 | 13.71 | 2.60 | 1/29/1969 | 9.88 | 2.60 |
| 70 | 0 | 1 | 4/19/1970 | 25677 |  | 7.64 | 4/19/1970 | 6.89 | -1.75 | 4/19/1970 | 6 89 | -1.75 |
| 71 | 0 | 1 | 10/24/1970 | 25865 |  | 5.78 | 10/27/1970 | 3.56 | 5.86 | 10/24/1970 | 3.39 | 5 22 |
| 72 | 1 | 1 | 12/ 9/1971 | 26276 | 70 | 15.73 | 12/ 9/1971 | 18.08 | -3.56 | 12/ 9/1971 | 18 08 | -3 56 |
| 73 | 1 | 0 | 4/18/1973 | 26772 | 566 | 10 42 | 10/31/1972 | 14.33 | 0.81 | 4/18/1973 | 7.86 | 0 81 |
| 74 | 1 | 1 | 6/ 5/1974 | 27185 | 979 | 12.63 | 6/ 5/1974 | 14.68 | -1.02 | 6/ 5/1974 | 14 68 | -1.02 |
| 75 | 1 | 1 | 3/27/1975 | 27480 | 1274 | 12.27 | 3/27/1975 | 10.34 | 1.40 | 3/27/1975 | 10.34 | 1.40 |
| 76 | 1 | 1 | 3/ 8/1976 | 27827 | 1621 | 3.63 | 3/ 8/1976 | 2.58 | -1.34 | 3/ 8/1976 | 2.58 | -1.34 |
| 77 | 1 | 1 | 3/27/1977 | 28211 | 2005 | 7.84 | 3/27/1977 | 10.34 | -2.12 | 3/27/1977 | 10.34 | -2.12 |
| 78 | 1 | 0 | 3/ 3/1978 | 28552 | 2346 | 3.82 | 5/ 4/1978 | 3 25 | 0.58 | 3/ 3/1978 | 1 68 | 0.58 |
| 79 | 1 | 1 | 3/30/1979 | 28944 | 2738 | 12.93 | 3/30/1979 | 12.88 | -0 31 | 3/30/1979 | 12.88 | -0.31 |
| 80 | 1 | 0 | 12/23/1979 | 29212 | 3006 | 3.52 | 5/16/1980 | 4 65 | -0.76 | 12/23/1979 | 3.67 | -0.76 |
| 81 | 1 | 1 | 6/ 3/1981 | 29740 | 3534 | 4.19 | 6/ 4/1981 | 6.05 | -1.60 | 6/ 3/1981 | 6.05 | -1 60 |
| 82 | 1 | 0 | 3/14/1982 | 30024 | 3818 | 6.85 | 1/31/1982 | 6.74 | -0.35 | 3/14/1982 | 5 22 | -1 78 |
| 83 | 1 | 1 | 11/27/1982 | 30282 | 4076 | 33.32 | 11/28/1982 | 26.67 | -0 83 | 11/27/1982 | 26.67 | -0.83 |
| 84 | 1 | 0 | 12/ 2/1983 | 30652 | 4446 | 5.52 | 5/ 2/1984 | 6.41 | 2.25 | 12/ 2/1983 | 3 24 | -0 24 |
| 85 | 1 | 1 | 10/19/1984 | 30974 | 4768 | 21 12 | 10/20/1984 | 16.84 | -0.68 | 10/19/1984 | 16.05 | -0 10 |
| 86 | 1 | 1 | 11/26/1985 | 31377 | 5171 | 11 88 | 11/27/1985 | 11 32 | 5.15 | 11/26/1985 | 11.32 | 5.15 |
| 87 | 1 | 0 | 2/26/1987 | 31834 | 5628 | 4.27 | 3/17/1987 | 7 02 | 1.81 | 2/26/1987 | 2.05 | -6.05 |
| 88 | 1 | 1 | 12/25/1987 | 32136 | 5930 | 11 68 | 12/25/1987 | 12.82 | 0.37 | 12/25/1987 | 12 82 | 0 37 |
| 89 | 1 | 1 | 2/14/1989 | 32553 | 6347 | 9.58 | 2/15/1989 | 9.90 |  | 2/14/1989 | 9 90 |  |

| OSWY | T | T14 | SDAY14 | DATE14 | TIME14 | SQ14 (cm) | NDAY14 | NQ14 (cm) | DP14 (cm) | NDAY14$^{+}$ | NQ14$^{+}$ (cm) | DP14$^{+}$ (cm) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 42 | 0 | 0 | 4/25/1942 | 15456 | | 9.41 | 10/21/1941 | 8.58 | 8 80 | 4/25/1942 | 7 23 | 2.55 |
| 43 | 0 | 0 | 12/27/1942 | 15702 | | 6.56 | 5/11/1943 | 5.70 | -6 19 | 12/27/1942 | 5.48 | 1 72 |
| 44 | 0 | 1 | 4/20/1944 | 16182 | | 18.23 | 4/20/1944 | 10.86 | 6 43 | 4/20/1944 | 10.86 | 6.43 |
| 45 | 0 | 1 | 3/20/1945 | 16516 | | 23.85 | 3/18/1945 | 25 83 | -1.90 | 3/18/1945 | 25.83 | -1.90 |
| 46 | 0 | 0 | 1/ 5/1946 | 16807 | | 12.77 | 5/20/1946 | 15.11 | -15.51 | 1/ 5/1946 | 11 82 | -1.98 |
| 47 | 0 | 1 | 12/10/1946 | 17146 | | 7.96 | 12/10/1946 | 10.39 | -6.18 | 12/10/1946 | 10.39 | -6.18 |
| 48 | 0 | 1 | 2/24/1948 | 17587 | | 12 36 | 2/25/1948 | 11.50 | 0.05 | 2/25/1948 | 11.50 | 0.05 |
| 49 | 0 | 1 | 1/16/1949 | 17914 | | 26.42 | 1/17/1949 | 22.13 | 1.78 | 1/17/1949 | 22 13 | 1.78 |
| 50 | 0 | 1 | 1/ 2/1950 | 18265 | | 20.98 | 1/ 2/1950 | 17.89 | -3.96 | 1/ 2/1950 | 17.89 | -3.96 |
| 51 | 0 | 1 | 2/15/1951 | 18674 | | 10.06 | 2/15/1951 | 9 76 | -3.60 | 2/15/1951 | 9.76 | -3.60 |
| 52 | 0 | 1 | 4/10/1952 | 19094 | | 13 95 | 4/10/1952 | 20 58 | -6.46 | 4/10/1952 | 20.58 | -6.46 |
| 53 | 0 | 1 | 11/25/1952 | 19323 | | 16.02 | 11/25/1952 | 9.20 | 7 46 | 11/25/1952 | 9 20 | 7.46 |
| 54 | 0 | 1 | 5/ 1/1954 | 19845 | | 10.54 | 5/ 2/1954 | 9.59 | 0 95 | 5/ 2/1954 | 9 59 | 0.95 |
| 55 | 0 | 1 | 3/14/1955 | 20162 | | 11.65 | 3/15/1955 | 7.06 | 3.20 | 3/15/1955 | 7 06 | 3 20 |
| 56 | 0 | 0 | 1/29/1956 | 20483 | | 15.94 | 2/ 9/1956 | 5 80 | 9 44 | 1/29/1956 | 3 60 | 2 13 |
| 57 | 0 | 0 | 5/23/1957 | 20963 | | 14.84 | 4/20/1957 | 18.34 | -0.25 | 5/23/1957 | 11.45 | -5 28 |
| 58 | 0 | 1 | 4/27/1958 | 21302 | | 19.80 | 4/27/1958 | 13.33 | 6.41 | 4/27/1958 | 13.33 | 6 41 |
| 59 | 0 | 0 | 2/14/1959 | 21595 | | 6.78 | 3/21/1959 | 6 38 | 5.77 | 2/14/1959 | 2.13 | -4.39 |
| 60 | 0 | 1 | 5/19/1960 | 22055 | | 8.32 | 5/19/1960 | 15 74 | -5 53 | 5/19/1960 | 15.74 | -5.53 |
| 61 | 0 | 0 | 3/27/1961 | 22367 | | 10.33 | 12/ 5/1960 | 8.09 | 5 93 | 3/27/1961 | 6.04 | -6.04 |
| 62 | 0 | 1 | 2/19/1962 | 22696 | | 10 22 | 2/23/1962 | 6.07 | 3.12 | 2/23/1962 | 6 07 | 3.52 |
| 63 | 0 | 1 | 3/11/1963 | 23081 | | 5 11 | 3/11/1963 | 4.68 | 0.88 | 3/11/1963 | 4 68 | 0 88 |
| 64 | 0 | 1 | 3/ 2/1964 | 23438 | | 14.19 | 3/ 5/1964 | 5.38 | 3 67 | 3/ 5/1964 | 5 38 | 3.22 |
| 65 | 0 | 1 | 2/ 9/1965 | 23782 | | 7 93 | 2/ 9/1965 | 6.44 | 2.22 | 2/ 9/1965 | 6 44 | 2.22 |
| 66 | 0 | 1 | 4/23/1966 | 24220 | | 20 61 | 4/23/1966 | 12.55 | 5 48 | 4/23/1966 | 12 55 | 5.48 |
| 67 | 0 | 1 | 4/26/1967 | 24588 | | 8.45 | 4/24/1967 | 7.03 | 0.84 | 4/24/1967 | 7.03 | 1.98 |
| 68 | 0 | 1 | 5/ 9/1968 | 24967 | | 19.60 | 5/ 8/1968 | 19.46 | 5.12 | 5/ 8/1968 | 19.46 | 5.12 |
| 69 | 0 | 0 | 1/23/1969 | 25226 | | 14.38 | 7/26/1969 | 14 03 | 3 25 | 1/23/1969 | 10 48 | 3.25 |
| 70 | 0 | 1 | 4/18/1970 | 25676 | | 12.28 | 4/18/1970 | 11.68 | 0.63 | 4/18/1970 | 11 68 | 0.63 |
| 71 | 0 | 1 | 10/24/1970 | 25865 | | 6.30 | 10/25/1970 | 4.05 | 4.72 | 10/25/1970 | 4.05 | 4 72 |
| 72 | 1 | 1 | 12/ 6/1971 | 26273 | 67 | 17 28 | 12/ 7/1971 | 20 58 | -5 90 | 12/ 7/1971 | 20 58 | -5 90 |
| 73 | 1 | 0 | 4/16/1973 | 26770 | 564 | 14.36 | 10/31/1972 | 17.90 | 0 91 | 4/16/1973 | 14 02 | 0.91 |
| 74 | 1 | 0 | 11/23/1973 | 26991 | 785 | 15.14 | 6/ 5/1974 | 16 05 | 4 68 | 11/23/1973 | 10 03 | 4.68 |
| 75 | 1 | 1 | 3/17/1975 | 27470 | 1264 | 16.11 | 3/17/1975 | 12 87 | 2.58 | 3/17/1975 | 12 87 | 2.58 |
| 76 | 1 | 1 | 3/ 8/1976 | 27827 | 1621 | 4.10 | 3/ 8/1976 | 3 06 | -1.19 | 3/ 8/1976 | 3 06 | -1.19 |
| 77 | 1 | 1 | 3/27/1977 | 28211 | 2005 | 8 61 | 3/27/1977 | 11 03 | -1 21 | 3/27/1977 | 11 03 | -1.21 |
| 78 | 1 | 0 | 3/ 2/1978 | 28551 | 2345 | 5.95 | 5/ 4/1978 | 3 91 | 1.67 | 3/ 2/1978 | 6 28 | 1.67 |
| 79 | 1 | 1 | 3/30/1979 | 28944 | 2738 | 15.89 | 3/30/1979 | 15 94 | -1.73 | 3/30/1979 | 15.94 | -1 73 |
| 80 | 1 | 0 | 4/14/1980 | 29325 | 3119 | 5.24 | 5/15/1980 | 5 89 | 4.40 | 4/14/1980 | 2.96 | -2.26 |
| 81 | 1 | 1 | 5/26/1981 | 29732 | 3526 | 6.60 | 5/26/1981 | 8.48 | -2 63 | 5/26/1981 | 8 48 | -2 63 |
| 82 | 1 | 0 | 3/ 4/1982 | 30014 | 3808 | 9.01 | 1/31/1982 | 8.35 | 1.10 | 3/ 4/1982 | 6 75 | -1.44 |
| 83 | 1 | 1 | 11/27/1982 | 30282 | 4076 | 38.12 | 11/26/1982 | 29.58 | 8 05 | 11/26/1982 | 29 58 | 8.05 |
| 84 | 1 | 0 | 12/ 2/1983 | 30652 | 4446 | 7.19 | 5/ 2/1984 | 7.35 | 2.61 | 12/ 2/1983 | 4.98 | -0.04 |
| 85 | 1 | 1 | 10/15/1984 | 30970 | 4764 | 29.17 | 10/20/1984 | 21 29 | 8 10 | 10/15/1984 | 21.18 | -0.50 |
| 86 | 1 | 0 | 11/26/1985 | 31377 | 5171 | 12.76 | 11/18/1985 | 12.61 | 5 22 | 11/26/1985 | 12 39 | 5.42 |
| 87 | 1 | 0 | 2/16/1987 | 31824 | 5618 | 5.74 | 3/17/1987 | 8 22 | 1 59 | 2/16/1987 | 3.90 | -6 01 |
| 88 | 1 | 1 | 12/18/1987 | 32129 | 5923 | 13.95 | 12/15/1987 | 15.96 | 0.21 | 12/18/1987 | 15 48 | 0 17 |
| 89 | 1 | 0 | 2/ 3/1989 | 32542 | 6336 | 12.537 | 2/14/1989 | 11 67 | | 2/ 3/1989 | | |

| OSWY | T | T60 | SDAY60 | DATE60 | TIME60 | SQ60 (cm) | NDAY60 | NQ60 (cm) | DP60 (cm) | NDAY60$^+$ | NQ60$^+$ (cm) | DP60$^+$ (cm) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 42 | 0 | 0 | 3/ 3/1942 | 15403 | | 26.03 | 3/30/1942 | 18.53 | | 3/ 3/1942 | 18.26 | 9.67 |
| 43 | 0 | 1 | 3/13/1943 | 15778 | | 14.03 | 3/26/1943 | 12.27 | | 3/13/1943 | 10.81 | -7.38 |
| 44 | 0 | 1 | 3/ 4/1944 | 16135 | | 35.08 | 3/16/1944 | 28.05 | | 3/ 4/1944 | 27.03 | 9.82 |
| 45 | 0 | 1 | 2/20/1945 | 16488 | | 57.00 | 2/17/1945 | 64 51 | -0.34 | 2/17/1945 | 64.51 | -0.34 |
| 46 | 0 | 1 | 3/27/1946 | 16888 | | 32.71 | 4/12/1946 | 30.23 | | 3/27/1946 | 23.78 | -0.83 |
| 47 | 0 | 1 | 11/ 4/1946 | 17110 | | 16.27 | 11/ 4/1946 | 20.02 | -11.23 | 11/ 4/1946 | 20.02 | -11.23 |
| 48 | 0 | 0 | 2/17/1948 | 17580 | | 25.01 | 12/31/1947 | 21.64 | -0.79 | 2/17/1948 | 20.50 | -0 79 |
| 49 | 0 | 1 | 1/16/1949 | 17914 | | 36.35 | 1/16/1949 | 34.32 | 0.26 | 1/16/1949 | 34.32 | 0.26 |
| 50 | 0 | 1 | 12/18/1949 | 18250 | | 43.05 | 12/27/1949 | 41.66 | -6.70 | 12/18/1949 | 40.99 | -7.17 |
| 51 | 0 | 1 | 1/13/1951 | 18641 | | 19.83 | 1/14/1951 | 14.60 | -0.53 | 1/14/1951 | 14.60 | -0.53 |
| 52 | 0 | 1 | 2/26/1952 | 19050 | | 30 26 | 3/ 2/1952 | 36.29 | -4.96 | 2/26/1952 | 36.08 | -5.27 |
| 53 | 0 | 1 | 3/18/1953 | 19436 | | 29.93 | 3/18/1953 | 27.45 | -2.18 | 3/18/1953 | 27 45 | -2.18 |
| 54 | 0 | 1 | 3/24/1954 | 19807 | | 13.20 | 3/28/1954 | 13.28 | -3.73 | 3/28/1954 | 13.28 | -2.30 |
| 55 | 0 | 1 | 2/19/1955 | 20139 | | 18.10 | 2/20/1955 | 15 35 | 2 56 | 2/20/1955 | 15.35 | 2.56 |
| 56 | 0 | 1 | 1/29/1956 | 20483 | | 24.81 | 1/30/1956 | 11.42 | 8.60 | 1/30/1956 | 11.42 | 8.60 |
| 57 | 0 | 1 | 3/31/1957 | 20910 | | 41 98 | 4/ 1/1957 | 41.17 | 1.59 | 4/ 1/1957 | 41.17 | 1.59 |
| 58 | 0 | 1 | 3/ 7/1958 | 21251 | | 32.14 | 3/ 7/1958 | 29.68 | 3.56 | 3/ 7/1958 | 29.68 | 3.56 |
| 59 | 0 | 0 | 2/13/1959 | 21594 | | 14.92 | 3/ 4/1959 | 16.03 | 1.00 | 2/13/1959 | 13.63 | -8.74 |
| 60 | 0 | 0 | 12/11/1959 | 21895 | | 17.47 | 3/27/1960 | 21.34 | 4.41 | 12/11/1959 | 18.62 | -10.02 |
| 61 | 0 | 1 | 2/18/1961 | 22330 | | 26.59 | 2/18/1961 | 21.53 | 10.12 | 2/18/1961 | 21.53 | 10.12 |
| 62 | 0 | 1 | 1/14/1962 | 22660 | | 19.79 | 1/15/1962 | 13.86 | 3.71 | 1/15/1962 | 13.86 | 3.71 |
| 63 | 0 | 1 | 2/14/1963 | 23056 | | 8.56 | 3/ 2/1963 | 7 92 | 4.94 | 2/14/1963 | 7.34 | 4.52 |
| 64 | 0 | 1 | 3/ 2/1964 | 23438 | | 22.51 | 3/ 9/1964 | 11.20 | 7.50 | 3/ 2/1964 | 10.52 | 6.24 |
| 65 | 0 | 1 | 2/ 9/1965 | 23782 | | 18.04 | 2/ 9/1965 | 16.88 | 9.14 | 2/ 9/1965 | 16.88 | 9.14 |
| 66 | 0 | 1 | 3/31/1966 | 24197 | | 24.71 | 4/ 3/1966 | 15.66 | 6.34 | 3/31/1966 | 15.65 | 6.34 |
| 67 | 0 | 1 | 4/10/1967 | 24572 | | 20.17 | 4/11/1967 | 16.93 | 4.33 | 4/11/1967 | 16.93 | 4.33 |
| 68 | 0 | 1 | 3/20/1968 | 24917 | | 33.92 | 3/20/1968 | 42.50 | -3.57 | 3/20/1968 | 42.50 | -3.57 |
| 69 | 0 | 1 | 12/13/1968 | 25185 | | 26.61 | 12/27/1968 | 23.65 | 6.68 | 12/13/1968 | 22.57 | 5.28 |
| 70 | 0 | 1 | 3/ 3/1970 | 25630 | | 22.37 | 3/ 3/1970 | 21.96 | 3 22 | 3/ 3/1970 | 21.96 | 3.22 |
| 71 | 0 | 0 | 12/22/1970 | 25924 | | 12.57 | 1/15/1971 | 8.27 | 1.89 | 12/22/1970 | 7.67 | 1.50 |
| 72 | 1 | 1 | 12/ 6/1971 | 26273 | 67 | 20.00 | 12/ 7/1971 | 23.76 | -6.29 | 12/ 7/1971 | 23.76 | -6.29 |
| 73 | 1 | 1 | 3/ 2/1973 | 26725 | 519 | 40.45 | 3/ 4/1973 | 38.09 | 2.57 | 3/ 4/1973 | 38.09 | -3.45 |
| 74 | 1 | 0 | 11/20/1973 | 26988 | 782 | 26.32 | 4/22/1974 | 23.49 | 6 19 | 11/20/1973 | 18.04 | 6.19 |
| 75 | 1 | 1 | 1/31/1975 | 27425 | 1219 | 31.90 | 2/ 1/1975 | 26.26 | 4 67 | 2/ 1/1975 | 26.26 | 4.67 |
| 76 | 1 | 0 | 2/ 8/1976 | 27798 | 1592 | 10.10 | 3/ 1/1976 | 5.07 | 3.52 | 2/ 8/1976 | 4.98 | -1.04 |
| 77 | 1 | 1 | 2/ 5/1977 | 28161 | 1955 | 17 75 | 2/ 4/1977 | 20.55 | -1.28 | 2/ 4/1977 | 20.55 | -1.28 |
| 78 | 1 | 0 | 1/17/1978 | 28507 | 2301 | 15.46 | 2/13/1978 | 9.73 | 2.11 | 1/17/1978 | 7 09 | -2.44 |
| 79 | 1 | 0 | 3/30/1979 | 28944 | 2738 | 39 23 | 2/12/1979 | 32.48 | -3.07 | 3/30/1979 | 32.25 | 2.03 |
| 80 | 1 | 1 | 3/24/1980 | 29304 | 3098 | 13.50 | 3/28/1980 | 12.64 | 5 58 | 3/28/1980 | 12.64 | 4 82 |
| 81 | 1 | 0 | 4/21/1981 | 29697 | 3491 | 17 63 | 5/10/1981 | 18.55 | -4 04 | 4/21/1981 | 17.71 | -1 02 |
| 82 | 1 | 1 | 1/22/1982 | 29973 | 3767 | 22.31 | 1/23/1982 | 22.64 | -1.05 | 1/23/1982 | 22.64 | -1.05 |
| 83 | 1 | 1 | 11/26/1982 | 30281 | 4075 | 47.68 | 11/23/1982 | 36 45 | 10.49 | 11/23/1982 | 36 45 | 12.26 |
| 84 | 1 | 1 | 2/12/1984 | 30724 | 4518 | 20 22 | 2/12/1984 | 19.15 | 3 10 | 2/12/1984 | 19 15 | 3.10 |
| 85 | 1 | 1 | 10/ 6/1984 | 30961 | 4755 | 47.48 | 10/ 6/1984 | 37.95 | 13.18 | 10/ 6/1984 | 37.95 | 13.18 |
| 86 | 1 | 0 | 11/15/1985 | 31366 | 5160 | 18.83 | 4/19/1986 | 21.95 | 5.57 | 11/15/1985 | 18.30 | -7.67 |
| 87 | 1 | 0 | 2/ 2/1987 | 31810 | 5604 | 12.17 | 2/15/1987 | 15 68 | -4.04 | 2/ 2/1987 | 15.51 | -3.76 |
| 88 | 1 | 1 | 11/ 9/1987 | 32090 | 5884 | 29 63 | 11/16/1987 | 24.03 | 4.35 | 11/ 9/1987 | 23.28 | 4.61 |
| 89 | 1 | 1 | 2/ 2/1989 | 32541 | 6335 | 31.55 | 1/26/1989 | 23.35 | | 2/ 2/1989 | | |

| OSWY | T | T90 | SDAY90 | DATE90 | TIME90 | SQ90 (cm) | NDAY90 | NQ90 (cm) | DP90 (cm) | NDAY90$^{+}$ | NQ90$^{+}$ (cm) | DP90$^{+}$ (cm) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 42 | 0 | 0 | 1/30/1942 | 15371 | | 31.67 | 2/24/1942 | 26.88 | | 1/30/1942 | 22.95 | 10.99 |
| 43 | 0 | 1 | 3/12/1943 | 15777 | | 17.88 | 3/13/1943 | 16.65 | 0.76 | 3/13/1943 | 16.65 | 0.76 |
| 44 | 0 | 1 | 2/ 8/1944 | 16110 | | 50 29 | 2/ 8/1944 | 43.71 | 9 64 | 2/ 8/1944 | 43.71 | 9 64 |
| 45 | 0 | 1 | 2/20/1945 | 16488 | | 65.31 | 2/18/1945 | 74.24 | -2.56 | 2/18/1945 | 74.24 | -2.56 |
| 46 | 0 | 0 | 1/ 5/1946 | 16807 | | 42.01 | 3/ 6/1946 | 35.75 | | 1/ 5/1946 | 31.27 | 8.56 |
| 47 | 0 | 1 | 11/ 3/1946 | 17109 | | 18.38 | 11/ 4/1946 | 21 79 | -12.290 | 11/ 4/1946 | 21.79 | -12.29 |
| 48 | 0 | 0 | 2/ 5/1948 | 17568 | | 29 55 | 12/ 7/1947 | 29.96 | -1 407 | 2/ 5/1948 | 24.72 | -1.41 |
| 49 | 0 | 1 | 1/ 4/1949 | 17902 | | 44.99 | 1/16/1949 | 42.42 | 2.817 | 1/ 4/1949 | 41.39 | 0.43 |
| 50 | 0 | 1 | 12/11/1949 | 18243 | | 47.33 | 12/26/1949 | 45.08 | -5.916 | 12/11/1949 | 44.11 | -9 95 |
| 51 | 0 | 0 | 1/13/1951 | 18641 | | 23 28 | 2/ 7/1951 | 17 42 | 2.060 | 1/13/1951 | 16 46 | -2.78 |
| 52 | 0 | 0 | 2/ 1/1952 | 19025 | | 35.31 | 2/26/1952 | 39.91 | -3.836 | 2/ 1/1952 | 39 79 | -5 40 |
| 53 | 0 | 1 | 2/21/1953 | 19411 | | 35.15 | 2/21/1953 | 33.70 | -2.381 | 2/21/1953 | 33 70 | -2.38 |
| 54 | 0 | 1 | 2/16/1954 | 19771 | | 16.21 | 2/16/1954 | 15 60 | -2.144 | 2/16/1954 | 15.60 | -2.14 |
| 55 | 0 | 1 | 2/ 4/1955 | 20124 | | 21.32 | 2/ 2/1955 | 19.59 | 3 357 | 2/ 4/1955 | 19.59 | 3 36 |
| 56 | 0 | 1 | 1/29/1956 | 20483 | | 27.85 | 2/ 2/1956 | 13.68 | 10.461 | 2/ 2/1956 | 13.68 | 4.54 |
| 57 | 0 | 1 | 3/17/1957 | 20896 | | 55.11 | 3/18/1957 | 54.89 | 1.365 | 3/18/1957 | 54 89 | 1.36 |
| 58 | 0 | 1 | 2/21/1958 | 21237 | | 37 04 | 2/27/1958 | 35.03 | 3 410 | 2/21/1958 | 34 98 | 1.91 |
| 59 | 0 | 1 | 1/15/1959 | 21565 | | 17.47 | 2/ 1/1959 | 18 82 | 0.316 | 1/15/1959 | 16.53 | -2.94 |
| 60 | 0 | 0 | 12/11/1959 | 21895 | | 20.80 | 2/27/1960 | 26.15 | 7.991 | 12/11/1959 | 22.19 | -5.20 |
| 61 | 0 | 1 | 2/18/1961 | 22330 | | 32 22 | 2/17/1961 | 26 97 | 11 871 | 2/17/1961 | 26.97 | 11.87 |
| 62 | 0 | 1 | 1/14/1962 | 22660 | | 26 38 | 1/15/1962 | 19 93 | 5.340 | 1/15/1962 | 19.93 | 5.34 |
| 63 | 0 | 1 | 2/12/1963 | 23054 | | 9 14 | 3/ 1/1963 | 9 48 | 3.778 | 2/12/1963 | 8.79 | -0 80 |
| 64 | 0 | 0 | 2/ 5/1964 | 23412 | | 24.82 | 3/ 2/1964 | 12.47 | 5.753 | 2/ 5/1964 | 11.53 | 7.63 |
| 65 | 0 | 1 | 1/ 9/1965 | 23751 | | 22 15 | 1/ 9/1965 | 21 60 | 13.578 | 1/ 9/1965 | 21.60 | 13 58 |
| 66 | 0 | 1 | 2/ 7/1966 | 24145 | | 27 72 | 2/ 9/1966 | 21.25 | 2.354 | 2/ 9/1966 | 21 25 | 2.35 |
| 67 | 0 | 1 | 3/ 6/1967 | 24537 | | 25.27 | 3/ 7/1967 | 18.30 | 5.342 | 3/ 7/1967 | 18 30 | 5 34 |
| 68 | 0 | 1 | 3/ 8/1968 | 24905 | | 41.25 | 3/10/1968 | 50.59 | -6.645 | 3/10/1968 | 50.59 | -5.40 |
| 69 | 0 | 1 | 11/27/1968 | 25169 | | 35 29 | 11/27/1968 | 35.35 | 5.476 | 11/27/1968 | 35.35 | 5.48 |
| 70 | 0 | 1 | 2/ 2/1970 | 25601 | | 26.71 | 2/ 3/1970 | 26 38 | 4.448 | 2/ 3/1970 | 26.38 | 4.45 |
| 71 | 0 | 1 | 12/16/1970 | 25918 | | 18 95 | 12/22/1970 | 11 95 | 5.067 | 12/16/1970 | 11.45 | 3.41 |
| 72 | 1 | 1 | 12/ 6/1971 | 26273 | 67 | 21.25 | 12/ 6/1971 | 25.12 | -6 572 | 12/ 6/1971 | 25 12 | -6.57 |
| 73 | 1 | 1 | 2/ 8/1973 | 26703 | 497 | 47.12 | 2/ 8/1973 | 47 48 | 1 152 | 2/ 8/1973 | 47 48 | 1 15 |
| 74 | 1 | 0 | 11/20/1973 | 26988 | 782 | 29.21 | 3/11/1974 | 25 60 | 7.484 | 11/20/1973 | 20 86 | -5.64 |
| 75 | 1 | 0 | 1/ 3/1975 | 27397 | 1191 | 36.22 | 1/31/1975 | 30.11 | 5 347 | 1/ 3/1975 | 29 28 | 4.45 |
| 76 | 1 | 1 | 12/26/1975 | 27754 | 1548 | 13.81 | 12/29/1975 | 7.00 | 7.026 | 12/29/1975 | 7 00 | 6 44 |
| 77 | 1 | 1 | 1/13/1977 | 28138 | 1932 | 21 28 | 1/14/1977 | 24.17 | -0.488 | 1/14/1977 | 24.17 | -0.49 |
| 78 | 1 | 1 | 2/13/1978 | 28534 | 2328 | 19 75 | 2/13/1978 | 14.31 | 1.093 | 2/13/1978 | 14.31 | 1 09 |
| 79 | 1 | 0 | 2/23/1979 | 28909 | 2703 | 56.14 | 3/19/1979 | 43 60 | 2 725 | 2/23/1979 | 41 02 | -3 63 |
| 80 | 1 | 1 | 2/28/1980 | 29279 | 3073 | 15.02 | 3/ 9/1980 | 14 50 | 7 224 | 2/28/1980 | 14 29 | 6.04 |
| 81 | 1 | 1 | 3/22/1981 | 29667 | 3461 | 22 45 | 3/22/1981 | 20.84 | -3.038 | 3/22/1981 | 20 84 | -3.04 |
| 82 | 1 | 1 | 1/22/1982 | 29973 | 3767 | 28 91 | 1/23/1982 | 26 82 | 0 162 | 1/23/1982 | 26 82 | 0 16 |
| 83 | 1 | 1 | 11/27/1982 | 30282 | 4076 | 52.62 | 11/26/1982 | 40 07 | 9.951 | 11/26/1982 | 40 07 | 9.95 |
| 84 | 1 | 1 | 2/12/1984 | 30724 | 4518 | 27.63 | 2/12/1984 | 28 06 | 2 860 | 2/12/1984 | 28.06 | 2.86 |
| 85 | 1 | 1 | 10/ 6/1984 | 30961 | 4755 | 56 32 | 10/ 6/1984 | 48 26 | 14.933 | 10/ 6/1984 | 48.26 | 14.93 |
| 86 | 1 | 0 | 11/16/1985 | 31367 | 5161 | 21 57 | 4/ 5/1986 | 28.72 | 0 582 | 11/16/1985 | 23.62 | -16.83 |
| 87 | 1 | 1 | 1/ 4/1987 | 31781 | 5575 | 16.72 | 1/ 5/1987 | 18 89 | -2 074 | 1/ 5/1987 | 18 89 | -2.07 |
| 88 | 1 | 1 | 11/ 9/1987 | 32090 | 5884 | 35.75 | 11/11/1987 | 27 85 | 7.400 | 11/11/1987 | 27 85 | 7 24 |
| 89 | 1 | 1 | 1/ 7/1989 | 32515 | 6309 | 36 72 | 1/26/1989 | 27 66 | | 1/ 7/1989 | | |

Conversion of high flows from cfs to centimeters

S Fourche Watershed: (ave daily high flow in CFS) * (no. of days) * 0.0004498

Control Watershed: (ave daily high flow in CFS) * (no of days) * 0.0002304

+ Flows on control watershed which correspond to high flow periods on S.Fourche watershed

* Variables defined:

SQ7 to SQ90: Indicates high flow (Q7-Q90) from South Fourche watershed (S).

NQ7 to NQ90: Indicates high flow (Q7-Q90) from [North] Fourche (control) watershed (N)

DP7 to DP90: Indicates difference in rainfall between the watersheds (S-N).

$NQ7^+$ to $NQ90^+$: Flow from control watershed which correspond to high flows from study watershed.

$DP7^+$ to $DP90^+$: Difference in rainfall between the watersheds (S-N) for common flows.

T. Indicator or dummy variable: T=0 for calibration period, T=1 for postcalibration period.

T7 to T90: A variable which indentifies the high flows in common to both watersheds, T7=1 for common flows.

DATE7 to DATE90. Date of high flow on South Fourche watershed given that DATE7=1 for Jan 1, 1900.

TIME7 to TIME90 Date of postcalibration high flows on South Fourche given that TIME7=1 for Oct 1, 1971.

# APPENDIX E

# DATA USED IN FREQUENCY ANALYSIS OF ANNUAL PEAKS AND HIGH FLOWS

Data Used in Frequency Analysis of High Flows and Annual Peaks

| WYEAR | SQ7 (cm) | SQ14 (cm) | SQ60 (cm) | SQ90 (cm) | SP7 (cm) | SP14 (cm) | SQPA ($m^3$/s) | SPA (cm) | NQ7 (cm) | NQ14 (cm) | NQ60 (cm) | NQ90 (cm) | NQPA ($m^3$/s) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 42 | 8.73 | 9.41 | 26.03 | 31 67 | 10 63 | 16.48 | 841.01 | 7 42 | 7.54 | 8.58 | 18.53 | 26.88 | 824 02 |
| 43 | 6 18 | 6.56 | 14.03 | 17 88 | 6 40 | 7 16 | 523.86 | 6.68 | 3.29 | 5.70 | 12.27 | 16.65 | 319.98 |
| 44 | 12 02 | 18.23 | 35.08 | 50 29 | 13.15 | 21 61 | 1330 89 | 9 96 | 8.22 | 10.86 | 28.05 | 43 71 | 481.39 |
| 45 | 21.79 | 23.85 | 57.00 | 65 31 | 25 10 | 27.08 | 1540.44 | 17.22 | 17.43 | 25 83 | 64.51 | 74.24 | 1076 04 |
| 46 | 11.01 | 12.77 | 32.71 | 42.01 | 12.93 | 13.11 | 628.63 | 8.66 | 9 58 | 15.11 | 30.23 | 35 75 | 713.58 |
| 47 | 7.53 | 7.96 | 16.27 | 18.38 | 10 25 | 10.25 | 603.15 | 6.53 | 9.68 | 10.39 | 20.02 | 21.79 | 815 53 |
| 48 | 10.15 | 12.36 | 25.01 | 29.55 | 11.25 | 4.68 | 413 43 | 4.95 | 9.56 | 11.50 | 21.64 | 29.96 | 1127 01 |
| 49 | 18.33 | 26.42 | 36.35 | 44.99 | 16.68 | 29 25 | 869.33 | 6.96 | 18.84 | 22.13 | 34.32 | 42.42 | 1529 11 |
| 50 | 11.51 | 20.98 | 43.05 | 47.33 | 14.68 | 21 73 | 515 37 | 0 66 | 11.74 | 17.89 | 41.66 | 45.08 | 1087.37 |
| 51 | 8.80 | 10.06 | 19.83 | 23.28 | 8 55 | 8.71 | 348.30 | 4.75 | 8.14 | 9 76 | 14 60 | 17.42 | 311 49 |
| 52 | 8 98 | 13.95 | 30.26 | 35 31 | 10.23 | 19 54 | 518 20 | 6.58 | 12 18 | 20 58 | 36 29 | 39.91 | 1067 55 |
| 53 | 10.32 | 16.02 | 29.93 | 35.15 | 12 57 | 23.16 | 798.54 | 7.26 | 7.83 | 9.20 | 27.45 | 33.70 | 639.96 |
| 54 | 10.10 | 10 54 | 13.20 | 16 21 | 12.89 | 15.13 | 917 47 | 5 89 | 8.55 | 9 59 | 13 28 | 15 60 | 945 78 |
| 55 | 10 41 | 11.65 | 18.10 | 21 32 | 10 83 | 12 02 | 540.85 | 4 04 | 6 03 | 7 06 | 15.35 | 19 59 | 393 60 |
| 56 | 11.93 | 15 94 | 24 81 | 27.85 | 21.46 | 25 73 | 481 39 | 8 64 | 4.71 | 5.80 | 11.42 | 13.68 | 356.79 |
| 57 | 12.62 | 14 84 | 41.98 | 55.11 | 13.37 | 18.31 | 679 60 | 3.40 | 14 81 | 18.34 | 41.17 | 54 89 | 617 31 |
| 58 | 15 32 | 19 80 | 32.14 | 37.04 | 17 96 | 22 67 | 679.60 | 5.87 | 9 38 | 13.33 | 29 68 | 35 03 | 688 10 |
| 59 | 5 62 | 6.78 | 14 92 | 17.47 | 5.90 | 8.63 | 334.14 | 6.38 | 5 07 | 6.38 | 16 03 | 18 82 | 467 23 |
| 60 | 7.97 | 8.32 | 17.47 | 20.80 | 14 06 | 15.10 | 744 73 | 11.00 | 15 26 | 15.74 | 21 34 | 26 15 | 1965.19 |
| 61 | 8 21 | 10.33 | 26.59 | 32.22 | 13 00 | 14 66 | 317.15 | 5.13 | 6.96 | 8.09 | 21 53 | 26.97 | 464 40 |
| 62 | 9 02 | 10.22 | 19 79 | 26.38 | 11.11 | 11.25 | 283 17 | 3 51 | 4 90 | 6.07 | 13.86 | 19.93 | 373.78 |
| 63 | 4 31 | 5 11 | 8 56 | 9.14 | 9 55 | 9.08 | 812.69 | 6.35 | 3 60 | 4 68 | 7 92 | 9 48 | 370 95 |
| 64 | 12 30 | 14 19 | 22.51 | 24.82 | 14.83 | 18 26 | 1070 38 | 11 00 | 4.98 | 5 38 | 11.20 | 12 47 | 518 20 |
| 65 | 7 37 | 7.93 | 18 04 | 22.15 | 9 65 | 9 72 | 538 02 | 13.92 | 5 69 | 6 44 | 16 88 | 21.60 | 484 22 |
| 66 | 18 42 | 20.61 | 24.71 | 27 72 | 22.62 | 26.65 | 1070.38 | 15.16 | 8.53 | 12.55 | 15.66 | 21 25 | 662 61 |
| 67 | 7 09 | 8 45 | 20.17 | 25 27 | 11 53 | 12 34 | 413.43 | 8.36 | 5 45 | 7.03 | 16 93 | 18.30 | 444 57 |
| 68 | 16 45 | 19 60 | 33 92 | 41.25 | 21.01 | 24 99 | 605 98 | 11.68 | 15.18 | 19 46 | 42 50 | 50 59 | 1059 05 |
| 69 | 13 49 | 14.38 | 26.61 | 35.29 | 14 37 | 15 45 | 1053.39 | 13.61 | 13.71 | 14 03 | 23 65 | 35.35 | 1965 19 |
| 70 | 7 64 | 12.28 | 22.37 | 26 71 | 10 18 | 18.38 | 487.05 | 6.50 | 6 89 | 11 68 | 21.96 | 26.38 | 605 98 |
| 71 | 5 78 | 6 30 | 12 57 | 18.95 | 13.99 | 14 91 | 515.37 | 9 42 | 3.56 | 4 05 | 8.27 | 11.95 | 314.32 |
| 72 | 15.73 | 17.28 | 20.00 | 21.25 | 19.88 | 23.81 | 991 09 | 15.77 | 18.08 | 20.58 | 23.76 | 25.12 | 1902 89 |
| 73 | 10.42 | 14 36 | 40 45 | 47.12 | 13 06 | 18 18 | 433.25 | 6.93 | 14 33 | 17.90 | 38.09 | 47.48 | 1192 14 |
| 74 | 12 63 | 15 14 | 26 32 | 29.21 | 19 46 | 17.97 | 809 86 | 8.81 | 14 68 | 16 05 | 23 49 | 25 60 | 1631 05 |
| 75 | 12 27 | 16.11 | 31.90 | 36.22 | 12.55 | 18.33 | 858.00 | 8 38 | 10 34 | 12.87 | 26.26 | 30 11 | 849 51 |
| 76 | 3.63 | 4.10 | 10.10 | 13.81 | 5.26 | 6.10 | 192.55 | 3.86 | 2 58 | 3 06 | 5.07 | 7.00 | 188 59 |
| 77 | 7 84 | 8.61 | 17.75 | 21 28 | 12 43 | 13 77 | 622 97 | 11.96 | 10.34 | 11.03 | 20 55 | 24.17 | 1237 45 |
| 78 | 3 82 | 5.95 | 15.46 | 19.75 | 14.14 | 7 53 | 128.06 | 2.31 | 3.25 | 3.91 | 9.73 | 14 31 | 240 41 |
| 79 | 12.93 | 15 89 | 39.23 | 56 14 | 14.51 | 18.13 | 868.38 | 2 97 | 12 88 | 15 94 | 32 48 | 43.60 | 835 35 |
| 80 | 3.52 | 5.24 | 13 50 | 15.02 | 5 40 | 10.87 | 254 22 | 5.38 | 4 65 | 5.89 | 12 64 | 14 50 | 419 09 |
| 81 | 4.19 | 6.60 | 17.63 | 22 45 | 7 69 | 15.08 | 203.37 | 3.71 | 6.05 | 8.48 | 18 55 | 20 84 | 351 13 |
| 82 | 6 85 | 9.01 | 22.31 | 28.91 | 5.70 | 8.29 | 402.23 | 4 88 | 6.74 | 8.35 | 22 64 | 26.82 | 770.22 |
| 83 | 33 32 | 38.12 | 47 68 | 52.62 | 36.24 | 42 53 | 3024 75 | 24 74 | 26 67 | 29.58 | 36.45 | 40 07 | 4587 33 |
| 84 | 5.52 | 7 19 | 20 22 | 27 63 | 9 75 | 13.13 | 379.70 | 3 40 | 6 41 | 7 35 | 19 15 | 28.06 | 424.75 |
| 85 | 21 12 | 29 17 | 47.48 | 56.32 | 23.01 | 37 94 | 1007 18 | 12 62 | 16.84 | 21 29 | 37 95 | 48 26 | 1248.77 |
| 86 | 11 88 | 12 76 | 18 83 | 21.57 | 19.69 | 19 78 | 1013.61 | 17 12 | 11 32 | 12 61 | 21.95 | 28.72 | 1291 25 |
| 87 | 4 27 | 5 74 | 12.17 | 16.72 | 6 74 | 9 46 | 231.04 | 1 45 | 7 02 | 8 22 | 15 68 | 18 89 | 889 15 |
| 88 | 11 68 | 13 95 | 29 63 | 35.75 | 15.61 | 19.40 | 431 19 | 12.29 | 12.82 | 15.96 | 24 03 | 27 85 | 908 97 |
| 89 | 9.58 | 12.54 | 31 55 | 36.72 | 11 15 | 17 12 | 402 23 | 6.89 | 9 90 | 11 67 | 23.35 | 27 66 | 835 35 |
| 90 | | | | | | | 466 58 | 14 78 | | | | | 1656 54 |

# VITA

Spencer R. Scoles

Candidate for the Degree of

Master of Science

Thesis: WATER YIELD, PEAK FLOW AND HIGH FLOW RESPONSE OF A LARGE FORESTED WATERSHED IN CENTRAL ARKANSAS TO SUSTAINED FOREST HARVEST OPERATIONS

Major Field: Environmental Science

Biographical:

Personal Data: Born in Honolulu, Hawaii, April 12, 1958, the son of Eugene A. and Eleanor M. Scoles.

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