A Site-Specific Rainfall Model for Western Virginia Ecosystems

by

Rebecca K. Wajda

Thesis submitted to the Faculty of the

Virginia Polytechnic Institute and State University

in partial fulfillment of the requirements for the degree of

Master of Science

in

Fisheries and Wildlife Sciences

APPROVED:

Robert H. Giles, Jr., Chairman

Donald J. Orth

Dean F. Stauffer

September 16, 1993

Blacksburg, Virginia

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(ABSTRACT)

A computerized system for estimating rainfall values was developed for western Virginia using data from 15 weather stations in that area. This system, called VARAINS for VirginiA RAINfall System, is designed to run on a microcomputer. System programs were created using Borland Pascal, version 7. The system models were developed using study station coordinates, elevation, aspect, distance from West Virginia, distance to the Virginia coast, as well as transformations, as independent variables. Additionally, a distance-weighting variable was developed using the inverse distance to each of the 5 closest study stations. The system provides estimates for annual, seasonal, and monthly rainfall at single or multiple ungaged sites. Rainfall models were validated using comparable periods of record from 3 stations within the study zone not previously used to develop study models. VARAINS was demonstrated using 4 sites occurring on the Havens Wildlife Management Area of the Virginia Department of Game and Inland Fisheries. Potential system applications for wildlife management include incorporating system output files into a geographic information system, using outputs as independent variables in regression analyses of habitat phenomena, and in ecosystem models of interest in endangered species research. Ideas for supplemental research on the model are explored and include testing VARAINS in other areas, evaluating the impact of using fewer years of data in model development, and combining these models with those developed in a recently completed temperature study.

Acknowledgements

I am grateful to Dr. Robert H. Giles, Jr., for his insight, support, and enthusiasm as my committee chairman. I also thank committee members Dr. Don Orth and Dr. Dean Stauffer for their expertise, advice, and patience.

I would also like to express my appreciation to Mr. Tom Johnson of the Virginia Water Resources Research Center. The data used in this project were obtained from the Center with his assistance.

I am indebted to Dr. Richard Neves, Dr. Larry Nielsen, and Dr. Charles Cushwa kept me gainfully employed during my residency. The experiences gained from each position have been invaluable.

To the graduate students who have been part of the Department of Fisheries and Wildlife Sciences during my stay, notably Betsy Stinson, Bret Preston, Susan Simonson, Steve Martin, Michael Odom, Mark Scott, Dave Coahran, and Scott Smith, thank you. Each of you have touched my life and changed it.

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Introduction

Objectives

Natural resource professionals have long documented the effects of climatic variables on their resources. Climatic elements are incorporated in many of the environmental sciences: geology, soil science, hydrology, fisheries, wildlife, agriculture, forestry, and natural resource planning. Munn (1970), Odum (1971), Whittaker (1975), and Ricklefs (1979) all discussed the importance of climate as an ecological parameter influencing the structure of habitats and populations. More specific applications of knowledge of climatic variables to wildlife, fisheries, forestry, and hydrology also exist and are discussed in detail in the "Literature Review". However, few attempts have been made to incorporate these climatic factors actively into resource management activities, decision-making, or planning. Bailey (1984:245) stated that

> without an ability to account for weather effects, managers will be less able to detect effects due to factors they can [account for], and they will be slow to realize when control [of resources] should be applied.

An effort is made herein to develop concepts and techniques for aiding wildlife resource managers in using climatic variables in decision-making, planning and management activities.

Computer storage, retrieval, manipulation, and display of data have become increasingly accepted methods of handling information. No one discipline in the natural resources can be totally separated from the others; computers appear to be an efficient instrument for integrating vast amounts of available information from one or more of these disciplines. This project uses computers for analyzing precipitation, presenting the results, making it readily available for use in other analyses, and thus making it available for use by decision makers.

This thesis does not attempt to address the complexity of a complete climatological model, but only one aspect, precipitation. The thesis is one of several studies being developed to create a comprehensive climatological information system for natural resource management. The specific objectives of this project have been:

1. to review the role of precipitation in wildlife-area and other natural resource management;
2. to develop a micro-computer system for analyzing, modeling, and presenting rainfall data in a useful, cost-effective format for natural resource professionals in western Virginia; and
3. to demonstrate capabilities of the developed system for a wildlife management area.

Selection of Climatic Variable

General models of the hydrologic cycle illustrate that precipitation is a key element in the successful flow of water through the biotic system (Steinhoff 1971, Silka 1984; Fig. 1). Water falling onto the soil surface typically leads to runoff into streams, ponds, lakes, reservoirs, and

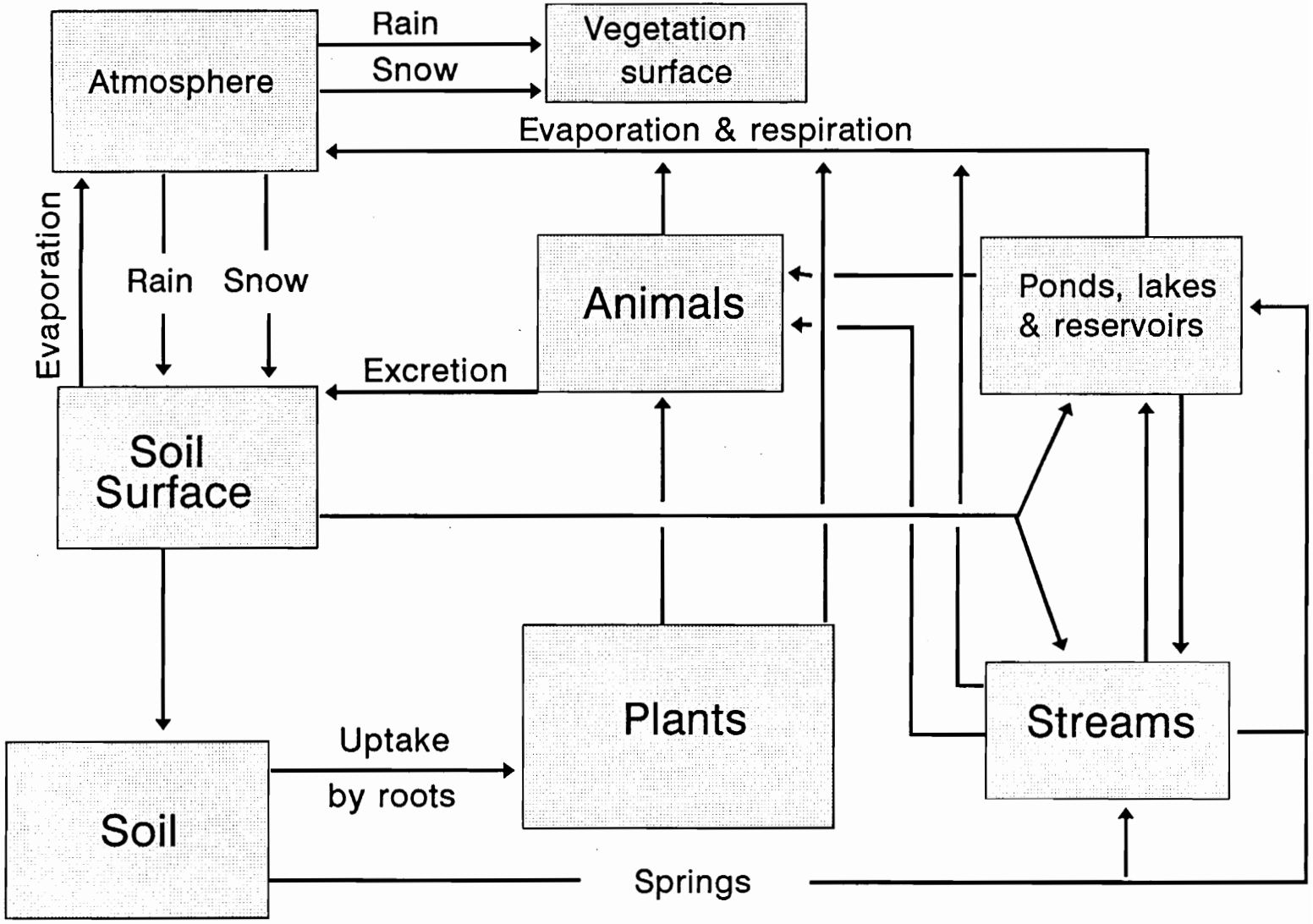

Figure 1. Compartment model of annual ecosystem water flow (from Steinhoff 1971).

oceans. Water percolating into the soil plays a role in adding to groundwater levels and maintaining springs. Once in the soil, water is also drawn up by vegetative root systems, directly affecting the primary productivity of the land. Having been incorporated into vegetation, water can then be transferred to animals, or it is obtainable by them from bodies of water which have received water by some other means.

A lack, or overabundance, of precipitation may adversely affect this flow of water at any, or several, of the stages of the cycle. The amount of precipitation in any one area affects resource responses at that location, as well as responses throughout the entire watershed. While precipitation and other climatic elements work to shape the basin, the landform and vegetative responses modify the local climate (Martin 1988).

Rainfall was specifically selected for modeling because it is a major climatic element which is often used as an independent variable in other models. While precipitation and temperature appear to be somewhat correlated, especially seasonally, these two elements are initially being modeled separately to determine features unique to each (Hamrick and Martin 1941, Madden and Williams 1978, Anderson 1981, Gruen 1993).

Animal Responses

Wildlife movement, reproductive success, and forage and habitat availability are all affected by variations in precipitation. The amount of precipitation, over short and long periods of time, and the form in which it falls, play major roles in the lives of animals and of animal populations. Obvious changes in water levels anywhere in the hydrologic cycle have generated changes in species and community structure and composition. Harsh, short-term

precipitation events (i.e., hail storms, blizzards) can cause temporary, but noticeable, changes in species population levels and age structure.

Globally, the amount of rainfall that annually falls often dictates the vegetative and faunal community compositions in an area. Holdridge's (1967) classification scheme for plant communities is based on climatic values. Kuchler's (1964) classification of potential natural vegetation follows climatic trends of temperature and precipitation. Bailey's (1976) classification of ecoregions in the United States is based primarily on climatic variables.

In summary, this thesis attempts to develop a system for allowing high quality information about precipitation to enter managerial decisions about terrestrial and other wildlife resources.

Literature Review

Climate

"Weather" and "climate" are often used interchangeably to describe atmospheric conditions such as temperature, precipitation, solar radiation, wind, and air pressure. While both terms focus on these conditions or observations, there are differences in the reference periods and statistics usually reported with each one. "Weather" is generally described as the condition of the atmosphere at a particular place and over a relatively short period of time (hour, day, week) (Bailey 1984). The statistics associated with weather are usually specific observations for that time and place, such as minima, maxima, (e.g., daily temperature high and low values), and actual values (e.g., amount of rainfall a particular day). "Climate" is usually considered the typical atmospheric conditions experienced at a location over a long period (Bailey 1984, Martiner 1986). It is generally described by averages (e.g., average annual rainfall), extremes (e.g., lowest/highest temperature for a particular month over the period of record), and probabilities of occurrence.

Climatic values have been shown not to vary significantly over a 50- to 60-year period (Gifford et al. 1967). However, due to some annual variability, 25-30 years of data must be used to develop valid monthly temperature statistics. A comparable time frame would presumably be needed for similar rainfall monthly statistics (Munn 1970, Anderson 1981).

Regional variations in climate, vegetation, and landform are important in how ecosystems develop. Climatic variables have been used to develop globally recognized vegetative classification schemes. Holdridge (1967) developed a classification of global plant formations based solely on climate. He considered the interaction of temperature and rainfall to dominate in determining vegetative formation (Ricklefs 1983). Kuchler's (1964) classification of potential natural vegetation follows climatic patterns for temperature and precipitation. Bailey's (1976) 4-level classification of the ecoregions of the United States delineates areas based primarily on climate. In Bailey's scheme, a "domain" (the largest level of identification) is a subcontinental area of broad climatic similarity. A "division" (second level) is determined by separating areas of differing vegetation and regional climates. A "province" (third level) corresponds to a vegetative region which had uniform regional climate and similar soil types. A "section" (fourth level) is further defined by the local climate.

Many vegetation classification schemes use several different elements in defining boundaries. Bailey (1980) used variations in climate, vegetation, and landform to determine ecoregions. However, as previously noted, climate greatly influences each of these features. It is often difficult to determine if the influence of climate on a particular element (e.g., vegetation, landform) is greater than the influence of that element on the climate.

Climatic information has also been incorporated into a variety of computerized management systems. The Forestry Weather Interpretations System (FWIS) was developed in the early 1980s to provide current climatic data from National Weather Service sites for forest management (Paul and Turner 1984). The data are used in planning a variety of management activities, including prescription fires and related smoke management, tree planting, and

nursery schedules. The Bureau of Land Management maintains a computer-satellite system to track storm activities in the western United States to assist the agency in allocating labor and resources for fire-fighting.

Precipitation

In general, precipitation can occur due to 1 of 3 circumstances (Pearson 1968, Griffiths 1976, Wang 1984, Ahrens 1985). Convectionally-caused precipitation occurs when air heated by contact with the warm earth is forced upward. As it rises, the air expands and cools; if sufficient cooling takes places, condensation begins, forming water droplets. Orographically-caused precipitation occurs when an air mass moving into a mountain range is forced upward by pressure from behind. As the air rises, it expands and cools, resulting in droplet formation. Finally, frontally-caused precipitation develops along the frontal line between two air masses having unlike temperatures. The warmer air rises and cools, leading to precipitation.

Due to the high altitude at which most precipitation is generated, droplets usually begin as ice crystals (Ahrens 1985). However, as these droplets fall, they may pass through temperature inversions and their state may be changed. Precipitation types are characterized generally by the state of the water and size of each droplet. While the state may be liquid, droplet size differences may result in rain or drizzle. The solid state may be classified as snow, hail, or sleet, dependent on droplet size (Table 1).

Fog drip, another form of precipitation, is caused by the collection of minute water droplets on leaves, branches, or bark. These droplets coalesce into larger drops, which then fall to the ground surface. The amount of fog drip is related to the size and density of the trees (Azevedo

Table 1. Descriptions of states of precipitation (hydrometric definitions) (from Mather 1974, Wang 1984).

Hydrometer	Definition
Precipitation	Atmospheric water, in any of its phases, deposited on the earth or its biotic surfaces (Wang)
Intercepted precipitation	Deposition caused by interception (e.g., rime, dew-fog, fog precipitation) (Wang)
Fog	Suspension of very minute water droplets ($4x10^{-3}$- $4x10^{-5}$mm) around the visible horizon (Wang)
Drizzle	Droplets < 0.5mm in diameter; intensity < 1mm/hr.; very small, numerous drops that seem to float in air following air currents (Mather)
Rain	Droplets > 0.5mm diameter; intensity > 1.25mm/hr.; larger but fewer drops than drizzle, less reduction in visibility (Mather)
Snow	White or translucent ice crystals often agglomerated into forms of flakes. Size depends primarily on water content and amount of moisture surrounding a crystal (Mather)
Snow pellets	White, opaque, round or conical ice particles with snowlike structure, 2-5mm in diameter. Pellets are crisp and easily crunched (Mather)
Sleet	Transparent, solid grains of ice formed from freezing of rain or slight melting and refreezing of snow as it falls (Mather)
Snow grains	Very small, white, opaque particles; the solid equivalent of drizzle (Mather)
Hail	Balls or lumps of ice, often with concentric layers of clear and milky ice; > 5mm in diameter (Mather)
Virga	Water or ice particles falling from clouds but evaporating before reaching the earth or its biotic surfaces (Mather)
Rime	White or milky granular deposit of ice formed by rapid freezing of supercooled water droplets hitting exposed objects (Mather)
Glaze	Coating of clear smooth ice on exposed objects by freezing of film of supercooled water deposited by rain, drizzle, or fog. Denser than rime (Mather)
Dew	Water condensed on objects near the ground the temperatures of which are above freezing but below the dew point (temperature at which air becomes saturated with moisture). Frost (hoarfrost) occurs if temperatures are below freezing (Mather)

and Morgan 1974, Harr 1982). Elevation, amount of exposure to fog, and species (and associated characteristics) of trees also directly affect fog drip values (Oberlander 1956, Azevedo and Morgan 1974, Harr 1982).

Several geomorphological factors have been shown to affect significantly the amount and distribution of rainfall. The most notable of these variables are elevation, aspect, and slope (Martin 1988). Precipitation generally increases with increased elevation (except in tropical rain forest areas) (Geiger 1965, Gifford et al. 1967, Chang and Lee 1975, Campbell and Ryan 1982).

Aspect is also a critical factor in determining the distribution of rainfall. Windward and leeward sides of mountains receive significantly different levels of precipitation, a phenomenon known as the "rain shadow" effect (Olgyay 1963, Gifford et al. 1967, Chang and Lee 1975, Campbell and Ryan 1982). As the air mass is forced up the windward side of a mountain, the moisture is lost as precipitation. This same cool, dry air mass then rushes down the leeward slope, warming up, and picking up moisture from the ground, creating arid conditions (Campbell and Ryan 1982, Ricklefs 1983).

While slope does not directly affect the amount of precipitation falling, it is a critical factor to be used in estimating the area upon which the moisture falls, the amount that infiltrates, and is stored in the soil (Geiger 1965). A steeper slope will allow for less penetration and increased runoff (Gifford et al. 1967, Strutzer 1972, Saunders 1977, Sharon 1980) than a less steep slope. Soils on steep slopes are generally well-drained, resulting in conditions of moisture stress, while lowlands are generally saturated (Ricklefs 1983). South-facing slopes receive the direct-heating effect of the sun, resulting in dry conditions to which xeric vegetation responds. North-facing slopes are generally cool and wet, with mesic vegetation (Ricklefs 1983).

Precipitation is measured using rain gages. These gages are generally a funnel-bucket apparatus, with some shielding to reduce evaporation and prevent higher-than-actual readings caused by wind-blown moisture. There are 12,000-13,000 gages located across the United States; of these, 3,000 are automatic recording gages (Mather 1974). These gages register amount, timing, and intensity of a precipitation event (Dunne and Leopold 1978). The remaining 9,000 sites are monitored daily, generally by private citizens in cooperation with the National Climatic Data Center. With these non-recording gages, it is possible to measure only the amount of precipitation falling since the last measurement was made (Dunne and Leopold 1978). Excluding Alaska and Hawaii, the gage distribution across the Unites States averages 1 gage/650 km^2 (Mather 1974). There are 325 stations located in Virginia, 8 of which are continuously monitored.

Precipitation measurements are generally made in inches in the United States. Rainfall measurements are taken directly from the gage, usually to the nearest 0.01 inch. Precipitation <0.01 inch is noted as "Trace". Snowfall depth is measured in inches and converted to a melted equivalent. The standard conversion rule is that 10 cm of snow are equivalent to 1 cm of water. However, this conversion can vary widely from 6 cm to 18 cm of snow, based on its density.

Gage observation time has been shown to affect the recorded rainfall values (Woolhiser and Roldan 1986). This effect can be attributed to the evaporation of small amounts of rain prior to measurement and the diurnal variability of precipitation occurrence. Gages serviced in the afternoon or evening often show smaller numbers of "wet" days (days with precipitation) than those serviced between midnight and noon (Woolhiser and Roldan 1986).

Gage placement and exposure are important factors in determining the accuracy of the recorded rainfall values for individual gages. Merva et al. (1976) found a relationship between the percent frequency pattern of gage catch and the topographic characteristics of the watershed extending approximately 1-2 miles on each side of the gage. Gages placed in the

path of "channeling" areas (e.g., valleys) were exposed to higher precipitation than when storms came from cross-valley directions (Merva et al. 1976).

Wind appears to be the major cause of error in gage measurements. Catch error increases with the site wind speed and is larger for solid than for liquid precipitation (Larson and Peck 1974). A 10% deficiency can be expected in gage catch for liquid precipitation at wind speeds of 16 km/h. A 45% deficiency can be expected in gage catch for solid precipitation at wind speeds of 16 km/h, while a 70% deficiency can be expected at wind speeds of 32 km/h (Larson and Peck 1974, Hanson 1989). Gage shields have proven to be very effective in reducing measurement errors by as much as 50% for solid precipitation (wind speed <32 km/h), but are not effective in reducing liquid precipitation measurement error (Larson and Peck 1974). Gages placed near high trees, buildings, or windbreaks are likely to be sheltered during a storm event and may inaccurately reflect the level of precipitation falling during that event (Merva et al. 1976, Poreh and Mechrez 1984). The most effective way to reduce such deficiencies has been to place the gage in a natural site, well-protected in all directions by objects of uniform height (Larson and Peck 1974).

Gage angle has also been shown to influence recorded values. James (1964) found that gages placed at a 90° angle from horizontal recorded 30% less precipitation on windward slopes than did gages placed at an angle parallel to the slope of the terrain. The conventional gages recorded 10% more precipitation on leeward slopes than did the inclined gages (James 1964, Sharon 1980).

The conclusion that may be reached as a result of this review is that while there are many observers of precipitation, sampling devices are extremely widely spaced, there are few continuous records, and even the best ones seem to have nearly unavoidable, perhaps inherent, errors of measurement. Some of the variance discovered in observations is likely to be due to measurement techniques and time, equipment, and observer error. Fog drip also

casts a cloud of uncertainty about conventionally measured precipitation and its role in any area with dense vegetation.

Relationship Between Precipitation and Temperature

The influences of precipitation and temperature on natural resources are often studied simultaneously. Later sections in this chapter will illustrate that the combined effect of the two climatic variables is often more influential on the resource than either factor separately.

Madden and Williams (1978) investigated possible correlations between seasonal mean temperatures and precipitation for weather stations in North America and Europe. Study results showed definite relationships during two seasons of the year over broad areas of the United States. During the summer period (June, July, and August), most of the area showed a significant negative correlation between mean monthly temperature and precipitation. This relationship supported similar findings by Hamrick and Martin (1941) in the midwestern states. A similar significant negative correlation was also found for the plains states during the winter period (December, January, and February). However, the majority of the rest of the country showed a positive correlation between temperature and precipitation during the winter period. Madden and Williams (1978) hypothesized that this positive correlation is due to tracks of cyclones and the relationship of temperature and precipitation within various parts of the cycle.

A climograph is one of the most common methods for simultaneously portraying monthly or seasonal changes in temperature and rainfall (Ricklefs 1983). The graph is set up as a two-dimensional system, with a horizontal rainfall scale and a vertical temperature scale. Each month is then plotted at the appropriate average temperature and rainfall. The seasonal

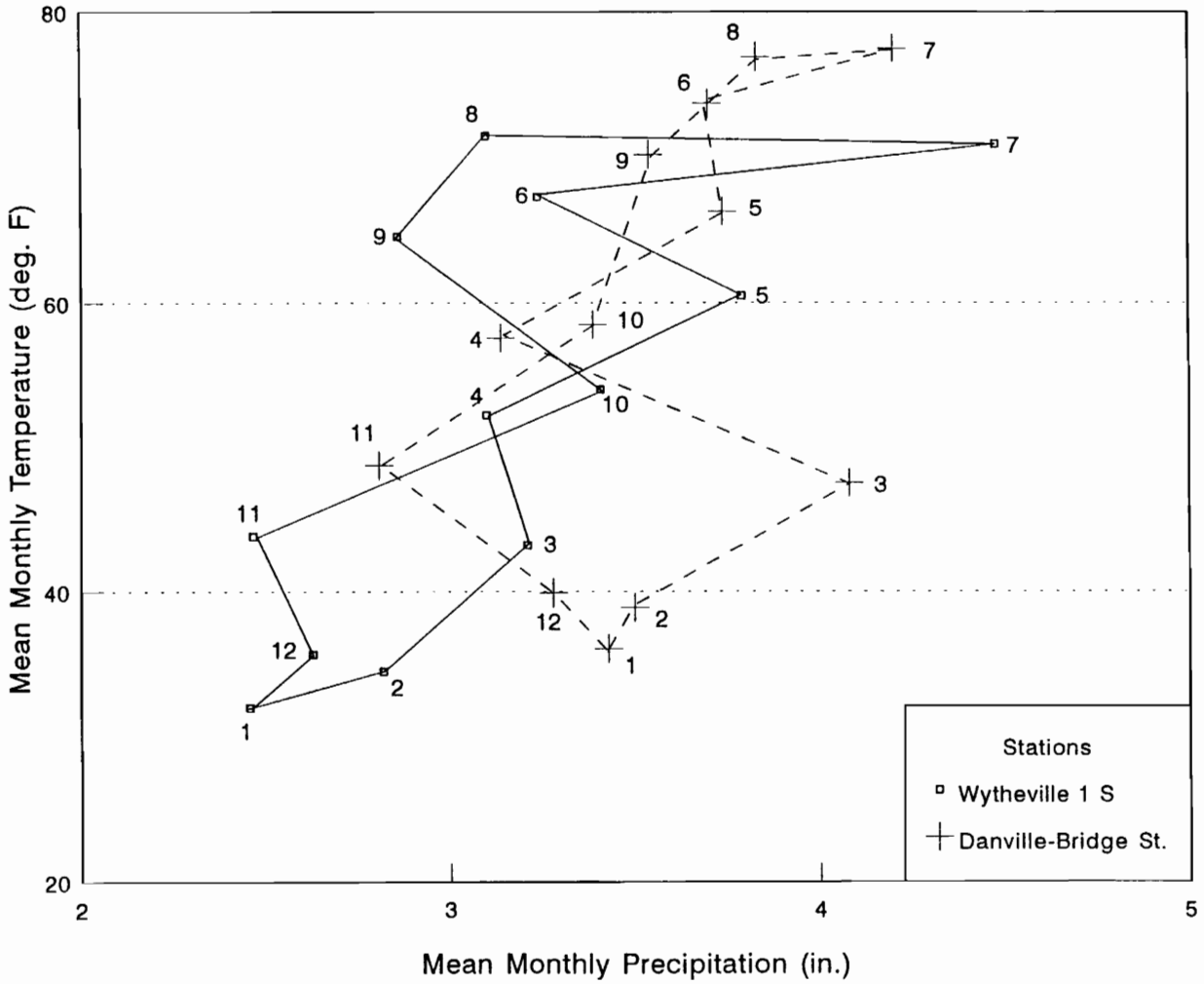

Figure 2. Climograph illustrating temperature/precipitation relationships for study stations at the highest and lowest elevations (data from Va. Water Resources Research Center, Blacksburg, Virginia).

change in climate is portrayed with lines joining monthly mean data. The resulting plots permit a visual comparision of key climatic factors at different locations (Fig. 2). Climographs do not account for other climatic factors, however, and may misrepresent important biological impacts of combinations of factors with their interplay of forces.

Ecological Interactions

Biometeorology is defined by the International Society of Biometeorology as "the science which investigates the effects of geophysical and geochemical elements of the atmospheric environment on living organisms" (Lowry 1967). An important addition to this definition should include the influence of these organisms on the atmosphere. Many reports describe the ecological interactions of climatic factors and natural resources. Swift and Ragsdale (1985) identified a variety of uses for meteorological data at long-term ecological research sites. These applications included: examining the spatial variation of precipitation and temperature in mountainous terrain to aid modeling of primary production; evaluating and modeling water availability to plants in sandy soils; identifying the influence of rain, snowmelt, and evapotranspiration on temporal and spatial variation of soil moisture; evaluating the influence of water and wind on movement and deposition of soils and plant materials; and evaluating the effects of wind, precipitation, and hydraulics in controlling daily variations of the nutrient content of water. The following review will focus on the fields of wildlife, fisheries, forestry, and hydrology, and the effects of precipitation. Where appropriate, the interactions with temperature will also be noted.

Wildlife

An extensive survey of the literature pertaining to wildlife and precipitation has shown 4 areas of important relationships. These are: forage quality and quantity, animal movement and energy expenditure, reproductive success, and hunter behavior.

Forage Quality and Quantity

> "I estimated that the winter of 1854-55 destroyed four-fifths of the birds in my own ground;...The action of climate seems at first sight to be quite independent of the struggle for existence; but in so far as climate chiefly acts in reducing food; it brings on the most severe struggle between the individuals, whether of the same or of distinct species, which subsist on the same kind of food."
>
> C.R. Darwin (1859:68), *On the Origin of Species*

Quality, quantity, and availability of forage can all be substantially affected by precipitation. Deep snow decreases availability of vegetation, especially to ungulates and birds (Roseberry 1964, Gilbert et al. 1970). Prolonged periods of concentration of individuals on critical areas where food supplies are inadequate have resulted in heavy deer (*Odocoileus* spp.) mortality (Walmo and Gill 1971).

Deep, dense snowpack can also work to the deer's advantage. Thick crusts or densely packed snow which would support an individual's weight may place the animal in reach of food which might otherwise have been too high (Moen and Evans 1971). For northern bobwhite (*Colinus virginianus*), however, snow cover lasting more than a few consecutive days may result in mortality (Edminster 1954).

Precipitation not only affects the availability of forage to wildlife, but also the quality and quantity of forage. Feldhamer et al. (1989) found a significant positive correlation between acorn yield and the cumulative number of days with precipitation the previous 3 winters. Prior

to this study, most research on the relationship between oak mast and precipitation targeted specific times of the year, or only 1 year. Frequency of precipitation and cumulative effects on yields were not addressed. Feldhamer et al. (1989) hypothesized that frequency of precipitation (and presumably, conversely, intervening deficits) may be more important than absolute amounts as a factor influencing forage production in areas with low water-holding capacity. Additional research is still needed to test further this hypothesis.

Variation in precipitation may act in a limiting manner through a direct effect on primary productivity and thus on food supplies. Francis (1970) hypothesized that the rainfall effect on California quail (*Callipepla californicus*) production may operate through an effect on vegetation (nutritional deficiencies, changes in cover, etc.). Good quail productivity occurred in years when green vegetation and annual forbs were abundant following high winter and spring rain. Poor productivity occurred in years when there was poor vegetative growth following low rainfall. Studies by Dunning and Brown (1982) and Laurance and Yensen (1985) that showed increased sparrow densities after periods of good rainfall during vegetative growing seasons, support this hypothesis.

Brown (1973) suggested that species diversity of pocket mice (Heteromyidae) in the southwest deserts is greater where rainfall is greater, even though there are no obvious differences in vegetation in the wetter areas. Rainfall may increase seed production, creating opportunities for greater niche diversification (Brown 1973).

Animal Movement and Energy Expenditure

Many ungulates, including several deer species, elk (*Cervus canadensis*), caribou (*Rangifer* spp.), and moose (*Alces alces*) use summer ranges at higher altitudes than ranges which they use during the winter. However, as snow covers available forage and increases movement energy expenditures, the animals are forced to move to lower winter ranges. These winter

ranges often concentrate the animals on land with poor quality and little available forage (Edwards 1956, Gilbert et al. 1970, Wallmo and Gill 1971, Peek 1971, Bailey 1984). Several authors suggested that the geographic distribution of cervids and their anatomical adaptations support the idea that snow is a primary factor in determining species distribution and location (Wallmo and Gill 1971, Bailey 1984).

Due to extreme energy expenditure required to move in snow, many wintering cervids decrease activity and movement substantially when snow levels reach sternum height (Severinghaus 1947, Edwards 1956, Gilbert et al. 1970, Moen and Evans 1971, Wallmo and Gill 1971). Gilbert et al. (1970) found that snow depths greater than 0.46 m (1.5 ft.) were impassable by mule deer (*Odocoileus hemionus*). Peek (1971) discovered that moose in Minnesota will shift to dense stands of trees when a differential in snow density, hardness, or depth occurs between the dense stands and the moose's usual open range. He also found that these individuals can last up to 90 days in these stands, with little loss in production or survival of calves. In his work with white-tailed deer (*Odocoileus virginianus*), Verme (1968) developed a "severity index" to determine the relative severity of winter climate for the species. The index is the sum of the "air chill" (read from a chillometer) and the "snow hazard" (based on the depth of snow pack and its supporting quality).

Many species benefit from snowfall. Subnivean rodents, such as the short-tailed shrew (*Blarina brevicauda*), masked shrew (*Sorex cinereus*), meadow vole (*Microtus pennsylvanicus*), and other mouse species (*Peromyscus* spp.), are able to use under-snow tunnels for moving about, thus locating areas of warm temperatures and reducing their exposure to predators (Schmid 1971, Young and Boyce 1971). Ruffed grouse (*Bonasa umbellus*) and sharp-tailed grouse (*Pedioecetes phasianellus*) have been found to derive thermal benefits by roosting in the snow on cold winter nights (Moen and Evans 1971, Moen 1973, Chang and Lee 1975). Precipitation has also been suggested as a proximate factor for black bear (*Ursus americanus*) denning and emergence patterns (Northcott and Elsey 1971, Lindzey and Meslow 1976, Johnson and Pelton 1980).

Many avian species are severely affected by prolonged cold rains. As the protective plumage becomes soaked, its insulating value sharply declines, and loss of body heat accelerates (Kendeigh 1934, Welty 1982). For this reason, long, cold, rainy periods are more hazardous to individuals than long, cold, dry periods.

Reproductive Success

Often, the condition of an animal after winter season will dictate spring reproductive success. Mule deer and other cervids in poor physical condition have shown increased post-natal fawn mortality and decreased fertility (Wallmo and Gill 1971). Significant decreases in deer populations have been seen in the year after heavy precipitation in winter and spring months (Wallmo and Gill 1971).

The greatest effect precipitation appears to have on reproductive success is the survivability of eggs or young during late winter and spring rains. Northcott and Elsey (1971) found that heavy spring rain may cause cub mortality in black bears due to den flooding. Bears nesting in the open in the flat areas of the Great Dismal Swamp National Wildlife Refuge and other southeastern wetlands are probably susceptible to a similar phenomenon (Hellgren and Vaughan 1989). The number of juvenile masked shrews (*Sorex cinereus*) in southeastern Manitoba populations has been negatively correlated with the rainfall amount from the preceding month (Buckner 1966). During the preceding month, these juveniles would have had very little insulating fur. However, an overall increase in spring rainfall has also been accompanied by increases in cottontail, deer, and fox populations, most likely due to increase forage (Richmond 1952, Hill 1966, Halls 1984).

Avian species appear to be more susceptible than other animals to late winter and spring rains. Olsen and Olsen (1989) found that rain affected peregrine falcon (*Falco peregrinus*) breeding success by: (1) destroying nests or making sites unusable; (2) decreasing the

number of pairs able to occupy nests if sites are too wet; and (3) increasing the mortality of the clutches and young broods exposed to the rain. Edminster (1954) and Rosene (1969) indicated that comparable effects (nest destruction, mortality of young) have been documented for the bobwhite. Kendeigh (1934) attributed the effect to the juveniles' inability to avoid being soaked; if nestlings or eggs get wet, death is usually quick. Jehl and Hussell (1966) found high mortality with passerines in the Canadian Arctic. During a 4-day period of cold rain (temperature $< 4.5°C$), 95% of the nestlings were lost, presumably due primarily to exposure while the parents were gathering food. Further study led them to conclude that the higher survival rate of non-passerines was largely due to the precocial condition of the young (Jehl and Hussell 1966). These young had greater mobility than altricial young that enabled them to move to sheltered areas. They also had dense downy plumage that helped prevent soaking.

Rainfall also appears to affect the starting time of the breeding season and litter size. Reynolds and Turkowski (1972) noted that the onset of the breeding season of round-tailed ground squirrels (*Spermophilus tereticaudus*) was advanced 9 days for every additional 0.5 in. of rain in December/January. They also discovered an increase in the number of embryos corresponding to additional rain between October and February (1 additional embryo for each additional inch of rain). As with a number of other researchers, Reynolds and Turkowski (1972) additionally concluded that the increased productivity or advanced breeding season was not directly related to the rainfall, but was related to the production and nutritional value of the spring annuals on which they fed during this period.

Decreases in rainfall can also affect species' reproductive success. For waterfowl nesting in prairie pothole regions, a decrease in rainfall results in the loss of breeding habitat, and a subsequent decline in overall populations (Di Silvestro 1985). Hill (1966) found that female cottontails can drop into dioestrus temporarily during the breeding season whenever conditions weigh against ovulation and pregnancy. Their reproduction has been shown to be affected by rainfall. Lactation terminated when females ate dry food.

The secondary effects of precipitation on plant production and food supplies, thus on reproductive success, are well-known and not reviewed in detail here.

Hunter Behavior

Hunter success has also been related to precipitation. Heavy rainfall during the first week of deer season has been negatively correlated with the number of deer killed (Fobes 1945, Cumming 1967, Mechler 1970, Curtis 1971). Mechler (1970) further refined this correlation and discovered that the amount of precipitation from 7:00 a.m. to 7:00 p.m. on opening day of deer season alone was a significant influential factor in total harvest. Curtis (1971) also found that 74% of western Virginia hunters interviewed would cancel a planned weekend hunt if the rainfall was "heavy" (>25mm of precipitation).

Conversely, a light to moderate rain (0.25mm - 1.27mm) or snowfall has been shown to contribute to an increase in deer sightings per hunter-hour (Fobes 1945, Curtis et al. 1972). Curtis (1971) found that 90% of western Virginia hunters interviewed considered a damp forest floor a prime component of excellent hunting conditions. Fobes (1945) and Mechler (1970) found significant increases in the number of deer killed apparently due to the muffling of hunters' footsteps and improving the ease of tracking.

Forestry

Climatic data are useful in forestry for planning a variety of activities. These data are helpful in planning for prescribed fires (establishing seasonal limits), insect control, tree planting, road or trail construction and maintenance, and environmental assessments and impact statements.

Rainfall during the growing season (March to August) has been positively correlated with site index and annual radial incremental growth in beech (*Fagus* spp.), yellow poplar (*Liriodendron tulipifera*), shortleaf pine (*Pinus echinata*), longleaf pine (*Pinus palustris*), loblolly pine (*Pinus taeda*), slash pine (*Pinus elliotti*), and white pine (*Pinus strobus*) (Coile 1936, Schulman 1942, Miller 1950, Dils and Day 1952, Tryon et al. 1957, Young and Brendemuehl 1973, Beck 1985). This knowledge could be instrumental in determining harvest rotation schedules, stand age, and faunal species associated with stand age. Beck (1985) suggested that adjustments of growth data for weather conditions could improve growth projections as well as models of the real effects of site, stand, and treatment variables. This adjustment appears to be a very real need. Dils and Day (1952) stressed that even a period of 10 days without rainfall diminished the radial increment of red pine (*Pinus resinosa*).

Site productivity and species diversity are also affected by precipitation. Stevens et al. (1974) developed a site productivity classification scheme for selected plant species on winter big game ranges of Utah. In all cases of species or species combinations, one of the required variables for determining site productivity was the annual water-year (October 1 - September 30) precipitation. May precipitation values were also important in determining site productivity potential of grasses. In studying the plant diversity of California, Richerson and Lum (1980) discovered that rainfall accounts for 52% of the variance in total floral diversity, 62% of the variance in tree species diversity, and 59% of the variance in perennial herb diversity. Annual herb diversity did not appear to be influenced at all by rainfall.

Precipitation is also a significant medium of plant nutrients. Twenty to 40% of the annual amount of calcium and potassium sequestered in temperate hardwood forests comes from precipitation (Swank 1984). Nitrogen found in precipitation makes up approximately 70% of the nitrogen incorporated annually in the woody tissue of some temperate hardwood forests (Swank 1984).

Extended periods of low precipitation, combined with several other factors (including high temperatures), produce conditions in which dead vegetation becomes highly flammable. Moisture content of this vegetation is one of the basic elements in the U.S. National Fire Danger Rating System (Reifsynder 1978). A basic graph of monthly total precipitation (mm) against temperature (°C) was developed as part of this system, plotting each 10°C increase with a 20mm increase in precipitation. Any time that conditions exceed this line, the tinder is considered dry and extremely flammable. The ability to monitor vegetation moisture content is instrumental in preventing major alteration and modification of wildlife habitat due to fire.

Weather variables are also a very large component of Canadian Forest Fire Danger Rating System (CFFDRS), currently being developed by Foresty Canada (Stocks et al. 1989). When completed, the CFFDRS will consist of 4 subsystems: the Canadian Forest Fire Weather Index (FWI) System (completed), the Canadian Forest Fire Behavior Prediction (FBP) System (completed), the Canadian Forest Fire Occurrence Prediction (FOP) System (proposed), and the Accessory Fuel Moisture System (incomplete). The FWI System depends solely on daily measurements of 4 weather variables: dry-bulb temperature, relative humidity, open wind speed, and 24-hour accumulated precipitation recorded at noon. Three fuel moisture codes (fine fuel, duff, and drought) in the system track actual fuel moisture by adding moisture after rain or subtracting water for each day's drying. Because the codes react at different rates, timelags, and rain amounts required for saturation of the represented fuel layer, any one of them may be high or low in contrast to the others at any one time. Data from the FWI System are then fed into other components of the CFFDRS to aid in planning, education, resource allocation, and training.

Fog precipitation plays a very important role in forest hydrology in the California/Oregon area of the United States. In fact, Oberlander (1956) stated that fog drip may increase total precipitation values in forested areas 2 to 3 times that of open areas. Obviously, the extent of forest cover (species and density) and the positions of plants partially dictates how much water is caught. Maximum accumulation occurs at the windward edge of the forest

(Oberlander 1956). This added water was first thought to be important primarily for coastal redwood forests (Byers 1953, Oberlander 1956, Azevedo and Morgan 1974). However, further studies have shown that this type of precipitation is used more by Douglas fir and other "slope" trees than by redwoods (Byers 1953, Rothacher 1963).

The phenomenon of fog drip was originally thought to affect only coastal forests, but it has since been shown to influence inland areas as well. Azevedo and Morgan (1974) measured fog precipitation for a 46-day period (July - September) at 1 coastal site and 2 inland sites. Twenty days of fog precipitation were recorded at the coastal site, totaling 173 cm of "fog water." The two inland sites each recorded 28 days of fog precipitation, totaling 123 cm and 388 cm of water, respectively.

Fog precipitation also plays a significant role in basin hydrology. A study was conducted on 2 logged watersheds in Oregon when hydrologists found a decrease in annual water yield from the logged areas instead of the expected increase of 100-150 mm of water. Harr (1982) monitored several areas over a 40-week period and found that the net precipitation under forested areas was 1739 mm compared to a net precipitation in clearcut areas of 1352 mm. He concluded that timber harvest, especially as part of the long-term management plan for an area, could decrease the quality and quantity of stream flow, particularly in the summer.

Fisheries

As with terrestrial wildlife, precipitation also affects aquatic resources. Availability of habitat and fishing pressure have both proven to be influenced by precipitation. One of the most obvious effects of precipitation to aquatic systems is the recharge of water supplies to springs, ponds, streams, and reservoirs (Tabler and Johnson 1971). Reduced water supplies often result in decreasing flows, concentrating toxicants or other harmful compounds, fragmenting

the system (habitat), and increasing water temperatures. Any of these factors, alone or in combination with one another, influence spawning success, availability of food resources, availability of appropriate cover, and general species health, potentially changing aquatic community composition (Waters 1983).

Neuhold and Lu (1957) conducted a creel survey of Utah anglers and found that fishing pressure was lower on days when it was raining or snowing and also on days of below average temperatures. This finding is not a new observation. Not only is there the physical discomfort to the angler, but the precipitation also changes water clarity and chemical parameters, affecting visibility and fish response to the lures.

Hydrology

Infiltration of water into the soil is necessary for recharging soil and groundwater water supplies (Tabler and Johnson 1971, Silka 1984). The most common sources of recharge are rainfall and snowmelt. To enhance the water potentially available in the Great Plains areas, researchers have even put up fences to trap blowing snow in areas where there are no natural barriers (Tabler and Johnson 1971). These snow fences serve two purposes: (1) increasing total snow storage by reducing sublimation of the snow, and (2) providing a means of artificially redistributing water over a drainage to improve on-site use or water yield downstream.

Acidic Precipitation

Another area of great concern across all of the natural resources is acidic precipitation, or "acid rain." While this subject is not a resource field *per se*, its effects and impacts have

become so dramatic that it warrants separate mention. Most of the research activities in this area have concentrated on the effects of acidic precipitation on flora and fauna, and it is these resources that will be the focus of this section. Rainfall acidity is qualitative, of course, and the work of this thesis is about quantitative estimates. Estimates of water volume are essential to understanding dilution rates and solution-forming phenomena.

The northeastern United States and Canada have extensive and severe acid precipitation problems (Cogbill and Likens 1974, Longcore et al. 1987). Low pH (<5.6) appears to have a generalized regional distribution over most of the eastern United States, with several areas experiencing rainfall pHs less than 4.0 (Cogbill and Likens 1974).

Kahn (1985) found that rain falling in Virginia was quite acidic. His review of the state's natural resources led him to predict that the soil's buffering capacity would be used up in 10 to 40 years. As with most researchers, he also indicated that continued levels of acidic precipitation would have a devastating effect on fish and other aquatic life (Kahn 1985).

Some of the most dramatic effects of acid precipitation are on the aquatic resources. Potter (1982) found that the median minimum pH tolerance for Pelecypoda (bivalves) is 6.65; for Gastropoda (snails), 6.6; for Crustacea, 5.2; for Anura, 4.1; and for salamanders, 6.0. Cyprinids (minnows) are particularly sensitive to acidification, with, generally, only a few species common in lakes with pH less than 5.5 (Diamond 1989).

Water with a pH less than 6.0 has a variety of effects on fishes: acute mortality, osmoregulatory failure and other physiological stress, a predisposition to disease, and reproductive stress (curtailed spawning, genetic damage, and recruitment failure) (Harvey 1982, Potter 1982). In a survey of acidifying Canadian lakes, Beamish (1976) found that smallmouth bass (*Micropterus dolomieui*), walleye (*Stizostedion vitreum*), and burbot (*Lota lota*) stopped reproducing at pH 6.0+ to 5.5. He also found that lake trout (*Salvelinus namayacush*) and troutperch (*Percopsis omiscomaycus*) stopped at pH 5.5 to 5.2; brown

bullhead (*Ictalurus nebulosus*), white sucker (*Catostomus commersoni*), and rock bass (*Ambloplites rupestris*), at pH 5.2 to 4.7; and lake herring (*Coregonus artedii*), yellow perch (*Perca flavescens*), and lake chub (*Cousius plumbeus*), at pH 4.7 to 4.5. His assessment of this reproductive failure is that the problem is with embryo loss, not a prey loss (Beamish 1976).

Harvey (1982) supported the theory that the most profound effect of acid stress is the failure of new age-classes to move into the population. This failure leads to altered age-class structures, decreases in population sizes, declines in intra-specific competition for food, and possibly, increased growth of survivors, assuming prey species are available (Beamish 1976, Harvey 1982). Harvey (1982) found that fish populations in acidified lakes tended to be smaller in number and skewed in size distribution. He also monitored changes in populations in lakes that had been neutralized and saw dramatic changes in both population numbers and size distributions.

As with fish, the most notable effect of acid precipitation on amphibians is reproductive failure. Approximately 50% of frog species and 30% of salamander species with aquatic larvae and terrestrial adults in North America breed in temporary ponds (Tome 1982, Schreiber and Newman 1988). These temporary ponds form largely from rain shortly before the breeding season begins. Because these ponds often begin dry, the precipitation that fills them is not diluted by mixing with standing water (Tome 1982). Compounding the problem, temperate zone amphibians often breed before deciduous tree canopies can be formed to help buffer the ponds (Tome 1982).

Most of the amphibian embryonic mortality occurs in the later stages of development (Freda 1982, Tome 1982). Amphibian embryos killed by low pH often display certain characteristic morphological traits: the mottled appearance of the surface layer of cells; shrunken, rubbery texture of the egg jelly and membranes; and a distinct curling of the embryo within the vitelline membrane (Potter 1982, Freda 1986). Freda (1986) found that many salamanders are able to

differentiate between acidic and neutral substrates, but it is unknown if they could detect small pH changes (0.2 to 0.5 units), which is often the difference between critical and lethal pHs.

Acid precipitation effects on terrestrial wildlife appear to be most notable on avian species in wetland environments. While it may affect reproductive success due to effects of toxic metals (as with fish and amphibians), acidic water also directly affects the birds' food sources by changing the species composition of the prey communities.

The American black duck (*Anas rubripes*) breeding range falls almost entirely within the acid sensitive areas of the northeast United States and Canada (Longcore et al. 1987). The primary breeding range of the hooded merganser (*Lophodytes cucullatus*) is also within the affected areas (Longcore et al. 1987). Species homing to such natal sites are obviously at greater risk than those species that do not show such site fidelity. Duckling survival of at least 7 waterfowl species appears to be lower in lower pH ponds or other wetlands (Longcore et al. 1987).

Loss or reduced diversity of acid-sensitive invertebrates, including those calcium-rich species often consumed during egg-laying is one of the primary effects of wetland acidity on waterfowl (Potter 1982, Blancher and McAuley 1987, McNicol et al. 1987, Stromborg and Longcore 1987). This loss of calcium has already had a significant impact on black ducks, ring-necked ducks (*Aythya collaris*), and common goldeneyes (*Bucephala elongula*) (Longcore et al. 1987). Piscivorous and herbivorous adult waterfowl often eat invertebrates as ducklings, so the effect on invertebrates (loss or community change) can be important to a wider variety of species than originally thought (Diamond 1989). However, waterfowl are not the only affected avian species. A variety of songbirds (swallows, warblers, flycatchers, and blackbirds) breed in vegetation surrounding water resources. These species feed on insects whose larval stages are aquatic, but which emerge as adults from the water (Diamond 1989).

Piscivorous species such as the common loon (*Gavia immer*), common merganser (*Mergus merganser*), and osprey (*Pandion haliaetus*) are also at risk from the loss of their fish food

supply at pH 6.0 or less (Longcore et al. 1987, McNicol et al. 1987). This change in fish availability may result in altered predator/prey relationships with those species able to switch effectively food sources to mollusks or other aquatic invertebrates, provided these species are not also affected by the acidity (Blancher and McAuley 1987, Longcore et al. 1987, McNicol et al. 1987, Stromborg and Longcore 1987).

If waterfowl recruitment is low due to either of these effects, and other causes of mortality (predation, hunting) are significant, then the effects of acidification would enhance the risk to the species. Acid pHs also increase the solubility of several toxic metals (mercury, lead, cadmium, and aluminum) (Stromborg and Longcore 1987). Aluminum is highly susceptible to leaching and mobilization, as well as being highly toxic to fish. The effects of this metal on wildlife are most likely due to its ability to interfere with the regulation of calcium and phosphorus (Diamond 1989). Methylmercury is also highly toxic, easily absorbed, and tends to bioaccumulate in aquatic systems. Because this metal is lipophilic, it can cause severe damage to the individual's central nervous system (Diamond 1989). Increased exposure to acidic water may heighten the potential for poisoning by these metals. If the response is specific, the species may be used as a biological indicator for acid deposition or metal toxicity (Schrieber and Newman 1988).

Damage from acid precipitation also occurs in forest ecosystems. Known and potential direct effects of acid deposition on forest vegetation (thus some wildlife foods) include: damage to protective surface structures; interference with the normal functioning of guard cells; poisoning of plant cells; disturbance of normal metabolism and growth; and interference with reproductive processes (Tamm and Cowling 1976, Schrieber and Newman 1988). Acid precipitation may also indirectly affect vegetation by accelerating leaching of nutrients from the foliage, increasing susceptibility to drought and other environmental stresses, and altering symbiotic or host-parasite interactions (Tamm and Cowling 1976).

Hornbeck et al. (1976) determined that precipitation is most acidic during the vegetative growing season (May through September) and least acidic during the winter months (December through February). During 1 growing season, Hornbeck et al. (1976) measured precipitation pHs above and below the forest canopy. They found that the precipitation above the canopy had a pH of 4.06 (H^+ concentration of 87 μeq/l) and a pH of 5.01 (H^+ concentration of 10 μeq/l) below the canopy. Ninety percent of the H^+ in the precipitation was left in the forest canopy. Bormann and Likens (1970) also found that almost the entire loss of nutrient cations from an undisturbed forest ecosystem is balanced by the input of H^+ in precipitation. Valuable nutrients are then unable to bind to anions and, therefore, leach out through the cycling process (Kahn 1985).

Almost by definition, any damage to the forest ecosystem from acid precipitation changes established relationships between the plant and associated animal communities. As with the waterfowl and wetlands scenario described above, the level of impact depends on the availability of alternate habitat or food sources. Damage to forest vegetation may interfere with specific requirements of a species. The northern parula warbler (*Parula americana*) requires *Usnea* spp. lichen for nesting materials. These lichen species are very sensitive to air pollution and their decline in eastern North America appears to be related to acid rain. Schrieber and Newman (1988) hypothesized that reductions in parula distribution is directly related to this decline of the lichen, and thus, to acid precipitation.

Methods

Action in 3 major tasks was needed to achieve the specified objectives of this project. These tasks were: literature review, data selection and analysis, and system development.

A literature review was conducted to determine the effects of precipitation on natural resources. While many of the natural resource fields were included, the primary focus of the review was on precipitation and wildlife. The literature review was also used to identify standard terminology and techniques used in describing and collecting precipitation information. All of these results are presented in the "Literature Review." A final segment of the literature review included an assessment and analysis of models developed to represent rainfall occurrence and distribution. A summary of these findings is presented later in this section displaying the bases for selecting the methods used.

A representative dataset of existing stations was selected prior to modeling rainfall in western Virginia. Once appropriate sites had been chosen, summary statistics were computed to identify trends or abnormalities in the data.

The initial step of system development was selecting appropriate models for describing various components of rainfall. A computer program was developed to incorporate those

models and to provide output to the user. System implementation, validation, and demonstration completed the development cycle.

Data Selection and Analysis

The annual average rainfall levels in Virginia have historically fallen within a small range, and followed definite topographic features in the state (Fig. 3). A total of 325 rainfall gauging stations are located throughout Virginia, but most locations have incomplete records. As mentioned in the "Literature Review," only 8 continuously recording stations occur in the state, and a total of 69 stations have "complete" historic records (Fig. 4). "Complete" records have been arbitrarily defined by the author as those locations with no missing data for greater than a 1-month interval, less than 6 missing months overall, and a period of record of at least 20 years.

Since the coastal plain and eastern piedmont regions of Virginia appear to conform fairly well to the topographic patterns of previously modeled areas, the decision was made to target the western portion of the state for model development, and, if possible, to concentrate testing efforts near or on the state-owned Havens Wildlife Management Area or similar area.

Site Location and Selection

Once the western portion of the state had been targeted, a selection process was begun to choose those gaged sites that had "complete" records (as defined above) and adequately represented the changes in topography. A review of the Hydrological Information Storage and Retrieval System (HISARS), maintained by the Virginia Water Resources Research Center

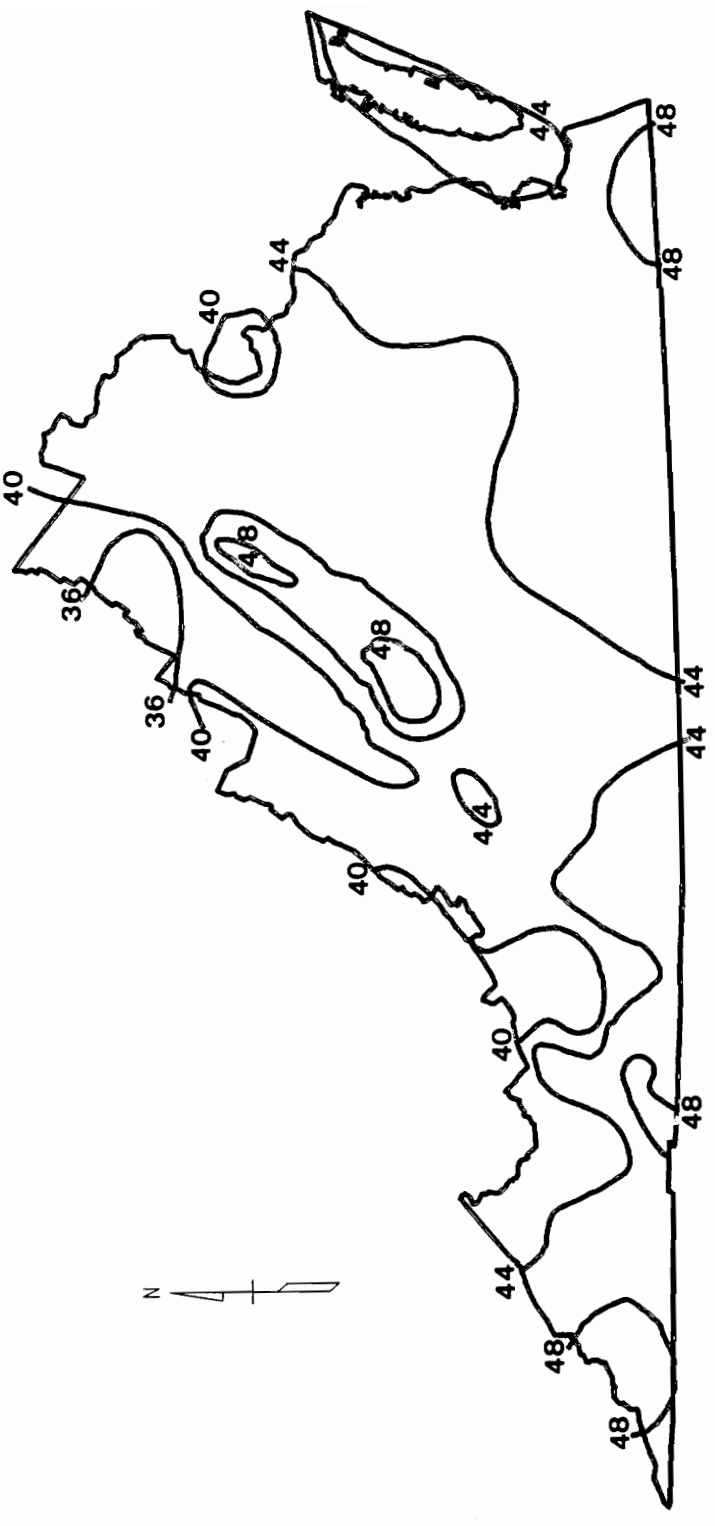

Figure 3. Distribution of average annual rainfall, in inches, in Virginia.

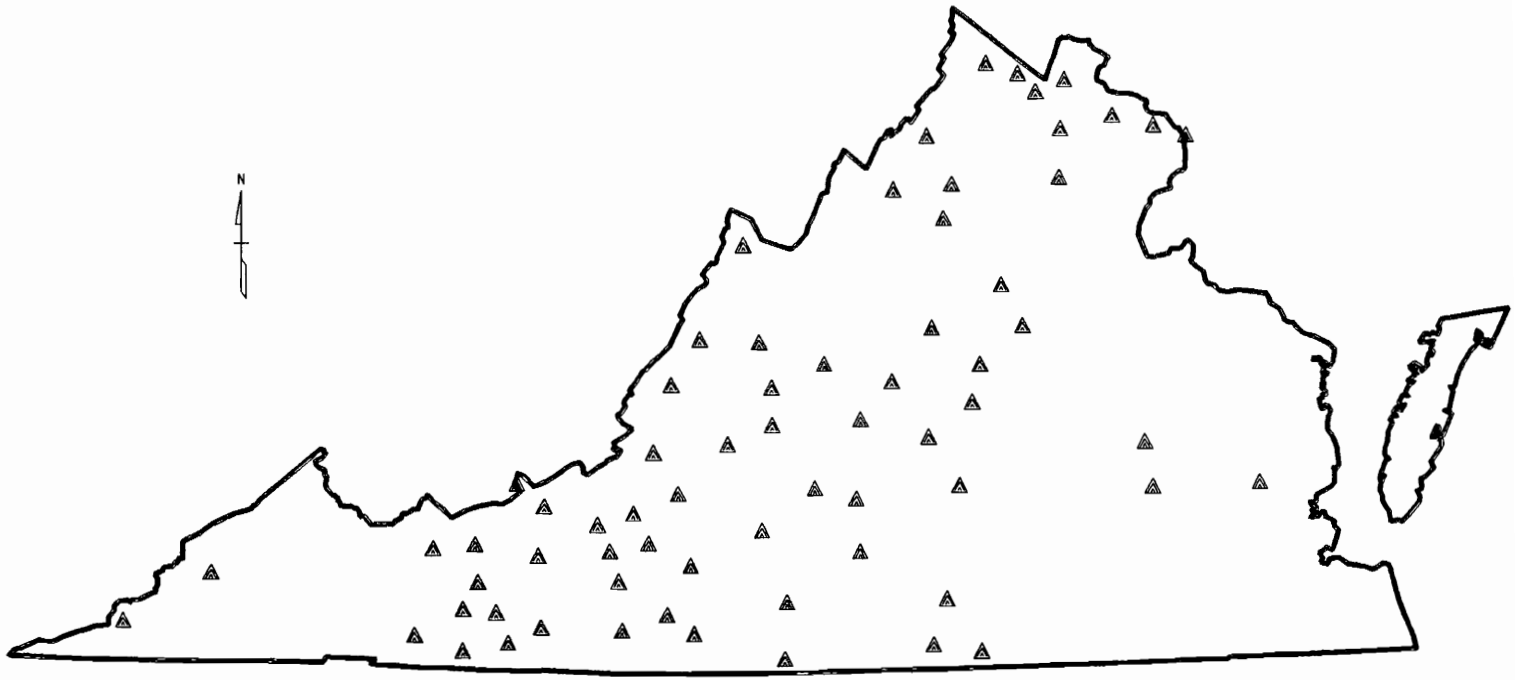

Figure 4. Distribution of rainfall stations with complete historic records in Virginia.

(VWRRC) at Virginia Polytechnic Institute and State University (VPI&SU), indicated that 42 stations could potentially be used for data analysis and system development (Johnson 1978). A more detailed review of site locations indicated that only 15 of these stations would actually be usable for this project, satisfying period-of-record and data completeness requirements (Fig. 5). A summary of information about the selected gages is presented in Table 2.

Data Conversion and Analysis

Data for each location were exported from the HISARS database and formatted for statistical analysis. A 25-year period (1960-1984) of data was selected for analysis, resulting in 9152 observations (wet and dry days) for each location. Trace values, indicated by a "T" in the original dataset, were converted to a numeric value of 0.005 inches for tracking[1]. Accumulated values were recorded and then divided out over the number of days during which the precipitation fell. Estimated values, indicated by an "E" following the value, were recorded and accepted as actual values. Missing values, indicated by a "--" in the original export, were replaced with the appropriate notation for missing values. Table 3 lists the changes made for accumulated and estimated data, and notes the actual number of missing values. Permanent disk datasets were then created for each site to facilitate information storage and retrieval. A master dataset was also created from all 15 sites. All subsequent analyses were performed using the Statistical Analysis System (SAS; SAS Institute, Inc., P.O. Box 8000, SAS Circle, Cary, NC 27511-8000).

A fundamental premise of this study is that rainfall data do not vary significantly over a 25-50 year period of time. One way of determining if the study data conform to this premise is to regress the site's annual totals to the years. This analysis would test the hypothesis that the

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[1] Because the rainfall data supplied were all in units of inches (25.4mm), these units have been retained throughout the analyses and discussion to avoid any incongruities in comparisons with historic tables or figures.

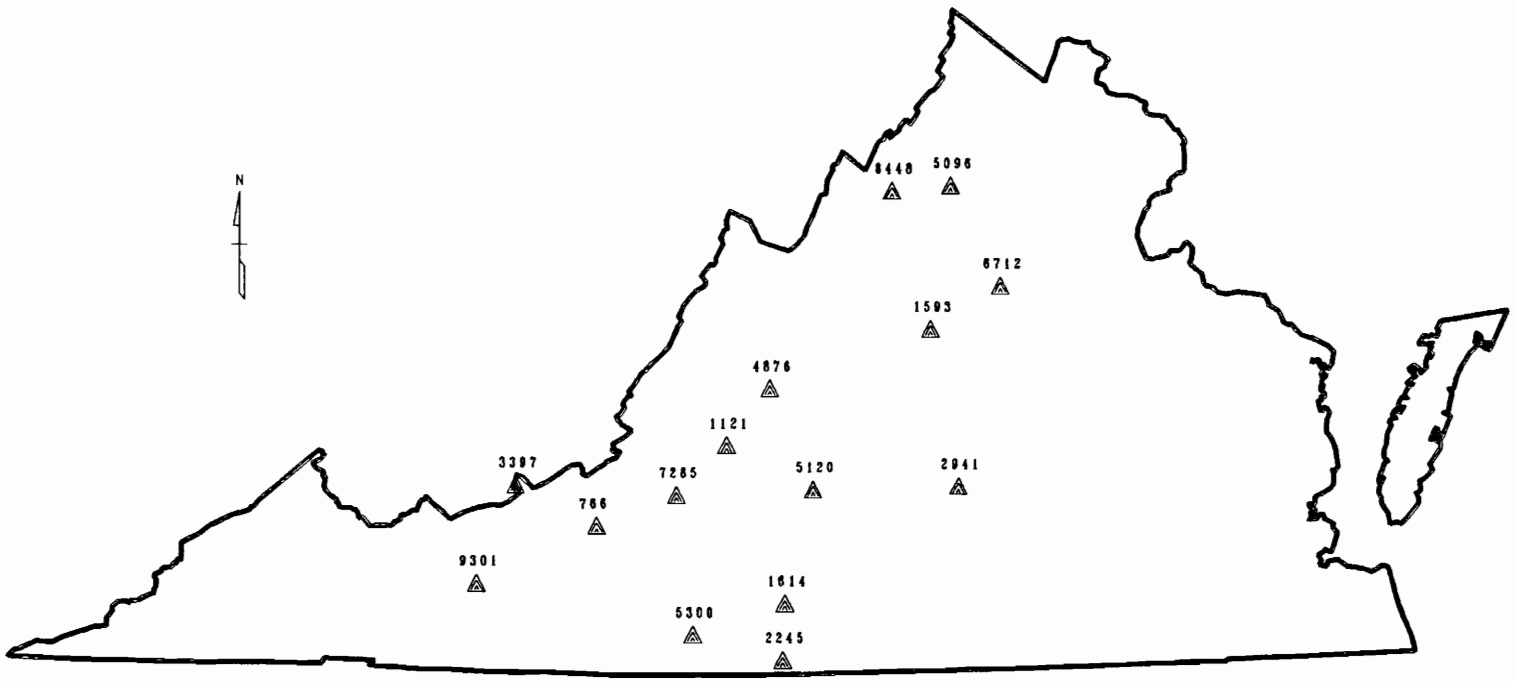


Figure 5. Location of rainfall stations selected for this study (numbers refer to HISARS station IDs; Table 2).

Table 2. Station locations and available records used for analysis of precipitation in western Virginia.

HISARS Station ID	Station Name	County Location	Coordinate Location (UTM)	Elevation (meters)	Period of Record	Number of Missing Months
0766	Blacksburg 3 SE	Montgomery	551780 4115165	606	11/52-12/84	0
1121	Buchanan	Botetourt	616335 4154648	267	01/30-12/84	1
1593	Charlottesville 2 W	Albemarle	717954 4212218	264	08/48-12/84	1
1614	Chatham 2 NE	Pittsylvania	645654 4077425	212	01/30-12/84	1
2245	Danville-Bridge St.	Pittsylvania	644635 4049665	124	08/48-12/84	0
2941	Farmville 2 N	Cumberland	731828 4134858	136	01/14-12/84[1]	1
3397	Glen Lyn	Giles	511808 4135352	462	01/30-12/84	0
4876	Lexington	Rockbridge	637962 4182726	321	08/48-12/84	0
5096	Luray 5 E	Page	727665 4282828	364	08/48-12/84	2
5120	Lynchburg WSO AP[2]	Campbell	659466 4133166	278	01/30-12/84	0
5300	Martinsville Filtration Plant	Henry	599750 4061971	230	08/48-12/84	5
6712	Piedmont Research Station	Orange	752435 4233579	156	08/48-12/84	0
7285	Roanoke WSO AP[2]	Roanoke	591563 4130299	348	08/48-12/84	0
8448	Timberville 3 E	Rockingham	698706 4280204	303	08/48-12/84	1
9301	Wytheville 1 S	Wythe	492579 4087276	742	01/30-12/84	2

[1]Station was operational for 2 months in 1914. Measurements were begun again in September, 1930.
[2]WSO AP=Weather Service Office, Airport

Table 3. Data correction summary, by station.

Station	Year	Number of Missing Days	Number of Estimated Days	Number of Periods of Accumulated Rain (Days/Period)[1]
Blacksburg	1960	1		
	1962		2	
	1966			1 (2)
	1967		1	
	1968		2	
	1969		1	
	1972		2	
	1973			1 (2)
	1977	1	1	
	1980		1	
	1981		3	
Buchanan	1961			1 (2)
Charlottesville	1969			1 (3)
	1983		2	
	1984		2	
Chatham	1974	8		
	1975			1 (2)
	1976	1		
	1977		3	
	1978	1	6	
	1980	2	1	
Danville-Bridge St.	1960			1 (2)
	1963	1		
	1980	35		
Farmville	1962			2 (4,2)
	1964		1	1 (2)
	1971		1	
	1979	4		
Glen Lyn	1966			1 (2)
	1976	1		
	1979	3		
	1980	39		
	1982		1	
	1983		1	
	1984		1	
Lexington	1966			1 (2)
	1981			1 (2)
	1983		2	
Luray	1960			1 (2)
	1962		4	
	1966	1		
	1974		1	
	1975			1 (3)

Table 3, cont. Data correction summary, by station.

Station	Year	Number of Missing Days	Number of Estimated Days	Number of Periods of Accumulated Rain (Days/Period)
Luray, cont.	1976	31		
	1978		1	
	1979	6	1	3 (3,2,3)
	1980	2	2	
Lynchburg Airport	1974	31		
Martinsville	1960			2 (2,3)
Filtration Plant	1963	7		
	1966			1 (2)
	1972	3	1	1 (2)
	1973		2	4 (2,2,2,2)
	1975	122		
	1978	31		
	1979	31		
	1980	30		
	1983		13	
Piedmont	1961			2 (2,2)
Research Station	1962		1	
	1963		2	
	1964		1	1 (2)
	1967		1	
	1969			1 (2)
	1973		1	
	1976		2	
	1977			1 (2)
	1980	3		
	1983		1	
Roanoke Airport	No corrections needed			
Timberville 3 E	1960		1	
	1964		1	
	1966		6	
	1977		1	
	1978	31		
	1979	1		
	1980		1	
Wytheville	1961	1		
	1962	5		
	1968		2	
	1969	1	7	
	1970		6	2 (2,2)
	1971		11	2 (2,2)
	1972		7	

[1]For example, a value of 2 (4,2) indicates that there were 2 periods, one 4 days long and one 2 days long, over which rainfall amounts were accumulated.

parameter estimate (i.e., the slope) of the "year" variable is equal to 0. If a test indicates that the hypothesis should be rejected, then the slope of the line identifies some trend in annual totals over time at that site. Regression tests were conducted, by site, for the annual totals of the period of record for this study (25 years).

Rainfall minima, maxima, means (of wet days only, and all days), medians (of wet days only), total number of wet days, and total number of trace precipitation days were calculated for each site for the period of record, by year, and by month (grouping months over 25 years). Comparable analyses were performed on the entire dataset, hereinafter referred to as "regional" assessments. Missing data were excluded from the analyses since no method exists to verify whether or not rainfall had actually occurred on those days.

Frequency analyses were also conducted for site-specific and regional data. Numbers of days with rainfall greater than 1.00 in. (25.4mm) , and successive 1.00 in. (25.4mm) increments, and their percent of the total number of days of rain were determined. Similar analyses were also done for 0.1 in. (2.5mm) increments of the rainfall values between 0.01 in. (0.25mm) and 0.99 in. (25.1mm).

Questions arose concerning the value, or appropriateness, of incorporating trace precipitation into the above mentioned site and regional analyses. Trace precipitation could possibly be indicative of fog precipitation. Studies previously cited in the "Literature Review" illustrate that, in some areas, fog precipitation can contribute significantly to the overall annual water input in an ecological system. The minimum actual recorded value in the datasets was 0.01 in. (0.25mm). In an attempt to address the potential contribution of trace precipitation in this study, an arbitrary value of 0.005 in. (0.13mm) was assigned as indicated above as the trace day rainfall value. This value was selected based on the assumption that the probability of over-estimating or under-estimating the true value ($0.00 < x < 0.01$) was 0.5.

A comparison was initially conducted using the station and year with the greatest number of trace days (Roanoke, 1960, 72 trace days). The reported rainfall for that station and year was 38.95 in. (989.33mm). The inclusion of the 72 trace days, at 0.005 in. (0.13mm) per day, would have added only 0.36 in. (9.14mm) to the annual total. A Duncan's multiple range test (from SAS PROC MEANS) performed on the regional annual totals indicated that mean annual totals differing by as much as 4.02 in. (102.11mm) were not significantly different ($\alpha = 0.05$). Based on the results of this test, trace precipitation days were excluded as "wet" days from the above mentioned summary statistics, and subsequent analyses, to minimize the possibility for erroneous interpretation of results. The "trace" condition is not believed to have any major ecological significance for most or all of western Virginia. In practical terms, "trace" probably has little effect on large organisms in any ecosystem because it is usually completely absorbed by surface materials or rapidly evaporated.

Rainfall values were also calculated on a site-by-site basis for a variety of important, and potentially important, ecological variables (Table 4). These variables have been selected from the literature as being important time periods, or values, for a variety of natural resource fields (see "Ecological Interactions" in the Literature Review).

Modeling Relationships

A model has been defined generally as a "simplified representation of reality which presents significant features or relationships in a generalized form" (Gelinas 1988). Models are used to assist in better understanding relationships, fill in specific information gaps, and influence decisions. In this project, models descriptive of rainfall have been developed. It is expected that they will be used within more complex ecosystem models, especially those leading to wildlife resource decisions. For example, incorporating such models into habitat suitability

Table 4. Ecologically significant variables calculated using rainfall data.

Class	Variable
Annual Variables	Mean annual rainfall and standard error Calendar year (January - December) Water year (October - September) Mean maximum annual rainfall and standard error Calendar year (January - December) Water year (October - September) Mean minimum annual rainfall and standard error Calendar year (January - December) Water year (October - September) Minimum/maximum annual rainfall Calendar year (January - December) Water year (October - September)
Monthly Variables	Mean monthly rainfall and standard error Mean maximum monthly rainfall and standard error Mean minimum monthly rainfall and standard error Median monthly rainfall Minimum/maximum monthly rainfall
Seasonal Periods	Mean rainfall and standard error Mean maximum rainfall and standard error Mean minimum rainfall and standard error
Extreme and Other Variables	Maximum of record (day, month, year) Minimum of record (month, year) Probability of rainfall (excluding trace) on a day

index models may assist wildlife managers in better understanding the absence or low numbers of a species in a seemingly optimal habitat (Hejl and Beedy 1986).

Developing a model from rainfall data requires using several approaches. Standard daily predictive rainfall models have two components: occurrence and amount. The occurrence segment of the model is used to describe the probability of occurrence. The distribution segment of the model is used to indicate the theoretical distribution of rain depth. Seasonal models have also been developed which incorporate the above two segments and show variability over time. Estimation models have been created to determine the precipitation values at an ungaged site.

In developing and designing the final model for this research, I attempted to address only the spatial aspect of the comprehensive modeling process. Since the final programs developed from this research are not designed to predict occurrence and distribution of rainfall, but rather to estimate the probable precipitation at ungaged sites, only spatial models are addressed below in detail. Daily and seasonal prediction models are also briefly summarized for information purposes.

Daily Models

Daily precipitation models are classed into 2 types: occurrence models and distribution models. Occurrence models are used to determine the probability of rain occurring on a given day (i.e., wet vs. dry). The most commonly used occurrence model is the Markov chain technique (Farmer and Homeyer 1974, Gates and Tong 1976, Chin 1977, Katz 1977, Katz 1981, Roldan and Woolhiser 1982). This procedure assumes that the probability of a wet or dry day depends on the rainfall occurrence (some vs. none) of a certain number of previous days, known as the "order of the chain" (Farmer and Homeyer 1974, Buishand 1978).

Distribution models are used to estimate daily precipitation amounts. A wide variety of models have been developed, but the most frequently used techniques are the exponential, mixed exponential, and gamma models (Todorovic and Woolhiser 1975, Woolhiser and Roldan 1982, 1986, Wilks 1989). Woolhiser and Roldan (1982) compared the above 3 techniques and determined that, for the 5 U.S. stations studied, the mixed exponential technique best modeled the distribution of daily precipitation.

Seasonal Models

Seasonal precipitation models are used to describe seasonal and annual variations in the parameters of the daily occurrence and distribution models. To date, the most common method used for describing this variation is the Fourier series (Todorovic and Woolhiser 1975, Woolhiser and Pegram 1979, Woolhiser and Roldan 1986). More concise models of daily precipitation over a season or year then can be developed, combining precipitation occurrence, amount distribution, and the results of the Fourier analysis.

Estimation Models

Many mathematical models have been developed for the spatial interpolation of precipitation, especially for use at ungaged locations. The complexity of the models ranges from the simplistic "nearest neighbor" and "arithmetic mean" methods to the more complex interpolation methods (Waymire and Gupta 1981, Creutin and Obled 1982, Bastin et al. 1984).

The "nearest neighbor" method estimates the value of any given point in an area as the observed value at the nearest neighboring station (Creutin and Obled 1982, Woolhiser and Roldan 1986). This method can be used with some success in areas with relatively small topographic changes, but is not recommended for use in mountainous areas, since

precipitation generally increases with elevation (Campbell and Ryan 1982, Woolhiser and Roldan 1986).

The "arithmetic mean" method functions with the assumption that a given parameter affecting precipitation values is constant over the particular region. The precipitation value at an ungaged station is estimated as the average of the observed values within the defined region or basin (Dunne and Leopold 1978, Creutin and Obled 1982). Like the "nearest neighbor" method, this estimation works with some success in topographically flat areas.

More complex models often include interpolation techniques. Each of these methods is a modification of the general form of an interpolation function. The general form for these equations is $h_o = \sum_{j=1}^{n} w_j h_j$, where h_o is the interpolated value at any point based on the observed values (h_j) times the weight (w_j) of the sampling point 'j' at *n* sampling points (Tabios and Salas 1985). For example, w_j might be $(\frac{1}{d^j})/(\sum_{j=1}^{n} d_j)$, where d_j is the distance from the sample point to a known location and $\sum_{j=1}^{n} d_j$ is the sum of these distances.

The "Thiessen polygon" method was widely recognized as the best method for estimating ungaged station values as the first interpolation model. In the "Thiessen" method, neighboring gages on a map are joined by lines, and perpendicular bisectors are drawn. The bisectors meet to form a polygon around each gage. The area of each polygon within the drainage basin is measured and expressed as a decimal fraction of the total drainage basin area. Rainfall at each gage is then multiplied by its appropriate fraction and the products are added, resulting in a total weighted average (Dunne and Leopold 1978, Swift and Cunningham 1986). This method has, however, been superceded by some of the more advanced methods described below.

The "inverse distance interpolation" method includes distance-weighting techniques. The weights of the interpolation function are solely a function of the distances between the point of interest (the ungaged location) and the sampling points (gaged stations) (Tabios and Salas

1985). One drawback to this method is that when 2 or more sample points are close to each other, redundant information from these stations is not discriminated against. Ideally, only data from such close stations would be used after they have been weighted by a proximity factor.

Most reviews of the "Gandin optimal interpolation" method indicate that this method computes rainfall values most accurately in areas of moderate topographic relief (Waymire and Gupta 1981, Creutin and Obled 1982, Bastin et al. 1984, Tabios and Salas 1985). The approach of this model is very similar to a multiple regression analysis. The value of the ungaged station is estimated as a linear combination of *n* surrounding gaged stations. The weights are determined by minimizing the variance of the error of interpolation (Creutin and Obled 1982, Tabios and Salas 1985).

The "Kriging interpolation" method is similar to the "Gandin optimal interpolation" method in that the value at the ungaged point is estimated as a linear combination of *n* surrounding gaged stations, which minimizes the estimation variance. However, in the interpolation equation, the spatial correlation function of the "optimal interpolation" method is replaced by a "variogram" (Creutin and Obled 1982, Tabios and Salas 1985, Woolhiser and Roldan 1986).

The "isohyetal" method is based on contouring precipitation values. The area between 2 adjacent contours (isohyets) is measured and expressed as a decimal fraction of the whole basin area. The average precipitation of the area between the 2 isohyets is the mean of the isohyetal values and is multiplied by the fractional area between the contours. The values are then summed to get an isohyetal average precipitation (Bethlahmy 1976, Dunne and Leopold 1978, Swift and Cunningham 1986). This method is often used for mountainous areas since it takes into account strong precipitation gradients caused by topography (Bethlahmy 1976, Dunne and Leopold 1978, Swift and Cunningham 1986).

Thesis System

One of the primary objectives of this thesis research was to develop or modify a computerized system modeling rainfall for use on a microcomputer, a system potentially useful to wildlife managers. A review of the literature indicates that very few programs such as this have been prepared for the personal computer. The majority of the systems and analyses have been prepared using mainframe computers.

Existing Microcomputer Systems

"The Weather Analyst", a microcomputer-based system, was developed by Climate Assessment Technology (CAT), in Houston, Texas, in 1982. The hardware requirements for this system are relatively basic: an IBM-PC or compatible computer with at least 256K Random Access Memory (RAM), at least one 5.25-in. disk drive, and a DOS version of 2.0 or higher. The application was developed using DOS and LOTUS 1-2-3 software packages (CAT 1987). The system allows the user to enter or edit weather data, and list daily or monthly weather values. One of the primary assumptions of this application is that the user can provide meteorological data for the location in question. The system will only allow the use of the data for one station at a time, and does not provide the user with the opportunity to select an ungaged site (such as a farm field, factory site, or forest stand). This particular package also does not allow the output displayed to be revised for incorporating information of interest to natural resource professionals. The cost of this application is approximately $100.00, plus the cost of formatted data from the company, at $10.00 per year of data. Twenty-five to 30 years of information are required to represent an area accurately, resulting in an approximate cost of $300.00 for data for the system.

"South Dakota Weather" is another microcomputer-based application for daily weather simulation. The application was developed in 1988 by staff at the Aridland Watershed Management Research Unit (USDA) for use in South Dakota. The hardware requirements are comparable to those of "The Weather Analyst," except that a 640K microcomputer is required. The application was developed using BASIC and FORTRAN. Several specific features of this application are noteworthy. The source code files may be accessed and changed to accommodate calculation or output modifications. It allows the user to select an ungaged station and will provide interpolated information (Woolhiser et al. 1988). Two interpolation methods were selected for this application: the "nearest neighbor" method and a spline function fit through the nearest 6 points (Woolhiser et al. 1986). Neither of these methods is appropriate for mountainous areas such as western Virginia because neither method accounts for changes in topography or distance between the gaged and ungaged sites.

System Design

The system developed for modeling rainfall in western Virginia is called VARAINS (VirginiA RAINfall System). VARAINS is a general system designed to generate and present rainfall variables like those noted in Table 4 for any natural resource area. A general system model consists of inputs, outputs, processes, feedforward, and feedback mechanisms set in an appropriate context (Giles 1978).

The inputs for VARAINS are basic geographic variables (latitude and longitude in Universal Transverse Mercator (UTM) coordinates (meters), elevation). Single site components can be entered individually, or multiple site data can be read from an appropriately formatted ASCII file. The system processes these variables through a series of regression equations (as requested by the user), and provides specific output for the user. The system is written using the Borland Pascal (version 7; Borland International, Inc., 1800 Green Hills Rd., Scotts Valley, CA 95067) programming language and provides the user with the opportunity for modifying

all existing elements of the system to meet changing demands, and is flexible enough to incorporate uses and outputs not now available. The selection of this software also facilitates the use of the program on most IBM-compatible microcomputers with a basic configuration of 640K base memory. No sizeable storage medium is required since the executable version of this system fits on a floppy diskette, unless the user has a large data file to read into the program.

System Objectives

Saunders (1977) and Martin (1988) outlined a series of objectives for modeling systems:

1. The model should require a minimum number of input variables. These inputs should be concrete and easily obtained.
2. The system should be user-friendly, explaining features and outputs. The user should not be required to have extensive knowledge of computer simulation concepts or theory.
3. The system should be flexible, allowing modification as needed.
4. The system should be compatible, or as compatible as possible, with existing systems or data sources. This compatibility includes exportability.
5. The system should use software readily available to the natural resource manager.
6. The models should use all pertinent information available so that the system models the variable (in this case rainfall) as completely as possible. The outputs should be tangible to the user.
7. The system should also automate as much work as possible to reduce user-introduced error.

In developing this system, I have strived to achieve as many of these objectives as possible. System inputs are minimal. The user is initially prompted for the site coordinates (using UTM

east and north values) and the site elevation (in meters). The user may choose to load an external file containing these data for more than one location.

VARAINS also provides the user with information about the system as a whole (use area, constraints, functions, hardware/software needs), system initialization, system use, and system output. Any step requiring user input or interface explains the need, the requirements, or the options available to the user. The system outputs can also be imported into microcomputer geographic information systems (GIS), such as those existing in the Department of Fisheries and Wildlife Sciences, VPI&SU.

The variables selected for system use (geographic features) were identified in the existing literature as important factors for interpolating and modeling rainfall. The output variables have also been identified from a variety of literature sources as relevant to natural resources (see "Literature Review").

Automated import and export features performed by the system are provided to reduce user-induced errors. The system is totally supported by microcomputers and does not require access to a mainframe computer facility.

Model Selection

Selection of appropriate models for the VARAIN system required evaluating the statistical, as well as biological, significance of the selected dependent and independent variables. The majority of the biological evaluation has been addressed in the "Literature Review" and within this section. In this segment, I shall describe the regression analyses of the statistical significance of the various models for some of the dependent variables identified in Table 4 (p. 42).

The independent variables used included: elevation, aspect, UTM east and north coordinates (longitude and latitude), the distance to Charleston, West Virginia (WV), and the distance to Virginia Beach, Virginia (VB). The latter two variables were included as indices to continental and oceanic climatic forces. A distance-weighting variable, common in interpolation, was also developed and used in model development.

A number of studies evaluated in the "Literature Review" identified the real or potential importance of latitude, longitude, and elevation in the amount of rainfall falling in a given area, and subsequent influences on flora and faunal species compositions. One question under evaluation in this study is the scale at which these factors influence rainfall amounts. At localized scales, these factors are probably not significant influences; however, at mesoscale levels, such as this study, it is hypothesized that location and elevation are key elements in describing and estimating rainfall values.

The 2 distance variables (WV, VB) were included to try to account for the potential influence of continental weather patterns (WV) and oceanic weather patterns (VB) on the distribution and intensity of rainfall in western Virginia. These distances were calculated from the map coordinates of an arbitrary site in each of the 2 named cities to the coordinates of each study station.

The distance-weighting variable is a function of the distance between a station (or point) of interest and the nearest 5 known stations. The estimated rainfall at the site of interest is based on the records of the known stations (based on inverse interpolation methods from Tabios and Salas 1985). The weighted variable is the rainfall at a known station, relative to its distance to the site of interest. This principle is also commonly used in forestry for rainfall (R.G. Oderwald, VPI&SU, pers. commun.) and is represented in Fig. 6. For each site, a variable, TDIST, was calculated as: $TDIST = \sum_{i=1}^{5} 1/d_i$ where d_i is the distance from the target site to each of the 5 known sites. The resulting weighted variable (WT_i) was calculated as:

$WT_i = \sum_{j=1}^{5}((1/d_j)/TDIST_i)(P_j)$ where d_j is the distance to one of the 5 closest stations, $TDIST_i$ is as described above, and P_j is the appropriate rainfall value for the 'j' site.

Transforming independent variables is very common in the natural resource and biological sciences. For example, a log transformation of an independent variable often stabilizes the error variance and reduces collinearity (Myers 1986). The residual plots are very helpful in identifying data trends and possible transformations. Several transformations were used in this study: natural log, log-base 10, reciprocals, and squares. These transformations were used on the coordinate and elevation variables. Table 5 lists all of the variables, transformations, and variable combinations used in the model development process.

All of the distance variables (north, east, VB, WV) were divided by 10,000 before being used in analyses to reduce the wide discrepany between the range of numbers for aspect and elevation and the distances. This modification ensured that the regression analyses would not be complicated by such disparity.

The selection of models in this thesis was based primarily on the value of the coefficient of determination, R^2. This coefficient represents the amount of variation in the response data that is explained by the variables in the model. The addition of more variables into the model will cause the R^2 value to increase or remain the same. Beyond a certain point, the resulting increase in the R^2 is generally minimal and can lead to overfitting of the model (i.e., increasing the associated error). The adjusted R^2 is another R^2 value that was preferred for use. This value has been adjusted for the number of variables in the model, which prevents overfitting of resulting models.

Several other statistics were included with the adjusted R^2 value and used to compare and select the best predictive model. Myers (1986) recommended the use of Mean Square Error (MSE), PRESS, and C_p values, as well as the R^2 value, in any model selection procedure.

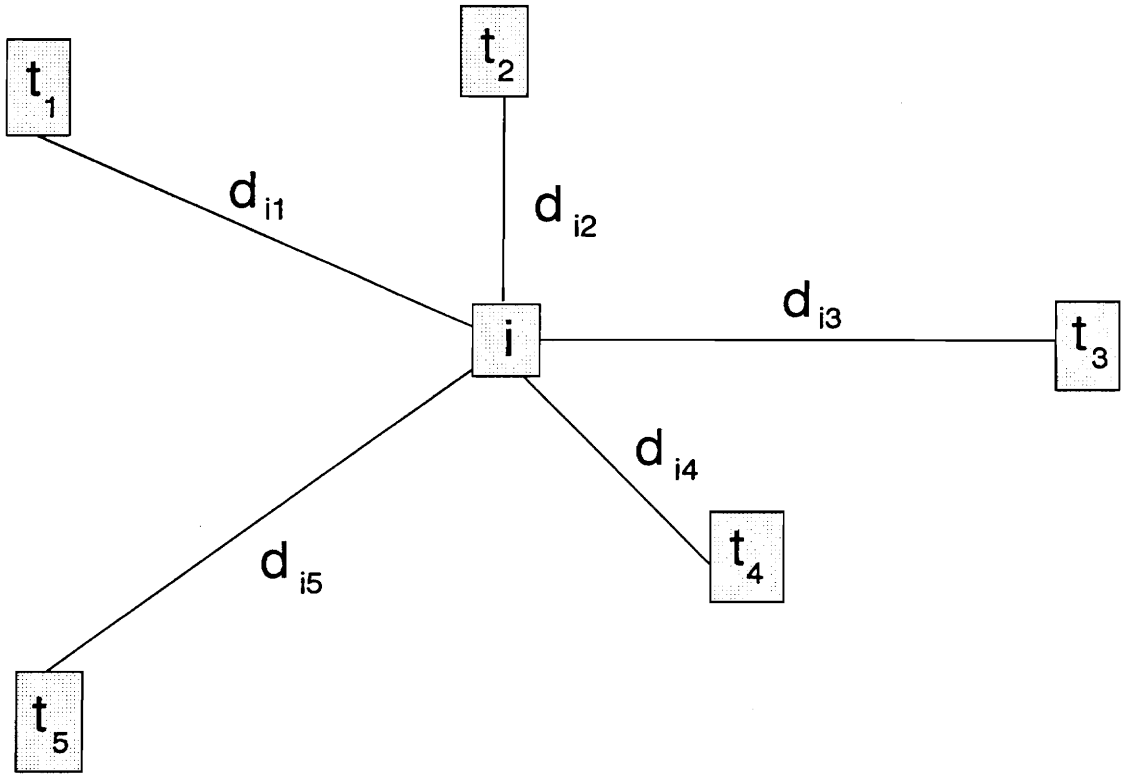


Figure 6. Representation of methods used to calculate distance-weighting variable used in rainfall model development.

Table 5. Independent variables used in rainfall model development.

Variable Name	Definition
LAT	Site latitude (UTM north)
LONG	Site longitude (UTM east)
ELEV	Site elevation (meters)
ASP	Site aspect (1-4)
VB	Distance of site to location in Virginia Beach, Virginia
WV	Distance of site to location in Charleston, West Virginia
WT	Distance-weighting value from 5 closest stations
LLAT	Natural log of LAT
LLONG	Natural log of LONG
LELEV	Natural log of ELEV
LVB	Natural log of VB
LWV	Natural log of WV
LATE	Log-10 of LAT
LONGE	Log-10 of LONG
ELEVE	Log-10 of ELEV
VBE	Log-10 of VB
WVE	Log-10 of WV
LAT2	LAT*LAT
LONG2	LONG*LONG
ELEV2	ELEV*ELEV
VB2	VB*VB
WV2	WV*WV
RLAT	1/LAT
RLONG	1/LONG
RELEV	1/ELEV
RVB	1/VB
RWV	1/WV
LATI2	1/(LAT*LAT)
LONGI2	1/(LONG*LONG)
ELEVI2	1/(ELEV*ELEV)
LATELEV	LAT*ELEV
LONGELEV	LONG*ELEV
RLATELEV	ELEV*(1/LAT)
RLONELEV	ELEV*(1/LONG)
LATRELEV	LAT*(1/ELEV)
LONRELEV	LONG*(1/ELEV)
ALL	LAT*LONG*ELEV

The MSE is an the estimate of model's error variance. Since it reflects a relation between the bias and the variance associated with the model, large MSE values indicate poorly fitted models (important variables have been ignored) (Myers 1986).

The PRESS statistic was used to identify the influence of individual points on the outcome of the regression. The $e_{i,-i}$ values (prediction errors) used to calculate the statistic were true prediction errors, since the response coefficients were independent of one another (Myers 1986). The PRESS statistic can be unduly affected by an outlier, even if the model is well fit elsewhere, and is not used as the sole diagnostic tool in model selection.

The C_p value is another tool used in model selection since it balances out the bias in the model with the increase in the MSE as variables are added to the model (Myers 1986). The optimal value for C_p is p, where p is the number of variables in the model of interest. When the $C_p = p$, the model contains no estimated bias. If the C_p value is much larger than p, the model is heavily biased.

Ideally, then, the selected model for any dependent variable should have a high R^2 value, low MSE value, low PRESS value, and a C_p value equal or approximately equal to the number of variables in the model (p). These values were calculated using SAS PROC RE STEPWISE model selection option.

Model assessment also included a review of the variable collinearity and possible transformations of independent variables. Collinearity diagnostics were run to identify any linear or near linear dependencies between independent variables. A statistic often used to identify collinearity is the Variance Inflation Factor (VIF) (Myers 1986). VIF values greater than 10 indicate high multiple correlation in the model and decreased precision in the estimated correlation coefficients.

Model Validation

Three sites occurring within the zone defined by the study data were used to validate the system models (Table 6). Daily rainfall data between January 1960 and December 1984 were obtained for each of these stations from the VWRRC. Summary statistics were calculated for each of these locations using SAS. Corresponding actual and calculated values were compared for each station for annual, seasonal, and monthly mean rainfall using a paired t-test.

System Demonstration

For purposes of demonstration, the system was run using data from the state-owned Havens Wildlife Management Area. Eight points from the area were identified for use (Figure 6). The needed system information was collected from U.S. Geological Survey 7.5′ topographic quadrangle maps (Table 7). This set of data was then read into VARAINS and output summaries were generated.

Table 6. Station locations and available records used for validation of study rainfall models.

HISARS Station ID	Station Name	County Location	Coordinate Location (UTM)	Elevation (meters)	Period of Record	Number of Missing Months
3470	Goshen	Rockbridge	631732 4204821	411	08/48-12/84	4
4676	Lafayette 1 NE	Montgomery	569487 4120840	421	06/51-12/84	2
6012	New Castle	Craig	579553 4150517	399	08/48-12/84	1

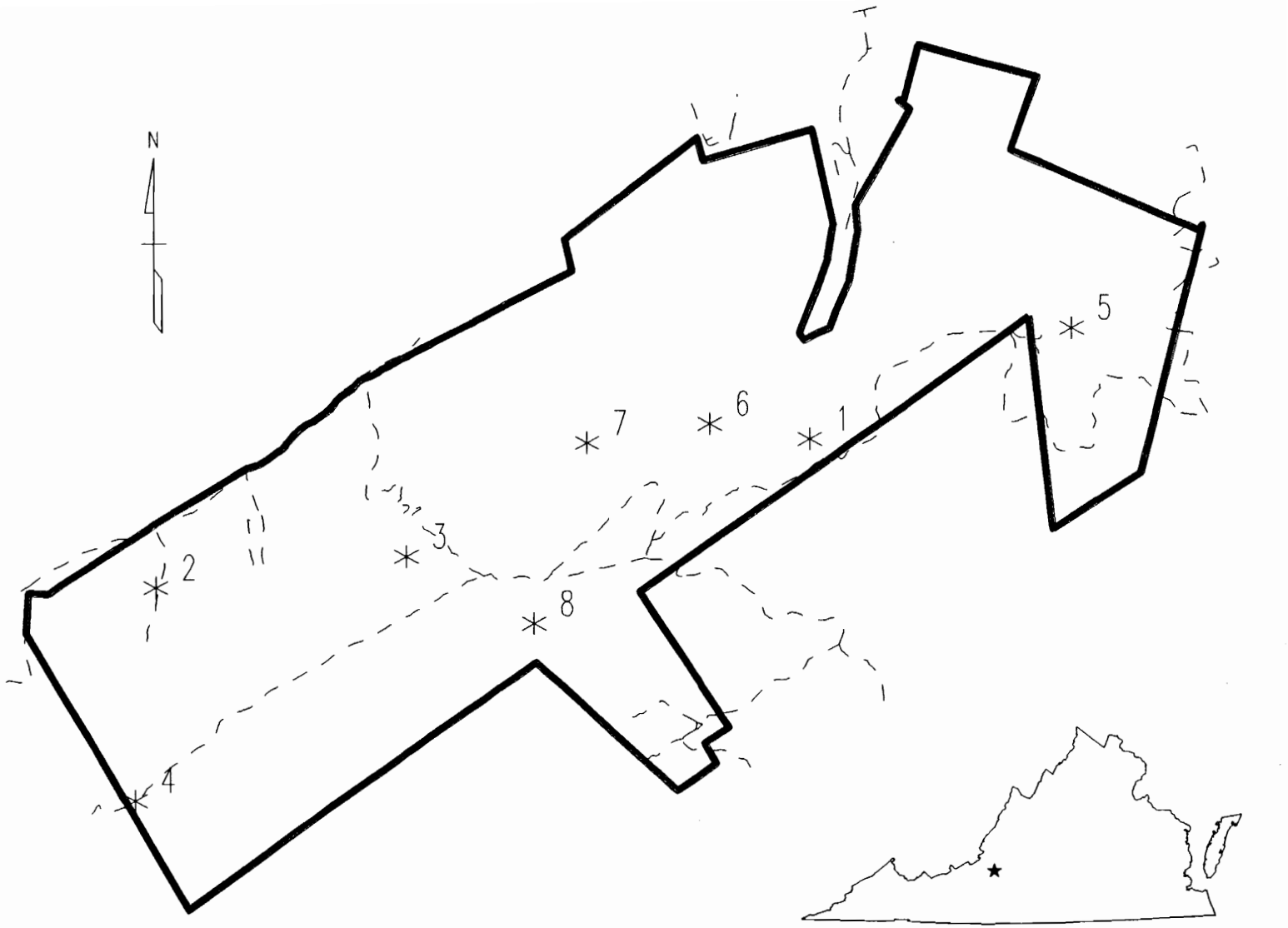


Figure 7. Location of 8 demonstration sites (*) on Havens Wildlife Management Area.

Table 7. Site locations and elevations used in VARAINS demonstration for Havens Wildlife Management Area.

Site	UTM Coordinates	Elevation (m)
1	580205, 4132310	762
2	574565, 4131059	579
3	576718, 4131320	671
4	574382, 4129247	997
5	581475, 4133250	922
6	579341, 4132443	878
7	578274, 4132284	701
8	577813, 4130742	701

Results

Data Conversion and Analysis

The number of occurrences of estimated values, accumulated values, and missing values are summarized in Table 3 (p. 38). Due to the low frequency of estimated or accumulated values, it was determined that the procedures outlined in the "Methods" used to correct these problems did not compromise the existing data integrity. A visual review of a PC version of HISARS rainfall data (which would be comparable to data used by site managers) indicated that these procedures were comparable to those used in transferring the data to diskettes (T. Johnson, Virginia Water Resources Research Center, pers. commun.).

The regression analyses performed to determine whether or not rainfall data varied significantly over the 25-year period of record indicated that annual totals did not vary significantly at 14 of the 15 locations (Table 8). At the Blacksburg site, the slope (0.38 ± 0.18) value shows a slightly increasing trend in annual totals over time ($p = 0.04$). However, the probability of a Type I error in this hypothesis testing (approximately 1 in 15) and the p-value suggest that this statistical significance may not be significant.

Table 8. Degree of variability of annual total precipitation over time based on regression analyses.

Station	β_1 (SE)	P[1]
Blacksburg 3 SE	0.38 (0.18)	0.04
Buchanan	0.24 (0.20)	0.24
Charlottesville 2 W	0.30 (0.27)	0.26
Chatham 2 NE	0.09 (0.19)	0.64
Danville-Bridge St.	0.13 (0.19)	0.50
Farmville 2 N	0.15 (0.19)	0.45
Glen Lyn	0.13 (0.17)	0.43
Lexington	0.29 (0.21)	0.17
Luray 5 E	0.16 (0.19)	0.40
Lynchburg WSO AP	0.43 (0.23)	0.07
Martinsville Filt. Plant	0.01 (0.20)	0.97
Piedmont Res. Sta.	0.34 (0.22)	0.13
Roanoke WSO AP	0.28 (0.19)	0.14
Timberville 3 E	0.12 (0.16)	0.44
Wytheville 1 S	0.09 (0.13)	0.51

[1] A P value < 0.05 indicates a trend in annual totals (increasing if β_1 is positive; decreasing if β_1 is negative).

Data Summaries

Extremes

Over the period of record (25 years), the Piedmont Research Station site recorded the highest single daily rainfall of 7.85 inches (1972). This station is located in the foothills of the Blue Ridge mountains, east of Charlottesville, Virginia. Table 9 shows the highest single daily rainfall, highest total monthly rainfall, lowest total monthly rainfall, highest annual rainfall, lowest annual rainfall, and the greatest number of days with precipitation (excluding trace) for each site in this study.

The maximum daily values for the stations ranged from 3.26 inches (Glen Lyn, 09/14/66, hereinafter "month/day/year") to 7.85 inches (Piedmont Research Station, 06/22/72). Five of the stations recorded the maximum daily value in 1964. Minimum daily values were not listed since each station recorded at least 1 day of 0.01 inches of rain.

The lowest recorded monthly rainfall totals occurred at 2 sites, Luray and Lynchburg, with only 0.02 inches of rain falling during their respective low months (October, September). The range of minimum monthly values is 0.02 inches to 0.30 inches (Chatham, August). Six stations reported their lowest monthly totals in the same month and year (October 1963) for the period evaluated. Maximum monthly rainfall values ranged from 8.49 inches (Wytheville, July) to 12.81 inches (Charlottesville, June). Three stations reported maximum monthly values in 1972 (all in June), while 3 other stations reported maximum monthly totals in 1976 (all in October).

Minimum and maximum annual totals appear to fall in much tighter groups. Minimum annual values ranged from 25.67 inches (Roanoke, 1963) to 32.06 inches (Martinsville, 1976), with 10 stations reporting their lowest annual totals in 1963. Maximum annual totals ranged from 46.31 inches (Wytheville, 1979) to 61.29 inches (Charlottesville, 1979), with 7 stations reporting

Table 9. Maximum daily, monthly, and annual values, and minumum monthly and annual values, by station (all values reported in inches).[1]

Station Name	Maximum Daily Value (Date)	Minimum Monthy Total (Month/Year)	Maximum Monthly Total (Month/Year)	Minimum Annual Total (Year)	Maximum Annual Total (Year)	Highest Number Days of Rainfall (Year)
Blacksburg	3.80 (06/17/76)	0.12 (10/1973)	9.75 (05/1971)	26.95 (1963)	57.63 (1972)	147 (1962)
Buchanan	3.80 (10/19/68)	0.15 (02/1968)	10.47 (08/1967)	27.96 (1963)	54.82 (1972, 1979)	134 (1979)
Charlottesville	7.49 (06/22/72)	0.18 (10/1963)	12.81 (06/1972)	30.39 (1963)	61.29 (1979)	146 (1975)
Chatham	6.47 (08/31/64)	0.30 (08/1980)	11.76 (03/1975)	31.52 (1980)	58.91 (1972)	138 (1972, 1975)
Danville	3.70 (08/31/64)	0.18 (12/1980)	10.44 (03/1975)	30.62 (1980)	54.00 (1975)	136 (1972)
Farmville	6.62 (06/22/72)	0.26 (10/1963, 10/1974)	12.17 (10/1971)	31.63 (1963)	57.61 (1961)	122 (1961)
Glen Lyn	3.26 (09/14/66)	0.03 (02/1968)	8.98 (07/1962)	26.96 (1968)	48.38 (1979)	144 (1961)
Lexington	4.95 (08/20/69)	0.28 (01/1981, 12/1965)	9.87 (08/1984)	27.75 (1963)	57.46 (1969)	142 (1972, 1979)
Luray	6.02 (10/06/72)	0.02 (10/1963)	10.71 (06/1972)	28.39 (1965)	58.17 (1972)	136 (1972)
Lynchburg	6.02 (10/06/72)	0.02 (09/1978)	11.40 (10/1976)	26.56 (1963)	59.71 (1972)	138 (1975)
Martinsville	5.60 (08/31/64)	0.19 (10/1963)	11.45 (10/1976)	32.06 (1975)	53.41 (1979)	124 (1962)
Piedmont	7.85 (06/22/72)	0.28 (12/1965)	12.78 (06/1972)	30.37 (1963)	59.69 (1972)	145 (1972)
Roanoke	3.89 (04/26/78)	0.18 (12/1965)	9.72 (10/1976)	25.67 (1963)	51.42 (1979)	141 (1979)
Timberville	3.53 (09/14/66)	0.17 (10/1963)	9.31 (08/1967)	26.32 (1963)	49.11 (1972)	138 (1972)
Wytheville	4.85 (07/18/64)	0.05 (10/1963)	8.49 (07/1964)	25.82 (1963)	46.31 (1979)	140 (1982)

[1]Minimum daily rainfall for every station over the period of record was 0.01 inches.

a maximum annual rainfall in 1972, and 6 stations, in 1979 (Buchanan recorded the same maximum annual total in both 1972 and 1979).

Annual Statistics

Calendar Year

Mean annual rainfall for the 15 sample sites is presented in Table 10. An ANOVA test indicated that the stations do differ significantly ($F=4.85$, $df=14$, $p=0.0001$) with respect to mean annual totals. A Duncan's means separation test ordered the stations as listed in Table 10.

The overall regional mean annual rainfall for 1960-1984 is 40.58 inches. One-sided t-test analyses of station mean annual totals indicate that 4 of the 15 stations were statistically different from this mean (Charlottesville above ($t=4.032$, $df=398$, $p<0.0005$), and Glen Lyn ($t=-2.973$, $df=398$, $p<0.005$), Timberville ($t=-4.102$, $df=398$, $p<0.0005$), and Wytheville ($t=-1.955$, $df=398$, $p<0.025$) below,) (Fig. 8).

Regional mean annual rainfall for the 25 years is presented in Table 11. An ANOVA test indicates that the years do vary significantly ($F=23.74$, $df=24$, $p=0.0001$) with respect to mean annual total. A Duncan's means separation test ordered the years as shown in Table 11. There was no apparent trend over time in regional mean annual rainfall (Fig. 9).

A visual comparison of the number of days of rain in a given year and the amount of rainfall measured in that year suggest a relationship may exist between these 2 variables (Fig. 10). Statistical comparison of the number of days of rain and the amount of rainfall measured in a particular year did indicate a significant correlation ($R=0.529$, $N=375$, $p=0.0001$).

Table 10. Mean annual rainfall and standard error (SE) in inches for the 15 sample sites.

Station	Mean (SE)	N	Duncan's[1]
Charlottesville	47.19 (1.94)	25	A
Chatham	43.84 (1.37)	25	AB
Martinsville	43.13 (1.40)	25	AB
Danville	42.55 (1.39)	25	B
Farmville	42.48 (1.38)	25	B
Piedmont	42.33 (1.63)	25	B
Blacksburg	40.94 (1.36)	25	BC
Buchanan	40.49 (1.45)	25	BCD
Roanoke	40.66 (1.39)	25	BCD
Lynchburg	40.55 (1.72)	25	BCD
Luray	39.29 (1.35)	25	BCD
Wytheville	37.59 (0.96)	25	CDE
Lexington	37.61 (1.52)	25	CDE
Glen Lyn	35.97 (1.18)	25	DE
Timberville	35.23 (1.12)	25	E
Regional	40.58 (0.39)	375	

[1]Duncan's means separation test; stations with the same letter are not significantly different ($\alpha = 0.05$).

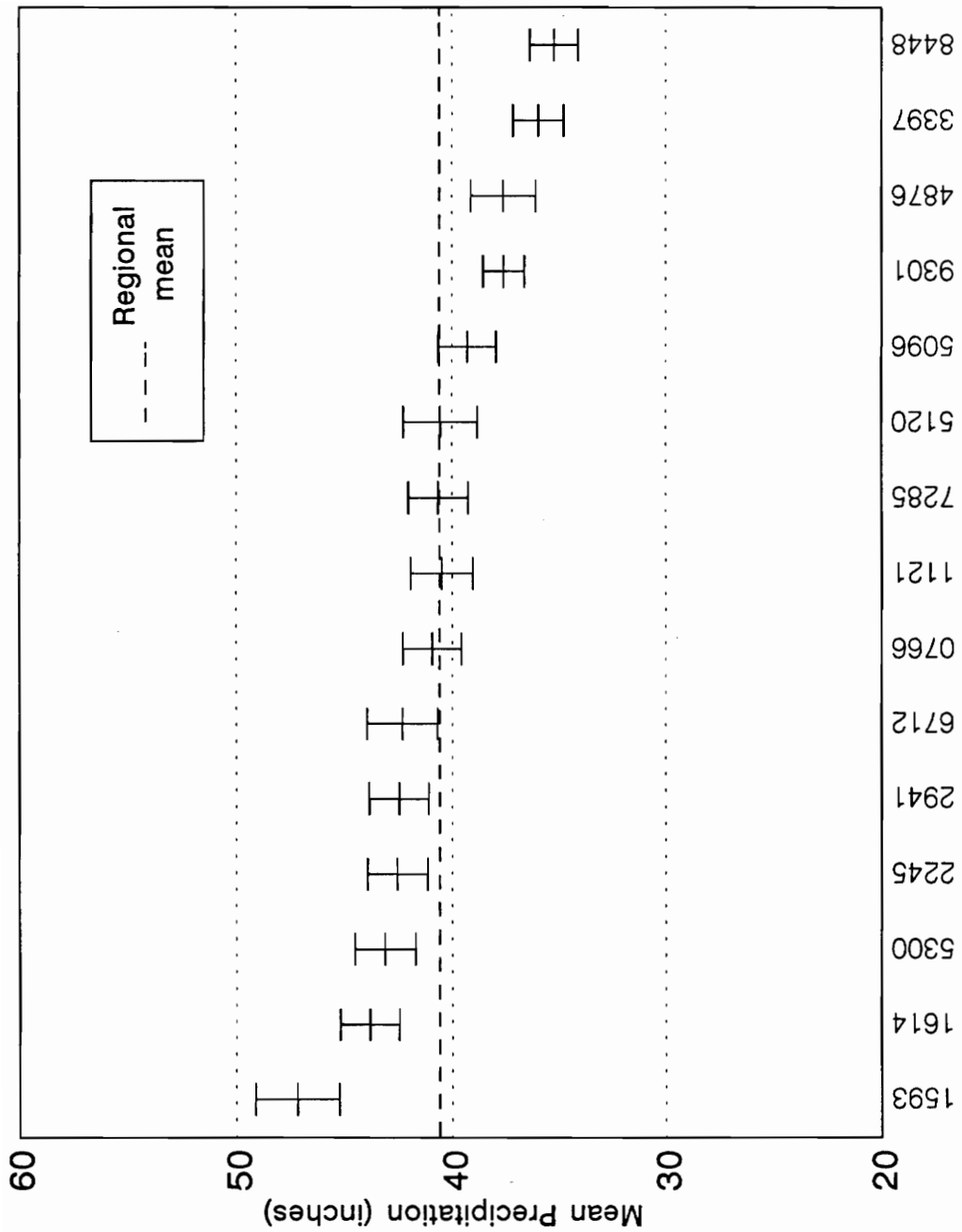


Figure 8. Relation of station mean annual rainfall to the regional mean.

Table 11. Mean annual rainfall and standard error (SE) in inches for the region for the study period (1960-1984).

Year	Mean (SE)	N	Duncan's[1]
1972	55.23 (1.45)	15	A
1979	52.35 (1.23)	15	A
1975	46.90 (2.03)	15	B
1961	46.32 (1.37)	15	BC
1983	45.65 (1.55)	15	BC
1973	44.39 (1.38)	15	BC
1971	44.25 (1.75)	15	BC
1982	43.91 (0.86)	15	BC
1984	43.89 (1.08)	15	BC
1978	43.47 (1.64)	15	BC
1962	42.48 (1.01)	15	CD
1976	39.55 (1.28)	15	DE
1966	39.52 (0.70)	15	DE
1967	39.31 (0.93)	15	DE
1974	39.12 (1.03)	15	DE
1969	38.83 (1.52)	15	DE
1964	38.42 (1.75)	15	DE
1960	37.17 (0.97)	15	EF
1970	36.56 (1.14)	15	EF
1977	35.82 (1.16)	15	EF
1968	34.21 (1.12)	15	F
1981	33.52 (0.93)	15	F
1965	33.30 (0.97)	15	F
1980	33.14 (0.57)	15	F
1963	29.35 (0.80)	15	G
Regional	40.58 (0.39)	375	

[1]Duncan's means separation test; stations with same letter are not significantly different ($\alpha = 0.05$).

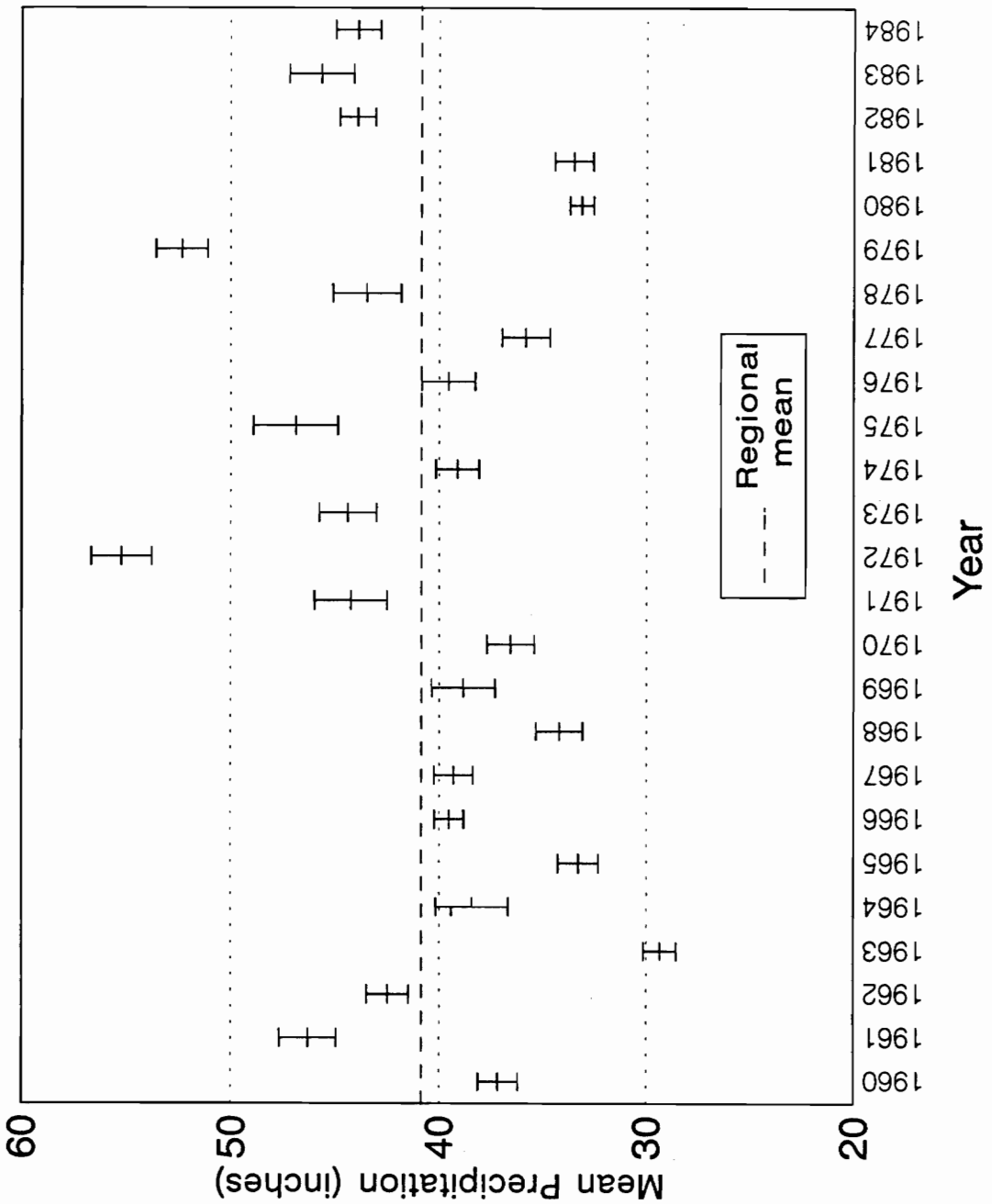


Figure 9. Relation of regional mean annual rainfall to overall regional mean.

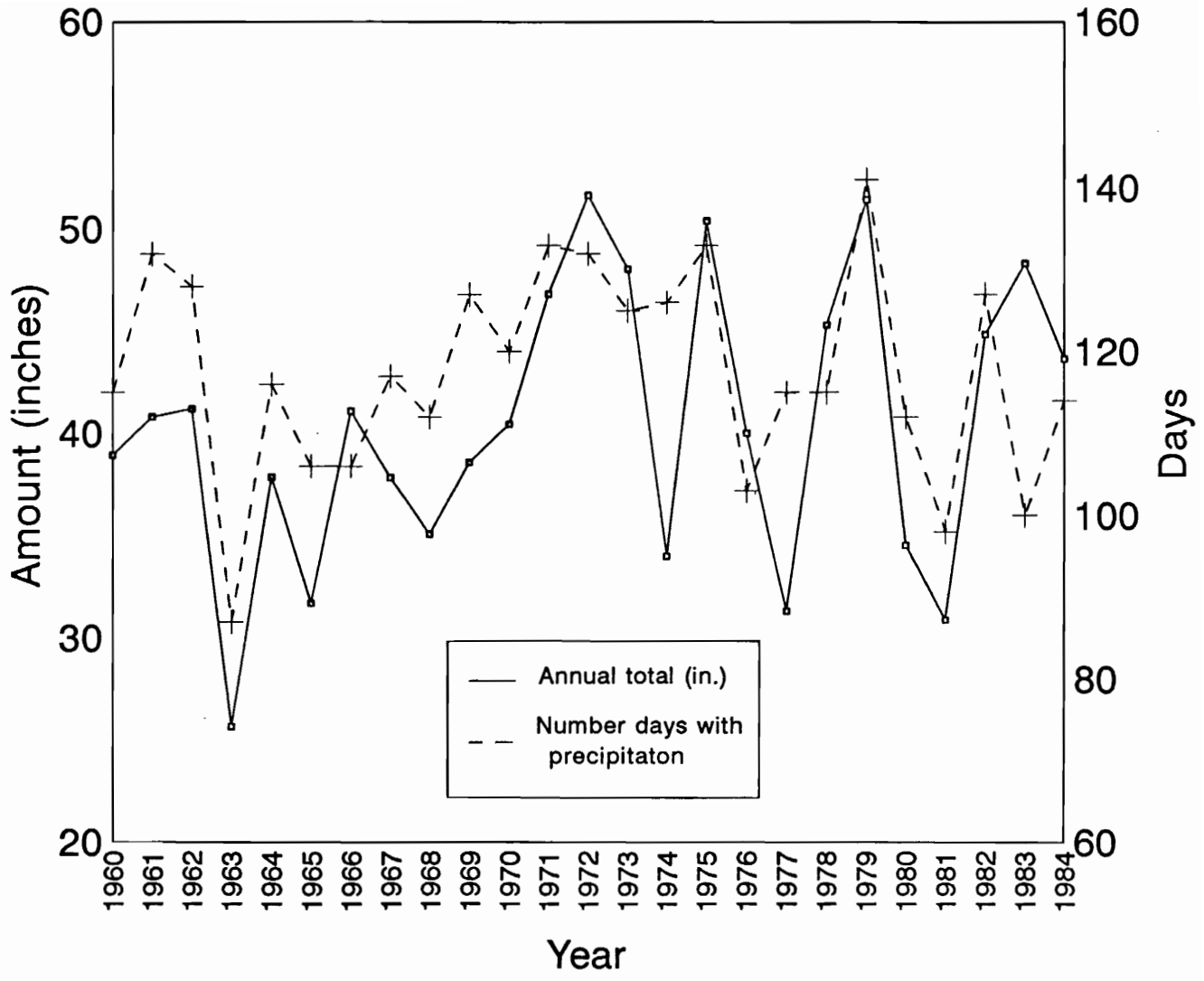


Figure 10. Comparison of annual rainfall totals to the annual numbers of days of rainfall at the Roanoke weather station.

The highest and lowest years of rainfall identified in the preceding section are supported by the maximum and minimum annual data discussed above. As previously noted, maximum annual rainfall occurred for 12 stations in either 1972 or 1979. These 2 years had significantly higher ($t=8.716$, $df=388$, $p<0.0005$; $t=7.013$, $df=388$, $p<0.0005$, respectively) rainfall than other years. Ten stations also reported minimum annual rainfall in 1963. This year had significantly lower rainfall ($t=-12.985$, $df=388$, $p<0.0005$) than all other years.

Detailed information on annual rainfall, numbers of days with precipitation, highest number of consecutive days of rainfall, mean daily precipitation for "wet" days, mean daily precipitation for all days, and median precipitation for "wet" days for each station are found in Appendix 1.

Water Year

Mean annual rainfall using water years (October-September) for the 15 sample sites is presented in Table 12. An ANOVA test indicates that the stations differ significantly ($F=2.42$, $df=14$, $p=0.0001$) with respect to mean annual water year totals. A Duncan's means separation test ordered the stations as listed in Table 12 and shown in Figure 11.

The overall regional mean annual water year rainfall for the 1961-1985 water years is 40.61 in. A review of station mean annual totals indicates that 3 of the 15 stations were statistically different from this mean (Charlottesville above ($t=3.018$, $df=398$, $p<0.005$), and Glen Lyn ($t=-2.138$, $df=398$, $p<0.025$) and Timberville ($t=-2.580$, $df=398$, $p<0.01$) below), while the remaining 9 were not significantly different from the mean.

Regional mean annuals for the 25 water years are presented in Table 13. An ANOVA test indicates that the years do vary significantly ($F=53.21$, $df=24$, $p=0.0001$) with respect to mean annual totals. As with the calendar year means, there is no apparent trend over time in regional mean annual rainfall (Figure 12).

Table 12. Mean annual rainfall and standard error (SE), maximum rainfall, and minimum rainfall, in inches, by water year (October-September) by station.

Station	Mean (SE) Rainfall	Maximum Rainfall	Minimum Rainfall	Duncan's Means Separation[1]
Charlottesville	47.18 (1.95)	61.32	32.77	A
Chatham	43.70 (1.47)	56.96	32.92	AB
Martinsville	43.14 (1.65)	59.33	29.79	AB
Danville	42.44 (1.49)	56.95	29.89	BC
Piedmont	42.39 (1.65)	56.02	32.40	BC
Farmville	42.16 (1.41)	56.35	32.03	BC
Blacksburg	41.10 (1.32)	53.50	31.23	BC
Lynchburg	40.53 (1.90)	59.64	28.19	BCD
Roanoke	40.50 (1.57)	55.30	27.20	BCD
Buchanan	40.46 (1.56)	51.89	27.53	BCD
Luray	39.24 (1.29)	50.81	26.89	BCD
Lexington	37.62 (1.48)	52.28	25.83	CDE
Wytheville	37.54 (0.81)	44.54	29.66	DE
Glen Lyn	36.08 (1.17)	45.93	27.20	DE
Timberville	35.11 (1.00)	44.96	27.60	E
Regional	40.61 (0.41)	61.32	25.83	

[1]Duncan's means separation test; stations with the same letter are not significantly different ($\alpha = 0.05$) with respect to mean annual rainfall.

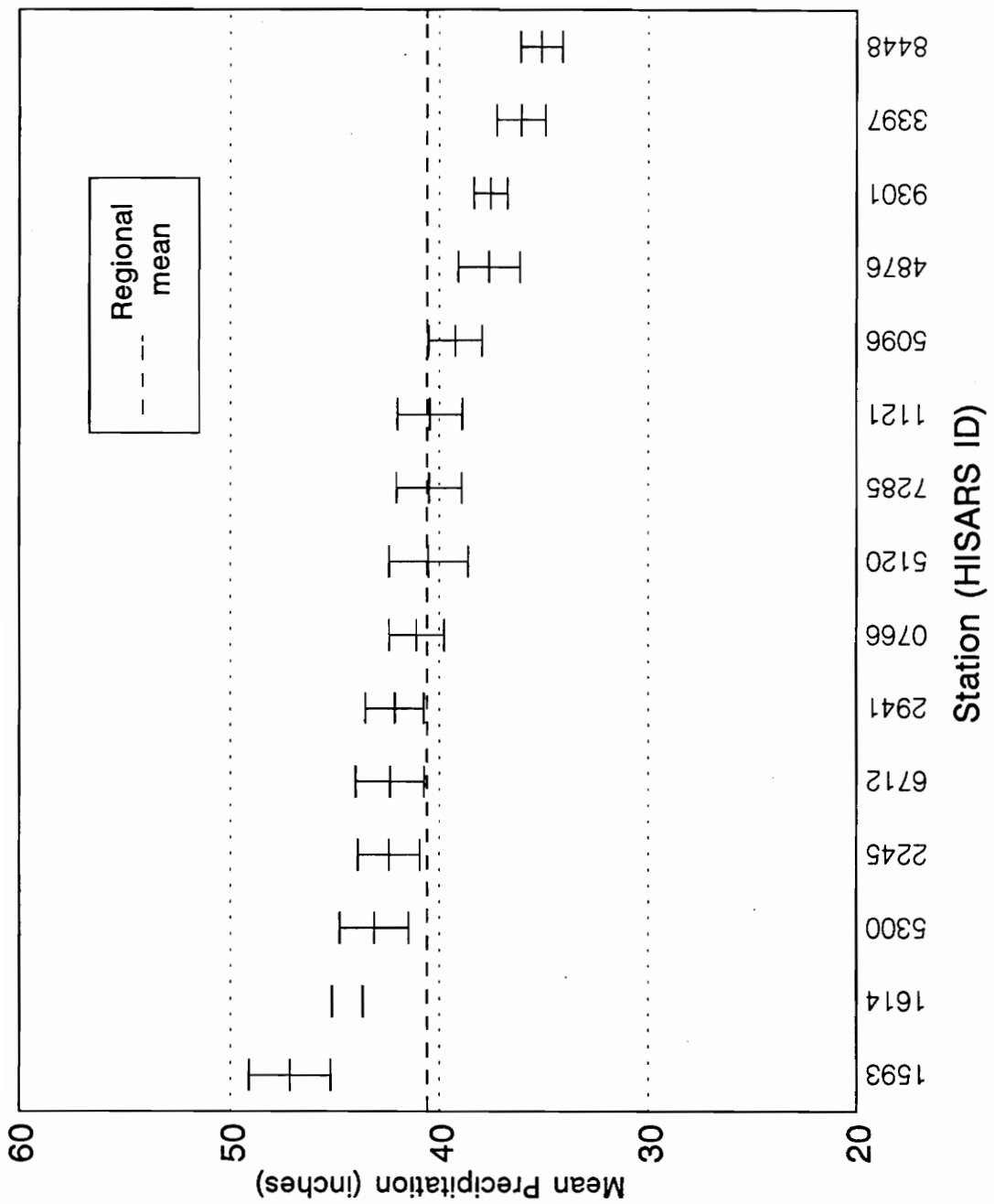


Figure 11. Relation of station mean annual water year rainfall to the regional mean.

Table 13. Mean annual rainfall and standard error (SE) in inches by water year (October-September) for the study region.

Year[1]	Mean (SE) Rainfall	Maximum Rainfall	Minimum Rainfall
1961	39.30 (1.21)	49.16	32.68
1962	43.34 (1.28)	54.20	35.89
1963	32.78 (0.82)	38.70	28.20
1964	36.47 (1.57)	48.25	28.90
1965	38.07 (1.10)	46.26	31.22
1966	34.26 (0.69)	38.26	27.79
1967	39.11 (0.81)	45.80	32.86
1968	34.03 (1.16)	43.95	28.16
1969	39.69 (1.54)	52.86	28.75
1970	34.45 (1.03)	40.13	27.67
1971	44.40 (1.72)	60.35	34.31
1972	49.66 (1.53)	59.33	37.12
1973	47.79 (1.50)	57.41	38.21
1974	44.85 (1.15)	51.47	35.29
1975	46.18 (1.67)	60.16	34.28
1976	33.01 (1.13)	41.87	26.89
1977	36.03 (1.09)	44.08	28.92
1978	48.77 (1.79)	57.22	35.95
1979	50.82 (1.30)	61.32	40.97
1980	37.13 (0.62)	42.20	33.22
1981	31.27 (0.88)	37.22	25.83
1982	42.16 (1.02)	51.52	35.77
1983	39.13 (1.13)	47.81	31.67
1984	52.00 (1.50)	61.15	41.87
Regional	40.61 (0.41)	61.32	25.83

[1]The water year 1960 was omitted since the study data do not include October-December, 1959.

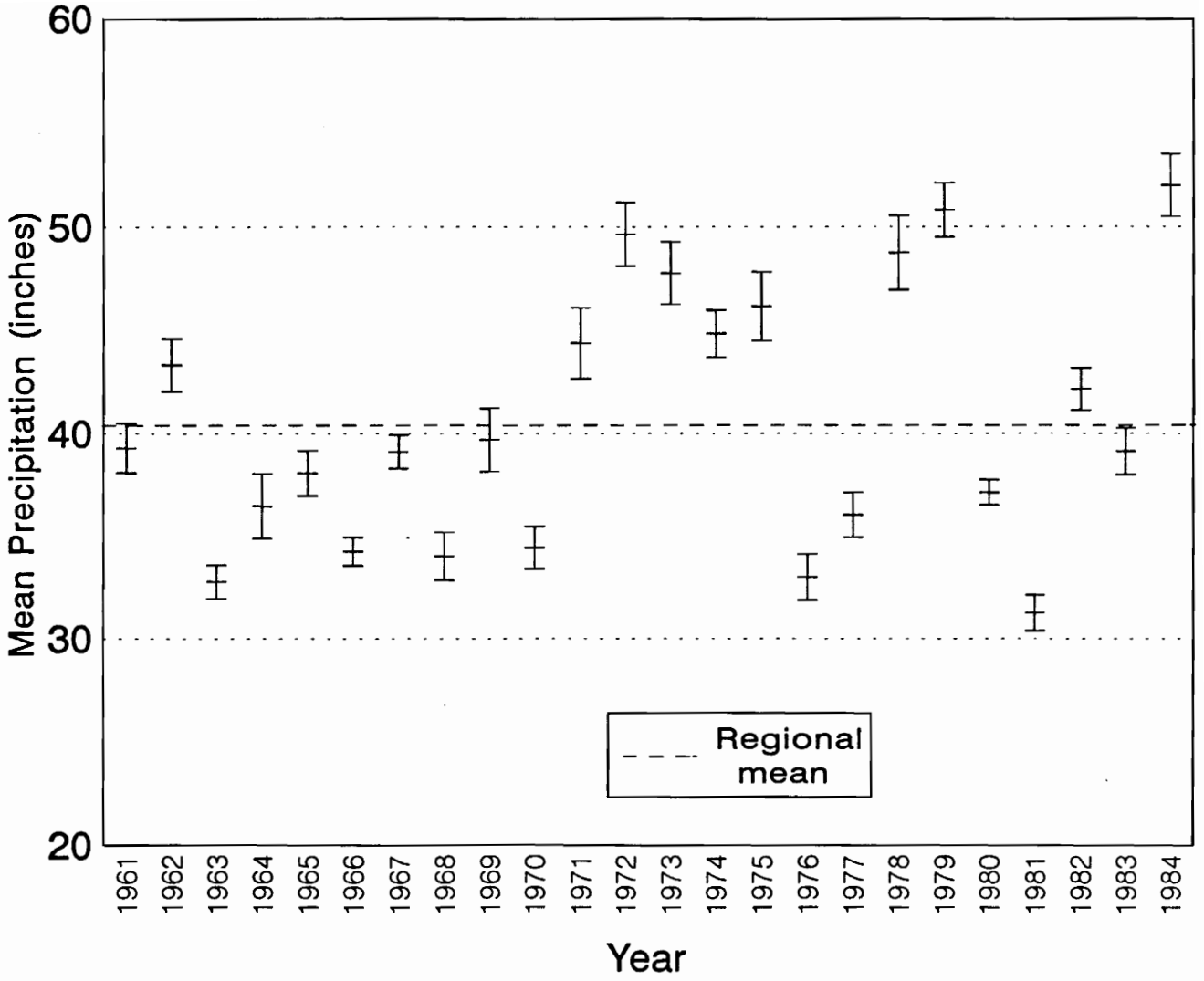


Figure 12. Relation of regional mean annual water year rainfall to overall regional mean.

The years of highest and lowest rainfall are slightly different than those calculated on the calendar year basis. The minimum regional annual rainfall still occurs in 1963 (October, 1962-September, 1963). The maximum regional rainfall, however, now occurs during the 1984 water year (October, 1983-September, 1984). A comparison of water year means to calendar year means suggests that higher amounts of rainfall in calendar years 1983 and 1984 may have been distributed in the later and earlier months of those years, respectively.

Monthly Statistics

Mean monthly site-specific and regional rainfall values are presented in Table 14. More detailed information on monthly mean rainfall, monthly mean number of days of rain, monthly mean number of "trace" days, and monthly maximum, minimum, and median rainfall for each station is provided in Appendix 2. An ANOVA test indicates that the months do differ significantly ($F = 20.65$, $df = 11$, $p = 0.0001$). This realization of differences suggests further justification for seeking discriminating models for individual sites.

Regionally, the mean monthly rainfall values do show some differences (based on a Duncan's Means Separation test). While the mean monthly values only range from 2.83 (November) to 4.05 (July), the July, May, and August means are significantly higher ($p < 0.05$) than the November, December, and January means (Table 15; example provided in Figure 13).

The only apparent consistencies within the overall minimum or maximum monthly totals appear in the minimum monthly totals. Six of the 15 stations recorded the lowest monthly total during the study period of record in October, 1963. This time period is also consistent with the regional record low annual rainfall measured for both the calendar and water year, 1963.

Table 14. Mean monthly rainfall and standard error (SE) in inches for each station, by month, for the period 1960-1984.

Station	Month											
	January	February	March	April	May	June	July	August	September	October	November	December
Blacksburg	2.82 (0.23)	3.01 (0.32)	3.79 (0.31)	3.63 (0.31)	3.99 (0.38)	3.50 (0.38)	3.89 (0.30)	3.63 (0.25)	3.31 (0.33)	3.68 (0.38)	2.66 (0.30)	2.97 (0.32)
Buchanan	2.67* (0.32)	2.98 (0.33)	3.57 (0.30)	3.00 (0.28)	3.89 (0.31)	3.37 (0.35)	4.15 (0.28)	4.07 (0.51)	3.18 (0.40)	3.83 (0.34)	2.89 (0.31)	2.84 (0.34)
Charlottesville	3.24 (0.40)	3.59 (0.38)	3.97 (0.33)	3.33 (0.38)	4.57 (0.36)	3.75 (0.59)	4.81 (0.51)	4.81 (0.48)	3.93 (0.58)	4.52 (0.64)	3.17 (0.42)	3.37 (0.41)
Chatham	3.39 (0.35)	3.59 (0.33)	4.28 (0.44)	3.25* (0.36)	4.22 (0.39)	3.33 (0.36)	4.04 (0.37)	3.75 (0.48)	3.79 (0.47)	3.71 (0.44)	3.06 (0.36)	3.36 (0.38)
Danville	3.43 (0.37)	3.50 (0.31)	4.08 (0.43)	3.14 (0.32)	3.74 (0.26)	3.70 (0.40)	4.20 (0.38)	3.83 (0.33)	3.54 (0.43)	3.39* (0.40)	2.81 (0.32)	3.28 (0.37)
Farmville	3.47 (0.37)	3.42 (0.33)	4.01 (0.35)	2.73* (0.29)	4.10 (0.36)	3.46 (0.48)	4.38 (0.40)	3.62 (0.45)	3.16 (0.39)	3.83 (0.59)	2.91 (0.35)	3.29 (0.38)
Glen Lyn	2.29 (0.25)	2.71 (0.27)	3.11 (0.26)	3.00 (0.25)	3.72* (0.31)	3.33 (0.30)	3.87 (0.33)	3.20 (0.27)	2.88 (0.31)	2.84 (0.29)	2.49 (0.23)	2.66 (0.28)
Lexington	2.56 (0.30)	2.99 (0.32)	3.51 (0.31)	2.77 (0.27)	3.50 (0.29)	3.29 (0.38)	3.53 (0.38)	3.12 (0.46)	3.11 (0.41)	3.49 (0.43)	2.71 (0.30)	2.97 (0.33)
Luray	2.83 (0.37)	2.92 (0.42)	3.11* (0.34)	2.94 (0.32)	3.63 (0.33)	3.53* (0.42)	3.66 (0.32)	3.70 (0.37)	3.55* (0.44)	3.47 (0.51)	3.16 (0.43)	2.86 (0.40)
Lynchburg	2.95 (0.35)	3.16 (0.31)	3.76 (0.36)	2.91 (0.28)	3.83 (0.42)	3.44 (0.43)	4.13 (0.45)	3.51 (0.44)	3.15 (0.43)	3.62 (0.50)	2.88 (0.31)	3.19* (0.36)
Martinsville	3.22** (0.39)	3.72 (0.38)	4.22* (0.36)	3.35* (0.35)	4.16 (0.33)	3.86** (0.48)	4.31 (0.36)	3.98** (0.39)	3.44* (0.47)	3.59** (0.61)	2.93 (0.32)	3.36 (0.39)
Piedmont	2.79 (0.35)	2.89 (0.33)	3.62 (0.28)	3.08 (0.33)	4.10 (0.37)	3.43 (0.51)	4.21 (0.38)	4.39 (0.44)	3.58 (0.51)	3.98* (0.63)	3.11 (0.36)	3.13 (0.39)
Roanoke	2.68 (0.30)	3.26 (0.36)	3.75 (0.34)	3.08 (0.38)	3.80 (0.36)	3.25 (0.32)	3.66 (0.29)	4.19 (0.39)	3.17 (0.40)	3.85 (0.48)	2.71 (0.32)	3.01 (0.31)

Table 14, cont. Mean monthly rainfall and standard error (SE) in inches for each station, by month, for the period 1960-1984.

Station	Month											
	January	February	March	April	May	June	July	August	September	October	November	December
Timberville	2.35 (0.29)	2.41 (0.27)	2.85 (0.30)	2.55 (0.26)	3.20 (0.30)	3.15* (0.41)	3.36* (0.37)	3.99 (0.37)	3.45 (0.34)	3.07 (0.43)	2.51 (0.27)	2.46 (0.29)
Wytheville	2.46 (0.21)	2.82 (0.29)	3.21 (0.24)	3.10 (0.29)	3.79 (0.32)	3.24 (0.30)	4.48 (0.33)	3.10 (0.38)	2.86 (0.31)	3.41 (0.33)	2.47 (0.23)	2.63 (0.30)
Regional	2.88 (0.09) (N=375)	3.13 (0.09) (N=375)	3.66 (0.09) (N=373)	3.06 (0.08) (N=375)	3.88 (0.09) (N=374)	3.44 (0.11) (N=373)	4.05 (0.10) (N=374)	3.79 (0.11) (N=373)	3.34 (0.11) (N=374)	3.62 (0.12) (N=373)	2.83 (0.08) (N=375)	3.02 (0.09) (N=374)

*N=24; **N=23; unmarked-N=25

Table 15. Mean monthly rainfall and standard error (SE) in inches for the region, by month, for the study period (1960-1984).

Month	Mean (SE)	N	Duncan's[1]
July	4.05 (0.10)	15	A
May	3.88 (0.09)	15	AB
August	3.79 (0.11)	15	AB
March	3.66 (0.09)	15	BC
October	3.62 (0.12)	15	BC
June	3.44 (0.11)	15	CD
September	3.34 (0.11)	15	DE
February	3.13 (0.09)	15	EF
April	3.06 (0.08)	15	FG
December	3.03 (0.09)	15	FG
January	2.88 (0.09)	15	FG
November	2.83 (0.08)	15	G

[1]Duncan's means separation test; stations with the same letter are not significantly different ($\alpha = 0.05$).

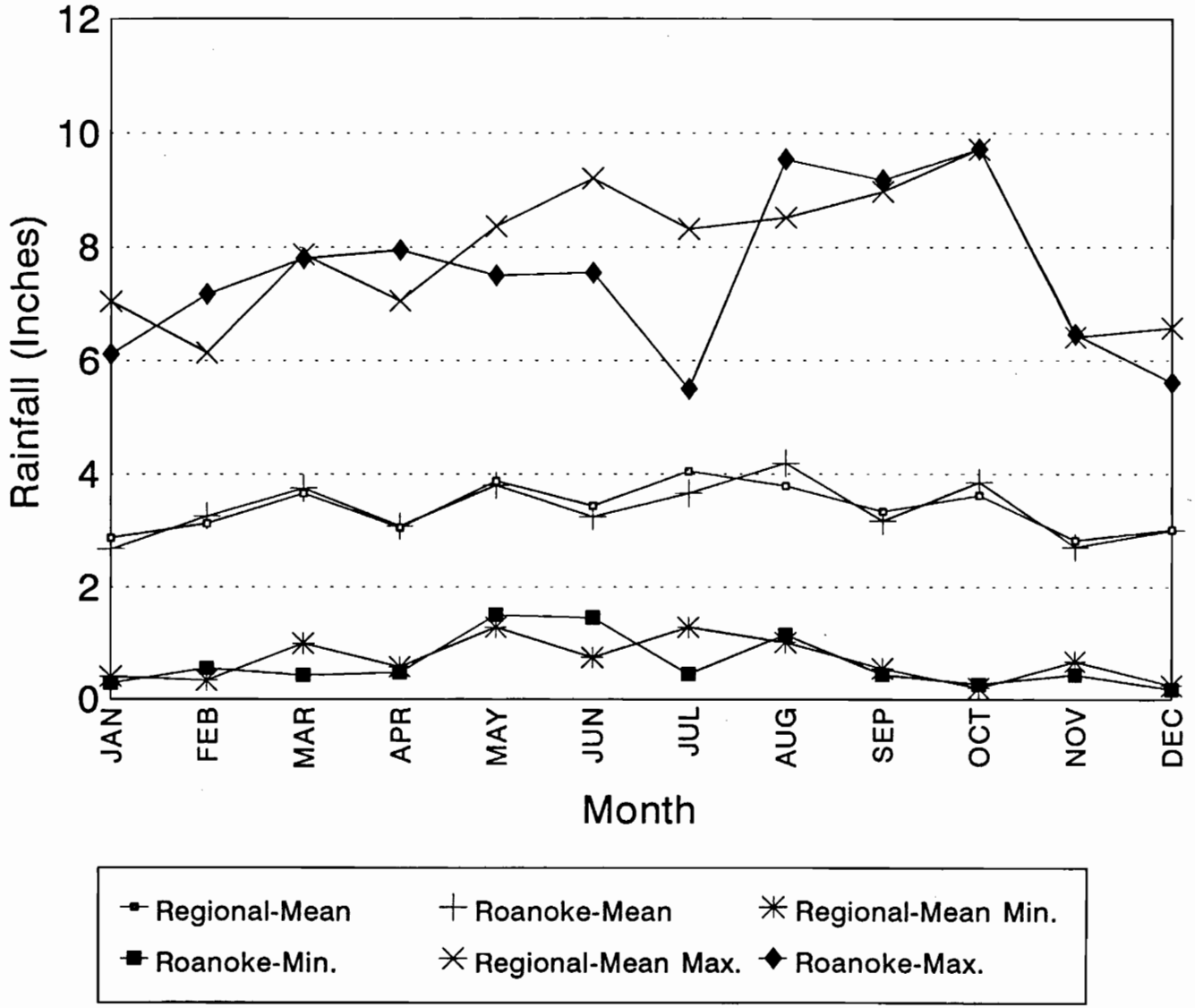


Figure 13. Comparison of mean, maximum, and minimum monthly rainfall values at Roanoke weather station.

Periods of Rainfall

Several of the papers reviewed for this project (see Daily Models in the "Literature Review") alluded to the precipitation on any day depending on the occurrence of precipitation during the preceding day (or days). In reviewing the number of consecutive days of rainfall for each of the stations, and the region, over the study period of record, there does not appear to be such a dependency in the study area (Table 16, Fig. 14).

The majority of the days of rain are single incidents; 50% of the mean number of periods of consecutive rainfall for the region are 1-day events. Thirty percent of the mean number of periods of consecutive rainfall for the region are 2-day events, 11% are 3-day events, and 5% are 4-day events. These percentages also hold true (within 1-2%) for each of the individual stations. With 96% of the mean number of periods of consecutive rain in 1-day, 2-day, 3-day, or 4-day events, the likelihood of extended rainfall ($>$ 4 consecutive days) in 1 year is very small.

Amount of Rainfall

Frequencies of daily rainfall amounts are presented in Tables 17 and 18. The majority of the "wet" days at any station received $<$1.00 inch of rain. During the period 1960-1984, no station reported daily rainfall $\geq$1.00 inch on more than 10% of the total number of "wet" days. The percentage of "wet" days receiving 1.00 inch or more of rain ranged from 5.1% (Timberville) to 10.0% (Farmville).

The sharp decline between the number of days with $\geq$1.00 inch and days with $\geq$2.00 inches indicates that most of the daily rainfall over 1.00 inches ranged from 1.00 to 1.99 inches (Fig. 15).

Table 16. Mean number of periods and standard error (SE) of consecutive rainfall in a year by station.

Station	Consecutive Days of Rain											
	1 Day	2 Days	3 Days	4 Days	5 Days	6 Days	7 Days	8 Days	9 Days	10 Days	11 Days	12 Days
Blacksburg	30.6 (1.1)	19.8 (0.8)	7.5 (0.4)	3.8 (0.4)	1.4 (0.3)	1.0 (0.2)	0.7 (0.2)	0.1 (0.1)	0.1 (0.1)	<0.1 (<0.1)	0.0 (0.0)	0.0 (0.0)
Buchanan	33.0 (1.0)	16.5 (0.9)	6.8 (0.4)	2.7 (0.4)	0.9 (0.2)	0.4 (0.2)	0.2 (0.1)	0.1 (0.1)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Charlottesville	28.3 (1.1)	18.1 (0.7)	7.9 (0.5)	3.7 (0.4)	1.4 (0.2)	0.8 (0.2)	0.5 (0.1)	0.1 (0.1)	0.1 (0.1)	<0.1 (<0.1)	0.0 (0.0)	0.1 (0.1)
Chatham	29.8 (0.9)	20.6 (0.7)	6.8 (0.5)	3.1 (0.3)	1.1 (0.2)	0.5 (0.1)	0.2 (0.1)	0.2 (0.1)	0.0 (0.0)	<0.1 (<0.1)	0.0 (0.0)	0.0 (0.0)
Danville	29.1 (1.0)	17.9 (0.8)	7.0 (0.4)	3.1 (0.4)	1.2 (0.2)	0.7 (0.2)	0.2 (0.1)	0.2 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Farmville	33.0 (0.9)	17.5 (0.9)	4.7 (0.4)	1.9 (0.3)	0.5 (0.2)	0.2 (0.1)	0.2 (0.1)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Glen Lyn	31.9 (1.0)	17.6 (0.7)	6.9 (0.4)	3.2 (0.3)	1.3 (0.2)	0.4 (0.2)	0.4 (0.1)	0.0 (0.0)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Lexington	31.4 (0.9)	18.4 (0.8)	7.2 (0.5)	3.2 (0.3)	1.2 (0.2)	0.6 (0.2)	0.4 (0.1)	0.1 (0.1)	<0.1 (<0.1)	<0.1 (<0.1)	0.0 (0.0)	<0.1 (<0.1)
Luray	31.4 (1.0)	18.5 (0.8)	7.8 (0.5)	2.7 (0.4)	1.1 (0.2)	0.5 (0.1)	0.2 (0.1)	0.2 (0.1)	0.0 (0.0)	<0.1 (<0.1)	0.0 (0.0)	0.0 (0.0)
Lynchburg	30.6 (1.0)	19.2 (0.7)	7.7 (0.6)	3.3 (0.3)	1.0 (0.2)	0.4 (0.1)	0.3 (0.1)	0.2 (0.1)	<0.1 (<0.1)	0.0 (0.0)	<0.1 (<0.1)	0.0 (0.0)
Martinsville	28.0 (0.9)	17.8 (0.8)	6.4 (0.5)	2.8 (0.4)	1.2 (0.2)	0.6 (0.1)	0.3 (0.1)	0.2 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Piedmont	30.3 (1.2)	18.2 (0.8)	7.4 (0.7)	2.8 (0.3)	1.4 (0.2)	0.4 (0.1)	0.4 (0.1)	0.2 (0.1)	0.2 (0.1)	<0.1 (<0.1)	0.0 (0.0)	<0.1 (<0.1)
Roanoke	32.4 (1.0)	18.9 (0.7)	7.7 (0.5)	2.8 (0.4)	1.0 (0.2)	0.6 (0.2)	0.4 (0.1)	0.2 (0.1)	<0.1 (<0.1)	<0.1 (<0.1)	0.0 (0.0)	0.0 (0.0)
Timberville	33.3 (1.1)	18.9 (0.8)	7.3 (0.6)	2.4 (0.3)	1.3 (0.2)	0.6 (0.1)	0.4 (0.1)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Wytheville	36.3 (1.2)	17.7 (0.9)	5.9 (0.6)	3.2 (0.4)	1.1 (0.2)	0.2 (0.1)	0.2 (0.1)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Regional	31.3 (0.3)	18.4 (0.2)	7.0 (0.1)	3.0 (0.1)	1.1 (0.1)	0.5 (<0.1)	0.3 (<0.1)	0.1 (<0.1)	<0.1 (<0.1)	<0.1 (<0.1)	<0.1 (<0.1)	<0.1 (<0.1)

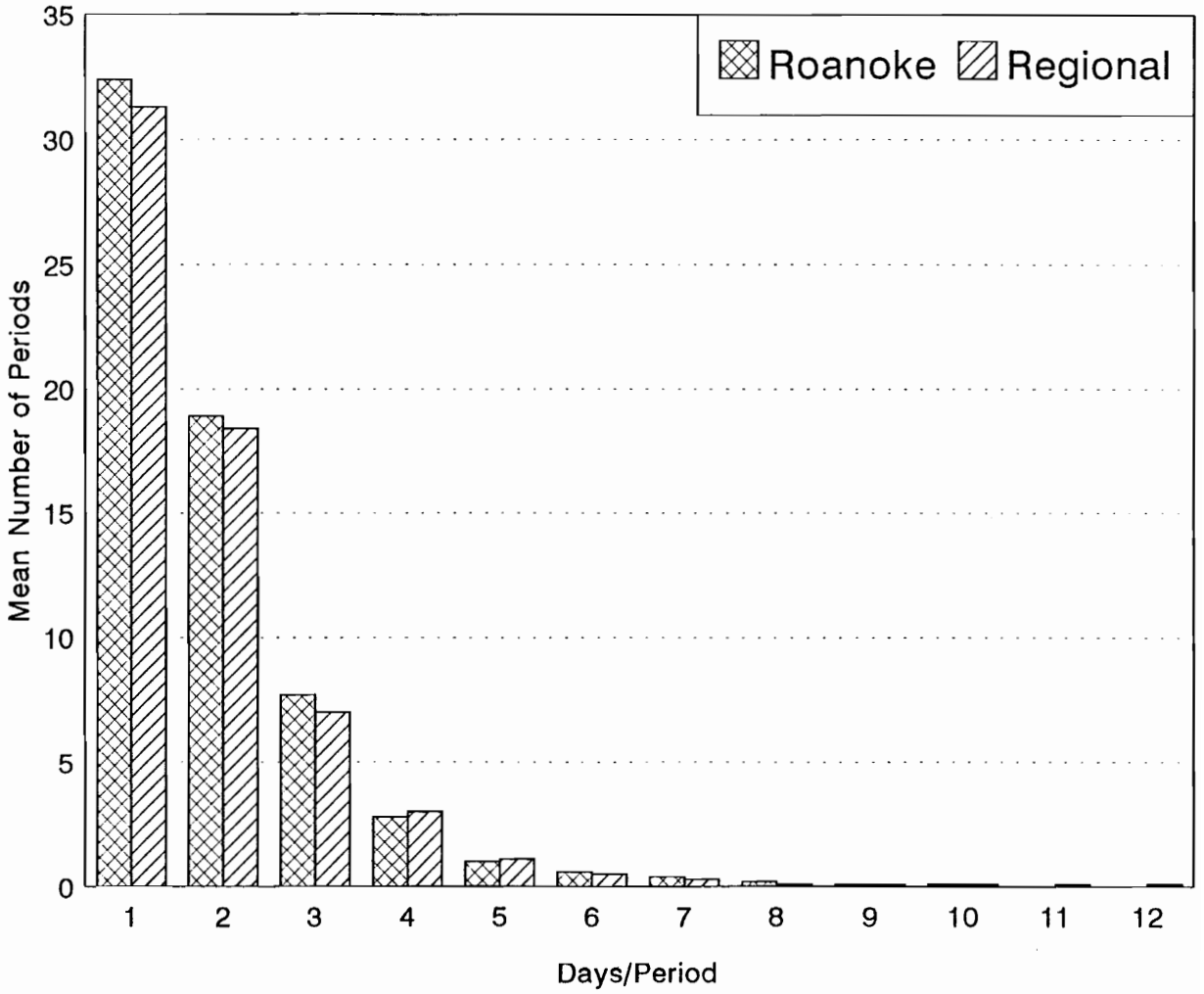


Figure 14. Comparison of mean number of periods of consecutive rainfall with the regional mean number of periods at Roanoke weather station.

Table 17. Frequency (percent) of daily rainfall greater than 0.01 inches, by station, from 1960-1984.

Station	No. Days ≥0.01" (%)	No. Days ≥0.10" (%)	No. Days ≥0.20 (%)	No. Days ≥0.30" (%)	No. Days ≥0.40" (%)	No. Days ≥0.50" (%)	No. Days ≥0.60" (%)	No. Days ≥0.70" (%)	No. Days ≥0.80" (%)	No. Days ≥0.90" (%)
Blacksburg	3159 (100)	2232 (70.7)	1580 (50.0)	1147 (36.3)	899 (28.5)	760 (24.1)	542 (17.2)	402 (12.7)	308 (9.7)	232 (7.3)
Buchanan	2688 (100)	1952 (72.6)	1460 (54.3)	1125 (41.9)	881 (32.8)	694 (25.8)	553 (20.6)	440 (16.4)	361 (13.4)	286 (10.6)
Charlottesville	3040 (100)	1893 (62.3)	1420 (46.7)	1129 (37.1)	918 (31.7)	752 (24.7)	647 (21.3)	544 (17.9)	450 (14.8)	380 (12.5)
Chatham	2892 (100)	1914 (66.2)	1441 (49.8)	1153 (39.9)	922 (30.3)	718 (24.8)	601 (20.8)	503 (17.4)	404 (13.9)	343 (11.9)
Danville	2808 (100)	1907 (67.9)	1447 (51.5)	1145 (40.8)	908 (32.3)	709 (25.2)	579 (20.6)	478 (17.0)	410 (14.6)	334 (11.9)
Farmville	2379 (100)	1809 (76.0)	1412 (59.4)	1112 (46.7)	923 (38.8)	750 (31.5)	608 (25.6)	501 (21.1)	419 (17.6)	330 (13.9)
Glen Lyn	2819 (100)	2003 (71.1)	1413 (50.1)	1020 (36.2)	767 (27.2)	591 (20.9)	450 (15.9)	342 (12.1)	262 (9.3)	202 (7.2)
Lexington	2925 (100)	1803 (62.6)	1334 (45.6)	1020 (34.9)	803 (27.5)	623 (21.3)	498 (17.0)	389 (13.3)	310 (10.6)	251 (8.6)
Luray	2849 (100)	1819 (63.8)	1317 (46.2)	1005 (35.3)	793 (27.8)	625 (21.9)	525 (18.4)	433 (15.2)	375 (13.2)	298 (10.5)
Lynchburg	2875 (100)	1826 (63.5)	1385 (48.2)	1092 (37.9)	870 (30.3)	687 (23.9)	559 (19.4)	445 (15.5)	344 (11.9)	287 (9.9)
Martinsville	2682 (100)	1885 (70.3)	1423 (53.1)	1132 (42.2)	897 (33.4)	719 (26.8)	574 (21.4)	482 (17.9)	393 (14.7)	326 (12.2)
Piedmont	2919 (100)	1836 (62.9)	1359 (46.6)	1056 (36.2)	853 (29.2)	710 (24.3)	589 (20.2)	494 (16.9)	414 (14.2)	349 (11.9)
Roanoke	2940 (100)	1855 (63.1)	1405 (47.8)	1094 (37.2)	858 (29.2)	682 (23.2)	519 (17.7)	419 (14.3)	361 (12.3)	286 (9.7)
Timberville	2892 (100)	1746 (60.4)	1249 (43.2)	949 (32.8)	739 (25.6)	592 (20.5)	470 (16.3)	370 (12.8)	299 (10.3)	234 (8.1)
Wytheville	2796 (100)	1914 (68.5)	1404 (50.2)	1074 (38.4)	788 (28.2)	595 (21.3)	450 (16.1)	372 (13.3)	295 (10.6)	243 (8.7)
Regional	42663 (100)	28421 (66.6)	21049 (49.3)	16253 (38.1)	12819 (30.0)	10207 (23.9)	8164 (19.1)	6614 (15.5)	5405 (12.7)	4381 (10.3)

Table 18. Frequency (percent) of daily rainfall greater than 1.00 inches, by station, from 1960-1984.

Station	No. Days ≥1.00" (%)	No. Days ≥2.00" (%)	No. Days ≥3.00 (%)	No. Days ≥4.00" (%)	No. Days ≥5.00" (%)	No. Days ≥6.00" (%)
Blacksburg	181 (5.4)	23 (0.7)	3 (0.1)	0	0	0
Buchanan	229 (7.9)	39 (1.3)	6 (0.2)	0	0	0
Charlottesville	324 (8.7)	62 (1.7)	20 (0.5)	10 (0.3)	2 (<0.1)	2 (<0.1)
Chatham	287 (8.8)	39 (1.2)	10 (0.3)	3 (0.1)	2 (0.1)	1 (<0.1)
Danville	271 (9.0)	47 (1.6)	9 (0.3)	1 (<0.1)	0	0
Farmville	288 (10.0)	43 (1.5)	13 (0.5)	3 (0.1)	1 (<0.1)	1 (<0.1)
Glen Lyn	164 (5.6)	11 (0.4)	1 (<0.1)	0	0	0
Lexington	205 (6.3)	29 (0.9)	8 (0.2)	1 (<0.1)	0	0
Luray	235 (7.6)	42 (1.4)	11 (0.4)	5 (0.2)	1 (<0.1)	1 (<0.1)
Lynchburg	238 (6.5)	40 (1.1)	8 (0.2)	1 (<0.1)	1 (<0.1)	1 (<0.1)
Martinsville	278 (9.3)	52 (1.7)	10 (0.3)	3 (0.1)	2 (0.1)	0
Piedmont	288 (9.5)	47 (1.5)	9 (0.3)	4 (0.1)	1 (<0.1)	1 (<0.1)
Roanoke	237 (5.7)	40 (1.0)	9 (0.2)	1 (<0.1)	1 (<0.1)	0
Timberville	189 (5.1)	28 (0.8)	6 (0.2)	0	0	0
Wytheville	193 (6.5)	29 (1.0)	4 (0.1)	1 (<0.1)	0	0
Regional	3607 (8.5)	571 (1.3)	127 (0.3)	33 (0.1)	11 (<0.1)	7 (<0.1)

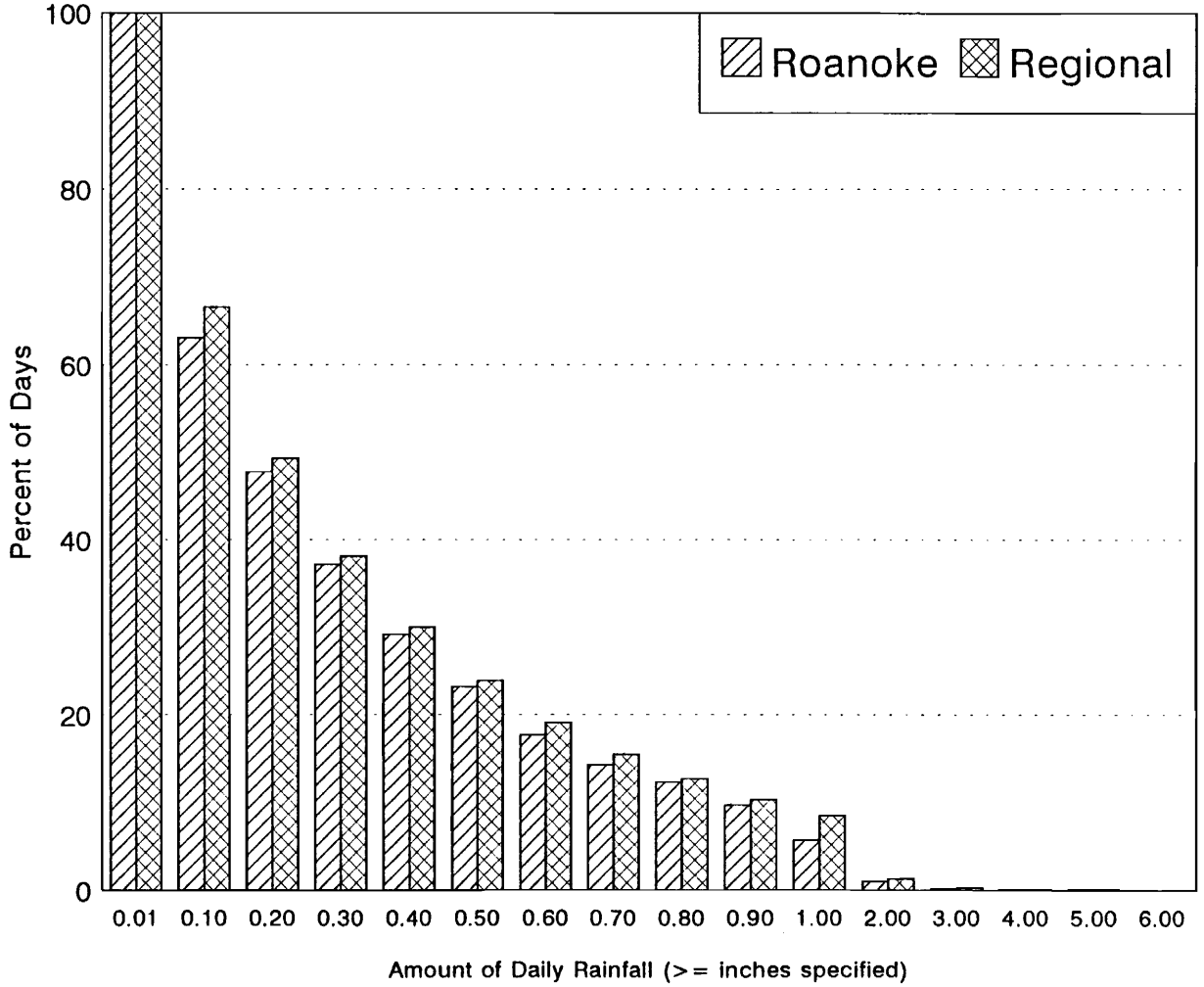


Figure 15. Relation of frequency of daily rainfall amounts between Roanoke weather station and the study region.

Seasonal Rainfall

The seasonality of western Virginia's rainfall is ecologically important. For the purposes of this study, the seasons were defined as follows: Winter-December, January, February; Spring-March, April, May; Summer-June, July, August; Fall-September, October, November. These assignments are in keeping with those made in many of the articles reviewed for this study.

A summary of mean, maximum, and minimum rainfall for each season for each station and the region is presented in Table 19. An ANOVA test indicated that the regional mean rainfall in each season is significantly different from any other season ($F=33.67$, $df=3$, $p=0.0001$). The seasons are ordered (from highest mean seasonal rainfall to lowest) as: Summer, Spring, Fall, Winter. This order confirms discussions with T. Johnson (VPI&SU) in which he indicated that his informal regional review showed less rainfall (or other precipitation) in western Virginia during the winter season.

A review of individual and regional season means using a 1-sided t-test indicates that a number of stations receive mean winter rainfall that is significantly higher (Charlottesville (1.9773, $df=398$, $p<0.025$), Chatham ($t=2.279$, $df=398$, $p<0.025$), Danville ($t=1.987$, $df=398$, $p<0.025$), Farmville ($t=1.932$, $df=398$, $p<0.025$), Martinsville ($t=2.155$, $df=398$, $p<0.025$)) or significantly lower (Glen Lyn (-2.378, $df=398$, $p<0.01$), Timberville ($t=-3.054$, $df=398$, $p<0.005$), Wytheville ($t=-1.918$, $df=398$, $p<0.025$)) than the regional mean. The station distribution suggests that the location (specifically the longitude) of these sites may be a factor in winter rainfall amounts. One station has mean spring rainfall that is significantly higher (Charlottesville, $t=2.053$, $df=398$, $p<0.025$) than the regional mean. The Charlottesville station also received significantly higher ($t=2.849$, $df=398$, $p< 0.005$) summer rainfall than the regional average. One station, Charlottesville, has a significantly higher ($t=2.436$, $df=398$,

Table 19. Mean, maximum and minimum seasonal rainfall in inches for the 15 sample sites.

Station	Season[1]	Mean (SE) Rainfall	Maximum Rainfall	Minimum Rainfall
Blacksburg	Winter	8.73 (0.57)	14.57	4.32
	Spring	11.41 (0.69)	18.52	5.31
	Summer	11.03 (0.47)	16.49	6.95
	Fall	9.66 (0.61)	17.83	5.76
Buchanan	Winter	8.43 (0.52)	14.26	2.84
	Spring	10.46 (0.63)	16.46	6.16
	Summer	11.59 (0.68)	20.54	6.78
	Fall	9.90 (0.64)	17.15	4.62
Charlottesville	Winter	10.13 (0.61)	17.36	4.51
	Spring	11.87 (0.64)	19.68	6.49
	Summer	13.37 (1.00)	26.72	3.30
	Fall	11.63 (0.94)	20.49	6.37
Chatham	Winter	10.27 (0.63)	17.80	5.25
	Spring	11.75 (0.67)	18.81	7.47
	Summer	11.12 (0.67)	16.94	5.02
	Fall	10.56 (0.67)	18.66	6.56
Danville	Winter	10.15 (0.65)	17.11	4.67
	Spring	10.95 (0.61)	17.92	6.32
	Summer	11.73 (0.56)	17.54	7.69
	Fall	9.61 (0.74)	17.88	4.03
Farmville	Winter	10.10 (0.58)	17.10	4.55
	Spring	10.84 (0.65)	19.00	6.65
	Summer	11.46 (0.73)	19.53	3.78
	Fall	9.90 (0.73)	17.48	4.31
Glen Lyn	Winter	7.57 (0.42)	12.02	3.49
	Spring	9.68 (0.46)	13.58	5.43
	Summer	10.40 (0.49)	16.21	6.80
	Fall	8.22 (0.50)	13.91	4.50
Lexington	Winter	8.42 (0.49)	14.57	3.81
	Spring	9.77 (0.51)	14.60	5.27
	Summer	9.94 (0.82)	19.66	5.14
	Fall	9.31 (0.74)	19.81	3.58
Luray	Winter	8.59 (0.54)	14.14	2.85
	Spring	9.56 (0.56)	16.39	4.66
	Summer	10.89 (0.55)	16.17	5.45
	Fall	10.18 (0.80)	18.53	4.40
Lynchburg	Winter	9.09 (0.53)	15.70	4.86
	Spring	10.50 (0.67)	18.09	5.60
	Summer	11.08 (0.85)	19.22	3.97
	Fall	9.65 (0.76)	17.84	4.08

Table 19, cont. Mean, maximum and minimum seasonal rainfall in inches for the 15 sample sites.

Station	Season[1]	Mean (SE) Rainfall	Maximum Rainfall	Minimum Rainfall
Martinsville	Winter	10.25 (0.69)	18.54	4.72
	Spring	11.56 (0.54)	17.45	7.64
	Summer	11.52 (0.77)	19.17	4.84
	Fall	9.68 (0.80)	18.53	1.75
Piedmont	Winter	8.75 (0.56)	14.61	3.93
	Spring	10.80 (0.61)	17.23	5.79
	Summer	12.02 (0.72)	18.87	6.75
	Fall	10.67 (0.85)	19.52	4.68
Roanoke	Winter	8.88 (0.49)	13.79	3.32
	Spring	10.63 (0.72)	18.31	6.26
	Summer	11.11 (0.63)	16.05	5.15
	Fall	9.72 (0.70)	16.51	3.85
Timberville	Winter	7.17 (0.47)	11.99	2.64
	Spring	8.61 (0.43)	13.61	4.52
	Summer	10.36 (0.75)	17.49	3.93
	Fall	9.03 (0.64)	17.14	4.30
Wytheville	Winter	7.84 (0.41)	11.61	4.36
	Spring	10.10 (0.47)	15.00	6.21
	Summer	10.81 (0.61)	16.33	5.28
	Fall	8.74 (0.54)	14.00	3.57
Regional	Winter	8.96 (0.15)	18.54	2.64
	Spring	10.57 (0.16)	19.68	4.52
	Summer	11.23 (0.18)	26.72	3.30
	Fall	9.76 (0.19)	20.49	1.75

[1]Winter = December, January, February; Spring = March, April, May; Summer = June, July, August; Fall = September, October, November

$p < 0.01$) mean autumn rainfall than the regional mean. There does not appear to be any obvious cause to explain the higher mean spring, summer, or autumn station values.

Model Selection

I conducted an initial comprehensive investigation with all independent variables to compile a subset of variable options for each of the major category groups (mean annual, mean seasonal, mean monthly rainfall). The test variables selected were those meeting criteria defined in the "Methods" section (low C_p value, significant F-statistic, and high partial R^2).

The final models selected were those that best met the criteria for good fit described in the "Methods" section (high adjusted R^2, low PRESS statistic, low MSE, and low VIF for each variable in the model) (Table 20).

A review of the variables used in the final models shows some surprises in the variables included or not included. As noted in the "Literature Review", location and elevation were expected to be important components in the modeling of rainfall.

Latitude and/or longitude variables were found in 9 of the 17 models. However, elevation variables were found in only 3 of the final models. The distance variables WV and VB, or respective transformations, were also found in 9 of the models. Aspect was not identified in any of the final models. The predominance of coordinate and distance variables in the regression models would suggest that rainfall amounts in western Virginia are influenced by both oceanic and continental weather patterns and by site locations.

Table 20. Final regression equations selected to model mean annual rainfall, mean seasonal rainfall, and mean monthly rainfall.

Dependent Variable	Regression Model	Adjusted R^2	MSE[1]	VIF[1]
ANNUAL	$Y = 0.9(WT) - (8.56 \times 10^{-4})(LAT2) - 1693.01(RELEV) + (7.33 \times 10^{-3})(LONG2) + 113.99(RWV) + 122.42$	0.68	7075.60	8
WINTER	$Y = 0.96(WT) - 40.50(RWV) - (0.0563)(LAT) + 25.52$	0.81	584.52	1
SPRING	$Y = 0.92(WT) - (2.18 \times 10^{-4})(LAT2) - 491.67(RELEV) + (1.54 \times 10^{-3})(LONG2) + 33.97$	0.71	1020.76	7
SUMMER	$Y = 0.88(WT) + 53.66(RVB) - (3.49 \times 10^{-5})(LAT2) + 5.62$	0.49	2392.24	1
AUTUMN	$Y = 0.95(WT) - (1.72 \times 10^{-3})(VB2) - 3.92(LLONG) + 18.52$	0.75	1209.53	9
JANUARY	$Y = 0.96(WT) + 0.85(LVW) - (2.8 \times 10^{-5})(LAT2) + 2.28$	0.82	185.43	1
FEBRUARY	$Y = 0.96(WT) - (3.72 \times 10^{-5})(LAT2) + (2.08 \times 10^{-4})(LONG2) + 5.66$	0.85	145.21	9
MARCH	$Y = 0.58(WT) - (6.24 \times 10^{-5})(LAT2) - (1.15 \times 10^{-3})(VB2) + 1.18(ELEVE) + 10.59$	0.32	733.53	5
APRIL	$Y = 0.94(WT) + 0.18$	0.72	253.73	1
MAY	$Y = 0.52(WT) + 1.84$	0.21	863.50	1
JUNE	$Y = 0.62(WT) + 1.29$	0.28	970.07	1
JULY	$Y = 0.80(WT) - (3.2 \times 10^{-5})(LAT2) + 44.93(RVB) + (1.33 \times 10^{-6})(ELEV2) + 4.72$	0.35	829.08	2
AUGUST	$Y = 0.63(WT) - (1.33 \times 10^{-6})(ELEV2) + 1.58$	0.25	1145.17	1
SEPTEMBER	$Y = 0.59(WT) + 1.35$	0.28	1055.74	1
OCTOBER	$Y = 0.23(WT) - (5.14 \times 10^{-4})(VB2) + 3.32$	0.05	2011.74	1
NOVEMBER	$Y = 0.96(WT) - (1.92 \times 10^{-4})(VB2) + 0.29$	0.81	184.49	1
DECEMBER	$Y = 0.64(WT) - 0.92(LVB) - (2.52 \times 10^{-5})(LAT2) + 8.61$	0.38	714.29	1

[1]MSE = mean square error; VIF = variance inflation factor (number listed is the highest individual variable VIF)

The distance-weighting variable was found in every equation and was the most influential component of any model. As noted in the "Literature Review", this dependence on values at surrounding known locations is not unexpected (Tabios and Salas 1985).

The adjusted R^2 values of the models show that there is a wide range of variability in the model fits (Table 20). These values are below 0.50 for 9 of the models (8 monthly models, 1 seasonal model), pointing partially to the intrinsic variability of precipitation and thus meteorological data. Other factors not evaluated in this program may be influencing rainfall values.

Model Validation

Three stations within the zone of the study were used to validate the models. These stations had not previously been included in the development process and, therefore, not influenced the resulting models.

Actual values for each stations (annual, seasonal, monthly) were compared with model-calculated values using a paired t-test (Table 21). There appears to be no trend in overestimation or underestimation. Rainfall values for Station 4676 are primarily underestimated, with significant differences between actual and modeled values for 9 models. Estimated values for Station 6012 are generally overestimates of the actual rainfall values at that site. In 5 instances, this discrepancy is significant. Estimated values for Station 3470 are mixed between overestimates and underestimates of the actual values. These differences were significant in 9 models.

Table 21. Comparison of mean difference of estimated rainfall and actual rainfall, in inches, at 3 independent stations in western Virginia.

	Station 6012				Station 4676				Station 3470			
Model	Mean	S.E.	t	p	Mean	S.E.	t	p	Mean	S.E.	t	p
ANNUAL	-1.06	0.64	-1.6690	0.1081	3.45	0.79	4.3316	0.0002	11.85	0.89	13.1969	0.0001
WINTER	-0.85	0.20	-4.1763	0.0003	0.13	0.20	0.6188	0.5419	2.82	0.39	7.1340	0.0001
SPRING	-0.67	0.22	-3.0434	0.0056	1.00	0.36	2.8053	0.0098	3.34	0.42	7.8577	0.0001
SUMMER	0.05	0.38	0.2454	0.8082	1.29	0.35	3.7032	0.0011	1.16	0.66	1.7406	0.0946
AUTUMN	0.03	0.28	0.1036	0.9183	0.54	0.23	2.3501	0.0273	-0.74	0.38	-1.9406	0.0641
JANUARY	-0.47	0.09	-4.8717	0.0001	-0.31	0.19	-1.6552	0.1109	1.02	0.18	5.7604	0.0001
FEBRUARY	-0.06	0.11	-0.5787	0.5681	0.35	0.07	4.8943	0.0001	0.96	0.15	6.2798	0.0001
MARCH	-0.18	0.17	-1.0561	0.3015	0.30	0.15	2.0249	0.0546	1.05*	0.28	3.590	0.0010
APRIL	-0.11	0.13	-0.8574	0.3997	0.27*	0.12	2.2338	0.0351	0.02	0.25	0.0682	0.9462
MAY	-0.07	0.16	-0.4253	0.6744	0.21	0.19	1.1342	0.2679	-0.36	0.28	-1.2617	0.2197
JUNE	-0.33	0.23	-1.4462	0.1610	0.08	0.19	0.4216	0.6774	0.08	0.29	0.2784	0.7831
JULY	0.25	0.19	1.3051	0.2042	0.43	0.22	2.0094	0.0559	0.92*	0.37	2.4915	0.0200
AUGUST	0.12	0.22	0.5393	0.5949	0.53	0.18	2.8982	0.0079	0.13	0.47	0.2878	0.7760
SEPTEMBER	-0.89*	0.27	-3.3582	0.0026	-0.57*	0.21	-2.7086	0.0123	-1.09*	0.27	-4.1031	0.0004
OCTOBER	-0.03	0.37	-0.0927	0.9269	0.05	0.34	0.1427	0.8877	-0.38	0.43	-0.8974	0.3784
NOVEMBER	-0.10	0.16	-0.6407	0.5278	-0.03	0.10	-0.2665	0.7921	-0.31	0.18	-1.7099	0.1002
DECEMBER	1.74	0.17	10.1207	0.0001	2.06	0.14	14.4415	0.0001	2.32*	0.20	11.4583	0.0001

* N = 24; in all other instances, N = 25

A review of the combined results of these test does not indicate any clear trend in estimation capabilities. Models for May, June, October, and November estimated appropriate values for all three stations, even though R^2 values for May, June, and October are below 0.30. Models for September, December, and spring season estimated significantly different values at all three stations, even though the R^2 value for spring is a relatively high 0.71. Finally, models for March, April, July, August, summer, and autumn estimated appropriate values for 2 of the 3 stations (no trend), while models for annual, winter, January, and February estimated significantly different values at 2 of the 3 stations (no trend).

System Demonstration

VARAINS was demonstrated using 8 sites on the Havens Wildlife Management Area. Estimated values for each of these sites are displayed in Figure 16. While inputting site information, I discovered that 4 of these sites exceeded the elevation range used in model development. While the estimated values appear to correspond with other site values, these figures may misrepresent the actual values at those sites since the models have not been tested or validated for elevations outside of the study range. Sample screens from VARAINS are shown in Figure 17.

VA-Rains v1.0 06/15/93

Predicted values for 1

Annual	41.75	Jan	2.51	Jul	4.33*
		Feb	3.05	Aug	3.29*
Winter	8.30	Mar	3.93*	Sep	2.16*
Spring	11.16	Apr	3.17	Oct	3.48*
Summer	10.92*	May	3.84*	Nov	2.65
Autumn	9.41	Jun	3.36*	Dec	4.77*

* these have an R-squared value of less than 0.50

a.

VA-Rains v1.0 06/15/93

Predicted values for 2

Annual	40.76	Jan	2.50	Jul	4.01*
		Feb	3.02	Aug	3.58*
Winter	8.23	Mar	3.75*	Sep	2.16*
Spring	10.92	Apr	3.21	Oct	3.45*
Summer	10.89*	May	3.85*	Nov	2.63
Autumn	9.34	Jun	3.38*	Dec	4.76*

* these have an R-squared value of less than 0.50

b.

VA-Rains v1.0 06/15/93

Predicted values for 3

Annual	41.28	Jan	2.51	Jul	4.16*
		Feb	3.03	Aug	3.44*
Winter	8.26	Mar	3.84*	Sep	2.16*
Spring	11.06	Apr	3.19	Oct	3.46*
Summer	10.90*	May	3.85*	Nov	2.64
Autumn	9.36	Jun	3.37*	Dec	4.77*

* these have an R-squared value of less than 0.50

c.

VA-Rains v1.0 06/15/93

Predicted values for 4

Annual	42.06	Jan	2.52	Jul	4.89*
		Feb	3.02	Aug	2.70*
Winter	8.26	Mar	4.04*	Sep	2.16*
Spring	11.32	Apr	3.21	Oct	3.45*
Summer	10.89*	May	3.85*	Nov	2.63
Autumn	9.34	Jun	3.38*	Dec	4.77*

* these have an R-squared value of less than 0.50

d.

Figure 16. VARAINS output for each of the 8 sample sites located on Havens Wildlife Management Area.

VA-Rains v1.0 06/15/93

Predicted values for 5

Annual	42.16	Jan	2.51	Jul	4.68*
		Feb	3.05	Aug	2.95*
Winter	8.30	Mar	4.04*	Sep	2.16*
Spring	11.27	Apr	3.16	Oct	3.48*
Summer	10.92*	May	3.84*	Nov	2.65
Autumn	9.42	Jun	3.36*	Dec	4.77*

* these have an R-squared value of less than 0.50

e.

VA-Rains v1.0 06/15/93

Predicted values for 6

Annual	41.98	Jan	2.51	Jul	4.58*
		Feb	3.04	Aug	3.03*
Winter	8.28	Mar	4.00*	Sep	2.16*
Spring	11.24	Apr	3.18	Oct	3.47*
Summer	10.92*	May	3.85*	Nov	2.64
Autumn	9.39	Jun	3.37*	Dec	4.77*

* these have an R-squared value of less than 0.50

f.

VA-Rains v1.0 06/15/93

Predicted values for 7

Annual	41.43	Jan	2.51	Jul	4.21*
		Feb	3.04	Aug	3.40*
Winter	8.27	Mar	3.87*	Sep	2.16*
Spring	11.09	Apr	3.18	Oct	3.47*
Summer	10.91*	May	3.85*	Nov	2.64
Autumn	9.38	Jun	3.37*	Dec	4.77*

* these have an R-squared value of less than 0.50

g.

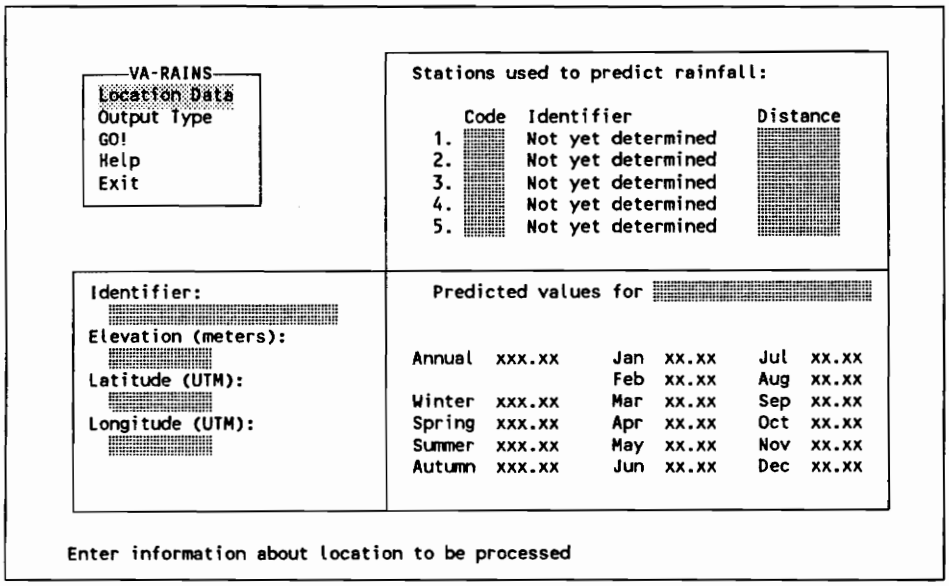
VA-Rains v1.0 06/15/93

Predicted values for 8

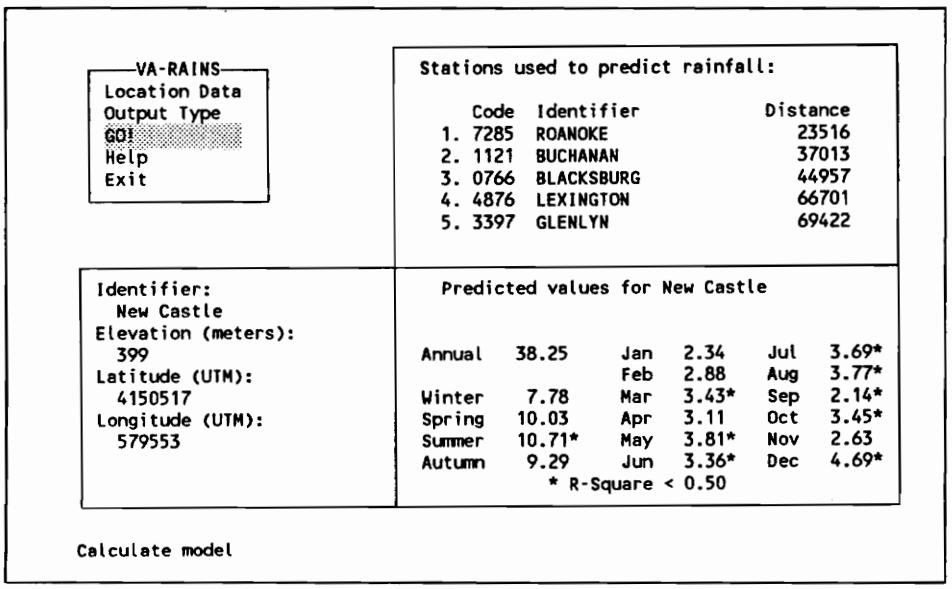
Annual	41.48	Jan	2.52	Jul	4.22*
		Feb	3.04	Aug	3.39*
Winter	8.29	Mar	3.88*	Sep	2.16*
Spring	11.11	Apr	3.19	Oct	3.46*
Summer	10.91*	May	3.85*	Nov	2.64
Autumn	9.38	Jun	3.37*	Dec	4.77*

* these have an R-squared value of less than 0.50

h.



a.



b.

Figure 17. Sample menus and screens from VARAINS.

Discussion

Review of Project Objectives

Precipitation and Ecological Interactions

> "The only certainty is that extreme events will eventually occur and for a time may completely override the effects of management on wildlife populations, perhaps requiring a reversal of management strategies. Wildlife managers should review weather records for their areas."
>
> J.A. Bailey (1984:240)

One of the primary objectives of this study was to review the effects of precipitation on wildlife and other natural resources. Such a synthesis was not feasible without first understanding climate in general, then precipitation.

Climate is generally defined as the long-term atmospheric conditions of an area. Climatic variables most often measured include temperature, precipitation, wind, and solar radiation. A variety of other descriptive weather variables can be calculated from combinations of these

four principle factors. Climatic influences on vegetation and landform have been well documented and are critical in the development of ecosystems.

Knowledge of precipitation forms, duration, intensity, and measurement techniques is also required to understand its effects on natural resources. A number of sampling stations exist in the state for capturing such information. However, most station records are incomplete and cannot accurately reflect the long-term precipitation events at those sites. Information indicating the time of measurement and type of equipment used is lacking or sporadic. Measurement bias may result from either one or a combination of these factors. Knowledge of these factors may allow some statistical control to be exercised.

Gage placement and exposure are critical for capturing accurate measurements of events. Wind plays a major role in causing gage measurement error. Inappropriated-placed or unshielded gages will often yield incorrect values.

Forage quality and quantity, animal movement and energy expenditure, and reproductive success are 3 important aspects of wildlife populations that appear to be influenced by precipitation. Extremes (typically noted as floods or droughts) can dramatically impact wildlife. Human elements of wildlife resource use, hunting pressure, use rates and hunter success, are also highly influenced by precipitation.

A majority of the literature pertaining to "weather and wildlife" focuses on short-term extreme storm events, and their immediate or short-term effects on local wildlife populations. These studies indicate that solid precipitation (snow, hail) falling for a prolonged period of time (i.e., >6-12 hours for snow) with high intensity will often remove large numbers of individuals from those affected populations.

Availability of forage is most adversely impacted by deep snow (>12 inches). Because this volume of snow is not the norm in Virginia, food availability does not appear to be influenced

significantly by precipitation. Quality and quantity of forage, especially forbs and fruit- and nut-bearing plants, can be affected by precipitation in Virginia, and should be of concern to the wildlife manager.

Most literature references to animal movement relate to the movement of individuals or groups from areas due to deep snow. Such depths are not normal in Virginia, thus precipitation-related large-scale animal movement are not expected.

Energy expenditure is another important factor that warrants the consideration of wildlife managers. Continuous evaporation of moisture off of an animal's skin, especially when combined with low temperature and wind result in high energy losses. Hibernation may be triggered in part by fall precipitation (type and amount). Avian species seem to be especially sensitive to precipitation-related energy losses during the spring season.

I believe that the most profound direct effect precipitation would have on the wildlife of Virginia is in population reproductive success. This effect does tie together some of the other factors mentioned above. Researchers have shown that individuals in poor physical condition in the spring (possibly from lack of appropriate forage, increased movement due to precipitation, or higher energy expenditure) show decreased fertility or low offspring survivability (Wallmo and Gill 1971). Avian species' reproductive success can be affected by precipitation in a variety of ways. Nests can be destroyed by heavy rainfall; nest sites can be lost; and mortality of young due to exposure can be high if rainfall is high, or if it is accompanied by low temperatures.

Estimation of species harvest can be aided by accounting for precipitation. Heavy rain during deer season, especially on opening day, could result in a lower than expected harvest (Curtis 1971). Similarly, fishing pressure is much lower during rainy periods (Neuhold and Lu 1957).

Aquatic environments are strongly influenced by climatic variables, especially precipitation. Low precipitation results in reduced flows, concentration of harmful compounds, fragmentation of habitat, increased water temperatures, lower oxygen supplies, and changes in prey availability. High precipitation causes excessive flows and cooler water temperatures, but does reoxygenate the system, and flushes concentrated compounds. These factors influence spawning success, availability of food resources, availability of appropriate cover, and general species health.

Precipitation data are also instrumental in forest management. This information can be used in determining harvest rotation schedules, stand age, species composition, and growth projections.

Finally, the wildlife area manager will find that rainfall contributes heavily to the success or failure of habitat management work. Planting times rely heavily on dry weather to allow easy sowing, followed by adequate rainfall to keep the seeds or plants moist. Excessive rainfall after planting washes seeds away or drowns seeds and seedlings. Too little rainfall after planting prevents the seed or plant from taking in water for continued development.

Modeling

Modeling has somewhat relucantly become an integrated part of most natural resource planning, research, and management activities. Many individuals in these fields continue to be frustrated by models because they expect these programs to provide concrete, definitive answers to the questions they are attempting to resolve. Indeed, it does seem that some of these individuals gain some personal satisfaction by demonstrating that a model or group of models has failed to answer a specific question.

Fortunately, there are many more individuals who have at least begun to see the utility in modeling and models. The benefits from modeling are not only specific answers to questions, but the reduction of variability in other known components. The more variability we can account for in any particular situation, the more confident we are in the final answer. For example, rainfall may not be a primary determinant of habitat quality, but it may explain part of the variance encountered in habitat and population analyses. The models developed in this study widely range in explaining rainfall amount variability. However, incorporating them with other models may reduce even further the unknown components in wildlife management practices and applications.

Model Validations

Three sites with complete periods of record within the bounds of this study were used to validate the system models. A large number of the calculated values were estimated correctly for these sites, indicating that these models appear to be valid for the region defined by the study stations. Some of the discrepancies in the remaining estimates may have been due to the relatively large distances of 2 of these sites from the 5 stations used to complete the estimations.

System Developed

I have developed the Virginia Rainfall System (VARAINS) to aid natural resource professionals to account better for an abiotic factor in their decision-making processes. The resulting estimates are designed to be planning tools, valid for another 15-20 years. System applications should be watershed or management area units; however, small changes in elevation or location (e.g., sites located less than 1 kilometer apart) will probably result in

inappreciable changes in estimates. Such minor changes are probably not biologically significant. Selected sites should be adequately spaced across an area to reflect changes in topography and boundary. The user may operate the system using a single location or by loading a file with data for multiple sites.

VARAINS has been developed in Borland Pascal (version 7) using equations calculated from SAS procedures. Several associated ASCII data files are used in developing a weight variable. This software package allows the program developer to prepare an "executable" file that allows use of the system on any microcomputer. The overall system or individual equations can be easily modified on any microcomputer supporting this software.

Eight locations on Havens Wildlife Management Area (near Salem, Virginia) were used to demonstrate the use of VARAINS. Estimates calculated for each of the points appear to be appropriate for the area, and reflect changes in precipitation with differences in site elevation and location.

System Limitations

This system has not been tested or validated outside of the bounds defined by the 15 sites originally selected. As mentioned in the "Methods" and "Results", several of the values used to select optimum regression equations identified that in at least some instances, specific models may not work well outside of the study area.

Applications to Wildlife Resource Management

One obvious use of this system is in developing data layers for use with geographic information systems (GIS). GIS software enables managers to overlay numerous types of information, visually and analytically evaluate combinations of these layers, and make informed management decisions based on these assessments. A file of data representing center points of a cellular matrix of an area would be analyzed by VARAINS, resulting in a corresponding output file that would be imported into the GIS or other similar mapping software.

Additional applications include using model outputs as independent variables in regression analyses of habitat phenomena and in ecosystem models in endangered species research. Specifically, these data could be used by managers to identify appropriate floral species for specific food plots on management areas, determine management options on property proposed for purchase, and develop potential species lists for existing or new property. As previously indicated, rainfall models may not dramatically change other models; however, any reduction of variability in the overall analyses is preferred to no change.

Future Enhancements and Research

Several obvious enhancements can be made to this system to expand its utility and usefullness to wildlife resource managers.

The addition of more stations in the associated "lookup" files would provide a greater network of sites to use with the models and may increase the certainty of the calculated values for the unknown site.

I have also identified several avenues for additional research during this project. Initially, research should be focused on testing and validating this system in other parts of Virginia, and in other mountainous areas in the eastern United States (e.g., North Carolina, Tennessee). These additional tests would furthur define the geographic area of usefullness of this system for application in resource management.

Probability of occurrence of rainfall has also been identified as an important element. Additional modeling efforts to address this issue would add a significant component to the VARAINS application.

Most of the existing literature on rainfall and temperature modeling have indicated that at least 25 years of data are required from known stations to adequately represent non-gaged areas. One potential avenue for research could be to address this issue, and determine if less information significantly modifies the regression equations and results.

Finally, I believe a concerted effort should be made to combine the results of this research with a similar study of temperature (Gruen 1993). The relationships between these two abiotic factors have already been demonstrated to be quite significant. The resulting combined model would most likely provide greater insight into the effects to these factors than either model will alone. As more information becomes available about the impacts of wind on wildlife resources, the addition of that variable into a temperature/precipitation model would provide a 3-dimensional view into the abiotic nature of a given area.

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Appendices

Appendix 1. Annual data by station

Station	Year	Annual Rainfall	No. Days Precipitation	No. Days Trace	Mean (SE) Precipitation on "Wet" Days	Mean (SE) Precipitation on All Days	Median Precipitation on "Wet" Days	Highest No. Consecutive Days Ppt.
Blacksburg 3 SE	1960	33.84	112	18	0.30 (0.03)	0.09 (0.01)	0.21	5
	1961	41.55	146	5	0.28 (0.03)	0.11 (0.01)	0.16	7
	1962	41.78	147	9	0.28 (0.03)	0.11 (0.01)	0.19	7
	1963	26.95	90	17	0.30 (0.04)	0.07 (0.01)	0.20	5
	1964	36.62	116	25	0.32 (0.04)	0.10 (0.01)	0.175	7
	1965	35.42	114	12	0.31 (0.03)	0.10 (0.01)	0.195	6
	1966	36.93	122	15	0.30 (0.04)	0.10 (0.02)	0.15	9
	1967	34.48	133	5	0.26 (0.03)	0.09 (0.01)	0.15	10
	1968	33.45	130	6	0.26 (0.03)	0.09 (0.01)	0.135	6
	1969	34.85	113	8	0.31 (0.03)	0.10 (0.01)	0.20	6
	1970	39.20	128	2	0.31 (0.03)	0.11 (0.01)	0.15	9
	1971	47.95	135	8	0.36 (0.03)	0.13 (0.01)	0.21	6
	1972	57.63	144	4	0.40 (0.04)	0.16 (0.02)	0.20	7
	1973	49.46	129	6	0.38 (0.04)	0.14 (0.02)	0.25	7
	1974	40.42	131	2	0.31 (0.03)	0.11 (0.01)	0.20	6
	1975	49.62	133	6	0.37 (0.04)	0.14 (0.02)	0.21	5
	1976	44.63	114	6	0.39 (0.05)	0.12 (0.02)	0.225	8
	1977	46.10	125	3	0.37 (0.04)	0.13 (0.02)	0.20	7
	1978	41.93	113	1	0.37 (0.04)	0.11 (0.02)	0.19	7
	1979	46.65	136	5	0.34 (0.03)	0.13 (0.02)	0.205	7
	1980	34.93	117	1	0.30 (0.03)	0.10 (0.01)	0.15	6
	1981	35.90	120	1	0.30 (0.04)	0.10 (0.01)	0.135	7
	1982	46.09	145	6	0.32 (0.03)	0.13 (0.01)	0.20	3
	1983	45.47	130	12	0.35 (0.03)	0.12 (0.01)	0.26	9
	1984	40.61	136	1	0.30 (0.03)	0.11 (0.01)	0.16	7
Buchanan	1960	35.57	101	0	0.35 (0.04)	0.10 (0.01)	0.20	9
	1961	46.14	113	0	0.41 (0.04)	0.13 (0.02)	0.25	5
	1962	43.70	115	1	0.38 (0.04)	0.12 (0.01)	0.27	5
	1963	27.96	80	0	0.35 (0.05)	0.08 (0.01)	0.17	4
	1964	34.41	91	1	0.38 (0.04)	0.09 (0.01)	0.27	7
	1965	31.81	95	0	0.33 (0.04)	0.09 (0.01)	0.18	5
	1966	40.98	99	0	0.41 (0.06)	0.11 (0.02)	0.23	9

Appendix 1, cont. Annual data by station

Station	Year	Annual Rainfall	No. Days Precipitation	No. Days Trace	Mean (SE) Precipitation on "Wet" Days	Mean (SE) Precipitation on All Days	Median Precipitation on "Wet" Days	Highest No. Consecutive Days Ppt.
Buchanan, cont.	1967	45.39	113	0	0.40 (0.05)	0.12 (0.02)	0.20	9
	1968	30.82	89	0	0.35 (0.05)	0.08 (0.01)	0.20	4
	1969	41.37	97	6	0.43 (0.05)	0.11 (0.02)	0.27	6
	1970	33.69	109	3	0.31 (0.04)	0.09 (0.01)	0.20	6
	1971	40.84	101	6	0.40 (0.05)	0.11 (0.02)	0.24	7
	1972	54.82	115	17	0.48 (0.05)	0.15 (0.02)	0.25	6
	1973	47.01	121	14	0.39 (0.05)	0.13 (0.02)	0.22	6
	1974	39.57	114	10	0.35 (0.03)	0.11 (0.01)	0.215	4
	1975	46.20	122	14	0.38 (0.04)	0.13 (0.02)	0.215	7
	1976	36.50	98	11	0.37 (0.04)	0.10 (0.01)	0.235	7
	1977	39.01	110	22	0.35 (0.04)	0.11 (0.01)	0.20	8
	1978	43.36	104	14	0.42 (0.05)	0.12 (0.02)	0.205	6
	1979	54.82	134	23	0.41 (0.05)	0.15 (0.02)	0.21	8
	1980	34.48	110	21	0.31 (0.03)	0.09 (0.01)	0.18	4
	1981	29.52	101	18	0.29 (0.03)	0.08 (0.01)	0.21	7
	1982	39.38	125	23	0.32 (0.03)	0.11 (0.01)	0.18	6
	1983	48.58	116	9	0.42 (0.04)	0.13 (0.02)	0.29	6
	1984	45.22	115	15	0.39 (0.04)	0.12 (0.02)	0.20	5
Charlottesville 2 W	1960	39.61	111	13	0.36 (0.04)	0.11 (0.01)	0.15	6
	1961	55.55	127	18	0.44 (0.07)	0.15 (0.03)	0.25	6
	1962	49.08	126	28	0.39 (0.05)	0.13 (0.02)	0.18	7
	1963	30.39	99	13	0.31 (0.04)	0.08 (0.01)	0.10	5
	1964	42.34	121	27	0.35 (0.05)	0.12 (0.02)	0.17	7
	1965	35.61	111	22	0.32 (0.04)	0.10 (0.02)	0.12	6
	1966	39.69	108	23	0.37 (0.06)	0.11 (0.02)	0.16	12
	1967	44.63	122	31	0.37 (0.05)	0.12 (0.02)	0.16	8
	1968	39.81	100	46	0.40 (0.06)	0.11 (0.02)	0.15	4
	1969	55.98	121	26	0.46 (0.06)	0. 15(0.02)	0.22	12
	1970	44.88	110	40	0.41 (0.05)	0.12 (0.02)	0.20	6
	1971	56.22	127	37	0.44 (0.06)	0.15 (0.02)	0.15	9
	1972	66.03	139	26	0.48 (0.07)	0.18 (0.03)	0.18	7

Appendix 1, cont. Annual data by station

Station	Year	Annual Rainfall	No. Days Precipitation	No. Days Trace	Mean (SE) Precipitation on "Wet" Days	Mean (SE) Precipitation on All Days	Median Precipitation on "Wet" Days	Highest No. Consecutive Days Ppt.
Charlottesville 2 W, cont.	1973	49.16	130	37	0.38 (0.04)	0.13 (0.02)	0.19	7
	1974	43.51	127	37	0.34 (0.04)	0.12 (0.02)	0.15	10
	1975	59.81	146	23	0.41 (0.05)	0.16 (0.02)	0.165	7
	1976	49.86	113	19	0.44 (0.05)	0.14 (0.02)	0.20	6
	1977	31.86	115	17	0.28 (0.03)	0.09 (0.01)	0.13	8
	1978	49.76	121	19	0.41 (0.05)	0.14 (0.02)	0.19	6
	1979	61.29	143	21	0.43 (0.06)	0.17 (0.02)	0.15	6
	1980	34.71	127	16	0.27 (0.03)	0.09 (0.01)	0.14	5
	1981	36.39	121	15	0.30 (0.04)	0.10 (0.01)	0.14	7
	1982	51.81	131	45	0.40 (0.05)	0.14 (0.02)	0.20	9
	1983	57.56	125	27	0.46 (0.05)	0.16 (0.02)	0.19	7
	1984	50.99	119	39	0.43 (0.06)	0.14 (0.02)	0.21	7
Chatham 2 NE	1960	41.45	92	19	0.45 (0.05)	0.11 (0.02)	0.34	4
	1961	51.37	129	12	0.40 (0.04)	0.14 (0.02)	0.20	6
	1962	44.65	124	15	0.36 (0.04)	0.12 (0.02)	0.18	6
	1963	33.39	97	17	0.34 (0.05)	0.09 (0.01)	0.19	5
	1964	50.15	116	14	0.43 (0.07)	0.14 (0.02)	0.175	5
	1965	41.12	109	13	0.38 (0.05)	0.11 (0.02)	0.16	4
	1966	41.92	108	9	0.39 (0.05)	0.11 (0.02)	0.18	8
	1967	42.06	113	8	0.37 (0.04)	0.12 (0.02)	0.21	7
	1968	34.19	107	15	0.32 (0.04)	0.09 (0.01)	0.17	5
	1969	39.65	116	13	0.34 (0.04)	0.11 (0.01)	0.145	6
	1970	38.94	108	17	0.36 (0.04)	0.11 (0.01)	0.22	7
	1971	45.82	117	15	0.39 (0.05)	0.13 (0.02)	0.21	8
	1972	58.91	138	11	0.43 (0.05)	0.16 (0.02)	0.19	8
	1973	41.36	125	12	0.33 (0.03)	0.11 (0.01)	0.19	10
	1974	41.63	126	8	0.33 (0.04)	0.12 (0.02)	0.17	8
	1975	52.36	138	9	0.38 (0.04)	0.14 (0.02)	0.19	7
	1976	41.31	97	5	0.43 (0.05)	0.11 (0.02)	0.25	5
	1977	38.95	115	15	0.34 (0.04)	0.11 (0.01)	0.19	7
	1978	51.10	102	12	0.50 (0.06)	0.14 (0.02)	0.255	5

Appendix 1, cont. Annual data by station

Station	Year	Annual Rainfall	No. Days Precipitation	No. Days Trace	Mean (SE) Precipitation on "Wet" Days	Mean (SE) Precipitation on All Days	Median Precipitation on "Wet" Days	Highest No. Consecutive Days Ppt.
Chatham 2 NE, cont.	1979	55.90	129	20	0.43 (0.06)	0.15 (0.02)	0.23	6
	1980	31.52	116	20	0.27 (0.03)	0.09 (0.01)	0.15	4
	1981	37.48	110	17	0.34 (0.04)	0.10 (0.01)	0.19	6
	1982	47.20	129	21	0.37 (0.04)	0.13 (0.02)	0.21	6
	1983	43.85	114	32	0.38 (0.04)	0.12 (0.02)	0.225	6
	1984	47.86	117	34	0.41 (0.05)	0.13 (0.02)	0.15	5
Danville-Bridge St.	1960	41.52	99	15	0.42 (0.05)	0.11 (0.02)	0.25	4
	1961	48.51	108	24	0.45 (0.05)	0.13 (0.02)	0.26	6
	1962	48.22	112	22	0.43 (0.04)	0.13 (0.02)	0.255	5
	1963	35.86	96	14	0.37 (0.05)	0.10 (0.02)	0.22	5
	1964	45.64	110	2	0.41 (0.06)	0.12 (0.02)	0.19	8
	1965	35.94	96	2	0.37 (0.05)	0.10 (0.02)	0.215	5
	1966	39.66	95	0	0.42 (0.06)	0.11 (0.02)	0.20	8
	1967	33.92	103	6	0.33 (0.03)	0.09 (0.01)	0.21	7
	1968	34.22	107	7	0.32 (0.04)	0.09 (0.01)	0.19	6
	1969	38.17	119	9	0.32 (0.04)	0.10 (0.01)	0.14	7
	1970	39.93	113	8	0.35 (0.04)	0.11 (0.01)	0.21	8
	1971	47.31	122	9	0.39 (0.05)	0.13 (0.02)	0.215	7
	1972	51.18	136	9	0.38 (0.04)	0.14 (0.02)	0.19	8
	1973	43.28	127	11	0.34 (0.04)	0.12 (0.02)	0.22	7
	1974	41.66	129	10	0.32 (0.04)	0.11 (0.02)	0.18	8
	1975	54.00	123	14	0.44 (0.05)	0.15 (0.02)	0.20	6
	1976	36.32	103	7	0.35 (0.04)	0.10 (0.01)	0.20	6
	1977	33.74	104	4	0.32 (0.04)	0.09 (0.01)	0.175	6
	1978	52.67	110	7	0.48 (0.06)	0.14 (0.02)	0.24	8
	1979	52.41	125	8	0.42 (0.05)	0.14 (0.02)	0.18	6
	1980	30.62	92	4	0.33 (0.05)	0.09 (0.02)	0.18	4
	1981	35.73	105	5	0.34 (0.04)	0.10 (0.01)	0.15	6
	1982	46.60	128	6	0.36 (0.04)	0.13 (0.02)	0.22	6
	1983	50.00	122	6	0.41 (0.04)	0.14 (0.02)	0.22	6
	1984	45.50	124	8	0.37 (0.05)	0.12 (0.02)	0.175	5

Appendix 1, cont. Annual data by station

Station	Year	Annual Rainfall	No. Days Precipitation	No. Days Trace	Mean (SE) Precipitation on "Wet" Days	Mean (SE) Precipitation on All Days	Median Precipitation on "Wet" Days	Highest No. Consecutive Days Ppt.
Farmville 2 N	1960	42.62	99	33	0.43 (0.05)	0.12 (0.02)	0.25	5
	1961	57.61	122	33	0.47 (0.05)	0.16 (0.02)	0.29	8
	1962	43.09	114	32	0.38 (0.04)	0.12 (0.02)	0.20	4
	1963	31.63	79	13	0.40 (0.06)	0.09 (0.02)	0.20	4
	1964	38.74	113	5	0.34 (0.04)	0.11 (0.01)	0.22	8
	1965	35.66	90	7	0.40 (0.05)	0.10 (0.01)	0.205	6
	1966	40.51	87	25	0.47 (0.06)	0.11 (0.02)	0.25	4
	1967	40.00	92	23	0.45 (0.05)	0.11 (0.02)	0.305	7
	1968	32.67	87	20	0.38 (0.06)	0.09 (0.02)	0.18	5
	1969	36.15	89	39	0.41 (0.04)	0.10 (0.01)	0.24	7
	1970	36.33	90	27	0.40 (0.04)	0.10 (0.01)	0.25	5
	1971	49.49	95	22	0.52 (0.07)	0.14 (0.02)	0.25	4
	1972	56.63	98	13	0.58 (0.09)	0.15 (0.03)	0.33	4
	1973	33.85	85	22	0.40 (0.04)	0.09 (0.01)	0.30	4
	1974	41.70	102	18	0.41 (0.05)	0.11 (0.02)	0.245	4
	1975	49.98	105	19	0.48 (0.05)	0.14 (0.02)	0.29	7
	1976	39.80	81	13	0.49 (0.06)	0.11 (0.02)	0.29	4
	1977	38.99	86	18	0.45 (0.05)	0.11 (0.02)	0.32	5
	1978	49.42	87	15	0.57 (0.06)	0.14 (0.02)	0.37	5
	1979	50.77	98	15	0.52 (0.06)	0.14 (0.02)	0.295	4
	1980	38.52	88	7	0.44 (0.05)	0.11 (0.01)	0.30	6
	1981	40.26	86	9	0.47 (0.05)	0.11 (0.02)	0.285	5
	1982	45.39	104	18	0.44 (0.04)	0.12 (0.02)	0.29	4
	1983	44.44	98	29	0.45 (0.05)	0.12 (0.02)	0.25	6
	1984	44.32	104	20	0.43 (0.05)	0.12 (0.02)	0.21	6
Glen Lyn	1960	30.36	116	32	0.26 (0.03)	0.08 (0.01)	0.085	4
	1961	40.07	144	14	0.28 (0.03)	0.11 (0.01)	0.16	3
	1962	42.10	138	14	0.31 (0.03)	0.12 (0.01)	0.14	5
	1963	27.66	109	15	0.25 (0.03)	0.08 (0.01)	0.085	5
	1964	32.52	120	14	0.27 (0.03)	0.09 (0.01)	0.12	7
	1965	33.05	103	18	0.32 (0.03)	0.09 (0.01)	0.15	4
	1966	41.02	111	2	0.37 (0.05)	0.11 (0.02)	0.20	7

Appendix 1, cont. Annual data by station

Station	Year	Annual Rainfall	No. Days Precipitation	No. Days Trace	Mean (SE) Precipitation on "Wet" Days	Mean (SE) Precipitation on All Days	Median Precipitation on "Wet" Days	Highest No. Consecutive Days Ppt.
Glen Lyn, cont.	1967	35.86	109	1	0.33 (0.03)	0.10 (0.01)	0.25	6
	1968	26.96	97	1	0.28 (0.03)	0.07 (0.01)	0.175	5
	1969	30.02	102	2	0.29 (0.03)	0.08 (0.01)	0.18	7
	1970	27.97	89	1	0.31 (0.03)	0.08 (0.01)	0.17	6
	1971	35.68	114	3	0.31 (0.03)	0.10 (0.01)	0.19	7
	1972	47.76	130	2	0.37 (0.04)	0.13 (0.02)	0.24	5
	1973	42.04	114	0	0.37 (0.04)	0.12 (0.02)	0.21	4
	1974	40.55	115	0	0.35 (0.04)	0.11 (0.01)	0.23	6
	1975	39.67	117	0	0.34 (0.03)	0.11 (0.01)	0.23	6
	1976	33.80	98	0	0.34 (0.04)	0.09 (0.01)	0.22	4
	1977	34.51	105	0	0.33 (0.03)	0.09 (0.01)	0.22	9
	1978	33.97	103	0	0.33 (0.04)	0.09 (0.01)	0.17	4
	1979	48.38	131	0	0.37 (0.04)	0.13 (0.02)	0.24	9
	1980	33.34	97	0	0.34 (0.04)	0.10 (0.01)	0.18	4
	1981	28.41	108	2	0.26 (0.03)	0.08 (0.01)	0.14	5
	1982	39.95	132	0	0.30 (0.03)	0.11 (0.01)	0.175	7
	1983	35.75	108	0	0.33 (0.03)	0.10 (0.01)	0.21	5
	1984	37.34	109	0	0.34 (0.04)	0.10 (0.01)	0.20	7
Lexington	1960	32.31	105	1	0.31 (0.03)	0.09 (0.01)	0.165	5
	1961	46.87	135	0	0.35 (0.04)	0.13 (0.02)	0.17	7
	1962	37.35	128	0	0.29 (0.03)	0.10 (0.01)	0.19	5
	1963	27.75	94	3	0.30 (0.04)	0.08 (0.01)	0.12	5
	1964	30.27	107	2	0.28 (0.03)	0.08 (0.01)	0.18	7
	1965	31.76	110	1	0.29 (0.03)	0.09 (0.01)	0.18	7
	1966	33.26	101	0	0.33 (0.04)	0.09 (0.01)	0.19	4
	1967	39.61	108	2	0.37 (0.06)	0.11 (0.02)	0.15	8
	1968	29.50	99	9	0.30 (0.05)	0.08 (0.01)	0.115	5
	1969	37.89	116	17	0.33 (0.05)	0.10 (0.02)	0.12	6
	1970	31.25	111	14	0.28 (0.03)	0.09 (0.01)	0.11	7
	1971	33.55	121	24	0.28 (0.03)	0.09 (0.01)	0.08	8
	1972	52.65	142	23	0.37 (0.05)	0.14 (0.02)	0.10	6
	1973	42.56	130	15	0.33 (0.04)	0.12 (0.02)	0.15	6

Appendix 1, cont. Annual data by station

Station	Year	Annual Rainfall	No. Days Precipitation	No. Days Trace	Mean (SE) Precipitation on "Wet" Days	Mean (SE) Precipitation on All Days	Median Precipitation on "Wet" Days	Highest No. Consecutive Days Ppt.
Lexington, cont.	1974	37.28	120	26	0.31 (0.04)	0.10 (0.01)	0.095	7
	1975	43.87	137	18	0.32 (0.03)	0.12 (0.02)	0.15	9
	1976	38.53	112	25	0.34 (0.04)	0.11 (0.02)	0.12	6
	1977	30.96	115	28	0.27 (0.03)	0.08 (0.01)	0.10	7
	1978	34.55	124	27	0.28 (0.03)	0.09 (0.01)	0.08	10
	1979	57.46	142	54	0.40 (0.05)	0.16 (0.02)	0.07	7
	1980	32.78	131	20	0.25 (0.03)	0.09 (0.01)	0.08	6
	1981	28.40	102	9	0.28 (0.03)	0.08 (0.01)	0.13	7
	1982	41.38	122	16	0.34 (0.04)	0.11 (0.01)	0.13	5
	1983	40.95	95	6	0.43 (0.04)	0.11 (0.02)	0.29	6
	1984	45.85	118	6	0.39 (0.04)	0.13 (0.02)	0.16	12
Luray 5 E	1960	38.42	117	9	0.33 (0.04)	0.10 (0.02)	0.14	6
	1961	45.68	130	5	0.35 (0.04)	0.13 (0.02)	0.24	6
	1962	39.50	117	8	0.34 (0.05)	0.11 (0.02)	0.17	6
	1963	29.66	97	11	0.31 (0.05)	0.08 (0.02)	0.13	4
	1964	35.73	114	13	0.31 (0.04)	0.10 (0.01)	0.14	8
	1965	28.30	114	9	0.25 (0.03)	0.08 (0.01)	0.14	6
	1966	40.41	107	7	0.38 (0.04)	0.11 (0.02)	0.18	10
	1967	38.99	119	16	0.33 (0.04)	0.11 (0.01)	0.18	6
	1968	35.43	102	10	0.35 (0.06)	0.10 (0.02)	0.145	5
	1969	40.47	115	16	0.35 (0.04)	0.11 (0.02)	0.13	8
	1970	35.33	105	17	0.34 (0.04)	0.10 (0.01)	0.18	7
	1971	44.32	116	12	0.38 (0.05)	0.12 (0.02)	0.22	7
	1972	58.17	136	20	0.43 (0.07)	0.16 (0.03)	0.185	6
	1973	39.54	125	12	0.32 (0.04)	0.11 (0.02)	0.14	5
	1974	33.83	135	3	0.25 (0.04)	0.09 (0.01)	0.10	4
	1975	39.30	128	13	0.31 (0.03)	0.11 (0.01)	0.175	8
	1976	34.03	93	5	0.37 (0.05)	0.10 (0.02)	0.16	6
	1977	35.32	115	5	0.31 (0.04)	0.10 (0.01)	0.11	8
	1978	42.34	101	3	0.42 (0.05)	0.12 (0.02)	0.20	4

Appendix 1, cont. Annual data by station

Station	Year	Annual Rainfall	No. Days Precipitation	No. Days Trace	Mean (SE) Precipitation on "Wet" Days	Mean (SE) Precipitation on All Days	Median Precipitation on "Wet" Days	Highest No. Consecutive Days Ppt.
Luray 5 E, cont.	1979	50.91	110	6	0.46 (0.06)	0.14 (0.02)	0.265	5
	1980	32.82	93	10	0.35 (0.03)	0.09 (0.01)	0.23	5
	1981	32.38	121	9	0.27 (0.03)	0.09 (0.01)	0.13	6
	1982	40.33	125	7	0.32 (0.03)	0.11 (0.01)	0.21	5
	1983	49.07	107	10	0.46 (0.05)	0.13 (0.02)	0.23	6
	1984	40.73	107	6	0.38 (0.05)	0.11 (0.02)	0.17	5
Lynchburg WSO AP	1960	35.91	113	40	0.32 (0.04)	0.10 (0.02)	0.15	5
	1961	44.69	132	32	0.34 (0.04)	0.12 (0.02)	0.185	6
	1962	39.62	120	46	0.33 (0.03)	0.11 (0.01)	0.225	4
	1963	26.56	93	49	0.29 (0.04)	0.07 (0.01)	0.15	4
	1964	33.77	107	48	0.32 (0.04)	0.09 (0.01)	0.16	5
	1965	28.28	100	47	0.28 (0.04)	0.08 (0.01)	0.11	4
	1966	37.38	106	40	0.35 (0.05)	0.10 (0.02)	0.15	5
	1967	41.51	107	36	0.39 (0.05)	0.11 (0.02)	0.23	7
	1968	28.42	99	35	0.29 (0.04)	0.08 (0.01)	0.16	4
	1969	33.89	113	34	0.30 (0.03)	0.09 (0.01)	0.16	7
	1970	32.87	109	26	0.30 (0.04)	0.09 (0.01)	0.15	7
	1971	44.27	127	34	0.35 (0.04)	0.12 (0.02)	0.17	7
	1972	59.71	136	33	0.44 (0.06)	0.16 (0.03)	0.22	8
	1973	50.73	115	29	0.44 (0.05)	0.14 (0.02)	0.28	5
	1974	36.36	121	22	0.30 (0.04)	0.11 (0.02)	0.14	8
	1975	55.60	138	22	0.40 (0.04)	0.15 (0.02)	0.23	9
	1976	44.72	103	23	0.43 (0.05)	0.12 (0.02)	0.21	6
	1977	38.70	116	23	0.33 (0.04)	0.11 (0.01)	0.16	8
	1978	44.59	127	25	0.35 (0.05)	0.12 (0.02)	0.14	6
	1979	52.28	134	29	0.39 (0.05)	0.14 (0.02)	0.145	8
	1980	30.90	104	27	0.30 (0.03)	0.08 (0.01)	0.215	4
	1981	35.92	102	17	0.35 (0.04)	0.10 (0.01)	0.185	6
	1982	41.59	128	15	0.32 (0.03)	0.11 (0.01)	0.22	11
	1983	42.46	111	14	0.38 (0.04)	0.12 (0.02)	0.17	5
	1984	49.21	114	24	0.43 (0.06)	0.13 (0.02)	0.165	5

Appendix 1, cont. Annual data by station

Station	Year	Annual Rainfall	No. Days Precipitation	No. Days Trace	Mean (SE) Precipitation on "Wet" Days	Mean (SE) Precipitation on All Days	Median Precipitation on "Wet" Days	Highest No. Consecutive Days Ppt.
Martinsville Filt. Plant	1960	40.40	107	22	0.38 (0.04)	0.11 (0.02)	0.16	6
	1961	46.08	120	16	0.38 (0.04)	0.13 (0.02)	0.205	5
	1962	48.37	124	19	0.39 (0.04)	0.13 (0.02)	0.22	7
	1963	33.03	87	14	0.38 (0.05)	0.09 (0.02)	0.20	5
	1964	51.66	114	15	0.45 (0.07)	0.14 (0.02)	0.24	8
	1965	37.83	114	12	0.33 (0.04)	0.10 (0.01)	0.175	6
	1966	38.52	102	18	0.38 (0.05)	0.11 (0.02)	0.16	8
	1967	37.03	103	19	0.36 (0.05)	0.10 (0.02)	0.21	7
	1968	43.70	114	16	0.38 (0.05)	0.12 (0.02)	0.24	6
	1969	43.62	122	7	0.36 (0.04)	0.12 (0.02)	0.16	6
	1970	41.17	97	13	0.42 (0.05)	0.11 (0.02)	0.25	7
	1971	43.71	100	15	0.44 (0.05)	0.12 (0.02)	0.23	6
	1972	58.56	116	3	0.50 (0.06)	0.17 (0.02)	0.265	8
	1973	52.17	116	2	0.45 (0.04)	0.14 (0.02)	0.25	7
	1974	46.29	107	10	0.43 (0.05)	0.13 (0.02)	0.26	6
	1975	32.06	80	4	0.40 (0.05)	0.13 (0.02)	0.215	8
	1976	42.90	96	5	0.45 (0.06)	0.11 (0.02)	0.30	7
	1977	37.88	105	2	0.36 (0.04)	0.10 (0.01)	0.22	7
	1978	46.86	93	9	0.50 (0.07)	0.14 (0.02)	0.35	6
	1979	53.41	122	12	0.44 (0.06)	0.16 (0.03)	0.20	6
	1980	32.45	97	17	0.33 (0.05)	0.10 (0.02)	0.18	5
	1981	33.63	99	11	0.34 (0.04)	0.09 (0.01)	0.24	8
	1982	42.58	119	17	0.36 (0.04)	0.12 (0.02)	0.20	6
	1983	51.22	106	11	0.48 (0.05)	0.14 (0.02)	0.275	7
	1984	41.55	122	10	0.34 (0.04)	0.11 (0.02)	0.15	8
Piedmont Res. Sta.	1960	36.13	108	15	0.33 (0.04)	0.10 (0.01)	0.12	5
	1961	44.57	127	17	0.35 (0.05)	0.12 (0.02)	0.18	9
	1962	41.79	126	10	0.33 (0.04)	0.11 (0.02)	0.15	8
	1963	30.37	86	9	0.35 (0.06)	0.08 (0.02)	0.135	4
	1964	34.11	106	10	0.32 (0.03)	0.09 (0.01)	0.215	6
	1965	32.48	102	6	0.32 (0.05)	0.09 (0.01)	0.125	6
	1966	43.55	114	5	0.38 (0.05)	0.12 (0.02)	0.185	12

Appendix 1, cont. Annual data by station

Station	Year	Annual Rainfall	No. Days Precipitation	No. Days Trace	Mean (SE) Precipitation on "Wet" Days	Mean (SE) Precipitation on All Days	Median Precipitation on "Wet" Days	Highest No. Consecutive Days Ppt.
Piedmont Res. Sta., cont.	1967	41.46	107	7	0.39 (0.05)	0.11 (0.02)	0.13	8
	1968	38.17	102	8	0.37 (0.05)	0.10 (0.02)	0.145	5
	1969	39.09	104	7	0.38 (0.05)	0.11 (0.02)	0.175	7
	1970	35.04	111	5	0.32 (0.04)	0.10 (0.01)	0.16	7
	1971	54.11	127	8	0.43 (0.06)	0.15 (0.02)	0.14	8
	1972	59.69	145	1	0.41 (0.07)	0.16 (0.03)	0.18	10
	1973	47.46	130	1	0.37 (0.05)	0.13 (0.02)	0.15	6
	1974	40.42	134	2	0.30 (0.03)	0.11 (0.01)	0.13	8
	1975	52.40	142	1	0.37 (0.04)	0.14 (0.02)	0.15	8
	1976	42.81	117	2	0.37 (0.05)	0.12 (0.02)	0.17	6
	1977	33.56	106	2	0.32 (0.04)	0.09 (0.01)	0.185	7
	1978	45.04	120	0	0.38 (0.05)	0.12 (0.02)	0.17	9
	1979	57.86	133	3	0.44 (0.05)	0.16 (0.02)	0.23	7
	1980	31.37	109	0	0.29 (0.03)	0.09 (0.01)	0.15	5
	1981	34.77	115	0	0.30 (0.04)	0.10 (0.01)	0.16	9
	1982	43.79	123	0	0.36 (0.04)	0.12 (0.02)	0.18	6
	1983	50.34	116	2	0.43 (0.05)	0.14 (0.02)	0.20	7
	1984	47.16	109	4	0.43 (0.05)	0.13 (0.02)	0.23	6
Roanoke WSO AP	1960	38.95	115	72	0.34 (0.04)	0.11 (0.02)	0.15	6
	1961	40.81	132	64	0.31 (0.03)	0.11 (0.01)	0.155	5
	1962	41.22	128	48	0.32 (0.04)	0.11 (0.01)	0.195	7
	1963	25.67	87	56	0.30 (0.03)	0.07 (0.01)	0.20	4
	1964	37.87	116	47	0.33 (0.04)	0.10 (0.02)	0.155	8
	1965	31.72	106	52	0.30 (0.04)	0.09 (0.01)	0.12	5
	1966	41.09	106	49	0.39 (0.05)	0.11 (0.02)	0.235	9
	1967	37.83	117	36	0.32 (0.04)	0.10 (0.01)	0.17	8
	1968	35.08	112	49	0.31 (0.05)	0.10 (0.02)	0.115	6
	1969	38.59	127	46	0.30 (0.04)	0.11 (0.01)	0.15	7
	1970	40.46	120	45	0.34 (0.05)	0.11 (0.02)	0.15	7
	1971	46.83	133	45	0.35 (0.04)	0.13 (0.02)	0.17	10

Appendix 1, cont. Annual data by station

Station	Year	Annual Rainfall	No. Days Precipitation	No. Days Trace	Mean (SE) Precipitation on "Wet" Days	Mean (SE) Precipitation on All Days	Median Precipitation on "Wet" Days	Highest No. Consecutive Days Ppt.
Roanoke WSO AP, cont.	1972	51.64	132	59	0.39 (0.04)	0.14 (0.02)	0.195	6
	1973	48.04	125	52	0.38 (0.04)	0.13 (0.02)	0.28	4
	1974	34.02	126	45	0.27 (0.03)	0.09 (0.01)	0.145	7
	1975	50.41	133	43	0.38 (0.04)	0.14 (0.02)	0.22	5
	1976	40.01	103	51	0.39 (0.06)	0.11 (0.02)	0.18	7
	1977	31.33	115	48	0.27 (0.03)	0.09 (0.01)	0.13	7
	1978	45.29	115	51	0.39 (0.06)	0.12 (0.02)	0.17	5
	1979	51.42	141	44	0.36 (0.04)	0.14 (0.02)	0.16	8
	1980	34.55	112	44	0.31 (0.03)	0.09 (0.01)	0.17	6
	1981	30.89	98	52	0.32 (0.04)	0.08 (0.01)	0.175	7
	1982	44.83	127	40	0.35 (0.04)	0.12 (0.02)	0.20	8
	1983	48.33	100	49	0.48 (0.05)	0.13 (0.02)	0.325	5
	1984	43.63	114	43	0.38 (0.05)	0.12 (0.02)	0.185	5
Timberville 3 E	1960	32.66	104	10	0.31 (0.04)	0.09 (0.01)	0.18	3
	1961	39.24	123	7	0.32 (0.03)	0.11 (0.01)	0.20	7
	1962	36.64	112	5	0.33 (0.03)	0.10 (0.01)	0.20	4
	1963	26.32	79	13	0.33 (0.05)	0.07 (0.01)	0.16	3
	1964	29.39	95	7	0.31 (0.03)	0.08 (0.01)	0.18	7
	1965	27.13	92	12	0.29 (0.04)	0.07 (0.01)	0.18	6
	1966	35.36	102	22	0.35 (0.05)	0.10 (0.02)	0.185	7
	1967	40.04	118	45	0.34 (0.05)	0.11 (0.02)	0.135	7
	1968	35.12	108	40	0.33 (0.04)	0.10 (0.01)	0.145	4
	1969	37.89	120	37	0.32 (0.03)	0.10 (0.01)	0.16	7
	1970	37.15	120	44	0.31 (0.03)	0.10 (0.01)	0.18	6
	1971	33.78	120	51	0.28 (0.04)	0.09 (0.01)	0.11	5
	1972	49.11	138	49	0.36 (0.05)	0.13 (0.02)	0.13	6
	1973	37.07	134	42	0.28 (0.03)	0.10 (0.01)	0.14	6
	1974	31.04	122	59	0.25 (0.04)	0.09 (0.01)	0.13	7
	1975	38.64	133	45	0.29 (0.04)	0.11 (0.01)	0.13	8
	1976	32.88	111	30	0.30 (0.04)	0.09 (0.02)	0.13	5
	1977	27.67	107	41	0.26 (0.03)	0.08 (0.01)	0.12	8
	1978	32.71	109	36	0.30 (0.04)	0.10 (0.01)	0.15	5

Appendix 1, cont. Annual data by station

Station	Year	Annual Rainfall	No. Days Precipitation	No. Days Trace	Mean (SE) Precipitation on "Wet" Days	Mean (SE) Precipitation on All Days	Median Precipitation on "Wet" Days	Highest No. Consecutive Days Ppt.
Timberville 3 E, cont.	1979	43.91	132	36	0.33 (0.04)	0.12 (0.02)	0.145	7
	1980	29.56	133	27	0.22 (0.03)	0.08 (0.01)	0.10	5
	1981	28.99	116	31	0.25 (0.03)	0.08 (0.01)	0.135	8
	1982	42.11	131	28	0.32 (0.04)	0.12 (0.02)	0.13	6
	1983	37.87	111	25	0.34 (0.04)	0.10 (0.02)	0.16	7
	1984	38.36	122	49	0.31 (0.04)	0.10 (0.02)	0.115	7
Wytheville 1 S	1960	36.26	98	4	0.37 (0.04)	0.10 (0.01)	0.20	4
	1961	44.83	110	7	0.41 (0.04)	0.12 (0.02)	0.25	3
	1962	38.76	110	4	0.35 (0.04)	0.11 (0.02)	0.20	6
	1963	25.82	91	4	0.28 (0.03)	0.07 (0.01)	0.17	5
	1964	41.84	97	5	0.43 (0.07)	0.11 (0.02)	0.22	7
	1965	32.26	86	5	0.38 (0.04)	0.09 (0.01)	0.265	4
	1966	41.45	103	3	0.40 (0.05)	0.11 (0.02)	0.25	5
	1967	34.63	99	0	0.35 (0.03)	0.09 (0.01)	0.25	8
	1968	34.36	100	1	0.34 (0.04)	0.09 (0.01)	0.19	5
	1969	33.55	101	1	0.33 (0.03)	0.09 (0.01)	0.25	5
	1970	32.94	105	1	0.31 (0.04)	0.09 (0.01)	0.18	7
	1971	38.49	106	0	0.36 (0.04)	0.11 (0.01)	0.24	7
	1972	44.64	120	2	0.37 (0.04)	0.12 (0.02)	0.22	7
	1973	40.91	125	3	0.33 (0.04)	0.11 (0.01)	0.18	6
	1974	37.21	131	14	0.28 (0.03)	0.10 (0.01)	0.16	6
	1975	38.45	134	5	0.29 (0.03)	0.11 (0.01)	0.125	7
	1976	34.15	108	4	0.32 (0.04)	0.09 (0.01)	0.17	6
	1977	37.50	126	7	0.30 (0.04)	0.10 (0.02)	0.14	8
	1978	37.33	107	13	0.35 (0.05)	0.10 (0.02)	0.17	5
	1979	46.31	135	14	0.34 (0.04)	0.13 (0.02)	0.17	6
	1980	33.43	113	11	0.30 (0.04)	0.09 (0.01)	0.14	4
	1981	33.04	116	17	0.28 (0.03)	0.09 (0.01)	0.135	5
	1982	44.39	140	14	0.32 (0.03)	0.12 (0.01)	0.21	8
	1983	37.67	118	17	0.32 (0.03)	0.10 (0.01)	0.23	5
	1984	38.68	117	14	0.33 (0.04)	0.11 (0.01)	0.18	5

Appendix 2. Monthly summary statistics by station

Station	Month	Mean (SE) Monthly Rainfall (in)	Mean (SE) No. Days Rainfall	Mean (SE) No. Days Trace	Maximum Monthly Rainfall (in)	Minimum Monthly Rainfall (in)	Median Monthly Rainfall (in)
Blacksburg 3 SE	January	2.82(0.23)	10.2 (0.5)	1.9 (0.3)	4.62	0.60	2.93
	February	3.01(0.32)	9.5 (0.6)	2.1 (0.6)	6.28	0.36	3.30
	March	3.79(0.31)	11.7 (0.5)	1.8 (0.3)	8.33	1.34	3.83
	April	3.63(0.31)	11.4 (0.8)	1.3 (0.2)	6.77	1.07	3.14
	May	3.98(0.38)	12.2 (0.7)	1.5 (0.2)	9.75	0.92	3.72
	June	3.50(0.38)	11.0 (0.7)	1.4 (0.3)	8.66	0.39	3.33
	July	3.89(0.30)	13.0 (0.5)	1.4 (0.2)	7.25	1.88	3.58
	August	3.63(0.25)	10.7 (0.5)	1.3 (0.2)	6.36	1.55	3.67
	September	3.31(0.33)	8.7 (0.6)	1.7 (0.4)	6.31	0.96	3.03
	October	3.68(0.38)	8.9 (0.6)	1.0 (0.0)	9.14	0.12	3.52
	November	2.66(0.30)	9.2 (0.6)	1.5 (0.3)	7.41	0.49	2.37
	December	2.97(0.32)	10.0 (0.6)	2.0 (0.3)	6.03	0.18	2.51
Buchanan	January	2.78(0.31)	8.9 (0.5)	2.0 (0.3)	6.77	0.00	2.585
	February	2.98(0.33)	8.3 (0.5)	1.9 (0.3)	6.44	0.15	3.47
	March	3.57(0.30)	9.7 (0.7)	2.0 (0.3)	7.60	1.35	3.37
	April	3.00(0.28)	9.2 (0.7)	2.1 (0.5)	7.12	0.60	2.45
	May	3.89(0.31)	10.8 (0.6)	1.7 (0.4)	7.67	1.73	3.55
	June	3.37(0.35)	9.1 (0.6)	2.5 (0.5)	8.80	0.75	3.09
	July	4.15(0.28)	11.1 (0.6)	1.5 (0.2)	7.65	1.91	4.51
	August	4.07(0.51)	9.5 (0.5)	1.5 (0.3)	10.47	0.85	3.47
	September	3.18(0.40)	7.2 (0.5)	1.2 (0.1)	8.80	0.36	2.69
	October	3.83(0.34)	7.9 (0.5)	1.9 (0.6)	7.52	0.27	3.79
	November	2.89(0.31)	8.8 (0.6)	1.9 (0.4)	6.04	0.62	2.46
	December	2.84(0.34)	4.5 (0.6)	2.1 (0.3)	6.30	0.26	2.64
Charlottesville 2 W	January	3.24(0.40)	10.0 (0.5)	2.1 (0.2)	9.70	0.21	2.98
	February	3.59(0.38)	9.4 (0.6)	1.9 (0.2)	6.37	0.20	3.64
	March	3.97(0.33)	10.8 (0.6)	2.8 (0.2)	7.91	1.10	3.45
	April	3.33(0.38)	10.0 (0.6)	2.6 (0.4)	9.82	0.89	2.94
	May	4.57(0.36)	11.9 (0.5)	2.5 (0.3)	10.53	1.47	4.41
	June	3.75(0.59)	9.2 (0.6)	2.7 (0.3)	12.81	0.44	2.75
	July	4.81(0.51)	12.8 (0.6)	2.6 (0.5)	9.93	1.14	4.81
	August	4.81(0.48)	10.8 (0.6)	2.7 (0.4)	10.49	0.98	4.46
	September	3.93(0.58)	9.3 (0.6)	2.3 (0.2)	11.81	0.88	2.81
	October	4.52(0.64)	8.6 (0.6)	2.7 (0.4)	12.70	0.18	3.80

Appendix 2, cont. Monthly summary statistics by station

Station	Month	Mean (SE) Monthly Rainfall (in)	Mean (SE) No. Days Rainfall	Mean (SE) No. Days Trace	Maximum Monthly Rainfall (in)	Minimum Monthly Rainfall (in)	Median Monthly Rainfall (in)
Charlottesville 2 W, cont.	November	3.17(0.42)	9.2 (0.6)	2.4 (0.3)	8.73	0.79	2.45
	December	3.37(0.41)	9.5 (0.6)	3.1 (0.5)	7.42	0.37	2.88
Chatham 2 NE	January	3.39(0.35)	10.5 (0.5)	2.2 (0.3)	7.55	0.55	3.00
	February	3.59(0.33)	9.1 (0.6)	1.6 (0.2)	6.26	0.31	3.31
	March	4.28(0.44)	11.0 (0.6)	2.0 (0.2)	11.76	1.48	4.06
	April	3.38(0.35)	9.7 (0.6)	2.4 (0.3)	7.80	0.00	3.07
	May	4.22(0.39)	11.3 (0.6)	1.9 (0.3)	10.73	1.98	3.72
	June	3.33(0.36)	9.8 (0.7)	1.7 (0.2)	8.19	0.92	2.82
	July	4.04(0.37)	11.3 (0.7)	1.7 (0.2)	7.90	0.51	3.87
	August	3.75(0.48)	9.5 (0.6)	1.9 (0.3)	8.69	0.30	2.62
	September	3.79(0.47)	8.1 (0.6)	1.3 (0.1)	10.81	0.49	3.46
	October	3.71(0.44)	8.1 (0.6)	2.1 (0.3)	10.18	0.48	3.67
	November	3.06(0.36)	8.4 (0.6)	1.9 (0.2)	7.49	0.80	2.40
	December	3.36(0.38)	9.3 (0.6)	2.0 (0.2)	7.53	0.37	3.31
Danville-Bridge St.	January	3.43(0.37)	10.4 (0.6)	1.3 (0.2)	8.73	0.72	3.04
	February	3.50(0.31)	9.0 (0.5)	2.1 (0.3)	6.38	0.41	3.55
	March	4.08(0.43)	10.6 (0.6)	1.9 (0.5)	10.44	1.32	3.22
	April	3.14(0.32)	9.5 (0.5)	1.8 (0.4)	7.70	0.82	2.80
	May	3.74(0.26)	10.8 (0.6)	1.6 (0.4)	7.54	1.77	3.59
	June	3.70(0.40)	9.2 (0.6)	1.5 (0.2)	8.15	1.24	3.13
	July	4.20(0.38)	11.1 (0.6)	1.3 (0.2)	8.81	1.60	3.84
	August	3.83(0.33)	9.6 (0.6)	1.7 (0.3)	7.49	0.86	3.70
	September	3.54(0.43)	7.3 (0.6)	1.2 (0.1)	9.00	0.40	3.44
	October	3.39(0.40)	7.4 (0.7)	1.7 (0.4)	7.47	0.48	3.355
	November	2.81(0.32)	8.6 (0.6)	1.2 (0.1)	7.04	0.72	2.14
	December	3.28(0.37)	9.2 (0.7)	1.7 (0.2)	6.42	0.18	3.39
Farmville 2 N	January	3.47(0.37)	8.4 (0.6)	2.8 (0.4)	8.16	0.90	2.70
	February	3.42(0.33)	7.8 (0.6)	2.5 (0.4)	6.74	0.63	3.34
	March	4.01(0.35)	8.9 (0.4)	2.7 (0.4)	8.31	0.93	3.95
	April	2.85(0.28)	8.3 (0.6)	2.3 (0.4)	7.21	0.00	2.815
	May	4.10(0.36)	9.2 (0.5)	2.3 (0.4)	8.74	1.39	3.69
	June	3.46(0.48)	7.5 (0.5)	1.9 (0.2)	9.04	0.87	2.37
	July	4.38(0.40)	8.9 (0.7)	2.8 (0.5)	7.79	1.28	3.92

Appendix 2, cont. Monthly summary statistics by station

Station	Month	Mean (SE) Monthly Rainfall (in)	Mean (SE) No. Days Rainfall	Mean (SE) No. Days Trace	Maximum Monthly Rainfall (in)	Minimum Monthly Rainfall (in)	Median Monthly Rainfall (in)
Farmville 2 N, cont.	August	3.62(0.45)	8.3 (0.6)	2.1 (0.4)	7.25	0.36	3.14
	September	3.16(0.39)	6.9 (0.5)	1.5 (0.2)	8.35	0.56	2.59
	October	3.83(0.59)	7.0 (0.5)	2.0 (0.3)	12.17	0.26	3.50
	November	2.91(0.35)	7.0 (0.5)	2.2 (0.3)	6.31	0.77	2.62
	December	3.29(0.38)	7.4 (0.6)	2.1 (0.3)	8.00	0.31	3.28
Glen Lyn	January	2.29(0.25)	8.9 (0.7)	3.0 (0.5)	4.54	0.36	2.20
	February	2.71(0.27)	8.8 (0.6)	2.7 (0.8)	5.19	0.03	2.71
	March	3.11(0.26)	10.2 (0.5)	2.1 (0.7)	6.08	0.77	2.97
	April	3.00(0.25)	10.1 (0.7)	1.9 (0.3)	4.91	0.63	3.25
	May	3.72(0.31)	11.7 (0.6)	1.0 (0.0)	7.43	1.00	3.32
	June	3.33(0.30)	9.4 (0.6)	1.0 (0.0)	7.32	0.92	3.15
	July	3.87(0.32)	11.5 (0.6)	1.0 (0.0)	8.98	1.87	3.57
	August	3.20(0.27)	9.5 (0.4)	1.5 (0.5)	5.81	1.79	2.78
	September	2.88(0.31)	7.6 (0.6)	1.3 (0.3)	7.56	0.60	2.80
	October	2.84(0.29)	7.9 (0.5)	1.0 (0.0)	6.70	0.08	2.54
	November	2.49(0.23)	8.7 (0.6)	2.0 (0.4)	4.72	0.82	2.29
	December	2.66(0.28)	9.0 (0.6)	2.9 (1.1)	5.05	0.13	2.72
Lexington	January	2.56(0.30)	9.6 (0.6)	3.1 (0.6)	6.31	0.28	2.21
	February	2.99(0.32)	9.1 (0.6)	1.9 (0.3)	5.75	0.36	3.00
	March	3.51(0.31)	10.5 (0.6)	2.1 (0.3)	6.18	0.57	3.37
	April	2.77(0.27)	9.8 (0.6)	2.4 (0.4)	6.01	0.69	2.50
	May	3.50(0.29)	11.7 (0.5)	2.3 (0.4)	6.83	1.10	3.69
	June	3.29(0.38)	10.0 (0.5)	2.0 (0.3)	9.12	1.41	2.65
	July	3.53(0.38)	10.9 (0.7)	2.7 (0.4)	8.61	0.80	3.50
	August	3.12(0.46)	10.8 (0.6)	2.1 (0.4)	9.87	0.93	2.56
	September	3.11(0.41)	8.6 (0.7)	2.2 (0.3)	8.88	0.34	2.58
	October	3.49(0.43)	7.9 (0.7)	2.1 (0.4)	9.78	0.30	3.21
	November	2.71(0.30)	8.7 (0.6)	2.4 (0.4)	5.45	0.74	2.53
	December	2.97(0.33)	9.5 (0.6)	2.1 (0.4)	6.87	0.28	2.83
Luray 5 E	January	2.83(0.37)	8.8 (0.5)	1.5 (0.2)	7.79	0.21	2.31
	February	2.92(0.42)	8.5 (0.6)	1.6 (0.2)	6.97	0.08	2.27
	March	3.11(0.34)	9.8 (0.5)	2.4 (0.3)	7.38	1.07	2.44
	April	2.94(0.32)	10.3 (0.7)	2.2 (0.4)	7.12	0.71	2.72

Appendix 2, cont. Monthly summary statistics by station

Station	Month	Mean (SE) Monthly Rainfall (in)	Mean (SE) No. Days Rainfall	Mean (SE) No. Days Trace	Maximum Monthly Rainfall (in)	Minimum Monthly Rainfall (in)	Median Monthly Rainfall (in)
Timberville 3 E, cont.	November	2.51(0.27)	8.6 (0.6)	3.2 (0.4)	5.53	0.34	2.44
	December	2.46(0.29)	9.2 (0.6)	3.5 (0.4)	5.60	0.27	2.48
Wytheville 1 S	January	2.46(0.21)	9.4 (0.6)	2.6 (0.3)	4.71	0.89	2.36
	February	2.82(0.29)	8.9 (0.5)	1.8 (0.2)	5.70	0.25	3.12
	March	3.21(0.24)	10.2 (0.5)	1.5 (0.2)	6.47	1.31	2.92
	April	3.10(0.29)	9.8 (0.6)	1.1 (0.1)	5.99	0.42	2.89
	May	3.79(0.32)	11.2 (0.6)	1.6 (0.3)	7.13	1.21	3.28
	June	3.24(0.30)	9.7 (0.7)	1.0 (0.0)	6.07	0.92	3.02
	July	4.48(0.33)	10.6 (0.5)	1.1 (0.1)	8.49	1.32	4.27
	August	3.10(0.38)	9.5 (0.4)	1.2 (0.2)	7.97	1.04	2.52
	September	2.86(0.31)	8.1 (0.6)	1.2 (0.2)	6.09	0.11	2.97
	October	3.41(0.33)	7.9 (0.6)	1.2 (0.2)	6.87	0.05	3.07
	November	2.47(0.23)	8.3 (0.6)	2.1 (0.3)	4.74	0.64	2.29
	December	2.63(0.30)	8.4 (0.5)	1.4 (0.2)	5.15	0.10	2.06

Appendix 3. VARAINS system program listing.

```
Program VARains;

{ This program implements a Rainfall prediction model developed by
  Rebecca K. Wajda in partial fullfillment of the requirements for a
  Masters Degree in Wildlife Sciences from Virginia Polytechnic Institute
  and State University.

  The Model predicts the rainfall for a specific point given the following
  information for that point:
     Elevation
     Lat/Long Coordinates

  Rainfall predictions are available for the following time periods:
     Annual
     Seasonal
     Monthly

  This program is written using Turbo Pascal v7.0 and utilizes the software
  library "Turbo Professional" by Turbo Power Software.  The remaining code
  was written by George A. Heitman, Jr, and Rebecca K. Wajda.}

{$N+,E+}  { Use Numeric Processor if possible }
uses
  TPString,  { These are the Turbo Power units }
  TPCrt,
  TPCmd,
  TPWindow,
  TPEdit,
  TPMenu,
  TPHelp;


const
   NumberOfStations = 15;             { Number of control stations   }
   IDLength         = 21;             { Length of station identifier }
   StationFileName  = 'RainData.sum'; { File of control station data }

   MinElevation     = 124;            { Elevation limits             }
   MaxElevation     = 742;

   MinLat           = 4049665;        { Latituse limits              }
   MaxLat           = 4282828;

   MinLon           = 492579;         { Longitude limits             }
   MaxLon           = 752435;

   YearCount        = 25;             { number of years of control data }

   { Dsplay color constants }
   OurHelpColorAttr : HelpColorArray = ($1D, $1B, $5F, $5F, $3F, $1E, $1F, $1B);
   OurHelpMonocAttr : HelpColorArray = ($0F, $07, $70, $70, $09, $0F, $0F, $0F);


type
   LocationRecord = record          { individual location variable type }
                      Code       : word;             { station ID }
                      Identifier : string[IDLength]; { name       }
                      Elevation  : longint;
                      UTMN       : longint;
                      UTME       : longint;
                      Distance,                      { Distance to point     }
                      DistanceVB,                    { Distance to VA. Beach }
                      DistanceWV : extended;         { Distance to W. VA     }
                      Annual,
                      Winter, Spring, Summer, Autumn,
                      Jan, Feb, Mar, Apr, May, Jun,
                      Jul, Aug, Sep, Oct, Nov, Dec
                                 : extended;
                    end;

   StationArray   = array[1 .. NumberOfStations] of LocationRecord;


var
   CurrentLocation : LocationRecord;  { The location to be tested }
   StationData     : StationArray;    { the control stations      }
```

```
    InputFile       : text;
    InPutFileName   : string;

    OutputFileName  : string;
    Printer         : text;           { write to printer, but redirect to
                                        a file if requested }

    Destination     : (ToScreen, ToPrinter, ToFile);

    SID             : extended;       { Sum of inverse distances }

    HelpP : HelpPtr;             {pointer to help system}
    HelpColors : HelpColorArray; {colors for TPHELP}

    BoxTextAttr : Byte;          {color of text in boxes}

{$I Menu.pas} { Include the pull down menu code }

Procedure ReadStationData(Var Stations : StationArray);
{  This procedure loads the Control Station data into the array StationArray }
var
    StationFile : text;
    x           : integer;

begin
    assign(StationFile,StationFileName);
    {$I-}
    reset(StationFile);
    {$I+}
    if IOResult <> 0 then begin
       writeln('*** Error encountered ***');
       writeln('Station data file "',StationFileName,'" not found.');
       writeln;
       Halt;
    end;

    { blank the array }
    fillchar(StationData,SizeOf(StationData),#0);

    { read the first two lines and discard }
    readln(StationFile);
    readln(StationFile);

    { read through the file }
    x := 1;
    while not eof(StationFile) do
       with StationData[x] do begin
          readln(StationFile, Code,
                              UTME,
                              UTMN,
                              Annual,
                              Winter, Spring, Summer, Autumn,
                              Jan, Feb, Mar, Apr, May, Jun,
                              Jul, Aug, Sep, Oct, Nov, Dec,
                              identifier);
          identifier := trim(identifier);
          inc(x);
       end;

    close(StationFile);
end;

Procedure SortStationData(Var Stations : StationArray; L : LocationRecord);
{ This procedure calculates the distance and sorts the stations }
var
    x,y   : extended;
    z     : longint;
    j, p  : integer;
    tmp   : LocationRecord;

begin
    { calculate the distances }
    for z := 1 to 15 do begin
       x := Stations[z].UTMN - L.UTMN;
       y := Stations[z].UTME - L.UTME;
       Stations[z].distance := Sqrt(x*x+y*y);
```

```
    end;

    { Use insertion sort to sort the values}
    { for each value from the second to the last..}
    for p := 2 to 15 do begin
       j := p;
       tmp := Stations[p];
       { move the value back to it's correct place }
       while (j > 1) and ( tmp.distance < Stations[j-1].distance) do begin
          Stations[j] := Stations[j-1];
          Dec(j);
       end;
       Stations[j] := tmp;
    end;

    { Calculate SID }
    SID := 0;
    for z := 1 to 5 do
       SID := SID + 1/(STATIONS[z].distance / 1e4);
end;

Procedure DisplayStationData;
{ This procedure prints the top 5 stations to the screen }
var
   x : integer;
begin
   For x := 1 to 5 do begin
      gotoxy(39,4+x);
      write(LeftPadCh(Long2Str(StationData[x].Code),'0',4),'  ');
      Write(Pad(StationData[x].Identifier,IdLength+1));
      write(StationData[x].Distance:8:0);
   end;
end;

Procedure Frame(x1,y1,x2,y2 : word);
{ draws a box on the screen }
var
   x : word;
begin
   gotoxy(x1,y1);
   write(#218,CharStr(#196,x2-x1-1),#191);
   gotoxy(x1,y2);
   write(#192,CharStr(#196,x2-x1-1),#217);

   for x := y1+1 to y2-1 do begin
      gotoxy(X1,x);
      write(#179);
      gotoxy(x2,x);
      write(#179);
   end;

end;

Procedure ClearCurrentLocation;
{ This procedure blanks the data entry portion of the screen }
begin
   { blank the current record }
   fillchar(CurrentLocation,SizeOf(CurrentLocation),#0);

   { clear that portion of the screen }
   GotoXY(5,13);
   write(CharStr('▒',IDlength+1));
   GotoXY(5,15);
   write('▒▒▒▒▒▒▒▒▒▒▒▒');
   GotoXY(5,17);
   write('▒▒▒▒▒▒▒▒▒▒▒▒');
   GotoXY(5,19);
   write('▒▒▒▒▒▒▒▒▒▒▒▒');
end;


Procedure DisplayForm;
{ this procedure draws the blank form to the screen }
var
   x : word;
```

```
begin
   { draw the boxes }
   frame(31,1,79,11);
   frame(1,11,31,22);
   frame(31,11,79,22);
   gotoxy(31,11);   write(#197);
   gotoxy(79,11);   write(#180);
   gotoxy(31,22);   write(#193);

   gotoxy(34,2);
   write('Stations used to predict rainfall:');
   gotoxy(39,4);
   write('Code  Identifier            Distance');
   For x := 1 to 5 do begin
      gotoxy(36,4+x);
      write(x,'. ▒▒▒  Not yet determined    ▒▒▒▒▒▒▒▒▒▒');
   end;

   GotoXY(3,12);
   write('Identifier:');
   GotoXY(3,14);
   write('Elevation (meters):');
   GotoXY(3,16);
   write('Latitude (UTM):');
   GotoXY(3,18);
   write('Longitude (UTM):');

   ClearCurrentLocation;

   gotoXY(36,12);
   write('Predicted values for ',CharStr('▒',IDLength));
   gotoXY(34,15);
   write('Annual  xxx.xx     Jan  xx.xx    Jul  xx.xx');
   gotoXY(34,16);
   write('                   Feb  xx.xx    Aug  xx.xx');
   gotoXY(34,17);
   write('Winter  xxx.xx     Mar  xx.xx    Sep  xx.xx');
   gotoXY(34,18);
   write('Spring  xxx.xx     Apr  xx.xx    Oct  xx.xx');
   gotoXY(34,19);
   write('Summer  xxx.xx     May  xx.xx    Nov  xx.xx');
   gotoXY(34,20);
   write('Autumn  xxx.xx     Jun  xx.xx    Dec  xx.xx');

end;

Procedure DisplayValues;
{ This procedure displays the calculated values to the screen }
begin
   with CurrentLocation do begin
      gotoXY(36,12);
      write('Predicted values for ',PadCh(Identifier,' ',IDLength));
      gotoXY(34,15);
      write('Annual  ',Annual:6:2,'     Jan ',Jan:6:2,'    Jul ',Jul:6:2,'*');
      gotoXY(34,16);
      write('                  Feb ',Feb:6:2,'    Aug ',Aug:6:2,'*');
      gotoXY(34,17);
      write('Winter  ',Winter:6:2,'     Mar ',Mar:6:2,'*   Sep ',Sep:6:2,'*');
      gotoXY(34,18);
      write('Spring  ',Spring:6:2,'     Apr ',Apr:6:2,'    Oct ',Oct:6:2,'*');
      gotoXY(34,19);
      write('Summer  ',Summer:6:2,'*    May ',May:6:2,'*   Nov ',Nov:6:2);
      gotoXY(34,20);
      write('Autumn  ',Autumn:6:2,'     Jun ',Jun:6:2,'*   Dec ',Dec:6:2,'*');
      gotoxy(34,21);
      write('           * R-Square < 0.50 ');
   end;

end;

Procedure PrintValues;
{ this procedure sends the calculated values to the file/printer }
begin
   with CurrentLocation do begin
      writeln(printer,'          VA-Rains  v1.0  06/15/93');
      writeln(printer);
```

```
      writeln(printer,Center('Predicted values for '+Identifier,45));
      writeln(printer);
      writeln(printer,'Annual  ',Annual:6:2,'     Jan ',Jan:6:2,'    Jul ',Jul:6:2,'*');
      writeln(printer,'                    Feb ',Feb:6:2,'    Aug ',Aug:6:2,'*');
      writeln(printer,'Winter  ',Winter:6:2,'     Mar ',Mar:6:2,'*   Sep ',Sep:6:2,'*');
      writeln(printer,'Spring  ',Spring:6:2,'     Apr ',Apr:6:2,'    Oct ',Oct:6:2,'*');
      writeln(printer,'Summer  ',Summer:6:2,'*    May ',May:6:2,'*   Nov ',Nov:6:2);
      writeln(printer,'Autumn  ',Autumn:6:2,'     Jun ',Jun:6:2,'*   Dec ',Dec:6:2,'*');
      writeln(printer);
      writeln(printer,'* these have an R-squared value of less than 0.50');
      writeln(printer);
      writeln(printer);
      writeln(printer);
   end;
end;

Procedure Message(s : string);
{ this is a util procedure to print a message to the screen }
begin
   FastWrite(Center(s+' <Enter>',79),23,1,$1e);
   sound(200);
   delay(200);
   nosound;
   repeat
   until readkey = #13;
   gotoxy(1,23); clreol;
end;

Procedure TestLocationData;
{ calculate some distances and check the model limits }
var
   x,y   : extended;
begin
  { calculate west Va and Va Beach distances }
  x := CurrentLocation.UTMN - 4243441;
  x := x / 1e4;
  y := CurrentLocation.UTME - 452662;
  y := y / 1e4;
  CurrentLocation.DistanceWV := Sqrt(x*x+y*y);
  x := CurrentLocation.UTMN - 4091150;
  x := x / 1e4;
  y := CurrentLocation.UTME - 944978;
  y := y / 1e4;
  CurrentLocation.DistanceVB := Sqrt(x*x+y*y);

  { test the limits }
  with CurrentLocation do begin
     if elevation < MinElevation then
        Message('Elevation is below model limits');
     if elevation > MaxElevation then
        Message('Elevation is above model limits');
     if UTMN < MinLat then
        Message('Latitude is below model limits');
     if UTMN > MaxLat then
        Message('Latitude is above model limits');
     if UTME < MinLon then
        Message('Longitude is below model limits');
     if UTME > MaxLon then
        Message('Longitude is above model limits');
  end;
end;


Procedure GetLocation(var L : LocationRecord);
{ this is the data entry procedure }
var
   Escaped : boolean;

begin
   EditHelpIndex := 100;
   ReadString('',13,5,IDLength,$07,$70,$70, Escaped, L.Identifier);
   EditHelpIndex := 101;
   if not escaped then
      Readlongint('',15,5,9,$07,$70, 0,0,Escaped, L.elevation);
   EditHelpIndex := 102;
```

```
    x  : integer;
begin
    WT := 0;
    for x := 1 to 5 do
        WT := WT + StationData[x].Annual/(StationData[x].distance / 1e4 * SID)/YearCount;
    with CurrentLocation do begin
        Annual := 0.9*WT;
        Annual := Annual - (0.000856 * (UTMn / 1e4)*(UTMn / 1e4));
        Annual := Annual - (1693.01/Elevation);
        Annual := Annual + (0.00733 * (UTME / 1e4) *( UTMe / 1e4));
        Annual := Annual + (113.99/DistanceWV);
        Annual := Annual + 122.42
    end
end;

Procedure CalculateWinter;
var
    WT : extended;
    x  : integer;
begin
    WT := 0;
    for x := 1 to 5 do
        WT := WT + StationData[x].Winter/(StationData[x].distance / 1e4 * SID)/YearCount;
    with CurrentLocation do begin
        Winter := 0.96*WT;
        Winter := Winter - (40.5/DistanceWV);
        Winter := Winter - (5.63e-2)*(UTMN/ 1e4);
        Winter := Winter + 25.52
    end
end;

Procedure CalculateSpring;
var
    WT : extended;
    x  : integer;
begin
    WT := 0;
    for x := 1 to 5 do
        WT := WT + StationData[x].Spring/(StationData[x].distance / 1e4 * SID)/YearCount;
    with CurrentLocation do begin
        Spring := 0.92*WT;
        Spring := Spring - (2.18e-4)*(UTMN / 1e4)*(UTMN / 1e4);
        Spring := Spring - 491.67 / elevation;
        Spring := Spring + (1.54e-3)*(UTME / 1e4)*(UTME / 1e4);
        Spring := Spring + 33.97;
    end
end;

Procedure CalculateSummer;
var
    WT : extended;
    x  : integer;
begin
    WT := 0;
    for x := 1 to 5 do
        WT := WT + StationData[x].Summer/(StationData[x].distance / 1e4 * SID)/YearCount;
    with CurrentLocation do begin
        Summer := 0.88*WT;
        Summer := Summer + 53.66/DistanceVB;
        Summer := Summer - (3.49e-5)*(UTMN / 1e4)*(UTMN / 1e4);
        Summer := Summer + 5.62;
    end
end;

Procedure CalculateAutumn;
var
    WT : extended;
    x  : integer;
begin
    WT := 0;
    for x := 1 to 5 do
        WT := WT + StationData[x].Autumn/(StationData[x].distance / 1e4 * SID)/YearCount;
    with CurrentLocation do begin
        Autumn := 0.95*WT;
        Autumn := Autumn - (1.72e-3)*DistanceVB*DistanceVB;
        Autumn := Autumn - 3.92*ln(UTME / 1e4);
```

```
      Autumn := Autumn + 18.52;
   end
end;


Procedure CalculateJan;
var
   WT : extended;
   x  : integer;
begin
   WT := 0;
   for x := 1 to 5 do
      WT := WT + StationData[x].Jan/(StationData[x].distance / 1e4 * SID)/YearCount;
   with CurrentLocation do begin
      Jan := 0.96*WT;
      Jan := Jan + 0.85 * Ln(DistanceWV);
      Jan := Jan - 2.8e-5 * (UTMN / 1e4) * (UTMN / 1e4);
      Jan := Jan + 2.28;
   end
end;


Procedure CalculateFeb;
var
   WT : extended;
   x  : integer;
begin
   WT := 0;
   for x := 1 to 5 do
      WT := WT + StationData[x].Feb/(StationData[x].distance / 1e4 * SID)/YearCount;
   with CurrentLocation do begin
      Feb := 0.96*WT;
      Feb := Feb - (3.72e-5) * (UTMN / 1e4) * (UTMN / 1e4);
      Feb := Feb + (2.08e-4) * (UTME / 1e4) * (UTME / 1e4);
      Feb := Feb + 5.66
   end
end;

Procedure CalculateMar;
var
   WT : extended;
   x  : integer;
begin
   WT := 0;
   for x := 1 to 5 do
      WT := WT + StationData[x].Mar/(StationData[x].distance / 1e4 * SID)/YearCount;
   with CurrentLocation do begin
      Mar := 0.58*WT;
      Mar := Mar - 6.24e-5 * (UTMN / 1e4) * (UTMN / 1e4);
      Mar := Mar - 1.15e-3 * DistanceVB * DistanceVB;
      Mar := Mar + 1.18 * log(elevation);
      Mar := Mar + 10.59;
   end
end;

Procedure CalculateApr;
var
   WT : extended;
   x  : integer;
begin
   WT := 0;
   for x := 1 to 5 do
      WT := WT + StationData[x].Apr/(StationData[x].distance / 1e4 * SID)/YearCount;
   with CurrentLocation do begin
      Apr := 0.94*WT + 0.18;
   end
end;


Procedure CalculateMay;
var
   WT : extended;
   x  : integer;
begin
   WT := 0;
   for x := 1 to 5 do
```

```
      WT := WT + StationData[x].May/(StationData[x].distance / 1e4 * SID)/YearCount;
   with CurrentLocation do begin
      May := 0.52*WT + 1.84;
   end
end;

Procedure CalculateJun;
var
   WT : extended;
   x  : integer;
begin
   WT := 0;
   for x := 1 to 5 do
      WT := WT + StationData[x].Jun/(StationData[x].distance / 1e4 * SID)/YearCount;
   with CurrentLocation do begin
      Jun := 0.62*WT + 1.29;
   end
end;


Procedure CalculateJul;
var
   WT : extended;
   x  : integer;
begin
   WT := 0;
   for x := 1 to 5 do
      WT := WT + StationData[x].Jul/(StationData[x].distance / 1e4 * SID)/YearCount;
   with CurrentLocation do begin
      Jul := 0.8*WT;
      Jul := Jul - 3.2e-5 * (UTMN / 1e4) * (UTMN / 1e4);
      Jul := Jul + 44.93  /  DistanceVB;
      Jul := Jul + 1.33e-6 * (elevation * elevation);
      Jul := Jul + 4.72;
   end
end;

Procedure CalculateAug;
var
   WT : extended;
   x  : integer;
begin
   WT := 0;
   for x := 1 to 5 do
      WT := WT + StationData[x].Aug/(StationData[x].distance / 1e4 * SID)/YearCount;
   with CurrentLocation do begin
      Aug := 0.63*WT;
      Aug := Aug - 1.33e-6 * (elevation * elevation);
      Aug := Aug + 1.58;
   end
end;

Procedure CalculateSep;
var
   WT : extended;
   x  : integer;
begin
   WT := 0;
   for x := 1 to 5 do
      WT := WT + StationData[x].Sep/(StationData[x].distance / 1e4 * SID)/YearCount;
   with CurrentLocation do begin
      Sep := 0.59*WT + 0.28;
   end
end;

Procedure CalculateOct;
var
   WT : extended;
   x  : integer;
begin
   WT := 0;
   for x := 1 to 5 do
      WT := WT + StationData[x].Oct/(StationData[x].distance / 1e4 * SID)/YearCount;
   with CurrentLocation do begin
      Oct := 0.23*WT;
      Oct := Oct - 5.14e-4 * (DistanceVB * DistanceVB);
```

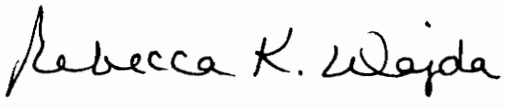
```
      Oct := Oct + 3.32;
   end
end;

Procedure CalculateNov;
var
   WT : extended;
   x  : integer;
begin
   WT := 0;
   for x := 1 to 5 do
      WT := WT + StationData[x].Nov/(StationData[x].distance / 1e4 * SID)/YearCount;
   with CurrentLocation do begin
      Nov := 0.96*WT;
      Nov := Nov - 1.92e-4 * (DistanceVB * DistanceVB);
      Nov := Nov + 0.29;
   end
end;


Procedure CalculateDec;
var
   WT : extended;
   x  : integer;
begin
   WT := 0;
   for x := 1 to 5 do
      WT := WT + StationData[x].Dec/(StationData[x].distance / 1e4 * SID)/YearCount;
   with CurrentLocation do begin
      Dec := 0.64*WT;
      Dec := Dec - 0.92 * Log(DistanceVB);
      Dec := Dec - 2.52e-5 * (UTMN / 1e4) * (UTMN / 1e4);
      Dec := Dec + 8.61;
   end
end;

Procedure Go;
{ Run the model on the current data and display }
begin
   SortStationData(StationData,CurrentLocation);
   DisplayStationData;
   CalculateAnnual;
   CalculateWinter;
   CalculateSpring;
   CalculateSummer;
   CalculateAutumn;
   CalculateJan;
   CalculateFeb;
   CalculateMar;
   CalculateApr;
   CalculateMay;
   CalculateJun;
   CalculateJul;
   CalculateAug;
   CalculateSep;
   CalculateOct;
   CalculateNov;
   CalculateDec;
   DisplayValues;
end;

Procedure RunModel;
{ Call Go if everything is OK and output values to file/printer }
begin
   with CurrentLocation do
   if (Elevation <>  0) and (UTMN <> 0) and (UTME <> 0) then begin
      Go;
      if Destination <> ToScreen then
         PrintValues;
   end else
      Message('Incomplete data for current point');
end;


Procedure SetDestination(x : byte);
{ Set the output destination }
```

```
var
   escaped : boolean;
begin
   if Destination = ToFile then
     {$I-}
     Close(printer);
     {$I+}
     if ioresult <> 0 then;
   case x of
    5 : Destination := ToScreen;
    6 : Destination := ToPrinter;
    7 : Destination := ToFile;
   end;
   if Destination = ToFile then begin
      ReadString('Enter the output file name ',23,1,IDLength,BoxTextAttr,$70,$70, Escaped, OutputFileName);
      if not escaped then begin
         Assign(printer,OutputFileName);
         Rewrite(printer);
      end;
      gotoxy(1,23); Clreol;
   end;
   if Destination = ToPrinter then begin
         Assign(printer,'prn');
         Rewrite(printer);
   end
end;


Procedure EnterFileName;
{ gets the batch input file }
var
   escaped : boolean;
begin
   ReadString('Enter the batch input file name ',23,1,IDLength,BoxTextAttr,$70,$70, Escaped, InputFileName);
   if not escaped then begin
      Assign(InputFile,InputFileName);
      {$I-}
      Reset(InputFile);
      {$I+}
      if IOResult <> 0 then begin
         Message('Sorry, the file '+InputFileName+' does not exist.');
         exit;
      end;
   end;
   gotoxy(1,23); Clreol;

   { run it for each location in the file }
   while not eof(InputFile) do with CurrentLocation do begin
      ClearCurrentLocation;
      readln(InputFile,elevation,UTME,UTMN,Identifier);
      TestLocationData;
      RunModel;
      if Destination = ToScreen then
         Message('To continue press')
   end;
   Close(InputFile);
end;

Procedure Help;
{ this is the help index }
var
   index : word;
begin
   repeat
      { select a topic }
      index := PickHelp(HelpP,8,7,19,3);
      { show the topic }
      if index <> 0 then
         if ShowHelp(HelpP,Index) then;
   until index = 0;
end;

var
  M : Menu;
  Ch : Char;
  Key : MenuKey;
```

```
  x   : integer;

begin
  ReadStationData(StationData);   { read the control station data }
  InitMenu(M);                    { setup the menus }
  InitColors;                     { setup screen colors }
  OpenHelp;                       { Open the help files }

  MenuHelpPtr := @DisplayHelp;    { setup the help system }
  EditHelpPtr := @DisplayHelp;

  OutPutFileName := '';           { init input and output files }
  InPutFileName := '';

  assign(printer,'prn');
  rewrite(printer);

  Destination := ToScreen;        { start destination to screen only }

  TextAttr := BoxTextAttr;
  ClrScr;

  DisplayForm;                    { Display the blank form }
  DisplayHelp(0,nil,104);         { show introduction      }

  repeat                          { this interprets the menu }
     Key := MenuChoice(M, Ch);
     EraseMenu(M, False);
     if Ch = #13 then
        Case Key of
          2 : GetLocation(CurrentLocation);
          3 : EnterFileName;
          5,6,7 : SetDestination(key);
          8 : RunModel;
          9 : Help;
        end;
  until (key = 10) or (Ch = #27);
  {$I-}
  close(printer);
  {$I+}
end.
```

Vita

Rebecca K. Wajda was born on June 5, 1963, in Arlington, Virginia. She graduated from West Springfield High School, Virginia, in 1981. Ms. Wajda entered the College of William and Mary in September, 1981, and graduated with a B.S. degree in Biology in May, 1985. She was admitted as a candidate for an M.S. degree in Fisheries and Wildlife Science (Wildlife Option) at Virginia Polytechnic Institute and State University in September, 1985. During her term at VPI&SU, Ms. Wajda was a department representative to the Graduate Student Assembly, and served as Treasurer of the VPI&SU Chapter of The Wildlife Society. In July, 1988, Ms. Wajda accepted a position with the Virginia Department of Game and Inland Fisheries in Richmond, Virginia, as the Fish and Wildlife Information Systems Coordinator.



Rebecca K. Wajda