12-1986

Some Statistical Analyses of the Climate of Nacogdoches, Texas for Applications in Natural Resources Management

Alexander Sayok

Stephen F Austin State University

Repository Citation

Sayok, Alexander, "Some Statistical Analyses of the Climate of Nacogdoches, Texas for Applications in Natural Resources Management" (1986). *Electronic Theses and Dissertations*. 32.
https://scholarworks.sfasu.edu/etds/32

Some Statistical Analyses of the Climate of Nacogdoches, Texas for Applications in Natural Resources Management

SOME STATISTICAL ANALYSES OF THE CLIMATE OF NACOGDOCHES, TEXAS FOR APPLICATIONS IN NATURAL RESOURCES MANAGEMENT

APPROVED:

Mingteh Chang

Dr. Mingteh Chang, Thesis Director

Hershel C Reeves

Dr. Hershel C. Reeves

Kenneth G. Watterston

Dr. Kenneth G. Watterston

James Reese

Dr. James V. Reese, Acting
Dean of the Graduate School

SOME STATISTICAL ANALYSES OF THE CLIMATE OF NACOGDOCHES, TEXAS FOR APPLICATIONS IN NATURAL RESOURCES MANAGEMENT

BY

Alexander K. Sayok, B.S.F.

Presented to the Faculty of the Graduate School of
Stephen F. Austin State University
In Partial Fulfillment
of the Requirements

For the Degree of
Master of Science in Forestry

STEPHEN F. AUSTIN STATE UNIVERSITY
DECEMBER 1986

ACKNOWLEDGEMENTS

I am deeply grateful to my thesis director, Dr. Mingteh Chang, Associate Professor of Forest Hydrology/Watershed Management, for his patience, dedication, and guidance throughout the study. Dr Chang's discussion and criticisms of manuscript were most helpful in the preparation and completion of this thesis. The advice, encouragement, and comments given by Dr. Hershel C. Reeves and Dr. Kenneth G. Watterston, Professor of Meteorology/Forest Fire and Forest Soils, respectively, are gratefully acknowledged.

I am especially grateful to my parents, Mr. and Mrs. Sayok Lingo, and my wife, Maria, for their sacrifice and encouragement. Maria's love, cooperation, and understanding were a continual source of inspiration.

Special thanks are extended to Dr. J. D. Lenhart for allowing me to use his Macintosh Cricket Graph software package, to Mrs. Jinnie Fleming, Mrs. Betty Morrow, Mrs. Kay O'Neal, Ms. Stacy Shaw, Ms. Jamie Taylor, Ms. Jennie Ting, and Mr. Jessie Wilson for their assistance in one way or another, to the School of Forestry for providing various facilities, to the Public Service Department of Malaysia for the financial support throughout my study, and most of all, to The Almighty God, who has given me the grace, health and opportunity to make this study possible.

TABLE OF CONTENT

PAGE

PAGE

LIST OF TABLES

PAGE

PAGE

LIST Of FIGURES

INTRODUCTION

Perhaps there is no single topic of conversation which is more popular and widespread than the weather and its various moods. Weather is an important element of our environment. It governs the physical and chemical processes, influences biological activities, and alters our routine operations. In some cases, conversation about the weather is a very serious matter because its variations may affect our lives, destroy our property, and influence our food supply. Prosperity and poverty are often closely related to climatic conditions and changes.

Man has dealt with weather for thousands of years. From the early ages of frightening religious cults, superstition and folklore to more recent periods of personal experience and observation, weather and climate have generally been considered as an act of the gods. It is only in the past generation that many new developments in science and technology have made it possible to transfer climatology from personal experience and instinct into science based on numerical expressions, mathematical functions, and models. Coupling this new technology with gradually accumulated climatic data at various locations around the world, man is now able to analyze and consequently understand, the climatic changes in the past with scale and capacity that could not possibly be achieved before. Likewise, man's ability to predict future climate will be greatly improved.

Due to differences in surface irradiation, topographic effects, land use, and land-water distribution, no climate on earth is exactly the same at any two locations. A mountain slope may experience different air temperature a transect-line from the ridge top to the valley below (Geiger, 1965), while precipitation may be recorded differently at the windward and leeward slopes of a hill (Lee,1978). In forested East Texas, annual precipitation and temperature are greatly affected by station latitude and longitude in a manner that can be mathematically calculated (Chang _et al_., 1980). Thus, any study of the local climate will contribute to our understanding of climatic variations of the earth and will help manage our natural resources and everyday activities.

Nacogdoches, the oldest town in Texas (Haltom, 1880), is located near the center of forested East Texas. Commercial logging in this area started in the early 18th century (Rice, 1976). It was not until 1880 that large scale logging was actually performed by lumber companies who had to move from the northeastern United States after the white pine resources had been exhausted. Due to poor logging and management practices by unscrupulous managers, East Texas suffered the same fate: the forest was almost denuded in the early 20th century (Maxwell and Martin, 1970). Cotton fields and other agricultural crops then spreaded in these areas. Today, through the reforestation program of the 1930s, these areas are covered by secondary growth of commercial southern pine forests. The forest, and its associated natural resources, has become an important sector in the local economy, and management of these resources requires information on climatic patterns and characteristics.

Officially, climatic observations started in Nacogdoches in 1892 and it is one of the oldest weather stations in Texas. Although studies dealing with the climate of Nacogdoches have been reported by investigators such as Haltom (1880), Reeves (1976a,b,c,d), Aguilar (1979), Chang et al. (1980), and Chang (1981), these studies either covered a period of time too short to reveal the nature of climatic fluctuation or included only a few elements and left a great number of climatic conditions unexplored. A comprehensive study of all aspects of Nacogdoches' climate using all available records, official or unofficial, seems warranted by its potential utility to a wide range of disciplines including resources managers, public officers, university researchers, and private citizens.

OBJECTIVES OF THE STUDY

The main objective of the study was to investigate and analyze long-term climatic characteristics of Nacogdoches for applications in planning and management of natural resources. Specific objectives were to:

a) Collect all the climatic data of Nacogdoches, Texas, published in periodic reports or kept in governmental files, and compile these data for convenience to various users;

b) Analyze, interpret, and summarize these data for applications in water resources, agriculture, forestry, and other pertinent disciplines;

c) Investigate the effects of climate on water resources, agricultural production, and forest growth in the Nacogdoches area.

LITERATURE REVIEW

Definitions

Weather is the state of the atmosphere surrounding the earth. Since the atmosphere is never static, weather is concerned with atmospheric changes as described by temperature, humidity, precipitation, wind, pressure, visibility, and other elements.

The characteristic weather conditions at any given location over a specified interval of time are called climate (Brown and Davis, 1952). Climate is concerned with the collective state of the earth's atmosphere (Landsberg, 1970) rather than the individual state which is called weather. Thus, climate is based on past experience and is an average state, while weather is established by physical measurements of various atmospheric elements which change from time to time.

Climatic Changes

Climate is not static; it varies with time and space. If any climatic element is plotted as a function of time, the line produced will fluctuate over any period of time. Although systematic weather observations have only been available since the middle of the 19th century (Bruce and Clark, 1966), studies of long-term climatic changes have been made through evidence other than direct measurements such as civilization written-records, widths of growth rings of old trees, migration of people, water-level fluctuations of lakes and rivers, plant succession, ice cores extracted from the deep ice fields, fossil pollen, ocean floor sediment cores, glacial fluctuations, and other geological evidence.

Schneider and Temkin (1977) stated that the climatic changes through geologic time were milder than what is experienced today and that " fairly large excursions in temperature, with cold and warm periods ...[were] separated in time by 10,000 to 100,000 years." During the history of man, there have been several distinctive climatic periods (Bruce and Clark, 1966): a relatively warm condition from 5000 to 3000 B.C., and a period of colder weather about A.D. 1500 to 1850. They further stated that "The period since 1850 has embraced a general warming trend with lake water levels and river flow decreasing materially."

Etkins and Epstein (1982) stated that the mean surface air temperature of the Northern Hemisphere rose between 0.5 to 1.1°F during the period from 1890 to 1940, and the global mean temperature decreased by about 0.36 °F over the past 40 years. Severe and extreme droughts in St. Louis, Missouri and the western third of Kansas occur every 20 and 4 years respectively (Palmer, 1964). Many observations around the world, such as the trends of devastating droughts in the Sahel (Kopec, 1975), the excessive rainfall and flooding in India, Bangladesh, and the midwestern United States, and the abnormally warm or cold winters and destructive winds in North America (Granger, 1978), have shown that extreme climatic condition occurred more frequently in recent years.

Why the climate is more dynamic and more unstable in this recent period is of great scientific interest. In searching for the causes of these complex variations in our recent climatic conditions, many have attributed to sunspot activity, volcanic activity, carbon dioxide content, and man's activities such as land use, deforestation, and urbanization. These causes are briefly discussed below:

Sunspot Activity

Practically all of the energy in the ecosystem originates from the sun -- solar radiation. This energy supplies the fuel necessary for the multitude of processes that make up the earth's weather and climate. Only about 19% of the solar radiation reaching the upper atmosphere is absorbed by the earth's atmosphere, 47% is absorbed by the surface of the earth and the remainder is either reflected into space by the clouds and the earth's surface or scattered in the atmosphere (Miller et al., 1983). The amount of solar radiation received at any point on earth depends on the latitude, season, intensity of solar radiation and variations in sunspot activity. This variation affects the atmospheric heat balance, and, consquently, the climate.

The association of sunspots with the output intensity of solar energy has been the subject of interest of many scientists including Galileo in the 17th century (Thompson, 1973). The number of sunspots, as well as their location on the face of the sun, varies from time to time (Miller et al., 1983). These variations have been reported to follow an 11-year cycle between successive maxima and minima (Palmer, 1964), or functions of the 11-year rhythm such as ¼,½,1,2 and so forth (Landsberg, 1968). However, numerous studies have shown that the 22-year (double sunspot) cycle has the highest correlation with drought frequency (Willet, 1961; Thompson, 1973).

Based on the past solar activity-climate relationship, prediction of future climatic conditions has been made possible. For example, Willet (1976) made the following predictions of climatic conditions over the next 25 years (18 years from now):

a) temperatures in all latitudes will fall to significantly lower levels than those reached in the mid-1960's;

b) no major prolonged drought will occur in the lower middle latitude, except along subtropical margins of Mexican border;

c) a predominantly dry period will occur during the next two decades in higher middle latitude and subtropical latitudes with a decade of severe drought.

He further predicted that between 2000 and 2030 A.D.:

a) there will be an abrupt return to markedly warmer weather in the first decade of the next century;

b) the warm decade of 2000 to 2010 will tend to be wetter in the higher, middle and subtropical latitudes, but drier in the lower middle latitudes;

c) the return of air temperature to a cooler condition between the year 2010 and 2030 should be associated with a return of relatively dry conditions in the upper parts of the subtropical latitudes.

However, some scientists such as Schneider and Temkin (1977) and Granger (1978) were not yet convinced by the existing evidence of sunspot-climatic relationship and believed that the relationship between the sunspot cycle and drought occurrence was merely coincidental. In the midst of this confusion, Stuiver (1980) compared ten different records of the climate from all over the world with varying carbon-14 contents of tree rings over the past 1,000 years (carbon-14 is an indirect measure of changing solar activity). Despite his failure to find any significant correlation between solar activity and any of the climatic records, he stated that "It's no solid fact, but I still have the feeling that it is true that there is some relationships between sunspot activity and climatic conditons."

Volcanic Activity

Dust particles and other pollutants in the atmosphere may intercept incoming solar radiation and consequently affect the heat budget on the ground. This phenomenon was first recorded in 1738 by Benjamin Franklin when he noticed that after a volcanic eruption, sunlight shining through a magnifying glass would no longer set fire to a piece of paper (Tilling, 1982). Budyko (1969), from his direct measurement of solar radiation under a cloudless sky, shows that the highest value of solar radiation transmittance in the 1920s and 1930s was associated with minimum volcanic activities. This idea leads scientists to believe that volcanic activities, which blow out dust particles in the atmosphere, may cause climatic changes. The dust is mainly composed of tiny droplets of sulfur dioxide gas from volcanic ash which interact with sunlight and atmospheric moisture. As reported by various investigators, these particles may lower or raise surface temperature in different parts of the world.

According to Tilling (1982), the Katmai eruption in Alaska in 1912 caused a decrease of 25 to 30% in sunlight and resulted in a drop of more than 3.6°F below the normal summer air temperature in the cities of Vienna and Budapest in 1913. Also, the Tambora eruption in 1815 caused a decrease in air temperature in Indonesia by as much as 2°F for as long as two years as a result of dust in the atmosphere. The big frost in late June and heavy frost in July of 1916 in New England was also suspected to be caused by the Tambora eruption (Taylor, 1984). However, an increase in mean surface air temperature has also been reported to be associated with volcanic eruption. For example, Kerr (1981) reported that an increase of air temperature of 14.5 to 15.5°F was recorded in the States of Idaho, Wyoming, Oregon, and Washington a few days after the Mount St. Helen's eruption. Taylor (1984) reported that the El Chichon's eruption of 1982 caused an increase of 7°F in air temperature in Mexico.

Carbon Dioxide

Carbon dioxide is a good intercepter of solar and infrared radiation in certain wavelengths. It is well-known that the CO_2 content of the atmosphere can be affected by burning of fossil fuels such as coal, petroleum and natural gas (SMIC, 1971), by the growing cycle of plants and deforestation (PMB, 1984), and by volcanic activity (Tilling, 1982; Taylor, 1984). This gas is important climatologically because it intercepts the outgoing longwave radiation from the earth, forming a condition similar to "greenhouse effect" and thus warms the environment.

Since the beginning of industrialization in the 19th century, energy consumption has steadily increased at a rate of about 5.3% per year which in turn resulted in an increase in the atmosphere CO_2 by 290 parts per million by volume (ppmv) around 1900, and exceeded 340 ppmv in 1981. If the energy consumption follows current projection, the atmospheric CO_2 will increase to 380 ppmv by the end of this century and reach twice the pre-industrial level around 2050 A.D. and even as early as 2040 A.D. (Bach, 1983; Berger, 1984). Because of its role in the atmospheric balance, the possible climatic consequence of a continuing rise of CO_2-level has been an increasing concern among scientists (WMO, 1979; Bach, 1983; Clark, 1982). Verification through climatic models has been carried out by Manabe and Stouffer (1980), Manabe and Wetherald (1980), and Manabe *et al.*(1981).

Water Bodies

Water, due to its high specific heat, responds slowly to temperature changes. This causes land in the proximity of oceans or large water bodies to experience mild climate.

In a review of studies conducted in the Great Lakes area of the United States, Changnon and Jones (1972) stated that "the amount of precipitation, and the frequency of thunderstorm and hailstorm activity over lakes and their downwind areas tend to decrease in the summer and increase in the fall and winter." This is due to the fact that the lake water in the fall and winter is warmer than the overlying air. Warm air is usually unstable. As it rises and its temperature drops below dewpoint precipitation is enhanced through condensation.

Lake Baikal of southeastern Siberia imposes even a more dramatic effect on the climate of the vicinity (Miller et al., 1983). Winter usually comes to Siberia with temperatures below freezing as early as September, but ice does not form on the lake until late December or early January. Irkutsk, which is about 30 miles southeast of the lake, often has a difference in air temperature as much as 20°F warmer or cooler (depending on season) than that of the areas near the lake.

Man's Activities

It is becoming more evident that man has affected climate through his activities, often to his detriment (Bayce, 1979) by altering the surface of the earth for food production and settlement, by tapping the natural resources, and by introducing various gaseous pollutants.

Food Production. Man did not intend to destroy his fragile land and disturb the environment. What he actually wanted was a better life, and in some cases, mere survival. In so doing, he changed his environment and climate.

History reveals that Mesopotamia was once a thriving region in continental Asia. Malpractices in land use gradually turned the area into a desert until it became too late for anyone to save the once fertile farmland (Chang, 1982). Such desert-making by man may be partly responsible for the drought in the Sahel and other monsoon lands today.

It has been a common and old practice that man clear and burn his fields to create space for planting crops and other land development. Deforestation by burning can contribute as much as 10 times the amount of CO_2 that nature can produce in the same period of time (Tombaugh, 1979). Tombaugh (1979) also stated that the global temperature has increased by 3.5 to 4.5°F and that the concentration of CO_2 in the atmosphere would double as early as 2000 A.D.

Apart from causing a change in the air temperature, the pattern of rainfall could also be affected by man's activities. Studies on the rainfall pattern by Warner (1968) at the sugar cane producing station Queensland, Australia show that smoke produced from the burning after harvesting operation hinders the coalescent process of rain formation and consequently causes reduction in rainfall in the area. Similar studies were carried out by Woodcock and Jones (1970) in the cane producing areas of Maui, Hawaii. They too found that there is a downward trend in the rainfall around these areas.

Urbanization. Urbanization is a by-product of modern civilization. Accomodating a large population in a relatively small area inevitably creates many disturbances in the environment compared to rural areas due to the great demand for clear land, residential and commercial buildings, water consumption, and transportation facilities. SMIC (1971) reported that:

> The industrial and urban activities within the cities and in the areas between them alter the landscape as well as injecting material and heat into the atmosphere and adjacent water bodies. In principal, all of these changes can influence the parameters determining climate.

Numerous studies have been done on the comparison of climate in cities with their adjacent country (rural) areas. Among the aspects discussed, air temperature is probably the most popular. Landsberg (1968), pointed out that the difference in temperature (night) between city and rural area is usually about 10°F and occasionally as great as 20°F. Wollum (1964) and Wollum and Canfield (1968) studied climatic records of 20 years collected at several stations around Washington,D.C. and found that the mean of minimum temperatures for each season was approximately 4°F warmer in downtown areas than in the outlying regions. Although temperature differences can easily be detected at any time of the year, the greatest temperature difference occurs in summer or fall (Wollum, 1964) and winter (Landsberg, 1970).

Forest and Climate Relationship

The growth, establishment, and colonization by any plant on a site requires the presence of favorable environmental conditions. Apart from soil, suitable climate is among the basic factors required (FAO, 1978). Once such a plant begins to grow, it exerts some influence on the microclimate.

The influence exerted by forests is similar to that exerted by other vegetation, except that the effect is of greater magnitude. The magnitude of influence that forests exert depends upon species, stage of growth, spatial distribution, aspect, topography, time of year, and space occupied. The environment affected by forests includes light and solar radiation, air and soil temperature, wind, atmospheric humidity, precipitation, evaporation and transpiration, and even soil properties. Some of these factors are more or less interrelated and are discussed briefly as follows:

Light and Solar Radiation

The sun is the main energy source for photosynthesis. A portion of the solar energy in the form of solar radiation and light is reflected back from the upper canopy of the forest. According to Landsberg (1970), illumination under a fully-leaved tree is only 25 to 30% of that received on a horizontal surface in an unshaded area. FAO (1978) reported that this percentage varies among species; illumination is reduced to 18% by the crown of a young oak, to 14% by a young pine, and to 10% by a fir.

The amount of solar radiation and light not only varies between species but also within species. This difference occurs as a result of varying tree densities. Cheo (1946) recorded light intensity from 25-year old *Pinus resinosa* stands of varying densities in Minnesota. He found that the amount of light at the ground increases to as much as three times with an increase in thinning intensities.

Air Temperature

Since the sun is the chief source of heat, the daytime and maximum air temperatures vary with forest cover in the same way as solar radiation. Similarly, minimum air temperatures which occur early in the morning before sunrise reflect varying intensities of outgoing radiation from forests or other vegetation.

Temperature fluctuations or differences are more evident when comparing land surfaces with varying vegetative cover. In an attempt to investigate this correlation, many studies have been conducted between cities and their adjacent forested or transitional areas. For example, Landsberg (1968) conducted a study on air temperature for different land use in Washington, D.C. and found that park areas and rural environments are slightly cooler during the day and considerably cooler during the night than business centers, industrial zones, and dense residential areas. He reasoned that downtown air is warmer because cities have higher thermal conductivity and heat capacity. Heat flows easily into the concrete surfaces during the day and is stored there. At night, as the surface cools, there is a flow of heat upward to balance the surface loss. This maintains the relatively higher temperatures at the surface, Thus, the city, with high thermal admittance, stores more heat during the day and gradually releases this heat at night. For these reasons, night temperatures in the city may be 10 to 15°F warmer than night temperatures over a rural field.

A study conducted in a copper smeltering area in Tennessee (Hursh, 1948)in which smelter fumes killed all the vegetation on an area of 4,940 acres before 1910 and has subsequently kept the area denuded has been a favorite subject of reference among scientists who try to study the influence of the forest on its environment. Hursh's study shows that the departure of maximum and minimum temperature of the forest from the open is as much as 1.2°C higher in February while in other months, especially September when the trees are in leaf, maximum temperatures are lowered by as much as 1.9°C. His study also shows that minimum temperatures in the forest are 1.0°C lower than in the open in most months with a maximum departure of -1.7°C in May.

Temperature extremes within the forest as stated above are generally less than the open when trees are in full leaf. Data collected by Spurr and Barnes (1980; Table 1) for a white pine plantation, showed that the range of summer air temperature was 15.9°C within the forest as compared to 21.6°C in the open. The temperature range in the winter was 19.4°C within the forest compared to 23.5°C in the open.

Table 1. Mean Weekly Maximum, Minimum, and Mean Temperatures (°C) in the Open and Under a Dense 20-year Old White Pine Plantation

	winter	spring	summer	fall
Open				
Maximum	5.1	22.8	29.7	14.2
Minimum	-18.4	-2.2	8.1	18.9
mean	-6.7	10.4	18.9	3.4
Under Forest				
Maximum	2.7	19.9	25.6	11.0
Minimum	-16.7	-2.8	9.7	-5.7
Mean	-7.1	9.8	17.7	2.7

Source: Spurr and Barnes (1980).

Forest and Precipitation

The idea of whether or not forests really increase precipitation has been a subject of debate among scientists for decades. Some scientists believe that the higher precipitation in forested areas is due to the moisture from forest transpiration, and that meteorological droughts result from forest cutting. Other scientists disagree with this idea and argue that forests exist as a result of abundant and frequent rainfall (Chang, 1982).

Both of the above opinions, however, are backed with strong evidence, making it difficult to give a clear conclusion. Before any evaluation is made, previous studies in connection with forest-precipitation should be scrutinized.

The earliest written opinion concerning the moistening effects of forests came from Christopher Columbus, who noticed that the forests in the West Indies have a great moistening effect on the island of Jamaica (Rakmanov, 1966). Numerous observations seem to confirm the long standing argument of a positive effect of forests on gross precipitation. Rainfall measurements near the cities of Nancy and Mantargis in France, near Vienna in Austria, and at various points in Germany, show that the rainfall over forests exceed the amount observed on neighboring treeless areas by 25 to 30% (Rakmanov, 1966). In a classic study, Hursh (1948) selected a most appropriate area: the Copper Basin in eastern Tennessee where 6,200 acres of forest land had been denuded by smelter fumes. Between the denuded area and the surrounding forest, there was a 10,000-acre zone (1.5-5 miles wide) which supported grass cover. Precipitation was measured at two stations in each zone over a 4-year period; the annual averages showed that forest precipitation exceeded that in the denuded area by about 14%. Studies conducted during 1948-50 in the vicinity of 71 meteorological stations within Moscow region (Rakmanov, 1966) showed a visible trend toward higher rainfall when forest cover was greater.

While many studies show that precipitation measurement is greater in forested areas, other studies indicate that forest have only a neglible direct effect upon the amount of precipitation (Brooks, 1928). For example, Chang and Lee (1973) argued that greater thunderstorm activity might be enhanced by greater ground surface heating in deforested areas which may increase the number of storm activities during the warmer months. Also, denuded lands may contribute more particulate dust to the air, thus increasing condensation nuclei in the atmosphere.

It is generally agreed that forests do effect the redistribution of precipitation under the canopy, but do not affect the precipitation above the canopy (Chang, 1982).

Climatic Study in the Nacogdoches Area

Spatial variation and characteristics of the climates in Texas have been reported by Lowry (1934), Portig (1962), Orton (1964, 1975), ESSA (1962), Tucker and Griffiths (1965), Carr (1966), Bomar (1983), and Larkin and Bomar, 1983 and a few others. Although these studies were not specifically for Nacogdoches area, they provided valuable information and references for the climate of Nacogdoches.

A few studies have been conducted in the past with direct and indirect interest in Nacogdoches climates. Haltom's (1880) brief description on the climatic characteristics of Nacogdoches was probably the earliest documentation found in the literature. However, no sources as to where he obtained the basic climatic statistics were given in his report. Obviously, the data were not obtained from the official records of the National Weather Service (NWS) since these official records did not begin prior to 1892.

Among the most recent studies on the climate of Nacogdoches were those of Reeves' (1976b,c,d) articles in the Daily Sentinel (local newspaper), Aguilar's (1979) masters thesis, Chang's *et al*. (1980)

analyses on the spatial distribution of precipitation and temperature in forested East Texas, and Chang's (1981) analysis of hourly rainfall activities.

There are three routine climatic observations in the Nacogdoches area. The National Weather Service (NWS) has maintained a climatic station in the city of Nacogdoches since 1892; the U.S. Forest Service (USFS) and the School of Forestry, Stephen F. Austin State University (SFASU) both have had a climatic station since 1954. In his study of temperature and precipitation records collected from the SFASU Climatic Station during the 1965-75 period, Reeves (1976b,c,d) stated that despite some extreme meteorological events in Nacogdoches, the climate generally had not changed much since 1965. Reeves (In Press) compared the NWS and the SFASU Climatic Station data for the period 1965-84 and found significant differences in both precipitation and temperature for some of the months.

Climatic conditions vary from place to place, and the magnitude of differences is an interesting subject to study. Chang et al. (1980) conducted an analysis on the spatial characteristics of the temperature and precipitation data collected at 39 stations, including Nacogdoches, over a 30-year (1941-70) period in East Texas. Mathematical equations were derived to simulate the spatial distribution of precipitation in this study area. As reported elsewhere, annual mean temperatures were found to decrease with an increase of latitude at a lapse rate of about 1.34°F/degree.

Knowledge of rain in terms of frequency occurrence, intensity, and duration is indispensible information in water resource planning and management. Chang (1981) analyzed hourly NWS rainfall data at Nacogdoches over a 21-year period and stated that summer (May-Oct) storms are of higher intensity, lower frequency, shorter duration, and had more afternoon occurrences than other seasons. Rainfall intensity in the Nacogdoches area can be estimated as a function of storm duration and probability level (return period). Frequency of storm occurrence and storm intensity were found to decrease with the increase in storm duration.

Thus far, probably the most comprehensive study of the climate of Nacogdoches was conducted by Aguilar (1979). To examine the relationship between climatic variation and growth of loblolly pines growing in the SFA Experimental Forest, he used a time series covering 56 years (1915-70) of data. Five variables were employed to study climatic fluctuation through correlogram and spectrum analysis: annual precipitation, number of days with precipitation equal to or greater than 0.01 inch, annual mean temperature, annual mean maximum temperature, and number of days with maximum temperature equal to or greater than 90°F. The result showed that rain days and previous summer rainfall have a positive effect on the radial growth while a negative effect occurred between the temperature range and the radial growth of the loblolly pine. Rain days were found to have a tendency toward a 4-year cycle in Nacogdoches.

The studies mentioned above either used data covering only a short period of time or included only a few climatic elements in the analyses.

A more comprehensive study using all available climatic records is, therefore, desirable to provide climatic information that can be used by a wide range of disciplines for planning and managing various operations and activities.

STUDY AREA

Nacogdoches, the oldest town in Texas, is the setting of the courthouse of Nacogdoches county (Figure 1). It is about 125 miles north of Houston and 160 miles southeast of Dallas. The area is characterized by gently rolling slopes with elevations hardly above 585 feet. The city is well-drained by two creeks, La Nana in the east and Banita Creek in the west. Banita Creek joins La Nana Creek south of downtown Nacogdoches, flows southerly into Angelina River, and drains south into Sam Rayburn Reservoir.

The county is mostly dominated by secondary growth of loblolly pines with scattered hardwoods. East Texas' forests attracted many lumber companies when the white pine of the northeastern United States was exhausted in the late 19th century. The land once covered with forest was denuded by the 1920s due to exploitative harvesting and poor management practices. These companies were again forced to move elsewhere (Maxwell and Martin, 1970). Cotton and other agricultural crops were grown on these "waste lands". Reforestation was initiated in the early 1930s to revive the forested area.

Nacogdoches is characterized by a humid subtropical climate with prevailing winds from the southeast. Aguilar (1979) reported that the average rainfall for the 1941-70 period was 47.5 inches with 50% of it occurring in the growing season. Mean monthly temperature ranges from 47.0°F in January to 82.7°F in August with an average value of 65.7°F.

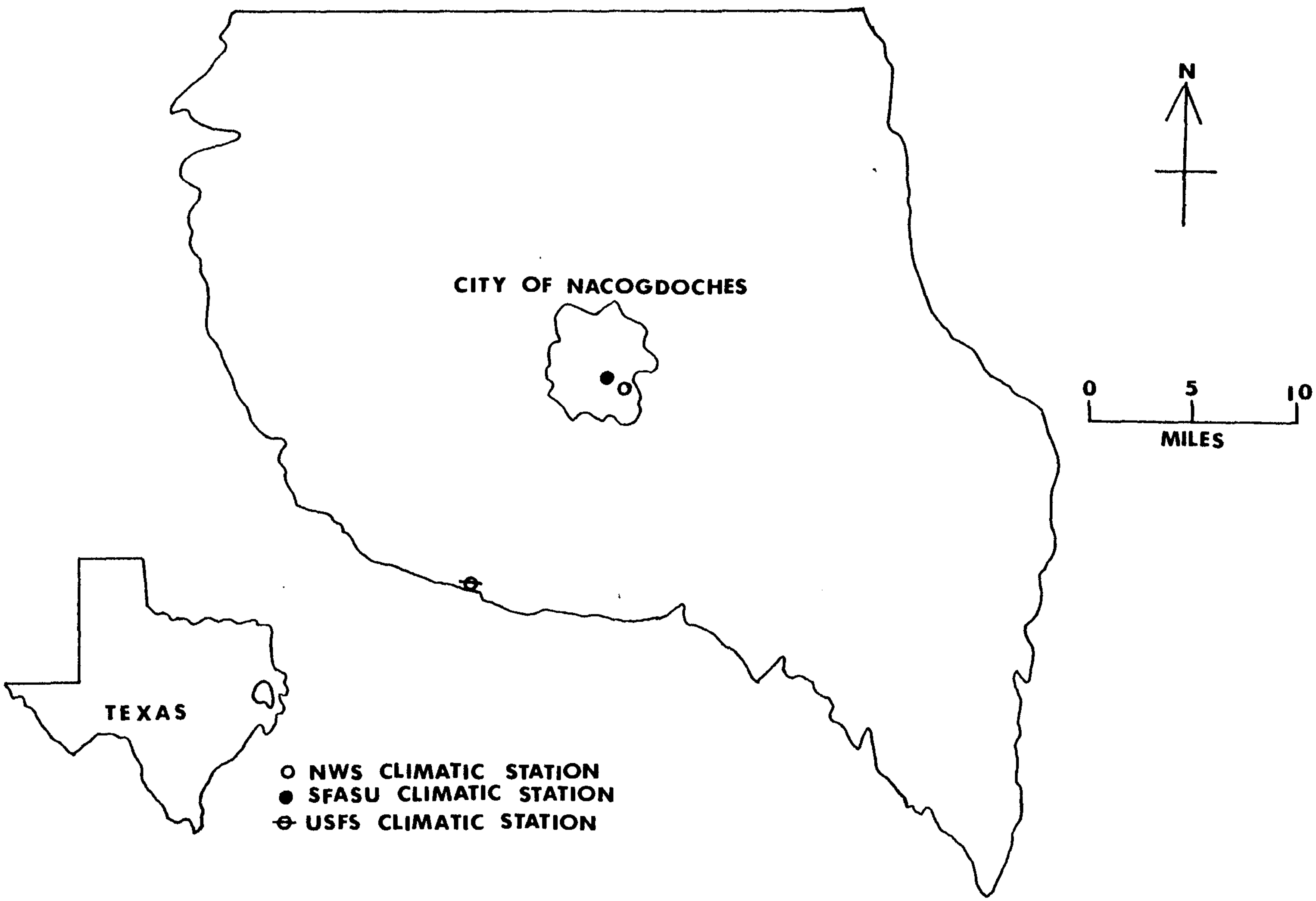

Figure 1. Location map of climatic stations in Nacogdoches County, Texas.

In summer, the total water deficit is about 5.2 inches while a surplus of 18.3 inches occurs in winter and spring. The potential evapotranspiration/precipitation ratio is about 0.78.

CLIMATIC DATA

Climatic observations

According to the National Archives located at the User Service Branch, National Climatic Center, Federal Building, Asheville, North Carolina and the "Report on Substation" files kept in the National Weather Service (NWS), Beaumont Airport, Texas, the collection of daily precipitation and temperature data at Nacogdoches were started as early as 1892 by Mr. L. Westfall under the supervision of the Weather Bureau, which was then a branch of the U.S. Department of Agriculture. However, the collections only lasted for 11 months and did not continued until October 1899 by Mr. H. H. Cooper. The station was located beside the one-story post office building in downtown Nacogdoches (about 94°38W. Longitude and 31°36' N Latitude).

Since the meteorological data were usually collected by volunteers, changes in both the observers and the station location from time to time were inevitable. The station has been moved among nine different locations in the city of Nacogdoches and the data have been collected by 22 different observers and occasional substitutes since 1892. During the history of observation, the longest period operated by a single observer was 42 years (Jun 1, 1903 to Jan 31, 1945) by Ms. Mary Hofmann. The staff of KSFA Radio Station has collected the climatic data since 1948 and is the second longest group of observers in service. The longest time at which the station location remained at a particular site was 39 years (1906-45) and was near Ms. Mary Hofmann's residence. Figure 2 shows the Cotton Region Shelter at the porch of Ms. Hofmann's house in the winter of 1925.

Although the station has been moved nine times in its history, none of its movements had a distance greater than 3.5 miles from the original location and the shortest distance was 30 feet from its previous site. The present station has been located at the compound of KSFA Radio Station at 3007 Martinsville Road. It has been there since 1973. Table 51 of Appendix I summarizes the history of the climatic observations at the NWS Climatic Station, Nacogdoches since 1901.

Apart from the official NWS Climatic Station, there are two other climatic stations being operated in the Nacogdoches area - the Stephen F. Austin State University (SFASU) Climatic Station and the U.S. Forest Service (USFS) Climatic Station. The SFA Climatic Station presently located near the southeastern side of the university campus in Nacogdoches, has been in operation since 1954. It is about 1.2 miles northwest of the NWS Climatic Station. Daily collections of climatic data from the station include maximum and minimum air temperature, precipitation, atmospheric pressure, pan evaporation, total wind movement at the ground level and relative humidity. Solar radiation has been observed with a mechanical pyranograph since 1982. The USFS Climatic Station is located in the northeast area of the SFA Experimental Forest, about 10 miles southwest of Nacogdoches and has operated since 1954. Only daily precipitation and temperature are being collected at the station. The relative location of the three climatic

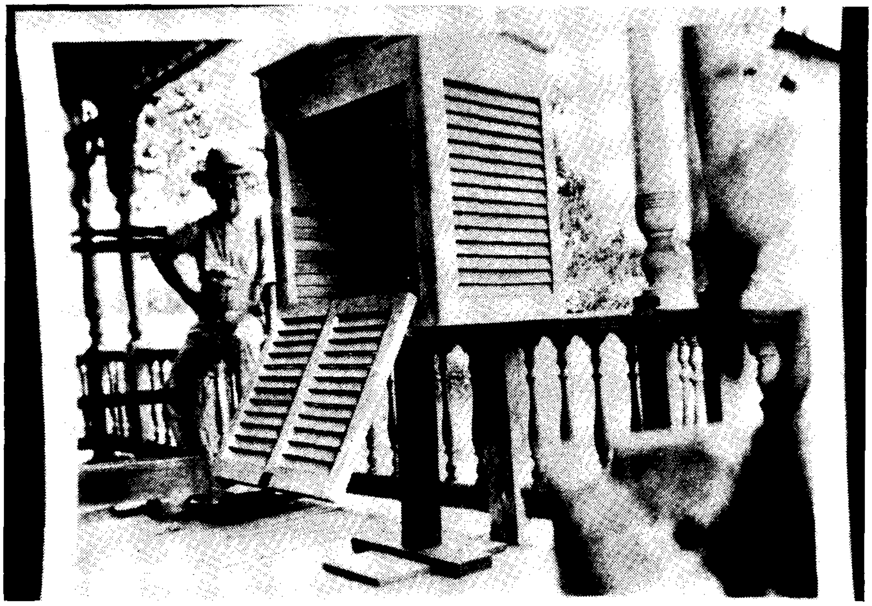

Figure 2. The Cotton Region Shelter located at the front porch of Ms. Hofmann's house with one of the earlier observers, Mr. Cooper, taken in 1925.

stations is shown in Figure 1 while Table 2 shows some simple statistics on data collected during the 1965-80 period.

Analyses in the following chapters are primarily based on the NWS data, however, it might be interesting to note that Reeves (In Press) performed some statistical analyses on the NWS and SFASU Climatic Stations for the 1965-84 period. Since the NWS Station was moved in 1973 and the data were incomplete, he used the periods 1965-72 and 1974-84. He found that the mean total precipitation in January and November for the NWS Climatic Station was significantly lower than the SFASU Climatic Station for the 1965-72 and 1974-84 periods, respectively. He also found that the mean monthly temperatures were significantly different in the months of February, April, May, June, July, August, and September during the 1965-72 period while during the latter period, the folowing months were significantly lower: January, March, April, May, June, July, September, November, and December. Higher temperatures were recorded during the earlier period because the instruments were located in a parking lot downtown where reflection and reradiation from nearby objects (cars, buildings, etc.) and pavement of the parking lot itself were high. There were no definite reasons to explain the causes of differences in temperatures for the second period since both locations have similar physical features.

Source of Climatic Data

Precipitation and Temperature

Daily precipitation and daily maximum and minimum temperature have been the most important climatic observations at Nacogdoches and are

Table 2. Simple Statistics on Some Climatic Variables for Three Climatic Stations at Nacogdoches, Texas, 1965-80

Month		NWS					SFASU					USFS				
		Rainfall		Temperatures(°F)			Rainfall		Temperatures(°F)			Rainfall		Temperatures(°F)		
		Depth (in)	Day	Max	Mean	Min	Depth (in)	Day	Max	Mean	Min	Depth (in)	Day	Max	Mean	Min
Jan	Mean	4.31	9	55.9	45.7	35.4	4.64	12	55.8	46.3	35.3	4.49	10	55.2	45.3	35.4
	S. D.	2.79	4	5.97	4.97	4.40	2.83	5	6.05	5.81	4.61	2.51	4	5.57	4.71	4.21
Feb	Mean	3.84	8	60.4	47.2	35.2	4.03	10	60.8	48.8	35.9	3.15	7	60.0	48.3	36.6
	S. D	2.90	3	4.66	3.76	3.14	2.95	3	5.56	4.71	4.39	1.65	2	5.17	4.63	4.52
Mar	Mean	3.79	9	68.6	57.2	45.6	3.77	11	68.5	55.8	44.1	3.42	9	67.9	56.4	44.9
	S.D.	2.19	3	4.54	4.04	3.95	2.05	4	3.92	4.54	4.86	1.94	2	5.55	5.25	5.24
Apr	Mean	4.40	7	77.5	65.4	53.8	4.40	9	76.4	64.9	53.2	4.34	8	76.8	65.7	54.6
	S. D	2.62	3	2.94	2.63	3.33	2.70	4	2.06	3.07	3.54	2.35	3	3.15	3.23	3.70
May	Mean	5.31	8	83.6	72.7	61.7	5.36	10	81.6	71.2	60.6	5.05	8	82.5	71.7	60.8
	S. D.	2.45	3	1.72	1.80	2.27	3.22	4	1.67	1.83	3.42	2.82	3	2.38	2.34	2.79
Jun	Mean	3.90	6	89.9	78.0	66.6	3.89	7	89.3	77.4	65.6	3.84	7	89.3	78.4	67.4
	S. D.	2.52	4	2.24	1.74	1.81	2.47	5	3.20	1.46	1.37	2.62	4	2.57	2.03	1.87
Jul	Mean	2.99	6	93.6	82.5	71.3	3.31	8	92.8	81.1	69.5	3.34	7	93.1	81.8	70.5
	S. D.	2.03	3	3.03	2.14	1.45	2.41	3	3.02	1.88	1.67	2.24	3	3.34	2.28	1.86
Aug	Mean	2.70	8	93.3	81.7	70.0	2.56	9	92.3	80.3	70.0	3.03	7	92.7	81.0	69.2
	S. D.	1.59	3	2.07	1.58	3.15	1.29	3	2.84	1.85	5.56	1.92	3	2.04	1.77	1.95
Sep	Mean	3.76	8	87.6	75.5	64.0	3.93	10	87.3	75.8	64.0	3.98	8	86.5	75.5	64.5
	S. D.	2.36	2	79.2	66.2	3.15	2.20	2	3.57	2.89	2.94	2.44	2	3.20	3.17	3.57
Oct	Mean	3.62	5	68.5	55.5	53.1	3.16	7	78.9	65.7	51.3	3.58	6	78.0	64.7	51.5
	S. D.	2.26	3	4.37	3.68	3.40	1.75	4	3.26	3.22	4.00	3.24	3	3.39	3.43	4.25
Nov	Mean	3.68	6	61.3	49.8	38.1	3.87	11	68.1	56.1	42.6	3.29	6	67.0	55.5	43.3
	S. D.	2.01	3	2.96	2.97	3.35	1.63	3	4.73	5.92	5.71	1.83	4	5.01	4.86	5.44
Dec	Mean	4.12	9	61.3	49.8	38.1	3.87	11	61.1	49.0	36.7	3.92	8	60.1	48.1	36.4
	S. D.	1.56	3	2.96	2.97	3.35	1.63	3	3.59	3.95	4.85	1.65	4	2.40	3.24	3.99
Ann	Mean	44.1	88	76.9	64.9	53.3	46.6	113	76.1	64.5	52.2	45.50	90	75.6	63.9	52.2
	S. D.	11.0	13	1.23	0.89	0.86	13.7	18	1.31	1.27	1.97	10.88	13.5	2.00	1.72	2.12

available from the NWS since 1900. They are official climatic records of the United States and the major source of data used by federal and state agencies as well as private organizations for characterizing the local or regional climate. These data, provided by the Texas Department of Water Resources through Texas National Resources Information System for the period between 1901 and 1983 on magnetic tape, were used as primary information for analysis and characterization of Nacogdoches' climate in this study. Because of numerous missing data, records prior to 1901 were not used in the analyses.

Precipitation and temperature data have also been collected at the campus of SFASU, Nacogdoches and in the SFA Experimental Forest by the USFS since 1954. These data were used as reference information in this study.

The U.S. National Weather Service has also collected hourly rainfall data through a weighing-type recording raingauge installed near the standard raingauge at Nacogdoches since 1965. Again, the hourly rainfall data were provided by the Texas Department of Water Resources on magnetic tape and were used to study rainfall intensity and storm activity in this area.

Streamflow and Floods

Daily streamflow data of La Nana Creek have been observed at the downstream side of the bridge on Farm Road 1878 (Starr Avenue) in Nacogdoches by the U.S. Geological Survey since October 1964. These records are published in the USGS Water Resources Data - Texas every year and were used to study flood frequency, magnitude, and duration in the Nacogdoches area. The occurrence of floods and their damages were collected from the back issues of the local newspaper (Daily Sentinel) since early 1900.

Humidity

Humidity characteristics were studied based on the humidity data collected at the SFASU Climatic Station by the School of Forestry, SFASU since 1965.

Solar Radiation

Time of sunrise and sunset everyday, duration of daylight, and potential solar radiation at Nacogdoches were calculated using the methods described by List (1971) and Frank and Lee (1966). Average net radiation for each month were estimated using the method described by Chang (1982).

Wind Movement

There were no wind observations made by the NWS in the Nacogdoches area. The closest one, observed at 16 feet above the ground at the Lufkin Airport about 25 miles south of Nacogdoches, is a good reference for general wind movement and direction in this area. Chang *et al*. (1980) summarized these observations made between August 1948 and July 1956 and were used as general information in this study.

CLIMATOLOGICAL ANALYSIS AND CHARACTERIZATION

1. The daily precipitation and temperature data collected above were used to generate the following climatic parameters for characterizing climatic conditions at Nacogdoches:

Precipitation

a. Total precipitation, by month and year,
b. Total number of rain days, by month and year,
c. Occurrences of dry-spells in different lengths, by year,
d. Occurrences of wet-spells in different lengths, by year,
e. Maximum daily precipitation, by month and year,
f. Frequency of occurrences,in days, for different amounts of daily precipitation, by month and year,
g. Greatest number of consecutive rain days, by month and year,
h. Greatest number of consecutive dry days, by month and year.

Temperature

a. Mean temperature, by day, month, and year,
b. Mean maximum temperature, by month and year,
c. Mean minimum temperature, by month and year,
d. Number of days with maximum daily temperature greater than 90°F, by year,
e. Number of days with minimum daily temperature less than 32°F by year,
f. Recorded highest maximum daily temperature by month and year,

g. Recorded lowest minimum daily temperature by month and year,

h. Heating degree days based on 65°F, by month and year,

i. Cooling degree days based on 65°F, by month and year,

j. Number of days with mean daily temperature less than 32°F occurred,

k. Time of year with the first minimum daily temperature less than 32°F occurred,

l. Time of the year with the last minimum daily temperature less than 32°F occurred,

2. The parameters generated above were tabulated for cross-examination, plotted for illustration of their fluctuation, and summarized through calculating means and standard deviations for every 30-year period ending at every decade and for the total records. The commonly used frequency distributions were performed on principal climatic variables to predict future events.

3. The characteristic hourly rainfall at Nacogdoches has been studied by Chang (1981) using 21 years (1955-76) of NWS rainfall record. Chang's (1981) study were repeated to include the newly available data (i.e. 1977-80). However, Chang's (1981) study did not include storm rainfall of shorter durations (in minutes) which are included in the present analyses.

5. The USGS streamflow data collected from La Nana Creek since 1964 were analyzed to construct flow duration curves, to estimate extreme events, and to examine any association of streamflow with climatic conditions. These analyses were performed using data collected for the

entire period (i.e., 1961-84) and for two separate segments (1964-74 and 1974-84) for evaluation of possible effects of urbanization on streamflows in La Nana Creek.

6. Historical data of hay production per unit area in Nacogdoches County were collected from reports compiled by the Texas Crop and Livestock Reporting Service of the Texas Department of Agriculture. Simple correlation coefficients were employed to evaluate the association of climatic variables with hay production in the study area, and step-wise multiple regression analyses were used to develop a prediction model for hay production for year to year.

RESULTS AND DISCUSSION

Solar Climate

The energy required for plant growth, the hydrologic cycle, and the thermal environment of earth comes from the sun. Solar energy is also a major factor affecting climatic variations and biological activities. Measurements of the flux density of the solar beam at normal incidence outside the atmosphere at the mean solar distance during the current century have varied between 1.94 and 2.06 ly $\min^{-1}$. When penetrating the atmosphere, the flux density is screened by atmospheric gases, solid colloidal substances, and moisture clouds. These substances and water vapor reflect a portion of the solar radiation energy to space, and diffuse or scatter a portion over the sky (sky radiation). Direct solar radiation is subject to the cosine law of the angle of incidence as varied with the time of day, season of year, terrestrial latitude, and slope aspect and inclination.

Measurements of solar radiation at the surface level are not routine activities at the NWS climatic stations. The closest stations around Nacogdoches with observed solar radiation data, either in the past or at the present, are College Station (100 mi), Fort Worth (250 mi), and Shreveport, La (70 mi). However, direct solar radiation at any surface can be adequately defined by solving trigonmetric functions (Humphreys, 1940; Frank and Lee, 1966; Buffo *et al.*,1972). These mathematical solutions provide the upper limits which can be served as a means of comparing solar climate for various locations and as a base for evaluating atmospheric screening effects.

Sunrise and Sunset

The altitude of the sun (a, angular elevation above the horizon) is a function of solar declination δ, the latitude of the observer ϕ, and the hour angle of the sun (wh, angular distance from solar noon), or

$$\text{Sin } a = \text{Sin } \phi \text{ Sin } \delta + \text{Cos } \phi \text{ Cos } \delta \text{ Cos } wh \qquad (1)$$

where wh is the product of the angular velocity (w) of the earth's rotation ($\pi/12$ radians per hour) and the elapsed time (h) from the solar noon. The times of sunrise or sunset can be defined when $a = 0°$, $\text{Sin } 0° = 0$, or

$$\text{Cos } wh = - \text{Tan } \phi \text{ Tan } \delta \qquad (2)$$

Values of ϕ and δ are positive for north latitudes and negative for south latitudes and wh is negative before the solar noon and positive after the solar noon. The magnitude of δ depends on the position of the earth in its orbit and can be approximated by

$$\delta = 23.5 \text{ Sin } n° \qquad (3)$$

where n is the number of days before (-) or after (+) the nearest equinox. The times of sunrise, sunset and daylight hours for every 15 days at Nacogdoches, Texas are plotted in Figure 3. Detailed information on the time of sunrise and sunset throughout the whole year can be found in Table 52 of Appendix II. It shows that the earliest hour of sunrise at Nacogdoches is at 5:13 a.m. on June 5-18 while the latest is 7:19 a.m on January 2-16. The lapsed time is 2 hours and 6 minutes. The table was provided by the local KTBC(KSFA) Radio Station

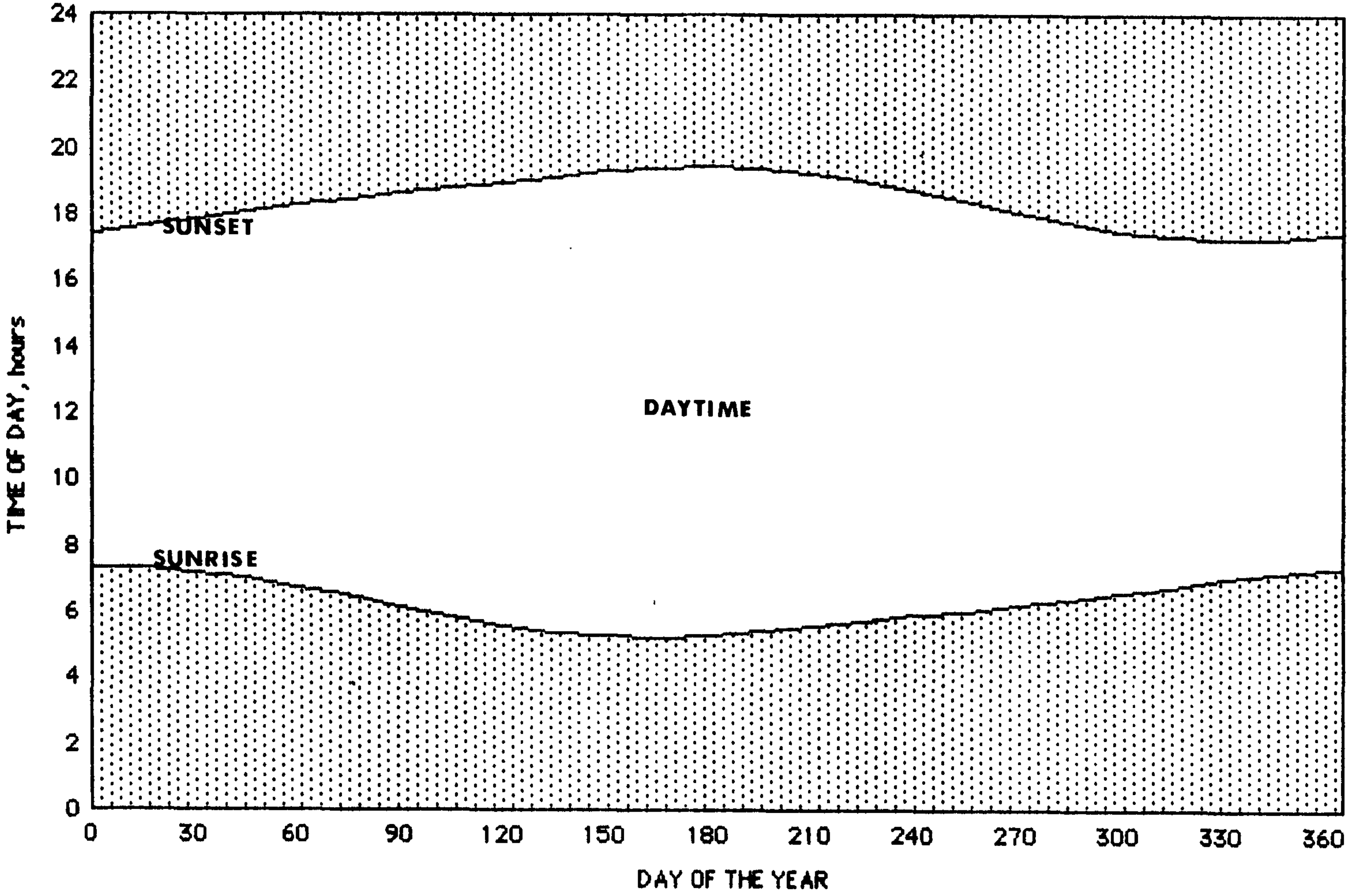

Figure 3. Time of sunrise and sunset along with the hours of daylight for various days of the year at Nacogdoches, Texas, Lat., 31:36N; Long., 94:40W.

and was calculated using Equation 2 with $\phi = 31.6°N$.

Duration of Daylight

Daylight is defined as the interval between sunrise and sunset. The duration of daylight at Nacogdoches for the four major orbital positions of the earth is given below:

Vernal equinox (March 21)	12 hr 9 min
Summer solstice (June 21)	14 hr 11 min
Autumnal equinox (September 23)	12 hr 7 min
Winter solstice (December 21)	10 hr 5 min

At the time of summer solstice, the sun appears directly overhead at noon of 23.5° North Latitude (Tropic of Cancer) and the length of the day reaches its maximum. At winter solstice, the sun reaches the southernmost point in its annual migration (23.5° South Latitude, Tropic of Capricorn), the length of the day is at its minimum value. The duration of daylight for each day at Nacogdoches is given in Table 53 of Appendix II.

Potential Solar Beam Irradiation

Potential solar beam radiation is a purely theoretical parameter neglecting the screening effects of the atmosphere. Thus, it is the upper limit of solar radiation and is proportional to the Cosine angle of the incidence Z, or

$$I_p = (I_o/r^2)\text{Cos } Z \qquad (4)$$

where Z is the sun's zenith distance (i.e. 90 - a), I_o is the solar constant, r is the ratio of the earth-sun distance and its mean, and I_p is the potential flux density on a plane parallel to the earth's surface. The zenith distance is affected by solar declination, latitude, and time angle in a manner similar to Equation 1. Thus Equation 4 can be written as:

$$I_p = (I_o/r^2)(\text{Sin}\phi\ \text{Sin}\delta + \text{Cos}\phi\ \text{Cos}\delta\ \text{Cos wh}) \tag{5}$$

The maximum value of I_p is reached when

$$\text{Cos Z} = \text{Sin}\phi\ \text{Sin}\delta + \text{Cos}\phi\ \text{Cos}\delta\ \text{Cos wh} = 1$$

or when wh = 0° (the sun is at the solar noon) and $\phi - \delta = 0$. The greatest solar declination is 23.5° which occurs at summer solstice in the Northern Hemisphere. Thus the instantaneous flux density of solar radiation at noon and at 23.5°N. Latitude on June 21 is the all time maximum in the Northern Hemisphere. Nacogdoches is located at about 31.6°N. Latitude; the smallest difference between ϕ and δ occurs at the summer solstice and consequently the greatest I_p.

Daily total of I_p can be obtained by integration of Equation 5 from sunrise to sunset. The total potential solar beam irradiation for certain selected days of the year at 30° and 32° N. Latitudes (Nacogdoches area) is listed in Table 3 (Frank and Lee, 1966).

Global Radiation

Solar radiation reaches the earth's surface in 2 different ways. One is the part of direct solar radiation I that is not reflected, absorbed, or diffused by the atmosphere. The other is that part of diffusely scattered radiation H that reaches the ground and provides the daylight within the visible spectrum. The sum of I and H is called global radiation R_s, or

$$R_s = H + I. \tag{6}$$

The 1980 monthly and annual global radiation observed at the SFASU Climatic Station (via R401-Mechanical Pyranograph, Weekly Weather Measure Corp.), Nacogdoches, Texas are given in Table 4. Observed data of global radiation were lower than that of the long-term averages interpolated from the Climatic Atlas of the United States (U.S. Dept. of Commerce, 1968). Annual precipitation and total number of rain days in 1980 were 34.51 inches and 78 days, respectively, which were 13.02 inches and 15.4 days below normals (1941-70). Drier weather implies less cloudy skies which would lead to a greater incoming solar radiation at the ground surface. It is not clear why lower radiation was observed in a dry year such as 1980 as compared to the long term averages. Further comparisons need to be made when more observation data become available. Probably the pyranograph needs to be tested and calibrated for accurate measurements.

Table 3. Daily Total Potential Insolation (in langleys) at Horizontal Surface for Some Selected Days at 30° and 32°N. Latitudes

Dates	30°	32°
June 22	1005.1	1010.4
June 1, July 12	994.9	998.6
May 18, July 27	976.3	977.3
May 3, Aug 10	947.3	944.6
Apr 19, Aug 25	906.9	899.7
Apr 4, Sep 9	855.7	843.8
Mar 21 , Sep 23	794.2	777.7
Mar 7, Oct 8	726.8	706.2
Feb 20, Oct 22	658.5	634.5
Feb 7, Nov 5	594.4	567.8
Jan 23, Nov 19	540.9	512.6
Jan 10, Dec 3	502.4	473.1
Dec 22	479.6	449.7

Table 4. Global Radiation observed at Nacogdoches, Texas in 1980 Versus the Long-Term Averages Interpolated from the Climatic Atlas of the United States (U.S. Dept of Commerce, 1968)

Month	1980 (ly/day)	Long-term Average (ly/day)
January	177	241
February	303	306
March	407	406
April	388	467
May	382	560
June	493	604
July	476	596
August	456	561
September	334	459
October	319	379
November	238	280
December	195	225
Annual	347	423

Net Radiation

The global radiation R_s given in Equation 6 is subjected to reflection when it reaches the ground surface. Magnitudes of the reflected shortwave radiation R depend on the altitude of the sun, wavelength, and the surface characteristics of the ground such as color, water content, and roughness, etc.

All objects emit radiation as long as their temperature is greater than absolute zero. Thus, there is a continuous exchange of radiation between the ground surface and the sky (atmosphere). However, this exchange of radiation is conducted with wavelengths greater than 4.0 , or so-called longwave or infrared radiation as compared to the shortwave of the sun. The incoming longwave radiation from the atmosphere is called counterradiation σT^4 since it counteracts the terrestrial radiation loss of the earth G.

The algebraic sum of all the items given above is termed as the net radiation Rn, or

$$R_n = R_s - R + G - \sigma T^4 \qquad (7)$$

where is the Stephen-Boltzmann constant (8.26×10^{-11} ly/min.°K^4) and T is the surface temperature in °K. The values of R_n can be estimated by a method described by Chang (1982) if actual observations are not available:

$$R_n = I_p(1-r)(0.3+0.5n/N) - \sigma T^4(0.56-0.09\sqrt{e_d})(0.1+0.9n/N) \qquad (8)$$

where r = albedo of the surface, or the ratio between R and R_s.

T = air temperature in °k,

n/N = percent of sunshine,

e_d = actual vapor pressure of the air in mm of mercury,

and I_p and σ have been defined previously. The R_n for some selected days of 1980 for Nacogdoches, Texas, is presented in Table 5.

Table 5. Potential Flux Density on a Plane Parallel to the Earth and Net Radiation for Some Selected Days at Nacogdoches, Texas, 1980

	Selected Dates of 1980															
	Mar 21	Apr 13	May 6	May 29	Jun 22	Jul 15	Aug 8	Aug 31	Sep 23	Oct 16	Nov 8	Nov 30	Dec 22	Jan 13	Feb 4	Feb 26
I_p	783	881	954	997	1007	990	946	872	773	663	559	483	455	485	562	671
R_n	279	360	434	495	568	527	490	449	389	379	187	223	76	109	152	202

Notes: All figures were rounded off.

Precipitation Climate

Precipitation is the major input in the hydrological cycle and is one of the most important elements in the physical environment of the earth. It is generally characterized in terms of depth, intensity, duration, number of storms (rain days), frequency on occurrence, areal distribution, and temporal variation. Knowledge on the characteristics of precipitation is an invaluable asset to man's daily activities, agricultural and forestry production, water resources planning, management, sports, and many other operations.

The precipitation analyses on this study are based on records available on magnetic tape obtained from the Texas Natural Resources Information System (TNRIS), Texas Department of Water Resources. The term 'precipitation' used here includes all forms of water particles or hydrometeors that fall to the ground. Only measurable amounts of rain or melted snow with depths equal to or greater than 0.01 inch were considered. Frequency of rain was counted by number of days with amounts of rain equal to or greater than 0.01 inch. Mean precipitation is the arithmetic average of all the individual amounts occuring within the period in question such as daily, monthly, or annual covered by the specific period of observation. Some errors are expected to arise in the process of forming arithmetic means or averages. Griffiths (1966), however, stated that:

> For any one station with an annual mean above 15 inches [of rain], there is about 75% chance that the annual totals shows a normal distribution ... In order to get a reliable mean value, due to these fluctuations, it is necessary to use 30 years of records because the standard error of the mean

> then be about 0.3x ± 0.04, or about 1.5 inches for a mean of 40 inches [of rain].

Precipitation and temperature averages based on 30 years of records are referred by the World Meteorological Organization (1967) as the normal; it is used to characterize the long-term conditions of a local climate. The normal precipitation (also for other variables in this study) for the 1980's is the arithmetic average for the period of 1951-80. Some simple statistics of the entire precipitation records (1901-80) at Nacogdoches, Texas are summarized in Table 6 and detailed discussion of the precipitation characteristics are given below:

Total Precipitation

Annual. The annual precipitation for the 80 years (1901-80) of observation at Nacogdoches, Texas (Table 54 of Appendix III) ranged from 28.09 (1954) to 74.27 (1957) inches with a mean and standard deviation of 45.96 and 11.58 inches, respectively. The difference and ratio between the maximum and minimum precipitation was as much as 46.18 inches and 2.64, respectively. This range and ratio were comparable to that of Center, Texas, another station with long records of precipitation located about 30 miles northeast of Nacogdoches (Bomar, 1983).

Throughout the period of records, there were 10 years having annual precipitation less than 35.00 inches and five years with precipitation greater than 65.00 inches. The greatest difference in precipitation between two consecutive years (1956-57) was 39.81 inches in which precipitation increased from 34.46 inches to 74.27, or 215.5%.

Table 6. Some Simple Statistics of Precipitation Records for Nacogdoches,Texas, 1901-80

Month	Total Precipitation				Number of Rain Days				Maximum Daily Rainfall	
	Mean	S.D.	Maximum	Minimum	Mean	S.D.	Maximum	Minimum	Depth	Year
Jan	4.03	2.34	11.61(1932)	0 (1911)	9.0	4.4	22(1937)	0(1911)	4.12	1966
Feb	3.91	2.19	12.80(1910)	0.58(1916)	8.1	3.2	17(1948)	1(1916)	7.63	1975
Mar	3.81	2.08	8.46(1969)	0.55(1971)	8.2	3.2	16(1945)	1(1916)	3.80	1922
Apr	4.72	2.53	13.96(1957)	0.48(1930)	7.4	3.0	16(1957)	1(1903)	6.78	1922
May	5.13	3.15	16.60(1935)	0.61(1911)	7.5	3.3	16(1965)	2(1937)	7.48	1935
Jun	3.68	2.56	14.22(1902)	0.21(1907)	6.7	3.4	17(1919)	1(1934)	14.22	1902
July	3.60	2.54	12.72(1933)	0 (1970)	7.2	3.3	16(1902)	0(1970)	8.20	1933
Aug	2.54	1.88	7.85(1915)	0 (1924)	6.3	3.2	14(1920)	0(1924)	3.37	1920
Sep	3.24	2.69	12.39(1913)	0 (1912)	6.3	3.2	17(1913)	0(1912)	4.83	1958
Oct	3.14	2.85	13.24(1949)	0 (1952)	5.0	3.1	15(1949)	0(1952)	9.13	1941
Nov	4.21	2.95	18.85(1940)	0.35(1933)	7.0	3.3	17(1957)	1(1949)	8.85	1940
Dec	4.78	2.31	10.51(1911)	0 (1910)	8.6	3.4	18(1932)	1(1923)	5.90	1939
Annual	45.96	11.84	74.27(1957)	28.09(1954)	87.4	16.5	120(1949)	50(1917)	14.22	1902

Notes: 1. Total precipitation and maximum daily rainfall are in inches.
2. The number in each parenthesis refers to the year of occurrence.
3. S.D. means standard deviation.

The three consecutive years ending with 1956 were the driest 3-year period in the records. Its average annual precipitation was only 32.46 inches and the highest annual total was 74.27 inches in 1957, the wettest year ever recorded at Nacogdoches. The wettest 3-year period was 1944-46 in which the average annual precipitation was 61.77 inches, about 190.3% of the driest 3-year period.

Figure 4 is a plot of annual precipitation data (1901-80) versus time for the NWS Weather Station at Nacogdoches, Texas extracted from Table 54 of Appendix III. There seemed to be no particular trend that could be observed from this plot. Coefficient of variation of the entire period was 0.234, a coefficient which is typical in humid East Texas and much smaller than those of West Texas stations. Statistically, there was about a 16% chance that the observed annual precipitation was either less than 35.51 inches or greater than 57.19 inches. In other words, 68% of the annual precipitation observations would fall between 35.51-57.19 inches.

As mentioned previously, the normal precipitation used to characterize any particular period of time is referred to as the mean of three complete decades immediately before the period of time in question. Thus, the entire 80 years of observation can be used to calculate six different periods of normal, i.e., 1901-30, 1911-40, 1921-50, 1931-60, 1941-70, 1951-80. The normal annual precipitation corresponding to the 6 periods mentioned above were 46.20, 46.10, 48.31, 48.04, 47.53, and 44.70 inches (Table 7). Apparently, the normal based on 1921-50 had the greatest precipitation (48.31 inches) while the most

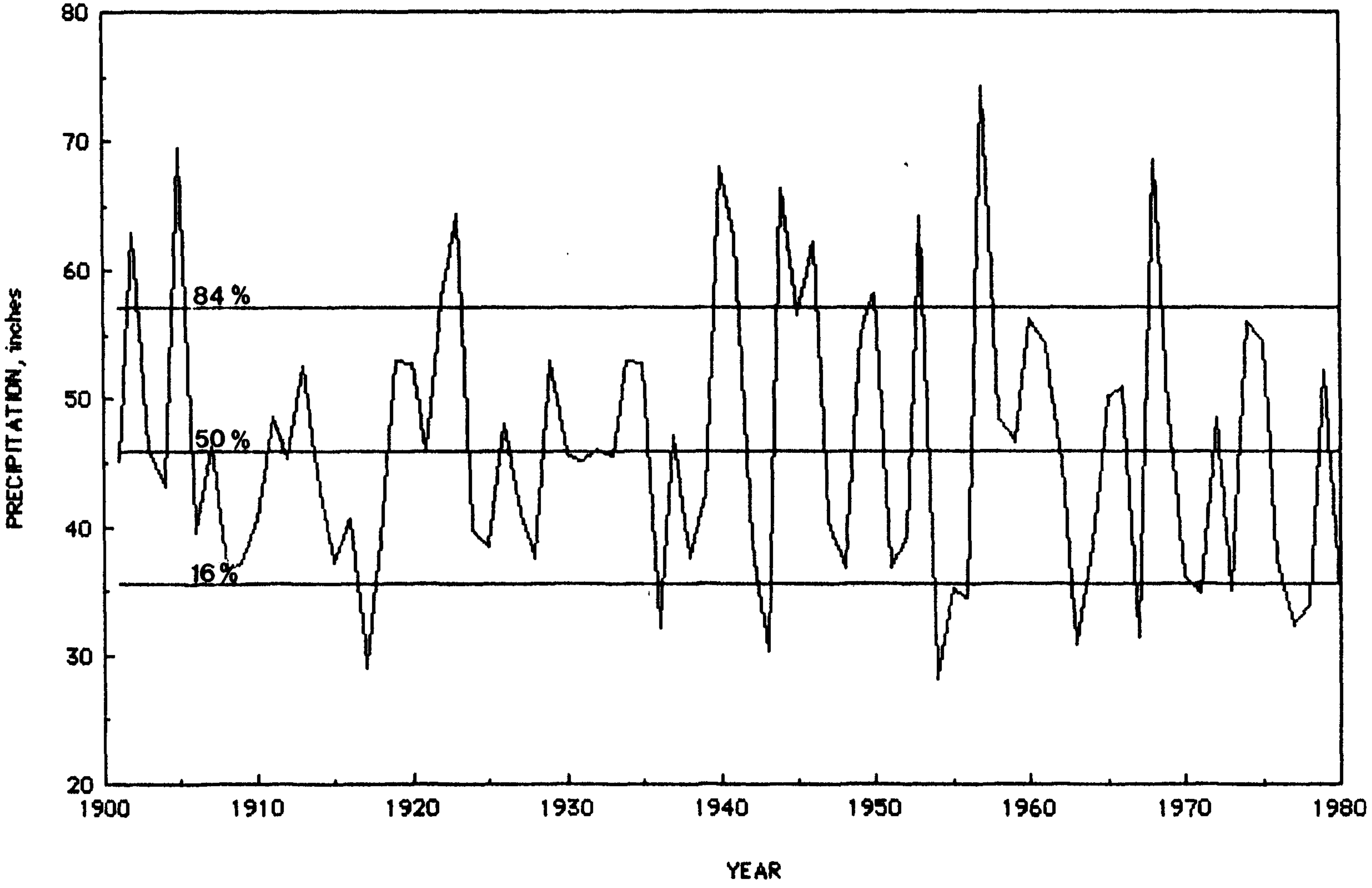

Figure 4. Precipitation fluctuations at Nacogdoches, Texas, 1901-80.

Table 7. Normal Total Precipitation (in inches) for Every Shift of Decade at Nacogdoches, Texas

Month		Periods					
		1901-30	1911-40	1921-50	1931-60	1941-70	1951-80
January	Normal	3.41	4.17	4.59	4.44	4.17	4.10
	Std. Dev.	2.01	2.60	2.41	2.31	2.07	2.35
February	Normal	3.72	3.77	4.10	4.24	3.95	3.74
	Std. Dev.	2.06	2.20	2.16	2.00	1.51	2.31
March	Normal	4.03	4.16	4.38	3.72	3.72	3.53
	Std. Dev.	2.24	2.25	2.21	1.92	2.08	2.08
April	Normal	4.93	5.01	4.77	4.72	4.87	4.68
	Std. Dev.	2.67	2.60	2.41	2.44	2.88	2.92
May	Normal	5.15	5.10	5.49	5.33	5.50	4.73
	Std. Dev.	3.24	3.58	3.57	3.48	3.08	2.72
June	Normal	3.77	2.92	3.33	3.31	3.97	4.05
	Std. Dev.	2.93	2.25	2.16	2.28	2.39	2.41
July	Normal	4.08	3.47	3.59	3.57	3.29	3.03
	Std. Dev.	2.80	3.00	2.64	2.05	2.00	2.05
August	Normal	2.42	2.59	2.24	2.69	2.53	2.64
	Std. Dev.	1.97	2.30	1.89	2.05	1.72	1.66
September	Normal	2.97	2.49	2.70	2.98	3.78	3.89
	Std. Dev.	2.97	2.55	2.14	2.57	2.77	2.73
October	Normal	3.09	2.64	3.07	3.15	3.28	3.21
	Std. Dev.	2.73	2.50	3.49	3.37	3.46	2.42
November	Normal	4.02	4.59	4.78	4.71	3.82	3.92
	Std. Dev.	2.77	3.51	3.66	3.65	2.43	2.09
December	Normal	4.69	5.32	5.32	5.25	4.68	4.29
	Std. Dev.	2.75	2.81	2.29	2.18	1.87	1.85
Annual	Normal	46.20	46.10	48.31	48.04	47.53	44.70
	Std. Dev.	9.21	11.56	10.39	12.31	12.89	12.08

recent normal (1951-80) had the smallest (44.70 inches). However, analysis of variance showed no significant differences between any pair of combinations.

Monthly. The seasonal distribution of precipitation at Nacogdoches is relatively uniform when compared to stations in arid or semi-arid regions. However, absolute uniform distribution is never observed around the world and the variations of precipitation in Nacogdoches are of a magnitude that cannot be ignored in water resources planning and management.

The greatest average monthly precipitation at Nacogdoches occurred in spring while the lowest was in late summer or early fall. Average lowest monthly precipitation during the entire 80 years of observation was 2.54 inches in August with a standard deviation of 1.88 inches (74% of the mean). It then increased with time until it reached the peak in May, or 5.13 inches with a standard deviation of 3.15 inches (Figure 5). The variation is somewhat different than that of West Texas where the lowest monthly precipitation occurred in the winter and early spring including December, January, February, and March.

Average 3-month total precipitation was greatest for March-April-May (14.72 inches) and lowest for August-September-October (8.92 inches). Coupling a greater evapotranspiration loss due to high air temperature and low precipitation make streamflows of August through October exceptionally low in the year. The 3-summer months seem to be an ideal season for forest harvesting activities.

By breaking down the 80 years of observation into 6 different

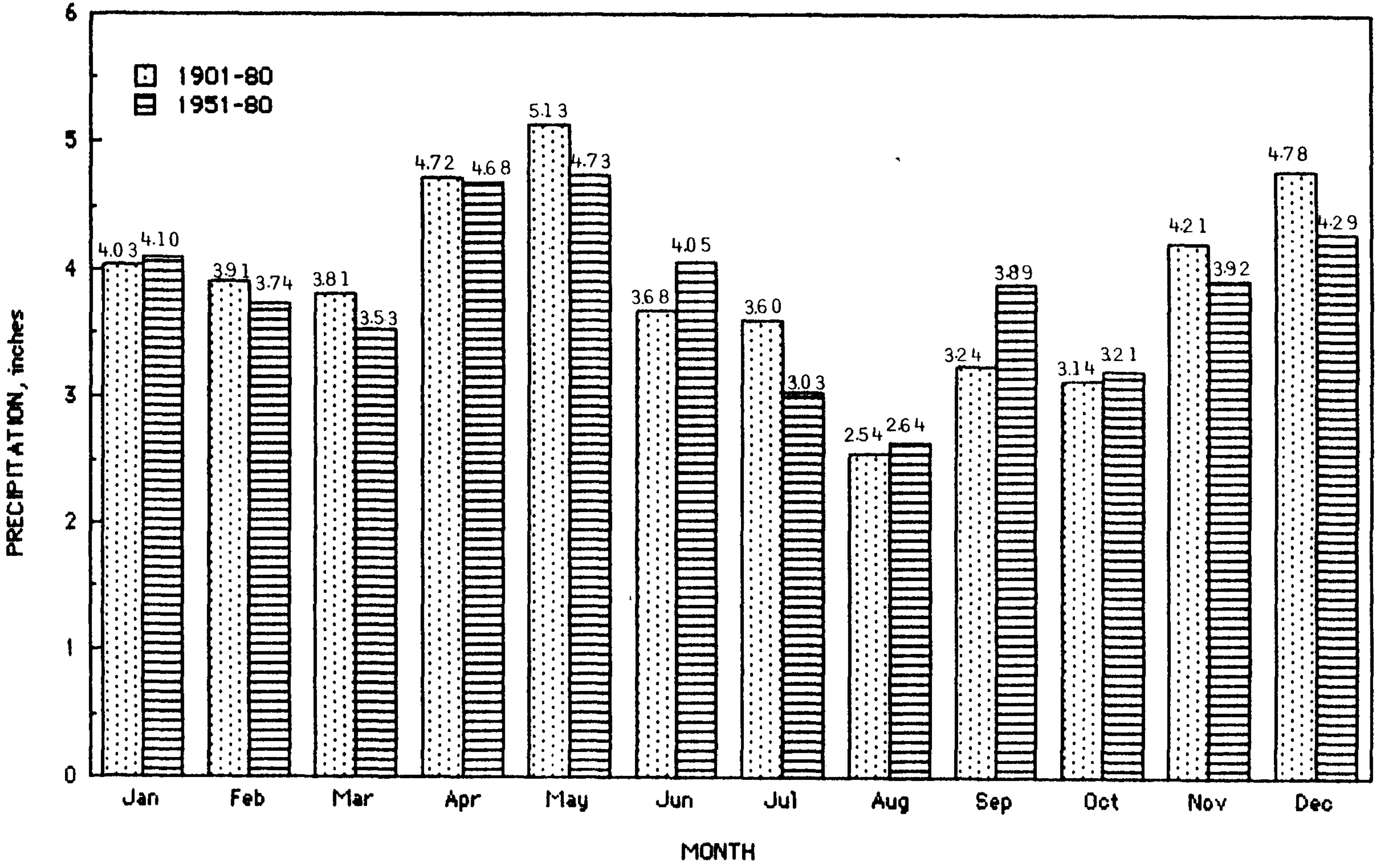

Figure 5. Monthly precipitation patterns for the most recent normal period (1951-80) and the long term period (1901-80) at Nacogdoches, Texas.

normal periods, May and August also were found to have the highest and lowest monthly precipitation in each period, respectively. The monthly precipitation distribution pattern for most the recent normal period was similar to that of the entire 80-year period, except July precipitation was 1.05 inches lower and September was 0.65 inches greater than the entire period. These changes make the coefficient of variation of the mean monthly precipitation for the 1951-80 period to be smaller than the entire period (0.173 vs 0.186), although the difference is too small to be significant.

The highest monthly precipitation in the entire period was 18.85 inches observed in November 1940, followed by 15.60 inches in May 1935, 14.22 inches in June 1902, and 13.96 inches in April 1957. Totally, there were 24 months having precipitation greater than 10.00 inches in the 80 years of record, 3 times each in the months of April, September, October, and November, and 6 times occurred in May. Only 6 months in the long-term record had no measurable precipitation recorded in an entire month at the NWS Station. Of these 6 months, 1 occurred in January, 1 in each month of July through October, and 1 in December.

Further examination of these 80-year records showed that there were 106 times with monthly total precipitation of an inch or less, 52 of them or 49% occurred in August, September, and October, and only 1 in May. This trend seems to reflect drier weather in warmer seasons. In fact, if the 6-month period of May through October is considered as "summer half-year", and the other 6-month as "winter half-year", then

46% of the annual precipitation or 21.33 inches occurred in the "summer" as compared to 54% or 25.46 inches in the "winter".

Daily. There were 6,910 days with precipitation equal to or greater than 0.01 inch in the 80 years of records. By deducting a period of nine months or 276 days without records in the 80 years, the average probability of a rain day at Nacogdoches was about 1 in every 4 days, 7 days in a month, or 87 days out of a year. This frequency was about double than that of El Paso, Texas (43 days a year) and 20 days less than Houston (U.S Department of Commerce, 1968).

Of the total 6,910 rain days at Nacogdoches, 2,942 days or 42.6% were with precipitation less than 0.20 inch (light precipitation), 2,826 days or 40.9% with precipitation between 0.21-1.00 inches (moderate precipitation), and 1,142 days or 16.5% precipitation greater than 1.00 inch (heavy rainfall). The rain day distribution among light, moderate, and heavy precipitation (Figure 7) was much uniform than that of West Virginia. Chang et al.(1976) reported that light, moderate, and heavy precipitation accounted for about 60%, 35%, and 5% of the total number of precipitation days at Charleston, West Virginia.

Table 8 summarizes the occurrence of daily precipitation for various classes at Nacogdoches, Texas. It is apparent that the distribution of rain days during the year was more uniform for moderate precipitation than for light and heavy precipitation. Most of the rain days with precipitation greater than 2.00 inches occurred between late spring and fall. Although these days with excessive rain contributed only about 4% (280 out of 6,910) of the total or about 3.5 days yr^{-1} on

Table 8. The Occurrence of Daily Rainfall (in days) for Various Size Classes at Nacogdoches, Texas(1901-80)

Size Class (inches)	Month												Annual
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
0.01 - 0.2	339	272	289	225	196	217	243	261	225	173	226	276	2942
0.21 - 0.4	134	125	116	93	112	97	118	92	81	55	95	110	1227
0.41 - 0.6	59	74	67	63	61	53	70	46	49	31	53	79	715
0.61 - 0.8	47	54	44	45	41	45	39	32	30	33	39	51	500
0.81 - 1.0	45	38	37	31	34	35	26	13	24	25	35	31	384
1.01 - 1.2	30	22	30	29	24	21	24	14	17	19	21	27	278
1.21 - 1.4	16	16	20	20	22	17	17	6	9	12	23	26	204
1.41 - 1.6	11	13	12	20	17	12	5	8	10	12	10	19	149
1.61 - 1.8	10	11	7	14	16	11	7	5	8	10	11	10	120
1.81 - 2.0	8	7	7	14	15	12	10	6	9	7	8	7	110
2.01 - 2.5	9	7	7	16	16	10	8	8	10	7	18	12	128
2.51 - 3.0	3	2	7	7	15	4	2	5	7	6	5	10	74
3.01 - 3.5	3	1	2	3	5	1	3	2	1	3	4		28
3.51 - 4.0		1	1	5	4		1	1	1	4	3	2	23
4.01 - 5.0	2	1			2		1		4	2	2	2	16
5.01 - 6.0				2								1	3
6.01 - 7.0				1			1				1		3
7.01 - 8.0		1			1								2
8.01 - 9.0							1				1		2
9.01 - 10.0										1			1
10.01 - 12.0													
12.01 - 14.0													
14.01 - 16.0						1							1
Total	716	647	646	588	591	536	576	499	484	400	555	672	6910
Mean	.42	.44	.44	.62	.60	.53	.47	.37	.48	.60	.58	.42	.51

Notes: 1. One-month missing data: March, May, July, August, September, and November.
2. Two-month missing data: October and December.
3. Grand total mean is based on 79-year record.

the average, they were distinctive features of precipitation characteristics in Nacogdoches. Heavy rainfall days not only influence the total rainfall values considerably, they also caused severe flooding and soil erosion problems in bottomlands or agricultural areas.

Maximum daily precipitation in each year ranged from 1.86 inches in May 1917, to 14.22 inches in June 1902. Throughout the 80-year period, only 4 years (5%) had a maximum daily precipitation less than 2.00 inches, 53 years (66.3%) between 2.01-4.00 inches, 14 years (17.5%) between 4.01-6.00 inches, and 9 years (11.2%) above 6.01 inches. These maximum daily precipitation occurred in each month throughout the year, but the greatest frequency was the month of May (29 times out of 80) and the least, February (2 times out of 80). The total number of occurrences for a 3-month period was 8, 29, 20, and 23 for January-March, April-June, July-September, and October-December, respectively. Although only 8 times out of 80 had the maximum daily precipitation in each year occurred in the first 3-month period of the year, the chances of flooding caused by storms in these colder seasons might be greater than storms of the same size occurred in the warmer seasons. This is probably due to less water loss to the air by evapotranspiration and canopy interception and a greater moisture content in the ground. Table 9 gave the maximum storm rainfall and maximum daily rainfall along with dates of occurrence of each of the 80 years of records at Nacogdoches, Texas. Except for the first 3-month period of the year (10 times out of 80), the maximum storm rainfall seemed to occur quite evenly distributed throughout the rest of

Table 9. Maximum Storm Rainfall and Maximum Daily Rainfall of each Year at Nacogdoches, Texas, 1901-80

Year	Maximum Storm Rainfall			Maximum Daily Rainfall	
	Depth (inches)	Duration (days)	Date	Depth (inches)	Date
1901	5.08	4	Sep 12 - 15	5.05	Apr 17
02	14.22	1	Jun 28	14.22	Jun 28
03	3.60	7	Jul 26 - Aug 1	2.82	Oct 5
04	6.71	2	Dec 25 - 26	4.35	Dec 25
05	6.05	1	Nov 5	6.05	Nov 5
06	6.02	1	Jul 28	6.02	Jul 28
07	6.05	2	Nov 18 - 19	3.95	Nov 19
08	3.84	3	Sep 18 - 20	2.50	Sep 20
09	4.07	2	Jul 23 - 24	4.00	Jul 24
10	6.22	4	May 17 - 20	2.30	Dec 16
1911	5.07	6	Jul 14 - 19	2.90	Dec 23
12	3.86	1	May 19	3.86	May 19
13	7.67	11	Sep 7 - Sep 17	2.78	Sep 13
14	3.66	4	Apr 5 - Apr 8	2.34	May 3
15	5.62	4	Aug 16 - Aug 20	2.90	Aug 18
16	4.95	2	May 2 - 3	4.37	May 2
17	3.21	2	Sep 4 - 5	1.86	May 11
18	3.17	2	Nov 15 - 16	3.05	Nov 15
19	6.43	9	Jun 20 - 28	2.75	Oct 22
20	3.58	2	Mar 31 - Apr 1	3.37	Aug 13
1921	4.28	4	Jul 9 - 12	2.61	Jul 10
22	9.44	7	Mar 25 - 31	6.78	Apr 27
23	5.11	6	Dec 18 - 23	3.05	Apr 12
24	6.79	5	May 30 - Jun 3	2.87	Apr 16
25	5.67	6	Nov 3 - 8	3.70	Nov 5
26	3.46	4	Dec 7 - 10	3.07	Apr 22
27	4.06	2	Apr 14 - 15	3.80	Apr 14
28	4.22	6	Jul 14 - 19	2.55	Mar 16
29	6.11	6	Nov 8 - 13	3.90	Dec 6
30	3.70	3	Oct 5 - 7	2.77	Nov 30
1931	3.20	5	Dec 16 - 20	1.95	Apr 30
32	8.82	5	Feb 17 - 21	4.15	Feb 19
33	9.00	5	Jul 22 - 26	8.20	Jul 24
34	5.95	4	Nov 19 - 22	4.50	Nov 21
35	8.95	4	May 3- 6	7.48	May 5
36	3.45	3	Aug 23 - 25	2.29	Dec 6

Table 9. Continued

Year	Maximum Storm Rainfall			Maximum Daily Rainfall	
	Depth (inches)	Duration (days)	Date	Depth (inches)	Date
1937	3.50	7	Jan 9 - 15	2.15	Dec 23
38	4.43	3	Apr 6 - 8	2.53	Nov 8
39	7.27	6	Dec 22 - 27	5.90	Dec 23
40	15.80	6	Nov 21 - 26	8.85	Nov 23
1941	9.37	3	Oct 30 - Dec 1	9.13	Oct 31
42	4.27	7	Jun 6 - 12	2.64	Sep 8
43	2.68	4	Feb 23 - 26	2.08	Aug 11
44	9.30	6	Apr 30 - May 5	3.32	Aug 31
45	4.01	5	May 30 - Apr 3	2.73	Apr 1
46	3.98	7	Aug 23 - 29	3.23	May 13
47	4.55	5	May 16 - 20	2.89	May 17
48	3.16	5	Nov 12 - 16	2.62	Apr 13
49	7.39	4	Oct 2- 5	4.28	May 29
50	4.00	1	Dec 3	4.00	Dec 3
1951	3.37	2	Sep 13 - 14	2.90	Sep 13
52	3.69	6	Nov 29 - Dec 4	3.18	Nov 18
53	9.04	8	May 11 - 18	5.90	Apr 29
54	5.21	8	Oct 22 - 29	2.89	Oct 23
55	3.98	3	Aug 3- 5	2.74	May 24
56	4.69	9	Jun 12 - 20	2.78	Jun 20
57	8.21	3	Oct 14 - 16	4.10	Oct 15
58	9.40	8	Sep 16 - 23	4.83	Sep 20
59	5.74	4	Jul 25 - 28	4.60	Jul 26
60	5.59	4	Oct 26 - 29	2.28	Sep 25
1961	7.03	2	Sep 12 - 13	4.74	Sep 12
62	4.69	5	Sep 6 - 10	3.41	Sep 6
63	2.71	2	Apr 5 - 6	2.19	Jun 17
64	3.13	2	Apr 26 - 27	2.61	Apr 5
65	3.74	2	May 10 - 11	3.68	May 11
66	5.62	4	Apr 23 - 26	4.12	Jan 2
67	5.65	4	May 29 - Jun 2	2.70	May 30
68	7.09	9	Jun 18 - 26	4.29	Sep 5
69	6.08	4	Mar 15 - 18	2.91	May 8
70	2.64	2	Oct 23 - 24	2.00	May 1
1971	3.46	2	May 11 - 12	2.91	May 11
72	4.88	2	Jul 4 - 5	3.23	Jul 4

Table 9. Continued

Year	Maximum Storm Rainfall			Maximum Daily Rainfall	
	Depth (inches)	Duration (days)	Date	Depth (days)	Date
1973	4.71	2	Mar 4 - 5	3.47	Mar 25
74	5.37	4	Mar 23 - 26	4.05	Jan 24
75	9.59	5	Feb 1 - 5	7.63	Feb 1
76	2.92	2	Dec 6 - 7	2.26	Jan 19
77	3.50	6	Aug 19 - 24	1.95	Mar 14
78	2.69	4	Jan 16 - 19	2.32	Nov 27
79	6.88	3	Nov 21 - 23	3.55	Nov 21
80	5.09	7	May 13 -19	3.01	May 16

the 3-month periods (24, 22, 24, respectively). These storms had the potential for generating floods. It is worthy to note that whenever the maximum storm rainfall was equal to or greater 4.00 inches, especially for those of shorter duration, a flood was almost inevitable (Maddox and Chappell, 1979).

For example, the maximum storm rainfall of 1940 was 15.80 inches over a period of 6 days and occurred on November 21st through 26th. The storm brought 0.60 inch of rainfall in the first 2 days, 8.55 inches in the 3rd days, and 3.82 inches, 2.20 inches, and 0.33 inch in the last 3 days, respectively. The 8.55 inches of rainfall which occurred on November 23rd was also the maximum daily precipitation of 1940. As a result, flooding occurred all over town and buildings along Banita and La Nana Creeks were damaged.

Rain Day

Annual. Rain day is an important climatic variable due to its association with total precipitation, solar radiation, cloudiness, air temperature, and evapotranspiration. A study on the relationships between tree-ring growth of loblolly pines and 48 climatic variables in Nacogdoches area showed that annual rain day has a higher correlation coefficients than any other climatic variables being tested, including total rainfall (Chang and Aguilar, 1980). However, the present analysis shows a low correlation coefficient between total rain days and total rainfall at Nacogdoches, Texas.

As mentioned earlier, 'rain day' refers to a day with measurable amount of rain, melted snow, sleet, and other hydrometeors which falls to the ground with a depth of 0.01 inch or more. The number of such days in Nacogdoches for each year is given in Table 55 of Appendix III and fluctuation of annual rain day and annual occurrence for various sizes of precipitation is shown in Figures 6 and 7, respectively. It can be seen that the number of rain days varied from year to year. Simple statistics of such variation is given in Table 6.

Breaking down the 80 years of records into 6 normal (30 years) periods, then the smallest number of rain days was 78.4 for the 1901-30, and the greatest was 95.6 of 1921-50 period (Table 10). The difference was as much as 17.2 days and was significantly different at the 0.01 level. The most recent normal period, 1951-80, is 88.3 which is about the same as the 80-year average. Total rain days in each year are further grouped into 5 size classes in Table 11.

Monthly. The long-term seasonal distribution of rain days exhibited a pattern different from total rainfall. Rain days were greater in winter and spring and smaller in summer and fall. The largest number of monthly rain days was 9.0 in January, then gradually decreased to 5.0 in October (Figure 8). On the other hand, the highest monthly total rainfall was in May, while the lowest was in August. Total rainfall seems to fluctuate more irregularly from month to month (Figure 5) than do total rain days.

The maximum consecutive monthly rain days in the long-term record was 22 days observed in January 1937 and only 26 times had the recorded monthly rain days equaled or exceeded 15 days. Of the 26 times, 10 occurred in January, none in August, and between 1 and 3 times for the

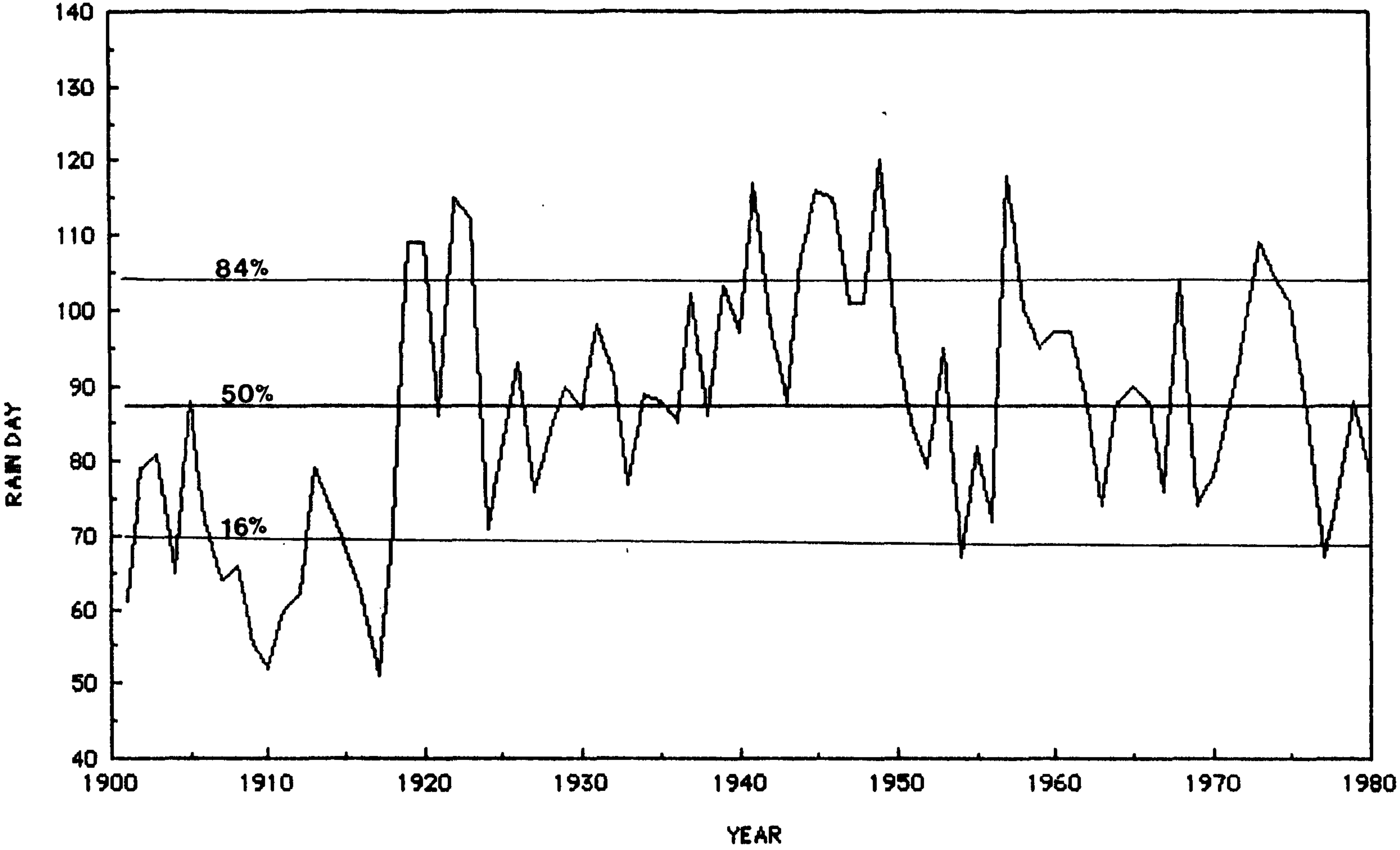

Figure 6. Fluctuations of rain days at Nacogdoches, Texas, 1901-80.

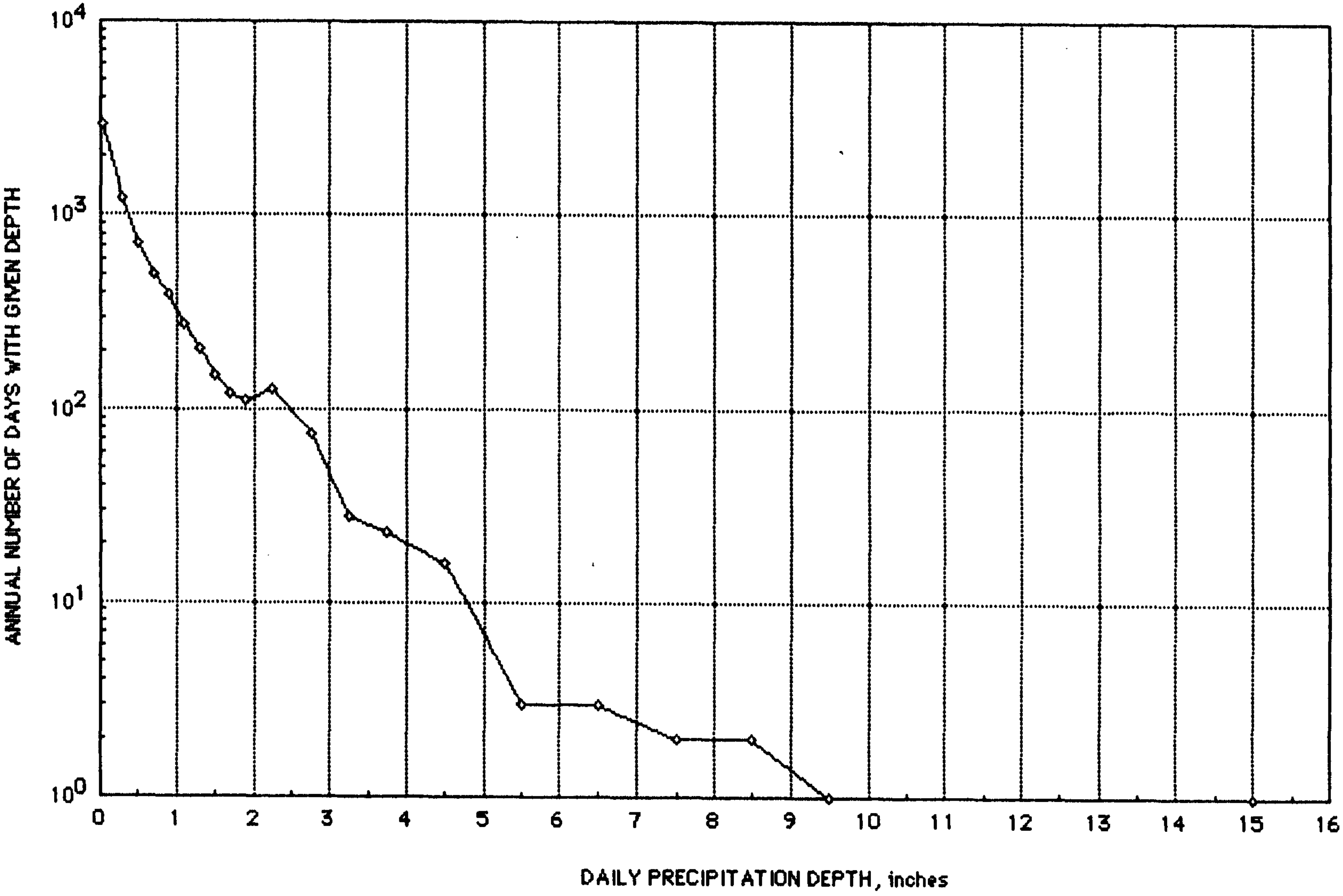

Figure 7. The total occurrence for daily rainfall of various sizes at Nacogdoches, Texas (1901-80).

Table 10. Normal Average Number of Rain Days for Every Shift of Decade at Nacogdoches, Texas

Month		Periods					
		1901-30	1911-40	1921-50	1931-60	1941-70	1951-80
January	Normal	6.9	8.7	10.8	10.8	10.0	9.3
	Std. Dev.	3.7	4.8	4.8	4.6	3.9	3.6
February	Normal	7.1	7.8	9.1	9.2	9.3	8.2
	Std. Dev.	3.2	3.2	3.2	3.3	2.9	2.8
March	Normal	7.3	7.7	9.1	8.6	8.6	8.4
	Std. Dev.	3.3	3.1	2.9	2.8	3.0	3.1
April	Normal	7.1	7.6	8.1	8.1	7.7	7.2
	Std. Dev.	3.3	3.1	3.1	2.8	2.9	2.9
May	Normal	7.2	7.2	8.1	7.7	7.8	7.3
	Std. Dev.	3.6	3.5	3.4	3.1	3.5	3.2
June	Normal	6.3	6.3	7.0	7.1	7.5	6.9
	Std. Dev.	3.7	3.9	3.1	3.1	2.9	3.3
July	Normal	7.1	7.2	7.9	8.1	7.2	6.3
	Std. Dev.	3.3	2.9	2.9	3.1	3.7	3.3
August	Normal	5.1	5.9	6.4	6.9	6.6	6.8
	Std. Dev.	3.1	3.2	2.9	3.0	2.9	3.3
September	Normal	5.3	5.6	6.0	6.0	6.8	7.5
	Std. Dev.	3.3	3.2	2.7	3.3	3.2	2.9
October	Normal	5.0	5.2	5.4	5.1	5.1	4.8
	Std. Dev.	3.5	3.3	3.3	3.1	3.4	2.6
November	Normal	6.1	7.0	7.9	8.1	7.7	7.1
	Std. Dev.	2.9	3.1	3.6	3.8	3.7	3.2
December	Normal	7.4	9.3	9.8	9.7	9.0	8.7
	Std. Dev.	3.5	3.7	3.5	3.5	3.1	3.0
Annual	Normal	78.4	85.5	95.6	95.4	93.4	88.3
	Std. Dev.	17.5	16.5	13.2	13.6	14.8	12.9

Table 11. Total Annual Number of Rain Days Grouped by Five Rainfall Sizes (in inches), Texas, 1901-80

Year	Daily Rainfall, inches					Total
	0.01 - 0.50	0.50 - 1.00	1.00 - 2.00	2.00 - 5.00	5.00	(Days)
1901	32	13	12	3	1	61
02	49	14	12	4	1	79
03	53	16	8	4		81
04	32	22	8	3		65
05	42	24	15	6	1	88
06	47	14	5	3	1	72
07	36	14	8	6		64
08	42	14	8	2		66
09	32	12	8	3		55
10	28	11	11	2		52
1911	25	18	12	4		60
12	33	13	11	4		62
13	40	17	20	2		79
14	31	12	7	1		52
15	38	18	9	2		68
16	35	15	7	5		61
17	26	14	10			50
18	41	17	11	2		71
19	66	28	14	1		109
20	76	19	8	6		109
1921	54	14	15	3		86
22	85	13	13	3	1	115
23	78	11	15	8		112
24	39	19	10	3		71
25	56	12	9	2		81
26	60	17	13	2		93
27	52	9	14	1		76
28	61	12	8	3		84
29	54	15	17	3		90
30	58	13	15	1		87
1931	65	17	14			98
32	62	12	11	3		91
33	55	7	12	2		77
34	58	16	9	5		89
35	60	11	10	5	1	88
36	67	9	6	2		85
37	68	17	16	1		102

Table 11. Continued

Year	Daily Rainfall, inches					Total
	0.01 - 0.50	0.50 - 1.00	1.00 - 2.00	2.00 - 5.00	5.00	(Days)
1938	62	11	8	5		86
39	78	13	11		1	103
40	64	10	13	9	1	97
1941	82	21	9	4	1	117
42	74	14	6	4		98
43	69	11	7	1		88
44	62	23	14	8		107
45	80	13	21	2		116
46	72	18	19	5		115
47	77	15	7	2		101
48	74	14	7	2		101
49	86	22	7	5		120
50	62	13	13	7		95
1951	64	11	5	4		84
52	54	15	7	3		79
53	58	16	11	8	1	95
54	50	7	8	2		67
55	59	18	8	2		82
56	52	10	7	3		72
57	68	23	23	4		118
58	69	16	13	2		100
59	69	15	10	2		95
60	52	24	17	3		97
1961	64	17	8	7		97
62	56	15	13	2		87
63	54	13	5	2		74
64	61	12	12	3		88
65	59	14	13	4		90
66	53	26	5	4		88
67	54	14	7	1		76
68	58	25	14	7		104
69	41	14	15	4		74
70	51	12	13			78
1971	68	9	6	3		86
72	66	17	7	6		96
73	70	21	12	6		109
74	65	21	14	4		104
75	69	18	10	3	1	101

Table 11. Continued

Year	Daily Rainfall, inches					Total
	0.01 - 0.50	0.50 - 1.00	1.00 - 2.00	2.00 - 5.00	5.00	(Days)
1976	57	18	8	3		86
77	44	13	9	1		67
78	58	8	10	1		77
79	54	20	8	6		88
80	58	8	11	1		78
Total	4562	1206	862	268	12	6910
Mean	57.0	15.08	10.78	3.35	0.15	87.4
Percent	66.02	17.45	12.47	3.88	0.17	100

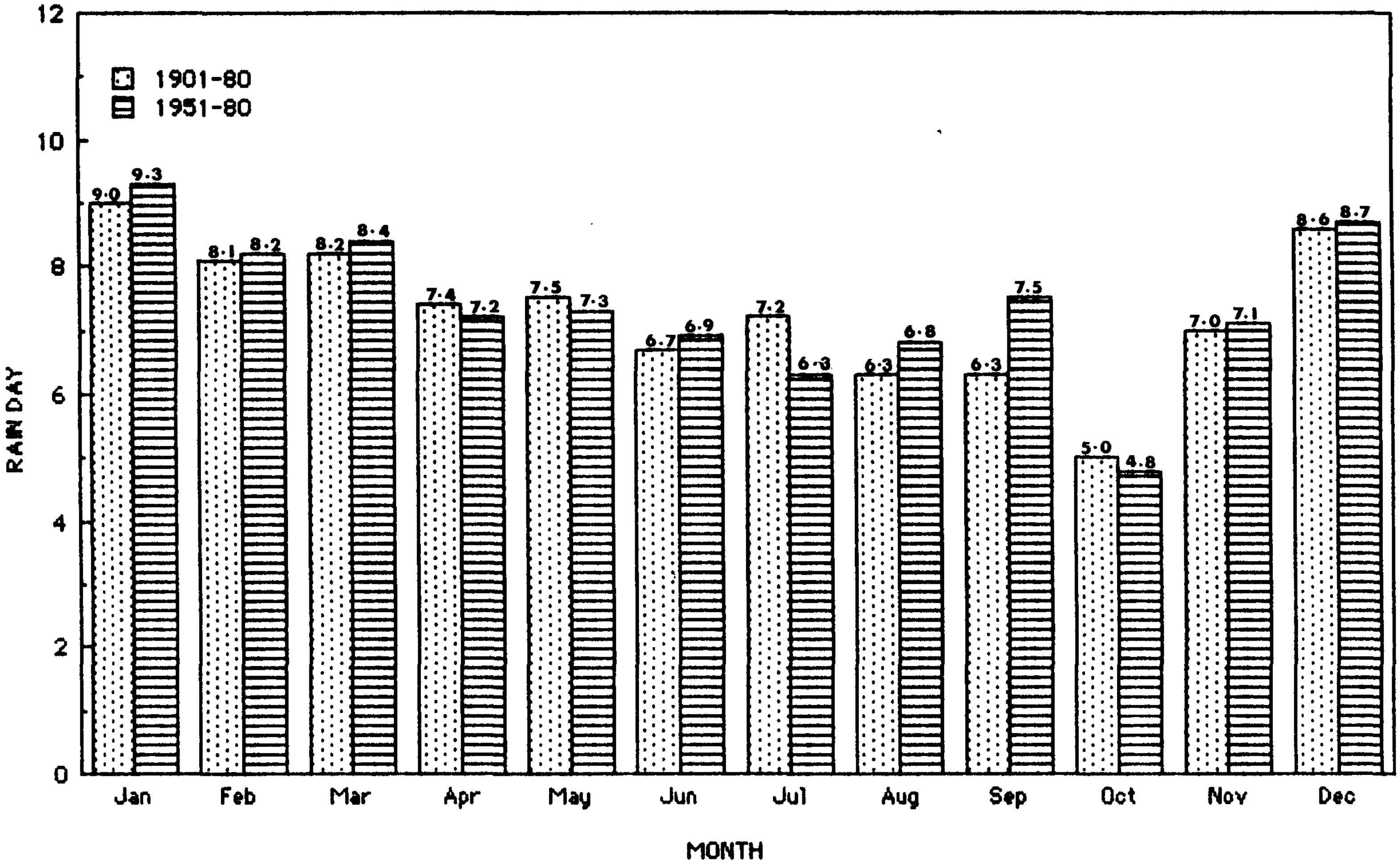

Figure 8. Monthly patterns of total rain days for the most recent normal period (1951-80) and the long term period (1901-80) at Nacogdoches, Texas.

rest of other months. That January had the greatest mean monthly rain days in the year is a general characteristic of the region. It also justifies the lowest mean percentage of possible sunshine of the year in the region as reported in the Climatic Atlas of the United States (U.S. Dept. of Commerce, 1968).

That October had the lowest and January had the highest mean number of days with 0.01 inch or more of precipitation. Similar data were also reported for Shreveport (La), Lexington (KY), Little Rock (AK), Jackson (MS), Birmingham (AL), and Knoxville (TN), and the northeastern regions of Nacogdoches. This southern region is generally dominated by low pressure in the fall and high pressure in the winter. The pattern is reversed in regions around Dodge City (KS) and Amarillo (TX) where the greatest number of rain days is in the summer, and the lowest in the winter.

Total rainfall of a specific period of time at any location is affected by the number of rain days (storms) and the size (intensity) of rainfall in each rain day. The long-term averages of daily rainfall intensity for each month are given in Table 8. It ranged from 0.37 inch day^{-1} for August to 0.62 inch day^{-1} for April. There were 6 months having mean daily intensity of 0.40-0.49 inch day^{-1}, i.e., January, February, March, July, September, and December. Low rainfall intensity and long duration of rainfall in the winter is a general phenomenon in this area, but the low mean daily intensity in August seems to be associated with its size distribution. In April, for example, about 38% of its daily rainfall was 0.20 inch or less, while 5.8% of the rainfall was 2.01 inches or more. In August, 52% of daily rainfall was 0.20 inch or less while 3.2% was 2.01 inches or more.

Wet Spells. A wet spell is a consecutive period of days with precipitation of 0.01 inch or more (Landsberg, 1966). It is different from the rain days discussed in the previous section. Rain days are the total number of days in a specified period with certain threshold values of precipitation, while wet spells are simply the duration of a storm described in days. Thus, a 7-day wet spells may be counted as seven rain days with precipitation of 0.01 inch or more, or it may be counted as 5 rain days with precipitation of at least 0.25 inch, or two rain days with amount of precipitation of 1.00 inch or more. Information on wet spells is of considerable practical importance.

As expected, wet spells at Nacogdoches decrease with lengths (duration). The most frequently occurring wet spells were 1 day (32% of the total) while the longest wet spell ever observed in the 80 years of record was 16 days (January 16 - February 4, 1957). Weighted average length of wet spells was about 2 days. Figure 9 is a plot of relative frequencies of wet spells in different lengths. Detailed information on the wet spells in different lengths from year to year can be found in Table 56 of Appendix III.

The longest wet spells in each year range from 2 in 1917 to 16 days in 1957 with the most frequent longest wet spells in 4 and 6 days (22.4% each). About 75% of the longest annual wet spells occurred with lengths between 4 to 7 days. Usually, wet spells are longer in winter and shorter in fall. The longest wet spells recorded from January 16 to

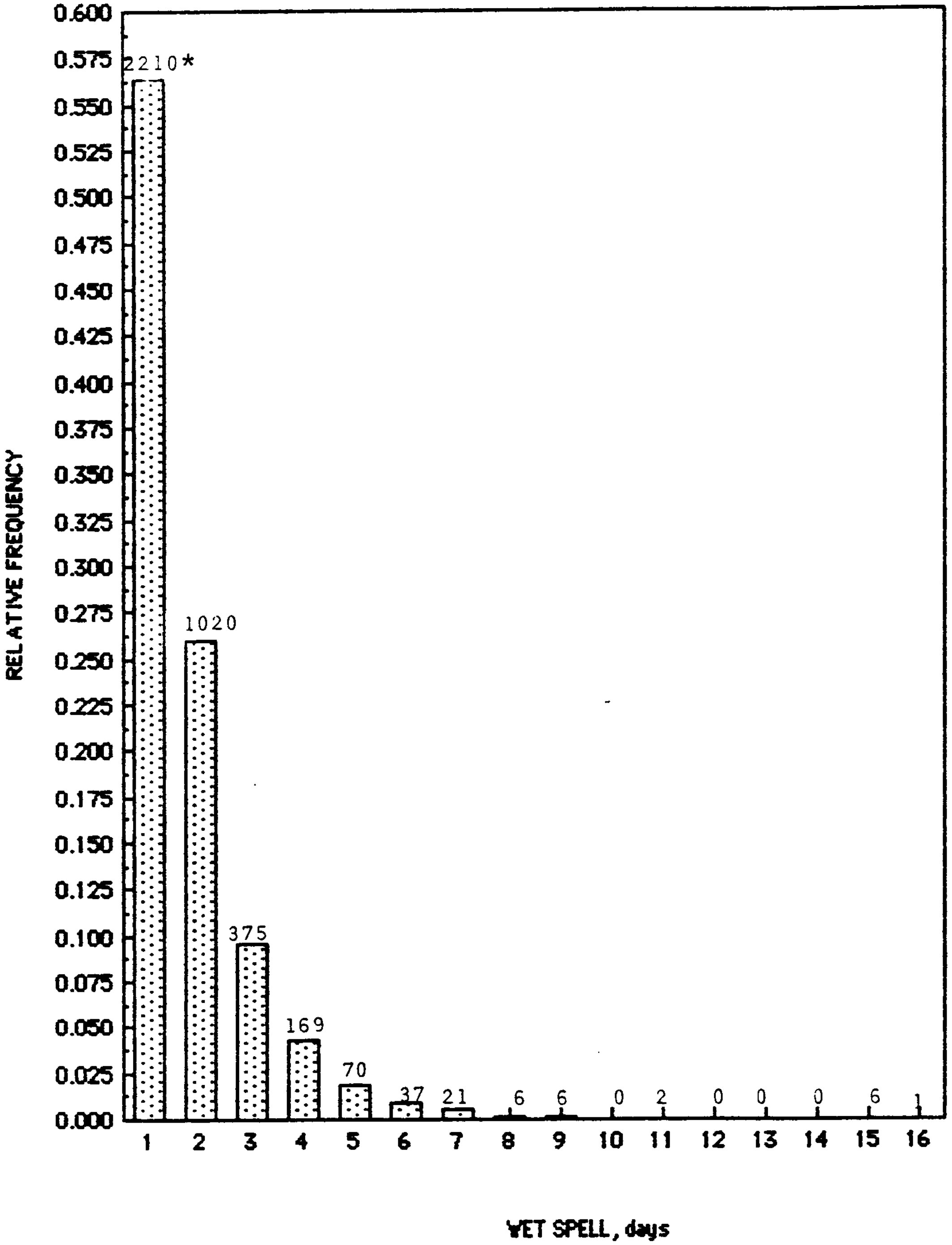

Figure 9. Relative frequencies of wet spells at Nacogdoches, Texas, 1901-80. (number of occurrence indicated on the top of each column).

February 4, 1957 (16 days) brought a total rainfall of 5.75 inches in Nacogdoches. Although it was far away from the greatest total rainfall in a single storm (Table 9), it made 1957 the year with the greatest amount of total precipitation (74.27 inches) and 2nd only to 1949 as the greatest total number of rain days (118 vs 120 days) in the long-term records. The next longest wet spells were 11 days recorded from September 6-17, 1913 with a total rainfall of 7.67 inches, and from April 25 to May 5, 1958 with a total rainfall of 5.55 inches (Table 12).

The amount of precipitation during wet spells is as important as its duration. The most pronounced 1-day wet spells in the long-term records included 14.22 inches of June 28, 1902, 9.13 inches of October 31, 1941, 8.85 inches of November 23, 1940, 8.20 inches of July 24, 1933, 7.63 inches of February 1, 1975, and 7.48 inches of May 5, 1935. Other important events included 15.80 inches generated in a 6-day wet spell (November 21-26,1940), 9.44 inches in 7 days (March 25-31, 1922), 9.0 inches in 5 days (July 22-26,1933), and 8.95 inches in 4 days (May 3-6, 1935) (Table 9). Storms of these sizes are potentially dangerous in causing floods.

Dry Spells. In this study, a dry spell is a number of consecutive days without measurable precipitation (less than 0.01 inch). Since interest in dry spells is due to their association with drought, some investigators define a dry spell if the duration of rainless period is greater than 2 weeks (Munn, 1970). This definition may have some weaknesses because a two-week dry spell which occurred in winter may have a different biological effect than 1 in summer or fall; on the

Table 12. The Longest Monthly and Annual Wet Spells (in days) at Nacogdoches, Texas, 1901-80

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann.*
1901	3	3	2	1	3	2	2	3	4	1	2	1	4
02	4	3	6	2	2	1	8	1	4	2	5	1	9
03	3	3	7	1	2	3	6	2	1	3	1	2	7
04	1	4	2	2	2	3	4	2	3	1	2	2	4
05	3	2	3	3	3	4	3	1	1	1	1	4	4
06	2	1	3	2	1	4	2	3	3	2	4	3	4
07	2	2	2	4	4	1	4	1	1	3	2	1	4
08	1	3	2	3	1	2	2	3	3	1	2	2	3
09	2	1	2	2	2	2	2	2	2	1	2	3	3
10	1	2	1	2	4	3	2	1	1	3	3	-	4
1911	0	1	2	3	1	2	6	1	1	1	1	3	6
12	1	2	3	3	2	2	1	3	1	2	1	3	3
13	2	1	3	2	3	2	1	1	11	5	2	3	11
14	2	3	4	4	5	3	3	-	-	-	-	-	5
15	1	2	2	6	2	1	3	4	2	2	2	2	6
16	3	1	1	1	2	2	4	1	2	1	2	2	4
17	2	2	1	2	1	1	2	1	2	1	1	1	2
18	1	2	3	2	1	1	1	3	2	2	3	2	3
19	4	10	2	2	5	9	5	4	4	9	2	2	9
20	4	2	3	3	2	4	2	7	2	3	2	3	7
1921	3	4	2	4	2	3	4	3	3	1	3	3	4
22	7	4	7	3	4	6	4	3	2	1	4	4	7
23	3	4	5	3	3	4	2	3	3	2	3	7	7
24	2	4	2	3	2	3	1	0	2	1	1	3	5
25	4	2	2	2	2	1	2	2	3	5	6	3	6
26	4	2	3	1	2	2	3	2	1	2	2	4	5
27	3	2	3	2	2	3	3	1	2	3	2	2	3
28	1	4	4	3	1	3	6	1	2	2	2	3	6
29	3	3	3	2	4	1	4	1	2	1	6	1	6
30	7	4	2	2	2	1	1	2	4	3	2	2	7
1931	2	2	2	2	2	2	4	3	1	1	5	5	5
32	4	5	1	2	2	2	2	2	3	2	3	5	5
33	2	3	2	2	2	2	5	2	3	1	1	4	5
34	3	2	4	2	6	1	3	1	3	1	4	6	6
35	2	3	3	3	4	3	3	3	3	1	4	2	4
36	2	2	4	2	4	1	2	3	3	2	2	5	5
37	7	3	3	2	1	2	3	5	2	2	3	2	7
38	4	2	3	3	2	3	7	3	3	1	2	6	7
39	5	4	2	2	4	5	2	5	2	2	5	6	6
40	1	5	2	3	3	2	3	3	3	2	6	5	6

Table 12. Continued

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann.
1941	3	2	2	5	4	3	6	2	3	3	4	3	6
42	2	3	2	4	2	7	2	2	3	2	2	4	7
43	3	3	3	2	2	2	4	3	4	1	3	4	4
44	4	6	2	3	5	3	3	5	3	1	5	5	6
45	2	3	4	3	2	3	6	4	5	3	3	2	6
46	5	3	4	3	4	3	2	7	4	4	6	4	7
47	7	2	3	3	5	5	1	1	2	2	3	4	8
48	5	6	3	4	3	1	2	7	2	1	4	1	7
49	8	3	3	2	2	4	6	3	2	5	1	7	8
50	6	6	2	2	3	2	2	2	2	2	1	1	8
1951	2	3	3	2	2	2	2	2	3	1	4	3	4
52	2	2	2	2	2	2	6	1	2	0	3	4	6
53	2	4	4	2	7	2	3	3	1	1	2	4	8
54	4	2	4	1	3	1	2	2	2	8	2	3	8
55	5	4	4	5	2	1	6	3	4	1	1	2	6
56	3	4	4	1	3	9	1	2	1	2	3	3	9
57	12	4	1	6	2	4	7	1	3	3	6	3	16
58	3	3	4	6	5	4	3	2	8	2	3	2	11
59	2	4	1	5	1	3	4	3	3	2	2	4	5
60	3	2	2	3	1	3	6	5	3	4	2	7	7
1961	4	6	2	1	2	7	3	2	2	2	4	4	7
62	7	3	3	2	1	2	1	3	5	1	4	6	7
63	2	2	1	2	1	5	5	2	3	1	3	3	6
64	3	3	2	2	3	3	1	2	4	2	2	3	4
65	2	7	4	2	5	3	2	3	5	1	2	6	7
66	2	2	2	4	3	2	2	2	2	1	4	3	4
67	4	2	3	1	2	2	4	1	2	1	3	4	4
68	5	3	4	3	3	9	4	2	4	1	3	2	9
69	3	2	4	3	4	1	1	1	1	3	3	3	5
70	2	3	2	1	2	4	0	2	4	2	1	2	4
1971	1	2	2	3	2	3	3	4	3	3	2	3	4
72	3	2	2	2	3	4	2	3	4	2	3	8	8
73	3	2	3	3	3	4	3	4	4	7	2	3	7
74	4	1	3	2	2	3	2	3	3	3	4	4	4
75	3	5	4	2	4	6	3	3	3	5	2	3	6
76	1	2	5	2	2	2	2	1	3	1	2	5	5
77	2	2	2	2	3	4	2	6	3	1	2	3	6
78	4	4	3	1	3	1	1	2	5	–	1	3	5
79	5	5	–	6	–	4	5	3	4	1	3	3	6
80	3	3	7	2	7	1	1	2	2	3	2	3	7
Mean	3.2	3.0	2.9	2.6	2.7	3.0	3.1	2.5	2.7	2.2	2.8	3.4	6

* indicates that period extended into either proceeding or following month

other hand, a light rainfall may not interrupt a dry spell if soil moisture content and relative humidity of the air are low.

Drought is a meteorological as well as a biological phenomenon. Definitions and criteria used to describe a drought vary with regions and with interest of users. Landsberg (1968) stated the number of dry spells and the total number of rainless days for a given season shows good correlation to observed damage of crops, and the shortest duration of a dry spell which can influence vegetation is 4 days. One such drought definition is a period of time such as a year, a season, a month, or a few weeks, during which the precipitation is less than a fraction of the normal value (15% or 30%) for the location (climatologic drought). Others define drought in terms of soil-moisture deficit (agricultural drought), in terms of streamflow level below normal (hydrologic drought), or in terms of index calculated from precipitation, runoff, potential evapotranspiration, and soil moisture (meteorologic drought). It is not the purpose of this study to investigate whether or not a dry spell of 15 consecutive days is an appropriate way of defining drought at Nacogdoches, but to provide information on the duration of rainless periods for outdoor activities and recreation planning. Thus, rainless days of all duration and of all seasons in the 80-year record were inclusively parts of the investigation.

Figure 10 is a plot of relative frequencies of dry spells in various durations for the long-term records at Nacogdoches. It clearly illustrates that the number of dry spells decreased with duration in a

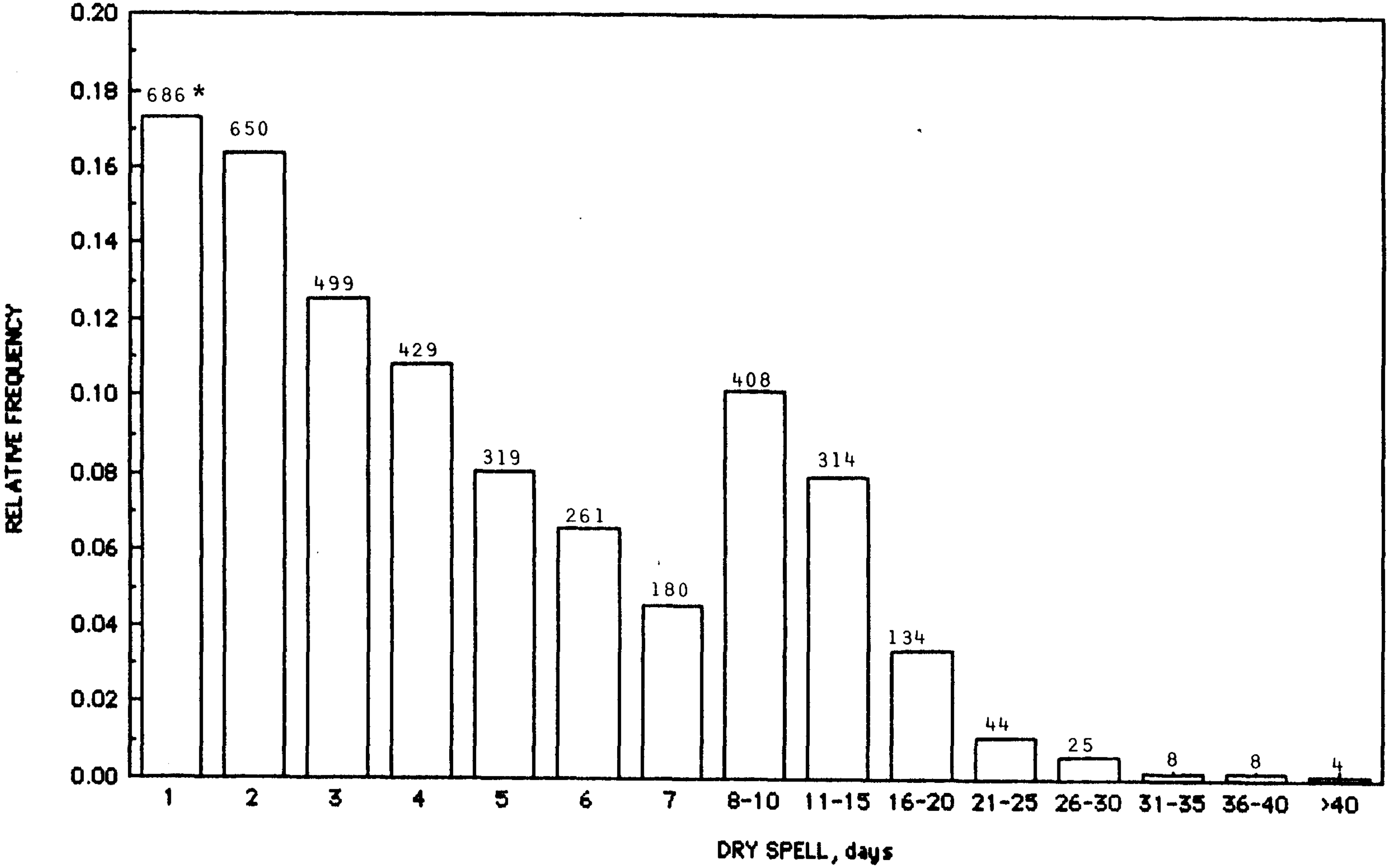

Figure 10. Relative frequencies of dry spells at Nacogdoches, Texas, 1901-80 (number of occurrence indicated on the top of each column).

more or less exponential manner. There were 22,015 dry days observed during the 80-year period, 46% of them with durations of 3 days or less, and about 2% with durations of 21 days or longer. Annual variation of dry spells is given in Table 57 of Appendix IV.

The longest dry spell without precipitation was 53 days in length occurred between August 25 and October 26, 1912. In fact, the last major storm (1.03 inches) prior to the 53-day dry spell occurred on August 11. A light rain of 0.09 inch did occur on August 24 immediately prior to the 53-day dry period. Average maximum daily temperature of the 14-day period (August 12-24, 1912) prior to the 53-day dry-spell was 90°F. The high temperature made the light rain of 0.09 inch to be insignificant in breaking the drought. The 53-day dry spell was broken when 0.03 and 0.40 inch of rain fell on October 17 and 18, 1912, respectively. It was the longest dry period and most prolonged drought known in the history of climate at Nacogdoches, Texas.

The longest annual dry spells in Nacogdoches fluctuated between 13-53 days with a mean of 22 days. There is 22.5% chance that the longest observed dry spell in any year will be equal to or greater than 30 days. The longest monthly dry spells were greater in the summer half-year (May-October) - September and October having the longest while February and March the shortest. Although this trend was based on the longest duration observed in each month, it can probably be applied to the general distribution of all dry spells in different durations (Table 13). If a dry spell of at least 15 days is defined as a drought, as many investigators do, then Table 13 shows that there were only 4

Table 13. The Longest Monthly and Annual Dry Spells (in days) at Nacogdoches, Texas, 1901-80

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1901	10	9	8	13	10	14	7	18	11	20	9	18	23
02	15	7	8	9	13	27	8	17	10	15	9	9	40
03	10	4	5	29	13	6	12	10	18	15	29	7	32
04	11	8	16	10	24	9	10	18	9	14	19	18	29
05	6	9	5	6	6	18	9	17	10	14	14	9	24
06	10	16	8	7	13	13	9	10	18	17	8	12	33
07	10	19	14	6	8	27	15	21	16	8	7	10	36
08	19	6	9	10	6	11	11	11	13	22	9	14	27
09	24	5	18	8	19	11	17	11	14	12	13	11	24
10	11	13	11	14	14	12	12	9	16	25	10	--	29*
1911	32	8	17	5	10	18	11	13	28	13	14	5	41
12	10	11	6	6	13	11	14	12	30	16	16	6	53
13	5	10	10	13	9	9	17	11	4	5	20	7	22*
14	24	4	7	12	6	15	9	--	--	--	--	--	24
15	8	8	15	9	19	14	15	11	17	12	9	8	21
16	9	16	24	8	12	7	10	10	12	17	8	11	40
17	7	7	10	7	13	27	10	17	14	25	17	20	40
18	10	10	17	7	14	9	16	6	13	6	7	11	17
19	8	8	7	19	5	6	17	9	13	7	14	12	19
20	4	9	7	12	12	7	6	4	8	14	10	6	15
1921	7	8	13	4	16	12	6	13	10	14	7	6	19
22	5	9	4	4	8	11	11	11	13	14	12	8	18
23	11	9	6	5	4	8	8	19	11	11	11	4	23
24	11	7	8	8	6	16	25	31	16	30	9	10	37
25	12	13	13	18	9	10	14	23	10	7	5	12	23
26	8	16	3	8	9	7	8	11	13	7	8	6	19
27	7	8	7	5	9	6	14	11	16	21	14	12	21
28	22	6	7	4	10	7	8	18	8	9	8	14	22
29	5	5	5	9	9	16	16	13	16	23	6	6	23
30	7	6	10	24	7	14	20	6	7	12	8	6	24
1931	7	6	8	17	11	9	8	6	19	9	11	6	24
32	5	8	18	13	14	12	15	8	13	11	12	3	25
33	10	6	6	8	19	22	4	14	11	13	19	9	22
34	6	6	8	5	9	15	11	15	11	14	15	9	26
35	9	11	19	6	9	5	8	11	11	18	14	9	21
36	9	9	6	7	9	19	14	9	10	14	13	8	23
37	2	14	4	15	27	8	18	10	16	10	5	7	30
38	10	17	7	7	13	7	7	8	16	13	8	7	17
39	4	4	16	9	9	8	10	11	18	13	10	13	19
40	8	5	14	5	8	9	14	8	21	14	9	6	23

Table 13. Continued

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1941	7	13	6	13	5	6	10	7	4	10	12	7	13
42	10	9	11	6	5	6	8	9	10	14	6	5	17
43	10	10	5	12	11	6	4	17	9	12	19	7	22
44	9	3	4	6	14	15	13	10	19	20	5	14	19
45	10	6	4	11	10	7	9	10	5	11	7	5	13
46	7	7	9	15	2	8	9	16	23	9	8	8	27
47	4	6	6	5	6	16	11	11	14	26	7	15	36
48	6	4	5	8	13	13	10	23	20	13	3	10	26
49	12	8	6	7	9	11	12	7	12	5	18	4	21
50	5	7	7	8	9	8	6	8	14	10	14	10	16
1951	12	9	7	9	21	7	12	17	6	15	17	5	24
52	16	8	6	7	7	16	13	11	13	31	7	9	47
53	13	4	5	10	13	18	12	10	14	15	8	6	28
54	9	15	13	11	12	16	17	20	9	10	14	11	25
55	5	12	16	7	11	6	7	9	9	18	9	27	27
56	17	9	12	11	10	10	20	26	29	16	11	6	29
57	14	11	6	5	4	6	19	13	7	13	9	10	20
58	10	9	5	8	10	8	19	8	5	13	8	10	14
59	7	4	5	9	11	8	7	6	10	15	15	7	16
60	6	11	10	14	14	10	14	7	20	6	6	12	19
1961	10	12	6	13	12	9	5	6	17	15	6	13	18
62	4	14	7	11	14	8	17	14	15	7	9	19	22
63	15	9	9	13	10	16	11	9	9	15	8	11	20
64	7	6	12	6	21	10	23	13	11	15	5	9	27
65	12	6	5	18	9	7	14	15	16	27	16	7	30
66	8	7	13	13	6	12	17	5	14	13	13	5	17
67	6	9	19	12	10	28	9	10	8	13	16	3	29
68	7	11	8	5	13	13	16	15	7	7	5	10	17
69	12	6	7	9	11	26	8	8	6	11	13	13	31
70	7	8	7	7	13	19	31	9	12	6	16	11	30
1971	14	6	8	16	7	13	19	9	7	10	17	12	27
72	8	17	6	11	13	13	7	6	10	19	5	8	19
73	6	8	6	5	11	13	10	8	10	10	10	7	13
74	3	8	9	11	9	6	15	3	9	14	4	6	16
75	6	10	7	7	8	8	17	13	8	15	16	7	23
76	8	9	5	7	9	14	6	8	8	8	11	11	14
77	9	11	15	10	28	13	7	14	10	16	19	14	41
78	4	9	7	7	15	23	14	14	6	--	8	11	37*
79	5	6	--	8	--	17	9	6	11	21	10	11	30*
80	7	12	4	9	9	20	21	13	7	16	15	21	30
Mean	9.4	8.9	9.0	9.6	11.1	12.4	12.3	11.8	12.6	14.0	11.0	9.6	22
Max	31	19	24	29	28	28	31	31	30	31	29	27	53

* Values not included in calculating means.

years out of the 1901-80 period in Nacogdoches with no occurrence of droughts. This means that, on the average, the probability of no drought in any year is about 5%, or once in every 20 years. Table 14 lists the dates of occurrence of all dry spells with a duration of 15 days or more. Since dry spells which occurred in the summer are more critical than other seasons, dry spells of 15 consecutive days or more without precipitation of 4 threshold amounts in June-July-August were further summarized in Table 15. The actual dry spells may be longer than those indicated in Table 15 because some of them might commence in May or extend into September.

Dry spells of 15 days or longer with rainfall 0.25 inch occurred in all summers (June-August) during the 80-year period except 3. The average duration of such dry spells was about 24.5 days.

A quarter inch of rainfall in a day during mid-summer may help the growth of grass and is welcomed by farmers such as corn growers, but it is inadequate in hot dry weather to benefit corn growth. The next higher unit, an inch of total rain in 2 consecutive days, was therefore set up. Practically every summer studied has spells of 24 or more consecutive days without an inch of rain. On the average, such a spell lasted about 30 to 35 days each summer. Half of the summers had these dry spells exceeding 45 consecutive days, nine summers or 11% had such dry spells equal to 70 days or more. The longest duration in this category was 92 days.

Table 16 is a summary of the monthly distribution of dry spells of 15 days or more with no measurable precipitation at Nacogdoches during

Table 14. Dry Spells of 15 Days or More with no Measurable Rainfall at Nacogdoches, Texas, 1901-80

Duration (Days)	Date	Year	Duration (Days)	Date	Year
23	Jul 27 - Aug 18	1901	30	May 5 - Jun 3	1937
40	May 19 - Jun 27	1902	17	Feb 1 - Feb 17	1938
32	Mar 28 - Apr 29	1903	19	Aug 31 - Sep 18	1939
29	Mar 7 - Jun 5	1904	23	Aug 30 - Sep 21	1940
24	May 26 - Jun 18	1905	17	Jul 24 - Aug 9	1942
33	Oct 15 - Nov 16	1906	19	Nov 8 - Nov 26	1943
36	Jun 4 - Jul 9	1907	19	Sep 8 - Sep 26	1944
27	Sep 26 - Oct 22	1908	27	Aug 30 - Sep 25	1946
24	Jan 5 - Jan 28	1909	36	Sep 21 - Oct 26	1947
22	Mar 14 - Apr 6	1909	26	Sep 11 - Oct 6	1948
32	Jun 16 - Jul 17	1909	21	Nov 13 - Dec 3	1949
29	Oct 7 - Nov 4	1910	16	Nov 7 - Dec 2	1950
41	Sep 3 - Oct 23	1911	24	May 11 - Jun 3	1951
53	Aug 25 - Oct 16	1912	47	Sep 19 - Nov 4	1952
22	Oct 30 - Nov 20	1913	41	May 19 - Jun 28	1953
24	Jan 5 - Jan 28	1914	25	Nov 17 - Dec 11	1954
21	Oct 20 - Nov 9	1915	26	Oct 14 - Nov 9	1955
40	Feb 14 - Mar 24	1916	27	Dec 5 - Dec 31	1955
40	Sep 17 - Oct 25	1917	36	Jul 22 - Aug 26	1956
17	Mar 2 - Mar 18	1918	21	Jun 29 - Jul 19	1957
22	May 18 - Jun 3	1918	19	Jul 8 - Jul 26	1958
19	Apr 10 - Apr 28	1919	16	Nov 16 - Dec 1	1959
15	Sep 30 - Oct 14	1920	20	Sep 2 - Sep 21	1960
19	May 16 - Jun 3	1921	18	Sep 13 - Oct 1	1961
19	Oct 29 - Nov 16	1921	22	Nov 28 - Dec 19	1962
18	Nov 19 - Dec 6	1922	20	May 28 - Jun 16	1963
23	Jul 28 - Aug 19	1923	27	Jun 27 - Jul 23	1964
37	Jul 27 - Sep 1	1924	30	Oct 5 - Nov 3	1965
23	Aug 2 - Aug 24	1925	17	Jul 5 - Jul 21	1966
19	Jul 24 - Aug 11	1926	29	Jun 3 - Jul 1	1967
21	Oct 9 - Oct 29	1927	17	Aug 17 - Sep 2	1968
22	Jan 9 - Jan 30	1928	32	Jun 5 - Jul 6	1969
23	Oct 5 - Oct 27	1929	39	Jun 26 - Aug 3	1970
24	Apr 3 - Apr 26	1930	27	Oct 22 - Nov 27	1971
24	Oct 12 - Nov 5	1931	19	Oct 1 - Oct 19	1972
25	May 18 - Jun 11	1932	16	Sep 29 - Oct 14	1974
22	Jun 13 - Jul 4	1933	23	Sep 23 - Oct 15	1975
26	Jun 6 - Jul 1	1934	41	May 5 - Jun 13	1976
32	Mar 12 - Apr 2	1935	37	Jun 8 - Jul 14	1977
21	Sep 28 - Oct 18	1935	30	Sep 22 - Oct 21	1979
23	Jul 18 - Aug 8	1936	30	Jun 21 - Jul 21	1980

Table 15. Dry Spells of 15 Days or More with Rainfalls Less Than Three Threshold Values in Three Summer-Months (June-August) at Nacogdoches, Texas, 1901-80

Year	Number of Consecutive Days With less Than			
	0.1 in/day	0.25 in/day	1.0 in/2 days	2.0 in/3 days
1901	19,23	26,23	24,32	24,17,44
02	27,17	27,15,30	27,17,31	27,64
03	none	none	24,19	32,46
04	18	19	24	48,17,23
05	18,17	18,17	18,24	18,24
06	none	17,21	17,32,34	57,34
07	36,15,22	39,17,32	39,50	92
08	15	24,34,15	57,33	92
09	24,15	24,21	51,38	53,38
10	17	17	26,65	92
1911	18	23,15	34,27,15	34,43
12	none	15,23,20	15,44,20	92
13	17	27,17,17	92	92
14	.... no record for August			
15	none	17,15,24	32,52	32,52
16	none	16,18	50,40	92
17	28,41	28,41	33,41	33,41
18	16	21,16	38,49	92
19	18,19	19,19	19,39	19,42
20	none	none	59,18	59,18
1921	17	18	22,17	26,34,17
22	17	23	48,22	92
23	23	16,23	69	80
24	17,70	17,70	17,7	92
25	24,15,24	34,15,24	44,6	92
26	19	22	39	25,16,39
27	20	32,28	70	20,70
28	21	21	42,35	53,35
29	16,16	16,24,17	22,59	32,59
30	16,20	25,20	33,52	92
1931	none	27,16	48	92
32	15,16	23,16	74	92
33	22,15	22,32	52,32	52,32
34	26,19	26,25,15	92	92
35	18	17,38	92	92
36	23,36	23,40	31,48	83
37	24,16	29,24,17	29,41	91
38	17,21,16	18,22,32	41,38	40,37
39	20,18	32,32	59,31	92
40	18	17,18	17,48	77

Table 15. Continued

Year	Number of Consecutive Days With less Than			
	0.1 in/day	0.25 in/day	1.0 in/2 days	2.0 in/3 days
1941	none	none	23,35	29,48
42	18,18	18,25	61	72
43	17	18,19	43,28,19	72,19
44	15,19,16	17,15,21,18	65,19	85
45	16	21,19	20,25,23	34,51
46	15,16,19	15,16,19	25,28,25	59,25
47	18,25,26	18,25,32	18,25,43	18,72
48	23,36	28,37	31,60	92
49	23	16,23	38,37	92
50	none	22	23,37	89
1951	17,28	35	44,35	44,35
52	19,16,19	22	45,31	45,44
53	28	28,24	28,21,30	28,22,39
54	16,16,17,21	21,50	92	92
55	none	28,22,17	63,27	92
56	30,36	30,37	19,67	17,72
57	21,20	21,20	47,38	50,39
58	19	27	62	15,65
59	none	28	54,29	54,28
60	18	18	18	17,50
1961	none	21	73	15,73
62	16	16,19	18,17,35	18,36,35
63	16	16,16	44,16	16,75
64	27,20	59	67	92
65	16,15	20,19	16,20,4	22,20,46
66	17	17	37,19,8	72,18
67	29,19	29,32	29,42	90
68	16,15	15,16,23	25,40	20,66
69	32	39,18	45,46	92
70	19,39	20,43	89	92
1971	19	20,20,21	20,24,21	70,21
72	none	none	24,32	16,57
73	none	24	72	72
74	15	21,15,19	35,23,19	44,44
75	17	26,23	66	82
76	none	17,37	18,43	18,73
77	23	23,23	67	67
78	37	45,31	68	92
79	15	19	51,34	51,34
80	20,30	20,36,15	20,36,15,18	92

the 80 years of observations. The total number for the entire period was 186, with an average occurrence of about 2.4 dry spells for each year. The average duration was 19.1 days; the longest duration in each month is of course 31 days. The table was prepared by months, so no overlapping dates were counted and the data, therefore, cannot be compared with those of the preceeding tables on this subject.

Table 16. Monthly Distribution of Dry Spells with No Measurable Precipitation in 15 Consecutive Days or more at Nacogdoches, Texas, 1901-80

	Dry Spell ≥ 15 Days												
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Number of Occurrence	9	7	12	8	9	24	23	18	22	29	18	7	186
Mean Duration (days)	20	17	16	21	22	19	19	20	20	18	18	20	19
Max. Duration (days)	31	19	24	29	28	28	31	31	30	31	29	27	31

Precipitation of Shorter Duration

Monthly and annual precipitation data are often used for studies of climatic changes and long-term resources planning and management. For water resource project design, however, information on precipitation of shorter duration is of prime importance. Chang's (1981) work on hourly precipitation characteristics at Nacogdoches covered the NWS data collected between 1955-76 and is the main source of information and major report in this area. The present study added 4 more years of newly available data (1977-80) to the 1955-76 data series and repeated

Chang's (1981) analysis. Some storm information of shorter than 1 hour in duration was also included in the analyses. The data collected by NWS during the 1981-85 period were not used in this study due to poor quality.

Number and Duration of Hourly Storms. In compliance with the "Hourly Precipitation Data" published monthly by the U.S National Weather Service (NWS), hourly storms are simply described as storm rainfalls without a break for more than 1 hour and their duration are counted by integer of hours.

Based on 18 years of complete hourly precipitation records between 1955-80, the average number of storms at Nacogdoches was about 108 per year or about 1 storm every 3.4 days. The addition of 5 newly available years of data (1976-80) did not significantly change the average number of storms at Nacogdoches reported by Chang (1981) for the earlier period, i.e., 1955-75. Not only was the long-term average of total number of storms per year not increased by the additional data of 5 years, but no alteration was observed on the monthly distribution pattern of the hourly storms. The occurrence of storms was still highest in February (10.4% of annual total) and least in July (5.6%). About 30% of the total or 34 storms occurred in the 3 coldest winter months (December-February), while 19% or 21 storms occurred in the three hottest summer months (June-August), a frequency of about identical to that reported earlier.

Storms in July were not only the least in frequency, but also the shortest in duration. The longest duration of storms in July in the records (1955-80) was 11 continuous hours; about 78% of the storms had durations no more than 2 hours; July storms occurred in 6 different durations. The longest duration in February was 22 hours, about 64% of February storms had durations no more than 2 hours, and they occurred in 15 different durations. Thus, the occurrence of storms in February was almost double that of July. The longest duration in the records was 28 hours observed in December.

Table 17 is a summary of monthly distribution of hourly storms, by duration, based on 18 years of complete records between 1955-80 at Nacogdoches. It shows that summer storms are dominated by convective activities of short duration, low frequency, and high intensity (with consideration of total rainfall discussed in earlier sections). Winter storms are largely generated by frontal systems and are longer in duration in general. The annual distribution of storms by duration can be generally described using an exponential function developed below:

$$P(D) = 0.364e^{-0.364D}, \; D \geq 0 \qquad (9)$$

where P is the probability density function, for any storm duration D, in hours, and e is the exponential constant. The equation provides satisfactory estimates for storms between 3 and 18 hours in duration or about 67% of the 24 different storm durations. The equation, however, underestimates those storms with durations less than 3 hours or greater than 18 hours.

Intensity-Duration-Frequency. By rule of thumb, a rainfall of long duration occurs in low intensity, and rainfall of high intensity tends to be of low frequency and short duration. Chang (1981) developed

Table 17. Number of Rainfalls, by Hourly Durations and Months, at Nacogdoches, Texas, 1955-80

Duration (Hours)	Frequency												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
1	77	94	79	67	75	47	45	47	74	60	68	57	808
2	44	35	28	38	53	51	40	50	47	25	41	30	482
3	23	20	27	19	20	7	11	8	15	11	11	23	195
4	13	17	12	14	15	13	10	9	4	15	18	17	157
5	4	14	6	9	7	6	2	6	6	7	8	8	83
6	9	5	4	5	6	4		1	5	6	11	7	63
7	6	4	3	2	1	3		1	6	5	7	6	44
8	4	1	5	5	2	1		1	1	4	1	3	28
9	2	5	3	1	3	1		2	1		2	4	24
10		2		1					2	1	2	4	12
11	2			3	1		1	1			1	1	10
12		1		1	1					1	1	5	10
13	1			1		1			1		1	1	6
14	3	1							1				5
15		1						1					2
16	1	2											3
17	1									1		1	3
18								1					1
19													0
20	1												1
21												1	1
22	1	1											2
23													0
24									1				1
25												1	1
.													.
.													.
28												1	1
Total	192	203	167	167	184	134	109	127	164	136	172	188	1943

an equation to describe such a relationship for the maximum storm events at Nacogdoches, Texas. His equation was later used in a runoff study in the area (Chang and Ting, 1986).

The present study re-evaluated Chang's (1981) storm intensity model by adding 5 years of newly available storm data in the analysis. The model, similar to the old one but different slightly in constants, appears as:

$$i = \frac{1.70\ T^{0.23}}{D^{0.77}}, \quad 1 \leq D \leq 48 \tag{10}$$

where i is the average maximum storm intensity in inches hr^{-1}, D is the duration in hours, and T is the return period in years. The value T is the reciprocal to the probability of an event being equal to or greater than a threshold value. For example, if the probability of occurrence of a storm rainfall being 5.00 inches or more in any year is 1%, then the return period is 1/0.01 or 100 years. In other words, the storm is expected, on the average, to occur once in a 100-year period.

Equation 10 gives estimates smaller than that of the equation developed by Chang (1981), and the differences are greater for longer return periods and longer storm durations. For example, the 3-hr 100-yr maximum storm rainfall is 6.31 inches estimated by Equation 10 and 6.74 inches by Chang's (1981) equation. The difference is -0.43 inch. For a 24-hr 100-yr maximum storm, the estimates are 10.18 inches versus 11.30 inches, in the same order. The difference is as much as -1.12 inches.

Also, estimates made by the new equation are a little lower than that interpreted from a rainfall frequency atlas published by the

National Weather Service (1961). For example, the intensity for a 48-hr 50-yr storm at Nacogdoches is 0.21 inch hr^{-1}, or 10.18 inches in total, computed from Equation 10, and 11.66 inches from the National Weather Service (1961).

Table 18 shows the maximum rainfall of 6 short durations in minutes (i.e., 15,30,45,60,120,180 minutes) at Nacogdoches, Texas for the 1976-80 period. As expected, an increase in storm duration results in an increase in depth of rainfall but a decrease in rainfall intensity. The maximum rainfall in 15 minutes during the 5-year period was 1.1 inches, or an intensity equivalent to 4.40 inches hr^{-1}. The maximum rainfall and means of these maximum rainfall depths for the 6 durations were plotted in Figure 11. The rainfall mean of maximum rainfall depth increased more rapidly for the first 60 minutes and it slowed down for longer durations. The trend of rainfall depth with duration can be described by the function shown below:

$$R_d = 0.397 + 0.36 \text{ Log } t \qquad (11)$$

where R_d is the estimated maximum storm rainfall in inches, and t is storm duration between 15 and 180 minutes.

Monthly distribution for the maximum storm rainfall of the 6 shorter durations during the 5-year period is given in Table 19. It is interesting to note that all the maximum storm rainfall of the 6 durations occurred in the months of November, with the lowest in December.

Frequency of Occurrence

The occurrences of monthly, seasonally, and annual events for total rainfall, rain day, wet spells, and dry spells have been discussed briefly in the previous sections. However, those occurrences were simply based on arithmetic averages and ratios observed in the long-term records. The variablity of data and types of their distribution functions were not involved in the discussion. Since many

Table 18. Maximum Rainfall (in inches) in Stated Period at Nacogdoches, Texas, 1976-80

Year	Rainfall Duration, minutes					
	15	30	45	60	120	180
1976	1.1	1.4	1.7	1.7	1.8	1.8
1977	0.8	1.4	1.5	1.5	1.5	1.6
1978	0.6	1.5	1.8	1.9	2.1	2.1
1979	1.1	1.9	2.5	2.9	3.5	3.7
1980	0.8	1.2	1.4	1.6	2.0	2.2

Table 19. Maximum Monthly Rainfall (in inches) for Stated Durations at Nacogdoches, Texas, 1976-80

Duration (min.)	Month												Year
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
15	0.3	0.5	0.5	0.8	1.1	0.8	0.5	0.7	0.6	0.6	1.1	0.3	1.1
30	0.5	0.8	0.8	1.5	1.4	1.4	0.9	1.2	0.7	1.0	1.9	0.4	1.9
45	0.7	1.0	1.1	1.8	2.1	1.5	1.0	1.3	0.7	1.4	2.5	0.5	2.5
60	1.0	1.1	1.3	1.9	2.5	1.5	1.6	1.3	0.7	1.6	2.9	0.6	2.9
120	1.1	1.3	1.5	2.1	2.9	2.0	1.9	1.4	1.1	1.8	3.5	0.8	3.5
180	1.3	1.5	1.6	2.2	2.9	2.6	2.2	1.5	1.3	2.0	3.7	1.0	3.7

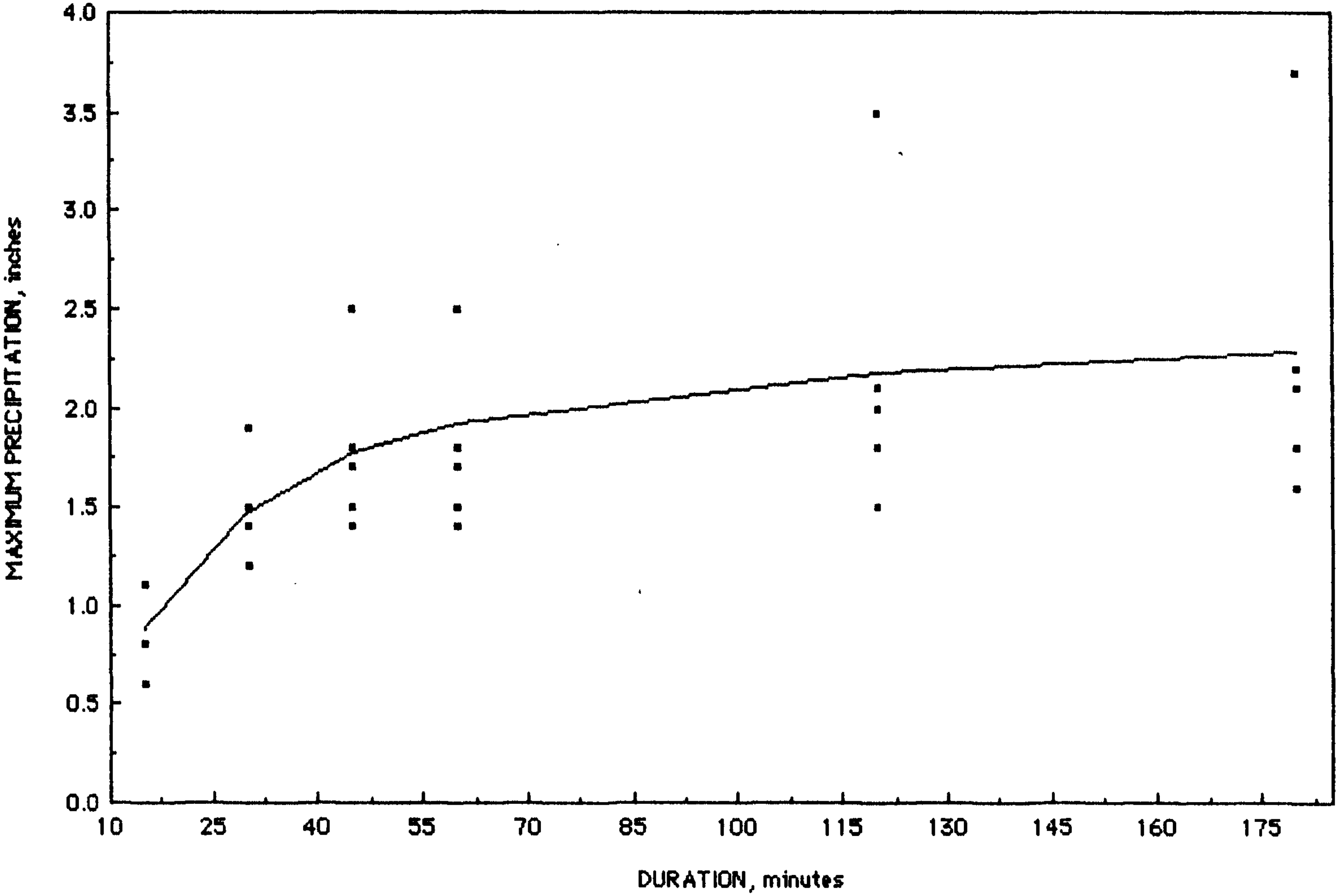

Figure 11. Maximum storm rainfall (inches) for duration periods less than 180 minutes at Nacogdoches, Texas, 1976-80.

design, planning, and management of water resources projects require climatic information in the distant future, occurrences of climatic events need to depend not only on the observed data but also on probability theory. This section presents results of frequency analysis for 5 major precipitation activities at Nacogdoches, i.e., total precipitation, total rain day, maximum wet spell, maximum dry spell, and maximum daily precipitation.

The normal and log-normal distributions were used to fit annual rain day and annual precipitation using the 30-year data collected from most recent normal period (1951-80). Based on visual judgement of predicted data plotted against observed data, both distributions seem to provide a satisfactory goodness-of-fit of the 2 annual data series. However, the expected values of higher return periods estimated by the normal distribution were lower than that estimated by the log-normal distribution model, and those expected values are especially low when compared with the extreme values observed during the 80-year period. For example, the estimated 100-yr annual precipitation is 73.00 inches by the normal distribution model, 80.00 inches by log-normal distribution model, and the maximum observed value in the 80-year period was about 74.00 inches.

The normal distribution model also underestimates rain days of higher return-period. For a 100-yr annual total rain day, its estimate is 118 days versus 123 days estimated by the log-normal distribution model, while the actual maximum observations in the 80-year period was 120 days. Thus, the log-normal distribution model seems to be more desirable than the normal distribution model and was employed to estimate probability events of annual total rain days and annual rainfall for the Nacogdoches area. The estimated values, expressed in terms of probabilities and return periods, are given in Table 20.

Table 20. Frequency of Occurrence for Five Precipitation Variables Observed During 1951-80 at Nacogdoches, Texas

Variables	Return Periods, years				
	2 (50%)	5 (20%)	10 (10%)	50 (2%)	100 (1%)
Annual Rainfall,inches	46.27	53.99	58.22	71.63	79.72
Annual Rain Day, days	89.3	98.7	102.1	114.4	122.5
Max. Daily Rainfall,inches	3.92	4.54	5.56	7.43	8.24
Max. Wet Spell, days	7.4	8.6	10.7	14.4	16.0
Max. Dry Spell, days	22.8	31.1	36.5	48.5	53.6

Notes: 1. Values in parentheses are the probabilities of an event equal to or greater than the indicated magnitude.
2. Annual rainfall and annual rain day were estimated by log-normal distribution function, while the other three maximum series were fitted by the Gumbel's extreme distribution model.

For an extreme data series, Gumbel's distribution function is one of the most popular techniques in frequency analysis. It has been employed to fit a number of extreme events in hydrology and climatology with satisfactory results (Chang and Boyer, 1980). Accordingly, the model was used to fit 3 maximum annual series of precipitation variables for the Nacogdoches area. Results of these frequency analysis are also given in Table 20. An example for each of the 2 frequency distribution analyses is plotted in Figures 12 and 13.

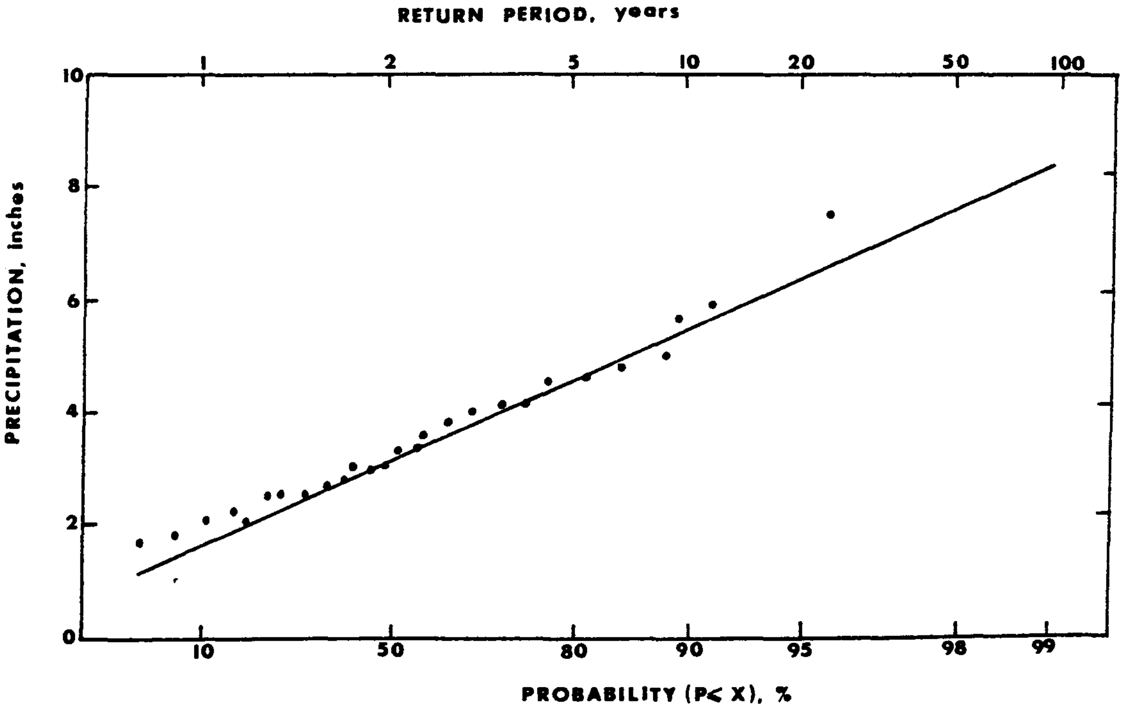

Figure 12. Gumbel distribution of maximum daily precipitation for most recent normal period (1951-80) at Nacogdoches, Texas.

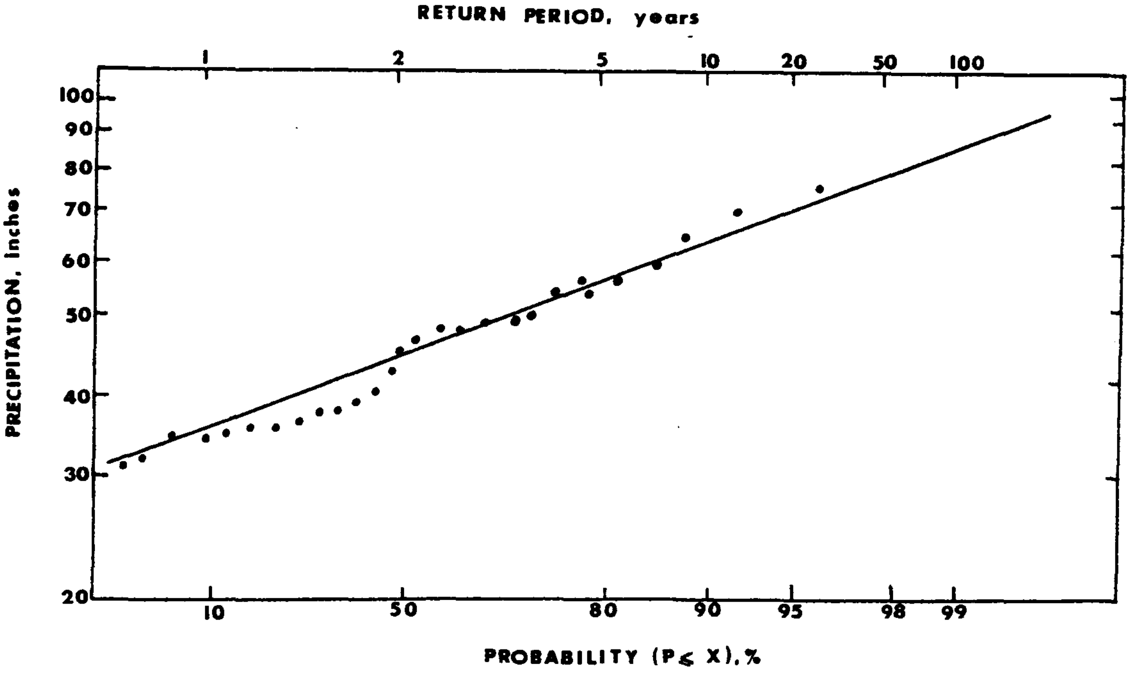

Figure 13. Log-normal distribution of annual total precipitation for most recent normal period (1951-80) at Nacogdoches, Texas.

Thermal Climate

Thermal environment reflects the uneven distribution of incoming solar radiation on the ground, vegetation cover, distribution of water bodies, and differences in thermal property between the ground and the air. The word "temperature" is a relative term with respect to the degree of molecular activity, or simply the hotness or coldness of a substance. The more rapid the movement of molecules, higher the temperature. To measure the degree of coldness or hotness, an arbitrary scale is used. In the U.S., temperature is commonly expressed in Fahrenheit (°F), where the boiling point of water at sea level is 212°F and the freezing point is 32°F.

To define thermal climates of an area, a variety of temperature statistics and indices are frequently used. The most common one is the average daily temperature. It is computed by summing the lowest and the highest readings in a 24-hr period, and then dividing that sum by 2 to get the average. Average monthly minimum (or maximum) temperature is the average of the daily minimum (or maximum) temperatures observed at that station for the month. The average monthly minimum and maximum temperatures are used to compute monthly average temperature. Annual temperature is the average value of the 12 monthly average temperatures, or the average of annual maximum and minimum temperatures. Similarly, the annual average temperature for a series of years may arithmetically be averaged to produce the long-term mean annual temperature for that period, and if the period is sufficiently long enough such as 30 years, the mean value is called annual normal temperature.

Besides average air temperature, parameters such as extreme air temperature, number of days with daily minimum (or maximum) temperature beyond a threshold value, frost-free days in a year, and cooling, heating, and growing degree days are frequently cited in literature to characterize the thermal climate of a place. These parameters are important because of their direct and indirect influences on 1) sensible and latent heat exchanges between the air and the surfaces, 2) human comfort, 3) plant and agriculture production, 4) animal migration, and 5) fuel consumption. Some simple statistics of air temperature recorded at Nacogdoches, Texas for the period 1901-80 are given in Table 21. Detailed thermal climates of Nacogdoches are discussed through various parameters below.

Mean Air Temperature

The term "mean" temperature used here refers to the arithmetic mean ($\bar{T}$) of a long-term temperature record and is the first moment about the origin, or

$$\bar{T} = (\Sigma T_i)/N \qquad (12)$$

where T_i is the surface air temperature with observations $i= 1,2,\ldots,N$. Equation 12 is an unbiased estimate of population mean providing that the population follows the normal distribution function. The assumption of normality seems to be satisfactory for air temperature of longer durations (i.e., seasonal, annual) and of long-term records. Thus, mean air temperature is used to characterize the long-term status of thermal environment at a place. It is assumed to be the unbiased estimate of the average state of the air temperature for that location.

Annual and Monthly. Air temperature at Nacogdoches is characterized by hot summers and mild winters. Annual (average) temperatures ranged from 62.5 to 67.6°F with a mean of 65.5°F and a standard deviation of 1.10°F (Table 21). This means that 68% of the time the observed annual temperature will fall between 64.4 and 66.6°F, and there is a 16% probability in any year that the observed annual temperature will be either less than 64.4°F or greater than 66.6°F.

Changes in average annual temperature from year to year were small in the 80 years of records. It fluctuated about 2.55°F above or below the mean annual temperature. The average absolute change of annual temperature between 2 consecutive years was ±1.0°F, and 33% of the time the absolute changes in annual temperature were 0.5°F or less. There were only 3 occasions when the changes in annual temperature between 2 consecutive years were greater than 3.0°F, a -3.4°F between 1911 and 1912, a -3.3°F between 1939 and 1940, and a -3.2°F between 1957 and 1958. The monthly and annual temperatures for the entire records (1901-80) at Nacogdoches are given in Table 58 of Appendix IV. Average, maximum, and minimum values of annual and monthly temperatures are plotted in Figure 14 and 15, respectively, for visual observations.

Since climatic records of 80 years or longer are generally not available, a period of records based on 30 years of observations was internationally adopted as a reference or a normal to characterize the long-term average of a location. Breaking down the 80 years of records into 6 chronological periods of 30 years (normal), the mean temperature for each 30-year normal was, beginning with first one (1901-30) and

Table 21. Some Simple Statistics of Monthly and Annual Temperature (°F) at Nacogdoches, Texas, 1901-80

Month	Maximum				Minimum				Average			
	Mean	S.D.	Highest	Lowest	Mean	S.D.	Highest	Lowest	Mean	S.D.	Highest	Lowest
January	57.8	4.7	69.5	44.6	36.9	4.9	46.2	27.0	47.4	4.9	56.6	35.7
February	61.6	4.7	72.4	48.9	38.8	4.8	49.1	27.9	50.2	4.3	58.5	38.5
March	69.1	4.7	78.3	55.6	46.3	4.8	57.9	36.7	57.7	4.4	68.1	46.6
April	76.3	3.2	83.4	68.2	53.6	3.0	61.2	47.8	64.9	2.8	72.3	59.0
May	82.8	2.7	88.3	76.9	61.6	2.4	66.7	55.0	72.2	2.2	76.2	66.0
June	89.7	2.6	94.8	82.6	67.7	2.2	71.7	59.2	78.7	2.0	83.1	70.9
July	92.9	2.9	98.5	87.6	71.1	1.4	74.4	66.9	82.0	1.8	86.2	78.5
August	93.7	3.0	103.3	87.1	70.5	1.6	73.2	66.0	82.1	1.8	86.1	78.0
September	88.6	3.3	97.1	79.4	64.7	3.0	75.5	57.5	76.7	2.6	82.9	69.4
October	80.0	3.7	89.4	71.3	54.2	4.3	75.3	45.2	67.2	3.0	77.3	59.1
November	68.2	4.0	78.3	57.7	44.0	4.2	54.8	34.0	56.1	3.6	64.8	48.6
December	60.0	4.2	68.9	51.7	38.5	3.7	46.3	29.6	49.5	3.7	53.9	41.3
Annual	76.8	1.8	81.4	73.2	54.1	1.4	57.3	51.0	65.5	1.1	67.6	62.5

Notes: S.D. = standard deviation

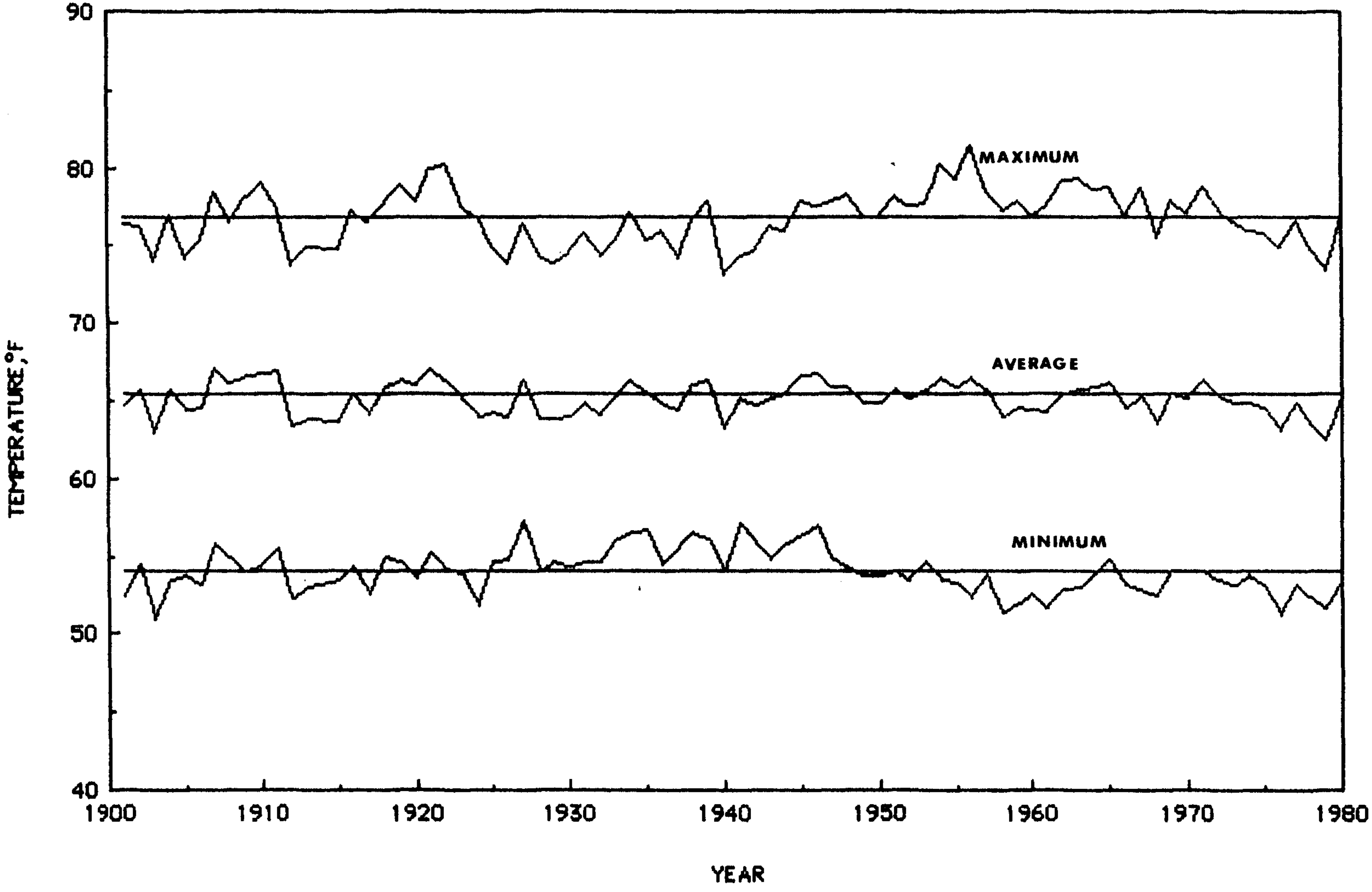

Figure 14. Average, maximum, minimum annual temperatures over years at Nacogdoches, Texas, 1901-80.

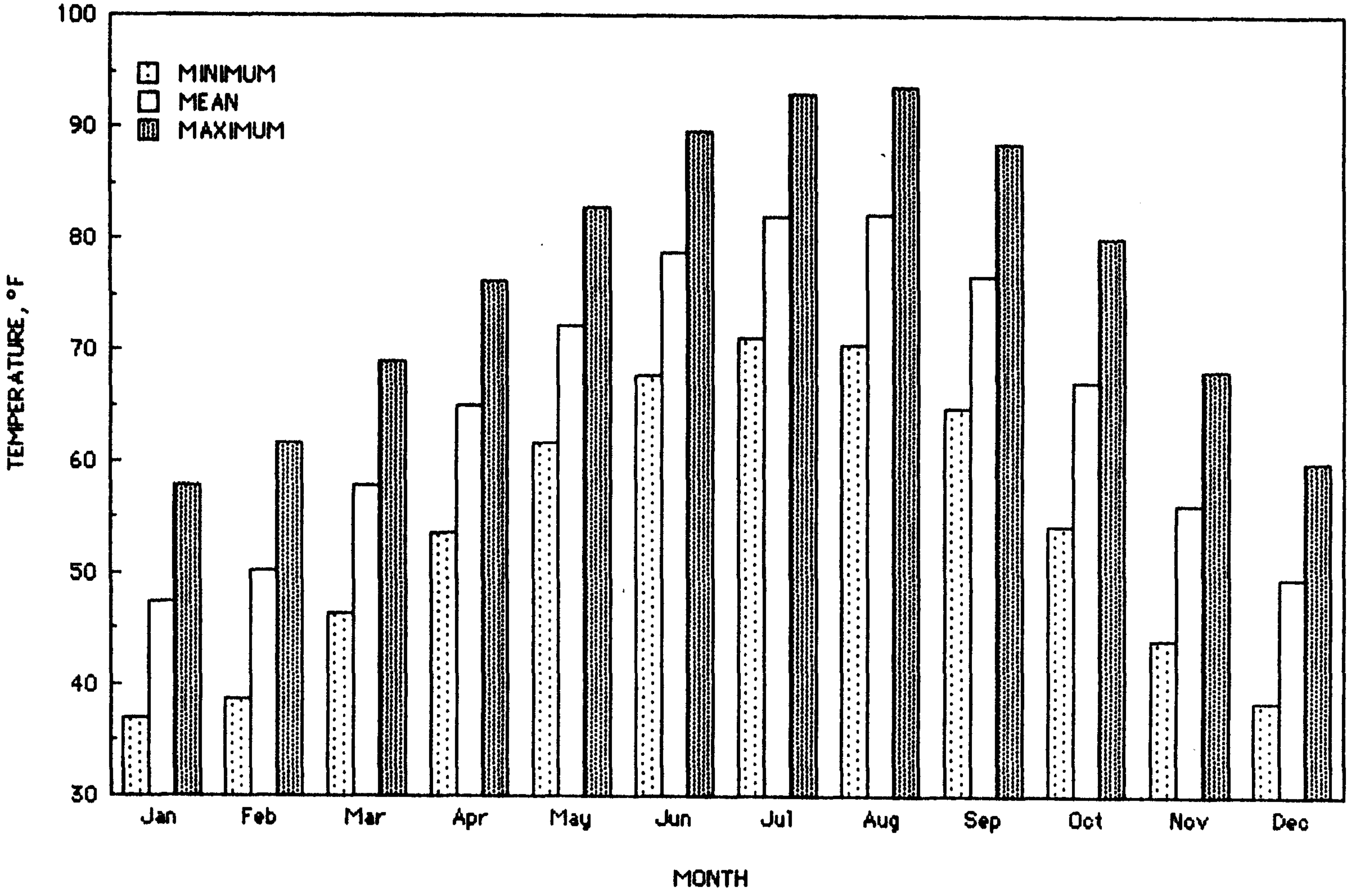

Figure 15. Means of the average, maximum, and minimum monthly temperature of the 80-year (1901-80) period, Nacogdoches, Texas.

ending with the most recent one (1951-80), 65.2, 65.4, 65.7, 65.9, 65.8, 65.5°F. It indicates that the normal air temperature was coldest for the earliest period (1901-30) and then gradually increased to a peak in the 4th normal period (1931-60). For the most recent period (1951-80), the annual temperature is identical to the mean of the 80 years. However, statistical analyses showed that there is no significant difference between any of these annual periods (Table 22).

Monthly temperature follows closely the fluctuation of solar radiation. Over the entire record, 1901-80, mean monthly temperature increased from the lowest, 47.4°F, in January to the highest, 82.1°F, in August, and then gradually decreased to 49.5°F in December (Figure 15). Although the mean temperature in August for the 80-year period was 0.1°F greater than that in July, both the highest and lowest August temperature, however, were lower than those in July. There were only 6 times in the whole records that the January temperature was lower than 40°F, and there was no record in the past with monthly temperatures drop below the freezing point (except minimum monthly temperature). The mean temperature of the coldest 3 winter months (January, February, and December) was 41.5°F in 1905, while the warmest was 53.8°F in 1921.

Daily. The variation in daily average temperature is much greater than that of monthly and annual temperatures. During the 30-year period (1951-80), normal daily average temperature never reached 90°F or above. Based on Table 23 the daily temperature of 80°F or above occurred about 70 days yr^{-1} or about 20% of the total annual days spread among the months of June to September. Of those days with daily mean temperature

Table 22. Normal Monthly and Annual Temperature (°F) for Six Chronological Decades at Nacogdoches, Texas

Month		Periods					
		1901-30	1911-40	1921-50	1931-60	1940-70	1951-80
January	Normal	48.0	48.3	48.2	48.4	47.1	46.2
	Std. Dev	4.36	4.70	4.24	3.87	3.83	4.64
February	Normal	50.0	51.3	51.8	51.6	50.8	49.4
	Std. Dev.	4.46	3.95	3.78	3.84	4.12	4.40
March	Normal	58.2	57.2	57.4	57.3	56.8	57.0
	Std. Dev.	4.91	4.51	4.15	4.22	4.05	3.88
April	Normal	64.1	64.1	64.9	65.1	66.4	65.6
	Std. Dev.	2.63	2.44	2.94	2.45	2.86	2.87
May	Normal	71.5	71.2	71.6	72.4	73.3	73.2
	Std. Dev.	2.30	2.13	1.96	2.10	1.80	2.03
June	Normal	78.2	78.7	7.88	79.3	79.6	79.0
	Std. Dev.	2.36	2.06	1.63	1.57	1.34	1.81
July	Normal	81.4	82.0	81.6	82.2	82.6	82.8
	Std. Dev.	1.71	1.44	1.29	1.47	1.71	1.84
August	Normal	81.9	81.9	82.1	82.3	82.7	82.4
	Std. Dev.	1.73	1.80	1.80	1.92	1.67	1.79
September	Normal	76.6	77.1	77.0	76.9	77.2	76.8
	Std. Dev.	2.60	2.58	2.37	2.13	2.20	2.83
October	Normal	66.5	67.3	67.9	68.1	67.8	67.0
	Std. Dev.	2.72	2.81	3.22	3.23	3.22	2.81
November	Normal	56.5	55.8	56.2	55.5	56.1	55.6
	Std. Dev.	3.91	3.99	3.83	3.17	3.17	3.41
December	Normal	48.7	49.9	50.4	50.4	49.6	49.2
	Std. Dev.	3.73	4.41	4.29	3.79	3.08	3.01
Annual	Normal	65.2	65.4	65.7	65.9	65.8	65.5
	Std. Dev.	1.27	1.21	1.08	0.96	0.88	1.00

Table 23. Recent Normal (1951-80) Mean daily Temperatures at Nacogdoches, Texas

Day of	Month											
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	35.1	51.7	55.3	62.4	68.9	76.2	81.9	82.3	81.3	72.5	47.3	38.9
2	47.4	53.0	55.7	59.9	68.7	76.3	82.6	83.0	80.7	72.1	60.7	50.8
3	46.6	45.7	57.0	63.5	68.8	76.4	83.0	82.5	80.8	72.1	58.8	52.5
4	43.5	46.5	47.4	63.3	68.9	76.0	82.3	82.9	80.4	68.5	57.0	49.5
5	44.0	50.7	52.7	59.0	70.0	76.6	82.3	82.5	79.8	71.7	51.5	53.7
6	44.6	51.0	52.7	61.7	64.1	77.0	82.3	82.9	79.1	70.5	56.9	53.1
7	46.0	50.1	54.1	63.7	71.7	78.0	82.2	76.5	79.6	69.5	57.5	45.5
8	45.3	50.9	54.6	61.6	72.2	78.9	82.2	83.7	79.2	68.0	57.6	49.6
9	45.3	47.8	49.8	64.1	73.1	79.8	83.1	83.7	79.4	68.5	56.2	50.7
10	43.1	47.3	49.4	63.1	71.1	79.6	83.1	83.5	78.8	69.6	55.9	43.3
11	41.0	51.8	56.3	63.3	71.6	79.6	83.0	82.9	77.7	70.1	53.6	48.3
12	43.1	50.4	57.6	64.3	69.1	80.0	82.8	79.4	78.9	70.8	58.2	40.7
13	45.5	49.4	43.4	61.3	72.1	79.7	82.6	78.9	77.1	70.7	58.3	43.8
14	48.4	52.3	53.2	61.4	72.3	80.4	82.7	82.8	76.4	59.7	59.1	45.4
15	47.4	52.3	54.1	59.6	72.3	80.7	82.7	82.7	76.3	58.6	59.2	44.2
16	46.1	51.2	53.4	59.6	72.0	80.3	82.6	83.0	76.4	57.1	58.3	43.7
17	44.8	49.7	53.4	66.4	73.5	79.5	82.4	83.7	77.5	55.1	58.4	41.6
18	47.1	45.3	55.7	62.0	74.4	79.2	82.7	83.8	77.1	56.2	53.8	43.7
19	46.7	50.2	55.9	68.7	74.1	80.1	83.2	82.9	76.8	64.6	51.3	48.3
20	47.1	48.3	50.2	69.9	67.3	80.3	82.9	83.2	77.2	62.9	54.0	46.9
21	46.8	47.0	54.7	68.0	73.9	80.2	83.2	82.8	77.4	63.2	53.8	48.3
22	47.7	45.0	57.1	69.0	74.5	80.5	82.8	82.0	76.9	61.1	54.0	47.5
23	47.8	46.6	58.5	70.2	76.1	80.4	83.2	82.3	75.3	65.6	56.7	42.0
24	44.9	45.1	58.9	69.8	75.9	81.2	76.7	81.5	74.5	64.8	57.6	41.1
25	46.9	48.5	57.1	68.9	76.4	80.6	76.3	80.6	74.5	63.5	53.7	42.6
26	49.9	50.1	55.5	68.8	76.8	80.7	76.9	74.5	73.9	63.0	56.2	36.6
27	50.2	49.8	57.6	69.3	76.7	80.5	76.8	81.5	73.8	60.1	55.6	42.5
28	49.1	51.2	60.5	69.3	76.3	80.8	76.4	75.0	73.6	61.7	50.9	39.6
29	48.6		59.2	69.1	75.7	81.5	76.9	81.2	72.2	60.5	47.3	43.4
30	49.5		60.9	69.3	69.8	81.8	70.4	80.7	71.8	61.8	47.0	49.6
31	48.3		60.3		76.4		83.0	81.8		63.0		47.9

of 80°F or greater, August had the most days (26 days or about 37% of these days in the year) and July the 2nd most (24 days) while September had the least (4 days). The mean daily temperature was 64.48°F and a standard deviation 13.74°F denoting that the data were widely spread; it ranged from 35.1°F on January 1 to 83.8°F on August 18.

Daily temperatures follow closely the movement of the sun. Figure 16 is the plot of average daily temperatures for the whole year (365 days) based on the 1951-80 period. March 21 was first day of 0 or 360°of the solar longitude plotted on the ordinate to correspond with the vernal equinox. It can be seen that the mean daily temperature trend follows a sine wave. The fluctuation of mean daily temperatures at Nacogdoches can be estimated by:

$$T_d = 64.31 + 11.80 \text{ Sin } t \qquad (13)$$

where T_d is the estimated daily temperature, t is the solar longitude with March 21 as 0 or 360°. The t for any day of the year can be obtained by finding the differences in days with March 21 and multiplying the difference by 360/365 or 0.986°. Equation 13 overestimates low temperatures by as much as 16°F and underestimates the high temperatures by as much as 13.4°F. Nonetheless, it explains about 72.5% of the variation in mean daily temperature.

Maximum Temperature

Maximum temperature is the key information for air-conditioning engineers and may be more important to plant growth (Chang and Aguilar, 1980) and snowmelt forecasting (U.S. Corps of Engineers, 1956) than average temperature. The mean and the range of maximum temperatures, by

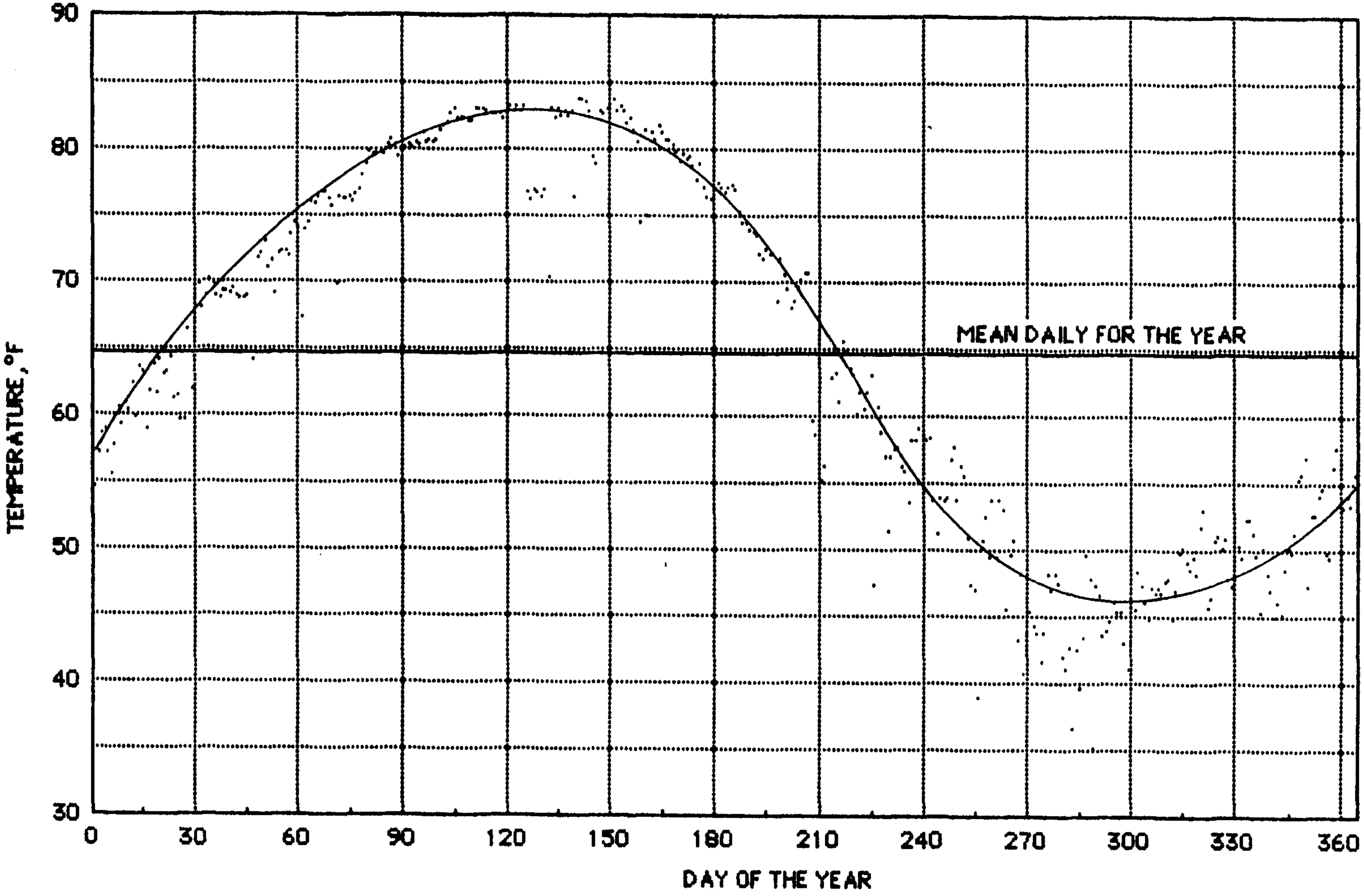

Figure 16. Annual wave of mean daily temperature (1951-80) at Nacogdoches, Texas. (Starting with March 21)

month and year, for the 80-year period are given in Table 21. Annual fluctuations of maximum temperature are plotted in Figure 14 and the monthly and annual data are listed in Table 59 of Appendix IV.

The mean annual maximum temperature over the 80-year period was 76.8°F, about 10.7°F above the mean annual temperature. It ranged from 73.2 to 81.4°F with a standard deviation of 1.78°F. There were only 3 years (i.e., 1922, 1954, and 1956) in the records with annual maximum temperature exceeding 80°F, and 4 years below 74°F. For the mean monthly maximum temperature, August was the highest while January was the lowest (Figure 15). Normal monthly and annual maximum temperatures for 6 reference periods are given in Table 24. Chang and Aguilar (1980) showed that the radial growth of loblolly pine is inhibited by the difference in average maximum air temperature between July and January. A greater difference in maximum temperature either between January and July, would enhance stress and inhibit growth.

Table 25 lists the greatest daily maximum temperature for each of the years for the period 1901-80 at Nacogdoches, Texas. It shows that temperatures over 100°F were rare except in June, July, August, and September. Indeed there were some summers that did not experience a temperature of 100°F or greater. Such conditions occurred in 32 summers or about 40% of the total 80 years. The hottest temperature recorded was 110°F which occurred on two occasions: June 28, 1918 and August 31, 1954. During the 80-year period, total number of occurrences with maximum daily temperature of 100°F or greater were 1 in May, 9 in June, 33 in July, 41 in August, and 19 in September. In other words,

Table 24. Normal Monthly and Annual Maximum Daily Temperature (°F) for Six Reference Periods at Nacogdoches, Texas

Month		Periods					
		1901-30	1911-40	1921-50	1931-60	1941-70	1951-80
January	Normal	58.4	58.0	57.5	58.4	58.1	57.4
	Std. Dev.	4.44	4.77	4.44	4.05	3.96	5.34
February	Normal	61.2	61.6	61.6	62.3	62.5	62.0
	Std. Dev.	4.77	4.36	4.48	4.34	4.43	5.04
March	Normal	69.2	67.9	67.9	68.9	69.1	69.5
	Std. Dev.	5.26	4.92	4.26	4.20	4.63	4.25
April	Normal	75.4	74.9	75.3	76.0	77.9	77.7
	Std. Dev.	3.24	3.32	3.59	2.98	2.95	2.80
May	Mean	81.7	81.3	81.6	82.8	84.4	84.5
	Std. Dev.	2.53	2.47	2.42	2.88	2.46	2.36
June	Normal	89.3	89.3	88.9	89.8	90.5	90.6
	Std. Dev.	3.01	3.02	2.54	2.42	2.07	2.17
July	Normal	92.2	92.8	92.2	93.0	93.9	94.3
	Std. Dev.	3.03	2.85	2.53	2.67	2.70	2.81
August	Normal	93.4	93.3	93.6	93.8	94.9	94.6
	Std. Dev.	3.23	3.36	3.16	3.12	2.67	2.73
September	Normal	88.9	88.8	88.3	88.8	89.3	89.1
	Std. Dev.	3.25	3.47	3.35	3.63	3.12	3.47
October	Normal	79.0	79.5	80.0	81.1	81.5	81.0
	Std. Dev.	3.51	3.59	3.83	3.92	3.72	3.82
November	Normal	68.4	67.0	67.1	67.6	69.1	68.6
	Std. Dev.	4.62	4.80	4.60	3.38	2.93	3.58
December	Normal	59.0	58.9	59.4	60.4	61.3	61.3
	Std. Dev.	4.69	4.92	4.76	4.31	3.87	3.59
Annual	Normal	76.3	76.1	76.1	76.9	77.7	77.8
	Std. Dev.	1.87	1.87	1.78	1.84	1.52	1.47

Table 25. The Highest Maximum Daily Temperature (°F) by Month and Year at Nacogdoches, Texas, 1901-80

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1901	75	80	85	87	90	100	101	102	93	91	80	73	102
02	71	70	84	87	90	97	93	98	94	87	81	77	98
03	81	74	80	86	87	94	95	96	95	87	85	74	96
04	73	84	90	85	91	95	94	98	96	95	82	81	98
05	74	75	84	86	89	95	93	95	95	91	83	62	95
06	78	75	77	85	92	95	94	92	93	82	83	80	95
07	--	80	87	86	92	97	101	98	99	94	79	74	101
08	75	76	89	86	88	94	96	96	96	85	84	79	96
09	82	81	87	86	87	94	98	109	103	96	85	80	109
10	77	72	89	85	88	93	97	97	97	92	85	--	97
1911	84	82	92	87	96	100	96	97	102	96	87	70	102
12	76	78	81	83	91	92	102	96	97	92	81	70	102
13	74	81	85	87	89	93	101	101	97	88	80	73	101
14	79	74	79	88	89	101	101	--	--	--	--	--	--
15	71	73	82	86	97	97	96	98	91	90	85	76	98
16	78	79	90	83	90	94	98	99	97	91	84	80	99
17	79	75	84	85	93	101	105	105	100	91	82	85	105
18	77	90	90	88	92	110	107	105	99	91	80	77	110
19	70	77	84	90	90	96	99	100	98	92	85	82	100
20	79	79	83	93	96	98	102	95	100	92	84	70	102
1921	72	79	81	78	98	97	99	104	98	96	91	82	99
22	74	85	85	88	92	99	102	103	102	96	88	85	103
23	78	83	81	87	95	96	104	105	98	96	79	82	105
24	75	77	84	90	92	98	106	106	103	91	83	83	106
25	68	71	82	87	91	98	100	104	100	92	80	73	104
26	68	77	80	79	91	92	95	97	95	91	79	77	97
27	77	79	81	85	92	91	96	101	100	86	84	80	101
28	77	75	86	80	93	91	97	97	94	93	78	76	97
29	75	69	88	97	87	94	94	98	95	89	79	75	98
30	70	81	76	90	88	99	101	101	94	84	79	67	101
1931	71	71	79	83	85	95	97	94	97	92	81	79	97
32	78	83	82	85	89	96	102	101	98	87	74	69	102
33	74	77	79	87	90	97	97	94	95	86	80	79	97
34	71	71	81	85	90	98	102	100	95	89	84	69	102
35	78	75	88	81	86	90	98	104	95	89	85	68	104
36	75	78	84	88	85	103	96	104	94	88	73	73	104
37	75	80	78	82	89	99	98	100	95	89	78	71	100
38	74	77	83	84	88	94	95	98	96	99	82	77	99
39	75	75	83	88	89	95	104	103	100	92	77	79	104
40	71	79	83	85	87	90	95	94	92	88	78	72	95

Table 25. Continued

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1941	71	70	78	85	88	91	93	95	92	88	77	74	95
42	75	74	75	84	88	93	95	97	91	88	83	79	97
43	83	77	81	88	91	97	102	103	95	85	83	70	103
44	72	77	80	86	88	95	103	100	94	90	82	66	103
45	71	83	85	86	90	97	95	99	97	84	86	74	99
46	67	76	93	89	87	95	99	99	93	86	82	77	99
47	80	80	79	87	92	92	99	108	105	95	83	75	108
48	80	80	83	88	93	96	97	97	97	89	85	75	97
49	84	81	87	84	90	94	93	97	92	87	86	81	97
50	78	82	84	89	95	95	102	106	104	91	84	82	106
1951	79	82	84	83	91	97	97	100	96	93	84	79	100
52	75	78	88	85	93	101	96	98	100	98	78	82	101
53	75	83	87	87	90	97	107	105	103	98	80	80	107
54	73	78	91	91	95	98	102	101	98	95	87	84	102
55	83	81	84	87	93	99	103	108	100	97	84	85	108
56	82	85	81	86	91	95	104	101	98	90	85	77	104
57	72	75	--	88	100	98	99	106	95	90	85	74	106
58	75	82	82	90	94	89	99	99	96	92	80	72	99
59	78	82	87	90	95	103	102	100	99	91	84	76	103
60	76	81	87	89	92	93	97	100	100	90	86	78	100
1961	76	81	87	89	92	93	97	100	100	90	86	78	100
62	78	84	84	86	94	95	99	103	98	93	84	78	103
63	78	79	87	94	96	101	103	103	101	96	85	74	103
64	74	73	79	87	95	97	104	107	99	87	83	80	107
65	76	**	89	90	91	95	100	103	100	91	87	75	103
66	72	72	84	88	92	95	102	98	95	91	81	80	102
67	76	78	91	88	94	98	98	101	95	92	84	79	101
68	72	75	80	86	92	96	95	96	93	90	85	74	96
69	77	78	81	86	94	98	102	105	98	92	85	74	105
70	80	79	78	88	99	99	101	102	97	91	77	78	102
1971	79	78	88	87	91	89	103	98	98	91	86	78	103
72	80	80	84	90	93	97	97	98	99	91	89	74	99
73	77	75	86	82	93	93	95	94	91	91	82	73	95
74	77	79	88	89	90	94	99	97	91	85	82	75	99
75	81	79	81	87	90	92	98	96	96	91	83	78	98
76	77	77	83	84	86	92	93	96	94	86	77	70	96
77	73	85	83	82	93	97	98	98	92	92	83	79	98
78	78	72	81	86	92	96	103	100	92	--	84	77	103
79	68	74	--	85	--	94	95	93	93	92	80	75	95
80	72	83	81	87	92	97	103	104	100	90	85	75	104
Max	84	90	93	93	100	110	107	110	105	99	91	85	110
Min	67	69	75	78	86	91	93	92	91	82	73	62	62

such a very hot day occurs once in every 80 years in May, every 9 years in June, every 2.4 years in July, every 2 years in August, and every 4.5 years in September.

Table 26 further breaks down the 80-year data of greatest maximum temperatures into days and months. It shows that temperatures of 100°F or higher have occurred at least once in about two-thirds of the days in May. The earliest date with maximum temperature of 100°F was May 28 and the latest date was September 29; while a temperature of 90°F or greater had occurred as early as February 25 and as late as November 16. A maximum temperature of 80°F had occurred 16 times in January and 22 in December in the 80-year records.

Air temperatures of 90°F and above are considered extremely warm as far as human comfort is concerned. Prolonged exposure to such temperatures may cause sunburn, sunscald, and even stroke. Also a persistence of such high temperatures may create a moisture stress to plants and can significantly decrease milk and egg production or even lower the rate of reproduction in most farm animals.

The annual number of days with maximum daily temperature of 90°F or greater at Nacogdoches are given in Table 27. Such number of days fluctuated between 24 (1940) and 127 (1956) with a mean of 82 days and a standard deviation of 22 days.

Minimum Temperature

Minimum temperature is important to foresters and farmers. Frost which affects juvenile trees, young buds, and fruits is a result of below freezing temperatures. Our interest in minimum temperatures is

Table 26. The Highest Temperature (°F) Record on each Day of the Year at Nacogdoches, Texas, 1901-80

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	80	83	84	89	94	97	101	104	105	99	89	82
2	79	79	85	88	92	95	101	104	103	95	87	80
3	80	80	83	88	94	102	102	105	104	96	88	80
4	79	79	85	86	91	103	103	106	104	95	85	80
5	77	85	87	87	96	97	101	107	102	95	87	80
6	77	81	85	90	91	97	107	105	102	96	84	85
7	83	79	87	90	90	96	102	104	103	97	84	82
8	78	81	90	90	91	97	104	105	102	95	85	85
9	78	83	89	94	92	99	101	108	100	95	85	82
10	82	84	90	92	91	100	105	106	103	96	87	81
11	78	87	92	92	93	97	100	105	102	96	84	77
12	78	85	91	89	94	100	104	104	102	95	85	78
13	77	83	91	88	95	100	102	105	102	94	86	81
14	78	84	85	90	93	101	102	104	100	93	91	82
15	79	82	90	90	95	100	103	105	100	92	90	79
16	79	84	87	93	92	99	102	108	100	91	90	80
17	77	84	87	89	93	100	104	106	98	93	85	79
18	79	85	89	96	92	103	104	109	100	92	85	83
19	78	82	88	88	94	100	104	105	99	96	82	78
20	79	83	88	88	92	100	103	104	103	88	82	80
21	83	84	90	92	93	103	103	104	100	90	84	77
22	80	83	87	88	92	100	105	105	99	92	82	77
23	83	79	89	89	96	101	105	104	96	90	83	79
24	82	85	85	89	94	99	106	106	97	90	85	85
25	80	90	86	87	97	98	104	103	97	91	84	84
26	84	85	87	90	97	100	107	106	99	91	85	82
27	82	88	86	88	98	99	102	107	98	90	87	79
28	81	85	86	89	100	110	104	106	99	90	81	77
29	80	84	87	90	93	98	103	104	100	90	83	82
30	83		93	91	96	101	102	105	99	91	80	80
31	84		91		96		104	110		90		81
Highest	84	90	93	93	100	110	107	110	105	99	91	85

Table 27. Total Number of Days with Maximum Daily Temperature Equal to or Greater Than 90°F by Year at Nacogdoches, Texas, 1901-80

Year	Days	Year	Days	Year	Days	Year	Days
1901	88	1921	80	1941	41	1961	80
02	88	22	114	42	39	62	105
03	58	23	97	43	83	63	132
04	81	24	95	44	68	64	91
05	66	25	89	45	72	65	97
06	66	26	52	46	56	66	89
07	92	27	63	47	107	67	79
08	57	28	64	48	95	68	68
09	91	29	54	49	64	69	104
10	54	30	76	50	55	70	87
1911	82	1931	80	1951	91	1971	99
12	77	32	46	52	103	72	111
13	77	33	61	53	92	73	80
14	--[1]	34	85	54	120	74	55
15	74	35	55	55	115	75	69
16	100	36	67	56	127	76	62
17	99	37	61	57	86	77	107
18	103	38	63	58	99	78	99[3]
19	97	39	98	59	105	79	60[4]
20	119[2]	40	24	60	102	80	122

---

[1] August through December data missing.
[2] January data missing.
[3] December data missing.
[4] March and May data missing.

not only the degree of coldness but also the duration, time of occurrence in the year, and drastic changes in temperature during the cold period. Both rapid freezing and thawing are very harmful to plants (Spurr and Barnes, 1980).

The annual minimum temperature over the 80-year period was 54.1°F with a standard deviation of 1.42°F, or about 11.4°F below the mean annual average temperature (65.5°F) and 22.8°F below the mean annual maximum temperature (Table 21). It ranged from 51.0°F in 1903 to 57.3°F in 1927. The range was about 11.7% of its mean and was the greatest among the 3 temperature variables (i.e, maximum, minimum, and average). Mean monthly temperatures over the 80 years period are plotted in Figure 14. Normal monthly and annual minimum temperatures for the 6 reference periods are given in Table 28. The present normal is lower by 0.9°F than the long-term average. No statistical significance was found among these periods at the 0.01 alpha level.

For the minimum monthly temperatures each year, there were 14, 5, and 3 times that an average of minimum temperatures equal to or less than the freezing point occurred in January, February, and December, respectively. Never was a monthly minimum temperature of 32°F or below observed in the other 9 months during the entire records. However, daily minimum temperatures of 32°F or below occurred as late as April 15th (1933) and as early as October 8th (1952). It occurred at least once in each of the 3 winter-months (January, February, and December) in each year, in March for 63 years, April for 12 years, October for 11 years, and November for 16 years. Table 29 is the lowest daily minimum

Table 28. Normal Mean Minimum Daily Temperature (°F) for Every Shift of Decade at Nacogdoches, Texas

Month		Periods					
		1901-30	1911-40	1921-50	1931-60	1941-70	1951-80
January	Normal	37.4	38.4	38.8	38.3	36.1	34.9
	Std. Dev.	4.47	5.02	4.53	4.73	4.64	4.66
February	Normal	38.7	41.1	42.2	41.1	39.0	36.7
	Std. Dev.	4.81	4.44	3.82	4.44	4.54	4.12
March	Normal	47.6	46.6	46.9	45.8	44.3	44.4
	Std. Dev.	4.96	4.35	4.27	4.98	4.33	4.32
April	Normal	52.9	53.5	54.7	54.2	54.8	53.2
	Std. Dev.	2.86	2.60	2.82	2.73	3.30	3.27
May	Normal	61.1	61.1	61.6	61.9	62.1	61.7
	Std. Dev.	2.86	2.69	2.45	2.05	1.96	2.22
June	Normal	67.0	68.1	68.7	68.9	68.7	67.4
	Std. Dev.	2.32	1.93	1.54	1.70	1.51	1.95
July	Normal	70.7	71.1	71.0	71.4	71.3	71.3
	Std. Dev.	1.68	1.54	1.43	0.91	1.16	1.13
August	Normal	70.5	70.3	70.5	70.8	70.6	70.3
	Std. Dev.	1.30	1.36	1.75	1.66	1.84	1.64
September	Normal	64.2	65.3	65.7	65.1	65.1	64.6
	Std. Dev.	2.89	2.55	2.39	2.35	3.10	3.35
October	Normal	54.0	55.0	55.7	55.2	54.0	53.0
	Std. Dev.	4.01	3.91	4.88	5.02	5.22	3.46
November	Normal	44.5	44.6	45.2	43.8	43.4	42.7
	Std. Dev.	4.14	4.05	3.92	4.26	4.27	4.10
December	Normal	38.3	39.8	40.5	39.4	37.7	37.0
	Std. Dev.	3.89	3.64	3.13	3.55	3.41	3.18
Annual	Normal	53.9	54.6	55.1	54.7	53.9	53.2
	Std. Dev.	1.29	1.34	1.25	1.55	1.48	0.90

temperature in each month and in each year at Nacogdoches, Texas.

The lowest minimum temperature ever recorded on any day during the entire 80-year period is provided in Table 30. On January 18, 1930, a temperature of -4°F was recorded, the only subzero temperature ever recorded in Nacogdoches. However, the lowest average daily temperature in the history was 11°F on February 2, 1951, 13.5°F higher than the recorded lowest minimum daily temperature (January 18, 1930).

There was no single day between April 16th and October 19th with a daily minimum temperature of 32°F or below. It represents a frost-free period of 175 days. The other 190 frost-susceptible days had at least 1 observation with temperature of 32°F and below. In the frost-susceptible period, temperatures of 20°F or below have occurred as early as November 19 and as late as March 19, while temperatures of 15°F or below occurred as early as November 29 and as late as March 3.

From the standpoint of crops, flowers, vegetables, tree seedlings and other plants, an important consideration is the number of hours per month or for the whole growing season that temperatures remain below certain minimum levels. Since long-term thermograph records are not available at Nacogdoches, the total number of days with minimum temperature of 32°F or below each year was investigated. The mean number of days each year with minimum temperature of 32°F or below in the 80-year period is about 35 with a standard deviation of 13 days (Table 13). It ranged from 13 days in 1907 to 64 days in 1959, which made the annual minimum temperature of 1907 about 1.7°F higher and 1959 about 2.1°F lower than the mean annual minimum temperature of the entire

Table 29. The Lowest Minimum Daily Temperature (°F) by Months and Years at Nacogdoches, Texas, 1901-80

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1901	24	22	27	36	47	56	71	67	47	38	28	15	15
02	22	25	34	46	56	55	66	71	45	42	31	25	22
03	23	13	34	35	40	48	62	68	45	35	17	22	13
04	15	25	31	34	46	60	66	61	61	37	23	21	15
05	17	8	42	41	56	66	59	64	55	36	29	23	8
06	19	20	27	39	49	62	62	56	61	34	27	27	19
07	--	27	39	38	49	53	57	67	52	46	21	27	21[1]
08	22	22	38	37	40	61	63	65	43	32	24	25	22
09	18	20	31	35	43	62	69	68	40	41	30	19	18
10	16	22	37	34	50	55	63	68	51	25	28	--	16[1]
1911	10	22	36	46	47	65	64	56	59	35	16	22	10
12	11	15	31	37	46	54	70	65	50	42	21	25	11
13	16	25	27	37	53	54	67	58	58	33	31	23	16
14	26	18	28	34	52	62	68	--	--	--	--	--	18[2]
15	23	27	21	28	48	61	63	59	59	42	27	22	21
16	15	21	28	33	49	57	70	59	40	34	20	16	15
17	24	15	24	38	41	51	64	56	49	26	27	11	11
18	2	24	32	37	51	67	63	65	43	35	29	19	2
19	16	27	28	37	46	53	66	65	53	50	27	11	11
20	--	27	23	28	55	58	65	61	58	33	24	21	21[1]
1921	26	26	34	34	45	53	57	53	54	35	31	21	21
22	26	24	23	41	53	52	56	51	55	35	29	26	23
23	27	22	18	37	46	60	61	56	53	31	27	25	18
24	12	16	27	31	43	57	53	64	53	41	27	15	12
25	20	24	31	46	38	65	69	63	62	34	28	18	18
26	25	30	30	36	46	54	62	66	54	39	29	29	25
27	20	29	30	40	53	62	64	57	54	44	30	21	20
28	10	28	34	31	45	62	68	68	48	41	32	21	10
29	18	18	27	44	40	60	65	63	57	31	21	1	1
30	-4	28	25	46	53	49	66	64	53	34	25	24	-4
1931	24	31	26	32	43	55	67	57	46	34	42	28	24
32	25	27	18	37	51	61	68	64	54	35	22	19	18
33	21	7	29	32	53	51	68	66	57	40	27	27	7
34	21	26	27	43	49	65	61	69	50	48	34	23	21
35	14	25	37	39	51	64	65	64	47	47	32	26	14
36	18	15	31	29	56	60	65	64	54	41	29	27	15
37	29	25	26	36	51	61	66	71	51	32	29	21	21
38	26	24	34	35	47	61	68	68	45	32	18	25	18
39	23	22	32	38	48	65	67	68	56	34	32	29	22
40	6	27	29	30	52	60	66	58	46	40	23	27	6

Table 29. Continued

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1941	22	24	31	45	57	63	66	69	58	43	27	28	22
42	22	27	28	33	49	66	64	70	41	35	32	26	22
43	10	26	15	37	55	68	61	60	54	32	27	18	10
44	18	24	31	36	43	65	67	66	59	37	27	24	18
45	27	29	36	37	43	60	64	64	52	41	27	15	15
46	21	31	37	41	51	53	66	61	59	36	38	21	21
47	16	18	27	45	48	65	57	69	53	49	30	27	16
48	15	25	18	41	54	60	68	65	50	33	29	28	15
49	10	14	32	36	53	64	67	55	43	40	26	25	10
50	26	31	29	36	56	57	61	62	55	46	21	14	14
1951	20	0	28	36	52	63	67	67	55	45	21	19	0
52	30	27	30	38	57	66	65	60	51	32	27	21	21
53	27	29	36	37	46	65	62	68	52	42	31	19	19
54	17	24	28	36	40	63	68	67	49	33	30	20	17
55	19	18	24	44	53	51	65	62	55	31	24	14	14
56	21	27	22	38	52	55	66	55	50	43	21	21	21
57	14	29	24	36	44	63	69	62	54	27	29	13	13
58	24	14	30	39	48	58	63	59	51	42	25	21	14
59	14	29	26	33	54	61	67	64	57	40	20	27	14
60	17	18	21	38	39	60	66	68	53	38	30	21	17
1961	18	29	31	35	45	61	60	62	47	36	28	18	18
62	5	29	25	27	45	62	68	60	54	41	30	16	5
63	13	19	28	40	47	64	67	56	43	41	28	12	12
64	10	22	29	39	54	54	65	68	57	38	27	22	10
65	17	20	23	41	48	61	67	59	53	34	31	28	17
66	19	22	26	36	56	55	68	57	52	35	24	18	18
67	20	20	25	51	48	58	54	54	38	37	29	23	20
68	20	23	22	39	46	59	58	61	52	38	26	23	20
69	20	26	25	45	47	61	69	65	52	40	24	26	20
70	14	23	30	33	44	54	60	61	52	36	22	24	14
1971	23	20	22	30	41	62	64	62	55	46	31	35	20
72	18	19	30	38	52	53	58	68	61	44	32	17	17
73	15	20	39	31	43	59	66	60	55	38	35	19	15
74	21	23	32	38	51	54	62	63	49	39	28	22	21
75	15	19	27	32	56	52	61	64	45	38	22	18	15
76	13	25	31	41	43	57	65	60	52	31	15	17	13
77	10	24	35	42	52	57	69	68	60	40	28	21	10
78	18	17	26	41	45	62	64	66	57	--	36	15	15[1]
79	10	17	--	38	--	54	63	65	50	41	21	18	10[3]
80	28	19	13	35	56	58	67	64	63	33	27	24	13
Min	-4	0	13	27	38	48	53	51	38	25	15	1	-4

---

[1] Based on 11 months [2] Based on 7 months [3] Based on 10 months

Table 30. The Lowest Temperature (°F) Record on each Day of the Year at Nacogdoches, Texas, 1901-80

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	13	10	22	32	38	49	61	59	56	39	26	21
2	10	0	13	27	39	48	56	62	53	43	28	22
3	12	3	15	29	40	48	54	62	55	42	22	16
4	10	13	21	35	40	50	55	60	51	40	24	22
5	14	20	22	28	43	53	57	61	51	40	28	25
6	12	16	22	33	47	51	58	64	49	35	29	17
7	14	18	22	31	43	57	53	62	52	42	22	12
8	13	7	23	34	41	58	53	64	55	32	23	14
9	17	10	21	33	42	57	60	63	52	34	23	13
10	10	17	23	31	43	58	57	63	50	36	22	15
11	11	18	20	31	43	51	61	62	52	36	22	18
12	2	9	18	37	39	52	62	57	48	36	21	13
13	15	8	18	30	45	54	61	54	46	37	23	16
14	14	15	27	35	46	54	64	47	46	37	25	11
15	19	21	28	32	45	54	54	58	45	41	20	16
16	18	19	25	32	43	51	55	56	51	36	22	14
17	14	13	25	34	44	51	66	60	50	36	22	15
18	-4	13	31	36	48	52	66	61	45	33	21	18
19	4	18	20	36	53	57	65	62	47	35	17	15
20	10	22	18	38	52	54	61	60	45	29	25	15
21	16	22	25	38	50	57	63	57	42	31	25	19
22	8	17	21	36	46	58	60	55	40	32	27	12
23	6	22	28	38	51	55	61	55	45	31	22	1
24	15	21	29	43	52	59	63	58	49	32	26	12
25	17	20	32	34	52	55	63	56	46	31	18	18
26	14	18	24	36	47	56	63	57	50	24	22	15
27	16	19	24	42	50	54	66	58	41	30	21	18
28	21	24	26	40	47	56	66	56	37	27	20	18
29	17	29	26	41	52	60	66	56	37	25	15	18
30	18		28	37	53	60	65	63	40	28	16	11
31	10		30		55		64	56		31		17
Lowest	-4	0	13	27	38	48	53	47	37	25	15	1

period. By fitting the annual series of number of days with daily minimum temperature of 32°F or less to the log-normal distribution function, the expected 100-yr value would be 76 days as compared to the maximum 64 in the 80-year records.

Although Table 31 gives the total number of days with daily minimum temperature of 32°F or less each year, it does not tell how these days are distributed throughout the cold seasons. The effects of minimum daily temperature on plants would be different if all the 35 days occur continuously in 1 period versus alternatively in 35 warm-cold periods. Also, the temperature gradient between daily maximum and minimum and the time of occurrence in the year might have a tremendous impact on plants.

Frost-Free Days

Frost is a state of environment when the air temperature is 32°F (0°C) or less. It is an important climatological element because of its role in planning, planting, and harvesting of crops. The interval between the last killing frost in spring and the initial killing frost in autumn is the most useful indicator of the growing season.

Freezing temperature in spring is perilous when it occur later than expected in the season. In the middle or late spring, an untimely freeze may catch field crops in the seedling stage, or trees and shrubs budding or blooming. An example was March 2, 1980, when it struck peach and plum trees that had budded just a week earlier in the midst of 80°F heat. About half of the peach crop, valued at more than $3 million was lost in the Texas Hill country (Bomar,1983).

Table 31. Total Number of Days with Daily Minimum Temperature Equal to or Less than 32°F for Each Year at Nacogdoches, Texas (1901-80)

Year	Length (days)	Year	Length (days)	Year	Length (days)	Year	Length (days)
1901	36	1921	18	1941	17	1961	48
02	33	22	25	42	35	62	49
03	42	23	29	43	37	63	56
04	42	24	51	44	28	64	46
05	49	25	37	45	26	65	43
06	36	26	29	46	18	66	43
07	13	27	23	47	29	67	49
08	29	28	23	48	46	68	54
09	31	29	43	49	32	69	34
10	24	30	37	50	28	70	46
1911	25	1931	20	1951	42	1971	28
12	42	32	38	52	28	72	38
13	35	33	19	53	23	73	34
14	25[1]	34	20	54	46	74	26
15	40	35	22	55	55	75	32
16	35	36	39	56	57	76	33
17	45	37	26	57	38	77	37
18	45	38	26	58	61	78	57[3]
19	40	39	18	59	64	79	42[4]
20	27[2]	40	39	60	59	80	33

[1] August through December data missing.
[2] January data missing.
[3] December data missing.
[4] March and May data missing.

As discussed previously, the earliest occurrence of freezing (which also means the end of the frost-free days) observed at Nacogdoches was October 8 of 1952 and the latest was April 15 of 1933. This represents an absolute frost-free period or a total of 175 days in a year that never had a daily minimum temperature of 32°F or less. Fortunately, this is not a common event in Nacogdoches. Out of the 80 years (1901-80) of record, only 11 years had freezing temperatures beginning in October and four beginning in December. The rest, 69 or 81% of the years, the frost began sometime in November. On the average, the first and last occurrences happened on November 11th and March 15th respectively (Figure 17).

The annual number of frost-free days varies with year (Table 32) with a maximum number of 278 days (76% of the total) in 1902 while the least was 204 days (56% of the year) in 1979. Even though the average for the period was 240 days, only 36 (46%) of the frost-free days for the 80 years were above average. For a 100-yr return period, the expected value, as calculated by the normal distribution function, is 284 days.

Tolerance of plants to freezing temperature varies with species and seasonal occurrence. Table 33 gives some mean freeze data for 1931-60 in accordance with five freeze threshold temperature, i.e., 32°F, 28°F, 24°F, 20°F, and 16°F. The mean number of frost free days with minimum daily temperature of 33°F or greater was 238 (240 days for the mean of the 80-year period) and it was 336 days with daily minimum temperature of 21°F or greater. There was a mean of 57 times yr^{-1} and 16 times yr^{-1}

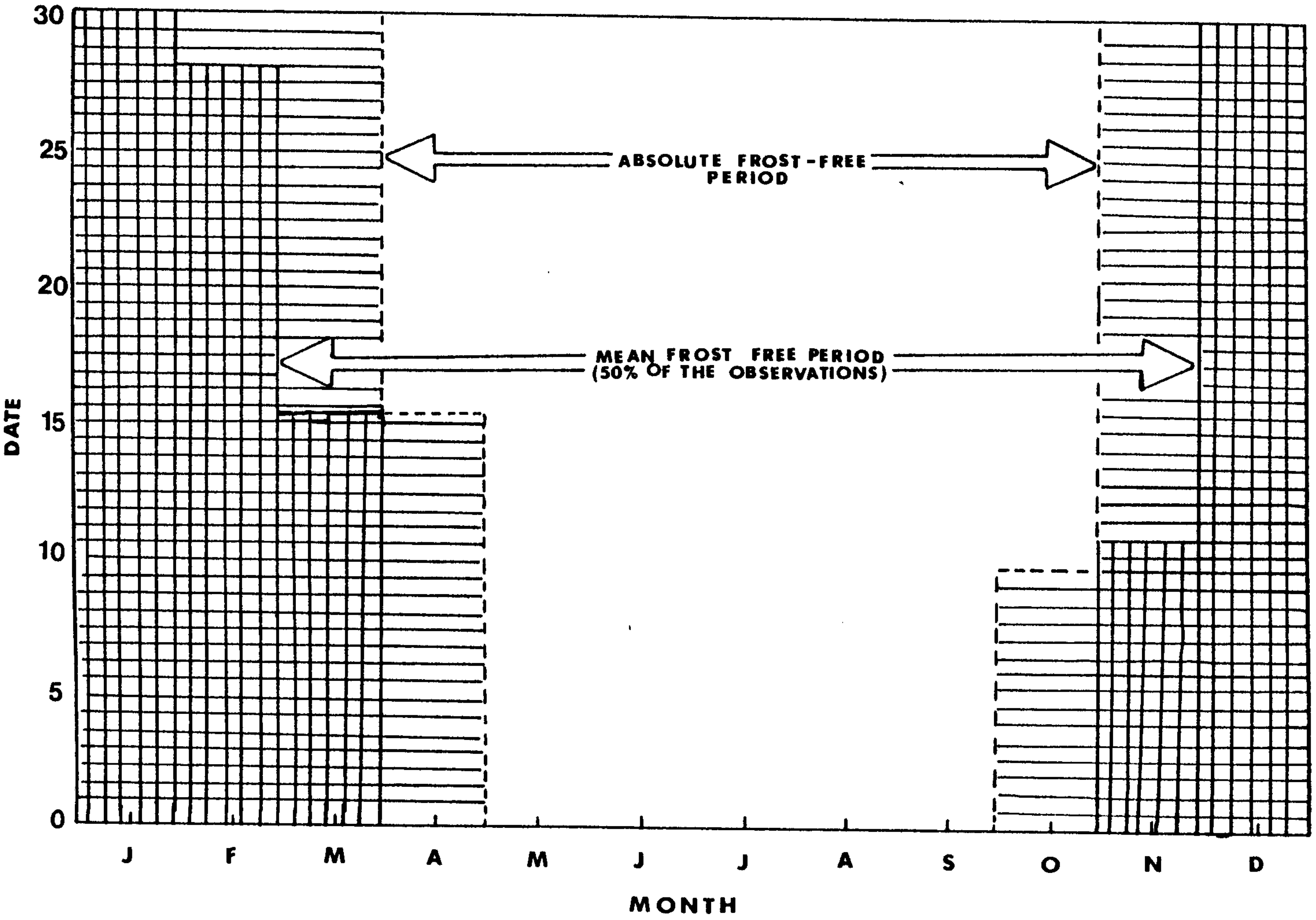

Figure 17. Periods of absolute frost-free and mean frost free (50% of the observations) at Nacogdoches, Texas.

Table 32. Frost Data, by Year, for Nacogdoches, Texas, 1901-80

Year	First Occurence	Last Occurrence	Frost-free Days
1901	Nov 15	Mar 20	239
02	Nov 27	Feb 15	278
03	Nov 18	Mar 13	260
04	Nov 12	Mar 14	240
05	Nov 29	Feb 21	272
06	Nov 12	Mar 20	234
07	Nov 11	Feb 15	268
08	Oct 24	Feb 21	242
09	Nov 18	Mar 16	245
10	Oct 28	Feb 25	245
1911	Nov 12	Feb 24	260
12	Nov 3	Mar 24	222
13	Nov 10	Mar 28	226
14	--	Mar 23	--
15	Nov 15	Apr 13	225
16	Nov 14	Mar 4	254
17	Oct 20	Mar 18	215
18	Nov 19	Mar 17	246
19	Nov 14	Mar 6	252
20	Nov 13	Apr 5	221
1921	Nov 21	Feb 21	262
22	Nov 6	Mar 4	266
23	Oct 22	Mar 20	215
24	Nov 25	Apr 1	237
25	Nov 23	Mar 3	264
26	Nov 5	Mar 14	235
27	Nov 17	Mar 4	257
28	Nov 4	Apr 11	249
29	Oct 25	Mar 2	236
30	Nov 25	Mar 26	240
1931	Nov 3	Apr 1	246
32	Nov 9	Mar 14	239
33	Nov 25	Apr 15	223
34	Dec 1	Mar 19	256
35	Nov 13	Feb 28	257
36	Nov 4	Apr 3	214
37	Oct 23	Mar 31	205
38	Oct 24	Feb 20	245
39	Nov 4	Mar 2	271
40	Nov 3	Mar 28	213

Table 32. Continued

Year	First Occurrence	Last Occurrence	Frost - Free Days
1941	Nov 24	Mar 11	257
42	Nov 12	Mar 28	228
43	Oct 28	Mar 8	233
44	Nov 27	Mar 30	241
45	Nov 21	Feb 23	271
46	Dec 3	Feb 25	288
47	Nov 7	Mar 26	236
48	Nov 10	Mar 3	241
49	Nov 1	Mar 2	243
50	Nov 5	Mar 5	234
1951	Nov 3	Mar 14	233
52	Oct 8	Mar 24	197
53	Nov 10	Feb 23	259
54	Nov 6	Mar 26	234
55	Oct 31	Mar 30	214
56	Nov 9	Mar 17	236
57	Oct 27	Mar 10	210
58	Nov 29	Mar 21	258
59	Nov 6	Mar 18	230
60	Nov 30	Mar 19	235
1961	Nov 9	Mar 10	241
62	Nov 4	Apr 2	215
63	Nov 2	Mar 6	240
64	Nov 21	Mar 9	255
65	Nov 30	Mar 22	253
66	Nov 2	Mar 25	221
67	Nov 3	Mar 9	238
68	Nov 15	Mar 26	232
69	Nov 4	Mar 22	233
70	Nov 25	Apr 22	252
1971	Nov 30	Mar 3	231
72	Dec 6	Apr 11	271
73	Nov 15	Mar 26	239
74	Nov 14	Apr 3	233
75	Oct 21	Mar 7	224
76	Nov 10	Feb 27	217
77	Dec 4	Mar 10	254
78	Nov 14	Feb 20	237
79	Nov 19	Mar 4	204
1980	Nov 21	Mar 19	259
Mean	Nov 11	Mar 15	241

Table 33. Normal Freeze Data for Nacogdoches, Texas, 1931-60

Freeze Threshold Temperature	Mean Date of Last Spring Occurrence	Mean Date of First Fall Occurrence	Mean Number of Days between Dates	Year of Record Spring	Number of Occurrence in Spring	Years of Record Fall	Number of Occurrence in Fall
32	3 - 16	11 - 10	238	29	29	28	28
28	2 - 26	11 - 26	272	30	28	29	23
24	2 - 6	12 - 21	317	30	18	28	12
20	1 - 23	12 - 24	336	30	12	29	4
16	1 - 12	12 - 29	352	30	6	29	1

Source: Climatography of the United States No. 81-4, Decennial Census of U.S. Climate with daily minimum temperature of 32°F or less and 20°F or less, respectively.

Degree days (DD)

Temperature is an important enviromental factor not only dominating plant growth and development but also affecting human comfort and health. In Nacogdoches, as elsewhere, temperature variations significantly prevail both within a year and between years. It is assummed that a relationship exists between biological (or non-biological) activities and temperature variation. Plants will start growth and houses will need cooling when the air temperature exceeds certain threshold values. The extent of plant growth and development or the amount of energy consumption due to heating and cooling is proportional to the excess of temperature above these thresholds. Thus, counting the air temperature in excess of these threshold values may serve as an index to the variations in plant growth or energy consumption.

Based on the concept mentioned above, a degree day was developed as an index not only to describe the thermal environment but also to forecast plant growth and development and to estimate heating and cooling demands.

Heating and Cooling Degree Days. For each degree that the daily average temperature is above or below the threshold value, a degree day is counted. The values are accumulated to obtain total degree days a specified period or season. The total degree days equation appears as:

$$DD = \Sigma (T_i - T_b) \qquad (14)$$

where T is the daily average temperature from the day ith = 1 to N, and T_b is the base temperature. For heating and cooling purposes, a base temperature of 65°F is usually used, and Equation 14 becomes:

$$DD = \Sigma(T_i - 65°F) \qquad (15)$$

A positive value of DD in Equation 15 implies that the daily average temperature is above 65°F and therefore energy is needed to cool down the room temperature. The DD in this case is termed "cooling degree days (CDD)". When DD is negative, some heat is required to warm up the room temperature and the degree days are termed "heating degree days (HDD)". It is assumed that there will be little or no demand for heating or cooling when the DD is zero.

There are several characteristics that make the DD data especially useful. It is cumulative so that the DD sum for a period of days represents the total heating load for that period. The relation between DD and fuel consumption is linear, i.e., doubling the DD usually doubles the fuel consumption (Miller et al., 1983). Comparing normal season DD in different locations gives a rough estimate of seasonal fuel consumption. For example, it would require roughly 4½ times as much fuel to heat a building in Chicago, Illinois where the mean total HDD is about 6,200 than to heat a similar building in New Orleans, Louisiana where the annual total HDD is around 1,400. Using DD has the advantages that the consumption ratios are fairly constant, i.e., the fuel consumed per 100 DD is about the same regardless if it occurs in only 3 or 4 days or is spread over 7 to 8 days (Keyes, 1974).

The annual HDD at Nacogdoches has varied from 1,458 in 1907 to 2,691 in 1978, with a mean of 2144 for the whole 80-year period (See Table 61 of Appendix IV). The normal (1931-60) HDD data for Nacogdoches along with several other cities in Texas is listed in Table 34. It shows that the normal HDD for Nacogdoches is about 703 greater than Houston, and 1,486 lower than Amarillo. Like other cities in Texas, the distribution of HDD per monthly basis is very irregular at Nacogdoches. The peak HDD is in January and gradually decreases to zero in the warmer months (May to September) and steadily rises again from October until January.

The cooling degree day, similar to HDD, is defined as the number of degrees that the observed mean temperature for the day is above the base temperature (65°F). This index is used for estimating the needs for air-conditioning equipment in homes and other buildings, and for scheduling electric power required to operate such equipment. The normal (1951-80) annual CDD at Nacogdoches was 2,380, with about 97% distributed in the summer half-year (May-October). In the 6 summer months, CDD was greatest in August and it was 3.86 times greater than October, the least. The monthly and annual variations of CDD are listed in Table 62 of Appendix IV.

Besides degree days, the American Society of Heating and Air-conditioning Engineers has used an index called "effective temperature" for many years (Thom, 1957). It is the temperature of a calm and saturated air that would induce the same sensation of comfort by the actual condition of temperature, humidity, and wind movement.

Table 34. Normal (1931-60) Total Heating Degree Days (Base 65°F) for Nacogdoches and Several other Stations in Texas

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Nacogdoches	521	359	262	87	9	0	0	0	3	59	306	467	2099
Abilene	642	470	347	114	0	0	0	0	0	99	366	586	2624
Amarillo	877	664	546	252	56	0	0	0	18	205	570	797	3585
Austin	468	325	223	51	0	0	0	0	0	31	225	388	1711
Brownsville	205	106	74	0	0	0	0	0	0	0	66	149	600
Corpus Christi	291	174	109	0	0	0	0	0	0	0	120	220	914
Dallas	601	440	319	90	6	0	0	0	0	62	321	524	2363
El Paso	685	445	319	105	0	0	0	0	0	84	414	648	2700
Fort Worth	614	448	319	99	0	0	0	0	0	65	324	536	2404
Galveston	350	258	189	30	0	0	0	0	0	0	138	270	1235
Houston	384	288	192	36	0	0	0	0	0	6	183	307	1396
Laredo	267	134	74	0	0	0	0	0	0	0	105	217	797
Lubbock	800	613	484	201	31	0	0	0	18	174	513	744	3578
Midland	651	468	322	90	0	0	0	0	0	87	381	592	2591
Port Arthur	384	274	192	39	0	0	0	0	0	22	207	329	1447
San Angelo	567	412	288	66	0	0	0	0	0	68	318	536	2255
San Antonio	428	286	195	39	0	0	0	0	0	31	207	363	1549
Victoria	344	230	152	21	0	0	0	0	0	6	150	270	1173
Waco	536	389	270	66	0	0	0	0	0	43	270	456	2030
Wichita Falls	698	518	378	120	0	0	0	0	0	99	381	632	2832

Source: Keyes, 1974. Harnessing the Sun - to Heat your Home. Morgan and Morgan Publ.

The U.S. Weather Bureau (non U.S. National Weather Service) also developed a discomfort index (DI) using the following equation:

$$DI = 0.4(T_d + T_w) + 15 \qquad (16)$$

where T_d and T_w are the dry and wet bulb temperatures in °F, respectively. Those indices were not computed in this study because of lack of information.

Growing Degree Days. Similar to heating and cooling degree days, an accumulation of daily average temperature above a certain threshold value of biological importance is called growing degree days. This threshold temperature is selected to be critical to plant growth, development, and maturation. Since plants respond to environmental temperature differently among species, varieties of the same species, or provenance, a different base temperature from which the growing degree days are used. The base temperatures for computing growing degree days for several economically important crops are given in Table 35. The term "heat units" used in the table is synonymous with growing degree days required for maturity.

In Nacogdoches, a base temperature of 50°F is generally accepted for corn crops in computing growing degree days (Dr. Hershel Reeves, personal comm.). The monthly and annual variations of GDD (base temperature 50°F) are listed in Table 63 of Appendix IV while normal (1951-80) growing degree days, by 3 base temperatures, of each month and the annual for the Nacogdoches area are given in Table 36.

Frequency of Occurrence

Since the probability of occurrence is important information in

Table 35. Estimated Heat*Units for Certain Agricultural Crops to Reach Maturity

Crop (Variety, Location)	Base Temperature (°F)	Heat Units to Maturity
Beans (Snap, S. Carolina)	50	1200 - 1300
Corn (Sweet, Indiana)	50	2200 - 2800
Corn (Golden Bantam, S. Carolina)	50	1400 - 1500
Cotton (Delta, Smooth Leaf, Arkansas)	60	1900 - 2500
Peas (Early, Indiana)	40	1100 - 1200
Peas (Medium or Late, Indiana	40	1400 - 1600
Peas (Alsweet, Wisconsin)	40	1300 - 1400
Peas (Perfection, Wisconsin)	40	1700 - 1800
Rice (Vegold, Arkansas)	60	1700 - 2100
Rice (Bluebonnet, Arkansas)	60	2400 - 2600
Wheat (Indiana)	40	2100 - 2400

* Source: Miller *et al.*, 1983.

Table 36. Normal (1951-80) Monthly and Annual Cumulative Growing Degree Days, by Three Base Temperatures, at Nacogdoches, Texas

Month	Cumulative Growing Degree Days					
	Base 60°F		Base 50°F		Base 40°F	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev
January	20.0	22.30	91.8	57.83	254.1	105.82
February	24.8	22.34	114.4	68.69	303.7	108.60
March	70.9	54.39	258.3	97.52	507.5	155.72
April	207.1	66.78	474.8	84.01	770.1	88.90
May	393.4	95.46	713.5	63.25	987.7	197.04
June	582.0	49.97	882.0	49.97	1182.0	49.97
July	701.3	60.17	1008.7	64.98	1316.0	71.32
August	691.9	54.51	1000.2	54.91	1308.6	55.81
September	510.9	71.79	810.5	72.35	1110.5	72.35
October	236.1	83.22	524.1	89.65	803.6	177.09
November	67.7	39.77	227.5	79.87	481.0	99.64
December	188.6	206.60	97.0	53.40	293.6	84.35
Annual	352.8	283.11	6125.9	384.13	9318.4	529.87

planning and management, frequency analyses were employed to determine the expected magnitudes of various return periods (recurrence interval) for 9 temperature variables observed at Nacogdoches, Texas. Those variables unbounded above or below (i.e., no upper or lower limits) such as annual temperature series and annual number of days with temperature of certain threshold values were fitted by the log-normal distribution. The Gumbel's distribution function was used to fit the extreme data series. No attempt was made to find the best model among various distribution functions.

Results of the analyses are tabulated in Table 37 along with the maximum values observed in the 80 years of records.

Table 37. Expected Values of Five Different Frequencies of Occurrence for Nine Temperature Variables at Nacogdoches, Texas

Variables	Return period, years						Maximum value in 80 years
	2	5	10	25	50	100	
	(50%)	(20%)	(10%)	(4%)	(2%)	(1%)	
Annual temperature, °F							
Average	65.5	66.3	66.6	67.2	67.4	67.8	67.6
Maximum	77.8	79.0	79.4	80.3	80.6	81.3	79.9
Minimum	53.1	52.4	52.2	51.6	51.5	51.0	51.0
Extreme temperature, °F							
Daily average	62.4	76.4	85.7	94.5	106.0	114.7	89.5
Daily maximum	101.2	107.5	110.4	114.1	116.8	119.4	110
Daily minimum	16.0	10.9	7.6	3.4	0.3	-2.8	-4
Days w/t_{max} 90°F	122.3	110.8	120.4	131.2	137.1	148.9	132
Days w/t_{min} 32°F	44.4	51.7	57.6	64.4	68.3	75.9	64
Frost-free days	234	249.7	254.7	267.0	270.6	279.3	288

Notes: 1. Values in the parentheses are the probabilities of the events being equal to or greater than indicated magnitudes.

2. The extreme temperature were fitted by the Gumbel extreme distribution function, the rest were by the log-normal distribution function.

3. t_{max} = daily maximum temperature; t_{min} = daily minimum temperature

Humid Climate

Humidity

The atmosphere is composed of gases, solid impurities, and water in various states. Of these constituents, water is the single most important one with respect to weather. It provides sources of water for precipitation, and condensation such as dew, fog, and clouds, affects the radiation balance of the atmosphere and the earth, influences evapotranspiration process, and is a dominant factor in environmental comfort. There would be no weather on the earth should water be absent from the atmosphere.

Water present in the atmosphere is often referred to as water vapor because it acts like other gases in the atmosphere. It is constantly moving about, occupies space, and exerts pressure in the atmosphere. The maximum pressure exerted by water molecules in the atmosphere is strictly a function of temperature and is usually expressed in millibars (mb). When the pressure exerted by water vapor reaches the maximum at a particular air temperature, the air is said to be "saturated", and the pressure is called saturation vapor pressure. The discrepancy between saturation and actual vapor pressure is "saturation deficit", and the ratio between actual and saturation vapor pressures is "relative humidity".

Relative humidity, and saturation vapor deficit, changes with air temperature and the absolute water vapor content of the air. Diurnal variations of actual vapor content are usually small, thus relative humidity is usually high at night when temperature of the air is low.

As temperature increases during the day, the saturation deficit increases but relative humidity decreases.

Although there are many different measures of atmospheric moisture, relative humidity is the most popular one in routine observation. In Nacogdoches, measurements of relative humidity have continued at the SFASU Climatic Station since 1965 and at a Forest Station operated by the SFA School of Forestry about 20 miles SE of Nacogdoches since 1980. Only the data obtained at a Forest Station at Etoile was used as a reference in this study. The record showed that relative humidity of 100% was common in the early morning in all seasons and about 40-50% in the afternoon. Average monthly and annual relative humidity observed at the forest station is given in Table 38.

Table 38. Average Monthly and Annual Relative Humidity (%) at a Forest Station (1980-85) about 20 Miles SE of Nacogdoches, Texas

Station	Monthly												Ann.
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Forest	71.0	71.7	71.3	72.5	74.3	74.5	72.5	70.4	70.4	73.5	71.8	71.2	72.1

The average annual relative humidity was 73.9% at SFASU campus and 72.1% at the Forest Station about 20 miles SE of Nacogdoches. Its annual variation during the observational period was about ±5% from its average. As a rule, relative humidity is higher for those years with lower air temperature and greater number of rain days, and is lower with more clear weather, bright sunshine, dry wind from the north or northwest, and higher air temperature.

Observations made at Chicago, Illinois shows that relative humidity is higher in the winter months and lower in the summer months (Cox and Armington, 1914), and the difference between the maximum (January) and the minimum (July) is as much as 12%. In Nacogdoches, seasonal and monthly differences are smaller with the monthly range less than 5%. The maximum monthly relative humidity occurred in May and June while the minimum occurred in August and September.

Pan Evaporation

Evaporation is the change of water from liquid state into vapor state. Since direct measurement of water loss to the air is infeasible, evaporation from a small pan becomes an alternative index to open water (reservoir) evaporation. Once pan evaporation is available, a pan coefficient is then applied to convert pan evaporation into open water evaporation. The method is a popular approach in climatology and hydrology not only because of its simplicity in operation and inexpensive cost, but also because of the stable relationship between pan evaporation and open water evaporation.

Table 39 lists the monthly and annual pan evaporation of a standard NWS Class-A pan observed at SFASU Climatic Station at Nacogdoches, Texas since 1965. Annual pan evaporation ranged from 37.03 inches in 1968 to 64.47 inches in 1980 with a mean of 48.21 inches and a standard deviation of 8.79 inches. Eagleman (1967) has developed the following equation to estimate pan coefficient (Cp) for any location in the United

Table 39. Pan Evaporation (inches) Observed at Stephen F. Austin State University Climatic Station, Nacogdoches, Texas, 1965-80

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1965	2.94	2.38	2.41	3.21	2.86	3.68	4.73	4.81	4.42	3.39	2.14	2.20	39.17
66	1.84	2.06	3.04	3.00	3.74	4.28	4.30	4.23	3.38	3.82	2.18	3.12	38.99
67	1.66	1.27	3.45	2.76	2.63	4.25	3.09	4.45	4.93	5.23	2.88	2.26	38.86
68	1.27	1.89	2.11	2.46	3.78	3.79	4.30	4.76	3.67	3.50	2.98	2.52	37.03
69	1.94	1.82	2.79	3.41	3.55	5.81	6.41	5.79	5.57	4.47	3.27	2.16	46.99
70	1.66	2.17	3.39	3.59	4.96	5.50	5.87	5.74	3.97	3.21	2.70	1.61	44.37
1971	1.61	2.64	3.33	4.12	3.75	3.92	5.55	4.55	3.16	2.90	3.35	0.90	39.70
72	1.82	2.52	4.08	5.26	4.56	6.50	5.25	4.30	3.51	3.72	2.70	2.03	46.25
73	1.70	1.87	3.08	3.48	3.73	4.72	4.94	4.83	4.74	4.13	3.52	2.97	43.71
74	1.49	3.19	3.92	5.13	5.35	5.32	7.39	6.36	4.14	4.19	2.23	1.88	50.59
75	2.96	2.45	3.19	4.75	4.87	6.05	6.94	6.72	5.89	4.55	3.34	1.70	53.41
76	1.70	2.92	3.69	5.57	5.71	5.62	6.98	7.83	5.82	6.04	2.38	1.77	56.03
77	0.73	2.60	4.76	6.12	8.76	8.02	9.69	7.17	6.10	4.69	2.91	1.64	63.19
78	0.35	1.32	4.70	8.12	7.03	8.17	7.69	8.32	4.67	3.53	1.90	0.73	56.47
79	0.23	2.03	3.43	3.67	5.98	7.39	6.12	7.20	6.06	5.02	3.08	1.92	52.13
80	1.96	3.34	4.42	6.26	5.61	8.77	10.49	8.32	6.25	4.93	2.55	1.57	64.47
Mean	1.62	2.28	3.30	4.43	4.80	5.73	6.23	5.96	4.77	4.21	2.76	1.94	48.21
S. D.	0.75	0.59	0.76	1.55	1.60	1.64	1.96	1.47	1.07	0.85	0.49	0.63	8.79

States:

$$Cp = 0.560 + 0.00275(RH) \tag{17}$$

where RH is the average relative humidity in percent. By applying RH = 73.9% (Table 39) in Equation 17, the Cp value for Nacogdoches is 0.763. The average annual open water evaporation in Nacogdoches is 48.21 inches X 0.763 or 36.78 inches which is about 80% of annual precipitation based upon data for the period 1965-80.

The 36.78 inches is the estimated average open water evaporation in Nacogdoches. Based on streamflow analysis, the actual total water loss (evaporation) in La Nana Creek Watershed is 32.27 inches. Comparing the 32.27 inches to the 48.21 inches of pan evaporation, then pan coefficient to convert pan evaporation into watershed evapotranspiration should be 0.67.

Monthly pan evaporation closely follows the monthly air temperature pattern. The lowest monthly pan evaporation was 1.62 inches in January as compared to a high of 6.32 inches in July. Variations of monthly pan evaporation and monthly temperature are plotted in Figure 18.

Simple correlation and regression analyses were performed to find the relationship between pan evaporation and selected climatic variables. Table 40 shows that monthly pan evaporation was positively correlated with temperature (T), and negatively correlated with saturation vapor deficits (SD) and relative humidity (RH). About 60% of the variation of monthly pan evaporation is explained by T and RH, or by T and SD. Transformations of these independent variables did not improve the predictability of the 3 equations.

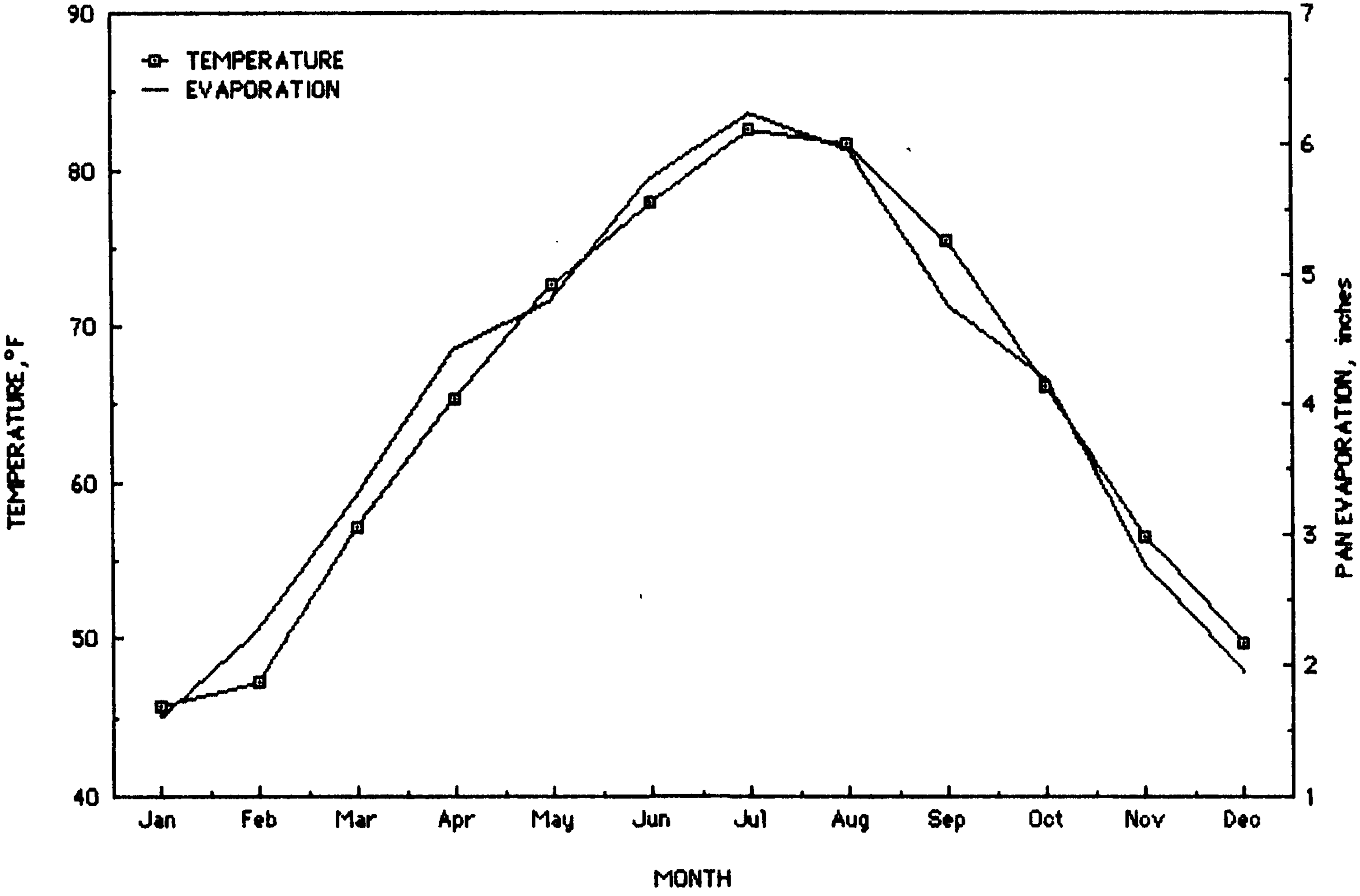

Figure 18. Average monthly pan evaporation and air temperature at the SFASU Climatic Station, Nacogdoches, Texas, 1965-80.

Table 40. Predictions Equation and Simple Statistics for Pan Evaporation (in inches) for Nacogdoches, Texas

	Equations	R^2	SEE,%
(18)	PE = -3.352 + .114(T)	0.58	31
(19)	PE = -6.55 + 0.114(T) - 4.405(RH)	0.60	30
(20)	PE = -4.586 + 0.156(T) - 0.262(SD)	0.60	30

Note: PE = Pan evaporation, RH = Relative humidity,
T = Temperature, SD = Saturation deficits.

Streamflow

Streamflow is the residual of a hydrological system. It is an integral hydrologic component resulting from a variety of factors of watershed topography, land use (vegetation cover), and climate acting upon a watershed. In other words, the input precipitation has to satisfy the watershed storage and evapotranspiration first, and the remainder will then run into stream channels through overland flow or interflow.

La Nana Creek is a major creek running through the east-side of the city of Nacogdoches. It is joined by Banita Creek from the west-side within the city limit, and flows southwards into Sam Rayburn Reservoir on the Angelina River. The U.S. Geological Survey installed a permanent stream gauging station to monitor the streamflow of La Nana Creek in October 1964. The station is located on East Starr Avenue (FM 1878) of the city, or more specifically on the right bank of the down stream side of the bridge and is about 14.5 miles north of its mouth.

Datum of the gauging station is 264.23 ft above mean sea level. The watershed area above the gauging station is 31.3 mi^2, which includes the northern section of University Drive, NE Loop 224, and Appleby Sand Road. The rapid development and urbanization since 1975 along this section of the city may have altered the streamflow regime. Some of the streamflow characteristics such as mean duration, frequency, peakflows and flood based on the 20 years of observation are given below. The streamflow analyses were further separated for the earlier period (1965-74) and the recent period (1975-83) to provide some insights on the hydrologic effects of urbanization within the watershed.

Mean Streamflow

On the average, about 30% of annual precipitation, or 13.86 inches, contribute to streamflow in La Nana Creek each year. The runoff ratio (i.e., streamflow/precipitation) is as much as 3 times greater than the ratio for the state of Texas (Texas Water Development Board, 1968). This is probably due to a greater input of precipitation and less loss of water to the air through evaporation as a result of more humid environment and slightly cooler air temperature.

As stated previously, August is not only the driest but also the hottest month of the year. Accordingly, August has the lowest streamflow of the year. The runoff ratio is only 0.034 (i.e., 0.087"/2.52") in August as compared to 0.452 (i.e., 1.98"/4.38") in April, the highest monthly streamflow. The mean monthly streamflow along with monthly precipitation for 1965-83 are plotted in Figure 19. Monthly and annual streamflows of each year are given in Table 64 of Appendix V.

The annual variation of streamflows is much greater than precipitation in Nacogdoches. Maximum annual streamflow of the creek was 42.20 inches in 1979 and the minimum was 1.57 inches in 1971, which gives a range of 40.63 inches or 294% of the mean annual discharge. Annual precipitation for the same period (1965-83) in Nacogdoches ranged from 31.41 inches to 68.57 inches with a mean of 45.51 inches which was was about the same with the long-term (1901-80) mean annual precipitation.

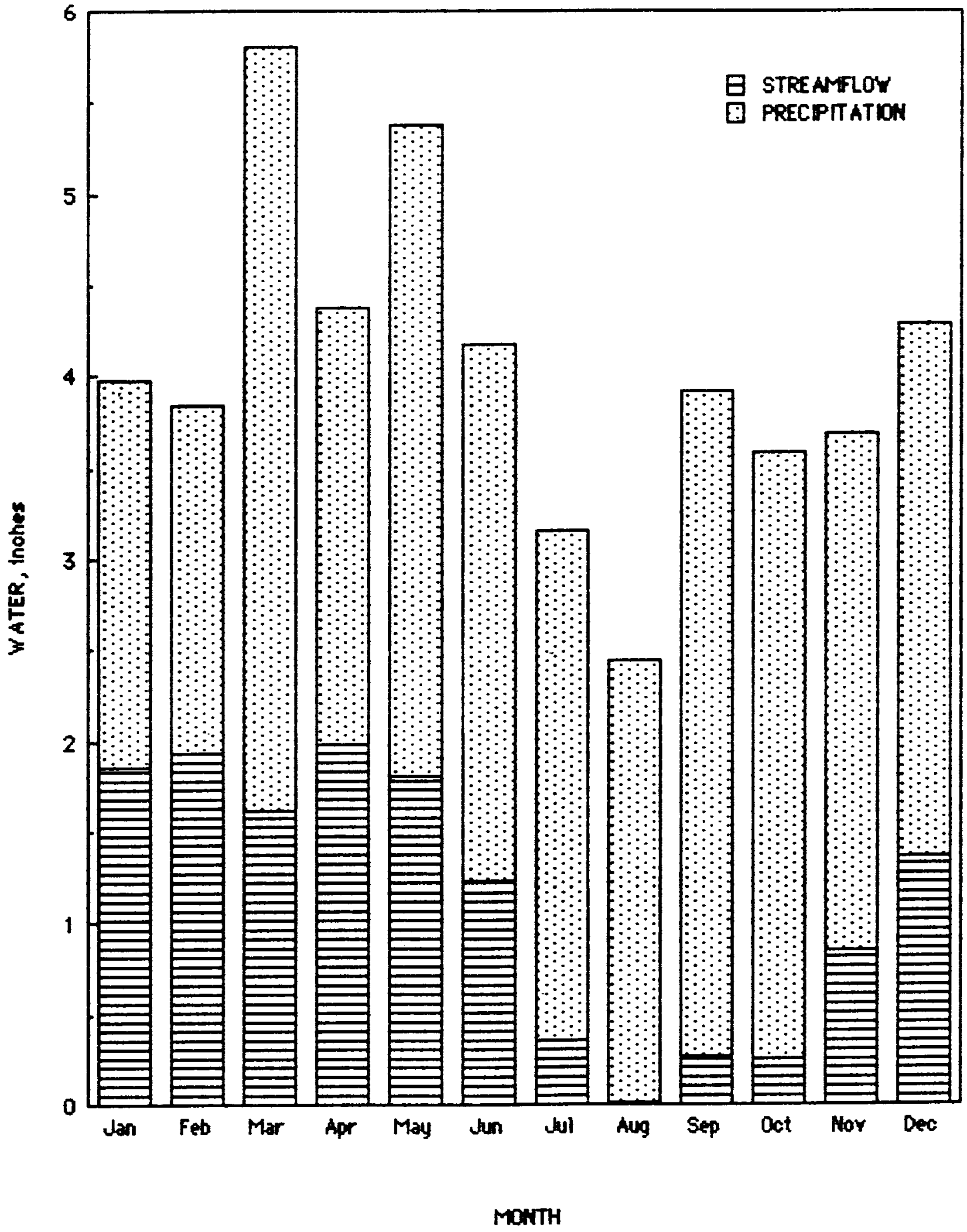

Figure 19. Mean monthly distribution of streamflow and precipitation for the 1965-83 period at La Nana Creek, Nacogdoches,Texas.

Annual streamflow is generally affected more by precipitation than by temperature. In La Nana Creek, a simple correlation coefficient between streamflow and precipitation was 0.673 and it was -0.607 for streamflow and temperature. Figure 20 is a plot of accumulated annual streamflow versus accumulated annual precipitation. The changes in slope along the line reflect the changes in annual runoff coefficients ratio from year to year. Based on visual observations the greatest slope in Figure 20 occurred in 1973 in which about 76% of annual precipitation were converted into annual streamflow, while the smallest slope was in 1971 with an annual runoff coefficient of 0.045. The runoff coefficients from year to year are in response to differences in precipitation characteristics including quantity, intensity, duration, and distribution, thermal environment, atmospheric humidity, other unidentified factors such as human errors in measurements or alteration of the watershed environment by man's activities.

The plot in Figure 20 seems to reveale some vague differences in trend between the old segment and the new segment. Breaking the entire period of observations into the old 10-year (1965-74) period and the recent 9-year (1975-83) period, average annual precipitation and temperature along with streamflow for these two periods are listed below:

	Old period (1965-74)	Recent Period (1975-83)
Annual streamflow (in)	12.60	15.21
Annual rainfall (in)	46.07	44.89
Annual temperature (°F)	65.31	64.10
Runoff coefficient	0.266	0.314

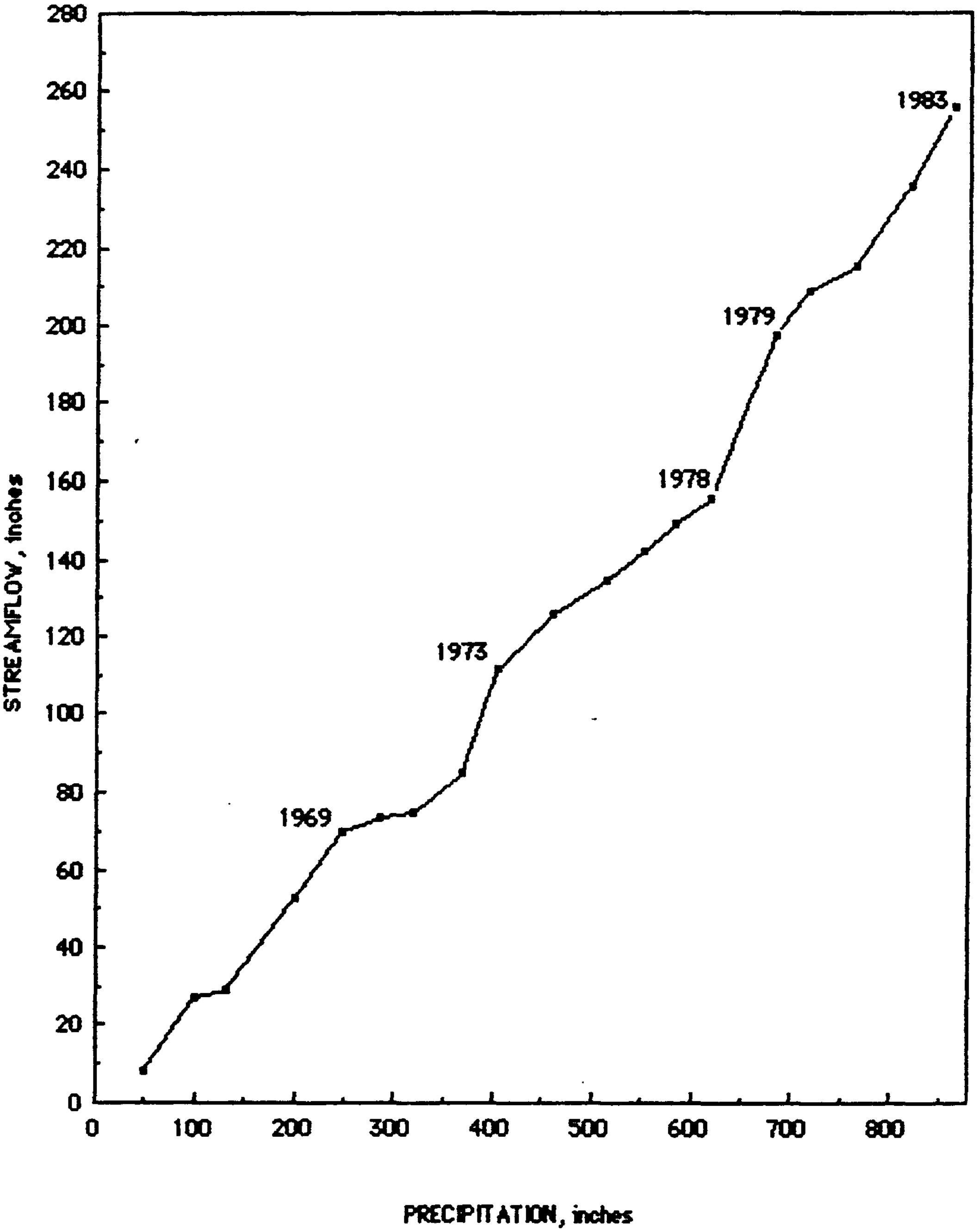

Figure 20. Accumulated annual streamflow versus accumulated annual temperature, 1965-83, for La Nana Creek, Nacogdoches, Texas.

The simple comparison listed above showed an average of 2.61 inches more streamflow per year for the recent period than the old period. Annual precipitation was 44.89 inches for the recent period and was 46.07 inches for the old period, or the recent period was 1.18 inches less than that of the old period. Thus the greater streamflow in the recent period in La Nana Creek cannot be explained by precipitation.

Annual temperature for the recent period was 1.21°F cooler than the old period which may reduce evapotranspiration in the watershed and consequently increasing streamflow in the channel. Simple correlation analysis showed a negative coefficient between streamflow and temperature, but the numerical effects of temperature on streamflow are difficult to evaluate because of insignificant effect for the recent period (Table 41).

There has been a marked increase in residential development in the La Nana Creek region of Nacogdoches since 1975. Urbanization may have increased the streamflow in the recent period as compared to the old period. It needs further investigation.

Flow Duration

The distribution of daily streamflow is usually expressed in terms of percent of time that a magnitude of daily discharge is equaled or exceeded. A graph showing such relationship is called a flow duration curve. Once a flow duration curve is available, it can be used to determine the water supply potential of the river, to extend the flow information of a short-term record to a long-term record, or to study a streamflow regime as affected by land use or urbanization.

The magnitude of daily streamflow in La Nana Creek was classified into 24 different groups of well distributed intervals. The number of times in each year that daily discharges fall in each of the classes was tallied, and the total number of occurrence (times) in each class in the whole records was summarized at the bottom of Table 42. The total number in each class was then accumulated, beginning with the highest class as shown in Table 42, and the accumulated value in the smallest class was then equal to the total number of days in the whole records. The accumulated value in each class was then divided by the total number of days in the whole records (accumulated value shown in the smallest class) to obtain the percent of times that daily streamflow was equal to or exceeded the indicated values.

Figure 21 is the flow duration curve for the 1964-83 water-year by plotting discharges versus percent of time given in Table 43. The analyses were further broken down into 2 periods, i.e., water years 1965-74, and 1975-83 for comparison of urbanization effects in La Nana Creek.

During the entire records, there were 17 times having an average daily discharge of 1,000 cfs or greater and the maximum was 5,730 cfs on June 2, 1979. For daily discharge of 100 cfs or greater, the percent of time was about 6%. Maximum daily streamflows of each month and year for La Nana Creek are given in Table 44.

The flow duration curves of Figure 21 seem to show clearly that daily streamflow regimes are significantly different between the old (1965-74) and the new (1975-83) periods. For example, the maximum daily

Table 41. Prediction Equations and Simple Statistics for Annual Streamflow of Three-Time Periods for La Nana Creek, Nacogdoches, Texas

Period		Prediction Equations	R^2	SEE,%
1965-74	(21)	$RO = 673.06 - 10.133(T)$	0.72	40
1975-83	(22)	$RO = -22.43 + 0.817(Pt)$	0.70	44
	(25)	$RO = 245.43 + 0.761(Pt) - 4.120(T)$	0.84	35
1965-83	(26)	$RO = -13.68 + 0.604(Pt)$	0.45	55
	(27)	$RO = 376.80 - 5.605(T)$	0.37	59
	(28)	$RO = 256.92 + 0.483(Pt) - 4.094(T)$	0.63	47

Notes: 1. RO = Annual runoff, inches; Pt = Annual precipitation, inches; and T = Annual average temperature (°F).

2. Those variables retained in the equations are significant at the probability level of 0.07 or less.

Table 42. Frequency (in days) of Daily Discharge, by Class and Year for La Nana Creek, Nacogdoches, Texas

Year	Classes of Daily Discharge*																								
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1964	61	9	0	14	1	0	2	1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
1965	98	10	9	32	13	4	2	3	11	23	17	21	27	21	2	24	9	6	4	2	6	1	0	1	0
1966	26	14	7	22	28	15	22	16	11	21	23	14	18	23	5	34	11	11	5	2	1	4	2	1	1
1967	150	12	4	6	11	8	7	12	43	40	30	14	11	4	0	4	1	0	2	0	2	0	0	0	0
1968	1	0	0	0	2	4	7	16	19	31	19	20	52	29	9	44	27	19	11	9	7	6	3	1	2
1969	62	20	17	26	24	13	10	7	8	10	5	8	7	11	1	54	19	15	10	4	4	5	4	2	2
1970	90	13	8	16	23	20	8	17	15	34	21	22	20	15	6	14	3	4	3	0	1	0	0	0	0
1971	122	21	12	20	16	12	39	34	18	16	7	18	12	3	2	5	0	3	1	0	0	0	0	0	0
1972	4	23	36	20	7	11	15	9	16	26	17	27	35	16	4	32	8	7	7	2	5	3	0	0	0
1973	2	0	0	0	1	3	13	6	6	28	25	19	22	26	4	66	29	23	20	6	7	6	2	4	2
1974	12	6	18	16	14	5	12	18	18	20	19	17	25	20	6	48	23	8	6	5	3	4	1	1	1
1975	2	0	0	0	0	7	38	18	50	26	13	12	18	31	6	57	15	11	6	3	2	5	2	0	1
1976	1	7	12	32	19	19	7	4	12	22	25	50	51	37	5	14	10	3	4	3	4	1	0	0	0
1977	13	75	23	11	15	31	20	10	9	11	5	8	18	31	8	27	9	2	0	0	3	2	1	0	0
1978	125	9	3	13	9	14	19	8	12	11	15	11	23	25	2	23	8	5	3	3	3	2	0	0	0
1979	2	5	10	22	9	18	8	10	16	15	14	18	19	13	1	50	26	18	12	15	6	13	4	2	3
1980	16	36	33	30	7	8	26	18	10	14	14	11	20	30	7	25	8	10	2	5	1	3	0	2	1
1981	14	6	7	9	14	18	29	40	38	34	30	44	31	9	4	5	6	5	5	2	1	1	0	0	1
1982	2	23	13	5	6	7	8	6	29	36	14	10	51	37	13	26	16	11	11	5	6	4	2	3	2
1983	2	0	0	21	20	22	18	9	10	24	19	15	21	28	9	52	14	7	7	4	5	4	1	3	1
1984	1	17	26	16	7	15	20	10	21	17	7	6	7	31	4	41	15	6	4	1	6	1	1	1	0
TOT	806	306	238	331	246	254	330	272	372	460	340	366	488	440	98	645	257	174	123	71	73	65	23	21	17

* See Table 43.

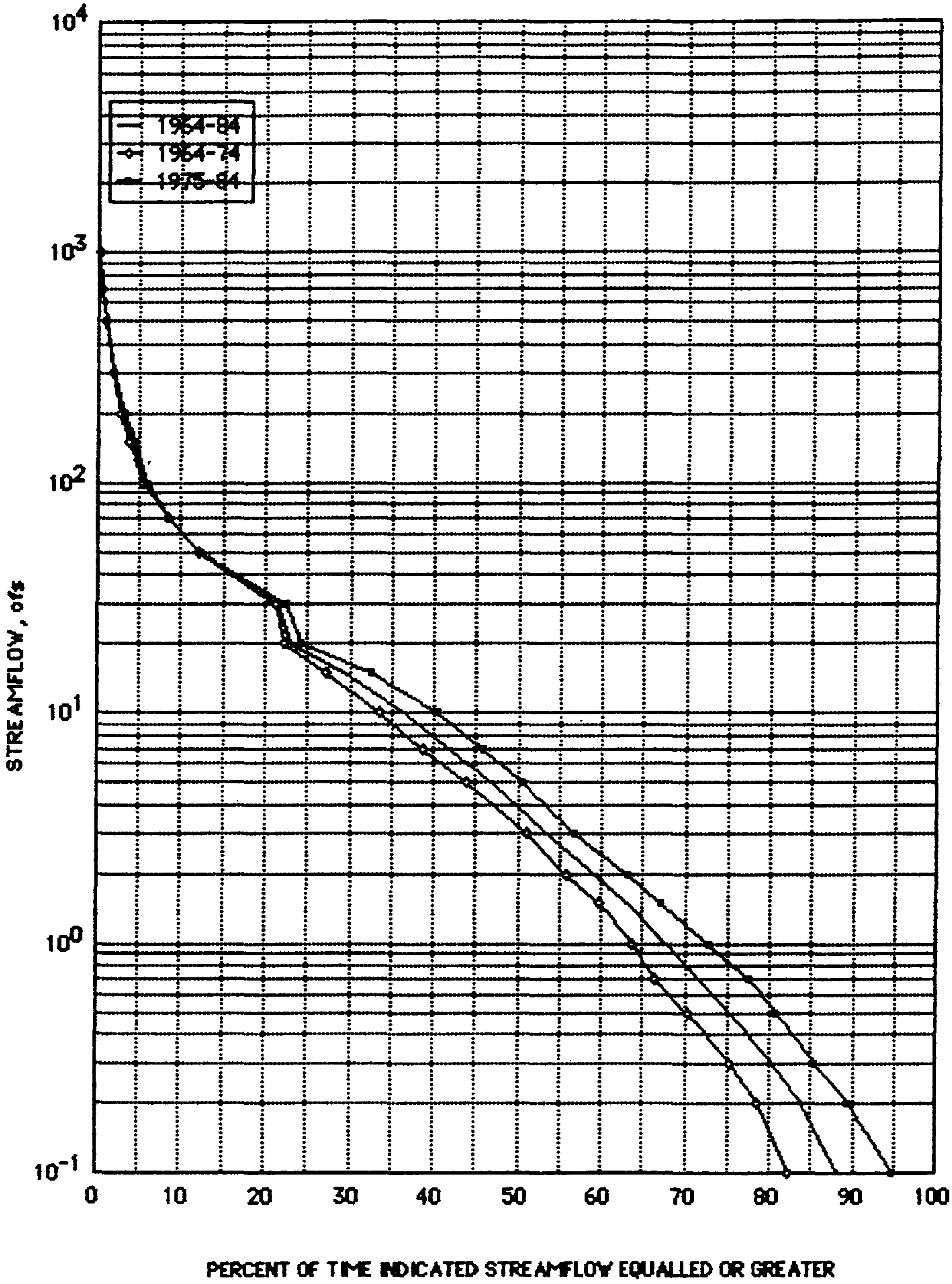

Figure 21. Streamflow duration curve for La Nana Creek, Nacogdoches, Texas, for three water-year periods (1964-84, 1964-74, and 1975-84).

Table 43. Duration Table of Daily Discharge, Water Year 1965-84, for La Nana Creek, Nacogdoches, Texas

Class	Daily Streamflow (cfs)	Total Number of Days		%
		Observed	Accumulated	
0	0.0 - 0.09	806	6816	100.0
1	0.1 - 0.19	306	6010	88.2
2	0.2 - 0.29	238	5704	83.7
3	0.3 - 0.49	331	5466	80.2
4	0.5 - 0.69	246	5135	75.3
5	0.7 - 0.99	254	4889	71.7
6	1.0 - 1.49	330	4635	68.0
7	1.5 - 1.99	272	4305	63.2
8	2.0 - 2.99	372	4033	59.2
9	3.0 - 4.99	460	3661	53.7
10	5.0 - 6.99	340	3201	47.0
11	7.0 - 9.99	366	2861	42.0
12	10.0 - 14.99	488	2495	36.6
13	15.0 - 19.99	440	2007	29.4
14	20.0 - 29.99	98	1567	23.0
15	30.0 - 49.99	645	1469	21.6
16	50.0 - 69.99	257	824	12.1
17	70.0 - 99.99	174	567	8.3
18	100.0 - 149.99	123	393	5.8
19	150.0 - 199.99	71	270	4.0
20	200.0 - 299.99	73	199	2.9
21	300.0 - 499.99	65	126	1.8
22	500.0 - 699.99	23	61	.9
23	700.0 - 999.99	21	38	.6
24	1000	17	17	.2

Table 44. Maximum Daily Streamflow (cfs) at La Nana Creek, Nacogdoches, Texas (1964-84 Calender Year)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1964	--	--	--	--	--	--	--	--	--	0.0	1.39	7.39	7.39*
1965	276	110	932	80	433	51	6.0	0.64	82	0.06	3.69	224	932
1966	397	351	48	1260	700	18	17	173	20	6.89	1.29	11	1260
1967	5.69	119	24	43	100	283	16	0.55	0.0	0.15	0.02	4.39	2.83
1968	1100	200	120	1500	583	325	726	16	1.59	11	192	664	1500
1969	87	821	1020	683	1330	19	2.39	0.59	1.79	12	9.40	31	1330
1970	29	149	204	77	98	16	0.11	15	8	28	11	9.40	204
1971	3.2	24	5.4	1.5	76	2.1	16	9.9	11	8.20	82	112	112
1972	190	49	35	94	17	42	285	6.5	3.1	286	468	402	468
1973	1060	160	1120	890	200	497	31	17	144	178	726	772	1120
1974	1440	778	29	51	46	24	47	20	232	122	500	215	1440
1975	607	3420	119	102	239	815	16	14	7.6	34	44	21	3420
1976	47	140	64	274	116	240	181	2.0	17	19	20	312	312
1977	267	521	414	52	40	51	2.3	85	7.4	18	34	57	521
1978	224	222	227	185	80	34	5.6	2.8	60	14	366	304	366
1979	1390	641	669	408	2660	5730	300	17	269	100	1000	247	5730
1980	759	479	171	763	1200	75	12	24	100	12	18	7.4	1200
1981	14	93	66	7.2	55	363	120	16	1000	273	150	9.3	1000
1982	300	150	97	1430	281	165	100	5.0	12	100	976	914	1430
1983	157	625	307	40	1160	822	18	38	17	4.0	40	980	1160
1984	99	958	663	48	60	75	238	5.2	19	--	--	--	958*
Mean	444.67	525.58	333.11	420.38	494.63	507.63	111.76	24.12	104.73	66.97	253.30	288.03	1296.53
S.D.	474.6	7565.0	363.8	510.1	676.0	1289.9	179.4	40.9	226.5	92.4	342.4	330.	1290.7

---

* Value not counted in calculating means.

streamflow in the older period was 1,500 cfs and there were 8 times having daily discharge of 1000 cfs or greater, while there were 3 times and nine times having daily discharge of 2,660 cfs and 1,000 cfs, respectively, for the most recent period. For daily streamflow of 10 cfs or greater, the percent of occurrence was about 34% for the old period and 40% for the new period.

Not only did the new period have a greater percentage of occurrence for high flows, but also had a smaller percentage for lower flows than did the old period. For example, there were only about 5% of times having daily discharges of 0.09 cfs or smaller for the new period, but it was 18% for the old period. The significant difference in streamflow regime between these 2 periods may be attributed to the rapid development in the La Nana Creek Watershed in the past 9 years. During this period the 4-lane University Drive was extended from East Austin Avenue a total length of about 2.2 miles north to Loop 224. Including the older section of University Drive the total length is about 1/3 of the main channel length, or about 3.1 miles. University Drive runs parallel to La Nana Creek at a distance of only about 600 ft from the channel.

University Drive is the new development center of Nacogdoches. Many big department stores, shopping centers, apartments, condominiums, subdivisions, along with individual buildings were constructed along University Drive during the recent period. Table 45 showed the total building permits issued by the City of Nacogdoches since 1964. It was 177 permits yr^{-1} for the old period and 321 permits yr^{-1} for the recent period. Although these building permits were issued for the whole city, they were a good indication for the rapid development in the recent period. Grouping these permits by region of construction may show a higher percentage of permits issued outside the La Nana Creek watershed for the older period and more permits issued inside the watershed for the recent period. Developments usually seal the ground surface and decrease rain water infiltrating into soils by additional roofing, parking lots, streets, highways, as well as man's and vehicular activities which compact the soil and increase runoff and streamflow.

Table 45. Total Building Permits Issued by the City of Nacogdoches Since 1964

Year	Residential	Apartment	Commercial	Total
1964	97	8	22	127
1965	106	7	27	140
1966	86	5	21	112
1967	88	3	30	121
1968	115	22	27	164
1969	129	19	35	183
1970	104	12	35	151
1971	122	24	85	231
1972	130	92	69	291
1973	114	24	68	206
1974	87	4	75	166
1975	143	6	24	173
1976	175	2	27	204
1977	205	10	55	270
1978	165	9	54	228
1979	116	5	78	201
1980	102	13	146	261
1981	105	170	217	492
1982	131	4	53	188
1983	589	281	—	870
1984	882	315	—	1197

Frequency

The Log-Pearson Type III distribution was recommended by the U.S. Water Resources Council (1967) as a unified method in flood flow frequency analysis. Using this method, the results of analysis in terms of return-periods and probability of occurrence for annual total streamflow, daily maximum, and maximum instantaneous discharges were given in Table 46. The probability for maximum annual daily discharge with a two-year return-period to occur in February or in October of a particular year is 17 and 1%, respectively. Seasonal probability of obtaining a maximum daily streamflow in any month of any year equal to or exceeding the yearly return-period values was plotted in Figure 22. It can be seen, however, that the probability of obtaining a maximum daily streamflow in any July equal to or exceeding the yearly return-period of 60 years is about 1%.

Table 46. Frequencies of Occurrence for Annual Streamflow, Maximum Daily Streamflow, Maximum Instantaneous Peakflow in La Nana Creek, Nacogdoches, Texas

Streamflow	Return Period, T, years				
	2 (50%)	10 (10%)	25 (4%)	50 (2%)	100 (1%)
Annual streamflow, inches	11.35	24.51	32.02	38.07	45.08
Max. daily streamflow, cfs	827.63	2865.09	4320.91	5570.38	7029.78
Instant. peakflow, cfs	1975.3	6998.7	12480.8	17004.6	22970.6

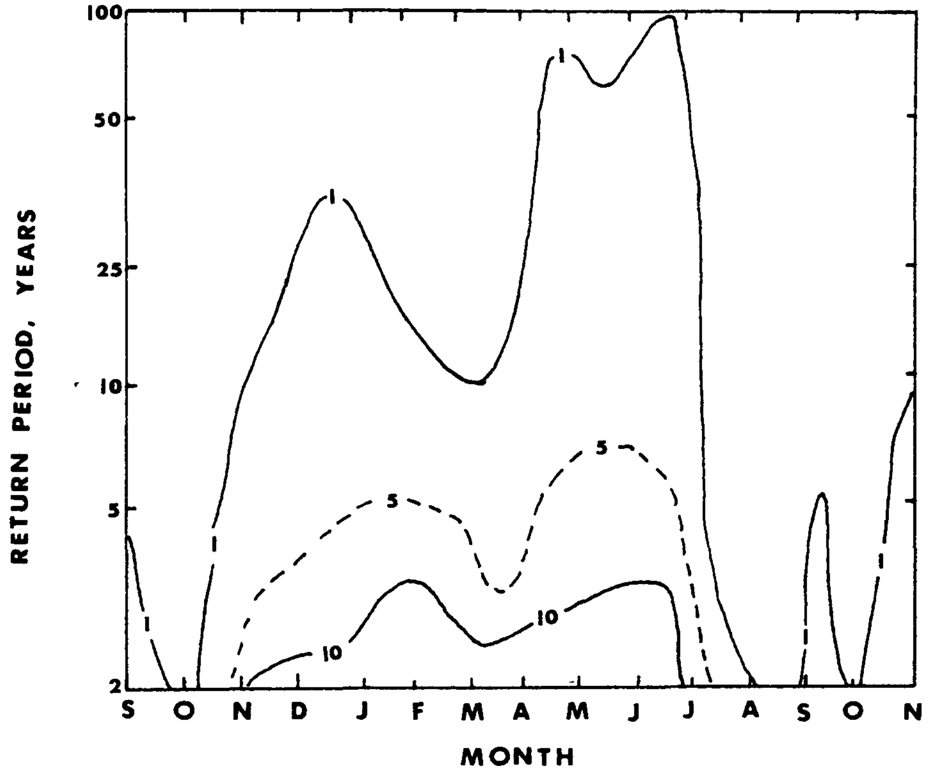

Figure 22. Seasonal probability of maximum daily mean streamflow at Nacogdoches, Texas, 1965-83. Probability in % of obtaining a maximum daily streamflow in any month of a particular year equal to or exceeding the yearly return period values indicated on the ordinates.

Flood

Flood is "an inundation of flood plain of a river which may cause substantial losses of life, personal property, public facilities or agricultural productivity ... It is a result of excessive rainfall, sudden release of water by snowmelt on frozen ground, inadequate channel capacity, and man's encroachment on flood plains" (Chang, 1982). Thus, flood is a normal part of the life of rivers. Hardly a year passes in which no disastrous floods occur somewhere in the United States. It would be of little consequence if man did not occupy the flood plain for agricultural production, residential development, industrial purposes, or public enjoyment and convenience.

Due to the proximity to the Gulf of Mexico and the slow drainage of two parallel creeks (Banita in the west and La Nana in the east) in the city, flooding is not an unusual event in Nacogdoches. Based on information published in the Daily Sentinel newspaper, Table 47 lists the major flood events at Nacogdoches, Texas during the 1901-80 period. It shows that there were 9 floods or an average of about 1 flood every 4 years during the first 40-year period (1901-40) and 18 floods or an average of about 1 in every 2 years during the second 40-year period (1941-80). Information reported in the Daily Sentinel was too brief in general and gave no detailed information such as depth of flood water in each event.

The earliest flood recorded in this century occurred on June 28, 1902 in which a total rainfall of 14.22 inches was observed between 5.00a.m. and 12:00 midnight, the greatest rainfall ever observed in a

Table 47. Flood Record at Nacogdoches, Texas, 1901-80

Date	Time of Occurrence	Rain Depth (inches)	Areas Affected	Damages Done		Estimated Cost
				Lives	Properties	
Jun 28, 1902	5.00 am to 24.00 pm	14.22	All over town	0	- Two bridges at Banita and La Nana Creek were badly damaged. - Several heads of cattle owned by Mr. Meisenheimer were drowned. - Cotton office at The Sturdevant's cotton yard was washed away. - Perkins Building was damaged. - Most of the telephone lines were disrupted.	few thousand dollars
Nov 5, 1905	afternoon	6.05	Lowlying areas of the city	0	- No damage except The Texas and New Orleans passenger train stopped service for a few days since the track was 12-16 inches under water.	no estimate made
May 2, 1916	noon till late night	5.35	Areas along the La Nana and Banita Creek	0	- Mr. Blount's dam at new lake was broken losing half of the water and damaged properties below the dam.	no estimate made

Table 47. Continued

Date	Time of Occurrence	Rain Depth (inches)	Areas Affected	Damages Done		Estimated Cost
				Lives	Properties	
					- Gardens in the town were completely destroyed. - County roads and bridges were badly damaged.	
Apr 28, 1922	11:00 am to 4:00 pm	3.48	Lower part of the town.	1	- The bridge and private belongings along Banita Creek were damaged.	\$50 - \$75,000
Apr 25 and Apr 27, 1923	8½ hours	6.78	All over the town.	0	- Mayo Dam broke and many stores along North and Main Street and Banita Creek were flooded.	No estimate done
Apr 22, 1926	11:00 am to 11:30 pm	3.80	Some parts of town but most affected were areas near to the creeks.	0	- No record of Damaged available.	No estimate made
Jul 24, 1933	late night to 6:00 am	9.30	S. Fredonia and W. Main affected.	0	- About 600 chickens a produce farm were drowned and several heads of cattle lost.	No estimate done

Table 47. Continued

Date	Time of Occurrence	Rain Depth (inches)	Areas Affected	Damages Done		Estimated Cost
				Lives	Properties	
Nov 23, 1940	night to 10:00 am	8.85	all over town	0 0	- Temporary bridge at W. Main was washed out - The Beck's home and furnitures were badly damaged. - Texan theater was flooded.	Greater than $3,500
Oct 30 and 31, 1941	7:00 am to 7:00 am	8.93	all over town	0	- No record except of the stores were closed.	No available estimate
Mar 6, 1946	4:00 pm to 10:00 pm	3.00	Lower part of the town	0	- No severe damage except trash was piled everywhere in town.	No estimate made
Jun 13, 1946	afternoon	3.23	Areas around the Creeks	0	- Business near the Creeks such as the lumber yard, feedmills, and Septic Tank Co. were affected.	More than $12,000
Apr 29, 1953	nighttime	5.90	All over the town	0	- Bridges at Highway 21 washed out	No estimate made
May 12, 1953	6:30 pm to 7:00 pm	3.00	Lower areas of the town	0	- Clogged sewers washed into homes.	about $2,000

Table 47. Continued

Dates	Time of	Rain Depth (inches)	Area Affected	Damages Done		Estimated Cost
				Lives	Properties	
Apr 24, 1957	5:30 pm to 9:00 pm	3.90	All over town	0	- Business damaged such as feedmills and stores, Light and Power co. - Many chicken were lost	$75 - 100,000
Oct 15, 1957	5:30 pm to morning	7.00	All over town	0	- Country roads and bridges were damaged	No estimate done
Dec 20, 1958	2:30 pm to 5:00 pm	2.07	Part of town	0	- No record on damage	No estimate
Jul 27, 1959	nighttime	5.00	Areas along Banita and La Nana Creek	0	- Minor damages to houses due to wind as a result of storm brought by Hurricane Debra.	No estimate
May 1, 1961	9:30 am to ?	4.47	Part of town	0	- About 1,300 acres of cotton crop damaged. - Power lines were broken by fallen trees struck by lightning associated with Hurricane Carla.	No estimate made
May 1, 1962	night time	3.60	Part of town but areas around creeks were most affected.	0	- Some houses and properties along Banita and La Nana Creek were damaged.	Not less than $100,00 cost of damages done.

Table 47. Continued

Date	Time of Occurrence	Rain Depth (inches)	Areas Affected	Damages Done		Estimated Cost
				Lives	Properties	
Sep 6, 1968	12:00 noon to 3:00 pm	6.00	All over town	0	- Some business centers such as Minimax, South Western Bell Telephone Company and Texas Farm Products were damaged - A home at 1901 South Fredonia was damaged by fallen trees struck by lightning.	At least $550
July 4 and 5, 1972	9:30pm to 11:00 am	7.34	All over town	0	- Power was cut off for 8 hr all over town. - 20-30 trees fell in town and damaged many buildings and power lines.	No estimate made
Mar 24 and 25, 1973	1:00am to 1:00pm	4.68	Lower places of the town	0	- Newly built complex, Rio Del Oro, was heavily flooded washing away construction material and lumber. - 3 mobile homes were washed away while another 9 were damaged.	No estimate

Table 47. Continued

Date	Time of Occurrence	Rain Depth (inches)	Areas Affected	Damages Done		Estimated Cost
				Lives	Properties	
Feb 1 to 5, 1975	3 days of intermittent rain	9.59	All over town	3	- 10 mobile homes were washed away. - All Part Inc. damaged - 75% of Rio Del Oro apartment was flooded. - Both city sewer plants were nonfunctioning. - City lost one boat. - Many automobiles moved, overturned or swept away.	$5.5 million
May 5, 1979	No record	3.09	Streets and Parks	0	- No record of damage	No estimate
May 31, 1979	No record	4.38	Southwest part of the town	0	- No record of damage	No estimate
Jun 9 to 11, 1979	Intermittent rain	4.88	Lower part of town	0	- 125 homes and 75 business and industries were damaged.	$3 million

19-hr period in the history of Nacogdoches. The flood seemed to affect the whole town and vicinity, but no record of flood elevation is available. The maximum flood on La Nana Creek prior to 1970, according to the U.S. Corps of Engineers (1970), occurred on April 24, 1957 in which a 3.5- hr storm of 3.9 inches rainfall raised the flood elevation to 283.8 ft at the bridge of East Starr Avenue. However, there were two occasions (1975 and 1979) when flood elevations were greater than the maximum level recorded in 1957.

A flood occurred during February 1 to 5, 1975 as a result of a 9.59-inch rain falling in the 5-day period. The total rainfall in the first day was 7.63 inches, rapidly raising instantaneous flood stage to 19.85 ft above the datum of the gauging station or 284.11 ft above the mean sea level. Three lives were lost in the flood and the estimated property damage was as high as $5.5 million. It was the most costly flood damage in the history of Nacogdoches or 50 times greater than the flood of 1957.

On June 2, 1979, a rain of 3.60 inches was observed between 1:00 p.m. and 1:00 a.m. with 3.10 inches falling in a 4-hr period. The storm raised flood stage to a record-high of 22.18 ft above the datum at 14:00 p.m, or an elevation of 286.41 ft. This is believed to be the maximum flood of record on La Nana Creek at East Starr Avenue, Nacogdoches. However, there was no report of damage.

The loss of life in the 1975 flood was probably due to panic caused by the sudden rise of flood water at midnight. Although the elevation of the 1979 flood was higher than that of 1975, it occurred at 2:00 p.m.

when people are more alert in response to disasters at daytime than at night. Also zoning of flood plains in the Nacogdoches area along with channelization projects in La Nana and Banita Creeks probably reduced damages of the 1979 flood to a minimum. In general, flood damage is greater if it occurs during cooler months and at night when evapotranspiration is at its minimum, soil is saturated, and flood warning is not as effective. In Nacogdoches, floods seem to occur more in April and May than other months probably due to heavy rainfall occurrences.

Maximum instantaneous discharge levels since 1965 on La Nana Creek are given in Table 48.

Table 48. Maximum Discharge for La Nana Creek, Nacogdoches, Texas, 1965-84

Year	Date	Time (hours)	Discharge (cfs)	Height (ft)
1965	Mar 30	17:00	1800	16.16
66	Apr 25	14:30	2750	17:20
67	Jun 2	02:00	744	12:66
68	Apr 2	11:00	2810	17:25
69	May 7	15:00	2870	17.29
70	May 3	-	472	10.30
1971	Sep 22	19:70	152	8.39
72	Jul 4	-	814	13.23
73	Mar 24	17:30	2500	16.55
74	Jan 24	12:30	1970	15.68
75	Feb 1	00:15	9000	19.85
76	Jul 5	no peak flow	707	9.47
77	Mar 3	-	952	11.39
78	Apr 17	-	1040	12.05
79	Jun 2	14:00	13500	22.18
80	May 16	04:00	2930	17.17
1981	Sep 1	08:00	2450	17.17
82	Apr 17	not known	3470	17.53
83	May 21	21:00	1920	15.87
84	Dec 11	03:00	4330	18.02

Wind

Wind occurs as a result of uneven pressures in the atmosphere. The difference in pressure, however, is not an independent element but a consequence of differences in temperature. Warm air is less dense and it moves upwards while the denser and cooler air moves downwards. Wind is then induced by the motion of the air to equalize the difference in pressure. Horizontal movement, however, is the dominant feature in wind motion; vertical movement is generally smaller in velocity and scale.

Among all the climatic elements, wind is perhaps the most variable element both with time and space. It can be calm at one instant but violent at the other, and shifts its directions frequently. Wind has both positive and negative contributions to our environment. For example, a low velocity wind is important to our environmental comfort, but it may carry air pollutants, bacteria, or diseases from one place to another. A strong wind is very destructive to crops, trees, and structures, but it may be used to generate energy for domestic and industrial purposes. In the field of hydrology and climatology, wind is an important element because of its effects on (1) the occurrence and spatial distribution of precipitation, (2) the errors involved in precipitation sampling, (3) the exchanges of sensible and latent heat at the surface (Chang, *et al.*, 1976), (4) evapotranspiration, and (5) snowmelt.

Wind speed and directions are not routine measurements at the NWS Climatic Station in Nacogdoches. However, wind measurements at ground level (across evaporation pan) are taken at the SFASU Climatic Station.

These measurements at 1.5 feet above the ground are made in conjunction with the evaporation observations. Wind speed at this level is greatly affected by vegetation and microtopography, and therefore, cannot represent the general wind movement in the area. Table 49 gives the mean monthly and annual wind speed at the ground level observed at the SFASU Climatic Station at Nacogdoches between 1965 and 1980. The lowest average monthly wind speed was 1.22 mph in July and August, while the highest was 2.72 mph in March. Generally speaking, wind speed is higher in the cold months and lower in the warm months. The average annual wind speed was 1.83 mph.

For the general wind movement in the area, the observations made 16 feet above the ground by the NWS at the Lufkin Airport, about 25 miles south of Nacogdoches, are cited in this study. Based on the data collected between 1948-56, wind flows predominantly from the south and southeast quadrants in the warmer months and virtually form all directions except west in the cooler months. Chang _et_ _al_. (1980) studied the geographic distribution of temperature in East Texas and stated that winter temperatures in the area are influenced by the frontal systems involving warm air masses from the south and cold air moving from the west and north. The average wind roses observed at the Lufkin Airport, Texas for the period 1948-56 are shown in Figure 23.

Table 49. Mean Ground-Level Wind Velocity (mph) Observed at The SFASU Climatic Station, Nacogdoches, Texas, 1965-80

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1965	2.51	3.10	3.67	2.80	2.47	1.56	1.35	1.36	1.85	1.45	1.60	1.94	2.14
66	2.23	2.68	3.20	2.91	1.94	3.21	1.24	1.27	1.00	1.65	2.29	2.19	2.15
67	3.02	1.82	2.82	2.21	2.32	1.57	1.60	1.51	1.50	2.17	1.90	2.63	2.09
68	2.47	2.20	3.04	2.63	1.89	1.45	1.25	1.16	1.19	1.34	2.28	2.30	1.93
69	2.73	3.50	3.06	2.27	1.54	2.33	1.69	1.47	1.36	2.24	1.93	2.07	2.18
70	2.15	2.61	2.88	2.41	1.74	1.81	1.55	1.53	1.71	2.02	2.68	2.45	2.13
1971	2.38	3.32	2.94	2.49	1.80	-	-	-	-	-	-	-	-
72	-	-	-	-	-	-	-	-	-	-	-	-	-
73	-	-	-	-	-	-	-	-	-	-	-	-	-
74	1.90	1.54	2.24	2.10	0.98	0.88	0.81	0.77	1.73	0.95	1.17	0.98	1.34
75	1.50	2.15	2.00	1.06	0.78	0.75	0.86	1.21	1.58	1.66	1.75	1.87	1.43
76	2.28	2.17	2.33	1.89	1.66	1.24	0.94	1.14	1.06	1.76	1.92	2.02	1.70
77	2.30	2.20	2.55	1.82	1.79	1.57	1.26	1.41	1.39	1.56	2.13	2.28	1.86
78	2.60	2.90	2.71	2.26	1.79	1.48	1.43	1.64	1.58	1.11	1.62	1.98	1.92
79	2.45	2.43	2.42	1.84	1.68	1.32	1.40	0.78	1.55	1.47	1.62	1.58	1.72
80	2.05	2.10	2.24	1.60	0.79	0.77	0.52	0.55	0.62	0.57	0.81	1.13	1.15
Mean	2.33	2.48	2.72	2.16	1.66	1.53	1.22	1.22	1.39	1.53	1.82	2.19	1.83

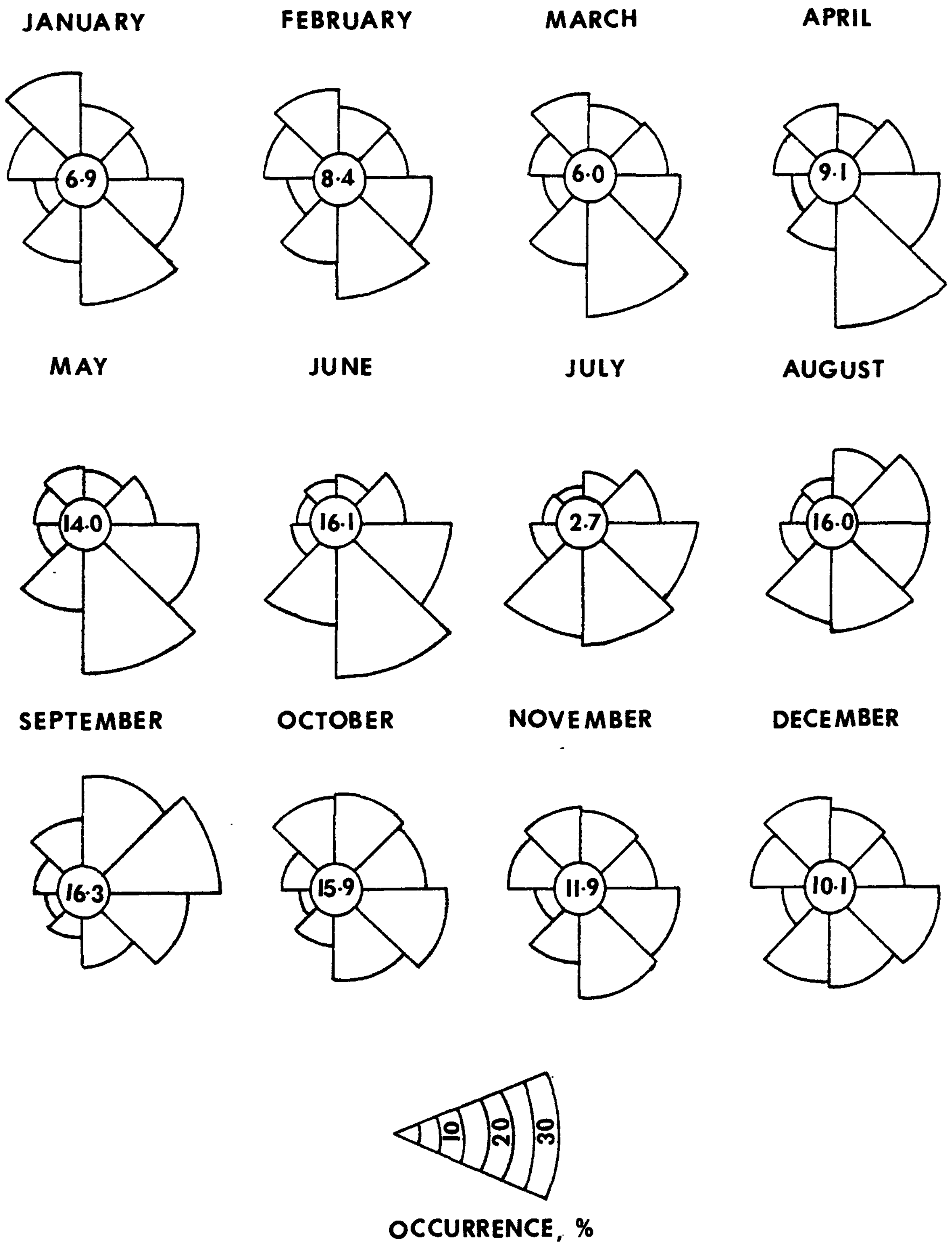

Figure 23. Average monthly wind roses (August 1948 - July 1956) observed at the Lufkin Airport, Texas (% of calms given in the circle, after Chang et al., 1980).

Effects of Climate on Agricultural Production and Forest Growth

The impact of weather and climate on plant growth has been observed throughout history and poses a challenge to science and modern technology. The Babylonians, for example, as early as 2000 B.C. (Miller *et al.*, 1983) showed that weather prediction could save or stabilize some of their crops. Today our interest in weather and plant growth centers on 1) identifying dominant climatic factors affecting plant growth, 2) evaluating the numerical effects of these climatic factors on plant growth, 3) predicting weather conditions in the future, 4) adapting adverse weather conditions either through management of cropping systems or through genetics engineering to produce more resistant varieties, and 5) weather modifications.

Agricultural crops are usually sensitive to environmental and site conditions. This is especially true for seasonal or agronomic plants such as vegetables which may wilt after a summer day's exposure to heat or die when exposed to a sudden frost. The response of most agricultural crops (short term crops such as corn, hay, rice, and cotton) to climatic fluctuation are often measured by production rate in terms of quantity per area basis. Corn has been one of the most popular crops studied in this respect (Palmer, 1964). For perennials, such as fruit trees, the response to climatic fluctuations can be determined by tree ring measurements (Bogue,1905).

Nacogdoches County is largely a forested region with agricultural and pastureland occupying 28% of its area. Agricultural production in the county is usually reported in the Texas County Statistics (TCS) compiled by the Texas Crop and Livestock Reporting Service of the Texas Department of Agriculture (1970-80). An examination of the TCS reports, however, showed that hay is the only crop having a meaningful length of records on production information. Thus, hay was selected as an example to evaluate the possible effects of 18 climatic variables on its annual production per unit area.

The 13 years of data for annual hay production in tons ac^{-1} in Nacogdoches County was collected from reports published by TCS and along with 18 other climatic variables are given in Table 65 of Appendix V. The matrix of simple correlation coefficients for the 19 variables is given in Table 50. Hay production in tons ac^{-1} in Nacogdoches County seems to be negatively correlated with variables relating to temperature (i.e., mean, maximum, minimum, range, degree days) and positively correlated with precipitation variables (i.e., rainfall, rain day). The negative effects of temperature variables probably describe the environmental stress stemming from their association with water supply. However, all the correlation coefficients for precipitation variables were much lower than the temperature variables and are not statistically significant at the 0.01 alpha level.

Of the 18 climatic variables tested, number of days in the summer (May-October) with maximum temperature of 90°F or greater (SDNT) had the highest correlation coefficient ($R = 0.52$) with annual hay production (Hay). Two regression models which employ three climatic variables predicted hay production in Nacogdoches with 65% coefficient of multiple determination are:

Table 50. Simple Correlation Coefficients of Some Climatic Variables and Hay Production Rate (tons ac^{-1})for Nacogdoches, Texas, 1968-80

Var.	Hay	MET	MIT	MAT	RDY	RFL	FFD	TRG	GDD	SRN	DNT	SDNT	SMET	SMIT	SMAT	SRDY	SFFD	SGGD	STRG
Hay	-																		
MET	-.49	-																	
MIT	-.47	.92	-																
MAT	-.51	.93	.85	-															
RDY	.15	-.12	-.08	-.16	-														
RFL	.28	-.33	-.23	-.24	.20	-													
FFD	-.23	.51	.40	.51	-.13	-.07	-												
TRG	-.19	.01	.14	-.04	-.37	.22	.28	-											
GDD	-.39	.94	.87	.94	-.09	-.25	.66	-.02	-										
SRN	.13	-.06	-.00	-.04	.90	.38	-.11	-.24	-.06	-									
DNT	-.50	.35	.25	.37	-.64	-.11	.55	.56	.29	-.53	-								
SDNT	-.52	.44	.33	.46	-.65	-.15	.62	.54	.41	-.57	.99	-							
SMET	-.44	-.11	-.15	-.21	.30	.05	-.31	.10	-.35	.36	.03	-.06	-						
SMIT	-.49	-.06	-.11	-.16	.23	-.07	-.32	.06	-.32	.27	.10	.01	.98	-					
SMAT	-.50	-.01	-.05	-.10	.25	.04	-.27	.12	-.24	.37	.05	-.03	.98	.94	-				
SRDY	.10	.22	.19	.20	.86	-.03	-.03	-.62	.23	.78	-.53	-.51	.10	.09	.09	-			
SFFD	-.35	.46	.52	.42	.08	-.05	.79	.32	.61	.07	.23	.31	-.14	-.21	-.07	.06	-		
SGDD	-.48	.60	.62	.60	-.39	.09	.37	.65	.48	-.15	.76	.75	.09	.11	.17	-.26	.25	-	
STRG	-.39	.29	.15	.23	-.48	-.54	.11	-.16	.26	-.68	-.28	.35	.01	.11	-.01	-.31	.10	-.07	-

Notes: Hay production data (tons ac^{-1}) obtained from "Texas County Agricultural Statistics".
MET = Mean annual temperature (°F); MIT = Annual minimum temperature (°F);
MAT = Annual maximum temperature (°F); RDY = Annual total rain day; RFL= Annual total rainfall
FFD = Annual total frost-free days; TRG = Range in annual mean temperature (°F);
GDD = Growing degree days; SRN = Summer total rainfall; DNT = Annual days with maximum temperatures of 90°F and above; SDNT = Summer days with maximum temperature of 90°F and above;
SMET = Summer mean temperature (°F); SMIT = Summer minimum temperature (°F); SMAT = Summer maximum temperature (°F); SRDY = Summer total rain days; SFFD = summer frost-free days;
STRG = Range in mean temperature during the summer.

$$\text{Hay} = 39.72 - 0.318(\text{MIT}) - 0.016(\text{SDNT}) - 0.214(\text{SMAT}) \qquad (27)$$

$$\text{Hay} = 29.26 - 6.5\times10^{-4}(\text{GDD}) - 0.015(\text{SDNT}) - 0.214(\text{SMAT}) \qquad (28)$$

where GDD is growing degree days, and MIT, SDNT, and SMAT have been defined above. All the four variables retained in the equations are statistically significant at the 0.05 alpha level. Inclusion of precipitation variables in the equations does not improve their predictability.

The effects of climatic variables on tree growth have been studied by several investigators in the Nacogdoches area. Chang and Aguilar (1980) studied the relationship between climate and the radial growth of loblolly pine in the SFA Experimental Forest. Of the 48 climatic variables studied, annual number of days with precipitation (RDY), summer precipitation of previous years (SPP), and difference of mean maximum air temperature between January and July (TMG) can be used to estimate the radial growth of loblolly pine in the following manner:

$$\text{RG} = -0.166 + 0.0401(\text{RDY}) + 0.0020(\text{SPP}) - 0.1356(\text{TMG}) \qquad (29)$$

where RG is the radial growth in mm yr^{-1}, and RDY, SPP, and TMG are in days, mm, and °C, respectively. Equation 29 explains 40% of the total variation of radial growth with a standard deviation of estimate of 1.0 mm. The relationship confirmed an earlier study made by Coile (1935) that radial growth was positively correlated with rainfall and negatively correlated with temperature of the previous year.

From his weekly analyses of the dendrograph records, Amonett (1982) found that temperature, in the absence of soil moisture deficits, was the most important climatic factor influencing growth initiation and termination of loblolly pine. Correlation between growth and climatic variables was stronger for hot and dry seasons; a higher summer air temperature generally limits diameter growth especially when combined with high evaporation.

SUMMARY AND CONCLUSIONS

Climate, the state of the atmosphere surrounding the earth, is never static with respect to time and space. Its changing moods are the dominant force in physical and chemical processes, biological activities, and our routine operations. Climatic conditions have been one of the prime considerations in planning and execution of many activities and operations.

Climatic changes in time and space may be influenced by migration of air between poles and the equator, earth rotation, volcanic eruption, sunspot variations, uneven distribution of land and water, topography, and deforestation. Studies of climatic fluctuations must depend either on historical weather records, or on other alternatives such as cores of lake sediment and ice fields, tree-rings, fossil pollen, or glacial fluctuations, etc.

Official weather observation in Nacogdoches started as early as 1892 and a fairly good record has been maintained since 1901. However, many people are not aware of these valuable records, or do not know where to get them. This study is a compilation of these records which were used to generate climatic variables for convenient use by various professionals and laymen. Moreover, interpretations and statistical analyses were conducted using these long-term records of the National Weather Service along with some supplemental records collected by the U.S. Forest Service and the School of Forestry, Stephen F. Austin State

University for applications in management and planning of natural resources.

Based on the analyses and results discussed above, some of the important findings are given below:

1. Nacogdoches is characterized by a humid climate with hot summer and mild winter. Winds blow predominantly from south and southeast in the summer and virtually from all directions in the winter.

2. The temperature means at Nacogdoches have been relatively stable from period to period during the 80 years of observation. The mean annual temperature for most recent normal period (1951-80) was 65.5°F which is identical to the long term average (1901-80). However, normal annual precipitation seemed to steadily decrease from 48.31 inches of the 3rd normal period (1921-50) of this century to 44.70 inches of the 6th or most recent normal period (1951-80) as opposed to 45.96 inches of the long-term average.

3. On the average, rainfall of equal to or greater than 0.01 inches occurred once every 4 days in Nacogdoches, or 87 rain days each year with a standard deviation of about 17 days. In other words, about a 68% chance that total number of rain days will fall between 70 and 104. Total rain days are usually associated with total precipitation, solar radiation, cloudiness, air temperature, and evapotranspiration. The maximum and minimum number of annual rain days recorded at Nacogdoches was 120 days in 1949 and 50 days in 1917, respectively. The maximum and minimum totals of annual precipitation were 74.27 inches in 1957, and 28.09 inches in 1954. The correlation coefficient (R = 0.234)

between annual rainfall and annual number of rain days for the whole period was low at Nacogdoches.

4. About 19% of annual precipitation (8.92 inches) and 20% of the annual rain days (17.6) occurred in August, September, and October (3 driest months in the year). August not only had the least amount of rainfall (2.54 inches), but also had the highest temperature (82.1°F). The highest monthly precipitation occurred in May, while the largest number of rain days was in January.

5. The expected 100-year maximum daily rainfall is 8.24 inches while the observed maximum daily rainfall during the 80-year period was 14.22 inches on June 28, 1902, a size equivalent to a return period of 150 years.

6. As expected, wet spells frequency in Nacogdoches decrease with an increase in length. The most frequently occurring wet spell was one day which comprised 32% of the total while the longest wet spell was 16 days (January 16 to February 4, 1957). Wet spells are usually longest in the winter and shortest in the fall.

7. There were 22,015 dry days observed during the 80-year period; 46% had durations of 3 days or less and only 2% had durations of 21 days or more. The longest annual dry spells ranged from 13 to 53 days with an average of 22 days yr^{-1}. There is a 22.5% chance that the observed longest dry spell will be equal to or greater than 30 days. Dry days are more critical during the months of high air temperatures.

8. Based on 18 years of complete hourly precipitation records (1955-80), the average number of storms at Nacogdoches was 108 per year

or about 1 storm in every 3.4 days. The hourly precipitation showed that February had the most (10.4% of annual total) and July (5.6%) the least. About 30% of the total or 34 storms occurred in the 3 coldest winter months, while 19% or 21 storms occurred in 3 hottest months. About 64% of storms had durations of no more than 2 hours. Summer storms are characterized with high intensity, short duration, less frequent, and are dominated by convective storm activity. Winter storms are mainly frontal systems of long duration and low intensity.

9. The log-normal distribution model seems to fit annual total events better than normal distribution while extreme events fit well with the Gumbel distribution model.

10. Daily maximum temperature of 90°F or greater and daily minimum temperature of 32°F or less occurred in every year of the entire record. The average number of such maximum and minimum temperature were 82 days and 35 days, respectively. The hottest temperature ever recorded at Nacogdoches was 110°F which occurred on June 28, 1918 and August 31, 1954, while the coldest temperature was -4.0°F on January 18, 1930.

11. The derived parameters based on some temperature indices such as frost-free days (FFD), growing-degree days (GDD), cooling-degree days (CDD), and heating degree days (HDD) are useful information for management of natural resources. To the farmers and foresters, the GDD and FFD are as important as HDD and CDD to the heating companies. The earliest day of freezing temperature ever recorded at Nacogdoches was October 8 of 1952 and the latest was April 15 of 1933 which represents

an absolute frost-free period of 175 days. On the average, however, the first frost occurred on November 11th and last on March 15th or a frost-free period of 240 days. For the recent normal (1951-80), the annual mean GDD for base temperatures 40, 50, and 60 were 9,318, 6,126, and 353, respectively.

12. Based on nearby 1980-85 data, the annual average relative humidity (RH) in the Nacogdoches area was 72.1%, with the highest in May and June while the lowest in August and September. Daily RH often reached 100% in the morning and dropped to 40% in the late afternoon.

13. Floods occurred about once every 3 years in Nacogdoches area. The maximum flood stage which was 286.41 ft above mean sea level occurred at 2:00 pm on June 2, 1979, 2.61 ft higher than the maximum stage reported by the Corps of Engineers earlier.

14. The runoff coefficient(streamflow/precipitation) for La Nana Creek is 0.30, about 3 times greater than the average for the state of Texas.

15. Flow duration patterns in the La Nana Creek may have been significantly altered by rapid urbanization in the last 9 years. Annual runoff in the Creek has been estimated using annual precipitation and annual temperature in a multiple regression analysis with a coefficient of multiple determination (R) ranging from 0.63 to 0.84, depending on period in question (i.e., 1965-74, 1975-83, or 1965-83).

16. Hay production per unit area and the radial growth of loblolly pines in Nacogdoches County are affected by number of days in the summer with maximum temperature of 90°F or greater, summer average maximum

temperatures, annual minimum temperature, rain days, summer precipitation of the previous year, and the mean maximum temperature range between July and January. These climatic variables can be used to delineate the variations in hay production or loblolly pine growth from year to year.

LITERATURE CITED

Aguilar, J. R. 1979. Climatic Fluctuation and its Effects on the Growth of Loblolly Pine at Nacogdoches, Texas. M.S.F. Thesis, Stephen F. Austin State University, Nacogdoches, Texas. 79pp.

Amonett, C. A. 1982. Relationships Between Weekly and Radial Growth of Mature Loblolly Pines and Selected Climatic Variables in East Texas. MSF Thesis, School of Forestry, Stephen F. Austin State University, Nacogdoches, Texas. 115pp.

Bach, W. 1983. Carbon Dioxide/Climate Threat: Fate or Forebearance? In "Carbon Dioxide Current Views and Developments in Energy/Climate Research." W. Bach et al., (ed). D. Reidel Publ. Co. Dordrecht. pp. 461-510.

Bayce, A. E. 1979. Man's Influence on Climate - Chairman's Summary. In "Water, Air, and Soil Pollution." Billy M. McCormac (ed). D. Reidel Publ. Co. 12(5):5-6.

Berger, A. 1984. Book Reviews on "Carbon Dioxide and Climate: A Second Assessment," and " The Long-term Impact of Increasing Atmospheric Carbon Dioxide Levels." EOS, Trans. Amer. Geophys. Union 65(1):54.

Bogue, E. E. 1905. Annual Rings of Tree Growth. Monthly Weather Review. 33:250-251

Bomar, G. W. 1983. Texas Weather. Univ. Texas Press, Austin. 265pp.

Brooks, E. E. P. 1928. Influence of Forests on Rainfall. Quart. Jour. Royal Meteorological Society, London 54:1-13.

Brown, A. A. and K. P. Davis. 1952. Fire Weather. In "Forest Fire, Control, and Use." McGraw-Hill Brook Co., pp. 51-66.

Bruce, J. P. and R. H. Clark. 1966. Introduction to Hydrometeorology. Pergammon Press, New York. 319pp.

Budyko, M. J. 1969. The Effect of Solar Radiation Variations on the Climate of the Earth. Tellus 21:611-619.

Buffo, J., L. J. Fritschen, and J. L. Murphy. 1972. Direct Solar Radiation on Various Slopes from 0° to 60°N Latitude. Forest Service Research Paper. PNW-142, Portland, Oregon. 74pp.

Carr, J. T., Jr. 1966. Texas Droughts, Causes, Classification, and Prediction. Texas Development Board, Report No. 30, 58 pp.

Chang, M. 1973. Effects of Topography and Site Exposure on Precipitation Distribution in Mountainous Areas. Ph. D. Dissertation. West Virginia University, Morgantown. 150pp.

Chang, M. and R. Lee. 1973. Do Forests Increase Precipitation? West Virginia Forestry Notes, West Virginia University, No. 2. pp.16-20.

Chang, M., R. Lee, and W. H. Dickerson. 1976. Adequacy of Hydrologic Data for Application in West Virginia. Water Research Institute West Virginia University. Bulletin 7. 145pp.

Chang, M. and G. J. R. Aguilar. 1980. Effects of Climate and Soil on the Radial Growth of Loblolly Pine (Pinus taeda L.) in a Humid Environment of Southeastern U.S.A. Elsevier Scientific Co. Amsterdam. Forest Ecology and Management. 3:141-150.

Chang, M. and D. G. Boyer. 1980. Distribution of Extreme Snowfall in West Virginia. Proc. 37th Eastern Snowfall Conf. Ontario, Canada - June 5-6, 1980.

Chang, M., S. P. Watters, and J. R. Aguilar. 1980. Geographical Analyses of Temperature and Precipitation in Forested East Texas. Texas Jour. Sci. 12(3):200-206.

Chang, M. 1981. Characteristics Hourly Rainfall at Nacogdoches, Texas. Texas Jour. Sci. 13(2,3,4):131-138.

Chang, M. 1982. Laboratory Notes: Forest Hydrology. School of Forestry, Stephen F. Austin State University, Nacogdoches, Texas. 203pp.

Chang, M. and J. C. Ting. 1986. Applications of the Universal Soil Loss Equation to Various Forest Conditions. In "Monitoring to Direct Changes in Water Quality Series", Proc. of the Budapest Sym. IAHS Publ. No. 157, pp.165-174.

Changnon, S. A. Jr. and D. M. A. Jones. 1972. Review of the Influences of The Great Lakes on Weather. Water Resources Res. 8(2):360-371.

Cheo, K. H. 1946. Ecological Changes due to Thinning Red Pine. Jour. For. 44:360-371.

Chow, V. T. 1951. A General Formula for Hydrological Frequency Analysis. Trans. Amer. Geophys. Union 32:321-237.

Chow, V. T. 1954. The Log-probability Law and its Engineering Applications. Proc. Amer. Soc. Civil Engrs. 80(536):1-25.

Chow, V. T. 1964. Handbook of Applied Hydrology. McGraw-Hill Book Co. Inc. New York.

Clark, D. L. 1982. Commentary on H. Flohn: Climate Change and Ice-Free Artic Ocean. W.C. Clark (ed). Carbon Dioxide Review:1982. Oxford Univ. Press, New York. pp.181-184.

Coile, T. S. 1935. The Effect of Rainfall and Temperature on the Annual Radial Growth of Pine in the South. M.F. Thesis. Yale School of Forestry. 72pp.

Cox, H. J. and J. H. Armington. 1914. The Weather and Climate of Chicago. The Geographical Society of Chicago. Bull. No. 4. Chicago Press, Chicago, Illinois. 375pp.

Eagleman, J. R. 1967. Pan Evaporation, Potential and Actual Evapotranspiration. Jour. Applied Meteo., 6(June):482-8.

Etkins, R. and E. S. Epstein. 1982. The Rise of Global Mean Sea Level as an Indication of Climatic Change. Science 215(4530):287-289.

ESSA, Environmental Data Service. 1962. Monthly Normals of Temperature, Precipitation, and Heating Degree Days:1931-1960. Washington, D.C.

FAO. 1978. Forest Influence: An Introduction to Ecological Forestry. FAO Forestry Series No. 9. Rome. 307pp.

Frank, E. C. and R. Lee. 1966. Potential Solar Beam Irradiation on Slopes:Tables for 30° to 50° Latitudes. USDA Forest Service Research Paper. RM-18. Fort Collins, Colorado. 116pp.

Geiger, R. 1965. The Climate Near the Ground. Harvard University Press, Cambridge, Massachussets. 611pp.

Granger, O. E. 1978. Toward Predictability in Agroclimatology. FAO of the United Nations 30(121):11-17.

Griffiths, J. F. 1966. Aplied Climatology - An Introductions. Oxford University Press, Ely House, London, W.I. 118pp.

Gumbel, E. J. 1954. Statistical Theory of Extremes Values and Some Practical Applications. National Bureau of Applied Mathematical Series. No. 33.

Haltom, R. W. 1880. The History of Nacogdoches County, Texas. Jenkins Publication Co. The Pemberton Press, Austin, Texas. 74pp.

Humphreys, W. J. 1940. Physics of the Air. Dover, New York. 676pp.

Hursh, C. R. 1948. Local Climate in the Copper Basin of Tennessee as Modified by the Removal of Vegetation. USDA Circular 774, 38pp.

Kerr, R. A. 1981. Mount St. Helens and a Climate Quandry. Science 21(4479):371-374.

Keyes, J. 1974. Harnessing the Sun - To Heat Your House. Morgan and Morgan Publishers. 61pp.+ Appedices A1 to G4.

Kopec, R. J. 1975. Introduction to the Second Carolina Geographical Symposium. In "Atmospheric Quality and Climatic Change." Richard J. Kopec (ed). Dept. of Geography, Univ. North Carolina. pp.1-3.

Landsberg, H. E. 1968. Physical Climatology. DuBois, Pennsylvania. Gray Publ. Co. 446pp.

Landsberg, H. E. 1970. Climates and Urban Planning. In "Urban Climates." WMO, Geneva. Technical Paper 141:364-374.

Larkin, T. J. and G. W. Bomar. 1983. Climatic Atlas of Texas. Texas Dept. of Water Resources. 151 pp.

Lee, R. J. 1978. Forest Microclimatolgy. Columbia University Press, New York. 276pp.

List, R. J. 1971. Smithsonian Meteorological Tables. Sixth Edition. Smithsonian Institution Press, City of Washington. 265pp.

Lowry, R. L., Jr. 1934. Excessive Rainfall in Texas. Texas Dept. of Reclamation, Bull. 25, 149 pp.

Maddox, R. A. and C. F. Chappell. 1979. Flash Flood Defenses. Water Spectrum 11(2):1-8.

Manabe, S. and R. Stouffer. 1980. Sensitivity of a Global Climatic Model to an Increase of CO_2 Concentration in the Atmosphere. Jour. Geophys. Res. 85:5529-5554.

Manabe, S. and R. T. Wetherald. 1980. On the Distribution of Climatic Change Resulting from Increased in CO_2 Content of the Atmosphere. Jour. Atmos. Sci.37:99-118.

Manabe, S.; R. T. Wetherald; and R. J. Stouffer. 1981. Summer Dryness due to an increased of Atmosphere Concentration. Climate Change. 3:347-386.

Maxwell, R. S. and J. W. Martin. 1970. A Short History of Forest Conservation in Texas 1880-1940. School of Forestry, Stephen F. Austin State University, Nacogdoches, Texas. 60pp.

Miller, A.; J. C. Thompson; R. E. Peterson; and D. R. Haragan. 1983. Elements of Meteorology. Charles E. Merill Publ. Co., Columbus, Ohio. 417pp.

Munn, R. E. 1970. Biometeorological Methods. Academic Press, New York. 336pp.

National Weather Service. 1961. Rainfall Frequency Atlas of the Untied States. Tech. Paper 40, 61pp.

Orton, R. 1964. The Climate of Texas and the Adjacent Gulf Waters. U.S. Weather Bureau, Washington, D.C. 195pp.

Orton, R. B. 1975. Climates of the United States - Texas. In "Climatology of the United States." No.41-60.

Palmer, W. C. 1964. Climate Variability and Crop Production. Center for Agric. Econ. Dev., Washington, D.C. CAED 20:173-188.

PMB. 1984. CO_2 Pulses. EOS, Trans. Amer. Geophys. Union 65(2):9.

Portig, W. H. 1962. Atlas of the Climate of Texas. Bureau of Engineering Research. The University of Texas at Austin. 33pp.

Rakmanov. V. V. 1966. Role of Forests in Water Conservation. Translated from Russian. IPST Inst. No.1688. 192pp.

Reeves, H. C. 1976a. Rain or Shine .. It's Recorded at SFASU. Daily Sentinel 4(12):A8.

Reeves, H. C. 1976b. Climate, Weather Have Much in Common but Differ in Emphasis. Daily Sentinel 4(13):13A.

Reeves, H. C. 1976c. Daily Rainfall Varies Greatly Since '65. Daily Sentinel 4(14):A6.

Reeves, H. C. 1976d. Nacogdoches Humid but Pleasant Since '65. Daily Sentinel 4(15):A2.

Reeves, H. C. (In Press). Local Rainfall and Temperature: How Much Do They Vary? Weatherwise.

Rice, W. 1976. Agriculture. In "The Bicentennial Commerative History of Nacogdoches." Nacogdoches Jaycees (eds). pp.156-161.

Schneider, S. H. and L. Temkin. 1977. Water Supply and Future Climate. In "Climate, Climate Change, and Water Supply." National Acad. Sci., Washington D.C. pp.25-33.

SMIC. 1971. Inadvertent Climate Modification. Report of the Study of Man's Impact on Climate. The Massachussetts Inst. of Tech. Cambridge, Mass. 308pp.

Spurr, S. H. and B. V. Barnes. 1980. Forest Ecology. John Wiley and Sons, Inc. New York. 687pp.

Stuiver, M. 1980. Oxygen and Carbon Isotope Ratios of Freshwater Carbonates as Climatic Indicators. Jour. Geophys. Res. 75:5247-5257.

Taylor, D. C. 1984. Increasing Volcanic Activity - Why? The Plain Truth 49(5):23-26.

Texas Department of Agriculture. 1970-80. Texas of County Statistics. Compiled by Texas Crop and Livestock Reporting Service, Annual Reports 1970-80 issues.

Texas Water Development Board. 1968. Symposium on Consideration of Some Aspects of Storms and Floods in Water Planning. Austin,Texas. Report No.33. 163pp.

Thom, E. C. 1957. A New Concept for Cooling Degree Days. Reprint from 'Air Conditioning, Heating and Ventilating. June 1957. 8pp.

Tombaugh, L. W. 1979. Man's Global Activities as they Impact Climate: An Overview. In "Water, Air, and Soil Pollution." Billy McCormac (ed). D. Reidel Publ. Co. Dordrecht-Holland. pp.35-36.

Thompson, L. 1973. Cyclic Weather Patterns in the Middle Latitudes. Jour. Soil and Water Conserv. 28:87-89.

Tilling, R. I. 1982. Volcanic Cloud May Alter Earth's Climate. National Geographic 162(5):672-675.

Tucker, J. E. and J. Griffiths. 1965. Precipitation Distribution and the Probability of Receiving Selected Amounts over Texas. Texas Agric. Expt. Sta. MP-794. 82pp.

U.S. Corps of Engineers. 1956. Snow Hydrology. North Pacific Div., Portland, Oregon. 437pp.

U.S. Corps of Engineers. 1970. Bayou La Nana and Banita Creeks, Interim Flood Hazard Information. 11pp.

U.S. Department of Commerce. 1968. Climatic Atlas of the United States. Washington, D.c. 80pp.

U.S. Water Resources Council. 1967. A Uniform Technique for Determining Flood Flow Frequencies. Washington D.C. 13pp.

Warner, J. 1968. A Reduction in Rainfall Associated with Smoke from Sugarcane Fires - An Inadvertant Weather Modification. Jour. Appl. Meteor. 7:247-251.

Willet, H. C. 1961. Pattern of Solar Climatic Relationships. Annals New York Acad. Sci. 95:89-166.

Willet, H. C. 1976. Do Recent Climatic Trend Portend an Imminent Ice Age? In "Atmospheric Quality and Climatic Change." Richard Kopec (ed). North Carolina Geographic Symp. Studies in Geography No. 9 Univ. of North Carolina at Chapel Hill. pp.4-36.

Wollum, C. A. 1964. Notes from a Study of the Microclimatology of the Washington, D.C. Area for the Winter and Spring Seasons. Weatherwise 17:262.

Wollum, C. A. and N. L. Canfield. 1968. Washington Metropolitan Area Precipitation and Temperature Patterns. ESSA Tech. Memo. WBTM-ER 28. Garden City, New York. 32pp.

Woodcock, A. H. and R. H. Jones. 1970. Rainfall Trends in Hawaii. Jour. Appl. Meteor. 9:690-696.

World Meteorological Organization (WMO). 1967. A Note on Climatological Normals. Tech. Note No. 84, Switzerland. 19pp.

World Meteorological Organization (WMO). 1979. Project on Research and Monitoring of Atmosphere CO_2 Report No.2, Geneva.

APPENDIX I
(History of the NWS Climatic Station at Nacogdoches, Texas)

Table 51. The History of Weather Observations made by the National Weather Service at Nacogdoches, Texas.

Date	Observers	Geographic Location			Instruments	Site, Exposure, and Others
		Long. (deg)	Lat. (deg)	Elev. (ft)		
Jan 1, 1892-Nov 30, 1892	L. Westfall	94.60W	31.50N	271	Max. and min. thermometer in standard C.R. shelter and standard 8-inch rain gauge.	1. The shelter was placed on one-story post office bldg, Nacogdoches. 2. The rain gauge was in the open space about 50 ft away from the bldg. 3. The station was inactive from Dec. 1, 1892 to Sept. 1899. 4. Time of observation was 7:00 a.m.
Oct 1899-Apr 30, 1903	H. H. Cooper	"	"	"	"	Station was again inactive from May 1 - 31, 1903.
Jun 1, 1903-1905	Mary Hofmann (H. H. Cooper)	"	"	"	"	The station remained where it was.
1906-Winter, 1925	"	94.63W	31.60N	350	"	1. The station was moved from the post office to Ms. Hofmann's residence at 425 W. Main St.(on hilltop about ½ mile west of post office), Nacogdoches, in 1906. 2. The shelter and the rain-

Table 51. Continued.

Date	Observers	Geographic Location			Instruments	Site, Exposure, and Others
		Long. (deg)	Lat. (deg)	Elev. (ft)		
						gauge were placed at the observer's front yard about 60 ft away (north) from the house
Winter, 1925-Jan 31, 1945	Mary Hofmann (Mr. Helpinstill)	94.63W	31.60N	350	Mercurial barometer was added in Nov. 20, 1936.	1. The shelter was moved to the observer's open porch (south) in Winter, 1925. It was placed on a pedestal (wired to post), 3 ft from porch floor, 19 ft from ground, and 4 ft from roof with doors opened southwest.
Feb 1-8, 1945	Harry F. Morris	"	"	"		The shelter and the barometer were repaired.
Feb 9, 1945-Apr 17, 1948	Harry F. Morris (R. C. Strahan)	94.65W	31.65N	375	Anemometer, 24"x72" sunken galvanized iron evaporation pan. A pyschrometer was added.	1. The station was moved to Texas Agr. Exp. Sta. Substation #1, on Feb 9, 1945, about 3.1 miles north of post office (2.7 miles from the former site). 2. The station was placed on the open field about 60 ft from nearest higher ob-

Table 51. Continued.

Date	Observers	Geographic Location			Instruments	Site, Exposure, and Others
		Long. (deg)	Lat. (deg)	Elev. (ft)		
						ject. The shelter was raised to a 4 ft stand with concrete base. 3. Time of observation changed from 7:00 a.m. to 9:00 a.m. since Feb 9, 1945. 4. Anemometer was badly out.
Apr 17, 1948- Apr 21, 1948	E. Muckleroy	94.65W	31.65N	375	Max. and min. thermometer in C.R. Shelter and rain gauge.	Same as that during Feb. 9, 1945 to April 17, 1948.
Apr 22, 1948- Dec 31, 1950	G. F. Middlebrook,Jr.	94.63W	31.60N	435	"	1. Station was moved from Texas Agr. Exp. Sta. to KSFA Radio Station at 2107 North St. in Apr 22, 1948, about 1.7 miles ENE of Post Office (2 mi SE of former station). 2. Shelter and rain gauge was 50 ft away from nearest object of higher height. 3. Hours of observation changed to 7:00 a.m. since April 22, 1948.

Table 51. Continued.

Date	Observers	Geographic Location			Instruments	Site, Exposure, and Others
		Long. (deg)	Lat. (deg)	Elev. (ft)		
Jan 1, 1951– May 31, 1951	Clarence C. Taylor	"	"	"	"	"
Jun 1, 1951– Dec 31, 1952	Leroy N. Morgan	"	"	"		"
Jan 1, 1953- Sept 30, 1953	Julius A. Seegers	94.63W	31.60N	435	Anemometer, evaporation pan, psychrometer, max. and min. thermometer, barometer, and raingauge	Townsend support for thermometer was installed from transmitter tower. Exposure for raingauge was poor due to surrounding buildings.
Oct 1, 1953- Dec 13, 1955	W. C. Frouts	94.63W	31.60N	435	Evaporation pan, anemometer, max. and min. thermometer,barometer, and rain gauge.	1. Shelter was moved from radio station tower to remote control room of KSFA radio station. Shelter was moved 10 ft away from building and mounted on a post at 8 ft above ground. 2. Trees were abundant in all directions.
Dec 14, 1955- Aug 17, 1959	Royce C. Smith	"	"	"	Microbarograph and hygrothermograph added.	The 8-inch guage was place upon an 8-ft. post for better exposure.

Table 51. Continued.

Date	Observers	Geographic Location			Instruments	Site, Exposure, and Others
		Long. (deg)	Lat. (deg)	Elev. (ft)		
Aug 18, 1959- Mar 10, 1961	Danny V. Speagle	"	"	"	"	"
Mar 11, 1961 July 13, 1961	Douglas G. Hurd	"	"	"	"	"
Jul 14, 1961 -1962	Ross Markwadt	94.50W	31.62N	308	Microbarograph and hygrothermograph removed on Nov 28, 1962.	1. KSFA Radio Station moved to 3rd Fl. Savings and Loan Bldg., 114 S. Pecan Nacogdoches about 600 ft or 0.1 mile NE of Post Office and 1.1 miles from previous station since March 2, 1962.
1962-1963	Dehl Wright (Bob Dunn)	"	"	"	Evaporation pan, anemometer, max. and min. thermometer, barometer, rain gauge.	Observation time changed from 8:00 a.m. to 9:00 a.m. since Jan 1, 1963.
1964-1965	Charles Coleman (Jay Broddy)	"	"	"	"	
1965-1968	Bob Dunn (Jerry Vardeman)	"	"	"	"	1. Equipment moved 140 yd. NW of former location on Feb. 5, 1965 to get better

Table 51. Continued.

Date	Observers	Geographic Location			Instruments	Site, Exposure, and Others
		Long. (deg)	Lat. (deg)	Elev. (ft)		
						exposure for the raingauge. 2. Observation time changed from 9:00 a.m. to 8:00 a.m. since Oct 8, 1965.
1968-1972	Larry Gunter	"	"	"	"	"
1972-1973	Bob Dunn (Jerry Vardeman)	94.50W	31.62N	308	Evaporation pan, anemometer, max. min. thermometer, barometer, and rain gauge.	Observation discontinued in early 1973 due to poor exposure as the trees near the station grew.
Oct 1973 to present	Bob Dunn	94.63W	31.60N	435	Hygrothermograph, max, and min. thermometer, standard raingauge, anemometer, barometer,	1. KSFA radio station moved to 3007 E. Martinsville Rd. (1.9 mi ENE) in Oct 1973. The climatic station was also moved together. 2. Observation resumed since Oct 1973.

Note: Names in parentheses served as occasional substitutes.

APPENDIX II
(Solar Climatic Data)

Table 52. The U.S. Central Standard Time of Sunrise and Sunset at Nacogdoches, Texas (Lat., 31:36N; Long., 94:40W).

Date	January		February		March		April		May		June	
	AM	PM	AM	PM	AM	PM	AM	PM	AM	PM	AM	PM
1	7:18	5:26	7:12	5:53	6:46	6:17	6:08	6:38	5:34	6:58	5:14	7:19
2	7:19	5:27	7:11	5:54	6:45	6:17	6:06	6:39	5:33	6:59	5:14	7:19
3	7:19	5:28	7:11	5:55	6:44	6:18	6:05	6:39	5:32	7:00	5:14	7:20
4	7:19	5:29	7:10	5:56	6:43	6:19	6:04	6:40	5:31	7:00	5:14	7:20
5	7:19	5:29	7:09	5:57	6:41	6:20	6:03	6:41	5:30	7:01	5:13	7:21
6	7:19	5:30	7:08	5:58	6:40	6:20	6:01	6:41	5:29	7:02	5:13	7:21
7	7:19	5:31	7:08	5:59	6:39	6:21	6:00	6:42	5:28	7:02	5:13	7:22
8	7:19	5:32	7:07	5:59	6:38	6:22	5:59	6:43	5:27	7:03	5:13	7:22
9	7:19	5:33	7:06	6:00	6:37	6:22	5:58	6:43	5:27	7:04	5:13	7:23
10	7:19	5:33	7:05	6:01	6:35	6:23	5:57	6:44	5:26	7:05	5:13	7:23
11	7:19	5:34	7:04	6:02	6:34	6:24	5:55	6:45	5:25	7:05	5:13	7:24
12	7:19	5:35	7:03	6:03	6:33	6:25	5:54	6:45	5:24	7:06	5:13	7:24
13	7:19	5:36	7:03	6:04	6:32	6:25	5:53	6:46	5:24	7:07	5:13	7:24
14	7:19	5:37	7:02	6:05	6:30	6:26	5:52	6:47	5:23	7:07	5:13	7:25
15	7:19	5:38	7:01	6:05	6:29	6:27	5:51	6:47	5:22	7:08	5:13	7:25
16	7:19	5:39	7:00	6:06	6:28	6:27	5:49	6:48	5:22	7:09	5:13	7:25
17	7:18	5:39	6:59	6:07	6:27	6:28	5:48	6:49	5:21	7:09	5:13	7:26
18	7:18	5:40	6:58	6:08	6:25	6:29	5:47	6:49	5:20	7:10	5:13	7:26
19	7:18	5:41	6:57	6:09	6:24	6:29	5:46	6:50	5:20	7:11	5:14	7:26
20	7:18	5:42	6:56	6:10	6:23	6:30	5:45	6:51	5:19	7:11	5:14	7:26
21	7:17	5:43	6:55	6:10	6:22	6:31	5:44	6:51	5:19	7:12	5:14	7:27
22	7:17	5:44	6:54	6:11	6:20	6:31	5:43	6:52	5:18	7:13	5:14	7:27
23	7:17	5:45	6:53	6:12	6:19	6:32	5:42	6:53	5:18	7:13	5:14	7:27
24	7:16	5:46	6:52	6:13	6:18	6:33	5:41	6:53	5:17	7:14	5:15	7:27
25	7:16	5:47	6:51	6:13	6:17	6:33	5:40	6:54	5:17	7:15	5:15	7:27
26	7:15	5:48	6:49	6:14	6:15	6:34	5:39	6:55	5:16	7:15	5:15	7:27
27	7:15	5:49	6:48	6:15	6:14	6:35	5:38	6:56	5:16	7:16	5:16	7:28
28	7:14	5:50	6:47	6:16	6:13	6:35	5:37	6:56	5:16	7:16	5:16	7:28
29	7:14	5:50	6:47	6:16	6:11	6:36	5:36	6:57	5:15	7:17	5:16	7:28
30	7:13	5:51			6:10	6:37	5:35	6:58	5:15	7:18	5:17	7:28
31	7:12	5:52			6:09	6:37			5:15	7:18		

Table 52. Continued.

DATE	July		August		September		October		November		December	
	AM	PM	AM	PM	AM	PM	AM	PM	AM	PM	AM	PM
1	5:17	7:28	5:34	7:15	5:54	6:43	6:12	6:04	6:35	5:30	7:00	5:15
2	5:17	7:28	5:35	7:14	5:55	6:42	6:13	6:03	6:35	5:29	7:01	5:15
3	5:18	7:28	5:36	7:13	5:55	6:40	6:13	6:01	6:36	5:28	7:02	5:15
4	5:18	7:27	5:36	7:13	5:56	6:39	6:14	6:00	6:37	5:27	7:03	5:15
5	5:19	7:27	5:37	7:12	5:56	6:38	6:15	5:59	6:38	5:26	7:03	5:15
6	5:19	7:27	5:38	7:11	5:57	6:36	6:15	5:58	6:39	5:26	7:04	5:15
7	5:20	7:27	5:38	7:10	5:58	6:35	6:16	5:56	6:40	5:25	7:05	5:15
8	5:20	7:27	5:39	7:09	5:58	6:34	6:17	5:55	6:40	5:24	7:06	5:15
9	5:21	7:27	5:40	7:08	5:59	6:33	6:17	5:54	6:41	5:23	7:07	5:15
10	5:21	7:26	5:40	7:07	5:59	6:31	6:18	5:53	6:42	5:23	7:07	5:15
11	5:22	7:26	5:41	7:06	6:00	6:30	6:19	5:52	6:43	5:22	7:08	5:16
12	5:22	7:26	5:42	7:05	6:01	6:29	6:19	5:50	6:44	5:22	7:09	5:16
13	5:23	7:26	5:42	7:04	6:01	6:27	6:20	5:49	6:45	5:21	7:09	5:16
14	5:23	7:25	5:43	7:03	6:02	6:26	6:21	5:48	6:46	5:20	7:10	5:17
15	5:24	7:25	5:43	7:02	6:02	6:25	6:22	5:47	6:46	5:20	7:11	5:17
16	5:24	7:25	5:44	7:01	6:03	6:24	6:22	5:46	6:47	5:19	7:11	5:17
17	5:25	7:24	5:45	7:00	6:04	6:22	6:23	5:45	6:48	5:19	7:12	5:18
18	5:26	7:24	5:45	6:59	6:04	6:21	6:24	5:44	6:49	5:18	7:12	5:18
19	5:26	7:23	5:46	6:58	6:05	6:20	6:24	5:42	6:50	5:18	7:13	5:18
20	5:27	7:23	5:47	6:57	6:05	6:18	6:25	5:41	6:51	5:18	7:14	5:19
21	5:27	7:22	5:47	6:56	6:06	6:17	6:26	5:40	6:52	5:17	7:14	5:19
22	5:28	7:22	5:48	6:55	6:07	6:16	6:27	5:39	6:53	5:17	7:15	5:20
23	5:29	7:21	5:49	6:54	6:07	6:14	6:27	5:38	6:53	5:16	7:15	5:20
24	5:29	7:21	5:49	6:52	6:08	6:13	6:28	5:37	6:54	5:16	7:16	5:21
25	5:30	7:20	5:50	6:51	6:08	6:12	6:29	5:36	6:55	5:16	7:16	5:22
26	5:31	7:19	5:50	6:50	6:09	6:10	6:30	5:35	6:56	5:16	7:16	5:22
27	5:31	7:19	5:51	6:49	6:10	6:09	6:31	5:34	6:57	5:16	7:17	5:23
28	5:32	7:18	5:52	6:48	6:10	6:08	6:31	5:33	6:58	5:15	7:17	5:23
29	5:32	7:17	5:52	6:46	6:11	6:07	6:32	5:32	6:59	5:15	7:17	5:24
30	5:33	7:17	5:53	6:45	6:12	6:05	6:33	5:31	6:59	5:15	7:18	5:25
31	5:34	7:16	5:53	6:44			6:34	5:31			7:18	5:25

Table 53. Duration of Daylight at Nacogdoches, Texas. (Latitude, 31:36N; Longitude, 94:40W).

Date	Month					
	January	February	March	April	May	June
1	10:08	10:41	11:31	12:30	13:24	14:05
2	10:08	10:43	11:32	12:33	13:26	14:05
3	10:09	10:44	11:34	12:34	13:28	14:06
4	10:10	10:46	11:36	12:36	13:29	14:06
5	10:10	10:48	11:39	12:37	13:29	14:08
6	10:11	10:50	11:40	12:40	13:33	14:08
7	10:12	10:51	11:42	12:42	13:34	14:09
8	10:12	10:52	11:44	12:43	13:36	14:09
9	10:14	10:54	11:45	12:45	13:37	14:10
10	10:14	10:56	11:48	12:47	13:39	14:10
11	10:15	10:58	11:50	12:50	13:40	14:11
12	10:16	11:00	11:52	12:51	13:41	14:11
13	10:17	11:01	11:53	12:53	13:42	14:11
14	10:18	11:03	11:56	12:55	13:43	14:12
15	10:19	11:04	11:58	12:56	13:45	14:12
16	10:20	11:06	11:59	12:59	13:46	14:12
17	10:20	11:08	12:01	13:01	13:47	14:13
18	10:22	11:10	12:04	13:02	13:50	14:13
19	10:23	11:12	12:05	13:02	13:51	14:12
20	10:24	11:14	12:07	13:06	13:52	14:12
21	10:26	11:15	12:09	13:07	13:53	14:13
22	10:27	11:17	12:11	13:09	13:55	14:13
23	10:28	11:19	12:13	13:11	13:55	14:13
24	10:30	11:21	12:15	13:12	13:57	14:12
25	10:31	11:22	12:16	13:14	13:58	14:12
26	10:33	11:25	12:19	13:16	13:59	14:12
27	10:34	11:27	12:21	13:17	14:00	14:12
28	10:36	11:29	12:22	13:19	14:00	14:12
29	10:36		12:25	13:19	14:02	14:12
30	10:38		12:27	13:19	14:03	14:11
31	10:40		12:28		14:03	

Note: All numbers on the left of colons are in hours, and the right, in minutes.

Table 53. Continued.

Date	Month					
	July	August	September	October	November	December
1	14:11	13:41	12:49	11:52	10:55	10:15
2	14:11	13:40	12:47	11:50	10:54	10:14
3	14:10	13:40	12:45	11:48	10:52	10:13
4	14:09	13:37	12:43	11:46	10:50	10:12
5	14:08	13:35	12:42	11:44	10:48	10:12
6	14:08	13:33	12:39	11:43	10:47	10:11
7	14:07	13:32	12:37	11:40	10:45	10:10
8	14:07	13:30	12:36	11:38	10:44	10:09
9	14:06	13:28	12:34	11:37	10:42	10:08
10	14:05	13:27	12:32	11:35	10:41	10:08
11	14:04	13:25	12:30	11:33	10:39	10:08
12	14:04	13:23	12:28	11:31	10:38	10:07
13	14:03	13:22	12:26	11:29	10:35	10:07
14	14:02	13:20	12:24	11:27	10:33	10:07
15	14:01	13:19	12:23	11:25	10:33	10:06
16	14:01	13:17	12:21	11:24	10:31	10:06
17	14:01	13:15	12:18	11:22	10:30	10:06
18	13:58	13:14	12:17	11:20	10:28	10:06
19	13:57	13:12	12:15	11:18	10:27	10:05
20	13:56	13:10	12:13	11:16	10:25	10:05
21	13:55	13:09	12:11	11:14	10:22	10:05
22	13:56	13:07	12:09	11:12	10:21	10:05
23	13:54	13:05	12:07	11:11	10:20	10:05
24	13:53	13:03	12:05	11:09	10:18	10:05
25	13:53	13:01	12:04	11:07	10:17	10:06
26	13:50	13:00	12:01	11:05	10:16	10:06
27	13:48	12:58	11:59	11:03	10:15	10:06
28	13:46	12:56	11:57	11:02	10:13	10:06
29	13:45	12:54	11:56	11:00	10:11	10:07
30	13:44	12:52	11:53	10:58	10:11	10:07
31	13:42	12:51		10:55		10:07

Note: All numbers on the left of colons are in hours, and the right, in minutes.

APPENDIX III
(Precipitation Data)

Table 54. Monthly and Annual Precipitation (in inches) at Nacogdoches, Texas, 1901-1980).

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1901	1.83	5.11	3.51	5.79	2.25	5.41	4.62	2.18	5.17	4.50	2.59	2.19	45.15
02	2.51	3.60	5.21	2.91	4.54	14.22	5.77	0.48	10.03	5.57	6.19	2.04	63.02
03	4.86	6.70	5.05	1.23	2.98	2.99	7.52	3.01	0.15	5.98	0.37	5.17	46.01
04	1.86	3.86	3.23	4.41	2.71	4.06	5.54	3.56	4.68	0.33	0.88	8.03	43.15
05	3.19	3.98	5.62	8.88	8.99	5.21	9.43	3.69	2.74	1.78	10.16	5.86	69.53
06	4.85	1.73	1.63	4.26	1.54	4.65	7.91	1.68	1.74	4.12	1.91	3.60	39.62
07	2.96	2.84	2.15	4.56	9.07	0.21	2.33	0.15	0.63	6.44	10.39	4.55	46.28
08	2.31	6.37	3.40	4.12	2.87	0.92	2.46	3.92	5.59	0.12	2.98	1.56	36.62
09	0.44	3.24	2.01	3.93	4.79	3.90	4.33	1.15	1.23	2.89	0.85	8.40	37.16
10	1.56	9.76	0.89	4.22	8.52	4.92	2.14	1.84	0.94	2.27	3.41	0.00	40.47
1911	0.00	2.93	3.89	9.62	0.61	0.52	11.17	2.09	0.53	1.84	5.00	10.51	48.71
12	1.96	3.57	7.18	7.46	9.44	4.66	0.64	2.30	0.00	0.91	0.80	6.49	45.41
13	4.04	3.98	4.63	4.42	5.01	1.61	1.59	1.45	12.39	4.46	2.94	6.14	52.66
14	1.22	5.03	4.24	4.08	8.96	1.25	0.26	5.22	1.83	0.67	4.11	8.90	42.91
15	4.61	3.19	2.30	2.82	2.87	0.75	4.61	7.85	1.53	1.21	3.03	2.44	37.21
16	7.66	0.58	0.81	5.28	10.74	2.43	3.57	0.76	0.67	1.27	3.75	3.18	40.70
17	3.79	4.26	1.91	3.27	3.25	0.77	5.83	0.06	3.74	1.38	0.69	0.11	29.06
18	1.45	0.92	1.81	6.99	1.67	2.63	2.28	3.31	3.87	4.50	6.55	3.02	39.00
19	4.16	4.49	2.48	1.29	6.96	8.72	1.82	5.49	2.42	9.65	4.06	1.50	53.06
20	6.93	1.17	5.33	4.94	4.57	3.06	4.74	6.83	1.47	3.51	4.66	5.69	52.90
1921	3.12	2.16	7.28	6.30	1.71	5.90	7.10	3.21	3.22	1.05	0.61	4.20	45.86
22	6.36	6.10	8.35	11.66	5.05	2.74	2.11	3.41	1.03	0.70	5.26	3.88	57.65
23	3.75	6.20	6.22	9.90	4.92	4.20	1.42	1.84	8.80	2.71	5.07	9.38	64.41
24	5.01	5.16	4.35	5.71	9.46	3.07	0.06	0.00	1.97	0.05	2.14	2.75	39.73
25	5.77	1.44	1.00	1.10	1.85	0.28	3.02	0.63	2.63	11.14	8.79	0.93	38.58
26	3.65	0.60	8.39	4.95	2.40	6.62	7.35	1.76	0.50	0.68	3.50	7.61	48.01
27	1.27	2.25	7.10	6.13	3.54	7.47	0.89	0.56	2.49	3.65	1.22	4.42	40.99
28	0.82	3.38	5.66	2.46	2.92	4.38	5.15	0.94	1.08	2.31	5.53	3.03	37.66
29	3.76	2.63	3.00	4.67	12.73	3.28	3.98	0.89	1.47	1.55	7.69	7.39	53.06
30	6.45	4.46	2.35	0.48	6.66	2.36	1.74	2.45	4.57	5.48	5.53	3.17	45.70

Table 54. Continued

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1931	3.63	5.73	3.52	3.85	2.96	0.78	1.99	6.41	0.22	2.10	4.17	9.77	45.13
32	11.61	9.50	3.42	2.42	2.37	0.95	1.43	2.36	0.92	1.32	2.98	6.85	46.13
33	1.90	4.32	5.50	4.09	5.50	0.60	12.72	0.60	1.77	0.73	0.35	7.4	45.48
34	8.01	4.86	6.68	6.38	4.39	0.93	1.28	0.96	3.64	1.88	9.45	4.55	53.01
35	3.03	2.25	2.37	7.23	15.60	2.73	1.61	0.50	3.44	2.83	5.65	5.53	52.77
36	1.77	1.72	1.02	3.04	4.89	0.40	4.09	3.55	1.00	2.90	2.79	5.01	32.18
37	7.75	2.70	3.91	5.11	1.44	3.86	3.15	3.34	2.96	3.65	4.18	5.13	47.18
38	4.13	2.47	5.88	5.32	2.46	3.60	3.81	0.43	0.56	1.72	4.64	2.56	37.59
39	5.62	6.89	1.86	2.64	4.20	1.38	2.88	0.94	0.58	2.55	3.84	9.05	42.43
40	1.85	8.09	2.44	6.67	3.96	5.78	0.80	7.46	2.53	0.67	18.85	8.87	67.97
1941	2.25	4.95	3.65	1.61	6.66	7.69	7.56	2.46	5.89	12.79	3.47	3.70	62.68
42	2.58	1.51	3.04	5.51	4.23	5.74	2.00	4.09	3.40	1.02	1.94	3.67	38.73
43	2.94	1.90	2.15	0.64	2.46	1.37	3.89	2.80	2.03	2.61	3.19	4.39	30.37
44	6.38	5.49	6.57	5.23	12.57	3.60	1.93	5.15	2.07	0.76	7.74	8.89	66.38
45	5.99	4.68	4.65	5.69	4.80	4.11	6.94	2.51	4.48	6.74	1.62	4.46	56.67
46	7.40	5.55	7.78	3.17	8.80	3.14	4.29	4.75	2.92	1.82	9.14	3.51	62.27
47	4.45	2.06	5.07	4.49	5.96	3.29	2.28	0.40	0.80	1.19	5.08	5.17	40.24
48	3.95	4.20	2.28	5.16	4.10	0.99	3.11	0.76	1.02	1.04	5.98	4.30	36.89
49	7.16	3.37	4.36	5.05	5.47	2.47	3.23	1.40	3.27	13.24	0.59	5.57	55.18
50	5.19	6.51	1.72	5.34	10.61	6.09	4.78	0.72	8.84	1.09	2.37	4.32	58.30
1951	3.84	3.56	4.31	1.53	1.40	3.59	2.77	0.46	5.45	0.64	3.06	6.30	36.91
52	2.79	3.16	3.71	5.12	5.34	1.01	4.21	0.82	0.94	0.00	6.05	6.02	39.17
53	3.09	4.14	7.57	8.71	11.82	5.41	6.15	3.21	1.94	3.05	3.21	6.02	64.32
54	3.59	0.82	1.15	2.68	6.04	1.00	1.08	0.48	0.54	5.30	3.34	2.07	28.09
55	3.80	4.57	2.02	3.06	5.95	0.80	2.07	5.28	1.47	2.46	1.25	2.41	35.14
56	3.51	4.59	2.68	3.79	3.06	4.98	0.39	3.75	0.43	0.98	3.58	2.72	34.46
57	5.69	3.99	5.95	13.96	6.33	4.40	3.23	1.35	6.74	9.97	9.73	2.93	74.27
58	4.71	2.40	3.39	4.24	3.68	6.97	1.24	4.21	11.35	1.51	2.59	2.13	48.42

Table 54. Continued

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
59	0.87	4.87	1.84	5.33	1.79	3.40	7.71	3.55	3.77	3.83	3.11	6.53	46.60
60	3.56	5.33	1.52	3.41	1.03	8.27	4.41	5.92	3.55	4.08	7.39	7.73	56.20
1961	8.12	5.57	5.53	1.18	1.79	5.50	3.07	1.19	7.49	2.84	3.89	8.06	54.23
62	4.04	1.59	1.82	4.89	4.84	4.95	4.13	1.20	6.64	2.10	4.77	3.81	44.78
63	1.09	2.91	0.66	4.64	1.00	6.75	2.61	2.15	1.90	0.04	4.63	2.53	30.91
64	5.23	2.40	3.56	7.56	3.41	2.04	0.10	2.43	4.27	1.91	2.21	3.39	38.51
65	3.93	4.61	5.13	1.87	9.87	5.24	3.02	1.44	5.54	0.29	2.55	6.72	50.21
66	7.54	4.44	1.75	8.56	7.16	2.38	1.58	6.05	2.50	2.58	1.08	5.36	50.98
67	0.99	3.74	2.01	2.01	4.78	2.94	4.66	1.30	0.69	2.36	0.64	5.29	31.41
68	7.28	3.36	2.68	10.57	8.25	9.21	3.46	1.38	8.00	1.68	6.46	6.24	68.57
69	1.70	6.66	8.46	7.32	7.03	0.76	2.69	1.56	2.44	3.53	2.35	4.28	48.78
70	1.57	4.64	4.74	2.70	4.79	1.08	0.00	3.22	2.98	6.91	1.71	1.74	36.08
1971	0.42	2.23	0.55	0.62	5.07	1.74	3.75	3.05	4.26	3.73	3.94	5.52	34.88
72	4.85	0.91	3.52	4.02	1.46	5.08	7.65	1.81	3.25	8.59	3.77	3.76	48.67
73	5.42	1.81	7.66	6.46	2.90	7.04	1.72	4.39	6.67	6.22	4.19	4.88	35.11
74	9.75	1.41	1.24	4.26	5.42	2.22	4.32	5.54	8.62	2.76	7.08	3.43	56.05
75	2.71	2.80	4.48	3.74	6.77	7.66	1.38	1.95	1.58	4.59	4.31	2.60	54.47
76	1.43	2.11	4.22	2.80	6.04	4.98	3.44	0.55	2.42	2.38	2.09	4.95	37.41
77	3.53	2.30	4.07	3.22	1.18	3.49	1.24	3.80	2.36	1.40	2.81	2.91	32.31
78	6.66	2.61	2.58	3.57	2.77	2.03	1.09	1.57	2.14	--	5.40	3.50	35.15*
79	7.20	5.85	--	4.28	--	5.01	6.24	3.24	4.87	5.02	7.02	3.57	63.61*
80	4.01	1.89	3.75	4.48	6.18	1.59	1.58	2.29	1.76	2.26	3.49	1.23	34.51
Mean	4.03	3.91	3.81	4.72	5.13	3.68	3.60	2.54	3.24	3.14	4.21	4.78	45.96
Most	11.61	9.76	8.46	13.96	15.60	14.22	12.72	7.85	12.39	13.24	18.85	10.51	74.27
Least	0	0.44	0.55	0.48	0.61	0.21	0	0	0	0.35	0	0	28.09

* Values not counted in calculating means

Table 55. Monthly and Annual Number of Rain Days at Nacogdoches, Texas, 1901-80

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann.
1901	4	8	6	3	6	7	8	4	5	2	5	3	61
02	8	6	9	5	4	1	16	2	9	4	11	4	79
03	8	14	14	1	6	8	12	5	1	6	1	5	81
04	7	6	7	7	3	8	9	4	5	2	3	4	65
05	8	6	10	11	9	8	10	3	4	4	4	11	88
06	4	2	7	8	6	9	7	7	5	4	6	7	72
07	7	4	4	9	13	1	6	1	1	9	6	3	64
08	3	9	5	5	6	4	5	9	6	1	9	4	66
09	3	5	3	5	6	6	3	4	3	2	5	10	55
10	3	5	3	4	7	7	6	4	4	4	5	--	52*
1911	0	5	4	11	3	3	12	4	1	3	3	11	60
12	3	4	9	9	6	7	3	5	0	3	4	9	62
13	6	5	6	4	6	4	4	5	17	11	3	8	79
14	3	11	9	6	15	3	5	--	--	--	--	--	52*
15	7	7	4	10	3	2	4	10	4	4	6	7	68
16	9	1	1	6	7	7	10	4	5	1	5	5	61
17	9	7	4	7	6	1	8	1	4	1	2	1	50
18	4	5	6	8	3	4	3	9	5	8	9	7	71
19	7	10	7	5	14	17	8	7	6	14	8	6	109
20	14	6	8	6	6	12	11	14	5	7	8	11	109
1921	7	7	7	14	3	9	9	5	8	3	4	10	86
22	17	9	12	11	13	9	9	8	5	4	8	10	115
23	8	11	13	14	10	7	5	5	9	5	7	1	112
24	8	10	7	9	10	6	1	0	5	1	5	9	71
25	9	5	5	2	5	3	7	4	7	14	14	6	81
26	11	3	14	5	8	10	8	8	4	5	6	11	93
27	6	6	10	7	6	11	7	3	5	5	4	6	76
28	2	11	8	11	3	9	9	2	8	7	8	6	84
29	11	13	10	6	14	4	6	2	4	3	11	6	90
30	11	11	7	3	9	2	3	8	10	7	7	9	87
1931	11	10	8	5	6	4	10	9	1	5	13	16	98
32	16	10	5	5	5	4	4	7	6	5	6	18	91
33	6	10	7	7	6	2	13	4	6	3	3	10	77
34	12	7	9	9	8	1	8	3	8	3	9	12	89
35	6	6	6	11	8	10	10	5	6	3	10	7	88
36	6	7	11	8	10	2	7	5	6	7	6	10	85
37	22	9	13	4	2	8	7	8	6	5	8	10	102
38	11	3	10	7	5	8	10	6	5	4	6	11	86
39	15	14	7	7	8	10	7	10	3	4	8	10	103
40	4	12	3	12	8	9	7	11	3	5	12	11	97

Table 55. Continued

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann.
1941	8	8	9	9	12	11	10	11	12	9	9	9	117
42	7	6	8	10	10	12	8	10	4	7	7	9	98
43	7	5	13	4	8	9	11	4	10	2	5	10	88
44	13	13	8	10	12	7	6	9	6	2	11	10	107
45	8	9	16	9	5	10	11	9	11	10	8	10	116
46	15	10	9	5	16	8	7	9	4	9	13	10	115
47	18	9	10	9	10	6	5	6	3	3	13	9	101
48	15	17	12	8	7	4	7	8	2	3	14	4	101
49	15	11	10	11	5	8	16	8	6	15	1	14	120
50	18	12	8	11	11	6	9	4	7	4	2	3	95
1951	9	8	7	8	3	7	5	3	12	3	6	13	84
52	6	9	9	7	9	5	7	2	4	0	10	11	79
53	7	14	12	7	10	2	11	8	2	1	9	12	95
54	13	3	8	4	7	3	4	3	4	9	3	6	67
55	11	7	5	8	7	7	12	8	7	2	5	3	82
56	7	8	7	6	7	11	1	3	1	6	7	8	72
57	14	11	7	16	11	11	8	4	9	5	17	5	118
58	6	8	11	12	8	9	4	7	13	7	9	6	100
59	6	14	5	9	3	10	9	10	9	5	4	11	95
60	12	7	6	5	3	8	8	14	5	7	9	13	97
1961	9	10	11	4	4	11	13	7	5	4	9	10	97
62	13	8	8	8	3	10	3	5	7	5	8	9	87
63	5	7	3	7	4	8	10	6	8	1	9	6	74
64	11	10	7	8	6	7	1	5	10	4	9	10	88
65	5	11	13	3	16	9	5	6	6	1	5	10	90
66	9	9	3	8	10	5	4	10	7	5	7	11	88
67	2	7	5	3	7	2	10	4	6	3	5	16	76
68	13	12	9	11	6	11	7	5	9	4	9	8	104
69	7	8	9	8	9	2	5	4	5	7	4	6	74
70	6	8	10	5	6	6	0	7	10	9	3	8	78
1971	3	7	7	5	7	8	7	8	11	7	4	12	86
72	10	4	9	5	7	5	10	10	10	7	8	11	96
73	10	7	12	10	8	11	6	12	9	10	7	7	109
74	18	4	6	3	7	8	5	14	11	4	15	9	104
75	11	8	10	8	12	13	6	8	6	7	5	7	101
76	5	5	14	7	9	5	8	6	8	5	5	9	86
77	6	5	6	8	3	4	5	8	6	3	5	8	67
78	13	9	9	5	8	2	4	4	10	--	7	6	77*
79	15	13	--	11	--	7	9	11	6	2	7	7	88*
80	10	7	15	6	12	1	2	3	9	5	5	3	78
Mean	9.0	8.1	8.2	7.4	7.5	6.7	7.2	6.3	6.3	5.0	7.0	8.6	87.4

* Value not included in calculating means

Table 56. The Occurrence of Wet Spell in Different Lengths (in days) at Nacogdoches, Texas, 1901-80

Year	1	2	3	4	5	6	7	8	9	10	11...16		Total Rainday
1901	23	11	4	1	0	0	0	0	0	0	0	0	61
02	28	10	1	2	1	1	0	0	1	0	0	0	79
03	23	11	6	1	0	0	2	0	0	0	0	0	81
04	28	10	3	2	0	0	0	0	0	0	0	0	65
05	40	6	8	3	0	0	0	0	0	0	0	0	88
06	33	8	5	2	0	0	0	0	0	0	0	0	72
07	28	9	2	3	0	0	0	0	0	0	0	0	64
08	24	11	5	1	0	0	0	0	0	0	0	0	66
09	27	11	2	1	0	0	0	0	0	0	0	0	55
10	24	5	3	1	0	0	0	0	0	0	0	0	52[1]
1911	25	7	3	0	0	1	0	0	0	0	0	0	60
12	38	6	4	0	0	0	0	0	0	0	0	0	62
13	34	8	3	2	1	0	0	0	0	0	1	0	79
14	13	5	4	3	1	0	0	0	0	0	0	0	52[2]
15	29	11	1	2	0	1	0	0	0	0	0	0	68
16	32	11	1	1	0	0	0	0	0	0	0	0	61
17	28	11	0	0	0	0	0	0	0	0	0	0	50
18	30	16	3	0	0	0	0	0	0	0	0	0	71
19	23	18	2	4	2	0	0	0	2	0	0	0	109
20	39	15	7	3	0	0	1	0	0	0	0	0	109
1921	27	10	9	3	0	0	0	0	0	0	0	0	86
22	28	13	4	6	1	1	2	0	0	0	0	0	115
23	28	12	10	3	1	1	1	0	0	0	0	0	112
24	26	12	4	1	1	0	0	0	0	0	0	0	71
25	21	13	5	2	1	1	0	0	0	0	0	0	81
26	40	12	4	3	1	0	0	0	0	0	0	0	93
27	29	13	7	0	0	0	0	0	0	0	0	0	76
28	26	16	4	2	0	1	0	0	0	0	0	0	84
29	34	10	6	3	0	1	0	0	0	0	0	0	90
30	39	13	1	3	0	0	1	0	0	0	0	0	87
1931	33	19	1	1	4	0	0	0	0	0	0	0	98
32	23	17	5	1	3	0	0	0	0	0	0	0	91
33	33	9	3	3	1	0	0	0	0	0	0	0	77
34	22	14	6	1	1	2	0	0	0	0	0	0	89
35	27	16	7	2	0	0	0	0	0	0	0	0	88
36	25	19	3	2	1	0	0	0	0	0	0	0	85
37	36	16	4	1	1	1	1	0	0	0	0	0	102
38	34	7	7	1	0	1	1	0	0	0	0	0	86
39	20	20	3	2	4	1	0	0	0	0	0	0	103
40	19	18	16	2	1	1	0	0	0	0	0	0	97

Table 56. Continued

Year	1	2	3	4	5	6	7	8	9	10	11...16		Total Rainday
1941	35	13	11	3	1	1	0	0	0	0	0	0	117
42	29	21	4	2	0	0	1	0	0	0	0	0	98
43	25	16	5	4	0	0	0	0	0	0	0	0	88
44	33	10	6	2	2	3	0	0	0	0	0	0	107
45	27	17	9	3	2	1	0	0	0	0	0	0	116
46	25	15	6	6	1	1	1	0	0	0	0	0	115
47	30	13	6	1	3	0	0	1	0	0	0	0	101
48	35	10	5	2	2	1	1	0	0	0	0	0	101
49	23	16	6	4	2	1	1	1	0	0	0	0	120
50	32	15	3	1	0	2	0	1	0	0	0	0	95
1951	23	21	5	1	0	0	0	0	0	0	0	0	84
52	18	22	2	0	1	1	0	0	0	0	0	0	79
53	19	15	4	4	2	0	0	1	0	0	0	0	95
54	19	10	4	2	0	0	0	1	0	0	0	0	67
55	33	6	3	3	2	1	0	0	0	0	0	0	82
56	22	10	3	3	0	0	0	0	1	0	0	0	72
57	25	10	8	1	2	2	1	0	0	0	0	1	118
58	28	11	4	2	1	1	0	1	0	0	1	0	100
59	34	12	5	3	2	0	0	0	0	0	0	0	95
60	25	11	8	2	1	1	1	0	0	0	0	0	97
1961	24	18	1	4	1	1	1	0	0	0	0	0	97
62	25	11	6	1	1	1	1	0	0	0	0	0	87
63	30	11	2	0	2	1	0	0	0	0	0	0	74
64	20	20	8	1	0	0	0	0	0	0	0	0	88
65	19	15	2	3	2	1	1	0	0	0	0	0	90
66	38	15	4	2	0	0	0	0	0	0	0	0	88
67	24	12	4	4	0	0	0	0	0	0	0	0	76
68	31	8	9	4	1	0	0	0	1	0	0	0	104
69	32	8	3	3	1	0	0	0	0	0	0	0	74
70	30	17	2	2	0	0	0	0	0	0	0	0	78
1971	27	17	7	1	0	0	0	0	0	0	0	0	86
72	29	16	3	3	1	0	0	0	1	0	0	0	96
73	32	17	8	3	0	0	1	0	0	0	0	0	109
74	30	16	6	6	0	0	0	0	0	0	0	0	104
75	34	9	7	3	2	1	0	0	0	0	0	0	101
76	38	14	2	1	2	0	0	0	0	0	0	0	86
77	22	11	3	2	0	1	0	0	0	0	0	0	67
78	32	8	4	3	1	0	0	0	0	0	0	0	77[1]
79	22	10	5	2	3	1	0	0	0	0	0	0	88[3]
80	22	12	6	0	0	0	2	0	0	0	0	0	78
Total	2210	1020	375	169	70	37	21	6	6	0	2	1	6910

[1] Base on 11-months [2] Base on 7-months [3] Base on 10-months

Table 57. The Occurrence of Dry Spell in Different Lengths at Nacogdoches, Texas, 1901-80

Year	Length of Dry Spell, Days																					
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16-20	21-25	26-30	31-35	36-40	>40	Total
1901	3	5	6	1	2	4	3	3	2	2	1	1	1			4	2					304
02	5	10	2	6	3	1	3	5	3	1		2			2	1				1		286
03	3	9	3	5	6	5	1			2		1	1		1	2			2			284
04	9	4	5	3	3	2	4		2	2	2			1		3	2	1				301
05	13	9	11	5	5	3	1	1	2	2		1		2		2	1					277
06	9	7	3	8	1	3	6	2	2			2	3			2			1			293
07	6	8	5	4		4		3		2		1		1	1	2	2		1	1		301
08	8	6	6	2	4	3	2	2	1	3	1	1	1	2	2	2		1				300
09	6	1	9	4	3	3	1	1	1		1	2	3		1	1	5					310
10	6	4	3	3	5	2	2	1	2	2	1	3	1			2		2				282
1911	12	6	7	4	3		2	1	1	2	1		1	1		2		1		1	1	305
12	6	9	7	6	1	6	2		3	2	1	1	1	2		1					1	304
13	3	7	6	8	7	4	3	1	3	1			2			2	1					286
14	4	4	5	3	2	1	1		2	1		1				2	1					160
15	7	6	5	4	4		3	6			2	1			2	4	1					297
16	5	9	2	7	3		3	2	2	3	1	2			1	2	1			1		305
17	4	7	2	2	3	5	3	1		4	1		1		1	2	1	1		1		315
18	4	6	6	6	7	5	3			5	1	1	1	1		3						294
19	10	7	6	2	5	4	2	3	1		1	3	1	1		2						256
20	15	10	6	12	5	4	3	2	1	1		2	1		1							258
1921	12	3	4	6	4	5	3	1	1	2	1	2	1	1		3						279
22	9	11	10	8	2	3	2	3	1		2	1		1		2						250
23	12	13	7	7	2	4		2	2	3	3	1					1					253
24	6	7	7	4	4	3	3	2	1	1	1					2			2	1		295
25	5	7	4	4	2	4	1		2	5	2	2	2	1		1	1					284
26	7	18	7	8	3	6	4	2	1	1			2	1		2	1					272

Table 57. Continued

Year	Length of Dry Spell, Days																					Total
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16-20	21-25	26-30	31-35	36-40	>40	
1927	10	4	4	4	8	5	2	4			4	1	1	1	1		1					289
28	9	6	6	4	4	3	4	3	3	2	2	1		1		1	1					282
29	12	7	9	5	7	4	1		3	1		1	1			3	1					275
30	9	8	10	10	5	4	2	2	1	1		1	1			2	1					278
1931	12	9	9	8	2	4	2	2	4		1	1		1		1	1					267
32	10	10	4	3	4	1	4	1	1	3	2	1	1		2	1	1					275
33	7	9	7	5	3	2	2	3	1	2	3				1	2	2					288
34	6	7	4	4	5	5	2	1	4	1	1	2		1	2		1					276
35	11	8	6	6	3	1	1	3	4		2	1		2		1	2					277
36	9	6	4	7	4	1	5	4	3	2	1		1	1		1	1					281
37	16	18	5	5	3	2	2	1		1				2	1	2		1				263
38	6	10	5	4	2	4	5	5	1	2	1		2	1		2						279
39	9	13	5	7	1	2		2	4	1	1		2			3						262
40	7	9	7	5	2	3	1	6	3			2		1	1	1	1					269
1941	14	13	9	9	3	3	5	1		1	2	2										248
42	11	7	9	6	7	5	1	1	3	2	3			1		1						267
43	9	6	6	9	3	2	4	2	1	3	1	1			1	3	1					277
44	10	14	10	7	4	1	1	1	1				1	2	1	2						259
45	14	7	11	9	3	3	2	1	1	3	3	1	1									249
46	12	15	5	2	5	4	3	2	3	1						2		1				250
47	9	13	6	8	2	5	1	1	1		2	1	1	1	1	1				1		264
48	16	11	5	4	4	3	1	3	1	3			3				1	1				265
49	15	6	9	6	4	5	2	1	1		1	1					1					245
50	10	10	6	1	7	4	4	2		6		1	1	1		1						270

Table 57. Continued

Year	Length of Dry Spell, Days																					Total
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16-20	21-25	26-30	31-35	36-40	>40	
1951	9	7	8	4	5	5	2	2	1			3			2	2	1					281
52	6	5	6	4	4	4	2	4	1	2		1			2	2					1	287
53	7	7	8	4	7	3			1	2	2	1	2	1			1	1				270
54	3	7	2	3	1		2		5	3	2	1	1	1	2	3	1					298
55	9	5	5	4	7	2	6	2	3			1	1				1	2				283
56	8	3	3	7	4		1	3	1	3	1					5		2				294
57	6	9	15	4	4	3	2			2	2		1	1		2						247
58	2	9	9	6	2	6	2	6	1	2	1		1	1								265
59	11	8	8	5	5	6	5	4		1	1				1	1						270
60	10	9	4	2	3	3	3		4	3	1	1	1	2		2						269
1961	6	11	4	5	8	5	2		1	2	1	1	3		1	1						268
62	6	7	6	6	4	2	4	1	3		1	1	1	2		2	1					278
63	6	6	2	5	7	1	3	3	4	3	1		1		1	3						291
64	7	7	10	6	5	2	2	1	3	1	1		1		1	1	1	1				278
65	12	2	4	4	3	5	4		1		1	1	1		1	4		1				275
66	13	11	8	5	6	4	2	1		1		1	2	3	1	1						277
67	4	4	8	6	2	4	4	2	2	1			2	1		3		1				289
68	9	11	6	5	7	6	2		3	1	1		1	1		2						262
69	10	5	3	5	3	3	3	4	1		4	1	2			2			2			291
70	6	10	9	7	5	4	3	2	2			1	1			1		2				287
1971	13	7	9	4	3	4	2	1	1	1		2	1	2		2		1				279
72	10	10	5	8	6	4	1	3		2	2		1			3						270
73	12	11	8	9	5	6	3	2		4	1		1									256
74	14	7	12	7	2	2	2	3	4			1			3	1						261
75	9	12	8	5	6	4	3	3	1	1			1			2	1					264

Table 57. Continued

Year	Length of Dry Spell, Days																					Total
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16-20	21-25	26-30	31-35	36-40	>40	
1976	10	8	6	8	7	4	3	4	1	1	1	4		1								280
77	3	8	7	2		6	1	1	3	2	1			3		2	1				1	298
78	8	7	3	11	5	3	1	2	2	1	2			1	1					1		257
79	10	9	5	3	3	3		3	1	2	1					2		1				215
80	5	9	3	5	6	2	2	1	1	1		1	1		1	2	1	2				288
Total	686	650	499	429	319	261	180	154	129	125	78	77	68	52	39	134	44	25	8	8	4	2,2015

APPENDIX IV
(Thermal Climatic Data)

Table 58. Mean Monthly and Annual Temperature for Nacogdoches, Texas, 1901-80

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1901	51.7	46.4	57.4	61.0	71.0	79.2	82.7	83.1	73.4	65.5	55.7	46.0	64.4
02	44.9	45.1	54.1	67.9	76.2	78.8	79.9	83.3	73.1	66.3	60.9	48.5	65.4
03	46.7	48.6	58.7	63.5	69.8	70.9	78.8	80.4	71.9	63.0	53.6	47.1	62.5
04	44.3	53.9	65.7	62.3	71.6	77.2	79.1	81.2	77.0	68.4	55.7	49.5	65.3
05	42.9	39.6	63.2	64.3	75.2	78.9	78.5	81.3	76.3	66.0	59.6	41.9	64.0
06	49.3	46.4	54.3	65.7	71.9	77.6	79.5	79.1	76.5	60.6	57.2	53.9	64.3
07	--	51.8	68.1	60.2	68.6	77.5	81.9	83.2	77.4	67.3	52.2	51.0	--
08	49.0	48.9	65.8	67.2	72.7	78.4	80.1	78.0	74.3	62.5	57.3	53.1	65.8
09	52.5	51.8	59.2	63.6	70.6	77.5	83.7	83.9	76.7	67.6	63.3	43.3	66.1
10	50.1	46.0	63.1	62.3	70.4	75.7	80.5	82.8	78.3	67.8	57.3	--	--
1911	56.6	56.1	61.7	63.9	71.0	80.8	79.7	81.1	80.9	67.1	51.6	47.5	66.4
12	44.4	43.9	53.0	64.0	72.0	74.1	82.5	80.7	75.9	67.7	52.8	45.7	63.1
13	48.5	46.1	54.4	62.5	70.8	75.5	82.2	82.1	71.8	63.3	62.5	48.0	64.0
14	52.4	45.3	54.7	63.8	71.9	80.5	84.6	--	--	--	--	--	--
15	43.3	50.7	46.6	63.3	72.8	81.1	80.7	78.1	76.5	66.6	58.8	49.9	64.1
16	52.6	50.3	60.0	62.8	71.6	79.3	82.5	82.0	76.3	66.6	55.3	50.5	65.8
17	50.9	52.1	57.4	62.9	66.0	79.2	84.3	83.7	76.2	62.6	54.3	45.0	64.6
18	39.7	55.1	64.4	64.1	74.0	83.1	83.4	82.5	72.8	68.9	54.1	54.2	66.3
19	47.5	51.4	60.6	66.7	70.8	77.3	82.2	82.9	78.4	73.8	60.6	48.4	66.8
20	48.1	54.4	58.8	65.9	75.8	78.6	82.4	79.7	79.6	66.0	52.2	47.1	65.8
1921	53.7	52.2	63.7	60.4	71.6	79.2	81.8	83.0	81.9	66.1	63.1	55.5	67.6
22	46.1	56.3	58.1	67.5	74.2	79.7	81.8	81.9	79.6	67.0	58.3	55.8	67.2
23	56.6	50.6	52.7	64.1	70.1	79.2	81.8	83.3	76.5	65.5	53.7	53.6	65.7
24	43.6	48.2	53.0	65.6	68.4	80.2	82.7	86.1	75.2	67.0	57.1	45.8	64.4
25	43.8	52.7	57.6	66.4	68.7	81.3	83.6	81.8	79.6	64.5	53.6	44.3	65.8
26	44.9	54.3	52.2	59.8	69.2	76.5	78.9	81.5	79.9	71.1	53.1	50.4	64.4
27	50.8	56.2	56.4	68.0	74.5	77.0	80.2	82.4	77.6	68.7	64.8	45.6	66.9

Table 58. Continued

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1928	48.0	49.5	57.7	59.0	71.2	76.7	80.7	82.1	74.2	69.7	54.2	47.3	64.2
29	49.3	42.3	60.4	68.1	69.9	77.4	80.0	81.5	77.0	67.3	49.7	48.3	64.3
30	41.2	55.8	53.4	68.4	71.5	77.0	82.7	82.0	76.5	63.8	55.2	45.1	64.4
1931	47.9	52.8	50.9	61.2	66.5	78.5	83.0	78.3	79.7	70.9	61.5	52.1	65.3
32	52.0	55.8	51.9	63.1	71.1	78.3	82.8	80.6	74.6	62.7	49.1	47.8	64.5
33	52.3	46.8	57.2	61.7	72.9	76.3	80.0	80.4	79.3	67.7	57.5	56.8	65.7
34	49.3	52.4	56.4	67.8	71.7	81.0	83.7	84.5	75.7	71.4	59.9	47.9	66.9
35	50.9	50.3	64.3	64.8	70.7	78.0	82.2	83.3	75.1	70.1	56.1	46.3	66.1
36	46.9	46.9	62.0	63.3	72.1	80.8	80.5	82.9	78.4	63.8	53.3	51.4	65.2
37	51.6	52.1	53.5	63.0	72.3	80.0	81.6	82.9	75.9	65.0	51.8	48.5	64.9
38	48.4	57.5	64.5	63.9	71.7	78.8	81.2	81.1	76.8	70.1	55.2	49.8	66.6
39	51.4	51.9	59.8	64.3	71.8	79.6	84.0	83.2	80.6	69.1	53.6	53.2	67.0
40	36.5	48.9	59.1	64.4	69.9	75.5	81.0	78.3	72.8	67.7	55.9	63.9	63.7
1941	51.4	47.2	53.3	66.3	72.4	77.9	80.7	82.0	78.5	77.3	53.7	51.7	65.7
42	45.6	48.4	56.8	66.0	71.3	78.8	80.7	81.9	74.2	67.3	60.5	50.7	65.3
43	48.4	54.5	55.5	67.3	74.9	81.4	82.4	82.9	74.0	64.6	53.2	47.6	65.6
44	47.3	56.9	58.4	65.2	70.9	80.0	82.6	83.2	76.4	67.2	57.2	45.6	65.9
45	46.3	56.0	65.4	67.1	71.7	80.4	81.4	82.1	79.1	65.4	62.3	48.3	67.2
46	47.9	53.3	62.8	69.8	72.5	77.7	81.8	81.6	76.1	68.7	60.6	55.2	67.3
47	48.7	45.6	53.1	67.9	72.0	79.8	81.2	84.8	80.4	75.0	55.5	52.2	66.5
48	42.5	51.7	60.7	69.9	73.8	80.9	83.0	83.8	76.1	66.3	54.9	52.3	66.3
49	46.6	53.1	56.9	62.2	74.9	79.4	81.3	78.7	75.2	66.5	57.0	51.2	65.3
50	55.4	54.2	55.5	62.5	73.9	77.5	79.3	80.1	74.4	68.8	53.9	47.7	65.3
1951	48.3	50.0	58.2	63.8	72.7	79.9	83.9	85.7	77.2	69.0	53.7	51.4	66.1
52	56.6	53.6	55.5	62.1	71.3	80.9	81.7	83.4	76.3	61.9	55.6	47.3	65.5
53	51.7	50.2	63.7	63.7	73.8	83.1	80.6	80.9	77.0	69.5	54.1	45.5	66.2
54	49.5	56.6	55.4	68.3	68.3	79.3	85.2	85.3	80.1	70.4	54.5	49.9	66.9

Table 58. Continued

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1955	46.8	49.6	60.3	68.9	75.6	77.6	83.1	81.7	80.2	66.6	55.4	49.7	66.7
56	48.1	53.1	57.1	63.9	75.7	79.3	85.0	84.8	77.6	70.2	53.8	53.5	66.9
57	48.7	58.2	55.4	65.4	73.9	79.7	84.2	82.8	75.3	69.1	55.4	51.7	67.6
58	44.7	44.5	52.0	64.5	73.6	80.2	82.8	82.7	76.7	66.3	57.6	46.5	64.4
59	43.3	51.7	54.9	62.9	76.2	79.9	82.4	82.6	78.2	67.8	49.3	50.4	65.0
60	46.2	44.4	49.9	66.7	72.2	79.8	83.3	81.9	75.4	67.8	53.9	47.2	64.7
1961	42.5	53.2	61.5	62.1	72.7	77.0	80.7	80.2	77.3	65.6	54.3	48.9	64.7
62	42.2	57.8	53.3	64.2	75.0	79.7	83.7	84.4	82.9	70.3	55.7	47.5	66.0
63	39.4	48.3	60.4	70.9	75.7	81.1	83.7	83.5	77.9	71.9	59.8	41.3	66.2
64	46.3	45.8	57.8	69.2	75.5	80.6	84.2	85.0	77.4	64.3	59.6	49.7	66.3
65	50.8	47.8	50.2	70.8	75.1	79.9	84.1	82.8	78.5	65.3	63.7	51.8	66.3
66	43.2	47.7	56.7	66.6	72.8	78.2	85.0	80.9	76.1	64.5	59.9	47.7	65.0
67	47.2	47.3	62.6	72.3	71.5	80.6	80.4	81.4	74.3	64.9	57.1	49.7	65.8
68	45.4	44.5	54.3	66.2	72.7	78.0	80.7	82.4	73.9	67.1	53.8	48.1	64.0
69	49.4	49.9	50.4	66.6	72.5	79.7	86.2	83.8	77.7	68.7	55.3	49.8	65.0
70	42.2	49.3	54.8	68.2	72.4	79.4	82.5	84.4	80.2	64.4	52.9	56.7	65.7
1971	51.3	49.3	56.3	64.0	71.6	80.5	83.7	80.6	76.9	70.8	56.4	55.7	66.4
72	50.3	50.0	61.1	66.7	72.5	78.8	80.1	82.1	79.5	65.9	52.3	45.0	65.3
73	42.6	46.8	60.9	61.1	71.6	76.2	81.7	79.2	75.6	69.0	63.4	49.0	64.8
74	48.2	50.6	63.7	64.5	74.8	76.4	81.4	80.0	69.4	66.7	55.6	48.6	64.8
75	51.4	48.1	57.5	63.6	73.5	76.4	80.2	80.6	71.9	66.8	55.3	49.3	64.5
76	46.9	56.1	58.4	65.0	67.7	74.6	79.6	79.7	73.7	59.1	48.6	46.4	63.1
77	38.4	48.5	59.6	64.4	74.0	79.2	83.6	82.0	77.1	66.5	56.8	48.7	64.8
78	36.5	38.5	54.7	65.9	74.6	78.4	84.4	82.6	76.2	-	59.5	50.1	--
79	38.0	44.0	-	64.1	-	76.5	81.0	80.2	72.4	68.5	52.9	49.3	--
80	49.0	46.4	55.2	61.3	72.4	80.3	85.4	83.7	80.9	65.0	53.4	50.3	65.1
Mean	47.4	50.2	57.7	64.9	72.2	78.7	82.0	82.1	76.7	67.2	56.1	49.5	65.5
Std. Dev.	4.45	4.29	4.39	2.75	2.20	2.01	1.75	1.80	2.59	3.04	3.61	3.68	1.10

Table 59. Monthly and Annual Maximum Temperature (°F) at Nacogdoches, Texas ,1901-80

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1901	62.8	58.1	70.4	74.1	82.5	91.6	92.7	94.6	85.3	79.0	68.0	57.6	76.4
02	56.5	56.1	70.0	79.0	85.6	91.4	88.4	93.6	85.2	78.3	70.5	59.8	76.2
03	57.2	56.7	67.0	75.9	78.3	82.6	88.9	90.2	86.6	75.6	67.4	61.3	74.0
04	56.8	65.8	74.0	73.4	82.6	89.2	89.7	90.2	88.6	82.4	70.7	60.4	77.0
05	52.6	50.3	73.3	74.6	84.1	89.1	87.6	91.0	88.2	76.4	70.4	51.7	74.1
06	60.4	59.6	64.6	77.2	82.7	89.3	89.1	89.3	87.3	72.1	69.8	63.5	75.4
07	--	66.9	78.3	70.7	78.6	88.7	92.4	95.1	91.1	76.8	63.6	61.1	--
08	59.6	60.7	75.1	77.1	81.8	88.8	90.2	89.3	85.5	76.4	71.0	63.3	76.6
09	62.3	66.0	71.3	75.6	80.9	88.6	93.7	95.7	92.0	82.9	76.0	53.8	78.2
10	61.7	58.4	77.5	75.8	80.5	86.8	90.4	93.0	92.9	81.7	69.9	--	--
1911	65.5	68.0	73.9	73.3	83.0	93.9	87.7	90.3	94.0	77.9	63.4	56.8	77.3
12	54.7	56.6	62.1	74.8	81.2	83.6	92.5	90.4	89.0	80.3	66.9	53.6	73.8
13	58.1	59.5	65.4	75.7	81.3	86.9	93.3	94.4	81.4	73.4	74.0	55.7	74.9
14	64.3	57.4	65.8	75.7	81.0	92.6	96.8	--	--	--	--	--	--
15	52.9	60.7	55.6	75.5	82.8	91.5	90.8	87.1	86.7	75.9	71.1	61.6	74.7
16	61.8	62.0	73.0	73.1	81.1	89.6	92.7	93.0	89.7	81.7	68.6	61.7	77.3
17	60.0	64.4	68.8	73.7	76.9	91.1	94.3	96.9	88.7	78.3	70.2	55.0	76.5
18	52.3	66.4	76.2	74.4	84.6	94.5	98.0	95.4	86.0	78.9	64.3	63.4	77.7
19	58.8	63.1	73.5	80.8	82.1	87.8	93.6	94.6	90.1	82.8	73.2	66.0	78.9
20	59.1	65.4	70.7	79.9	87.8	91.8	95.0	91.0	93.2	79.5	64.1	56.6	77.9
1921	62.3	63.5	72.0	70.1	84.4	90.4	93.0	97.0	95.3	84.0	78.3	68.9	79.9
22	55.5	66.8	70.8	80.3	86.0	92.0	94.7	95.7	95.4	85.5	71.4	67.8	80.2
23	69.5	60.4	62.8	75.6	80.2	91.8	95.1	97.7	88.8	78.5	66.8	62.4	77.5
24	56.5	58.4	65.0	77.0	80.8	92.3	98.5	103.3	88.0	81.0	68.5	53.1	76.9
25	54.5	63.7	69.2	76.2	80.4	92.2	94.0	92.8	89.1	71.3	61.8	53.4	74.9
26	53.1	65.3	61.8	68.3	78.6	85.9	87.8	91.3	90.2	81.3	63.4	59.2	73.9
27	59.6	65.0	65.5	76.5	82.7	85.1	90.2	94.0	88.9	81.2	74.7	53.4	76.4

Table 59. Continued

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1928	57.8	58.1	68.1	68.2	82.4	85.2	90.3	93.0	85.5	81.1	64.1	57.5	74.3
29	59.0	48.9	70.5	77.7	77.5	86.6	89.2	93.6	88.8	78.9	57.7	58.1	73.9
30	49.3	64.5	63.2	80.8	79.1	87.9	94.6	93.8	86.7	73.5	64.7	54.3	74.4
31	58.1	62.4	61.2	71.7	76.9	89.7	94.0	89.0	92.1	83.1	71.4	60.0	75.8
32	69.0	68.7	64.0	77.0	80.7	87.8	92.9	90.1	83.8	74.6	59.7	51.8	74.3
33	60.4	54.6	65.9	71.8	80.7	87.9	88.2	90.5	89.4	78.1	68.8	67.6	75.3
34	56.1	62.1	67.0	78.4	81.9	91.7	95.5	95.7	87.0	83.9	70.2	55.8	77.2
35	59.2	58.4	73.8	72.3	79.0	86.1	92.0	94.8	84.8	82.0	66.1	55.2	75.4
36	59.3	57.6	73.5	75.4	80.9	91.8	89.6	94.2	88.5	74.8	64.4	60.4	75.9
37	59.1	61.2	62.9	72.4	83.3	89.7	91.6	93.4	86.2	75.3	60.9	53.6	74.1
38	55.0	66.3	73.7	72.3	81.0	88.4	90.6	91.0	89.7	84.1	66.9	59.5	76.6
39	61.4	61.7	71.0	74.6	82.3	88.5	95.3	95.1	93.6	81.6	63.5	64.0	77.8
40	45.4	57.9	69.8	73.4	79.5	83.4	90.8	87.3	83.3	80.6	64.5	62.4	73.2
1941	60.6	55.1	61.4	75.4	81.1	86.1	89.4	90.9	86.5	79.3	64.5	59.8	74.3
42	56.0	56.3	67.4	74.6	79.7	87.0	89.8	90.8	83.2	79.1	71.1	60.5	74.7
43	57.8	65.7	65.7	78.4	85.3	91.9	93.2	94.8	84.1	77.1	65.9	55.5	76.3
44	55.7	64.8	67.8	74.6	79.9	89.8	93.8	94.6	86.6	82.0	66.1	54.5	75.9
45	55.3	66.9	76.3	78.2	83.0	90.3	90.7	92.8	90.6	77.7	74.3	58.4	77.9
46	56.2	64.5	74.3	81.2	82.1	87.2	91.8	92.1	86.3	80.3	70.0	65.6	77.6
47	56.2	58.0	64.2	78.1	83.1	89.7	93.7	97.5	93.9	89.3	67.0	62.6	77.9
48	52.8	61.7	71.8	81.7	84.2	92.3	94.4	97.7	89.6	81.1	67.4	64.4	78.3
49	56.4	64.1	68.9	72.9	86.4	90.5	92.1	91.2	87.9	76.5	72.3	62.0	76.8
50	64.6	65.1	68.1	73.4	84.8	87.5	89.5	92.8	85.5	81.7	68.0	59.6	76.8
1951	60.6	61.7	70.3	75.5	84.4	90.2	96.0	99.4	89.4	81.4	65.5	63.7	78.2
52	67.6	64.7	67.7	73.7	82.2	92.1	92.7	95.8	90.6	78.6	67.3	58.1	77.6
53	63.0	61.3	74.6	75.5	83.6	94.8	90.0	90.7	90.4	83.6	66.7	56.8	77.7
54	61.0	71.4	68.1	79.2	78.8	91.3	97.9	99.4	97.1	84.3	70.7	65.1	80.3

Table 59. Continued

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1955	57.6	62.4	73.6	81.3	87.3	90.9	95.2	93.0	93.7	84.0	70.0	62.5	79.4
56	63.0	65.6	71.7	77.7	87.9	91.4	98.5	99.7	95.2	88.1	70.1	67.7	81.4
57	60.1	69.8	69.4	77.0	85.3	89.3	96.7	95.7	87.9	77.1	66.6	67.0	78.5
58	59.0	56.6	67.2	77.6	86.7	92.0	94.5	95.7	86.5	79.4	71.6	60.4	77.3
59	56.4	63.9	72.0	75.3	87.5	91.6	94.5	94.4	90.5	81.7	64.6	62.9	77.9
60	57.0	58.1	62.4	80.3	85.6	92.3	95.2	93.8	90.8	83.3	70.4	55.1	77.0
1961	55.0	66.7	76.0	76.2	85.8	87.1	91.1	94.4	90.1	80.5	66.2	62.0	77.6
62	56.6	72.4	67.4	77.5	87.4	91.5	95.7	98.2	90.2	83.9	69.6	59.6	79.2
63	51.4	62.9	76.0	82.9	88.3	94.1	95.5	98.0	89.9	88.9	71.5	53.0	79.4
64	59.3	57.5	70.9	81.3	86.5	91.3	97.2	96.7	87.9	79.6	72.4	62.7	78.6
65	64.1	59.3	60.9	82.9	84.6	91.2	96.0	96.3	90.1	78.7	75.0	65.0	78.7
66	52.7	60.1	69.2	78.5	83.0	89.8	96.4	91.6	87.9	79.2	73.3	59.7	76.8
67	59.6	60.3	76.6	83.4	84.0	92.0	91.3	94.4	87.3	81.8	71.5	62.1	78.7
68	53.8	56.7	66.0	77.1	84.3	88.2	91.1	93.8	86.4	80.8	66.4	60.9	75.5
69	59.4	60.6	60.7	77.8	83.9	91.4	98.0	96.0	91.0	81.5	69.9	62.3	77.8
70	52.4	61.6	65.9	79.2	84.4	90.6	93.7	96.2	90.7	75.9	66.7	68.4	77.2
1971	62.9	64.0	69.6	78.0	83.0	93.2	95.0	92.0	88.3	82.8	70.9	65.2	78.8
72	60.9	63.5	74.5	79.8	85.0	91.9	90.5	93.5	91.9	77.5	61.6	56.3	77.3
73	53.2	59.4	72.4	72.7	84.9	86.9	92.1	91.0	86.8	80.5	75.8	62.1	76.5
74	57.1	64.6	73.7	76.6	84.2	87.4	93.1	91.0	79.4	78.5	65.9	59.0	75.9
75	62.0	61.7	67.1	74.2	82.8	88.0	90.6	91.2	84.7	79.8	68.5	59.4	75.8
76	59.9	69.5	69.3	77.2	78.3	86.0	89.2	92.2	86.3	71.9	60.6	58.1	74.9
77	48.8	63.4	70.1	76.5	84.9	91.1	95.1	92.1	88.2	79.1	67.9	60.2	76.5
78	44.6	49.1	66.7	77.8	84.5	91.3	97.5	94.4	86.1	-	70.9	60.1	-
79	46.0	53.8	-	74.3	-	87.6	90.2	90.6	83.9	82.3	65.2	61.0	-
80	57.5	58.5	66.6	74.4	82.1	92.3	98.3	96.0	92.7	77.5	65.6	61.5	76.9

Table 60. Monthly and Annual Minimum Temperature (°F) at Nacogdoches, Texas, 1901-80

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1901	40.5	34.6	44.4	47.8	59.9	66.7	72.7	71.5	61.4	52.2	43.4	34.3	52.4
02	33.2	34.1	48.2	56.8	66.7	66.2	71.3	73.0	61.0	54.3	51.3	37.2	54.5
03	36.2	36.6	50.3	51.1	59.2	59.2	68.7	70.5	57.1	50.3	39.8	32.9	51.0
04	31.7	42.0	57.4	51.1	60.5	65.2	68.4	72.2	65.4	54.3	40.6	38.6	53.5
05	33.1	28.8	53.1	53.9	66.3	68.6	69.3	71.6	64.4	55.6	48.7	32.0	53.8
06	36.2	33.2	44.0	54.2	61.1	65.9	69.8	68.9	65.7	49.1	44.6	44.3	53.1
07	--	36.6	57.9	49.6	58.6	66.2	71.3	71.2	63.6	57.7	40.7	40.9	--
08	38.4	37.1	56.5	57.2	63.6	68.0	70.0	70.6	63.0	48.5	43.5	42.8	54.9
09	42.7	37.5	47.1	51.5	60.2	66.4	73.6	72.0	61.3	52.2	50.5	32.8	54.0
10	38.5	33.6	48.7	49.4	60.3	64.5	70.5	72.5	63.7	53.8	44.6	--	--
1911	45.7	44.2	49.5	54.5	58.9	67.7	71.6	71.9	67.7	56.3	39.8	38.2	55.5
12	34.1	31.2	43.9	53.1	62.8	64.6	74.4	70.9	62.8	55.0	38.7	37.7	52.4
13	38.9	32.6	43.3	49.2	60.3	64.1	71.0	69.7	62.1	53.1	51.0	40.2	53.0
14	40.5	33.1	43.6	51.8	62.8	68.3	72.4	--	--	--	--	--	--
15	33.7	40.6	37.5	51.0	62.8	70.7	70.5	69.1	66.2	53.6	46.5	38.1	53.4
16	43.3	38.6	47.0	52.4	62.1	68.9	72.2	71.0	62.9	51.5	41.9	39.3	54.3
17	41.7	39.8	46.0	52.1	55.0	67.3	74.2	70.4	63.6	46.8	38.4	35.0	52.6
18	27.0	43.7	52.5	53.7	63.4	71.7	68.7	69.5	59.5	58.9	45.1	44.9	54.9
19	36.1	39.6	47.7	52.6	59.5	66.6	70.8	71.1	66.7	64.8	47.9	30.7	54.6
20	37.1	43.4	46.9	51.8	63.8	65.4	69.8	68.7	66.0	52.5	40.3	37.7	--
1921	43.0	40.8	55.4	50.7	58.8	68.0	70.5	69.0	68.4	48.2	47.9	42.0	55.3
22	36.6	45.7	45.4	54.6	62.4	67.7	68.8	68.0	63.7	48.5	45.1	43.7	54.2
23	43.7	40.7	42.6	52.6	59.9	66.6	68.5	68.8	64.2	52.5	40.5	44.8	53.9
24	30.7	37.9	41.0	52.1	55.9	68.0	66.9	68.9	62.3	53.0	45.6	38.5	51.8
25	33.1	41.6	45.9	56.6	56.9	70.3	73.2	70.8	70.0	57.6	45.4	35.1	54.7
26	36.7	43.2	42.5	51.3	59.8	67.1	70.0	71.6	69.5	60.8	42.7	41.6	54.8
27	42.0	47.3	47.3	59.5	66.3	68.8	70.1	70.8	66.3	56.1	54.8	37.8	57.3
28	38.2	40.9	47.3	49.8	59.9	68.1	71.1	71.2	62.9	58.2	44.2	37.1	54.1

Table 60. Continued

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1929	39.5	35.6	50.3	58.5	62.3	68.2	70.7	69.4	65.2	55.6	41.6	38.5	54.6
30	33.0	47.0	43.5	56.0	63.9	66.0	70.7	70.2	66.2	54.0	45.6	35.9	54.4
1931	37.6	43.2	40.5	50.7	56.1	67.2	72.0	67.5	67.2	58.7	51.5	44.2	54.7
32	43.0	49.1	42.5	54.5	61.4	68.8	72.7	71.0	65.3	50.7	38.4	37.7	54.6
33	44.1	39.0	48.5	51.5	65.0	64.7	71.8	70.3	69.1	57.2	46.1	46.0	56.1
34	42.5	42.7	45.8	57.2	61.4	70.2	71.9	73.2	64.3	58.9	49.5	39.9	56.5
35	42.5	42.2	54.7	57.2	62.4	69.9	72.4	71.8	65.4	58.1	46.1	37.3	56.7
36	34.4	36.1	50.5	51.2	63.3	69.7	71.4	71.5	68.3	52.7	42.1	42.3	54.5
37	44.1	42.9	44.9	53.6	61.2	70.2	71.6	72.4	65.5	54.6	42.7	43.4	55.6
38	41.8	48.6	55.2	55.5	62.4	69.1	71.7	71.1	63.8	56.1	43.5	40.0	56.6
39	41.4	42.1	48.6	53.9	61.2	70.7	72.6	71.2	67.6	56.5	43.7	42.3	56.1
40	27.5	39.9	48.3	55.3	60.2	67.5	71.1	69.2	62.3	54.7	47.3	45.3	54.1
1941	42.2	39.2	44.5	57.1	63.7	69.7	72.0	73.0	70.4	75.3	42.8	43.6	57.1
42	35.2	40.4	46.2	57.3	62.9	70.6	71.6	73.0	65.1	55.4	49.8	40.8	55.8
43	38.9	43.3	45.2	56.1	64.4	70.9	71.6	71.0	63.8	52.0	40.4	39.6	54.8
44	38.9	48.9	48.9	55.7	61.8	70.2	71.3	71.7	66.1	52.4	48.2	36.6	55.9
45	37.2	45.0	54.5	56.0	60.4	70.5	72.0	71.3	67.5	53.1	50.3	38.1	56.4
46	39.5	42.1	51.2	58.3	62.9	68.2	71.7	71.0	65.9	57.0	51.1	44.8	57.0
47	41.1	33.2	42.0	57.7	60.8	69.8	68.7	72.0	66.9	60.7	43.9	41.8	55.0
48	32.1	41.7	48.4	58.0	63.4	69.4	71.6	69.9	62.6	51.5	42.4	40.2	54.3
49	36.7	42.1	44.8	51.4	63.3	68.3	70.5	66.2	62.4	56.5	41.6	40.4	53.7
50	46.2	43.3	42.9	51.5	62.9	67.5	69.0	67.3	63.2	55.8	39.7	35.7	53.8
1951	36.0	38.2	46.1	52.1	60.9	69.5	71.7	72.0	65.0	56.6	41.8	39.0	54.0
52	45.7	42.5	43.2	50.4	60.3	69.6	70.7	71.0	61.9	45.2	43.9	36.5	53.4
53	39.5	39.0	52.8	51.8	64.0	71.4	71.2	71.0	63.6	55.3	41.5	34.2	54.7
54	38.0	41.7	42.7	57.4	57.8	67.3	72.5	71.3	63.1	56.4	38.3	34.7	53.4
55	35.9	36.7	47.0	56.4	63.8	64.3	71.0	70.3	66.7	49.2	40.8	36.8	53.3
56	33.2	40.5	42.5	50.1	63.5	67.2	71.4	69.9	60.0	52.2	37.4	39.3	52.3
57	37.2	46.6	41.3	53.7	62.4	70.1	71.7	69.9	62.6	50.0	44.2	36.3	53.8

Table 60. Continued

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1958	30.4	32.3	36.7	51.3	60.5	68.4	71.1	69.6	66.8	53.1	43.5	32.5	51.4
59	30.2	30.7	37.8	50.5	64.9	68.2	70.2	70.8	65.9	53.8	34.0	37.8	52.0
60	35.4	30.7	37.3	53.0	58.8	67.9	72.0	72.9	64.2	57.5	46.2	35.0	52.6
1961	29.9	39.6	46.9	48.0	59.6	66.9	70.2	66.0	64.5	50.6	42.3	35.8	51.7
62	27.8	43.1	39.2	50.8	62.6	67.9	71.6	70.5	75.5	56.6	41.8	35.4	52.8
63	27.3	33.7	44.8	58.9	63.1	68.1	71.8	69.0	65.8	54.8	48.0	29.6	53.0
64	33.2	33.9	44.7	57.0	64.4	69.8	71.2	73.2	66.8	49.0	46.7	36.7	53.9
65	37.5	36.3	39.5	58.6	65.5	68.6	72.1	69.3	66.8	51.8	52.4	38.6	54.8
66	33.7	35.3	44.2	54.6	62.6	66.5	73.5	70.2	64.2	49.7	46.5	35.6	53.1
67	34.8	34.2	48.5	61.2	58.9	69.1	69.5	68.4	62.3	47.9	42.6	37.3	52.8
68	36.9	32.3	42.6	55.2	61.0	67.8	70.3	71.0	61.3	53.3	41.2	35.2	52.4
69	39.3	39.2	40.1	55.4	61.0	67.9	74.4	71.5	64.4	55.8	40.6	37.2	54.0
70	32.0	36.9	43.6	57.2	60.3	68.1	71.2	72.6	69.6	52.9	39.0	44.9	54.1
1971	39.6	34.6	42.9	49.9	60.2	67.8	72.4	69.2	65.5	58.7	41.9	46.3	54.1
72	39.6	36.6	47.8	53.6	60.0	66.3	69.7	70.6	67.0	54.3	40.9	33.8	53.4
73	32.0	34.3	49.5	49.5	58.3	65.6	71.3	67.5	64.5	57.6	51.0	35.9	53.1
74	39.4	36.5	53.8	52.3	65.4	63.5	69.7	69.0	59.5	54.8	43.4	38.3	53.8
75	40.7	34.6	47.8	52.9	64.1	64.7	69.8	70.0	59.0	53.8	42.0	39.3	53.2
76	33.9	42.7	49.5	52.8	59.2	63.2	70.0	67.2	61.2	46.3	36.7	34.6	51.3
77	27.9	33.7	47.1	52.3	63.0	67.3	72.1	71.8	66.0	53.9	45.7	37.3	53.2
78	28.5	27.9	42.8	54.0	62.7	65.4	71.3	70.9	66.4	--	48.1	38.1	--
79	29.9	34.2	--	53.9	--	65.4	71.8	69.7	60.8	54.7	38.7	37.6	--
80	40.5	34.4	43.9	48.2	62.7	68.2	72.4	71.4	67.1	50.4	41.1	39.1	53.3
Mean	36.9	38.8	46.3	53.6	61.6	67.7	71.1	70.5	64.7	54.2	44.0	38.5	54.1
Maximum	46.2	49.1	57.9	61.2	66.7	71.7	74.4	73.2	75.5	75.3	54.8	46.3	57.3
Minimum	27.0	27.9	36.7	47.8	55.0	59.2	66.9	66.0	57.1	45.2	34.0	29.6	51.0

---

*Values not included in calcualting means

Table 61. Heating Degree Days at Nacogdoches, Texas, 1901-1980

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1901	416.5	474.5	258.0	142.0	12.5	.0	.0	.0	13.5	46.0	270.0	591.0	2224.0
2	625.5	505.5	199.5	22.5	.0	.0	.0	.0	16.5	43.0	142.5	511.0	2066.0
3	576.0	466.0	216.5	99.0	43.0	16.5	.0	.0	6.0	146.0	353.0	554.0	2478.0
4	645.0	319.5	175.5	121.0	10.0	.0	.0	.0	.0	63.0	263.0	488.5	2085.5
5	687.0	670.6	100.0	65.5	.0	.0	.0	.0	.0	114.5	188.0	718.0	2543.5
6	530.5	472.0	343.5	48.5	29.0	.0	.0	.0	.0	155.0	231.0	356.0	2165.0
7	-	324.5	87.0	158.0	28.5	.0	.0	.0	.0	64.5	350.0	445.5	1458.0
8	497.0	429.0	123.0	52.5	24.0	.0	.0	.0	19.0	136.0	229.5	385.5	1895.5
9	397.5	341.5	210.5	99.0	31.5	.0	.0	.0	16.5	52.0	105.0	676.5	1930.0
10	468.5	483.5	107.5	103.0	6.0	.0	.0	.0	.0	100.5	246.5	-	1515.5
1911	331.0	240.5	178.0	90.5	18.5	.0	.0	.0	.0	92.0	413.5	520.0	1884.5
12	638.0	563.0	386.0	87.5	6.0	.0	.0	.0	1.0	43.5	352.5	600.5	2678.0
13	514.5	482.5	357.0	111.0	4.0	1.5	.0	.0	11.5	186.0	102.0	530.5	2300.5
14	399.5	503.5	348.0	83.0	7.5	.0	.0	-	-	-	-	-	-
15	671.0	400.5	575.5	90.5	3.0	.0	.0	.0	.0	47.0	245.0	470.0	2502.5
16	401.0	428.5	203.5	124.0	18.5	.0	.0	.0	12.0	72.0	311.0	467.0	2037.5
17	457.5	380.0	287.0	134.5	81.5	.0	.0	.0	.0	169.5	320.0	604.0	2434.0
18	765.5	312.0	102.0	101.0	8.0	.0	.0	.0	17.0	27.5	344.5	357.0	2024.5
19	514.0	380.0	161.5	62.5	6.0	.0	.0	.0	.0	9.5	170.0	519.0	1822.5
20	-	310.5	223.0	78.0	0.5	.0	.0	.0	4.5	75.0	403.0	552.0	1647.0
1921	382.5	359.5	110.0	161.5	23.5	.0	.0	.0	.0	62.0	140.0	312.5	1551.5
22	585.5	287.5	237.0	33.0	.0	.0	.0	.0	.0	51.5	220.5	334.0	1749.0
23	276.5	417.5	387.5	103.0	23.0	.0	.0	.0	.0	114.0	339.0	369.5	2030.0
24	662.0	487.5	380.0	91.0	30.5	.0	.0	.0	15.5	78.5	285.5	619.0	2649.0
25	655.5	347.5	249.5	62.5	36.5	.0	.0	.0	.0	174.5	352.0	646.5	2523.0
26	621.0	308.5	400.0	176.0	21.0	.0	.0	.0	2.5	30.5	364.5	450.5	2374.5
27	438.5	260.0	299.0	59.5	4.5	.0	.0	.0	.0	38.5	103.0	615.5	1818.5

Table 61. Continued

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1928	537.5	448.0	358.5	329.0	17.5	.0	.0	.0	.0	72.5	343.0	548.5	2444.5
29	492.0	635.0	211.5	36.5	24.0	.0	.0	.0	.0	70.0	468.5	524.5	2462.0
30	737.5	270.5	364.5	1.5	1.5	.0	.0	.0	2.0	108.0	313.0	616.0	2414.5
1931	529.5	341.0	437.0	145.0	43.5	.0	.0	.0	.0	44.0	165.5	415.5	2121.0
32	419.5	207.5	377.5	62.0	.0	.0	.0	.0	.0	127.0	477.5	626.5	2297.5
33	371.5	515.0	262.5	142.5	13.0	.0	.0	.0	.0	32.5	247.0	271.0	1855.0
34	484.5	352.0	289.5	26.5	2.5	.0	.0	.0	.0	2.0	197.5	530.0	1884.5
35	453.5	409.5	127.0	103.0	5.0	.0	.0	.0	5.5	19.5	304.0	579.0	2006.0
36	562.0	537.0	137.0	121.5	.0	.0	.0	.0	3.0	99.0	376.0	424.5	2260.0
37	432.0	378.5	364.0	142.0	.0	.0	.0	.0	.0	102.5	405.0	510.5	2325.5
38	520.5	240.0	96.0	124.5	14.0	.0	.0	.0	1.5	35.0	349.5	475.0	1856.0
39	422.0	370.5	191.0	109.5	3.5	.0	.0	.0	.0	63.5	343.0	376.0	1880.0
40	884.0	467.0	217.5	109.5	6.0	.0	.0	.0	21.0	33.5	248.0	344.0	2366.5
1941	424.0	498.0	381.5	43.0	0.5	.0	.0	.0	.0	38.5	343.5	410.0	2139.0
42	600.0	406.5	284.5	57.5	14.5	.0	.0	.0	28.5	38.5	211.0	454.5	2155.5
43	531.5	296.5	310.0	47.0	.0	.0	.0	.0	11.5	96.5	371.0	546.0	2210.0
44	547.5	257.5	224.5	80.5	22.0	.0	.0	.0	.0	47.5	275.0	604.5	2059.0
45	580.0	255.0	71.5	55.5	28.0	.0	.0	.0	.0	71.0	168.0	516.5	1745.5
46	531.0	335.0	118.0	25.5	.0	.0	.0	.0	.0	42.5	184.0	320.5	1556.5
47	520.0	542.5	372.0	38.5	0.5	.0	.0	.0	.0	.0	296.5	404.5	2174.0
48	697.5	398.0	234.5	26.5	3.0	.0	.0	.0	.0	66.5	321.0	419.5	2166.5
49	576.5	343.0	259.5	142.0	.0	.0	.0	.0	6.5	78.5	264.5	432.5	2103.0
50	336.0	315.5	322.0	131.5	.0	.0	.0	.0	3.5	22.5	362.0	543.0	2036.0
1951	517.5	390.5	257.5	126.5	3.5	.0	.0	.0	.0	35.0	361.5	440.0	2132.0
52	305.0	334.0	303.5	117.0	14.5	.0	.0	.0	.0	164.0	325.0	551.5	2114.5
53	417.5	415.5	98.5	97.5	17.5	.0	.0	.0	.0	51.5	331.5	603.0	2032.0
54	481.5	247.0	327.0	48.5	46.5	.0	.0	.0	.0	89.5	313.0	394.5	1947.5

Table 61. Continued

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1955	567.0	434.0	249.0	41.5	.0	1.0	.0	.0	.0	95.0	343.0	481.0	2211.5
56	529.5	368.0	376.5	105.0	3.5	.0	.0	.0	.0	18.0	350.0	385.0	2035.5
57	504.5	220.0	297.5	94.0	15.5	.0	.0	.0	.0	110.5	314.5	418.5	1975.0
58	626.5	576.0	210.0	67.0	7.0	.0	.0	.0	1.5	50.0	253.5	471.5	2263.0
59	670.5	384.0	311.5	137.5	.0	.0	.0	.0	.0	63.5	454.5	453.0	2474.0
60	593.5	596.5	460.0	56.0	18.5	.0	.0	.0	1.0	44.5	196.0	618.5	2584.5
1961	696.5	333.0	165.5	158.5	5.0	2.5	.0	.0	0.5	96.5	340.5	497.5	2296.0
62	704.5	209.0	361.5	86.5	1.5	.0	.0	.0	.0	46.5	262.0	542.0	2213.5
63	794.0	466.0	176.0	35.5	6.0	.0	.0	.0	3.5	12.0	208.5	733.0	2434.5
64	582.0	558.5	229.5	20.0	1.5	.0	.0	.0	5.5	90.0	208.5	431.0	2126.5
65	436.5	296.0	538.5	33.0	.0	.0	.0	.0	1.0	98.5	82.0	255.0	1660.5
66	653.5	483.5	258.0	71.0	7.5	.0	.0	.0	.0	96.5	192.0	553.0	2315.0
67	567.0	495.0	169.0	9.5	15.0	.0	.0	.0	22.5	79.5	246.0	471.0	2074.5
68	610.0	597.5	351.0	69.5	1.0	.0	.0	.0	2.5	61.0	351.5	525.0	2569.0
69	494.0	420.5	452.0	35.5	9.5	2.5	.0	.0	.0	69.5	317,5	471.0	2272.0
70	706.5	440.5	325.0	66.0	18.5	.0	.0	.0	.0	127.0	375.5	291.5	2350.5
1971	435.5	394.5	295.0	39.5	27.5	.0	.0	.0	6.5	8.5	270.0	299.0	1826.0
72	475.5	414.0	154.0	59.0	2.5	.0	.0	.0	.0	114.0	409.0	618.5	2246.5
73	694.5	459.5	152.5	155.5	11.0	.0	.0	.0	.0	45.0	110.0	496.5	2124.5
74	530.0	364.5	144.0	79.0	3.5	.0	.0	.0	29.5	43.5	318.5	508.0	2020.5
75	443.0	422.5	270.5	103.0	2.5	.0	.0	.0	15.0	65.5	289.5	496.0	2107.0
76	560.5	231.5	222.0	48.5	34.5	.0	.0	.0	2.5	213.5	475.5	578.0	2366.5
77	825.5	416.5	220.0	50.5	.0	.0	.0	.0	.0	68.5	245.0	476.0	2302.0
78	887.5	700.5	328.0	56.0	29.0	.0	.0	.0	.0	-	192.0	498.0	2691.0
79	838.5	542.0	-	62.5	-	.0	.0	.0	2.0	43.0	386.0	486.5	2360.5
80	497.0	510.0	311.0	127.0	4.5	.0	.0	.0	.0	123.5	354.5	449.0	2376.5

Table 62. Cooling Degree Days for Nacogdoches, Texas, 1901-80

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1901	3	3	22	45	205	458	547	558	294	64	12	1	2209
02	0	0	30	140	321	447	461	567	290	92	47	46	2394
03	8	7	21	80	160	223	427	476	240	82	82	31	1752
04	2	39	105	64	212	398	436	503	393	167	3	8	2327
05	0	0	45	70	317	418	450	505	371	145	48	0	2368
06	13	1	12	97	244	412	448	438	377	19	19	11	2089
07	0	8	183	37	135	406	522	563	387	133	2	11	2385
08	0	0	148	145	262	435	469	463	328	65	19	15	2348
09	33	27	31	81	205	407	578	584	397	130	76	4	2553
10	6	1	49	55	174	353	478	550	431	186	36	--	2317*
1911	38	58	76	85	203	507	454	500	482	156	31	0	2588
12	1	0	17	83	223	306	540	484	361	126	6	0	2144
13	3	0	27	59	183	349	532	528	245	132	53	3	2112*
14	8	0	28	72	222	499	609	--	--	--	--	--	--
15	0	0	5	40	247	484	488	409	344	97	60	1	2173
16	17	4	51	59	225	430	542	527	352	122	21	20	2367
17	21	26	54	73	113	427	598	579	336	95	0	7	2327
18	6	35	83	74	289	544	570	509	251	153	26	22	2560
19	0	0	28	115	188	367	534	556	403	284	37	4	2513
20	--	6	32	104	337	409	542	461	443	108	20	0	2461 *
1921	1	0	71	25	192	426	521	560	472	97	83	18	2464
22	1	45	24	108	286	447	520	524	438	115	19	48	2572
23	17	14	7	77	151	428	523	568	346	132	0	17	2277
24	0	0	11	79	136	456	551	656	320	141	49	26	2422
25	0	2	20	106	150	489	579	522	437	159	12	5	2479
26	0	9	3	21	153	346	433	511	449	220	7	0	2150
27	1	15	34	150	301	359	471	540	379	155	97	16	2514
28	16	0	34	41	209	351	489	532	277	219	19	2	2182

Table 62. Continued

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1929	5	0	70	131	177	374	435	213	361	142	9	9	2224
30	0	15	5	105	204	360	549	528	347	71	18	0	2199
1931	0	0	0	33	92	405	559	412	441	229	60	18	2247
32	17	32	15	86	189	400	553	485	287	56	0	0	2119
33	5	7	22	44	257	341	466	480	429	117	21	19	2206
34	0	0	24	112	210	481	581	605	322	201	44	0	2577
35	18	0	105	97	184	391	536	569	310	177	39	0	2424
36	2	12	46	71	221	473	481	555	406	62	24	3	2352
37	10	18	8	83	227	450	516	556	302	103	10	1	2281
38	8	30	80	93	224	414	502	500	355	195	57	4	2460
39	2	5	32	89	215	440	590	566	469	192	3	11	2609
40	0	2	34	92	158	315	375	413	256	117	12	0	1772
1941	3	0	10	82	233	387	489	528	406	267	5	0	2408
42	0	1	33	88	211	415	487	525	305	110	75	12	2260
43	18	4	16	116	307	493	542	556	282	84	17	7	2440
44	0	23	20	86	205	451	545	564	341	118	41	3	2394
45	0	16	85	119	237	463	509	530	423	85	87	0	2553
46	1	8	52	169	234	382	522	515	335	158	51	18	2442
47	14	0	5	127	217	444	503	615	463	311	10	10	2717
48	1	14	84	154	277	477	560	583	334	108	20	27	2637
49	7	11	8	58	308	433	507	411	312	127	24	6	2209
50	41	15	30	55	275	376	443	468	286	139	29	6	2161
1951	2	24	49	92	242	447	464	642	367	161	23	19	2529
52	48	6	9	31	211	477	519	572	338	70	45	5	2329
53	5	0	60	58	293	544	487	494	362	192	6	0	2497
54	2	12	32	149	150	428	627	631	454	257	0	9	2751
55	3	4	105	158	329	380	563	517	457	146	57	7	2723

Table 62. Continued

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1956	8	23	33	73	337	431	621	615	379	179	13	30	2739
57	0	36	0	106	291	441	596	554	310	67	28	5	2433
58	0	2	0	52	275	457	553	549	352	89	31	0	2358
59	0	12	1	76	349	448	539	546	397	151	15	0	2532
60	13	1	7	107	221	454	578	538	378	214	19	3	2530
1961	0	3	58	78	246	365	487	473	370	116	20	0	2214
62	0	8	1	63	314	443	580	601	386	210	4	0	2607
63	0	0	36	213	340	484	580	574	391	226	52	0	2893
64	2	0	13	150	315	467	597	598	376	70	47	12	2646
65	11	3	2	206	302	448	553	517	406	108	45	0	2599
66	0	1	19	119	252	396	621	495	332	82	41	17	2371
67	17	0	95	230	216	468	480	511	303	76	10	13	2416
68	1	4	22	105	240	391	488	542	268	125	17	1	2203
69	10	0	2	84	241	442	659	583	383	184	26	0	2613
70	2	0	9	163	248	432	543	604	455	109	11	34	2607
1971	10	6	25	83	233	500	579	484	396	188	34	11	2546
72	19	17	35	138	235	456	468	529	467	141	17	0	2521
73	0	3	27	63	216	369	518	441	350	171	88	2	2245
74	9	15	105	89	307	345	508	466	192	96	29	0	2159
75	21	3	36	87	265	374	471	484	251	122	19	11	2140
76	0	15	49	75	119	321	453	455	295	31	3	0	1813
77	0	5	22	59	278	460	576	526	396	116	23	0	2460
78	5	0	10	110	295	434	601	547	371	--	52	5	2429*
79	0	6	--	63	--	378	495	470	254	152	13	0	1829*
80	0	6	9	39	234	493	631	581	481	91	26	2	2590
Mean	6.6	8.9	36.6	92.2	233.9	421.6	524.3	528.8	360.9	137.0	29.0	7.2	2380

* Values not included in calculating means

Table 63. Growing Degree Days for Nacogdoches, Texas, 1901-80

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1901	163.0	65.5	266.5	357.5	657.0	907.5	1012.0	1023.0	730.5	483.0	211.5	60.5	5937.5
02	42.0	74.5	286.5	552.5	741.0	897.0	926.0	1032.0	723.5	453.5	367.0	84.0	6179.5
03	64.0	98.5	284.0	431.0	582.5	656.0	891.5	941.0	684.0	400.5	211.5	32.5	5277.0
04	53.0	226.5	401.5	395.0	667.0	848.0	900.5	968.0	842.5	569.0	209.5	130.0	6210.5
05	24.0	55.5	410.0	454.5	781.5	900.0	882.5	969.5	821.0	495.5	335.0	1.0	6130.0
06	114.0	90.5	193.5	498.0	697.5	861.5	912.5	903.0	827.5	332.5	268.0	189.0	5869.5
07	--	158.5	562.5	329.0	556.5	856.0	986.5	1028.0	821.5	533.5	147.0	115.0	--
08	80.5	94.5	495.0	543.0	702.5	885.0	933.5	928.0	759.0	380.5	279.0	172.5	6253.0
09	209.0	197.0	305.0	432.0	638.0	857.5	1043.0	1049.0	830.0	543.0	430.5	63.5	6597.5
10	130.0	63.0	406.5	403.5	633.0	802.5	942.5	1014.5	881.0	558.5	272.0	--	--
1911	292.0	303.0	366.5	444.0	649.5	957.0	918.5	964.5	902.0	529.5	192.5	59.0	6578.0
12	75.5	46.5	166.0	445.5	681.5	755.5	1005.0	949.5	809.5	547.0	160.0	33.5	5675.0
13	106.5	62.5	199.0	402.0	644.0	797.0	997.0	993.0	683.0	424.5	403.0	72.5	5783.0
14	155.5	64.0	201.0	444.5	679.0	948.5	1073.5	--	--	--	--	--	--
15	32.5	79.5	76.5	417.5	709.0	934.0	952.5	874.0	794.0	515.0	295.5	114.0	5794.0
16	209.5	120.0	335.0	391.0	671.5	879.5	1007.0	992.0	789.5	503.5	218.5	165.0	6282.0
17	181.0	181.0	283.0	390.0	496.5	876.5	1063.0	1044.0	785.5	405.5	148.5	104.5	5959.0
18	38.0	210.5	446.5	422.5	745.5	994.0	1034.5	943.5	684.0	575.5	208.0	231.5	6534.0
19	72.5	83.0	338.5	502.5	646.5	816.5	999.0	1020.5	852.5	739.5	332.0	82.0	6485.0
20	--	166.5	327.0	479.5	801.5	859.0	1007.0	926.0	888.5	498.0	167.0	63.5	--
1921	162.0	121.5	431.5	322.0	558.5	876.0	986.0	1024.5	906.5	500.0	393.0	210.0	6491.5
22	55.0	223.0	305.0	524.5	751.0	897.0	985.0	898.0	887.5	528.5	254.0	217.5	6617.0
23	239.5	117.0	161.0	428.5	532.5	877.5	988.0	1032.5	796.0	483.5	143.0	183.5	5982.5
24	35.0	67.5	168.0	440.5	570.0	905.5	1015.5	1120.5	754.5	528.0	253.5	150.5	6009.0
25	15.0	124.5	225.0	493.0	578.5	938.5	1043.5	987.0	887.0	482.0	159.0	56.5	6019.5
26	38.5	148.0	116.0	296.5	596.5	796.0	897.5	976.0	896.5	654.5	143.5	146.5	5706.0
27	145.0	228.0	251.5	543.0	761.5	809.0	935.5	1004.5	828.5	581.0	454.5	104.0	6646.0

Table 63. Continued

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1928	131.0	85.5	266.5	300.0	656.5	800.5	953.5	997.0	726.5	615.5	167.0	72.5	5772.0
29	130.0	37.0	345.5	544.5	618.0	823.5	869.5	977.5	811.0	536.5	121.0	179.5	5993.5
30	65.0	186.5	177.5	553.0	667.0	809.5	1013.0	993.0	795.0	431.5	184.0	33.0	5908.0
1931	61.5	107.0	113.0	340.5	513.0	854.5	1024.0	877.0	891.0	651.5	355.5	155.5	5944.0
32	154.5	275.5	242.5	474.0	654.0	850.0	1018.0	950.0	736.5	394.0	110.5	94.5	5954.0
33	140.0	102.0	256.5	360.5	709.0	790.5	931.0	945.0	879.0	549.0	246.0	255.5	6164.0
34	80.5	127.5	235.0	535.0	672.0	930.5	1046.0	1069.5	771.5	663.5	322.0	83.0	6536.0
35	171.5	83.5	452.5	448.0	644.0	840.5	1000.5	1034.0	754.5	622.5	222.5	55.0	6329.0
36	48.0	102.0	373.5	403.0	685.5	923.0	946.5	1020.0	852.5	429.0	145.5	121.5	6050.0
37	152.5	134.5	178.0	401.0	692.0	900.0	980.5	1021.0	676.5	473.0	179.0	133.0	5921.0
38	110.5	267.5	449.5	438.0	674.5	863.5	966.5	965.0	803.0	626.0	261.0	95.5	6520.0
39	110.0	126.5	323.0	431.5	676.0	889.5	1054.5	1030.0	919.0	593.0	153.0	186.5	6493.0
40	24.0	73.5	301.0	439.5	616.5	764.5	719.5	877.5	685.0	548.0	242.0	147.5	5438.5
1941	103.0	48.5	144.5	488.5	697.0	837.0	954.0	993.0	855.0	693.5	151.0	128.0	6093.5
42	74.5	81.5	246.5	480.0	661.5	865.0	952.0	989.5	726.0	536.0	336.0	121.5	6070.0
43	144.5	164.0	244.0	519.0	772.0	943.0	1006.5	1020.5	720.5	456.0	137.0	123.0	6250.0
44	89.5	261.0	274.0	455.5	647.5	900.0	1010.0	1029.0	790.5	535.0	258.5	40.0	6291.0
45	33.0	194.0	478.5	516.0	673.5	913.0	974.0	995.0	873.0	479.0	387.0	100.0	6617.0
46	83.5	136.0	368.5	593.5	699.0	831.5	986.5	980.0	784.5	580.0	321.5	239.0	6603.5
47	141.5	51.5	160.0	538.5	681.0	894.0	968.0	1079.5	912.5	776.0	173.5	155.0	6531.0
48	68.5	175.0	364.0	517.0	739.0	926.5	1025.0	1048.0	784.0	512.5	201.0	151.0	6511.5
49	115.0	156.0	243.0	371.0	772.5	882.5	972.0	861.0	775.0	513.5	233.5	136.0	6011.0
50	268.5	162.0	218.5	374.5	739.5	826.0	908.0	933.0	732.5	581.5	210.0	88.5	6042.5
1951	102.5	184.0	302.0	417.5	703.0	897.0	838.5	1107.0	817.0	590.5	217.5	169.5	6346.0
52	272.0	155.5	203.5	368.0	661.0	926.5	984.0	1037.0	788.0	374.0	247.5	56.5	6073.5
53	137.5	96.0	430.5	413.0	740.0	993.5	951.5	959.0	811.5	605.0	158.5	47.0	6343.0

Table 63. Continued

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
54	120.5	204.0	256.0	556.0	568.0	878.0	1092.0	1096.0	904.0	636.0	157.0	82.0	6549.5
55	52.5	108.5	381.0	566.0	794.0	828.5	1028.0	981.5	907.0	515.5	228.0	122.0	6512.5
56	74.5	174.0	259.5	420.5	798.5	881.0	1085.5	1079.5	829.0	626.0	189.0	167.0	6584.0
57	114.5	245.5	202.0	468.5	740.5	891.0	1061.0	1019.0	759.5	431.0	212.0	135.0	6279.0
58	19.0	34.5	70.5	359.5	733.0	907.0	1018.0	1013.5	800.5	458.5	269.5	28.0	5711.5
59	68.0	137.0	173.5	389.5	813.5	898.0	1004.0	1011.0	846.5	552.2	117.0	73.5	6084.0
60	92.0	28.5	123.0	500.5	622.5	903.5	1043.0	972.5	826.5	634.0	253.0	53.0	6052.0
1961	25.0	154.0	345.5	344.0	705.5	812.0	952.0	937.5	819.5	484.0	153.0	86.0	5818.0
62	33.5	242.0	173.5	428.0	777.0	892.5	1045.0	1065.5	835.5	628.0	174.5	80.0	6375.0
63	42.0	52.0	338.0	627.5	798.5	934.0	1045.0	1039.0	837.0	677.5	312.5	24.5	6727.5
64	75.5	22.0	250.5	564.5	763.5	917.0	1062.0	1048.0	820.5	445.0	328.0	102.0	6398.5
65	132.0	57.5	135.5	623.0	752.0	898.0	987.5	952.0	855.0	474.0	400.0	78.5	6345.0
66	55.0	64.5	227.5	498.5	709.0	845.5	1086.0	959.5	781.5	450.0	329.0	101.5	6107.5
67	102.0	67.5	414.0	670.0	666.0	917.5	944.5	976.0	730.0	461.0	238.0	112.0	6298.5
68	93.0	34.5	220.0	485.0	704.0	841.0	952.5	1007.0	715.5	529.0	167.5	57.5	5806.5
69	146.0	74.0	106.5	498.5	696.5	889.5	1124.0	1048.0	832.5	579.0	216.0	78.0	6288.5
70	61.0	65.5	199.0	548.0	694.5	881.5	1007.5	1069.0	904.5	447.0	157.0	250.0	6284.5
1971	190.5	147.5	235.5	447.5	670.5	949.5	1044.0	948.5	839.5	644.0	239.0	226.0	6582.0
72	168.0	154.5	355.0	528.5	697.0	906.0	933.0	994.0	917.0	494.5	154.5	51.0	6353.5
73	46.0	84.0	340.0	366.0	669.5	819.0	983.0	906.0	800.0	590.5	430.5	111.5	6146.0
74	121.0	155.5	453.0	460.0	768.5	795.0	973.0	930.5	612.5	517.0	190.0	79.0	6055.0
75	156.0	98.0	280.5	436.0	727.0	823.5	936.0	948.5	685.5	521.5	259.0	127.5	5999.5
76	83.0	263.0	316.5	476.5	549.0	770.5	917.5	919.5	742.0	296.5	102.5	18.0	5454.5
77	4.0	93.5	276.5	458.0	743.0	910.0	1041.0	990.5	846.0	512.0	253.5	79.5	6207.5
78	36.5	15.0	203.0	504.0	731.0	883.5	1065.5	1012.0	820.5	--	327.5	99.5	--
79	45.0	98.5	--	450.5	--	827.5	960.0	935.0	701.5	574.0	138.0	95.5	--
80	85.0	122.0	220.0	369.5	694.5	942.5	1095.5	1045.0	930.5	450.5	206.0	118.5	6279.5

APPENDIX V
(Miscellaneous)

Table 64. Monthly and Annual Streamflow (inches) of La Nana Creek, Nacogdoches, Texas, 1964-84 - Calender Year

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1964	-	-	-	-	-	-	-	-	-	0	0.002	0.03	0.032*
65	0.46	0.92	2.06	0.72	2.86	0.59	0.04	0.001	0.12	0.0002	0.02	0.74	8.5312
66	2.23	1.82	0.74	3.39	3.49	0.26	0.06	0.33	0.08	0.03	0.02	0.10	12.55
67	0.10	0.33	0.29	0.34	0.27	0.76	0.05	0.0007	0	0.0003	0.00002	0.02	2.1610
68	2.40	0.85	1.44	6.36	3.53	1.37	2.46	0.22	0.66	0.11	0.75	3.57	23.72
69	1.16	3.93	5.35	4.96	3.92	0.18	0.02	0.006	0.007	0.03	0.04	0.12	19.723
70	0.19	0.68	1.56	0.68	0.30	0.04	0	0.03	0.03	0.12	0.07	0.05	3.75
1971	0.06	0.15	0.09	0.02	0.19	0.008	0.05	0.02	0.03	0.04	0.12	0.79	1.568
72	1.45	0.80	0.39	0.37	0.15	0.15	0.72	0.04	0.02	0.71	2.09	2.94	9.83
73	5.56	1.42	3.63	4.65	0.89	2.59	0.23	0.15	0.73	1.24	3.24	2.45	26.78
74	5.48	1.96	0.64	0.30	0.29	0.08	0.12	0.07	0.88	0.49	3.05	1.52	14.88
75	2.80	8.18	1.62	1.25	1.67	2.07	0.30	0.12	0.06	0.11	0.20	0.17	18.55
76	0.27	0.79	0.87	0.73	1.05	1.18	0.82	0.02	0.06	0.07	0.10	1.54	7.50
77	1.25	1.98	1.97	0.80	0.24	0.14	0.01	0.13	0.04	0.04	0.09	0.15	6.84
78	1.21	1.33	1.21	0.82	0.52	0.10	0.01	0.01	0.09	0.01	0.58	0.67	6.56
79	5.67	4.34	4.54	2.91	8.63	10.50	0.65	0.17	0.46	0.30	2.26	1.68	42.11
80	2.36	1.98	1.26	2.21	2.74	0.25	0.03	0.04	0.21	0.03	0.10	0.06	11.27
1981	0.09	0.24	0.28	0.07	0.43	0.78	0.59	0.04	1.40	1.25	0.88	0.25	6.30
82	0.92	1.21	0.76	6.27	1.25	0.45	0.31	0.04	0.05	0.33	2.50	6.14	20.23
83	1.46	3.72	2.07	0.73	3.89	1.89	0.18	0.22	0.06	0.03	0.18	2.99	17.42
84	1.14	2.75	2.68	0.57	0.28	0.23	0.40	0.03	0.08	-	-	-	8.16*
Mean	1.81	1.97	1.675	1.908	1.83	1.18	0.34	0.08	0.25	0.247	0.815	1.30	13.699

---

* Values not included in calculating means

Table 65. Hay Production Rate (tons ac^{-1}) and Various Climatic Data (1968-80) for Nacogdoches, Texas

Year	Hay (ton/ac)	Climatic Variables																
		MET	MIT	MAT	RDY	RFL	FFD	TRG	GDD	SRN	SDNT	SMET	SMIT	SMAT	SRDY	SFFD	SGDD	STRG
1968	2.90	64	52	76	104	68.57	232	24	5806	31.98	68	78	65	90	42	182	4748	19
1969	1.20	65	54	78	76	48.78	233	25	6289	18.01	104	76	64	87	32	191	5169	29
1970	2.27	66	54	77	78	36.08	226	21	6284	18.98	87	78	66	90	38	189	5003	39
1971	1.90	66	54	79	86	34.88	231	14	6582	21.60	99	77	66	89	48	144	5096	33
1972	1.99	65	53	77	96	48.67	271	18	6354	27.84	108	77	66	89	49	215	4942	28
1973	2.23	65	53	77	109	35.11	239	17	6146	28.94	80	77	65	88	56	190	4768	22
1974	3.11	65	54	76	104	36.05	233	20	6055	28.88	55	76	64	87	49	192	4596	19
1975	3.52	65	53	76	101	54.47	224	15	5999	23.93	69	75	64	86	52	167	4642	31
1976	3.70	63	51	75	86	37.41	217	9	5454	19.81	62	75	64	86	41	144	4195	32
1977	3.70	65	53	77	67	52.31	254	25	6208	13.47	107	72	61	84	29	180	5042	22
1978	1.80	64	52	75	77	33.92	237	21	5698	9.60	99	77	66	88	28	180	4542	46
1979	2.90	63	52	73	88	52.30	204	26	4825	24.38	85	79	67	91	35	129	4954	17
1980	2.50	65	53	77	78	34.51	259	32	6279	15.66	122	76	65	87	32	197	5188	34

Notes: 1. Hay = Hay production rate (tons ac^{-1}); MET = Annual mean temperature (°F);
MIT = Annual minimum temperature (°F); MAT = Annual maximum temperature (°F);
RDY = Annual total rain days; RFL = Annual total rainfall (inches);
FDD = Annual total frost-free days; TRG = Range in annual mean temperature (°F);
GDD = Annual growing degree days; SRN = Total rainfall in summer (inches);
SDNT = Total days with maximum temperatures of 90°F and above in summer;
SMET = Summer mean temperature (°F); SMIT = Summer minimum temperature (°F)
SMAT = Summer maximum temperature (°F); SRDY = Summer total rain days;
SFFD = Summer frost-free days; STRG = Range in mean temperature during the summer;

2. All values except Hay rate, RFL, SRN, SDNT, SRDY, and SFDD were rounded off.

APPENDIX VI
(Frequency Distribution Models)

FREQUENCY DISTRIBUTION MODELS

Since the occurrence of hydrological and climatological events changes from time to time, many numerical models have been employed to study these changes in terms of probability distribution. Some of the most popular models frequently used in climatological analyses are briefly discussed below:

Normal Distribution

The most important and widely employed continuous distribution in hydrology and climatology is the normal distribution. Its probability density function for observation x is given as below:

$$P(x) = \frac{1}{\sigma\sqrt{2\pi}} \exp \{ - \tfrac{1}{2} (\frac{x - \mu}{\sigma})^2 \} \tag{30}$$

where μ and σ are the population mean and standard deviation, respectively, and are estimated by sample mean $\bar{x}$ and sample standard deviation S_x by the relations:

$$\mu \simeq \bar{x} = \Sigma x/N \tag{31}$$

$$\sigma \simeq S_x = (\Sigma(x - \bar{x})^2/(N - 1))^{\frac{1}{2}} \tag{32}$$

Since all standard tables of the normal distribution are prepared for the distribution with $\mu = 0$, and $\sigma = 1$, the table must be rescaled if the population mean and the standard deviation are other than zero and one, respectively. The rescaled measurement is given by

$$Z = \frac{x - \mu}{\sigma} \tag{33}$$

where Z is the standard normal deviate.

The normal distribution fits well in most hydrological and climatological variables unbounded above or below such as temperature and pressure. It provides better fit for rainfall of longer periods, such as seasonal or annual, than shorter periods. For example, in their probability analysis on 40 years of monthly and annual rainfall data at 34 stations in Texas, Tucker and Griffiths (1965) found that 62% of the annual data fit a normal distribution and 84% of the monthly data fit a square-root normal distribution.

Gumbel Distribution

Gumbel's (1954) approach to fit the Fisher-Tippet Type I extreme distribution is generally expressed in the form:

$$P(X \leq x) = e^{-e^{-y}} \tag{34}$$

where e is the base of Napierian logarithms, P is the probability of an event X equal to or less than x, and y_n, the reduced variate, is given by

$$y = a(x - b) \tag{35}$$

For finite sample size, Gumbel (1954) developed theoretical equations which stated "a" (dispersion parameter) and "b" (mode or location parameter) as

$$b = (\bar{x} - \bar{y}_n)/a \tag{36}$$

$$a = \sigma_n/S_x \tag{37}$$

where $\bar{x}$ = sample mean,

S_x = sample standard deviation,

σ_n = expected standard deviation of the population, and

$\bar{y}_n$ = expected mean of the population.

Substitution for b and a in Equation 35 yields:

$$y = \frac{\sigma_n (x - \bar{x})}{S_x} + \bar{y}_n \quad (38)$$

or

$$x = \bar{x} + \frac{S_x (y - \bar{y}_n)}{\sigma_n} \quad (39)$$

Gumbel has shown that $\bar{y}_n$ and σ_n are 0.57722 (Euler's Constant) and $\pi / \sqrt{6}$ respectively, in infinite sample. For finite sample size, the estimates of $\bar{y}_n$ and σ_n are a function of the sample size which can be obtained by the following equations:

$$y = -\ln(-\ln P) \quad (40)$$

$$\bar{y}_n = (\Sigma\, y)/N \quad (41)$$

$$\bar{y}^2 = (\Sigma\, y^2)/N \quad (42)$$

$$\sigma_n = (\bar{y}^2 - (\bar{y}_n)^2)^{\frac{1}{2}} \quad (43)$$

where P = probability obtained by Kimball's plotting equation, and

N = sample size.

Chow (1951) has shown that the frequency analysis in hydrology can be written in the general form as:

$$\hat{X} = \bar{X} + K_f S_x \quad (44)$$

where K_f is the so-called frequency factor depending on the frequency models. From equation 39, the K_f values for the Gumbel's extreme distribution is

$$K_f = (y - \bar{y}_n)/\sigma_n \qquad (45)$$

The $\bar{y}_n$ and σ_n values for samples size, N = 10 - 109, with an accuracy of 0.000001, and the y values for 111 different return periods with an accuracy of 0.0001 are given in Chang's (1982) book. In practical application, the expected x of different return periods (T) can be calculated using Equation 44 with K_f value obtained from Equation 45. The expected X values plotted in the Gumbel extreme paper appears as a straight line. The relationship between T and P is

$$T = 1/(1 - P) \qquad (46)$$

or

$$P = 1 - 1/T \qquad (47)$$

The Gumbel extreme distribution has a wide application in the hydrological analysis. In West Virginia, the model was found to fit the distributions of extreme snowfall (Chang and Boyer, 1980) better than five other distribution models.

Log-Normal Distribution

Many attempts have been made to normalize the probability distribution by transforming the variate x into different scales. The transformation of x into its logarithmic value is one of the most commonly employed methods in hydrology. The probability density function is

$$P(x) = \frac{1}{\sigma_n \sqrt{2\pi}} e^{-(y - \mu_y)^2/2\sigma_y} \qquad (48)$$

where y = ln(X), μ_y is the mean of y, and σ_y is the standard deviation of y. Chow (1954, 1964) has shown that the frequency factor K_f (Equation

44) of the log-normal distribution is a function of return period and the coefficient of variation (C_v) of the sample, or

$$K_f = \frac{\text{Exp}\ ((\sigma_y)(Z_p) - \sigma_y^2/2\ ) - 1}{(\text{Exp}(\sigma^2_y) - 1)^{\frac{1}{2}}} \tag{49}$$

$$= \frac{\text{Exp}((\sigma_y)(Z_p) - \sigma_y^2/2) - 1}{C_v} \tag{50}$$

where $C_v = S_x/\bar{x}$,

Z_p = normal variate corresponding to the probability equal to or greater than x, and

$\sigma_y^2 = \ln(C_v^2 + 1)$

Chow (1964) prepared a table of K_f value as a function of T, C_v, or C_s (coefficient of skewness). He showed that

$$C_s = 3C_v + C_v^3 \tag{51}$$

and the Type I Extreme distribution is essentially a special case of the log-normal distribution when $C_s = 1.139$ or $C_v = 0.364$. For C_s or $C_v = 0$, the sample follows normal distribution with the mean at 50% probability. Using K_f values from Chow's (1964) table or from Equation 50, the predicted values (Equation 44) plotted on the log-probability paper appears as a straight line.

Log - Pearson Type III Distribution

The distribution is suggested by the U.S. Water Resources Council (1967) as the standard method for annual flood flow frequency analysis. It is the Pearson Type III distribution with the input data logarithmically transformed, then use the log-transformed set of data to compute mean, standard deviation, and coefficient of skewness. The frequency factor (K_f) of Equation 45, a function of probability level and coefficient of skewness (C_s) of Equation 51, can be found in a hydrology textbook or in Chang's (1982) work. The expected flood flows can be calculated by Equation 44 using transformed mean and standard deviation. Finally, the calculated flood flows, which are in log unit, is antiloged to convert the flood flows into observation units.

SOME STATISTICAL ANALYSES OF THE CLIMATE OF NACOGDOCHES, TEXAS FOR APPLICATIONS IN NATURAL RESOURCES MANAGEMENT

APPROVED:

Mingteh Chang

Dr. Mingteh Chang, Thesis Director

Hershel C Reeves

Dr. Hershel C. Reeves

Kenneth G. Watterston

Dr. Kenneth G. Watterston

James V Reese

Dr. James V. Reese, Acting
Dean of the Graduate School

SOME STATISTICAL ANALYSES OF THE CLIMATE OF NACOGDOCHES, TEXAS FOR APPLICATIONS IN NATURAL RESOURCES MANAGEMENT

BY

Alexander K. Sayok, B.S.F.

Presented to the Faculty of the Graduate School of
Stephen F. Austin State University
In Partial Fulfillment
of the Requirements

For the Degree of
Master of Science in Forestry

STEPHEN F. AUSTIN STATE UNIVERSITY
DECEMBER 1986

ABSTRACT

Analyses of a variety of climatic variables generated from 80 years (1901-80) of daily precipitation and temperature data collected by the National Weather Service showed that Nacogdoches is characterized by a humid subtropical climate with an average annual precipitation and temperature of 45.96 inches and 65.5°F, respectively. The summer is warm and dry with mean maximum temperature of 91.6°F while winter is mild with mean minimum temperature of 38°F. There were no statistical differences between mean annual temperature and precipitation on the 1951-80 and 1901-80 periods or between any 2 normal periods. Rain day occurred once in every 4 days with 32% of rain days lasted only a day. The longest annual dry spells ranged from 13 to 53 days with an average of 22 days. The earliest and latest dates of frost recorded at Nacogdoches were October 15 and April 15, respectively. Recorded maximum and minimum temperatures recorded in this area were 110°F and -4.0°F, respectively. Regression equations have been developed to estimate mean annual streamflow of La Nana Creek, pan evaporation, daily temperature, maximum storm intensity, and hay production. Runoff coefficient for La Nana Creek was 0.30 and maximum flood stage was 286.41 ft above sea level. Flow duration patterns of the Creek may have been altered significantly by urbanization in the recent 9 years.

VITA

Alexander Kiew ak Sayok was born in Bau, Sarawak, Malaysia, on September 14, 1955, the son of Sayok Lingo and Rose Sarang. After completing his secondary education at Bau Government Secondary School, Sarawak, in 1974, he joined the Agriculture Department Sarawak as a Junior Agricultural Assistant. In June 1976, he pursued his tertiary education at Universiti Pertanian Malaysia, Kampus Sarawak and graduated in April 1980 with Diploma Perhutanan (Diploma in Forestry). He was later employed by the Forest Department as a Forest Officer. In June 1982, he went to study at Louisiana State University, Baton Rouge and graduated with a Bachelor of Science in Forestry in December 1984. In January 1985, he joined the Graduate School at Stephen F. Austin State University.

He is married to Maria Ng Boo Yun; they have a son, Maurice.

Permanent Address: No. 3, Kampung Peros Krokong,
94000 Bau, Sarawak, Malaysia

This thesis was typed by Alexander K. Sayok.