United States
Department of
Agriculture

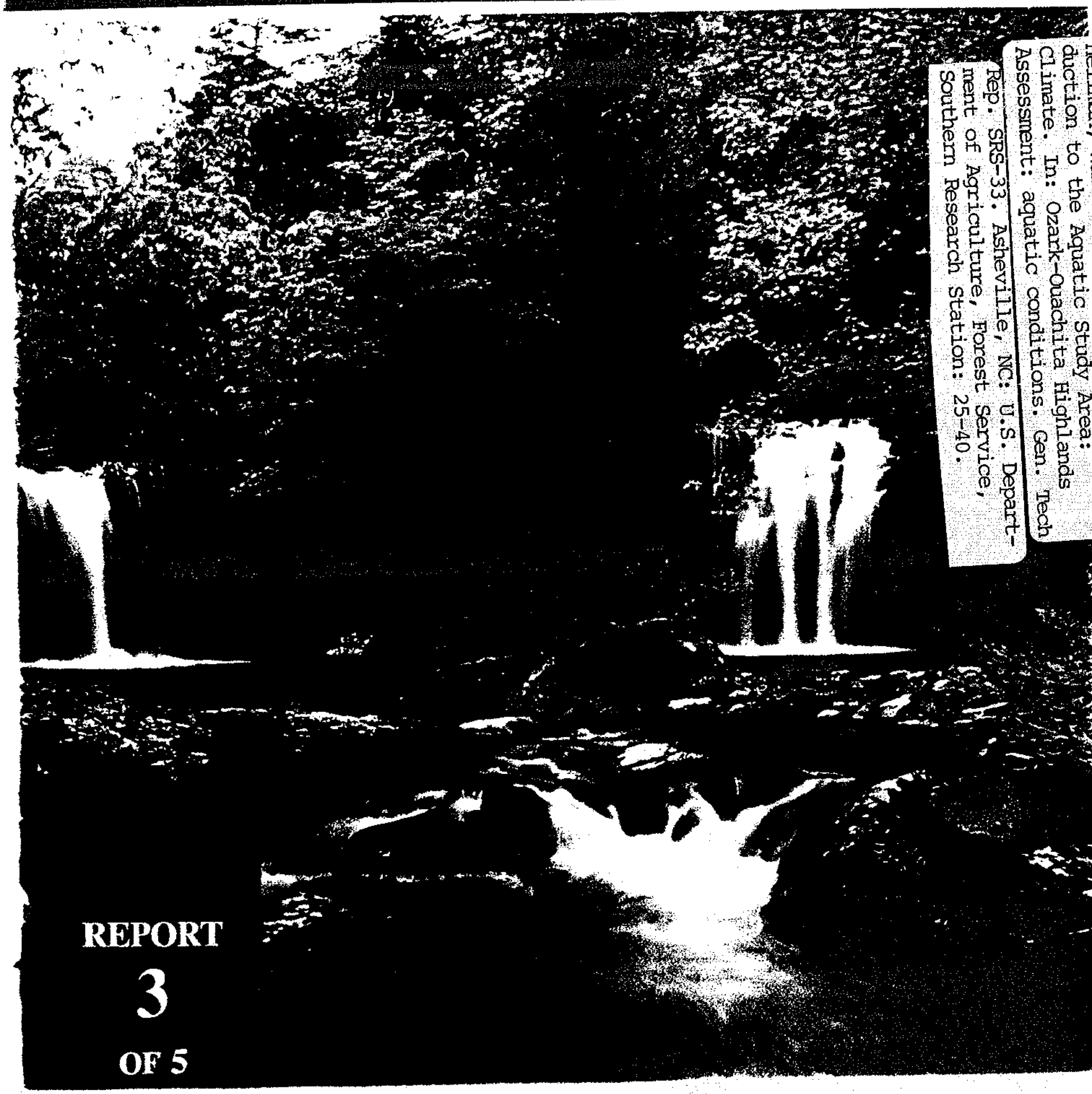
Forest Service

Southern
Research Station

General Technical
Report SRS-33

Ozark-Ouachita Highlands Assessment

Aquatic Conditions



REPORT
3
OF 5

Contributors to This Report

Assessment Team Leader

William F. Pell, Ecologist, USDA Forest Service, Hot Springs, AR

Aquatic-Atmospheric Team Leader

J. Alan Clingenpeel, Forest Hydrologist, USDA Forest Service, Ouachita National Forest, Hot Springs, AR

Authors

Chapter 1: Introduction to the Aquatic Study Area

Physiography: Phillip D. Hays
Major River Basins: Richard W. Bell
Major Lakes: Richard W. Standage
Ground Water: Phillip D. Hays
Climate: Warren E. Heilman
Runoff: Richard W. Bell
Geology: Phillip D. Hays, David A. Freiwald
Soils: Len Weeks
Changing Land Conditions : Phillip D. Hays

Chapter 2: Status of Aquatic Resources

Surface Water Quality (Streams): Richard W. Bell
Surface Water Quality (Lakes): Richard W. Standage
Ground Water Quality: Phillip D. Hays, David A. Freiwald
Diversity of Fishes: Melvin L. Warren, Jr., Lisa Hlass
Diversity of Mussels: John L. Harris
Diversity of Crayfishes: Melvin L. Warren, Jr., Henry W. Robison, Karen Tinkle
Diversity of Aquatic Insects: Betty G. Crump, Melvin L. Warren, Jr.
Endangered, Threatened, and Other Aquatic Species of Special Concern: Melvin L. Warren, Jr., Karen Tinkle
Commercially and Recreationally Important Species: Richard W. Standage
Management Indicator Species: Richard W. Standage
Aquatic Habitats: Melvin L. Warren, Jr., J. Alan Clingenpeel
Riparian Areas: J. Alan Clingenpeel
Wetlands: Len Weeks

Chert is the only formation in the Ouachita Mountains that is an aquifer throughout its area of occurrence.

Most wells completed in the Ouachita Mountains are less than 200 ft deep, though some wells with large yields are completed to depths between 400 and 600 ft. Aquifer tests at 10 locations across the area show that transmissivity generally is less than 135 ft^2/d and is often less than 6.7 ft^2/d. Specific capacities range from 0.013 to 0.13 ft^2/min after 90 minutes of pumping (Albin 1965, Halberg and others 1968, Cordova 1963).

Climate

The Ozark-Ouachita Highlands region in Missouri, Arkansas, and Oklahoma is characterized by a temperate climate due to its mid-latitude location in the interior of the North American continent. Air masses that move across the Assessment area generally originate from the Eastern Pacific Ocean, Western United States, the Gulf of Mexico, and Canada. The sources of moisture for the region are the Pacific Ocean and the Gulf of Mexico. Because of the general circulation characteristics of the atmosphere, weather systems generally move from west to east across the Highlands. The average temperature and precipitation patterns over the region are the result of these weather systems moving across the region as well as interactions between topography and atmosphere that introduce additional temperature and precipitation variations. For example, mountain induced lifting of air can affect local levels of precipitation. As air rises over a mountain, it cools and condenses, thus enhancing precipitation on the windward side of mountains and producing drier conditions on the leeward side.

This section provides an overview of the monthly average temperature and precipitation patterns over the Assessment area using data from the National Climate Data Center. It also includes a discussion of extreme temperature, precipitation, and wind (e.g., tornado) events (using data obtained from the National Severe Storms Laboratory), which are particularly important atmospheric disturbance factors that impact the region's natural resources and human population. The patterns of monthly average temperatures and precipitation along with the patterns of extreme temperature, precipitation, and wind events are discussed in the context of the region's topography and seasonal variations in atmospheric circulation (wind and weather patterns).

Monthly Average Maximum Temperature Patterns

Figure 1.15 shows the average daily maximum temperatures for the Assessment area for January, April, July, and October. The months of December, January, February, and March are characterized by very large north-to-south variations in maximum temperature. For example, in January, average maximum temperatures range from about 34 °F in northern Missouri to about 54 °F in southern Arkansas. Within the Assessment area, the largest spatial variations in maximum temperature in the winter exist along the Arkansas-Missouri border north of the Boston Mountains in Arkansas and in central Missouri just to the north of the Ozark Plateaus. These topographic features tend to inhibit the southward movement of cold air masses from the Northern United States into the southern sections of the Assessment area and pool the cold air so that relatively large temperature gradients can develop in the vicinity of these topographic features. Very little east-to-west variation in monthly average maximum temperatures is observed in winter except for east of the Ouachita Mountains in Arkansas where warm air tends to protrude northward. This tongue of slightly higher temperatures is evident in January but is most significant in March.

With the onset of the spring months and higher daily maximum temperatures, the large gradients in monthly average maximum temperatures begin to diminish. Daily maximum temperatures in northern Missouri increase more significantly than temperatures in southern Arkansas, resulting in an overall decrease in the north-to-south average maximum temperature range from winter to spring. The maximum temperature range generally decreases through the spring months. In April, average maximum temperatures range from about 64 °F in northern Missouri to about 76 °F in southern Arkansas (fig. 1.15). By June, average maximum temperatures range from about 83 °F in northern Missouri to near 90 °F in southeastern Arkansas. Even though the north-to-south temperature variations are smaller in the spring than in the winter, the most significant variations

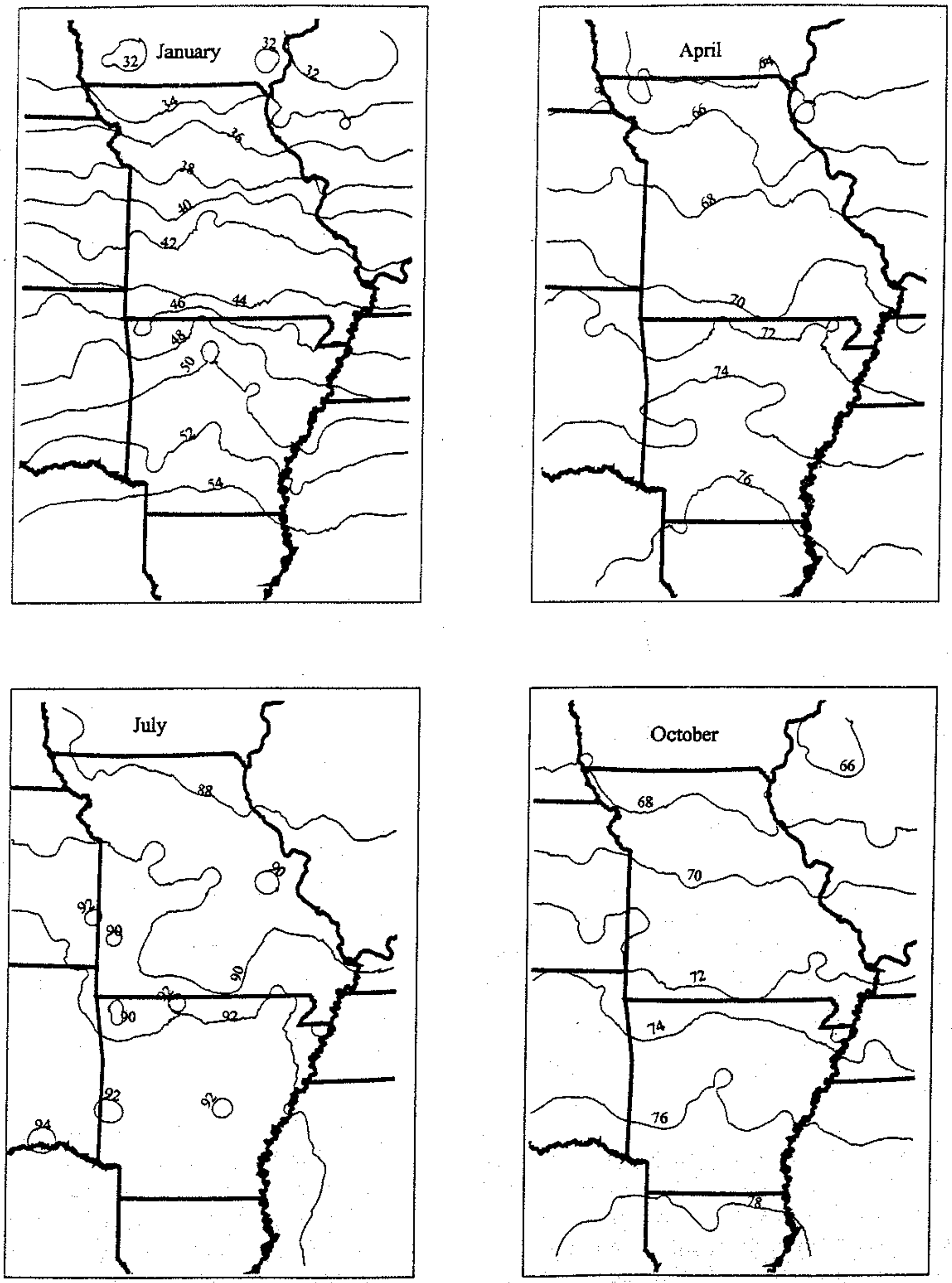


Figure 1.15—Average daily maximum temperatures (°F) during January, April, July, and October for the region within and surrounding the Ozark-Ouachita Highlands Assessment area.

throughout the spring still occur mainly along the Missouri-Arkansas border. As in the winter months, east-to-west variations in average maximum temperatures across the Assessment area are minimal.

During the summer, very warm conditions usually develop over the southern Great Plains. Average maximum daily temperatures exceed 94 °F in eastern Oklahoma and northeastern Texas in July and August. The very warm air masses that dominate the southern Great Plains during the summer also influence maximum daily temperatures in the western sections of the Assessment area, resulting in a general southwest-to-northeast temperature gradient over the Highlands, with average maximum daily temperatures ranging from about 94 °F in southeastern Oklahoma to about 88 °F in west-central Illinois in July (fig. 1.15). The terrain effects on temperature over the Ozark Plateaus are evident during the summer, with typically lower daily maximum temperatures occurring over the plateaus and a significant average maximum temperature gradient existing near the border area of northeastern Oklahoma, northwestern Arkansas, and southwestern Missouri. The elevation variations associated with the Ozark Plateaus and Ouachita Mountains tend to confine the warmest air to areas west of the Assessment area during the summer. With the onset of cooler conditions in the southern Great Plains in September, the overall maximum temperature pattern over the Highlands returns to one that is similar to the late spring pattern. East-to-west maximum temperature variations decrease in late summer and early fall, although the Ozark Plateaus still cause noticeable temperature variations from northeastern Oklahoma into southwestern Missouri and northwestern Arkansas.

Through September, October, and November, maximum daily temperatures decrease throughout the Assessment area. The decreases are more pronounced in the northern sections of the region than in the southern sections, resulting in significant temperature gradients in the north-south direction like those occurring during the winter. For example, in September, the average maximum temperature ranges from about 78 °F in northern Missouri to about 87 °F in southern Arkansas. However, in November, the average maximum temperature ranges from about 51 °F in northern Missouri to about 66 °F in southern Arkansas. The October average maximum temperature pattern is shown in fig. 1.15.

Monthly Average Minimum Temperature Patterns

Average minimum temperature patterns over the Assessment area exhibit many of the same characteristics as the maximum temperature patterns, although distinct differences exist. In the winter, most of the variation in average minimum temperature over the region is in the north-south direction as it is for the average maximum temperatures. However, the east-to-west temperature variations in Arkansas are also significant, with average minimum temperatures in the Mississippi Alluvial Plain about 3 to 4 °F higher than minimum temperatures in the Ouachita Mountains region. Figure 1.16 shows the average January minimum temperature pattern over the area that encompasses the Assessment area and suggests the importance of topography and bodies of water in keeping nocturnal temperatures higher in the Mississippi Alluvial Plain than in the Ouachita Mountains and Ozark Plateaus. Very strong northwest-to-southeast gradients in the average minimum temperature field are observed from north central Arkansas to southeastern Missouri in the winter. Average January minimum temperatures range from about 14 °F in northern Missouri to about 32 °F in southern Arkansas. Average minimum temperatures remain below freezing during December, January, and February for all of the Assessment area except for the southernmost counties.

The average minimum temperature patterns over the Assessment area during the spring months of April, May, and June are similar to the patterns during the winter months, with relatively high minimum temperatures occurring in the Mississippi Alluvial Plain in Arkansas and relatively low minimum temperatures extending from the Ouachita Mountains northeastward to eastern Missouri. Average minimum temperatures for the month of April are shown in fig. 1.16. The strong northwest-to-southeast gradient in average minimum temperature is evident from north central Arkansas to southeastern Missouri. The lowest minimum temperatures during the spring months are usually observed over the eastern half of Missouri. In May, for example, average minimum

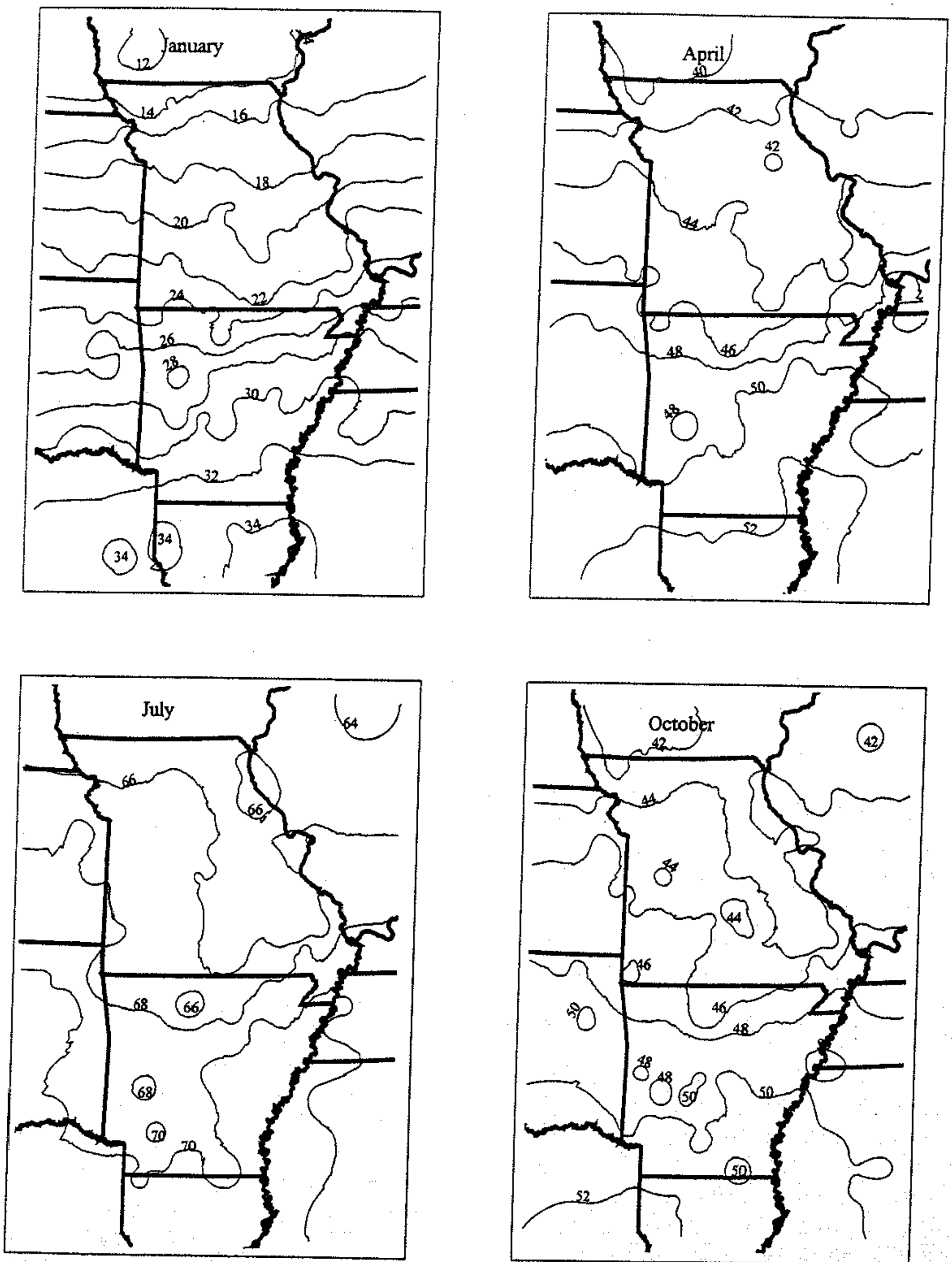


Figure 1.16—Average daily minimum temperatures (°F) during January, April, July, and October for the region within and surrounding the Ozark-Ouachita Highlands Assessment area.

temperatures are about 51 °F in eastern Missouri (including much of the Mark Twain National Forest) compared to average minimum temperatures of about 60 °F in nearby northeastern Arkansas.

The highest minimum temperatures in the Assessment area typically occur during the month of July, ranging from about 66 °F in parts of eastern and northern Missouri to about 70 °F in the Mississippi Alluvial Plain in eastern Arkansas and in eastern Oklahoma (fig. 1.16). Through the summer, the spatial pattern of minimum temperatures in the Assessment area is very similar to the spring pattern.

The months of October (fig. 1.16), November, and December bring a return to the wintertime pattern of average minimum temperatures, when relatively strong north-to-south gradients dominate the temperature field. The prominent tongue of low average minimum temperatures extending southward through eastern Missouri in early fall becomes less prominent later in the fall. The significant minimum temperature variations in the east-west direction become less significant as winter approaches, while the average north-to-south minimum temperature variations increase dramatically. By December, the average minimum temperatures over the region range from about 20 °F in northern Missouri to about 35 °F in southern Arkansas. This typical minimum temperature range is much greater than the summertime range in minimum temperatures of about 6 to 8 °F over the same region. Diurnal (day/night) variations are much more significant during the late fall and winter than during the summer because the atmospheric moisture content is much less when the air is cold. Atmospheric moisture tends to moderate diurnal temperature fluctuations.

Extreme Maximum Temperature Occurrences

Average monthly or seasonal temperature variations help determine what types of vegetation and wildlife thrive under normal conditions. However, extreme climatic events can introduce stresses that can affect the health and productivity of ecosystems. The occurrence of temperature extremes is one type of climatic disturbance that can affect the region's natural resources. "Extreme temperature" is defined as an occurrence of daily maximum or minimum temperature greater than 20 °F above or below normal for that particular day. Using this definition, the Aquatic Team compiled the number of abnormally high and low daily maximum temperature occurrences during the 1950 through 1993 period for the region encompassing the Assessment area.

Figure 1.17 shows the total number of days from 1950 through 1993 when the maximum temperature was observed to be 20 °F above or below normal over and surrounding the Assessment area. As shown in fig. 1.17, most days during which maximum temperature exceeds 20 °F above normal happen in east-central Missouri at the northern edge of the Assessment area. More than 500 extreme maximum temperature events occurred in this area from 1950 through 1993 (corresponding to about 11 events per year). Fewer than 100 extreme maximum temperature events occurred over the southern sections of the Assessment area (corresponding to about 2 events per year). Figure 1.17 suggests that the probability of extreme maximum temperature occurrences increases significantly in the region between northern Arkansas and central Missouri. Most of these extreme maximum temperature events happen during the late fall and winter. Analyses of monthly extreme maximum temperature events during winter from 1950 through 1993 show that the number of extreme events in January ranged from about 40 over the Ouachita Mountains to about 110 over east-central Missouri north of the Ozark Plateaus (including Boone and Calloway Counties). During the month of February from 1950 through 1993, the number of events ranged from about 25 over much of southern Arkansas to 85 over the same east-central area in Missouri. In March, the events ranged from about 15 to 110.

Very few episodes of anomalously (unusually) high maximum temperatures have occurred over the Assessment area during the months of May through September. Over the entire region, fewer than eight events occurred during each month between 1950 and 1993. In July, for example, the largest number of episodes of anomalously high daily maximum temperatures over the region was seven in west-central Missouri. It is not until November that the probabilities of occurrence of extreme maximum temperature increase significantly.

Figure 1.17 also shows the total number of anomalously low maximum temperature events (daily maximum temperatures 20 °F or more below normal) that occurred from 1950 through 1993 over the Assessment area. Most of these extreme temperature events tend to occur in central Missouri and eastern Kansas and are least

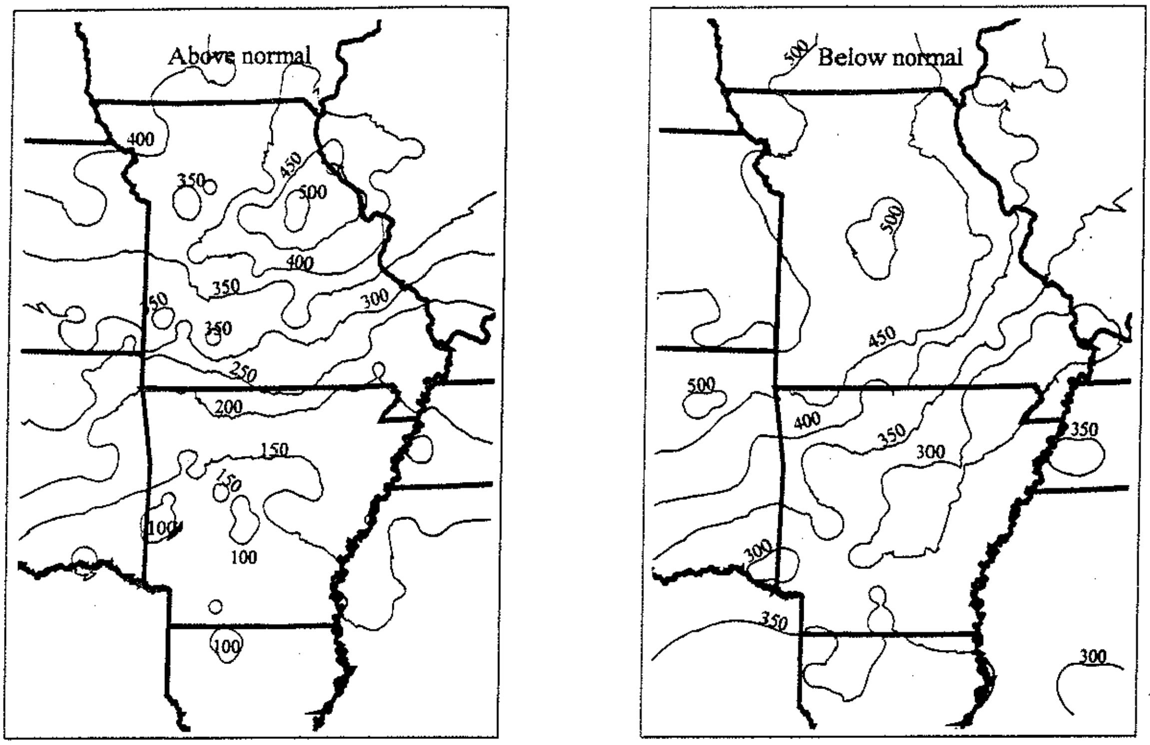


Figure 1.17—Total number of occurrences where daily maximum temperatures were 20 °F above normal and 20 °F below normal in the region within and surrounding the Ozark-Ouachita Highlands Assessment area from 1950 through 1993.

likely to occur in southeastern Missouri and in the far southwestern section of Arkansas. As with anomalously high maximum temperature events, the low maximum temperature events tend to occur during the late fall and winter. However, for the entire region as a whole, there is a tendency for more anomalously low maximum temperature events than high temperature events. Figure 1.17 indicates that more than 500 extreme low maximum temperature events occurred in central Missouri from 1950 through 1993 (about 11 events per year) while about 300 events occurred in northeastern Arkansas over the same period (less than 7 events per year). The location and month of the highest probability of anomalously low maximum temperature events shifts from northwestern and western Missouri and eastern Kansas in January to central Missouri in March and April. From May until October, extremely low maximum temperature occurrences, as defined here, are fairly rare (averaging less than 0.5 events per year).

Extreme Minimum Temperature Occurrences

Using the same definition of "extreme" for determining anomalously high or low minimum temperature occurrences as that used for maximum temperatures, the Aquatic Team developed maps (fig. 1.18) of the total number of occurrences of extreme minimum temperatures over the Assessment area. Figure 1.18 shows the pattern of anomalously high minimum temperature occurrences over the Assessment area based on minimum temperature data from 1950 through 1993. Numerous relative maximums appear over much of the Assessment area, which is a reflection of the influence of specific observation sites and the limitations of the kriging (statistical interpolation method) process in determining temperatures at locations between observation sites over the region. However, the larger scale pattern over the region suggests more extreme events over the western half of Arkansas and the southern half of Missouri. Fewer extremely high minimum temperature events tend to occur in the Mississippi Alluvial Plain in Arkansas and north of the Missouri River in Missouri.

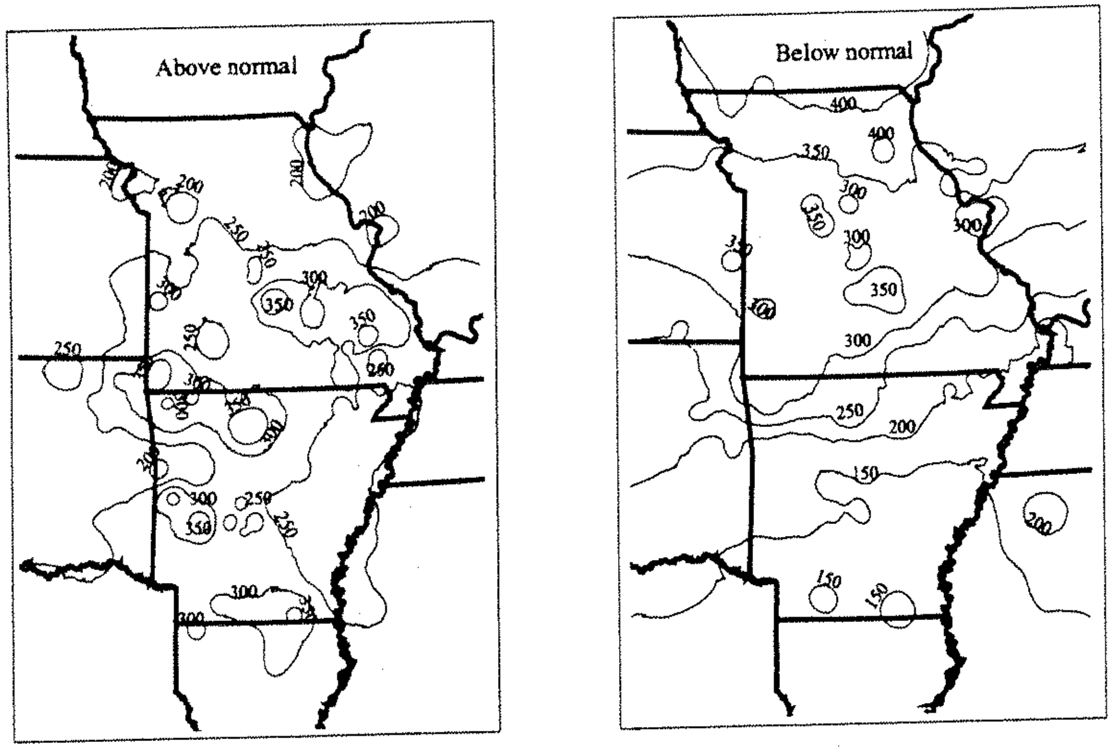


Figure 1.18—Total number of occurrences where daily minimum temperatures were 20 °F above normal and 20 °F below normal in the region within and surrounding the Ozark-Ouachita Highlands Assessment area from 1950 through 1993.

As with the extreme maximum temperature events, ›st extreme minimum temperature events tend to :ur during the late fall and winter; extremely high nimum temperatures are most likely to occur in ıuary. From 1950 through 1993, the number of treme minimum temperature episodes in January ıged from about 90 (average of about 2 events) in the · southeastern sections of Arkansas to about 40 to 45 verage of about 1 event) in the northern half of issouri. Extreme events over the Assessment area are ıch less likely from April through the spring, summer, d early fall. No more than one extreme episode curred from 1950 through 1993 at any observation site the region during the months of June, July, and August.

The number of extreme cold temperature events over ɜ Assessment area during the 44 years from 1950 rough 1993 is also shown in figure 1.18. There is a neral north-to-south decrease in the number of these treme events over the region, with a significant adient existing over the Ozark Plateaus. Northern Missouri experienced about 400 extremely low minimum temperature events during this 44-year period (about 9 events per year), while the southern half of Arkansas generally experienced less than 150 events (about 3 events per year). Over the Ozark Plateaus, the number of extreme events differed by about 100 over a distance of about 50 to 100 mi. The influence of cold air masses moving southward from Canada and the northern United States into the Assessment area is evident in the relatively large number of extreme minimum temperature events that happen during the winter. Most of the extremely cold episodes happen in December, January, and February. For example, from 1950 through 1993, northern Missouri experienced about 80 to 110 events in December, about 90 to 110 events in January, and about 70 to 90 events in February. During those same 44 years, southern Arkansas experienced about 25 to 30, 25 to 40, and 15 to 20 events in those months, respectively. With the onset of warmer conditions and higher atmospheric moisture in the spring, fewer extremely low minimum temperature episodes occur. Through the late spring, summer, and early fall, extreme minimum temperature episodes are rare over the Assessment area (less than one episode every 2 years from May to October). In November, the probability of extreme minimum temperatures increases again under the colder and normally lower atmospheric moisture conditions of late fall.

Average Monthly Precipitation Patterns

Oceans are the primary sources of atmospheric moisture that lead to precipitation events over the Earth's surface. Evaporation from inland lakes and evapotranspiration (total water loss from soil from direct evaporation and transpiration of plant moisture) from vegetation can also contribute to the moisture content of the atmosphere. Because warm air has a greater capacity for holding water vapor than cold air, air masses that originate over the warm tropical zones of oceans are responsible for the evaporation and transport of more precipitable water (water that may fall as rain or frozen precipitation) than air masses originating over the cold sections of oceans (Hirschboeck 1991). On an annual basis, the precipitable water vapor content of the atmosphere is greatest over the Southeastern United States and decreases moving northward and westward. During the summer, precipitable water contents increase over the entire United States. In July, average atmospheric precipitable water vapor content over the Assessment area is about 1.6 inches (in.), compared to average July values of about 1.9 in. and 0.7 in. over Florida and the northwestern United States, respectively (Hirschboeck 1991). The primary sources of moisture that lead to higher average precipitation over the southeastern United States, including the Assessment area, are the Gulf of Mexico and the western Atlantic Ocean. Water vapor carried aloft is transported northward by upper level winds over much of the Eastern United States from the Gulf of Mexico. The transport of water vapor by weather systems is most prominent during the spring and summer (Hirschboeck 1991).

Average yearly precipitation over the Assessment area and surrounding areas reflects the large-scale, northwest-to-southeast variation in precipitable water over the United States, with southern Arkansas averaging more than 55 in. of precipitation while northern Missouri and eastern Kansas average about 35 in./year (fig. 1.19). The topography of the Assessment area also plays a significant role in influencing precipitation in the region. A yearly average maximum of more than 55 in. of precipitation can be found in parts of the Ouachita Mountains. The decrease in yearly precipitation between Arkansas and eastern Oklahoma is quite significant. Throughout the central sections of the Assessment area, precipitation is about 40 to 45 in./year.

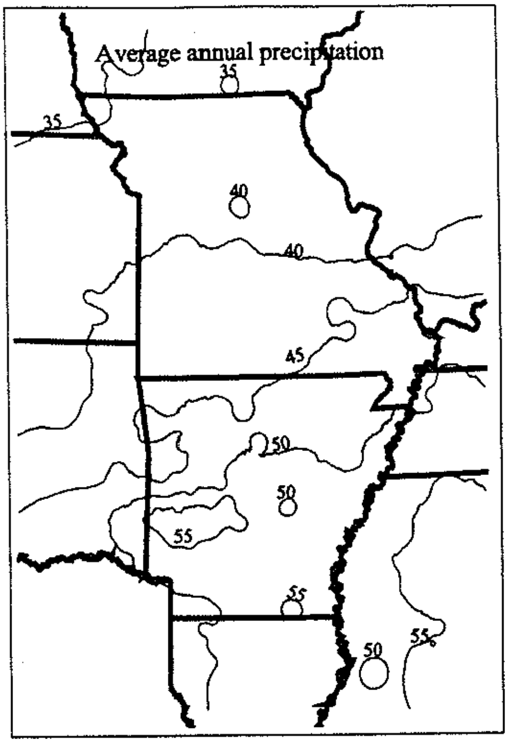


Figure 1.19—Average yearly precipitation (in inches) in the region within and surrounding the Ozark-Ouachita Highlands Assessment area.

Figure 1.20 shows the average precipitation over the Assessment area for January, April, July, and October. During the winter, a very strong northwest-to-southeast gradient in precipitation exists over the region. In January, amounts range from about 1 inch in northwestern Missouri to more than 4.5 in. in southeastern Arkansas (fig. 1.20). The spatial change in precipitation is most significant in Arkansas and southeastern Missouri. From January to March, average monthly precipitation generally increases over the region, especially in Missouri and over the Ouachita Mountains in Arkansas. In March, precipitation ranges from 2.5 in. in northwestern Missouri to more than 5.5 in. over the Ouachita Mountains.

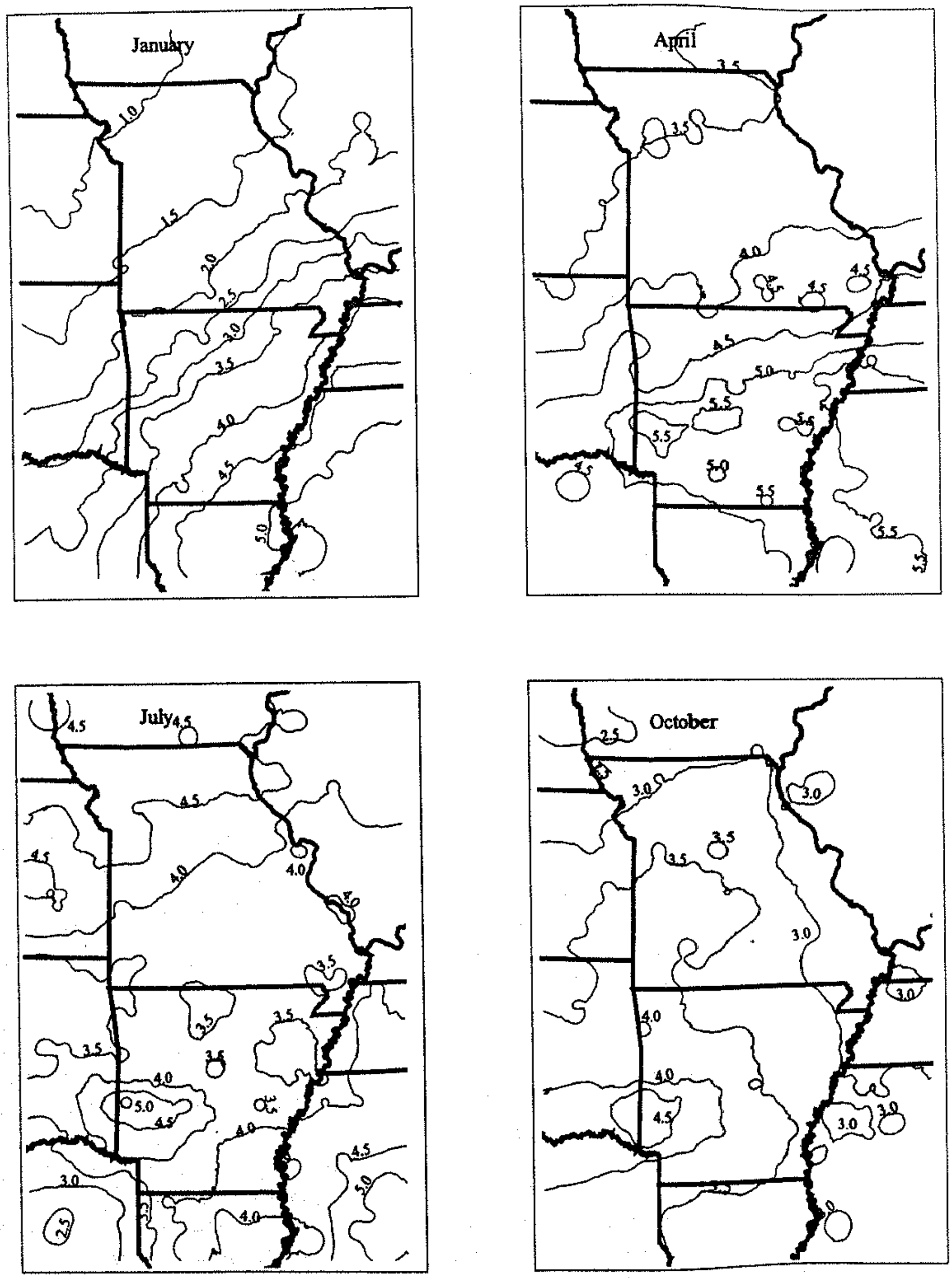


Figure 1.20—Average monthly precipitation (in inches) during January, April, July, and October in the region within and surrounding the Ozark-Ouachita Highlands Assessment area.

With the onset of higher temperatures during the spring months and more convective precipitation events (heat-induced cloud formation with associated rainfall), the average monthly precipitation patterns change dramatically from the wintertime pattern. In April and May, the area of maximum precipitation over the Assessment area shifts to the west, while precipitation over Missouri continues to increase. In April (fig. 1.20), average precipitation totals range from about 3.5 to 4.5 in. in Missouri and from about 4.0 to 5.5 in. in Arkansas. The peak in total precipitation shifts to west-central Arkansas and eastern Oklahoma in May, with amounts exceeding 6 in. in this area. The increase in convective precipitation events over the southern and central Great Plains during the spring leads to a general increase in monthly precipitation from east to west over the region. In June, the driest sections of the Assessment area generally can be found in eastern Missouri and eastern Arkansas—where precipitation totals for the month average less than 4 in.—and northeastern Arkansas and southern Missouri where there is less than 3.5 in. These totals greatly differ from precipitation totals exceeding 5 in. in western Missouri and eastern Kansas. Low precipitation also occurs over the Arkansas Valley between the Boston and Ouachita Mountains in western Arkansas; this area receives about 3.5 to 4.0 in. of rain in June.

During most of the summer, more rain tends to fall in northern Missouri than in any other part of the Assessment area, except in July when the southern slopes of the Ouachita Mountains tend to experience a peak in precipitation as well (fig. 1.20). Typical monthly precipitation totals range from about 4.5 in. in northern Missouri to 3.5 to 4.0 in. over the rest of the Assessment area in July, excluding the Ouachita Mountains region where precipitation totals in July tend to exceed 4.5 in. A sharp decrease in precipitation is evident moving southwestward into northeastern Texas, where totals in July fall below 2.5 in. By late summer, the wettest portions of the Assessment area are again the western sections of Missouri and Arkansas. In September, average precipitation ranges from 3.5 to 4.0 in. over the eastern half of Missouri and Arkansas. Average rainfall is a bit higher at 4.5 to 5.0 in. over the far western sections of Missouri and Arkansas and the far eastern sections of Kansas and Oklahoma. The east-to-west gradient in precipitation in September is similar to the precipitation gradient observed in June.

From October (fig. 1.20) to December, the location of the peak monthly precipitation moves from the southern slopes of the Ouachita Mountains to the far southeastern section of Arkansas and into Mississippi and Louisiana. By late fall, the east-to-west gradient in precipitation observed during the late summer and early fall is replaced by the normal wintertime northwest-to-southeast gradient. The relative maximum precipitation in southwestern Arkansas (> 4.5 in.) moves slightly eastward in November and increases to about 5.5 in. Average precipitation totals in November also decrease quite rapidly from southeastern Missouri (~ 4.5 in.) to northwestern Missouri (~ 1.8 in.). Most of Arkansas experiences between 4 to 5 in. of precipitation in November. December brings an overall reduction in precipitation over the entire region, ranging from less than 1.5 in. in northwestern Missouri to about 5 in. in the far southeastern sections of Arkansas. Average precipitation in December shows significant northwest-to-southeast variations over the entire region, with the largest northwest-to-southeast variation existing along a line from west-central Arkansas to north-central Arkansas.

Extreme Precipitation Occurrences

Extreme precipitation events in the Assessment area can lead to floods that can have a profound effect on the region's natural resources. For example, floods can decrease nutrient, trace metal, and organic chemical concentrations in streams and deposit gravel in streambeds, which can enhance fish spawning (USDI GS 1991). Flooding can increase the concentrations of contaminants in reservoirs and increase algal blooms (noticeable growth of fresh water algae) within them as a result of enhanced nutrient concentrations. Floods also can deposit large amounts of sediment on croplands, at times destroying food crops. Finally, property damage associated with extreme precipitation events and flooding can create severe economic stress on a region.

Extreme precipitation events that can lead to flooding depend on the amount of precipitable atmospheric water vapor present coupled with an uplift mechanism that can steer water vapor aloft to higher altitudes where condensation can occur, thereby producing clouds and eventual precipitation (Hirschboeck 1991). The lifting of moist air can be accomplished through (1) convectional processes like thunderstorms, mesoscale convective complexes (organized, multiple-celled thunderstorm systems), and tropical cyclones; (2) the large-scale convergence of air masses and associated extratropical cyclones and frontal passages; and (3) orographic (mountain-related) effects. All of these mechanisms can play a role in the occurrence of extreme precipitation events in the Assessment area.

Thunderstorm activity in the Assessment area is most common during the spring, summer, and fall. On average, thunderstorms develop in the region from 10 to 25 days during each of these seasons. The number of thunderstorms during the winter is usually fewer than 10. Although thunderstorms are relatively small in size, they can produce intense precipitation and cause flash floods in small drainage basins. Mesoscale convective complexes can produce both local and widespread intense precipitation. They can produce significant flooding because of their size (> 40,000 mi^2) and duration (6 to 36 hours). In the Assessment area, mesoscale convective complexes are most common during the spring and summer. Tropical cyclones (e.g., hurricanes, tropical storms, and tropical depressions) and associated thunderstorms embedded within them are responsible for many extreme precipitation events in the southern and eastern sections of the United States. Tropical cyclones have typical diameters on the order of 60 to 600 mi when they are fully developed, usually from June to October. Those that impact the Assessment area usually originate over the Gulf of Mexico or Caribbean Sea. Flooding from tropical cyclones can be both local and widespread.

Precipitation associated with extratropical cyclones and frontal passages is usually characterized as covering a larger geographical area and being less intense and of longer duration than the precipitation associated with convectional processes. However, the convergence of air masses along frontal boundaries can lead to significant convection, thunderstorm development, and intense precipitation. Large-scale riverine flooding and local flash flooding are possible under these conditions. Even though precipitation tends to be less intense with extratropical cyclones, such cyclones are responsible for most of the major floods that occur in large drainage basins in the conterminous United States (Hirschboeck 1991). Extratropical cyclones mostly affect the Assessment area during winter and spring. They usually originate in the Western United States and move eastward across the Great Plains into the Eastern United States.

The topographically forced lifting of air as it passes over hills or mountains can result in the formation of orographic clouds that may produce precipitation (Wallace and Hobbs 1977). As air is forced upward when prevailing winds pass over hilly or mountainous terrain, it can cool sufficiently at higher altitudes to allow for cloud formation and potential precipitation. Precipitation associated with orographic lifting is usually found along the windward slopes of hills or mountains and can be locally intense. Orographic lifting in combination with convectional processes or the convergence of air masses can result in significant precipitation events and potential flooding. Within the Assessment area, topography plays an important role in precipitation events. The Ouachita Mountains and Ozark Plateaus are important topographic features that are responsible for orographic lifting effects. Depending on the direction of prevailing winds and the moisture content of the atmosphere over the Assessment area, extreme precipitation events are possible along the windward slopes of these topographic features.

For this Assessment report, an "extreme precipitation event" is defined as an event occurring within 24 hours that results in 2 or more in. of precipitation. Large amounts of precipitation and flooding are certainly possible from longer lasting events. However, to identify areas of extreme precipitation, the Aquatic Team used this definition. Figure 1.21 shows the total number of extreme precipitation events that have occurred over the Assessment area from 1950 through 1993. West-central Arkansas experienced more than 200 extreme precipitation events during the 44 years, equivalent to about 4 or 5 events per year. In this portion of the Assessment area, orographic lifting associated with the Ouachita Mountains plays a significant role in precipitation processes. The number of extreme events was less in Missouri; the northeastern half of Missouri experienced less than 100 events during the 44 years.

The monthly distribution of extreme precipitation events over the 44-year period indicates important

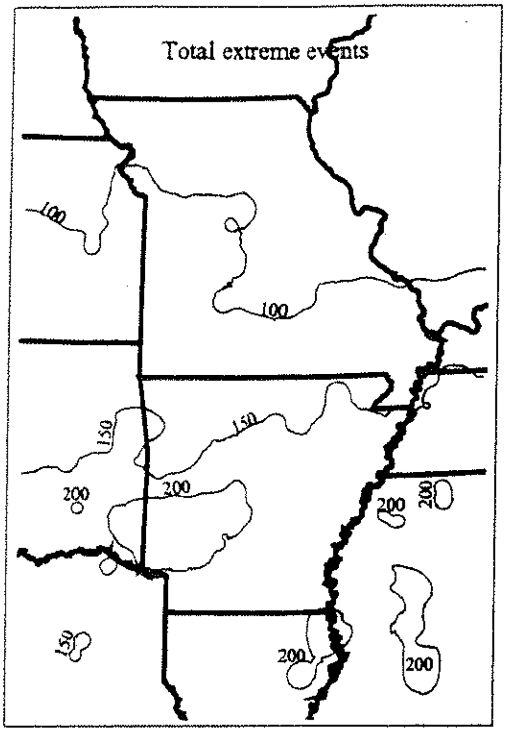


Figure 1.21—Total number of occurrences where daily precipitation was 2 inches or more in the region within and surrounding the Ozark-Ouachita Highlands Assessment area from 1950 through 1993.

seasonal changes in the number and locations of these events. Figure 1.22 shows the number of extreme precipitation episodes that occurred from 1950 through 1993 over the Assessment area during January, April, July, and October. For the months of December, January, and February, more extreme events tend to occur in the southeastern quarter of Arkansas. For example, in January, 10 to 15 extreme precipitation events occurred from 1950 through 1993 over this part of Arkansas. The numbers of extreme events for December and February over this same area were slightly higher, exceeding 20 events in parts of southern and east-central Arkansas in December and in the far southeastern parts of Arkansas in February. For December, January, and February, fewer than four extreme events on average characterized most of Missouri.

During spring, more extreme precipitation events tend to occur over the entire Assessment area than during the colder winter months. As shown in fig. 1.22, more extreme events tend to occur in western Arkans: and eastern Oklahoma (Ouachita Mountains) with the onset of warmer spring weather. Although still rare, extreme precipitation events in Missouri during April also are more frequent than wintertime events. The Ouachita Mountains have experienced more heavy precipitation events in May than in any other month. More than 32 events occurred from 1950 through 1993 in this part of the Assessment area.

The summer months are characterized by a shift in locations of extreme precipitation events from southwestern Arkansas to eastern Oklahoma and Kansas and western and northern Missouri. More than 20 events have occurred in parts of northwestern and west-central Missouri, while fewer than 10 events have occurred in parts of north-central Arkansas and east-central Missouri during July. The shift in locations of the relative maximums of extreme events is consistent with the similar shift in relative maximums of average monthly precipitation totals during the summer.

With the return of cooler conditions during the fall, extreme precipitation events in Missouri become much less frequent. The maximums in the number of events that characterize the western sections of Missouri and the eastern sections of Kansas in summer disappear during the fall. In October, the preferred location for extreme precipitation is over southeastern Oklahoma and southwestern Arkansas (fig. 1.22). Very few extreme events have occurred over the eastern half of Missouri in October. In November, extreme events are rarest in the northern half of Missouri, and most common in central Arkansas. More events also tend to occur in southeastern Missouri in November than in October. By late fall, most extreme precipitation events tend to occur in southeastern Arkansas and over the Ouachita Mountains in southwestern Arkansas.

Droughts

Most definitions of drought incorporate the characteristic of abnormal dryness (McNab and Karl 1991); drought is most often recognized during seasons when substantial precipitation is expected but fails to occur (Karl and others 1987). The lack of precipitation over a region for an extended period is the result of persistent atmospheric circulation patterns that are not conducive to precipitation (Namias 1985). For example, high

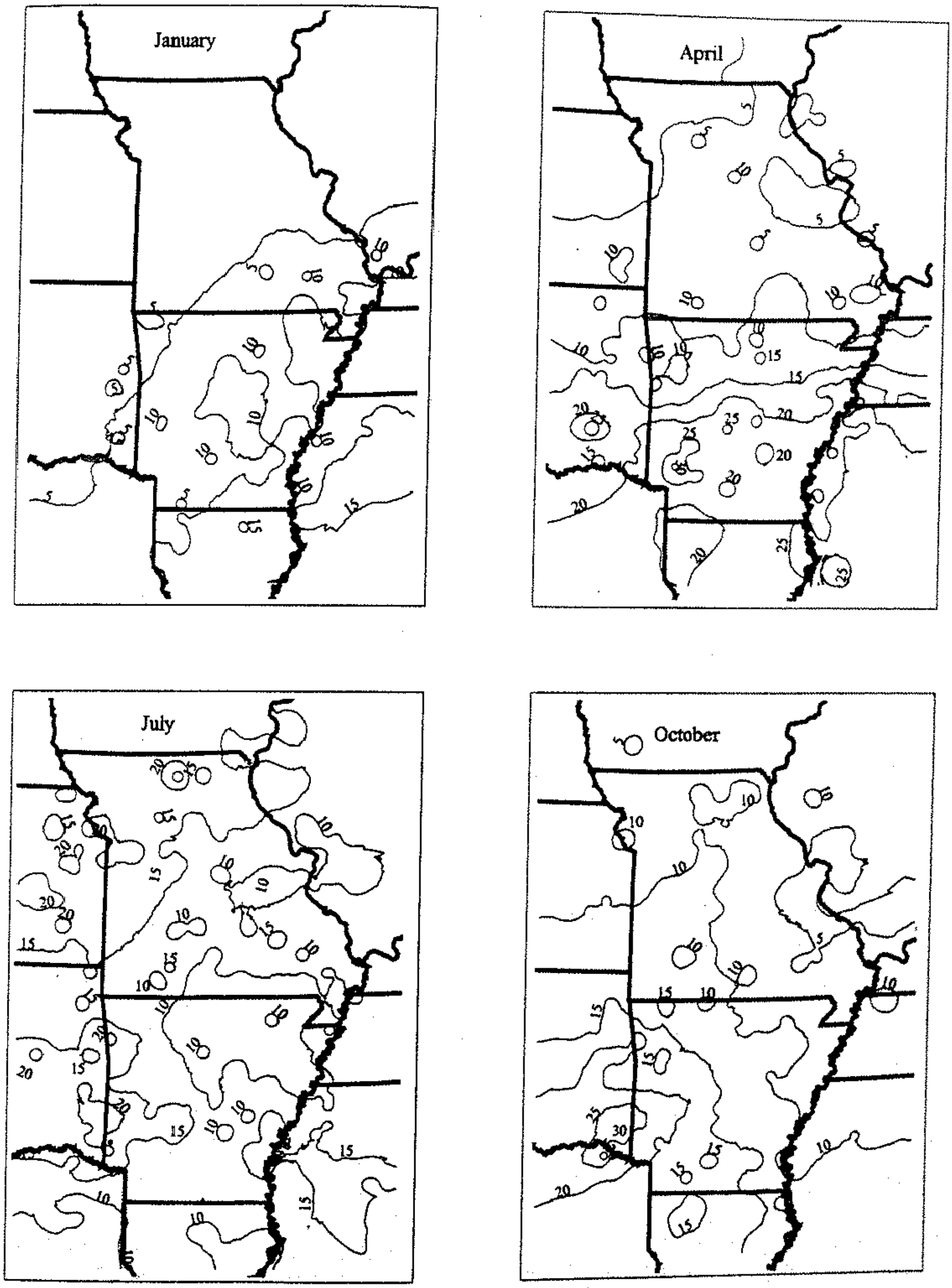


Figure 1.22—Total number of occurrences where daily precipitation was 2 inches or more in January, April, July, and October in the region within and surrounding the Ozark-Ouachita Highlands Assessment area from 1950 through 1993.

pressure (anticyclonic) circulations over a region usually result in very little precipitation. If this type of circulation pattern persists for an extended period, drought probabilities are likely to increase. Drought occurrence over a region is also possible when weather systems consistently produce only minimal precipitation (Bergman and others 1986, Karl and Young 1987).

In addition to a lack of precipitation, droughts are also associated with higher than normal surface temperatures and drier than normal atmospheric moisture contents. There are many examples of past drought occurrences where average surface air temperatures exceeded normal temperatures for an extended period of time (Bergman and others 1986; Karl and Young 1987; Namias 1982, 1983; Karl and Quayle 1981). However, some droughts are associated with lower than normal surface temperatures (Namias 1966). Relative humidity values are typically lower than normal during droughts, and these values usually characterize all levels of the atmosphere that contain substantial water vapor (Namias 1966).

Numerous droughts have occurred over the Assessment area during the past 50 years. The U.S. Department of the Interior Geological Survey (USDI GS 1991) noted that in Missouri, four major droughts occurred between 1950 and 1991: 1952 to 1957—statewide, 1962 to 1969—statewide, 1975 to 1982—statewide, and 1988—northern part of the State. In Arkansas, five major droughts occurred between 1950 and 1991: 1954 to 1956—statewide, 1963 to 1967—statewide, 1970 to 1972—statewide except southwest and northeast corners, 1976 to 1978—statewide except the north-central section, and 1980 to 1983—the northern part of the State).

The National Drought Mitigation Center (1997) examined the amount of time individual climate divisions within States experienced severe drought conditions, defined by a Palmer Drought Severity Index value of -3 or less (Palmer 1965) over 10-year periods beginning in 1900. From 1950 to the present, the most severe drought conditions over a decade in the Assessment area occurred from 1950 to 1959. During this period, the southwestern section of Missouri was under severe drought conditions 40 to 50 percent of the time while the west-central and northwestern sections of Missouri were under severe drought conditions 30 to 40 percent of the time. Less severe drought conditions were present in eastern Missouri and in Arkansas. Severe drought conditions were also prevalent throughout the southern Great Plains and eastern Rocky Mountains during the 1950's. From 1960 to the present, 10-year drought conditions have not been significant over the Assessment area, as measured by extended periods of Palmer Drought Severity Index values of -3 or less.

Tornadoes

The Assessment area is located in that portion of the United States called "Tornado Alley." This area of relatively frequent tornado occurrence encompasses the southern and central Great Plains and the lowland areas of the Mississippi, Ohio, and lower Missouri River Valleys. Specific atmospheric conditions are required for tornadoes to develop. Such favorable conditions frequently occur over the central portions of the United States and include: (1) a large supply of atmospheric moisture (northward transport of moisture from the Gulf of Mexico), (2) low-level wind shear (wind speed increase with height and wind-direction shift from southerly at low levels to southwesterly and westerly at mid-levels of the atmosphere), and (3) a dry and stable atmospheric layer above the moist low-level atmospheric layer. The atmospheric conditions that can lead to severe thunderstorm development and tornado occurrence are more frequent over "Tornado Alley" than over other parts of the Nation.

Each year in the United States, tornadic winds are responsible for death, injury, and millions of dollars in damages to property and natural resources. Wind speeds associated with tornadoes can range from about 40 mi per hour (mi/h) up to about 320 mi/h. Tornadoes are classified according to the amount and type of wind damage they cause using the Fujita Scale, which ranks tornado intensity from F0 through F5:

- F0 (40 to 72 mi/h): gale tornado that causes light losses such as damage to chimneys, breakage of tree branches, and the pushing over of shallow-rooted trees.
- F1 (73 to 112 mi/h): moderate tornado that can peel the surface off roofs, push mobile homes off their foundations or overturn them, and push autos off roads.
- F2 (113 to 157 mi/h): significant tornado that can pull roofs off frame houses, demolish mobile homes, push boxcars over, and snap or uproot large trees.

- F3 (158 to 206 mi/h): severe tornado that can tear the roof and walls off well-constructed houses, overturn trains, and uproot most trees in a forest.
- F4 (207 to 260 mi/h): devastating tornado that can level well-constructed houses, blow structures with weak foundations considerable distances, and throw cars.
- F5 (261 to 318 mi/h): incredible tornado that can lift strong frame houses off foundations and carry them considerable distances, move automobile-sized missiles through the air in excess of 100 yards, debark trees, and badly damage steel-reinforced concrete structures.

Most reported tornadoes are classified as F0, F1, or F2 tornadoes. For example, out of the 24 tornadoes reported in Arkansas in 1995, 17 were F0 tornadoes, 4 were F1 tornadoes, and 3 were F2 tornadoes. Of the 35 tornadoes that were reported in 1996 in Missouri, 22 were F0 tornadoes, 8 were F1 tornadoes, 3 were F2 tornadoes, and 2 were F3 tornadoes.

Between 1950 and 1994, 1,166 tornadoes were reported in Missouri and 854 tornadoes were reported in Arkansas. Missouri and Arkansas rank 7th and 16th, respectively, in the number of reported tornadoes from 1950 through 1994 in the entire country. During these 45 years, 279 and 155 fatalities due to tornadoes occurred in Arkansas and Missouri, respectively. Arkansas ranked third in the Nation in fatalities due to tornadoes, while Missouri ranked12th. Injuries attributed to tornadoes ranged from 3,697 in Arkansas to 2,252 in Missouri, corresponding to ranks of 5th and 15th, respectively. The dollar losses (adjusted by the Consumer Price Index) due to these tornadoes from 1950 through 1994 were about $517 million in Arkansas and $739 million in Missouri.

Figure 1.23 shows the yearly distributions of reported tornadoes in Arkansas and Missouri during the 1950 through 1995 period. Missouri tends to have slightly more tornadoes each year than Arkansas. Over the 46 years, an average of 26 tornadoes per year were reported in Missouri; Arkansas averaged 19 reported tornadoes yearly. Peak numbers of reported tornadoes in Missouri occurred in 1967, 1973, and 1982. Arkansas also experienced relatively large numbers of tornadoes in 1973, 1978, 1979, and 1982. There is no statistically significant long-term trend in the number of tornadoes occurring in this region based on the 1950 through 1995 data.

Although tornadoes have been reported during every month of the year in Arkansas and Missouri, there are certain months in which tornadoes are more likely to occur. Figure 1.24 shows the distribution by month of the number of reported tornadoes that occurred from 1950 through 1995 in these States. More tornadoes tend to occur during April and May over this region than in any other months. In Arkansas, April is the peak month for tornado activity, while in Missouri, most tornadoes

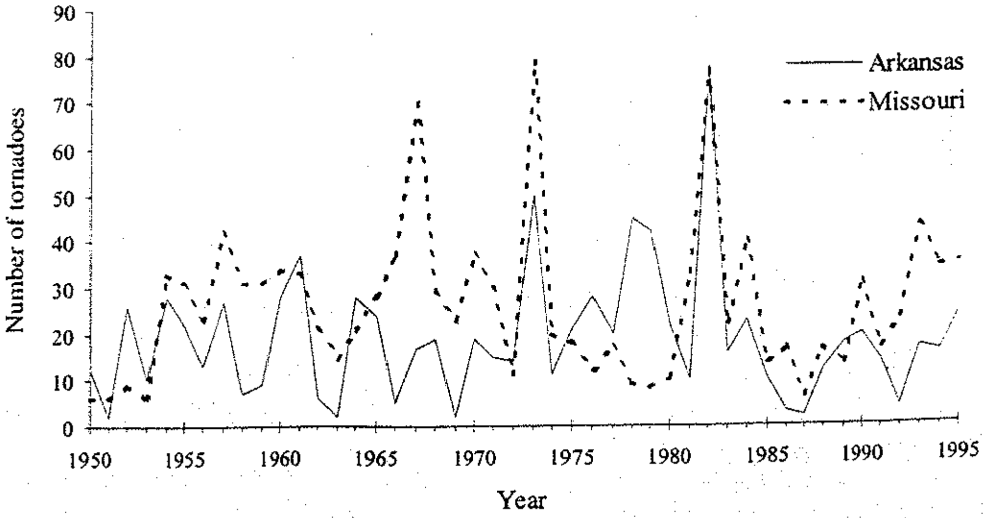


Figure 1.23—Total number of reported tornadoes in Arkansas and Missouri from 1950 through 1995.

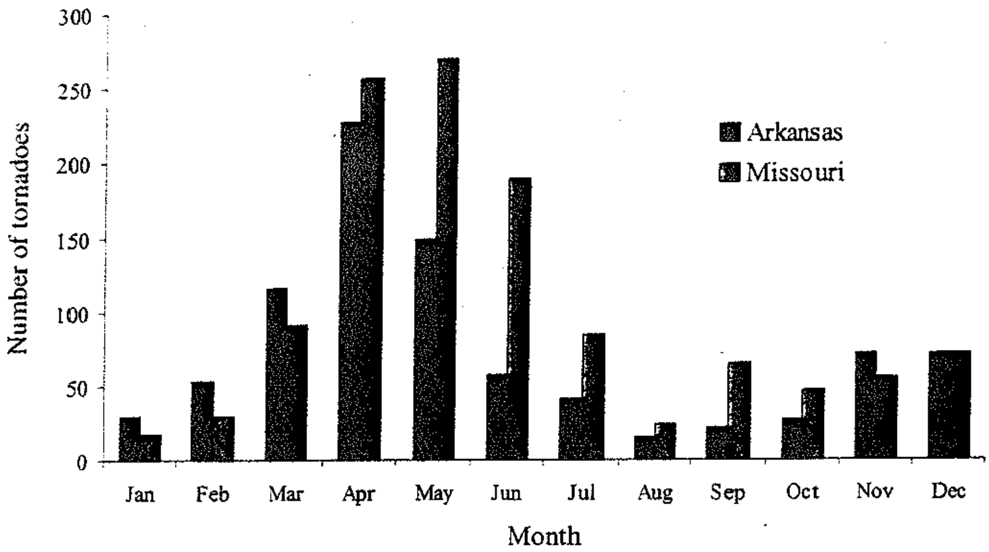


Figure 1.24—Total number of reported tornadoes each month in Arkansas and Missouri from 1950 through 1995.

are reported in May. Although Missouri typically experiences more tornadoes during an entire year, tornado activity is usually greater in Arkansas during January, February, and March. This is due to the greater probability of severe thunderstorm development in more southern latitudes during winter. By April, tornado activity in Missouri usually exceeds the activity in Arkansas and remains greater throughout the late spring to mid-autumn. The number of reported tornadoes in May and June from 1950 through 1995 was considerably larger in Missouri than in Arkansas. Figure 1.24 suggests that tornado activity in the region falls off significantly in the months of July and August. Less than 25 tornadoes were reported for the month of August from 1950 through 1995 in Arkansas and Missouri. The numbers are somewhat higher for September and show a marked decrease for January and February with the onset of the region's lowest average temperatures.

Runoff

Runoff is the water that drains from the land into stream or river channels after precipitation. Runoff volume is a function of the combined influence of precipitation, topography, geology, soil moisture, and other factors. Mean annual runoff per square mile of basin is often used to compare runoff characteristics between basins. Mean annual runoff can be computed by dividing the mean annual volume of water leaving the basin (measured as streamflow at a gauging station) by the area of that basin.

Mean annual runoff within the Ozark-Ouachita Highlands Assessment area is shown in figure 1.25 (Gebert and others 1987). Mean annual runoff generally is least in the Osage Plains, where it ranges from 8 to 10 in. Mean annual runoff in the Springfield and Salem Plateaus and St. Francois Mountains generally ranges from 10 to 15 in., although values are more variable in the eastern Salem Plateau, where they range from about 8 to 16 in. per year. Mean annual runoff in the Boston Mountains ranges from 14 to 20 in. Mean annual runoff is about 16 in. in the Mississippi Alluvial Plain at the eastern edges of the Assessment area (Gebert and others 1987). The mean annual runoff generally is greatest in the Arkansas Valley and Ouachita Mountains, where it ranges from 8 to 22 in. and 14 to 22 in., respectively.

U.S. Department of Agriculture, Forest Service. 1999. Ozark-Ouachita Highlands Assessment: aquatic conditions. Report 3 of 5. Gen. Tech. Rep. SRS-33. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 317 p.

This publication provides citizens, private and public organizations, scientists, and others with information about the aquatic conditions in or near national forests in the Ozark-Ouachita Highlands: the Mark Twain in Missouri, the Ouachita in Arkansas and Oklahoma, and the Ozark-St. Francis National Forests in Arkansas. This report includes water quality analyses, status of aquatic species, aquatic and riparian habitat conditions, water laws and policies, effects of human activities, and water resource usage and trends in the Ozark-Ouachita Highlands Assessment area.

Keywords: Climate, crayfishes, fishes, geology, invertebrates, lakes, land use, mussels, nonpoint sources, point sources, rivers, soils, threatened and endangered species, water.