systems available to various scientists for the classification of climates on a more local scale. The Köppen system, however, has been widely adopted by physical geographers and other scientists; in a modified version, it will be the basis for the worldwide regional study of present-day climates in Chapters 9 and 10.

The remainder of this chapter focuses on climate change. Climates in the past were not the same as they are today, and there is every reason to believe that future climates will be different as well. It is now widely recognized that humans may also alter Earth’s climate.

For decades scientists have realized that Earth has experienced major climate shifts during its history. It was believed that these shifts were gradual and could not be detected by humans during their lifetimes. However, recent research reveals that climate has shifted repeatedly between extremes over some exceedingly short intervals. Moreover, the research has revealed that climate during the most recent 10,000 years has been extraordinarily stable compared to similar intervals in the past.

To predict future climates, it is critical that we examine the details of past climate changes, including both the magnitude and rates of prehistoric climate change. Earth has experienced both ice ages and lengthy periods that were warmer than today. These fluctuations serve as indicators of the natural variability of climate in the absence of significant human impact. Using knowledge of present and past climates, as well as models of how and why climate changes, we conclude this chapter with some predictions of future climate trends.

Classifying Climates

Knowledge that climate varies from region to region dates to ancient times. The early Greeks (such as Aristotle, circa 350 BC) classified the known world into Torrid, Temperate, and Frigid zones based on their relative warmth. It was also recognized that these zones varied systematically with latitude and that the flora and fauna reflected these changes as well. With the further exploration of the world, naturalists noticed that the distribution of climates could be explained using factors such as sun angles, prevailing winds, elevation, and proximity to large water bodies.

The two weather variables used most often as indicators of climate are temperature and precipitation. To classify climates accurately, climatologists require a minimum of 30 years of data to describe the climate of an area. The invention of an instrument to reliably measure temperature—the thermometer—dates only to Galileo in the early 17th century. European settlement of and sporadic collection of temperature and precipitation data from distant colonies began in the 1700s but was not routine until the mid-19th century. This was soon followed in the early 20th century by some of the first attempts to classify global climates using actual temperature and precipitation data.

As we have seen in earlier chapters, temperature and precipitation vary greatly over Earth’s surface. Climatologists have worked to reduce the infinite number of worldwide variations in atmospheric elements to a comprehensible number of groups by combining elements with similar statistics (Fig. 8.1). That is, they can classify climates strictly on the basis of atmospheric elements, ignoring the causes of those variations (such as the frequency of air mass movements). This type of classification, based on statistical and mathematical parameters or physical characteristics, is called an empirical classification. A classification based on the causes, or genesis, of climate variation is known as a genetic classification.

Ordering the vast wealth of available climatic data into descriptions of major climatic groups, on either an empirical or a genetic basis, enables geographers to concentrate on the large-scale causes of climatic differentiation. In addition, they can examine exceptions to the general relationships, the causes of which are often one or more of the other atmospheric controls. Finally, differentiating climates helps explain the distribution of other climate-related phenomena of importance to humans.

Despite its value, climate classification is not without its problems. Climate is a generalization about observed facts and data based on the averages and probabilities of weather. It does not describe a real weather situation; instead, it presents a composite weather picture. Within such a generalization, it is impossible to include the many variations that actually exist. Thus, classification systems must sometimes be adjusted to changes in climate. On a global scale, generalizations, simplifications, and compromises are made to distinguish among climate types and regions.

The Thornthwaite System

One system for classifying climates concentrates on a local scale. This system is especially useful for soil scientists, water resources specialists, and agriculturalists. For example, for a farmer interested in growing a specific crop in a particular area, a system classifying large regions of Earth is inadequate. Identifying the major vegetation type of the region and the annual range of both temperature and precipitation does not provide a farmer with information concerning the amounts and timing of annual soil moisture surpluses or deficits. From an agricultural perspective, it is much more important to know that moisture will be available in the growing season, whether it comes directly in the form of precipitation or from the soil.

Developed by an American climatologist, C. Warren Thornthwaite, the Thornthwaite system establishes moisture availability at the subregional scale (Fig. 8.2). It is the system preferred by those examining climates on a local scale. Development of detailed climate classification systems such as the Thornthwaite system became possible only after temperature and precipitation data were widely collected at numerous locations beginning in the latter half of the 19th century.

The Thornthwaite system is based on the concept of potential evapotranspiration (potential ET), which approximates the water use of plants with an unlimited water supply. (Evapotranspiration, discussed in Chapter 6, is a combination of evaporation and transpiration, or water loss through vegetation.) Potential ET is a theoretical value that increases with increasing temperature, winds, and length of daylight and decreases with increasing hu-
midity. In contrast, actual evapotranspiration (actual ET) reflects actual water use by plants. This water can be supplied during the dry season by soil moisture if the soil is saturated, the climate is relatively cool, and/or the day lengths are short. Thus, measurements of actual ET relative to potential ET and available soil moisture are the determining factors for most vegetation and crop growth. Figure 6.8 shows a visual representation of the Thornthwaite system as it applies to the San Francisco, California area.

The Thornthwaite system recognizes three climate zones based on potential ET values: low-latitude climates, with potential ET greater than 130 centimeters (51 in.); middle-latitude climates, with potential ET less than 130 but greater than 52.5 centimeters (20.5 in.); and high-latitude climates, with potential ET less than 52.5 centimeters. Climate zones may be subdivided based on how long and by how much actual ET is below potential ET. Moist climates have either a surplus or a minor deficit of less than 15 centimeters (6 in.). Dry climates have an annual deficit greater than 15 centimeters.

Thornthwaite’s original equations for potential ET were based on analyses of data collected in the midwestern and eastern United States. The method was subsequently used with less success in other parts of the world. Over the past few decades, many attempts have been made to improve the accuracy of the Thornthwaite system for regions outside the United States.

The Köppen System

The most widely used climate classification is based on regional temperature and precipitation patterns. It is referred to as the Köppen system after the German botanist and climatologist who developed it. Wladimir Köppen recognized that major vegetation associations reflect the area’s climate. Hence, his climate regions were formulated to coincide with well-defined vegetation regions, and each climate region was described by the natural vegetation most often found there. Evidence of the strong influence of Köppen’s system is seen in the wide usage of his climatic terminology, even in nonscientific literature (for example, steppe climate, tundra climate, rainforest climate).

Advantages and Limitations of the Köppen System

Not only are temperature and precipitation two of the easiest weather elements to measure, but they are also measured more often and in more parts of the world than any other variables. By using temperature and precipitation statistics to define his boundaries, Köppen was able to develop precise definitions for each climate region, eliminating the imprecision that can develop in verbal and sometimes in genetic classifications.

Moreover, temperature and precipitation are the most important and effective weather elements. Variations caused by the atmospheric controls will show up most obviously in temperature and
precipitation statistics. At the same time, temperature and precipitation are the weather elements that most directly affect humans, other animals, vegetation, soils, and the form of the landscape.

Köppen’s climate boundaries were designed to define the vegetation regions. Thus, Köppen’s climate boundaries reflect “vegetation lines.” For example, the Köppen classification uses the $10^\circ\text{C}$ ($50^\circ\text{F}$) monthly isotherm because of its relevance to the timberline—the line beyond which it is too cold for trees to thrive. For this reason, Köppen defined the treeless polar climates as those areas where the mean temperature of the warmest month is below $10^\circ\text{C}$. Clearly, if climates are divided according to associated vegetation types and if the division is based on the atmospheric elements of temperature and precipitation, then the result will be a visible association of vegetation with climate types. The relationship with the visible world in Köppen’s climate classification system is one of its most appealing features to geographers and other scientists.

There are of course limitations to Köppen’s system. For example, Köppen considered only average monthly temperature and precipitation in making his climate classifications. These two elements permit estimates of precipitation effectiveness but do not measure it with enough precision to permit comparison from one specific locality to another. In addition, for the purposes of generalization and simplification, Köppen ignored winds, cloud cover, intensity of precipitation, humidity, and daily temperature extremes—much, in fact, of what makes local weather and climate distinctive.

**Simplified Köppen Classification** The Köppen system, as modified by later climatologists, divides the world into six major climate categories. The first four are based on the annual range of temperatures: humid tropical climates ($A$), humid mesothermal (mild winter) climates ($C$), humid microthermal (severe winter) climates ($D$), and polar climates ($E$). Another category, the arid and semiarid climates ($BW$ and $BS$), identifies regions that are characteristically dry based on both temperature and precipitation values. Because plants need more moisture to survive as the temperature increases, the arid and semiarid climates include regions where the temperatures range from cold to very hot. The final category, highland climates ($H$), identifies mountainous regions.
weather and climate are different ways of looking at how our atmosphere affects various locations on Earth. Weather deals with the state of the atmosphere at one point in time, or in the short term. It describes what is going on outside today or in the next few days. Climate deals with the conditions of the atmosphere in the long term, in other words, how the atmosphere behaves in a particular area through the months and years. Usually, a minimum record of 30 years is required to establish what an area’s climate might bring. Therefore a climate can be described as, but is not restricted to, a compilation of average values used to summarize atmospheric conditions of an area.

It is possible to summarize the nature of the climate at any point on Earth in graph form, as shown in the accompanying figure. Given information on mean monthly temperature and rainfall, we can express the nature of the changes in these two elements throughout the year simply by plotting their values as points above or below (in the case of temperature) a zero line. To make the pattern of the monthly temperature changes clearer, we can connect the monthly values with a continuous line, producing an annual temperature curve. Monthly precipitation amounts are usually shown as bars reaching to various heights above the line of zero precipitation. Such a display of a location’s climate is called a climograph. To read the graph, one must relate the temperature curve to the values given along the left side and the precipitation amounts to the scale on the right. Other information may also be displayed, depending on the type of climograph used.

The climograph shown here represents the type that we use in Chapters 9 and 10. This climograph can be used to determine the Köppen classification of the station as well as to show its specific temperature and rainfall measures. The climate classification abbreviations relating to all climographs are found in Table 8.1.

A standard climograph showing average monthly temperature (curve) and rainfall (bars). The horizontal index lines at 0°C (32°F), 10°C (50°F), 18°C (64.4°F), and 22°C (71.6°F) are the Köppen temperature parameters by which the station is classified.
where vegetation and climate vary rapidly as a result of changes in elevation and exposure.

Within each of the first five major categories, individual climate types and subtypes are differentiated from one another by specific parameters of temperature and precipitation. Table 1 in the “Graph Interpretation” exercise, pages 226–229, outlines the letter designations and procedures for determining the types and subtypes of the Köppen classification system. This table can be used with any Köppen climate type presented in this chapter as well as Chapters 9 and 10.

The Distribution of Climate Types  Five of the six major climate categories of the Köppen classification include enough differences in the ranges, total amounts, and seasonality of temperature and precipitation to produce the 13 distinctive climate types listed in Table 8.1. The tropical and arid climate types are discussed in some detail in the next chapter; the mesothermal, microthermal, and polar climates are presented in Chapter 10, along with a brief coverage of undifferentiated highland climates.

Tropical (A) Climates  Near the equator we find high temperatures year-round because the noon sun is never far from 90° (directly overhead). Humid climates of this type with no winter season are Köppen’s tropical climates. As his boundary for tropical climates, Köppen chose 18°C (64.4°F) for the average temperature of the coldest month because it closely coincides with the geographic limit of certain tropical palms.

Table 8.1 shows that there are three humid tropical climates, reflecting major differences in the amount and distribution of rainfall within the tropical regions. Tropical climates extend poleward to 30° latitude or higher in the continent’s interior but to lower latitudes near the coasts because of the moderating influence of the oceans on coastal temperatures.

Regions near the equator are influenced by the intertropical convergence zone (ITCZ). However, the convergent and rising air of the ITCZ, which brings rain to the tropics, is not anchored in one place; instead, it follows the 90° sun angle (see again “The Analemma,” Chapter 3), migrating with the seasons. Within 5°–10° latitude of the equator, rainfall occurs year-round because the ITCZ moves through twice a year and is never far away (Fig. 8.3). Poleward of this zone, the stabilizing influence of subtropical high pressure systems causes precipitation to become seasonal. When the ITCZ is over the region during the high-sun period (summer), there is adequate rainfall. However, during the low-sun period (winter), the subtropical highs and trade winds invade the area, bringing clear, dry weather.

We find the tropical rainforest climate (Af) in the equatorial region flanked both north and south by the dry-winter tropical savanna (Aw) climate (Fig. 8.4). Finally, along coasts facing the strong, moisture-laden inflow of air associated with the summer monsoon, we find the tropical monsoon (Am) climate (Fig. 8.5). Note the equatorial regions of Africa and South America shown in Figure 8.6. The atmospheric processes that produce the various tropical (A) climates are discussed in Chapter 9.

| TABLE 8.1 |
| Simplified Köppen Climate Classes |

<table>
<thead>
<tr>
<th>Climates</th>
<th>Climograph Abbreviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Humid Tropical Climates (A)</td>
<td></td>
</tr>
<tr>
<td>Tropical Rainforest Climate</td>
<td>Tropical Rf.</td>
</tr>
<tr>
<td>Tropical Monsoon Climate</td>
<td>Tropical Mon.</td>
</tr>
<tr>
<td>Tropical Savanna Climate</td>
<td>Tropical Sav.</td>
</tr>
<tr>
<td>Arid Climates (B)</td>
<td></td>
</tr>
<tr>
<td>Steppe Climate</td>
<td>Low-lat./Mid-lat. Steppe</td>
</tr>
<tr>
<td>Desert Climate</td>
<td>Low-lat./Mid-lat. Desert</td>
</tr>
<tr>
<td>Humid Mesothermal (Mild Winter) Climates (C)</td>
<td></td>
</tr>
<tr>
<td>Mediterranean Climate</td>
<td>Medit.</td>
</tr>
<tr>
<td>Humid Subtropical Climate</td>
<td>Humid Subt.</td>
</tr>
<tr>
<td>Marine West Coast Climate</td>
<td>Marine W.C.</td>
</tr>
<tr>
<td>Humid Microthermal (Severe Winter) Climates (D)</td>
<td></td>
</tr>
<tr>
<td>Humid Continental, Hot-Summer Climate</td>
<td>Humid Cont. H.S.</td>
</tr>
<tr>
<td>Humid Continental, Mild-Summer Climate</td>
<td>Humid Cont. M.S.</td>
</tr>
<tr>
<td>Subarctic Climate</td>
<td>Subarctic</td>
</tr>
<tr>
<td>Polar Climates (E)</td>
<td></td>
</tr>
<tr>
<td>Tundra Climate</td>
<td>Tundra</td>
</tr>
<tr>
<td>Ice-sheet Climate</td>
<td>Ice-sheet</td>
</tr>
<tr>
<td>Highland Climates (H)</td>
<td></td>
</tr>
<tr>
<td>Various climates based on elevation differences.</td>
<td>No single climograph can depict these varied (or various) climates</td>
</tr>
</tbody>
</table>
Polar (E) Climates Just as the tropical climates lack winters (cold periods), the polar climates—at least statistically—lack summers. Polar climates, as defined by Köppen, are areas in which no month has an average temperature exceeding 10°C (50°F). Poleward of this temperature boundary, trees cannot survive. The 10°C isotherm for the warmest month more or less coincides with the Arctic Circle, poleward of which the sun does not rise above the horizon in midwinter and though the length of day increases during polar summers, the insolation strikes at a low angle.

The polar climates are subdivided into tundra and ice-sheet climates. The ice-sheet (EF) climate (● Fig. 8.7) has no month with an average temperature above 0°C (32°F). The Tundra (ET) climate (● Fig. 8.8) occurs where at least 1 month averages above 0°C (32°F). Look at the far northern regions of Eurasia, North America, and Antarctica in Figure 8.6. The processes creating the polar (E) climates are explained in Chapter 10.

Mesothermal (C) and Microthermal (D) Climates Except where arid climates intervene, the lands between the tropical and polar climates are occupied by the transitional middle-latitude mesothermal and microthermal climates. As they are neither tropical nor polar, the mild and severe winter climates must have at least 1 month averaging below 18°C (64.4°F) and 1 month averaging above 10°C (50°F). Although both middle-latitude climate categories have distinct temperature seasons, the microthermal climates have severe winters with at least 1 month averaging below freezing. Once again, vegetation reflects the climatic differences. In the severe-winter climates, all broadleaf and even some species of needle-leaf trees defoliate naturally during the winter (generally, needle-leaf trees do not defoliate in winter) because soil water is temporarily frozen and unavailable. Much of the natural vegetation of the mild-winter mesothermal climates retains its foliage throughout the year because liquid water is always present in the soil. The line separating mild from severe winters usually lies in the vicinity of the 40th parallel.

A number of important internal differences within the mesothermal and microthermal climate groups produce individual climate types based on precipitation patterns or seasonal temperature contrasts. The Mediterranean, or dry summer, mesothermal (Csa, Csb) climate (like Southern California or southern Spain in Figure 8.6) appears along west coasts between 30° and 40° latitude (● Fig. 8.9). On the east coasts, in generally the same latitudes, the humid subtropical climate is found (● Fig. 8.10). This type of climate is found in regions like the southeastern United States and southeastern China in Figure 8.6.

The distinction between the humid subtropical (Cfa) and marine west coast (Cfb, Cfc) climates illustrates a second important criterion for the internal subdivisions of middle-latitude climates: seasonal contrasts. Both mesothermal climates have year-round precipitation, but humid subtropical summer temperatures are much higher than those in the marine west coast climate. Therefore, summers are hot. In contrast, the mild summers of the marine west coast climate, located poleward of the Mediterranean climate along continental west coasts, often extend beyond 60° latitude.
FIGURE 8.6
World map of climates in the modified Köppen classification system.
A Western Paragraphic Projection
developed at Western Illinois University
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*FIGURE 8.7*
Polar ice-sheet climate: glaciers near the southern coast of Greenland.

*FIGURE 8.8*
Tundra climate: caribou in the Alaskan tundra during the summer.

*FIGURE 8.9*
Mediterranean mesothermal climate: village in southern Spain.

*FIGURE 8.10*
Humid subtropical climate: grapefruit grove in central Florida.

Some examples of marine west coast climates, shown in Figure 8.6, are along the northwest coast of the United States and extending into Canada, the west coast of Europe, and the British Isles.

Another example of internal differences is found among microthermal (*D*) climates, which usually receive year-round precipitation associated with middle-latitude cyclones traveling along the polar front. Internal subdivision into climate types is based on summers that become shorter and cooler and winters that become longer and more severe with increasing latitude and continentality. Microthermal climates are found exclusively in the Northern Hemisphere (Fig. 8.12) because there is no land in the Southern Hemisphere latitudes that would normally be occupied by these climate types. In the Northern Hemisphere, these climates progress poleward through the humid continental, hot-summer (*Dfa, Dwa*) climate, to the humid continental, mild-summer (*Dfb, Dwb*) climate, and finally, to the subarctic (*Dfc, Dfd, Dwc, and Dwd*) climate (Fig. 8.13). Microclimate regions can be seen in the eastern United States and Canada or northward through eastern Europe in Figure 8.6.

*Arid (*B*) Climates*

Climates that are dominated by year-round moisture deficiency are called *arid climates*. These climates will penetrate deep into the continent, interrupting the latitudinal zonation of climates that would otherwise exist. The definition of climatic aridity is that precipitation received is less than potential ET. Aridity does not depend solely on the amount of precipitation received; potential ET rates and temperature must also be taken into account. In a low-latitude climate with relatively high temperatures, the potential ET rate is greater than in a colder, higher-latitude climate. As a result, more rain must fall in the lower latitudes to produce the same effects (on vegetation) that smaller amounts of precipitation produce in areas with lower temperatures and, consequently, lower potential ET rates. Potential ET rates also decrease with altitude, which helps to explain why higher altitude (highland) climates are distinguished separately.
Arid climates are concentrated in a zone from about 15°N and S to about 30°N and S latitude along the western coasts, expanding much farther poleward over the heart of each landmass. The correspondence between the arid climates and the belt of subtropical high pressure systems is quite unmistakable (like in the southwestern United States, central Australia, and north Africa in Fig. 8.6), and the poleward expansion is a consequence of remoteness from the oceanic moisture supply.

In desert (BW) climates, the annual amount of precipitation is less than half the annual potential ET (Fig. 8.14). Bordering the deserts are steppe (BS) climates—semiarid climates that are transitional between the extreme aridity of the deserts and the moisture surplus of the humid climates (Fig. 8.15). The definition of the steppe climate is an area where annual precipitation is less than potential ET but more than half the potential ET. B climates and the processes that create them are discussed in more detail in Chapter 9.
Highland \((H)\) Climates The pattern of climates and extent of aridity are affected by irregularities in Earth’s surface, such as the presence of deep gulfs, interior seas, or significant highlands. The climatic patterns of Europe and North America are quite different because of such variations.

Highlands can channel air mass movements and create abrupt climatic divides. Their own microclimates form an intricate pattern related to elevation, cloud cover, and exposure (Fig. 8.16). One significant effect of highlands aligned at right angles to the prevailing wind direction is the creation of arid regions extending tens to hundreds of kilometers leeward. Look at the mountain ranges in Figure 8.6: the Rockies, the Andes, the Alps, and the Himalayas show \(H\) climates. These undifferentiated highland climates are discussed in more detail in Chapter 10.

Climate Regions

Each of our modified Köppen climate types is defined by specific parameters for monthly averages of temperature and precipitation; thus, it is possible to draw boundaries between these types on a world map. The areas within these boundaries are examples of one type of world region. The term region, as used by geographers, refers to an area that has recognizably similar internal characteristics that are distinct from those of other areas. A region may be described on any basis that unifies it and differentiates it from others.

As we examine the climate regions of the world in the chapters that follow, you should make frequent reference to the map of world climate regions (see again Fig. 8.6). It shows the patterns of Earth’s climates as they are distributed over each continent. However, a word of caution is in order. On a map of climate regions, distinct lines separate one region from another. Obviously, the lines do not mark points where there are abrupt changes in temperature or precipitation conditions. Rather, the lines signify zones of transition between different climate regions. Furthermore, these zones or boundaries between regions are based on monthly and annual averages and may shift as temperature and moisture statistics change over the years.

The actual transition from one climate region to another is gradual, except in cases in which the change is brought about by an unusual climate control such as a mountain barrier. It would be more accurate to depict climate regions and their zones of transition on a map by showing one color fading into another. Always keep in mind, as we describe Earth’s climates, that it is the core areas of the regions that best exhibit the characteristics that distinguish one climate from another.

Now, let’s look more closely at Figure 8.6. One thing that is immediately noticeable is the change in climate with latitude. This is especially apparent in North America when we examine the East Coast of the United States moving north into Canada. Here the sun angles and length of day play an important role. We can also see that similar climates usually appear in similar latitudes and/or in similar locations with respect to landmasses, ocean currents, or topography. These climate patterns emphasize the close relationship among climate, the weather elements, and the climate controls. These elements and controls are more fully correlated with their corresponding climates in Chapters 9 and 10. There is an order to Earth’s atmospheric conditions and so also to its climate regions.

A striking variation in these global climate patterns becomes apparent when we compare the Northern and Southern Hemispheres. The Southern Hemisphere lacks the large landmasses of the Northern Hemisphere; thus, no climates in the higher latitudes (in land regions) can be classified as humid microthermal, and only one small peninsula of Antarctica can be said to have a tundra climate.

Scale and Climate

Climate can be measured at different scales (macro, meso, or micro). The climate of a large (macro) region, such as the Sahara, may be described correctly as hot and dry. Climate can also be described at mesoscale levels; for example, the climate of coastal Southern California is sunny and warm, with dry summers and wet winters. Finally, climate can be described at local scales, such as on the slopes of a single hill. This is termed a microclimate.

At the microclimate level, many factors will cause the climate to differ from nearby areas. For example, in the United States and other regions north of the Tropic of Cancer, south-facing slopes tend to be warmer and drier than north-facing slopes because they receive more sunlight (Fig. 8.17). This variable is referred to as slope aspect—the direction a mountain slope faces in respect to the sun’s rays. Microclimatic differences such as slope aspect can cause significant differences in vegetation and soil moisture. In what is sometimes called topoclimates, tall mountains often possess vertical zones of vegetation that reflect changes in the microclimates as one ascends from the base of the mountain (which may be surrounded by a tropical-type vegetation) to higher slopes with middle latitude–type vegetation to the summit covered with ice and snow.

Human activities can influence microclimates as well. Recent research indicates that the construction of a large reservoir leads to greater annual precipitation immediately downwind of this impounded water. This occurs because the lake supplies addi-
The key to understanding any system of classification is found by personally practicing use of the system. This is one reason why the Consider & Respond review sections of both Chapters 9 and 10 are based on the classification of data from sites selected throughout the world. Correctly classifying these sites in the modified Köppen system may seem complicated at first, but you will find that, after applying the system to a few of the sample locations, the determination of a correct letter symbol and associated climate name for any other site data should be routine.

Before you begin, take the time to familiarize yourself with Table 1. You will note that there are precise definitions in regard to temperature or precipitation that identify a site as one of the five major climate categories in the Köppen system (A, tropical; B, arid; C, mesothermal; D, microthermal; E, polar). Furthermore, you will note that the additional letters required to identify the actual climate type also have precise definitions or are determined by the use of the graphs. In other words, Table 1 is all you need to classify a site if monthly and annual means of precipitation and temperature are available. Table 1 should be used in a systematic fashion to determine first the major climate category and, once that is determined, the second and third letter symbols (if needed) that complete the classification. As you begin to classify, it is strongly recommended that you use the following procedure. (After a few examples you may find that you can omit some steps with a glance at the statistics.)

**TABLE 1**

**Simplified Köppen Classification of Climates**

<table>
<thead>
<tr>
<th>First Letter</th>
<th>Second Letter</th>
<th>Third Letter</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>E</strong></td>
<td><strong>T</strong></td>
<td>NO THIRD LETTER (with polar climates)</td>
</tr>
<tr>
<td>Warmest month less than 10ºC (50ºF)</td>
<td>Warmest month between 10ºC (50ºF) and 0ºC (32ºF)</td>
<td>SUMMERLESS</td>
</tr>
<tr>
<td>POLAR CLIMATES</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ET—Tundra</td>
<td>EF—Ice Sheet</td>
<td></td>
</tr>
<tr>
<td><strong>B</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arid or semi-arid climates</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ARID CLIMATES</td>
<td>Semi-arid climate (see Graph 1)</td>
<td></td>
</tr>
<tr>
<td>BS—Steppe</td>
<td>h</td>
<td>Mean annual temperature greater than 18ºC (64.4ºF)</td>
</tr>
<tr>
<td>BW—Desert</td>
<td>k</td>
<td>Mean annual temperature</td>
</tr>
<tr>
<td><strong>W</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arid climate (see Graph 1)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Graph 1 Humid/Dry Climate Boundaries**

**THE KÖPPEN CLIMATE CLASSIFICATION SYSTEM**

Madison
### TABLE 1
Simplified Köppen Classification of Climates (Continued)

<table>
<thead>
<tr>
<th>First Letter</th>
<th>Second Letter</th>
<th>Third Letter</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>f</td>
<td>NO THIRD LETTER (with tropical climates)</td>
</tr>
<tr>
<td>TROPICAL CLIMATES</td>
<td></td>
<td>WINTERLESS</td>
</tr>
<tr>
<td>Am—Tropical monsoon</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aw—Tropical savanna</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Af—Tropical rainforest</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>f</td>
<td>Driest month has at least 6 cm (2.4 in.) of precipitation</td>
</tr>
<tr>
<td></td>
<td>m</td>
<td>Seasonally, excessively moist (see Graph 2)</td>
</tr>
<tr>
<td></td>
<td>w</td>
<td>Dry winter, wet summer (see Graph 2)</td>
</tr>
<tr>
<td>C</td>
<td>s</td>
<td>a Warmest month above 22°C (71.6°F)</td>
</tr>
<tr>
<td>Coldest month between 18°C (64.4°F) and 0°C (32°F), at least one month over 10°C (50°F)</td>
<td></td>
<td>b Warmest month below 22°C (71.6°F), with at least four months above 10°C (50°F)</td>
</tr>
<tr>
<td>MESOTHERMAL CLIMATES</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CsA, CsB—Mediterranean</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cfa, Cwa—Humid subtropical</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cfb, Cfc—Marine west coast</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>s (DRY SUMMER)</td>
<td>Driest month in the summer half of the year, with less than 3 cm (1.2 in.) of precipitation and less than one third of the wettest winter month</td>
</tr>
<tr>
<td>D</td>
<td>w</td>
<td>c Warmest month below 22°C (71.6°F), with one to three months above 10°C (50°F)</td>
</tr>
<tr>
<td>Coldest month less than 0°C (32°F); at least one month over 10°C (50°F)</td>
<td></td>
<td>d Same as c, but coldest month is below −38°C (−36.4°F)</td>
</tr>
<tr>
<td>MICROTHEMAL CLIMATES</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dfa, Dwa—Humid continental, hot summer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dfb, DwB—Humid continental, mild summer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dfc, DwC, Dfd, DwD—Subarctic</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>w (DRY WINTER)</td>
<td>Driest month in the winter half of the year, with less than one tenth the precipitation of the wettest summer month</td>
</tr>
<tr>
<td></td>
<td>f (ALWAYS MOIST)</td>
<td>Does not meet conditions for s or w above</td>
</tr>
</tbody>
</table>

#### Graph 2 Rainfall of driest month (cm)
Step 1. Ask: Is this a polar climate (E)? Is the warmest month less than 10°C (50°F)? If so, is the warmest month between 10°C (50°F) and 0°C (32°F) (EF) or below 0°C (32°F) (EF)? If not, move on to:

Step 2. Ask: Is there a seasonal concentration of precipitation? Examine the monthly precipitation data for the driest and wettest summer and winter months for the site. Take careful note of temperature data as well because you must determine whether the site is located in the Northern or Southern Hemisphere. (April to September are summer months in the Northern Hemisphere but winter months in the Southern Hemisphere. Similarly, the Northern Hemisphere winter months of October to March are summer south of the equator.) As the table indicates, a site has a dry summer (s) if the driest month in summer has less than 3 centimeters (1.2 in.) of precipitation and less than one third of the precipitation of the wettest winter month. It has a dry winter (w) if the driest month in winter has less than one tenth the precipitation of the wettest summer month. If the site has neither a dry summer nor a dry winter, it is classified as having an even distribution of precipitation (f). Move on to:

Step 3. Ask: Is this an arid climate (B)? Use one of the small graphs (included in Graph 1) to decide. Based on your answer in Step 2, select one of the small graphs and compare mean annual temperature with mean annual precipitation. The graph will indicate whether the site is an arid (B) climate or not. If it is, the graph will indicate which one (BW or BS). You should further classify the site by adding h if the mean annual temperature is above 18°C (64.4°F) and k if it is below. If the site is neither BW nor BS, it is a humid climate (A, C, or D). Move on to:

Step 4a. Ask: Is this a tropical climate (A)? The site has a tropical climate if the temperature of the coolest month is higher than 18°C (64.4°F). If so, use Graph 2 in Table 1 to determine which tropical climate the site represents. (Note that there are no additional lowercase letters required.) If not, move on to:

Step 4b. Ask: Which major middle-latitude climate group does that site represent, mesothermal (C) or microthermal (D)? If the temperature of the coldest month is between 18°C (64.4°F) and 0°C (32°F), the site has a mesothermal climate. If is below 0°C (32°F), it has a microthermal climate. Once you have answered the question, move on to:

Step 5. Ask: What was the distribution of precipitation? This was determined back in Step 2. Add s, w, or f for a C climate or w or f for a D climate to the letter symbol for the climate. Then, move on to:

Step 6. Ask: What is needed to express the details of seasonal temperature for the site? Refer again to Table 1 and the definitions for the letter symbols. Add a, b, or c for the mesothermal (C) climates, or a, b, c, or d for the microthermal (D) climates, and you have completed the classification of your climate. However, note that you may not have come this far because you might have completed your classification at Steps 1, 3, or 4a.

We should now be ready to try out the use of Table 1, following the steps we have recommended. Data for Madison, Wisconsin, is presented below for our example.

<table>
<thead>
<tr>
<th>J</th>
<th>F</th>
<th>M</th>
<th>A</th>
<th>M</th>
<th>J</th>
<th>J</th>
<th>A</th>
<th>S</th>
<th>O</th>
<th>N</th>
<th>D</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>T (°C)</td>
<td>21</td>
<td>21</td>
<td>16</td>
<td>10</td>
<td>2</td>
<td>–6</td>
<td>7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P (cm)</td>
<td>9.6</td>
<td>7.9</td>
<td>8.6</td>
<td>5.6</td>
<td>4.8</td>
<td>3.8</td>
<td>77.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The correct answer is derived below:

Step 1. We must determine whether or not our site has an E climate. Because Madison has several months averaging above 10°C, it does not have an E climate.

Step 2. We must determine if there is a seasonal concentration of precipitation. Because Madison is driest in winter, we compare the 2.5 centimeters of February precipitation with the precipitation of June (1/10 of 11.0 cm, or 1.1 cm) and conclude that Madison has neither a dry summer nor a dry winter but instead has an even distribution of precipitation (f). [Note: The 2.5 cm of February precipitation is not less than 1/10 (1.1 cm) of June precipitation.]

Step 3. Next we assess, through the use of Graphs 1(f), 1(w), or 1(s), whether our site is an arid climate (BW, BS) or a humid climate (A, C, or D). Because we have previously determined that Madison has an even distribution of precipitation, we will use Graph 1(f). Based on Madison’s mean annual precipitation (77.0 cm) and mean annual temperature (7°C), we conclude that Madison is a humid climate (A, C, or D).

Step 4. Now we must assess which humid climate type Madison falls under. Because the coldest month (–8°C) is below 18°C, Madison does not have an A climate. Although the warmest month (21°C) is above 10°C, the coldest month
(−8°C) is not between 0°C and 18°C, so Madison does not have a C climate. Because the warmest month (21°C) is above 10°C and the coldest month is below 0°C, Madison does have a D climate.

Step 5. Because Madison has a D climate, the second letter will be w or f. Because precipitation in the driest month of winter (2.5 cm) is not less than one tenth of the amount of the wettest summer month (1/10 × 11.0 cm = 1.1 cm), Madison does not have a Dw climate. Madison therefore has a Df climate.

Step 6. Because Madison is a Df climate, the third letter will be a, b, c, or d. Because the average temperature of the warmest month (21°C) is not above 22°C, Madison does not have a Dfa climate. Because the average temperature of the warmest month is below 22°C, with at least 4 months above 10°C, Madison is a Dfb climate.