CHAPTER

2

COORDINATE SYSTEMS

CHAPTER OUTLINE

A basic principle in GIS is that map layers to be used together must align spatially. Obvious mistakes can occur if they do not. For example, Figure 2.1 shows the road maps of Idaho and Montana downloaded separately from the Internet. Obviously, the two maps do not register spatially. To connect the road networks across the shared state border, we must convert them to a common spatial reference system. Chapter 2 deals with coordinate systems, which are the basis for the spatial reference.

GIS users typically work with map features on a plane. These map features represent spatial features on the Earth's surface. The locations of map features are based on a plane coordinate system expressed in *x*- and *y*-coordinates, whereas the locations of spatial features on the Earth's surface are based on a geographic coordinate system expressed in longitude and latitude values. A map projection bridges the two types of coordinate systems. The process of projection transforms the Earth's surface to a plane, and the outcome is a map projection, ready to be used for a plane or projected coordinate system.

We regularly download data sets from the Internet or get them from government agencies for GIS projects. Some digital data sets are measured in longitude and latitude values, whereas others are in different projected coordinate systems. Invariably, these data sets must be processed before they can be used together. Processing in this case means projection and reprojection. **Projection** converts data sets from geographic coordinates to projected coordinates, and **reprojection** converts from one type of projected coordinates to another type. Typically, projection and reprojection are among the initial tasks performed in a GIS project.

Chapter 2 is divided into the following five sections. Section 2.1 describes the geographic

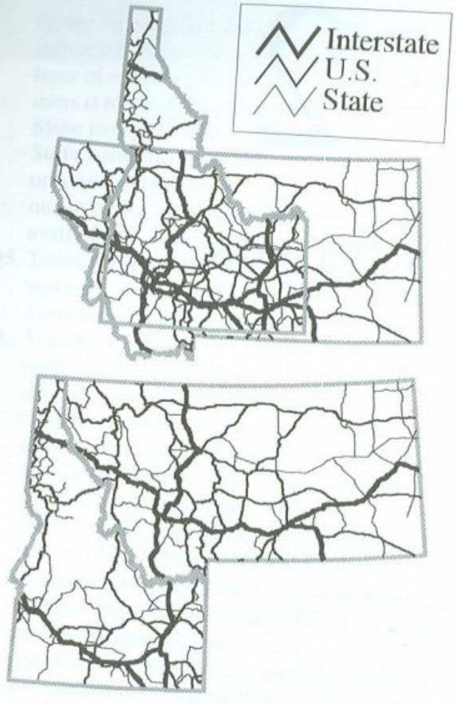

Figure 2.1
The top map shows the road networks in Idaho and Montana based on different coordinate systems. The bottom map shows the road networks based on the same coordinate system.

coordinate system. Section 2.2 discusses projection, types of map projections, and map projection parameters. Sections 2.3 and 2.4 cover commonly used map projections and coordinate systems, respectively. Section 2.5 discusses how to work with coordinate systems in a GIS package.

2.1 GEOGRAPHIC COORDINATE SYSTEM

The **geographic coordinate system** is the location reference system for spatial features on the Earth's surface (Figure 2.2). The geographic coordinate system is defined by **longitude** and **latitude.** Both longitude and latitude are angular measures: longitude measures the angle east or west from the prime meridian, and latitude measures the angle north or south of the equatorial plane (Figure 2.3).

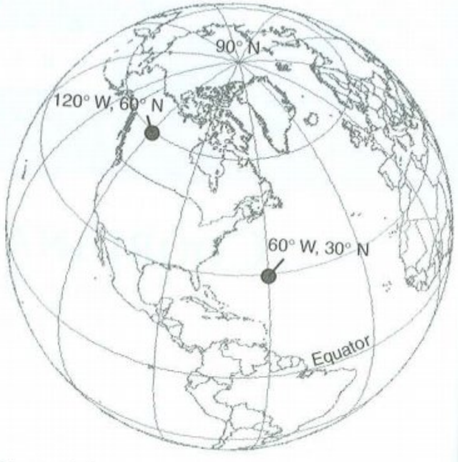

Figure 2.2
The geographic coordinate system.

Meridians are lines of equal longitude. The prime meridian passes through Greenwich, England and has the reading of 0°. Using the prime meridian as a reference, we can measure the longitude value of a point on the Earth's surface as 0° to 180° east or west of the prime meridian. Meridians are therefore used for measuring location in the E–W direction. **Parallels** are lines of equal latitude. Using the equator as 0° latitude, we can measure the latitude value of a point as 0° to 90° north or south of the equator. Parallels are therefore used for measuring location in the N–S direction. A point location denoted by (120° W, 60° N) means that it is 120° west of the prime meridian and 60° north of the equator.

The prime meridian and the equator serve as the baselines of the geographic coordinate system. The notation of geographic coordinates is therefore like plane coordinates: longitude values are equivalent to x values and latitude values are

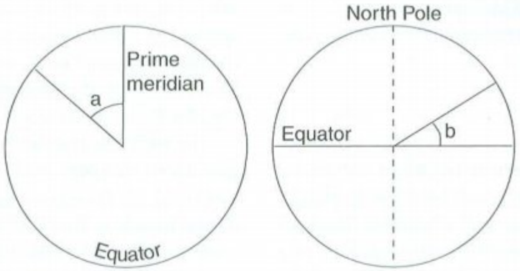

Figure 2.3
A longitude reading is represented by a on the left, and a latitude reading is represented by b on the right. Both longitude and latitude readings are angular measures.

equivalent to y values. And it is conventional in GIS to enter longitude and latitude values with positive or negative signs. Longitude values are positive in the eastern hemisphere and negative in the western hemisphere. Latitude values are positive if north of the equator, and negative if south of the equator.

The angular measures of longitude and latitude may be expressed in **degrees-minutes-seconds (DMS), decimal degrees (DD),** or radians (rad). Given that 1 degree equals 60 minutes and 1 minute equals 60 seconds, we can easily convert between DMS and DD. For example, a latitude value of 45°52′30″ would be equal to 45.875° (45 + 52/60 + 30/3600). Radians are typically used in computer programs. One radian equals 57.2958°, and one degree equals 0.01745 rad.

2.1.1 Approximation of the Earth

The first step to map spatial features on the Earth's surface is to select a model that approximates the shape and size of the Earth. The simplest model is a sphere, which is typically used in discussing map projections (Section 2.3). But the Earth is not a perfect sphere: the Earth is wider along the equator than between the poles. Therefore a better approximation to the shape of the Earth is a **spheroid,** also called **ellipsoid,** an ellipse rotated about its minor axis.

A spheroid has its major axis (a) along the equator and its minor axis (b) connecting the poles (Figure 2.4). A parameter called the flattening (f), defined by $(a - b)/a$, measures the difference between the two axes of a spheroid. Geographic coordinates based on a spheroid are known as **geodetic coordinates,** which are the basis for all mapping systems (Iliffe 2000). In this book, we will use the generic term *geographic coordinates.*

The geoid, an even closer approximation of the Earth, has an irregular surface, which is affected by irregularities in the density of the Earth's crust and mantle. The geoid surface is treated as the surface of mean sea level, which is important for measuring elevations or heights. For example, elevation readings from a GPS (global positioning

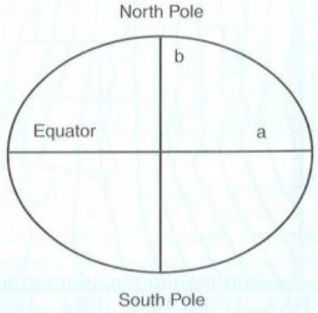

Figure 2.4
The flattening is based on the difference between the semimajor axis a and the semiminor axis b.

system) receiver are measured from the surface of the geoid (Chapter 6). This chapter is mainly concerned with spheroids.

2.1.2 Datum

A **datum** is a mathematical model of the Earth, which serves as the reference or base for calculating the geographic coordinates of a location (Burkard 1984; Moffitt and Bossler 1998). The definition of a datum consists of an origin, the parameters of the spheroid selected for the computations, and the separation of the spheroid and the Earth at the origin. Many countries have developed their own datums for local surveys. Among these local datums are the European Datum, the Australian Geodetic Datum, the Tokyo Datum, and the Indian Datum (for India and several adjacent countries).

Until the late 1980s, **Clarke 1866,** a ground-measured spheroid, was the standard spheroid for mapping in the United States. Clarke 1866's semimajor axis (equatorial radius) and semiminor axis (polar radius) measure 6,378,206.4 meters (3962.96 miles) and 6,356,583.8 meters (3949.21 miles), respectively, with the flattening of 1/294.979. **NAD27** (North American Datum of 1927) is a local datum based on the Clarke 1866 spheroid, with its origin at Meades Ranch in Kansas.

In 1986 the National Geodetic Survey (NGS) introduced **NAD83** (North American Datum of 1983), an Earth-centered (also called geocentered) datum based on the **GRS80** (Geodetic Reference System 1980) spheroid. GRS80's semimajor axis and semiminor axis measure 6,378,137.0 meters (3962.94 miles) and 6,356,752.3 meters (3949.65 miles), respectively, with the flattening of 1/298.257. In the case of GRS80, the shape and size of the Earth were determined through measurements made by Doppler satellite observations.

The horizontal shift from NAD27 to NAD83 can be substantial (Figure 2.5). Positions of points can change between 10 and 100 meters in the conterminous United States, more than 200 meters in Alaska, and in excess of 400 meters in Hawaii. For example, for the Ozette quadrangle map from the Olympic Peninsula in Washington, the shift is 98 meters to the east and 26 meters to the north. The horizontal shift is therefore 101.4 meters ($\sqrt{98^2 + 26^2}$).

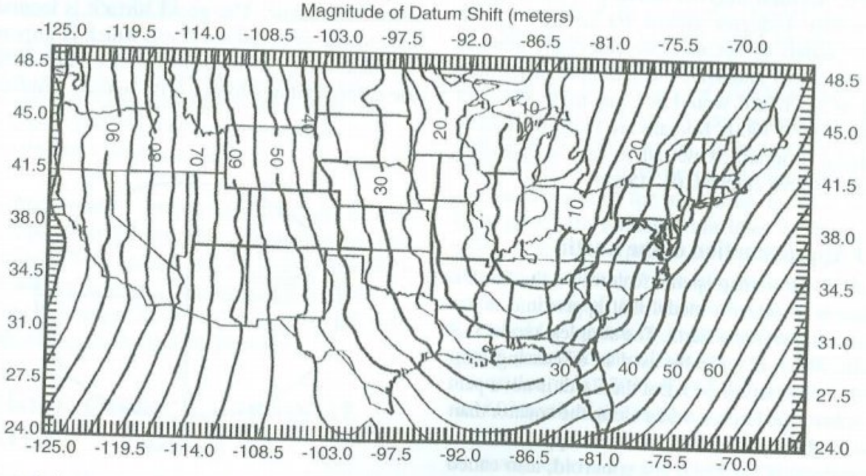

Figure 2.5
The isolines show the magnitudes of the horizontal shift from NAD27 to NAD83 in meters. See Section 2.1.2 for the definition of the horizontal shift. (By permission of the National Geodetic Survey.)

Many GIS users in the United States have migrated from NAD27 to NAD83, while others are still in the process of adopting NAD83. The same is true with data sets downloadable from GIS data clearinghouses: some are based on NAD83, and others on NAD27. Until the switch from NAD27 to NAD83 is complete, we must keep watchful eyes on the datum because digital layers based on the same projection but different datums will not register correctly. (Datum shift is taking place in other parts of the world as well; as an example, GIS users in Taiwan are migrating from TWD67 to TWD97.)

WGS84 (World Geodetic System 1984) is a reference system or datum established by the National Imagery and Mapping Agency (NIMA, now the National Geospatial-Intelligence Agency or NGA) of the U.S. Department of Defense (Kumar 1993). WGS84 agrees with GRS80 in terms of measures of the semimajor and semiminor axes. But WGS84 has a set of primary and secondary parameters. The primary parameters define the shape and size of the Earth, whereas the secondary parameters refer to local datums used in different countries (National Geospatial-Intelligence Agency 2000; Iliffe 2000). WGS84 is the datum for GPS readings. The satellites used by GPS send their positions in WGS84 coordinates and all calculations internal to GPS receivers are based on WGS84.

Migrating from NAD27 to NAD83 or from NAD27 to WGS84 requires a datum transformation, which recomputes longitude and latitude values from one geographic coordinate system to another. A commercial GIS package may offer several transformation methods such as three-parameter, seven-parameter, Molodensky, and abridged Molodensky. A good reference on datum transformation and its mathematical methods is available online from the NGA (2000). Free software packages for data conversion are also available online (Box 2.1).

Although the migration from NAD27 to NAD83 is still underway, new developments on datums continue in the United States for local surveys (Kavanagh 2003). In the late 1980s, the NGS began a program of using GPS technology to establish the High Accuracy Reference Network (HARN) on a state-by-state basis. In 1994, the NGS started the Continuously Operating Reference Stations (CORS) network, a network of over 200 stations that provide measurements for the postprocessing of GPS data. The positional difference of a control point may be up to a meter between NAD83 and HARN but less than 10 centimeters between HARN and CORS (Snay and Soler 2000).

HARN and CORS networks can provide data for refining NAD83. NAD83 (HARN) is a refined NAD83 based on HARN data, and NAD83 (CORS96) is a refined NAD83 based on CORS data. Both refined NAD83 datums are more accurate than the original NAD83 and are

Box 2.1 Conversion between Datums

Conversion between datums involves the transformation and computation of geographic coordinates. Free software packages can be downloaded from the Internet for datum conversion. For example, Nadcon is a software package developed by the National Geodetic Survey (NGS) for conversion between NAD27 and NAD83. Nadcon can be downloaded at the NGS website (**http://www.ngs.noaa.gov/TOOLS/Nadcon/Nadcon.html**) or at the Topographic Engineering Center of the U.S. Army Corps of Engineers website (**http://crunch.tec.army.mil/software/corpscon/corpscon.html**). GPS receivers usually have the options to read coordinates based on different datums (other than the default of WGS84). Many GIS packages offer a large number of datums and spheroids to accommodate users from different countries.

thus important to surveyors and GPS users, who require highly accurate data (e.g., centimeter-level accuracy) for their work.

This section has focused on the use of datums and reference systems for measuring horizontal positions (i.e., geographic coordinates). Before we leave the topic, it should be noted that the concept of datum also applies to measurements of elevations or heights. The National Geodetic Vertical Datum (NGVD) of 1929 was based on observations at tidal stations on the Atlantic, Pacific, and Gulf of Mexico shorelines. Refinement of the 1929 datum, including gravimetric and other anomalies, has resulted in the North American Vertical Datum of 1988 (NAVD88). NAVD88 is now the reference vertical datum for elevation readings in North America.

2.2 MAP PROJECTIONS

The process of projection transforms the spherical Earth's surface to a plane (Robinson et al. 1995; Dent 1999; Slocum et al. 2005). The outcome of this transformation process is a **map projection:** a systematic arrangement of parallels and meridians on a plane surface representing the geographic coordinate system.

We can use data sets based on geographic coordinates directly in a GIS and, in fact, we are seeing more maps made with such data sets. But a map projection provides a couple of distinctive advantages. First, a map projection allows us to use two-dimensional maps, either paper or digital, instead of a globe. Second, a map projection allows us to work with plane or projected coordinates rather than longitude and latitude values. Computations with geographic coordinates are more complex and yield less accurate distance measurements (Box 2.2).

But the transformation from the Earth's surface to a flat surface always involves distortion, and no map projection is perfect. This is why hundreds of map projections have been developed for mapmaking (Maling 1992; Snyder 1993). Every map projection preserves certain spatial properties while sacrificing other properties.

Box 2.2 How to Measure Distances on the Earth's Surface

The equation for measuring distances on a plane coordinate system is:

$$D = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2}$$

where x_i and y_i are the coordinates of point i.

This equation, however, cannot be used for measuring distances on the Earth's surface. Because meridians converge at the poles, the length of 1-degree latitude does not remain constant but gradually decreases from the equator to 0 at the pole. The standard and simplest method for calculating the shortest distance between two points on the Earth's surface uses the equation:

$$\cos(d) = \sin(a)\sin(b) + \cos(a)\cos(b)\cos(c)$$

where d is the angular distance between points A and B in degrees, a is the latitude of A, b is the latitude of B, and c is the difference in longitude between A and B. To convert d to a linear distance measure, one can multiply d by the length of 1 degree at the equator, which is 111.32 kilometers or 69.17 miles. This method is accurate unless d is very close to zero (Snyder 1987).

Most commercial data producers deliver spatial data in geographic coordinates so that they can be used with any projected coordinate system the end user needs to work with. But more GIS users are using spatial data in geographic coordinates directly for data display and even simple analysis. Distance measurements from such spatial data are usually derived from the shortest spherical distance between points.

2.2.1 Types of Map Projections

Map projections can be grouped by either the preserved property or the projection surface. Cartographers group map projections by the preserved property into the following four classes: conformal, equal area or equivalent, equidistant, and azimuthal or true direction. A **conformal projection** preserves local angles and shapes. An **equivalent projection** represents areas in correct relative size. An **equidistant projection** maintains consistency of scale along certain lines. And an **azimuthal projection** retains certain accurate directions. The preserved property of a map projection is often included in its name such as the Lambert conformal conic projection or the Albers equal-area conic projection.

The conformal and equivalent properties are mutually exclusive. Otherwise a map projection can have more than one preserved property, such as conformal and azimuthal. The conformal and equivalent properties are global properties, meaning that they apply to the entire map projection. The equidistant and azimuthal properties are local properties and may be true only from or to the center of the map projection.

The preserved property is important for selecting an appropriate map projection for thematic mapping. For example, a population map of the world should be based on an equivalent projection. By representing areas in correct size, the population map can create a correct impression of population densities. In contrast, an equidistant projection would be better for mapping the distance ranges from a missile site.

Cartographers often use a geometric object and a globe (i.e., a sphere) to illustrate how to construct a map projection. For example, by placing a cylinder tangent to a lighted globe, one can draw a projection by tracing the lines of longitude and latitude onto the cylinder. The cylinder in this example is the projection surface, also called the developable surface, and the globe is called the **reference globe.** Other common projection surfaces include a cone and a plane. Therefore, map projections can be grouped by their projection surfaces into cylindrical, conic, and azimuthal. A map projection is called a **cylindrical projection** if it can be constructed using a cylinder, a **conic projection** if using a cone, and an **azimuthal projection** if using a plane.

The use of a geometric object helps explain two other projection concepts: case and aspect. For a conic projection, the cone can be placed so that it is tangent to the globe or intersects the globe (Figure 2.6). The first is the simple case, which results in one line of tangency, and the second is the secant case, which results in two lines of tangency. A cylindrical projection behaves the same way as a conic projection in terms of case. An azimuthal projection, on the other hand, has a point of tangency in the simple case and a line of tangency in the secant case. Aspect describes the placement of a geometric object relative to a globe. A plane, for example, may be tangent at any point on a globe. A polar aspect refers to tangency at the pole, an equatorial aspect at the equator, and an oblique aspect anywhere between the equator and the pole (Figure 2.7).

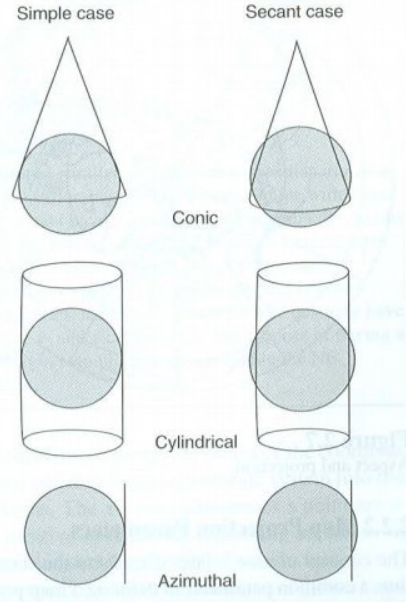

Figure 2.6
Case and projection.

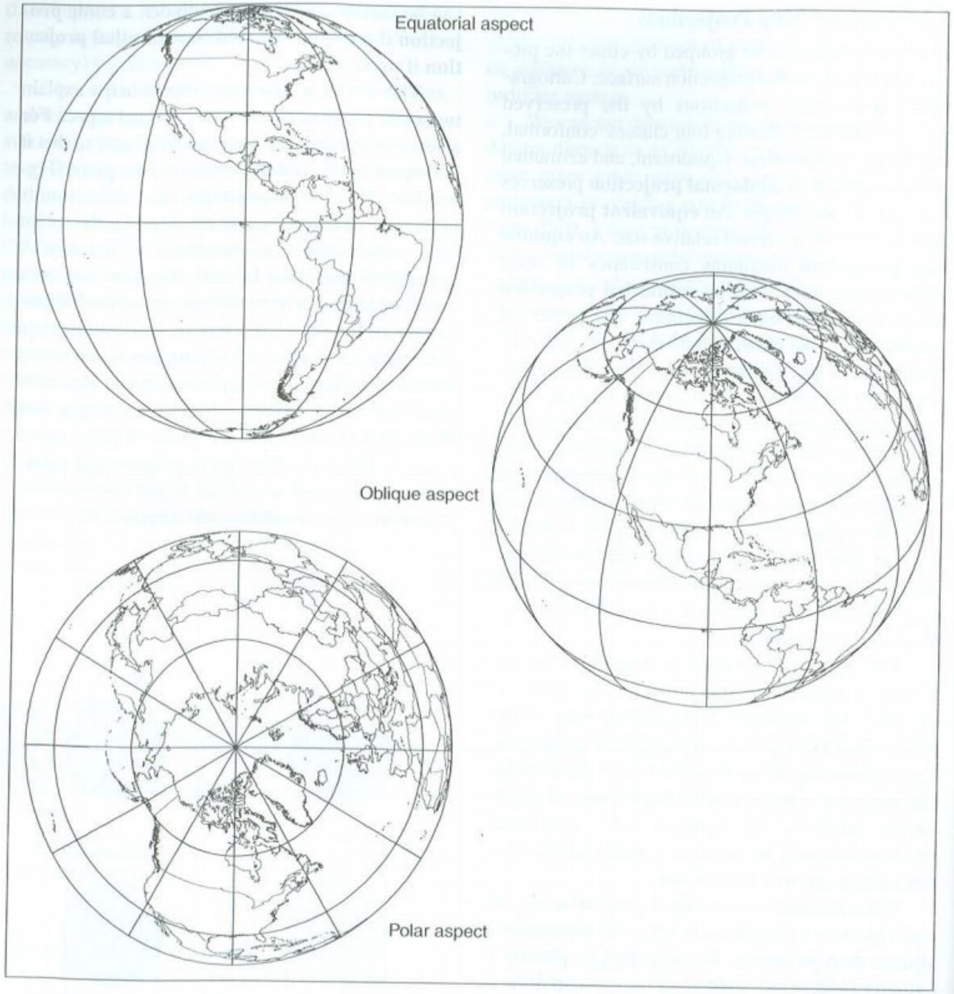

Figure 2.7
Aspect and projection.

2.2.2 Map Projection Parameters

The concept of case relates directly to the standard line, a common parameter in defining a map projection. A **standard line** refers to the line of tangency between the projection surface and the reference globe. For cylindrical and conic projections the simple case has one standard line whereas the secant case has two standard lines. The standard line is called the **standard parallel** if it follows a parallel, and the **standard meridian** if it follows a meridian.

Because the standard line is the same as on the reference globe, it has no distortion from the projection process. Away from the standard line, projection distortion can result from tearing, shearing, or compression of the spherical surface to meet the projection surface. A common measure of projection distortion is scale, which is defined as the ratio of a distance on a map (or globe) to its corresponding ground distance. The **principal scale,** or the scale of the reference globe, can therefore be derived from the ratio of the globe's radius to the Earth's radius (3963 miles or 6378 kilometers). For example, if a globe's radius is 12 inches, then the principal scale is 1:20,924,640 (1:3963 × 5280).

The principal scale applies only to the standard line in a map projection. This is why the standard parallel is sometimes called the latitude of true scale. The local scale applies to other parts of the map projection. Depending on the degree of distortion, the local scale can vary across a map projection (Bosowski and Feeman 1997). The **scale factor** is the normalized local scale, which is defined as the ratio of the local scale to the principal scale. The scale factor is 1 along the standard line and becomes either less than 1 or greater than 1 away from the standard line.

The standard line should not be confused with the central line. Whereas the standard line dictates the distribution pattern of projection distortion, the **central lines** (the central parallel and meridian) define the center of a map projection. The central parallel, sometimes called the latitude of origin, often differs from the standard parallel. Likewise, the central meridian often differs from the standard meridian. A good example showing the difference between the central meridian and the standard line is the transverse Mercator projection. Normally a secant projection, a transverse Mercator projection is defined by its central meridian and two standard lines on either side. The standard line has a scale factor of 1, and the central meridian has a scale factor of less than 1 (Figure 2.8).

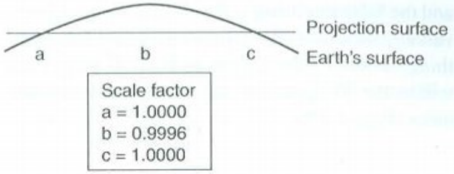

Figure 2.8
The central meridian in this secant case transverse Mercator projection has a scale factor of 0.9996. The two standard lines on either side of the central meridian have a scale factor of 1.0.

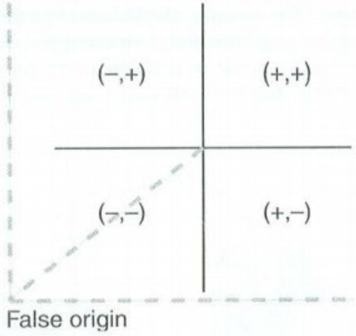

Figure 2.9
The central parallel and the central meridian divide a map projection into four quadrants. Points within the NE quadrant have positive *x*- and *y*-coordinates, points within the NW quadrant have negative *x*-coordinates and positive *y*-coordinates, points within the SE quadrant have positive *x*-coordinates and negative *y*-coordinates, and points within the SW quadrant have negative *x*- and *y*-coordinates. The purpose of having a false origin is to place all points within the NE quadrant.

When a map projection is used as the basis of a coordinate system, the center of the map projection, as defined by the central parallel and the central meridian, becomes the origin of the coordinate system and divides the coordinate system into four quadrants. The *x*-, *y*-coordinates of a point are either positive or negative, depending on where the point is located (Figure 2.9). To avoid having negative coordinates, we can assign *x*-, *y*-coordinate values to the origin of the coordinate system. The **false easting** is the assigned *x*-coordinate value and the **false northing** is the assigned *y*-coordinate value. Essentially, the false easting and false northing create a false origin so that all points fall within the NE quadrant and have positive coordinates (Figure 2.9).

2.3 COMMONLY USED MAP PROJECTIONS

Hundreds of map projections are in use. Commonly used map projections in GIS are not necessarily the same as those we see in classrooms or in magazines. For example, the Robinson projection is a popular projection for general mapping at the global scale because it is aesthetically pleasing (Dent 1999). But the Robinson projection is not suitable for GIS applications. A map projection for GIS applications usually has one of the preserved properties mentioned earlier, especially the conformal property. Because it preserves local shape and angles, a conformal projection allows adjacent maps to join correctly at the corners. This is important in developing a map series such as the U.S. Geological Survey (USGS) quadrangle maps.

2.3.1 Transverse Mercator

The **transverse Mercator projection,** also known as the Gauss-Kruger, is a variation of the Mercator projection, probably the best-known projection for mapping the world (Figure 2.10). The Mercator projection uses the standard parallel, whereas the transverse Mercator projection uses the standard meridian. Both projections are conformal.

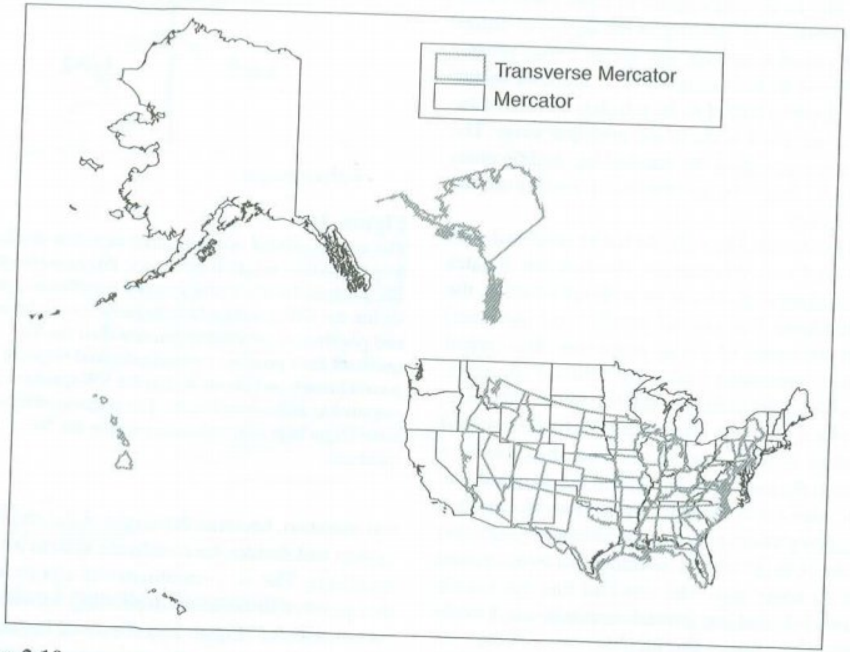

Figure 2.10
The Mercator and the transverse Mercator projection of the United States. For both projections, the central meridian is 90° W and the latitude of true scale is the equator.

The transverse Mercator is the basis for two common coordinate systems to be discussed in Section 2.4. The definition of the projection requires the following parameters: scale factor at central meridian, longitude of central meridian, latitude of origin (or central parallel), false easting, and false northing.

2.3.2 Lambert Conformal Conic

The **Lambert conformal conic projection** is a standard choice for mapping a midlatitude area of greater east–west than north–south extent, such as the state of Montana or the conterminous United States (Figure 2.11). The USGS has used the Lambert conformal conic for many topographic maps since 1957.

Typically used as a secant projection, the Lambert conformal conic is defined by the parameters of the first and second standard parallels, central meridian, latitude of projection's origin, false easting, and false northing.

2.3.3 Albers Equal-Area Conic

The Albers equal-area conic projection has the same parameters as the Lambert conformal conic projection. In fact, the two projections are quite similar except that one is equal area and the other is conformal. The Albers equal-area conic is the projection for the National Land Cover Data 1992 for the conterminous United States.

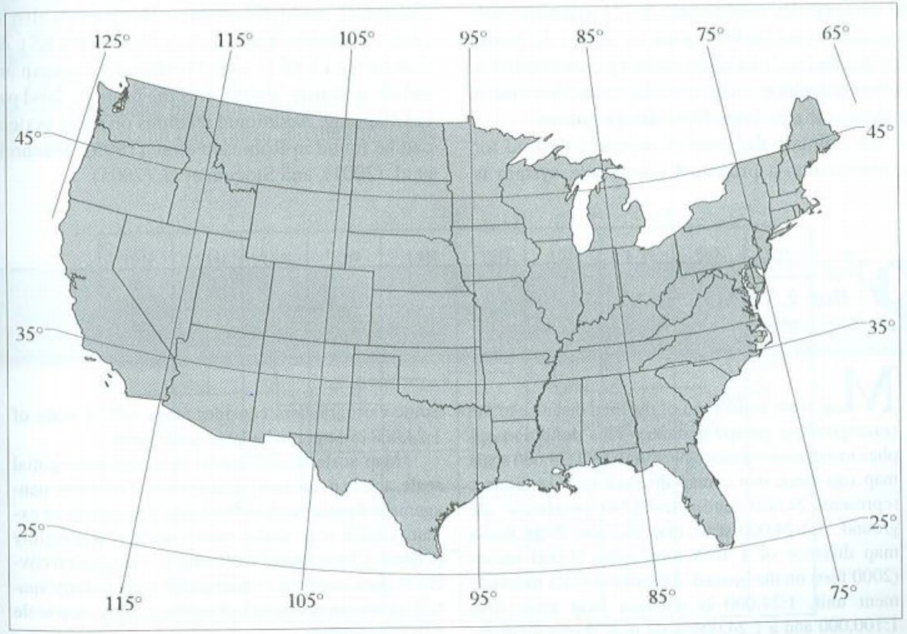

Figure 2.11
The Lambert conformal conic projection of the conterminous United States. The central meridian is 96° W, the two standard parallels are 33° N and 45° N, and the latitude of projection's origin is 39° N.

2.3.4 Equidistant Conic

The equidistant conic projection is also called the simple conic projection. The projection preserves the distance property along all meridians and one or two standard parallels. It uses the same parameters as the Lambert conformal conic.

2.4 PROJECTED COORDINATE SYSTEMS

A **projected coordinate system,** also called a plane coordinate system, is built on a map projection. Projected coordinate systems and map projections are often used interchangeably. For example, the Lambert conformal conic is a map projection but it can also refer to a coordinate system. In practice, however, projected coordinate systems are designed for detailed calculations and positioning, and are typically used in large-scale mapping such as at a scale of 1:24,000 or larger (Box 2.3). Accuracy in a feature's location and its position relative to other features is therefore a key consideration in the design of a projected coordinate system.

To maintain the level of accuracy desired for measurements, a projected coordinate system is often divided into different zones, with each zone defined by a different projection center. Moreover, a projected coordinate system is defined not only by the parameters of the map projection it is based on but also the parameters (e.g., datum) of the geographic coordinate system that the map projection is derived from. As mentioned in Section 2.1.1, all mapping systems are based on a spheroid rather than a sphere. The difference between a spheroid and a sphere may not be a concern for general mapping at small map scales but can be a matter of importance in the detailed mapping of land parcels, soil polygons, or vegetation stands.

Three coordinate systems are commonly used in the United States: the Universal Transverse Mercator (UTM) grid system, the Universal Polar Stereographic (UPS) grid system, and the State Plane Coordinate (SPC) system. As a group, coordinates of these common systems are sometimes called real-world coordinates. This section also includes the Public Land Survey System (PLSS). Although the PLSS is a land partitioning system and not a coordinate system, it is the basis for land parcel mapping. Additional readings on these systems can be found in Robinson et al. (1995), Muehrcke et al. (2001), and Slocum et al. (2005).

Box 2.3 **Map Scale**

Map scale is the ratio of the map distance to the corresponding ground distance. This definition applies to different measurement units. A 1:24,000 scale map can mean that a map distance of 1 centimeter represents 24,000 centimeters (240 meters) on the ground. A 1:24,000 scale map can also mean that a map distance of 1 inch represents 24,000 inches (2000 feet) on the ground. Regardless of its measurement unit, 1:24,000 is a larger map scale than 1:100,000 and a 1:24,000 scale map shows more details in a smaller area than a 1:100,000 scale map. Some cartographers consider maps with a scale of 1:24,000 or larger to be large-scale maps.

Map scale should not be confused with spatial scale, a term commonly used in natural resource management. Spatial scale refers to the size of area or extent. Unlike map scale, spatial scale is not rigidly defined. A large spatial scale simply means that it covers a larger area than a small spatial scale. A large spatial scale to an ecologist is therefore a small map scale to a cartographer.

2.4.1 The Universal Transverse Mercator (UTM) Grid System

Used worldwide, the **UTM grid system** divides the Earth's surface between 84° N and 80° S into 60 zones. Each zone covers 6° of longitude and is numbered sequentially with zone 1 beginning at 180° W. Each zone is further divided into the northern and southern hemispheres. The designation of a UTM zone therefore carries a number and a letter. For example, UTM Zone 10N refers to the zone between 126° W and 120° W in the northern hemisphere. The inside of this book's front cover has a list of the UTM zone numbers and their longitude ranges. Figure 2.12 shows the UTM zones in the conterminous United States.

Because datum is part of the definition of a projected coordinate system, the UTM grid system may be based on NAD27, NAD83, or WGS84. To complete the preceding example, if UTM Zone 10N is based on NAD83, then its full designation reads NAD 1983 UTM Zone 10N.

Each UTM zone is mapped onto a secant case transverse Mercator projection, with a scale factor of 0.9996 at the central meridian and the equator as the latitude of origin. The standard meridians are 180 kilometers to the east and the west of the central meridian (Figure 2.13). The use of a projection per UTM zone is designed to maintain the accuracy of at least one part in 2500 (i.e., distance measured over a 2500-meter course on the UTM grid system would be accurate within a meter of the true measure) (Muehrcke et al. 2001).

In the northern hemisphere, UTM coordinates are measured from a false origin located at the equator and 500,000 meters west of the UTM zone's central meridian. In the southern hemisphere, UTM coordinates are measured from a false origin located at 10,000,000 meters south of the equator and 500,000 meters west of the UTM zone's central meridian.

The use of a false origin means that UTM coordinates are very large numbers. For example, the NW corner of the Moscow East, Idaho quadrangle map has the UTM coordinates of 500,000 and 5,177,164 meters. To preserve data precision for computations with coordinates, we can apply ***x*-shift** and ***y*-shift** values to all coordinate readings to reduce the number of digits. For example, if the

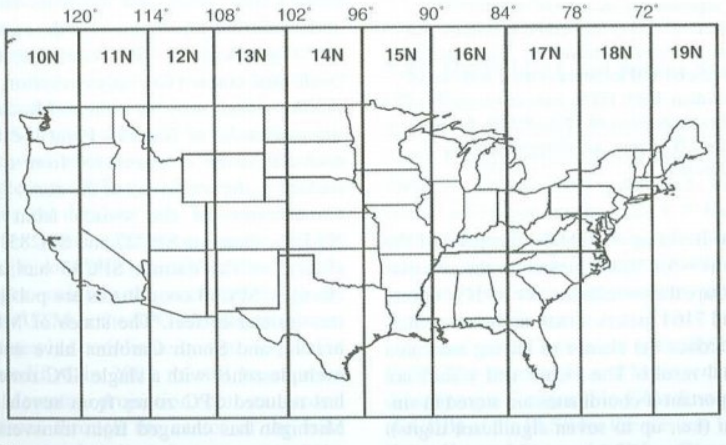

Figure 2.12
UTM zones range from zone 10N to 19N in the conterminous United States.

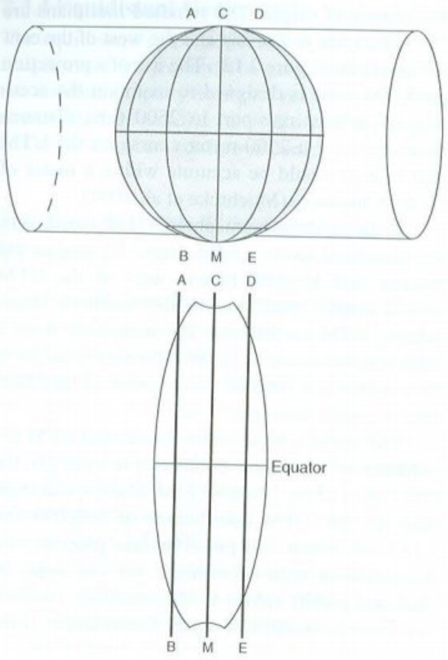

Figure 2.13
A UTM zone represents a secant case transverse Mercator projection. CM is the central meridian, and AB and DE are the standard meridians. The standard meridians are placed 180 kilometers west and east of the central meridian. Each UTM zone covers 6° of longitude and extends from 84° N to 80° S. The size and shape of the UTM zone are exaggerated for illustration purposes.

x-shift value is set as −500,000 meters and the *y*-shift value as −5,170,000 meters for the previous quadrangle map, the coordinates for its NW corner become 0 and 7164 meters. Small numbers such as 0 and 7164 reduce the chance of having truncated computational results. The *x*-shift and *y*-shift are therefore important if coordinates are stored in single precision (i.e., up to seven significant digits). Like false easting and false northing, *x*-shift and *y*-shift change the values of *x*-, *y*-coordinates in a data set. They must be documented along with the projection parameters in the metadata (information about data, Chapter 6), especially if the map is to be shared with other users.

2.4.2 The Universal Polar Stereographic (UPS) Grid System

The **UPS grid system** covers the polar areas. The stereographic projection is centered on the pole and is used for dividing the polar area into a series of 100,000-meter squares, similar to the UTM grid system.

2.4.3 The State Plane Coordinate (SPC) System

The **SPC system** was developed in the 1930s to permanently record original land survey monument locations in the United States. To maintain the required accuracy of one part in 10,000 or less, a state may have two or more SPC zones. As examples, Oregon has the North and South SPC zones and Idaho has the West, Central, and East SPC zones (Figure 2.14). Each SPC zone is mapped onto a map projection. Zones that are elongated in the north-south direction (e.g., Idaho's SPC zones) use the transverse Mercator and zones that are elongated in the east-west direction (e.g., Oregon's SPC zones) use the Lambert conformal conic. (The only exception is zone 1 of Alaska, which uses the oblique Mercator to cover the panhandle of Alaska.) Point locations within each SPC zone are measured from a false origin located to the southwest of the zone.

Because of the switch from NAD27 to NAD83, there are SPC27 and SPC83. Besides the change of the datum, SPC83 has a few other changes. SPC83 coordinates are published in meters instead of feet. The states of Montana, Nebraska, and South Carolina have each replaced multiple zones with a single SPC zone. California has reduced SPC zones from seven to six. And Michigan has changed from transverse Mercator to Lambert conformal conic projections. A list of SPC83 is available on the inside of this book's back cover.

Figure 2.14
SPC83 zones in the conterminous United States. The thinner lines are county boundaries, and the bold lines are state boundaries. This map corresponds to the SPC83 table on the inside of this book's back cover.

Some states in the United States have developed their own statewide coordinate system. Montana, Nebraska, and South Carolina all have a single SPC zone, which can serve as the statewide coordinate system. Idaho is another example. Idaho is divided into two UTM zones (11 and 12) and three SPC zones (West, Central, and East). These zones work well as long as the study area is within a single zone. When a study area covers two or more zones, the data sets must be converted to a single zone for spatial registration. But the conversion to a single zone also means that the data sets can no longer maintain the accuracy level designed for the UTM or the SPC coordinate system. The Idaho statewide coordinate system, adopted in 1994 and modified in 2003, is still based on a transverse Mercator projection but its central meridian passes through the center of the state (114° W). (A complete list of parameters of the Idaho statewide coordinate system is included in Task 1 of the applications section.) Changing the location of the central meridian means one zone for the entire state.

2.4.4 The Public Land Survey System (PLSS)

The **PLSS** is a land partitioning system (Figure 2.15). Using the intersecting township and range lines, the system divides the lands mainly in the central and western states into 6 × 6 mile squares or townships. Each township is further partitioned into 36 square-mile parcels of 640 acres, called sections. (In reality, many sections are not exactly 1 mile by 1 mile in size.)

Land parcel layers are typically based on the PLSS. The Bureau of Land Management (BLM) is developing a **Geographic Coordinate Data Base (GCDB)** of the PLSS for the western United States **(http://www.blm.gov/gcdb/).** Generated from BLM survey records, the GCDB contains coordinates and other descriptive information for section

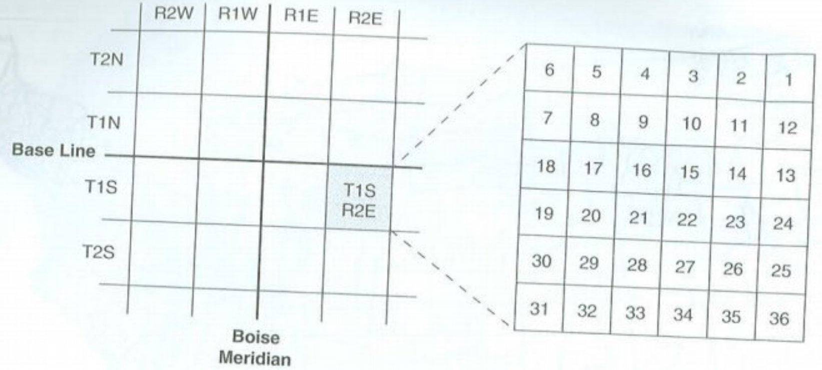

Figure 2.15
The shaded survey township has the designation of T1S, R2E. T1S means that the survey township is south of the base line by one unit. R2E means that the survey township is east of the Boise (principal) meridian by 2 units. Each survey township is divided into 36 sections. Each section measures 1 mile by 1 mile and has a numeric designation.

corners and monuments recorded in the PLSS. Legal descriptions of a parcel layer can then be entered using, for example, bearing and distance readings originating from section corners.

2.5 WORKING WITH COORDINATE SYSTEMS IN GIS

Basic GIS tasks with coordinate systems involve defining a coordinate system, projecting geographic coordinates to projected coordinates, and reprojecting projected coordinates from one system to another.

A GIS package typically has many options of datums, spheroids, and coordinate systems. For example, Autodesk Map offers 3000 global systems, presumably 3000 combinations of coordinate system, datum, and spheroid. A constant challenge for us is how to work with this large number of coordinate systems. Recent trends suggest that commercial GIS companies have tried to provide assistance in the following three areas: projection file, predefined coordinate systems, and on-the-fly projection.

2.5.1 Projection File

A projection file is a text file that stores information on the coordinate system that a data set is based on. Box 2.4, for example, shows a projection file for the NAD 1983 UTM Zone 11N coordinate system. The projection file contains information on the geographic coordinate system, the map projection parameters, and the linear unit.

Besides identifying a data set's coordinate system, a projection file serves at least two other purposes: it can be used for projecting or reprojecting the data set, and it can be exported to other data sets that are based on the same coordinate system.

2.5.2 Predefined Coordinate Systems

A GIS package typically groups coordinate systems into predefined and custom (Table 2.1). A predefined coordinate system, either geographic or projected, means that its parameter values are known and are already coded in the GIS package. The user can therefore select a predefined coordinate system without defining its parameters. Examples of predefined coordinate systems include NAD27 (based on Clarke 1866) and Minnesota SPC83, North (based on a Lambert conformal conic projection). In contrast, a custom coordinate system requires its parameter values to be specified by the user. The Idaho statewide coordinate system (IDTM) is an example of a custom coordinate system.

Box 2.4 A Projection File Example

The following projection file example is used by ArcGIS to store information on the NAD 1983 UTM Zone 11N coordinate system:

```
PROJCS ["NAD_1983_UTM_Zone_11N", GEOGCS["GCS_North_American_1983",
DATUM["D_North_American_1983",SPHEROID["GRS_1980",6378137.0,298.257222101]],
PRIMEM["Greenwich",0.0], UNIT["Degree",0.0174532925199433]],
PROJECTION ["Transverse_Mercator"], PARAMETER["False_Easting",500000.0],
PARAMETER["False_Northing",0.0], PARAMETER["Central_Meridian",-117.0],
PARAMETER["Scale_Factor",0.9996], PARAMETER["Latitude_Of_Origin",0.0],
UNIT["Meter",1.0]]
```

The information comes in three parts. The first part defines the geographic coordinate system: NAD83 for the datum, GRS80 for the spheroid, the prime meridian of 0^0 at Greenwich, and units of degrees. The file also lists the major axis (6378137.0) and the denominator of the flattening (298.257222101) for the spheroid. The number of 0.0174532925199433 is the conversion factor from degree to radian (an angular unit typically used in computer programming). The second part defines the map projection parameters of name, false easting, false northing, central meridian, scale factor, and latitude of origin. And the third part defines the linear unit in meters.

TABLE 2.1 A Classification of Coordinate Systems in GIS Packages

	Predefined	Custom
Geographic	NAD27, NAD83	Undefined local datum
Projected	UTM, State Plane	IDTM

2.5.3 On-the-Fly Projection

On-the-fly projection is a feature that has been heavily advertised by GIS vendors. On-the-fly projection is designed for displaying data sets that are based on different coordinate systems. The software package uses the projection files available and automatically converts the data sets to a common coordinate system. This common coordinate system is by default the coordinate system of the first data set in display. If a data set has an unknown coordinate system, the GIS package may use an assumed coordinate system. For example, ArcGIS uses NAD27 as the assumed geographic coordinate system.

On-the-fly projection does not actually change the coordinate system of a data set. Thus it cannot replace the task of projecting and reprojecting data sets in a GIS project. If a data set is to be used frequently in a different coordinate system, we should reproject the data set. And if the data sets to be used in spatial analysis have different coordinate systems, we should convert them to the same coordinate system to obtain the most accurate results.

Like other GIS packages, ArcGIS provides a suite of tools to work with coordinate systems. Box 2.5 is a summary of how to work with coordinate systems in ArcGIS.

Box 2.5 Coordinate Systems in ArcGIS

ArcGIS divides coordinate systems into geographic and projected. The user can define a coordinate system by selecting a predefined coordinate system, importing a coordinate system from an existing data set, or creating a new (custom) coordinate system. The parameters that are used to define a coordinate system are stored in a projection file. A projection file is provided for a predefined coordinate system. For a new coordinate system, a projection file can be named and saved for future use or for projecting other data sets.

The predefined geographic coordinate systems in ArcGIS have the main options of world, continent, and spheroid-based. WGS84 is one of the world files. Local datums are used for the continental files. For example, the Indian Datum and Tokyo Datum are available for the Asian continent. The spheroid-based options include Clarke 1866 and GRS80. The predefined projected coordinate systems have the main options of world, continent, polar, national grids, UTM, State Plane, and Gauss Kruger (one type of the transverse Mercator projection mainly used in Russia and China). For example, the Mercator is one of the world projections; the Lambert conformal conic and Albers equal-area are among the continental projections; and the UPS is one of the polar projections.

A new coordinate system, either geographic or projected, is user-defined. The definition of a new geographic coordinate system requires a datum including a selected spheroid and its major and minor axes. The definition of a new projected coordinate system must include a datum and the parameters of the projection such as the standard parallels and the central meridian.

KEY CONCEPTS AND TERMS

Azimuthal projection: One type of map projection that retains certain accurate directions. Azimuthal also refers to one type of map projection that uses a plane as the projection surface.

Central lines: The central parallel and the central meridian. Together, they define the center or the origin of a map projection.

Clarke 1866: A ground-measured spheroid, which is the basis for the North American Datum of 1927 (NAD27).

Conformal projection: One type of map projection that preserves local shapes.

Conic projection: One type of map projection that uses a cone as the projection surface.

Cylindrical projection: One type of map projection that uses a cylinder as the projection surface.

Datum: The basis for calculating the geographic coordinates of a location. A spheroid is a required input to the derivation of a datum.

Decimal degrees (DD) system: A measurement system for longitude and latitude values such as 42.5°.

Degrees-minutes-seconds (DMS) system: A measuring system for longitude and latitude values such as 42°30'00", in which 1 degree equals 60 minutes and 1 minute equals 60 seconds.

Ellipsoid: A model that approximates the Earth. Also called *spheroid*.

Equidistant projection: One type of map projection that maintains consistency of scale for certain distances.

Equivalent projection: One type of map projection that represents areas in correct relative size.

False easting: A value applied to the origin of a coordinate system to change the *x*-coordinate readings.

False northing: A value applied to the origin of a coordinate system to change the *y*-coordinate readings.

Geodetic coordinates: Geographic coordinates that are based on a spheroid.

Geographic Coordinate Data Base (GCDB): A database developed by the U.S. Bureau of Land Management (BLM) to include longitude and latitude values and other descriptive information for section corners and monuments recorded in the PLSS.

Geographic coordinate system: A location reference system for spatial features on the Earth's surface.

GRS80: A satellite-determined spheroid for the Geodetic Reference System 1980.

Lambert conformal conic projection: A common map projection, which is the basis for the SPC system for many states.

Latitude: The angle north or south of the equatorial plane.

Longitude: The angle east or west from the prime meridian.

Map projection: A systematic arrangement of parallels and meridians on a plane surface.

Meridians: Lines of longitude that measure locations in the E–W direction on the geographic coordinate system.

NAD27: North American Datum of 1927, which is based on the Clarke 1866 spheroid and has its center at Meades Ranch, Kansas.

NAD83: North American Datum of 1983, which is based on the GRS80 spheroid and has its origin at the center of the spheroid.

Parallels: Lines of latitude that measure locations in the N–S direction on the geographic coordinate system.

Principal scale: Same as the scale of the reference globe.

Projected coordinate system: A plane coordinate system that is based on a map projection.

Projection: The process of transforming the spatial relationship of features on the Earth's surface to a flat map.

Public Land Survey System (PLSS): A land partitioning system used in the United States.

Reference globe: A reduced model of the Earth, from which map projections are made. Also called a *nominal* or *generating globe*.

Reprojection: Projection of spatial data from one projected coordinate system to another.

Scale factor: Ratio of the local scale to the scale of the reference globe. The scale factor is 1.0 along a standard line.

Spheroid: A model that approximates the Earth. Also called *ellipsoid*.

Standard line: Line of tangency between the projection surface and the reference globe. A standard line has no projection distortion and has the same scale as that of the reference globe.

Standard meridian: A standard line that follows a meridian.

Standard parallel: A standard line that follows a parallel.

State Plane Coordinate (SPC) system: A coordinate system developed in the 1930s to permanently record original land survey monument locations in the United States. Most states have more than one zone based on the SPC27 or SPC83 system.

Transverse Mercator projection: A common map projection, which is the basis for the UTM grid system and the SPC system.

Universal Polar Stereographic (UPS) grid system: A grid system that divides the polar area into a series of 100,000-meter squares, similar to the UTM grid system.

Universal Transverse Mercator (UTM) grid system: A coordinate system that divides the Earth's surface between 84° N and 80° S into 60 zones, with each zone further divided into the northern hemisphere and the southern hemisphere.

WGS84: A satellite-determined spheroid for the World Geodetic System 1984.

x-shift: A value applied to *x*-coordinate readings to reduce the number of digits.

y-shift: A value applied to *y*-coordinate readings to reduce the number of digits.

REVIEW QUESTIONS

1. Describe the three levels of approximation of the shape and size of the Earth for GIS applications.
2. Why is the datum important in GIS?
3. Describe two common datums used in the United States.
4. Pick up a USGS quadrangle map of your area. Examine the information on the map margin. If the datum is changed from NAD27 to NAD83, what is the expected horizontal shift?
5. Go to the NGS-CORS website (**http://www.ngs.noaa.gov/CORS/cors-data.html**). How many continuously operating reference stations do you have in your state? Use the links at the website to learn more about CORS.
6. Explain the importance of map projection.
7. Describe the four types of map projections by the preserved property.
8. Describe the three types of map projections by the projection or developable surface.
9. Explain the difference between the standard line and the central line.
10. How is the scale factor related to the principal scale?
11. Name two commonly used projected coordinate systems that are based on the transverse Mercator projection.
12. Find the GIS data clearinghouse for your state at the Geospatial One-Stop website (**http://www.geo-one-stop.gov/**). Go to the clearinghouse website. Does the website use a common coordinate system for the statewide data sets? If so, what is the coordinate system? What are the parameter values for the coordinate system? And, is the coordinate system based on NAD27 or NAD83?
13. Explain how a UTM zone is defined in terms of its central meridian, standard meridian, and scale factor.
14. Which UTM zone are you in? Where is the central meridian of the UTM zone?
15. How many SPC zones does your state have? What map projections are the SPC zones based on?
16. Describe how on-the-fly projection works.

APPLICATIONS: COORDINATE SYSTEMS

This applications section has four tasks. Task 1 shows you how to project a shapefile from a geographic coordinate system to a custom projected coordinate system. In Task 2, you will also project a shapefile from a geographic to a projected coordinate system but use the coordinate systems already defined in Task 1. In Task 3, you will create a shapefile from a text file that contains point locations in geographic coordinates and project the shapefile onto a predefined projected coordinate system. In Task 4, you will see how on-the-fly projection works and then reproject a shapefile onto a different projected coordinate system.

All four tasks use the Define Projection and Project tools in ArcToolbox, which are available in ArcCatalog as well as ArcMap. The Define Projection tool defines a coordinate system. The Project tool projects a geographic or projected coordinate system. ArcToolbox has three options for defining a coordinate system: selecting a predefined coordinate system, importing a coordinate system from an existing data set, or creating a new (custom) coordinate system. A predefined coordinate system already has a projection file. A new coordinate system can be saved into a projection file, which can then be used to define or project other data sets.

This applications section uses shapefiles (i.e., feature classes) for all four tasks. ArcToolbox has separate projection tools in the Coverage Tools/Data Management/Projections toolset to work with coverages. These tools use projection files to define coordinate systems. ArcToolbox also has a separate tool in the Data Management Tools/Projections and Transformations/Raster toolset for projecting the coordinate system of a raster.

Task 1: Project a Shapefile from a Geographic to a Projected Coordinate System

What you need: *idll.shp*, a shapefile measured in geographic coordinates and in decimal degrees. *idll.shp* is an outline layer of Idaho.

For Task 1, you will first define *idll.shp* by selecting a predefined geographic coordinate system and then project the shapefile onto the Idaho transverse Mercator coordinate system (IDTM). IDTM is not a predefined system. IDTM has the following parameter values:

Projection Transverse Mercator
Datum NAD83
Units meters
Parameters
scale factor: 0.9996
central meridian: −114.0
reference latitude: 42.0
false easting: 2,500,000
false northing: 1,200,000

1. Start ArcCatalog, and make connection to the Chapter 2 database. Highlight *idll.shp* in the Catalog tree. On the Metadata tab, the FGDC summary information lists the coordinate system as geographic. Click the link to Spatial Reference Information. The information shows that the coordinate system is GCS_Assumed_Geographic_1, an assumed coordinate system.
2. First define the coordinate system for *idll.shp*. Click Show/Hide ArcToolbox Window to open the ArcToolbox window in ArcCatalog. Right-click ArcToolbox and select Environments. Click the General Setting dropdown arrow and select the Chapter 2 database for the current workspace. Double-click the Define Projection tool in the Data Management Tools/Projections and Transformations toolset. Select *idll.shp* for the input feature class. The dialog shows that *idll.shp* already has a coordinate system. But it is an assumed coordinate system. Click the button for the coordinate system to open the Spatial Reference Properties dialog. Click Select. Double-click Geographic Coordinate Systems, North America, and North American Datum 1927.prj. Click OK to dismiss the dialogs. Check the spatial reference information of *idll.shp* again. The Metadata tab should show GCS_North_American_1927.
3. Next project *idll.shp* to the IDTM coordinate system. Double-click the Project tool in the Data Management Tools/Projections and Transformations/Feature toolset. In the Project dialog, select *idll.shp* for the input feature class, specify *idtm.shp* for the output feature class, and click the button for the output coordinate system to open the Spatial

Reference Properties dialog. Click the New dropdown arrow and select Projected. In the New Projected Coordinate System dialog, first enter idtm for the Name. Then you need to provide projection information in the Projection frame and for the Geographic Coordinate System. In the Projection frame, select Tranverse_Mercator from the Name dropdown list. Enter the following parameter values: 2500000 for False_Easting, 1200000 for False_Northing, –114 for Central_Meridian, 0.9996 for Scale_Factor, and 42 for Latitude_Of_Origin. Make sure that the Linear Unit is Meter. Click Select for the Geographic Coordinate System. Double-click North America, and North American Datum 1983.prj. Click OK to dismiss the New Projected Coordinate System dialog. Click Save As in the Spatial Reference Properties dialog, and enter *idtm83.prj* as the file name. Dismiss the Spatial Reference Properties dialog.

4. A green dot appears next to Geographic Transformation in the Project dialog. This is because *idll.shp* is based on NAD27 and IDTM is based on NAD83. The green dot indicates that the projection requires a geographic transformation. Click Geographic Transformation's dropdown arrow and select NAD_1927_To_NAD_1983_NADCON. Click OK to run the command.
5. On the Metadata tab, you can verify if *idll.shp* has been successfully projected to *idtm.shp*.

Q1. Summarize in your own words the steps you have followed to complete Task 1.

Task 2: Import a Coordinate System

What you need: *stationsll.shp,* a shapefile measured in longitude and latitude values and in decimal degrees. *stationsll.shp* contains snow courses in Idaho.

In Task 2, you will complete the projection of *stationsll.shp* by importing the projection information on *idll.shp* and *idtm.shp* from Task 1.

1. On the Metadata tab, verify that *stationsll.shp* has an assumed geographic coordinate system. Double-click the Define Projection tool. Select *stationsll.shp* for the input feature class. Click the button for the coordinate system. Click Import in the Spatial Reference Properties dialog. Double-click *idll.shp* to add. Dismiss the dialogs.

Q2. Describe in your own words what you have done in Step 1.

2. Double-click the Project tool. Select *stationsll.shp* for the input feature class, specify *stationstm.shp* for the output feature class, and click the button for the output coordinate system. Click Import in the Spatial Reference Properties dialog. Double-click *idtm.shp* to add. Dismiss the Spatial Reference Properties dialog. Click the Geographic Transformation's dropdown arrow and select NAD_1927_To_NAD_ 1983_NADCON. Click OK to complete the operation. *stationstm.shp* is now projected onto the same (IDTM) coordinate system as *idtm.shp.*

Task 3: Project a Shapefile by Using a Predefined Coordinate System

What you need: *snow.txt,* a text file containing the geographic coordinates of 40 snow courses in Idaho.

In Task 3, you will first create an event layer from *snow.txt*. Then you will project the event layer, which is still measured in longitude and latitude values, to a predefined projected (UTM) coordinate system and save the output into a shapefile.

1. Launch ArcMap. Rename the new data frame Tasks 3&4 and add *snow.txt* to Tasks 3&4. (Notice that the table of contents is on the Source tab.) Click the Tools menu and select Add XY Data. In the next dialog, make sure that *snow.txt* is the input table, longitude is the X field, and latitude is the Y field. The dialog shows that the spatial reference of the input coordinates is an unknown coordinate system. Click the Edit button to open the Spatial Reference Properties dialog. Click Select. Double-click Geographic Coordinate Systems, North America, and North American Datum 1983.prj. Dismiss the dialogs.
2. *snow.txt Events* is added to ArcMap. You can now project *snow.txt Events* and save the output to a shapefile. Click Show/Hide ArcToolbox Window to open the ArcToolbox window in ArcMap. Double-click the Project tool in the Data Management Tools/ Projections and Transformations/Feature toolset. Select *snow.txt Events* for the input dataset, and specify *snowutm83.shp* for the output feature class. Click the button for the output coordinate system. Click Select in the Spatial Reference Properties dialog. Double-click Projected Coordinate Systems, Utm, Nad 1983, and NAD 1983 UTM Zone 11N.prj. Click OK to project the data set.

Q3. You did not have to ask for a geographic transformation in Step2. Why?

Task 4: Convert from One Coordinate System to Another

What you need: *idtm.shp* from Task 1 and *snowutm83.shp* from Task 3.

Task 4 first shows you how on-the-fly projection works in ArcMap and then asks you to convert *idtm.shp* from the IDTM coordinate system to the UTM coordinate system.

1. Right-click Tasks 3&4, and select Properties. The Coordinate System tab shows GCS_North_American_1983 to be the current coordinate system. ArcMap assigns the coordinate system of the first layer (i.e., *snow.txt Events*) to be the data frame's coordinate system. You can change it by clicking Import in the Data Frame Properties dialog. In the next dialog, double-click *snowutm83.shp*. Dismiss the dialogs. Now Tasks 3&4 is based on the NAD 1983 UTM Zone 11N coordinate system.
2. Add *idtm.shp* to Tasks 3&4. Although *idtm* is based on the IDTM coordinate system, it registers spatially with *snowutm83* in ArcMap. (A couple of snow courses are supposed to be outside the Idaho border.) ArcGIS can reproject a data set on-the-fly (Section 2.5.3). It uses the spatial reference information available to project *idtm* to the coordinate system of the data frame.
3. The rest of Task 4 is to project *idtm.shp* to the UTM coordinate system and to create a new shapefile. Double-click the Project tool. Select *idtm* for the input feature class, specify *idutm83.shp* for the output feature class, and click the button for the output coordinate system. Click Select in the Spatial Reference Properties dialog. Double-click Projected Coordinate Systems, Utm, Nad 1983, and NAD 1983 UTM Zone 11N.prj. Click OK to dismiss the dialogs.

Q4. Can you use Import instead of Select in step 3? If yes, how?

4. Although *idutm83* looks exactly the same as *idtm* in ArcMap, it has been projected to the UTM grid system.

Challenge Task

What you need: *idroads.shp* and *mtroads.shp.*

The Chapter 2 database includes *idroads.shp* and *mtroads.shp,* the road shapefiles for Idaho and Montana respectively. *idroads.shp* is projected onto the IDTM, but it has the wrong false easting (500,000) and false northing (100,000) values. *mtroads.shp* is projected onto the NAD 1983 State Plane Montana FIPS 2500 coordinate system in meters, but it does not have a projection file.

1. Use the Project tool and the IDTM information from Task 1 to reproject *idroads.shp* with the correct false easting (2,500,000) and false northing (1,200,000) values, while keeping the other parameters the same. Name the output *idroads2.shp.*
2. Use the Define Projection tool to first define the coordinate system of *mtroads.shp.* Then use the Project tool to reproject *mtroads.shp* to the IDTM and name the output *mtroads_idtm.shp.*
3. Use the Metadata tab in ArcCatalog to verify that *idroads2.shp* and *mtroads_idtm.shp* have the same spatial reference information.