CHAPTER

2

GIS DATABASES

Map Projections, Structures, and Scale

OBJECTIVES

Chapter 2 represents an introduction to the concepts of map projections and data structures. Natural resource management professionals will often be confronted with issues related to map projections and data structures when using GIS. After completing this chapter, students should understand and be able to discuss the pertinent aspects of topics related to the structure and composition of GIS databases:

1. The definition of a map projection and the components of a projection
2. The components and characteristics of a raster data structure
3. The components and characteristics of a vector data structure
4. The structure and purpose of metadata
5. The sources of GIS databases that describe the natural resources in the United States
6. The definition of scale and resolution as they relate to a GIS database

Performing GIS processes and analyses in support of natural resource management decisions requires obtaining and working with spatial databases. Many GIS users find that they spend a great deal of time and effort acquiring and modifying GIS databases to ensure that the most suitable and appropriate data are being used in subsequent analyses. One of the great challenges in working with features located on the surface of the Earth is that the Earth is very irregularly shaped, and is in a constant state of change. When one attempts to create a two-dimensional representation of the Earth (as is typically represented on maps), the Earth's irregularities must be accounted for. For this purpose, map projections have been created. Understanding that spatial data can be represented in a number of projections, and that data can be transformed from one projection to another, is a very important component in the process of learning to manage GIS databases successfully. This chapter is intended to introduce readers to common GIS database formats, the ways in which GIS data can be structured and adjusted to represent the Earth's surface, and the ways in which GIS databases are documented and described. Some direction is also provided to allow readers to begin to think about sources of GIS databases, although a more detailed treatment of this subject is provided in chapter 3.

THE SHAPE AND SIZE OF THE EARTH

GIS software programs are designed to work with data describing the Earth's features and to allow one to make measurements and to compare features of interest. There are a number of options by which one can collect, structure, and access GIS data; however, users of spatial data must always be cognizant that representations of landscape features are subject to distortion based on the spherical shape of the Earth. If the Earth were perfectly flat, collecting and mapping data from its surface would be a straightforward process. The Earth, however, has an uneven surface, which, for mapping purposes, can only be approximated through mathematical models. Depending on the source of the data, the data collection method, the geographical shape and size of a landscape, or the goals of a particular analysis, one may need to make adjustments to a GIS database to compensate for the shape of the Earth. GIS databases are generally corrected for the shape and curvature of the Earth by fitting them to a map projection. It is important for users of GIS databases to ensure that each is presented in the same map projection. Failure to do so can result in inaccurate analyses.

The true size and shape of the Earth have been issues of debate for millennia, and, despite the recent advancements in measurement technology, data related to the size and shape of the Earth continue to be collected and analyzed today. The field of collecting or calculating exact measurements of the Earth's size, shape, and gravitational forces is called geodesy. It is unclear who originally declared the Earth to be round (or spherical) rather than flat, but Greek philosophers Pythagoras (6th century B.C.) and Aristotle (4th century B.C.) considered the Earth to be round. Another Greek scholar, Eratosthenes (276–194 B.C.), provided the first mathematical calculation of the Earth's perimeter through an ingenious method, which is still used today. Eratosthenes observed that the bottom of a deep well located in Syene, today near Aswan in southern Egypt, was fully lit only during the summer solstice (June 21). He reasoned that the sun must be directly overhead at that time. Eratosthenes traveled to neighboring Alexandria and measured the length of a shadow from a vertical column of known height during the summer solstice. An angular departure from a vertical position (90° angle) of 7°12′ was calculated, and Eratosthenes subsequently applied geometric principles to determine the circumference of the Earth (figure 2.1). By dividing the calculated angle into the total number of degrees of a circle approximating the Earth (360°), Eratosthenes reasoned that the distance between Syene and Alexandria should represent 1/50th of the Earth's circumference. Eratosthenes estimated the distance between Syene and Alexandria to be 500 miles and multiplied this by 50 to get an estimate of the Earth's circumference (25,000 miles). This figure actually overestimates the circumference of the Earth, but it is remarkably close to today's estimate (24,900 miles), given the tools at Eratosthenes' disposal.

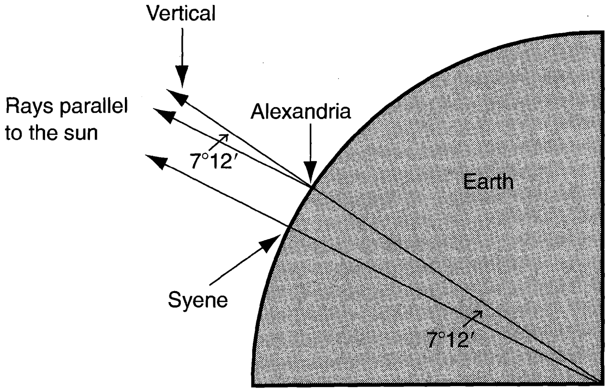


Figure 2.1 Eratosthenes' approach to determining the Earth's circumference.

ELLIPSOIDS, GEOIDS, AND DATUMS

The Earth was thought to be represented by a perfect sphere until about the end of the seventeenth century, when Isaac Newton advanced his theory of gravity. Newton theorized that, if the Earth were rotating along an axis, the shape of the Earth would tend to bulge along the equator and tend to be flattened at the poles, due to the centrifugal force created by the rotation. This theory was confirmed by field measurements of the Earth's surface, beginning in 1735, in Peru and Lapland, and later in other areas (Snyder 1987).

The shape of the Earth is thus referred to as an oblate **ellipsoid** or oblate spheroid. When comparing the location of the Earth's most northern point on this spheroidal shape with where one would expect to find it on a perfect sphere, there is a 20 km difference. This difference can be described as the **flattening ratio** (f) and is described by the relationship $(a - b)/a$, where a is the equatorial (or semi-major) radius and b is the polar (or semi-minor) radius (figure 2.2). The resulting flattening ratio is usually expressed as $1/f$. More than a dozen official ellipsoid models are used throughout the world. Most of these have flattening ratios around 1/298, but some differences exist due to variations in measurement techniques. The Clarke Ellipsoid of 1866 was designed to describe North America and, until very recently, was commonly used. Technological advancements in Earth measurement collection have led to improved ellipsoid models, including the Geodetic Reference System of 1980 (GRS80) and the World Geodetic System of 1984 (WGS84).

A further refinement and approximation of the Earth's shape can be described with a **geoid.** A geoid

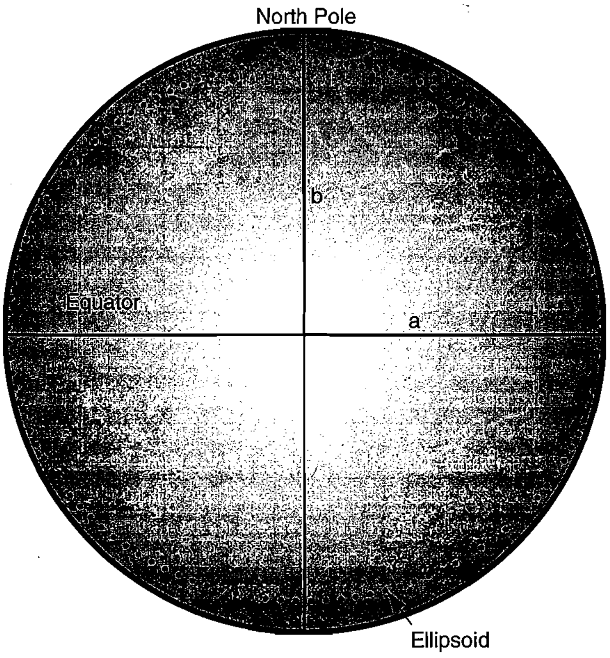


Figure 2.2 The ellipsoidal shape of the Earth deviates from a perfect circle by flattening at the poles and bulging at the equator.

attempts to reconcile Earth's local irregularities with the differing gravitational forces that are caused by varying Earth densities. The shape of a geoid is irregular and approximates Earth's mean sea level perpendicular to the forces of gravity. Within the continental United States, the geoidal surface can be found, on average, about 30 m below the GRS80 and WGS84 ellipsoids, whereas usually a few meters separates its surface from the Clarke 1866 ellipsoid (figure 2.3). Once one can define the Earth's shape and irregularities, a control system is needed on which to base the approximate locations of landscape features.

A **datum** is a smooth, mathematical representation of the Earth's surface that creates a "control surface," on which an ellipsoid and other location data are referenced. Datums are created from large numbers of measurements of the Earth's surface, typically assembled by land surveyors or others involved in Earth measurements, where the location of each point has been measured using precise control surveys. From these points, a theoretical surface of the Earth is constructed. The greater the number of point locations, the greater the datum's potential to act as a reliable surface on which one can reference other landscape features. Hundreds of datums have been developed to describe the Earth, many of which are specific to a particular country or region. Within North America, two datums are prominent: the North American Datum of 1927 (NAD27) and the North American Datum of 1983 (NAD83). The World Geodetic System of 1984 is commonly used in conjunction with GPS data collection efforts. The NAD83 and WGS84 are very similar and are sometimes used interchangeably, although this practice may not be suitable for applications that require high data accuracy levels. The NAD83 was designed for North America, whereas the WGS84 takes a global approach in representing the Earth. The primary differences between the NAD27 and NAD83 datums are the number of longitude and latitude locations that were measured to create each datum, and the way in which the measured locations are referenced to the surface of the Earth. About 25,000 point locations were used in creating the NAD27 datum, each of which was referenced to a central location, the Meades Cattle Ranch located in Kansas. Some 270,000 locations were used to create the NAD83 datum, and, rather than reference each to a central location on the Earth's surface, they are referenced to the center of the Earth's mass. The NAD83 datum has become the preferred datum for use in North America, although many GIS databases continue to contain landscape features described by the NAD27 datum.

Geoids and ellipsoids are often associated with a particular datum. The Clarke Ellipsoid of 1866 was designed to describe the landscape features of North America, and it is commonly used in conjunction with

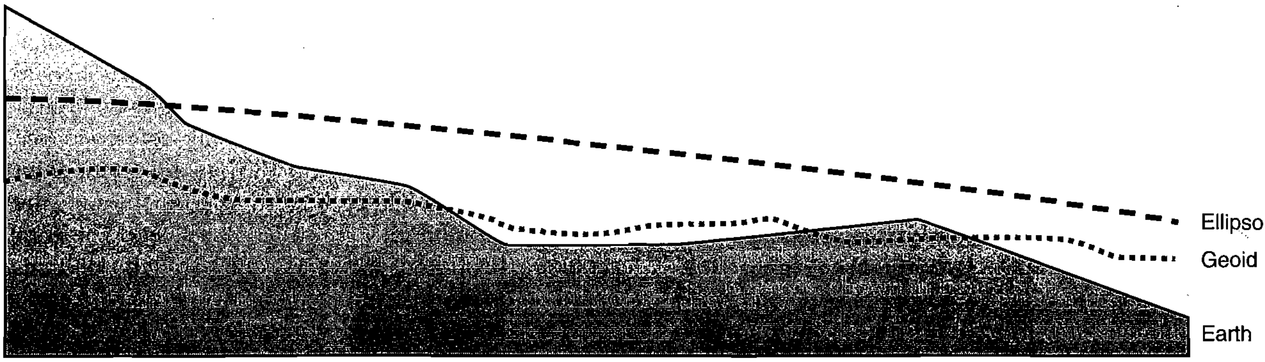


Figure 2.3 Ellipsoid and geoid surfaces.

the NAD27 datum. The Geodetic Reference System of 1980 (GRS80) and the World Geodetic System of 1984 (WGS84) are better suited for describing worldwide surfaces and are commonly used in conjunction with the NAD83 datum.

Many agencies and organizations that are involved in working with spatial data in North America use either the NAD27 or the NAD83. A common error among users of GIS, especially those who have acquired data from a number of sources, is in forgetting to convert their databases to a common datum. In terms of comparison, in the western United States, landscape features referenced in both of the datums will appear only slightly offset (10–20 meters) in latitude and about 80–100 meters offset in longitude. These differences may vary by region. Due to the relatively small differences, they are hard to differentiate with a visual examination and sometimes escape notice. Obviously, this oversight can lead to inaccurate analysis results.

The discussion of datums, to this point, has focused on those related to horizontal surfaces. When working with elevation data, GIS users must also be aware that datums have also been developed to describe the vertical dimension. The National Geodetic Vertical Datum of 1929 (NGVD29) was established from 26 gauging stations in the United States and Canada and forms the basis for determining mean sea level. The North American Vertical Datum of 1988 (NAVD88) used additional measurements from a large number of elevation profiles to create a single sea level control surface. The NAVD88 has become the preferred vertical datum.

THE GEOGRAPHICAL COORDINATE SYSTEM

René Descartes, a seventeenth-century French mathematician and philosopher, devised one of the first methods for locating landscape features on a planar surface. Descartes superimposed two axes, oriented perpendicular to one another, with gradations along both axes to create equal distance intervals. The horizontal axis is termed the x-axis and the vertical is the y-axis. The location of any point on the planar surface covered by this type of **grid** can be defined with respect to the interval lines that it intersects or most closely neighbors. This basis of determining location is known as a **Cartesian coordinate system** (figure 2.4).

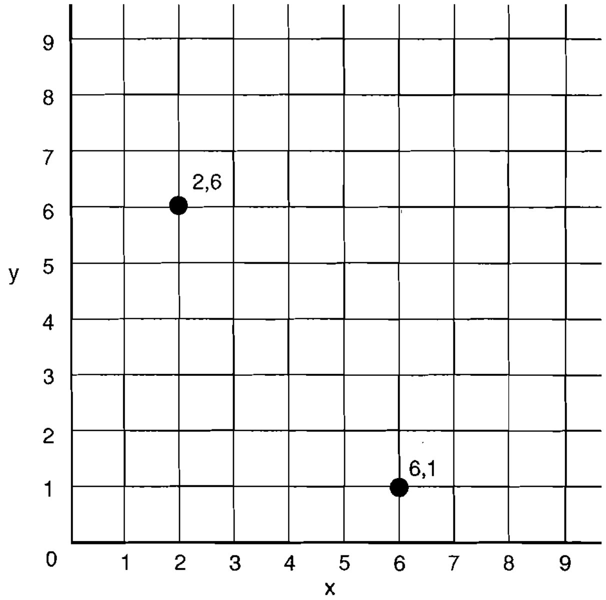


Figure 2.4 Example of point locations as identified by Cartesian coordinate geometry.

The most common coordinate system is the system of latitude and longitude, which is sometimes referred to as the geographical coordinate system. This system has an origin at the center of the Earth and contains a set of perpendicular lines running through the center to approximate the x- and y-axes of the Cartesian coordinate system. The orientation of the perpendicular lines is based on the rotation of the Earth. The Earth spins on an axis that, if extended, coincides very closely with the North Star (Polaris) and is called the axis of rotation. This rotation axis divides the Earth in half to create a line of longitude that approximates the y-axis. A line perpendicular to the line of longitude falls along the equator (Earth's widest extent) to create a line of latitude that is conceptually similar to the x-axis. Latitudes are expressed to a maximum of 90°, in a north or south direction from the equator, with the equator denoting 0° (figure 2.5). Traveling 90° north from the equator would leave one at the most northern point of the Earth and would be noted as 90° N. Similarly, a position halfway between the South Pole and the equator would be referenced as 45° S. The equator and other lines of latitude that parallel the equator are also called parallels.

Although the axis of rotation splits the Earth in half, a reference line must be established from which coordinates can start. This reference line is referred to as the prime meridian; although there are dozens in existence, the most widely recognized prime meridian circles the globe while passing across the British Royal Observatory located in Greenwich, England. Longitude measurements are made from this reference line and are designated from 0° to 180°, in a western or an eastern direction. Other lines that pass through the North and South Poles are called meridians. The conceptual collection of meridians and parallels superimposed on the Earth's surface is known as a **graticule.**

The geographical coordinate system can be used to locate any point on the Earth's surface. To achieve a high level of precision in locating landscape features,

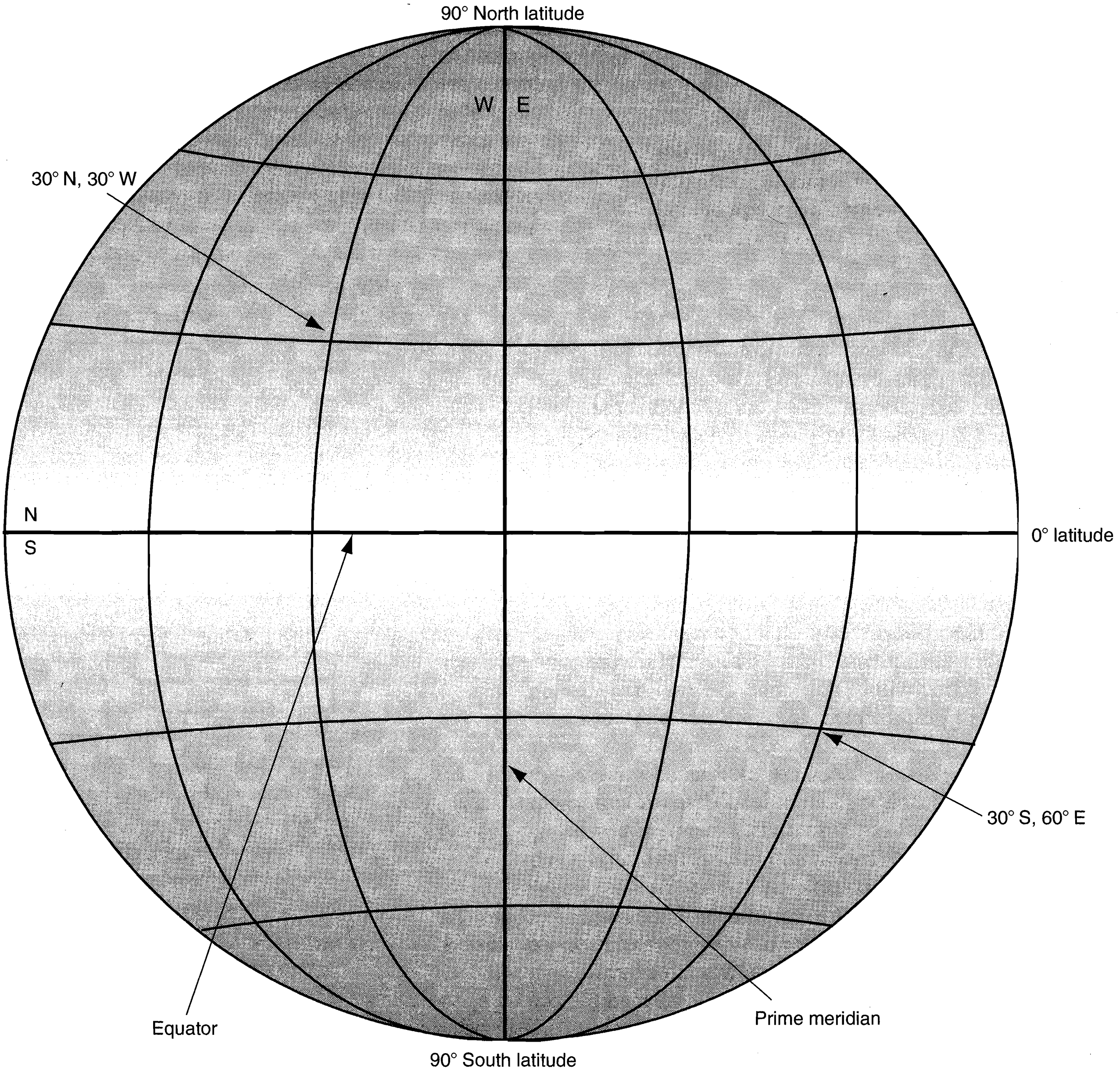


Figure 2.5 **Geographic coordinates as determined from angular distance from the center of the Earth and referenced to the equator and prime meridian.**

degrees are further subdivided into minutes and seconds. There are 60 minutes (noted by ′) within each degree and 60 seconds (noted by ″) within each minute. A location that is described as 38°30′ latitude indicates a line between 38° and 39°. Because this measurement system does not lend itself conveniently to mathematical calculations, conversions to the decimal degree system are common. The conversion of 38°30′45″ (spoken as 38 degrees, 30 minutes, and 45 seconds) would result in 38.575° decimal degrees. By using this coordinate system and describing measurements to the nearest second, one can locate objects on maps that are within 100 feet of their true locations on the ground (Muehrcke and Muehrcke 1998).

Although the geographical coordinate system provides a relatively straightforward solution to the complicated issue of establishing a regular system of measurements on a spherical surface, there are complications to its use. A primary problem is that the units of an arc (arc is used to describe angular distance—a sphere contains 360° of arc) are not constant throughout the system of geographical coordinates. Due to the convergence of the meridians at the Earth's polar areas, 1° of longitude ranges from 69 miles long at the equator to 0 miles long at the poles. Latitude measurements, in contrast, differ by minor amounts but average 69 miles across the Earth. Field measurements of longitude are also difficult to collect without the use of GPS or other similar navigational technology. Whereas one can calculate latitude by measuring the distance between the horizon and the North Star (in the Northern Hemisphere), calculating longitude involves understanding the difference between one's location and the prime meridian. In addition, the calculations and conversions involved when using degrees-minutes-seconds measurements are cumbersome and time-consuming.

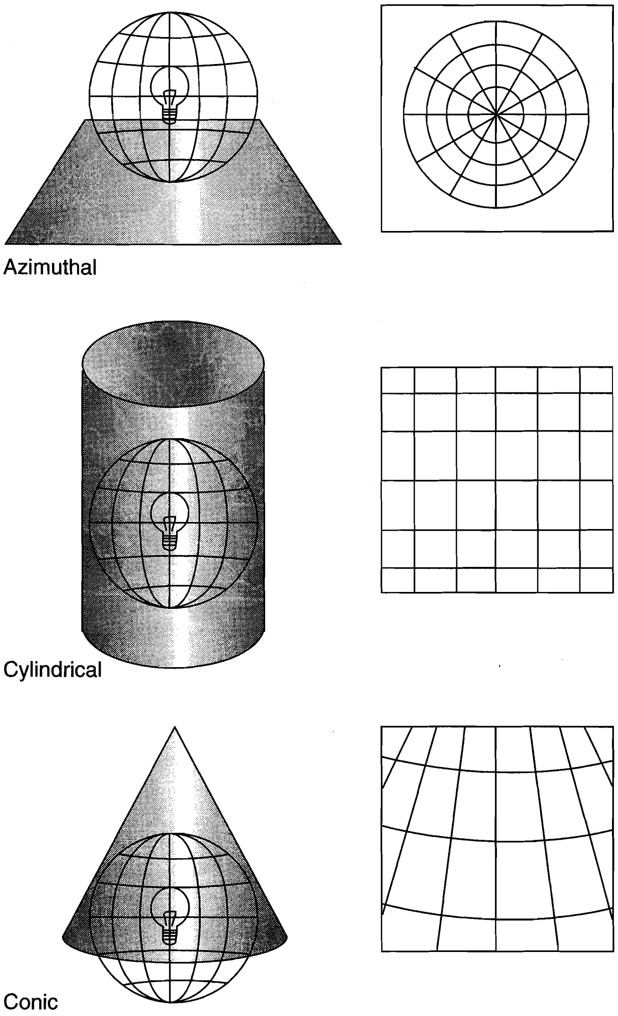


Figure 2.6 **Earth's graticule projected onto azimuthal, cylindrical, and conic surfaces.**

MAP PROJECTIONS

The map projection process can be considered a two-stage sequence (Robinson et al. 1995). First, measurements collected from the Earth's surface are placed on a globe that reflects the reduced scale on which one wishes to visualize the measurements. This conceptual globe is called a reference globe. The second step is to take the mapped measurements from the three-dimensional reference globe and place them onto a two-dimensional, flat surface. Perhaps the easiest way to understand this concept is to picture a transparent plastic globe with a graticule placed on its surface. If a lightbulb is placed within the globe, the outline of the graticule will be projected onto any surrounding surface.

Three primary flat surfaces are used to describe map projections: planes, cylinders, and cones (Dent 1999). Map projections on these surfaces are referred to as azimuthal, cylindrical, and conic, respectively (figure 2.6). With all three surfaces, a graticule on a map will appear in a different location than it does on a globe, and a graticule will appear in a different location on each surface. In general, if one were to examine a resulting map after a projection has been made with one of these three surfaces, one would see that a projected graticule appears more distorted along the edges of the maps, away from the point or line(s) where a globe actually coincides with the map surface. In fact, the areas where a globe and a map surface meet are the places where distortion is minimized. With simple, or tangent, map projections, a globe touches an azimuthal map surface at one location. In the case of the cylindrical and conic surfaces, a globe intersects a map along one meridian, parallel, or other line that circles the perimeter of the globe. One can, however, develop a map that alters the flat surfaces, so that a globe intersects them in two places rather than one (figure 2.7). This is known as a secant projection and can increase the ability of a map projection to describe landscape features accurately. A standard parallel exists when the intersecting line is coincident with a line of latitude; otherwise, the intersecting line is known as a standard line. For this reason, in the case of cylindrical and conic map surfaces, a tangent projection may have only one standard line or parallel, whereas a secant projection surface may have two. Regardless of line location, secant projections provide two areas where map distortion is minimized.

There are hundreds of types of map projections, and they can be classified according to how they manage the distortion related to the shape and direction of mapped landscape features. Three such classifications are the conformal, the equal area, and the azimuthal projections (Robinson et al. 1995). Each of these classifications has strengths and limitations when illustrating landscape features. Users must decide which of these classifications is the most appropriate for their GIS databases.

Conformal projections are most useful when the determination of directions or angles between objects is important. Applications of conformal projections include navigation and topographic maps. Examples include the Mercator projection, the transverse Mercator projection, and the Lambert conformal conic

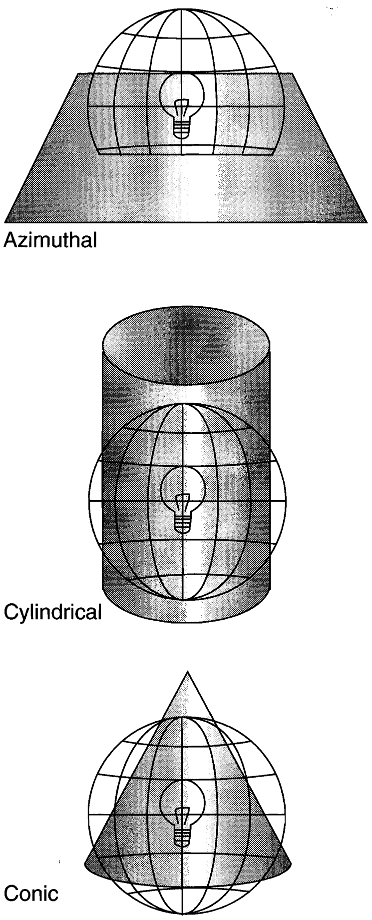


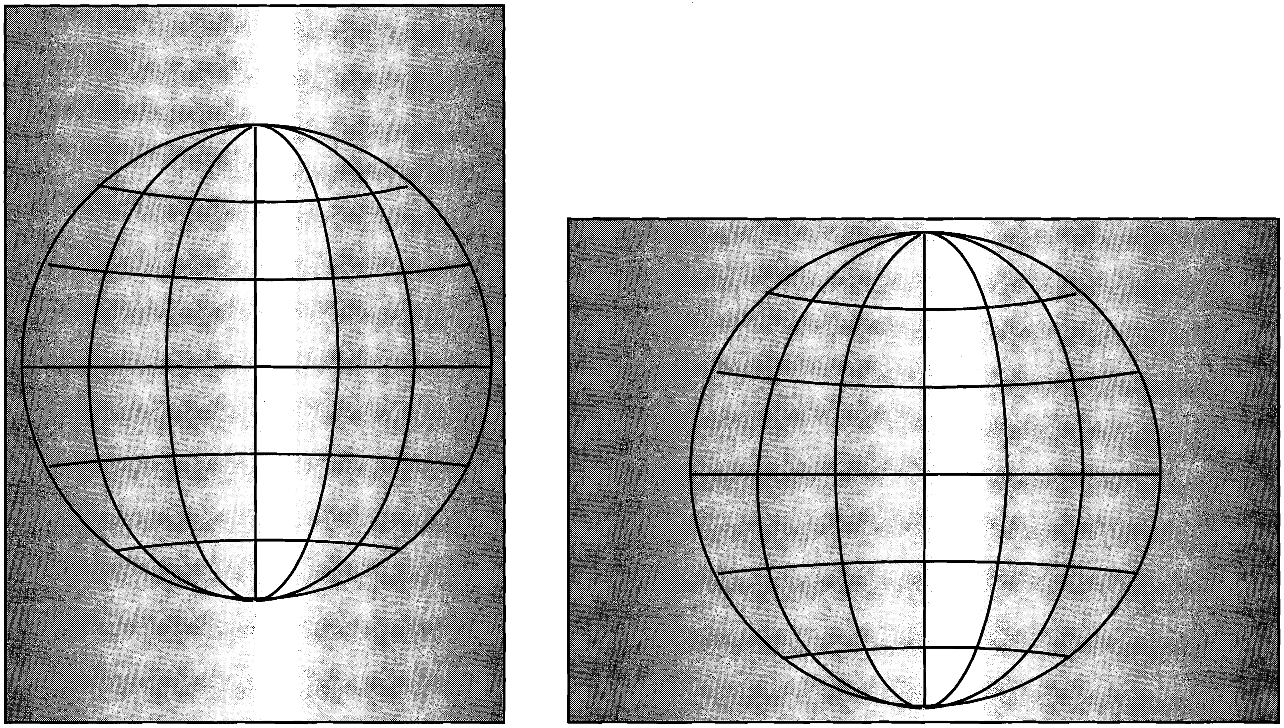
Figure 2.7 **Examples of secant azimuthal, cylindrical, and conic map projections.**

projection. The Mercator projection is a cylindrical projection, originally created for nautical navigation, and is probably the most widely recognized projection in the world. One useful feature of this projection system map, as it relates to navigational purposes, is that a line of constant azimuth or direction (called a rhumb line) will appear as a straight line. In contrast to the Mercator, the transverse Mercator rotates the cylinder, so that it is aligned with a parallel rather than a meridian (figure 2.8). The transverse Mercator projection is useful for navigational purposes in areas that have an extensive north-south orientation but are limited in their east-west orientation. The transverse Mercator has served as the base map projection for the USGS topographic map series and as the basis for the universal transverse Mercator coordinate system, described in the section "Planar Coordinate Systems." The Lambert conformal conic projection is useful for mid-latitude areas of the world with an extensive east-west orientation and a limited north-south orientation. When a secant method is used for small areas, the Lambert conformal conic projection can provide a highly accurate description of directions and shapes of landscape features. Large areas of land, however, will include distorted shapes when mapped with a conformal projection. Applications of the Lambert conformal conic projection include those related to aerial navigation, meteorological uses, and topographic maps. The emphasis is usually placed on mid-latitude features of the world, such as those found in the conterminous United States. Detailed applications of this projection system should focus on smaller land areas, since maintaining angular integrity across large areas is difficult.

Equal area, or equivalent, projections are well suited for maintaining the relative size and shape of landscape features when size comparisons are of interest. Equal area projections preserve the size and shape of landscape features but sacrifice linear and distance relationships in doing so. A tenet of map projection techniques and an important distinction between equal area and conformal projections is that areas and angles cannot both be maintained simultaneously—one must decide which is more important than the other. One example of the equal area projection is the Albers' equal area projection. This projection is widely used and is typically based on a secant conic map surface. As in the Lambert conformal conic projection, mid-latitude areas that have extensive east-west orientations are better candidates. This projection system has been selected by many U.S. agencies as a base map projection. The Lambert equal area projection is another commonly used equal area projection, yet it is based on an azimuthal map surface.

Azimuthal projections are useful for maintaining direction on a mapped surface. Azimuthal projections can be based on one (tangent) or two (secant) points of reference. With one point of reference, distortion will occur radially from the reference point, but directions near the reference point should remain true. For this reason, the azimuthal projection is appropriate for maps that have relatively the same amount of area in north-south and east-west orientations. When using two points of reference, directions emanating from either reference point should be true. The azimuthal equidistant projection offers the unique ability of maintaining uniform direction and distance from reference points. Azimuthal projections are useful for demonstrating the shortest route between two points (Robinson et al. 1995). Applications include those related to air navigation routes, radio wave ranges, and descriptions of celestial bodies. Azimuthal projections include Lambert's equal area, stereographic, orthographic, and gnomic.

When pondering the choice of a projection system to describe GIS databases, one should consider the size of the area being managed, as well as whether maintaining direction or area is important (Clarke 2001). Projection distortions, and resulting analytical errors, can become magnified as the size of a management



Mercator Transverse Mercator

Figure 2.8 **Orientation of the Mercator and transverse Mercator to the projection cylinder.**

area increases. A conformal or an azimuthal projection should be considered when navigational or other directional properties are important. If maintaining the size, shape, and distribution of landscape features is important, an equal area projection should be used. In addition, the shape of landscape features may influence projection choice.

PLANAR COORDINATE SYSTEMS

Now that the process of taking shapes located on the surface of a sphere and projecting them onto a flat surface has been discussed, it is time to explore the coordinate systems that are useful for locating landscape features on a flat surface. These systems are known as **plane coordinates,** or rectangular coordinates. The framework for examining plane coordinates was introduced with the concept of the Cartesian coordinate system. The same framework applies to plane coordinates, with a few minor modifications. For example, with planar coordinate systems, coordinates are referred to as **eastings** or **northings.** An easting measures distance east of the coordinate system's origin, whereas a northing measures distance north of the origin. These are usually specified by following the "right-up" approach; eastings are numerically organized so that positive measurements begin at the origin and increase to the right (to the east) of the origin, whereas northings are numerically organized so that positive measurements begin at the origin and increase up (to the north) from the origin. One inconvenience of this approach is that, if a coordinate system's origin is in the middle of a landscape, negative eastings and northings may occur, since some of the landscape is to the west and south of the origin. These negative coordinates might complicate the calculation of distances and areas. As a remedy, false origins can be constructed to prevent negative coordinates. This involves shifting the coordinate grid's numeric origin from the center of a landscape to the lower left-hand corner (the farthest west and south location of the landscape) or just outside the lower left-hand corner, so that all areas of the landscape are located east and north of the origin.

The most common coordinate system in the United States is the **universal transverse Mercator (UTM),** which has even been used to describe the surface of Mars (Clarke 2001). The UTM system has been used for remote sensing, forestry, and topographic map applications, as well as in many other countries, due in part to its reliance on the metric system as the primary system of measurement. The UTM system divides the Earth into 60 vertical zones, each zone covering 6° of longitude. The zones are numbered 1–60, starting at 180° longitude (the international date line) and proceeding eastward. The 10 zones that cover the conterminous United States are illustrated in figure 2.9. The

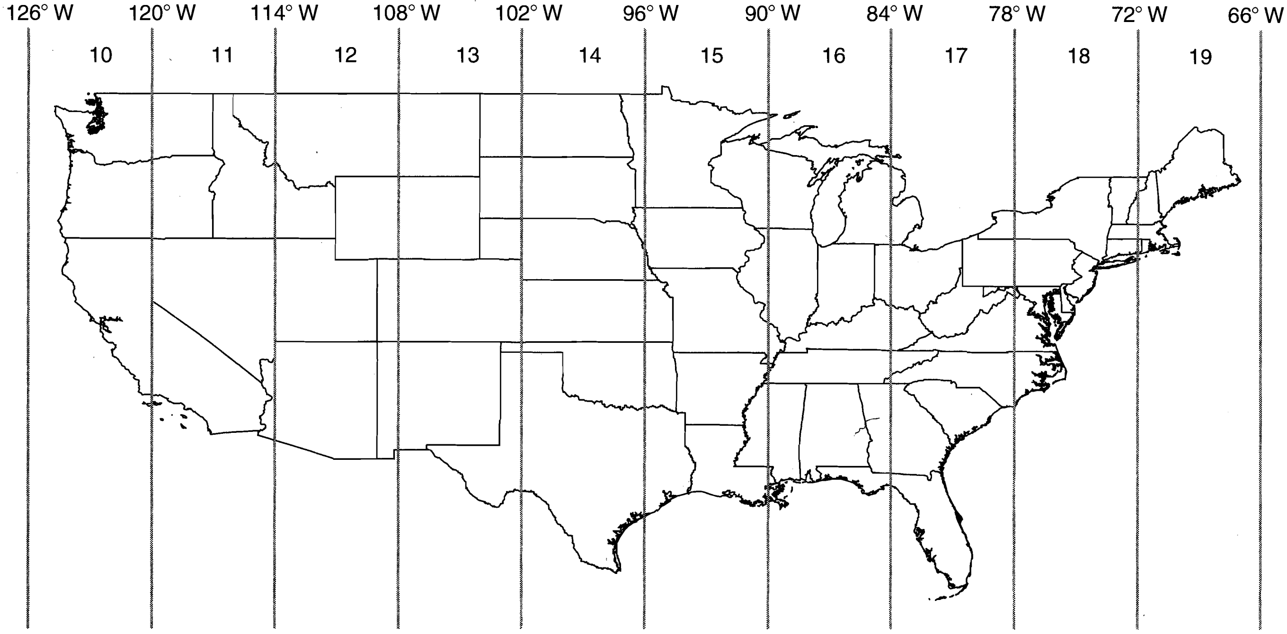


Figure 2.9 UTM zones and longitude lines for the United States.

system extends northward to 84° N latitude and southward to 80° S latitude. A universal polar stereographic (UPS) grid system is used for the polar regions. Coordinates for each zone start at the equator for areas covering the Northern Hemisphere and at 80° S latitude for areas in the Southern Hemisphere. A false origin is established for each zone, so that the central meridian of each zone has an easting of 500,000 meters. This arrangement ensures that all eastings are positive and that areas of zones can overlap, if needed. As the name implies, the UTM coordinate system uses the Mercator projection to minimize distortion. The level of accuracy in the system is assumed to be 1 part in every 2,500 (Robinson et al. 1995). Another version of the UTM is the military grid version, which uses many principles of the UTM yet divides each zone into rows, and each row covers 8° of latitude. Rows are denoted using the letters *C* to *X,* with *X* occupying the northern latitude between 72° and 84°. The military UTM can be used to define blocks of zones further into 100,000-meter squares.

The **state plane coordinate (SPC) system** was developed in the 1930s by the U.S. Coast and Geodetic Survey (known today as the U.S. Chart and Geodetic Survey), which created a unique set of planar coordinates for each of the 50 United States. The SPC was originally designed for land surveying purposes, so that location monuments could be established permanently. Under this system, each state is split into a smaller set of zones, depending on the size and shape of the state. For instance, Florida has two zones; California has four. The SPC system uses either a Lambert's conformal conic or transverse Mercator projection, the choice of which is usually influenced by the dimensions of the state and the dimensions of the zones of each state. The level of accuracy of the SPC system is approximately 1 part in 10,000.

The U.S. **Public Land Survey System (PLSS)** was established in 1785, by the U.S. Congress, as a national system for the measurement and subdividing of public lands. Approximately 75 percent of the United States was subject to measurement by the PLSS. The objectives of the PLSS were to measure the United States quantitatively, to create land portions that could be sold or distributed, and to provide a means of recording ownership information. The PLSS is not associated with a map projection. The PLSS begins with an initial point for a region or state, through which a principal meridian is astronomically derived (figure 2.10). A baseline is also established, intersecting a principal point at a right angle to the principal meridian. Thirty-seven principal points exist within the United States. At 24-mile intervals north and south of each baseline, standard parallels are established that extend east and west of the principal meridian (thus parallel to the baseline). Parallels are numbered and are referred to as being either north or south from the baseline (e.g., 2nd parallel north or 7th parallel south of a baseline). Guide meridians were also established at 24-mile intervals east and west of the principal meridian (thus parallel to the principal meridian). The guide meridians were established astronomically and are numbered relative to their position east or west of the principal meridian (e.g., 4th meridian east, 8th meridian west of the principal meridian). The grid of meridians and parallels creates blocks, each nominally

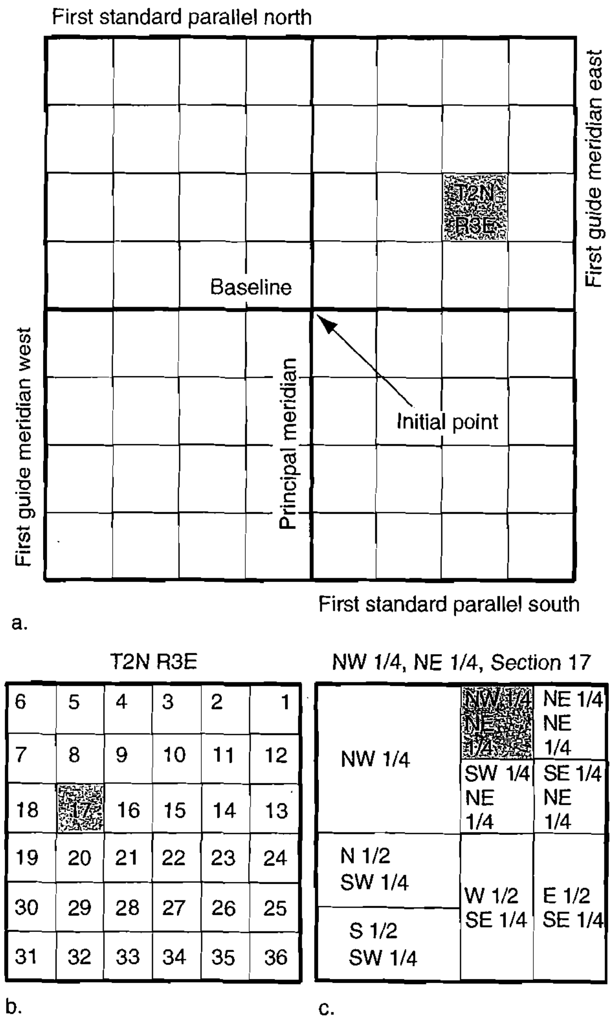


Figure 2.10 Origin (a), township (b), and section (c) components of the Public Land Survey System.

24 miles square. Townships are created within each block by forming range lines (running north and south) and township lines (running east and west) both at 6-mile intervals. The grid of range and township lines creates 16 townships within each block, each township being 6 miles square. Each township is further divided into sections, with each section measuring 1 square mile; there are 36 sections within a township. Sections are numbered 1–36, starting at the upper right-hand corner of a township. Sections can be apportioned into smaller components, such as quarter sections, half sections, or quarter quarter sections. In the naming convention, the smallest component is named first, starting with the portion of a section that a piece of land resides, then the township, range, and name of the principal meridian. An example is the NW 1/4, NE 1/4, Section 17, T2N, R3E, Mt. Diablo Meridian. Use of the PLSS is limited within GIS, but it is likely, especially in forestry applications, that one will encounter this system as work with GIS progresses. At some point, one may be required to re-project ownership boundaries derived from the PLSS, so that they match the projection systems used in other GIS databases.

Mismatched projections have been the bane of many spatial analysis efforts, and there are published and reported study results that suffer from this malady. Part of this problem is that many GIS users are unaware of the intent of projections and fail to realize that there are subcomponents, such as coordinate systems and datums, that need to be considered when working with a projection. Another contributor to this problem is the inability of many desktop GIS software programs to manipulate spatial database projections. Although projection algorithms are becoming more common to desktop GIS software programs, they are typically more robust in full-featured GIS software programs. As a GIS user or analyst, one must be cognizant of the projections used. When obtaining GIS databases, either from within or from outside an organization, it is critical to obtain as much information as possible about the structure of the data.

GIS DATABASE STRUCTURES

In natural resource management applications of GIS, two types of GIS data structures dominate: raster and vector. They are as different as night and day, and both have strengths and weaknesses when considered for use in various applications. Although many of the applications in this book involve the use of vector databases, most GIS users will eventually find themselves using a combination of both raster and vector databases.

Raster Data Structure

Raster data structures are generally made up of what can be considered **grid cells,** or **pixels,** that are organized and referenced by their row and column position in a database file. Raster data structures attempt to divide up and represent the landscape through the use of regular shapes (Wolf and Ghilani 2002). The shape that is almost exclusively used is the square (figure 2.11), yet other shapes, such as triangles, hexagons, and octagons, can also cover the Earth completely and regularly. Some common raster GIS databases are those related to satellite imagery, digital elevation models, digital orthophotographs, and digital raster graphs.

Satellite Imagery

Satellite imagery is a term used to describe a wide array of products generated by remote sensors contained

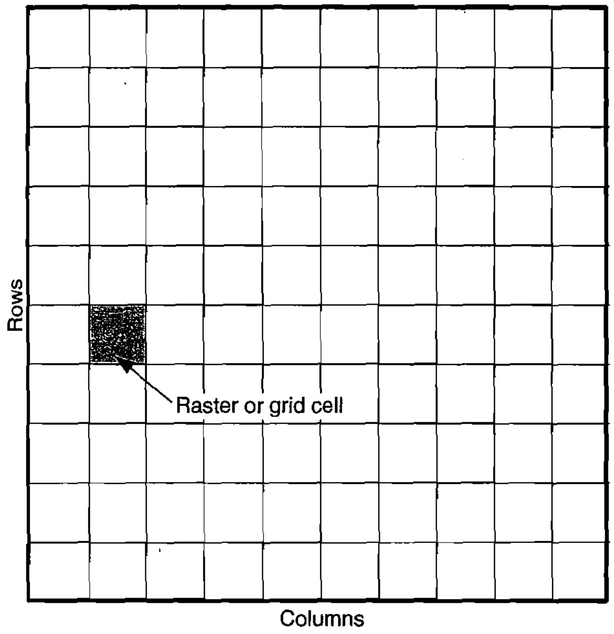


Figure 2.11 Generic raster data structure.

within satellites (figure 2.12). Satellites either are positioned stationary above a location on the Earth or circumnavigate the Earth using a fixed orbit. Although satellites have been sent into deep space, and have returned imagery to Earth, natural resource management is generally concerned only with imagery that provides information about the Earth and its natural resources.

Digital Elevation Models

When viewing satellite imagery of the Earth, it may seem as if there is no relief associated with the landscape, since the images were collected from a very high elevation (100+ miles); however, one can associate elevation data with raster images and, subsequently, view them in three dimensions. A **digital elevation model (DEM)** is a database that contains information about the topography of a landscape. The grid cells in these databases contain measurements of elevation across a landscape (figure 2.13). One can derive terrain models from DEMs that represent aspect, ground slope classes, and shaded relief maps. One can also perform a wide variety of terrain-based analyses, such as landscape visualization or watershed analysis. Elevation data can be collected by a variety of means, including sensors located on satellite or aerial platforms and photogrammetric techniques that use aerial photography in conjunction with GPS data. Elevation data may also be collected from the bottom of water bodies, such as oceans, lakes, or streams, through the use of sonar and acoustical sensors operated from boats or submersible water craft.

Digital Orthophotographs

A **digital orthophotograph** is essentially a digital aerial photograph (or an aerial photograph that has been scanned) that has been registered to a coordinate system. The displacement common to aerial photographs is greatly reduced through the use of precise positional data, DEMs, and information about the platform sensor (e.g., the camera system used). Most of the United States has been represented by digital orthophotography, created through a mapping program sponsored by the U.S. Geological Survey (USGS). Digital orthophotographs are generally made available in portions that match the **extent** of USGS 7.5 Minute Series Quadrangle maps and are often referred to as digital orthophoto quadrangles (DOQs). Since the USGS Quadrangle maps cover large ground areas (7.5 minutes of longitude and latitude), digital orthophotographs have been developed to cover portions of Quadrangle maps as well and are abbreviated DOQQ (digital ortho quarter quadrangle). Many counties in the United States have also commissioned more detailed digital orthophotographs, as have private companies. Digital orthophotographs provide a data source for those interested in obtaining a relatively fine scale image of landscape or in obtaining a base data layer for digitizing landscape features (figure 2.14).

One of the strengths of digital orthophotographs is that each image is georeferenced to a coordinate and projection system; thus, GIS users can employ desktop GIS software programs to digitize and create GIS databases using "heads-up" digitizing. The term *heads-up digitizing* indicates that the person doing the digitizing is looking at a computer screen (i.e., his or her head is up), rather than a digitizing table (which requires the person to look down), when digitizing landscape features. With heads-up digitizing, one can quickly create a GIS database from a digital orthophotograph image on a computer screen.

Digital Raster Graphics

Digital raster graphics (DRGs) are digitally scanned representations of the USGS 7.5 Minute Series Quadrangle maps (figure 2.15). Since the 7.5 Minute Series Quadrangle maps typically illustrate cultural resources, such as roads, large buildings, elevation contours, and natural features (such as water bodies), the DRGs also include this information. DRGs are available for the entire United States at a scale of 1:24,000. As with the DOQs, this georeferenced raster GIS database can be used as a base layer for digitizing other landscape features of interest.

Each type of raster GIS database provides a different dimension to the description of the Earth and landscape features located on (or beneath) the Earth's

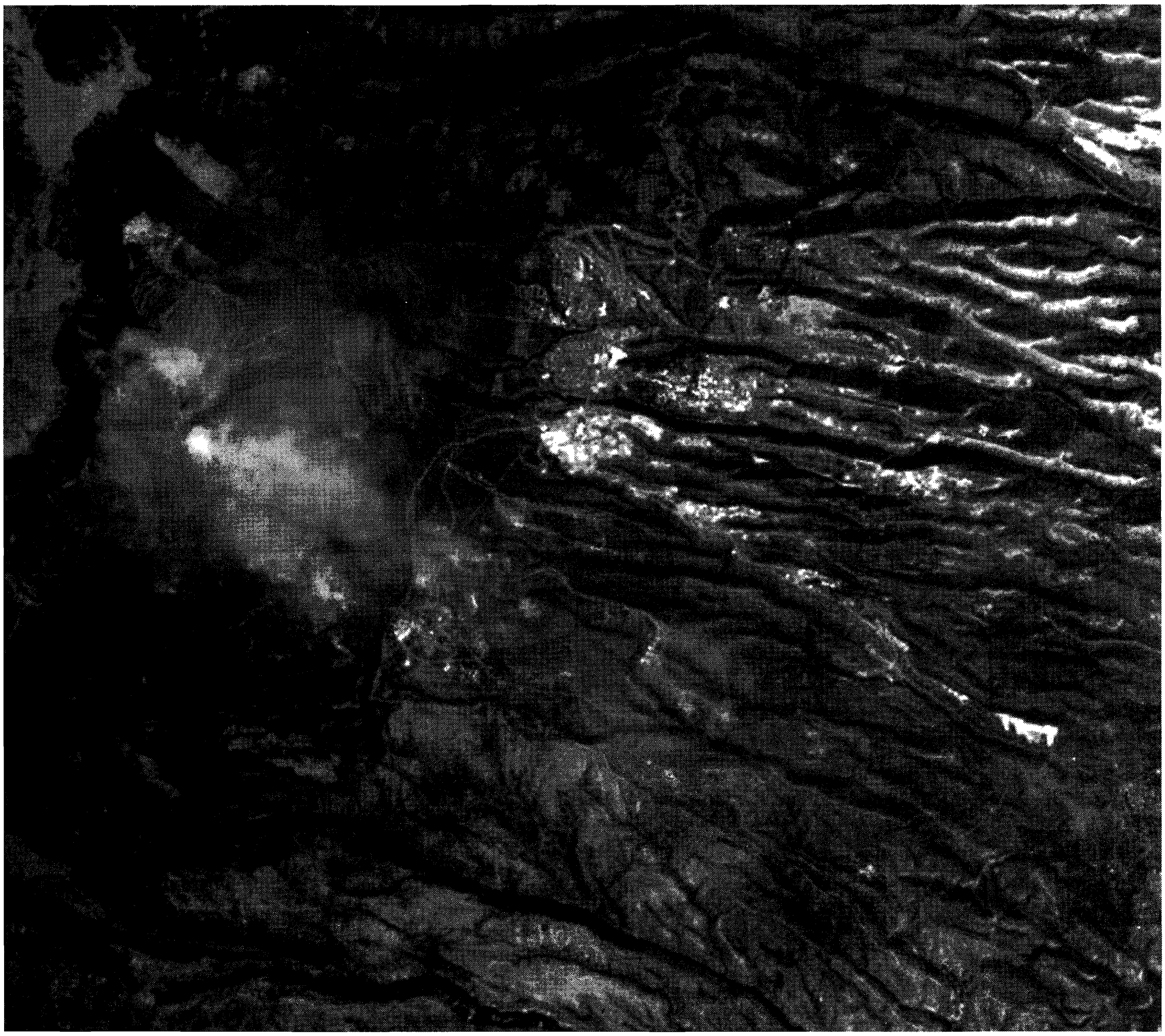


Figure 2.12 Landsat 7 satellite image captured using the Enhanced Thematic Mapper Plus sensor that shows the Los Alamos/Cerro Grande fire in May 2000. This simulated natural color composite image was created through a combination of three sensor bandwidths (3,2,1) operating in the visible spectrum.

(Image courtesy of Wayne A. Miller, USGS/EROS Data Center.)

surface. The usefulness of raster GIS databases depend on the needs and capabilities of each natural resource management organization.

Vector Data Structure

Vector data, as compared with raster data, are generally considered "irregular." This is not a comment on the quality or usefulness of vector data structures but, rather, a characterization of the type of data they represent. Vector data are generally grouped into three categories: **points, lines,** or **polygons.** Almost any landscape feature on the Earth can be described using one of these three shapes, or a combination of the shapes (figure 2.16). Points are the most basic of the shapes but define the essence of all three forms. A line is a set of connected points. A polygon is a collection of lines that forms a closed loop.

Point, line, and polygon vector features can be referenced by almost any coordinate system. To represent a point, a single measure from each x- (east-west) and y- (north-south) axis is needed to describe the location of the point within a coordinate system. With lines and polygons, pairs of connected points are used to describe these features.

Most GIS software programs store location information (X, Y coordinates that describe the landscape features) in separate GIS databases for each theme of

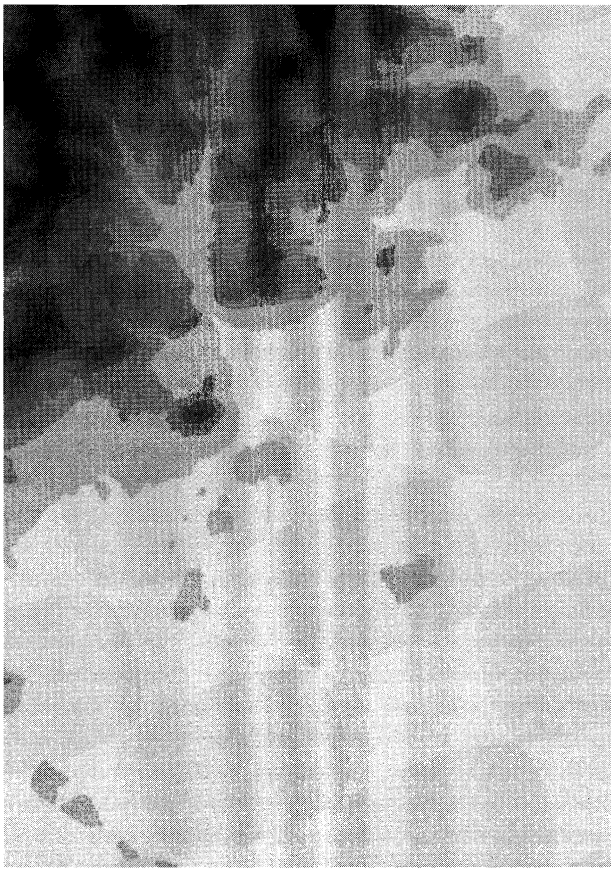


Figure 2.13 Digital elevation model (DEM).

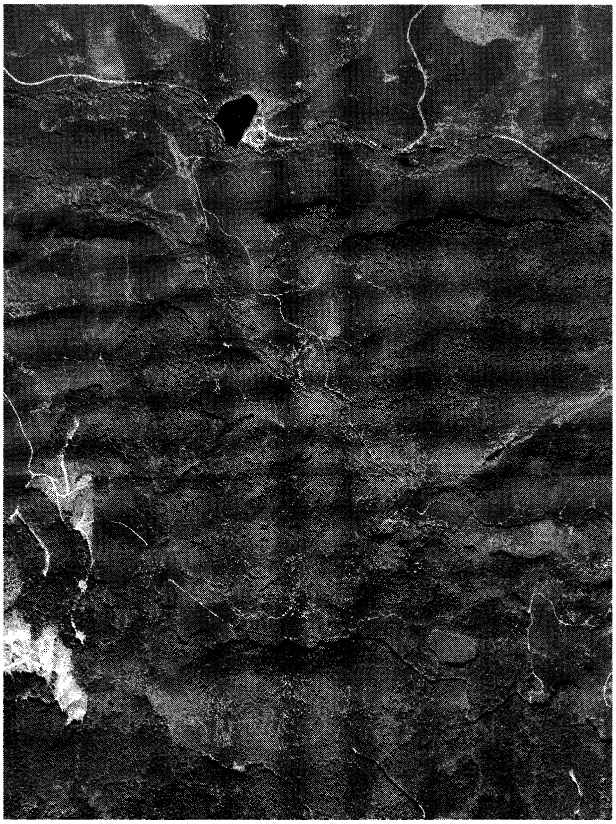


Figure 2.14 Digital orthophoto quadrangle (DOQ).

interest. For example, the coordinates that are used to describe a roads GIS database are separate from the coordinates that describe a streams GIS database. Although most of the location information that defines vector features will be transparent to users of desktop GIS software programs, it is vital in establishing and maintaining **topology.** Topology describes the spatial relationships between (or among) points, lines, and polygons and is a very important consideration when conducting spatial analyses. Topology allows one to determine such things as the distance between points, whether lines intersect, or whether a point (or a line) is located within the boundary of a polygon.

Topology can be defined in a number of ways, but the most common definitions involve aspects of adjacency, connectivity, and containment (figure 2.17). **Adjacency** is used to describe a landscape feature's neighbors. One might use adjacency relationships to describe polygons that share borders (e.g., in support of green-up requirements in a forest management context), or to identify the lines that make up a polygon (area). Connectivity is typically used to describe linear **networks,** such as a network of culverts that might be connected by drainage ditches. Connectivity would allow one to trace the flow of water through a stream system. One can also incorporate direction into a description of connectivity. Based on the topography of a landscape in which a culvert system is situated, one could determine the overland flow paths of water through the system, given that water flows downhill. Containment allows one to describe which landscape features are located within, or intersect, the boundary of polygons. One could use containment information to describe the well locations (points) or the power lines (lines) that are located within a proposed urban growth boundary, for example.

In order for topology to exist, a system for coding topology that can be understood and manipulated by a computer must also exist. With GIS databases containing point features, there is little need for anything more than a file of coordinate pairs (**X, Y coordinates**), since all points are ideally separated from one another and, thus, there are no issues of adjacency, connectivity, and containment to resolve. However, more detail is needed in describing feature locations and linkages when using GIS databases containing line and polygon features. The spatial integrity of lines and polygons is maintained by managing the nodes, vertices, and links of each feature. A **node** is the starting and ending point of a line, and may represent the intersection of two or more lines (figure 2.18). A **vertex** is any point that is not a node but specifies a location or creates a

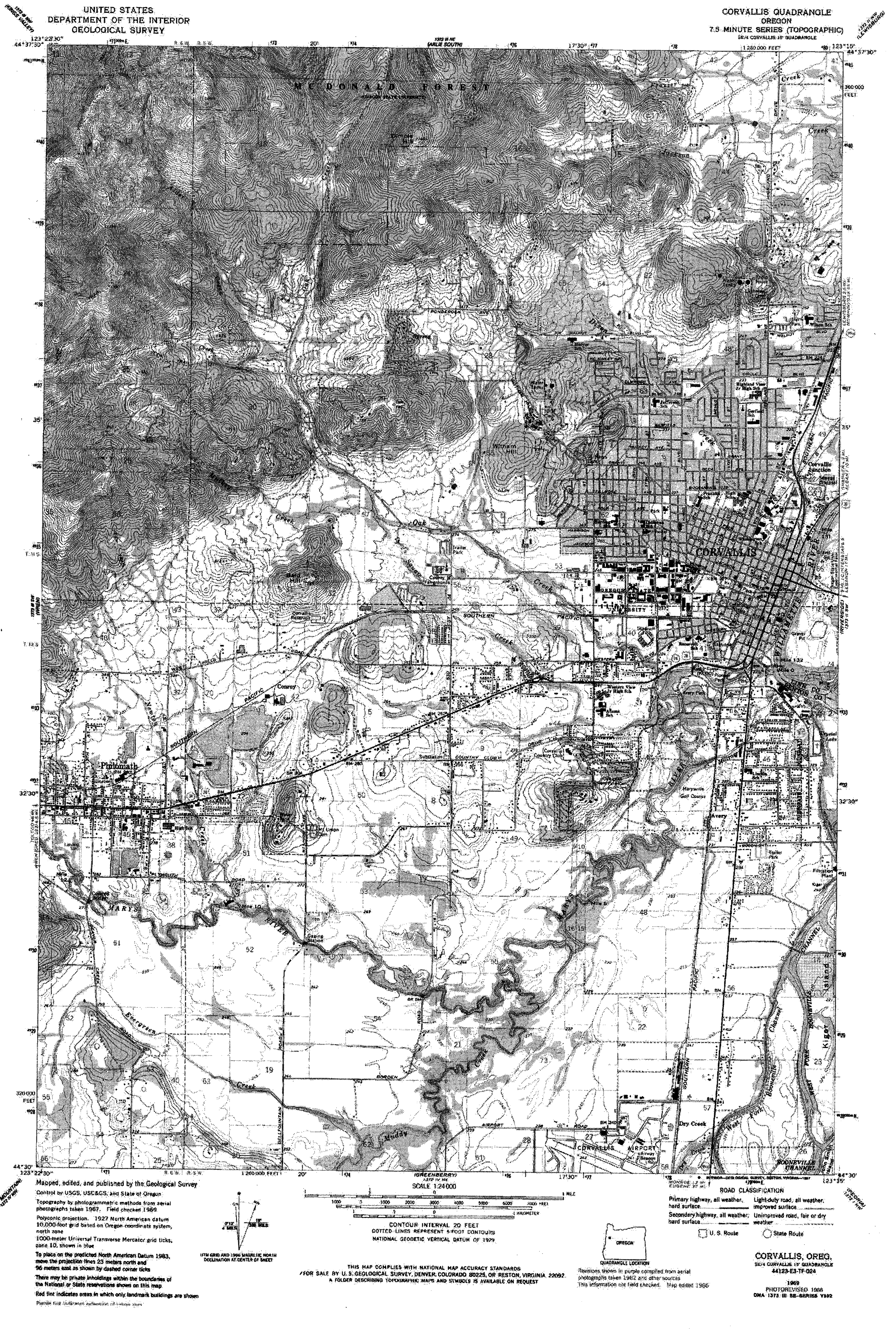


Figure 2.15 Digital raster graphics (DRG) image.

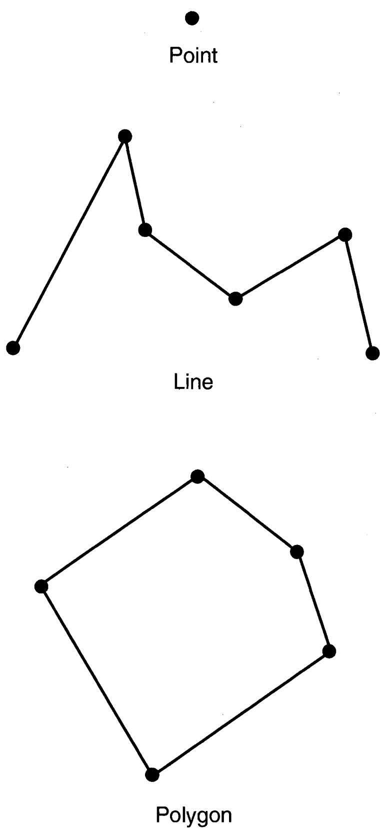


Figure 2.16 **Point, line, and polygon vector shapes.**

directional change in a line. A **link,** sometimes called an **arc,** is a line that connects points as defined by nodes and vertices. Nodes, vertices, and links are usually numbered and maintained in a GIS database file to maintain topology. In a network of lines and polygons (figure 2.19), this would involve using numeric codes for network pieces (nodes and links) to identify the node locations, the nodes that are attached to each link, and the polygons that may form on either side of each link.

Topology also allows one to inspect the spatial integrity of lines and polygons. For instance, one can use topological information to determine whether any breaks or gaps occur in lines that are meant to represent streams. From a polygon perspective, topology would allow one to determine whether a polygon forms a closed boundary or whether an extraneous polygon exists inside, or along the outside border, of another polygon (figure 2.20).

One of the primary differences between full-featured GIS software programs and desktop GIS software programs is their ability to identify and correct topological problems in vector GIS database features. Many desktop GIS software programs, such as ArcView, GeoMedia, and MapInfo, have vector data formats that are not topologically based (Chang 2002).

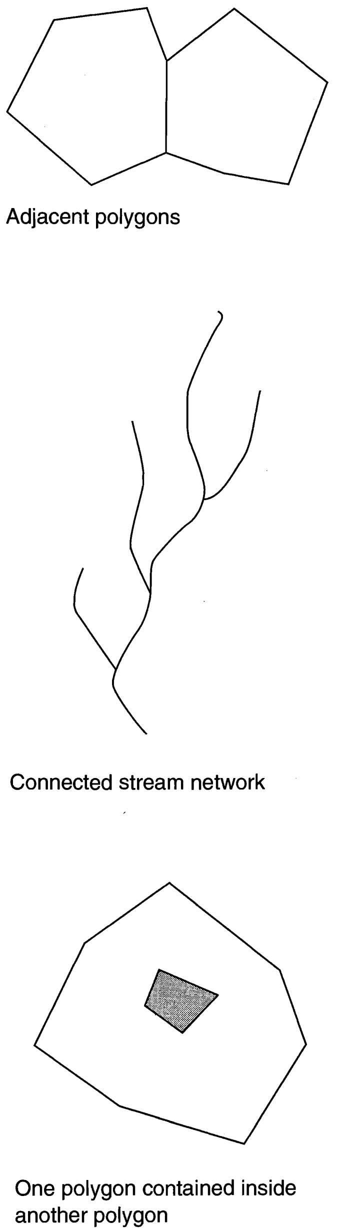


Figure 2.17 **Examples of adjacency, connectivity, and containment.**

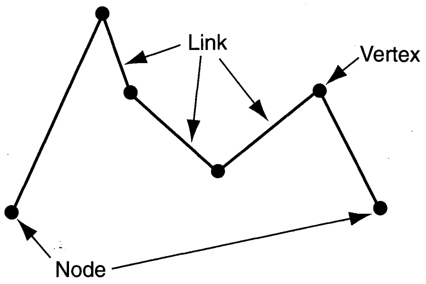
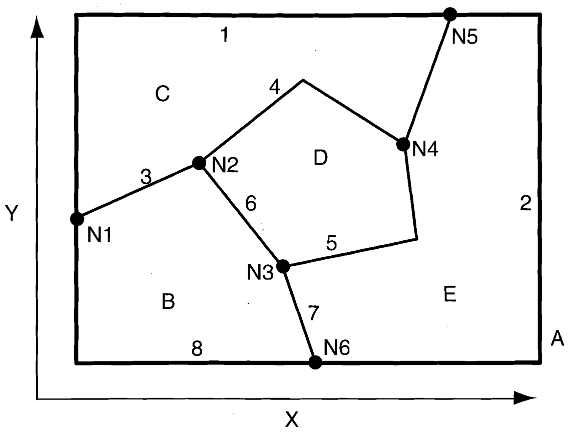


Figure 2.18 **Examples of nodes, links, and vertices.**



a. Network of nodes, links, and polygons (polygon A is outside the rectangle)

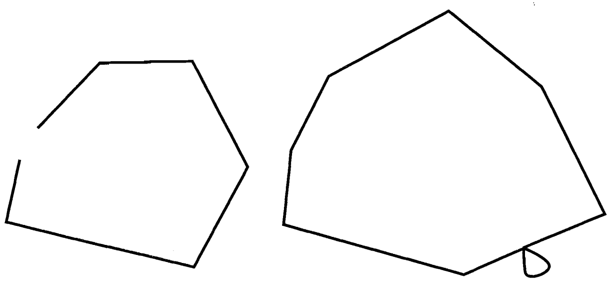
Node	X	Y
N1	0.5	2.4
N2	2.1	3.1
N3	3.2	1.7
N4	4.7	3.3
N5	5.4	5.0
N6	3.6	0.5

b. Node coordinate file

Link	Begin node	End node	Left polygon	Right polygon
1	N1	N5	A	C
2	N5	N6	A	E
3	N1	N2	C	B
4	N2	N4	C	D
5	N4	N3	E	D
6	N3	N2	B	D
7	N3	N6	E	B
8	N1	N6	B	A

c. Topological relationship file

Figure 2.19 **Vector topological data: network of nodes, links, and polygons (a); node coordinate file (b); and topological relationship file (c).**



a. An unclosed polygon b. An extraneous polygon

Figure 2.20 **Examples of topological errors.**
In (a), an undershoot has occurred; instead of a closed figure creating a polygon, a line has been created. In (b), a small loop has been formed extraneously adjacent to a polygon. This might represent a digitizing error or the result of a flawed overlay process.

Thus, landscape features, such as adjacent polygons, may not be represented as sharing boundary lines with other polygons. Most full-featured GIS software programs have tools that allow GIS users to check and manipulate topology. The danger for users of desktop GIS software programs is that some programs allow users to proceed, without warning, with spatial processes and analyses, even though topological problems exist. Users of desktop GIS software programs may become aware of topological problems only after careful examination of GIS databases and associated analyses, or may miss them altogether.

The point, line, and polygon vector data structure provides a method for representing irregularly shaped Earth features. More often than not, vector GIS databases do not completely cover a landscape of interest; for example, a vegetation GIS database may contain only the vegetation located within the ownership boundary of a natural resource management organization, not the vegetation outside of the ownership boundary (quite different from satellite imagery or digital orthophotographs). Also, vector GIS databases represent landscape features that are quite diverse—for example, polygons of different sizes and shapes, rather than a regular size and arrangement of pixels. Examples of diverse vector databases include road and stream representations. Both of these types of databases tend to have unique geographic shapes that do not completely occupy a landscape, unless, of course, the "landscape" is the size of a pothole or a pool in a stream. Some point databases, such as those that describe timber inventory cruise plots, come close to a regular arrangement across a landscape, yet they usually deviate from regularity as a result of the sampling method selected for each stand. Point locations of wildlife sightings are usually very irregularly distributed across a landscape. Polygons, whether they represent stands of similar trees, soils, or recreation areas, tend to be very irregular in shape, although in areas where the Public Land Survey System or other culturally based land delineations have been implemented, some edges of timber stands now seem to have an aspect of regularity built into them.

In Depth

What is topology? Topology, or topological coding, provides the intelligence in the data structure relative to the spatial relationships among landscape features (Lillesand and Kiefer 2000). For example, in a vector GIS database containing polygons, topological coding keeps track of each line that forms each polygon, as well as the nodes each line shares with each other line. In addition, the polygons that are formed on either side of each line (since polygons may share a boundary defined by a line) are known. Thus, for example, with topology one can understand which timber stands are next to which other timber stands.

A Comparison of Raster and Vector Data Structures

TABLE 2.1 Comparison of Raster and Vector Data Structures

	Raster	Vector
Structure complexity	Simple	Complex
Location specificity	Limited	Not limited
Computational efficiency	High	Low
Data volume	High	Low
Spatial resolution	Limited	Not limited
Representation of topology among features	Difficult	Not difficult

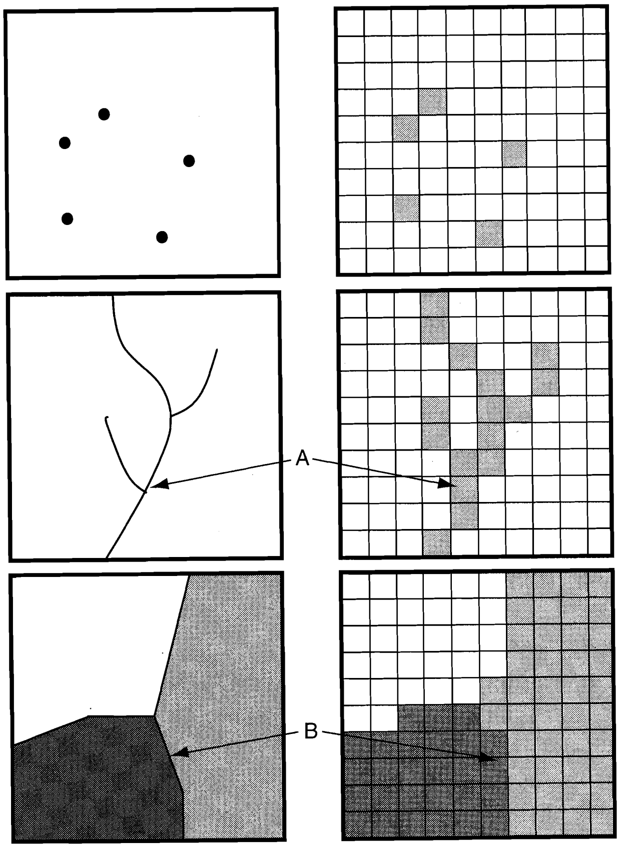


Figure 2.21 **Point, line, and polygon features represented in vector and raster data structures.**

The differences between vector and raster GIS data can be described in a number of ways (table 2.1). Since GIS users will ultimately use databases representing both structures, and since users sometimes convert raster to vector data and vice versa, an illustration of the differences is needed. Therefore, an examination of a generic data structure conversion process might be helpful in illustrating how the three main types of vector data (points, lines, and polygons) can be represented in a raster GIS database. The right-hand side of figure 2.21 illustrates these three features and demonstrates their representation in a raster database structure. The vector representation of points can yield fairly precise locations, depending on the type of coordinate system used to reference the points. This means that one could use a GIS to determine with some degree of precision where these points could be located on a map that includes coordinate reference marks on its axes. Although the raster representation also shows these point locations, there is less precision in their map location, which is dependent on the raster grid cell size assumed. One would know that the point is located somewhere in the grid cell, but the precise location is elusive.

One can also see some similar relationships between the data structures when describing line and polygon features. Both the line and polygon vector features have very discrete shapes, which are sometimes lost when converted to the raster data structure. This fact is perhaps most noticeable in figure 2.21 when one examines the junctions, or nodes, of the line feature (A) or the places where polygon features intersect (B).

The loss of specificity when converting a vector feature into a raster can, at least in part, be overcome by selecting a smaller raster grid cell size to represent the rasterized vector features. This choice comes with a price, however: an increasing storage size requirement for the resulting raster GIS database and greater strain on computer processing resources. The loss of specificity when converting from vector to raster data structures may be acceptable if one simply wants to represent the relative locations of landscape features. However, if one needs to know the precise location of a well, road junction, or property boundary, representing these landscape features with a vector data structure may be preferred.

In general, raster data structures may be more appropriate than vector data structures for representing continuous surfaces. For example, if one is interested in describing precipitation, temperature, or species diversity across a landscape, raster data structures may do this more efficiently, since the data are continuous, and may be more appropriately stored and illustrated with grid cells. The computer processing requirements are lower when using raster data structures, due to the regularity of features—that is, each grid cell is the same size and shape. When performing GIS processes with raster data, generally no calculation of the intersection of landscape features (lines or polygons) is needed, given the regular shape of the cells. In contrast, analysis processes that involve vector GIS data usually must deal with the potential intersection of landscape features, such as overlapping polygons.

Unfortunately, GIS databases stored in the raster data structure can become very large, especially when fine-resolution cells are assumed. One of the hindrances to using raster data is that every cell must have a value associated with it, even cells for which no landscape features of interest are present, such as vegetation outside of an ownership. From a computer storage perspective, this means that all raster grid cells have a value (either a valid value or a null value) and must be stored and maintained.

Alternative Data Structures

Although points, lines, and polygons represent the most common forms of vector GIS data, several other forms of vector GIS data may also be useful in representing landscape features. These other data structures include triangular irregular networks (TINs), dynamic segmentation of networks, and regions. What follows is a brief discussion of each of these mysterious-sounding data structures and an application that might be useful in understanding the potential uses of these alternative data structures.

Triangular Irregular Network

A **triangular irregular network (TIN),** like a raster data structure, is useful for representing a continuous surface (an entire landscape). A TIN, however, addresses some of the problems that raster data structures have in accurately representing landscape features, especially the problems that result when one uses regularly sized raster grid cells to describe landscape features. If the raster grid cells were small, in comparison with the size of other landscape features, one would probably have success in representing those features accurately. If the raster grid cells were large, in comparison with other landscape features, one could lose some of the integrity of the landscape features in the resulting raster GIS database. A TIN attempts to avoid this problem by using, as the name implies, a set of triangles, rather than a set of squares, to represent landscape features (DeMers 2000). Each of the three sides of each triangle can, in fact, have a different length, making the triangles irregular. Thus, a TIN is composed of irregularly shaped objects, yet it covers an entire landscape. In most applications, TINs are used to represent elevation models; thus, an elevation is associated with each triangle corner, as illustrated in figure 2.22. In landscapes that are highly irregular in terms of elevation (as are many forested landscapes), the TIN may better represent topography than a raster-based data structure. Working with TINs, however, is beyond the ability of many standard desktop GIS software programs, due to the complexity involved in storing and processing irregularly sized triangles and in representing three-dimensional surfaces. Some software developers offer modules associated with desktop GIS software programs (at additional cost) that allow GIS users to utilize TINs.

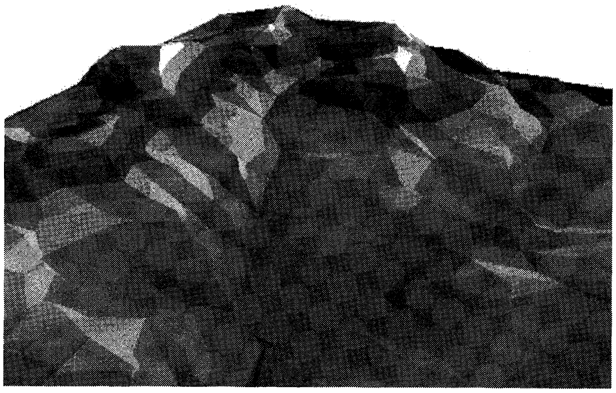


Figure 2.22 **TIN representation of an elevation surface.**

Dynamic Segmentation of Networks

A data structure that uses **dynamic segmentation** is based on a network of lines and, thus, is a variation of the vector data structure. The dynamic segmentation data structure is designed to represent linear features, and traditional uses of this structure include modeling efforts related to river systems, utility distributions, and road networks (ESRI 1994). Dynamic segmentation allows GIS users to create routes to represent the movement or presence of an entity along a linear network. The routes are actually stored as information within a vector GIS database. Dynamic segmentation eliminates the need to create a separate GIS database for each route and facilitates advanced data handling and manipulation of GIS databases.

Underlying the route structure are sections and events. Sections are the linear components or segments that, when added together, form a route. Events are the data sources, or attribute tables, that are connected to the routes. The dynamic segmentation data model can associate information with any portion or segment of a linear feature. Events can be associated with each line or a single point on a line. This information can then be stored, queried, analyzed, and displayed without affecting the structure of the original vector GIS database.

Dynamic segmentation attempts to link a network of lines, based on a common attribute, so that the lines are grouped into categories of interest. An example of this approach might relate to a streams GIS database. A typical streams GIS database uses a series of lines to represent a stream network. Each of the lines has a set of nodes, or beginning and ending points, placed at all tributary junctions along the stream network. Depending on the size of the stream network, hundreds or thousands of lines might exist. A stream ecologist interested in analyzing the stream system, for example, could associate all lines that are used to represent the main channel of a river. Any attributes that are used to describe the main channel, such as length, depth, or temperature, can then be summarized. The stream ecologist might use this dynamic segmentation approach for the entire stream network to create a new GIS database that groups all lines based on an attribute, such as the stream name. Dynamic segmentation allows GIS users to organize a GIS database so that analysis and storage can be easier and more efficient. Dynamic segmentation can also be used to assist in scheduling forest harvest operations or in planning or tracking almost any phenomenon that is associated with a linear network.

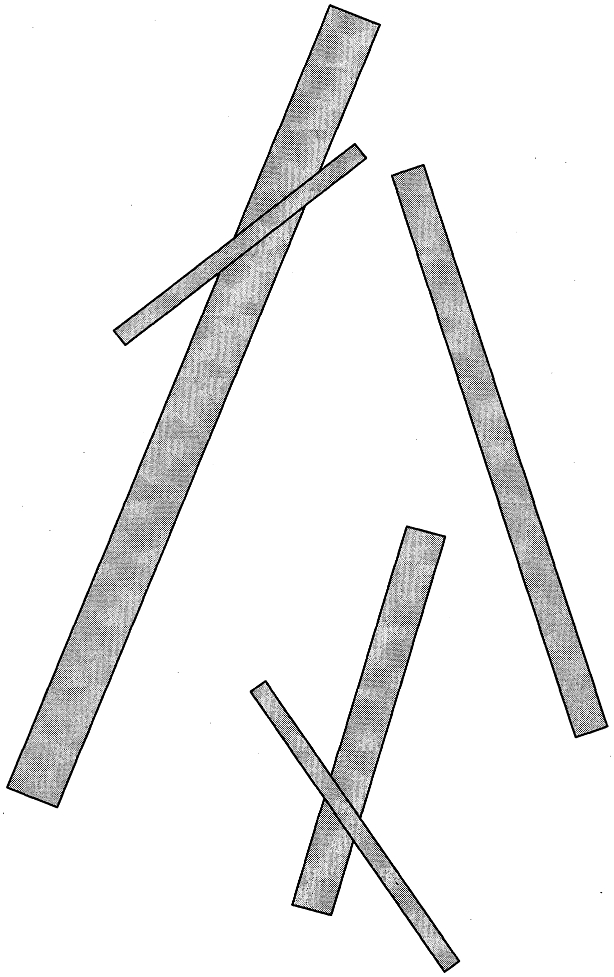


Figure 2.23 Example of the region data structure used to capture the placement of downed woody debris in a stream channel. Typical polygon topology would create 11 polygons to represent the 5 woody debris pieces. Regions allow for polygons to overlap and lead to 5 shapes in a database, or 1 for each piece.

Regions

Another alternative vector data structure is called the **region.** This data structure is based on polygons or approximations of areas, such as stand boundaries or ownership parcels. One of the characteristics of a "topologically correct" polygon structure is that polygon features do not overlap, but, when they do, a new polygon is created to represent the overlapping area (some desktop GIS software programs do not allow one to determine whether polygons are topologically correct). A region data structure will allow the existence of overlapping polygons yet will also maintain topology (ESRI 1995). One application in which regions might be useful is when a forest scientist is interested in capturing the locations of fallen logs within a stream channel (figure 2.23). Polygons can be used to represent the lengths and widths of the logs, but any logs that are stacked on top of each other, as one might expect to find in a log jam, will not be represented accurately in a topologically correct polygon structure. Two logs that overlap each other might result in multiple topologically correct polygons: one or more polygons to represent the nonoverlapping areas of logs and other polygons for each of the overlapping areas of logs. For the 5 objects (logs) displayed in figure 2.23, enforcing correct topology for these landscape features would create a total of 11 polygons, resulting not only in a loss of information but also in a larger set of database records than might be appropriate to describe the logs. With the use of the region data structure, one can retain individual log data records, while associating the overlapping logs with one another.

METADATA

Metadata are simply "data about data," a relatively recent phenomenon in working with spatial databases. Metadata make up a document that accompanies a GIS database and describes the content and quality of the data. With recent advancements in some of the full-featured GIS software programs, it is now possible to have a metadata file digitally linked to a GIS database. Metadata documents are an excellent place to store and retrieve information about the characteristics of a database, including the projection and coordinate systems used. Other useful information in a metadata file includes a description of the original data source, any **editing** that has been done, a list of the attributes, the intended use of the database, and information related to the database developer. The descriptions should allow users to trace the evolution of the GIS database. In the United States, all federal, and some state, agencies have made it mandatory that metadata must accompany any GIS database that is made available to the public. The U.S. federal government has developed standards for producing and reporting metadata. Requirements for producing metadata are highly variable among private natural resource management organizations, since there is no governing body to enforce metadata compliance. GIS users should always ask for metadata whenever acquiring a GIS database.

ACCESS TO SPATIAL DATA

The USGS has developed the most comprehensive collection of spatial data in the world. This collection includes DEMs, DOQs, DRGs, digital line graphs (DLGs), and many sources of raster and vector data for the United States. The majority of this collection is available for access over the Internet, along with associated metadata. Several U.S. federal agencies produce and maintain spatial databases for the lands they manage and make this information available to the public through the Internet. A growing number of U.S. states have also produced comprehensive collections of spatial data, that are available over the Internet. A more detailed discussion of data acquisition processes is provided in chapter 3.

SCALE AND RESOLUTION OF SPATIAL DATABASES

GIS databases are often characterized in terms of their scale, or resolution. Issues of scale are usually associated with vector GIS databases, whereas issues of resolution are associated with raster GIS databases. *Scale* and *resolution* both refer to characteristics of the landscape features represented in GIS databases. Typically, this relates to the source material from which the GIS databases were created. Source material, as described in chapter 1, includes aerial photographs, existing maps, satellite data, and information gathered from survey instruments, such as total stations or GPS receivers. Many sources of vector data are derived from remote sensing techniques, particularly from aerial photographs. The scale that is associated with the vector GIS databases typically relates to photographic scale, a function of camera height, lens length, and photo size. Scale is often expressed as a ratio, or representative fraction, such as 1:24,000 or 1:100,000 (Muehrcke and Muehrcke 1998). The ratio expression is unitless and implies that 1 unit of measurement on a map or photo represents 24,000 or 100,000 units on the ground. Sometimes, confusion exists as to the correct use of the terms *large scale* and *small scale*. The ratio 1:24,000 is a larger ratio than 1:100,000 (1 is a larger portion of 24,000 than of 100,000); thus, 1:24,000 is a larger scale than 1:100,000. If one examined both 1:24,000 and 1:100,000 scale maps printed on the same size paper, the 1:24,000 map would show less area but greater detail than the 1:100,000 map (figure 2.24). Scale can also be referred to in terms of relative units, such as 1 cm = 1 km, or through the use of a scale that graphically illustrates approximate ground distances.

With imagery derived from satellite and aerial platforms, the ability of the electromagnetic sensor on the platform to delineate landscape features on the ground determines the resolution. A 1 m resolution image implies that the sensors used to collect the imagery captured a value for each square meter of the landscape. For raster GIS databases that were developed by scanning from maps or photographs, such as a DRG or DOQ, the size of the raster grid cell in representing landscape features determines the resolution. If each raster grid cell spans a 30 m ground distance, the raster GIS database is said to have a "30 m resolution." This means that each raster grid cell represents 900 m^2 (30 m × 30 m) of ground area. Perhaps an interesting topic of conversation over a cup of coffee might be how well 30 m grid cells obtained from satellite images portray forest vegetation and can help one develop management recommendations.

Although scales, or resolutions, are associated with spatial databases, some users mistakenly believe that they can improve the detail of GIS databases by focusing on small land areas. Users need to be aware of the fact that the scale, or resolution, of a GIS database remains static, regardless of how closely one views an area of the landscape.

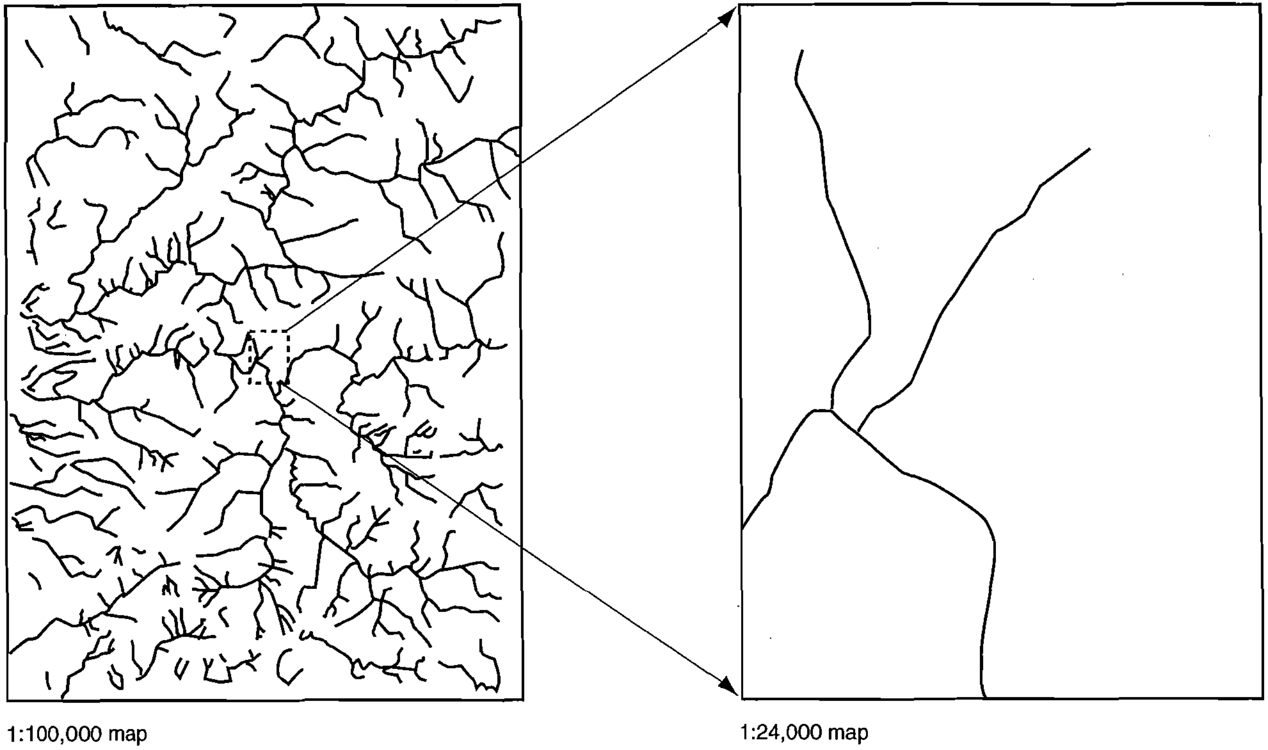


Figure 2.24 Map of stream network displayed at scales of 1:100,000 and 1:24,000.

SUMMARY

This chapter discussed one of the fundamental pieces of any successful GIS program: the data. One of the main issues when working with GIS databases is knowing what projection system the database is set within and how this coincides with other databases being used within an organization, or perhaps by other organizations with which data are shared. This chapter briefly described data projections and data structures, both raster and vector, as well as a few alternatives. How GIS databases are stored and managed is a function of the decisions natural resource managers make regarding the purpose and intent of use of each GIS database. In many cases, however, one has no choice regarding the structure of GIS databases. For example, satellite imagery uses a raster data structure, whereas vegetation and soils databases acquired from the U.S. Forest Service generally use the vector data structure. In addition, most timber companies use vector data structures to represent management units, roads, and other landscape features. Metadata are useful in helping one determine the characteristics of a GIS database, including the projection system. Finally, understanding the scale, or resolution, of GIS databases and their associated landscape features is important, as it relates to the usefulness of a GIS database in assisting with analyses related to management decisions.

APPLICATIONS

2.1. *Projection parameters.* Your supervisor, Steve Smith, has just learned that another natural resource organization with which you intend to share spatial data stores its GIS databases in a map projection format that is different from yours. Steve is unfamiliar with projections and asks you to provide some background for him.

a. What is a projection?
b. Why are projections necessary?
c. What is an ellipsoid?
d. What is a geoid?
e. What are the major projection types, what are their assumptions, and how have they been used?

2.2. *GIS data structures.* You have been hired as a land management forester for a timber company in the southern United States. As a recent college graduate, you are expected to have the most current knowledge of forest measurement and data acquisition techniques. Your supervisor, John Delaney, an older forester, is interested in GIS and is curious about database structures. Describe to him the difference between a raster and a vector data structure, and give an example of a GIS database that might be designed with each structure.

2.3. *Resolution and scale.* A consultant has proposed using satellite imagery to quickly update the forest resources that your natural resource management organization manages. Some in your organization are arguing for a complete and fresh photo interpretation of the land base to accomplish this goal, resulting in a vector GIS database of the vegetation condition of the landscape. The differences in resolution and scale are two of the hot topics when comparing these alternatives. Explain the difference between resolution and scale and how they relate to raster and vector data structures.

2.4. *Designing GIS databases.* You have been hired by a natural resource consulting agency to develop and maintain a small GIS operation. Although your expertise is in natural resource management, the owners of the consulting agency are intrigued by your GIS background and have been interested in providing these services to their clients. You, of course, took the job due to its opportunity to put your GIS and natural resource management skills to use. As a start, what data structure might you use to describe the landscape features in the following databases?
a. Timber stands
b. Streams
c. Roads
d. Inventory plots
e. Culverts
f. Logs in stream
g. Precipitation
h. Land ownership
i. Stream buffers
j. Owl locations
k. Owl habitat

2.5. *Map scale and ground distances.* You are employed as a field forester for the U.S. Forest Service in Colorado and have been inventorying timber for the past three hours, and now it is time for lunch. Your lunch, of course, is located in your truck. The distance you measure on your map from your current position to the truck is 6 cm. If the map scale is 1:24,000, how far are you from your truck?

2.6. *Spatial resolution.* The natural resource management agency you work for in the intermountain West is considering the purchase of 30 m satellite imagery for assisting in the management of its natural resources. How much area, in acres, does a single 30 m grid cell cover? How much area, in acres, does a 10 m grid cell cover?

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