CHAPTER 1
Introducing GIS

Learning objectives

- **Learn the uses of geographic information systems (GIS)**
- **Learn how GIS layers work**
- **Differentiate between GIS features and surfaces**
- **Obtain preliminary understanding of feature locations, scale, and attributes**
- **Obtain preliminary understanding of spatial relationships between features**

GIS allows you to study and explore everything about a place. With a GIS, you can identify and analyze the land features, climate, boundaries, population, resources, and many other things about places that interest you. In the past, you needed to use paper maps, globes, and a variety of hard-copy data sources to perform these analyses. Now, a GIS makes the maps, globes, data, and analysis tools available on your computer, allowing you to perform sophisticated analysis, map your results, and store and share your information digitally.

An example of the type of map you could study or create in a GIS is a population density map, which shows the distribution of population in relation to specific areas (e.g., cities, census tracts, counties, states, countries). Population density information is important to consider when you are mapping areas that vary greatly in size; for example, 200,000 people living in an 8-square-mile county and 200,000 people living in an 80-square-mile county are very different conditions. Population density, in turn, provides context for other maps in your study, which may show demographics, economic statistics, or housing prices.

Another analysis you can perform with a GIS is to find locations that meet specific criteria. For example, if you work for a real estate company, you might have access to a GIS database of properties with associated property values that you could use to generate sales data. If you work for a utility company, you might use a GIS to coordinate, map, and manage the thousands of repairs you have to complete each year.

You can also use a GIS to analyze what is happening around a specific area. For example, if you work for an environmental agency, you might map wildlife species' habitats and take inventory of

vegetation across a region to better understand the relationship between them. If you work for a water conservation agency, you might analyze areas adjacent to stream watersheds to gauge how natural features, seasonal water flow, and existing habitats change.

You can also use a GIS to map how and where things evolve over a period of time to learn about subject movement and behavior. If you work for a public health agency, for example, you might track an influenza outbreak geographically to try to determine its origin, find disease clusters, and identify areas of high risk. You can use a GIS to evaluate current situations and anticipate future conditions. For example, you could track and model hurricane data to provide early warning for evacuation schedules that can help save people's lives.

Basic GIS principles

The following sections will introduce you to some basic principles of GIS. These concepts will become clearer and more understandable as you work with the software in chapters 3 through 20.

A GIS map contains layers

On a paper map, you cannot peel cities away from countries or countries away from the ocean, but on a GIS map, you can. A GIS map is made up of layers, or collections of geographic objects that are alike and defined by a visual symbol. To make a map, you can add as many layers as you want. On the map shown, the transmission lines are layered on top of the electricity generation circles, which are then layered on top of the coal basins, and finally are layered on top of the terrain and ocean layers. This creates an important layer hierarchy on the map.
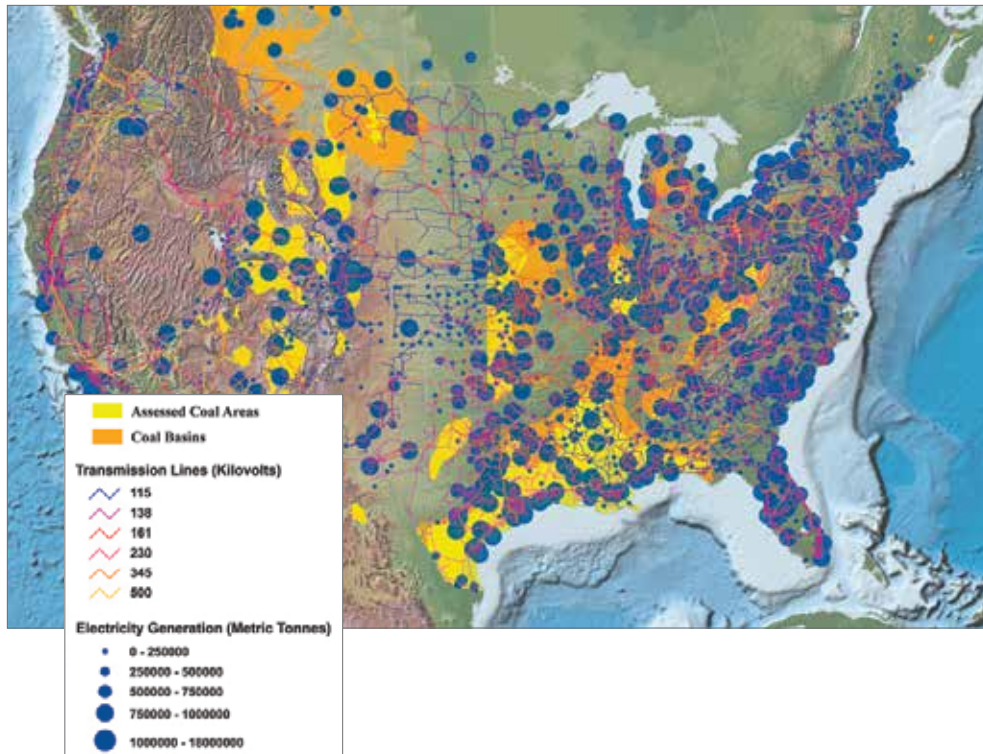
This map of North America shows state boundaries, lakes, rivers, terrain, and the ocean. It also shows the amount of electricity generation, transmission lines, and locations of coal basins. The map is accompanied by a legend that shows some of its layers. Map courtesy of Kansas Geological Survey at the University of Kansas. Data from Regional Carbon Sequestration Partnerships.

Layers may contain features or surfaces

On the map shown, the coal basins layer includes many basins, and the transmission lines layer contains many lines. The same is true of the states and lakes layers—each layer contains many of the same types of things. Each geographic object in a layer—each state, lake, transmission line, or coal basin—is called a feature.

Not all layers contain features. The ocean layer is not a collection of geographic objects as are the other layers. It is considered a single, continuous expanse that changes from one location to another according to the depth of the water. Similarly, the terrain layer shows the elevation of the landscape. A geographic expanse such as this is called a surface.

This topographic map shows the terrain of a landmass and the seafloor. Map made with Natural Earth.

Features have shape and size

Geographic objects have an endless variety of shapes; however, they can all be represented as one of three geometrical forms: a polygon, a line, or a point.

Polygons represent objects that are large enough to have boundaries, such as countries, lakes, and tracts of land. Lines represent objects that are relatively too narrow to be polygons, such as rivers, roads, and pipelines. Points are used for objects that are relatively too small to be polygons, such as cities, schools, and fire hydrants. The same object may be represented by a polygon in one layer and a line or a point in a different layer, depending on the scale of the layer.

Polygons, lines, and points, collectively, are called **vector** data.

Earthquake epicenters and seismic hazards in Indonesia. Polygons are used to represent landmasses, points to represent earthquakes, and lines to represent subduction zones. Map and data courtesy of US Geological Survey.

Surfaces have numeric values rather than shapes

Unlike countries or rivers, natural phenomena, such as elevation, slope, temperature, rainfall, and wind speed, have no distinct shape. What they have instead are measurable values for any location on the earth's surface. For instance, wherever you go, you are either at sea level or a number of meters above or below it. Geographic phenomena such as this are easier to represent as surfaces than as features.

The most common kind of surface is a raster, a matrix of identically sized square cells. Each cell represents a unit of surface area—for example, 10 square meters—and contains a measured or estimated value for that location.
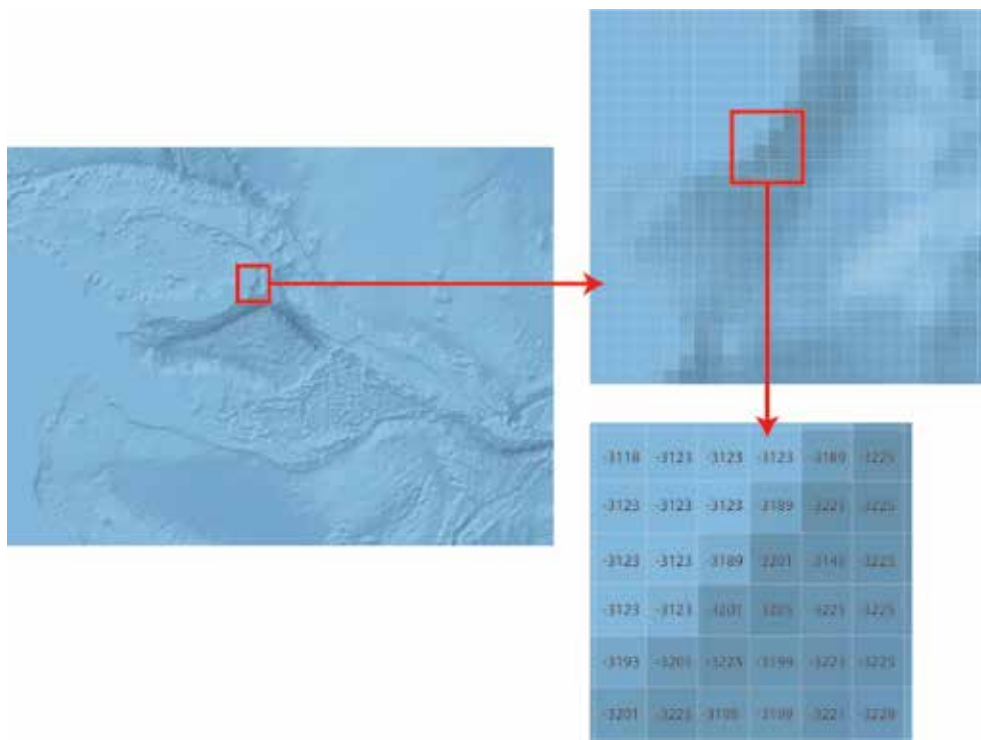
A close look at this raster of ocean depth shows that it is composed of square cells. Each cell holds a numeric value indicating ocean depth. Map made with Natural Earth.

The world is not divided neatly into features and surfaces. Many things can be looked at either way—as a feature or as a surface. For example, polygons are often used to mark the boundaries of different vegetation types in a region, but this implies that the change from one type to another is more abrupt than it probably is because one type of vegetation often blends into another. Vegetation can be represented not only as a polygon, but also as a raster surface, with each cell value standing for a type of vegetation.

Features have locations

If you were asked to find Berlin, Germany, on a map of the world, it probably wouldn't take you very long. But suppose Berlin wasn't shown on the map. Could you make a pencil mark exactly where it should be?

Now suppose you could lay a grid or graticule over the world map and you knew that Berlin was a certain number of marks up from and to the right of a given starting point. In that case, it would

be easy to put your pencil on the right spot. A grid of this kind is called a coordinate system, and it is what a GIS uses to put features in their proper place on a map.

On this map, a coordinate system has an x-axis and a y-axis. The intersection of the axes is called the origin. Feature locations are specified by their distance from the origin in meters, feet, or a similar unit of measure— in this case, lines of latitude and longitude. Data from Data and Maps for ArcGIS 2010, courtesy of ArcWorld, DeLorme, Esri®, and ArcWorld Supplement.

The location of a point feature on a map is defined by a pair of coordinates. Berlin has coordinates of 52°30′ N (latitude) and 13°25′ E (longitude). A straight line needs two pairs of coordinates— one at the beginning of the line and one at the end. If the line bends, like a river, there must be a pair of coordinates at every location where the line changes direction. The same holds true of a polygon, which is simply a line that returns to its starting point.

Features can be displayed at different sizes

On a GIS map, you can zoom in to see features at a closer range. As you do, the scale of the map changes.

Scale, commonly expressed as a ratio, is the relationship between the size of the features on a map and the size of the corresponding places in the world. If the scale of a map is 1:1,000,000, it means that features on the map are 1/1,000,000th of, or 1 million times smaller than, their true size.

A utilities map at a scale of approximately 1:1,000,000. County, state, and shoreline boundaries are shown.

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Zooming in gives you a closer view of features within a smaller area of the map. The amount of detail in the features does not change, but what details you can see changes. A river has the same bends, and a coastline has the same crenulations, whether you are zoomed in and can discern them or are zoomed out and cannot.

A city transit map at a scale of approximately 1:12,000. Building footprints, roads, and transit lines are visible.

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How much detail the features have depends on the layer you are using. Just as a paper map of the world generalizes the boundaries of Brazil more than a map of South America does, so do different GIS layers contain more feature detail or less.

Internet basemaps, such as those on the ArcGIS® Online platform, cover a wide range of map scales—and a wide level of detail. A map can have several levels of detail that correlate to the scale

range. As you zoom in, layers at small scale with less detail will be turned off, and new layers at large scale with more detail will be turned on. Each zoom level can be perceived as being made up of seamless data—each level, however, is made up of layers composed of several datasets, all with varying amounts of detail, and all of which are contained within a spatial database.

Features are linked to information

A feature is more than its physical shape and location. A feature also includes everything else that might be known about that feature. For a country, this might be its population, capital, system of government, leading imports and exports, average rainfall, and mineral resources. For a road, it might be the speed limit, the number of lanes, whether it is paved or unpaved, and whether it has one-way or two-way traffic. A great deal of information exists about any feature, whether it be a humble length of sewer pipe or the vastness of an ocean.

Information about the features in a layer is stored in a table. The table has a record (row) of each feature in the layer and a field (column) for each category of information. These categories are called attributes, and the table is called an attribute table.

Object ID *	Shape *	FIPS_CNTRY	CNTRY_NAME	LONG_NAME	POP2007	SQKM	SQMI
183	Polygon	CH	China	People's Republic of China	1321851888	9402886.58	3630454.7
159	Polygon	IN	India	Republic of India	1129866154	3153009.5	1217377.13
150	Polygon	US	United States	United States of America	301139947	9426295	3639492.5
236	Polygon	ID	Indonesia	Republic of Indonesia	234693997	1847033	713139.44
20	Polygon	BR	Brazil	Federative Republic of Brazil	190010647	8493132	3279198.25
178	Polygon	PK	Pakistan	Islamic Republic of Pakistan	169270617	880202.69	339846.25
180	Polygon	BG	Bangladesh	People's Republic of Bangladesh	150448339	135692.92	52391.03
103	Polygon	RS	Russia	Russian Federation	141377752	16897294	6524043.5
117	Polygon	NI	Nigeria	Federal Republic of Nigeria	135031164	913387.88	352659.06
197	Polygon	JA	Japan	Japan	127467972	370726.88	143137.66
39	Polygon	MX	Mexico	United Mexican States	108700891	1953851.13	754381.88

The attribute table of a layer of countries includes each feature's shape, ID number, name, population, and area, among other things. Data from Data and Maps for ArcGIS 2010, courtesy of ArcWorld Supplement and Esri.

Features on a GIS map are linked to the information in the feature's attribute table. If you select Brazil on a map, you can bring up all the information stored about Brazil in the attribute table of countries. If you select a record in the table, you will see the corresponding feature highlighted on the map.
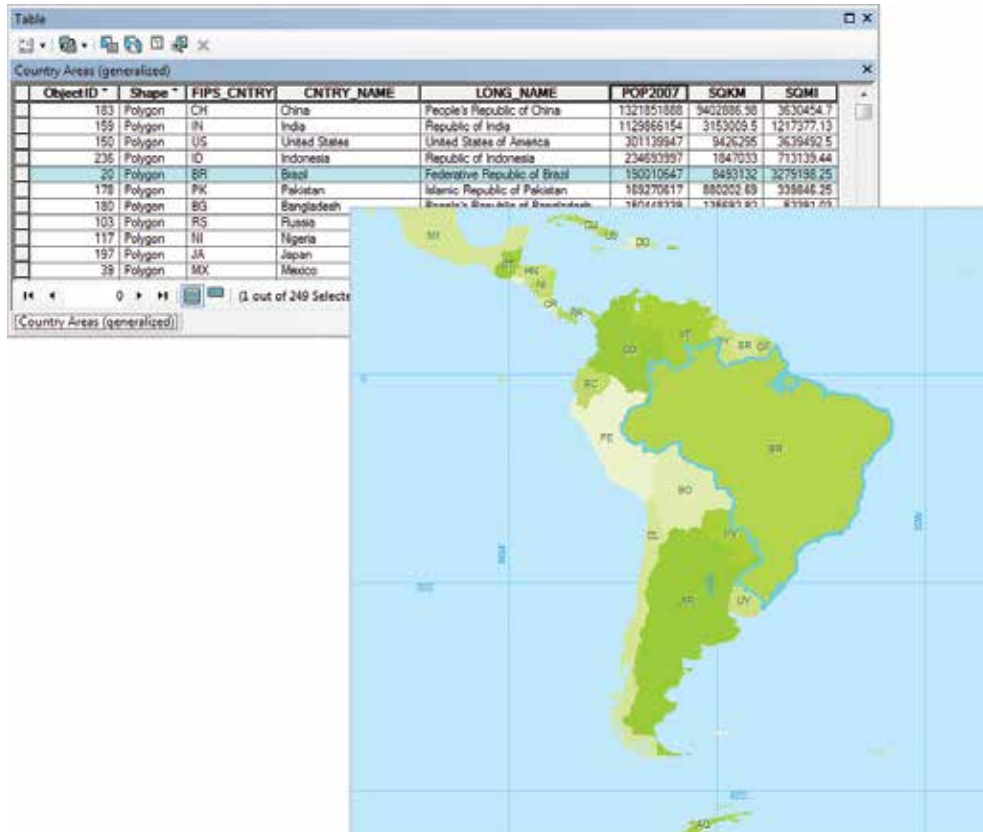
Brazil is highlighted in the attribute table of countries, and it is similarly highlighted on the map. Data from Data and Maps for ArcGIS 2010, courtesy of ArcWorld, DeLorme, Esri, and ArcWorld Supplement.

The link between features and their attributes makes it possible to ask questions about the information in an attribute table and display the answers on the map. You can use this ability to locate and identify specific features.

Which countries belong to the continent of Asia? Data from Data and Maps for ArcGIS 2010, courtesy of ArcWorld, DeLorme, Esri, and ArcWorld Supplement.

Which countries have a population of 1 billion or greater? Data from Data and Maps for ArcGIS 2010, courtesy of ArcWorld, DeLorme, Esri, and ArcWorld Supplement.

Which cities in Asia are national capitals, and which are not? Data from Data and Maps for ArcGIS 2010, courtesy of ArcWorld, DeLorme, Esri, and ArcWorld Supplement.

Which cities in Asia are capitals and have populations of 5 million or greater? Data from Data and Maps for ArcGIS 2010, courtesy of ArcWorld, DeLorme, Esri, and ArcWorld Supplement.

Similarly, you can use attributes to create thematic maps—maps that use colors or other symbols to indicate the nature of feature attributes.
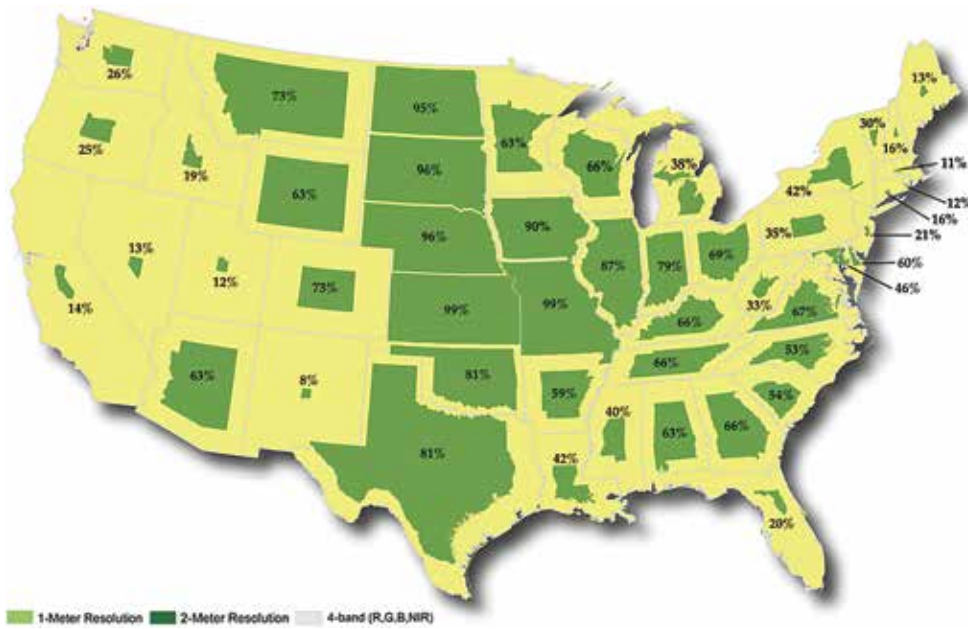
This map shows the percentage of a state covered by the common land unit, the smallest unit of agricultural land that can be enrolled in a farm program administered by the US Department of Agriculture. Map and data courtesy of US Department of Agriculture Farm Service Agency Aerial Photography Field Office (USDA-FSA-APFO), 2009.

Features have spatial relationships

In addition to asking questions about the feature information stored in attribute tables, you can ask questions about the spatial relationships between features—for example, which features are nearest others, which cross others, and which are contained by others. The coordinates of features are used in a GIS to compare their locations. On the map shown, the relationships between parcel locations, waterlines, and valves are established in the GIS.

This utility map shows parcel locations, waterlines, and valves for Cobb County Water System in Marietta, Georgia. Map courtesy of Cobb County Water System. Data from Cobb County GIS.

It is critical to the utility's distribution operation to ensure the isolation of the high-pressure system from the normal-pressure system. The map provides detail for each of the essential valves located in the high-pressure water system. Which water valve belongs to which parcel? Which waterline crosses a main road? Which valve affects the water pressure of which waterline? By taking a close look at the map, engineers can quickly make informed decisions on pressure problems reported in the area and determine whether extending the high-pressure zone is a potential solution.

New features can be created from areas of overlap

Queries about attributes and spatial relationships identify existing features based on whether they have or do not have certain qualities. To solve some geographic problems, however, it is necessary to use a GIS to create features from existing ones.

On the map shown, a GIS database containing layers such as soils, slopes, rivers and streams, wetlands, floodplains, parks and natural areas, significant habitat inventory, greenways, and natural hazard data was used to identify regionally significant areas.
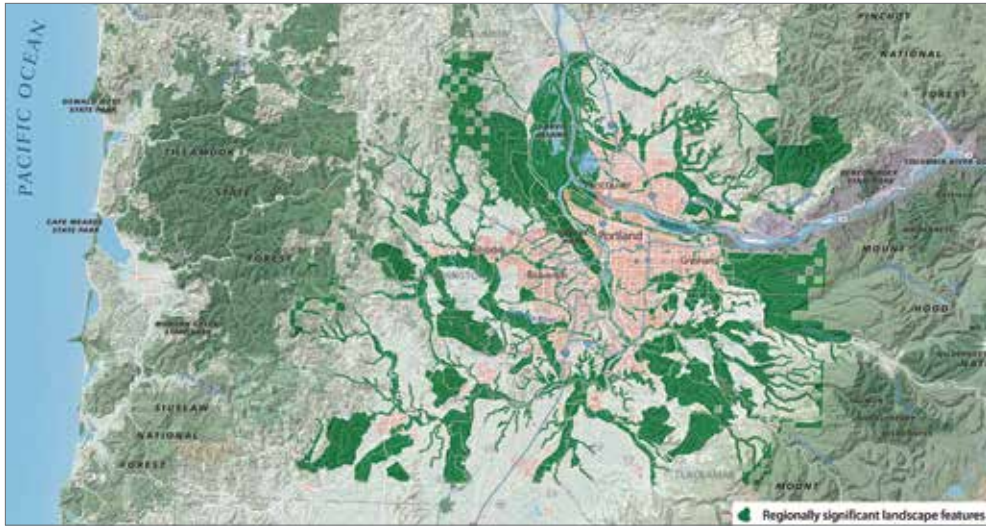
Regionally significant landscape features are derived from other features in the area surrounding Portland, Oregon. Map courtesy of Matthew Hampton, Oregon Metro. Data from Metro Regional Land Information System, Esri, National Park Service Natural Earth, Nature Conservancy, and Oregon Natural Heritage Program.

To find places that meet the specified conditions, the cooperative expertise of various federal, state, local, and private organizations was used in a GIS to find areas of overlap among features in the different layers. The map shows significant natural systems and land patterns that define the quality and character of the region and capture its sense of place. This allows for resource protection at a larger landscape and ecosystem scale and helps define where future growth should and should not occur. The new feature's boundary is the area of overlap that is different from the boundaries of the features from which it was created. The result of the analysis is a new layer that shows regionally significant landscape features.

Data requires management

GIS data can quickly grow complicated. Early in the planning stages of a GIS project, you must decide how to organize your spatial data, for example, by type, geography, or granularity. Regardless of which approach you use, recording metadata (information about data) for your spatial data is a key tool in your data management strategy.

Where to store data is often another problem. Small projects can be stored on a local drive, but some datasets are extremely large and need to be accessed by many people. In this case, storing data on a central server is a good solution. Large-scale shared data strategies, such as those employed by government agencies, private companies, and individuals who collect large datasets, use server GIS or cloud networks to ensure secure data governance, reduced redundancy, and compatibility with a wide range of systems.

You now have some idea of what a GIS is and what it can do. In chapter 2, you will learn more about ArcGIS® Desktop.

Terms

GIS
vector
raster
graticule