CHAPTER ONE

History and Scope of Remote Sensing

1.1. Introduction

A picture is worth a thousand words. Is this true, and if so, why?

Pictures concisely convey information about positions, sizes, and interrelationships between objects. By their nature, they portray information about things that we can recognize as objects. These objects in turn can convey deep levels of meaning. Because humans possess a high level of proficiency in deriving information from such images, we experience little difficulty in interpreting even those scenes that are visually complex. We are so competent in such tasks that it is only when we attempt to replicate these capabilities using computer programs, for instance, that we realize how powerful our abilities are to derive this kind of intricate information. Each picture, therefore, can truthfully be said to distill the meaning of at least a thousand words.

This book is devoted to the analysis of a special class of pictures that employ an overhead perspective (e.g., maps, aerial photographs, and similar images), including many that are based on radiation not visible to the human eye. These images have special properties that offer unique advantages for the study of the Earth's surface: We can see patterns instead of isolated points and relationships between features that otherwise seem independent. They are especially powerful because they permit us to monitor changes over time; to measure sizes, areas, depths, and heights; and, in general, to acquire information that is very difficult to acquire by other means. However, our ability to extract this kind of information is not innate; we must work hard to develop the knowledge and skills that allow us to use images (Figure 1.1).

Specialized knowledge is important because remotely sensed images have qualities that differ from those we encounter in everyday experience:

- Image presentation
- Unfamiliar scales and resolutions
- Overhead views from aircraft or satellites
- Use of several regions of the electromagnetic spectrum

This book explores these and other elements of remote sensing, including some of its many practical applications. Our purpose in Chapter 1 is to briefly outline its content, origins, and scope as a foundation for the more specific chapters that follow.

FIGURE 1.1. Two examples of visual interpretation of images. Humans have an innate ability to derive meaning from the complex patterns of light and dark that form this image—we can interpret patterns of light and dark as people and objects. At another, higher, level of understanding, we learn to derive meaning beyond mere recognition of objects, to interpret the arrangement of figures, to notice subtle differences in posture, and to assign meaning not present in the arbitrary pattern of light and dark. Thus this picture tells a story. It conveys a meaning that can be received only by observers who can understand the significance of the figures, the statue, and their relationship.

1.2. Definitions

The field of remote sensing has been defined many times (Table 1.1). Examination of common elements in these varied definitions permits identification of the topic's most important themes. From a cursory look at these definitions, it is easy to identify a central concept: the gathering of information at a distance. This excessively broad definition, however, must be refined if it is to guide us in studying a body of knowledge that can be approached in a single course of study.

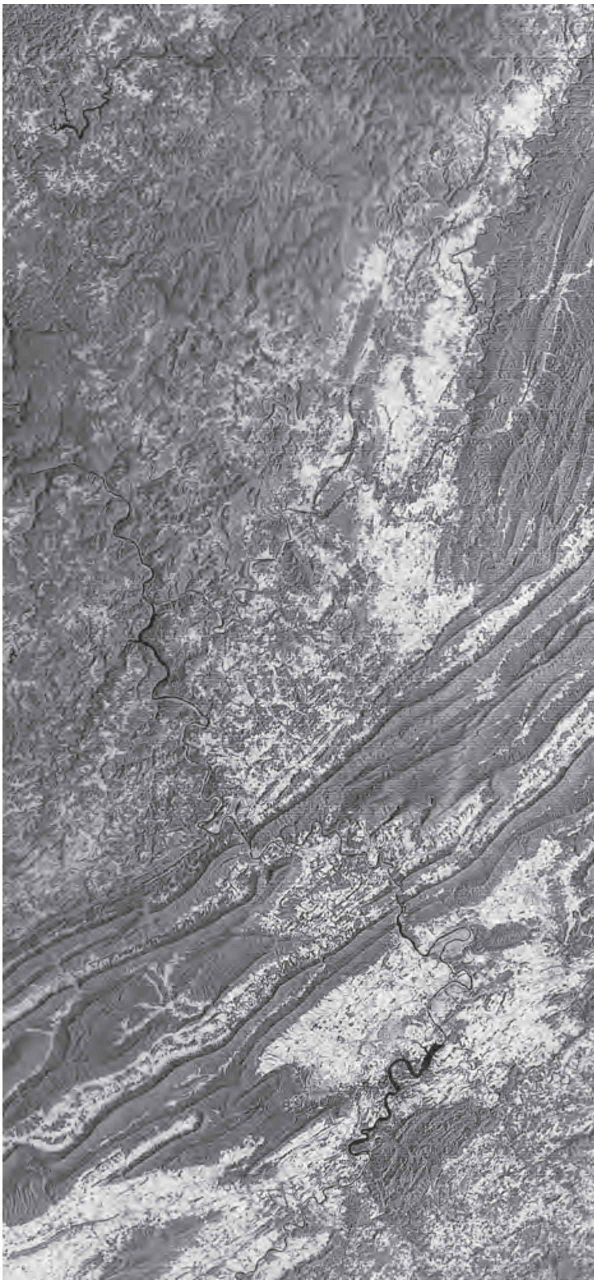

FIGURE 1.1. (cont). So it is also with this second image, a satellite image of southwestern Virginia. With only modest effort and experience, we can interpret these patterns of light and dark to recognize topography, drainage, rivers, and vegetation. There is a deeper meaning here as well, as the pattern of white tones tells a story about the interrelated human and natural patterns within this landscape—a story that can be understood by those prepared with the necessary knowledge and perspective. Because this image employs an unfamiliar perspective and is derived from radiation outside the visible portion of the electromagnetic spectrum, our everyday experience and intuition are not adequate to interpret the meaning of the patterns recorded here, so it is necessary to consciously learn and apply acquired knowledge to understand the meaning of this pattern.

The kind of remote sensing to be discussed here is devoted to observation of the Earth's land and water surfaces by means of reflected or emitted electromagnetic energy. This more focused definition excludes applications that could be reasonably included in broader definitions, such as sensing the Earth's magnetic field or atmosphere or the temperature of the human body. For our purposes, the definition can be based on modification of concepts given in Table 1.1:

TABLE 1.1. Remote Sensing: Some Definitions

Remote sensing has been variously defined but basically it is the art or science of telling something about an object without touching it. (Fischer et al., 1976, p. 34)
Remote sensing is the acquisition of physical data of an object without touch or contact. (Lintz and Simonett, 1976, p. 1)
Imagery is acquired with a sensor other than (or in addition to) a conventional camera through which a scene is recorded, such as by electronic scanning, using radiations outside the normal visual range of the film and camera—microwave, radar, thermal, infrared, ultraviolet, as well as multispectral, special techniques are applied to process and interpret remote sensing imagery for the purpose of producing conventional maps, thematic maps, resources surveys, etc., in the fields of agriculture, archaeology, forestry, geography, geology, and others. (American Society of Photogrammetry)
Remote sensing is the observation of a target by a device separated from it by some distance. (Barrett and Curtis, 1976, p. 3)
The term "remote sensing" in its broadest sense merely means "reconnaissance at a distance." (Colwell, 1966, p. 71)
Remote sensing, though not precisely defined, includes all methods of obtaining pictures or other forms of electromagnetic records of the Earth's surface from a distance, and the treatment and processing of the picture data. . . . Remote sensing then in the widest sense is concerned with detecting and recording electromagnetic radiation from the target areas in the field of view of the sensor instrument. This radiation may have originated directly from separate components of the target area; it may be solar energy reflected from them; or it may be reflections of energy transmitted to the target area from the sensor itself. (White, 1977, pp. 1–2)
"Remote sensing" is the term currently used by a number of scientists for the study of remote objects (earth, lunar, and planetary surfaces and atmospheres, stellar and galactic phenomena, etc.) from great distances. Broadly defined . . . , remote sensing denotes the joint effects of employing modern sensors, data-processing equipment, information theory and processing methodology, communications theory and devices, space and airborne vehicles, and large-systems theory and practice for the purposes of carrying out aerial or space surveys of the earth's surface. (National Academy of Sciences, 1970, p. 1)
Remote sensing is the science of deriving information about an object from measurements made at a distance from the object, i.e., without actually coming in contact with it. The quantity most frequently measured in present-day remote sensing systems is the electromagnetic energy emanating from objects of interest, and although there are other possibilities (e.g., seismic waves, sonic waves, and gravitational force), our attention . . . is focused upon systems which measure electromagnetic energy. (D. A. Landgrebe, quoted in Swain and Davis, 1978, p. 1)

> *Remote sensing is the practice of deriving information about the Earth's land and water surfaces using images acquired from an overhead perspective, using electromagnetic radiation in one or more regions of the electromagnetic spectrum, reflected or emitted from the Earth's surface.*

This definition serves as a concise expression of the scope of this volume. It is not, however, universally applicable, and is not intended to be so, because practical constraints limit the scope of this volume. So, although this text must omit many interesting topics (e.g., meteorological or extraterrestrial remote sensing), it can review knowledge and perspectives necessary for pursuit of topics that cannot be covered in full here.

1.3. Milestones in the History of Remote Sensing

The scope of the field of remote sensing can be elaborated by examining its history to trace the development of some of its central concepts. A few key events can be offered to trace the evolution of the field (Table 1.2). More complete accounts are given by Stone (1974), Fischer (1975), Simonett (1983), and others.

Early Photography and Aerial Images Prior to the Airplane

Because the practice of remote sensing focuses on the examination of images of the Earth's surface, its origins lie in the beginnings of the practice of photography. The first attempts to form images by photography date from the early 1800s, when a number of scientists, now largely forgotten, conducted experiments with photosensitive chemicals. In 1839 Louis Daguerre (1789–1851) publicly reported results of his experiments with photographic chemicals; this date forms a convenient, although arbitrary, milestone for the birth of photography. Acquisition of the first aerial photograph has been generally credited to Gaspard-Félix Tournachon (1829–1910), known also by his pseudonym, Nadar. In 1858, he acquired an aerial photo from a tethered balloon in France. Nadar's aerial photos have been lost, although other early balloon photographs survive. In succeeding years numerous improvements were made in photographic technology and in methods of acquiring photographs of the Earth from balloons and kites. These aerial images of the

TABLE 1.2. Milestones in the History of Remote Sensing

1800	Discovery of infrared by Sir William Herschel
1839	Beginning of practice of photography
1847	Infrared spectrum shown by A. H. L. Fizeau and J. B. L. Foucault to share properties with visible light
1850–1860	Photography from balloons
1873	Theory of electromagnetic energy developed by James Clerk Maxwell
1909	Photography from airplanes
1914–1918	World War I: aerial reconnaissance
1920–1930	Development and initial applications of aerial photography and photogrammetry
1929–1939	Economic depression generates environmental crises that lead to governmental applications of aerial photography
1930–1940	Development of radars in Germany, United States, and United Kingdom
1939–1945	World War II: applications of nonvisible portions of electromagnetic spectrum; training of persons in acquisition and interpretation of airphotos
1950–1960	Military research and development
1956	Colwell's research on plant disease detection with infrared photography
1960–1970	First use of term *remote sensing*
	TIROS weather satellite
	Skylab remote sensing observations from space
1972	Launch of Landsat 1
1970–1980	Rapid advances in digital image processing
1980–1990	Landsat 4: new generation of Landsat sensors
1986	SPOT French Earth observation satellite
1980s	Development of hyperspectral sensors
1990s	Global remote sensing systems, lidars

Earth are among the first to fit the definition of remote sensing given previously, but most must be regarded as curiosities rather than as the basis for a systematic field of study.

Early Uses of the Airplane for Photography

The use of powered aircraft as platforms for aerial photography forms the next milestone. In 1909 Wilbur Wright piloted the plane that acquired motion pictures of the Italian landscape near Centocelli; these are said to be the first aerial photographs taken from an airplane. The maneuverability of the airplane provided the capability of controlling speed, altitude, and direction required for systematic use of the airborne camera. Although there were many attempts to combine the camera with the airplane, the instruments of this era were clearly not tailored for use with each other (Figure 1.2).

World War I

World War I (1914–1918) marked the beginning of the acquisition of aerial photography on a routine basis. Although cameras used for aerial photography during this conflict were designed specifically for use with the airplane, the match between the two instruments was still rather rudimentary by the standards of later decades (Figure 1.3). The value of aerial photography for military reconnaissance and surveillance became increasingly clear as the war continued, and its applications became increasingly sophisticated. By the conclusion of the conflict, aerial photography's role in military operations was recognized, although training programs, organizational structures, and operational doctrine had not yet matured.

FIGURE 1.2. Early aerial photography by the U.S. Navy, 1914. This photograph illustrates difficulties encountered in early efforts to match the camera with the airplane—neither is well-suited for use with the other. From U.S. Navy, National Archives and Records Administration, ARC 295605.

FIGURE 1.3. Aerial photography, World War I. By the time of World War I, attempts to match the camera and the airplane had progressed only to a modest extent, as illustrated by this example. The aircraft (with the biplane design typical of this era) has a port for oblique photography to allow the photographer to aim the camera through the port from within the fuselage to avoid the disadvantages of leaning over the edge of the cockpit. The photographer wears a chest-mounted microphone for communication with the pilot and is shown holding a supply of extra plates for the camera. From U.S. National Archives and Records Administration, Still Pictures, E-4156.

Interwar Years: 1919–1939

Numerous improvements followed from these beginnings. Camera designs were improved and tailored specifically for use in aircraft. The science of *photogrammetry*—the practice of making accurate measurements from photographs—was applied to aerial photography, with the development of instruments specifically designed for analysis of aerial photos. Although the fundamentals of photogrammetry had been defined much earlier, the field developed toward its modern form in the 1920s, with the application of specialized photogrammetric instruments. From these origins, another landmark was established: the more or less routine application of aerial photography in government programs, initially for topographic mapping but later for soil survey, geologic mapping, forest surveys, and agricultural statistics.

Many of the innovations during this era were led by visionary pioneers who established successful niches in private industry to develop civil applications of aerial mapping. Sherman Fairchild (1896–1971) founded numerous companies, including Fairchild Surveys and Fairchild Camera and Instruments, that became leaders in aviation and in aerial camera design. Talbert Abrams (1895–1990) led many innovations in aerial survey, in aviation, in camera design, in training, and in worldwide commercial operations. During this period, the well-illustrated volume by Lee (1922), *The Face of the Earth as Seen from the Air*, surveyed the range of possible applications of aerial photography in a variety of disciplines from the perspective of those early days. Although the applications that Lee envisioned were achieved at a slow pace, the expression of governmental interest ensured continuity in the scientific development of the acquisition and analysis of aerial photography, increased the number of photographs available, and trained many people in uses of aerial photography. Nonetheless, the acceptance of the use of aerial photography in most governmental and scientific activities developed slowly because of resistance among traditionalists, imperfections in equipment and technique, and genuine uncertainties regarding the proper role of aerial photography in scientific inquiry and practical applications.

The worldwide economic depression of 1929–1939 was not only an economic and financial crisis but also for many nations an environmental crisis. National concerns about social and economic impacts of rural economic development, widespread soil erosion, reliability of water supplies, and similar issues led to some of the first governmental applications of aerial surveys to record and monitor rural economic development. In the United States, the U.S. Department of Agriculture and the Tennessee Valley Authority led efforts to apply aerial photography to guide environmental planning and economic development. Such efforts formed an important contribution to the institutionalization of the use of aerial photography in government and to the creation of a body of practical experience in applications of aerial photography (Figure 1.4).

FIGURE 1.4. Progress in applications of aerial photography, 1919–1939. During the interval between World War I and World War II (1919–1939) integration of the camera and the airplane progressed, as did institutionalization of aerial photography in government and industry. By June 1943, the date of this photograph, progress on both fronts was obvious. Here an employee of the U.S. Geological Survey uses a specialized instrument, the O*blique* S*ketchmaster*, to match detail on an aerial photograph to an accurate map. By the time of this photograph, aerial photography formed an integral component of the U.S. Geological Survey operations. From U.S. Geological Survey and U.S. Library of Congress, fsa 8d38549.

World War II

These developments led to the eve of World War II (1939–1945), which forms the next milestone in our history. During the war years, use of the electromagnetic spectrum was extended from almost exclusive emphasis on the visible spectrum to other regions, most notably the infrared and microwave regions (far beyond the range of human vision). Knowledge of these regions of the spectrum had been developed in both basic and applied sciences during the preceding 150 years (see Table 1.2). However, during the war years, application and further development of this knowledge accelerated, as did dissemination of the means to apply it. Although research scientists had long understood the potential of the nonvisible spectrum, the equipment, materials, and experience necessary to apply it to practical problems were not at hand. Wartime research and operational experience provided both the theoretical and the practical knowledge required for everyday use of the nonvisible spectrum in remote sensing.

Furthermore, the wartime training and experience of large numbers of pilots, camera operators, and photointerpreters created a large pool of experienced personnel who were able to transfer their skills and experience into civilian occupations after the war. Many of these people assumed leadership positions in the efforts of business, scientific, and governmental programs to apply aerial photography and remote sensing to a broad range of problems.

During World War II, the expansion of aerial reconnaissance from the tactical, local focus of World War I toward capabilities that could reach deep within enemy territory to understand industrial and transportation infrastructure and indicate long-term capabilities and plans greatly increased the significance of aerial intelligence. Perhaps the best publicized example of this capability is the role of British photointerpreters who provided key components of the intelligence that detected the German V-1 and V-2 weapons well in advance of their deployment, thereby eliminating any advantage of surprise and enabling rapid implementation of countermeasures (Babington-Smith, 1957).

World War II also saw an expansion of the thematic scope of aerial reconnaissance. Whereas photointerpreters of the World War I era focused on identification and examination of military equipment and fortifications, their counterparts in World War II also examined topography, vegetation, trafficability, and other terrain features, thereby expanding the scope and knowledge base and the practice of photointerpretation.

Cold War Era

The successes of strategic photointerpretation during World War II set the stage for continued interest in aerial surveillance during the cold war era. Initially, technological trends established during World War II were continued and improved. However, as the nature of the cold war conflict became more clearly defined, strategic photointerpretation was seen as one of the few means of acquiring reliable information from within the closed societies of the Soviet bloc. Thus the U-2 aircraft and camera systems were developed to extend aviation and optical systems far beyond their expected limits; and later (1960) the CORONA strategic reconnaissance satellite (see Day, Logsdon, and Latell, 1998, and Chapter 6, this volume) provided the ability to routinely collect imagery from space. The best known contribution of photoreconnaissance within the cold war conflict came during the Cuban Missile Crisis. In 1962 U.S. photo interpreters were able to detect with confidence the early stages of Soviet introduction of missiles into Cuba far sooner than

Soviet strategists had anticipated, thereby setting the stage for defusing one of the most serious incidents of the cold war era (Brugioni, 1991).

The cold war era saw a bifurcation of capabilities, with a wide separation between applications within civil society and those within the defense and security establishments. The beginnings of the cold war between the Western democracies and the Soviet Union created the environment for further development of advanced reconnaissance techniques (Figure 1.5), which were often closely guarded as defense secrets and therefore not immediately available for civil applications. As newer, more sophisticated instruments were developed, the superseded technologies were released for wider, nondefense applications in the civilian economy (Figure 1.6).

Robert Colwell's Research in Applying Color Infrared Film

Among the most significant developments in the civilian sphere was the work of Robert Colwell (1956), who applied color infrared film (popularly known as "camouflage detection film," developed for use in World War II) to problems of identifying small-grain cereal crops and their diseases and other problems in the plant sciences. Although many of the basic principles of his research had been established earlier, his systematic investigation of their practical dimensions forms a clear milestone in the development of the field of remote sensing. Even at this early date, Colwell delineated the outlines of modern remote sensing and anticipated many of the opportunities and difficulties of this field of inquiry.

FIGURE 1.5. A U.S. Air Force intelligence officer examines aerial photography, Korean conflict, July 1951. From U.S. Air Force, National Archives and Records Administration, ARC 542288.

FIGURE 1.6. A photograph from the 1950s shows a forester examining aerial photography to delineate landscape units. By the 1950s, aerial photography and related forms of imagery had become integrated into day-to-day operations of a multitude of businesses and industries throughout the world. From Forest History Society, Durham, North Carolina. Reproduced by permission.

Civil Applications of Aerial Imagery

By the late 1950s aerial photography had been institutionalized in applications in government and civil society as a source of cartographic information (Figures 1.7 and 1.8). The 1960s saw a series of important developments occur in rapid sequence. The first meteorological satellite (TIROS-1) was launched in April 1960. This satellite was designed for climatological and meteorological observations but provided the basis for later development of land observation satellites. During this period, some of the remote sensing instruments originally developed for military reconnaissance and classified as defense secrets were released for civilian use as more advanced designs became available for military application. These instruments extended the reach of aerial observation outside the visible spectrum into the infrared and microwave regions.

Remote Sensing

It was in this context that the term *remote sensing* was first used. Evelyn Pruitt, a scientist working for the U.S. Navy's Office of Naval Research, coined this term when she recognized that the term *aerial photography* no longer accurately described the many forms of imagery collected using radiation outside the visible region of the spectrum. Early in the 1960s the U.S. National Aeronautics and Space Administration (NASA) established a research program in remote sensing—a program that, during the next decade, was to support remote sensing research at institutions throughout the United States. During this same period, a committee of the U.S. National Academy of Sciences (NAS) studied opportunities for application of remote sensing in the field of agriculture and forestry. In

FIGURE 1.7. A stereoscopic plotting instrument used to derive accurate elevation data from aerial photography, 1957. During much of the twentieth century, photogrammetric analyses depended on optical–mechanical instruments such as the one shown here, designed to extract information by controlling the physical orientation of the photograph and optical projection of the image. By the end of the century, such processes were conducted in the digital domain using electronic instruments. From Photographic Library, U.S. Geological Survey, Denver, Colorado. Photo by E. F. Patterson, no. 223.

FIGURE 1.8. A cartographic technician uses an airbrush to depict relief, as interpreted from aerial photographs, 1961. Within a few decades, computer cartography and GIS could routinely create this effect by applying hill-shading algorithms to digital elevation models. From Photographic Library, U.S. Geological Survey, Denver, Colorado. Photo by E.F. Patterson, no. 1024.

1970, the NAS reported the results of their work in a document that outlined many of the opportunities offered by this emerging field of inquiry.

Satellite Remote Sensing

In 1972, the launch of Landsat 1, the first of many Earth-orbiting satellites designed for observation of the Earth's land areas, marked another milestone. Landsat provided, for the first time, systematic repetitive observation of the Earth's land areas. Each Landsat image depicted large areas of the Earth's surface in several regions of the electromagnetic spectrum, yet provided modest levels of detail sufficient for practical applications in many fields. Landsat's full significance may not yet be fully appreciated, but it is possible to recognize three of its most important contributions. First, the routine availability of multispectral data for large regions of the Earth's surface greatly expanded the number of people who acquired experience and interest in analysis of multispectral data. Multispectral data had been acquired previously but were largely confined to specialized research laboratories. Landsat's data greatly expanded the population of scientists with interests in multispectral analysis.

Landsat's second contribution was to create an incentive for the rapid and broad expansion of uses of digital analysis for remote sensing. Before Landsat, image analyses were usually completed visually by examining prints and transparencies of aerial images. Analyses of digital images by computer were possible mainly in specialized research institutions; personal computers, and the variety of image analysis programs that we now regard as commonplace, did not exist. Although Landsat data were initially used primarily as prints or transparencies, they were also provided in digital form. The routine availability of digital data in a standard format created the context that permitted the growth in popularity of digital analysis and set the stage for the development of image analysis software that is now commonplace. During this era, photogrammetic processes originally implemented using mechanical instruments were redefined as digital analyses, leading to improvements in precision and in streamlining the acquisition, processing, production, and distribution of remotely sensed data. A third contribution of the Landsat program was its role as a model for development of other land observation satellites designed and operated by diverse organizations throughout the world.

By the early 1980s, a second generation of instruments for collecting satellite imagery provided finer spatial detail at 30-m, 20-m, and 10-m resolutions and, by the 1990s, imagery at meter and submeter resolutions. Finally, by the late 1990s, development of commercial capabilities (e.g., Geoeye and IKONOS) for acquiring fine-resolution satellite imagery (initially at spatial resolutions of several meters but eventually submeter detail) opened new civil applications formerly available only through uses of aerial photography. It is important to note that such progress in the field of remote sensing advanced in tandem with advances in geographic information systems (GIS), which provided the ability to bring remotely sensed data and other geospatial data into a common analytical framework, thereby enhancing the range of products and opening new markets—mapping of urban infrastructure, supporting precision agriculture, and support of floodplain mapping, for example.

Hyperspectral Remote Sensing

During the 1980s, scientists at the Jet Propulsion Laboratory (Pasadena, California) began, with NASA support, to develop instruments that could create images of the Earth at unprecedented levels of spectral detail. Whereas previous multispectral sensors collected data in a few rather broadly defined spectral regions, these new instruments could collect 200 or more very precisely defined spectral regions. These instruments created the field of *hyperspectral remote sensing*, which is still developing as a field of inquiry. Hyperspectral remote sensing will advance remote sensing's analytical powers to new levels and will form the basis for a more thorough understanding of how to best develop future remote sensing capabilities.

Global Remote Sensing

By the 1990s, satellite systems had been designed specifically to collect remotely sensed data representing the entire Earth. Although Landsat had offered such a capability in principle, in practice effective global remote sensing requires sensors and processing techniques specifically designed to acquire broad-scale coverage, which requires coarse spatial detail, often at coarse details of several kilometers. Such capabilities had existed on an *ad hoc* basis since the 1980s, primarily based on the synoptic scope of meteorological satellites. By December 1999, NASA had launched Terra-1, the first satellite of a system specifically designed to acquire global coverage to monitor changes in the nature and extent of Earth's ecosystems. The deployment of these systems marks the beginning of an era of broad-scale remote sensing of the Earth, which has provided some of the scientific foundations for documenting spatial patterns of environmental changes during recent decades.

Geospatial Data

Beginning in the 1980s but not maturing fully until the mid-2000s, several technologies began to converge to create systems with a unique synergy that each enhanced and reinforced the value of the others to create *geospatial data*, a term applied collectively to several technologies—primarily remote sensing, GIS, and global positioning systems (GPS). Many of these systems are implemented in the digital domain, replacing manual and mechanical applications developed in previous decades (Figure 1.9). Although these technologies had developed as interrelated technologies, by the first decade of the 2000s, they came to form integrated systems that can acquire imagery of high positional accuracy and that enable the integration of varied forms of imagery and data. Thus, during this interval, collection and analysis of geospatial data transformed from relying on several separate, loosely connected technologies to forming fully integrated and synergistic instruments that each reinforce the value of the others. These increases in quality and flexibility of geospatial data, linked also to decentralization of the information technology (IT) services and acquisition of aerial imagery, increased the significance of a broad population of entrepreneurs motivated to develop innovative products tailored to specific markets. Driving concerns included needs for planning and construction, civil needs in agriculture and forestry, hydrology, and consumer services and products (but, it should be noted, often in very specific niches within each of these areas). Widespread availability of fine-resolution satellite data has opened markets within news media, nonprofit and nongovernmental organizations, and behind-the-scenes continuing markets within the military and national security communities. After the events associated with 9/11 and Hurricane Katrina, the value of satellite imagery for homeland security was more for-

FIGURE 1.9. Analysts examine digital imagery displayed on a computer screen using specialized software, 2008. From Virginia Tech Center for Geospatial Information and Technologies.

mally recognized and integrated into emergency response and homeland security planning at national, regional, and local levels.

Public Remote Sensing

During the first decade of the 21st century, the increasing power of the Internet began to influence public access to remotely sensed imagery, in part through design of image-based products made for distribution though the Internet and in part through design of consumer products and services that relied on remotely sensed imagery presented in a map-like format. Whereas much of the previous history of remote sensing can be seen as the work of specialists to produce specialized products for the use of other specialists, these developments hinged on designing products for the use of the broader public.

Google Earth, released in 2005, forms a virtual representation of the Earth's surface as a composite of varied digital images, using basic concepts developed by Keyhole, Inc., which had been acquired by Google in 2004. Google Earth was designed to communicate with a broadly defined audience—a public without the kind of specialized knowledge that previously was an assumed prerequisite for use of remote sensing imagery. The new product assumed only that users would already be familiar with the delivery mechanism—i.e., use of the Internet and World Wide Web.

A basic innovation of Google Earth is the recognition of the value of a broad population of image products formed by accurate georeferencing of composite images acquired at varied dates, scales, and resolutions. Such composites can be viewed using an intuitive interface for browsing and roaming, changing scale, orientation, and detail. Google Earth has added specialized tools for tailoring the software to needs of specific users, enhancing display options, and integrating other data within the Google Earth framework. The product is based on the insight that the Google Earth tool could appeal to a population of nonspecialists, while at the same time providing specialized capabilities for narrowly defined communities of users in defense, security, emergency response, and commerce that require immediate, simultaneous access to a common body of geospatial data.

Google Earth and similar online services represent a new class of applications of remotely sensed imagery that contrast sharply with those of earlier eras. Campbell, Hardy, and Bernard (2010) outlined the context for the development of many of these new cartographic applications of remotely sensed data, including (1) a public policy that has maintained relaxed constraints on acquisition of fine-resolution satellite data, (2) personal privacy policies that favor widespread collection of imagery, (3) availability and popularity of reliable personal navigation devices, and (4) increasing migration of applications to mobile or handheld devices. Such developments have led to a class of cartographic products derived from remotely sensed data, including, for example, those created by MapQuest and related navigation software, which rely on road networks that are systematically updated by analysis of remotely sensed imagery. Ryerson and Aronoff (2010) have outlined practical applications of many of these technologies.

1.4. Overview of the Remote Sensing Process

Because remotely sensed images are formed by many interrelated processes, an isolated focus on any single component will produce a fragmented understanding. Therefore, our initial view of the field can benefit from a broad perspective that identifies the kinds of knowledge required for the practice of remote sensing (Figure 1.10).

Consider first the *physical objects*, consisting of buildings, vegetation, soil, water, and the like. These are the objects that applications scientists wish to examine. Knowledge of the physical objects resides within specific disciplines, such as geology, forestry, soil science, geography, and urban planning.

Sensor data are formed when an instrument (e.g., a camera or radar) views the physical objects by recording electromagnetic radiation emitted or reflected from the landscape. For many, sensor data often seem to be abstract and foreign because of their unfamiliar overhead perspective, unusual resolutions, and use of spectral regions outside the visible spectrum. As a result, effective use of sensor data requires analysis and interpretation to convert data to information that can be used to address practical problems, such as siting landfills or searching for mineral deposits. These interpretations create *extracted information*, which consists of transformations of sensor data designed to reveal specific kinds of information.

Actually, a more realistic view (Figure 1.11) illustrates that the same sensor data can be examined from alternative perspectives to yield different interpretations. Therefore, a single image can be interpreted to provide information about soils, land use, or hydrology, for example, depending on the specific image and the purpose of the analysis. Finally, we proceed to the *applications*, in which the analyzed remote sensing data can be combined with other data to address a specific practical problem, such as land-use planning, mineral exploration, or water-quality mapping. When digital remote sensing data are combined with other geospatial data, applications are implemented in the context of GIS. For example, remote sensing data may provide accurate land-use information that can be combined with soil, geologic, transportation, and other information to guide the siting of a new landfill. Although specifics of this process are largely beyond the scope of

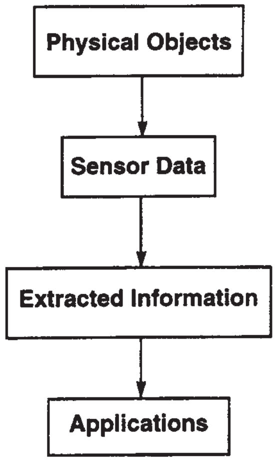

FIGURE 1.10. Overview of the remote sensing process.

this volume, they are presented in books, such as Burrough and McDonnell (1998) and Demers (2009), devoted to applications of GIS.

1.5. Key Concepts of Remote Sensing

Although later chapters more fully develop key concepts used in the practice of remote sensing, it is useful to provide a brief overview of some of the recurring themes that are pervasive across application areas.

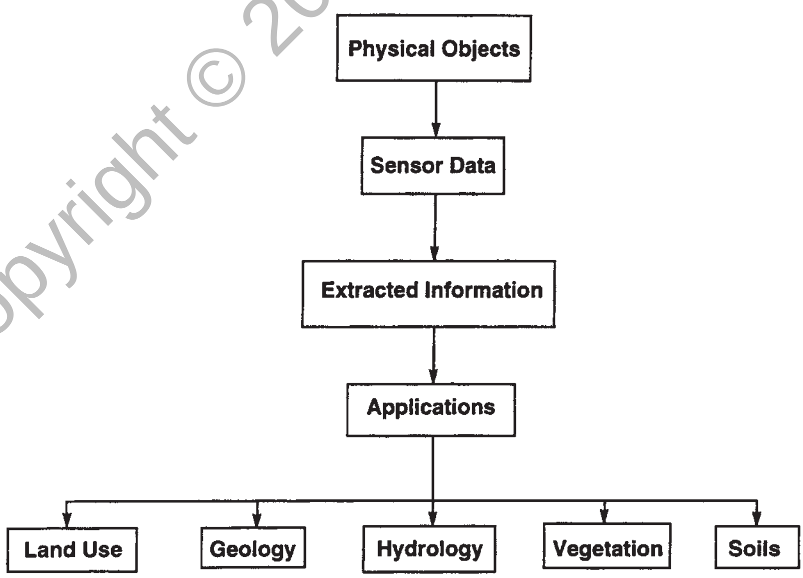

FIGURE 1.11. Expanded view of the process outlined in Figure 1.10.

Spectral Differentiation

Remote sensing depends on observed spectral differences in the energy reflected or emitted from features of interest. Expressed in everyday terms, one might say that we look for differences in the "colors" of objects, even though remote sensing is often conducted outside the visible spectrum, where "colors," in the usual meaning of the word, do not exist. This principle is the basis of *multispectral remote sensing*, the science of observing features at varied wavelengths in an effort to derive information about these features and their distributions. The term *spectral signature* has been used to refer to the spectral response of a feature, as observed over a range of wavelengths (Parker and Wolff, 1965). For the beginning student, this term can be misleading, because it implies a distinctiveness and a consistency that seldom can be observed in nature. As a result, some prefer *spectral response pattern* to convey this idea because it implies a less rigid version of the concept. Later chapters revisit these ideas in more detail.

Radiometric Differentiation

Examination of any image acquired by remote sensing ultimately depends on detection of differences in the brightness of objects and the features. The scene itself must have sufficient contrast in brightnesses, and the remote sensing instrument must be capable of recording this contrast, before information can be derived from the image. As a result, the sensitivity of the instrument and the existing contrast in the scene between objects and their backgrounds are always issues of significance in remote sensing investigations.

Spatial Differentiation

Every sensor is limited in respect to the size of the smallest area that can be separately recorded as an entity on an image. This minimum area determines the spatial detail—the fineness of the patterns—on the image. These minimal areal units, known as *pixels* ("picture elements"), are the smallest areal units identifiable on the image. Our ability to record spatial detail is influenced primarily by the choice of sensor and the altitude at which it is used to record images of the Earth. Note that landscapes vary greatly in their spatial complexity; some may be represented clearly at coarse levels of detail, whereas others are so complex that the finest level of detail is required to record their essential characteristics.

Temporal Dimension

Although a single image can easily demonstrate the value of remotely sensed imagery, its effectiveness is best demonstrated through the use of many images of the same region acquired over time. Although practitioners of remote sensing have a long history of exploiting the temporal dimension of aerial imagery, through the use of sequential aerial photography (using the archives of photography preserved over the years since aerial photography was first acquired in a systematic manner), the full value of the temporal dimension was realized later, when satellite systems could systematically observe the same regions on a repetitive basis. These later sequences, acquired by the same platforms using the same instruments under comparable conditions, have offered the ability to more fully exploit the temporal dimension of remotely sensed data.

Geometric Transformation

Every remotely sensed image represents a landscape in a specific geometric relationship determined by the design of the remote sensing instrument, specific operating conditions, terrain relief, and other factors. The ideal remote sensing instrument would be able to create an image with accurate, consistent geometric relationships between points on the ground and their corresponding representations on the image. Such an image could form the basis for accurate measurements of areas and distances. In reality, of course, each image includes positional errors caused by the perspective of the sensor optics, the motion of scanning optics, terrain relief, and Earth curvature. Each source of error can vary in significance in specific instances, but the result is that geometric errors are inherent, not accidental, characteristics of remotely sensed images. In some instances we may be able to remove or reduce locational error, but it must always be taken into account before images are used as the basis for measurements of areas and distances. Thus another recurring theme in later chapters concerns the specific geometric errors that characterize each remote sensing instrument and remedies that can be applied to provide imagery that has geometric qualities appropriate for their use.

Remote Sensing Instrumentation Acts as a System

The image analyst must always be conscious of the fact that the many components of the remote sensing process *act as a system* and therefore cannot be isolated from one another. For example, upgrading the quality of a camera lens makes little sense unless we can also use technologies that can record the improvements produced by the superior lens. Components of the system must be appropriate for the task at hand. This means that the analyst must intimately know not only the capabilities of each imaging system and how it should be deployed but also the subject matter to be examined and the specific needs of those who will use the results of the project. Successful applications of remote sensing require that such considerations be resolved to form a system with compatible components.

Role of the Atmosphere

All energy reaching a remote sensing instrument must pass through a portion of the Earth's atmosphere. For satellite remote sensing in the visible and near infrared, energy received by the sensor must pass through a considerable depth of the Earth's atmosphere. In doing so, the sun's energy is altered in intensity and wavelength by particles and gases in the Earth's atmosphere. These changes appear on the image in ways that degrade image quality or influence the accuracy of interpretations.

1.6. Career Preparation and Professional Development

For the student, a course of study in remote sensing offers opportunities to enter a field of knowledge that can contribute to several dimensions of a university education and subsequent personal and professional development. Students enrolled in introductory remote sensing courses often view the topic as an important part of their occupational and professional preparation. It is certainly true that skills in remote sensing are valuable in the initial search for employment. But it is equally important to acknowledge that this topic should form part of a comprehensive program of study that includes work in GIS and in-depth study of a specific discipline. A well-thought-out program appropriate for a student's specific interests and strengths should combine studies in several interrelated topics, such as:

- Geology, hydrology, geomorphology, soils
- Urban planning, transportation, urban geography
- Forestry, ecology, soils

Such programs are based on a foundation of supporting courses, including statistics, computer science, and the physical sciences. Students should avoid studies that provide only narrowly based, technique-oriented content. Such highly focused studies, perhaps with specific equipment or software, may provide immediate skills for entry-level positions, but they leave the student unprepared to participate in the broader assignments required for effective performance and professional advancement. Employers report that they seek employees who:

- Have a good background in at least one traditional discipline.
- Are reliable and able to follow instructions without detailed supervision.
- Can write and speak effectively.
- Work effectively in teams with others in other disciplines.
- Are familiar with common business practices.

Table 1.3 provides examples.

Because this kind of preparation is seldom encompassed in a single academic unit within a university, students often have to apply their own initiative to identify the specific courses they will need to best develop these qualities. Table 1.3 shows a selection of sample job descriptions in remote sensing and related fields, as an indication of the kinds of knowledge and skills expected of employees in the geospatial information industry.

Possibly the most important but least visible contributions are to the development of conceptual thinking concerning the role of basic theory and method, integration of knowledge from several disciplines, and proficiency in identifying practical problems in a spatial context. Although skills in and knowledge of remote sensing are very important, it is usually a mistake to focus exclusively on methodology and technique. At least two pitfalls are obvious. First, emphasis on fact and technique without consideration of basic principles and theory provides a narrow, empirical foundation in a field that is characterized by diversity and rapid change. A student equipped with a narrow background is ill prepared to compete with those trained in other disciplines or to adjust to unexpected developments in science and technology. Thus any educational experience is best perceived not as a catalog of facts to be memorized but as an experience in *how to learn* to equip oneself for independent learning later, outside the classroom. This task requires a familiarity with basic references, fundamental principles, and the content of related disciplines, as well as the core of facts that form the substance of a field of knowledge.

Second, many employers have little interest in hiring employees with shallow preparation either in their major discipline or in remote sensing. Lillesand (1982) reports that a panel of managers from diverse industries concerned with remote sensing recommended that prospective employees develop "an ability and desire to interact at a conceptual level

TABLE 1.3. Sample Job Descriptions Relating to Remote Sensing

SURVEY ENGINEER
XCELIMAGE is a spatial data, mapping, and geographic information systems (GIS) services company that provides its clients with customized products and services to support a wide range of land-use and natural resource management activities. The company collects geospatial data using a variety of airborne sensing technologies and turns that data into tools that can be used in GIS or design and engineering environments. With over 500 employees in offices nationwide, the XCELIMAGE group and affiliates represent one of the largest spatial data organizations in the world. XCELIMAGE is affiliated with six member companies and two affiliates. XCELIMAGE Aviation, located in Springfield, MA, has an immediate opening for a Survey Engineer.

XCELIMAGE Aviation supplies the aerial photography and remote sensing data from which terrain models, mapping, and GIS products are developed. XCELIMAGE Aviation operates aircraft equipped with analog, digital, and multispectral cameras; global positioning systems (GPS); a light detection and ranging system (LIDAR); a passive microwave radiometer; and thermal cameras.
This position offers a good opportunity for advancement and a competitive salary and benefits package. Position requires a thorough knowledge of computer operation and applications including GIS software; a basic understanding of surveying, mapping theories, and techniques; a thorough knowledge of GPS concepts; exposure to softcopy techniques; and the ability to efficiently aid in successful implementation of new technologies and methods. This position includes involvement in all functions related to data collection, processing, analysis, and product development for aerial remote sensing clients; including support of new technology.

ECOLOGIST/REMOTE SENSING SPECIALIST
The U.S. National Survey Northern Plains Ecological Research Center is seeking an Ecologist/Remote Sensing Specialist to be a member of the Regional Gap Analysis Project team. The incumbent's primary responsibility will be mapping vegetation and land cover for our region from analysis of multitemporal Landsat Thematic Mapper imagery and environmental data in a geographic information system. To qualify for this position, applicants must possess (1) ability to conduct digital analysis of remotely sensed satellite imagery for vegetation and land cover mapping; (2) ability to perform complex combinations and sequences of methods to import, process, and analyze data in vector and raster formats in a geographic information system; and (3) knowledge of vegetation classification, inventory, and mapping.

REMOTE SENSING/GIS AGRICULTURAL ANALYST
Position located in Washington, DC. Requires US citizenship. Unofficial abstract of the "Crop Assessment Analyst" position: An interesting semianalytic/technical position is available with the Foreign Agricultural Service working as an international and domestic agriculture commodity forecaster. The position is responsible for monitoring agricultural areas of the world, performing analysis, and presenting current season production forecasts. Tools and data used in the position include imagery data (AVHRR, Landsat TM, SPOT), vegetation indexes, crop models, GIS software (ArcView, ArcInfo), image processing s/w (Erdas, PCI), agro-meteorological data models, web browsers, web page design s/w, graphic design s/w, spreadsheet s/w, GIS software, digital image processing, weather station data, climate data, historical agricultural production data, and assessing news stories. The main crops of concern are soybeans, canola, wheat, barley, corn, cotton, peanuts, and sorghum of the major export/import countries.
A background in agronomy, geographical spatial data, good computer skills, information management, and ag economics will prove beneficial in performing the work.

REMOTE SENSING SPECIALIST POSITION, GEOSPATIAL AND INFORMATION TECHNOLOGIES INFORMATION RESOURCES UNIT
The Remote Sensing Specialist is generally responsible for implementing remote sensing technology as a tool for natural resources management. Responsibilities include planning, coordinating, and managing a regional remote sensing program, working with resource specialists at the regional level, forests and districts, to meet information needs using remotely sensed data. Tasks include working with resource and GIS analysts to implement the recently procured national image processing software, keeping users informed about the system, and assisting with installation and training. The person in this position is also the primary contact in the region for national remote sensing issues, and maintains contact with other remote sensing professionals within the Forest Service, in other agencies, and in the private and academic sectors.
The position is located in the Geospatial and Information Technologies (GIT) group of the Information Resources (IRM) unit. IRM has regional responsibility for all aspects of information and systems management. The GIT group includes the remote sensing, aerial photography, photogrammetry, cartography, database, and GIS functions.

Note. Actual notices edited to remove information identifying specific firms. Although listed skills and abilities are typical, subject area specialties are not representative of the range of applications areas usually encountered.

with other specialists" (p. 290). Campbell (1978) quotes other supervisors who are also concerned that students receive a broad preparation in remote sensing and in their primary field of study:

> It is essential that the interpreter have a good general education in an area of expertise. For example, you can make a geologist into a good photo geologist, but you cannot make an image interpreter into a geologist.
>
> Often people lack any real philosophical understanding of why they are doing remote sensing, and lack the broad overview of the interrelationships of all earth science and earth-oriented disciplines (geography, geology, biology, hydrology, meteorology, etc.). This often creates delays in our work as people continue to work in small segments of the (real) world and don't see the interconnections with another's research. (p. 35)

These same individuals have recommended that those students who are interested in remote sensing should complete courses in computer science, physics, geology, geography, biology, engineering, mathematics, hydrology, business, statistics, and a wide variety of other disciplines. No student could possibly take all recommended courses during a normal program of study, but it is clear that a haphazard selection of university courses, or one that focused exclusively on remote sensing courses, would not form a substantive background in remote sensing. In addition, many organizations have been forceful in stating that they desire employees who can write well, and several have expressed an interest in persons with expertise in remote sensing who have knowledge of a foreign language. The key point is that educational preparation in remote sensing should be closely coordinated with study in traditional academic disciplines and should be supported by a program of courses carefully selected from offerings in related disciplines.

Students should consider joining a professional society devoted to the field of remote sensing. In the United States and Canada, the American Society for Photogrammetry and Remote Sensing (ASPRS; 5410 Grosvenor Lane, Suite 210, Bethesda, MD 20814-2160; 301-493-0290; *www.asprs.org*) is the principal professional organization in this field. ASPRS offers students discounts on membership dues, publications, and meeting registration and conducts job fairs at its annual meetings. ASPRS is organized on a regional basis, so local chapters conduct their own activities, which are open to student participation. Other professional organizations often have interest groups devoted to applications of remote sensing within specific disciplines, often with similar benefits for student members.

Students should also investigate local libraries to become familiar with professional journals in the field. The field's principal journals include:

Photogrammetric Engineering and Remote Sensing

Remote Sensing of Environment

International Journal of Remote Sensing

IEEE Transactions on Geoscience and Remote Sensing

Computers and Geosciences

GIScience and Remote Sensing

ISPRS Journal of Photogrammetry and Remote Sensing

Although beginning students may not yet be prepared to read research articles in detail, those who make the effort to familiarize themselves with these journals will have prepared the way to take advantage of their content later. In particular, students may find *Photogrammetric Engineering and Remote Sensing* useful because of its listing of job opportunities, scheduled meetings, and new products.

The world of practical remote sensing has changed dramatically in recent decades. Especially since the early 1990s, commercial and industrial applications of remote sensing have expanded dramatically to penetrate well beyond the specialized applications of an earlier era—to extend, for example, into marketing, real estate, and agricultural enterprises. Aspects of remote sensing that formerly seemed to require a highly specialized knowledge became available to a much broader spectrum of users as data became less expensive and more widely available and as manufacturers designed software for use by the nonspecialist.

These developments have created a society in which remote sensing, GIS, GPS, and related technological systems have become everyday tools within the workplace and common within the daily lives of many people. In such a context, each citizen, especially the nonspecialist, must be prepared to use spatial data effectively and appropriately and to understand its strengths and limitations. Because of the need to produce a wide variety of ready-to-use products tailored for specific populations of users, the remote sensing community will continue to require specialists, especially those who can link a solid knowledge of remote sensing with subject-area knowledge (e.g., hydrology, planning, forestry, etc.). People who will work in this field will require skills and perspectives that differ greatly from those of previous graduates of only a few years earlier.

1.7. Some Teaching and Learning Resources

AmericaView

AmericaView is a nonprofit organization funded chiefly through the U.S. Geological Survey to promote uses of satellite imagery and to distribute imagery to users. It comprises a coalition of state-based organizations (such as OhioView, VirginiaView, WisconsinView, AlaskaView, and other "StateViews"), each composed of coalitions of universities, businesses, state agencies, and nonprofit organizations and each led by a university within each state. StateViews distribute image data to their members and to the public, conduct research to apply imagery to local and state problems, conduct workshops and similar educational activities, support research, and, in general, promote use of remotely sensed imagery within the widest possible range of potential users. Each StateView has its own website, with a guide to its members, activities, and data resources. AmericaView's Education Committee provides access to a variety of educational resources pertaining to teaching of remote sensing in grades K–12 through university levels, accessible at

www.americaview.org

Geospatial Revolution Project

The Geospatial Revolution Project (*geospatialrevolution.psu.edu*), developed by Penn State Public Broadcasting, has an integrated public media and outreach initiative focused on the world of digital mapping and how it is shaping the way our society functions. The project features a Web-based serial release of several video episodes, each focused on an specific narrative illuminating the role of geospatial knowledge in our world. These episodes will combine to form a full-length documentary. The project also will include an outreach initiative in collaboration with partner organizations, a chaptered program DVD, and downloadable outreach materials. The 5-minute trailer available at the website provides an introduction to the significance of geospatial data.

geospatialrevolution.psu.edu

www.youtube.com/watch?v=ZdQjc30YPOk

American Society for Photogrammetry and Remote Sensing

The American Society for Photogrammetry and Remote Sensing (*www.asprs.org*) has produced a series of short videos (each about 2 minutes or less in length) focusing on topics relevant to this chapter. The link to "ASPRS films" (under the "Education and Professional Development" tab) (*www.asprs.org/films/index.html*) connects to a series of short videos highlighting topics relating to ASPRS history and its contributions to the fields of photogrammetry and remote sensing.

Videos in this series that are especially relevant to this chapter include:

- Aerial Survey Pioneers
  www.youtube.com/watch?v=wW-JTtwNC_4&fmt=22
- Geospatial Intelligence in WWII
  www.youtube.com/watch?v=hQu0wxXN6U4&fmt=22
- Role of Women
  www.youtube.com/watch?v=kzgrwmaurKU&fmt=22
- Photogrammetry in Space Exploration
  www.youtube.com/watch?v=KVVbhqq6SRg&fmt=22
- Evolution of Analog to Digital Mapping
  www.youtube.com/watch?v=4jABMysbNbc&fmt=22

This list links to YouTube versions; the ASPRS site provides links to versions of higher visual quality.

Britain from Above

The British Broadcasting Corporation project Britain from Above has multiple short video units (usually about 3–5 minutes each) that are of interest to readers of this book. At *www.bbc.co.uk/britainfromabove*, go to "See Your World from Above" ("Browse stories"), then "Stories Overview." Then from "Stories Overview," select the "Secrets" tab and play the "The Dudley Stamp Maps." Or, from the"Stories Overview" section, select the "Behind the Scenes" tab, then play the "Archive." There are many other videos of interest at this site.

Canada Centre for Remote Sensing

The Canada Centre for Remote Sensing (*www.ccrs.nrcan.gc.ca/resource/tutor/fundam/index_e.php*) has a broad range of resources pertain to remote sensing, including introductory level tutorials and materials for instructors, including quizzes and exercises.

- Earth Resources Technology Satellite (ERTS)–1973
  www.youtube.com/watch?v=6isYzkXlTHc&feature=related
- French Kite Aerial Photography Unit, WWI
  www.youtube.com/watch?v=O5dJ9TwaIt4
- 1940 British Aerial Reconnaissance
  www.youtube.com/watch?v=PhXd6uMlPVo
- Forgotten Aircraft: The Abrams Explorer
  www.youtube.com/watch?v=gsaAeLaNr60

Review Questions

1. Aerial photography and other remotely sensed images have found rather slow acceptance into many, if not most, fields of study. Imagine that you are director of a unit engaged in geological mapping in the early days of aerial photography (e.g., in the 1930s). Can you suggest reasons why you might be reluctant to devote your efforts and resources to use of aerial photography rather than to continue use of your usual procedures?
2. Satellite observation of the Earth provides many advantages over aircraft-borne sensors. Consider fields such as agronomy, forestry, or hydrology. For one such field of study, list as many of the advantages as you can. Can you suggest some disadvantages?
3. Much (but not all) information derived from remotely sensed data is derived from spectral information. To understand how spectral data may not always be as reliable as one might first think, briefly describe the spectral properties of a maple tree and a cornfield. How might these properties change over the period of a year? Or a day?
4. All remotely sensed images observe the Earth from above. Can you list some advantages to the overhead view (as opposed to ground-level views) that make remote sensing images inherently advantageous for many purposes? List some disadvantages to the overhead view.
5. Remotely sensed images show the combined effects of many landscape elements, including vegetation, topography, illumination, soil, drainage, and others. In your view, is this diverse combination an advantage or a disadvantage? Explain.
6. List ways in which remotely sensed images differ from maps. Also list advantages and disadvantages of each. List some of the tasks for which each might be more useful.
7. Chapter 1 emphasizes how the field of remote sensing is formed by knowledge and perspectives from many different disciplines. Examine the undergraduate catalog for your college or university and prepare a comprehensive program of study in remote

sensing from courses listed. Identify gaps—courses or subjects that would be desirable but are not offered.

8. At your university library, find copies of *Photogrammetric Engineering and Remote Sensing*, *International Journal of Remote Sensing*, and *Remote Sensing of Environment*, some of the most important English-language journals reporting remote sensing research. Examine some of the articles in several issues of each journal. Although titles of some of these articles may now seem rather strange, as you progress through this course you will be able to judge the significance of most. Refer to these journals again as you complete the course.
9. Inspect library copies of some of the remote sensing texts listed in the references for Chapter 1. Examine the tables of contents, selected chapters, and lists of references. Many of these volumes may form useful references for future study or research in the field of remote sensing.
10. Examine some of the journals mentioned in Question 8, noting the affiliations and institutions of authors of articles. Be sure to look at issues that date back for several years, so you can identify some of the institutions and agencies that have been making a continuing contribution to remote sensing research.

References

Alföldi, T., P. Catt, and P. Stephens. 1993. Definitions of Remote Sensing. *Photogrammetric Engineering and Remote Sensing*, Vol. 59, pp. 611–613.

Arthus-Bertrand, Y. 1999. *Earth from Above*. New York: Abrams, 414 pp.

Avery, T. E., and G. L. Berlin. 1992. *Fundamentals of Remote Sensing and Airphoto Interpretation*. Upper Saddle River, NJ: Prentice-Hall, 472 pp.

Babington-Smith, C. 1957. *Air Spy: The Story of Photo intelligence in World War II*. New York: Ballantine, 190 pp. (Reprinted 1985. Bethesda, MD: American Society for Photogrammetry and Remote Sensing, 266 pp.)

Barrett, E. C., and C. F. Curtis. 1976. *Introduction to Environmental Remote Sensing*. New York: Macmillan, 472 pp.

Bossler, J. D. (ed.). 2010. *Manual of Geospatial Science and Technology* (2nd ed.). London: Taylor & Francis, 808 pp.

Brugioni, D. A. 1991. *Eyeball to Eyeball: The Inside Story of the Cuban Missile Crisis*. New York: Random House, 622 pp.

Burrough, P. A., and R. A. McDonnell. 1998. *Principles of Geographical Information Systems*. New York: Oxford. 333 pp.

Campbell, J. B. 1978. Employer Needs in Remote Sensing in Geography. *Remote Sensing Quarterly*, Vol. 5, No. 2, pp. 52–65.

Campbell, J. B. 2008. Origins of Aerial Photographic Interpretation, U.S. Army, 1916–1918. *Photogrammetric Engineering and Remote Sensing*, Vol. 74, pp. 77–93.

Campbell, J. B., and V. V. Salomonson. 2010. Remote Sensing—A Look to the Future. Chapter 25 in *Manual of Geospatial Science and Technology* (2nd ed.). (J. D. Bossler, ed.) London: Taylor & Francis, pp. 487–510.

Campbell, Joel, T. Hardy, and R. C. Barnard. 2010. Emerging Markets for Satellite and Aerial Imagery. Chapter 22 in *Manual of Geospatial Science and Technology* (2nd ed.). (J. D. Bossler, ed.). London: Taylor & Francis, pp. 423–437.

Collier, P. 2002. The Impact on Topographic Mapping of Developments in Land and Air Survey 1900–1939. *Cartography and Geographic Information Science*, Vol. 29, pp. 155–174.

Colwell, R. N. 1956. Determining the Prevalence of Certain Cereal Crop Diseases by Means of Aerial Photography. *Hilgardia*, Vol. 26, No. 5, pp. 223–286.

Colwell, R. N. 1966. Uses and Limitations of Multispectral Remote Sensing. In *Proceedings of the Fourth Symposium on Remote Sensing of Environment*. Ann Arbor: Institute of Science and Technology, University of Michigan, pp. 71–100.

Colwell, R. N. (ed.). 1983. *Manual of Remote Sensing* (2nd ed.). Falls Church, VA: American Society of Photogrammetry, 2 vols., 2240 pp.

Curran, P. 1985. *Principles of Remote Sensing*. New York: Longman, 282 pp.

Curran, P. 1987. Commentary: On Defining Remote Sensing. *Photogrammetric Engineering and Remote Sensing*, Vol. 53, pp. 305–306.

Day, D. A., J. M. Logsdon, and B. Latell (eds.). 1998. *Eye in the Sky: The Story of the Corona Spy Satellites*. Washington, DC: Smithsonian Institution Press, 303 pp.

Demers, M. N. 2009. *Fundamentals of Geographic Information Systems*. New York: Wiley, 442 pp.

Estes, J. E., J. R. Jensen, and D. S. Simonett. 1977. The Impact of Remote Sensing on United States' Geography: The Past in Perspective, Present Realities, Future Potentials. In *Proceedings of the Eleventh International Symposium on Remote Sensing of Environment*. Ann Arbor: Institute of Science and Technology, University of Michigan, pp. 101–121.

Executive Office of the President. 1973. *Report of the Federal Mapping Task Force on Mapping, Charting, Geodesy, and Surveying*, Washington: Government Printing Office.

Fischer, W. A. (ed.). 1975. History of Remote Sensing. Chapter 2 in *Manual of Remote Sensing* (R. G. Reeves, ed.). Falls Church, VA: American Society of Photogrammetry, pp. 27–50.

Fischer, W. A., W. R. Hemphill, and A. Kover. 1976. Progress in Remote Sensing. *Photogrammetria*, Vol. 32, pp. 33–72.

Foody, G. M., T. A. Warner, and M. D. Nellis. 2009. A Look to the Future. Chapter 34 in *The Sage Handbook of Remote Sensing* (T. A. Warner, M. D. Nellis, and G. M. Foody, eds.). Washington, DC: Sage, pp. 475–481.

Fussell, J., D. Rundquist, and J. A. Harrington. 1986. On Defining Remote Sensing. *Photogrammetric Engineering and Remote Sensing*, Vol. 52, pp. 1507–1511.

Hall, S. S. 1993. *Mapping the Next Millennium: How Computer-Driven Cartography Is Revolutionizing the Face of Science*. New York: Random House, 360 pp.

Jensen, J. R. 2002. Remote sensing—Future considerations. Chapter 23 in *Manual of Geospatial Sciences and Technology* (J. D. Bossler, Ed.). London: Taylor & Francis, pp. 389–398.

Jensen, J. R. 2007. *Remote Sensing of the Environment: An Earth Resource Perspective*. Upper Saddle River, NJ: Prentice-Hall, 608 pp.

Lee, W. T. 1922. *The Face of the Earth as Seen from the Air* (American Geographical Society Special Publication No. 4). New York: American Geographical Society.

Lillesand, T. M. 1982. Trends and Issues in Remote Sensing Education. *Photogrammetric Engineering and Remote Sensing*, Vol. 48, pp. 287–293.

Lillesand, T. M., R. W. Kiefer, and J. W. Chipman. 2008. *Remote Sensing and Image Interpretation*. New York: Wiley, 756 pp.

Lintz, J., and D. S. Simonett. 1976. *Remote Sensing of Environment*. Reading, MA: Addison-Wesley. 694 pp.

Madden, M. (ed.). 2009. *Manual of Geographic Information Systems*. Bethesda, MD: American Society for Photogrammetry and Remote Sensing, 1352 pp.

Monmonier, M. 2002. Aerial Photography at the Agricultural Adjustment Administration: Acreage Controls, Conservation Benefits, and Overhead Surveillance in the 1930s. *Photogrammetric Engineering and Remote Sensing*, Vol. 68, pp. 1257–1261.

National Academy of Sciences. 1970. *Remote Sensing with Special Reference to Agriculture and Forestry*. Washington, DC: National Academy of Sciences, 424 pp.

Parker, D. C., and M. F. Wolff. 1965. Remote Sensing. *International Science and Technology*, Vol. 43, pp. 20–31.

Pedlow, G. W. and D. E. Welzenbach. 1992. *The Central Intelligence Agency and Overhead Reconnaissance: The U-2 and OXCART Programs, 1954–1974*. Washington, DC: Central Intelligence Agency.

Ray, R. G. 1960. *Aerial Photographs in Geological Interpretation and Mapping* (U.S. Geological Survey Professional Paper 373). Washington, DC: U.S. Geological Survey, 230 pp.

Reeves, R. G. (ed.). 1975. *Manual of Remote Sensing*. Falls Church, VA: American Society of Photogrammetry, 2 vols., 2144 pp.

Ryerson, B., and S. Aronoff. 2010. *Why "Where" Matters: Understanding and Profiting from GPS, GIS, and Remote Sensing*. Manotick, ON: Kim Geomatics, 378 pp.

Simonett, D. S. (ed.). 1983. Development and Principles of Remote Sensing. Chapter 1 in *Manual of Remote Sensing* (R. N. Colwell, ed.). Falls Church, VA: American Society of Photogrammetry, pp. 1–35.

Swain, P. H., and S. M. Davis. 1978. Remote Sensing: The Quantitative Approach. New York: McGraw-Hill, 396 pp.

Warner, T. A., M. D. Nellis, and G. M. Foody. 2009. *The Sage Handbook of Remote Sensing*. Washington, DC: Sage, 504 pp.

Wetherholt, W. A., and B. C. Rudquist. 2010. A Survey of Ethics Content in College-Level Remote Sensing Courses in the United States. *Journal of Geography*. Vol. 109, pp. 75–86.

White, L. P. 1977. Aerial Photography and Remote Sensing for Soil Survey. Oxford: Clarendon Press, 104 pp.