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Guidelines for the Use of Remotely Sensed Data

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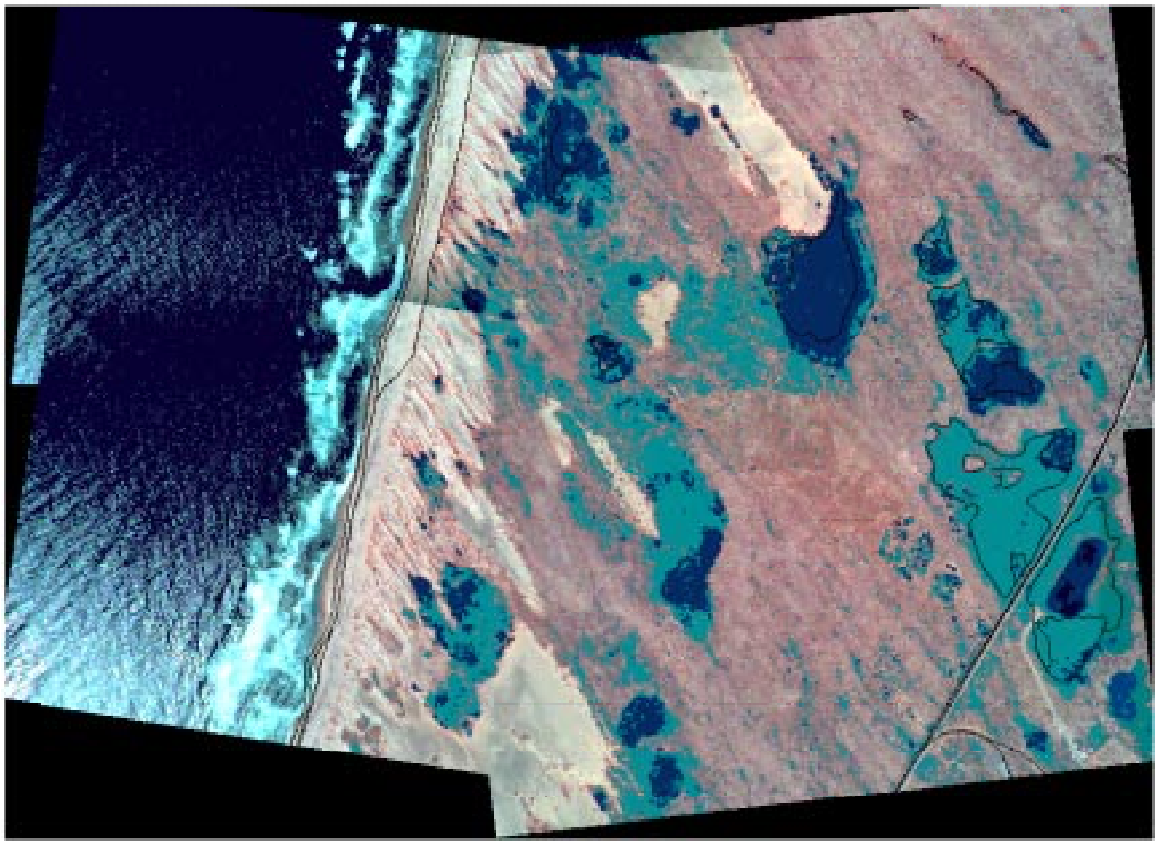
Guidelines For The Use Of Remotely Sensed Data

MANAGEMENT OF NATURAL AND CULTURAL RESOURCES USING IMAGE PROCESSING, CADD, AND GIS TECHNOLOGY



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Preface

This guide was designed to be used by organizations investigating the option of using remotely sensed data for the management of natural and cultural resources using image processing, Computer Aided Design and Drafting (CADD), Geographic Information Systems (GIS) and Automated Mapping and Facilities Management Systems (AM/FM), into the day-to-day business of installation and civil works management. The purpose of this report is to provide the technical guidance for DoD installations that have a need to integrate remotely sensed data with GIS for various planning, analysis, management, maintenance, operations activities. A basic overview of these two technologies is provided, followed by the applicability of remote sensing and a detailed description of the current remote sensing processes available for data retrieval and manipulation. Specific methodologies are discussed independently to differentiate between the unique data retrieval methods and processing techniques used to identify the desired features. An overall discussion of sensors and data sources is provided to use as a comparison tool and to aid in determining the right sensor(s) to meet your feature extraction needs. Finally, case studies which demonstrate the integration of remote sensing into corresponding applications for use on a daily basis as a decision support tool are presented.

SUMMARY

Department of Defense installations are becoming increasingly involved in advanced mapping technologies, including Geographic Information Systems (GIS), as a way to streamline various planning and maintenance activities. The spatial data required to run these systems are derived from a variety of sources including pre-existing paper maps, aerial photographs, and digital data available from remotely sensed imagery. In fact, remote sensing is now viewed as a primary means of effectively gathering large, synoptic views of the Earth's surface which can then be digitally analyzed and integrated into a GIS (Cullis, 1995).

Effective management and operation of military installations require the application of professional expertise in land use planning, civil engineering, forestry, hydrology, coastal studies, cultural resource and natural resource management, among other specialties. All of these disciplines can benefit greatly from use of remotely sensed data. Thus, it is in the military's best interest to incorporate GIS and remote sensing technologies into their normal day-to-day methods for accomplishing their mission, and to understand the steps necessary for implementing a productive and cost-effective system.

The Tri-Services CADD/GIS Center Field Working Group for Natural and Cultural Resources Management recognized the need for information specifically slanted to DOD installation needs. It is the purpose of this report to provide the technical guidance for DOD installations that have a need to integrate remotely sensed data with a GIS for various planning, analysis, management, maintenance, and operations activities. A basic overview of these two technologies is provided, followed by the applicability of remote sensing and a detailed description of the current remote sensing processes available for data retrieval and manipulation. Specific methodologies are discussed independently to differentiate between the unique data retrieval methods and processing techniques used to identify the desired features. An overall discussion of sensors and data sources is provided to use as a comparison tool and to aid in determining the right sensor(s) to meet feature extraction needs. Finally, case studies which demonstrate the integration of remote sensing into corresponding applications for use on a daily basis as a decision support tool are presented.

PART I: INTRODUCTION TO REMOTE SENSING

Definition of Remote Sensing

Our environment is comprised of human and other life forms and is considered the biosphere or the life-bearing layer. It interacts with the atmosphere (the gaseous layer), the hydrosphere (the water layer), and the lithosphere (the solid Earth crust). Remote sensing is used to collect the information required to understand these various components of our environment without making physical contact. In this context, animal or human sight, smell, and hearing as well as the bat's radar system are all examples of remote sensing. To this list of living remote sensors we can add human-made systems that include cameras, scanners, television, radar, lasers, radio receivers, sonars, seismographs, gravimeters, magnetometers, and perhaps others. Although the diversity of applications is great, remote sensing is primarily used for surveying, inventorying, and mapping environmental features (Lo, 1986). This gives rise to several forms of data for application in agriculture, archaeology, forestry, geology, planning, and other fields (see Table 1.1). Remote sensing in the context of this report is the acquisition of data about an object or scene by a sensor that is far from the object, and covers both surface/near-surface and image based retrieval methods. In particular, remotely sensed data are addressed as an important tool for creating information layers for geographic information systems (GIS).

This part is a brief introduction to the definition of remote sensing. Many books are available for more detailed information. They are: Colwell, *Manual of Remote Sensing*, Swain and Davis, *Remote Sensing: The Quantitative Approach*, Slater, *Remote Sensing: Optics and Optical Systems* (please see "Bibliography on page 123").

Table 1.1 Disciplines that use Space Remote Sensing

- Archaeology and Anthropology
  - underwater
  - near surface
- Cartography
- Geology
  - surveys
  - mineral resources
- Land Use Planning
  - urban land use
  - agricultural land use
  - soil survey
  - health of crops
  - soil moisture
  - evapotranspiration
  - yield predictions
- Coastal Studies
  - erosion, accretion, bathymetry
  - sewage, thermal and chemical pollution monitoring
- Climatology
  - atmospheric minority constituents
  - surface albedo
  - desertification
- Meteorology
  - weather systems tracking
  - weather forecasting
  - sounding for atmospheric profiles
  - cloud classification
- Natural Disasters
  - floods, earthquakes

rangelands and wildlife
forestry - inventory
forestry, deforestation, acid rain, disease

Civil Engineering
site studies
water resources
transport facilities

Water Resources
surface water, supply, pollution
underground water
snow and ice mapping
volcanoes, forest fires
subsurface coal fires
landslides

Oceanography
surface temperature
geoid
bottom topography
winds, waves, and currents
circulation
mapping of sea ice
oil pollution monitoring

Development of Remote Sensing

The earliest known map dates back to 2500 B.C. Since then, humans have been continually improving methods of conveying spatial information. The mid-eighteenth century brought the use of map overlays to show troop movements in the Revolutionary War. This could be considered an early GIS. The need to know troop movement then set the precedent for establishing remote sensing. During the 1800's many different cartographers and surveyors were discovering the value of overlays to convey multiple levels of information about an area. From the time flight was first possible, humans have been perfecting methods of airborne observation. Table 1.2 provides a detailed outline of the development of this technology:

Table 1.2 Development of Remote Sensing

1800	Sir William Herschel describes the infrared region of the light spectrum.
1839	Beginning of photography.
1840	Argo, Director of the Paris Observatory, advocates the use of photography for topographic surveying and mapping.
1847	Infrared spectrum shown to share properties with visible light.
1858	First known aerial photograph taken from a balloon at a height of 80 meters.
1860	Earliest existing photograph taken from a balloon over Boston, Massachusetts.
1873	James Maxwell derives the theory of electromagnetic energy.
1909	Airplane first used as a camera platform.
1912	Camera carried to a height of 790 meters by a rocket.
1914-1918	World War I : Aerial reconnaissance.
1920-1930	Development and initial application of aerial photography and photogrammetry.
1930-1940	Development of radar.
1939-1945	World War II : Application of nonvisible portions of the electromagnetic spectrum; training of persons in acquisition and interpretation of aerial photographs.
1946-1950	Cameras carried by captured German V-2 rockets.
1950-1960	Military research and development in aerial photography, radar, and satellite-based imagery.
1956	Colwell's research on plant disease detection using infrared photography.
1960	Office of Naval Research coins the phrase "remote sensing".
1960	Launch of TIROS-1 satellite for monitoring weather.
1972	Launch of Landsat 1 satellite.

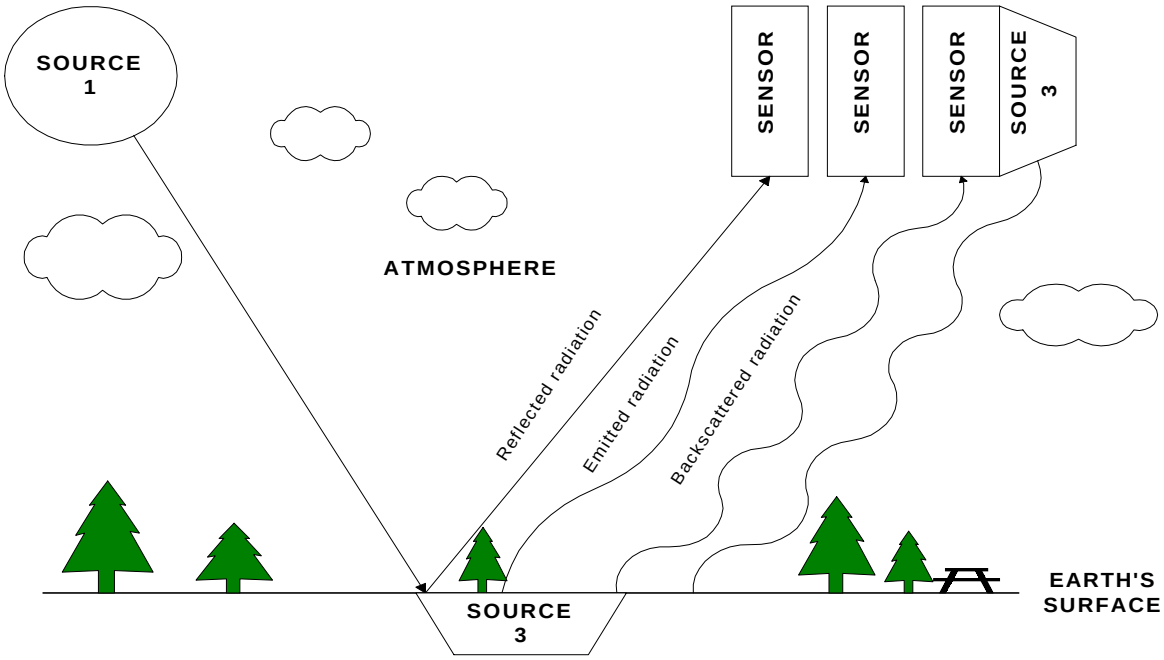
1973	Skylab takes 35,000 images of earth from space using Earth Resources Experimentation Package (EREP) on board.
1970-1980	Rapid advances in computer technology and digital image processing techniques.
1974	NOAA and NASA make GOES meteorological imagery available.
1975	Launch of Landsat 2 satellite.
1978	Launch of Landsat 3 satellite.
1978	Launch of Seasat satellite.
1978	Advanced Very High Resolution Radiometer (AVHRR) imagery available from NOAA's POES satellites.
1980	Launch of USSR Meteor satellite.
1981	First flight of Space Shuttle.
1982	Launch of Landsat 4 with new Thematic Mapper (TM) sensor.
1984	Launch of Landsat 5 satellite.
1986	Launch of first French SPOT satellite.
1988	Launch of India's IRS-1a satellite.
1990	Availability of Russian Almaz data.
1991	Launch of European Space Agency's ERS-1 satellite.
1992	Japan launches JERS-1 satellite.
1995	Launch of Canada's Radarsat satellite.

Today a combination of airborne and satellite-based cameras and sensors provide imagery to be used as data, that can be transformed into information to solve a multitude of problems, pushing scientists and land managers to the modern era of GIS which started in the 1970's. Analysts began to program computers to automate some of the manual processes in order to reduce the time it took to interpret and analyze the image data. Software companies began writing software packages that could input, display, and manipulate geographic data to create new layers of information. The steady advances in features and speed of computer hardware over the last ten years combined with the decrease in costs have made GIS technology accessible to a wide range of users. This accessibility has increased the demand for remotely sensed data.

Principles of Remote Sensing

Remote sensing refers to techniques for collecting information about an object and its surroundings from a distance without contact (Lo, 1986). Most remote sensing systems function by measuring reflected electromagnetic energy that is radiated at approximately the speed of light (3 X 10 to the 8th m/sec) from a source. The change in the amount of reflected radiation from different objects on the Earth's surface is detected by the remote sensor, and becomes a valuable source of data about the object (Agile, 1989). Figure 1.1 shows this relationship with four components: the source, the sensor, interaction with the Earth's surface, and interaction with the atmosphere.

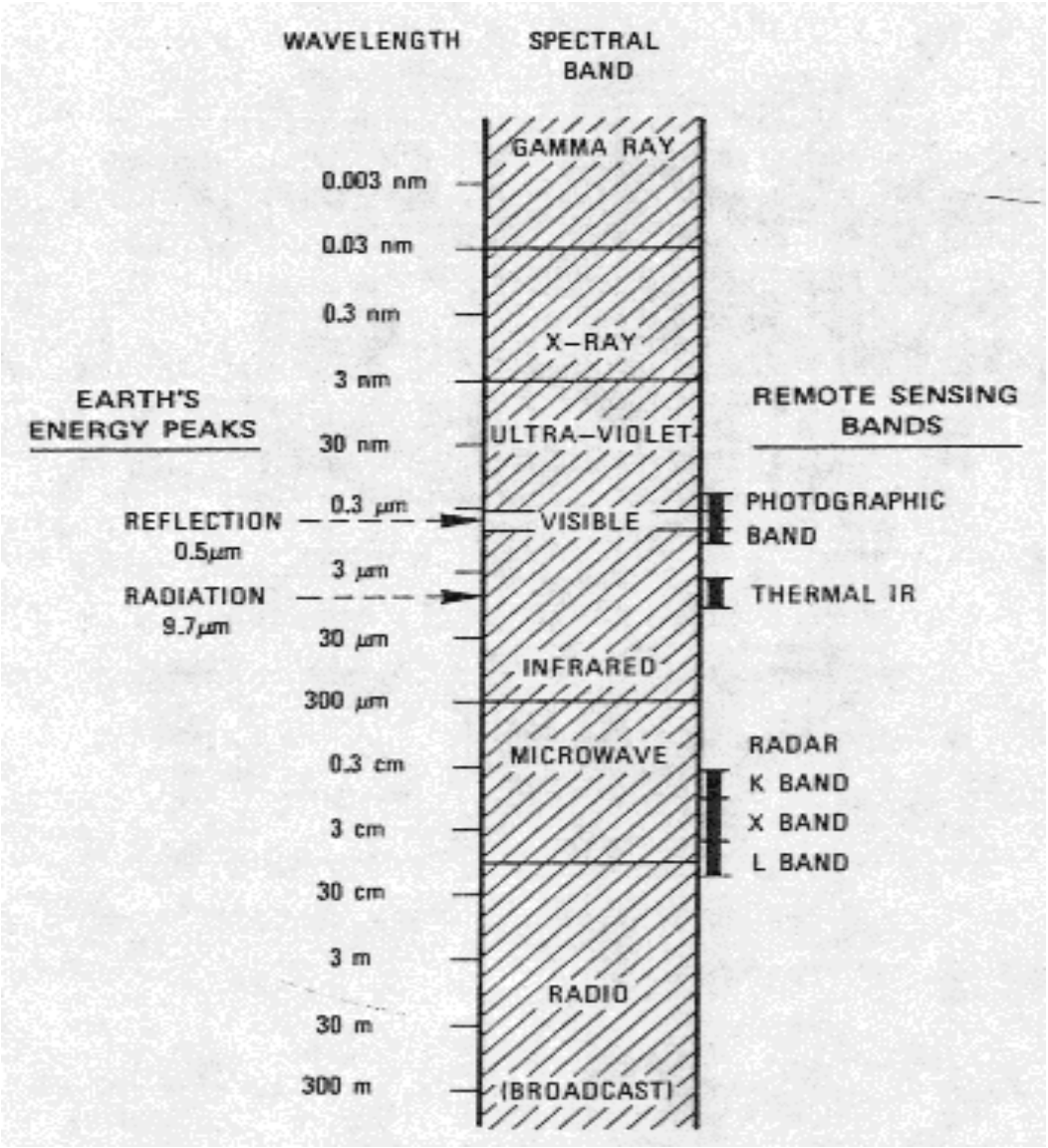
FIGURE 1.1 THE BASIC PRINCIPLES OF REMOTE SENSING



Electromagnetic Spectrum (EMS)

The electromagnetic field is measured in an array (known as a spectrum, with a range from cosmic waves to radio waves) which is a continuum of energy wavelengths ranging in size from kilometers to nanometers measured between the end points of each wave. The sensors on remote sensing platforms usually record electromagnetic radiation (reflected light). Electromagnetic radiation (EMR) is energy transmitted through space in the form of electric and magnetic waves. The EMS can be divided into regions or bands based on dispersion and reflectivity (see Figure 1.2). Each band has a range of wavelengths which define its position in the spectrum. Different land cover types absorb and reflect different portions of the EMS, often generating a distinct spectral response over measured bands. This distinct response or “signature” can be used to identify the detected feature. Knowledge of the spectral signatures of different land cover types in conjunction with powerful computer algorithms can then be used to extract thematic information from image data. TABLE 1.3 provides some further definition of the various bands and their uses.

FIGURE 1.2 THE ELECTROMAGNETIC SPECTRUM REPRESENTED AS REMOTE SENSING BANDS



(Sabins, 1978)

Table 1.3 Bands, Wavelength Represented, and Remote Sensing Applicability for Figure #1.2.

BAND	WAVELENGTH	REMARKS
Gamma ray	<0.03 nm	Incoming radiation from the sun is completely absorbed by the upper atmosphere, and is not available for remote sensing. Gamma radiation from radioactive minerals is detected by low-flying aircraft as a prospecting method.
X-ray	0.03 to 3 nm	Incoming radiation is completely absorbed by atmosphere. Not employed in remote sensing.
Ultraviolet, UV	3 nm to 0.4 µm	Incoming UV radiation at wavelengths <0.3 µm is completely absorbed by ozone in the upper atmosphere.
Photographic UV	0.3 to 0.4 µm	Transmitted through the atmosphere. Detectable with film and photodetectors, but atmospheric scattering is severe.
Visible	0.4 to 0.7 µm	Detected with film and photodetectors. Includes Earth reflectance peak at about 0.5 µm.
Infrared, IR	0.7 to 300 µm	Interaction with matter varies with wavelength. Atmospheric

		transmission windows that are separated by absorption bands.
Reflected IR.	0.7 to 3 μm	This is primarily reflected solar radiation and contains no information about thermal properties of materials. Radiation from 0.7 to 0.9 μm is detectable with film and is called *photographic IR radiation*.
Thermal IR	3 to 5 μm 8 to 14 μm	These are the principal atmospheric windows in the thermal region. Imagery at these wavelengths is acquired through the use of optical-mechanical scanners, not by film.
Microwave	0.3 to 300 cm	These longer wavelengths can penetrate clouds and fog. Imagery may be acquired in the active or passive mode.
Radar	0.3 to 300 cm	Active form of microwave remote sensing

(Sabins, 1978)

Spectroscopy

When EMR interacts with features such as soil or vegetation, some wavelengths are absorbed. Thus far, this discussion has only considered reflected EMR. Spectroscopy is the study of both absorption and reflectance of EMR waves. Consideration of absorbed EMR is very useful and can significantly reduce image processing times. For example, radar devices emit EMR toward a target and measure what is returned. Since the level of EMR emitted is known, the amount of absorption can be calculated. Interpretation of radar images is thus simpler and can be more precise.

Spectral Response

A remotely sensed object can be defined by its spectral signature, which is a characteristic used to identify individual objects present on an image or photograph. This signature is a signal value in the EMS which is determined by the characteristics of an object (e.g. color, moisture content, vigor) and its interaction with electromagnetic energy. Digitally remote sensed data are presented as a group of picture elements, or *pixels* which are tiny equal areas, arranged in uniform rows and columns. Assembling enough rows and columns creates a picture on a computer screen known as an image. For an image, each pixel is represented by its spectral pattern which is a set of signal values in the EMS. These spectral patterns are typically assigned labels used to characterize common distributions throughout an image area. Examples of a label could be percent slope or land use value.

Resolution (or resolving power) is a broad term commonly used to describe the number of pixels you can display on a display device (like a computer monitor) or the area on the ground that a pixel represents in an image file. Four distinct types of resolution characteristics of remotely sensed imagery should be considered to determine its applicability for specific projects. These characteristics are spatial, spectral, radiometric, and temporal resolution.

Spatial resolution is a measure of the smallest angular or linear separation between two objects that can be resolved by the sensor (Swain and Davis, 1978) . For example, an image with 100 meter resolution (cannot display objects that are smaller than 100 meters) will generally be applied to a large, regional project. While an image with 1 meter

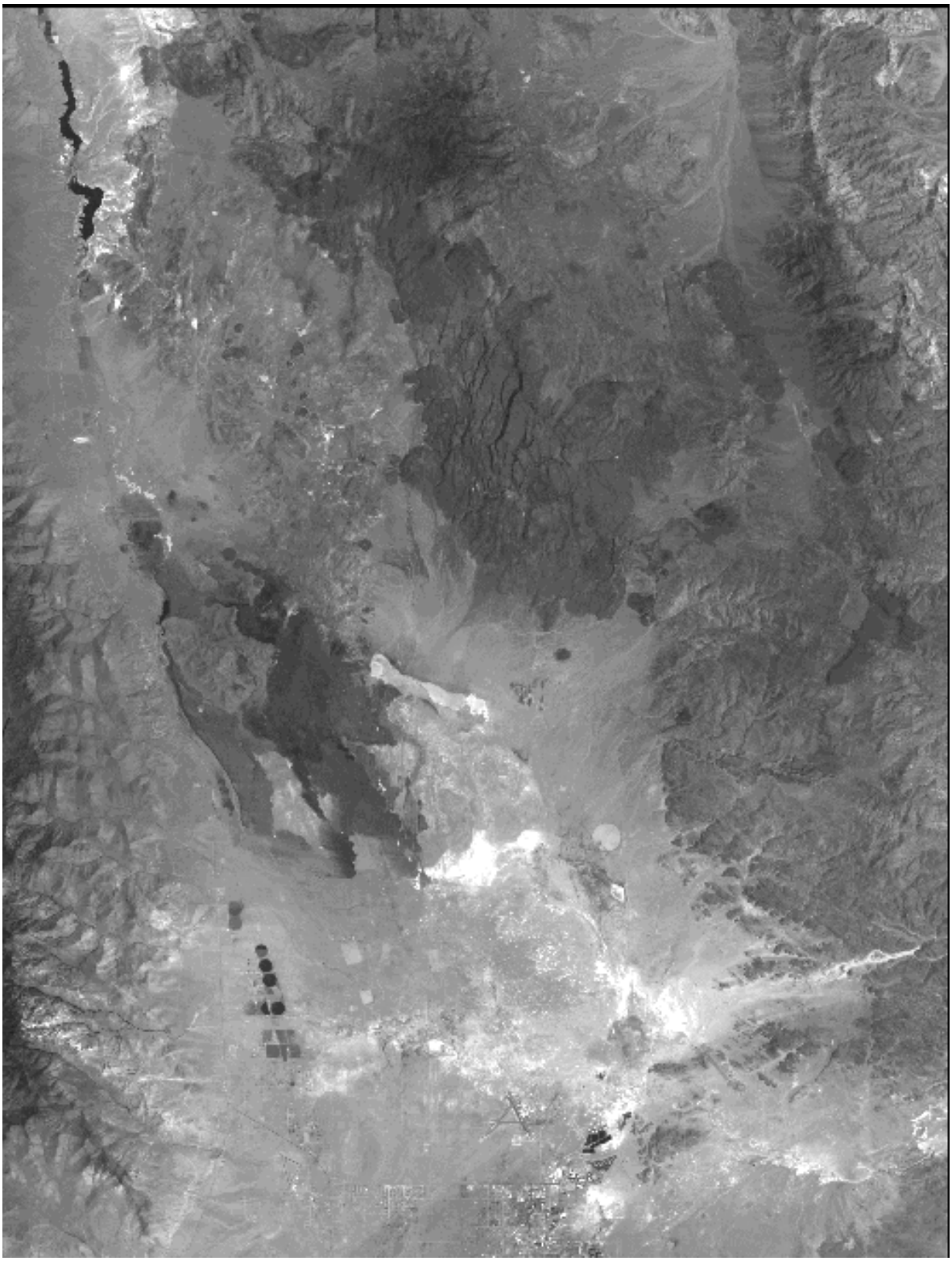
resolution will be used for projects requiring a higher degree of detail. Figures1.3, 1.4-1.6. display the difference between various spatial resolutions. An aerial photograph as a hardcopy source is typically measured in the number of resolvable line pairs per millimeter or microns. Spatial resolution defines a scale threshold for various applications. As a general rule the spatial resolution of the sensor system should be less than half the size of the feature desired measured in its smallest dimension**.** For example, if you are mapping 10 meter wide streets, 5 meter spatial resolution data is recommended.

Spectral resolution is determined by a sensor's capability to detect specific wavelength intervals in the EMS. Some sensors are limited to recording wavelengths from only one EMS band while others can measure spectral sensitivity across a number of bands. Wide intervals in the EMS are referred to as *coarse spectral resolution*, and narrow intervals are referred to as *fine spectral resolution*. The SPOT panchromatic sensor is considered to have coarse spectral resolution because it records EMR between 0.51 μm and 0.73 μm. Careful selection of the spectral bands may improve the probability that a feature will be detected, thus, making the remote sensing project a success.

Radiometric resolution is measured by a sensor’s ability to discriminate between two objects whose reflective or emissive properties differ slightly. A sensor with high radiometric resolution may be able to distinguish among 1000 different levels in a single band while another sensor can only differentiate 100 levels. This measurement is in *bits*. Today 7 and 8 bit data is common, allowing for color levels of 0 to 127 and 0 to 255 possible data values that are represented in colors on the computer monitor.

Temporal resolution (relating to time) is a measure of the frequency of coverage, or how often an area is recorded. Ideally, the sensor obtains data repetitively to capture unique discriminating characteristics of the phenomena of interest. Satellite imagery is characterized as having a recording schedule of a few hours to a few days and a high temporal resolution for gathering weather data and ocean coverage. The temporal requirements will differ for each application and are most important for studies in change detection (see Table 1.4). Weather and seasonality effect satellites the same as aircraft. Airborne acquisition within the U.S. and Europe has a very high temporal resolution because airplanes can fly below the clouds and scheduling can be dictated by the user. For example, the California coast is often foggy during the summer, and may offer only a 1 hour window during the hottest part of the day. Since the user can determine when the aircraft flies, the most desirable time for acquisition can be achieved. Satellites work well in arid climates over very large land areas and oceans. The re-visit time for Landsat is every 16 days and for SPOT is every 3 days, whereas aircraft can fly every hour every day.

FIGURE 1.3 SPOT 10 METER RESOLUTION IMAGE OF CHINA LAKE NAWS, CA.



NOTE: This is a 10 meter per pixel (MPP) panchromatic SPOT image of NAWS, CA.

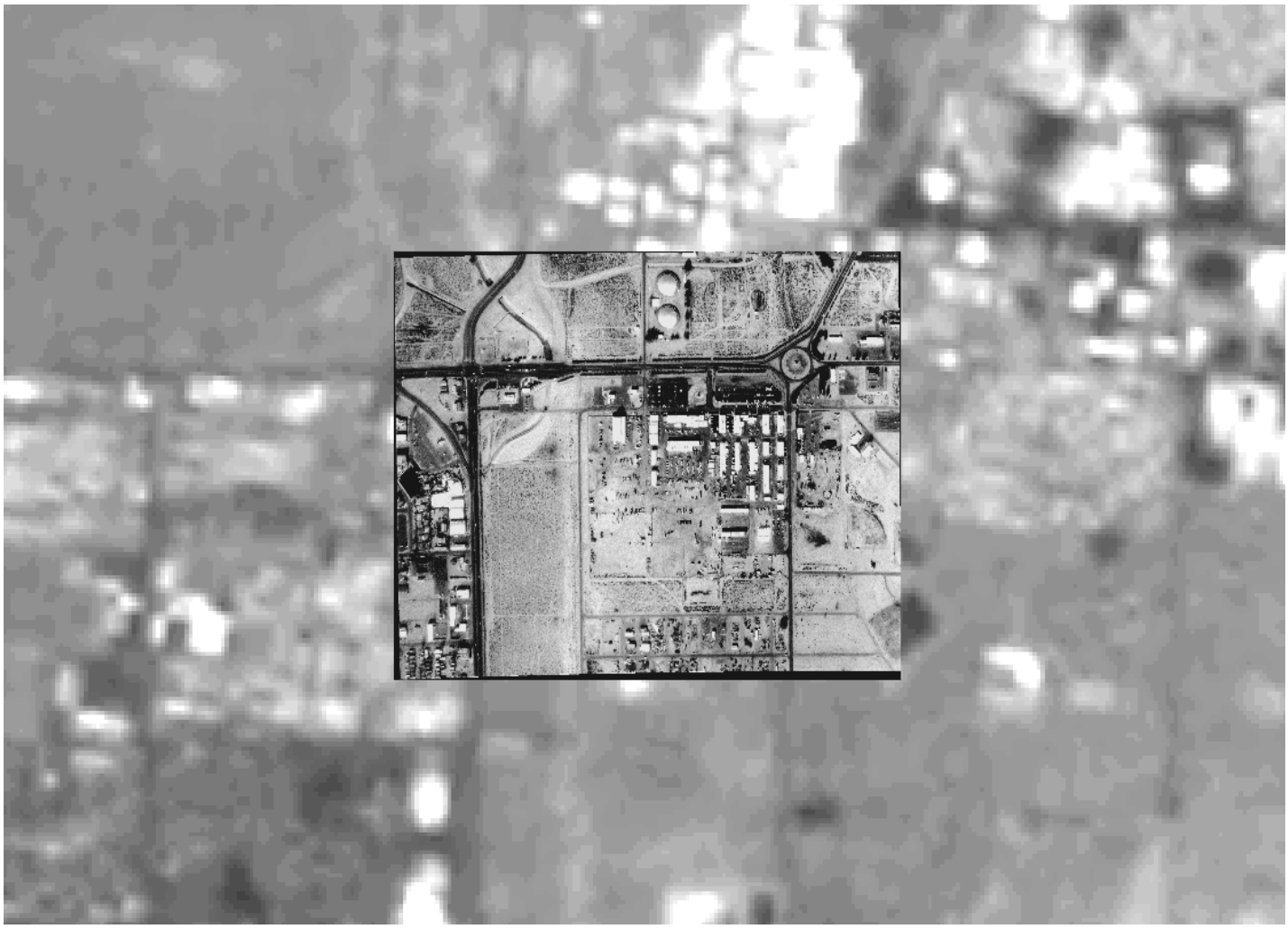
FIGURE 1.4 BLACK AND WHITE AERIAL PHOTOGRAPH AT 1MPP OF CHINA LAKE NAWS, CA.

NOTE: This is a 1MMP black and white aerial photograph of the public works compound at China Lake NAWS, CA. This represents a 1 centimeter by 1 centimeter area on the bottom of the SPOT image shown in FIGURE 1.3.

FIGURE 1.5 SPOT SCENE REPRESENTED AT THE SAME SCALE AS THE AERIAL PHOTOGRAPH IN FIGURE 1.4.

NOTE: The public works compound at China Lake NAWS, CA. This is the 10 MPP SPOT image presented at the same scale as the aerial photograph in FIGURE 1.4. This represents a 1 centimeter by 1 centimeter area on the bottom of the SPOT image shown in FIGURE 1.3.

FIGURE 1.6 AERIAL PHOTOGRAPH AT 1 MPP OVERLAID ON A SPOT 10 MPP PANCHROMATIC SCENE.



NOTE: The public works compound China Lake NAWS, CA. The 1 MPP aerial photograph from FIGURE 1.4 overlaid on the 10 MPP SPOT panchromatic image displayed in FIGURE 1.5.

Table 1.4 General Temporal Data Requirements by Discipline.

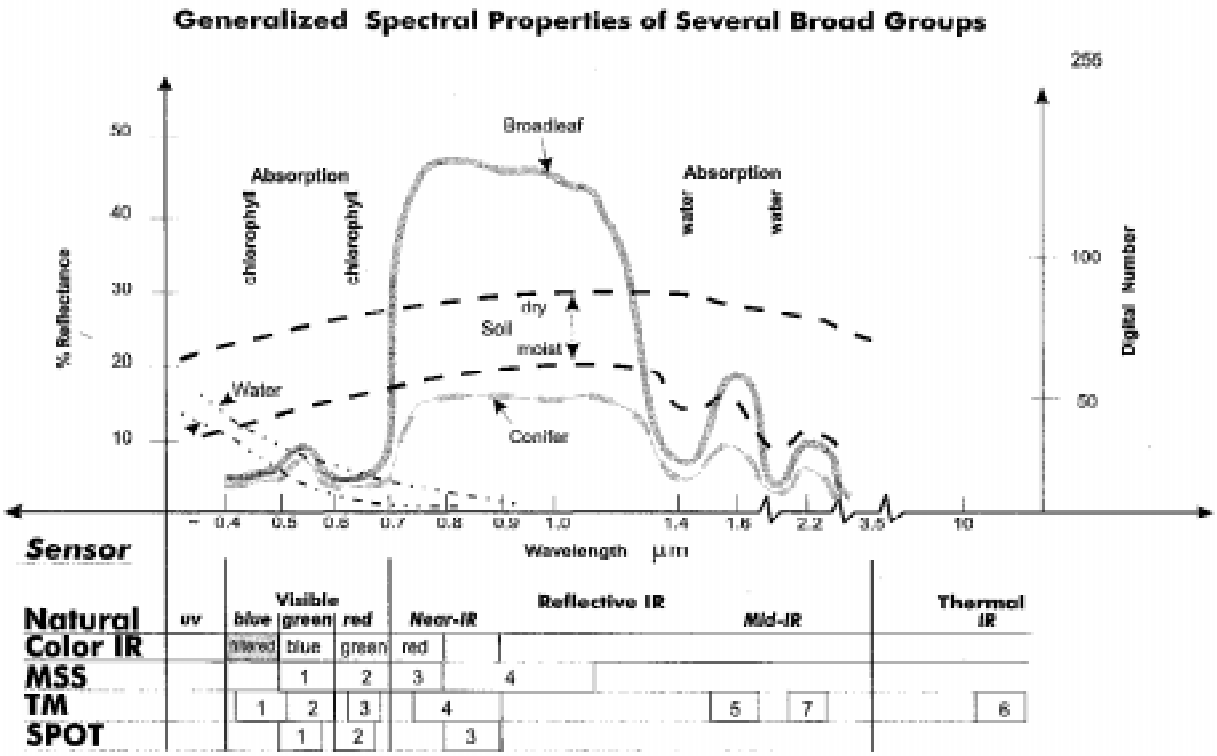
Discipline	Average Temporal Revisit
Archaeology	Yearly
Cartography	Yearly
Infrastructure mapping	Yearly
Forestry-Geology	Monthly
Agriculture	Weekly to bi-weekly
Hydrology	Weekly
Oceanography	Weekly to monthly
Marine pollution	Hourly to daily
Natural Disasters	Hourly to daily
Environmental monitoring	Hourly to daily
Meteorology	Hourly to daily

(Star, 1991)

Initially, remote sensing data is received as digital numbers data that are commonly acquired in the form of an array using one of the following mechanisms: cameras, along-track (line) scanners, cross-track (mirror) scanners, or active sensors (radar, sonar). There is a fundamental difference between the raw (original) data recorded by the sensor and the products that are commonly extracted from them. Datasets that were once composed of raw data are usually irreversibly transformed through image-processing techniques to provide information for a wide range of applications (Star, 1991).

A number of biophysical parameters may be obtained from remotely sensed data including an object's position on the Earth's surface (X,Y location), elevation (z or height), color, chlorophyll-absorption characteristics, biomass, temperature, surface roughness (texture), and moisture content. These biophysical characteristics can then be evaluated in conjunction with other data to yield derivative information such as vegetation stress, land use and/or land cover information, and socioeconomic characteristics. This remote sensing-derived information is crucial to the successful modeling of numerous natural and cultural processes such as watershed runoff and land-use conversion studies. In fact, many models that rely on spatially distributed information are dependent upon remote sensing data (Gaile and Willmott, 1989). The following figure (1.8) illustrates the correlation between the spectral properties, the wavelength of light, and the associated bands of some common remote sensing platforms.

FIGURE 1.7 SPECTRAL PROPERTIES OF OBJECTS ASSOCIATED TO COMMON SATELLITE BANDS.



Natural natural color film, and the names given to segments of the electromagnetic spectrum.

Color IR color infrared film, and the wavelengths displayed as blue, green, and red on "false color image"

MSS Multispectral Scanner — Pixel Size Resolution (m): 79-82

Band 1	0.5-0.6 µm
Band 2	0.6-0.7
Band 3	0.7-0.8
Band 4	0.8-1.1

TM Thematic Mapper

		Pixel Size Resolution (m)	Applications
Band 1	0.45-0.52 µm	30	Water body penetration, soil/veg. discrimination, forest mapping, cultural resources
Band 2	0.52-0.60	30	Peak green reflectance, veg. vigor assessment, cultural resource identification
Band 3	0.63-0.69	30	Chlorophyll absorption region, plant species differentiation, cultural resources
Band 4	0.76-0.90	30	Veg. type and vigor, water body delineation, soil moisture discrimination
Band 5	1.55-1.75	30	Veg. moisture condition, soil moisture, differentiation of clouds vs. snow
Band 6	10.4-12.5	120	Veg. stress analysis, soil moisture, thermal mapping applications
Band 7	2.08-2.35	30	Mineral and rock type discrimination, veg. moisture content

(Band 6 and 7 are out of wavelength sequence because Band 7 was added to the TM late in the design process.)

SPOT — 20

Band 1	0.50-0.59 µm
Band 2	0.61-0.68
Band 3	0.79-0.89

(SPOT = Systeme Pour l'Observation de la Terre)

References: Lillesand, Thomas M. and Ralph W. Kiefer. 1994. Remote Sensing and Image Interpretation, 3rd Edition. John Wiley and Sons, NY
Fox, Larry. 1995. Advanced Remote Sensing, Lectures. Unpublished. Humboldt St. Univ.

Image Interpretation

Introduction

Image interpretation is the examination of images of objects on film or digital representations for the purpose of identifying the objects and deducing their significance. Sources of information such as maps, ground photographs, and ground surveys provide the image interpreter with corroborative details which enable him or her to substantiate a hypothesis, plan, or analysis.

Imagery has advantages and limitations when compared with other data sources. Sensors can collect information over otherwise inaccessible areas. The imagery is a permanent record of the detail within the sensor field of view, and provides a first-hand impression of the subject to the interpreter, though he or she may be many miles distant. The imagery is unbiased and reproducible; it can be studied and restudied for various purposes by different users. It can be compared, detail by detail, with other imagery of the same area to provide comparative or time sequence analysis. Imagery also provides vital mensural (measurement) data.

Remotely sensed imagery also has limitations. The image interpreter cannot always see the fine details of an object or pattern. For example, while the height and length of a wall may be determined from an aerial image, information as to whether its stones are loose or mortared must usually come from a ground observer. Sometimes detail not directly discernible on the imagery can be inferred by the interpreter through associated features. For example, grain size of beach sand may be estimated from a study of geomorphic beach features visible on the imagery, but this remains a special case.

Three major problems in imagery reconnaissance have been the acquisition of usable imagery at night, and in adverse weather conditions, and for discerning ground features through dense vegetation. The development of image-producing sensors has come a long way toward solving this problem. Great improvements have been made in the resolution capabilities of radar equipment, and infrared detection equipment has been designed which portrays a thermal picture of the terrain.

The observations of the image interpreter are limited to the areas shown on the imagery. It is quite possible that the most important feature in an area may occur just off the edge of the imagery or under a patch of clouds. The interpreter's observations are further limited by objects such as overhanging vegetation, shadow, or intervening terrain.

A body of common knowledge about any area is likely to be available in documents, maps, charts, reports, and photographs. These data provide a foundation upon which further image collection is based. The image interpreter must know how to use imagery to confirm, supplement, or amplify these other sources. The relationship of imagery to other sources cannot be exactly predicted for every case, but the following may serve as

guidance. Imagery may be used to map or chart the geographic and cultural detail of an area as well as provide beach and coastal information including bottom conditions in the shore area. It can sometimes provide detailed data on shore-water depths, but it cannot confirm deep-water soundings.

Aerial imagery, in general, provides more precise 1ocational data and more accurate measurements than ground observation for large geospatial features. In addition, aerial imagery can be used to relate widely separated features beyond the view of the ground observer. On the other hand, the ground observer can sometimes provide much more detailed information for a limited area. Unless he or she has a measuring device, however, the ground observer may be less accurate in reporting length, width, height, and slope and may not be able to pinpoint the area accurately on a small-scale map. The aerial imagery can confirm some phases of ground observation and can serve as a base on which various ground observation reports can be plotted and related. Further, the image interpreter can use ground observation to increase his or her own knowledge of the area, thus increasing the effectiveness of subsequent interpretations.

Ground photography is very useful in supplementing the information derived from aerial or satellite imagery and in covering areas for which aerial or satellite imagery is lacking. In addition, ground photography can provide qualitative information on subjects which cannot be observed from the air, such as interiors of buildings and close-ups of the components of plants or man-made devices. The value of ground photography to the image interpreter increases as the scope of aerial coverage decreases.

The aerial observer has much the same view of the terrain as the image interpreter, but there are several important differences. First, the aerial observer cannot truly see the terrain in three dimensions except at very low altitudes; the interpreter, with the aid of a stereoscope or a digital soft-copy photogrammetry system, can. Second, the aerial observer has only a limited time to observe a piece of terrain, whereas the image interpreter can study the same area for hours and with the aid of magnifiers or specialized image exploitation software. For these reasons, aerial observations lack the accuracy and detail of image analyses. On the other hand, the aerial observer can scan the area horizon-to-horizon and thus can sometimes fill in gaps left by the sensor, or he or she can determine the most likely areas for spot sensor coverage. Finally, the aerial observer is better able to detect activity and motion. The image interpreter may report the number and locations of animals in a particular area; the aerial observer may know how many animals were moving in what direction and from where.

Image Characteristics

Several characteristics aid the image interpreter in detecting and identifying objects from sensor imagery. Brief descriptions of the more important characteristics follow.

Shape

Shape relates to the general configuration of an object. The vertical, or planimetric, view will be encountered on vertical and panoramic aerial photography, on side looking airborne radar (SLAR), and on infrared (IR) imagery. Although the shape of an object as seen from overhead is sometimes difficult to interpret, it often provides the most important clue to identification. For example, the shape of a tree distinguishes it. Shape is frequently distorted on radar and infrared imagery because of such factors as spot size, pulse length, and beam width (radar), and temperature, spot size, and instantaneous field of view (infrared). Errors introduced by roll, pitch, and yaw are common to both.

Size

Size relates to the dimensions, surface, and volume of an object. The size of one object can often be estimated from the relative size of other objects in the area and its identity established. In instances where dimensions are required, the scale of the imagery must be determined and the size calculated. For example, the exact dimensions of an above ground storage tank may well indicate the volume of the tank. Size is frequently distorted on radar and infrared imagery by the same factors that cause shape distortion.

Pattern

Pattern refers to the spatial arrangement of objects. The repetition of certain general forms or relationships is characteristic of many objects, both natural and man-made, and establishes a pattern which helps the image interpreter recognize them. For example, circular ponds arranged in a pattern with associated structures would normally indicate a wastewater treatment plant.

Tone

Tone refers to the brilliance with which light is reflected by an object. Without tone differences between images, the shapes of objects obviously could not be discerned on imagery. The photographic tone of an object is one of the best clues, and sometimes the only one, to its identity. For example, certain indicator species of vegetation, so-called because they indicate particular plant communities in their areas, can be distinguished from one another on aerial imagery by tone differences. The tone of infrared imagery depends on the amount of infrared radiation emitted and reflected by objects on the ground. The tone of radar imagery depends on the amount of radar energy reflected back to the sensor by objects on the ground.

Shadow

Shadow describes the condition wherein an intervening object prevents direct sun rays from striking certain areas shown on the imagery. Shadows are important because their shapes are indicative of the profile views of objects, and thereby facilitate recognition, as in the case of a tall tower.

Shadows on infrared imagery can be caused by reflected infrared energy and by the difference in temperature caused by the shadow. A peculiarity of infrared imagery is that the shadow (sometimes called a ghost) of an object may persist for several hours after the object that cast the shadow has moved away. Shadows on radar imagery are caused by objects intervening between the transmitted radar energy source and objects further away.

Texture

In photographic imagery, texture may be defined as the frequency of tone change within the image. Texture is the primary characteristic used in certain types of image interpretation. For example, the photographic texture of a beach may indicate the coarseness of particles composing the beach. The size of an object required to influence texture increases as the imagery scale decreases. For example, on very large scale imagery of a wooded area, leaves on the trees contribute to the texture of the crown; on smaller scale imagery, crowns contribute to the texture of the overall timber stand.

Site

Site, the location of an object in relation to its environment, is an important factor in the interpretation of man-made and natural features. For example, many types of vegetation are characteristically confined to specific geographic sites such as swamps, stream banks, sandy flats, or rocky knolls. In some of these cases, it is possible to identify a site directly on the imagery and then deduce the probable species of vegetation. Usually, however, a combination interpretation of site and vegetation will result in a more accurate knowledge of the area.

Scale

Scale, the ratio of image size to object size, may be varied by the use of optical instruments. Enhancement of target detail by magnification is a useful interpretation technique. However, certain properties of the film itself limit the enlargement to which imagery may be subjected and still retain characteristics which can be interpreted.

The Role of the Image Interpreter

Between the sensor imagery and the interpretation stands the interpreter. In the final analysis, he or she exploits or fails to exploit the potential usefulness of the imagery.

The interpretation of imagery can be accomplished by anyone with a strong knowledge of a subject discipline, such as wildlife biology, and fundamental knowledge of the principles of mapping and geography. The interpreter's job is to understand the nature of significant information and to identify, collate, evaluate, report, and disseminate that information as may be appropriate. This appears to be a straightforward job, but the range of knowledge required can make data extraction complex work.

Image interpreters may be part of any organization and come from any of a number of disciplines. No matter where the assignment, the image interpreter remains engaged in producing information through the analysis of images on film or digital imagery and in disseminating this information. This analysis may take the form of oral or written image interpretation reports, manuscripts, amphibious studies, navigational aids, detailed urban studies, vegetation classifications, etc.

Image interpretation reports must be accurate. Accurate reporting means more than writing identifications and conclusions. It means presenting the information so that the reader will understand both the meaning and the reliability of the information. Here, careful choice of language becomes particularly important. Facts, once established to the image interpreter's satisfaction, should be reported as facts without qualifying words of phrases. However, some cases unavoidably arise where the interpreter cannot be completely certain of the accuracy of his results. The reason may be the small scale or poor quality of imagery, or a gap in the interpreter's knowledge and experience, or the lack of adequate information to confirm a conclusion.

The interpreter must continue to study if he or she is to maintain or improve his or her proficiency. First, he or she must keep abreast of new developments in image interpretation. Education in the following subjects will usually enhance the capability of the image interpreter: agronomy, botany, city planning, civil engineering, forestry, geography, geology, geographic information systems (GIS), image processing, physics, oceanography, and photogrammetry. The interpreter's knowledge of the natural and cultural conditions within an area aids him or her in arriving at conclusions from sensor imagery. Education and experience result in reliable and accurate interpretation.

Under optimum conditions, image interpretation can produce highly accurate and detailed information. These results are influenced by four main factors: the sensor coverage with which the interpreter works; the facilities and technology available to the interpreter; the time available; and, most important of all, the ability of the interpreter.

From an earlier discussion of image characteristics, it is clear that some types of imagery may be excellent for a given purpose and other types practically useless. In addition, the quality of the imagery must be of a high order. To realize this quality, good weather, good equipment, and skill are needed. Scale of imagery is an important factor. No amount of enlarging or viewing through high-powered lenses or digital methods will compensate for original imagery of inadequate scale unless extremely high resolution imagery is available such as that obtained from high resolution cameras operating in stable air (high altitude) or by satellite. Therefore, managers who direct imagery acquisition flights must understand the problems involved in the collection and processing of imagery. The prospects for success of an image acquisition mission will be greatly enhanced if the managers concerned are cognizant of the validity and importance of the request specifications.

The facilities that should be available to the interpreter include a working place, image processing hardware and software, manual image interpretation equipment, scanning equipment and software, storage space, access to documents, reports, ground-truth materials, and reference material.

Time factors are always vital in producing information, especially when sensor coverage is flown and a report is produced in response to an urgent request. Less obvious are the time factors involved when reference material must be prepared and sensor coverage for comparative analysis must be flown months or even years in advance of a study or plan. The skill and experience of the interpreter determine to a very large degree the success or failure of the work. The interpreter must know what to look for; he or she must be able to identify what they find; they must know the significance of an object in its location; they must be able to utilize effectively information from other sources; they must know how to use comparative imagery coverage; and they must know the study subject matter or discipline. To these general requirements may be added many more specific ones, depending on the particular kind of interpretation involved. For example, an interpreter preparing detailed reports on forest cover types should have experience in forestry, silviculture, or forestry management. The interpreter should understand forest communities, ecological processes, common forest components, and multistory vegetation structure. With a good background, an interpreter will, by induction and deduction, accurately associate visible features with others that do not appear on the imagery. The skill of an image interpreter arises not only from his or her ability to read sensor imagery but also from their background experience. This factor cannot be overemphasized, for an interpreter cannot be expected to analyze correctly an image of an object he or she could not recognize even if they were on the site.

Remote Sensing Media

REMOTE SENSING PLATFORMS GENERALLY ABOARD AIRCRAFT

Aerial Photography

Aerial photography offers the highest precision and spatial resolution (0.1 MPP to 5 MPP) of all remote sensing products. The air photo industry does not refer to its products in MPP; most photos are referred by scale or photo scale reciprocal. Scale is represented as a ratio of distances between corresponding points on the photo and on the ground. For example, a scale of 1:400 ft. means 1 unit of measurement (UOM) on the photo equals 400 UOM on the ground. If the UOM equaled inches then a distance of 1 inch on the photo would equal 400 inches on the ground (33.3333 feet). One disadvantage of air photos is that they are not computer ready. Air photos must be scanned using a high precision scanner (a piece of equipment not available in computer hardware stores); the scanning process's UOM is microns. Twenty-three microns is one of the highest scanning resolutions and yields very large file sizes. A 1:400' (1 inch equals 400 feet) orthophoto created at 23 microns will yield a 63-megabyte file for black and white, and

larger for color. Once the photo(s) are scanned, the spatial pixel resolution is dependent on the scale of the photo. A photo with a scale of 1:5000 will yield a 0.25 MPP resolution, 1:10,000 will yield 0.5 MPP, and 1:20,000 will yield 1 MPP. Figure 2.4 represents one piece of a 1:400 ft, orthophoto at 0.5 MPP, created from 1:10,000 photography scanned at 23 microns; the image is 63 megabytes in file size.

Ground Coverage

Aerial photography is available for the continental U.S., Alaska, and many foreign countries. Obtaining copies of this photography is cheaper than contracting new photography and may be readily available. Frequently, however, there is no suitable existing photography, the existing photography may be out of date, at the wrong scale for optimal use, of poor quality, or not the desired film type.

Four types of photography are common in the industry: black and white (BW) also known as panchromatic (PAN), black and white infrared (BWIR), natural color, and color infrared (CIR).

Conventional Black and White Photographs (BW)

Conventional aerial photographs are imaged on panchromatic film which is sensitive to all wavelengths of the visible portion of the electromagnetic spectrum. That is, it is sensitive to approximately the same range of visible lights as the human eyes (. Richardson, 1983). The spectral sensitivity of panchromatic (PAN) film extends from about 290 nanometers (0.29 µm) in the ultraviolet (UV) portion of the electromagnetic spectrum to about 720 nanometers (0.72 µm) in the red portion. PAN film provides moderate to good tonal contrast, reasonable exposure speed, and low grayness. It is useful as a BW film medium to view distinct colors for gray-tone separation, but it lacks a high sensitivity in the green portion (0.5 - 0.6 µm) of the spectrum. This low sensitivity makes identification of green vegetation and tree-type species quite difficult. Figures 1.4 and 2.4 are examples of PAN film scanned with a precision scanner to enable integration with computers and Geographic Information Systems (GIS), which are explained in Part II “Computer Systems for Visualizing and Interpreting Media”.

Conventional Color Photography

Natural color photography is a very useful form of aerial photography because the human eye can perceive a far greater number of color tones than gray scale tones. Color film has layers in the emulsion which are sensitive to the red, green, and blue wavelengths of light. Surface resources such as crop types, tree species separation, soil moisture indices, and land-water interfaces are more easily identified using color films as compared to using black and white photography. Plant species and subtle to moderate overall health are difficult to delineate with natural color film.

Black and White Infrared Photography (BWIR)

The human eye can only detect the visible light region of the spectrum; however, a very important portion of the spectrum lies just beyond the visible portion. This area is the reflective near-infrared (IR) region (0.7 µm to 1.5 µm). BWIR photography can use a

special filter which passes the infrared radiation reflected by the subject and excludes ultraviolet and other undesirable radiation. BWIR photography is useful in a variety of scientific fields. Many plants under stress from disease, moisture loss, or insect infestation can be detected by (IR) photography. It may also be employed in separating sediment-laden water bodies from clear water and to trace pollution sources near discharge points in water bodies.

Color Infrared Photography (CIR)

Color infrared film (CIR) is similar to color film, and it has its sensitivity extended to the infrared (to 0.9 µm) portion of the electromagnetic spectrum. Color infrared film is frequently called false color film because the colors in the final product do not match the natural colors of the objects photographed. The most obvious color difference is that all live, healthy, and green foliage appears shades of red while dead foliage appears green or some color in between. This property is the key to understanding the benefit of CIR film and imagery. To reinforce this concept, think of a healthy, well watered tree next to a road that was painted green, on the other side of the green road is a tree with yellow leaves and definite signs of drought. The results on the CIR film or imagery would yield a blue-green road, a very bright pink tree on one side (the healthy tree) and a dark brick red to green tree on the other side (the dying tree). The most common uses of CIR photographs have been in the fields of agriculture and forestry for the detection of crop types, tree types, moisture deprivation, and insect infestation.

General Properties of Photography

Advantages of Panchromatic and Natural Color Films

1. Natural color film is more natural to the human eye than CIR film. Panchromatic is more natural to the human eye than black-and-white infrared, because we are more accustomed to viewing film that is the same color as our surroundings.
2. Good for engineering applications and as a navigation tool.
3. More detail can be seen within areas covered by shadows.
4. Usually there is better resolution with panchromatic than with infrared film, partly because our eyes do not immediately recognize the features so we must “look harder” to discriminate or interpret the features.
5. These films offer better penetration of water.

Advantages of Black-and-White (BWIR) and Color Infrared Films (CIR)

1. Better penetration of haze.
2. Emphasizes water and moist areas.
3. Good differentiation between hardwoods and conifers
4. Sick, dying, or stressed vegetation is more easily detected—most notably on CIR film.

There are as many advantages listed above for IR as for panchromatic film, so it might appear that it is an equally good film for overall interpretation of natural resources. This is not usually the case. The overriding disadvantage of IR film (particularly black and white) is that details within shadowed areas are not visible. This becomes a very serious problem in areas with tall dense forests and/or steep topography. This effect can be reduced, however, by obtaining what is known as shadowless photography.

Digital Aerial Imagery

Multispectral Aerial Photography

With the advancements in computer technology, digital data is becoming feasible for the average user and is now commercially available. Two of the greatest attributes digital aerial imagery offers is computer compatibility and superior spatial resolution (0.5MPP - 3 MPP). Today most mapping takes place using computers and GIS. While conventional photography must be scanned using a precision scanner to be computer compatible, this format does not require scanning. In addition to being in an immediately usable format for computer viewing and processing, digital imagery can capture the exact wavelengths of light the user desires, in multiple bands. Digitally acquired data offer the user the ability to display on the computer screen natural color information and CIR information from the same digital data product. These products are now dual purposed and allow for the sharing of acquisition costs. For example, the installation engineer who only uses natural color photography may fund a project that provides this data in conjunction with the installation planner who is interested in wetlands protection and uses CIR imagery. The two departments can share the acquisition cost, thus reducing each other's overall cost, or spend the same amount of money and receive a higher quality product.

Ground Coverage

Although digital aerial photography data can be applied to virtually any field of study, it is a low altitude imaging source which is usually used for large scale (1:50 to 1:400 output product mapping and analysis) projects covering a relatively small area. A most recent advancement in this technology is a mosaic of the entire data set; this allows for seamless coverage at significantly higher pixel resolution, ultimately reducing processing times for the end user. Figures 2.5 to 2.9 are digitally acquired data;three bands were acquired in the visible range and 1 band in the infrared range at 850 µm with an 80-µm bandwidth (810 µm to 890 µm).

See Appendix A for points of contact and ordering information.

Side-Looking Airborne Radar (SLAR)

SLAR was first developed for military reconnaissance purpose in the early 1950's. In 1980, the U.S. Geological Survey began its application of the Side-Looking Airborne Radar (SLAR) program. SLAR is an active sensor which provides its own source of illumination in the form of microwave energy. As such, SLAR can be used to prepare an image of cloud-covered areas since microwave can penetrate most clouds. It has evolved

into a powerful tool for acquiring natural resource data not only because of its all-weather operating capability but also because it is an active, day-or-night imaging system.

The word radar is an acronym for radio detection and ranging. As its name suggests, radar was developed as a means of using radio waves to detect the transmitted short bursts, or pulses, of microwave energy in the direction of interest, and recording the strength and origin of "echoes" or "reflections" emitted from objects within the system's field of view (FOV). The spatial resolution of a radar system is determined, among other things, by the size of its antenna. For any given wavelength, the larger the antenna, the better the spatial resolution. To circumvent this problem, most airborne radar remote sensing is done with systems that use an antenna fixed below the aircraft and pointed to the side. Such systems are termed side-looking radar or side-looking airborne radar (SLAR). SLAR systems produce continuous strips of imagery depicting very large ground area located adjacent to the aircraft flight line.

Ground Coverage
SLAR imagery is available for selected project areas in the conterminous U.S. and Alaska. See Appendix A for points of contact and ordering information.

Spatial Resolution
The ground resolution cell size of a SLAR system is controlled by two independent sensing system parameters: pulse length and antenna beamwidth. The pulse length of the radar signal is determined by the length of time that the antenna emits its burst of energy. The signal pulse dictates the spatial resolution in the direction of energy propagation. This direction is referred to as the range direction. The width of the antenna beam determines the resolution cell size in the flight, or azimuth, direction.

Commercial SLAR systems produce images that have a constant range and azimuth resolution of approximately 10 by 15 meters (average of 10 MPP) or better. However, resolution and detectability are not synonymous; some objects that are smaller than one meter in size may be routinely detected because of their stronger radar return (e.g. pieces of aluminum in a field).

Spectral Range
Most commercially available SLAR systems operate in the X band frequency range of 12.0 to 8.0 gigahertz (GHz) or at wavelengths of 2.4 to 3.8 cm. The following is a list of the common wavelength bands used in pulse transmission. The letter codes for the various bands (K,X,L,etc.) were originally selected to ensure military security in the early stages of development of radar.

Band Designation	Wavelength (cm)	Frequency (MHz)
Ka	0.75 - 1.1	40,000 - 26,500
K	1.1 - 1.67	26,500 - 18,000
Ku	1.67 - 2.4	18,000 - 12,500
X	2.4 - 3.75	12,500 - 8,000
C	3.75 - 7.5	8,000 - 4,000

S	7.5 - 1.5	4,000 - 2,000
L	5 - 30	2,000 - 1,000
P	30 - 100	1,000 - 300

SLAR images have been successful in many fields of application. These include, for example, mapping major rock units and surface materials, mapping geological structure, mapping vegetation types, determining sea ice types, and mapping surface draining features.

Synthetic Aperture Radar (SAR)

The synthetic aperture radar (SAR) is the most exciting and progressive field of remote sensing this decade. Airborne SAR applications continue to prove their applicability to many problems in land and oceanographic remote sensing. Since its origins in the 1950's (as a military surveillance instrument) synthetic aperture radar has developed into a mature technology and is now recognized as a highly successful imaging tool. The first SARs were carried on aircraft, but in 1978 NASA launched the first space-borne SAR as part of the Seasat satellite. Today space-borne systems are becoming increasingly advanced.

Unlike conventional optical and IR imagers, which measure reflected sunlight from the scene being observed, SAR instruments use pulses of microwaves as an active source of illumination. And, rather than producing an image as function of the look angle (like a simple camera, or a scanner), a SAR system, being a radar, produces images as function of the distance from the instrument. A SAR system therefore uses pulse of microwaves in much the same way that a bat or a submarine uses pulses of sound. SAR systems can see through clouds, ice, and surface, and as an active system they can image both day and night because of the properties of microwave.

Spatial Resolution

SAR instruments can produce fine spatial resolution data. Many measurements are made up of return signals from the same area on the ground. This long integration time is used to synthesize a large aperture. The result is images of useful spatial resolution even at the extreme distance associated with orbital platforms.

SAR Data Application

SAR data are widely used in environmental, agricultural, meteorological, and hydrological applications. They are particularly useful for large scale projects or smaller areas as compared to other satellite data.

Airborne Visible Infrared Imaging Spectrometer (AVIRIS)

The airborne visible infrared imaging spectrometer (AVIRIS) instrument contains 224 different detectors. It uses a scanning mirror to sweep back and forth ("whisk broom" fashion), producing 614 pixels for the 224 detectors each scan. Each pixel produced by the instrument covers an approximately 20 meter square area on the ground-20 MPP- (with some overlap between pixels), thus yielding a ground swath of about 11 km wide.

Spectral Resolution

For all AVIRIS detectors, each has a wavelength sensitive range (known as spectral resolution) of approximately 10 nanometers (nm), allowing it to cover the entire range between 380 nm and 2500 nm. When the data from each detector is plotted on a graph, it yields a spectrum. Comparing the resulting spectrum with those of known substances reveals information about the composition of the area being viewed by the instrument.

Data Description

The ground data is recorded on board the instrument along with navigation and engineering data and the readings from the AVIRIS on-board calibrator. When all of this data is processed and stored on the ground, it yields approximately 140 Megabytes (MB) for every 512 scans (or lines) of data. Every 512 line set of data is called a "scene," and corresponds to an area about 10 km long on the ground.

Light Detection and Ranging (LIDAR)

LIDAR is a remote sensing technique that uses laser light in much the same way that sonar uses sound, or radar uses radio waves. The basic principle is simple: a pulse of laser light is emitted into the night sky, and the amount of return due to backscatter from the atmosphere is measured versus time. With knowledge of the speed of light, the time is converted into altitude. The number of photons counted for each altitude bin is proportional to the atmosphere density. LIDAR is usually used in conjunction with other sensors to produce a final product. A good example would be to identify the ground surface in a jungle or dense forest. Photography would provide the picture and the tree canopy; LIDAR would provide a picture of what the surface is like under the canopy.

LIDAR has several advantages over traditional methods. It can perform measurements from about 880 km, which is a very large scale. Due to the rapid nature of laser pulses, the time resolution is very short. Height resolution is also very small due to the speed of photon counters

REMOTE SENSING PLATFORMS ABOARD SATELLITES

This section is provided to give an overall familiarization with remote sensing satellites being developed, planned, and currently in use. Figure 1.8 gives a comprehensive overview of remote sensing satellites, who's operating them, the year they were put into service, the spatial resolution (where provided or applicable), and a brief description of the design of the platform. Succeeding the Figure1.8 are the specifications, range of the sensors on board, and example applications of several satellites providing data to support most cultural and natural resources applications.

FIGURE 1.8 OPERATIONAL AND PLANNED EARTH OBSERVING SATELLITES
(Note: Bolded Platforms Are Discussed Following This Figure)

Satellite Platform	Country	Agency	Year of Launch	Description
Landsat 4	U.S.	NOAA	1982	Land remote sensing
Landsat 5	U.S.	NOAA	1984	Land remote sensing
NOAA-11	U.S.	NOAA	1988	Meteorology (polar)
NOAA-12	U.S.	NOAA	1991	Meteorology (polar)
GOES-7	U.S.	NOAA	1987	Meteorology (GEO)
GOES-8	U.S.	NOAA	1994	Meteorology (GEO)
UARS	U.S.	NASA	1991	Atmospheric chemistry
SPOT 1	France	CNES	1986	Land remote sensing
SPOT-2	France	CNES	1990	Land remote sensing
SPOT-3	France	CNES	1993	Land remote sensing
SPOT 4	France	CNES	1996	Land remote sensing
Meteosat 3	Europe	Eumetsat	1988	Meteorology (GEO)
Meteosat 4	Europe	Eumetsat	1989	Meteorology (GEO)
Meteosat 5	Europe	Eumetsat	1991	Meteorology (GEO)
Meteosat 6	Europe	Eumetsat	1993	Meteorology (GEO)
Meteosat 7	Europe	Eumetsat	1995	Meteorology (GEO)
Meteosat 8	Europe	Eumetsat	2000	Meteorology (GEO)
ERS-1	Europe	ESA	1991	Ocean dynamics; Ice
ERS-2	Europe	ESA	1994/95	Ocean dynamics, ice, atmospheric chemistry
Topex/Poseidon	U.S./France	NASA/CNES	1992	Ocean dynamics
GMS-4	Japan	JMA	1989	Meteorology (geosynchronous)
GMS-5	Japan	NASDA	1994	Meteorology (GEO)
MOS-1b	Japan	NASDA	1990	Land and ocean color
JERS-1	Japan	NASDA	1992	Ocean/ice and land remote sensing
IRS 1a	India	ISRO	1988	Land remote sensing
IRS 1b	India	ISRO	1991	Land remote sensing
INSAT IIa	India	ISRO	1992	Meteorology (GEO) and telecommunications
Meteor 2	Russia	Hydromet	1975 (series)	Meteorology (polar)
Meteor 3	Russia	Hydromet	1984 (series)	Meteorology (polar)
Okeun-O	Russia	Hydromet	1986 (series)	Ocean
Resurs-O	Russia	Hydromet	1985 (series)	Land
NOAA-J	U.S.	NOAA	1994	Meteorology (polar)
NOAA-K	U.S.	NOAA	1996	Meteorology (polar)

NOAA-L	U.S.	NOAA	1997	Meteorology (polar)
NOAA-M	U.S.	NOAA	1999	Meteorology (polar)
NOAA-N	U.S.	NOAA	2000	Meteorology (polar)
GOES-J	U.S.	NOAA	1995	Meteorology (GEO)
GOES-K	U.S.	NOAA	1999	Meteorology (GEO)
GOES-L	U.S.	NOAA	2000	Meteorology (GEO)
TOMS Earth Probe	U.S.	NASA	1995	Atmospheric chemistry
EOS AM-1	U.S.	NASA	1998	Climate, atmospheric chemistry, ocean color, land remote sensing
EOS PM-1	U.S.	NASA	2000	Climate and meteorology
EOS Aero-1	U.S.	NASA	2000	Atmospheric chemistry and aerosols
EOS Color	U.S.	NASA	1998	Ocean color
Landsat 7	U.S.	NASA	1998	Land remote sensing
SeaStar	U.S. / Commercial	NOAA Orbital Sciences Corp.	1995	Ocean color
WorldView	U.S. / Commercial	WorldView Imaging Corp.	1995	High-resolution land remote sensing
Space Imaging	U.S. / Commercial	Lockheed Corp.	1997	High-resolution land remote sensing
Eyeglass	U.S. / Commercial	Orbital Sciences Corp. Itek Corp. GDE Systems Corp.	1997	High-resolution land remote sensing
TRMM	US/Japan	NASA NASDA	1997	Climate and tropical precipitation
METOP	Europe	Eumetsat	2000	Polar meteorological satellite
Envisat-1	Europe	ESA	1998	Atmospheric chemistry, ocean dynamics and color
Radarsat	Canada	CSA / Radarsat, Int.	1995	Ocean surface, ice
ADEOS	Japan	NASDA	1996	Climate, atmospheric chemistry, ocean dynamics, ocean color, land remote sensing
GOMS	Russia	Hydromet	1994	Meteorology (GEO)

Almaz-1B	Russia		1996	Ocean surface, ice
Almaz-2	Russia		1999	Ocean surface, ice
IRS-1c	India	ISRO	1994	Land remote sensing
IRA-1d	India	ISRO	1996	Land remote sensing
IRS-P2	India	ISRO	1994	Land remote sensing and ocean color
FY-2	China	NRSC	1994	Meteorology (GEO)
MECB SSR-1	Brazil	INPE	1996	Land/vegetation
MECB SSR-2	Brazil	INPE	1997	Land/vegetation

Satellite Pour L'Observation de la Terra (SPOT)

Satellite Pour L'Observation de la Terra (SPOT) is the European Earth observing satellite system. The first satellite in the program, SPOT-1, was launched on February 21, 1986, on board an Ariane launch vehicle. This satellite began a new era in space remote sensing, for it was the first to provide full scene stereoscopic imaging from two different satellite tracks permitting coverage of the same area. See Figure 1.3 for an example of 10 MPP panchromatic imagery. SPOT data include visible and near-infrared radiance data obtained from High Resolution Visible (HRV) sensors carried on the SPOT-1 and SPOT-2 satellites. Each satellite carries two HRV sensors with the capability of scanning in either a multispectral mode or a panchromatic mode. The multispectal mode captures data in three spectral bands: 0.50-0.59, 0.61-0.68 and 0.79-0.89 micrometers. The three bands are co-registered and have a ground resolution of 20 meters. The panchromatic mode images data in the spectral range of 0.51-0.73 micrometers at a 10 meter ground resolution. The viewing angle of each HRV sensor can be adjusted to collect data up to 27 degrees right or left of the satellite location. This cross-track pointing capability allows the same point on the Earth to be viewed from several different orbits and enables the acquisition of stereoscopic imagery. The SPOT system provides global coverage between North 87 degrees latitude and South 87 degrees. Each nominal scene covers a 60 by 60 km (37 by 37 square mile) area.

Data Description / Spatial Resolution

Mode	Band	Resolution
Multispectral	1	20 meters
	2	20 meters
	3	20 meters
Panchromatic		10 meters

Spectral Resolution

Mode	Type of Radiation	Wavelength µm (Micrometers)	NASA Code
Multispectral	Visible, green	0.50 - 0.59	Band 1
	Visible, red	0.61 - 0.68	Band 2
	Visible, red-invisible IR	0.79 - 0.89	Band 3
Panchromatic	Visible, green-red	0.51 - 0.73	-

Temporal Resolution (Frequency of Coverage)

The SPOT satellites operate from a sun-synchronous, near-polar orbit 832 km (517 miles) above the Earth. The satellites are inclined 98.7 degrees, cross the equator at 10:30 am local time, and have an orbit cycle of 26 days.

Applications and Related Data Sets

Current uses of SPOT data include: preparing basemaps for environmental impact studies; evaluating major geologic faults and structures; merging SPOT data with elevation information to produce a perspective view used in geologic exploration; forecasting crop yields; assessing natural disaster damage and preparing thematic maps for cartographic, urban and regional planning, or transportation needs.

Landsat Satellites

The idea of a civilian Earth resource satellite was conceived by the Department of the Interior in the mid-1960's. The National Aeronautics and Space Administration (NASA) with the cooperation of the Department of Interior began a conceptual study of the feasibility of a series of Earth Resource Technology Satellites (ERTS) designed to provide repetitive global coverage of the Earth's land masses. On July 3, 1972, NASA launched the ERTS-A. It used a Nimbus-type platform that was modified to carry sensor system and data relay equipment. When operational orbit was achieved, it was designated ERTS-1, later renamed Landsat 1. The satellite continued to function beyond its designed life expectancy of 1 year and finally ceased to operate on January 6, 1978, more than 5 years after its launch date. The second in this series of Earth resources satellites (designated ERTS-B) was launched January 22, 1975, renamed Landsat 2. Three additional Landsats were launched in 1978, 1982, and 1984 (Landsats 3, 4, and 5 respectively).

Landsats 1, 2, and 3 carried two sensor systems: Return Beam Vidicon (RBV) and a Multispectral Scanner (MSS). These satellites were launched into circular orbits at a nominal altitude of ~900 km (the altitude varied between 880 and 940 km). The orbits passed within 9 degrees of the North and South Poles. They circled the Earth once every 103 min., resulting in 14 orbits per day. They crossed the equator at 9:42 am local time on each revolution. This schedule was selected to take advantage of early morning skies that are generally clearer than those later in the day.

A new generation of sensor system is carried on board Landsats 4 and 5, aiming at improving the spatial resolution, spectral reparation (compensation for a loss), geometeric fidelity, (limited distortion) and radiometric accuracy of the data. Thematic Mapper TM, in addition to the MSS, form this new system. They were also launched into repetitive, circular, sun-synchronous, near-polar orbits; however, these orbits were lowered from 900 km to 705 km. These lower orbits were chosen to make the satellites potentially retrievable by the Space Shuttle and to aid in the improvement of the ground resolution of the sensors on board. Landsats 4 and 5 orbits have an inclination angle of 98.2 degrees (8.2 degrees from normal) with respect to the equator. The satellite crosses the equator on the north-to-south portion of each orbit at 9:45 am local time. Each orbit takes

approximately 99 min, with just over 14.5 orbits being completed in a day. The MSS systems were the first global monitoring systems capable of producing multispectral data in a digital format. The MSS systems flown on Landsats 1, 2, and 3 covered a 185 km swath width in four wavelength bands: two in the visible spectrum at 0.5 to 0.6 µm (green) and 0.6 to 0.7µm (red), and two bands are in the near-infrared at 0.7 to 0.8 µm and 0.8 to 1.1 µm. These bands were designated as bands 4, 5, 6, and 7. The MSS onboard Landsat 3 had a thermal band (band 8) within the wavelength of 10.4 to 12.6 µm but operating problems caused this channel to fail shortly after launch.

Return Beam Vidicon (RBV) and MSS

The Return Beam Vidicon (RBV) system consisted of three television-like cameras aimed to view the same 185 by 185 km ground area simultaneously. The nominal ground resolution of the cameras was about 80 m and the spectral sensitivity of each camera was essentially akin to that of a single layer of color infrared film: 0.475 to 0.575 µm (green); 0.580 to 0.680 µm (red); and 0.690 to 0.830 µm (near infrared). These bands were designated as bands 1, 2, and 3. RBVs do not contain film, but instead their images are exposed by a shutter device and stored on a photosensitive surface within each camera. This surface is then scanned in raster form by an internal electron beam to produce a video signal just as in a conventional television camera. RBV has 30 meter ground resolution.

While it was not intended as such, the RBV became a secondary data resource in comparison to the MSS systems on board the Landsats 1, 2, and 3. This is because RBV operations were plagued with various technical malfunctions.

Coverage of the Earth

The two RBV cameras on board Landsats 1, 2, and 3 were configured side-by-side and were aligned to view adjacent 98 km square ground scenes with a 13 km sidelap, yielding 183 by 98 km scene pair. Two successive scene pairs coincided nominally with one MSS scene.

The instantaneous fields of view (IFOV) of the MSS scanner is square and results in a ground resolution cell of approximately 79 m per side. The total field of view scanned is approximately 11.56 degrees. Because this angle is so small (compared to 90 to 120 degrees in airborne scanners), an oscillating, instead of spinning, scan mirror is installed. The mirror oscillates once every 33 msec. Six contiguous lines are scanned simultaneously with each mirror oscillation. This permits the ground coverage rate to be achieved at one-sixth the single line scan rate, resulting in improved system response characteristics. The MSS scans each line from west to east with the southward motion of the spacecraft providing the along track progression of the scan lines. Each Landsat MSS scene covers approximately 185 by 185 km area with 10 percent endlap between successive scenes.

Data Description / Spatial Resolution

Sensor	Band	Resolution
RBV	1	80 meters
RBV	2	80 meters
RBV	3	80 meters
MSS (Multispectral)	4	79/82* meters
MSS (Multispectral)	5	79/82 meters
MSS (Multispectral)	6	79/82 meters
MSS (Multispectral)	7	79/82 meters
MSS (Multispectral)	8**	240 meters

* 79 m Landsats-1 to 3, and 82 m for Landsats-4 and 5
** Failed shortly after launch (band 8 of Landsat-3)

Spectral Resolution

Type of Radiation	Wavelength (µm)	NASA Code
Visible, yellow-green	0.475 - 0.575	Band 1
Visible, green-red	0.580 - 0.680	Band 2
Visible, red-invisible IR	0.690 - 0.750	Band 3
Visible, green	0.50 - 0.60	Band 4
Visible, red	0.60 - 0.70	Band 5
Invisible reflected IR	0.70 - 0.80	Band 6
Invisible reflected IR	0.80 - 1.10	Band 7
Invisible thermal IR	10.40 - 12.60	Band 8

Temporal Resolution (Frequency of Coverage)

The Landsat satellites have an orbit cycle of 16 days.

Application of MSS data

The application of Landsat MSS data has been demonstrated in many fields, such as agriculture, botany, cartography, civil engineering, environmental monitoring, forestry, geology, land-use planning, and oceanography.

Thematic Mapper (TM)

The TM, which is flown on board Landsats-4 and 5, is a highly advanced multispectral scanner incorporating a number of spectral radiometric design improvements relative to the MSS. It works on the same principle as the MSS, but it provides higher spatial and radiometric resolution. Spectral improvements include the acquisition of data in seven bands instead of four, with new bands in the visible (blue), mid-infrared, and thermal portions of the spectrum.

Geometrically, TM data are collected using a 30 m IFOV (for all but the thermal band which has a 120 m IFOV). Radiometrically, the TM performs its onboard analog-to-digital signal conversion over a quantization range of 256 digital numbers (8 bits). This corresponds to a fourfold increase in the gray scale range relative to the 64 digital numbers (6 bits) used by MSS. This finer radiometric precision permits observation of smaller changes in relationships between bands. Thus, differences in radiometric values that are lost in one digital number in MSS data may now be distinguished. Also the TM detectors arrays are located within the primary focal plane of the telescope so that the incoming radiation can be transmitted directly onto the detectors.

Coverage of the Earth

The TM covers approximately 185 by 185 km area with 10 percent endlap between successive scenes.

Data Description / Spatial Resolution

Sensor	Band	Resolution
TM	1	30 meters
(It is only on board Landsats-4 and 5)	2	30 meters
	3	30 meters
	4	30 meters
	5	30 meters

Spectral Resolution

Type of Radiation	Wavelength (µm)	NASA Code
Visible, blue	0.45 - 0.52	Band 1
Visible, green	0.52 - 0.60	Band 2
Visible, red	0.63 - 0.69	Band 3
Invisible, near-IR	0.76 - 0.90	Band 4
Invisible, mid-IR	1.55 - 1 .75	Band 5
Invisible thermal-IR	10.4 - 12.5	Band 6
Invisible mid-IR	2.08 - 2.35	Band 7

The wavelength range and location of the TM bands were designed based on experience with MSS data and extensive field radiometer research results. The following description is a summary of intended principal application of each band.

Band 1 was designed for water body penetration, making it useful for coastal water mapping. It is also useful for the differentiation of soil from vegetation, and deciduous and/or coniferous flora. Band 2 was designed to measure the visible green reflectance peak of vegetation for vigor assessment. Band 3 is a chlorophyll absorption band important for vegetation discrimination. Band 4 is useful for determining biomass content and for the delineation of water bodies. Band 5 is indicative of vegetation moisture content and soil moisture and is also useful for differentiation of snow from clouds. Band

6 is a thermal infrared band used in vegetation stress analysis, soil moisture discrimination, and thermal mapping. Band 7 is a band selected for its potential for discriminating rock types and for hydrothermal mapping.

Typically, TM bands 4, 3, and 2 can be combined to make false-color composite images where band 4 represents red, band 3, green, and band 2, blue. This band combination makes vegetation appear as shades of red, with brighter reds indicating more vigorously growing vegetation. Soils with little or no vegetation will range from white (sands) to greens or browns depending on moisture and organic matter content, while water bodies will appear blue. Deep, clear water will be dark blue to black in color, while sediment-laden or shallow waters will appear lighter in color. Urban areas will appear blue-gray in color. Clouds and snow will be bright white and are usually distinguishable from each other by the shadows associated with the clouds.

Application of TM Data

Landsat TM data have a much wider range of applications than MSS data. This is because the TM has both an increase in the number of spectral bands and an improvement in spatial resolution as compared with MSS. The MSS data is most useful for large area analysis, such as geologic mapping. TM data is better suited to more specific mapping, such as detailed land cover mapping.

AVHRR Data from NOAA Satellites

The advanced Very High Resolution Radiometer is a broad-band, four or five channel (depending on the model) scanner, sensing in visible, near-infrared, and thermal infrared portions of the electromagnetic spectrum. This sensor has been carried on NOAA's Polar Orbiting Environmental Satellites (POES), beginning in 1978. The even-numbered missions have daylight (7:30 am) north-to-south equatorial crossing times and the odd-numbered missions have nighttime (2:30 am) north-to-south equatorial crossing times. Coverage is acquired at a ground resolution of 1.1 km at nadir. This resolution naturally becomes coarser with increases in the viewing angle off-nadir.

Coverage of the Earth

The AVHRR sensor provides for global (pole to pole) on board collection of data from all spectral channels. Each pass of the satellite provides a 2399 km (1491 miles.) wide swath. The satellite orbits the Earth 14 times each day from 833 km (517 miles.) above its surface.

Data Description

AVHRR data are acquired in three formats:

High Resolution Picture Transmission (HRPT)

Local Area Coverage (LAC)

Global Area Coverage (GAC)

Spatial Resolution

Mode	Band	Resolution
Multispectral	1	1.1 km
	2	1.1 km
	3	1.1 km
	4	1.1 km
	5	1.1 km

Spectral Resolution

Band #	Type of Radiation	Wavelength (µm) Satellites: NOAA 6, 8, 10	Wavelength (µm) Satellites: NOAA 7, 9, 11, 12, 14
1	Visible, green-red	0.58 - 0.68	0.58 - 0.68
2	Invisible, near-IR	0.725 - 1.10	0.725 - 1.10
3	Invisible, thermal-IR	3.55 - 3.93	3.55 - 3.93
4	Invisible, thermal-IR	10.50 - 11.50	10.3 - 11.3
5	Invisible, thermal-IR	band 4 repeated	11.5 - 12.5

Temporal Resolution

NOAA satellites provide daily (visible) and twice daily (thermal IR) coverage.

Application of AVHRR Data

AVHRR data provide opportunities for studying and monitoring vegetation conditions in ecosystems including forests, tundra, and grassland. Applications include agriculture assessment, land cover mapping, tracking regional and continental snow cover, and producing image maps of large areas such as countries or continents. AVHRR data are also used to retrieve various geophysical parameters such as sea surface temperature and energy budget data.

Seasat

Seasat was the first Earth-orbiting satellite designed for remote sensing of the Earth's oceans with the first space-borne synthetic aperture radar (SAR) on board. Seasat was managed by NASA Jet Propulsion Laboratory (JPL) and was launched on June 28, 1978 into a nearly circular 800 km orbit with an inclination of 108 degrees.

Coverage of the Earth

The Seasat had a 100 km swath width, and 14 Earth orbits were completed by Seasat each day.
Seasat carried five complementary experiments designed to return the maximum information from ocean surfaces on board:

- Radar altimeter to measure spacecraft height above the ocean surface.
- Microwave scatterometer to measure wind speed and direction.

- Scanning multichannel microwave radiometer to measure sea surface temperature.
- Visible and infrared radiometer to identify cloud, land, and water features.
- Synthetic Aperture Radar (SAR) L-band, HH polarization, fixed look angle to monitor the global surface wave field and polar sea ice condition.

The Seasat SAR operated for 105 days until October 10, 1978, when a massive short circuit in the satellite electrical system ended the mission. During Seasat operations, approximately 42 hours of data were collected. Although it was only operated for a short time, it returned a wealth of oceanographic data, with a fully focused resolution of 6.25 m by 25 m.

SMS and GOES Satellites

The SMS/GOES program, like the other civilian meteorological satellite programs, is a cooperative venture between NOAA and NASA. The synchronous Meteorological Satellites (SMS), or Geostationary Operation Environmental Satellites (GOES), are part of a global network of meteorological satellites spaced about 70 degrees longitude apart around the world. The domestic SMS/GOES program began providing image data in 1974. The program consists of multiple spacecraft orbiting the Earth at 36,000 km, where they are synchronous with the rotation of the equator. The three-axis, body-stabilized spacecraft design enables the sensors to “stare” at a part of the Earth, including the continental U.S., neighboring environment of the Pacific and Atlantic oceans, and South America. Thus the sensors encounter more frequent image clouds, monitor Earth’s surface temperature and water vapor fields, and sound the atmosphere for its vertical thermal and vapor structure. Similar systems are in operation or planned by Japan. Also, the European Space Agency and Soviet Union have established a cooperative venture within the World Meteorological Organization.

Defense Meteorological Satellite Program (DMSP)

The U.S. Air Force administers its own meteorological satellite program called Defense Meteorological Satellite Program (DMSP). Each DMSP satellite monitors the atmosphere and solar-geophysical environment of the Earth on a twice-daily basis. The visible and infrared sensors collect images of global cloud distribution across a 3,000 km swath during both daytime and nighttime conditions. The coverages of the microwave imagery and sounders are one half the visible and infrared sensors coverage. They cover the polar region above 60 degrees latitude on a twice daily basis but the equatorial region on a daily basis. DMSP satellites are in a sun-synchronous, low altitude polar orbit. Current equatorial crossing times are 5:36 am and 10:52 am local time.

Coverage of the Earth

The DMSP program operates a two-satellite constellation, thus providing complete global coverage of clouds every six hours.

Data Description

High resolution data are averaged, recorded and sent to ground receiving stations once an orbit, or every 101 min. The data can be received on 8 mm tapes on a daily basis.

Operational Linescan System Data (OLS)

Visible and infrared data imagery from DMSP Operational Linescan System (OLS) instruments are used to monitor the global distribution of clouds and cloud top temperatures twice each day during daytime and nighttime. The archive data set consists of low resolution, global coverage, and high resolution, regional coverage. Images are recordings along a 3,000 km scan, satellite ephemeris and solar and lunar data.

OLS Data Application

Visible data from OLS applications record visible and near-IR emissions from the sun or the moon reflected off clouds and other features. Ground-based sources such as fires and upper atmospheric sources like the northern lights are also seen. OLS data also record thermal emissions by the Earth's surface and atmosphere. OLS data can be used for cloud analysis and to detect manmade and natural fires, and natural gas flaring.

SSJ/4 Data

The DMSP SSJ/4 was designed to measure the fluxes of charged particles as they enter the Earth's upper atmosphere from the near-Earth space environment. The SSJ/4 data provide a complete energy spectrum of the low energy particles that cause the aurora and the other high latitude phenomena. The data set consists of electron and ion particle fluxes between 30 degrees latitude and other high latitude phenomena.

SSJ/4 Data Application

The DMSP SSJ/4 data have been used primarily in space physics research for monitoring the space environment and space weather forecasting.

SSM/I Data

The SSM/I is a seven-channel, four frequency, linear-polarized, passive microwave radiometric system which measures atmospheric, ocean, and terrain microwave brightness temperature at 19.35, 22, 23.5, 37.0, and 8.5 GHz. The data are used to obtain synoptic maps of critical atmospheric, oceanographic, and selected land parameters on a global scale. The SSM/I archive data set consists of antenna temperatures recorded across a 1,400 km conical scan, satellite ephemeris, Earth surface positions for each pixel and instrument calibration.

SSM/I Data Application

SSM/I data are used to derive geophysical parameters, notably, ocean surface wind speed, area covered by ice, age of ice, ice edge, precipitation over land, cloud liquid water, integrated water vapor, precipitation over water, soil moisture, land surface temperature, snow cover, and sea surface temperature.

Coastal Zone Color Scanner (CZCS) On board Nimbus Satellites

Satellite images can provide a synoptic view of the oceans over large areas for extended periods of time. This task is virtually impossible to accomplish with traditional oceanographic measurement techniques. Monitoring the ocean environment began with the launch of Seasat on June 27, 1978. Unfortunately, system failure 99 days after launch limited the image data produced by the satellite. Right after the launch of Seasat-1, another satellite, Nimbus-7, was also launched to monitor the oceans.

The Nimbus technology satellite program was initiated by NASA in the early 1960's to develop an observational system which would: develop advanced passive radiometric and spectrometric sensors for surveillance of the atmosphere and oceans; develop and evaluate new active and passive sensors for sounding the atmosphere and for mapping surface characteristics; develop advanced space technology and ground data processing techniques for meteorological and scientific research; and participate in global observation programs such as the World Weather Watch (WWW). Eight spacecrafts were built, of which 7 were launched, with one failure. The Nimbus satellites were placed in polar orbits and acquired global data twice every 24 hours.

The CZCS experiment was designed to map chlorophyll concentration in water, sediment distribution, gelbstoffe concentration as a salinity indicator, and temperature of coastal waters and ocean currents. It was launched aboard Nimbus-7 in October 1978. Due to power demands of the various on board experiments, the CZCS sensor was operated on an intermittent schedule, and it was official non-operational on December 18, 1986.

Coverage of the Earth

The system had a 1566 km swath width and an 825 km IFOV at nadir.

Data Description / Spatial Resolution

Band	Resolution
1	825 meters
2	825 meters
3	825 meters
4	825 meters
5	825 meters

Spectral Resolution

Type of Radiation	Wavelength (µm)	Principal Parameter Measure	NASA Code
Visible, blue	0.43 - 0.45	Chlorophyll absorption	Band 1

Visible, green	0.51 - 0.53	Chlorophyll absorption	Band 2
Visible, green	0.54 - 0.56	Gelbstoffe (yellow substance)	Band 3
Visible, red	0.66 - 0.68	Chlorophyll concentration	Band 4
Invisible, near-IR	0 70 - 0.80	Surface vegetation	Band 5
Invisible, thermal-IR	10.50 - 12.50	Surface vegetation	Band 6

CZCS Data Application

The first four (visible) bands of CZCS were very narrow (0.02 µm wide) and centered to enhance the discrimination of very subtle water reflectance differences. Data from these bands have been used to successfully map phytoplankton concentrations and inorganic suspended matter such as silt. The near-infrared channel has been used to map surface vegetation and to aid in separating water from land areas prior to processing data in the other bands. The thermal infrared channel has been used to measure sea surface temperature, suspended solids, and gelbstoffe (yellow substance) in the combinations and concentrations typical of near-shore and coastal waters.

European Remote Sensing Satellites (ERS)

In July 1991, the European Space Agency (ESA) launched the first European Remote Sensing Satellite (ERS-1) as a forerunner to a new generation of satellites for environmental monitoring. ERS-1 uses advanced microwave techniques to acquire measurements and images regardless of cloud and sunlight conditions. Such techniques have been used previously only by the short-lived Seasat mission in 1978, and during brief Space Shuttle experiments. In comparison to contemporary satellites systems, ERS-1 is unique in the measurement of certain parameters, including those of sea state, sea surface winds, ocean circulation, sea and ice levels, as well as all-weather imaging of the ocean, ice, and land. It also measures the sea's surface temperature with greater accuracy than any of the current space systems.

Furthermore, much more data may be collected from remote areas such as the polar regions and the southern oceans, for which little comparable information has previously been collected. The nature of the satellite's orbit and its complement of sensors enables a global mission providing world-wide geographical and repetitive coverage, primarily oriented toward ocean and ice monitoring, but with an all-weather high resolution imaging capability over land coastal zones.

ERS-1 can provide a wealth of observations through its excellent suite of sensors. Its Synthetic Aperture Radar (SAR) provides cloud-free radar images of mainly the Earth's surface, for monitoring vegetation and the cultivation of land. When two consecutive images are merged through the techniques of an interferometer, the instrument can even detect landslides and depressions over spanning an approximate area of 100 by 100 km.

An on board Active Microwave Instrument (AMI) produces extremely detailed images of 100 km swaths of the Earth's surface. Data is retrieved at 4.6 million pixels per second and downlinked directly to the Earth. In wind and wave modes, the instrument continuously measures global wind speed and direction and ocean waves. A Radar

Altimeter (RA) provides accurate measurements of sea surface elevation, significant wave heights, various ice parameters, and an estimate of sea wind speed.

Along Track Scanning Radiometer (ATSR) combined with an infrared radiometer and a microwave sounder can be used for the measurement of sea surface temperature, cloud top temperature, cloud cover, and atmospheric water vapor content. A Microwave Sounder operates together with the ASTR to provide a measurement of the total water vapor content in the Earth's atmosphere vertically below the satellite orbit. This measurement is essential for the correction of the radar altimeters (RA) height measurement.

Precise Range and Range-Rate Equipment (PRARE) are applied for the accurate determination of the satellite's position, orbit characteristics, and precise position determination. ERS-2 was built in 1990. The prime concern was to provide a follow-on satellite to ERS-1. Its main tasks were, therefore, to ensure the necessary continuity of data supply to scientists and applications-oriented users.

Data Application

The ERS data have been widely used in forest monitoring, hydrology, land use topography and geology, meteorology, ocean and wave imaging, oceanography, and vegetation and crop monitoring.

Coverage of the Earth

ERS-2 circles the Earth every 100 min. at an altitude of 785 km in an orbit passing over the North and South Poles. As the orbit itself is fixed, the Earth in effect turns below the satellite around its own axis. This means that its instruments scan the Earth's surface and atmosphere in "swaths". In this way it takes ERS-2 three days and 43 orbits to observe the entire planet. However, the imaging radar does require more time to do so, 35 days or 501 orbits, due to its higher resolution and narrower swaths.

ERS-2 On-Board Systems

AMI - active microwave instrument consisting of a synthetic aperture radar (SAR) and a wind scatterometer (both in the C-band).

RA - Radar altimeter: takes precise measurement of the distance from the ocean surface and wave heights.

ATSR - see ERS-1.

GOME - global ozone monitoring experiment, an absorption spectrometer which measures the presence of ozone, trace gases, and aerosols in the stratosphere and troposphere.

MS: microwave sounder: supplies data on atmospheric humidity.

PAARE - see ERS-1.

LRR - laser reflector: determines satellite position using ground-based laser stations.

IDHT: instrument data handling and transmission: temporary on-board data storage by means of two 6.5 Gbit tape recorders, equivalent to the data volume acquired in one orbit.

Data Application

ERS-2 data can be used in many fields the same as ERS-1 data. Moreover, ERS-2 carries the best ever ozone monitor—GOME. It is an entirely new passive instrument which will monitor the ozone content of the atmosphere with a precision hitherto unobtainable from space.

Japanese Earth Resources Satellites (JERS)

JERS-1 was launched on February 11, 1992, from Tanegashima Space Center in Kagoshima, Japan. It is three-axis stabilized and is a sun-synchronous subrecurrent orbit. JERS-1 has an on board Mission Data Recorder (MDR) which allows it to collect data when a ground station is not in view.

Coverage Information

JERS-1 has an altitude of approximately 580 km with an inclination of approximately 98degrees. Its repeat cycle is 44 days and its SAR swath width is 75 km.

On board Sensors

JERS-1 has two instruments—a Synthetic Aperture Radar (SAR) and an Optical Sensor (OPS). The SAR on board JERS-1 is an L-band (24 cm wavelength) instrument. Its orbit height is about 750 km and range of incidence angles within a typical image is typical fixed between 32 degrees at near range and 38 degrees at far range. A typical image area is 80 X 75 km. The OPS has seven bands with spectrum ranging from visible to short-wave infrared. It is made up of two sensors—the Visible and Near Infrared Radiometer (VNIR) and Short-Wave Infrared Radiometer (SWIR). The SWIR failed in 1993. The SAR onboard JERS-1 can produce similar data to the SAR on board ERS-1. The only difference is that the SAR of JERS-1 is a L-band radar system and SAR of ERS-1 is a C-band radar system.

Data Availability

Same as ERS-1.

Data Application

The mission of JERS-1 is focused on the Earth resources, geology, agriculture, forestry, land use, sea ice monitoring, and coastal monitoring.

Radarsat

Radarsat is an advanced Earth observation satellite project developed by Canada to monitor environmental change and to support resource sustainability.

It was launched on November 4, 1995. The orbit height of Radarsat is 790 to 820 km above the Earth with 98.6 degrees inclination. Radarsat uses sun synchronous orbits, and

it can view a scene at the same local time. Moreover, its dawn to dusk orbit places the satellite's solar arrays in almost continuous sunlight. The major advantage of the orbit is that the RADAR SAR will primarily rely on solar rather than battery power. Radarsat, with a planned lifetime of five years, is equipped with an advanced active SAR sensor. It can capture data up to 28 minutes and imaging up to 1.1 million square km of the Earth's surface with each orbit. In order to serve commercial and international users, data will be downlinked in real time or stored on one of two tape recorders until the spacecraft is within range of a receiving station.

Coverage Information

Radarsat will provide complete coverage with the flexibility to support specific requirements. The satellite's orbit repeats every 24 days, and makes 14 orbits per day. It also provides daily coverage of the Arctic, views any part of Canada within three days, and achieves complete coverage at equatorial altitudes every six days using a 500 km wide swath.

Data Description

Using a single frequency, C-band, the Radarsat SAR will have the unique ability to shape and steer its radar beam over a 500 km range. Users will have access to a variety of beam selections that can image swaths from 35 km to 500 km with resolution from 10 m to 100 m respectively.

Data Application

Due to the feature of SAR, Radarsat can monitor and map renewable resources for agriculture and forestry industry. It gathers data essential for more efficient resource management, ice, ocean, and environmental monitoring, and Arctic and off-shore surveillance. It also supports fishing, shipping, oil exploration drilling, and ocean research.

Space Imaging

The Space Imaging satellite will be launched in late 1997 on a Lockheed Launch vehicle 2 (LLV2) from Vandenberg Air Force Base, California. It will be comprised of a space segment and a ground segment. Initially, the space segment will consist of a single satellite. The ground segment will be composed of data communications, product production and image archiving, customer service, and satellite control and tasking.

Coverage Information

The Space Imaging satellite will be at 680 km near-circular with an inclination of 98.2 degrees to maintain a sun-synchronous ground track. The satellite will cross the equator between 10:00 am and 2:00 pm local time. The system shall provide same scene access from each satellite every four days at better than one-meter ground sample distance any place on the globe. It will also provide the 11 by 11 km single image or a strip of 11 by 110 km image.

Sensors On board Space Imaging

A totally reflective optical telescope with a primary mirror is combined into a digital focal plane array. The focal plane array is capable of generating 6500 lines per second of panchromatic image data. The panchromatic band ranges from 0.45 - 0.9 µm and consists of thousands of 12 micrometer detectors. The four multispectral bands provide data across the same radiation spectrum as Landsat 5 band-1 through band-4 (0.45 - 0.52 µm, 0.52 - 0.60 µm0.63 - 0.69 µm, 0.76 - 0.90 µm respectively).

Spectral Resolution

Bands	Resolution	Wavelength (µm)
panchromatic	1 meter	0.45 - 0.90
Blue	4 meter	0.45 - 0.52
Green	4 meter	0.52 - 0.60
Red	4 meter	0.63 - 0.69
Near-Infrared	4 meter	0.76 - 0.90

Data Application

The Space Imaging satellite will routinely collect both panchromatic and multispectral digital imagery of the Earth's surface. These data are simultaneously collected as one-meter ground sampling distance (GSD) panchromatic and four-meter GSD multispectral (four bands) imagery. Based on the customer's application for the imagery, a variety of end-user image products are generated from these data with varying degrees of positional accuracy.

Global Positioning System

While not in the strictest sense a remote sensing media type, a discussion of space-borne remote sensing platforms would be incomplete without some mention of the Global Positioning System (GPS). The GPS utilizes a constellation of satellites operated by the Department of Defense and a web of ground based receiving stations to generate positional data for users throughout the scientific and military community. Using hand held GPS receivers, users can pinpoint their position on the Earth's surface with varying degrees of accuracy. These commercially available receiving units can be equipped with databases to allow field users to enter attributes describing the positional data they collect. Archaeologists conducting field surveys, for example, may capture spatial coordinates for a series of proposed excavations and record user defined attributes for each point. Once the locational data is corrected for error using commercially available software, these data may be converted into GIS compatible format and integrated with other data sets. The ability of field technicians to record accurate positional information for features of interest and simultaneously record attributes represents a significant time savings when the GIS data development process is considered as a whole. Until recently, creating a digital representation of points in an archaeological survey would have required

field personnel to record point locations on paper maps, and thematic information in some other analog fashion. Once the field survey was complete, GIS technicians would use digitizing tablets to convert points on the paper maps to digital form and database technology to assign the attributes. These procedures result in increased opportunity for error and are significantly less efficient than the technique described above.

SURFACE / NEAR SURFACE DATA RETRIEVAL METHODS

Materials that are buried in the subsurface will exhibit characteristic properties, whether they be in a gas, liquid, or solid state. Very often these properties are lost within or attenuated by the presence of encapsulating geologic materials which make them indistinguishable from their surroundings. Several geophysical methods provide a means for active or passive investigation of these properties (Heimmer and De Vore, 1995).

Passive Geophysical Investigations

Passive geophysical methods primarily measure naturally occurring processes such as elemental decay and thermal interactions. The magnetometer and the gravimeter provide for highly sensitive investigations which measure the effect of a buried feature upon their respective naturally occurring, planetary fields.

Magnetometers

These instruments are considered one of the most useful passive measurement devices to be incorporated in archaeological assessments. A magnetometer provides a measurement of the Earth's total magnetic field, in a unit termed gamma or nanotesla (nT). As the magnetic susceptibility of materials is the basis for this technique, magnetometer surveying is very useful for detecting buried ferrous metallic objects or magnetic contrasts of soils. Its usefulness in archaeological investigations has been well documented.

Gravimeter

These instruments provide for accurate measurement of the Earth's gravitational field. They are used to map subsurface geology based on localized and regional rock density variations. Its use in archaeology is somewhat limited given its inability to measure small density variations generally characteristic of cultural features.

Active or Induced Techniques

Active methods involve the introduction of electrical currents, electromagnetic or acoustic energies with the subsurface. The interaction of these transmitted signals within subsurface materials alter specific properties or atttributes of the input signal. Changes in the signal related to amplitude, frequency, wavelength, and time delayed properties are observable with the appropriate geophysical technique. Specific techniques applied to archaeological investigations include electrical resistivity, electromagnetic ground conductivity, and ground penetrating radar.

Electrical Resistivity

The electrical resisitivity of a material or conversely, its ability to conduct electricity, is directly related to its porosity, permeability, saturation, and chemical nature of entrapped fluids. These properties are measured as the introduction of an electrical current of known intensity and frequency is observed at some distant point(s). A measured loss in voltage indicates variations in the subsurface materials, and provides some indication of the type of material as well as their porosity.

Electromagnetic Ground Conductivity

Often referred to as EM, these methods measure near surface conductivity. Similar to resistivity surveying, a measurement is obtained by inducing an electromagnetic field into the Earth causing an electrical current flowage. A transmitter-receiver instrument is used to measure the Earth's conductivity and detect lateral changes in subsurface material. The advantage of EM methods over resistivity surveying is the ability to move the near-surface instrument easily and without the aid of several surveyors (a resistivity surveying crew of three or four is often required to move and place electrodes along a profile line).

Ground Penetrating Radar

Often referred to as GPR, this method is used most for archaeological purposes. With the introduction of a low frequency electromagnetic signal (80-1000 MHz) into the ground via a surface contact transmitting antenna, the signal passes through the Earth to encounter subsurface materials of varying electrical properties. The receiving antenna receives the reflected signal and compares the signal delay time or the time it takes the signal to travel back to the receiver. This is referred to as two way time (TWT) or transit time. The observation of these two way travel times allow the surveyor to detemine the depth of a buried feature. Ground penetrating radar has also been used in relatively shallow freshwater.

Marine Investigations

Useful acoustic methods consist primarily of side scan sonar, tuned transducer, color fathometer, and slightly lower frequency, sub bottom profiler.

Side Scan Sonar

Side scan sonar transmits and receives reflected high frequency acoustic pulses in the 50-500 kilo Hertz (kHz) range from targets across the sea floor. An image is then produced with coverage out to distances of one kilometer. Sub bottom profilers and other fathometer systems are similar to side scan although they use a lower frequency energy transmission (5050 kHz), and a downward signal beaming to reflect off or penetrate the seabed.

PART II: COMPUTER SYSTEMS FOR VISUALIZING AND INTERPRETING MEDIA

General Requirements

There are a plethora of PC and UNIX based software packages for viewing, interpreting, altering and analyzing raster and vector data sets like those mentioned above. In the geoprocessing industry three distinct categories of software are used to visualize, interpret, analyze, and produce soft or hard copy maps of the media outlined above. The current industry terms for the three are: Geographic Information Systems (GIS), Image Processing Systems (IPS), and Computer Aided Drafting (CAD). Many of the softwares which make up this group have overlapping functionality, and data outputs, however, are designed for specific uses of remotely sensed data for management and planning of natural and cultural resources. A brief discussion of each will help broadly define the functionality and outline similarities and differences.

Geographic Information Systems (GIS)

A GIS can be defined as "a unique system designed to input, store, retrieve, manipulate, and analyze layers of geographic data to produce interpretable information" (Marble 1990). Although the term GIS is commonly used to describe computer software, consideration should be taken for knowledgeable staff, effective training programs, budgets, internal marketing to achieve awareness, hardware, data, analysis, and computer software. A GIS should include the ability to create reports and maps which include images, vectors, and text. This creation is the art and science known as cartography - creating 2-dimensional representations of our 3-dimensional Earth. These representations were once hand-drawn with paper an d pen. Today, map production is automated and the final product is not always paper. An example would be a large screen on the wall of a 911 dispatch office and icons of police vehicles moving on it.. A spatial analysis occurs with objects and their surroundings. The "objects" of study and their "surroundings" do not have to be tied to the surface of the Earth for evaluation. An example is, floorplans are not tied to the surface of the Earth, yet much space analysis and planning occur from them.

As an information system, a GIS requires a defined sequence of operations starting with a work plan or study design, data definition, data collection, storage and analysis, and ending with the output of derived information for use toward some decision-making process (Star, 1991). Although the productivity of base-mapping operations have been increased with Computer-Aided Design (CAD) and Automated Mapping and Facilities Management (AM/FM) systems, they fail to meet the needs of GIS functions. CAD systems are not concerned with the areas created by the spaces between lines, nor with

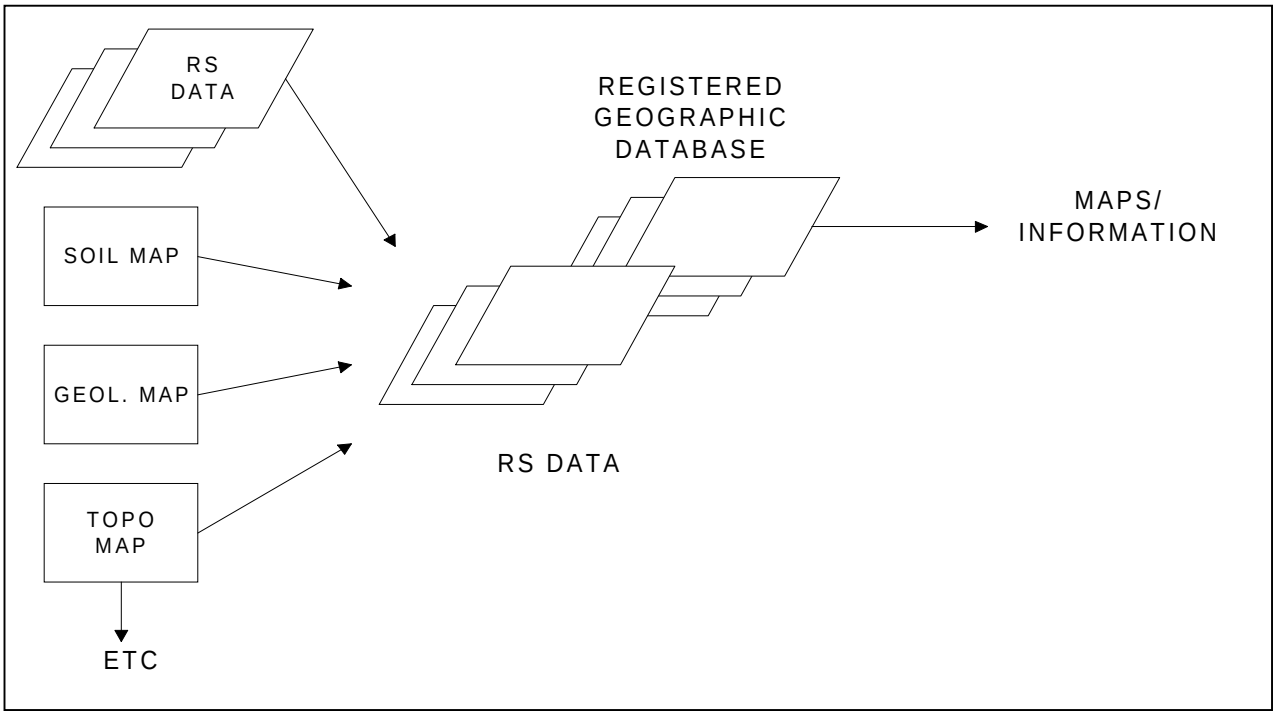
topological attributes such as connectivity and adjacency. CAD systems are applicable and cost effective tools for vector data input like roads and political boundaries from engineering drawings, existing paper maps, and brainstorming of proposed construction ideas. A GIS extends beyond the CAD system to employ geographical data processing which relies on the attributes that describe and differentiate the spaces defining geographic entities on the map. A GIS's ability to manipulate spatial data through the execution of detailed analyses allow the user to extract additional information not previously known and/or recorded (Gaile and Willmott, 1989). This emphasis on analysis is what distinguishes a GIS from other forms of spatial data handling activities

Data types for a GIS fall into three broad categories: alphanumeric, vector, and raster. The first category, alphanumeric data, is data contained in the form of numbers or text and is easily retrieved in computer-readable form. The second is pictorial or graphic data, known as vector (lines and points) data such as occur on existing maps or photographs, and that require the use of a digitizer to convert pertinent features into strings of coordinate values. The third category is raster data which may originate with the use of optical scanners which convert graphic material to computer-readable images automatically (Lo, 1986). This third category of data acquisition also includes remotely sensed data and has been shown to be particularly advantageous for correcting, updating, and maintaining GIS databases. In fact, integrative hardware and software systems have been developed to exploit this link between geographic information processing and remote sensing analysis, thus the integration of GIS and IPS. IPS excel in the extraction of features from the raster products and can export them in a form compatible with the GIS

A common trait among GIS applications is their dependence on thematic data which is organized as a series of georeferenced layers (see Figure 2.1). Data in these layers are in either raster or vector format depending on the source from which they are derived. Before raster image data can be incorporated into a GIS, it may need to be enhanced, filtered, or geometrically transformed with an IPS. Vector data, which is the most common data source for GIS, comes from existing map data. Features of interest are manually extracted using tablets or large-format digitizing tables. The quality of the resulting data depends largely on the skill of the operator and the quality of the digitizer and its inherent accuracy.

The effective interface between raster and vector data is a common challenge for integrated system implementation. A number of approaches have been identified to overcome such problems, and provide an integrated, problem solving system. Various conversion programs have been developed to efficiently convert vector to raster data and vice versa. Common routines such as line following and polygon-capturing are currently available for raster-to-vector conversions of data. These routines require advanced computer hardware and software systems to perform the tasks and also involve considerable manual labor.

FIGURE 2.1 THEMATIC DATA ORGANIZATION OF A GIS.



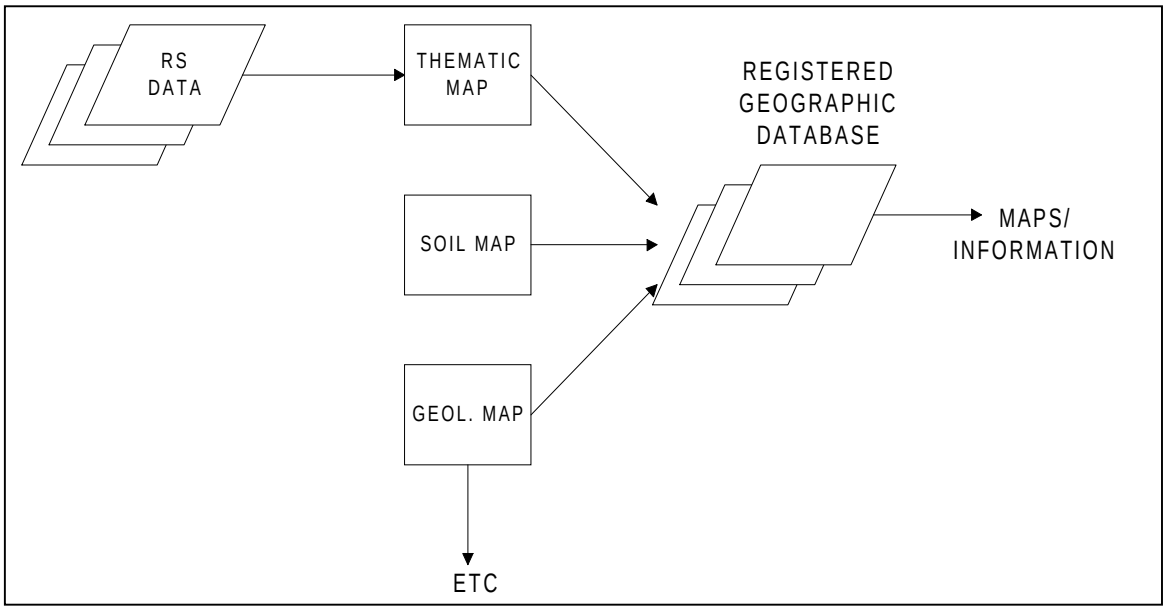
Most integrated systems provide a conventional cartographic projection and the means to import point, vector, and raster data from other projections. A common practice is to register raster data sets to a common base map containing vector data in the GIS. For example, a satellite image (raster data) that has been imported from magnetic tape, and placed as an image file on hard disk, may be rectified (for an explanation on this term see Part IV "Remote Sensing Techniques"-"Image Rectification"). Once the data is rectified to the known projection and pixel size, the resulting image is said to be georeferenced.. Georeferenced images are commonly applied as a major source of information for revising conventional linework, and are useful reference layers in a GIS database, especially when maps are out-of-date (Bonham-Carter, 1989).

A modification to the geocoded approach is to merge image data recorded by different sensors with a topographic map. In doing so, the user will be able to revise the map or extract its thematic information. The merging of images and maps to form a cartographic database requires that all source material be in digital format, rectified to a standard coordinate reference system, and resampled to a common pixel dimension (i.e. all pixels equal one standard unit of measure). This technique produces a fully raster-based GIS which is best suited for fast overlay and analysis of multiple maps due to the easy addressability of a pixel's row and column. An adequate spatial resolution of about 4000 rows by 4000 columns should be provided for most tasks (Bonham-Carter, 1989).

Remotely sensed data that is acquired for GIS analysis is often processed using a classification technique in an IPS which yields current thematic information for a given

region. Classification is defined as the process of assigning individual pixels of a multispectral image to categories, generally on the basis of spectral-reflectance characteristics. For example, a known stand of oak trees may be known or tested to reflect a specific amount of radiation. Given that reflectance information, a user may identify similar pixels throughout an image, and classify them as being part of an oak tree distribution. When this classification is complete, a thematic layer composed of oak tree locations is created. Although these layers are still in raster form, a user may digitize around the visual extents of the area(s) to produce a vector polygon for input into a GIS. This updating technique is consistently applied to maintain a current, accurate spatial database. It produces a fully vector-based GIS which is ideal for describing the boundaries of objects, requires much less storage space than a raster-based system, and is convenient for coordinate transformations (see Figure 2.2).

FIGURE 2.2 RASTER UPDATE OF GIS.



Committing to a fully raster or fully vector based GIS system does require some thought as to the limitations imposed by selecting a static format. In choosing the raster approach, the remotely sensed data required for input exacts a scale restriction due to the resolution limit of the sensor. This means that if your image has a resolution of 10 MPP then you will not be able to identify a 1 meter utility manhole or a 5 meter utility shed. As a result, a system requirement of very high levels of precision (such as for installation engineering and design) tend to be vector-based or are flown with high resolution aerial photography or digital imagery in the ¼ meter to 2 meter pixel range (MPP). Conversely, for applications where spatial precision is less important, and data sampling is fairly uniform, a raster approach can work reasonably well (Star, 1991).

Many systems are now being implemented to take advantage of both data formats through recent advances in raster and vector interface. As such, GIS technology frequently contains image processing as a subclass of its total functionality. These integrated systems are able to support raster operations for image processing tasks as well as vector

operations for map objects (see Figure 2.3). Commercial software vendors have driven this approach by developing conversion software for moving data from one format to the other. Additional software programs allow vector coverages to be displayed over raster color digital images (see Figure 2.4- 2.7,2.8 , and 2.9).

FIGURE 2.3 OVERALL DATA INTEGRATION OF RS AND VECTOR PRODUCTS.

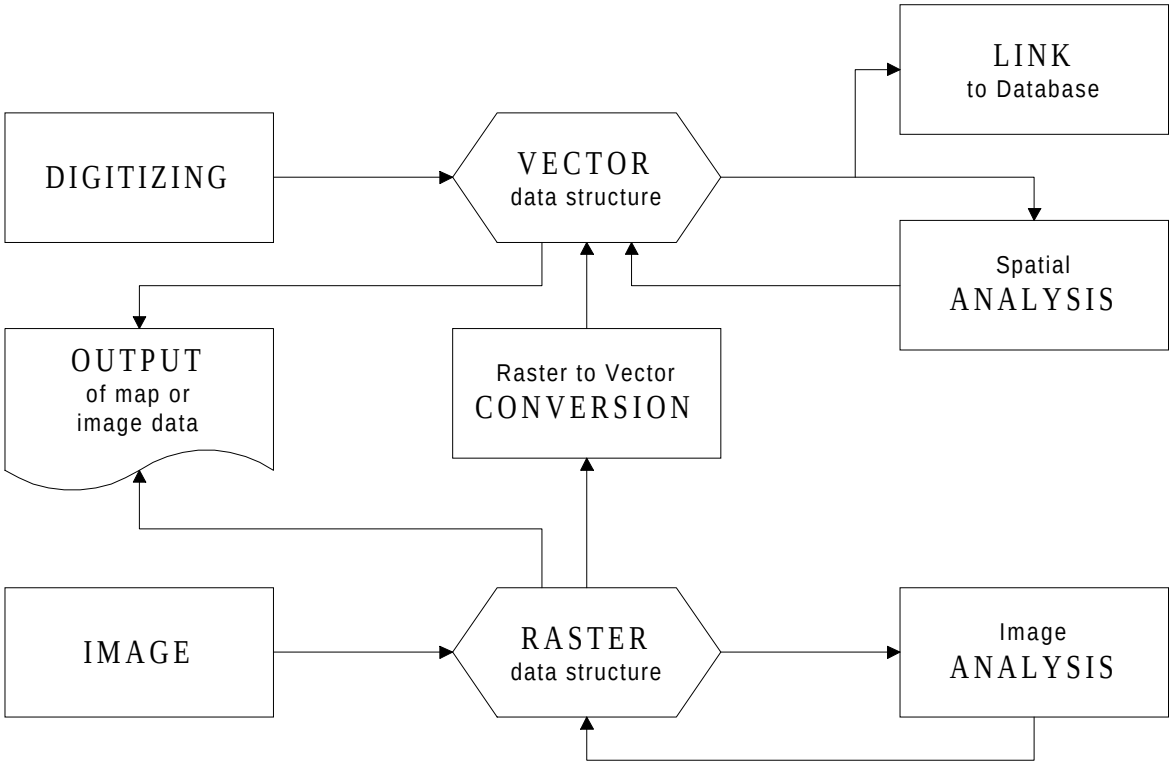
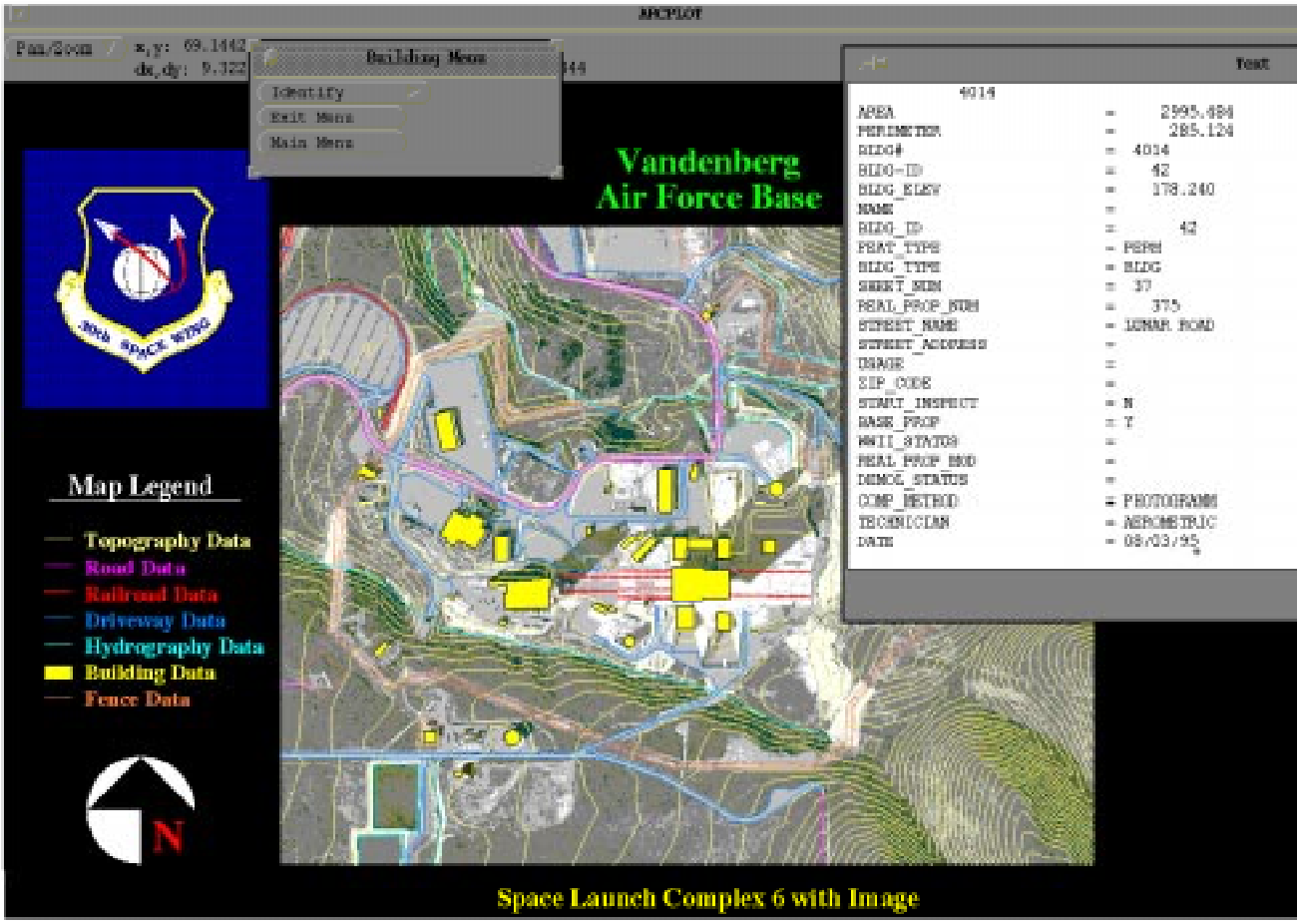


Figure 2.4 Integration of an Orthophoto, Vectors, RDBMS, and MENUS.

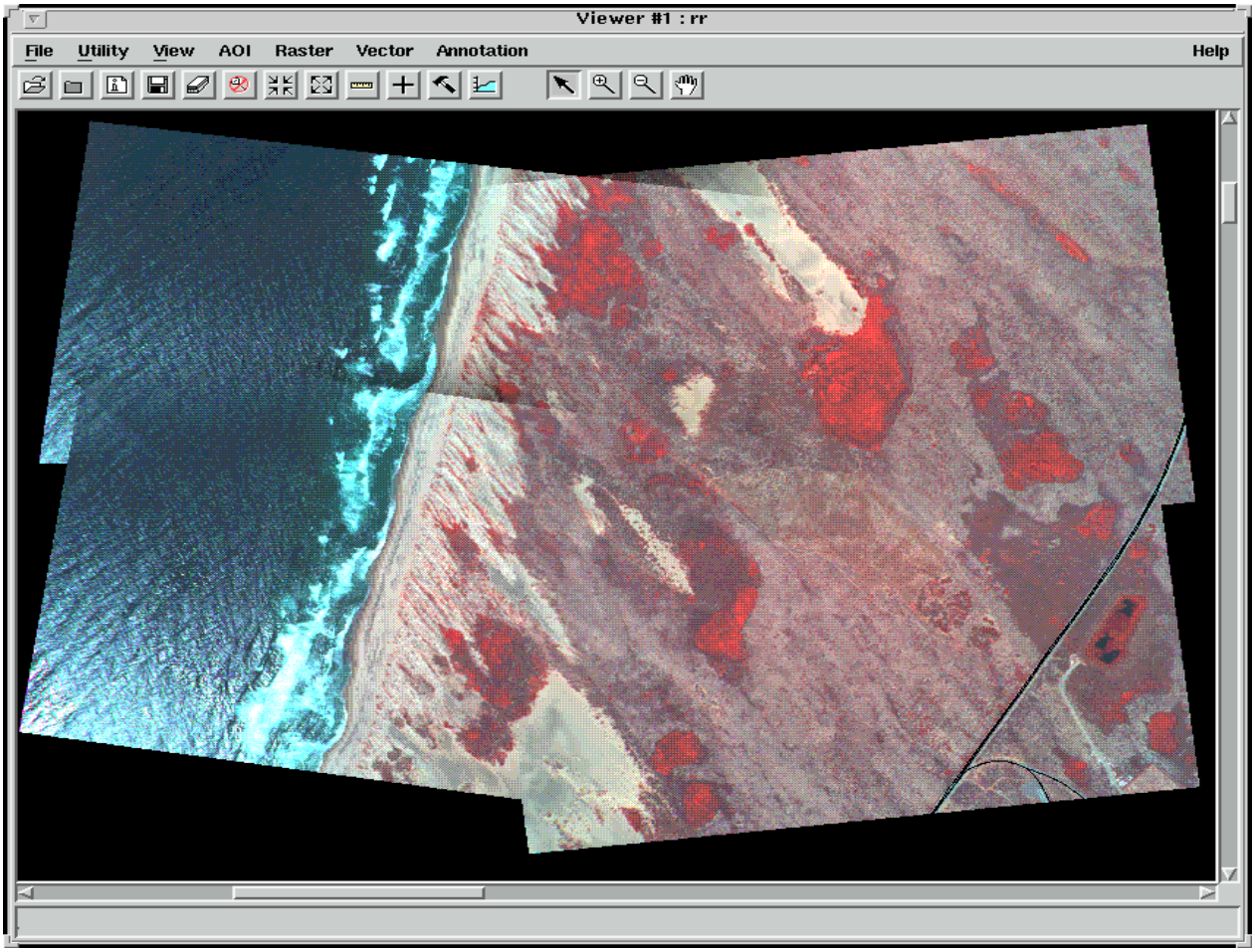


NOTE: This is a ½ meter resolution digital orthophoto of SLC-6 at Vandenberg AFB, CA. The vectors were compiled from aerial photography. The text in the top right is a sample of information maintained for each facility at Vandenberg. The small menu at the top allows the user to select facilities with the mouse while the text window displays the corresponding database information.

FIGURE 2.5 DIGITAL CIR AERIAL PHOTOGRAPH.

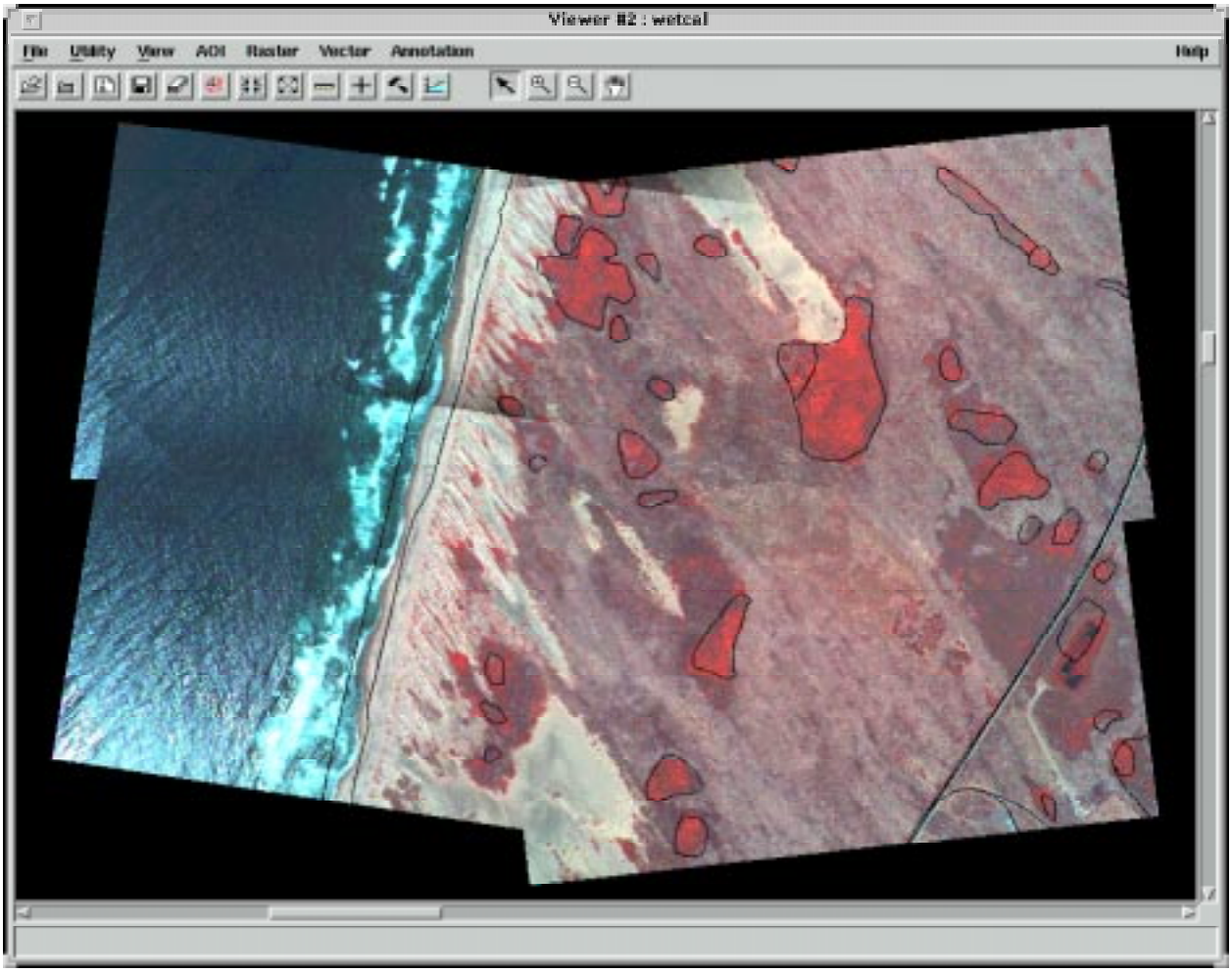
NOTE: This is a ¾ meter resolution digital aerial photograph of SLC-6 at Vandenberg AFB, CA. It was acquired using a series of digital cameras capturing 3 bands of light in the visible range and 1 band in the infrared range. This image can be drawn as an infrared image as depicted above, or as a natural color photo. The red color is highlighting the vegetation and would be green in a natural color photo. The infrared band helps to identify the health of vegetation as well as vegetation cover (e.g. wetlands can be derived). This scene is taken directly from the aircraft and no processing has been performed; the scene has not been rectified or georeferenced. Notice the image is rotated 180 degrees and north is toward the bottom of the page.

FIGURE 2.6 FOUR DIGITAL CIR PHOTOS MOSAICKED FOR WETLAND DELINEATION (SCENE 1)



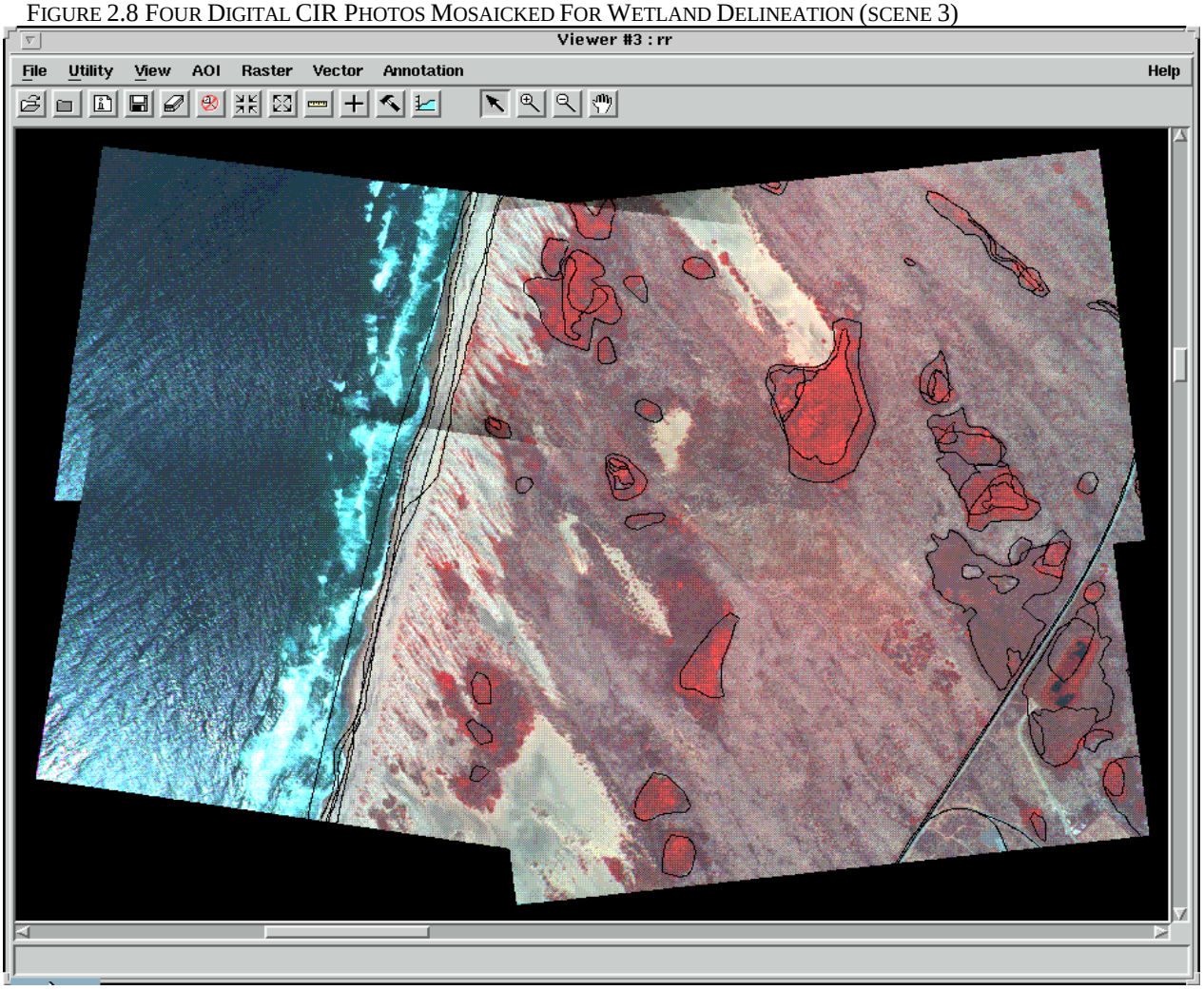
NOTE: This is a mosaic of four scenes from Vandenberg AFB, CA. This IPS was used to rectify, mosaic, and classify potential wetlands in this dune area along the California coast Figure 2.7-2.9 demonstrate the ability of a vector overlay and a classification comparison. This data is at 1 meter pixel resolution. The black and white orthophotos were used as reference to rectify these four scenes.

FIGURE 2.7 FOUR DIGITAL CIR PHOTOS MOSAICKED FOR WETLAND DELINEATION (SCENE 2)



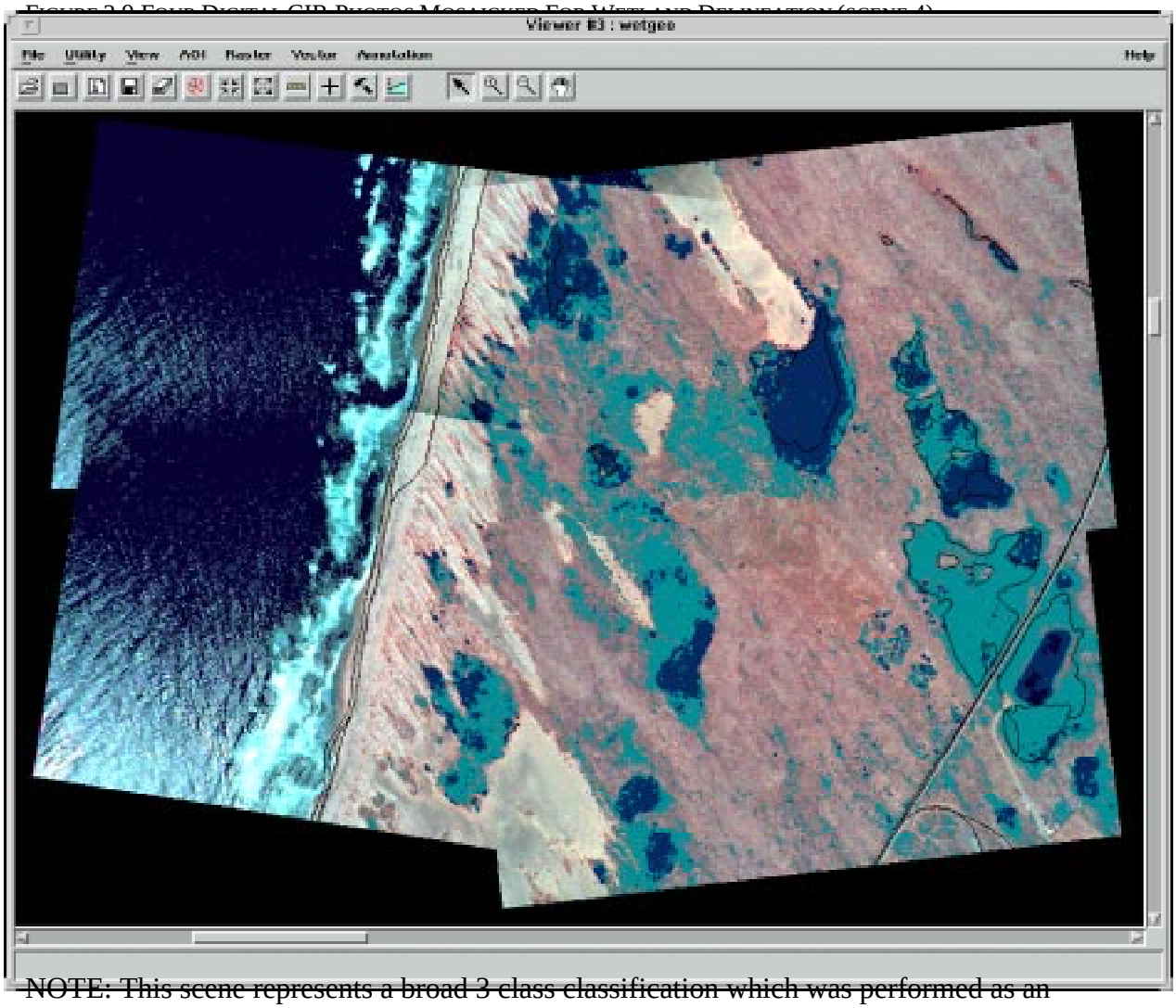
NOTE: The vector overlay in this scene is a wetlands delineation performed using USGS Quadrangles and a pair of binoculars. Please note how fast you can visually access the classification. Think about the amount of time saved if you were to walk this 1 KM square area, then multiply that savings for a 98,000 acre installation.

FIGURE 2.8 FOUR DIGITAL CIR PHOTOS MOSAICKED FOR WETLAND DELINEATION (SCENE 3)



NOTE: This classification was performed using 1:40000 aerial photography, USGS Quadrangles and a stereo plotter. If you compare this figure with Figure 2.7 and 2.9 you will see many differences in classification. The GPS control used in this study allowed for better integration with other data sets due to its spatial accuracy.

FIGURE 3.9 FOUR DIGITAL CIR PHOTOS MOSAICKED FOR WETLAND DELINEATION (SCENE 4)



NOTE: This scene represents a broad 3 class classification which was performed as an initial comparison to the vector overlay. A field study would now be appropriate to determine if the classification requires any modification. Note that vectors for the railroad and the coastline are also included.

PART III: APPLICABILITY OF REMOTE SENSING

Introduction

Given the geographic nature of a GIS and remote sensing systems, there is a very broad application base for their use. Both systems are capable of utilizing digital representations of the Earth at vastly different scales. They employ very high accuracy standards and allow for in depth, spatial analyses. Individual disciplines requiring the use of this type of geographic information are drawn to the technology for their betterment.

Remote sensing in particular has proven it is ideal in presenting information that, at a glance, affords the infinite variety of environmental and cultural patterns and addresses dynamic interrelationships. Very often, this type of information is needed for an application and must be obtained from sensor outputs. Such information is extracted from the resultant images using visual-interpretation or image processing techniques. For some types of applications, the performance characteristics of the sensor are a limiting factor, such as its ability to discriminate required spectral signatures.

Although sensors have different performance characteristics, the byproducts of their data are very similar and are often utilized across numerous disciplines. In fact, the image processing techniques applied to remotely sensed imagery can become redundant in nature. For example, a classification technique which generates subclasses within an image may produce a map that is useful for a variety of applications (i.e. forestry, biology, ornithology, etc.). Themes derived from a classification may differ across the disciplines, but the process to obtain them is essentially the same.

A Geographic Information System (GIS) may be used to interface with remote sensing systems. GIS requires consistent updates of spatial attributes, which remote sensing can often provide. Likewise, remote sensing efforts benefit from access to ancillary information which helps to improve classification accuracy and supports predictive modeling.

Engineering

General Use

Any major civil engineering project includes an understanding of the physical characteristics of the Earth's surface. Remote sensing is considered one of the most appropriate means of measuring and recording existing ground conditions, and is accepted as a highly cost-effective means by which the civil engineer can obtain up-to-date, and often repetitive, information about the terrain. Photographic, scanning, and image processing systems can be applied to assess the potential of an engineering project and to evaluate the effect, or potential effects, of the subsequent construction on the

environment. These applications, however, are only part of an engineering investigation and are considered complementary to data obtained from field measurements, site visits, and existing sources of data such as maps and project reports. In fact, it is essential for the site survey to include "ground truth" information which can be used to verify the results of a remote sensing investigation (Kennie and Matthews, 1985).

The decision to incorporate remotely sensed data within a civil engineering project will depend largely on the extent of existing material and the reliability of the information. If remote sensing is considered, a number of decisions will need to be made including the type of data to be acquired, a method for viewing and interpreting the imagery, the means of verifying the interpretation results, and the resultant project costs. In developing such an approach, consideration as to the scale of the project (regional or local) as well as the stage of the investigation (reconnaissance, feasibility, design, construction or post-construction) should be given. Most construction projects in the United States are of a more local nature given the high demand for land and the economic and environmental restrictions. Also, the amount of available information about the project area is generally high and may include topographic maps, geological survey reports, site investigation reports, records of mines and mineral deposits, hydrological information, and aerial photography (Kennie, 1985). As such, a greater emphasis is placed on investigating the ground conditions at a local level, particularly for design purposes.

Site Investigations

Detailed site investigations are normally carried out at the design stage of a project. The objective of these investigations is to provide an assessment of ground condition and the necessary geotechnical parameters on which to base the final design (Kennie, 1985). Since the ground resolution of satellite imaging systems is not suitable for detailed site studies, digital or film based aerial photographs are preferred for such investigations. This comprehensive yet inexpensive source of data leads the engineer to significant conclusions on soil type, drainage conditions, slope stability, location of mine shafts, sink holes, springs, areas of seepage, faults, rock outcrops, sources of construction material, and erosion. Much of the information gained from aerial photographs can be acquired by non-specialists who often develop interpretation skills rapidly. The information obtained from such interpretation may be used for the following:

- An overview of the terrain and other obstacles to help in the planning and distribution of site investigation work such as the movement of drilling rigs and other equipment.
- The interpretation of a site's geology may dictate the location and usage of fill, aggregates, and other construction materials.
- Identification of hydrological features, which are clearly visible on aerial photographs,to help locate the pattern and density of streams, springs, and seepages. An evaluation of run-off can also be made.
- Identification of areas of potential instability and landslide activity.

- Examination of photographs taken over a period of time help determine the site history. This may include the identification of landfills, areas of tree removal, and areas subject to flooding. The rate of cliff recession may also be apparent in coastal areas.
- Identification of localized features such as sinkholes, land drains, infilled trenches and natural drainage channels, disturbed drainage, gullies, and abandoned mine shafts..
- Generalizations on the topographic and geologic features in and around the project area (Kennie Matthews, 1985).

Obviously, aerial photography is considered a valuable source of data for the civil engineer, and its benefits are fully realized with the complementary use of maps and other information about the project area. Although aerial photographs are used in many engineering projects, there are a number of limitations which include:

- Only small areas can be covered in any one photographic scene.
- Complete coverage of large areas in a short time is difficult, especially in humid tropics with frequent cloud cover.
- Data recordings are limited to one broad spectral range which limits the ability to discriminate between ground features with similar photographic tone.
- Seasonal limitations on aerial surveys may inhibit timely data requirements.
- Variations in lighting may impede temporal comparisons of the same feature.
- Limited availability of existing coverage and variability in scale of coverage worldwide.
- Difficult transfer of photographic record to digital record for computer-based interpretation and analysis (Kennie and Matthews, 1985).

Many of the shortcomings listed above have been overcome with the emergence of satellite imagery. The most obvious advantages are increased coverage, multispectral capabilities, and digital formats that can be processed by computers. Satellite imagery provides some of the best data for engineering activities at the regional level. Various interpretation techniques are available to acquire information relevant to engineering investigations, particularly for highway planning.

Landsat data provide all the factors which influence route selection through the interpretation of single band and multispectral imagery. As the planning of a highway project progresses from reconnaissance and feasibility through design and construction, the need for accurate assessments of the terrain increases. A detailed examination of the landforms, drainage, soils, and materials must be made along the proposed route corridor. A significant savings in construction costs are realized by reducing earthworks, bridge and drainage structures; by selecting the strongest soil foundation and locating sources of durable road building materials; and by avoiding swamps, shifting sands, landslides and

other areas prone to erosion (Kennie and Matthews, 1985). The ability to quickly examine features relative to detailed designs in a regional and often remote setting is a considerable advantage of remotely sensed imagery.

Given the selection of route alignments for highways, Landsat data may be further utilized to interpret physical and cultural features of the ground surface to plan and select suitable sites for airports and for town developments or expansions. These interpretations may also be studied in relation to existing land use categories and land potential to predict traffic patterns and characteristics. Landsat imagery can also help with investigations of the relationship between different modes of transportation. Satellite imagery has become an invaluable tool for various transport planning efforts through its ability to provide an up-to-date picture of a large area of the Earth's surface at a single point in time (Kennie, 1985).

Soil Studies

Development activities are directly affected by soil properties. Improper identification of soil cover may lead to unaffordable maintenance of engineering structures because of structural failure. As such, one of the most important tools for site analysis is the use of various remotely sensed data to evaluate the proper soil specifications for engineering projects such as dams, highways, and airports. Satellite images are used to define the major physical units of land surface and to delineate the boundaries. Larger scale aerial photographs can then be applied to terrain analysis processing and soil type reporting.

Engineers define soils as all loose unconsolidated material above bedrock which has been weathered from its original conditions. Both photographs and satellite images may be used to record soil attribute values or global parameters such as photographic tone. That is, a specific tone may indicate the presence of a specific soil type. A parameter is only accepted if it can provide a piece of evidence based on which different soils are discriminated. Some parameters include: landform identity (each representing a distinct soil characteristic, topography, rock material, and groundwater condition), erosion characteristics, DTM (digital terrain model) information, tonal aspects, drainage clues, and site associations.

An Expert System Model for Soil Mapping (ESM-FSM) has been developed to enhance manual methods of mapping soils. This Artificial Intelligence (AI) model is comprised of the following methodologies which represent the logical concepts and procedures that a human expert performs while conducting image interpretation for soil mapping.

- Investigate landforms and report their identity.
- Incorporated relevant information obtained from basic elements of image interpretation about soils.
- Input DTM information and obtain topographic and slope information.
- Investigate photographic tones and/or model brightness values of relevant soils.
- Identify all associations in the study area including land use and land cover.

- Formulate a hypothesis about expected soils in the study area.
- Verify the hypothesis with detailed investigations of erosion and drainage information.
- Conduct field checks if required.
- Accept or reject the final mapping of soils.

With the use of this system, as well as with manual methods, remote sensing techniques have provided efficient and rapid methods for identifying different types of soils, delineating their boundaries, and quantifying their suitability to different development activities.

Hydrogeology

Engineering investigations often involve consideration of the subsurface features of a site, particularly its hydrogeology. The mapping of different levels of suitability, and the detection of discontinuities and cavities, is one of the main problems of engineering geology. Knowledge of subsurface hydrographic networks is very important to evaluate the potential pollution related to the usual discharge of urban wastes into some cavities, and to explain alluvial events not apparently linked to local rainfall. Further, karst activities near coastal areas may allow the discharge of valuable freshwater springs along the sea shore. It is understandable that these territories, affected by considerable problems of water supply, present a number of concerns for the geologists and engineers in detecting and evaluating spring activity.

Thermal infrared flights and the analysis of the recorded images are very useful in dealing with the above mentioned problems. The existence of a physical underground discontinuity can be revealed by the surface distribution of thermal levels in both space and time. Due to the small content of heat in the soil over cavities, the temperature at the surface tends to drop. Negative thermal anomalies are then recorded on the thermography. Contour lines divide the content information of the thermography into isoradiants which are used to identify the most obvious anomalies. Figure 3.1 outlines the likely methods for indicating underground discontinuities (Marion, 1984).

FIGURE 3.1 METHODS FOR INDICATING UNDERGROUND DISCONTINUITIES.

HOMOGENEOUS ROCKS	Conventional photos	Unsuitable
	Near infrared	The superficial moisture, if existing, appears distributed in a homogeneous fashion
	Thermal data processing	Soft, slow variations of the gradient constant value of the thermal inertia
FRACTURED ROCKS	Conventional photos	Useful wherever surface phenomena are observable
	Near infrared	Useful for detecting the not homogeneous drainage at the surface
	Thermal data processing	High texture spatial frequency high thermal inertia wherever the water content is high

SINKS (dolinas)	Conventional photos	Very useful (particularly stereo pairs)
	Near infrared	Very useful. Superficial moisture stagnation revealed by near infrared opacity
	Thermal data processing	Of complementary utility
HYPOGEAL CAVITIES	Conventional photos	Unsuitable
	Near infrared	Unsuitable
	Thermal data processing	Very useful. Over empty cavities (no water inside) the inertia appears low. The texture analysis enhances the radial symmetry of the gradients.
UPWELLING SPRINGS (monitoring)	Conventional photos	Unsuitable
	Near Infrared	Unsuitable
	Thermal data processing	Mandatory. In particular: - level slicing -texture analysis

(Marino and Del Pero,1984)

The civil engineer may investigate a number of other hydrogeologic features which also become apparent with thermal infrared analysis. The presence of palaeoriverbeds is particularly important as they have the potential to supply building materials (sands, gravel, stones, etc.). Wet palaeoriverbeds may provide water for agricultural use and/or act as a cold source for heat pumps. The extent of moist areas as well as diffuse leakage is clearly important for civil engineering interventions. Local losses of water must also be kept under control to prevent them from becoming points of breakdown which decrease site stability. The identification of these hydrogeologic features is the goal of photo-interpretation and thermogram processing techniques. Figure 3.2 outlines the likely methods for indicating their presence (Marino, 1984).

FIGURE 3.2 HYDROGEOLOGIC FEATURES—LIKELY METHODS FOR INDICATING THEIR PRESENCE.

PALAEORIVERBED RECOGNITION:		
DRY (sterile) BURIED CHANNEL	Conventional photos	If detectable, revealed by the shape of field, old roads, etc.
	Thermogram	If detectable, revealed by the alternate anomaly along the edges
	Thermal data processing	Detectable mainly through the thermal texture analysis (frequency analysis, regional variation)
WET (flows through buried channel)	Conventional photos	If detectable, revealed by the physical status of the vegetation
	Thermogram	Observable as a continuous strip anomaly. For surveys performed in summer at the early morning, a positive anomaly has normally been expected
	Thermal data processing	Minimal value of normalized gradients -flat response in texture -soft, slow variation of the regional
MOIST AREAS, DIFFUSE LEAKAGES:		
SUPERFICIAL MOISTURE	Conventional photos	Useless
	Near infrared	Reduction of reflectivity

	Thermogram	Negative anomaly
	Thermal data processing	Low values of thermal levels - flat response in the texture - soft, slow regional variation
MASS MOISTURE	Conventional photos	Useless
	Near infrared	Useless
	Thermogram	Anomaly whose sign is related to the temperature of the supplying water. For surveys in the summer, early morning, the anomaly is positive
	Thermal data processing	High values of thermal levels, low values of co-albedo/emission
MOISTURE AT THE SURFACE AND IN DEPTH (saturation)	Conventional photos	useless
	Near Infrared	Reduction of reflectivity
	Thermogram	Negative anomaly
	Thermal data processing	Low values of thermal levels, very flat response in the texture, very slow regional variation, high values of co-albedo/emission
LINEARS:		
LINEARS ACCOMPANIED BY MORPHOLOGIC ASPECTS	Conventional photos	Very useful
	Thermal data processing	Useful
LINEARS WITHOUT ANY MORPHOLOGIC EVIDENCE	Conventional photos	Sometimes useful
	Thermal data processing	Very useful. In particular the texture analysis and the regional variation (whenever a hydrologic barrage exists)
LINEARS HIDDEN BY SEDIMENTS	Conventional photos	Not useful
	Thermal data processing	Very useful. In particular the texture analysis

(Marino and Del Piro, 1984)

A large portion of the information derived from remotely sensed data is very applicable to functions available in a GIS. This data combined with several other data sources can be efficiently stored, retrieved, manipulated and analyzed using the various GIS spatial operations. A significant potential exists for the integration of this data source at a local and regional level. The benefit of such input can provide extensive analysis for such areas as land and resource management, traffic planning, urban planning, and maintenance. For the installation engineer, the GIS can be an important tool for studies which concern the environment, irrigation, pollution, hazard warning and safety, and maintenance inventory of infrastructure.

Cultural Resource Management / Archaeology

Cultural resource managers often use a more broad definition of remote sensing since they are accustomed to examining surface as well as subsurface characteristics. The following categories of remote sensing are known to apply to cultural resource management.

Category 1: The above ground systems. This includes spaceborne and airborne platforms providing surface data in multispectral, hyperspectral, and radar data formats. The processing techniques for these formats have been standardized subjects of geography textbooks for years. There is plenty of software available that can simplify the task of processing this data, which offer a great deal of surficial analysis potential at all scales.

Category 2: The terrestrial based and subterranean systems. This group has primarily evolved from geophysical methodologies and basically collects stratigraphic data in formats such as: radar, acoustics, and magnetics. These systems are known to be applied extensively for intra-site characterization.

Category 3: Underwater systems. These systems are exclusively active systems. This is due to the opacity of water as a transmission medium for much of the electromagnetic spectrum. Acoustic, magnetic, and radar surveying have been utilized to discover and investigate numerous shipwrecks and underwater engineered structures because of their ability to see through the water. However, ground penetrating radar (GPR) is limited to fresh water applications due to high signal attenuation caused by salt minerals. The most prevalent problem with underwater remote sensitivity is that water efficiently absorbs infrared energy, it generally carries a lot of sediments, and it will reflect sunlight off of its surface, thereby causing visible darkness.

General Use

The concerns of cultural resource managers go beyond modeling the contemporary environment. Most often it is elements of some past environment that are of importance to cultural resource managers. The accurate representation of current conditions, however, can be necessary for a good historical model to be produced. Category 1 remote sensing techniques have been applied to cultural resource investigations for surficial contemporary environmental characterization at practically any resolution with great success. These characterization data sets are developed using automated classification techniques that can provide high thematic classification accuracy and sub-pixel spatial registration to other data sets such as: slope, aspect, elevation, proximity to water, soil drainage, and other non-spatial data with the aid of a GIS.

While remote sensing has been used for archaeological applications for some time, it is within the context of GIS that its potential is being realized (Madry, et al; 1995. Image processing alone can be used to characterize archaeological sites or their environmental associations successfully; but with the creative use of ancillary (non-image) data in a GIS, the themes of interest can be significantly better approximated.

Environmental characterization data sets that are ground truthed and registered into a GIS can function as a modeling parameter with a wide range of application. The search for archaeological sites may require many different methods, some of which have traditionally been performed by other land managers. For example, wildlife biologists and paleobotanists may be interested in developing a prehistoric habitat model which could be used to develop or upgrade cultural site probabilities constraints data. Remote sensing applications in these fields should be viewed as contributors to cultural resource investigations. As has been emphasized throughout this document, it is the versatility of remotely sensed data integrated with GIS that is its most important feature.

Predictive modeling emerged only recently as an important component of archaeological research (Carr, 1985; Kokler and Parker, 1986). An underlying key to the success of predictive models is the fact that archaeological sites tend to occur in favorable environmental settings (Warren, 1990). Classifying human induced alterations to the landscape serves two purposes. First, it is important to know the variation in site types that are present in a given area. Second, it is of major importance to demonstrate that cultural alteration to the landscape can readily occur at each type of site, as the function of each site dictates certain kinds of cultural landscape alterations (Cartsens et. al., 1983). As with other environmental phenomena, remote sensing techniques can be used to identify 'signatures' associated with cultural alterations of the landscape.

There are two major aspects of cultural signature recognition: interpretation and surface truth evaluation. Without careful consideration of these two components of cultural feature recognition, the validity of applying remote sensing to site identification, prediction, or management is meaningless (Cartsens, *et. al*., 1983).

Although artifacts are the most common material constituents of archaeological sites, followed by features and anthropic soils, the importance of these classes for remote sensing is reversed, with the most important group of site constituents for remote sensing being anthropic soils and anomalies in soil chemistry, followed by features, and then artifacts (Limp, 1989). Temperature and moisture retention differences caused by cultural compaction, deposition, or extraction can be used to locate anthropic soils. Visual and thermal infrared sensors are sufficiently sensitive to detect these differences in thermal exchange rates of the soil with the atmosphere.

The kinds of empirical methods used with environmental and archaeological data to develop cultural site probabilities have many dependent variables; however, some things are universal. The spatial coverage of both data types must be large enough to include significant heterogeneity; yet the spatial resolution must be fine enough for site characterization. Remote sensing techniques, particularly those involving the use of multispectral imagery, often provide the most cost effective approach for high resolution site prediction over large areas. This is because the thematic information that can be extracted from high resolution multispectral imagery can be finer, better quantified, and characterized with less field sampling than any other method.

Thematic precision like that which can characterize anthropic soils is necessary for identification. However, spatial precision is another fundamental consideration which is

necessary to characterize with some degree of accuracy. This consideration is usually the most heavily weighted variable in the overall scheme. It is the main determinant in choosing the image spatial resolution and georeferencing method. As with scale, the method of georeferencing chosen can place severe analysis limitations on the data.

Since Atkinson's utilization of electrical resistivity in 1946, archaeologists have increasingly employed classical geophysical methods (category 2 remote sensing) to successfully enhance many cultural resource evaluations (Weymouth, 1986). These methods include: seismic, gravity, magnetic, electrical resistivity, self-potential, electromagnetic and ground penetrating radar (Heimmer, and De Vore, 1995).

Throughout the seventies and early eighties, geophysical techniques have been used to create a 'context' for the results of archaeological excavations. However, as the needs of archaeologists have changed in the past decade, so has the role of geophysical techniques. Many surveys are now conducted to identify the most promising area in which to concentrate the scarce resources that are available for excavation and other intensive investigations. Some planning authorities have taken this concept one step further. Increasingly the object of a geophysical survey is not to establish where the limits of the site are, or where best to excavate, but to answer the question "...is there any reason to excavate within this threatened area?" (Gaffney et al; 1991).

Geophysical methods originated, and have been refined, by hydrocarbon and mineral prospecting. Typical target features for hydrocarbon and mineral prospecting are much larger than what can be expected for archaeological features. In order to apply these methods onto smaller targets, a higher degree of instrument sensitivity (finer spectral resolution) and more sampling points (finer spatial resolution) must be obtained for effective characterization of cultural indicators. The most applicable methods provided to date that fulfill this criteria include: magnetic, electromagnetic, and electrical resistivity techniques. Assessments utilizing acoustic (seismic), gravity and other variations of electromagnetic techniques have been reported in the literature and have exhibited limited success on a site specific basis (Heimmer, and De Vore, 1995).

A *magnetometer* may be used in surveys to identify the presence of historic shipwrecks (HS) and historic shipwreck/prehistoric sites (HS/PS). The magnetometer sensor is towed at a distance of six meters or less over the seafloor. A digital depth sensor is attached to the magnetometer sensor to record sensor depth. A sampling rate of <1 second intervals is recommended while the instrument is towed behind the vessel to at a distance of two and one-half vessel lengths to eliminate the magnetic influence and effect of the vessel.

A *dual channel side-scan sonar* system may be used to record continuous planimetric images of the seafloor. Various seafloor objects and features within the survey area may be obtained.

A *subbottom profiler* may be used to determine the character of near-surface geological features. The data obtained can be evaluated to determine if the features have any possible prehistoric archaeological significance. Resultant resolutions can equal 1 to 2 meters within the upper 15 meters of sediment.

Depth sounders are used to obtain continuous water depth measurements. A high-frequency narrow-beam depth sounder can produce bathymetric data from a recording sweep that is approximated to existing topography and current water depth.

Additional offshelf coastal investigations may be made through the use of underwater television, still video or movie cameras, divers, remote or manned submersibles, coring, and additional geophysical survey lines. One of the most sensitive devices is the Thermal Infrared Multispectral Scanner (TIMS), which can measure thermal radiation given off by the ground. TIMS can distinguish forested areas that reflect heat differently from less densely vegetated regions and may be able to distinguish the wavelength emitted from one species of tree that is often associated with Mayan ruins. Another instrument which has obtained favor among archaeologists is the Calibrated Airborne Multispectral Scanner (CAMS), a 9-channel instrument that scans the visible and near infrared.

Advancements in the high-tech methods of surveying the landscape from satellites, the space shuttle, and airplanes have given archaeology and paleoanthropology a considerable boost. Archaeologists were once skeptical of satellite observation because of its cost and complexity; however, they are now beginning to accept it as a standard modeling method. Current images from Landsat, SPOT, and the space shuttle are much sharper than their predecessors, and new airborne instruments cover a far greater range of the electromagnetic spectrum. This is extremely useful to anthropologists, since human made features, such as ancient ruins, often emit infrared radiation at different wavelengths from their surrounding vegetation.

Case Studies

A team of paleoanthropologists have successfully analyzed Landsat data to select an area which had a high potential of fossil beds. A likely place to look for these fossils was in ancient sediments which reflected light in a characteristic signature that set them apart from more modern terrain. The team looked for the signature of eroded sediments, which were recognizable in Landsat scenes as highly reflective gray patches. Using both the Landsat images and photos taken by aircraft and the space shuttle's Large Format Camera, they studied the faults and drainage patterns to predict which regions had the right kind of geologic structure to contain fossil beds. Following a subsequent survey on foot, the team found a remarkably rich sequence of ancient sediments in a 45 km x 5 km area. Their findings included 3.76 - 2.23 million year old rocks and the fossils associated with them, and 1.04 - 1 million year old volcanic layers with hand axes and fossils sandwiched between them. The most significant discovery was fossil hominid teeth that are at least 3.7 million years old and are among the oldest remains of the species *Australopithecus afarensis.* These teeth are now helping anthropologists pinpoint the age and distribution of that species, which is thought to be ancestral to humans and several other hominids. The satellite data proved to be an effective navigational tool which helped turn an enormous area into a manageable one.

Another team searching for the remains of the 31 B.C. city of Nikopolis, in Greece, has employed SPOT satellite data as well as multispectral aerial photos to prioritize buildings and areas that need further study and excavation. This data saved them time and gave

them a broader view of the buildings, roadways, and other structures in the walled city and its suburbs. Other remote sensing studies of the range and subsistence strategies of ancient and modern people in the Amazon, Africa, and North America are also improving anthropologists' understanding of how these cultures used the environment and interacted with their neighbors.

Table 3.1 offers some guidance regarding the preferred data characteristics for classification tasks across the categories defined above.

Table 3.1 Preferred Data Characteristics For Classification Tasks.

Instruments	**Platform Data Is Acquired From**	**Category**	**Spectral Characteristics**	**Spatial Resolution**
SPOT	Satellite	ONE	3 channels	10 - 20 meters
Landsat	Satellite	ONE	7 channels	30 - 80 meters
DAEDULUS	Airborne	ONE	11 channels	
ADAR	Airborne	ONE	4 channels	0.5 - 20 meters
BENDIX	Airborne	ONE	N/A	
TIMS	Airborne	ONE	6 channels	
XYBION	Airborne	ONE	N/A	0.2 - 20 meters
AVIRIS	Airborne	ONE	>200	
HYDICE	Airborne	ONE	>200	
SOVIET, KATE	Satellite	ONE	3 channels	15 - 30 meters
SOVIET, MKF	Satellite	ONE	6 channels	20 meters
SOVIET, KFA	Satellite	ONE	2 channels	5 - 10 meters
SOVIET, SMK-6M	Satellite	ONE	6 channels	
CAMS	Airborne	ONE	9 channels	
RESISTIVITY METER	Satellite	TWO	N/A	N/A
PORTABLE PROTON MEMORY	Ground Based	TWO	0.1 gamma	N/A
MAGNETOMETER MODEL G-856	Ground Based	TWO	0.1 gamma	N/A
GROUND PENETRATING RADAR	Ground Based	TWO	40 Hz	N/A
SEISMOGRAPH	Ground Based	TWO	1000 channels	N/A
SIDE SCAN SONAR 500SS	Water Based	THREE	4 bits	N/A

Soil Studies

General Use

Few people would argue about the value of soil moisture data for irrigation, planting, and other related fields. Estimates of soil moisture are useful in many scientific fields, such as global change, wetland delineation, troop deployment, and mobility. Because remote sensing has some notable advantages over traditional soil moisture data collection methods, it also has been applied to agriculture for the determination of irrigation requirements and in determining the most optimal time for crop planting.

Microwave data (1.4 to 18 GHz) has been used to measure soil wetness under different surface roughness and vegetation cover conditions. The optimum frequency for soil moisture studies is 1.4 GHz (Schmugge, et al., 1986), although higher frequencies have shown promising results (Choudury and Golus, 1988). The effects of surface roughness and vegetation are the main difficulties in estimating soil moisture.

The survey of passive microwave remote sensing for soil moisture in the U.S.S.R conducted by T. J. Jackson (1982) indicated that microwave radiometer shows apparent variation of soil moisture. Basharinov et al. (1979) utilized a 3-cm wavelength radiometer to survey soil moisture in an area of the Krymsie region of U.S.S.R. Data from a 10 km2 area was acquired using an aircraft sensor. The soil moisture analysis was produced with 100 m resolution.

Ulaby (1979) also studied the active microwave radar image to map soil moisture. His conclusions were:

1) The effect of surface roughness can be minimized.
2) Vegetation shows a minor influence on the soil moisture.

Microwave remotely sensed data can also be used to detect shallow water tables. Basharinov et al. (1979) conducted a study to estimate water table parameters underneath dry soil.

Yield Prediction

Remote sensing applications in crop yield prediction are theoretically simple and straight forward. Use of remote sensing techniques in this field have proven very cost effective and successful. In a given study area, the interpreter needs to determine or estimate the area and yield crop type. The total production effort can be estimated as the product of the area times the yield per unit. In practice, this process is complex. Successful crop yield prediction involves climatic and meteorological conditions. This process requires correlation between leaf reflectance and crop yield. Also disease, insect infestation and other stress-producing agents must be considered.

Large Area Crop Inventory Experiment (LACIE) was the first comprehensive study conducted on a regional and/or country level (Macdonald and Hall, 1980) of wheat production forecasting using satellite data. Similar studies have since been carried out in many countries including Argentina (Redondo, et al. 1985), Australia (Dawbin and Evans, 1988), Brazil (Moreira et al., 1986) and Sweden (Hall-Knoyves ,1990).

In 1992, V. N. Sridhar and a team of experts conducted a study of wheat production forecasting in a predominately dry farming region of Madhya, Pradesh, India, using digital data from LISS-I (Linear Imaging Self Scanner) on board India Remote Satellite (IRS-1B) for the crop season 1991 - 1992. The procedure involved a sample segment approach for acreage estimation, and created a spectral index-yield relation for yield forecasting. Also, it used the conventional yield forecasts as a component which combined remotely sensed data in the procedure to produce lower bias and higher precision forecasts. The study suggests that higher accuracy could be archived by

reducing remotely sensed based acreage bias as well as sampling errors, and the yield forecasts could be improved by incorporating acquisition date correction using weather-based yield models (Sridhar et al., 1994).

Pest Infestation Studies

General Use

Crop disease and insect infestation are one type of crop stress. As previously mentioned, the IR wavelength can discriminate healthy crops and stressed crops because they have different reflectance at the designated wavelength. This is the basic principle behind the application of remote sensing to this type of crop stress.

Aerial photography is the most commonly used remotely sensed data for crop condition assessment because of its high resolution. Studies have proven it useful for identification of numerous crop's deleterious conditions due to disease, insect damage, and plant stress from other causes (Lillesand, 1987). However, it is much more difficult than aerial photo interpretation for crop identification and area inventory. In aerial photo application, ground reference data are essential, and in most studies to date, comparisons have been made between healthy and stressed crops growing in neighboring fields. Under these circumstances, analysts might discriminate between finer differences in spectral response than would be possible in a noncomparative analysis. This means the level of success would be lower if the analyst did not know a stress existed in an area. It would also be more difficult to differentiate among the effects of disease, insect damage, nutrient deficiencies, or drought, from variations caused by plant variety, planting rate, or background soil color differences. Because many stress effects are most obvious during dry spells, photographs should not be taken soon after rainy weather.

The best-known and most successful use of IR and color IR photography is that on potato blight detection in Maine (Manzer and Cooper, 1967). Infrared photography was acquired from periodic survey flights over potato fields sprayed by aircraft. This data successfully determined where added fungicide protection may be needed. Moreover, the ability to obtain current information on disease incidence over a large area was useful in plant protection work. Some of the plant diseases that have been detected using aerial photo interpretation include southern corn leaf blight, potato wilt, sugar beet leaf spot, stem rust of wheat and oats, and bacterial blight of field beans. Examples of insect damage previously detected include aphid infestation in corn fields, red mite damage to peach tree foliage, and plant damage due to fire ants (Lillesand, 1987).

Natural Vegetation Management

General Use

Steadily increasing world population, global warming, acid rain, and rapid losses in biodiversity, as well as a diminishing supply of fossil fuel and nonrenewable resources, have focused the world's scientific communities' attention on the world's renewable resources and their conservation and development. Forests serve as a vital part of the

important renewable resource base and are one of the most important components of terrestrial ecosystems. Forests have considerable influence both on the hydrologic cycle and the carbon cycle. They exchange a large amount of energy between the tree canopy and the atmosphere and offer a substantial source of oxygen when growing and carbon dioxide when burning or undergoing decomposition. Forests become a substantial sink of carbon dioxide during forest regeneration. As a consequence, it is important to provide quantitative tools to analyze the dynamic changes occurring in forests. Management of the world's forest resources varies widely in purpose, intensity, and degree of sophistication.

Classification and inventory of current vegetation is useful for all land management activities and essential for missions such as forest planning, ecological unit mapping, and wildlife habitat modeling. Unfortunately a vegetation classification is also expensive, and the data can be difficult to acquire, interpret, and update. Traditional vegetation classification methods, such as interpretation of aerial photographs, require large expenditures of time, money, and effort and are required to be frequently performed.

The only practical and economic way to regularly monitor forest extent and productivity on a large scale is by satellite remote sensing. The possibility of using satellite data for land cover classification and vegetation mapping has been explored for almost two decades. This technology provides an extremely useful tool for vegetation mapping and forest inventory management. In the remote sensing of forest resources, there is a need for a variety of resolutions, both to cover the range of problems involved and to integrate detailed and broad-scale knowledge into management planning. Timber inventory, for example, requires detailed information on species composition, which can be determined in many cases only with very-low-altitude aircraft photography (necessary to obtain fine resolution, large scale, and stereoscopy). At the same time, this very detailed, localized information may be ignored when addressing much larger areas. For such large areas, the very detailed resolution is neither necessary nor reasonable in terms of cost, acquisition, or processing.

Tree Species Identification

Tree species identification is part of detailed vegetation classification for forest-level planning. It is generally more complex than agricultural crop identification. A given area of forest land is often occupied by a complex mixture of many tree species, as contrasted with agricultural land where large, relatively uniform crop fields are encountered.

Usually a detailed vegetation classification scheme is divided into three basic vegetation characteristics: cover types, tree crown closure, and tree size and/or structure. Individual tree species have their own characteristic crown shape and size. The arrangement of crowns produces a pattern that is distinct for many tree species. Also, when trees are isolated, shadows can provide an unique image of the tree and are useful in species identification.

For over two decades, various ways have been established to identify tree species. Microwave remote sensing has been widely applied in tree species classification because of its intrinsic capability to image the Earth's surface independently of cloud cover and

solar illumination. This characteristic gives a considerable advantage over visible and near-infrared imaging systems. Microwave remote sensing systems also provide different information from that obtained by optical systems, especially at the longer wavelengths, which penetrate deep into the vegetation canopy.

A fundamental understanding of the interaction of microwave backscatter with vegetation is required before radar can be completely interpreted for vegetation classification. By first modeling the interaction of microwave data with the forest canopy, and using a model to study relatively small areas using microwave imagery and detailed ground survey information, it is possible to determine the optimum characteristics of the microwave image system for reliable tree species classification.

A study was conducted by J.R. Baker and others in tree species identification using aircraft synthetic aperture radar (SAR) systems. The purpose of the study was to establish the relationship between physical characteristics and polarimetric radar backscatter for Corsican pine in Thetford Forest, U.K. and then predict the timber volume based on the classification (. Baker et al;1994).

In this study, the SAR data was first processed and calibrated including polarimetric calibration, and absolute calibration. Secondly, six to ten sample plots were laid out for measurement of tree height and diameter according to the standard methods of normal forest measurement, which do not include measurements on felled trees. The plots were 0.01 to 0.04 hectare in area, so as to include at least seven trees. The study demonstrated the relationship of stand characteristics of Corsican pine with age are highly correlated with each other. Trees normally increase in size over time and stands decrease in density as thinning takes place.

The study conclusion was that the longer wavelength P and L band data show a systematic increase of backscatter with age of Corsican pine. Age was used as a surrogate for measures of tree size and stand size. This relationship is particularly well defined for some angles of the SAR image. It also appears that the shorter wavelength C band has difficulty discriminating between grassy ground vegetation and young groups of surface layers of tree canopies resulting in little differentiation with group age. However, the C band data does supply information on the difference in the twig and leaf structure in the outer layer of the canopy thereby providing a discrimination capability between age groups of different species.

Another study (Woodcock et al., 1994) used Landsat TM imagery of Sierra Nevada Mountains of California to estimate mean tree size and cover for each forest stand from a canopy reflectance model. The Landsat TM images were analyzed to determine the growth form of all vegetation types and the physical structure of the conifer forest stands in particular. Ecological models based on terrain relations were used to predict species associations for the conifer, hardwood, and brush growth forms. Through the study, the assessment of thematic map accuracy was shown to be high as well as high accuracy for growth forms, species association labels, and conifer cover. However, the tree size labels were unreliable on a stand-by-stand basis.

Vegetation Classification

To monitor forests at regional and national level, very detailed, localized information needs to be ignored. For such a large area, the very detailed resolution is neither necessary nor reasonable in terms of cost, acquisition, or processing. Following is a case study conducted by the National Park Service for vegetation mapping. The National Park Service used a specific approach to reduce classification error.

Project Approach Steps:

1. Project Design

Five land cover classes for the forest were developed to meet needs for monitoring the regional level. These five classes are Conifer, Hardwood, Shrub, Rock, and Water.

2. Study Area and Data Acquisition

The Flatfoot National Forest covers two million acres of forest and rangeland. Existing data sources include forest inventory plot data, 5-year-old 1:24,000 color resource aerial photography for most of the forest, 10-year-old orthophotos, and miscellaneous field plot data from soil, habitat, and ecosystem surveys. The forest used current Landsat TM satellite imagery for this forest-wide vegetation map.

3. Preprocessing

Essential preprocessing details include preparation of ancillary data (existing data other than the imagery) and spectral band analysis. Spectral band analysis is a statistical investigation of the satellite image prior to the actual classification. It also includes atmosphere and geometric correction for the original remote sensing data. Aerial photographs and orthophoto quads should be organized and made available at this time.

4. Unsupervised Classification

An unsupervised classification produces a map of the variation inherent in the image based only on the imagery. Because it does not require training sites, the classification is relatively quick and should be done in the office prior to beginning field work. It will produce the spectral classes which are labeled and grouped into five land cover classes to form a preliminary map.

5. Produce Draft Maps for the Field

Hard copy output of the unsupervised classification should be carried into the field. Field personnel can then evaluate spectral groupings shown on the unsupervised classification with actual ground conditions. In this way field personnel gain hands-on familiarity with the differences between what the computer “sees” as distinct vegetation classes on the imagery and what the field personnel can identify on the ground and on the aerial photos.

6. Field Evaluation and Data Collection

Field work for digital image classification consists of identifying and collecting data on areas representing the various vegetation types in the classification scheme. Suitable sites

are identified from the unsupervised classification, from aerial photographs, and from other sources such as inventory plots. These sites will be used to:

- Label the unsupervised classification
- Aid in a subsequent supervised classification
- Provide reference data to assist the image analyst

When a supervised classification is used, these areas are called training sites since they will "train" the image processing software to recognize the rest of the image. Multiple training sites must be identified in each category of the classification system so that all of the variation in the vegetation is covered. Once field personnel are familiar with the vegetation, additional training sites can be identified and interpreted on aerial photographs without field visits, thereby increasing the number of training sites.

Accuracy assessment sites should also be collected at this time. These sites are generally identical to supervised training sites, with the exception that those sites are not used in the classification but serve for assessing accuracy after the classification.

7. Supervised Classification

A supervised classification is often employed to provide further separation of vegetation classes when unsupervised classification alone proves inadequate.

During supervised classification, each training site is located on the satellite image, and its value is entered into a database accessible to the image analyst. The image analyst determines which parts of a classification are acceptable, then uses additional training sites and ancillary data to reclassify the trouble areas.

8. Final Image Analysis and Accuracy Assessment

Final image processing steps include: stitching the classification back together to form a seamless file, integrating the training site database into a GIS database, and preparing the classified image for input into GIS.

Accuracy assessment is the comparison of the classified data for these sites to the reference data for the same sites. Accuracy depends on the collection of reference data. Accuracy assessment sites collected during the field work are pixels, groups of pixels, and polygons, and they are supposed to be 100% accurate in theory. They are then located on the final classified imagery, and entered into the database.

This project produced 74% overall accuracy. For specific categories, such as conifer, barren, and shrub, it has 79%, 74%, and 64% accuracy, respectively.

9. Create Final Products

Hard copy maps and digital products must be finalized for the end user. Digital products can be used as inputs into GIS and for creation of more specialized output products.

Vegetation Change Monitoring

Changes to our environment are of critical concern in our world today; consequently, monitoring such changes and assessing their impacts are tasks demanding considerably higher priority. The knowledge of vegetation type and status is considered extremely important in order to assess a land cover stratification and to monitor the behavior of the ecosystem. The knowledge of vegetation classes is fundamental for the assessment of the plant community ecosystem, but it is not very useful to monitor environmental changes over time.

Vegetation monitoring is usually accomplished by computing "vegetation indices," which are generally ratios or linear combinations of red and near-infrared (NIR) spectral bands. Vegetation indices are more sensitive than individual bands to vegetation parameters such as biomass and percent vegetation cover. This is especially useful when satellite data are available at high temporal frequencies, with fine spatial resolutions. Vegetation index is a number that is generated by some combination of remote sensing bands and may have some relationship to the amount of vegetation in a given image pixel.

Among all vegetation indices, Normalized Difference Vegetation Index (NDVI) is the most commonly used index. The concept of NDVI was first presented by Kriegler et al. (1969). The Normalized Difference Vegetation Index was computed on a pixel by pixel basis for each image:

$$NDVI = \frac{NIR - red}{NIR + red}$$

This equation produces NDVI values in the range of -1.0 to 1.0, where negative values generally represent clouds, snow, water, and other non-vegetated surfaces, and positive values represent vegetated surfaces.

The utilization of satellite data for vegetation change monitoring has been explored for more than two decades. One of the most important IR data sets is AVHRR data from NOAA satellites. AVHRR data is one of the best data sets available for large scale environmental monitoring because of its high temporal resolution and relative low cost.

Some theoretical models on primary production significance of vegetation indices (Seller, 1986) indicated NDVI by AVHRR data as representative of plant assimilation condition and of its photosynthetic apparatus capacity. These results have been confirmed by a number of studies where the vegetation index has been correlated with the gross assimilation rate and dry matter increase (Maligreau, 1986). Strong evidence was also found of vegetation index correlation with plant phenology. Phenological changes in time have been detected by NDVI for cultivated and natural vegetation in normal and exceptional years (Maligreau, 1986).

Water Resource Management

General Use

The role of water resource management research is to assess the activity of hydrologic features above and below the Earth's surface. Areas of research focus include ground-water exploration, mapping of snow and ice, description of the dynamic and chemical parameters of water bodies, the measurement of evaporation and transpiration, and erosion and sedimentation studies. These water management studies are particularly important due to the direct impact which water development projects have upon the environment, and the indirect impact of such projects upon the social and economic well being of our society (Friedman, 1968).

Many remote sensing applications have resulted from the various problems created by climate, topography, and the fact that water resources management involves the assessment of water resources underground, on the surface, and in the atmosphere (Simons, 1975). More specifically, terrestrial water supply, water demands, watershed runoff characteristics, and water quality are commonly studied with the use of aerial photography and satellite imagery. Remotely sensed data can provide wetland managers with a wealth of information for the inventory, classification, and monitoring of wetlands, and also for many water-resource management decisions. The advantages of applying remote sensing techniques to solving these problems are several:

- Reduction in costs and manpower for extensive ground surveys.
- More rapid completion of inventory or mapping.
- More efficient monitoring and change detection, whether seasonal, successional, or manmade.
- Collection of multipurpose data useful to future projects and projects not under consideration when data collection was planned.

Some of the disadvantages include:

- The necessity for field checks or "ground truth" data.
- The difficulties encountered in scheduling simultaneous ground data collection for subsequent interpretation of the remote-sensing image data.
- The lack of efficient storage and retrieval methods for the large quantities of data generated by remote sensors (Anson, 1973).

Specific Applications of Remote Sensing

Some of the specific remote sensing data sources which contribute to hydrologic studies include:

- Satellite imagery and aerial photography (can display surface drainage patterns which help to identify surface input and output).

- Thematic extractions from imagery (can show standing water beneath trees and moisture conditions).
- Aerial photography (can be used to establish areas for detailed study, such as the drilling of observation wells, location of stream gauges, and observation of stress).
- High and low altitude aerial photography and imagery (can be useful for vegetation mapping, whether gross or detailed. The various vegetation communities are associated with differences in water level and soils).
- Thermal imagery taken from low altitude during the winter (could yield important information on areas of ground-water inflow. As wetlands represent a surface-groundwater interface, the movement of water beneath the surface is as important to a swamps existence as the surface water). (Anson, 1973)

While remote sensing can be used to define the landcover differences the hydrologist must consider, the GIS is needed to define differences in watershed shape, topography, and soil conditions (Brooner et al., 1987). In one instance, a GIS has been developed in which a land cover classification and a terrain model have been interfaced with a groundwater recharge model to provide estimates of the spatial variation of recharge which had previously not been possible. Very often, a GIS will be used to create a Digital Elevation Model (DEM) to allow the calculation of slope, aspect, and altitude. When drainage details and land cover information from remote sensing are integrated with the DEM, a spatially based hydrological perspective is generated (Barrett and Brown., 1989).

The U.S. Army Corps of Engineers developed an integrated groundwater and land-use GIS for impact assessment using information obtained from the Red River Groundwater Impact Study. The GIS was used to evaluate the effects of navigational pools on groundwater conditions. The goal was to evaluate the change in groundwater conditions and conduct an objective evaluation of land-use impacts, particularly upon agricultural crop lands. The integrated GIS consisted of pre-project and post-project groundwater levels, ground surface elevations, and land-use types. Landsat data was classified using unsupervised and supervised remote sensing techniques to generate land use types. It was determined that GIS was an efficient and objective method for the comparison of varied data sets through time. It was also determined that GIS technology can be accepted as another analytical tool for groundwater assessment.

Early work by the Hydrologic Engineering Center (HEC) and many other organizations realized the limitations of applying satellite imagery to hydrologic modeling. One of the main problems was in the management of the data. Landsat proponents did not fully recognize that land cover was only one of several data sets required for the modeling of a watershed. Even though broad area land cover could be defined in a matter of hours, it still required many weeks to develop the soils, topography and socioeconomic information before the land cover could be “overlaid” on the other data sets. The critical missing element needed for success had been an efficient, readily available, method for digitizing, merging and managing the numerous data sets. Today information requirements and simulation models have been developed for the Corps of Engineers, and water resource management organizations throughout the world.

Landsat MSS data had previously been used to analyze the watersheds of four drinking water reservoirs. Land uses in the watershed were determined using maximum likelihood techniques for subsequent years and placed into a GIS. Other variables which are known to influence the quality of water flowing over the land surface (e.g. soil type, slope, length of slope, and rainfall occurrence) were also entered into the GIS. Watershed predictions of average reservoir water quality were made which ultimately helped decision makers responsible for drinking water in the reservoir. The predictions guided the selection of water treatment options, whether the options involve non-point pollution control or treatment of water at the point of withdrawal.

Aquifer Recharge Studies

The concept of recharge, or the balance of rainfall, evapotranspiration, and infiltration is important to water resource management. Remote sensing techniques provide a way to make spatially varied estimates of the key parameters in recharge including climate, land cover, soil type, and topography (Barrett and Brown, 1989). Agricultural water-demand prediction may also be made with the modeling of crop types, evapotranspiration characteristics of the crops, and soil moisture characteristics (Gaile Willmott, 1989).

Soil Moisture

A distinct relationship between the radiometric temperature and the soil moisture content near the land surface has been discovered through the analysis of microwave data. Passive microwave emission in the 1.4 GHz region is found to be highly correlated with soil moisture in the top 5 cm of the soil. Multispectral thermal remote sensing may also be used for estimating soil moisture and evapotranspiration from bare soil and vegetated surfaces. This type of information is extremely valuable to all groups and individuals interested in watershed utilization and development. Knowledge of the moisture values at any point in time over the total watershed can greatly increase the precision of runoff and sediment discharge estimates which may be critical during periods of storm.

Evapotranspiration Studies

Evapotranspiration rates are vital to irrigated agriculture and water supply for all users. By studying the agricultural landscape, these rates may be mapped and subsequently used in the development of operational irrigation scheduling management systems. Although rate estimations may be made from the analysis of satellite and aircraft sensed data, their accuracy's are increased with ground measurements.

Flood Analysis

During periods of flooding, large areas adjacent to river and stream channels can be subjected to various degrees of inundation. Basic information on the extent and potential frequency of flooding is essential for efficient land utilization. In evaluating the potential for flooding, the hydrologist may obtain information regarding the watershed's characteristics (geometry and geology), vegetative cover, soil type, soil utilization, antecedent moisture, snow cover, and so forth. Aerial photographs may be studied in

parallel with stream gauging records to assess past flooding occurrences and help predict future storm potential.

Water Quality Management

The study of water quality can greatly benefit from remotely sensed data. The inflow of contaminated streams to main-streams, as well as the mixing of flows from sewage treatment plants and industrial plants, greatly effect water quality. Remotely sensed data has been used to differentiate between these polluted effluents and the better quality water, while providing information concerning the rates and extents of this mixing with respect to time and space. Satellite imagery has been analyzed to classify water quality on both lakes and rivers according to their depth of biomass and sediment. Thermal infrared sensing have been instrumental in detecting and identifying ocean-surface oil slicks and vapors associated with schooling fish and petroleum-oil pollution.

Wells and Springs Studies

Locating and mapping flowing artesian wells and natural springs is a very time-consuming task. Successful remote mapping of flowing springs and artesian wells has been accomplished using thermal predawn imagery. A snow-covered terrain provided optimal temperature contrasts between the well sites and springs and the surrounding landscape. By obtaining nocturnal thermal imagery, features such as trees, haystacks, etc. (Anson, 1973) can be identified.

River and Lake Management

Both present day conditions as well as those occurring over time can be recorded through the application of remotely sensed data. Given the spatial characteristics of extensive lake and river systems, an aerial view of the region is very convenient for study. Detailed studies of rivers are made to record information concerning the location of the navigation channel, the distribution of sediments in a river cross section, the distribution of stream velocities, and so on. Thermal characteristics of lakes and streams are made using thermal-infrared sensors. Landsat MSS satellite data is used to study suspended sediments and chlorophyll concentrations in lakes and to compute relations between rainfall and seasonal lake surface areas.

Geologic controls and other major structures along a river may be identified by using remotely sensed information from satellites and aircraft. Such data can help to identify the different types of soils making up the riverbanks and the land adjacent to the rivers. Different types of vegetation can also be observed and related to soil type. Rivers can be classified according to form and, because they are so dynamic in nature, a sequence of photographs taken over a period of time provides information on the rate of change with respect to time.

Coastal Zone Management

Coastal studies encompass the near shore hinterland including coastal dunes, estuaries, wetlands, sea cliffs, and the shore zone (Gaile and Willmott, 1989). Remote sensing in the coastal zone is used to inventory and model geomorphology, shore-protection

conditions, and estuaries. These studies require data that have high spatial and temporal resolution. Historical and short-time lapse aerial photography are ideal for the high spatial and temporal resolution that is required. Ground-penetrating radars show promise for assessing depth information in terms of stratigraphic relationships of deposited coarse sediments. Active and passive microwave techniques are used to obtain water-depth information. The spatial resolution of Landsat and SPOT sensor systems make satellite data viable for regional-scale studies of coastal morphology. Infrared and microwave techniques have been used to monitor and survey coastal water temperatures and salinity characteristics. Multispectral scanner data has been analyzed with computer based pattern recognition techniques to classify marsh vegetation (Bock et al, 1974).

It is possible to study the long term changes in beach width utilizing multi-dated aerial photographs and satellite images. In a recent study, multi-date remotely-sensed data has been used to monitor recent changes along the coast in parts of India. Satellite imagery provided a synoptic view of the terrain which lead to detailed studies at different scales, utilizing available data such as aerial photographs and topo-sheets. The information obtained has been utilized to identify possible paleoshorelines, indicating subsequent stages in the advancement of land. This combination of different approaches has led to a deciphering of the evolution of part of the west coast of India.

Ocean Studies

The ability to remotely monitor the temporal and spatial variations of sea-surface temperature and salinity is useful in the study of ocean circulation problems and is of economic value to ocean-oriented industries (Ulaby, 1986). Water temperature is a commonly measured characteristic of the sea since it is fundamentally related to many marine processes, including the distribution of marine life. Oceanographers have a need for highly accurate (+ or - 0.01 degree C) data on water temp, usually as a function of depth. However, there are many large scale dynamic thermal features of the ocean which are characterized by sizable discontinuities in the sea surface temp. These can be adequately studied only through near-synoptic and frequent repetitive measurements over wide areas, a need which remote sensors mounted in aircraft and spacecraft are helping to satisfy.

Both launched in 1978, the Seasat-A and Nimbus-7 satellites afforded the first opportunity to conduct a comprehensive evaluation of the use of microwave radiometric techniques to monitor the dynamics of the ocean surface from space. Each of these satellites carried a *Scanning Multi-channel Microwave Radiometer* (SMMR) whose purpose was to provide “nearly all-weather observations of the sea-surface temps, near-surface winds over the oceans, water vapor over oceans, sea ice concentration, sea ice age, sea ice radiating temp, and snow cover over terrain (Ulaby et al, 1986). Thus, SMMR became a primary ocean sensor.

Other remote sensing techniques can be used to map water quality and pollution through the study of physical and biological oceanography. By obtaining the spatial characteristics of biophysical properties of water such as temperature, chlorophyll pigments, suspended sediments, and salinity, so called “natural tracers” can be monitored on time sequential

images that are spatially registered to infer circulation patterns (Gaile and Willmott, 1989). Physical oceanographic studies are primarily associated with the use of AVHRR infrared imagery. Studies of living marine resources in the sea have made use of the Nimbus Coastal Zone Color Scanner (CZCS) and AVHRR imagery. Aircraft, Shuttle Imaging Radar (SIR), and Landsat MSS data have been used for the detection and mapping of surface oil slicks.

Sea Ice Studies

Sea ice interacts closely with the global heat budget (heat loss through open water is roughly 100 times the value through thick ice) and is an extremely sensitive indicator of climatic change. Monitoring the spatial and temporal variations of sea ice is also important to industries involved in exploration for the transportation of mineral and petroleum resources in the polar regions. Further, military and civilian vessels navigating in polar seas are likely to be safer, and more efficient, if they have access to information about the types of ice they may encounter. (Ulaby et al, 1986)

A number of remote sensing studies have evolved from the need to monitor important variations in sea ice. The scientific community is interested in mapping the distribution of sea ice and sensing its properties. Passive microwave radiometers and imaging radars are used routinely by scientists for sea-ice observations and studies. The value of microwave observations for these studies stems from the all-weather capability and the large contrast between the microwave-brightness temperature or radar-backscatter properties of sea ice and open water.

Snow Cover Analysis

Snow cover is also an integral part of the hydrologic process. The effects of snowmelt contribute to floods and droughts, and to the availability of water for irrigation, industrial production, hydropower development, recreation, and so on (Simons, 1975). Remotely sensed imagery in the 1.55 to 1.75 μm region can be used to discriminate snow and clouds. Also, near-infrared Landsat and NOAA meteorological satellite data may be used to distinguish new snow from that which has been melted. Unlike satellite visible and infrared data, passive microwave remote sensing allows for data acquisition during cloudy conditions and provides measurements of snow-water equivalency (Gaile and Willmott, 1989).

When using AVHRR 1 imagery, the spectral response of snow and clouds overlaps considerably which prevents a reliable discrimination; however, the snow/no snow contrast is strongest in this channel. AVHRR 3 imagery also overlaps in response with clouds composed of small ice particles and water droplets; however, clouds in which the particle diameter exceeds the wavelength (3.55-3.95 μm), are considerably brighter in AVHRR 3 imagery and contrast dramatically with the darker snow. In AVHRR 4 imagery, clouds often maintain a lower temperature than the snow, allowing some separation between the two surface types. Overall, a combination of AVHRR 1, AVHRR 3 and AVHRR 4 in allows for the clear detection of snow covered surfaces (Barrett Brown., 1989). Furthermore, it has been verified that there is a dramatic decrease

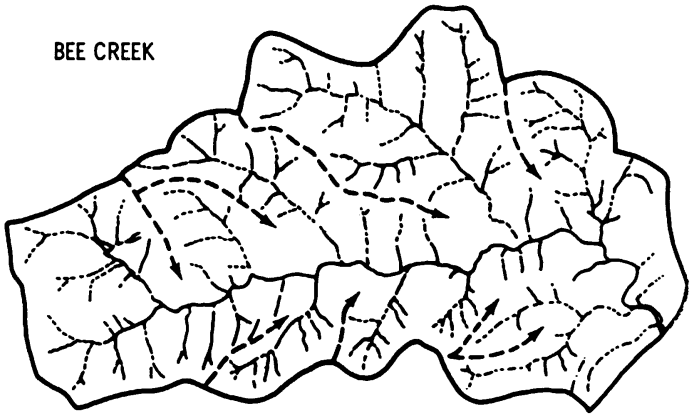
in the reflectance of snow cover in the near-infrared (1.55 to 1.75 μm) portion of the EM spectrum which enables a differentiation between snow and clouds (Simons, 1975).

Multispectral comparison of satellite imagery has been used to delineate that part of the snowpack actively undergoing snowmelt as continued surveillance identified the active and inactive parts of the packs. These recordings were then measured as against the runoff of the watershed at any particular period in time. As such the measurement of satellite-derived snow cover areas have been systematically related to seasonal streamflow (Simons, 1975).

Watershed Management

In order to understand and utilize our water resources, it is necessary to understand the complexities of our watershed systems. Figure 3.3 is a schematic of a stream network for a particular watershed. These intricate networks may be identified and studied using data from Landsat and aircraft sensors. Satellite data is indispensable for an overview of the watershed and in determining some of its major features. On the other hand, aircraft data is extremely valuable for studying in detail a short river or riverbank with a concentration on small areas.

FIGURE 3.3 STREAM NETWORK FOR A PARTICULAR WATERSHED.



Hydrologic land use classifications are important to watershed management. Multispectral satellite data may be analyzed to yield vital information regarding the water surface in the watershed and the agricultural activity and type of agriculture in the watershed. Other notable characteristics include urban development in and around the watershed, residential construction, forested areas, and marsh areas. Analysis techniques have been applied to satellite and aircraft data to provide both a broad and detailed information base related to conditions on the flood-prone areas in the watershed (Simons, 1975). The cost of conducting a watershed study varies greatly depending upon the details desired; however, comparison studies have shown that significant financial savings result from utilizing remotely sensed data properly.

High altitude imagery has a number of applications to water resource management, particularly color infrared (CIR) imagery. This type of imagery has been shown to have a greater sensitivity to subtle soil moisture and vegetation conditions than conventional panchromatic data and/or field survey crews. As such, CIR data provide for an increase in the ability to locate flood boundaries and vegetative anomalies associated with lineaments (Simons, 1975).

Airborne laser altimeter profiles can be used to quantify landscape topography, gully and stream cross sections, and vegetation canopy properties. While topography and other landscape features can be routinely measured using ground techniques and aerial photography, determining spatial patterns with these conventional methods can be difficult, time consuming, expensive, and limited to small areas. Altimeter profiles display variations due to a combination of soil roughness and vegetation which influence seed germination, water retention, infiltration, evaporation, runoff, and soil erosion by water and wind. Such information can be used to more accurately predict evaporation, soil moisture, runoff, and soil erosion at landscape scales (Simons, 1975). In addition, with the generation of cross sections, channel and gully development and degradation can be measured and used to estimate soil loss and explain water quality and flow patterns.

PART IV: Remote Sensing Techniques

Introduction

The processing of remotely sensed data is a four step procedure: **Image Preprocessing, Image Processing, Visualization of Results** (softcopy or hardcopy output) **and Accuracy Assessment**. At the center of these remote sensing techniques, "Image Processing" also involves four distinct categories that are not often well articulated. These four categories are: *Enhancement, Classification, Rectification*, and *Terrain Analysis*. Together these categories are capable of providing solutions to solve problems individually as well as a process to learn more about our environment as a whole.

Digital image processing involves the manipulation and interpretation of digital images with the aid of a computer. Digital imagery records the reflectance of all objects on the Earth in different numerical ranges as they produce different reflectance values within the same spectral range (see detail in Part I Principles of Remote Sensing). For any digital image, a digital number (DN) is recorded within a numerical range such as 0 to 63, 0 to 127, 0 to 255, 0 to 511, or 0 to 1023. These ranges represent the set of integers that can be recorded using 6, 7, 8, 9 and 10-bit binary computer coding scales, respectively (that is, 2^6 = 64, 27 = 128, 28 = 512, and 210 = 1024). Such formats allow for computerized manipulation and image analysis.

The basic idea behind digital image processing is quite simple: the digital data is fed into a computer one pixel at a time, with the computer programmed to put the data into one or multiple equations and then store the results of the computation. The next few pages outline each process and its purpose in the image processing environment.

Image Preprocessing

Raw remotely sensed data contain distortion produced during acquisition resulting from the surface terrain, instrumental errors, geometric distortions, radiometric noise, etc. Further, there is no link between the raw data and any physical coordinate location on the Earth. Typically, the initial preprocessing of raw image data is to correct for geometric distortion, to calibrate the data radiometrically, and to eliminate noise present in the data. The current format the data is in when it is received from the imaging platform typically is not recognized by many image processing software packages. This data may have computer programs called '*filters*' to correct the errors listed at the beginning of this paragraph, perform band to band alignment, corrections for known errors in the sensor (e.g. one of the several sensors on a platform may consistently record darker than the others causing an effect called *banding*, or *striping*, and when the sensor does not work at all the effect is called *line dropout*), and data file formatting (e.g. ASCII, TIFF, BIL, BIP, BSQ, GIF, LAN, IMG, GIS, ADRG, ORV, ADRI, USGS DEM) Typically each sensor

has a preprocessing application, and **it is highly recommended to receive data only when this process is complete and quality checked**.

Image Processing

Rectification

Raw digital images usually contain geometric distortions so significant that they cannot be used as maps. Various factors could cause digital image distortions, such as altitude and velocity of the sensor platform, panoramic distortion, Earth surface, atmosphere refraction, etc. The intent of geometric correction is to compensate for these distortions so that the corrected image will have the geometric integrity of a map (T. M. Lillesand 1987). Rectification is the process of transforming the data from one grid system into another grid system using an *n*th order polynomial. In many cases, north must also be oriented so that it corresponds with the top of the image. There are five methods of rectification which yield significantly different results. When purchasing data it is important to understand these differences so that you order the data in the right format the first time, and you understand what it is you are ordering so that it overlays with other data you may already have. The five rectification methods are as follows: registration, georeferencing, geocoding, latitude/longitude, and orthorectification.

Registration

In many cases, images of one area that are collected from different sources will be used together. To be able to compare separate images to each other or side by side, each image must conform to the other images in the data base. The tools for rectifying image data are used to transform disparate images to the same coordinate system. Registration is the process of making an image conform to another image. A map coordinate system is not necessarily involved. For example, if image 1 is not rectified and you are using it with image 2, then you need to register image 2 to 1, so that they conform to each other. This includes the fact that they may not be registered to anything else, neither image is rectified to a particular map projection.

Georeferencing

Georeferencing refers to the process of assigning map coordinates to image data. The image data may already be projected on the desired plane, yet not referenced to the proper coordinate system, Rectification, by definition, involves georeferencing, since all map projection systems are associated with map coordinates. Image-to-image registration involves georeferencing only if the reference image is already georeferenced. Georeferencing, itself, involves changing only the map coordinate information in the image file. The grid of the image does not change.

Geocoding

Geocoded data are images that have been rectified to a particular map projection and pixel size and usually have radiometric corrections applied. Image data can be purchased

that is already geocoded. Geocoded data should be rectified only if they must conform to a different projection system or be registered to other rectified data. When purchasing geocoded data, map projection, datum, zone, and spheroid are terms that you will need to understand in order to specify your requirements.

Latitude/Longitude

Latitude/longitude (Lat/Lon) is a spherical coordinate system that is not associated with a map projection. Lat/Long: expresses locations in the terms of a **spheroid**, not of a **plane**. Therefore, an image is not usually "rectified" to Lat/Long :although you can convert images to Lat/Long, it is not recommended if your data is not stored this way.

Orthorectification

This is the best way to receive your data, but it will probably be the most expensive. Orthorectification is a form of rectification that corrects for terrain displacement and can be used if you have a digital elevation model (DEM) of your area. In relatively flat areas, orthorectification is not necessary, but in mountainous areas (or low level aerial photography or photographs of buildings) where a high degree of accuracy is required. Orthorectification is required to mosaic data together.

When to consider rectification:

1. Developing GIS databases for GIS modeling and analysis.
2. Overlaying an image with vector data.
3. Mosaicking images and their classified products.
4. Scene-to-scene comparisons of individual pixels in applications such as change detection or thermal inertia mapping (day and night).
5. Identifying training samples according to map coordinates prior to classification.
6. Creating accurate scaled photomaps.
7. Comparing images that are originally at different scales.
8. Extracting accurate distance and area measurements.
9. Performing any other analyses requiring precise geographic locations.

Before rectification, you must determine the appropriate coordinate system for your database. To select the optimum map projection and coordinate system, or must consider the primary use for the database. This may come from a user needs assessment at your installation.

Image Restoration

This operation is to restore distorted image data to a more faithful representation of the original scene. It involves correcting for a variety of geometric and radiometric distortions present in the original image data.

There are two types of geometric distortions: systematic and random. *Systematic distortions* are predictable and random distortions are not predictable. It is easy to correct for systematic distortions through the application of formulas derived by modeling the sources of distortions mathematically. For instance, a highly systematic source of distortion involved in multispectral scanning from satellite altitudes is eastward rotation of the Earth beneath the satellite during data capture. This problem is known as skew distortion. The correctional process is known as de-skewing with the resulting imagery being offset slightly to the west for each successive scan line. The skewed-parallelogram appearance of satellite multispectral scanner data is a result of this correction.

Random distortions are unknown systematic distortions that are corrected by analyzing the appearance of well selected ground control points (GCPs) in an image. GCPs are features of known ground location that can be accurately located on digital imagery. Those features that make good ground control points include highway intersections, the intersection of two rivers, the corners of large buildings, etc. For this correction process, numerous GCPs are located both in the raw imagery and a map of a corrected image in terms of their spatial coordinates (column and row number on the raw imagery and ground coordinates, usually UTM coordinates, on the map or corrected imagery). These values are then applied to a least-square regression analysis to determine coefficients for two coordinate transformation equations that can be used to interrelate the geometrically corrected coordinates and the distorted imagery. Once the coefficients for these equations are determined, the distorted image coordinates for any map position can be precisely calculated.

Raw imagery also contains *radiometric distortion* caused by atmospheric conditions and illumination of objects on the Earth. This varies based on the sensor platform, and can be greater or less than geometric distortion depending on the data acquisition method. For airborne digital imagery, radiometric distortions are smaller than that of spaceborne imagery. Also, the need to perform correction for any or all of these influences depends directly upon the particular data application.

Image noise is any disturbance in image data that is due to a limitation in the sensing, signal digitization, or data recording process. The potential sources of noise range from periodic drift or malfunction of a detector to electronic interference between sensor components, to intermittent “hiccups” in the data transmission and recording sequence. Noise can either degrade or totally mask the radiometric information content of a digital image. Therefore, noise removal usually precedes any subsequent enhancement or classification of the image data.

Noise Removal

This procedure is a part of image restoration. The nature of noise is very similar to geometric distortion in that it includes both systematic and random noise. For example, multispectral scanners that sweep multiple scan lines simultaneously often produce data containing systematic striping, or banding. This kind of systematic noise can be removed with various destriping procedures. One method is to compile a set of histograms for the image – one for each detector involved in a given band. For MSS data this means that

for a given band, one histogram is generated for scan lines 1, 7, 13 (MSS has 6 bands), etc.; a second histogram is generated for lines 2, 8, 14, etc.. These histograms are then compared in terms of their mean and median values to identify the problem detector(s). A scale adjustment factor(s) can then be determined to adjust the histogram(s) for the problem lines and to resemble those for the normal data lines. This adjustment is applied to each pixel in the problem line(s) while the others are not altered.

The processing of random noise in digital data is quite different than systematic noise. This type of noise is characterized by nonsystematic variations in gray levels from pixel to pixel called bit errors. Such noise is often referred to as being "spiky" in character and may causes images to have a "salt and pepper" or "snowy" appearance. The reason for this "salt and pepper" effect is because the digital value of the noise pixels are much higher, or lower, than their neighboring pixels which are true image values. Therefore, noise can be identified by comparing each pixel in an image with its neighbors. If the difference between a given pixel value and its surrounding values exceeds an analyst specified threshold, the pixel is assumed to be a noise pixel. Filters can be designed to remove all noise pixels. A high-pass filter is designed to clear out all the pixels that have much lower Digital Number (DN) values compared to their neighbors. A low-pass filter is designed to remove pixels that have much higher DN values than their neighbors. The value of these noisy pixels can be replaced by averaging their neighboring values.

Image Enhancement

The purpose of image enhancement is different than image rectification. It allows the analyst to improve the visual interpretability of an image by increasing the appearance between the features in the scene. Because human eyes are poor at discriminating the subtle radiometric or spectral differences that may be critical for interpreting spatial attributes of an image object, it is possible to amplify these slight differences by using a computer to make them readily observable.

Enhancement operations are normally applied to image data after proper restoration procedures have been performed. The following are the most commonly used digital enhancement techniques:

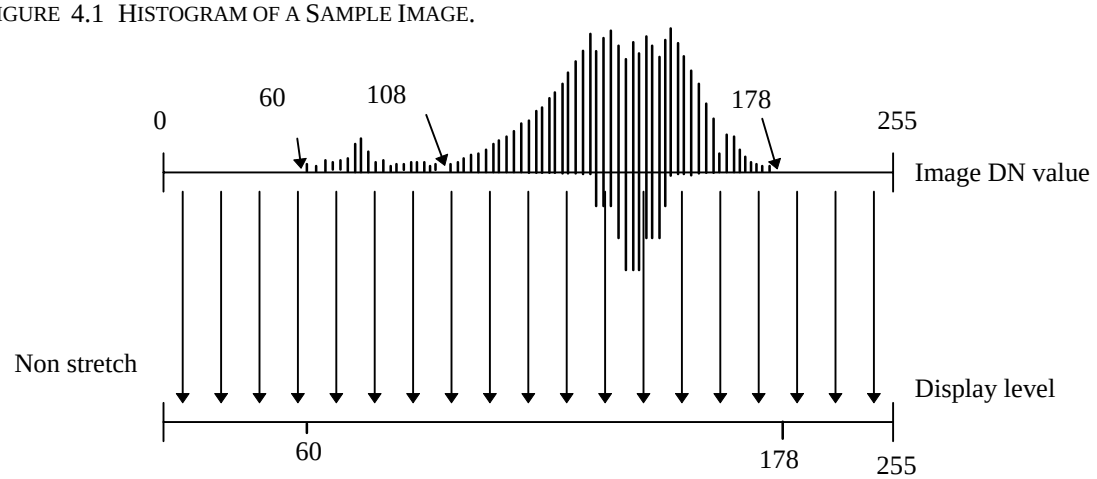
Image Contrast Enhancement

As mentioned above, the digital values of image data range from 0 to 63, 0 to 127, 0 to 255, 0 to 511, or 0 to 1023 depending on the computer coding scale. However, image display and recording devices typically operate over a range of 256 gray levels while remotely sensed data in a single image rarely extend over this entire range. Hence, the goal of *contrast stretching* is to expand the narrow range of brightness values typically present in an input image over a wider range of gray values. The result is an output image that is designed to increase the contrast between features of interest to the image analyst.

In order to describe the contrast stretching process, consider a hypothetical sensing system whose image output levels can vary from 0 to 255. Figure 4.1 illustrates a histogram of brightness levels recorded in one spectral band over a scene. Assume that an output device, usually a computer terminal, is also capable of displaying 256 gray

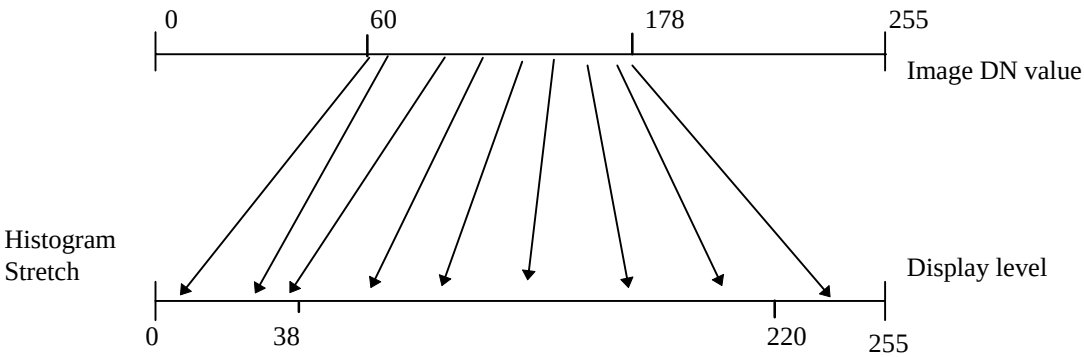
levels (0 to 255). It can be seen from the figure that the histogram displays scene brightness values occurring only in the limited range of 60 to 178. If these image values were to be used directly in the display device, only a small portion of the display levels would be used. Therefore, we utilize contrast stretching to view the full range of the display levels.

FIGURE 4.1 HISTOGRAM OF A SAMPLE IMAGE.



The most common method of contrast stretching is the histogram-equalization stretch. As shown in Figure 4.2, image values are assigned to the display levels on the basis of their frequency of occurrence. In this case, more display values (more spectral detail) are assigned to the frequently occurring portion of the histogram. The original image value range of 109 to 158 is now stretched over a larger portion of the display levels (39 to 255). A smaller portion (0 to 38) is assigned to display less frequently occurring image values of 60 to 108.

FIGURE 4.2 THE BASIC PRINCIPLE OF A HISTOGRAM STRETCH.



Spatial Feature Enhancement

Edge enhancement is used to exaggerate the contrast over the original image in order to more clearly define the linear features or edges of an image. This technique increases the image analyst's ability to conduct visual interpretation since all the linear features such as highways and rivers can be easily recognized. The enhanced image is actually a composite image of the high frequency component image and the all gray levels of the original image. Thus, the edge enhanced image preserves both enhanced linear features and low frequency brightness information. To approach this goal, the following two steps are implemented:

a) A high frequency component image is produced containing the edge information.
b) All of the gray level in each pixel of the original scene is added back to the high frequency component image.

The composite image is then contrast stretched and contains both low and high frequency features.

In the realm of general digital image processing, two-dimensional *fourier transformations* are used for enhancement, compression, texture classification, cross-correlation and many other operations. In this approach, an image is separated into its various spatial frequency components. Spatial frequency is defined as the number of changes in brightness value per unit distance for any particular part of an image. If there are very few changes in the brightness value over a given area, this is referred to as being "low frequency" area. If the brightness values change dramatically over very short distances, this is an area of "high frequency." Because spatial frequency by its nature describes the brightness values over a spatial region, it is necessary to adopt a spatial approach to extracting quantitative spatial information. It can be done by looking at the local or neighboring pixel brightness rather than just an independent pixel value. conceptually, this operation amounts to fitting a continuous function through the application of the discrete DN values as they were plotted along each row and column in the image (T. M. Lillesand and Kiefer, 1987).

After an image is separated into its component spatial frequencies, it is possible to display these values in a two-dimensional scatter diagram called a Fourier Spectrum. Fourier analysis is useful for many image processing operations including the simple example of contrast improvement.

Multi-Image Operations

A process which produces a different presentation of multiband image data is *image ratioing*. Simply, it is the division of DN values in one spectral band by the corresponding values in another band. Ratioed images are often developed for differentiating subtle spectral variations in a scene that consists of brightness variations from individual spectral bands or in standard color composites. For example, vegetation has a high reflectance in TM data band 4 but it is difficult to discriminate between grass and trees if only one band is used. When ratioed images are used these features can be differentiated since more than one band is being used to describe spectral variations. Of course, the utility of any given spectral ratio depends upon the particular reflectance characteristics of the features involved, and the application. The form and number of ratio combinations available to the image analyst also varies depending on the source of digital data. The number of possible ratios that can be used from n bands of data is n (n-1).

In remote sensing applications, images generated by digital data from various wavelength bands often appear similar and convey essentially the same information. This causes extensive interband correlation in the analysis of multispectral image data. *Principal components analysis* is designed to remove or reduce such redundancy in multispectral data. The purpose of this process is to compress all of the information contained in an original n-channel data set into fewer than n “new channels” or components. This technique can be used either as an enhancement operation or as a preprocessing technique prior to image classification. Principal component analyses can improve the efficiency of image classification as it reduces the dimensionality of the original data set and decreases computation time. For example, TM data has 7 bands, but the result of principal components analyses may compress such data down to just 3 channels for further processing. Principal component analysis technique is particularly appropriate where little prior information regarding the area is available.

Image Classification

Image processing is one of the most widely used applications for pattern recognition. The overall objective of remotely sensed data classification is to automatically categorize all image pixels into specific classes or themes. From there the analyst can determine the size, shape, and relative location of individual classes, and their temporal characteristics. Although a single band data can be used, multispectral data for the same area is usually used to perform the classification, and the spectral patterns of the pixels are used as the numerical basis for categorization. In other words, multispectral image classification is the process of simplifying a continuous spectral pattern into discreet groups of known identity. The classification of a remotely sensed image involves two procedures: unsupervised classification and supervised classification.

In a *supervised classification*, the image analyst dictates a part of the pixel categorization process by specifying numerical descriptors of the various land cover types to a computer algorithm. To do so, representative sample sites of known cover types, which are called training areas, are used as the numerical "interpretation key" that describes the spectral attributes for each feature type of interest. The analyst defines training areas on an image by identifying regions that can be clearly matched to areas of known identity on the ground. Such areas should typify the spectral properties of the categories they represent, and must be homogeneous with respect to the informational category. Pixels located within these areas form the training samples used to guide the classification algorithm to assign the specific spectral values of known pixels to appropriate informational classes. There are three stages involved in a supervised classification.

1) Training Stage: The user will define the final classes (categories) of the land cover type of interest in the scene. The analyst identifies representative training areas (training samples) and develops a numerical key (description) of the spectral attributes of each category.
2) Classification Stage: Each pixel in the image data set is categorized into the land cover class it most closely resembles and labeled by the predefined class name. If the pixel is not similar to any training data set it is usually labeled "unknown." The label assigned to each pixel in this stage is recorded in the corresponding cell of an interpreted data set (an "output image"). Therefore, the multidimensional image matrix is used to develop a corresponding matrix of interpreted land cover category types.
3) Output Stage: The output of the classified image can be hard copy maps, statistical tables, or digital format. The digital format data can be converted into a data layer of GIS and subsequently used as an updating tool. In this case, the classification output becomes a GIS input.

Unsupervised classification is used to classify the image by aggregating pixels which have similar DN values into natural spectral groupings or clusters present in the scene. The image analyst will then determine the land cover identity of those spectral groups by comparing the classified data to ground reference data. In this procedure, there are two important specifications: s*pectral classes* and *information classes*. Spectral classes are defined by the analyst by systematically grouping spectral signatures. The basic principle of this approach is that the values within a given land cover type tend to be spatially close together in measurement space, while data of different classes tend to be comparatively well separated. The classes generated by an unsupervised classification are spectral classes based on the natural groupings in the image; however, the identification of these spectral classes is not initially known. The analyst must compare the classified data with the ground truth (field survey data, larger scale maps or imagery) to determine the identity of the spectral group. Thus the final classes, known as the information classes, are defined by known identities.

From the above discussion, it can be seen that in the supervised classification approach, the analyst defines land cover categories and then examines their spectral separability. In

the unsupervised classification method, the spectral classes are determined first and then the analyst determines the land cover type for each groups. For a supervised classification, the analyst needs solid a priori knowledge of the area to be classified, which may be gained through a combination of field work, analysis of aerial photography, maps, and personal experience (Heaslip, 1975). On the other hand, in unsupervised classification, only a minimum amount of input from the analyst is required.

Post Classification Smoothing

Once an image has been classified there are techniques which may be applied to further process the output. Often a vegetation classification may need to be combined with vector (point, line, polygon) data to fuel a habitat suitability model. In most cases, while raster and vector data may be combined in a GIS for visual analysis, more complex spatial analyses are designed to work with only one data type at a time. A polygon overlay of soils and vegetation layers which would identify associations between particular plant species and soil types, for example, requires that both sets of information be of the same format. In this case, the GIS analyst would need to convert the classified image into vector format. The logic behind this conversion process is straightforward, and there are a number of algorithms designed to accomplish this task. A common limitation of vector based GIS software, however, is that there is often a finite number of polygons that can exist in any one layer. A classified image may contain millions of pixels, and when converted may have too many polygons to be of any use. Post classification smoothing is the process of removing some of the variability in the classified image to render it more amenable to vector GIS processing. The process is quite similar to techniques described in the Noise Reduction section of this document, but instead of acting to reduce the 'salt and pepper' character of raw imagery, the thematic layer is filtered such that within class variability is reduced. A large pasture, for example, may be composed predominantly of dry grass with perhaps a few scattered trees. Depending on the object of the classification, it may be acceptable to filter the image in such a way that the few pixels representing trees in the pasture are computed to the value of the majority of their neighbors (dry grass). This process of generalization may need to be repeated multiple times until the desired effect is produced.

Terrain Analysis

Terrain analysis involves the processing and graphic simulation of elevation data. Terrain analysis can be associated with topographic data, in which an elevation is recorded at each X,Y location. Terrain analysis functions are not restricted to topography. Any series of values, such as population densities, ground water pressure values, magnetic and gravity measurements, and chemical concentrations can be modeled. Topographic data are essential for studies of traffic, route design, non-point source pollution, intervisibility, siting of recreation areas, etc. (Welch 1990). Some of the most useful products derived form topographic data are: (1) Slope images-which show changes in elevation over distance. Slope images are usually color-coded according to the steepness of the terrain at each pixel. (2) Aspect images-which show the prevailing direction that the slope faces at each pixel. (3) Shaded relief images-illustrating variations in terrain by differentiating areas that would be illuminated or shadowed by a light source simulating the sun. These

types of terrain derivatives are often used as a component in complex GIS modeling or classification routines. They can, for example, be a key to identifying wildlife habitats that are associated with specific elevations. Slope and aspect images are often an important factor in assessing the suitability of a site for a proposed use or be used for vegetation classification based on species that are elevation sensitive.

To create orthophotos a DEM is required. If one does not exist to suit the needs of the data, a DEM can be delineated If the image data overlaps by 50 % or more. through terrain analysis techniques.

Visualization

Visualization is defined in this document as soft or hard copy images to express an idea or concept. Visualization is the transformation of data to information by way of a computer screen, hard copy maps, statistical data, or as a integral layer in a GIS. Data exists as points with values, information is the interpretation of the data to produce meaningful results (e.g., Land cover with a value of 8 is on slopes too steep for development, is information that shows where not to build.). Image processing gives us the slope and the ability to assign the slope values. Visualization provides information to users and consumers of the area of interest. Geographic information systems offer many solutions for visualization and creation of new layers of information, they are covered in more detail under the section “Remote Sensing Systems.”

Hard copy maps and plots are a very common medium for sharing information. Roger F. Tomlinson, an authority on GIS and image processing stated “Mapped and related statistical data do form the greatest storehouse of knowledge about the condition of the living space of mankind.” On this note maps should be created as accurately as possible and be as accessible as possible too.

In the past, mapping was performed by agencies who took the surveyors’, photogrammetrists’, or drafters’ information and created a map to illustrate the data as information. Today the analyst is the cartographer/analyst/computer operator and can design maps to best suit the data and the end user. It is important to understand that cartographic methods and standards still need to be adhered to since maps and information is intended for a wide range of viewers. What appears to be apparent to the map creator may not be so apparent to the viewer or user; hence, information has not been articulated. One of the most important aspects of visualization is to plan the map before it is created. Once the analysis is complete a few questions need to considered:

1. How will this map be used?
2. Will the map have a single theme or many?
3. Is this a single map, or is it part of a series of similar maps?
4. Who is the intended audience? What is the level of their knowledge about the subject matter?
5. Will the map remain in digital form and be viewed on the computer screen or will it be printed?

6. If the map is going to be printed, how big will it be? Will it be printed in color or black and white?
7. Are there map guidelines already established in your organization?

The answers to these questions will give a good foundation for what type of data and information that will be needed to create an informative presentation.

Accuracy Assessment

Accuracy assessment is a general term for comparing the classification to geographical data that are assumed to be true to determine the accuracy of the classification process. Usually, the assumed-true data are derived from ground truth data. Accuracy assessments exist because it is not practical to ground truth or otherwise test every pixel of a classified image.

Unfortunately, there is no simple, standardized methodology for determining classification accuracy. The most commonly used approaches involve comparing the results obtained from a digital classification to the "known" identity of land cover in test areas derived from reference data. In order to assess the classification, one of the following procedures may be employed:

1) Homogeneous test areas selected by the analyst.
2) Test pixels or areas selected randomly.

Homogeneous test areas are located during the training stage of a supervised classification by intentionally designating more training areas than are actually needed to develop the classification statistics. Once these subsets are determined, they may then be used for a classification accuracy assessment. However, as homogeneous areas, they might not provide a valid indication of classification accuracy at the individual pixel level.

A random sampling of pixels may avoid the above mentioned problems, but introduces problems of its own. First, the collection of reference data for a large sample of randomly distributed points is often very difficult and costly. Second, the validity of random sampling depends on the ability to precisely register the reference data to the image data. One way to overcome this problem is to sample only pixels whose identity is not affected by potential registration errors. Sample size also plays an important role in the classification accuracy assessment. It has been shown that more than 250 test pixels are necessary to estimate the mean accuracy of a class to within $\pm$ 5 percent.

There are two issues which need to be emphasized in classification accuracy assessment. One is that the quality of any accuracy estimate is only as good as the information used to establish the "true" informational class present in the test sites. Some estimate of the errors in the reference data should be incorporated into the accuracy assessment process. Secondly, the accuracy assessment procedure must be designed to reflect the intention of the classification.

PART V: THE MANAGERIAL PROCESS: WE-CAN-DO-IT

This part has been compiled to provide the project manager with an outline of issues and concerns that should be reviewed before a remote sensing project begins. The **"WE-CAN-DO-IT"** acronym should become a helpful reminder for recalling pertinent project details.

Work plan

The objective of the project will need to be planned and clearly defined in order to ensure a thorough and systematic approach toward implementation. The plan should be outlined, formalized, and presented to decision makers for approval. You will need (1) a "selling" plan to formally present your requirements to upper management and (2) a complete computer requirements plan. In the DOD, this latter plan is known as a Computer Systems Requirements Definition (CSRD). Both the selling plan and the CSRD should include details on cost, staffing, and equipment requirements. Include diagrams and workflows in your presentation style since they are usually strong vehicles for expressing your objectives. Information on how to put together a CSRD is generally available from the Communications or Computer Support Unit on the installation.

A clear understanding of the technology should be expressed to increase management's awareness of your teams' competence. Have an answer ready for any and all questions which may be proposed. In particular, the following questions should be anticipated. Exactly what is the technology capable of telling you? What are the limitations of the technology and how can they be overcome? Is this just another example of technological promise running far ahead of performance, or has it proven its usefulness in advancing the effectiveness of management, planning, and decision-making enough to justify substantial additional investment?

Effort

The amount of time and manpower resources required to implement an effective system are always concerns. Remember the timeline has already begun with the writing of your plan and will not be complete until a fully integrated system is in place and operational. Although system maintenance is generally not considered part of the initial implementation, a maintenance schedule and its first few cycles are required for complete system design. This includes such things as systems management manpower allocation, user training, hardware configuration and repair, software upgrades, system backups, and so on.

Cost

Virtually every aspect of your work plan is going to have a cost associated with it. A good starting point is to consider what resources you have and which ones you will need to purchase or for which special authorizations are required, including manpower. Always try to utilize what is already available to you. For example, you may be able to utilize in-house personal computers for low level system tasks rather than purchasing advanced, state-of-the-art workstations. Data that has already been compiled from various other mapping efforts should strongly be considered for integration into your system plan. Any in-house knowledge should also be identified and accessed to save on training costs.

User defined requirements are essential to understanding the overall cost of a system. These requirements are often revealed with the development of a graphical decision model which describes what types of information are needed, the source of the information (such as existing National Wetlands Inventory mapping data), when they are available, when they are needed, and what decisions or operations are based on the information (Muir, 1968). Although your immediate users are the primary target for this model, try to incorporate other groups and/or organizations who may benefit from the system's capabilities. This strategy will help to maximize the use of the system, and also serve as a basis for joint allocation of incurred costs. Be sure to include automatic methods of data processing wherever possible. These include such techniques as spectrum and/or pattern recognition which often reduce the costs and delays caused by large amounts of human photo interpretation. Lastly, be sure to consider any modifications in current workflows which may offset your current operating budget while users become adjusted to new tasks.

A remote sensing program may be integrated with an existing mapping and/or GIS system in order to improve specific tasks as well as lower operating costs. Historically, the major costs associated with the implementation of a GIS system have been in the gathering and updating of the geocoded data. Remotely sensed imagery has been proven to be a natural and cost effective means for updating GIS data sets by replacing and/or enhancing an existing data collection system (Star, 1991).

The total costs can be compared with the total benefits as a basis for deciding on the suitability of a project. This comparison is usually expressed as a cost/benefit ratio. The following system costs should be accurately determined for each project:

1) All research and development costs, including those required to bring the sensing equipment and techniques to a usable state of development.
2) Investment costs for the sensors, sensor platform, data recording, transmission, and processing system, information dissemination system, and all other parts of the system required for the application(s). Note, these investment costs must be repeated if the period under study exceeds the lifetime of the equipment.

3) Annual operating and maintenance costs, including personnel costs, aircraft operating expenses, maintenance and repair of equipment, rental of equipment or services, and so on (Muir, 1968).

A cost/benefit analysis should identify several obvious money saving aspects of the system. For example, technological improvements in the production process may allow the same resources to be committed while production levels increase and operating costs decrease. In addition, certain system capabilities may also decrease costs through a real savings in property damage. Additional savings may be stated in qualitative terms only, such as the acquisition of new knowledge or improved job satisfaction. The bottom line of the cost/benefit analysis will inevitably determine if the proposed remote sensing system is the least costly way of achieving the desired objective (Muir, 1968).

Available hardware and software

A complete inventory of all system resources will include the existing hardware and software available for the project. All hardware requirements should first be identified such as the number of CPUs, processor speed, memory (RAM and ROM), internal storage space, external or networked space, monitor size, screen resolution (based on pixels), backup device(s), storage media, and so on. Careful consideration should be given to data retrieval, manipulation, distribution, and storage methods. Remember that remotely sensed imagery can have tremendous storage and sophisticated scanning, printing, and plotting requirements. Existing resources can then be compared to these system requirements to determine overall coverage. Next, all software needs should be established and again compared to current holdings. Consultation with those knowledgeable of the system software will help to determine its applicability to the desired application. Consider all types of system software components including the operating system, image processing software, translation programs, and so on.

Number of people

Perhaps the most valuable resources are the individuals chosen to work on the project. A careful assessment of in-house capabilities is imperative. As the work plan is developed, decisions should be made as to what tasks will be assigned to specific individuals. A lack of manpower and/or trained individuals may become apparent and contingency plans will need to be identified. Training classes and/or other outside contractor assistance may be necessary, particularly during the initial phases of implementation. Finally, consider the life of the project and the demand for trained manpower, retraining over time, and new staff training as the system grows and develops.

Data

The effectiveness of any automated information system may be directly related to the quality of its data, particularly for those which integrate remotely sensed data with GIS. Within the category of remote sensing systems, there are a large number of sensor characteristics which need to be reviewed in order to decide on the type of sensor(s), as well as the data extraction and analysis techniques. One can select from a variety of

sensor systems and combinations including multiband cameras; infrared, radar, and multispectral scanners; microwave radiometers and scatterometers; laser profilers and others. However, it is essential to recognize the benefits and limitations pertaining to each sensor system and the data produced. Once the source of the remotely sensed data is defined, the type of aircraft, satellite, or other sensor platform will also be considered. How often the data is updated, as well as the frequency with which it is updated becomes an issue. Flight parameters can be decided on, such as altitude, flight path, total area coverage, and frequency or availability only after the preferred data type and source is known (Muir, 1968). In general, the data collection choices make it possible to plan other portions of the complete information system such as updating cycles, storage requirements, hardware demands, and manpower.

In addition to the information provided by the remote sensing system, many other sources of information may be required. Depending on the nature of the system's application(s), various economic, social, or political data may be incorporated. An inventory of existing GIS systems may reveal a large amount of this data including topographic coverage, census tracts and population data, ownership boundaries, transportation networks, hydrography, vegetation, historical buildings, wildlife habitats, and so on. When reviewing the GIS data layers, keep in mind the integration issues inherent with vector and raster data (see General view of GIS above).

Obstacles

The most obvious obstacle will be project funding and manpower. Very often the decision to drop a project is due to the lack of a coherent, well thought out work plan. A plan that covers all issues and concerns of management on investing in new technology will very often be selected over those which offer some degree of uncertainty. The Cost section above should guide the development of the plan to avoid such pitfalls.

Another common obstacle is the lack of trained manpower. Although training may eliminate this problem initially, a high turnover rate will very often set the project back. Consider the life of the project and determine if the best alternative for system maintenance is use of in-house personnel, contracted out system support, or a combination of both.

A third obstacle is the lack of upper level awareness. The project manager will need to identify the fine line between general functionality and specific methodology in presenting the proposal. Citing proven projects from other installations may prove to be a good crutch in an uncertain situation.

A fourth obstacle may be the lack of a "champion" or the person who takes ownership of the project from start to finish. With the present decrease in manpower and increase in workload, this is an understandable situation. However, if the project is to survive it will require a leader to oversee its successful planning, implementation, operation, and maintenance. Without such guidance, the project is faced with certain failure. A well defined CSRD package will serve as a useful briefing tool on the history and projected future of the undertaking should a transition in personnel take place.

A final obstacle is cooperation among the project participants, particularly if numerous organizations are involved with the project. It is likely that an integrated system may serve a number or different groups as the products from such technology are very versatile in nature. A flowchart may be developed to track the distribution of data as it is used throughout the installation. Data ownership is an issue, and it should be clearly defined with the onset of the project. Differing levels of data access must be defined in the security plans including limitations on read, write, alter, and delete privileges or the data files may be corrupted by well intentioned but uninformed staff. Any known or anticipated schedules and timelines imposed on the total effort should be incorporated into the data flowchart. All parties who are responsible for the total effort success, and those who could cause failure through non-cooperation, should review and agree to an effective, logical use of all system resources before a project begins.

Integration

With the advancements in system networking, and the decrease in proprietary systems, it has become easier to establish integrated systems. Data formats are becoming more and more "open" with translation requirements becoming a thing of the past. The push for standards in the data community has also increased the demand for integrated systems. Advanced networking capabilities, and other telecommunication operations, have made it all too easy to share information across systems. The successful link between GIS and remote sensing systems relies upon all these advancements. However, maintenance of data integrity and security are critical matters that must be addressed during the initial phases of planning.

More specifically, commercial software vendors have accepted the need to integrate GIS with remotely sensed data. Leading software developers can no longer ignore the integration requirements of their users. Programmers are applying integrated workflows to software functionality, while others work to solve the vector-raster issues. These efforts are providing the foundation for a new generation of GIS technology which contains image processing as a subclass of its total functionality (Star, 1991). A careful assessment of software capabilities will help to determine the highest level of applicability to a desired objective.

Tracking System

The work plan will need to include some type of tracking system which serves to monitor system progress and success. A number of comparisons can be made including:

Proposed Funding vs. Actual Expenditure

Proposed phased implementation and operational date vs. actual phased implementation and operational dates. Proposed number of users and product output customers vs. actual number of users and product output customers

System Down Time vs. System Operational Time

Time/cost per task before system vs. time/cost per task after system is implemented All records should be kept consistently and accurately. These comparisons will prove invaluable for assessing system success (or failure) or for requesting additional funding.

PART VI: INTEGRATION OF REMOTE SENSING AND GIS—CASES STUDIES

The Integration Of GIS And Remote Sensing At Vandenberg AFB --by Delta Research Corp.

In industries that routinely use both textual and graphical information, the need for one central system that can collectively manage both the textual and graphical data is self evident. Prior to the advent of graphic or image-oriented data management systems and geographic information systems (GIS), data managers used separate systems to manage their textual and graphical data. However, with today's technology it is possible to combine both functions within one suitable and easy to use system—GIS. A GIS is a computer-based system that can deal with virtually any type of information about features that can be referenced by geographical location. This system is capable of handling both locational data and attribute data about such features. That is, not only does a GIS permit the automated mapping or display of the locations of features, but also provides a relational database capability for recording and analyzing descriptive characteristics about the features. (Lillesand and Kiefer, 1994) One of the most important benefits of a GIS is the ability to spatially interrelate multiple types of information derived from a range of sources.

Aerial photography, remote sensing, photogrammetric mapping and computer graphics should be used to provide digital graphics and an alphanumeric database to be used on an interactive basis with GIS.

Most GIS use either a raster (grid cell) or vector (polygon) format to represent the locational component of geographic information. In the raster format the location of geographic objects or conditions is defined by the row and column position of the cells. The finer the grid cell size used, the more geographic specificity there is in the data file, and the more data storage required. Using vector format, feature boundaries are converted to straight-sided polygons that approximate the original regions. These polygons are encoded by determining the coordinates of their vertices, or nodes, which can be connected to form arcs.

Digital remote sensing images are collected in a raster format. Accordingly, digital images are inherently compatible spatially with other sources of information in a raster domain. These "raw" images can easily be included directly as layers in a raster-based GIS.

How Vandenberg AFB Uses GIS and Remote Sensing

History

Vandenberg Air Force Base (VAFB) is the third largest installation in the U. S. Air Force encompassing more than 98,000 acres of land. It was originally established in 1941 as an army tank training facility. Vandenberg now conducts military and commercial space launch operations. With 35 miles of pristine California Coastline; VAFB is biologically important and generally considered to be within the ecological transition zone between northern and southern California providing habitat for native plants and animals. The mission of the 30TH Space Wing at VAFB is to "... conduct west coast space lift and ballistic missile operations; operate the Western Range for government and commercial space, missile, and aeronautical operations; to ensure safety for all operations, protect and enhance the VAFB environment, and provide host base support for the entire VAFB community". VAFB has maintained an average of one launch a week for the last 30 years, totaling over 1700 launches since 1958. The base mission requires extensive and uninterrupted land space to provide sufficient safety corridors for launching vehicles into polar orbit and conducting Inter Continental Ballistic Missiles (ICBM) test programs.

Today on VAFB there are over 4900 structures along 532 miles of roads and 25 miles of rail spur, 7 power plants, 3 water treatment plants, 575 miles of electrical power distribution, and 367 miles of water pipe to manage and maintain on a daily basis. VAFB has turned to GIS to provide the tools to manage its mission. Prior to GIS implementation, data was scattered among many different offices with no centralized fashion for managing and storing data. Some offices had good data but could not view it, or no one knew what was the most current data set. VAFB personnel recognize GIS has the ability to significantly improve the communication, coordination, and availability of usable information among the 6,000 Air Force personnel and their dependents and over 7,000 daily employees.

Delta Research Corp. was awarded the task of designing, developing, and implementing the installations Geographic Information System (GIS) automation project to produce the decision support tools the Civil Engineering and Environmental management offices desired. In late 1993, work was started to automate the Comprehensive Plan and the Comprehensive Planning process at VAFB. Approximately 2 years since its conception GIS is used to support the user community both on and off the installation. This comprehensive planning process encompasses physical, social, economic, ecological, and other considerations, and in addition incorporates traditional Air Force master planning, natural resources planning, and environmental protection. Comprehensive planning is a process in which very early and yet critical programming and design decisions are made which will provide the foundation for sound, economical, and efficient community development.

Air Force comprehensive planning includes all areas/activities affecting, or affected by, base development and operations. This includes all land areas within the boundaries of an installation. Air Force comprehensive planning with respect to off-base areas that are not under the jurisdiction of the Air Force promotes compatible, comprehensive, and

coordinated environmental planning policies by all concerned local, regional, state, and federal agencies.

Vandenberg's plans are to automate the digging permit process, produce an overall constraints map that includes threatened and endangered species of plants and animals, wetlands, archaeological, historical, and Installation Restoration Program (IRP) sites that would be integrated into an overall mission constraints map. A goal is to provide minimum, moderate, and severe constraints zones to be considered for infrastructure development, growth, and new construction. Future plans include providing tools and emergency response information to the fire department for chemical plume analysis and fighting wildland fires, as well as to have GIS considered as an information source when the disaster control center is activated.

Data Collection / Generating Imagery

The initial GIS effort called for the completion of aerial photography, multispectral imagery, photogrammetric compilation, digital production of existing collateral source documents, and field studies of selected base layout elements of the Comprehensive Plan. In the initial phase of the GIS effort, Delta obtained installation-wide aerial photography, photogrammetric compilation, and data conversion.

The decision was made to generate the aerial photography at two scales. The base cantonment area-the "built-up" part of the installation that includes family housing, restaurants, office buildings, and central maintenance facilities- was flown at a scale of 1:5,000 to acquire the level of detail required within this populated area. It was determined that the less populated noncantonment area could be flown at a scale of 1:20,000 and still maintain the level of detail needed for digital compilation. Digital orthophotos were generated from the aerial photography at a quarter-meter resolution for the cantonment area and half-meter resolution for the noncantonment area. These digital orthophotos were geographically referenced and used as backdrops for the installation's GIS. Orthophotography was extremely helpful during the heavy January rainstorms that hit the California coast, washing out roads.

The installation's base planimetric features were photogrammetrically compiled, including the generation of digital terrain model (DTM) data. The planimetric and DTM data that were compiled will serve as the primary source layer for all additional GIS layers. The initial planimetric layers include building footprints, street edge-of-pavement, center lines, bridges, trails, driveways, railroads, parking areas, sidewalks, fences, hydrography, general vegetation, airport runways, taxiways, weather and communication antennas, spot elevations, and topography. In addition to the primary layers, several other features were added from the aerial photography or collateral sources to enhance the scope of the GIS. The additional layers included emergency safety zones, helicopter pads, aircraft approach zones, alert areas, clear zones, flood maps, recreation areas, training areas, and sand dunes.

Applicability / Environmental Management

The Environmental Squadron (30th CEV) invested in GIS from the start as part of a management plan to recognize, visualize, control, and manage the extremely sensitive environmental areas located throughout VAFB, including 5,000 acres of wetlands, 98,000 acres of pristine sand dunes (home to the snowy plover, a protected bird)- with 89 percent of the 98,000 acres being open space, with no structures or occupants- and more than 1,400 archaeological and historical sites. More than 50 IRP sites are managed and continuously monitored to ensure environmental compliance. The CEV staff recognized that GIS would provide them with the necessary tools to protect the environment and perhaps prevent important or fragile areas from being disrupted in the future.

To understand the vegetation, VAFB is using multispectral imagery flown with Airborne Data Acquisition and Registration (ADAR) 5500 from Positive Systems as a backdrop to verify the delineation of wetlands and look for change as well. Using the aerial imagery reduces the time it takes to travel to every site for verification and resolving differing opinions of delineation. VAFB is using this one-meter resolution imagery to generate an overall, detailed vegetation layer, which can be used for fire modeling and for verifying the status of plant communities at VAFB.

The GIS system installed at VAFB in support of the BCP is designed to provide current users with all the tools needed to fulfill the base management requirements. To provide future users with the opportunity for growth and advancement as GIS technology continues to change, the GIS project at VAFB is evolving into a complex base-wide, distributed information system. The initial user needs assessment completed in November 1993 outlined that a base wide implementation would require a substantial need for many departments to share data and access the GIS database. While the BCP was initially viewed outside of Civil Engineering as an engineering application; once implemented: GIS has sparked a base wide interest as a tool to help the members of VAFB to meet the mission of the 30th Space Wing,

Remote Sensing Applications Used in the Kings Bay Coastal and Estuarine Program

--by Laurel Gorman

Study Background

In upgrading the Kings Bay Naval base for the Trident submarine fleet, the navigation channels in Cumberland Sound, GA and through St. Marys Entrance, GA/FL into the Atlantic Ocean were deepened, widened, and lengthened. The State of Florida and the U.S. Department of Interior raised concerns about the potential adverse physical impacts on Amelia Island and Cumberland Island National Seashore, respectively. Specific areas of concern on both barrier islands included the ocean shoreline, the backbarrier wetlands, and the Cumberland Sound estuary. This led to the development of a 6-year study (1988-1993), called the Kings Bay Coastal and Estuarine Physical Monitoring and Evaluation Program, to assess the effects of the channel improvements on the estuarine and coastal processes in the area of Cumberland and Amelia Island, and Cumberland Sound.

This case study is based on the research findings from the Kings Bay Monitoring Program. The summary presented here is based on the final report edited by Kraus, Gorman, and Pope (1994), and conference papers written by Knowles and Gorman (1991), and Cofer-Shabica, Molzan, and Pope (1991).

Site Description

The study area extends from the northern tip of Cumberland Island to the northern half of Little Talbot Island, Florida). St. Marys Entrance is part of the Atlantic coastal plain of the southeastern United States, on the border of Georgia and Florida. The inlet separates two "drumstick"-type barrier islands, Cumberland Island, GA and Amelia Island, FL. Cumberland Island, about 30 km long, is mostly undeveloped and is the site of Cumberland National Seashore. Amelia Island, about 20 km long, is moderately developed. Fernandina Beach at the northern end and Amelia Island Plantation at the southern end are the principal areas of development on the island.

Discussion of Remote Sensing Applications

Aerial Photos

As part of the Biological Monitoring Program, the National Park Service was tasked to collect the aerial photography during the Kings Bay monitoring period. The photography was flown in order to assess the current state of the beaches and barrier island seashore and evaluate marsh productivity. All photography conformed to pre-set flight lines. The study area photography was flown by the high altitude ER-2 aircraft through the NASA satellite program. Photographs were taken with a standard RC-10, 9"x9" format camera, the HR732 Hi-con, 9"x 18"format camera with 24 in. lens, and the Daedalus Thematic Mapper Simulator. Products were delivered in color, color-infrared, negatives, and black-and-white prints.

Aerial photos were used to provide a physiographic framework of the study area. Morphological changes within the beach zone and interior of both barrier islands were identified and assessed from the photos, and supplemented by shoreline position and volumetric changes. The study area was subdivided into seven unique compartments which encompassed the dune/beach zone seaward to the limits of data coverage. These morphologic compartments unique to the Kings Bay study area served as the spatial boundaries for the bathymetry change, profile surveys, and sediment data analyses. The following compartments were designated from north to south within the study limits: St. Andrew Sound Tidal Inlet Complex, Stafford Shoal, Cumberland Embayment, St. Marys Tidal Inlet Complex, North Amelia Platform, Amelia Embayment, and Nassau Sound Tidal Inlet Complex.

For the historical analysis task of the monitoring program, the color-infrared photos were used to identify dredged material mounds created by the excavation and maintenance of the upper Kings Bay navigational channel. Based on grain size analysis, the fine-grained material was determined not to be suitable for beach renourishment purposes. Then the

material was stockpiled along the inlet throat shoreline and along the sound side of the southern tip of Cumberland Island and the northern tip of Amelia Island.

A third use of the aerial photography was for the wave data analysis. There were intervals of no data or the buoy records were associated with system failures during which time data were not recorded. For these instances, the wave direction was visually checked using the aerials. Verification of the wave pattern was also useful in shoal areas associated with the St. Marys ebb-delta and wave gage statistics. Frequently, the aerials were used as a secondary source in interpreting the shoreline position, bathymetry and profile survey changes. For the biological monitoring program, sediment plumes were delineated from the photographs. Biochemical impacts were determined primarily from water samples but were also checked using the high resolution aerials.

Global Positioning System (GPS) Survey

A GPS survey was conducted in October 1991 to characterize the shoreline at Kings Bay. The Kings Bay shoreline was one of six shorelines characterized between 1857-1871 and 1991. The GPS output was used to evaluate the long and short-term changes in coastal response to physical processes in the near shore of Cumberland Island, GA, and Amelia Island, FL. This GPS output was critical in determining the impact of the Navy authorized channel deepening that occurred between 1978 and 1989 to accommodate Poseidon and Trident class submarines.

The GPS technology was preferred over traditional mapping techniques for collecting accurate field data in a timely manner. Two six-channel Trimble Navigation Pathfinder Professional GPS receivers were used to accomplish the task. One unit was stationed at the first-order level bench mark located at the southern end of Cumberland Island. The other unit was used to collect shoreline position information from a four-wheel All-Terrain Vehicle (ATV) and a four-wheel-drive pickup. The base station collected a data point every 10 sec while the mobile unit collected information at a 1-sec interval. Base station data were used to differentially correct the lines representing shoreline position.

The high water shoreline on the beach was determined by a well marked limit of wave uprush associated with high tide. This location was generally recognized as a dune or beach scarp which is considered the upper limit of the foreshore (Shore Protection Manual,1984). Estimate of potential error associated with shoreline position survey was estimated to range between +/- 1 and 3 meters. The GPS survey provided the most accurate measurement of shoreline position with an estimated maximum rms error of +/- 5.8 meters.

Shoreline data for both islands were collected in about 4 hours. There was a minimum of four satellite signals available when the GPS data was collected. The GPS procedures provided direct measurement of the shoreline without cartographic parameters and limitation. The GPS survey provided rapid field data collection, highly accurate measurements, reduced cartographic errors, and streamlined the data compilation efforts.

Conclusion
Remote sensing techniques were an integral part of the coastal monitoring program conducted for the Kings Bay project. Aerial photography was used to identify shoreline and beach morphological changes and features. During the analysis phase of the study, additional uses and interpretations were made from the high-resolution satellite images to identify dredged material mounds, wave directions, and sediment plumes over the water surface. Aerial photography and satellite imagery were primary sources of data for the coastal monitoring program at Kings Bay.

EELGRASS MAPPING AND ECOSYSTEM PLANNING IN SAN DIEGO BAY

--by Mitchell Perdue and James Kellogg

As part of a long term, interagency ecosystem planning effort, the Navy has been perfecting methods of mapping eelgrass habitat in the San Diego Bay. The integrated digital side-scan sonar, a real-time differentially corrected global positioning system, and submerged video. It will be one of many components of an inter-jurisdictional San Diego Bay Natural Resources Management Plan. The pursuit and implementation of this Plan will enable the Navy to execute its mission and remain committed to proper stewardship of the Bay's natural resources.

History / San Diego Bay Natural Resources
The San Diego Bay is home port to over one fourth of the Navy's fleet as well as an active commercial and recreation port. Ecologically, it is a nursery for many fish species, and an important foraging area for sea and shore birds, including the federally endangered Least Tern and Western Snowy Plover.

The Bay's eelgrass meadows function as habitat to a variety of fish and other wildlife. They enhance the physical and biological environment in a number of ways. Dense rhizome and root structures help to stabilize the substrate. Leafy shoots produce a dense, erect leaf mass that forms a baffle, trapping suspended particulate matter. Thus, the sediments in eelgrass beds are rich in nutrients. Eelgrass meadows form a nursery and a refuge for plants and a higher diversity and abundance of fishes than comparable nonvegetated soft bottom areas.

Requirement / The Need To Map Eelgrass
The San Diego Bay has been extensively dredged since the 1940's which greatly reduced the area of intertidal and near shore habitats. At that time, there was no real documentation of the in-water natural resources. In 1987, the eelgrass mitigation policy for San Diego Bay was established by the National Marine Fisheries Service, United States Fish and Wildlife Service, and the California Department of Fish and Game to replace eelgrass lost to dredge and fill projects at a 1.2:1 ratio.

Over the years, the environmental review process was delayed for numerous Navy in-water construction projects due to lack of Bay-wide biological data to evaluate cumulative impacts. Many site-specific studies have been conducted and project-by-project mitigations have been imposed and implemented. However, to evaluate cumulative impacts that multiple users can cause over time, it was necessary to collect baseline ecological information for the San Diego Bay.

Data Gathering / Formation of the San Diego Bay Working Group

This lack of Bay-wide data became critical with the anticipated homeporting of two nuclear class carriers in San Diego Bay. Together with the regulatory agencies, the Navy agreed that it was time to improve understanding of long term impacts to the biological resources of the Bay. First, a San Diego Bay Working Group was established with the Navy as the lead. The importance of including the owners, regulators, and biological experts in the data gathering process was recognized early. This cooperative participation fosters a sense of data ownership so that there would be broader acceptance during the analysis phase. Representatives from the following agencies were included:

National Marine Fisheries Service
US. Fish and Wildlife Service
U.S. Army Corps of Engineers
U.S. Coast Guard
California Department of Fish and Game
California Coastal Commission
Port of San Diego
San Diego State University
San Diego Super Computer Center
Local Consulting Groups

Next, to fill the gaps between site-specific data and the rest of the Bay, several data gathering priorities were agreed upon to facilitate cumulative effect determinations for present and future in-water construction:

(1) Determine percent ownership of sensitive resources.
(2) Determine total area of eelgrass in the Bay and proportional ownership.
(3) Determine the relationship between Least Tern foraging and eelgrass beds.
(4) Determine the impacts of Bay coverage with regards to Least Tern foraging.
(5) Identify potential eelgrass mitigation areas.

To accomplish these data gathering priorities the group determined to:

1. Digitize the San Diego Bay boundary into a Geographical Information System (GIS) to include tidal boundaries, jurisdictions, and bathymetry to the nearest tenth of a

foot.

2. Map all the existing eelgrass beds using side scan sonar.

3. Conduct fisheries inventories to determine locations and concentrations of top smelt and anchovies, favored by Least Terns

4. Conduct Least Tern and sea bird foraging studies.

5. Study migratory waterfowl distribution and use in San Diego Bay

6. Study Bay surface utilization to determine proportional recreation, commercial, and military usage and navigation requirements

Eelgrass Mapping

The first phase of the Bay Natural Resources Management Plan was to conduct a survey of the Bay hydrography, boundary, and jurisdictions, loaded into Computer Aided Design (CAD), Aptitude, and Geographical Information Systems (GIS) (ARC/INFO and Intergraph MGE). These would serve as the base maps for all other data layers generated by this project.

The work was conducted aboard a survey vessel (Scientific Services Inc. San Diego, CA), using a sophisticated computer-controlled hydrographic survey system, and high frequency (500 Khz) digital side scan sonar Ground-truthing was conducted using real time, differentially corrected Global Positioning System (GPS) with submerged video.

The horizontal position of the survey vessel during the surveys was determined using an on-board computer which computes the geographic location of the vessel at half-second intervals, and records the ship's heading and water depth on hard copy and floppy diskettes. This method also provided video steering information to the vessel's operator. The sensing system for horizontal positioning of the vessel was from Range/Azimuth Laser, Range-Range Microwave, or Differential GPS. The three types of positioning equipment work into the same set of software for the on-board computer. Small microwave transceiver stations on several Navy buildings throughout San Diego Bay were established to provide horizontal positioning. The ship's heading information is determined by an on board gyroscope while the water depth is determined by a digital depth sounder.

The side scan sonar system consisted of a two channel (port and starboard) towed transducer, interconnecting tow cable, and a digital graphic recorder. Linear piezoelectric crystals emit fan-shaped acoustic beams from both sides of the towed transducer as it is towed along the ship's path above the sea bottom. The acoustic beams are focused perpendicular to the ship's heading (hence the need for ships head information) and broad enough in the vertical plane to scan from directly below the towed transducer out to the full range of the system. The side scan sonar data is corrected for slant range and ship

speed by a built-in microprocessor, thereby removing virtually all distortion. The resulting record depicts the sea bottom to nearly photographic quality. The final base map was generated at one foot contours at a scale of 1" = 200'. The English units were necessary because the horizontal datum was in State Plane coordinates. The eelgrass beds were then interpreted and delineated on the side scan strips. This information was then digitized onto the base maps depicting the location and density of the beds. The CAD information was downloaded into the GIS for spatial analysis.

The San Diego Bay Working Group assisted in ground-truthing the data by jointly diving the mapped areas using a GPS linked with an on-board plotter and submerged video to insure accurate mapping.

To determine the importance of the macro and micro environments the Bay was partitioned into four distinct ecoregions. Each ecoregion was further refined into five subregions including deep water, nearshore-vegetated, nearshore-nonvegetated, intertidal-vegetated, and intertidal nonvegetated. These areas were then gridded to allow for the incorporation of other types of polygon data.

Applicability

Of the 11,000 acres that comprise San Diego Bay, 1,250 are vegetated with eelgrass. Potential habitat that could be vegetated under existing conditions is 6,300 acres. Of the vegetated area, the State owns 55%, the Port owns 35%, and the Navy owns 10%. Early results from these studies reveal that San Diego Bay is healthy with regards to species diversity and species recruitment. It was also found that Terns may not rely heavily on eelgrass for foraging, but do rely on eelgrass habitat to produce forage fish. Only one fifth of the potential eelgrass habitat in the Bay was vegetated and has potential for restoration.

With these data, we have now begun cumulative Bay modeling to determine potential mitigation and habitat restoration sites. By overlaying fisheries and waterfowl data, the relationship between Least Tern foraging and eelgrass will be further defined. The effect of coverage on sea and shorebird foraging is now being investigated.

Finally, this expanded database is helping to make each agency accountable for the cumulative impacts that its individual projects can have on the San Diego Bay natural resources. Most importantly, it was found that government agencies at all levels in southern California could work together to reach a common goal.

*Use of Remotely Sensed Data and GIS in Management of the Federally Endangered Stephens' Kangaroo Rat (*Dipodomys stephensi*)*

--by Robin Church and Jerry Boggs, PhD

The principal purpose of DoD lands and waters is to support mission-related activities such as military training and testing. In addition, DoD Conservation Instruction 4715.3 outlines policy which states that while ensuring the mission, natural and cultural resources entrusted to DoD care are to be "sustained in a healthy condition for scientific research, education, and other compatible uses by future generations." It also states that "all DoD facilities and installations shall within available resources plan, program, and budget to achieve, monitor, and maintain compliance with applicable executive orders and Federal natural and cultural resources statutory and regulatory requirements, and State regulations…etc." Many federally endangered and threatened species occur on Navy and Marine Corps installations within the footprint of responsibility of the Southwest Division Naval Facility Engineering Command, Natural Resources Office. One such species is the Federally Endangered Stephens' Kangaroo Rat.

History

Some scientific data exists that indicate rodents are less active on nights with full moon light. This is thought to be a result of their potentially increased susceptibility to predation. As a result of a range improvement project, on a range occupied by Stephens' Kangaroo Rat, future use will include night illumination flares. The United States Fish and Wildlife Service believes that this may interfere with the animals ability to forage and ultimately may have a negative impact on the species at this location.

Requirement

As a result of the indirect effects of the range improvement project, the biological opinion requires that the Navy monitor the behavior patterns of the animals prior to the new use, and subsequent to the new use and determine if behavior patterns are altered as result of the night illumination. The study shall assess foraging, breeding, territorial behaviors, as well as distribution and population densities.

Data Collection

Radio-telemetry methods combined with the use of night-vision goggles as data collection methods were selected to determine activity and behavior patterns and home ranges. Prior to construction of the new range, Stephens' Kangaroo Rats will be live-trapped and radio-chipped with mouse-style transmitters with internal antenna and individually tuned frequencies. The animals will subsequently be located with the use of a hand held Yagi antenna at regular intervals during the night to determine above-ground activity patterns and once during the day to determine daytime burrows. With the aid of night-vision goggles and infrared lights, behavioral observations will be performed. This will be done prior to the range improvement project to collect baseline data and subsequent to the new use to provide a comparison of above ground activity patterns. In addition, live- trapping with traps laid out in a grid pattern will add to the spatial data set.

Locations of each animal will be field mapped and later digitzed to be included in the base GIS which will allow for mapping and geospatial analysis of the data. In addition, the points will be input into CALHOME software to determine home range of the animals. Home range will be assessed using three different statistical techniques:

minimum convex polygon, adaptive kernel, and harmonic mean. Each statistical technique has different strengths and weaknesses. The resulting home range sizes will be compared to determine similarity in both size and shape. The most appropriate statistical method for estimation of the animals home range will be selected based on the known biology of the species. A comparison of home range will be made for baseline data and data collected for post project implementation.

Statistical activity measures that can be performed with the radiotelemetry data include mean distance moved, standard deviation around the center of activity, summing measure and cluster analysis. These measures allow for various comparisons between individuals, sexes, seasons, control and experimental plots. This along with behavioral observations gathered with the aid of the night vision goggles can be compared statistically to detect differences in above ground activity patterns before and after the range improvement project.

Applicability

We are using the best available technology and resources to meet the requirements of DoD Conservation Instruction 4715.3 to maintain compliance with Federal regulatory requirements, in this case, the biological opinion that requires monitoring of the animals prior to and subsequent to the new use. Use of remotely sensed data such as the radio-telemetry data and behavioral observations aided by the use of night vision goggles and infrared spotlights in addition to live trapping was determined to be the most effective means to gather sufficient data with minimal disturbance to the animals. This information can easily be incorporated into the base GIS for the purposes of mapping the actual home ranges of the animals and conducting spatial analyses to determine changes in density and distribution. Not only is the Navy meeting our regulatory requirements, we will be adding to the body of biological information known about the species and thus be able to more effectively manage the them.

PART VII: APPENDICES

APPENDIX A: Points of Contact And Data Sources

Aerial Photography

Aerial photography is represented by the largest number of vendors both public and private. This paragraph will only cover the initial public centers. They should be able to point you to recommended private companies in their area if needed.

The Federal government is the source of much existing photography that can usually be obtained at the cost of reproduction and handling. The NCIC handles all photography for the following agencies: USGS, the Bureau of Land Management (BLM), the Bureau of Reclamation (BR), the National Aeronautics and Space Administration (NASA), the U.S. Air Force, the U.S. Navy, and the U.S. Army. The NCIC has four general centers that specifically operate in their area of the U.S.

THE NATIONAL CARTOGRAPHIC INFORMATION CENTER (NCIC)

NCIC
U.S. GEOLOGICAL SURVEY (USGS)
507 NATIONAL CENTER
RESTON, VA. 22092
PHONE: (703) 860-6045 FTS 928-6045

THE EASTERN MAPPING CENTER (ATLANTIC COAST TO 80 LONG.)

NCIC
U.S. GEOLOGICAL SURVEY
536 NATIONAL CENTER
RESTON, VA. 22092
PHONE: (703) 860-6336 FTS: 928-6336

THE MID-CONTINENT MAPPING CENTER (80 LONG. TO 95 LONG.)

NCIC
U.S. GEOLOGICAL SURVEY
1400 INDEPENDENCE ROAD
ROLLA, MO. 65401
PHONE: (314) 364-3680 X107 FTS: 267-9107

THE ROCKY MOUNTAIN MAPPING CENTER (95 LONG. TO 110 LONG.)

NCIC

U.S. GEOLOGICAL SURVEY
BOX 25046, STOP 504
DENVER FEDERAL CENTER
DENVER, CO 80225
PHONE: (303) 234-2326 FTS: 234-2326

THE WESTERN MAPPING CENTER (PACIFIC COAST TO 110 LONG.)

NCIC

U.S. GEOLOGICAL SURVEY
345 MIDDLEFIELD ROAD
MENLO PARK, CA. 94025
PHONE: (415)423-8111 X 2427 FTS: 467-2427

AVHRR

Data Product and Service

The EROS Data Center provides standard AVHRR digital Level 1b and georegistered products on 9-track tapes 6250 bpi, 3480 cartridge, 8 mm cassette, and via network access. For more information contact:

EOSAT

4300 Forbes Boulevard
Lanham, MD 20706
Phone: 1-800-344-9933

AVIRIS

Ordering information: (Each scene -- 512 lines, all bands, $250):

Martin Olah
M/S 169-315
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109

Or contact:

EMAIL: avorders@ophelia.jpl.nasa.gov

DIGITAL AERIAL PHOTOGRAPHY

There are 2 or 3 firms in the U.S. operating digital cameras. The most recognized in the field and the only to fly U. S. military installations is the Airborne Data Acquisition and Registration system (ADAR) 5500. This platform provides natural color and CIR imagery from 0.5 MPP to 3 MPP. The company offers a composite color system, ADAR 3000 which offers composite color images. See figures 3.11 to 3.15 in this guide. Sales and service offered by:

POSITIVE SYSTEMS

WHITEFISH, MT.

(406) 862-7745

DMSP

DMSP satellites data are available as 8 mm copies of the archived 6,250 bpi tapes from the National Geophysical Data Center (NGDC) or the National Snow and Ice Data Center.

For further information:

EMAIL: dmsp@mail.ngdc.noaa.gov, or

Fax: 303-497-6513

ERS-1

The ERS-1 can produce high resolution and low resolution data products. The high resolution data product has 8192 x 8192 12.5 x 12.5 m pixels, with 25 - 30 m resolution and takes up 64 MB of disk space. The low-resolution has 1024 by 1024 100 x 100 m pixels, with 200 meter resolution, and takes up 1 MB disk space.

ERS-1 data can be accessed through the order desk at the following address:

Radarsat International ERS Order Desk

3851 Shell Road

Suite 200

Richmond, BC, V6X 2W2

Canada

Phone: 604-244-0400

Fax: 604-244-0404

Landsat

The distribution of Landsat data in the United States has gone through three distinct phases: experimental, transitional, and operational. During the experimental phase of

Landsat-1, 2, and 3, all imagery and computer-compatible tapes were disseminated by the Earth Resource Observation System (EROS) Data Center at Sioux Falls, SD. The Satellites were operated by NASA and the data distribution process was operated by the USGS within the Department of Interior at that time. Gradually, all operations were assumed by the National Oceanic and Atmospheric Administration (NOAA) within the U.S. Department of Commerce during the transitional period. During this time, the operation of the Landsat program was transferred from the Federal government to a commercial firm—The Earth Observation Satellite Company (EOSAT). EOSAT assumed system operation on September 27, 1985.

For more information contact:

EOSAT
4300 Forbes Boulevard
Lanham, MD 20706
Phone: 1-800-344-9933

Radarsat

For more information, please contact:

Canadian Space Agency
Radarsat Project
6767, Route De l'Aeroport
Saint-Hubert, (Quebec)
CANADA, J3Y 8Y9

Phone: (514)926-4436
Fax: (514))926-4973
EMAIL: coord@adro.radar/sp-agency.ca
Web Site: http://radarsat.space.gc.ca

Seasat

All of the Seasat data were processed and archived at JPL. Digital data are available as byte products on 9 track 6250 bpi CCT or as 8 X 10 black and white prints, positive transparencies, or duplicate negatives. The photo products are approximately 1:500,000 scale.

For more information contact:

NOAA/NESDIS
Satellite Data Services Division
Princeton Execute Square, Rm. 100
5627 Allentown Road
Camp Springs, MD 20746

301-763-8402

SPACE IMAGING

For more information, contact:

EMAIL: webmaster@spaceimage.com

SPOT

SPOT image system was conceived and designed by the French Center National d'Etudes Spatiales (CNES). Sweden and Belgium also participate in the program. Today SPOT has developed into a large scale international program with ground stations and data distribution outlets located in more than 30 countries. Standard SPOT products consist of digital 9-track tapes at 1600 or 6250 bpi and black and white or color films products. Special products such as perspective view images, complete geologic basin scenes, images corresponding to specific map areas, and special slide sets are offered by distribution offices.

For more information contact: SPOT Image Corporation
1897 Preston White Drive
Reston, VA 22091-4368
Phone: 1-800-ASK-SPOT
Fax: 1-703-648-1813

GLOSSARY

Absorption: Penetration of electromagnetic waves into a medium and their subsequent reduction in strength governed by dielectric properties of the material.

AIRSAR: An acronym for the NASA/JPL airborne imaging radar system. This imaging radar is capable of simultaneously collecting data at three different frequencies (C-, L-, and P-band) and at all different polarizations.

Alluvial fan: A fan-like surface layer of eroded rocks and sand, usually found at the foot of a mountain range.

Altitude: Vertical elevation of an object above a surface or sea level.

Amplitude: Measure of the strength of a signal (units in volts).

Antenna: Part of the radar system which transmits and/or receives electromagnetic energy.

ASI: An acronym for the Italian Space Agency.

Aspect Angle: A description of the geometric orientation in the horizontal plane of the object with respect to the illuminating or transmitted radar beam.

AVHRR: An acronym for the Advanced Very High Resolution Radiometer, a low-resolution (1 kmx1 km pixels) infra red imaging satellite launched by NASA.

Azimuth: The angular position of an object within the field of view of an antenna in the plane intersecting the moving radar's line of flight. The term is commonly used to indicate linear distance or image scale in the direction parallel to the radar flight path. (In an image, azimuth is also known as the along-track direction).

Backscatter: The (microwave) signal reflected by elements of an illuminated scene back toward the radar. It is named to make clear the difference between energy scattered in arbitrary directions, and that which

returns to the radar and therefore may be received and recorded by the sensor.

Bandwidth: A measure of the span of frequencies available in the signal, or passed by the band limiting stages of the system. Bandwidth is a fundamental parameter of any imaging system, and determines the ultimate resolution available.

Beamwidth: An angular measure of the width of the radiation pattern or beam of an antenna. For imaging radar, both the vertical beamwidth (affecting the width of the illuminated swath) and the horizontal or azimuth pattern (which determines, indirectly, the azimuth resolution) are frequently used concepts.

BFPQ: An acronym for Block Floating Point Quantizer, a form of data compression used to reduce the number of bits per sample, notably on Magellan and SIR-C.

Brightness: Property of a radar image in which the strength of the radar reflectivity is expressed as being proportional to a DN or digital number (digital image file) or to a gray scale (photographic image) which for a photographic positive shows 'bright' as 'white'.

Cartography: The making of maps.

C-band: Microwave band in which the wavelengths are at or near 5.6 cm (5.3 GHz).

CD-ROM: Compact Disc - Read Only Memory, a convenient way of storing image data files, with a capacity of 600 Mbytes.

Circulator: A switch used in many types of radar systems.

Classification: The process of assigning classes or types to image pixels. As an example, if the digital number (DN) value of a pixel is greater than 128, it may be assigned to class A; if the DN value is less than or equal to 128, it may be assigned to class B. Applying this process to an entire image, it is classified into classes A and B.

Corner Reflector (dihedral): Combination of two orthogonal intersecting reflecting surfaces that combine to enhance the signal back in the direction of

the radar (see Double-bounce).

Corner Reflector (trihedral): Intersection of three mutually orthogonal reflecting surfaces. Returns are very strong.

DARA: An acronym for the German Space Agency.

Desertification: The process in which land turns into desert. Although this can be a natural process - usually due to long-term climate change - it is often caused by human activities, including overgrazing, and over use of water resources.

Detection: Processing stage at which the strength of the signal is determined. Detection removes phase information from the data.

DLR: An acronym for the German Institute for Aerospace Research.

DN: Digital Number, often between 0 and 255 for byte values, quantifying the brightness of a pixel.

Doppler (frequency): Shift in frequency caused by relative motion along the line of sight between the sensor and the observed scene.

Double-bounce: A type of scattering, in which the electromagnetic wave is reflected by two surfaces at right angles to each other.

Dynamic Range: The ratio of largest measurable signal to minimum detectable signal.

Electromagnetic Spectrum (EMS): The ordered array of known electromagnetic energy extending from the shortest rays, through gamma rays, X rays, UV, visible, infrared, and including microwave and all other wavelengths of radio energy.

Electromagnetic Wave: A wave described by variations in electrical and magnetic fields. All such waves move through the atmosphere at the speed of light, 3.0 x 108 m per second.

EOS SAR: Satellite proposed by JPL to carry a three frequency (L-, C-, and X-bands) polarimetric SAR for the Earth Observation Satellite (EOS) series. If approved by NASA, it would be operational after the year 2000.

ERS-1: Satellite launched by ESA in July 1991. The main instrument

(AMI) includes a C-band SAR, VV polarization and 23° incidence angle.

ESA: European Space Agency, with headquarters in Paris, France.

Foreshortening: Distortions related to the imaging geometry of the radar system through which terrain slopes facing the antenna appear smaller (compressed) in the resulting imagery.

Frequency: Rate of oscillation of a wave. In the microwave region, frequencies are on the order of 0.3 GHz - 300 GHz having wavelengths of 1 mm to 1 m, respectively.

Galileo: a NASA space probe to Jupiter, launched in 1989.

GHz: Gigahertz (109 cycles per sec). A measure of frequency of electromagnetic energy.

Ground Truth: Data collected on the ground, often at the same time as or close to the time the area is imaged.

Histogram: A plot of the frequency of occurrence of values (DN or so) in an image.

Hydrology: The study of water on land and underground.

Image: A pictorial representation acquired in any wavelength of the electromagnetic spectrum. For radar, the image pixel values represent the radar reflectivity of the scene.

Incidence Angle: Defined as the angle between the line of sight (between the radar and object) and the vertical. The local incidence angle takes into account the slope of the terrain at the object's location. Incidence angle can have an important influence on radar backscatter.

Infrared: A type of electromagnetic radiation, usually associated with heat.

Interferometer: Device such as an imaging radar that uses two different paths for imaging, and deduces information from the coherent interference between the two signals. In imaging radar applications, spatial interferometry has been demonstrated to measure terrain height, and time delay interferometry is used to measure movement in the scene such as oceanic currents.

Isotropic: In all directions.

J-ERS-1: Japanese satellite launched February 1992. L-band SAR, HH polarization, 38.5 degree incidence angle and optical sensor.

L-band: Microwave band in which the wavelengths are at or near 23.5 cm (1.0 GHz).

Landsat: A series of optical/infrared imaging satellites launched by NASA.

Layover: Displacement of the top of an elevated feature with respect to its base on the radar image (extreme form of foreshortening).

Look Direction: The angle between geographic North and the direction in which the radar beam is pointing, i.e. perpendicular to the flight direction.

Macsigma0: A software program for displaying and analyzing radar images on the Macintosh computer.

Magellan: A NASA/JPL space probe to Venus which mapped over 98% of the planet's surface using imaging radar.

MHz: Megahertz (106 cycles per sec). A measure of frequency of electromagnetic energy.

Microwave: Electromagnetic wavelength 1 m to 1 mm (0.3 GHz to 300 GHz). The most common imaging radars operate at frequencies between 24 cm - .85 cm (1.25 GHz and 35.2 GHz).

Nadir: Point on the surface of the Earth directly below the radar source.

NASA: National Aeronautics and Space Administration, headquarters in Washington, DC,USA.

Near Polar Orbit: Orbital plane within 10° of a plane containing true North (90 degrees latitude).

NIH Image: A general purpose image processing program for the Macintosh computer.

Normalized RCS (so): A measure of backscatter used by radar scientists (dimensionless).

Non-isotropic: towards a particular direction or region.

Optical: Electromagnetic radiation at wavelengths visible to the human eye.

P-band: Microwave band in which the wavelengths are at or near 68 cm (440 MHz).

Phase: A particular appearance or state in a regularly recurring cycle of changes. In electromagnetic waves, the phase ranges from -180 degrees to + 180 degrees.

Photon: A particle of light.

Pixel: Any of the small discrete elements that together constitute an image. A resolution cell in satellite imagery having both spatial and spectral characteristics and represented by a digital value; an abbreviation of 'picture element'.

Polarization: Orientation and ellipticity of the electric (E) vector in a propagating electromagnetic wave. Imaging radars are able to generate and receive with the same or different polarization. Some commonly used poarization combinations are:

HH - horizontal transmit/horizontal receive
VV - vertical transmit/vertical receive
HV - horizontal transmit/vertical receive
VH - vertical transmit/horizontal receive

Pulse: A short burst of electromagnetic energy.

Radar: An acronym for Radio Detection and Ranging. The science of locating and/or identifying distant objects by means of radio techniques. Radar depends on two processes: the reflection of radar waves by material energy, and the use of short pulses of high frequency energy to make possible the accurate measurement of distance.

Radar Cross Section (RCS): A measure of backscatter used by radar scientists.

Radar Images: A pictorial representation of the reflected microwave energy received at the antenna. The image pixel values represent the amount of reflected energy received from the surface.

Radar Pulse: A packet or burst of microwave radiation transmitted by a radar.

Radar Shadow: A dark area of no return on a radar image resulting from an elevated object, such as a mountain ridge, because the object cuts off the radar beam and prevents illumination of the area behind it.

Radarsat: Canadian remote sensing C-band SAR satellite to be launched in 1995.

RAM: Random access memory.

Range: Distance along the line of sight between the radar and each illuminated scatterer. In imaging radar, the term is also applied to the dimension of an image at right angles to the flight path of the radar. Slant range is the distance as measured by the radar directly, in effect along each line perpendicular to the flight vector and directly connecting the radar and each scatterer. Ground range is the same distance projected (through a geometrical transformation) onto the ground.

Reflectivity: Property of illuminated objects and surfaces to re-radiate a portion of incident energy.

Remote Sensing: A technique of acquiring information about an area or object from a distance.

Resolution: The smallest discernible unit or the smallest unit represented. In satellite imagery it refers to the smallest object that can be discerned. Also referred to as spatial resolution. Resolution in an imaging radar system differs in two directions: the azimuth or along-track direction and the range or across-track direction.

SAR: Synthetic Aperture Radar: A type of imaging radar. SAR systems use the motion of the aircraft/satellite and Doppler frequency shift to electronically synthesize a large antenna in order to obtain high resolution.

Scattering: Reflection of an electromagnetic wave in many directions.

Scattering Mechanism: The way in which electromagnetic waves are scattered.

Seasat: NASA satellite that was in operation July - September of 1978. Seasat

was the first (civilian) imaging radar satellite. It operated at L-band, using horizontal polarization at a 22° incidence angle. Data from Seasat is still important for applications and processing technique development.

SIR (-A and -B): NASA sponsored radar missions flown on the Shuttle, each lasting about one week. SIR-A (November 1981) was an L-band, HH polarization imaging radar, with nominally 50o incidence angle and was optically processed. SIR-B (October 1984) was also at L-band, HH polarization, and offered a variety of incidence angles from about 20° to 50°, and was digitally processed.

SIR-C/X-SAR: A Shuttle radar being built for missions in 1994 and 1995. It will carry a SAR with different polarizations at C- and L-bands, and an X-band HH polarized SAR (contributed by Germany and Italy). It will offer a variety of incidence angles, band selections, resolutions and polarization modes.

Slotted Waveguide: A type of antenna used in radars, notably X-SAR.

Specular: A specular surface is one that is smooth at the wavelength of illumination, having the qualities of a mirror.

SPOT: An acronym for the Optical/Infrared imaging satellite operated by the French Space Agency. Notable for its high resolution (10m) and stereo capabilities.

SRL: An acronym for NASA's Spaceborne Radar Laboratory, which includes SIR-C/X-SAR.

Stereo: A technique for combining image pairs of the same site, viewed from different directions, to produce a 3-D image.

Stokes Matrix: Data format for NASA/JPL AIRSAR radar images. Radar images of different polarizations can easily be generated from this data format.

Supersite: A site selected by the SIR-C/X-SAR Science Team for priority coverage.

Swath (width): Total field of view. The overall plane angle or linear ground distance (width) of the imaged scene in the range or across-track direction.

TOPSAT: An imaging radar mission proposed by JPL to NASA for an

interferometric radar to map topography over the whole Earth.

Track Angle: Angle of spacecraft trajectory with respect to True North.

Trajectory: The path followed by a spacecraft.

Transmission: Energy sent by the radar, normally in the form of a sequence of pulses, to illuminate a scene of interest.

Volume Scattering: Scattering occurring at more than one interface, such as in a forest canopy or by buried objects. The strength (i.e. brightness of the backscatter) of volume scattering is controlled by the dielectric properties of the material.

Wavelength: The distance travelled by a photon (particle of light) during one complete cycle (wave).

X-band: Microwave band in which the wavelengths are at or near 3 cm (8 Hz).

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