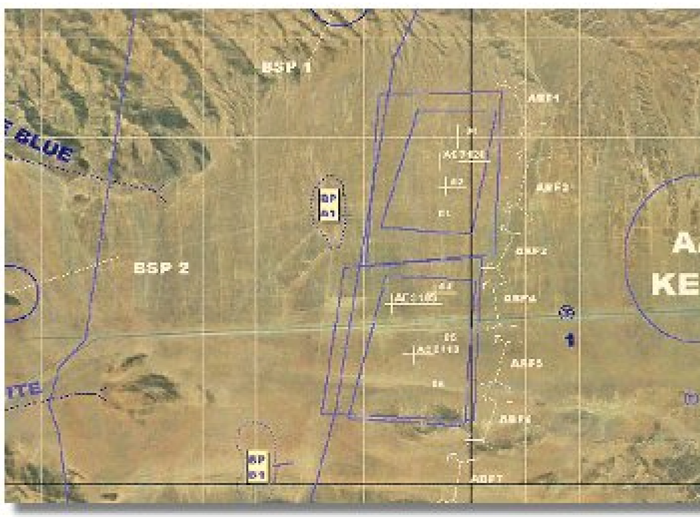
SFIM-AEC-EQ-TR-200053

REMOTE SENSING

USERS' GUIDE



Version 2.5 / April 2002

DISTRIBUTION UNLIMITED; APPROVED FOR PUBLIC RELEASE

SFIM-AEC-EQ-TR-200053

Remote Sensing Users' Guide

Version 2.5

Jointly produced by:
The U.S. Army Environmental Center (USAEC)

U.S. Army Corps of Engineers
Engineer Research and Development Center
Topographic Engineering Center (TEC) & Construction Engineering Research Labs

Authors:
Terri A. Bright and Stephen Getlein

This publication is intended to be a resource for information, and the procurement sources listed are not considered to be all-inclusive. Credit given to suppliers of imagery used in this document does not constitute endorsement on the part of either USAEC or TEC.

April 2002

Distribution Unlimited; Approved for Public Release

Executive Summary

The *Remote Sensing Users' Guide* describes available and near-term remote sensors for land managers. Inexperienced and advanced users alike can refer to this document for information and guidance when making remote sensing decisions.

The **Introduction** outlines briefly what remote sensing can do and provides explanatory sections that cover the elements of a remotely sensed image and describe how image interpreters use those elements to extract information. This section also introduces some general remote sensing terminology, discusses various imagery sources, and provides a comprehensive section on digital aerial orthophotography.

The **Basic Sensor Information** section includes sensor matrices with information about spectral and spatial resolutions of various sensors.

The **Sensor Fact Sheets** provide details on each sensor, including information on spatial resolution, bandwidth, cost, revisit time and other image characteristics. Users can remove sheets from the binder for side-by-side comparison of the sensors identified in the Selection Key.

The **Selection Key** contains three sections: vegetation, soils, and land management objectives. Each section is organized by ecoregion, allowing users to find the imagery that best meets their needs. Several management objectives in the keys contain references to scientific articles that can provide resource managers with additional information and ideas.

This guide also includes **Procurement** assistance and sample **Statements of Work**. Land managers can use this information to obtain imagery themselves or decide if they need assistance.

The authors created this guide to help resource managers better understand the nature of remotely sensed imagery and how to select sensors for specific tasks. We also hope it will help readers decide whether to work independently or use contractor expertise, find literature that addresses relevant case studies, interpret historical imagery, and locate free or inexpensive imagery owned by government agencies.

Written by Ms. Terri A. Bright and Mr. Stephen Getlein for the ITAM program.

Jointly produced by:
The U.S. Army Environmental Center (USAEC)

U.S. Army Corps of Engineers
Engineer Research and Development Center
Topographic Engineering Center (TEC) & Construction Engineering Research Labs (ERDC-USACERL)
Questions or comments about this document?
Contact the U.S. Army Environmental Center at 1-800-USA-3845

Introduction

Guide Overview

Objective

This guide provides an organized tool to help land managers take advantage of existing remote sensing technology.

Included In This Guide

- What remote sensing can do
- Keys to help users select appropriate imagery
- Sensor fact sheets with details on sensors and samples of imagery
- Statement of Work (SOW) samples and procurement assistance information
- Explanation of how image interpreters use texture, color, tone and shape to analyze images
- Advanced user appendices with spectral information, imagery sources, and literature citations for additional information

This Guide Provides Tools to Help Users:

- Better understand remote sensing capabilities and limitations
- Make informed decisions that consider cost and other factors necessary to select the appropriate sensor and meet their needs
- Determine whether to proceed independently or use contractor expertise to order imagery or custom photo flights
- Find literature that addresses similar remote sensing needs
- Interpret archival (historical) imagery available to resource managers
- Locate inexpensive or free imagery available to federal agencies

Remote sensing technology, sensors, space-borne platforms and application change rapidly, and this guide is the second in a series of updated versions We encourage the Army community to use and contribute remote sensing experiences to manage and monitor its valued resources. We welcome corrections, additions and suggestions.

How To Use This Guide

Step 1: Locate your broad management objective and ecoregion in the Selection Key
Step 2: Locate your specific land management objective
Step 3: Make note of the sensors listed
Step 4: Remove applicable Sensor Fact Sheets from binder
Step 5: Do a side-by-side comparison of the sensors (costs, frequency of collection, etc.)
Step 6: Determine which sensor best meets your needs
Step 7: Use the Procurement section for guidance on imagery acquisition

Remote Sensing

Remote sensing has been used by the military at least since the use of balloons for mapping enemy lines during the Civil War. Color infrared photography has emerged as a standard assessment tool for natural resource managers. Spaceborne sensors such as Thematic Mapper and SPOT are increasingly used to detect change in forests, water resources, rangelands, and other natural resources.

What Remote Sensing Can Do

- Show changes in the resource base
- Detect impacts such as erosion, disease, fire extent
- Estimate areal extent of impacts
- Delineate wetlands, wildlife habitats and floodplains
- Plan wildlife corridors and mitigation projects
- Minimize training impacts
- Map vegetation in impact areas and other denied areas
- Give managers an overall view of their installations

Image Interpretation

Image interpretation is the process of identifying objects or conditions on remotely sensed images and inferring their significance (Avery et. al. 1992). Since the late 19th century, viewing imagery and distinguishing subtle differences in brightness and darkness, textures, depth perception, and recognizing complex shapes and feature has become a part of our everyday life. However, image interpretation requires conscious, explicit effort not only to learn about the subject matter, geographic setting and imaging systems in unfamiliar contexts, but also to develop our innate abilities for image analysis (Campbell 1987).

Three Ways in Which Remote Sensing Differs from "Real" Life:

1. Imagery is usually acquired from overhead; not too many family photos are taken from this perspective (except perhaps by bungee jumpers).
2. Many sensors record imagery beyond the visible portion of the electromagnetic spectrum. A color infrared image of healthy vegetation will appear red rather than green.
3. Imagery may be acquired at unfamiliar resolutions and scales. Familiar objects on a high resolution photo may not be recognizable on a coarse MSS image (Campbell 1987).

When interpreting imagery, there are a number of characteristics that enable the viewer to detect, recognize or even identify objects from the vertical imagery. These recognition elements are: shape, size, pattern, shadow, tone or color, texture, association and site (Avery et al. 1992, Campbell 1987, Simonett 1983).

The **shape** of an object is described as the geometric form represented on an image. Regular shapes, squares, rectangles and circles are signs of man-made objects, e.g., buildings, roads, and cultivated fields. Irregular shapes with no distinct geometrical pattern are signs of a natural environment, e.g., a wetland area. Dr. Koeln, in *Applications of Satellite Data for Mapping and Monitoring Wetlands* (1992), states that in order to make proper use of data collected from remotely sensed platforms the "various dependent variables from the satellite data are needed such as area of basin (size) length of basin perimeter (element of size), shape, and square and cubic transformations of these variables."

Shape was one of four elements of object recognition used by Carter et al. (1979) to identify and classify wetlands in the Tennessee Valley area. The shapes of wetlands in Carter's Tennessee Valley area project were not as regular as wetlands in the Prairie Pothole region, which are often circular. Where tone is temporally dependent, shape tends to be geographically dependent.

Size describes the two-dimensional measurement of a given object. If the interpreter knows the dimensions of an object, it might be possible to identify that a rectangular object on an image is a football field, if the image's scale is known. Relative size is also important in differentiating between objects of the same shape. Avery et al. (1992) argues that "there is a relative size difference between a house and an apartment building and between multiple-lane and single-lane streets."

Pattern refers to the repetition of some form over space. A pattern on an image usually illustrates "a functional relationship between the individual features that compose the pattern" (Campbell 1987). In nature, for example, naturally dispersed trees are randomly spaced versus the orderly distribution of trees in an orchard.

Shadows cast due to low sun angle are important to imagery interpretation because their shapes provide profile views of certain features that can aid in their identification. Shadows can also obscure detail. In dense urban environments, for example, shadows might hinder the identification of certain shapes and patterns. On the other hand, shadows might aid in the identification of certain objects like bridges, transmission towers and water towers.

Tone denotes the lightness or darkness of a feature in an image. Color refers to the reflective characteristics of objects within the photographic spectrum. The reflected radiation of an object is dependent on its "surface composition and physical state plus the intensity and angle of illumination" (Avery et al. 1992). Carter et al. (1979) uses tone to separate the various wetland classes in the Tennessee Valley area. Carter argues that tonal difference can be dependent on seasonality. In order to determine evergreen/deciduous boundaries, winter photographs were necessary. Forested swamp, for example, appeared blue-green with some red and yellow in October, dark brown in February, and dark blue in November using high-altitude color infrared photography. To detect excess soil moisture, which aids in the demarcation of wetlands, Nixon et al. (1987) states "... inundated or wet low field areas produced a dark bluish color... and ... wet soil conditions were distinctively evident in the infrared image (videography) in which the areas gave a dark and dull gray appearance."

Texture refers to the visual impression of the roughness or smoothness of an image region. Texture is often used to identify objects that are too small to resolve individually, i.e., tree leaves and leaf shadows. Howland (1980) claims that “texture, pattern and the height of the canopy were for many (wetland) signatures the differentiating factors.”

“Identification of certain objects . . . {is usually accomplished} . . through their **association** with other known objects. Sometimes the reverse is true because some objects are rarely, if ever, associated with the other” (Mbobi 1992). Stewart et al. (1980) applies association to identify small wetlands by correlating that the “absence of trees in the citrus groves serves to indicate the low spots in this karst topography because citrus trees will not thrive in places where water will stand for even a short period of time.”

Change Detection Basics

Change detection involves using multiple imagery of different dates in an attempt to identify areas of land cover change. The basis for this approach is the high correlation between spatial variation in imagery and land cover change. Applications include monitoring training impacts, deforestation, fire, insect defoliation, floods, and urbanization.

Methods

The are two main categories of change detection methods: **postclassification** and **image-to-image** change detection.

Comparison of Classifications (postclassification)

This method involves independently classifying each image (supervised or unsupervised), geo-registering the classifications, and identifying pixels that have changed land cover classification between dates.

A similar approach is to combine the images into one image file (stack), then perform a classification of the combined image. Areas of change may appear as discreet classes.

The success of these techniques depends on how spectrally different the change classes are from the non-change classes and the accuracy of the independent classifications. Also, the classification may become overly complex (redundancy) if all spectral bands are included.

Image Differencing and Ratioing

Image differencing is the most common change detection technique in use.

This method involves subtracting imagery from two dates, band for band, pixel by pixel. The result is a multi-band monochromatic 8-bit grayscale image with pixel values increasing in brightness with amount of change.

Similarly, image ratioing divides one image date by another, with results ranging in value from 0 to 1.

This method results in change images, which can be visually difficult to interpret. The analyst's task is to determine meaningful change threshold (recode) values.

It is important to calibrate the imagery prior to differencing or ratioing. This involves selecting common areas within the images that change little over time, e.g., an airport runway. The image acquisition date with the lowest average value for each band of the area of interest (i.e., runway) is calculated, and the value is subtracted from every pixel of the other images, band by band. This process is done prior to geo-referencing the imagery.

In addition, it is often desirable to transform satellite image digital number (DN) values to radiance or reflectance values, thus effectively correcting for illumination and atmospheric effects.

Principal Components Analysis

Another widely used method, Principal Components Analysis (PCA), allows redundant data to be compacted into fewer bands that are non-correlated and independent. The output PCA image is often easier to interpretable than the source data (Jensen 1996, Faust 1989).

This method also requires calibration.

Linear Regression

A least-squares regression model may also be used to compare the two dates of imagery. Again, the analyst's task is to determine meaningful change threshhold (recode) values.

Vegetation Indicies

Vegetation indicies have been developed to exploit spectral differences between the red (absorbance) and near-infrared (reflectance). These two spectral bands are ratioed, creating a new single band image with brightness values increasing with vegetation biomass.

One of many well-known and accepted vegetation index is the Normalized Differenced Vegetation Index (NDVI).

$$\frac{NIR - Red}{NIR + Red}$$

A false color composite created from up to three years of NDVI images is easy to interpret and relatively quick to produce. By creating three-year color composites it is very easy to discriminate change areas.

General Remote Sensing Terminology

Ten remote sensing data sources are presented in the sensor matrix and are referenced in the ecoregion-organized Selection Key of this guide. The matrix references the various specifications as defined in this section.

"The major characteristics of an imaging Remote Sensing instrument operating in the visible and infrared spectral bands are described in terms of its spatial, temporal, spectral and radiometric resolution. Other important features are the manner of operation of the scanning devices (electromechanical or electric) and its geometrical properties" (Mather 1987). The four elements of spatial resolution are: geometrical properties of an imaging system; the ability to distinguish between point targets; the ability to measure the periodicity of targets; and the ability to measure the spectral properties of small objects.

The **instantaneous field of view (IFOV)** of a sensor is one way to measure the geometrical properties of an imaging system. The IFOV represents the area of ground, viewed by the instrument from a given altitude at any given time. It can be measured in one of two ways: as angular measurement or the area on the ground. Because the actual altitude of a platform may vary, the spatial resolution will vary accordingly. As the altitude of a platform decreases the area of the ground (pixel size) observed will also decrease. The spatial resolution of Landsat's 1 to 3 multispectral scanner, for example, is reported as 79 m. The actual resolution varies from 76 to 81 m.

Defining **spatial resolution on the IFOV** does not take into account the spectral properties of the target. Determining "the size of an area for which a single radiance value can be assigned with reasonable assurance that the response is within 5 percent of the value representing the actual relative radiance" (Simonett 1983) is known as the effective resolution element (ERE) of a platform. Other methods focus on the spatial resolving power of a detector depend on the ability of the detector to distinguish between specified targets. The resolution is expressed in terms of lines pairs per millimeter on the image.

Spatial resolution can also be thought of in terms of the **ground surface distance (GSD)** capability of the sensor. GSD for an image is comparable to the minimum mapping unit for a map. A rough but useful rule to use when selecting imagery to discern attributes of given size is that the sensor must be able to detect objects one-half the size of the object to be identified (i.e., if you want to be able to find something 20 meters in size, you must have imagery that collects data in pixels 10 meters square.)

Except for a few microwave emitting platforms, recent sensors have **been multi-band or multi-spectral**. This means that an image is recorded in discrete spectral bands. Spectral resolution refers to the width of these spectral bands. Individual bands and their widths "will determine the degree to which individual targets (vegetation species, crop or rock types) can be discriminated on a multispectral image. The use of multispectral imagery can lead to a higher degree of discriminating power than any single band on its own. (Mather 1987)

The **spectral resolution** of a remote sensing instrument is determined by the bandwidths of the channels used. "High spectral resolution is achieved by narrow band widths which, collectively, are likely to provide a more accurate spectral signature for discrete objects than broad band widths" (Simonett 1983). Higher spectral resolution reduces the signal-to-noise ratio of the data collected.

Pushbroom scanners, for example, look at each scan line longer "and this gives a better signal-to-noise ratio than does the mechanical scanner that has a single detector, which observes each scan line element sequentially. The time available to look at each point is therefore greater for the pushbroom scanner, thus narrower bandwidths and a larger number of quantization levels are theoretically possible without decreasing the signal to noise ratio to unacceptable levels" (Mather 1987).

The **radiometric resolution** of a sensor is determined by its sensitivity to different levels of reflected electromagnetic radiation. For example, Landsat TM detectors produce digital number (DN) values that range from 0 to 255. The number of DN values are expressed in terms of the number of binary digits of bits needed to store the value of the maximum DN values. This gives Landsat's TM sensor a radiometric resolution of 8 bits. Higher radiometric resolution does not mean a higher quality image. Slater (1980) illustrates that the signal to noise ratio decreases with the increase of radiometric resolution. Tuker (1979) showed that there was only a 2% to 3% gain in distinguishing vegetation types using a 8-bit resolution as compared to a 6-bit resolution.

Temporal resolution is the frequency of repeat coverage. Hence, low temporal resolution refers to a platform that infrequently repeats coverage whereas high temporal resolution refers to a platform that frequently repeats coverage. Simonett (1983) argues that with some applications, temporal resolution is an important factor. For example, to monitor crop growth/stress, image intervals of 10 days would be required, but one-year intervals would be appropriate to monitor urban growth patterns.

False Color Band Combinations: Image analysts possess a variety of techniques that can be used to artificially increase the difference between attributes in an image. In Landsat imagery, for example, analysts can change the selection of bands displayed to emphasize attributes they want to study. Similarly, color and texture patterns within images can be emphasized (at the cost of distorting the information contained in the image). While several sophisticated image-processing systems make this technique easier to intermittent users, these techniques deliver increased analytical power at a cost of increased jeopardy of creating "artifacts" in the image that are not indicative of on-the-ground attributes but are rather creations of the image-processing process.

Technology Transfer

Very few people are able to use remotely sensed imagery productively without at least some training. A logical follow-on to this guide would be a series of short courses or tutorials (two to five days) designed to acquaint military natural resource managers with the imagery described in this guide and the manual and digital imagery-analysis techniques needed to exploit that imagery. The Defense Mapping School offers courses that are close to meeting that description. Many universities and colleges offer courses of varying lengths that focus on remote sensing; the more hands-on exercises that are offered, the more beneficial the course.

New satellites have the potential for acquiring near-real-time, cost-effective, high-resolution imagery; however, that potential can only be exploited by users who understand it. After taking a basic remote sensing course, resource managers should be able to study promotional literature from imagery vendors and ascertain from demonstration data sets whether the new imagery is appropriate for their needs.

Digital Aerial Orthophotography With Multispectral

This section covers a special aerial photographic product called a Digital Orthophoto Quad (DOQ). These computer-ready images are really a type of photographic map based on the well-known USGS 7.5 minute quadrangle map.

Background

The U.S. Geological Survey (USGS) is the lead Federal agency for the collection and distribution of digital orthophoto data.

Partners in the National Digital Orthophoto Program (NDOP)

U.S. Department of Agriculture's Farm Service Agency (FSA)
U.S. Department of Agriculture's Natural Resources Conservation Service (NRCS)
U.S. Forest Service (USFS)

Distribution Agency

USGS Earth Science Information Centers (ESICs)

Digital Orthophoto Quads (DOQ)

The USGS offers two orthophoto products: the 3.75 minute DOQ and the 7.50 minute DOQ. The 7.50 minute DOQ, available as a "county size" product, is only available in black/white with coverage not as complete as its counterpart. The 3.75 minutes DOQ, commonly refered to as a Digital Orthophoto Quarter-Quad (DOQQ), is more popular due to its greater availability, higher spatial resolution, and availability of color IR for some areas.

The National Aerial Photography Program (NAPP) imagery and NAPP-like photography are the primary sources of aerial photography used in the production of 3.75 minute DOQs., although additional aerial photographs or digital images may be used in the future. The National High Altitude Photography Program (NHAP) imagery and NHAP-like photography are the primary sources of aerial photography used in the production of 7.50 minute DOQs.

NAPP Characteristics

Geographic Extent:	5x5 miles (3.75-minutes of latitude by 3.75-minutes of longitude)
Aircraft altitude:	approximately 20,000 feet above mean terrain
Camera:	152-millimeter focal-length camera.
Scale:	1:40,000 (approximately)
Film Type:	Color infrared (CIR) or black & white (B/W)

NHAP Characteristics

Geographic Extent:	10 x 10 miles (7.50-min of latitude by 7.50-min of longitude)
Aircraft altitude:	approximately 40,000 feet above mean terrain
Camera:	8.25-inch lens.
Scale:	1:80,000 (B/W),1:58,000 (CIR)
Film Type:	black & white (B/W)

Characteristics Of Digital Orthophotos Quads

What is the Difference Between an Aerial Photograph and an Orthophoto?

- A conventional aerial photograph contains image displacements caused by the tilting of the camera and terrain relief (topography). It does not have a uniform scale, and distances cannot be measured on an aerial photograph like you can on a map.

- The effects of tilt and relief are removed from the aerial photograph by geocorrection to create an orthophoto.

- An orthophoto is a uniform-scale photographic map.

- Since an orthophoto has a uniform scale, it is possible to measure directly on it like other maps.

Extent of Coverage

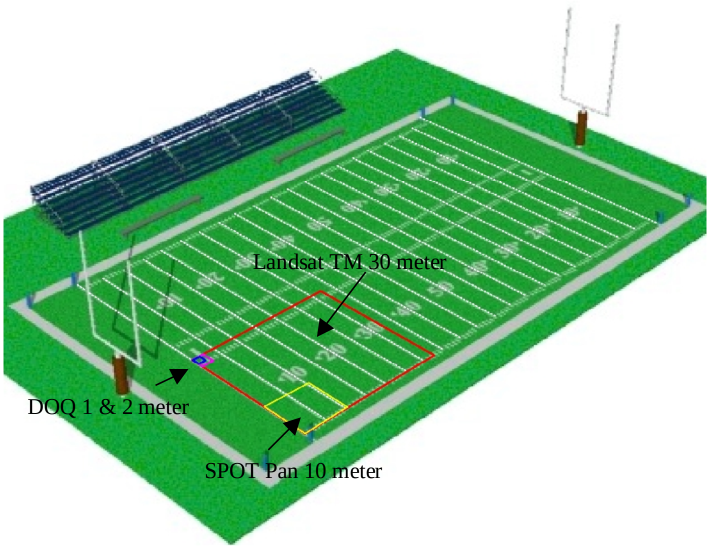
The DOQ coverage includes the conterminous United States, Alaska, Hawaii, and Puerto Rico.

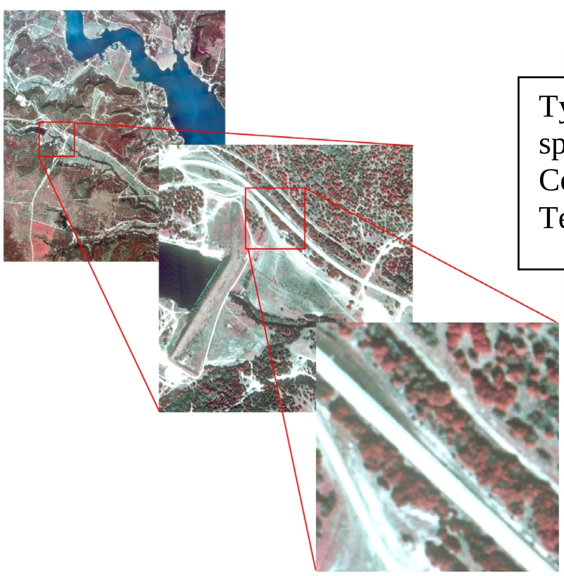
The geographic extent of the digital orthophoto is equivalent to an USGS orthophoto quarter-quadrangle (3.75-minutes of latitude and longitude), plus a 50 meters to 300 meters of overlap, useful for edgematching and mosaicking of quadrangles.

Every orthophoto is a rectangle, but may be larger or smaller than its neighbor.

Spatial Resolution (what is the smallest object I can see?)

Resolution is the fineness or sharpness of the spatial detail visible in an image. Generally speaking, at 1 meter pixel resolution, cars and trucks can be distinguished from background, but not people. The 3.75 minute DOQQ photos are 1 meter spatial resolution while the 7.50 minute DOQ photos range from 1 to 2 meters.





Typical full DOQQ and detail illustrates high spatial resolution of the data (1 meter). From NAPP Color Infrared (CIR) photo source (Fort Hood, Texas).

The image shown above provided by U.S. Army Corps of Engineers Construction Engineering Research Laboratories, PO Box 9005, Champaign, IL 61826-9005.

Projection / Coordinate System

Standard digital orthophotos, 3.75 minute coverage, are cast on the Universal Transverse Mercator (UTM) projection on the North American Datum of 1983 (NAD83) with coordinates in meters.

When displayed on a computer, north is at the top.

The four primary and secondary datum (NAD83) corners are imprinted into the image as four solid and dashed white crosses respectively.

Accuracy

Digital orthophoto quadrangles and quarter-quadrangles must meet horizontal National Map Accuracy Standards (NMAS) at 1:24,000 scale and 1:12,000 scale, respectively.

The NMAS specify that 90 % of the well-defined points tested must fall within 40 feet (1/50 inch) at 1:24,000 scale and 33.3 feet (1/30 inch) at 1:12,000 scale.

Ordering Digital Ortho Photo Products

Uncompressed DOQ files are available from the USGS on

- $ 8-mm tape
- $ compact disc (CD)
- $ 3480 cartridge tape
- $ via semi-anonymous file transfer protocol (FTP)
- $ GeoTIFF format*

*TIFF is an acronym for Tag(ged) Image File Format. Further information on GeoTIFF software specifications can be found at http://mcmcweb.er.usgs.gov/sdts/geotiff.html

Compressed DOQ files are distributed in a JPEG format on CD-ROM. Each CD-ROM contains DOQ coverage for an individual county or area.

Each compressed DOQ on a county CD-ROM consists of a binary image file and an associated metadata file. The metadata file includes descriptive information, such as file identification, data sources and dates, data storage, coordinate systems and datums, and image compression

DOQQ Prices

Eros Data Center (Estimated) as of April 1999
http://edcwww.cr.usgs.gov/glis/hyper/order_info/prices#NAPP

DOQQ -- Digital Orthophoto Quad - Quarter Quad

Compact Disk or 8mm tape

Base Charge per Order	$ 45.00
Black and White	Plus 7.50 per File
Color IR	Plus 15.00 per File
Handling Charge: $3.50	

Semi-anonymous Ftp

Base Charge per Order	$ 30.00
Black and White	Plus 7.50 per File
Color IR	Plus 15.00 per File
Handling Charge: $0.00	

(A few areas are available by county at a reduced price.)

DOQ -- Digital Orthophoto Quad by County

Compact Disk Only *

1 CDROM	$ 32.00
2 CDROM Set	$ 42.00
3 CDROM Set	$ 52.00

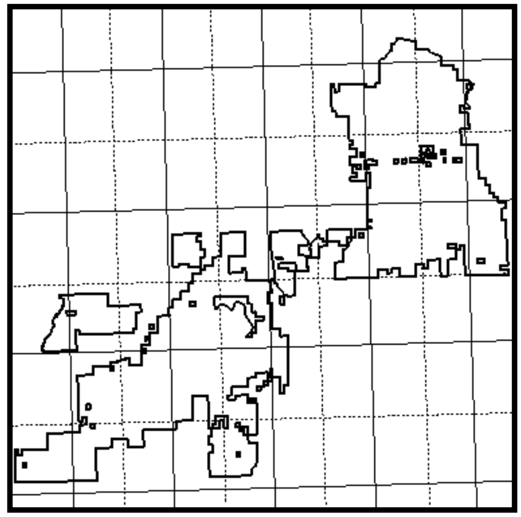
* Doq file size may require multiple CDs

Examples of costs associated with acquiring full digital orthophoto quarter-quads for an installation.

Installation A:

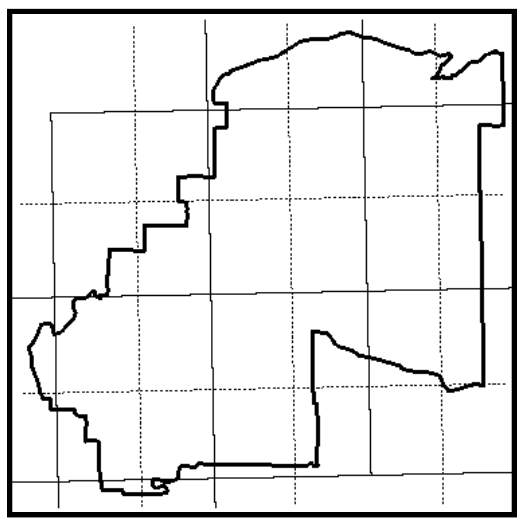
Full DOQQ Coverage
150,000 Acres with complex boundary
Number of quarter quads to cover = 37
CD Media

Base charge:	$45.00
37 x 15.00	$555.00
S&H:	$ 3.50
Total	$603.50

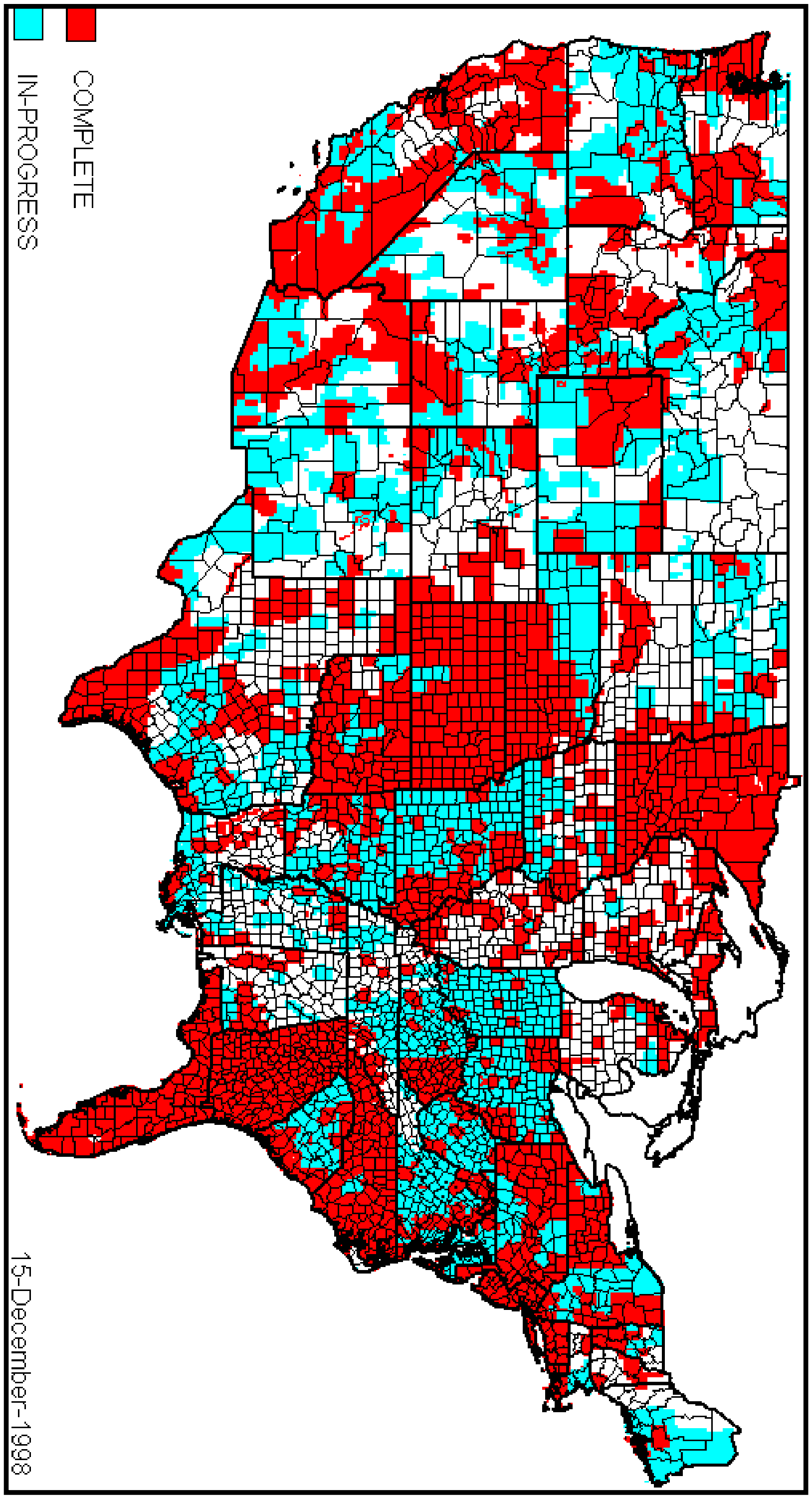


Installation B:
Full DOQQ Coverage
183,912 Acres with simple boundary.
Number of quarter quads to cover = 30
CD Media

Base charge:	$45.00
37 x 15.00	$450.00
S&H:	$3.50
Total	$498.50



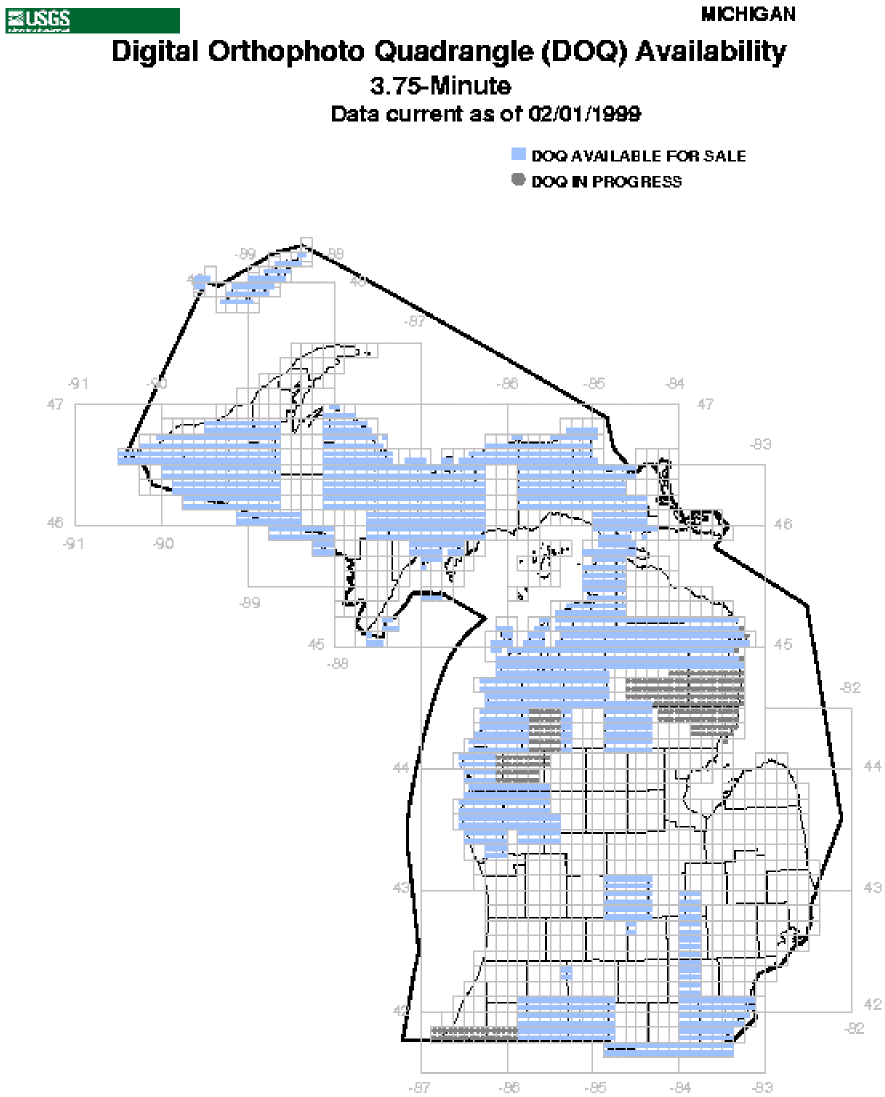
(Note: Solid grid lines represent USGS 7.5 minute quads, dotted grid lines represent quarter quads.)



(Image Source: http://mapping.usgs.gov/pub/doi_high_priority/html/doq_stat.html)

The completion status can be checked quickly from this USGS graphic.

The completion status can be checked in greater detail on a state by state basis. These graphics provide more current information than the DOQ status graphic for the entire US. Higher resolution Adobe Acrobat .PDF files featuring county boundaries, can be downloaded and viewed with free Acroreader.



(Image Source: http://mcmcweb.er.usgs.gov/status/doq_stat.html)

Applications and Related Data Sets

An orthophoto may serve as a base map onto which other map information is overlaid.

The DOQ data may be used as one layer in a geographic information system (GIS), as a tool for various kinds of spatial analyses, and as information for plotting base maps. It has the potential to be used for gathering a wide range of information such as fire damage, woodland classification, habitat classification, structures, road, tracks and paths.

Fort Hood, Texas, cantonment with roads vector overlay.

Color infrared photography

Some DOQQs are available as CIR (color infrared). Originally referred to as camouflage-detection film, CIR is widely used for interpretation of natural resources. Often called false color photography, it differs from conventional color film in that its emulsion layers are sensitive to green, red, and near-infrared radiation (0.5 micrometers to 0.9 micrometers).

Vegetation Analysis

Color IR DOQQ photos are very useful in vegetation interpretation analyses. The intensity values of the red tone are almost always associated with live vegetation. Vigorously growing dense vegetation appears as very intense red tones. An example of this type of vegetation would be central Illinois cornfields in July. A dense stand of evergreen will not appear as bright red as the corn crop because of the decreased level of photosynthetic activity.

Generally, as the vigor and density of vegetation decreases, the tones may change to light reds and pinks. Even various shades of greens, white, blue and tans are possible if plant density becomes low enough and is overcome by the tones of the soils on which the plants are growing, depending on soil type and its moisture content. Dead vegetation will often be shades of green or tan.

Knowledge of the vigor and density of vegetation is important to the interpretation of the red colors on color infrared aerial photography.

Soils

Composition of the soil and soil moisture will affect the color tones shown on the photographs.

Dry sand will appear white, but with more moisture may vary from a light gray to a light tan. Clayey soils will generally be darker in color than sands and tend toward tans and blue-greens. Soils high in organic matter, like silts and loams, will be even darker in color and usually appear in shades of blues and greens.

In general, the wetter the soil, the darker the shade of that particular soil color.

Man-made features

The color of roads, buildings and streets of towns are dependent on the material they are made of. For example, asphalt roads will appear dark blue or black, gravel or dirt roads appear lighter depending on their composition, and clean concrete roads will appear light in tone.

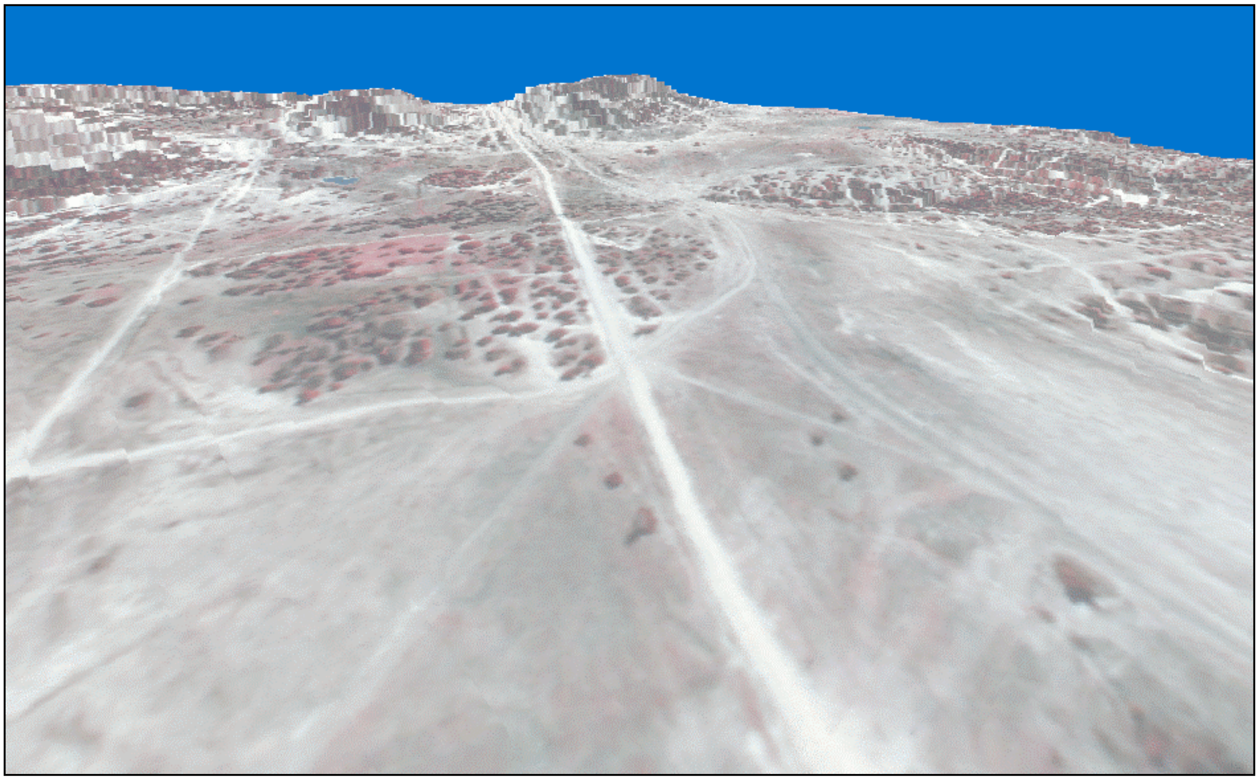
Water

Water will appear as shades of blue, varying from nearly black for clear clean water, to very pale blue lighter in tone as the amount of sediment increases. The color of very shallow water will often appear as the material present in the bottom of the stream.

Black-and-white panchromatic (B/W)

Black-and-white films, sensitivity range is comparable to that of the human eye. This film type, though less useful than CIR, can be used for general base mapping applications.

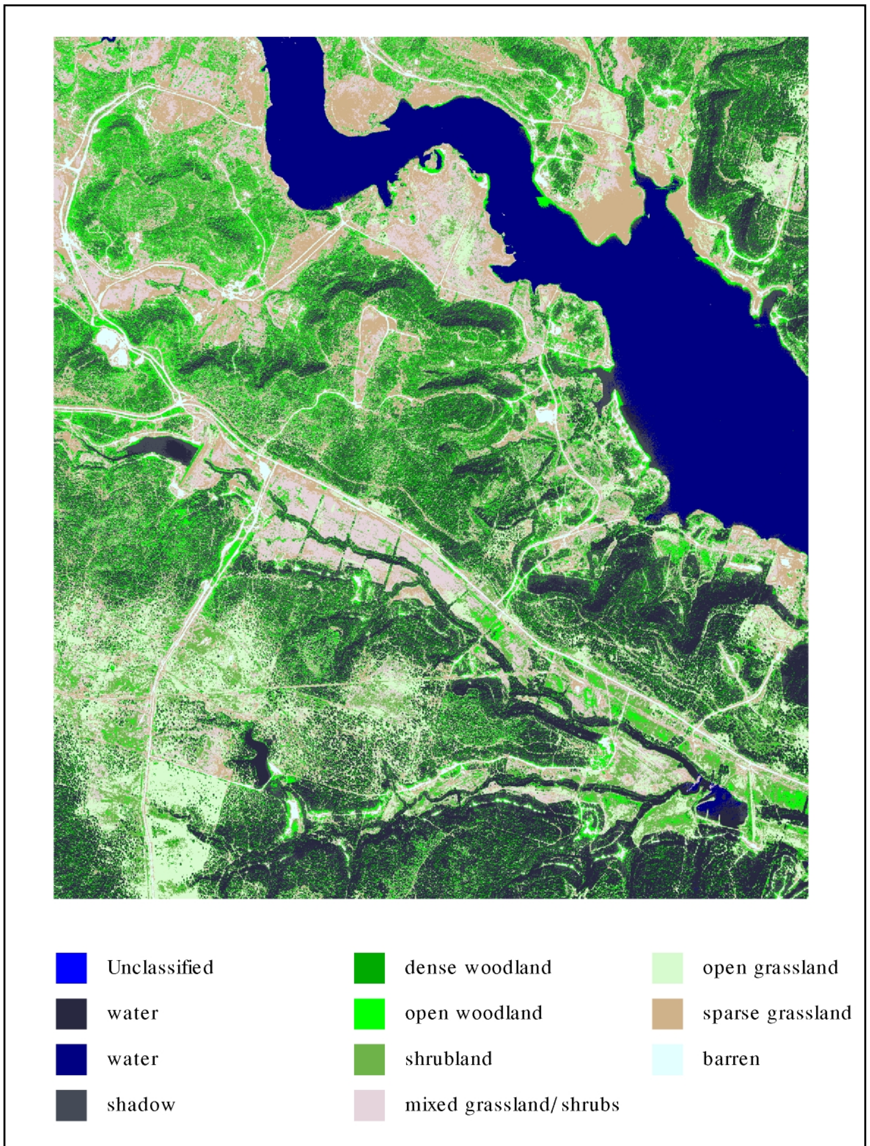
The following image is an example of how 3D maps based on orthophotos draped over digital terrain elevation data (DTED) can be used to uniquely visualize a site. Of questionable value for environmental analysis, these views along with Global Positioning Systems (GPS) may be useful for locating field plots. Army trainers may find them useful for planning purposes, hence cost sharing possibilities may exist.



Fort Hood, Texas, looking northwest. Digital orthophoto quarter quad 1 meter (DOQQ) draped over 30 m digital terrain elevation data (DTED) resampled to 1 m, 90° view angle, vertical exaggeration 3, viewpoint 150 meters above ground level (AGL)

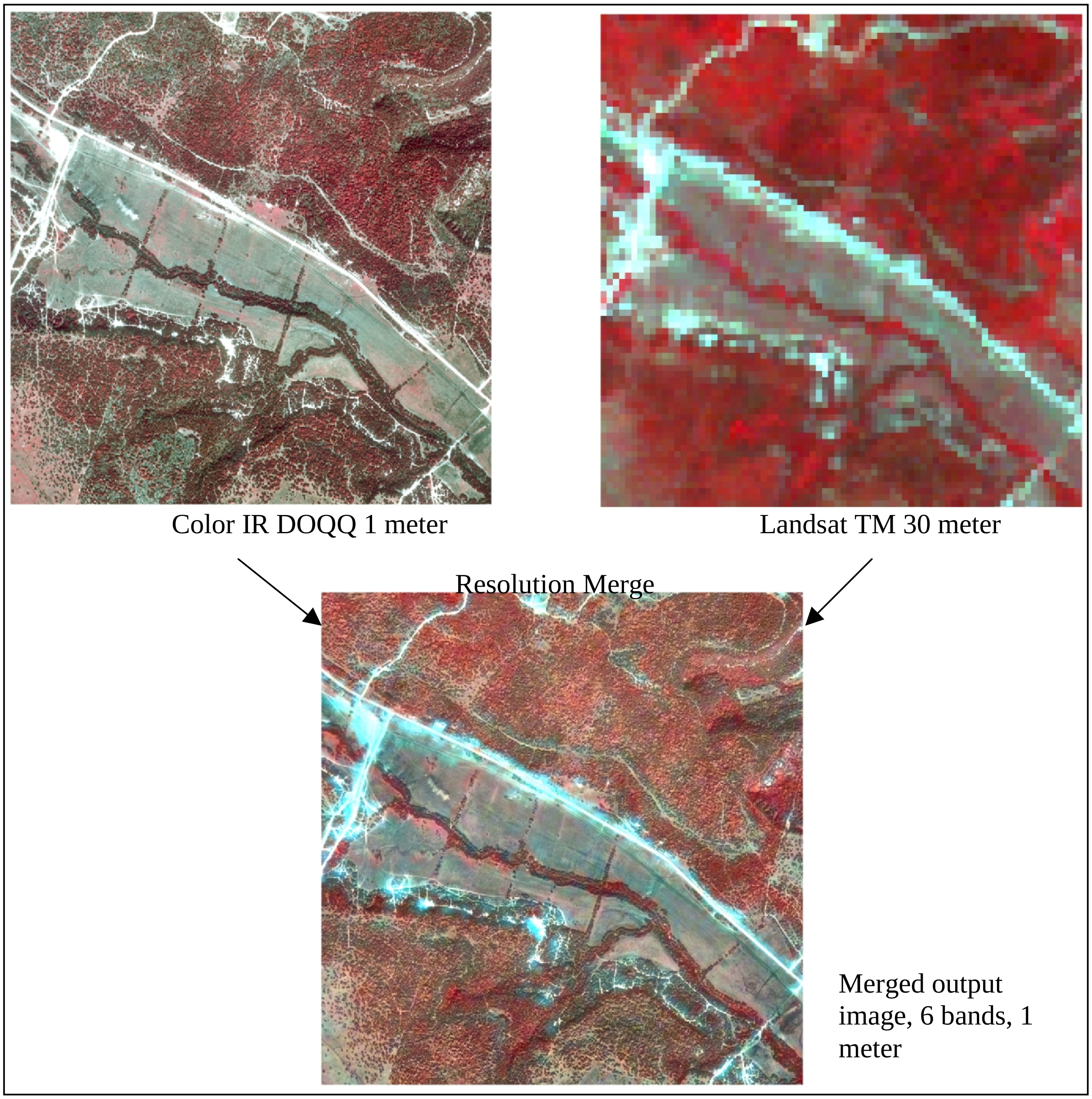
The image shown above provided by U.S. Army Corps of Engineers Construction Engineering Research Laboratories, PO Box 9005, Champaign, IL 61826-9005

The following image illustrates how high resolution CIR-based DOQQs may be useful for land cover classification. Utility of the photos for classification is subject to flight acquisition date during leaf-on periods, availability of CIR-based orthos and year of interest.



Fort Hood, Texas Hypothetical Maximum Likelihood Classification (10 classes)
Digital Orthophoto Quarter Quad

The image shown above provided by U.S. Army Corps of Engineers Construction Engineering Research Laboratories, PO Box 9005, Champaign, IL 61826-9005

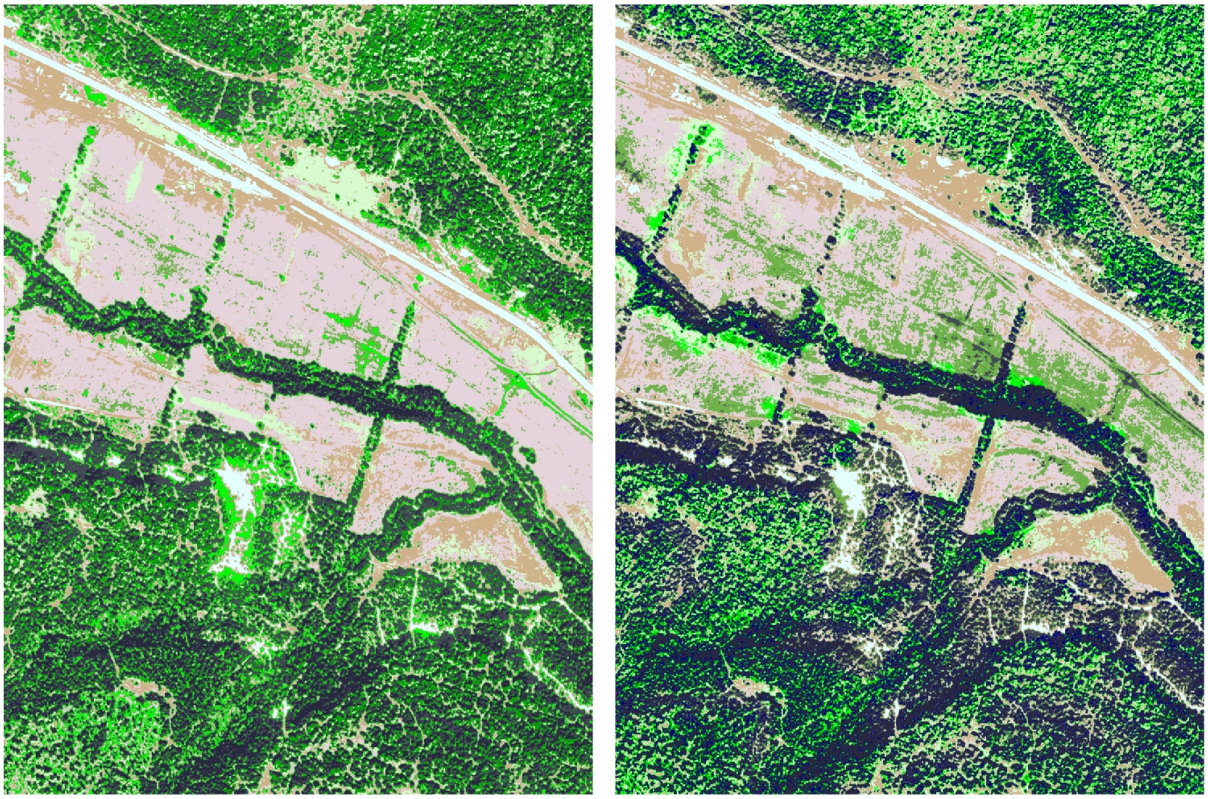


Resolution Merge

High spatial resolution DOQQ can be merged with coarser resolution satellite images to create a new high resolution image with the spectral characteristics of multispectral satellite imagery.

This example shows an image created by merging band 1 of a Color IR orthophoto with six spectral bands of a Landsat TM scene.

The image shown above provided by U.S. Army Corps of Engineers Construction Engineering Research Laboratories, PO Box 9005, Champaign, IL 61826-9005



On the left, a classified DOQQ. The image on the right is of the same area on a DOQQ/Landsat TM merge image, also with 10 classes. The figure illustrates how the added dimension of merging six spectral bands of Landsat TM data to the high resolution DOQQ can yield a clearly different classification.

The image shown above provided by U.S. Army Corps of Engineers Construction Engineering Research Laboratories, PO Box 9005, Champaign, IL 61826-9005

Limitations Of DOQ Products

The USGS DOQ products are attractive to Army land managers due to their relatively low cost, little or no processing required, and high spatial resolution. They are suitable for many applications.

There are some limitations to the data however.

- Lack of control over coverage acquisition dates
- Inconsistent or partial coverage, or mixed acquisition dates within a common geographic area

- Film type may be black/white, color IR, or a mix

Fifteen Army installations were sampled to determine the variability of USGS DOQQ attributes. The following table illustrates the variability of the photos available for the Army installations sampled.

Year Acquired	**%**
1988	5
1990	6
1991	2
1992	4
1993	27
1994	16
1995	24
1996	12
1997	4

Month Acquired	**%**
January	20
February	17
March	8
April	6
May	12
June	6
July	5
August	9
September	6
October	9
November	1
December	0

Film Type	**%**
Black/White	71
Color IR	29

The photos most useful for vegetation analysis are those acquired during peak plant growth periods (leaf-on) with CIR film. The table above clearly shows that the majority of photos were acquired during leaf-off periods using less desirable B/W film. Another limitation is the wide range of years acquired. This may be important if the photos are used for detecting changes to vegetation cover over time and a specific year is required.

The black and white film based DOQs acquired during leaf-off periods are still very useful for base mapping, developing elevation data, and, in the hands of a skilled interpreter, can still be used in a limited way for separating major land cover types. Some users actually prefer B/W film because they have a difficult time interpreting the seemingly “unnatural’ colors in Color IR. USGS support staff indicate that the actual percentages of B/W vs. CIR based orthos for the entire US coverage is not known or is the data is unavailable.

Basic Sensor Information

Various sensors have been developed and deployed with each having different characteristics, such as varying spatial resolution, spectral resolution, and radiometric resolution. The following tables provide an overview of basic sensor information: Table 1 Sensor Matrix - provides basic information on common sensors; Table 2 Frequent Global Coverage, Landsat Like Classification Capability - shows a comparison of sensors with similar characteristics to the venerable Landsat Thematic Mapper sensor; Table 3 High Spatial Resolution, Small Area Coverage - contains information related to the recent high spatial resolution satellites; Table 4 Satellite Hyper Spectral - contains satellites with hyper spectral sensors; Table 5 Sensor Abbreviations - contains descriptions of abbreviations found in the preceding tables. Following these tables are fact sheets that provide more detailed imagery product information.

Table 1. Sensor Matrix

Sensor	Spatial Resolution	Revisit Time	Operational Dates	Wavelength Regions		# of Bands	Fact Sheet #	Order Time	Cost	Utility
Landsat MSS Landsat TM	80 m 30 m 120 m	16-18 days 16 days 16 days	since 1972 since 3/84 since 3/84	0.50-1.1 *um* 0.45-2.35 *um* 10.4-12.4 *um*		4 6 1	1 2 2	Fast Fast Fast	Low Low Low	Low Med Med
SPOT PAN SPOT XS	10 m 30 m	26 days 26 days	since 2/86 since 2/86	0.51-0.73 *um* 0.50-0.89 *um*		1 3	4 4	Fast Fast	Med Med	High High
Standard Aerial Photo	variable	user-defined	since 1980	B&W, Color IR Color		N/A	5 5	Med Med	Low Low	High High
Radar (RADARSAT)	10-30 m	2-9 days	since 10/95	C-Band SAR		N/A	6	Fast	Med	Med
Radar (IFSAR)	5-10 m elevations	user-defined	since 1995			N/A	6	Med	High	High
Digital Aerial Orthophotography	variable	user-defined	since 1980s	user-defined		N/A	7	Slow	High	High
Digital Multispectral Imagery	0.25 m potential	user-defined	since 1994	0.35-0.95 *um*		4	9	Slow	High	High
Pre-production Digital Globe EarlyBird-1-Pan EarlyBird-1-Multicolor	3 m 15m	2-3 times/day	launch in 1997 Failed orbit	0.45-0.80 *um*	Panchromatic	1	N/A	N/A	N/A	N/A
Digital Globe EarlyBird-2-Pan EarlyBird-2-Multicolor	3 m 15m	2-3times/day	Cancelled	0.45-0.80 *um*	Panchromatic	1		N/A	N/A	N/A
Digital Globe QuickBird 2-Pan QuickBird 2-Multicolor	.67cm 2.44 m		launch 2001	0.45-0.90 *um* 0.45-0.52 *um* 0.52-0.60 *um* 0.63-0.69 *um* 0.76-0.89 *um*	Panchromatic Blue Green Red NIR	1 4	8	Fast	N/A	High
Space Imaging, Inc. Carterra IKONOS Panchromatic Multispectral	1 m 4 m	2-4 days	launch 1999	0.45-0.90 *um* 0.45-0.52 *um* 0.52-0.60 *um* 0.63-0.69 *um* 0.76-0.90 *um*	Panchromatic Blue Green Red NIR	1 4	10	Fast	N/A	High

Sensor	Spatial Resolution	Revisit Time	Operational Dates	Wavelength Regions		# of Bands	Fact Sheet #	Order Time	Cost	Utility
Space Imaging, Inc.										
Carterra 5 meter pan	5 m	48-50 days	Feb. 1996	0.45-0.90 *um*	Panchromatic	1	11	Fast	Low	High
Carterra 5 meter OrthoPan	5 m	N/A	Variable	0.45-0.90 *um*	Panchromatic	1	12		Low	High
Carterra 5 meter	5 m	N/A			Natural Color	3				Low
OrthoColor	5 m	N/A			or				Low	Low
Carterra5 meter DOQ					False Color					

Table 2. Frequent Global Coverage, Landsat Like Classification Capability

Country	Program	Instrument(s)	Launch Date	Sensor Types	Spatial Resolution in Meters									Fact Sheet #	Order Time	Cost	Utility	SW KM	Revisit Days
					Thematic Mapper Bands														
					PAN	VNIR				MIR		TIR	RADAR						
						1	2	3	4	5	7	6	RES, BAND						
CHINA BRAZIL	CBERS-1	CCD, IRMSS	'99	M & P	20 80	20	20	20	20	80	80	160	-	**N/A**	N/A	N/A	Med	120	26
FRANCE	SPOT-4	HRVIR, (VEGETATION)	'97	M & P	10	-	20	20	20	20	-	-	-	4	Fast	Med	Med	120	26
INDIA	IRS-1 C,D*	LISS-3 PAN (WIFS)	'95	M & P	6	23	23	23	70	-	-	-	-	N/A	Fast	Med	Med	148	22
INDIA	IRS-P5*	LISS-4 LISS-3	'98	M	-	-	<10	<10	<10	70	-	-	-	N/A	Fast	Med	High	148	22
INDIA	IRS-2A*	LISS –4 LISS-3 (WIFS)	'00	M	-	-	5	5	5	70	-	-	-	N/A	Fast	N/A	N/A	148	22
U.S.	LANDSAT 1-3**	MSS	'72-78 RETIRED	M	-	-	-	-	80	80	80	120	-	1	Fast	Low	Low	185	18
U.S.	LANDSAT 4-5	TM	'82-'84	M	-	30	30	30	30	30	30	60	-	2	Fast	Low	Med	185	16
U.S.	LANDSAT 7	ETM+	'98	M & P	15	30	30	30	30	30	30	60	-	3	Fast	Low	Med	185	16
U.S.	RESOURCE 21***	XXX	'99? UNKNOWN	M	10	10	10	10	10	20	-	-	-	N/A	N/A	N/A	N/A	200	4

* IRS satellite images are brokered by SpaceImaging and resold under the Carterra imagery product line.
****** Archival images available from EROS Data Center.
******* Status inquiries were not returned.

Table 3. High Spatial Resolution, Small Area Coverage

Country	Program	Instrument(s)	Launch Date	Sensor Types	Spatial Resolution in Meters / Thematic Mapper Bands: PAN	VNIR 1	VNIR 2	VNIR 3	VNIR 4	MIR 5	MIR 7	TIR 6	RADAR RES, BAND	Fact Sheet #	Order Time	Cost	Utility	SW KM	Revisit Days
RUSSIA	SPIN-2	KVR-1000, TK-350	'96	P(f)	2,10	-	-	-	-	-	-	-	-	N/A	Fast	Med	Med	40, 300	N/A
U.S.	Digital Globe	EarlyBrid FAILED	'96	M & P	3		15	15	15	-	-	-	-	N/A	N/A	N/A	N/A	36	120
U.S.	Digital Globe	QuickBird 2	'02	M & P	1	4	4	4	4	-	-	-	-	N/A	N/A	N/A	N/A	20	148
U.S.	SpacingImaging	IKONOS	'99	M & P	1	4	4	4	4	-	-	-	-	10		Med	High	13	2-4
U.S.	Orbimage	OrbView	'98	M & P	1&2	8	8	8	8	-	-	-	-	16	N/A	N/A	High	4&8	740,370
INDIA	IRS-P6	PAN	'99	P	2.5	-	-	-	-	-	-	-	-	N/A	N/A	N/A	N/A	10	296

Table 4. Satellite Hyper Spectral

Country	Program	Instrument(s)	Launch Date	Sensor Types	Spectral Range / Number Bands						Fact Sheet #	Order Time	Cost	Utility	SW KM	Revisit Days
					Total # Bands	PAN	VNIR	MIR	TIR	Spatial Resolution in Meters						
USA	HYPERION TRW	EO-1	2000?	M & P	242	0.38 - 2.45um	0.38 – 1.0um	0.1 – 2.45um	-	30	N/A	N/A	N/A*	High	7.5x 100	16
USA	ORBVIEW-4		Launched 2001 Failed	M & P	205	0.45 - 2.5um	0.45 - 0.90	0.1 - 2.5um	-	1, 4, 8	16	N/A	N/A*	High	8,5	3
USA	NEMO-1	HSI	2000-2001	M & P	200	0.45 - 2.5um	0.45 - 0.90	0.1 - 2.5um	-	5, 30, 60	N/A	N/A	N/A*	High	200x 50	2.5-7
AUSTRALIA	ARIES	ARIES-1	2000	M & P	96	0.4 - 2.5um	0.40 - 1.1um	2.0 - 2.5um	-	10, 30	N/A	N/A	N/A*	High	15,30	7

* Satellite data is anticipated to provide significant cost savings over airborne data.

Table 5. Landsat Thematic Mapper spectral bands and sensor abbreviations

Landsat Thematic Mapper Spectral Bands

Band#	**Wavelength *um***	**Spectrum**	**Application**
Band 1:	0.45-0.52	blue-green	separation of soil and vegetation
Band 2:	0.52-0.60	green	reflection from vegetation
Band 3:	0.63-0.69	red	clorophyll absorption
Band 4:	0.76-0.90	near infrared	delineation of water bodies
Band 5:	1.55-1.75	mid infrared	vegetation moisture
Band 6:	10.4-12.5	far infrared	hydrothermal mapping
Band 7:	2.08-2.35	mid infrared	plant heat stress

Abbreviations

M	=	Multispectral
H	=	Hyperspectral
(f)	=	film
IR	=	Infrared
P	=	Panchromatic
R	=	Radar
MIR	=	Mid IR
VNIR	=	Visible through Near Infrared
TIR	=	Thermal IR

Fact Sheet #1 - Landsat MSS

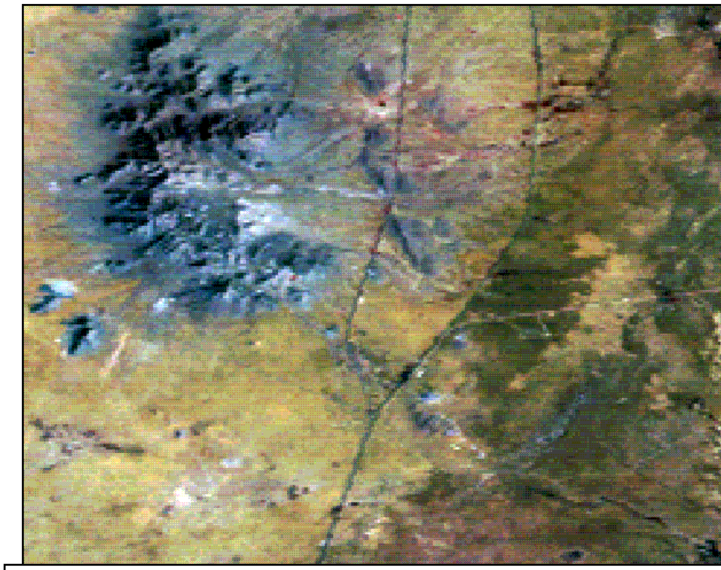


Image 1. Landsat MSS 4-2-1 False Color Composite
Ft. Bliss, Texas 09-30-76

Sensor Specifications

Spatial Resolution: 80-meter-square-pixels
Swath Width: 185 km
Revisit Time: 16 – 18 days
Operational Dates: since 1972

Wavelength Regions

0.50 to 0.60 um (green)	0.70 to 0.80 um (near infra-red (NIR))
0.60 to 0.70 um (red)	0.80 to 1.10 um

General Discussion

The system can provide users with coarse scale imagery that covers large areas at relatively low cost. The costs could be minimal (i.e. $0 - $600) depending on the date of the imagery and if the imagery has been previously procured by another DOD agency.

Vendor Information

For more detailed information contact:
Space Imaging Customer Services Department
(301) 552-0537 or 1-800-344-9933 x537
email: mailto:info@spaceimaging.com
web: http://www.spaceimaging.com
or
EROS Data Center, USGS
User Services Section
Sioux Falls, SD 57198
Phone: (605) 594-6151 fax x6589
email: custserv@edcserver1.cr.usgs.gov
web: http://edcwww.cr.usgs.gov/webglis

U.S. Army Civil Imagery Acquisition Program

For availability questions and purchasing, contact:
Topographic Engineering Center - Ops Directorate
7701 Telegraph Road
Alexandria, VA 22315-3864
email: msantoro@tec.army.mil
web: http://www.tec.army.mil/OD/service.html
and go to Imagery Acquisition

Fact Sheet #2 - Landsat TM

Image 2. Landsat TM imagery acquired over Joshua Tree National Park and Palm Springs, CA using 3-2-1 True-Color Band Comination.

Image 3. Landsat TM imagery acquired over Joshua Tree National Park and Palm Springs, CA using 4-2-1False-Color Band Comination that emphasizes vegetation communities.

Sensor Specifications

Spatial Resolution: Bands 1-5 and 7 are 30-meter-square pixels; Band 6, the thermal band, acquires 120-meter-square pixels.
Swath width: 185 km
Revisit time: 16 days
Operational Dates: since March 1984

Wavelength Regions

0.45 to 0.52 *u*m (blue)
0.52 to 0.60 *u*m (green)
0.63 to 0.69 *u*m (red)
0.76 to 0.90 *u*m (NIR)
1.55 to 1.75 *u*m (Short Wave Infra-Red (SWIR))
2.08 to 2.35 *u*m (SWIR)
10.4 to 12.4 *u*m (thermal)

General Discussion

Landsat TM can provide users with coarse scale imagery that covers large areas at a relatively low cost. Costs could be as low as $0 - $600 depending on the date of the imagery and if it was previously procured by another DOD agency. If extensive processing is required, the costs may be $5,000 per frame.

Vendor Information

For more detailed vendor information contact:
Customer Services Department
0537 or 1-800-344-9933 x537
email: mailto:info@spaceimaging.com
web: http://www.spaceimaging.com/
or
EROS Data Center, USGS
User Services Section
Sioux Falls, SD 57198
Phone: (605) 594-6151 fax x6589
email: custserv@edcserver1.cr.usgs.gov
web: http://edcwww.cr.usgs.gov/webglis

US Army Civil Imagery Acquisition Program

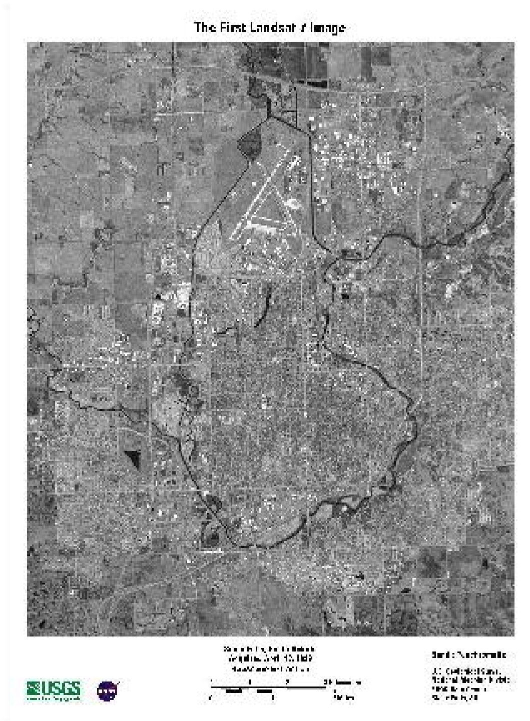
For availability questions and purchasing contact:
Space Imaging's Topographic Engineering Center - Ops Directorate
Phone: (301) 552-0537 or 1-800-344-9933 x537
7701 Telegraph Road Alexandria, VA 22315-3864
email: mailto:info@spaceimaging.com
Phone: (703) 428-6909
DSN 328-6909
email: msantoro@tec.army.mil
web: http://www.tec.army.mil/tio/index.html

Landsat TM Data Grant Collection

The Landsat TM Data Grant Collection of over 500 scenes is available free to qualified U.S. government and affiliated users. Other TM data may be available at approximately $425 to $600. Contact:

EDC DAAC User Services, EROS Data Center
Sioux Falls, SD 57198
Phone: (605) 594-6116 fax x6589
email: edc@eos.nasa.gov
web: http://edcwww.cr.usgs.gov

Fact Sheet #3 - Landsat 7 ETM+



Sensor Specifications

Band	Micrometers	Spectrum	Resolution
1	0.45 to 0.52	blue	30
2	0.52 to 0.60	green	30
3	0.63 to 0.69	red	30

Swath width: 183 km
Revisit time: 16 days
Operational Dates: April 15, 1999-present

General Discussion

Landsat TM can provide users with coarse scale imagery that covers large areas at a relatively low cost. Costs could be as low as $0 - $600 depending on the date of the imagery and if it was previously procured by another DOD agency. If extensive processing is required, the costs may be $5,000 per frame.

Vendor Information

For more detailed vendor information contact:
Space Imaging's Customer Services Department
Phone: (301) 552-0537 or 1-800-344-9933 x537
email: mailto:info@spaceimaging.com
web: http://www.spaceimaging.com/
or
EROS Data Center, USGS
User Services Section
Sioux Falls, SD 57198
Phone: (605) 594-6151 fax x6589
email: custserv@edcserver1.cr.usgs.gov
web: http://edcwww.cr.usgs.gov/webglis

Landsat TM Data Grant Collection

The Landsat TM Data Grant Collection of over 500 scenes is available free to qualified U.S. government and affiliated users. Other TM data may be available at approximately $425 to $600.
Contact:
EDC DAAC User Services, EROS Data Center
Sioux Falls, SC 57198
Phone: (605) 594-6116 fax x6589
email: edc@eos.nasa.gov
web: http://edcwww.cr.usgs.gov

US Army Civil Imagery Acquisition Program

For availability questions and purchasing contact:
Topographic Engineering Center - Ops Directorate
7701 Telegraph Road
Alexandria, VA 22315-3864
Phone: (703) 428-6909 DSN 328-6909
email: msantoro@tec.army.mil
web: http://www.tec.army.mil/tio/index.html
and go to Imagery Acquisition

Fact Sheet #4 - SPOT

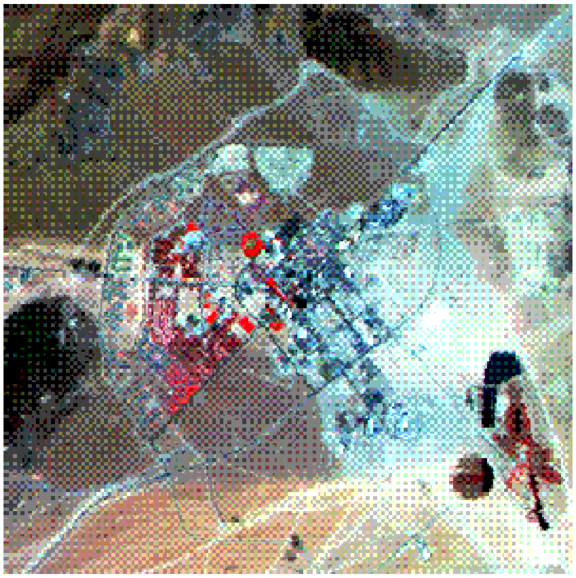


Image 5. SPOT XS (multispectral) image acquired over Fort Irwin, The infrared spectra emphasizes the vegetation communities.

Image 4. SPOT Panchromatic image acquired over Fort Irwin, CA. Panchromatic imagery is primarily intended for applications requiring fine geometric detail.

Sensor Specifications

Spatial Resolution: 10 m for the Panchromatic sensor
30 m for the Multispectral sensor
Swath Width: 60 km
Revisit Time: 26 days for nadir view; 1 to 3 days off-nadir
Operational Dates: since February 1986

Wavelength Regions

Panchromatic
0.51 to 0.73 *u*m

Multispectral
0.50 to 0.59 *u*m (green)
0.61 to 0.68 *u*m (red)
0.79 to 0.89 *u*m (NIR)

General Discussion and Costs

SPOT imagery has a small footprint relative to MSS and TM and is good for seasonal green-up in arid regions. Because the sensor can be pointed at areas of high interest, users can receive revisit images and stereo capabilities faster. SPOT employs different levels of processing for its customers: Level 1A, Level 1B, and SPOTView. SPOTView is a precision-processed, GIS compatible, map projected product. SPOTView products are intended for GIS and image map applications. SPOT 4 was successfully launched March 4, 1998. With an additional spectral band in the mid-infrared (MIR) range and a new vegetation instrument, the sensor will have improved capability for global monitoring of vegetation cover. Level 1A and 1B products, for an area approximately 60-km x 60-km, cost range from $700 for film, $850 for print, and $2,000 to $2,800 for digital. The SPOTView products range from $1,000 on up to about $13,000, depending on the size of the area and the sensor used. Large area coverage is also available and is priced on a cost per-square-mile basis.

Vendor Information

For more detailed vendor information contact:
SPOT Image Corp.
1897 Preston White Drive
Reston, VA 22091-4368
Phone: 1-800-ASK-SPOT
Phone (703) 715-3100 Fax (703) 648-1813
email: [Bill Creech, Defense Sales] creech@spot.com
web: http://www.spot.com
also http://developers.ivv.nasa.gov/rem_sen/earth_sci/spot.html

U.S. Army Civil Imagery Acquisition Program

For availability questions and purchasing contact:
Topographic Engineering Center - Ops Dir
7701 Telegraph Road
Alexandria, VA 22315-3864
Phone: (703) 428-6909 DSN 328-6909
email: msantoro@tec.army.mil
web: http://www.tec.army.mil/tio/index.html

Fact Sheet #5 - Standard Aerial Photography (NHAP/NAPP)

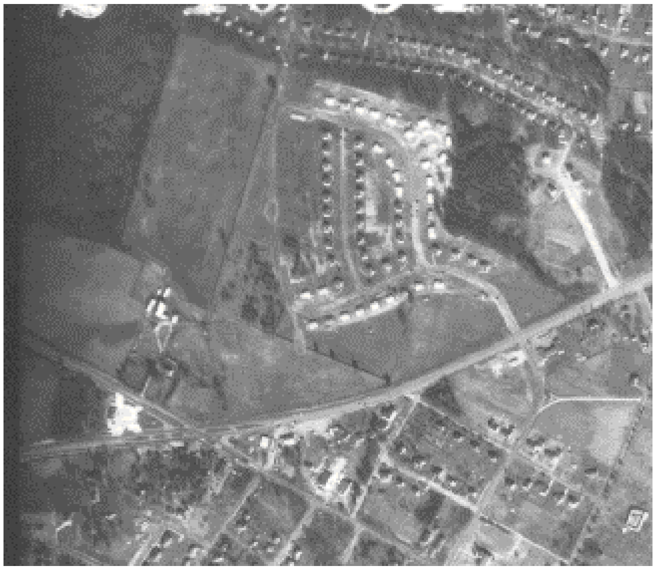


Image 6. A 1954 black & white photograph over Fairfax County, VA. Historical photography is useful for monitoring changes.

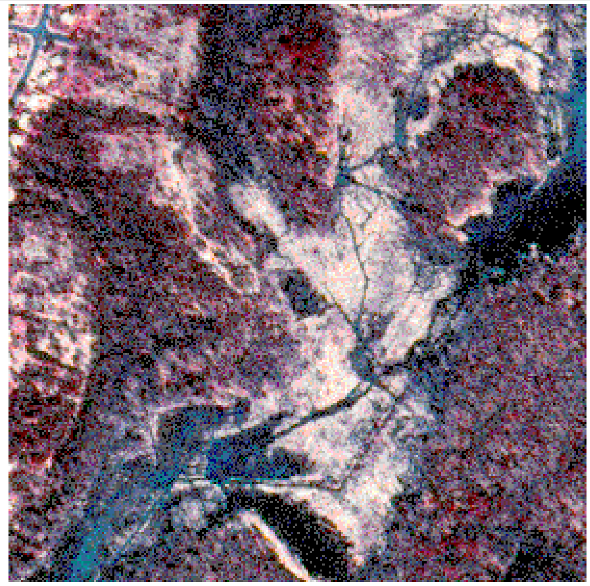


Image 7. A color infrared photograph over a portion of Huntley Meadows Park in Fairfax County, VA.

NHAP National High-Altitude Photography

Photographic Specifications

Spatial Resolution:

1:58000 (using CIR film and a 8.25-inch focal-length mapping camera flown at 40,000 ft. above mean terrain)

1:80000 (using PAN film and a 6-inch focal-length mapping camera flown at 40,000 ft. above mean terrain)

Revisit Times: Varied coverage over the 48 conterminous states

Flight Lines: Centered on the 1:24,000-scale USGS map series

Operational dates: Flown between 1980 and 1987

NAPP National Aerial Photography Program

Photographic Specifications

Spatial Resolution:

1:40,000 (using B&W or CIR film and a 6-inch focal-length mapping camera flown at 20,000 feet above mean terrain)

Revisit Times: Varied coverage over the 48 conterminous states

Flight Lines: Quarter quad centered on the 1:24,000-scale USGS map series

Operational dates: Flown since 1987, as follow-up to NHAP

NHAP/NAPP General Discussion and Costs

Standard aerial photography is used extensively for eastern forest and wetland mapping. Photographs are a high detail source for relatively small areas at a low cost. Conversely, a large number of photos would be required for large area analysis. Aerial photography additionally serves as a source of historical data useful for change detection analysis. Costs: $8.00 and up for black and white prints.

Vendor Information

For more detailed vendor information contact:
EROS Data Center
User Services Section
Sioux Falls, SD 57198
Phone: (605) 594-6151 Fax (605) 594-6589
email: custserv@edcserver1.cr.usgs.gov
web: http://edcwww.cr.usgs.gov/webglis

U.S. Army Civil Imagery Acquisition Program

For availability questions and purchasing contact:
Topographic Engineering Center - Ops Directorate
7701 Telegraph Road
Alexandria, VA 22315-3864
Phone: (703) 428-6909 DSN 328-6909
email: msantoro@tec.army.mil
web: http://www.tec.army.mil/tio/index.html

Fact Sheet #6 - Radar

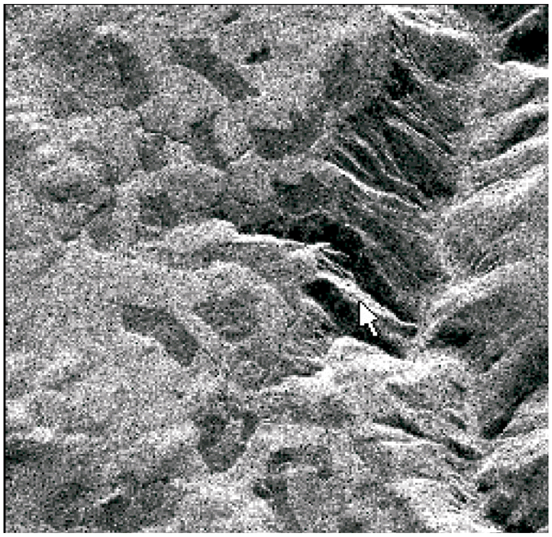


Image 8. Radarsat image of clear-cut forests over Okanangan, Canada.

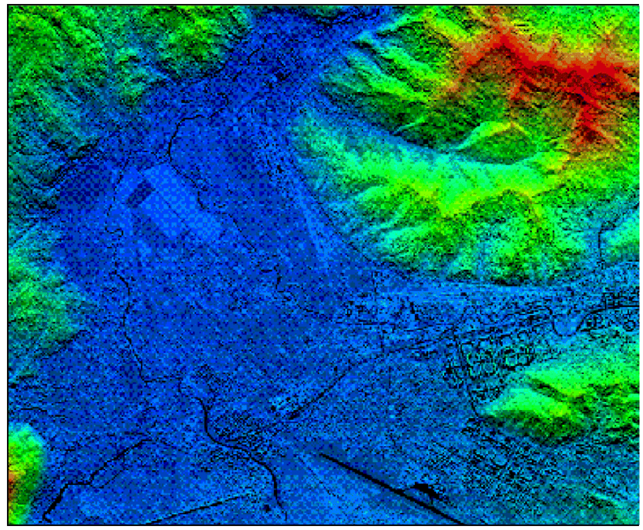


Image 9. IFSARE image over Sarajevo.

Radarsat International

Sensor Specifications

Spatial Resolution: 10 to 30 m
Swath Width: 50 to 150 km
Revisit Time: Varies from two to nine days depending on sensor latitude and beam mode
Operational Dates: October 1995
Wavelength Region: C-Band SAR

General Discussion and Costs

Unlike optical sensors, the Radarsat microwave energy penetrates darkness, clouds, rain, dust, or haze and enables data collection under any atmospheric condition. The microwave energy is capable of gathering data on ice conditions, crops, forests, oceans, and geology.
10-m resolution images run from $3750 to $5250 for 50-km x 50-km area
30-m resolution images run from $2750 to $4750 for 100-km x 100-km and 150-km x 150-km areas

IFSARE (Interferometric Synthetic Aperture Radar for Digital Terrain Elevation)

Sensor Specifications

Swath Width: 10 km
Operational Dates: Preliminary flights in 1996.

Wavelength Regions: The X-Band is capable of operating in all weather, day or night, and in the presence of obscurants.

General Discussion

IFSARE is an airborne radar system with accompanying ground processing equipment focused on quickly generating high-density elevation data with 5- or 10-m post spacing and 3 m elevation and spatial accuracy.

Vendor Information

For more detailed Radarsat information contact:
Lockheed-Martin Astronautics
Deer Creek Facility P.O. Box 179
Denver, CO 80201
Mr. Cal Harr (303) 977-3938
Fax (303) 977-9827
email: cal.d.harr@den.mmc.com or
Radarsat International
web: http://radarsat.space.gc.ca also
http://www.ccrs.nrcan.gc.ca/ccrs/radarsat/photos/radspece.html

U.S. Army Civil Imagery Acquisition Program

For availability questions and purchasing contact:
Topographic Engineering Center - Ops Directorate
7701 Telegraph Road
Alexandria, VA 22315-3864
Phone: (703) 428-6909 DSN 328-6909
email: msantoro@tec.army.mil
web: http://www.tec.army.mil/tio/index.html

Fact Sheet #7 - Digital Aerial Orthophotography Merged With Multispectral Data

Image 10. Digital Aerial Orthophotography.
Very large-scale photography enabled mapping of vegetation, drainage, trails, and various cultural features. The imagery in the project can be used by all agencies at the location. More than

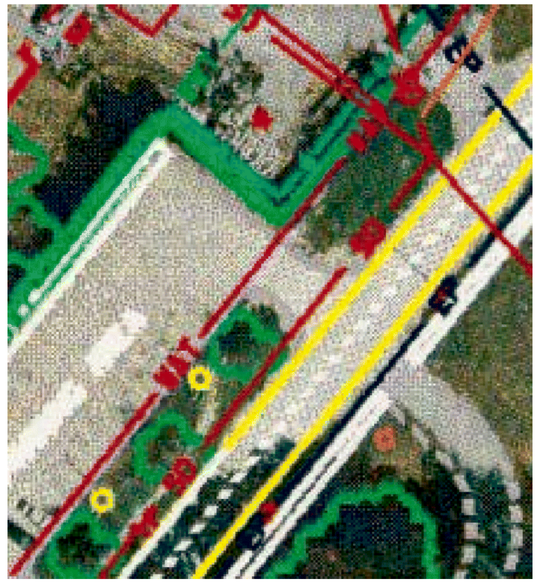


Image 11. Digital Aerial Orthophotography.
Color-infrared and natural-color aerial photography were merged to delineate wetlands and other environmentally sensitive areas. The work was part of a Geographic Information Systems project.

Sensor Specifications

Spatial Resolution: Variable
Swath Width: Variable
Revisit Time: User-defined

Spectral Resolution

Variable, relatively wide-band compared to individual satellite bands

General Discussion and Costs

Useful for wetland delineation in coastal and other DOD wetlands. Costs are variable depending on resolution, area, and level of processing. Higher costs are justified by the more accurate (i.e., rectified) images.

Vendor Information

For more detailed information, contact:
William French, Executive Director
American Society for Photogrammetry and Remote Sensing
5410 Grosvenor Lane, Suite 210
Bethesda, MD 20814-2160
Phone: (301) 493-0290 Fax (301) 493-0208
email: billf@asprs.org

The images shown above were provided by Photo Science, Inc.
45 W. Watkins Mill Road
Gaithersburg, MD 20878
Phone: (301) 948-8550
web: http://www.photoscience.com

Fact Sheet #8 – Digital Globe

Image 14. This Digital Globe image depicts natural and cultural resource information required to locate a suitable lumber processing site.

Sensor Specifications

QuickBird 2 Satellite
Panchromatic Sensor
Spatial Resolution: 67cm
Wavelength Region: 0.45 to 0.90 um

QuickBird 2 Satellite
Multispectral Sensor
Spatial Resolution: 2.44 m
Wavelength Regions: 0.45 to 0.52 um (blue)
0.52 to 0.60 um (green)
0.63 to 0.69 um (red)
0.76 to 0.90 um (NIR)

Revisit Time: The Digital Globe system will revisit most populated parts of the world every 1 to 3.5 days.
Operational Dates: The QuickBird 2 satellite was launched on October 18, 2002. Broad commercial image availability is expected by the third quarter of 2002.

General Discussion

The Digital Globe system is composed of a QuickBird satellite that carries 2 sensors: a 67-cm resolution panchromatic sensor and a 2.44-m multispectral (4-band) sensor. Both multispectral and panchromatic imagery can be taken over the same area at the same time. The image sizes are 16.5-km x 16.5-km for both the multispectral and panchromatic sensors.

Vendor Information

For more detailed Digital Globe information, contact:
Digital Globe
1900 Pike Road
Longmont, CO 80501-6700
POC: Mr. Ron Birk, Director Civil Government Marketing
Phone: (303) 682-3800 Fax (303) 682-3800 Ext. 3848
web: http://www.digitalglobe.com

U.S. Army Civil Imagery Acquisition Program

For availability questions and purchasing:
Topographic Engineering Center – Ops Dir
7701 Telegraph Road
Alexandria, VA 22315-3864
Phone: (703) 428-6909 DSN 328-6909
email: msantoro@tec.army.mil
web: http://www.tec.army.mil/tio/index.html

Fact Sheet #9 - Digital Multispectral Video (DMSV)

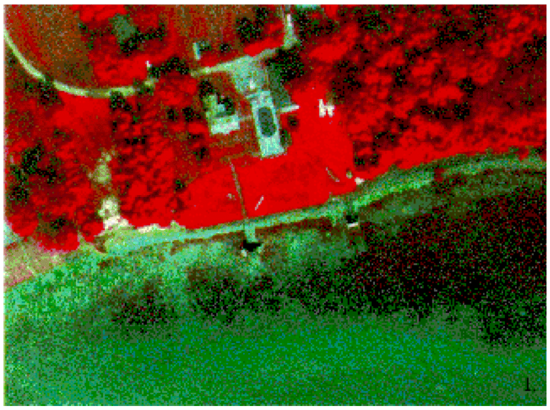


Image 12. Digital Multispectral Video image compiled using bands 0.75, 0.65, and 0.55 um. This combination shows the shoreline vegetation as well as the presence or absence of aquatic vegetation.

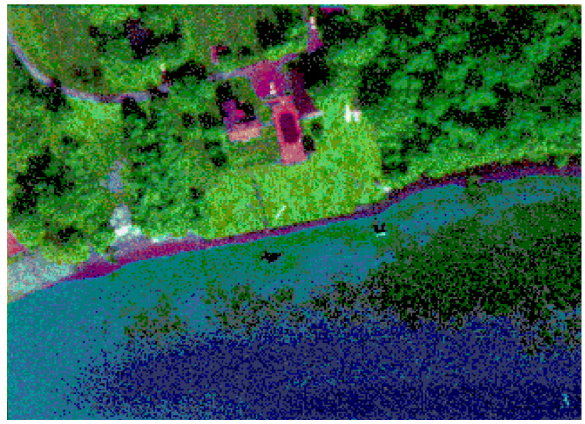


Image 13. DMSV image using a different combination of bands. Changing the band combinations to 0.77, 0.75, and 0.55 um shows density of aquatic vegetation.

Sensor Specifications

Spatial Resolution: Variable resolution (dependent on aircraft height) with a potential of 0.25 m
Swath width: Variable from 300 to 550 m
Revisit Time: User-defined

Wavelength Sensitivity

Four bands that are user selectable within the range of 0.350 um to 0.950 um (UltraViolet (UV) to Visible (VIS) to NIR) with a band, pass width greater than or equal to 0.010 um

Typical wavelength regions may be:

0.325 to 0.575 um (blue)
0.425 to 0.675 um (green)
0.525 to 0.775 um (NIR)
0.625 to 0.875 um (NIR)

General Discussion and Costs

The Digital Multispectral Video (DMSV) is being developed by the Topographic Engineering Center. It has been used to delineate endangered species habitat, map wetland vegetation, measure reactions to stream acidification and study nutrient flow in wetland plant communities. DMSV imagery is typically used for customized applications and has a proven high capability in mid-Atlantic aquatic/wetland studies. The selectable bandwidths offer high spatial and high spectral resolution. Frame processing costs $25-50. Travel, setup costs and large geographical areas are extra.

Vendor Information

For more detailed information contact:
Topographic Engineering Center - Technology Directorate
7701 Telegraph Road
Alexandria, VA 22315-3864
John Anderson Ph.D., Research Biologist
Phone: (703) 428-8203 DSN 328-8203
email: johna@tec.army.mil

Fact Sheet #10 - Space Imaging, Inc. CARTERRA IKONOS

Image 14. 1-m Panchromatic
Subset of first IKONOS image released
Subject: Jefferson Memorial, Washington D.C.
(Photo courtesy of Space Imaging Inc.)

Sensor Specifications

	Panchromatic Sensor	Multispectral Sensor
Spatial Resolution:	1 m	4 m
Wavelength Region:	0.45 to 0.90 um	0.45 to 0.52 um (blue)
		0.52 to 0.60 um (green)
		0.63 to 0.69 um (red)
		0.76 to 0.90 um (NIR)

Swath Width: Images will cover areas of 11 km x 11 km, but smaller or larger areas can be purchased.
Revisit Time: 2-4 days.
Operational Dates: The launch of IKONOS in April 1999 failed to place the satellite into orbit. The second IKONOS satellite was successfully launched September 24, 1999.

General Discussion

Prior to ordering products, customers can review reduced-resolution @browse@ imagery in the Space Imaging archive that meets specific criteria such as geographical location, maximum cloud cover, time of image collection, ground sample distance, and where appropriate, mono and stereo views. Products will include radiometrically corrected images; geometrically corrected images; orthorectified images made from one meter pan imagery that meet the U.S. National Map Accuracy Standards for map scale accuracy up to 1:2400; pan-sharpened color imagery; and digital terrain models generated from stereo image pairs.

Vendor Information

Space Imaging, Inc.
9351 Grant Street, Suite500
Thornton, CO 80229-0939
Phone (800) 425-2997 or (303) 254-2000
email: info@spaceimaging.com
web: http://www.spaceimaging.com

U.S. Army Civil Imagery Acquisition Program

For availability questions and purchasing contact:
Engineering Center - Ops Directorate
7701 Telegraph Road
Alexandria, VA 22315-3864
Phone: (703) 428-6909 DSN 328-6909
email: msantoro@tec.army.mil
web: http://www.tec.army.mil/tio/index.html
and go to Imagery Acquisition

Fact Sheet #11 - Space Imaging, Inc. CARTERRA 5-Meter Pan

Image 15. 5-m Pan, Toronto, Canada. (Photo courtesy of Space Imaging Inc.)

Sensor Specifications

Sensor:	Panchromatic (1 band)
Spatial Resolutiom:	5 m
Wavelength Region:	0.45 to 0.90 um
Swath Width:	Images will cover areas of 70x70 km, 23x23 km, or 23x70 km strip
Revisit Time:	48-50 days
Archive Dates:	February 1996-present

General Discussion

Prior to ordering products, customers can review reduced-resolution ”browse” imagery in the Space Imaging archive that meets specific criteria such as geographical location, maximum cloud cover, time of image collection, ground sample distance, and where appropriate, mono and stereo views. Products will include radimetrically corrected images; geometrically corrected images; orthorectified images made from one meter pan imagery that meet the U.S. Photo courtesy of Space Imaging National Map Accuracy Standards for map scale accuracy up to 1:2400; pan-sharpened color imagery; and digital terrain models generated from stereo image pairs.

Vendor Information

For more detailed vendor information contact:

Space Imaging, Inc.
9351Grant Street, Suite 500
Thornton, CO 80229-0939
Phone (800) 425-2997 or (303) 254-2000
email: info@spaceimaging.com
web: http://www.spaceimaging.com

U.S. Army Civil Imagery Acquisition Program

For availability questions and purchasing contact:
Topographic Engineering Center - Ops Directorate
7701 Telegraph Road
Alexandria, VA 22315-3864
Phone: (703) 428-6909 DSN 328-6909
email: msantoro@tec.army.mil
web: http://www.tec.army.mil/tio/index.html
and go to Imagery Acquisition

Fact Sheet #12 - Space Imaging, Inc. CARTERRA 5-Meter Ortho Pan and Color

Image 16. 5-meter Pan fused with 20-25 multispectral Washington, DC area. (Photo courtesy of Space Imaging Inc.)

Sensor Specifications

Sensor:	Panchromatic (1 band)
Spatial Resolution:	5 m
Wavelength Region:	0.45 to 0.90 um (panchromatic) Natural Color (Landsat TM bands R,G,B), or False Color IR (with Landsat TM bands R,G, Near-IR)
Swath Width:	Images will cover areas of 70x70 km, 23x23 km
Revisit Time:	N/A
Archive Dates:	February 1996-present

General Discussion

Prior to ordering products, customers can review reduced-resolution ”browse” imagery in the Space Imaging archive that meets specific criteria such as geographical location, maximum cloud cover, time of image collection, ground sample distance and, where appropriate, mono and stereo views. Products will include radimetrically corrected images; geometrically corrected images; orthorectified images made from one meter pan imagery that meet the U.S. National

Map Accuracy Standards for map scale accuracy up to 1:2400; pan-sharpened color imagery; and digital terrain models generated from stereo image pairs.

Vendor Information

For more detailed vendor information contact:
Space Imaging, Inc.
9351Grant Street, Suite 500
Thornton, CO 80229-0939
Phone (800) 425-2997 or (303) 254-2000
email: info@spaceimaging.com
web: http://www.spaceimaging.com

U.S. Army Civil Imagery Acquisition Program

For availability questions and purchasing contact:
Topographic Engineering Center - Ops Directorate
7701 Telegraph Road
Alexandria, VA 22315-3864
Phone: (703) 428-6909 DSN 328-6909
email: msantoro@tec.army.mil
web: http://www.tec.army.mil/tio/index.html
and go to Imagery Acquisition

Fact Sheet #13 - Earth Resources Satellite (ERS) 1-2

Image 17. ERS-1 image of north Saskatchewan colored to enhance information content.

Sensor Specifications

Spatial Resolution:	30 meter
Wavelength Region:	C-band (5.6 cm)
Polarization:	VV
Incidence Angle:	30 meters
Swath Width:	100 km.
Revisit Time:	ERS-1 35 days
	ERS-2 35 days
Operational Dates:	ERS-1 1991-present. Now on standby
	ERS-2 1995-present. Three-year design life.

General Discussion

Unlike optical sensors, the ERS microwave energy penetrates darkness, clouds, rain, dust, or haze, enabling data collection under any atmospheric condition. Capable of gathering data on ice conditions, crops, forests, ocean sand geology.

Vendor Information

For more detailed vendor information contact:
Radarsat International
13800 Commerce Parkway
MacDonald Dettwiler Building
Richmond, British Columbia V6V2J3
CANADA
Phone: (604) 231-5000
Fax: (604) 231-4900
web: http://earth.esa.int/ers/

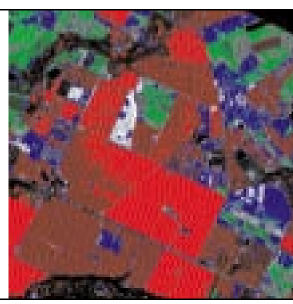
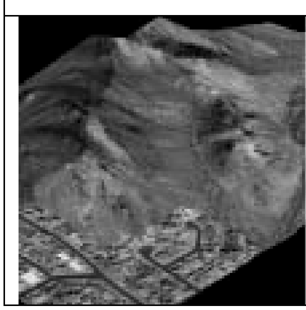
U.S. Army Civil Imagery Acquisition Program

For availability questions and purchasing contact:
Topographic Engineering Center - Ops Directorate
7701 Telegraph Road
Alexandria, VA 22315-3864
email: msantoro@tec.army.mil
web: http://www.tec.army.mil/tio/index.html
and go to Imagery Acquisition

Fact Sheet #14 - OrbView 3

ORBIMAGE's high-resolution satellite, OrbView-3 is currently in production. OrbView-3 is now scheduled for launch in second quarter of 2002. OrbView-3's imaging instrument will provide both 1-m panchromatic imagery and 4-m multispectral imagery with a swath width of 8 km.

ORBIMAGE's OrbView-3 satellite will be one of the world's first commercial satellites to provide high-resolution imagery from space. OrbView-3 will produce one-meter resolution panchromatic and four-meter resolution multispectral imagery. One-meter imagery will enable the viewing of houses, automobiles and aircraft, and will make it possible to create highly precise digital maps and three-dimensional fly-through scenes. Four-meter multispectral imagery will provide color and infrared information to further characterize cities, rural areas and undeveloped land from space.

	Orbview-3 will be one of the first commercial satellites to provide high-resolution images from space.
Orbview-3's multispectral data will enable early detection of crop stress.	
	OrbView-3's stereo imaging capability will provide 3-D terrain images.

- OrbView-3's imaging instrument will provide both one-meter panchromatic imagery and four-meter multispectral imagery with a swath width of 8 km.

- The satellite will revisit each location on Earth in less than three days with an ability to turn from side-to-side up to 45 degrees.
- OrbView-3 imagery will be downlinked in real-time to U.S. ground stations located around the world or stored on-board the spacecraft and downlinked to ORBIMAGE's master U.S. ground stations.
- To access OrbView-3 imagery, customers will either directly downlink the data with their own ground station, purchase imagery from regional distributors or order individual images from ORBIMAGE's online service.
- OrbView-3 will provide imagery useful for a variety of applications such as telecommunications and utilities, oil and gas, mapping and surveying, agriculture and forestry, and national security.

Sensor Specifications

Imaging Mode:	Panchromatic	Multispectral
Spatial Resolution:	1 meter	4 meter
Imaging Channels:	1 channel	4 channels
Spectral Range:	450-900 nm	450-520 nm
		520-600 nm
		625-695 nm
		760-900 nm
Swath Width:	8 km	
Image Area:	64 km^2	
Maximum Data Rate:	150 Mbps	
Revisit Time:	Less than 3 days	
Orbital Altitude:	470 km	
Nodal Crossing:	10:30 A.M.	
System Life:	5 years	

Vendor Information

ORBIMAGE
21700 Atlantic Boulevard
Dulles, VA 20166
Phone: (703) 406-5800
Fax: (703) 404-8061
email: info@orbimage.com

Fact Sheet #15 - SPIN-2

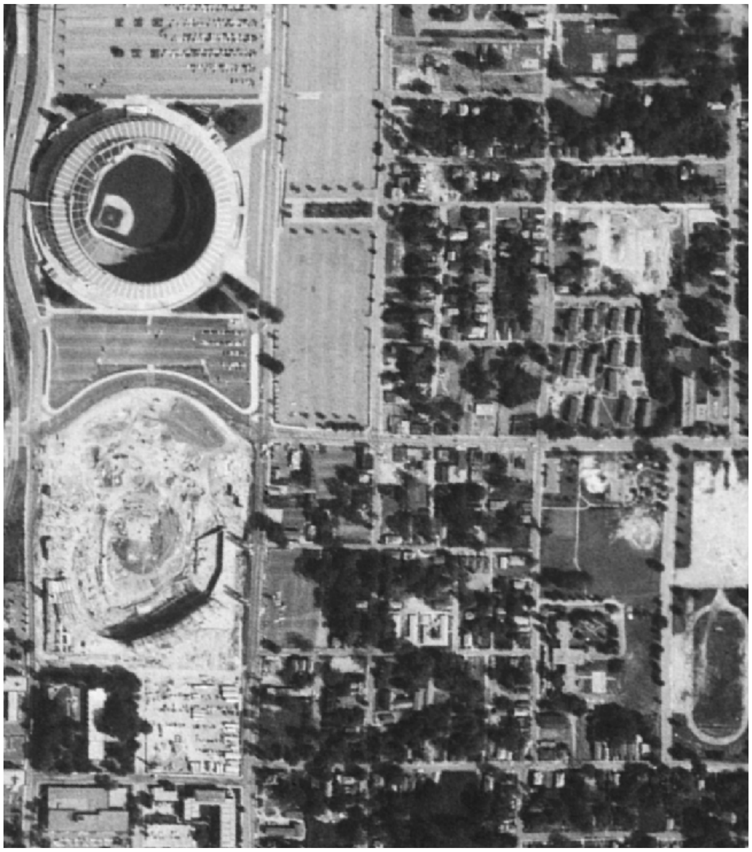


Image 18. Fulton County Stadium, Downtown Atlanta, Georgia (August 1995). (Courtesy: SOVINFORMSPUTNIK)

Sensor Specifications

Spatial Resolution: 2 m
Operational Dates: since 1972
Wavelength Regions: 0.50 to 0.60 um (green)
0.60 to 0.70 um (red)
0.70 to 0.80 um (NIR)
0.80 to 1.10 um

Vendor Information

Aerial Images, Inc.
615 Hillsborough Street
Raleigh, NC 27603
Phone: (800) 478-8898 (US) or (919) 833-9662 for voice & (919) 833-9614 for fax
email: sales@aerial-images.com
web: http://www.sovinformsputnik.com/spin-2.htm

U.S. Army Civil Imagery Acquisition Program

For availability questions and purchasing contact:
Topographic Engineering Center - Ops Directorate
7701 Telegraph Road
Alexandria, VA 22315-3864
email: msantoro@tec.army.mil
web: http://www.tec.army.mil/OD/service.html
and go to Imagery Acquisition

Fact Sheet #16 - Hyperspectral Imaging (HSI)

Figure 1. Example HSI product. Color composite is overlain with healthy (green) and stressed (red) vegetation map. Results were obtained with AVI IS data and Abacus software.

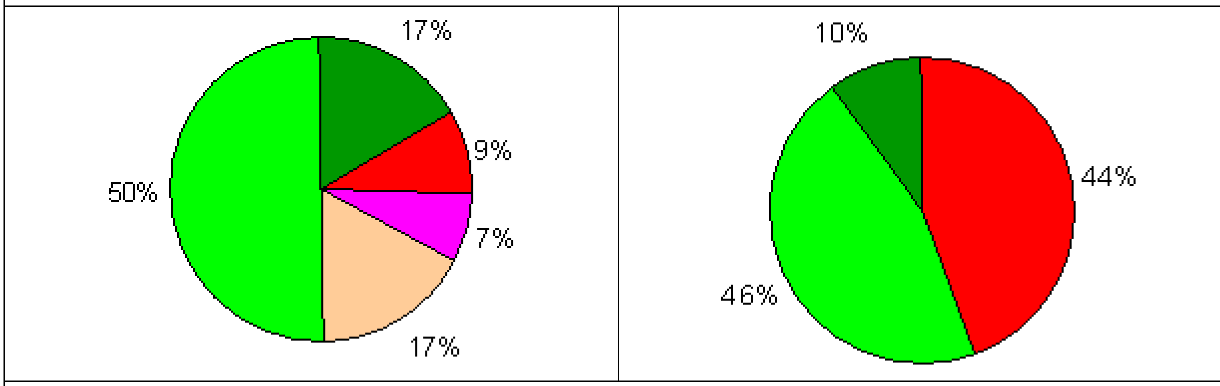


Figure 2. Example HSI product. Hyperspectral data is transformed from raw data into quantitative, interpretable products. Here, the stressed vegetation from Figure 1 is shown on the left as indicated by 17% dry vegetation (peach color). The healthy vegetation (right) contains no dry vegetation.

Sensor Specifications

Spatial Resolution: 1-30 m
Swath Width: Variable (1-30 km)
Revisit Time: Variable
Operational Dates: Various instruments since 1987
Wavelength Regions: 0.4 to 2.5 um (50-250 contiguous bands)

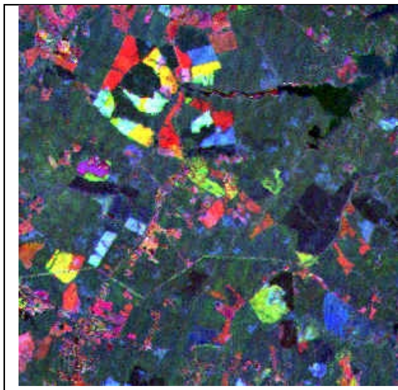
General Description

Hyperspectral imaging (HSI) measures the spectra of materials observed within each pixel of a scene. Unlike multispectral imaging (MSI), which is measured across 3-10 broad spectral channels, HSI is collected in up to 250 channels. The spectral channels for MSI are typically 100-400 nanometers (nm) in width, while HSI channels are much narrower (typically 10-20 nm). As a result, HSI gathers substantially more spectral data and provides more detailed information about the observed area, including identification and discrimination of specific materials and species. For instance, while MSI provides broad classification of vegetation types (trees vs. grasses), HSI can potentially identify various species and offer more sensitive information on the health of trees and vegetation (including pre-visual vegetative stress).

HSI origins are in the scientific community, where imaging spectrometers have been used in earth and planetary science investigations for over twenty years. Recently, the technology has been used by the military for target detection and terrain classification. Several commercial uses of the technology are also being developed. Today, HSI data can be gathered using government and commercial aircraft-based sensors (AVIRIS, HYDICE, HyMap, Probe-1). Satellite-based sensors are now in development and are scheduled for launch within 1-2 years (Orbview-4/Warfighter-1, NEMO, Hyperion, and Aries-1).

The detailed spectral information gathered by HSI does result in large, complex data sets. While panchromatic and MSI data are typically interpreted through spatial pattern recognition and by analyzing the relative intensity of a few bands, HSI exploitation requires the analysis of continuous spectral signatures. HSI is therefore best exploited by automatic processing that first transforms the data into useful information layers.

In the past, HSI data processing and interpretation required extensive efforts and custom software. Today, there are tools available to simplify the process and make the information available from HSI much more accessible. For instance, software tools are available to classify HSI data based on spectral characteristics. Typically these tools attach one class name to an entire region. However, in nature, boundaries between classes are not static and several classes often co-exist in varying proportions. In addition, environmental problems might require knowledge of how one class grades into another over time. Advanced techniques, recently developed by SAIC, automatically determine the proportions of classes in a pixel based on the physical processes driving the data and transform HSI data sets into readily interpretable products that can be imported into a GIS data base (note Figures 1 and 2 above). These advanced techniques can also be applied to MSI data, allowing users to take advantage of historic LANDSAT data and other MSI data sources. Gradual changes in the proportion of ground cover types to be detected over time. An example is presented in Figure 3 below.



Color	Interpretation
Gray	No change from 94 to 96 to 98
Red (R)	Cleared in 98
Green (G)	Cleared in 96; regrowth in 98
Blue (B)	Clear in 94, regrowth in 96 and 98
Cyan (-R = G + B)	Clear in 94; still clear in 96; regrowth in 98
Magenta (-G = R + B)	Clear in 94; regrowth in 96; cleared again in 98
Yellow (-B = R + G)	Cleared in 96; still clear in 98
Black	Masked out saturated pixels

Figure 3. Abacus change detection product using LANDSAT TM. Data was acquired and co-registered from 1994, 1996, and 1998. Land cover changes are indicated by different colors.

Vendor Information

Science Applications International Corporation (SAIC)
Advanced Technology Applications Division
4501 Daly Drive, Suite 400
Chantilly, VA 20151
Phone: (703) 814-7708
email: ATAD@saic.com

Fact Sheet #17 - Light Detection And Ranging (LIDAR)

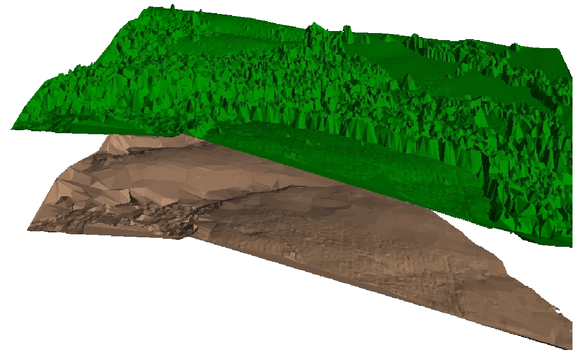


Image 19. Comparison of continuous surface and bare ground surface

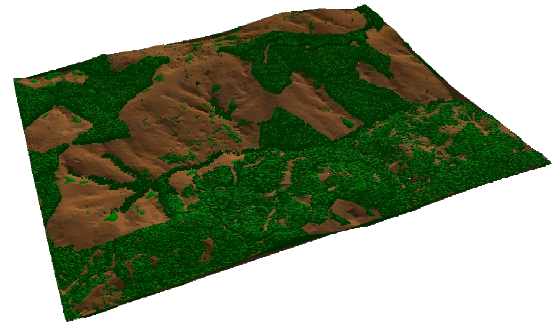


Image 20. Composite of both surfaces LIDAR posting of 10 meters

General Description

Light detection and ranging (LIDAR) uses a pulsed laser combined with positioning subsystems to create accurate and detailed digital elevation models for use in topographic mapping, digital orthophoto production and terrain analysis. LIDAR systems are not dependent on sunlight and operate effectively in a much broader weather window than conventional aerial photography. Dependent on the system, advanced LIDAR systems emit 15,000 pulses per second with the ability to record up to 5 returns from each outgoing pulse. Since all of the necessary measurement takes place in the aircraft and post processing is automated, elevation data can be delivered much faster than by photogrammetric means.

LIDAR initially produces a continuous surface, which can be a valuable tool in preparing isometric view studies or models. Vegetation removal is a crucial component of LIDAR and is accomplished through post-processing that selectively edits or removes points on above-ground features, including vegetation, buildings, and other cultural features. The values for elevation points falling in these areas are interpolated from surrounding points which produces a high fidelity representation of the bare-earth surface. This is a critical step if the data is to be used for mapping applications.

Several LIDAR systems are currently in operation. Capabilities of the different systems vary, but overall, LIDAR data is suitable for mapping at scales ranging from 1” = 50’ to 1” = 1,000’. LIDAR data retains a high level of vertical and horizontal accuracy at higher altitudes. LIDAR provides data that meet the following accuracies:

ALTITUDE (FT)	VERTICAL ACCURACY (CM)	TYPICAL POST SPACING (M)	CONTOUR INTERVAL (M)	HORIZONTAL ACCURACY
2,000	15	3	0.5	20 cm
4,000	15	4	0.5	20 cm
6,000	15	5	0.5	25 cm
8,000	15	5	1	25 cm
12,000	25	7	2	50 cm
20,000	60	10	3	1 m

Potential applications for LIDAR data include: topographic mapping, slope mapping, watershed mapping, vegetation mapping, hydraulic modeling, digital orthophotography, 3D visualization and volumetric surveys.

Vendor Information

For more detailed EarthData information, contact:
EarthData International of Maryland, Inc.
45 West Watkins Mill Road
Gaithersburg, MD 20878
POC: Chris Barnard
Phone: (301) 948-8550, ext. 110
email: cbarnard@earthdata.com

US Army Civil Imagery Acquisition Program

For availability questions and purchasing contact:
Topographic Engineering Center - Ops Directorate
7701 Telegraph Road
Alexandria, VA 22315-3864
Phone: (703) 428-6909 DSN 328-6909
email: msantoro@tec.army.mil
web: http://www.tec.army.mil/tio/index.html
and go to Imagery Acquisition

Vegetation Mapping Case Study

Introduction

This case study details the development of a generalized vegetation map of a large military installation using coarse resolution Landsat Thematic Mapper (TM) satellite imagery. Development of more detailed, large scale maps usually requires high resolution aerial photography or high spatial resolution satellite imagery. The intended use of a vegetation map should determine the necessary scale and level of detail required, which in turn, will dictate the types of data required and the appropriate classification scheme. However, the typical procedures for developing a vegetation map are similar and are described below.

For a more detailed summary of the vegetation mapping process, please refer to the *Protocol for Vegetation Mapping at Military Installations*, U.S. Army Corps of Engineers ERDC, (Draft 2000, POC: Jean O'Neil, ERDC-WES)

Materials and Methods

Mapping Strategy

- Select a classification scheme
- Combine ecological field studies and remote sensing imagery
- Acquire and process (multi-temporal) Landsat Thematic Mapper (TM) imagery.
- Conduct preliminary analysis
- Stratify image analysis with ancillary data; soils, geology, biological information
- Supervised classification of satellite imagery by landscape unit using ground vegetation survey
- Combine classes into map units based on; vegetation composition, spatial continuity and landscape structure similarity
- Accuracy assessment of final map using independent, ground and airborne data

Data Sources

Satellite imagery

Landsat Thematic Mapper (TM) satellite imagery was selected over aerial photography because it is suitable for mapping vegetation at a general level of detail over a large area. Again, aerial photography would be necessary for more detailed, large-scale mapping.

- Lower direct and development costs per square mile
- 30m spatial resolution

- 7 spectral bands
- 183km footprint
- RelativeIy easy to geometrically correct
- Fewer radiometric problems
- Ability to detect greater spectral range enabling quantitative measure of vegetation reflection and absorption

Ancillary Map Coverages

GIS

- USGS Digital Line Graphs (DLGs) of road and drainage networks
- Soils, Digital Elevation Model (DEM), slope, aspect, landform, and other coverages

Aerial Photography

- Color-IR film positives used as reference for accuracy checking image analyses

Biological Data

- Ground survey vegetation data
- airborne videography derived validation points

Preliminary Analysis

Results indicated that a combination of individual TM spectral bands and vegetation indices combined from multi-dates produced the best results.

Prior to field work and extensive map development:

- Perform preliminary analysis to determine optimal vegetation mapping procedure
- Select test areas to evaluate various techniques

Evaluation of Different Image Processing Techniques

Vegetation Indices

Select vegetation indice(s); which enhance the difference in the chlorophyll absorption feature of TM band 3 and peak vegetation response in TM band 4; or enhance separation of soil background from vegetation.

- Normalized Difference Vegetation Index (NDVI)

- Soil Adjusted Vegetation Index (SAVI)

Stepwise Discriminant Analysis of Band Combinations

- Perform stepwise discriminant analysis procedure to determine which combination of TM bands is most effective in differentiating vegetation patterns

Discriminant Analysis Models of Vegetation Types

- A discriminant analysis procedure is used to derive a new set of image bands using the spectral means of sets of pixels representing specific vegetation community types.

Evaluation

- An independent set of field data points was used to evaluate the various classified images resulting from the analysis.

Image Processing

Acquisition of Multi-temporal Images

- Both winter and summer images were acquired for spectral separation of deciduous from evergreen dominated vegetation types.

Radiometric Corrections

- Histogram equalization adjustments were made to the images to account for sun angle illumination effects for different days and years.
- Radiometic correction performed on all TM bands to account for the systematic signal distortion of the sensor.

Geometric Corrections

- Determine appropriate projection, spheroid and datum
- Georeference all satellite imagery to common projection, spheroid and datum.

Field Survey Data and Image Analysis

- Pre-select field plots using a GIS stratified random sampling procedure incorporating general vegetation types, geomorphology, and soils.
- Locate the plots in the field using GPS.
- Apply predetermined sampling protocol (e.g. plots located within large stands of more or less uniform vegetation).

Landscape Unit Stratification

- Spectral discrimination between different vegetation classes.
- Use ancillary GIS data and analysis techniques to delineate landscape units based on relatively homogeneous topography, elevation, slope, aspect, geology, surface substrate and other known biotic distribution.

Image Classification

- Create preliminary vegetation map using supervised Classifications, statistical signatures derived from field plot data, and ancillary data.
- Apply signatures through an interactive process called "seeding."
- Check accuracy using independent field data, air photos and other ancillary data.
- Reclassify landscape units by adding and/or eliminating problematic seeded signatures.
- Create preliminary vegetation map with as many map classes as seeds used in the classification.

Final Map Unit Development

- Aggregate map classes into a limited number of Mapping Units (MU's).
- May be based on floristic composition, landscape position, spatial contiguity, and spectral similarity, e.g. group together floristically similar seed classes with similar landscape positions and were spatially near each other.

Final Vegetation Map

- Eliminate mapping units with less than six contiguous pixels (0.5 Hectares).
- Fill in eliminated map units using a 3 x 3 pixel majority filter.
- Mask out roads, military cantonment and other highly disturbed areas from sampling.
- In addition, buffer and mask areas those already masked to reduce effects of diffuse reflection.

Map Validation

Accuracy testing of the vegetation map was performed using :

- Field plots which were not used in the classification process.
- Randomly select color frames extracted from airborne videography footage.

Discussion

The final digital map contained 34 final mapping units. Although this map could have been reproduced at much finer or coarser scales, a scale of 1:50,000 or greater was selected due to inherent limits of the source TM data and available ancillary data. The final vegetation map was in a digital format, and therefore could be readily integrated into a commercial GIS, ecological modeling, or decision support system to assist with ecological land management of the installation.

Developing Baseline Vegetative Cover Estimates for Change Detection Case Study

Introduction

Background

A U.S. Army National Guard installation was required to monitor changes in vegetative cover to fulfill obligations of the Environmental Impact Statement (EIS) covering the construction of a new Multi-Purpose Range Complex (MPRC). The expected recovery of vegetation within the new range, due to a change in land use, was considered a mitigating factor in construction of the new range.

Objectives

The overall goal of this project was to develop a cost-effective method to detect and monitor spatial and temporal changes in vegetative cover within the MPRC and the training area it replaced.

Approach

Study area boundaries and high priority regions were determined through consultations with the Camp natural resource personnel.

- Vegetative cover and physiognomic classes were sampled in the field within the identified study areas during peak growing season.
- A coincident Landsat Thematic Mapper (TM) satellite image was acquired at the approximate time that the vegetation field survey was conducted.
- Relationships between field data and vegetation indices derived from satellite imagery were investigated in order to develop spatially explicit baseline vegetative cover data.
- A summary report of results and a detailed description of methods used to establish a baseline survey, as well as recommendations for future monitoring were provided.

Methods

Remote Sensing/Image Pre-processing

- **Image Acquisition:** A Landsat5 Thematic Mapper (TM) image was acquired, the closest available to the field collection dates, without cloud cover and/or excessive haze over the installation.

- **Image Classification:** An unsupervised classification was performed on study areas with other areas masked
- **Vegetation Index Calculation:** Vegetation indices calculated from satellite imagery represent relative amounts of vegetative characteristics such as percent cover or biomass.

The Transformed Normalized Vegetation Index (TNDVI) was selected for analysis:

TNDVI = SQRT ((TM Band4(NIR) - TM Band3(Red) / TM Band4(NIR) + TM Band3(Red)) + 0.5)

Plot Allocation: A systematic sample design was used placing sample plots at the intersections of a 550 x 550 m grid within the study areas. This resulted in 64 plots allocated within the ~2000 ha MPRC and 82 plots allocated within the ~2500 ha former training area.

Plot location: Vegetation data were collected over a two week period with field crew navigating to approximate plot locations using GPS. Exact locations were later determined based on differential correction.

Plot Survey Methods: Each site was preliminarily classified based upon the physiognomy of the surrounding vegetation. The preliminary classifications were based upon the Nature Conservancy's (1994) Standardized National Vegetation Classification System (SNVCS). The preliminary classification dictated which field methods were used.

Combined Remote Sensing/Field Surveys for Monitoring

Field surveys and remotely sensed imagery were utilized to develop an initial inventory of vegetation cover. Field survey information was used to quantify vegetation cover at individual sample sites. TNDVI values derived from TM imagery provided *relative* differences in vegetation cover across the study area. To increase the utility of TNDVI, vegetation index values were calibrated or correlated with ground-based sample data. Calibrating the vegetation index with ground data resulted in the transformation of each pixel value from a *relative*, dimensionless number to an absolute value of percent vegetative cover.

Regression Analysis

A simple statistical correlation was applied to imagery-derived vegetation indexes and paired field-based measures of the vegetation. This process was necessary to determine the direct relationship between TNDVI values derived from imagery and a number of field-based measurements of vegetative cover. Once correlation analysis successfully identified a relationship between vegetation index value (independent variable) and vegetative cover (dependent variable), the regression equation was applied to every pixel in the TNDVI image, resulting in new pixel values calibrated to ground-based vegetation measurements.

Results

Strong correlations were found between TNDVI and several field measurements, allowing for extrapolation of this information.

Conclusions

The initial survey of vegetative cover was successfully completed using a combination of field surveys and remotely sensed imagery. Field survey data and remotely sensed spectral vegetation indices were correlated to develop spatially explicit baseline data on vegetative cover within these areas. The survey technique was designed so that it could be replicated in the future to assess changing vegetative conditions in relation to the baseline survey conducted in this report.

Detection and Monitoring Vegetation Changes Using Remotely Sensed Data Case Study

Introduction

Background

The use of multi-year remotely sensed data to provide timely acquisition of landcover/landuse information for the proper planning and management of land resources was investigated at the 40,000 acre Combat Maneuver Training Center (CMTC) Hohenfels, Federal Republic of Germany.

Objectives

To determine the feasibility of using satellite imagery to detect seasonal and annual ground cover changes occurring on military installations.

Approach

- Multi-year satellite images acquired were compared and analyzed.
- Normalized Difference Vegetation Index (NDVI) images were calculated from reflectance values of geo-referenced and atmospherically corrected images.
- Percent change between multi-year images was calculated on a pixel by pixel basis.
- A preliminary investigation of a possible relationship between NDVI values and percent groundcover, from groundcover data collected since 1987.

Methodology

This study involved the following basic steps:

- Image acquisition,
- Image data processing,
- Image data extraction
- Examination of relationships between spectral and ground data.

Image Acquisition

Three summer SPOT multispectral images and one summer Landsat TM image were used in this study; these images are listed below in Table 1.

Table 1. Image acquisition dates for images used in this study.

Date	Satellite	Sensor	Solar Zenith Angle
13 September 1987	SPOT-1	HRV1	45.9^{o}
15 August 198	SPOT-1	HRV1	36.1^{o}
25 August 1990	SPOT-1	*	39.8^{o}
03 August 1990	Landsat4	TM	39.0^{o}

* Information not available at this time.

Image Data Processing

Image data processing consisted of:

- Converting digital numbers to reflectance values
- Correcting for atmospheric interferences
- Calculation of Vegetation Index images (NDVI)
- Calculation of Tassled Cap components; brightness, greenness, and wetness, for TM image.

Convert digital numbers to reflectance values:

- For intercalibration and comparison of various satellite imagery data sets, it is necessary to transform the digital values of the various sensors to a common scale that corrects for varying zenith angle, solar irradiance, sensor spectral band location, and bandwidth.

Correct for atmospheric interferences:

- A first-order atmospheric correction procedure was used to eliminate atmospheric interferences in all three SPOT images.
- No atmospheric corrections were applied to the TM image

Calculation of NDVI:

The Normalized Difference Vegetation Index (NDVI) values were calculated for all images used in this study. The NDVI value is based on the interaction of red and near-infrared radiation with green biomass.

NDVI is defined as: NDVI = (NIR - R) / (NIR + R)

Where: NIR = near-infrared spectral band
R = red spectral band.

- SPOT bands 2 (red) and 3 (near-infrared)
- TM bands 3 (red) and 4 (near-infrared).

Tasseled Cap Transformations:

The Tassled Cap transformation is one form of several linear data transformations developed to reduce the number of spectral channels required in vegetation and soils studies.

Three Tassled Cap components were calculated for the TM image in this study:

- soil
- vegetation
- wetness

LCTA Field Plots

The ground data were collected as part of the US Army-wide field monitoring program known as the Land Condition-Trend Assessment (LCTA) program.

The LTCA program uses standard methods to collect, analyze, and report natural resources data on an annual basis at permanent ground line transects (6- by 100-m). (Tazik et al., 1992).

Image Data Extraction

Average cell values for each image (Digital Number (DN), reflectance, NDVI, and Tassled Cap components) were extracted from LCTA transects within the study area.

Relationships between Spectral and Ground Data

Relationships between spectral and ground data were subsequently examined using correlation and linear regression techniques.

LCTA ground data analyzed included:

- total aerial hits on plot,
- percent aerial cover on plot,
- percent exposed bare ground on plot,
- percent plot cover on plot.
- percent bare ground on plot.

Results

Results indicated seasonal and annual land cover changes could be detected as well as changes for areas heavily damaged by training activities. Correlation between NDVI image data and field data for percent ground cover revealed R^2 values of 0.61, 0.64, 0.65 and 0.78.

Conclusions

The results of this study indicate that satellite data can be used to estimate groundcover in non-forested areas. Strong relationships were found between both SPOT multispectral and Landsat TM spectral data and ground data. TM data provided the opportunity to derive more combinations of band ratios, but did not necessarily improve the R^2 values. Especially encouraging were the tests done in this study to compare the predicted groundcover variables with those actually measured on the ground.

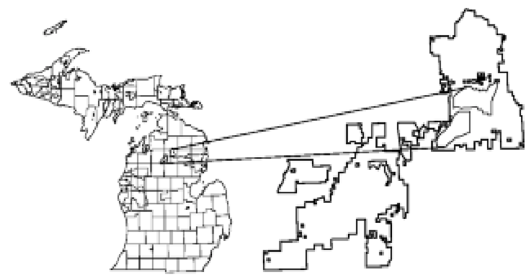
Suggestions for continued research efforts in developing an operational method of monitoring percent groundcover on military installations would include:

- Exploring all possible TM band combinations to determine which would be most useful.
- Calibration of Landsat data to produce images of groundcover

Integration of Remote Sensing and Field Data for Monitoring Changes in Vegetative Cover on a Multipurpose Range Complex and Adjacent Training Lands at Camp Grayling, Michigan Case Study

by Scott Tweddale, Verl Emrick and William Jackson

Introduction



Camp Grayling, a U.S. Army National Guard installation in northern Michigan, was required to monitor changes in vegetative cover to fulfill obligations of the Environmental Impact Statement (EIS) covering the construction of a new Multi-Purpose Range Complex (MPRC). The expected recovery of vegetation within the new range, due to a change in land use, was considered a mitigating factor in construction of the new range (National Guard Bureau and Michigan Dept. of Military Affairs 1994). The ability to monitor the changes in vegetative cover within the MPRC and training area immediately north (Hereafter referred to as the Northern Training Area - NTA) is critical to fulfilling the intent of the EIS and training land management.

Objectives

The overall goal of this project was to develop a cost-effective method to detect and monitor spatial and temporal changes in vegetative cover within the MPRC and NTA.

Approach

Study area boundaries and high priority regions at Camp Grayling were determined through consultations with natural resource personnel at Camp Grayling and the Michigan National Guard.

- Vegetative cover and physiognomic class were sampled in the field within the identified study areas during peak growing season at Camp Grayling during 1997.
- A coincident Landsat Thematic Mapper (TM) satellite image was acquired covering the approximate time that the vegetation field survey was conducted.
- Relationships between field data and vegetation indices derived from satellite imagery were investigated in order to develop spatially explicit baseline vegetative cover data.
- A summary report of results and a detailed description of methods used to establish a baseline survey, as well as recommendations for future monitoring were provided.

Methods

Remote Sensing/Image Pre-processing

Image Acquisition: An August 8, 1997 Landsat5 Thematic Mapper (TM) image was acquired, the closest available to the field collection dates June 30 through July 11, 1997, without cloud cover and/or excessive haze over the installation.

Systematic Noise Correction: Periodic striping apparent in bands 2, 3 of the Landsat TM image were corrected using ERDAS Imagine 8.2 Fourier correction routines prior to geo-referencing the image.

Geo-referencing: The Landsat TM scene was geo-referenced to a previously acquired and August 25, 1991 Landsat TM image in a UTM coordinate system, Clark1866 Spheroid, NAD27 Datum, using a 1st order transformation, nearest neighbor resampling, XY Root Mean Squared (RMS) error of < 15 meters. The geo-referenced image was checked for accuracy using vector roads overlay, and by visually checking Global Positioning System (GPS) field plot locations with known natural and man made geographic features.

Image Classification: An unsupervised classification was performed on study areas using the ISODATA classification routine in ERDAS Imagine8.3.

Vegetation Index Calculation: Green healthy vegetation is characterized by strong chlorophyll absorption and low reflectance in red wavelengths and high reflectance in the near infrared wavelengths of the electromagnetic spectrum (Kauth et al, 1978; Tucker, 1979; Curran, 1980). Vegetation indices have been developed to reduce multispectral scanner data to a single number or index, for the purpose of qualitatively and quantitatively assessing vegetation conditions

(Tucker, 1979). Vegetation indices calculated from satellite imagery represent relative amounts of vegetative characteristics such as percent cover or biomass.

The Transformed Normalized Vegetation Index (TNDVI) was selected for analysis. The TNDVI is a transformation of the Normalized Difference Vegetation Index (NDVI), which is the most commonly used vegetation index.

TNDVI = SQRT ((TM Band4(NIR) - TM Band3(Red) / TM Band4(NIR) + TM Band3(Red)) + 0.5)

To avoid changing the TM image digital number values (DN), the vegetation indices were calculated directly from the non-geo-referenced TM image. The resulting vegetation index images were then geo-referenced using the Transformation Matrix calculated previously.

Field Data Collection: After the establishment of the training area boundaries, the number of Land Condition Trend Analysis (LCTA) plots present within the study areas were determined and considered insufficient for the purposes of this study. Therefore, specific field survey methods were developed to accomplish the objectives of the study.

Plot Allocation: A systematic sample design was used to allocate field plots. Systematic sampling involves the placement of sample plots at fixed, regular intervals, originating from a randomly selected starting point (Thompson 1992). Systematic sampling is considered desirable for use in describing vegetation pattern because it samples evenly across populations (Krebs 1989). Plots were located at the intersections of a 550 m x 550 m grid within the boundaries of the two survey regions. This sample design resulted in 64 plots being allocated within the 2041 ha MPRC and 82 plots allocated within the 2567 ha NTA.

Plot location: Vegetation data were collected for a two week period that commenced on June 30, 1998 and terminated on July 12, 1998. The field crew was provided UTM coordinates to the grid intersections and navigated to the approximate locations using GPS[1]. Exact locations were to be determined by differentially correcting GPS coordinates collected in the field. However, there were difficulties associated with the base station files. Therefore, coordinates collected in the field were averaged to obtain the final plot locations. Each plot was permanently marked with a orange plastic stake to assist in the relocation of the plots at a later date.

Plot Survey Methods: Once the plot location was identified the site was preliminarily classified based upon the physiognomy of the surrounding vegetation. The preliminary classifications were based upon the Nature Conservancy's (1994) Standardized National Vegetation Classification System (SNVCS). The preliminary classification dictated which field methods were used.

Forest and Woodland Classes

[1]Due to the selective availability of the GPS satellites navigation to plot locations were approximate.

The following data collection technique was employed if the plot was physiognomically classified as a forest or woodland.

Total vegetative cover was visually estimated, utilizing a modified Braun Blanquet cover abundance scale (Table 1) for the tree (5 + meters) stratum, shrub stratum (1-5 meters), and herb stratum (0-1 meter) at four locations (Mueller-Dombois and Ellenberg 1974).

These four locations were 5 meters from the permanent stake in each cardinal direction. In addition, cryptogamic cover (mosses lichens and liverworts), cover of organic debris (duff, leaf litter, roots, branches etc) and bareground (mineral soil and rocks) were visually estimated using the same cover scale. Dominant species, in terms of cover, in each stratum were also identified.

Table 1. Modified Braun-Blanquet cover abundance table utilized to estimate aerial vegetative cover (Mueller-Dombois and Ellenberg 1974).

Aerial Vegetative Cover	Cover Class	Class Midpoints
95-100%	6	97.5
75-95%	5	85.0
50-75%	4	62.5
25-50%	3	37.5
5-25%	2	15.0
1-5%	1	2.5
Several, cover less than 1%	+	1.0
Rare	r	0.5

Table 2. Summarization the methods used to calculate the various field variables in the forest and woodland physiognomic classes.

Field Variable	**Method of Calculation**
Tree Stratum Cover (TC)	$(TC_1 \ldots TC_4) / 4 =$ TC
Shrub Stratum Cover (SC)	$(SC_1 \ldots SC_4) / 4 =$ SC
Herbaceous Stratum Cover (HC)	$(HC_1 \ldots HC_4) / 4 =$ HC
Organic Cover (OC)	$(OC_1 \ldots OC_4) / 4 =$ OC
Cryptogamic Cover (CC)	$(CC_1 \ldots CC_4) / 4 =$ CC
Bare Ground (BG)	$(BG_1 \ldots BG_4) / 4 =$ BG
Total Vegetative Cover (TVC)	TC + SC + HC = TVC
Visible Bare Ground (VBG)	100 - TVC = VBG
Total Vegetative Cover + Crytogamic Cover (TVCC)	TVC + CC = TVCC
Total Vegetative Cover + Organic Cover (TVOC)	TVC + OC = TVOC
Total Cover (TC)	TC + SC + HC + OC + CG = TC

Open and Sparse Woodland Physiognomic Classes

The following data collection technique was employed if the plot was physiognomically classified as herbaceous or sparse woodland.

It was the belief of military land mangers that the open and sparse woodland physiognomic classes would experience the greatest change in vegetative cover due to changes in training patterns . Consequently a more detailed method of data collection was employed. A 400 m^2 base plot was constructed and a 5m x 5m grid superimposed on the base plot (figure 3). At each grid intersection, including boundaries, a 1m^2 quadrat was placed.

The vegetative cover below one meter was estimated in each sub quadrat utilizing the Braun-Blanquet cover abundance scale (Table1). Total cover of cryptogamic flora, organic debris and bare ground was also visually estimated in each sub quadrat using the same cover scale. This data collection method is a more detailed version of the method described by Daubenmire (1959) and similar methods have been used by Anderson et. al (1993), and Dymond et al. (1992) to interpret remote sensing imagery.

Total vegetative cover for the shrub stratum and tree stratum (if applicable) was visually estimated in the same manner as described for the forest and woodland physiognomic classes. Dominant species in each strata within the base plot were also identified.

Table 3. Summarization the methods used to calculate the various field variables in the open and sparse woodland physiognomic classes.

Field Variable	**Method of Calculation**
Tree Stratum Cover (TRC)	$(TC_1 \ldots TC_4) / 4 =$ TRC
Shrub Stratum Cover (SC)	$(SC_1 \ldots SC_4) / 4 =$ SC
Herbaceous Stratum Cover (HC)	$(HC_1 \ldots HC_{25}) / 25 =$ HC
Organic Cover (OC)	$(OC_1 \ldots OC_{25}) / 25 =$ OC
Cryptogamic Cover (CC)	$(CC_1 \ldots CC_{25}) / 25 =$ CC
Bare Ground (BG)	$(BG_1 \ldots BG_{25}) / 25 =$ BG
Total Vegetative Cover (TVC)	TC + SC + HC = TVC
Visible Bare Ground (VBG)	100 - TVC = VBG
Total Vegetative Cover + Crytogamic Cover (TVCC)	TVC + CC = TVCC
Total Vegetative Cover + Organic Cover (TVOC)	TVC + OC = TVOC
Total Cover (TC)	TRC + SC + HC + OC + CG = TC

Combined Remote Sensing/Field Surveys for Monitoring

Field surveys and remotely sensed imagery were utilized to develop an initial inventory of vegetation cover. Field survey information was used to quantify vegetation cover at individual sample sites. TNDVI values derived from TM imagery provided *relative* differences in vegetation cover across the study area. To increase the utility of TNDVI, vegetation index values were calibrated or correlated with ground-based sample data. Calibrating the vegetation index with ground data resulted in the transformation of each pixel value from a *relative*, dimensionless number to an absolute value of percent vegetative cover.

Regression Analysis

A simple statistical correlation was applied to imagery-derived vegetation indexes and paired field-based measures of the vegetation. This process was necessary to determine the direct relationship between TNDVI values derived from imagery and a number of field-based measurements of vegetative cover. The least squares fitting algorithm found in the MINITAB statistical software package was used for regression analysis. The relationship between TNDVI values and field-based measurements was then evaluated by determining the existence of linear relationships and evaluating coefficients of determination (R^2) between TNDVI values for a number of different field measurements. Ground-based samples within the MPRC and Northern Training Area were first analyzed separately, and then were pooled together.

Once correlation analysis successfully identified a relationship between vegetation index value (independent variable) and vegetative cover (dependent variable), the regression equation was applied to every pixel in the TNDVI image, resulting in new pixel values which were calibrated to ground-based vegetation measurements. .

For some field measurements such as CC, the extremely low correlation between the field measure and TNDVI value can be attributed to the limitations of the Landsat TM sensor. Although variations in cryptogamic crusts were observed during field sampling, these same variations were not detectable with TM imagery. Within an individual TM 30m data element or pixel, a single reflectance value is recorded for each wavelength. The 30m area on the ground that is observed by the sensor for each pixel may be a heterogeneous mix of landcover types, each contributing a fraction of the total reflectance which is recorded by the TM sensor. Within any certain wavelength of the TM sensor, there may not be sufficient spectral contrast between landcover types within the same pixel, and therefore, it would be impossible to differentiate between landcover types using remotely sensed spectral information.

Table 5. Coefficients of Determination between all field variables and TNDVI for the MPRC using four co-registration methods.

	Pixel to Pixel n=51	**Pixel to Pixel n=45***	**3x3 Mean Filter n=51**	**3x3 Mean Filter n=48****
FIELD MEASURE	**Adjusted R2**		**Adjusted R2**	
VBG	50	64.3	59.3	65.6
BG	42.6	53	42.2	48.7
CC	1.7	0	1.2	0
OC	61.2	66.1	63.1	69.1
HC	40.7	42.1	42.5	46.2
SC	33.5	33.5	38.3	39.7
TC	61.2	74.5	68.1	77.6
TVCC	50.3	64.3	58.5	66.7
TVOC	63.7	75.1	70.5	79.2
TVC	54.5	66.5	62.5	70.4
TRC	29.8	32.9	38.4	39.7

*Less Outliers (plot ID = 8, 10, 12, 44, 47, 48)

**Less Outliers (plot ID = 47, 48, 12)

In addition to a lack of spectral contrast, the spatial resolution of the TM sensor (30m) may also be a limiting factor. Assuming that a heterogenous mix of landcover types exist within a single pixel, landcover types that cover the most geographic area within the pixel tend to dominate the spectral response recorded by the sensor. Plant communities are distributed spatially across the pixel area, but they are also stratified vertically. Therefore, due to the nature of the downward looking TM sensor, those landcover or vegetation types which dominate the highest vertical strata within a pixel also tend to dominate the spectral reflectance recorded by the satellite. Since TNDVI is calculated directly from reflectance data, these same limitations also affect vegetation index values. Cryptogamic cover was typically sparse in comparison to cover of other life forms within the area of a single TM pixel and was always the lowest vertical strata of cover. For these reasons, essentially no relationship between vegetation index values and field measurements of CC was identified. In general, measures of cumulative cover which represent a summation of cover at several different strata, such as TVC and TC, exhibited higher Coefficients of Determination than those measures of a single cover type or strata, such as SC or TRC.

The influence of vertical stratification of cover on vegetation index values is particularly evident when comparing results between BG and VBG. The difference in strength of correlation between these two dependent variables and TNDVI can be attributed to vertical stratification of cover. Measurements of BG did not take into account cover at higher strata. Large amounts of bare ground may have occurred at some sample points, but vegetative cover may have existed at higher strata. Therefore, reflectance observed by the TM sensor, and the corresponding TNDVI values calculated from this reflectance data, were heavily influenced by cover at higher strata, and did not correlate well with measured BG on the surface. Conversely, VBG represented effective bare ground as observed from looking downward from above the canopy. In this case, vegetative cover at any strata that would tend to mask underlying bare ground was measured and used to calculate "visible" bare ground measurements. In essence, this measure represented the amount of bare ground that was observable by the satellite, which explains the higher correlation between TNDVI and VBG (R2=59.3) versus BG (R2=42.2).

Similar to results for the MPRC, Mean Filtering was found to be the optimal spatial co-registration method for the NTA. Coefficients of Determination were consistently higher for the Mean Filtering method than for Pixel to Pixel and Weighted Averaging methods. However, the overall strength of correlations between the various field measurements and TNDVI were consistently lower for the NTA in comparison to results for the MPRC. Again, the influence of vertical stratification of cover on vegetation index values was particularly evident within the NTA. Unlike the MPRC, where there was minimal tree canopy, the NTA included more forested and woodland cover types. The increased cover at higher strata within forested and woodland areas may have effectively masked understory and ground cover to the extent that correlations were not as strong. In addition, the NTA was more heterogeneous than the MPRC. As heterogeneity in cover types increases, the possibility of "mixed" pixels increases, which may also decrease the strength of correlation between field measurements and vegetation index estimates of cover. This would explain, to some extent, the lower Coefficients of Determination for all dependent variables in the NTA. Adjusted R^2 values for the NTA ranged from 0.0 for OC to 49.5 for TVCC (Table 6).

Table 6. Coefficients of Determination between all field variables and TNDVI for the MPRC using four co-registration methods.

	Pixel to Pixel n=51	**Pixel to Pixel n=45***	**3x3 Mean Filter n=51**	**3x3 Mean Filter n=48****
FIELD MEASURE	**Adjusted R^2**		**Adjusted R2**	
VBG	50	64.3	59.3	65.6
BG	42.6	53	42.2	48.7
CC	1.7	0	1.2	0
OC	61.2	66.1	63.1	69.1
HC	40.7	42.1	42.5	46.2
SC	33.5	33.5	38.3	39.7
TC	61.2	74.5	68.1	77.6
TVCC	50.3	64.3	58.5	66.7
TVOC	63.7	75.1	70.5	79.2
TVC	54.5	66.5	62.5	70.4
TRC	29.8	32.9	38.4	39.7

*Less Outliers (plot ID = 8, 10, 12, 44, 47, 48)

**Less Outliers (plot ID = 47, 48, 12)

A final corrective measure was tested to insure that spatial mis-registration was not introducing any additional errors in correlation analysis. Included in the results of each regression were a list of outliers as identified by the MINITAB statistical package. For each outlier plot that was identified, a visual examination was conducted to determine geographic location of the plot with respect to any ecotonal boundaries which were evident in the satellite image. As mentioned earlier, some field plots were located in close proximity to an ecotonal boundary in the field. Any slight registration error for these sample point locations could result in an incorrect pairing of field observations with corresponding vegetation index values. Through visual examination of plot location and examination of field notes for respective outlier plots, those outliers which fit this criteria were identified and eliminated from further analysis.

A total of three plots were removed from the 3X3 Mean Filter analysis for the MPRC as a result of this examination (Table 5). Five field measures of cover (BG, CC, HC, SC, and TRC) exhibited relatively low Coefficients of Determination, even after removing outliers. However, as expected, the strength of correlation between all field measures and TNDVI increased after removing outliers. The largest increase in R2 occurred for TC and TVOC. After removing these outliers, TVOC had the highest coefficient of determination.

A similar process was used to remove a single outlier from the 3X3 Mean Filter analysis for the NTA. Again, removal of this outlier improved correlations for most field measures. However, all independent variables exhibited low coefficients of determination, even after removing the outlier. Coefficients of Determination ranged from 0.0 for OC to 57.1 for TVCC (Table 6).

Conclusions

The initial survey of vegetative cover for the MPRC and NTA at Camp Grayling, MI was successfully completed using a combination of field surveys and remotely sensed imagery. Field survey data and remotely sensed spectral vegetation indices were correlated to develop spatially explicit baseline data on vegetative cover within these areas. The survey technique was designed so that it could be replicated in the future to assess changing vegetative conditions in relation to the baseline survey conducted in this report. This report provides a detailed description of the methods used to conduct the survey.

Empirical relationships established in this report provide a calibrated baseline data from which absolute changes in vegetative cover and biomass can be estimated and spatially extrapolated. These same empirical relationships can be applied to future satellite images. However, an annual field survey should be conducted to re-calibrate the relationship between vegetation index values and field measurements. Should annual field surveys become cost prohibitive, previously calculated baseline regression formulas can be applied to subsequent images. In this baseline study, strong correlations were discovered between TNDVI and number of field variables. However, there was variance associated with extrapolating point estimates across the entire study area using satellite imagery. As time passes between initial baseline calibration and subsequent un-calibrated estimates, the reliability of the empirical relationship decreases. Therefore, it is recommended that empirical relationships between vegetation indices and field data be re-calibrated as often as possible. Ultimately, the level of accuracy and detail required to meet monitoring objectives, along with logistical and financial constraints should dictate how often a field survey is performed. However, if precise measures of change in vegetation cover are required, field surveys are necessary.

References

Anderson, G.L., Hanson, J.D., Haas, R.H., 1993. Evaluating Landsat thematic Mapper Derived Vegetation Indices for Estimating Above Ground Biomass on Semiarid Rangelands. *Remote Sensing of Environment*,.45:165_175.

Campbell, J.B. (1987), *Introduction to Remote Sensing*, Guilford Press, New York, New York.

Curran, P.J., 1980. Multispectral Remote Sensing of Vegetation Amount. *Progress in Physical Geography*, 4:315-341.

Daubenmire, R. 1959. A Canopy-Coverage Method of Vegetational Analysis. *Northwest Science* 33:43-64.

Dave, J.V., 1980. Effect of Atmospheric Conditions on Remote Sensing of Vegetation Parameters. *Remote Sensing of Environment*, 10:87-99.

Deering, D. W., Rouse, J.W., Hass, R.H., and Schell, J.A., 1975. Measuring Forage Production of Grazing Units from Landsat MSS Data. *Proceedings of the 10th International Symposium Remote Sensing of Environment*. II: 1169-1178.

Dymond, J. R. , P.R. Stephens, P. F. Newsome, and R. H. Wilde. 1992. Percentage Vegetation Cover of a Degrading Rangeland from SPOT. *Int. J. Remote Sensing*. 13:1999-2007.

ERDAS Field Guide, Version 8.3, Fourth Edition, ERDAS Inc., Atlanta, GA, 1997.

Federal Geographic Data Committee Vegetation Subcommittee. June 1996. Federal Geographic Data Committee Vegetation Classification and Information Standards. Reston, Virginia

Heilman, J.L., Boyd, W.E., 1986. Soil Background Effects on the Spectral Response of Three_Component Rangeland Scene. *Remote Sensing of Environment*.19:127_137.

Kauth, R.J., Lambeck, P.F., Richardson, W., Thomas, G.S., and Pentland, A.P. 1978. Feature Extraction Applied to Agricultural Crops As Seen by Landsat. *Proceedings of the Technical Sessions Vol II, The LACIE Symposium*. Oct 1978, NASA Johnson Space Center.

Krebs, C. 1989. *Ecological Methodology*. Harper and Row, Publishers, New York.

Law, B.E., Waring, R.H., 1994. Remote Sensing of Leaf Area Index and Radiation Intercepted by Understory Vegetation. *Ecological Applications*. 4:272_279.

Lillesand, Thomas M. and Ralph W. Kiefer, 1987. *Remote Sensing and Image Interpretation.* John Wiley & Sons, New York, NY.

Mueller-Dombois & Ellenberg, H. 1974. *Aims & Methods of Vegetation Ecology*. John Wiley & Sons. New York, NY.

National Guard Bureau and Michigan Department of Military Affairs, 1994. Mission Expansion/Multiple Construction: Camp Grayling Army National Guard Training Site, Michigan - Final Environmental Impact Statement.

Pickup, G., V.H. Chewings, and D.J. Nelson. 993. Estimating Changes in Vegetation Cover over Time in Arid Rangelands Using Landsat MSS Data. *Remote Sensing of Environment*. 43: 243-263.

Pfinder Software Reference, Trimble Navigation, Ltd., 1991.

Qi, J., A. Chehbouni, A.R. Huete, Y.H. Kerr, and S. Sorooshian. 1994. A Modified Soil Adjusted Vegetation Index. *Remote Sensing of Environment.* 48:119-126.

Rouse, J.W., Haas, R.H., Schell, J.A., and Deering, D.W.. 1973. Monitoring Vegetation Systems in the Great Plains with ERTS, *Third ERTS Symposium,* Vol. I.

Richardson, A.J., Wiegand, C.L.1977. Distinguishing Vegetation from Soil Background Information, *Photogrammetric Engineering and Remote Sensing*. 43:1541_1552.

Senseman,Gary M., Bagley, Calvin, F., and Scott A. Tweddale, 1996 "Correlation of Rangeland Cover Measures to Satellite-Imagery-Derived Vegetation Indices" GeoCarto. International, Vol 11, No. 3. pp.29 - 38.

Satterwhite, M.B., 1984. Discriminating Vegetation and Soils Using Landsat MSS and Thematic Mapper Bands and Band Ratios. American Society of Photogrammetry Technical Paper, *50th Ann. Meeting American Society Photogrammetry* . 2:479_490.

The Nature Conservancy. 1994. *Standardized national Vegetation classification System (SNVCS)*. Final Draft, National Biological Survey/National Park Service Vegetation Mapping Program, Arlington, Virginia.

Thompson, Steven K. 1992. *Sampling*. John Wiley & Sons. New York

Tucker, C.J., 1979. Red and Photographic Infrared Linear Combinations for Monitoring Vegetation. *Remote Sensing of Environment.* 8:121_150.

Tucker, C.J., Holben, B.N., Elgin, J.H., McMurtrey, J.E., 1981. Remote Sensing of Total Dry-Matter Accumulation in Winter Wheat. Remote Sensing of Environment. 11:171-189.

Walsh, S.J., and Bian, L., 1988. Comparison of NOAA AVHRR and LANDSAT MSS Digital Data to In-Situ Measures of Plant Biomass and Soil Characteristics - the Local Versus the Regional Perspective. *Proceedings of the American Society for Photogrammetry and Remote Sensing*. 229-309.

Wu, X., and Westervelt, J.1994 *Using Neural Networks to Correlate Satellite Imagery and Ground-truth Data.* USACERL Special Report (SR) EC-94/28.

Zhuang, H.C., Shapiro, M., Bagley, C.F. , 1993. Relaxation Vegetation Index in Non-Linear Modelling of Ground Plant Cover by Satellite Remote Sensing Data. *International Journal of Remote Sensing*.14:3447_3470.

Estimating Vegetation Cover Case Study: Spectral Demixing and Spectral Index Correlations for Sub-Pixel Quantification of Land Cover Components from Coarse Resolution Imagery at Fort Bliss, Texas

by Scott Tweddale, William Jackson, and Paul Pope

Introduction

Ft. Bliss, TX is a Training and Doctrine Command (TRADOC) installation located in the Northern Chihauhan Desert of Western Texas and South Central New Mexico. At 1.1 million acres, is the single largest TRADOC installation. Ft. Bliss exists within a fragile and sensitive ecosystem, and therefore is more susceptible to disturbance. Vegetation abundance, condition, and species composition are important indicators of training land condition. Therefore, Ft. Bliss natural resource managers require a timely and cost-effective method for characterizing and monitoring land condition at various different spatial scales and levels of detail. Typically, land degradation in arid environments such as Ft. Bliss is associated with a decrease in vegetative cover and abundance and an increase in soil erosion potential. Such degradation may result from both anthropogenic or allogenic disturbances, including impacts from training, and can occur at many different scales.

Examples of requirements for detailed characterization and monitoring:

- Monitor vegetative cover changes to evaluate susceptibility of the landscape to soil erosion
- Develop method for monitoring percent vegetative cover of specific plant species or plant communities indicative of disturbance.
- Improve input into land-based carrying capacity and other ecological models enabling prediction of future land condition.

In response to these requirements, many Department of Defense (DOD) training and testing installations, including Ft. Bliss, have implemented the Land Condition Trend Analysis (LCTA) program, which is part of the Integrated Training Area Management (ITAM) plan for the U.S. Army (Tazik, et al., 1992). LCTA provides a standardized method for inventory and monitoring of vegetation and wildlife on military lands whereby permanent plots are established and visited annually to conduct a detailed census of vegetation and wildlife.

Some issues and limitations regarding traditional monitoring of large areas of arid land:

- Satellite imagery's large areal coverage and relatively high temporal frequency, provides a good supplement to costly field surveys.

- Spatial resolution of contemporary satellite imagery (20-30m) is not suitable for large scale characterization and monitoring of arid environments where land cover disturbance may occur at sub-pixel scale.

- Satellite imagery pixels represent a mixture of the spectral responses of all surface components within them.

- Due to sparse vegetation, the mixed spectral signature is usually dominated by the spectral signature of background soil.

- At the subject scale (1.1m acres), its necessary to determine overall spectral contribution of land cover components.

- High spatial and spectral resolution imagery more likely to represent single homogenous land cover type

- High resolution spectral imagery is difficult to store and costly to collect, process and interpret.

- Complete coverage with high spatial resolution imagery not acquired for installations for monitoring on a regular basis.

Alternative Method Proposed

Given these limitations, an alternative method is required to estimate, extrapolate, and monitor more detailed percent vegetative cover from coarse resolution imagery across arid landscapes such as Ft. Bliss.

Objective: The primary objective of this investigation was to evaluate linear spectral demixing and spectral brightness and greenness index correlations with abundance of land cover types as alternative methods for more detailed characterization and monitoring of land condition using coarse resolution satellite imagery.

Approach: Three study areas where chosen which represent the 3 primary vegetation/land form areas of Ft. Bliss, TX.

- **Study Site #1** Characterized by mesquite covered coppice dunes in the Tularosa Basin, primarily located within Maneuver Areas #4 and #5.
- **Study Site #2** A grassland dominated site on Otero Mesa.

- **Study Site #3** Characterized by mixed desert shrub/grassland area in the foothill transition zone between the Tularosa Basin and Otero Mesa.

At each site, four digital 1:16,000 Color Infrared (CIR) images were acquired as samples of the study areas. Classifications of the CIR photos provided a ground reference of abundance or percent cover of individual land cover types. A Landsat Thematic Mapper (TM) image of Ft. Bliss, TX was also acquired at approximately the same acquisition date as the CIR photos.

Using spectral demixing, percent cover of individual land cover components, as derived from CIR photo classifications, and TM spectral response in 6 spectral wavelengths were used to determine the spectral contribution of each land cover component to the mixed spectral response recorded in a single TM pixel. These equations were then inverted so that given the known spectral contribution of individual land cover components and known spectral response recorded in an individual TM pixel, other TM pixels were demixed to estimate percent cover of individual land cover components.

Background

Many applications of spectral demixing analysis and spectral brightness correlations utilizing spectral imagery for the purpose of assessing land cover types and vegetation abundance have been described in the literature. These approaches have been applied successfully and validated statistically, including applications of these techniques to resource characterization and monitoring in arid and semi-arid environments similar to Ft. Bliss, TX.

Spectral Demixing

Various studies have shown that spectral demixing of multi-band satellite imagery can provide estimates of the aerial percentage of various land cover types (Marsh, et al., 1980; Foody and Cox, 1994; Foschi, 1994; Smith, et al., 1990).

Linear spectral demixing

The key assumption of linear spectral demixing is that the mixed spectrum associated with each pixel of multi-band satellite image is assumed to be a linear combination of weighted pure spectra. Each pure spectra, or 'spectral endmember', is assumed to be unique and representative of a particular type of land cover. The weight associated with each pure spectrum is assumed to be equal to the fractional area of the pixel occupied by the land cover types associated with that pure spectrum. These weights are called 'percent covers'.

Non-linear spectral demixing

Non-linear spectral demixing is similar in principle to linear demixing, except that non-linear demixing accounts for *multiple* interactions of reflected light with several groundcover or "endmember" components (Borel and Gerstl, 1994; Roberts, 1993; Smith, et al., 1990; Ray and Murray, 1996). However, non-linear demixing was not tested in this research.

Different than statistical classification

Demixing techniques offer a method of classification of land cover, which differs from statistical classification schemes in two important ways.

- First, the method is *deterministic*. It attempts to physically model the reflection of light from various land covers which make up the terrain.

- Secondly, unlike statistical classifiers, it does not assume a homogenous classification for each individual pixel in an image.

Therefore, the surface area imaged by each pixel element can have several different land cover classes, which is more realistic classification output since almost all pixels in a scene will contain a mixture of land cover types (Foschi, 1994). Therefore, the resulting output from demixing analysis provides an individual abundance image for each endmember or land cover type used to develop the demixing model. This image depicts the spatial distribution and abundance of that respective land cover type (Bateson and Curtiss, 1996). This can greatly improve accuracy of vegetative cover and abundance estimates, especially in arid and semi-arid environments with incomplete or sparse canopy covers. In such environments, the ratio of vegetation to bare ground can change rapidly over distances that are smaller than the spatial resolution of coarse resolution satellite imagery (Smith, et al., 1990; Huete, 1986; Tueller, 1987).

A number of methods have been proposed for spectral demixing, but most methods can be categorized into two types.

Percent Cover Known: The first method assumes that the percent cover of each of the land cover types of interest within several pixels is known. The pure spectrum of each land cover type can then be determined by inverting the model (Huete, 1986; Puyou-Lascassies, et al., 1994; Adams, et al., 1995; Marsh, et al., 1980). The model is developed by correlating known percent cover values of land cover types with the spectral values for a sample of pixels from the course resolution imagery using regression techniques. The known percent cover estimates used to parameterize the model are typically derived from field measurements or corresponding high spatial resolution imagery or photography. This is the method applied in this research.

Pure Spectra Known: If the pure spectra of land cover types or spectral endmembers are known, then the percent cover of each type within a single mixed pixel can be determined (Ray and Murray, 1996; Farrand, et al., 1994; Asrar, et al., 1986, Smith, et al., 1990, Smith, et al., 1994).

In either case, this image processing technique is referred to as spectral demixing or spectral unmixing.

Spectral Demixing has been evaluated as a technique for estimating vegetative cover and abundance in arid environments using multispectral imagery with mixed results. Typically, spectral demixing is capable of providing estimates of green leaf vegetative matter, gray matter and litter, and bare ground with some degree of success (Sohn and McCoy, 1997; Smith, et al., 1990; Marsh, et al., 1980;) However, there are still recognized problems with demixing analysis in arid environments, including difficulties in identifying spectrally unique endmembers and accounting for shadowing effects within sparse canopy desert shrubs (Ray and Murray, 1996; Pech, et al., 1986; Ustin, et al. 1986)

Data

A Landsat Thematic Mapper(TM) satellite image and KODAK color infrared aerial (CIR) photography were acquired to evaluate spectral demixing and spectral index correlations as alternative methods for estimating and extrapolating abundance of vegetative cover at Ft. Bliss, TX.

A single Landsat-5 Thematic Mapper (TM) image of Ft. Bliss was acquired on November 9, 1994 (Scene ID: 94313). This acquisition date was the nearest available date to the acquisition date of existing KODAK CIR photography. Thematic Mapper is a space borne scanning sensor that records reflected and emitted energy in the blue, green, red, near infrared, middle infrared, and thermal regions of the electromagnetic spectrum. Landsat-5, the satellite that carries the TM sensor, is in a sun-synchronous orbit of approximately 705km above the earth's surface. TM has a temporal revisit time of 16 days and a spatial resolution of approximately 30m. The spectral characteristics of the Landsat-5 TM are summarized below.

LANDSAT-5 TM

Channel #	Band Width (micrometers)	Ground IFOV (m)
1	0.45 - 0.52	30
2	0.53 - 0.60	30
3	0.63 - 0.69	30
4	0.76 - 0.90	30
5	1.55 - 1.75	30
6	10.42 - 12.50	120
7	2.08 - 2.35	30

Table 1. LANDSAT-5 TM specifications. *Adopted from Table 2-4 of Jensen (1986)

Ft. Bliss DOE contracted NASA (Stennis Space Center) to acquire airborne high spatial and spectral imagery for all of Ft. Bliss, TX over an 8-day period beginning October 29, 1994 and ending November 5, 1994. CIR aerial photographs were acquired also. The mission was flown at an elevation at 8200 ft. above mean terrain level. With a six-inch focal length, the resulting KODAK CIR photographs had a nominal scale of 1:16000 (1"=1333').

Study Site Selection

Three general study areas where chosen which represent the 3 primary vegetation/landform areas of Ft. Bliss, TX. Study Site #1 was chosen to represent the Honey Mesquite/Coppice Dunes area of the Tularosa Valley, primarily located within Maneuever Areas #4 and #5. Study Site #2 was chosen to represent a grassland dominated site on Otero Mesa. Study Site #3 was located in a mixed desert shrub/grassland area in the foothill transition zone between the Tularosa Valley and Otero Mesa. Not only were these sites chosen to represent the primary vegetation and landform areas of the installation, but they also correspond to locations of other related field studies ongoing at Ft. Bliss, TX. Study Site #2 was located in close proximity to the Wheeled Vehicle Carrying Capacity Controlled Impact Sites on Otero Mesa. Study Site #3 was located in close proximity to the Controlled Burn Study Sites directly south of Highway 506.

NASA provided the KODAK CIR photos to Ft. Bliss DOE on color positive transparencies on drum type reels. No photo index was supplied. CIR transparencies were visually inspected and several CIR photos were identified for each general study site. Four digital 1:16,000 Color Infrared (CIR) images were ultimately selected as samples for each of the 3 general study areas. These photos were selected based upon their suitability for testing spectral diversity in land cover and vegetation types.

Methodology

Scanning Aerial Photos

Digital copies of the CIR photos were required to conduct demixing and spectral index correlation analysis. Spectral demixing also required accurate radiometric scanning. Therefore, scanning services were contracted to Image Scans, Inc. of Denver, Co. Image Scans used a professional quality Leica/Helava DSW200 scanner with a maximum scan rate of 5microns (um).

Preliminary classifications were applied to the 12.5 micron (.2 m), 25 micron (.4m) and 50 micron (.8m) images to determine if scanning rates and resulting spatial resolution affected image classification results. Before any preliminary comparison of the multi-resolution photos could be done it was necessary to co-register the imagery. The 50micron and 25micron images were registered to the 12.5micron image using a first-order linear transformation by selecting 4 control points at the image tic marks (retaining original pixel size). It was also necessary to subset an area common to each resolution image.

Classification Methods

A variety of classification methods were used to test the variable scanning rates, including Iterative Self Organizing Data Analysis Technique (ISODATA) in ERDAS Imagine, maximum-likelihood discriminant analysis classifier (MAXLIK) in ERDAS Imagine, and sequential maximum a posteriori (SMAP) estimation in Geographical Resources Analysis Support System (GRASS).

Statistical comparison between ISODATA, MAXLIK, and SMAP results showed no significant difference in classifications for the same spatial resolutions and for different spatial resolutions. Therefore, ISODATA, the default unsupervised classification tool in ERDAS Imagine, was used for all classifications in this research.

After evaluating all test results for 3 different scan rates, it was determined that there was no significant difference in classification of land cover types at the different spatial resolutions. Therefore, the remaining photos were scanned at 25 microns, or .4m spatial resolution, and were supplied in an ERDAS Imagine .lan file format.

Image Pre-Processing

CIR Photography Exposure Falloff

Further image processing was required to correct a geometric effect called exposure falloff present in all of the photos. This effect is evident by maximum exposure at the center of the film with gradual dimming with increased radial distance from the center. (Lillesand and Keifer, 1987) The effect was corrected satisfactorily with a detrend function using TNTmips software.

Thematic Mapper Systematic Noise

Undesirable systematic striping apparent in the subject Landsat TM images were corrected using ERDAS Imagines' Fast Fourier Transform (FFT) tool. (ERDAS Field Guide, 1997)

Classification Of CIR Photos

Since there was no opportunity to collect temporally coincident field data necessary to perform a *supervised* classification, all CIR photographs were classified using the previously selected ERDAS Imagine unsupervised classification routine, ISODATA, prior to co-registration to the TM imagery.

Determining the number of classes requested during the unsupervised classification was also critical. The number of classes requested was equivalent to identifying the number of unique land cover types (eq. plant species, litter, bare ground) to be characterized in terms of abundance or percent cover using demixing analysis.

Through visual observations in the field and consultation with Ft. Bliss DOE staff, a decision was made to request 5 land cover categories for all classification of CIR photos.

Due to the ambiguities in assigning information classes to the spectral classes resulting from unsupervised classification of the photos, the 5 class unsupervised results were recoded or aggregated in a number of different ways in an attempt to simply distinguish between cover and bare ground.

Geometric Registration

Selection of Ground Control Points

Spectral Demixing requires accurate spectral information for each pixel in the image. Therefore, to avoid resampling the Landsat TM image and effectively changing the TM pixel values, the photographs were instead co-registered to the TM image using ERDAS Imagine. Wherever possible, a first order transformation was used. A transformation matrix file (.cff) was saved and later used to transform unsupervised classifications of the CIR photographs rather than the original CIR photographs. Ideally, the aerial photos should have been photogrammetically corrected, however lack of camera data made this impossible.

Accuracy Assessment of Geometric Registration

Rectification results were visually checked with ERDAS Imagine's **Blend/Fade** utility, a very effective visualization tool whereby two images are overlaid in a single viewer. The analyst is able to fade the newly rectified image interactively into the underlying source image to check overlap.

Subset TM Scene and Airphoto to Common Area

Common areas between the TM image and the georeferenced aerial photo classification were defined. Because of the CIR photos were aligned along the flight line of the aircraft and not in a truth North-South orientation, the maximum square area of TM imagery that fell within the footprint of the CIR photo had to be identified first. This was accomplished using ERDAS Imagine by displaying the TM and the aerial photo images in separate viewers, side by side, linking the viewers together, then running an **inquire box** in the TM viewer and roughly defining the common area with the box, taking care not to expand the box beyond the photo image area. File coordinates returned from the inquire box tool were rounded by increasing smaller numbers and decreasing larger numbers (to integers) to insure that the TM subset was clearly within the footprint of the CIR photo. These file coordinates were used to subset the 6 band TM scene.

Secondly, the CIR photo was subsetted by using **imageinfo** on the subsetted TM scene to get **map** coordinates and pixel sizes. Map coordinates for the upper left pixel and lower right pixel of the photo were computed based on map coordinates for the TM subset as follows.

Notation:

TM_ULX	Upper Left X Map Coordinate for the TM subset
TM_ULY	Upper Left Y Map Coordinate for the TM subset
TM_LRX	Lower Right X Map Coordinate for the TM subset
TM_LRY	Lower Right Y Map Coordinate for the TM subset
TM_XSZ	X Pixel size (in Map Coordinates) the TM subset
TM_YSZ	Y Pixel size (in Map Coordinates) the TM subset

and similarly for the photo:

P_ULX Upper Left X Map Coordinate for the photo subset
P_ULY Upper Left Y Map Coordinate for the photo subset
P_LRX Lower Right Map Coordinate for the photo subset
P_LRX Lower Right Map Coordinate for the photo subset
P_XSZ X Pixel size (in Map Coordinates) the photo subset
P_YSZ Y Pixel size (in Map Coordinates) the photo subset

P_ULX = TM_ULX - TM_XSZ/2 + PSZ/2
P_ULY = TM_ULY + TM_XSZ/2 - PSZ/2
P_LRX = TM_LRX + TM_XSZ/2 - PSZ/2
P_LRY = TM_LRY - TM_XSZ/2 + PSZ/2

Spectral Demixing

Spectral demixing utilized twelve 1:16K CIR photos resampled to 1m spatial resolution and a temporal coincident Landsat TM imagery at 30m resolution. For each CIR footprint, a subset of the TM scene which matched the geographic extent of the CIR footprint was extracted from the TM scene, resulting in 12 pairs of CIR photos and matching TM subsets. Band 6 of TM was not used in this analysis. Only bands 1-5 and 7, or a total of 6 bands, were used. Thus, any reference to band 6 in this report actually refers to band 7 of the TM sensor. Therefore, there were six pixel values associated with spatial position of any given pixel, each corresponding to TM bands 1-5 and 7, respectively.

Example Implementation of Spectral Demixing

Define Percent Cover
In this example, five land cover types were classified from the CIR photo and used to model the landscape; honey mesquite, mesquite/dune edge/shadow/litter, 2 interdunal vegetation cover types, and bare soil. A simple GIS program (AIRCOVER) was written which summarizes the percent cover of each land cover component in the CIR photo map that falls within each individual 30 meter TM pixel. The AIRCOVER output is a five-band GIS data file, with each pixel of each band representing the fractional percentage of a single land cover type. The AIRCOVER images served as reference or ground truth of percent covers for both spectral demixing and spectral index correlation analysis.

Defining Training Data Set
Next, both the AIRCOVER output (in this example, 5 bands) and the matching TM subset (6 bands) were input into a sampling program called TRAINDAT.
Approximately 500 pixels (user can specify number) were randomly sampled for each photo. The pixel values of the coincident sample TM subset (6 bands) and fractional percent covers for each land cover component are extracted and output to a tabular ascii file, then formatted for input into the MINITAB statistical package. A singular value decomposition method of least squares is used to obtain *pure signature values* for each land cover type for each of the 500 samples for each spectral band spectral band.

DEMIX TM Scene
Finally, the 6 TM bands and the pure spectra for each land cover type were input into the DEMIXing program. The DEMIX routine outputs a multiband image estimate of fractional percent cover of each individual land cover type within each TM pixel. In this example, DEMIX produced 5 bands corresponding to the five land cover types.

The above procedure was repeated for each individual CIR photo-TM pair and repeated for each recode of the original 5class unsupervised classification for each photo.

Demixing Evaluation and Accuracy Assessment

An evaluation of demixing performance was conducted on a photo by photo basis, including all possible recode combinations tested. Performance was evaluated based upon how closely demixing estimates of fractional cover by land cover type matched reference fractional cover estimates derived directly from the classified aerial photography. This was accomplished by subtracting each band of the reference AIRCOVER image from each corresponding band of the demixing output on a pixel by pixel basis.

Descriptive statistics such as mean and standard deviation of each difference image were used to evaluate performance. A mean difference of 0 between estimated and reference cover would indicate that the demixing procedures accurately predicted fractional percent covers of land cover categories. The standard deviation provided some indication of the variance in these estimates. However it was recognized that this may not have provided a suitable method for evaluating accuracy, as demixing could potentially overestimate cover in some areas, while under estimating cover in other areas. These types of errors may have canceled each other out and therefore, the mean difference may still have been be relatively low.

An additional descriptive statistic used to compare estimated versus reference fractional percent land cover values for each photo was the sum of *absolute difference* between estimated and reference cover values on a pixel by pixel basis. By computing absolute differences, the possibility of a mean difference equaling 0 resulting from an equal number of overestimation and underestimation of cover was eliminated. By tabulating absolute difference, the amount by which estimates of cover exceed or underestimate reference cover values are summed, providing a more robust evaluation of demixing accuracy for the purpose of evaluating each combination for each study site.

Inferential statistics were also calculated to compare estimated vegetative cover amounts derived from demixing and reference vegetative cover amounts, including a Paired Students T-Test Statistic (t-value), Probability Value (P), and a 95% confidence interval for mean difference between estimated and reference abundance amounts. The t-value and P were used to evaluate the null hypothesis that the mean difference between estimated percent covers from demixing analysis and reference percent cover values from air photo classifications were equal to zero at alpha = .05, or 95% confidence. The 95% confidence interval indicates that for any paired sample for any given pixel, the mean difference between demixing estimates of cover and reference cover values will fall within this interval with 95% confidence. Again, the reference image was always subtracted from the estimated image. Therefore, positive confidence intervals indicated that demixing consistently overestimated cover, intervals straddling zero indicated that differences were close to zero, and negative intervals indicated that demixing consistently underestimated cover. The same null hypothesis was tested for assessing all demixing and spectral index correlation estimates of cover in this research.

Spatial Extrapolation of Demixing Results

A final evaluation of demixing results was to evaluate demixing capabilities for spatially extrapolating fractional land cover percentage estimate to areas beyond the photo footprint locations that were used to parameterize the demixing model. Extrapolation capabilities were tested at each study site. For each study site, 3 of the 4 photos were randomly chosen to parameterize the demixing model. The remaining TM subset, which matched the 4 CIR footprint, was then demixed from the other 3 photo/TM subset pairs. Demixing procedures using 3 photos were conducted in the same manner as demixing of a single TM/photo pair described above. The only variation was that paired samples of mixed TM pixel values and fractional land cover percent coverages from classified CIR photo were taken form 3 photos instead of one. Instead of random sampling of 500 pixels in one photo, 1500 random samples were collected across 3 photos. These 1500 samples were then used to solve for pure spectra values. These same values, along with TM mixed spectra values for the remaining TM subset to be demixed were input to solve for the fractional percent coverage of each land cover component, whether it be 2 cover types or 5, within each TM pixel.

Conclusions

Summary Of Results

Descriptive statistics such as mean difference, standard deviation of mean difference, and sum of absolute difference between estimates of abundance extracted from either coarse resolution TM imagery using spectral demixing or spectral index correlation models and reference abundance amounts extracted from high resolution CIR photography were used to evaluate the accuracy of abundance estimates derived from these models. Inferential statistics were also used to evaluate the predictive ability of these models for estimating and extrapolating cover estimates derived from coarse resolution satellite imagery.

Inferential statistics were based upon random samples of results. However, because remotely sensed imagery provides a complete census of a population, sampling and inferential statistics were not necessary because automated analysis of imagery provided the ability to rapidly compile descriptive statistics of entire populations of image pixels in a rapid and cost effective manner. Inferential statistics such as the student’s T-test were useful for understanding the predictive capabilities of demixing and spectral index correlation analysis for estimating and extrapolating percent groundcover estimates. However, the sum of absolute difference between estimated and reference cover percentages were ultimately used to identify the best performing models. The same descriptive statistics were also useful for identifying the reclassification or recode of spectral categories into cover vs. bare ground which resulted in the most accurate estimates of abundance of cover and bare ground.

The same statistics were compiled for 4 CIR photos and matching TM subsets for each of 3 sites, resulting in a total of 12 photo samples. Although all statistics were utilized in evaluating performance of the respective models, sum of absolute differences for all pixels in each individual photo, for the sum of all pixels in all 4 photos for an individual study site, and for estimates derived from sampling 3 photos and extrapolating to a 4^{th} were used to identify the best model and recode for each respective site.

In all CIR photo samples, bare ground was clearly delineated using an unsupervised, 5 category classification. Dense shrub or grass cover was also clearly identified as a separate spectral class. However, the remaining spectral categories appeared to delineate a gradient of foliar cover and canopy closure rather than a distinction between different plant species. Attempts were made to estimate abundance of 5 five land cover categories using demixing and spectral index correlations, but results indicated this would not be possible. Therefore, all 5 land cover categories were reclassified as either Cover or Bare Ground. However, some land cover categories were difficult to classify as Cover or Bare Ground Therefore, a number of different reclassifications were tested, each with a slightly different grouping of the original five land cover categories. Categories were assigned so that higher category numbers represented lower abundance of cover (Category 1= Highest Cover, Category 5 = Bare Ground). The top performing recodes for Study Sites #2 and #3 were Recode 1_25, where Land cover Category #1 was reclassified as Cover and all remaining land cover categories were reclassified as Bare Ground, or Recode 14_5, where Land cover Categories 1 through 4 were reclassified as Cover and Land cover Category #5 was reclassified as Bare Ground. One exception to this was Study Site #1 (Coppice Dunes Maneuver Areas), where a reclassification of Land cover Categories #1 and #2 to Cover and Land cover Categories 3 through 5 as Bare Ground performed slightly better than other reclassifications. Although photos selected were within relatively close proximity to each other within each individual study site, there was still considerable heterogeneity in abundance of vegetative cover between individual photos for any given study site. This would explain why different reclassification or recodes, and in some cases, different demixing models preformed best for each photo. However, the top performing models and respective recodes for each study site were selected based upon examination of descriptive statistics for all photos for each site.

The top performing demixing model was derived using the 1_25 recode, although Recode 14_5 also performed relatively well.

The opposite was true for demixing, where recode 14_5 performed relatively well, but recode 1_25 was clearly the top performer. Spectral demixing was able to estimate percent cover and bare ground, but could not provide reasonable estimates of different vegetative cover types.

Recommendations

The goal of this research was to investigate alternative methods for characterization and monitoring of vegetative cover at Ft. Bliss, TX which would be cost effective, yet provide information to installation land managers at a higher level of detail. The alternative methods that were investigated were designed to overcome deficiencies in currently available ground monitoring efforts by utilizing and integrating remote sensing technologies into a characterization and monitoring protocol.
Secondly, methods were evaluated which could potentially provide a means to extract vegetative cover information from coarse resolution satellite imagery at a higher level of detail than previously possible.

The primary focus of this research was to evaluate spectral demixing and vegetation abundance as potential methods for estimating percent cover for several land cover types within a single coarse resolution satellite image pixel.
These same techniques were also evaluated for their utility in extrapolating fractional cover estimates across various regions of the installation. Both methods utilized high resolution Color IR photography as a sampling technique for collecting measurements of percent vegetative cover and bare ground.

Therefore, the results of this research not only provided an evaluation of demixing but also an evaluation of a sampling and validation methodology which utilizes high resolution photography rather than ground surveys. Field sampling will always be a necessity for natural resources characterization and monitoring efforts, but will always remain cost prohibitive, especially for such large land areas as Ft. Bliss, TX. Therefore, in order to adequately sample a large area, Ft. Bliss DOE land managers can benefit from alternative sampling techniques such as high resolution photography or digital imagery to augment existing field sampling efforts.

In many cases, observations from high-resolution imagery are unacceptable as surrogate measurements of ecological data measured on the ground for survey and monitoring purposes. However, for the purpose of sampling aerial vegetative cover and bare ground, high resolution aerial photography was adequate as a sampling technique for an arid environment such as Ft. Bliss, TX. There are always challenges, as there were in this investigation, in interpreting photographic or spectral images and translating that information to quantitative ecological data. Any type of sampling that utilizes remote observations should always be validated with in-situ measurements. Unfortunately, in this research, historical photography and satellite imagery were used to evaluate spectral demixing and correlation analysis. Therefore, ground observations of vegetative cover at the time the imagery and photography were collected were not available. If ground observations had been available, problems associated with the uncertainty in assigning spectral classes derived from photography into Cover vs. Bare Ground information classes would have been minimized, thus improving the reference cover estimates derived from aerial photography classifications. Minimizing these types of errors would have improved reference cover values used to develop demixing and correlation models, thus improving the accuracy of abundance estimates derived from these models.

In addition to the lack of field validation data, there were other aspects of the techniques evaluated that could potentially be improved.
Specifically, further research is required to determine the number and location of samples necessary to adequately sample and characterize the diversity of land cover types and land uses at Ft. Bliss, TX.
Results from this research attempted to characterize 3 general regions of Ft. Bliss; the Coppice Dunes Maneuver Areas, the Otero Mesa Grasslands, and the transition zone between Tularosa Valley and Otero Mesa, in close proximity to the Controlled Burn Study Site.

There was considerable diversity within these large, generalized land areas that was not adequately sampled. There was also considerable diversity in abundance of various land cover types within the relatively small areas that were sampled with CIR photography for each study site.

A larger and more distributed sample of photography and ground surveys would certainly increase the accuracy of these estimates.

In addition, both the CIR photography and TM imagery used to evaluate demixing analysis were collected in late October and early November, 1994, well beyond the peak precipitation events and corresponding peak greenness and photo synthetically active period of most vegetation at Ft. Bliss, which typically occurs in August and September. As a result, because of minimal green biomass and photo synthetic activity at this time, minimal Near Infrared spectral response was observed in the CIR photography and satellite imagery. This may have adversely affected spectral demixing results, where each spectral endmember or land cover type to be characterized must be spectrally unique from all other endmembers. In addition, spectral indices, and in particular, spectral greenness indices, may have also been adversely affected by the timing of the image collection. A sample of imagery collected during peak photo synthetic activity of vegetation may improve estimates of abundance derived from demixing and correlation analysis.

Despite these potential areas for improvement, results from this research were promising and the techniques which were demonstrated and evaluated have great potential for future characterization and monitoring of land condition at Ft. Bliss, TX. Estimates of vegetative cover derived from these techniques may never be exact for any given pixel location, yet these estimates of cover are more accurate that what would be possible based upon existing field surveys alone. In addition, they can be derived by supplementing existing field surveys with relatively low cost samples of high resolution photography or imagery and course resolution satellite imagery.

Several options exist for implementation of the techniques evaluated in this investigation to support future resource characterization and monitoring objectives of Ft. Bliss DOE. One alternative would be to sample with a combination of ground surveys and high resolution photography or imagery on a regular interval, but not necessarily on an annual basis, for example. Using this alternative, either demixing or spectral index correlation models would be developed from the most recent sample and applied to TM imagery for successive years in which field and aerial samples are not collected. During these interim years, the only requirements to conduct an inventory would be a single coarse resolution satellite image and field validation plots, thereby reducing the total cost of the monitoring program. Once a new sample of high resolution imagery is collected, the demixing or spectral index correlations could be recalibrated.

A second alternative would be to sample with high resolution imagery on annual basis. The accuracy of abundance estimates derived from demixing and spectral index correlation models should increase with the frequency at which sampling occurs, but increased sampling frequency would incur a greater cost. A third option would be to sample sensitive areas or areas of intense use at a higher frequency than those areas of the installation that are used less frequently, thereby reducing the total cost of monitoring while focusing characterization and monitoring efforts on critical areas of the installation. Characterization and monitoring objectives of installation land managers, as well as resources allocated to meeting these monitoring objectives, will ultimately dictate how such a monitoring program might be implemented. Regardless of sampling frequency, if suggested improvements to the techniques evaluated in this investigation are researched, validated, and implemented, spectral index correlations and demixing techniques should improve the capability of Ft. Bliss managers to characterize and monitor land condition at Ft. Bliss, TX.

Imagery Selection Keys

About the Keys

Ecoregion Organization:

Each imagery selection key is organized into five ecoregions for the conterminous United States. Ecoregions used in this report are "lumped" to reduce the confusion that may result from repeated references for applications in similar areas. The ecoregion combinations selected for inclusion in the key are based on adjacency and similarities between ecoregions, presence or absence of Army installations, and other factors. The regions given the greatest attention were those with the highest concentration of Army installations: Southeast, Southern Plains, Pacific Southwest, and Northwest United States.

Alaska and Hawaii are ecologically unique compared to the mainland United States. Installation natural resources managers in either state should contact either the USAEC's Conservation Assistance Program or TEC's Operations Directorate directly for assistance in determining the most appropriate imagery for their needs, locating imagery, or developing Statements of Work. Points-of-Contact are listed in the procurement section of this guide.

Applicable Sensors Based on Management Objective & Region:

Three sections of broad management objectives are included in the Selection Keys: Vegetation, Soils & Soil Erosion, and Land Management/Disturbance Detection. Each objective is organized by ecoregion. Within these sections, more specific objectives are listed from large to small scale, with recommended sensor platforms for each level.

Imagery Selection Key Example:

Vegetation Key

EcoRegion: Southeast / Northeast (Vegetation Key)

1. Major Cover Types (Physiognomic Group/Subgroup
    a. Definition: listed for each map scale and ecoregion
    b. Applicable Sensors: listed for each map scale and ecoregion
2. Broad Vegetation Groups (Formation)
3. Major Community Types (Alliance)
4. Single Trees/Large Shrubs (Community Association)
5. Single Plants/Grassland Types (Community Association)
6. Seasonal Greenup
7. Water Stress
8. Other Plant Stress
9. Large Floodplains/Wetlands, Playas
10. Stream Floodplain/Small Marshes, Swamps

Soils & Soil Erosion Key

EcoRegion: Southeast / Northeast (Soils and Erosion Key)

1. Landscapes/Large Soil Units
    a. Definition: listed for each map scale and ecoregion
    b. Applicable Sensors: listed for each map scale and ecoregion
2. Detailed Base-scale Soil Maps
3. Individual Erosion Sites
4. Sedimentation in Receiving Water Bodies
5. Soil Moisture
6. Flooding

Land Management / Disturbance Detection Key

EcoRegion: Southeast / Northeast (Land Management / Disturbance Detection Key)

1. To Examine Management Effects
    a. Definition: listed for each map scale and ecoregion
    b. Applicable Sensors: listed for each map scale and ecoregion
2. To Examine Disturbance/Horticulture Effects

Note: Corresponding Federal Geographic Data Committee Vegetation Subcommittee terms are in parentheses next to this key's categories.

Vegetation Keys

Ecoregion: Southeast/Northeast (Vegetation Key)

1. ***Major Cover Types (Physiognomic Group/Subgroup)***
   a. Definition: Separation of major vegetation types from other types (e.g., forest from agricultural from barren). Information that may be expected to be found at the level of an early earth-satellite image.
   b. Applicable Sensors:
   Landsat TM (Hodgson et al. 1988) (Cook et al. 1989) (Brockhaus et al. 1993)
   SPOT XS (Rutchey and Vilcheck 1994)
   Hyperspectral Imaging (HSI) (Steinmaus et al. 1997) (Jia and Richards 1994)

2. ***Broad Vegetation Groups (Formation)***
   a. Definition: Recognition of broad vegetative types, such as herbaceous versus shrub meadows, deciduous versus evergreen forests, croplands versus orchards.
   b. Applicable Sensors:
   Landsat TM (Brannon et al. 1996) (Schriever and Congalton 1993)
   SPOT XS (Muchoney and Haack 1994)
   SPOT PAN
   Standard Aerial Photography (Cablk et al. 1994)
   Digital Aerial Orthophotography with Multispectral
   Hyperspectral Imaging (HSI) (Steinmaus et al. 1997) (Jia and Richards 1994)

3. ***Major Community Types (Alliance)***
   a. Definition: Direct identification of major community types and species occurring in pure stands, such as white pine versus cedar, mixed oak versus maple, and seasonal dominant grasses.
   b. Applicable Sensors:
   SPOT XS (Narumalani and Carbone 1993)
   SPOT PAN (Jensen et al. 1991)
   Standard Aerial Photography (Jensen et al. 1986, 1991)
   Digital Aerial Orthophotography (Needham and Smith 1987)
   Digital Aerial Orthophotography with Multispectral
   Hyperspectral Imaging (HSI) (Steinmaus et al. 1997) (Jia and Richards 1994)

4. ***Single Trees/Large Shrubs (Community Association)***
   a. Definition: Identification of individual trees and large shrubs.
   b. Applicable Sensors:
   Standard Aerial Photography (Jacobs et al. 1993)
   Digital Multispectral Video

Digital Aerial Orthophotography
Hyperspectral Imaging (HSI)

5. ***Single Plants/Grassland Types (Community Association)***
    a. **Definition:** Identification of individual plants and grassland types.
    b. **Applicable Sensors:**
        Digital Aerial Orthophotography
        Digital Multispectral Video
        Hyperspectral Imaging (HSI)

6. ***Seasonal Greenup***
    a. **Definition:** Detection of increased reflectance caused by spring revegetation.
    b. **Applicable Sensors:**
        Landsat TM
        SPOT XS
        SPOT PAN
        Standard Aerial Photography
        Digital Multispectral Video
        Hyperspectral Imaging (HSI) (Steinmaus et al. 1997) (Jia and Richards 1994)

7. ***Water Stress***
    a. **Definition:** Detection of change in plant conditions caused by flooding, drought, effects of high temperatures.
    b. **Applicable Sensors:**
        Standard Aerial Photography (Welch et al. 1988)
        Digital Multispectral Video
        Hyperspectral Imaging (HSI) (Carter and Miller 1994).

8. ***Other Plant Stress***
    a. **Definition:** Detection of stress caused by disease, insect attack, fire, air pollution, seasonal senescence.
    b. **Applicable Sensors:**
        Landsat MSS (Muchoney and Haack 1994) (Mukai et al. 1987)
        Landsat TM (Muchoney and Haack 1994)
        SPOT XS (Muchoney and Haack 1994) (Ciesla et al. 1989)
        Standard Aerial Photography (Ciesla et al. 1989)
        Digital Aerial Orthophotography (Murtha and Wiart 1989)
        Digital Multispectral Video
        Hyperspectral Imaging (HSI) (Carter and Miller 1994)

9. ***Large Floodplains/Wetlands, Playas***
    a. **Definition:** Detection of floodplains for streams of stream order 3 or higher; delineation of wetlands of five acres or larger.
    b. **Applicable Sensors:**
        Landsat MSS

Landsat TM (Tao 1993)
SPOT XS (Rutchey and Vilcheck 1994)
SPOT Panchromatic (Jensen et al. 1993)
Standard Aerial Photography (Tiner and Smith 1992) (Jacobs et al. 1993)
Hyperspectral Imaging (HSI)

10. Stream Floodplain/Small Marshes, Swamps

a. Definition: Detection of headwater (stream order 2 or lower) floodplains; meander floodplain detection (characterized by features such as channel scars, oxbow lakes, meander scrolls); identifying riverine floodplains.

b. Applicable Sensors:

Standard Aerial Photography (Jensen et al. 1993) (Mackey 1993) (Rizzo et al. 1996)
Digital Multispectral Video
Digital Aerial Orthophotography
Hyperspectral Imaging (HSI)

Ecoregion: Southern Plains/Southwest/Pacific Southwest (Vegetation Key)

1. ***Major Cover Types (Physiognomic Group/Subgroup)***
   - **a. Definition:** Separation of major vegetation types from other types (e.g., grassland from agricultural from barren). Information that may be expected to be found at the level of an early earth-satellite image.
   - **b. Applicable Sensors:**
     - Landsat MSS (Pickup et al. 1993) (Satterwhite 1984) (Chavez 1994)
     - Landsat TM (Franklin et al. 1991) (Stenback and Congalton 1990) (Collins and Woodcock 1996) (Smith et al. 1990) (Satterwhite 1984)
     - SPOT XS
     - Hyperspectral Imaging (HSI)

2. ***Broad Vegetation Groups (Formation)***
   - **a. Definition:** Recognition of broad vegetative types, such as herbaceous versus shrub rangelands, deciduous versus evergreen forests, croplands versus rangelands.
   - **b. Applicable Sensors:**
     - SPOT XS
     - SPOT PAN
     - Standard Aerial Photography (Baker 1989)
     - Digital Aerial Orthophotography with Multispectral
     - Hyperspectral Imaging (HSI)

3. ***Major Community Types (Alliance)***
   - **a. Definition:** Direct identification of major community types and species occurring in pure stands, such as grama grass versus mesquite, oak/juniper versus pine, and seasonal dominant grasses.
   - **b. Applicable Sensors:**
     - SPOT XS
     - SPOT PAN
     - Standard Aerial Photography
     - Digital Aerial Orthophotography with Multispectral
     - Hyperspectral Imaging (HSI)

4. ***Single Trees/Large Shrubs (Community Association)***
   - **a. Definition:** Identification of individual trees and large shrubs.
   - **b. Applicable Sensors:**
     - Standard Aerial Photography
     - Digital Multispectral Video
     - Hyperspectral Imaging (HSI)

5. ***Single Plants/Grassland Types (Community Association)***
    a. **Definition:** Identification of individual plants and grassland types.
    b. **Applicable Sensors:**
        Digital Aerial Orthophotography
        Digital Multispectral Video
        Hyperspectral Imaging (HSI)

6. ***Seasonal Greenup***
    a. **Definition:** Ability to detect increased reflectance caused by spring revegetation.
    b. **Applicable Sensors:**
        Landsat TM
        SPOT XS
        SPOT PAN
        Standard Aerial Photography
        Digital Multispectral Video
        Hyperspectral Imaging (HSI)

7. ***Water Stress***
    a. **Definition:** Detection of change in plant conditions caused by flooding, drought, and high temperatures.
    b. **Applicable Sensors:**
        Standard Aerial Photography
        Digital Multispectral Video
        Hyperspectral Imaging (HSI)

8. ***Other Plant Stress***
    a. **Definition:** Detection of stress caused by disease, insect attack, fire, air pollution, seasonal senescence.
    b. **Applicable Sensors:**
        Landsat MSS
        Landsat TM
        SPOT XS
        Standard Aerial Photography
        Digital Aerial Orthophotography
        Digital Multispectral Video
        Hyperspectral Imaging (HSI)

9. ***Large Floodplains/Wetlands, Playas***
    a. **Definition:** Detection of floodplains for streams of stream order 3 or higher; delineation of wetlands/playas of five acres or larger.

b. Applicable Sensors:

Landsat MSS
Landsat TM
SPOT XS
Standard Aerial Photography

10. Stream Floodplain/Small Marshes, Swamps

a. Definition: Detection of headwater (stream order 2 or lower) floodplains; meander floodplain detection (characterized by features such as channel scars, oxbow lakes, meander scrolls); identifying riverine floodplains.

b. Applicable Sensors:

Standard Aerial Photography
Digital Multispectral Video
Digital Aerial Orthophotography
Hyperspectral Imaging (HSI)

Ecoregion: Pacific Northwest (Vegetation Key)

1. ***Major Cover Types (Physiognomic Group/Subgroup)***
   - **a. Definition:** Separation of major vegetation types from other types (e.g., forest from agricultural from barren). Information that may be expected to be found at the level of an early earth-satellite image.
   - **b. Applicable Sensors:**
     - Landsat MSS (Talbot and Markon 1988) (Felix and Binney 1989)
     - Landsat TM (Fiorella and Ripple 1993)
     - SPOT XS
     - Hyperspectral Imaging (HSI)

2. ***Broad Vegetation Groups (Formation)***
   - **a. Definition:** Recognition of broad vegetative types, such as deciduous versus evergreen forests, croplands versus orchards.
   - **b. Applicable Sensors:**
     - SPOT XS
     - SPOT PAN
     - Standard Aerial Photography (Winterberger and Larson 1988)
     - Digital Aerial Orthophotography with Multispectral
     - Hyperspectral Imaging (HSI)

3. ***Major Community Types (Alliance)***
   - **a. Definition:** Direct identification of major community types and species occurring in pure stands, such as douglas fir versus cedar, hemlock versus silver fir, and seasonal dominant grasses.
   - **b. Applicable Sensors:**
     - SPOT XS
     - SPOT PAN
     - Standard Aerial Photography (Paine and McCadden, 1988)
     - Digital Aerial Orthophotography with Multispectral
     - Hyperspectral imaging (HSI)

4. ***Single Trees/Large Shrubs (Community Association)***
   - **a. Definition:** Identification of individual trees and large shrubs.
   - **b. Applicable Sensors:**
     - Standard Aerial Photography (Paine and McCadden 1988)
     - Digital Multispectral Video
     - Digital Aerial Orthophotography
     - Hyperspectral Imaging (HSI)

5. ***Single Plants/Grassland Types (Community Association)***
   - **a. Definition:** Identification of individual plants and grassland types.
   - **b. Applicable Sensors:**
     - Digital Aerial Orthophotography

Digital Multispectral Video

6. ***Seasonal Greenup***

a. Definition: Ability to detect increased reflectance caused by spring revegetation.

b. Applicable Sensors:

Landsat TM
SPOT XS
SPOT PAN
Standard Aerial Photography
Digital Multispectral Video
Hyperspectral Imaging (HSI)

7. ***Water Stress***

a. Definition: Detection of change in plant conditions caused by flooding, drought, effects of high temperatures.

b. Applicable Sensors:

Standard Aerial Photography
Digital Multispectral Video
Hyperspectral Imaging (HSI)

8. ***Other Plant Stress***

a. Definition: Detection of stress caused by disease, insect attack, fire, air pollution, seasonal senescence.

b. Applicable Sensors:

Landsat MSS
Landsat TM
SPOT XS
Standard Aerial Photography
Digital Aerial Orthophotography
Digital Multispectral Video
Hyperspectral Imaging (HSI)

9. ***Large Floodplains/Wetlands, Playas***

a. Definition: Detection of floodplains for streams of stream order 3 or higher; delineation of wetlands of five acres or larger.

b. Applicable Sensors:

Landsat MSS
Landsat TM
SPOT XS
Standard Aerial Photography
Hyperspectral Imaging (HSI)

10. Stream Floodplain/Small Marshes, Swamps

a. Definition: Detection of headwater (stream order 2 or lower) floodplains; meander floodplain detection (characterized by features such as channel scars, oxbow lakes, meander scrolls); identifying riverine floodplains.

b. Applicable Sensors:

Standard Aerial Photography
Digital Multispectral Video
Digital Aerial Orthophotography
Hyperspectral Imaging (HSI)

Ecoregion: Northern Plains/North Central (Vegetation Key)

1. ***Major Cover Types (Physiognomic Group/Subgroup)***
   - **a. Definition:** Separation of major vegetation types from other types (e.g., forest from agricultural from barren). Information that may be expected to be found at the level of an early earth-satellite image.
   - **b. Applicable Sensors:**
     - Landsat MSS (Karteris 1988)
     - Landsat TM (Ormsby and Lunetta 1987) (Warner et al. 1991) (Johnston and Bonde 1989) (Cook et al. 1989) (Chavez and Kwarteng 1989) (Anderson et al. 1993)
     - SPOT XS
     - Hyperspectral Imaging (HSI)

2. ***Broad Vegetation Groups (Formation)***
   - **a. Definition:** Recognition of broad vegetative types, such as prairies versus groves versus deciduous strips, croplands versus orchards.
   - **b. Applicable Sensors:**
     - Landsat TM (Lauver and Whistler 1993) (Johnston and Bonde 1989) (Heilman and Boyd 1986) (Herr and Queen 1993)
     - SPOT XS (Briggs and Nellis 1991)
     - SPOT PAN
     - Standard Aerial Photography
     - Digital Aerial Orthophotography with Multispectral
     - Hyperspectral Imaging (HSI)

3. ***Major Community Types (Alliance)***
   - **a. Definition:** Direct identification of major community types and species occurring in pure stands, such as cottonwood versus black willow and seasonal dominant grasses.
   - **b. Applicable Sensors:**
     - SPOT XS
     - SPOT PAN
     - Standard Aerial Photography (Frank and Isard 1986)
     - Digital Aerial Orthophotography with Multispectral
     - Hyperspectral Imaging (HSI)

4. ***Single Trees/Large Shrubs (Community Association)***
   - **a. Definition:** Identification of individual trees and large shrubs.
   - **b. Applicable Sensors:**
     - Standard Aerial Photography
     - Digital Multispectral Video
     - Digital Aerial Orthophotography
     - Hyperspectral Imaging (HSI)

5. ***Single Plants/Grassland Types (Community Association)***
   a. **Definition:** Identification of individual plants and grassland types.
   b. **Applicable Sensors:**
      Standard Aerial Photography (Chapman et al. 1993)
      Digital Aerial Orthophotography
      Digital Multispectral Video
      Hyperspectral Imaging (HSI)

6. ***Seasonal Greenup***
   a. **Definition:** Ability to detect increased reflectance caused by spring revegetation.
   b. **Applicable Sensors:**
      Landsat TM
      SPOT XS
      Standard Aerial Photography
      Digital Multispectral Video
      Hyperspectral Imaging (HSI)

7. ***Water Stress***
   a. **Definition:** Detection of change in plant conditions caused by flooding, drought, effects of high temperatures.
   b. **Applicable Sensors:**
      Standard Aerial Photography
      Digital Multispectral Video
      Hyperspectral Imaging (HSI)

8. ***Other Plant Stress***
   a. **Definition:** Detection of stress caused by disease, insect attack, fire, air pollution, seasonal senescence.
   b. **Applicable Sensors:**
      Landsat MSS
      Landsat TM (Joria et al. 1991)
      SPOT XS (Joria et al. 1991)
      Standard Aerial Photography
      Digital Aerial Orthophotography
      Digital Multispectral Video
      Hyperspectral Imaging (HSI)

9. ***Large Floodplains/Wetlands, Playas***
   a. **Definition:** Detection of floodplains for streams of stream order 3 or higher; delineation of wetlands/playas of five acres or larger.
   b. **Applicable Sensors:**
      Landsat MSS
      Landsat TM
      SPOT XS

Standard Aerial Photography (Carter et al. 1979)
RADARSAT Radar (Paterson et al. 1996)
Digital Aerial Orthophotography (Lyon and Greene 1992)
Hyperspectral Imaging (HSI)

10. Stream Floodplain/Small Marshes, Swamps

a. Definition: Detection of headwater (stream order 2 or lower) floodplains; meander floodplain detection (characterized by features such as channel scars, oxbow lakes, meander scrolls); identifying riverine floodplains.

b. Applicable Sensors:

Standard Aerial Photography
Digital Multispectral Video
Digital Aerial Orthophotography
Hyperspectral Imaging (HSI)

Ecoregion: Great Basin/Rocky Mountains (Vegetation Key)

1. ***Major Cover Types (Physiognomic Group/Subgroup)***
   - **a. Definition:** Separation of major vegetation types from other types (e.g., forest from agricultural from barren). Information that may be expected to be found at the level of an early earth-satellite image.
   - **b. Applicable Sensors:**

     Landsat MSS (Price et al. 1992)
     Landsat TM (Frank 1988) (Chavez and Kwarteng 1989)
     (Stenback and Congalton 1990)
     (Collins and Woodcock 1996)
     (Walsh 1993) (Evans and Smith 1991)
     SPOT XS (Walsh 1993)
     Hyperspectral Imaging (HSI)

2. ***Broad Vegetation Groups (Formation)***
   - **a. Definition:** Recognition of broad vegetative types, such as herbaceous versus shrub meadows, deciduous versus evergreen forests, croplands versus orchards.
   - **b. Applicable Sensors:**

     Landsat TM (Frank 1988) (Franklin 1994) (Price et al. 1992)
     (Hewitt 1990)
     SPOT XS
     SPOT PAN
     Standard Aerial Photography (Befort 1986) (Tueller et al. 1988)
     Digital Aerial Orthophotography with Multispectral
     Hyperspectral Imaging (HSI)

3. ***Major Community Types (Alliance)***
   - **a. Definition:** Direct identification of major community types and species occurring in pure stands, such as ponderosa pine versus fir, sagebrush versus grass, and seasonal dominant grasses.
   - **b. Applicable Sensors:**

     SPOT XS
     SPOT PAN
     Standard Aerial Photography (Frank and Isard 1986)
     (Paine and McCadden 1988) (Meyer et al. 1996)
     Digital Aerial Orthophotography with Multispectral
     Hyperspectral Imaging (HSI)

4. ***Single Trees/Large Shrubs (Community Association)***
   - **a. Definition:** Identification of individual trees and large shrubs.
   - **b. Applicable Sensors:**

     Standard Aerial Photography (Paine and McCadden 1988)
     Digital Multispectral Video
     Hyperspectral Imaging (HSI)

5. ***Single Plants/Grassland Types (Community Association)***
    - **a. Definition:** Identification of individual plants and grassland types.
    - **b. Applicable Sensors:**
        - Digital Aerial Orthophotography
        - Digital Multispectral Video
        - Hyperspectral Imaging (HSI)

6. ***Seasonal Greenup***
    - **a. Definition:** Ability to detect increased reflectance caused by spring revegetation.
    - **b. Applicable Sensors:**
        - Landsat TM
        - SPOT XS
        - SPOT PAN
        - Standard Aerial Photography
        - Digital Multispectral Video
        - Hyperspectral Imaging (HSI)

7. ***Water Stress***
    - **a. Definition:** Detection of change in plant conditions caused by flooding, drought, effects of high temperatures.
    - **b. Applicable Sensors:**
        - Standard Aerial Photography
        - Digital Multispectral Video
        - Hyperspectral Imaging (HSI)

8. ***Other Plant Stress***
    - **a. Definition:** Detection of stress caused by disease, insect attack, fire, air pollution, seasonal senescence.
    - **b. Applicable Sensors:**
        - Landsat MSS
        - Landsat TM
        - SPOT XS
        - Standard Aerial Photography
        - Digital Aerial Photography
        - Digital Multispectral Video
        - Hyperspectral Imaging (HSI)

9. ***Large Floodplains/Wetlands, Playas***
    - **a. Definition:** Detection of floodplains for streams of stream order 3 or higher; delineation of wetlands of five acres or larger.
    - **b. Applicable Sensors:**
        - Landsat MSS
        - Landsat TM
        - SPOT XS
        - Standard Aerial Photography

Hyperspectral imaging (HSI)

10. Stream Floodplain/Small Marshes, Swamps

a. Definition: Detection of headwater (stream order 2 or lower) floodplains; meander floodplain detection (characterized by features such as channel scars, oxbow lakes, meander scrolls); identifying riverine floodplains.

b. Applicable Sensors:

Standard Aerial Photography
Digital Multispectral Video
Digital Aerial Orthophotography
Hyperspectral Imaging (HSI)

Soils and Erosion Key

Soils types are often inferred from the vegetation types that have adapted to specific soils. Level of detail in soil mapping may be limited by the ability to map vegetation on those soils. Elevation differences, which can be derived from stereo photographs or obtained directly from digital elevation models, can be useful in separating landscape features and major soil types.

Ecoregion: Southeast/Northeast (Soils and Erosion Key)

1. Landscapes/Large Soil Units

a. Definition: Capability to identify major soil units or landscape elements indirectly using drainages, topography and vegetation; delineating land and rural areas; identification of objects at scales ranging from 1:100,000 to 1:8,000.

b. Applicable Sensors:

Landsat MSS
Landsat TM
SPOT PAN (Bolstad and Stowe 1994)
SPOT XS
Hyperspectral Imaging (HSI)

2. Detailed Base-scale Soil Maps

a. Definition: Analogous to Natural Resources Conservation System soil maps at scales ranging from 1:6000 or larger. Detects small landscape patterns that control soil development, such as microtopography (drainages, slopes, etc.).

b. Applicable Sensors:

Standard Aerial Photography
Digital Aerial Orthophotography
Digital Multispectral Video
Hyperspectral Imaging (HSI)

3. Individual Erosion Sites

a. Definition: Identification of gully and rill erosion almost at the inception of such erosion.

b. Applicable Sensors:

SPOT PAN
Standard Aerial Photography
Digital Multispectral Video
IFSAR Radar
Hyperspectral Imaging (HSI)

4. Sedimentation in Receiving Water Bodies

a. Definition: Delineating coastal shorelines; determining water current direction as indicated by color differences (i.e., tributary entering larger water feature, chlorophyll or sediment patterns).

b. Applicable Sensors:

Landsat MSS (Ritchie et al. 1990)
Landsat TM (Ritchie et al. 1990)
SPOT XS
SPOT PAN
Standard Aerial Photography
Digital Aerial Orthophotography
Digital Multispectral Video
Hyperspectral Imaging (HSI)

5. Soil Moisture

a. Definition: Detection of saturated or flooded soil.

b. Applicable Sensors:

Standard Aerial Photography
SPOT XS
SPOT PAN
IFSAR and RADARSAT Radar
Hyperspectral Imaging (HSI)

6. Flooding

a. Definition: Detection of overbank and overdune flooding in lake and river floodplain or coastal overwash areas.

b. Applicable Sensors:

SPOT XS (Houhoulis and Michener 1996)
SPOT PAN
Standard Aerial Photography
IFSAR and RADARSAT Radar
Digital Aerial Orthophotography
Digital Multispectral Video
Hyperspectral Imaging (HSI)

Ecoregion: Southern Plains/Southwest/Pacific Southwest (Soils and Erosion Key)

1. ***Landscapes/Large Soil Units***
   - **a. Definition:** Capability to identify major soil units or landscape elements indirectly using drainages, topography and vegetation; delineating land and rural areas; identification of objects at scales ranging from 1:100,000 to 1:8,000.
   - **b. Applicable Sensors:**
     - Landsat MSS
     - Landsat TM (Paisley et al. 1991)
     - SPOT PAN
     - SPOT XS
     - IFSAR Radar (Zebker et al. 1994)
     - Hyperspectral Imaging (HSI)

2. ***Detailed Base-Scale Soil Maps***
   - **a. Definition:** Analogous to Natural Resources Conservation System soil maps at scales ranging from 1:6000 or larger. Detects small landscape patterns that control soil development, such as microtopography (drainages, slopes, etc.).
   - **b. Applicable Sensors:**
     - Standard Aerial Photography
     - Digital Aerial Orthophotography
     - Digital Multispectral Video
     - Hyperspectral Imaging (HSI)

3. ***Individual Erosion Sites***
   - **a. Definition:** Identification of gully and rill erosion almost at the inception of such erosion.
   - **b. Applicable Sensors:**
     - SPOT PAN
     - Standard Aerial Photography
     - Digital Aerial Orthophotography (Lyon et al. 1986)
     - Digital Multispectral Video
     - IFSAR Radar
     - Hyperspectral Imaging (HSI)

4. ***Sedimentation in Receiving Water Bodies***
   - **a. Definition:** Delineating coastal shorelines; determining water current direction as indicated by color differences (i.e., tributary entering larger water feature, chlorophyll or sediment patterns).
   - **b. Applicable Sensors:**
     - Landsat MSS
     - Landsat TM
     - SPOT XS
     - SPOT PAN

Standard Aerial Photography
Digital Aerial Orthophotography
Digital Multispectral Video
Hyperspectral Imaging (HSI)

5. ***Soil Moisture***
    a. **Definition:** Detection of saturated or flooded soil.
    b. **Applicable Sensors:**
        Standard Aerial Photography
        SPOT XS
        SPOT PAN
        IFSAR and RADARSAT Radar
        Hyperspectral Imaging (HSI)
6. ***Flooding***
    a. **Definition:** Detection of overbank and overdune flooding in lake and river floodplain or coastal overwash areas.
    b. **Applicable Sensors:**
        SPOT XS
        SPOT PAN
        Standard Aerial Photography
        IFSAR and RADARSAT Radar
        Digital Aerial Orthophotography
        Digital Multispectral Video
        Hyperspectral Imaging (HSI)

Ecoregion: Pacific Northwest (Soils and Erosion Key)

1. ***Landscapes/Large Soil Units***
   - **a. Definition:** Capability to identify major soil units or landscape elements indirectly using drainages, topography and vegetation; delineating land and rural areas; identification of objects at scales ranging from 1:100,000 to 1:8,000.
   - **b. Applicable Sensors:**
     - Landsat MSS
     - Landsat TM
     - SPOT PAN
     - SPOT XS
     - Hyperspectral Imaging (HSI)

2. ***Detailed Base-scale Soil Maps***
   - **a. Definition:** Analogous to Natural Resources Conservation System soil maps at scales ranging from 1:6000 or larger. Detects small landscape patterns that control soil development, such as microtopography (drainages, slopes, etc.).
   - **b. Applicable Sensors:**
     - Standard Aerial Photography
     - Digital Aerial Orthophotography
     - Digital Multispectral Video
     - Hyperspectral Imaging (HSI)

3. ***Individual Erosion Sites***
   - **a. Definition:** Identification of gully and rill erosion almost at the inception of such erosion.
   - **b. Applicable Sensors:**
     - SPOT PAN
     - Standard Aerial Photography
     - Digital Multispectral Video
     - IFSAR Radar
     - Hyperspectral Imaging (HSI)

4. ***Sedimentation in Receiving Water Bodies***
   - **a. Definition:** Delineating coastal shorelines; determining water current direction as indicated by color differences (i.e., tributary entering larger water feature, chlorophyll or sediment patterns).

b. Applicable Sensors:

Landsat MSS
Landsat TM
SPOT XS
SPOT PAN
Standard Aerial Photography
Digital Aerial Orthophotography
Digital Multispectral Video
Hyperspectral Imaging (HSI)

5. Soil Moisture

a. Definition: Detection of saturated or flooded soil.

b. Applicable Sensors:

Standard Aerial Photography
SPOT XS
SPOT PAN
IFSAR and RADARSAT Radar
Hyperspectral Imaging (HSI)

6. Flooding

a. Definition: Detection of overbank and overdune flooding in lake and river floodplain or coastal overwash areas.

b. Applicable Sensors:

SPOT XS
SPOT PAN
Standard Aerial Photography
IFSAR and RADARSAT Radar
Digital Aerial Orthophotography
Digital Multispectral Video
Hyperspectral Imaging (HSI)

Ecoregion: Northern Plains/North Central (Soils and Erosion Key)

1. ***Landscapes/Large Soil Units***
   a. **Definition:** Capability to identify major soil units or landscape elements indirectly using drainages, topography and vegetation; delineating land and rural areas; identification of objects at scales ranging from 1:100,000 to 1:8,000.

   b. **Applicable Sensors:**
      Landsat MSS
      Landsat TM
      SPOT PAN
      SPOT XS (Agbu and Nizeyimana 1991) (Senseman et al. 1994)
      Hyperspectral Imaging (HSI) (Satterwhite and Henley 1990)

2. ***Detailed Base-Scale Soil Maps***
   a. **Definition:** Analogous to Natural Resources Conservation System soil maps at scales ranging from 1:6000 or larger. Detects small landscape patterns that control soil development, such as microtopography (drainages, slopes, etc.).

   b. **Applicable Sensors:**
      Standard Aerial Photography
      Digital Aerial Orthophotography
      Digital Multispectral Video
      Hyperspectral Imaging (HSI)

3. ***Individual Erosion Sites***
   a. **Definition:** Identification of gully and rill erosion almost at the inception of such erosion.

   b. **Applicable Sensors:**
      SPOT PAN
      Standard Aerial Photography
      Digital Multispectral Video
      IFSAR Radar
      Hyperspectral Imaging (HSI)

4. ***Sedimentation in Receiving Water Bodies***
   a. **Definition:** Delineating coastal shorelines; determining water current direction as indicated by color differences (i.e., tributary entering larger water feature, chlorophyll or sediment patterns).

   b. **Applicable Sensors:**
      Landsat MSS
      Landsat TM (Lathrop 1992)
      SPOT XS (Lathrop and Lillesand 1989)
      SPOT PAN
      Standard Aerial Photography
      Digital Aerial Orthophotography
      Digital Multispectral Video

Hyperspectral Imaging (HSI) (Satterwhite and Henley 1990)

5. Soil Moisture

a. Definition: Detection of saturated or flooded soil.

b. Applicable Sensors:

Standard Aerial Photography
SPOT XS
SPOT PAN
IFSAR and RADARSAT Radar
Hyperspectral Imaging (HSI)

6. Flooding

a. Definition: Detection of overbank and overdune flooding in lake and river floodplain or coastal overwash areas.

b. Applicable Sensors:

SPOT XS
SPOT PAN
Landsat TM (Hough, 1994)
Standard Aerial Photography
IFSAR and RADARSAT Radar
Digital Aerial Orthophotography
Digital Multispectral Video
Hyperspectral Imaging (HSI)

Ecoregion: Great Basin/Rocky Mountains (Soils and Erosion Key)

1. ***Landscapes/Large Soil Units***
   a. **Definition:** Capability to identify major soil units or landscape elements indirectly using drainages, topography and vegetation; delineating land and rural areas; identification of objects at scales ranging from 1:100,000 to 1:8,000.
   b. **Applicable Sensors:**
      Landsat MSS
      Landsat TM (Frazier and Cheng 1989)
      SPOT PAN
      SPOT XS
      IFSAR Radar (Zebker et al. 1994)
      Hyperspectral Imaging (HSI) (Satterwhite and Henley 1990)
         (Indorante et al. 1996) (Xu et al. 1995)

2. ***Detailed Base-Scale Soil Maps***
   a. **Definition:** Analogous to Natural Resources Conservation System soil maps at scales ranging from 1:6000 or larger. Detects small landscape patterns that control soil development, such as microtopography (drainages, slopes, etc.).
   b. **Applicable Sensors:**
      Standard Aerial Photography
      Digital Aerial Orthophotography
      Digital Multispectral Video
      Hyperspectral Imaging (HSI)

3. ***Individual Erosion Sites***
   a. **Definition:** Identification of gully and rill erosion almost at the inception of such erosion.
   b. **Applicable Sensors:**
      SPOT PAN
      Standard Aerial Photography
      Digital Multispectral Video
      IFSAR Radar
      Hyperspectral Imaging (HSI)

4. Sedimentation in Receiving Water Bodies

a. Definition: Delineating coastal shorelines; determining water current direction as indicated by color differences (i.e., tributary entering larger water feature, chlorophyll or sediment patterns).

b. Applicable Sensors:

Landsat MSS
Landsat TM (Lathrop 1992)
SPOT XS
SPOT PAN
Standard Aerial Photography
Digital Aerial Orthophotography
Digital Multispectral Video
Hyperspectral Imaging (HSI) (Satterwhite and Henley 1990)

5. Soil Moisture

a. Definition: Detection of saturated or flooded soil.

b. Applicable Sensors:

Standard Aerial Photography
SPOT XS and PAN
IFSAR and RADARSAT Radar
Hyperspectral Imaging (HSI) (Carter and Miller 1994)

6. Flooding

a. Definition: Detection of overbank and overdune flooding in lake and river floodplain or coastal overwash areas.

b. Applicable Sensors:

SPOT XS
SPOT PAN
Standard Aerial Photography
IFSAR and RADARSAT Radar
Digital Aerial Orthophotography
Digital Multispectral Video
Hyperspectral Imaging (HSI)

Land Management / Disturbance Detection Key

Ecoregion: Southeast/Northeast (Land Management / Disturbance Detection Key)

1. ***To Examine Management Effects***
   - **a. Definition:** Detection of large-scale prescribed burns, wildfire, chemical or physical vegetation removal, conservation or forage mowing/seeding, habitat identification, habitat suitability, land use management, water quality.
   - **b. Applicable Sensors:**
     - Landsat TM (Hodgson et al. 1987, 1988)
     - SPOT XS
     - SPOT PAN
     - Digital Aerial Orthophotography
     - Standard Aerial Photography (Welch et al. 1988) (Breininger et al. 1991)
     - Hyperspectral Imaging (HSI) (Steinmaus et al. 1997) (Jia and Richards 1994)

2. ***To Examine Disturbance/Horticulture Effects***
   - **a. Definition:** Maneuver damage, bivouac effects, training effects, firing range fires, natural or seeded/planted revegetation progress, conservation plantings.
   - **b. Applicable Sensors:**
     - Landsat TM
     - SPOT XS
     - SPOT PAN
     - Standard Aerial Photography
     - Digital Aerial Orthophotography
     - Digital Multispectral Video
     - Hyperspectral Imaging (HSI)

Ecoregion: Southern Plains/Southwest/Pacific Southwest (Land Management / Disturbance Detection Key)

1. ***To Examine Management Effects***
   a. **Definition:** Detection of large-scale prescribed burns, wildfire, chemical or physical vegetation removal, conservation or forage mowing/seeding, habitat identification, habitat suitability, land use management.
   b. **Applicable Sensors:**
      Landsat TM
      SPOT XS
      SPOT PAN
      Digital Aerial Orthophotography
      Standard Aerial Photography (Chou et al. 1990)
      Hyperspectral Imaging (HSI) (Warner 1997)

2. ***To Examine Disturbance/Horticulture Effects***
   a. **Definition:** Maneuver damage, bivouac effects, training effects, firing range fires, natural or seeded/planted revegetation progress, conservation plantings.
   b. **Applicable Sensors:**
      Landsat MSS (Pilon et al. 1988)
      Landsat TM
      SPOT XS
      SPOT PAN
      Standard Aerial Photography
      Digital Aerial Orthophotography
      Digital Multispectral Video
      Hyperspectral Imaging (HSI)

Ecoregion: Pacific Northwest (Land Management / Disturbance Detection Key)

1. To Examine Management Effects

a. Definition: Detection of large-scale prescribed burns, wildfire, chemical or physical vegetation removal, conservation or forage mowing/seeding, habitat identification, habitat suitability, land use management.

b. Applicable Sensors:

Landsat TM
SPOT XS
SPOT PAN
Digital Aerial Orthophotography
Hyperspectral Imaging (HSI)

2. To Examine Disturbance/Horticulture Effects

a. Definition: Maneuver damage, bivouac effects, training effects, firing range fires, natural or seeded/planted revegetation progress, conservation plantings.

b. Applicable Sensors:

Landsat TM
SPOT XS
SPOT PAN
Standard Aerial Photography
Digital Aerial Orthophotography
Digital Multispectral Video
Hyperspectral Imaging (HSI)

Ecoregion: Northern Plains/North Central (Land Management / Disturbance Detection Key)

1. ***To Examine Management Effects***
   - **a. Definition:** Detection of large-scale prescribed burns, wildfire, chemical or physical vegetation removal, conservation or forage mowing/seeding, habitat identification, habitat suitability, land use management, water quality.
   - **b. Applicable Sensors:**

Landsat TM	(Ormsby and Lunetta 1987) (Roseberry et al.1994) (Lathrop 1992) (Jakubauskas et al. 1990) (Herr and Queen 1993)
SPOT XS	(Senseman et al. 1994)
SPOT PAN	
Digital Aerial Orthophotography	
Hyperspectral Imaging (HSI)	

2. ***To Examine Disturbance/Horticulture Effects***
   - **a. Definition:** Maneuver damage, bivouac effects, training effects, firing range fires, natural or seeded/planted revegetation progress, conservation plantings.
   - **b. Applicable Sensors:**

     Landsat TM
     SPOT XS
     SPOT PAN
     Standard Aerial Photography
     Digital Aerial Orthophotography
     Digital Multispectral Video
     Hyperspectral Imaging (HSI)

Ecoregion: Great Basin/Rocky Mountains (Land Management / Disturbance Detection Key)

1. ***To Examine Management Effects***
   - **a. Definition:** Detection of large-scale prescribed burns, wildfire, chemical or physical vegetation removal, conservation or forage mowing/seeding, habitat identification, habitat suitability, land use management, water quality.
   - **b. Applicable Sensors:**
     - Landsat TM (Lathrop 1992) (Lathrop et al. 1994)
     - SPOT XS (Verbyla et al. 1993)
     - SPOT PAN
     - Digital Aerial Orthophotography
     - Hyperspectral Imaging (HSI)

2. ***To Examine Disturbance/Horticulture Effects***
   - **a. Definition:** Maneuver damage, bivouac effects, training effects, firing range fires, natural or seeded/planted revegetation progress, conservation plantings.
   - **b. Applicable Sensors:**
     - Landsat TM
     - SPOT XS
     - SPOT PAN
     - Standard Aerial Photography
     - Digital Aerial Orthophotography
     - Digital Multispectral Video
     - Hyperspectral Imaging (HSI) Basic Cartographic Information

Procurement

Important First Steps in Acquisition

Sources of remote imagery may be closer and cheaper than you think. After determining that you need imagery, check some of the following sources before buying it from a vendor.

Your Installation

Someone may have already purchased imagery at your installation. Talk to your installation's facilities or master planning staffs, or with local or federal agencies that have field offices on the installation.

Check your own file drawers, closets, in and under desks – sometimes you don't know what you have until you look! Make an inventory list of images you find.

Local Organizations

An organization near your installation may have already purchased imagery. Look in the phone book or talk to people who have worked in the area for a long time. Find out what organizations operate near your installation – they can be allies when you need imagery and various other types of assistance.

Aerial photos from federal agencies are archived at the U.S. Geological Survey's EROS Data Center. Participating agencies include the U.S. Army, U.S. Air Force, U.S. Navy, Bureau of Indian Affairs, Bureau of Land Management, Bureau of Reclamation, Environmental Protection Agency, National Park Service and National Aeronautics and Space Administration. Coverage, dates, scales and available products vary by agency. For more information, contact the EROS Data Center at (605) 594-6151 or visit its web site at http://edcwww.cr.usgs.gov/glis/hyper/guide/govtphotos#gp1.

Potential Partners

Remote images can cover large areas and may be useful to others, so ask installation tenants and organizations or off-post groups if they want to share the costs of acquiring imagery. The costs of an aerial photo mission can drop significantly if the vendor can accomplish missions for two or more organizations in one flight.

Imagery Acquisition Assistance

Once you determine that you need to procure imagery, check the following sources for assistance.

Conservation Assistance Program

The Army's Conservation Assistance Program (CAP) provides rapid-response, short-duration support to installation natural and cultural resource managers. Expertise from U.S. Army Corps of Engineers laboratories and other federal agencies is available to installations through this program. The U.S. Army Environmental Center (USAEC) provides funding for this assistance; amounts vary by project and are subject to availability. Requests must be within CAP guidelines.

For more information on the Conservation Assistance Program, contact Steve Getlein of USAEC at (410) 436-1592 (DSN 584-1592), sgetlein@aec.apgea.army.mil; or call the Army Environmental Response Line at (800) USA-3845 (DSN 584-1699).

Nearby Installations and Agencies

Nearby installations or other federal agencies may be able to help with regional remote-sensing problems and provide references to land managers who may have dealt with similar issues.

Army Civil Imagery Acquisition Program

The U.S. Army Civil Imagery Acquisition Program, a data acquisition service operated by the U.S. Army Topographic Engineering Center (TEC), serves as a repository of selected civil imagery pertaining to terrain analysis, water resources analysis and operations. Most importantly for natural resource and installation managers, the program monitors Army purchases of civil imagery and any scenes available to the Department of Defense (DoD) considered crucial to Army missions. This program can help installations find, select and obtain useful imagery at the lowest costs.

For more information on the U.S. Army Civil Imagery Acquisition Program, contact Mary Pat Santoro at (703) 428-6909 (DSN 328-6909) or msantoro@tec.army.mil; Karen Moore at (703) 428-6263 (DSN 328-6263) or Kmoore@tec.army.mil; or Alana Hubbard at (703) 428-6717 (DSN 328-6717) or Ahubbard@tec.army.mil.

Technical Centers of Expertise

Help with estimating costs, acquiring images and post processing is available through the Technical Center of Expertise (TCX) for Photogrammetric Mapping in the U.S. Army Corps of Engineers St. Louis District. The district's Geospatial Engineering Branch can plan for, estimate costs of and acquire aerial photography, remote sensing, photogrammetric map compilation, electronic photogrammetry and related spatial and digital mapping products used in Geographic Information System (GIS), Computer-Aided Drafting and Design (CADD), Land Information System (LIS) and AM/FM databases.

The center provides services to the Army Corps of Engineers and other government agencies on a reimbursable basis.

> *For more information on the TCX for Photogrammetric Mapping, contact Dennis Morgan at (314) 331-8373 or Dennis.D.Morgan@MVS02.usace.army.mil; Danny McMurphy at (314) 331-8389 or Danny.J.McMurphy@MVS02.usace.army.mil; or visit the center's Web page at http://lms61.mvs.usace.army.mil/tcx.html.*

National Imagery and Mapping Agency

The National Imagery and Mapping Agency's (NIMA) Central Imagery Tasking Office (CITO) Commercial Imagery Program (CIP) is the DoD action agency for purchasing commercial and foreign-government-owned imagery-related remote sensing data by Defense components.

The CIP:
- Places customers' orders for commercial imagery.
- Fills orders for commercial imagery from existing vendor archives or by tasking new collections.
- Provides assistance in selecting the appropriate commercial source to satisfy a collection requirement.
- Coordinates with NIMA's comptroller, procurement and contracting functions to ensure use of appropriate contract vehicles and availability of funding.
- Provides financial tracking for commercial imagery billings.
- Owns a variety of user-distribution licenses to share commercial imagery with DoD, the intelligence community and other appropriate organizations.

DoD customers can order through CIP if the images they seek are not available from the EROS Data Center or Commercial Satellite Imagery Library (see item No. 6), or they do not wish to register with a vendor for new or existing imagery. Customers must establish an account by providing funding authority through a Military Interdepartmental Purchase Request (MIPR). Customers can forward the MIPR to NIMA quarterly or annually in an amount equal to the estimated purchases for that period.

For more information, contact the Central Imagery Tasking Office at (301) 227-3520, fax (301) 227-3473, or visit the NIMA Web site at http://www.nima.mil. Customers can send MIPRs to: Terry Booze, NIMA CITO/TODC, Commercial Imagery Program, 4600 Sangamore Road, Mail Stop D-58, Bethesda, MD 20816-5003.

The Commercial Satellite Imagery Library

The Defense Intelligence Agency maintains the Commercial Satellite Imagery Library (CSIL) as the executive agent for NIMA. The CSIL is the focal point for the storage and retrieval of commercial imagery, serving all DoD and intelligence community users.

The CSIL holds all images purchased by DoD/Title 50 organizations, which may obtain imagery from the CSIL free of charge. All images in the CSIL have the DoD/title 50 license. The CSIL offers metadata, reduced-resolution "browse" images, standard NIMA library data management tools and software, and image storage. Most of the imagery is stored on compact disc, but a limited amount of film and images are available on other media.

For assistance with imagery acquisition requests, contact the NIMA/CIP Customer Support Team at (301) 227-3520 or by fax at (301) 227-3473.

Imagery on the World Wide Web

1. **EROS Data Center**
   EROS Data Center's *WebGlis* (http://edcwww.cr.usgs.gov/webglis) includes aerial photography, satellite imagery and other types of spatial data. Users can search the images using an interactive map or by entering site information. Many of the scenes are available as browse images and contain detailed information.
2. **SpaceImaging, Inc**
   SpaceImaging's Carterra site (http://www.spaceimaging.com/) also allows users to search for images on an interactive map or by entering place names and other site information. Many of the scenes are available as browse images and contain basic information. Landsat, IRS multispectral and panchromatic images are available for browsing. The most recently acquired scenes may be seen here first.

3. **SPOT Image Corp.**
   SPOT Image's *SIRIUS* catalog (http://www.spot.com/spot/spot-us.htm) will be available during the summer of 1999. Its predecessor, *DALI*, allows users to log in as "guests" for access limited to the five most recent SPOT images (with 10% or less cloud cover) for an area of interest. The archive boasts 2.2 million "Quick Looks" (thumbnail-size browse images) and metadata for 6 million SPOT images.

Remotely Sensed Imagery Costs

Imagery Contacts

Satellite images in the TEC archive are also in the CSIL; however, CSIL has a more extensive collection (with the exception of IFSARE radar images). TEC staff can obtain unclassified imagery through CSIL, which they browse through the Joint Worldwide Intelligence Communications System (JWICS) network. DOD entities with JWICS network access can also browse the CSIL.

Newer Landsat Products

DOD entities can purchase Landsat MSS and TM imagery through TEC at prices set under a NIMA contract.

Full Landsat TM Scene: 185 x 170 kilometers (115 x 106 miles)	
System corrected (not geometrically corrected)	$2,500
Precision corrected (geometrically corrected)	3,600
Terrain corrected (radiometrically and geometrically corrected)	4,050

Prices may vary but will not exceed those in the table above. There is a base charge of $425 per scene. In addition, there is a processing charge based on the number of scenes on a high-density tape (HDT) sent from SpaceImaging (EOSAT). The tape could contain from one to 30 images, though the usual range is 20 to 28 images. The actual price depends on the number of images searched before reaching the one requested.

If the EROS Data Center already has a processed scene in its archives, the cost is $425. The metadata fields in the *WebGlis* archives specify availability of digital cassette tape (DCT). If this field is marked “yes,” then the scene price is $425. These prices are limited to U.S. government customers and images should be ordered through TEC’s Civil Imagery Acquisition Program.

Availability of Smaller Scenes

Quarter scenes (100 x 100 kilometers) may be available but cost the same or more than full scenes. Prices depend on the amount of processing required.

Older Landsat Scenes

The EROS Data Center distributes Landsat MSS and TM imagery. Prices for full Landsat MSS scenes range from $200 to $675; TM images cost from $425 to $900. The difference in prices reflects additional corrections, or enhancements, to the system-corrected satellite data. These prices are limited to U.S. government customers and images should be ordered through TEC's Civil Imagery Acquisition Program.

SPOT Imagery

SPOT platform prices are based on the level of preprocessing desired. A full scene of panchromatic imagery ranges from $1,950 to $3,450. The SPOT-3 multispectral imagery ranges from $1,550 to $3,050, and SPOT-4 short-wave infrared (SWIR) band images are available for an additional $1,950 to $3,450.

The decision to purchase Landsat or SPOT imagery involves tradeoffs between the higher resolution of SPOT-3 multispectral images (20-meter pixels versus Landsat TM5's 28.5-(30 nominal) meter pixels) and Landsat's spectral bands (seven versus SPOT-3's three).

Newer Satellites

While pricing information for the next generation of satellites is not yet available, technologies such as SpaceImaging's IKONOS and EarthWatch's QuickBird will offer high spatial resolutions of 1 meter (panchromatic) and 4 meters (multispectral), plus a greater number of spectral bands than current satellites.

Aerial Photos

Many factors – time of year, distance from fixed base of operations, weather conditions, specifications (such as film type) and fluctuations in business costs – can affect the final costs of contract aerial photographic surveys. Generally, as the photographic scale is doubled, approximately four times as many frames are needed to cover the tract area. Further, as tract size increases, the number of frames required for coverage increases and unit costs increase proportionally (Avery and Berlin, 1985).

The TCX for Photogrammetric Mapping can help government agencies estimate costs, plan missions and acquire aerial photos on a reimbursable basis.

Aerial Photography: A Case Study

In 1996, the Topographic Engineering Center conducted a research project at Fort A.P. Hill, Virginia, purchasing a complete aerial survey with true color photographs covering approximately 75,000 acres of training land. The deliverable included:

- A complete set of 9 x 9 inch, true color paper prints.
- Documentation of the photo mission, including a detailed photo index.
- A radiometrically balanced, digital, orthorectified photo mosaic transfer on CD-ROM.

The total cost for complete image acquisition and digital conversion to GeoTIFF format was approximately $2.75 per acre.

Planning an Aerial Survey

Preliminary Estimates

Although good aerial mapping firms use software to develop flight plans, installation personnel should draw a preliminary plan before issuance of an aerial photo survey contract. Installations can accomplish this using topographic quadrangle base maps ranging in scale from 1:24,000 to 1:250,000, and by using the parameters in the following section (after Avery and Berlin, 1985).

Parameters and Typical Values for Large-Scale Mapping

Area of Survey Dimensions
Typical surveys are flown in a due east-west or due north-south direction. Estimate dimensions using a rectangular box large enough to cover the entire area of interest.

Desired scale of Photographic Negative
1:25,000, or 250 meters/centimeter

Scale of Base Map
1:50,000, or 500 meters/centimeter

Average Ground Elevation Above Mean Sea Level
500 meters

Average Forward Overlap
60 %

> *Note: Stereoscopic viewing of aerial photos is only possible with overlapping photographs.*

Average Sidelap
30 %

Photographic Format
23 x 23 centimeters (9 x 9 inches), or 5,750 x 5,750 meters on the ground

Camera Focal Length
153 millimeters (0.153 meters) or 6 inches, common for large- and medium-scale photography

a. Calculating the Flight Plan

The following example of a flight plan includes several typically calculated items:

1. Example Area of Interest

20 kilometers (east-west) x 30 kilometers (north-south), or 600 square kilometers

2. Estimated Flight Altitude (based on the desired photographic scale)

H = [(RFd)(f)] + (elevation)
H = [25,000 x 0.153] + (500) = 4,325 meters

Where:

- H = flying height of the aircraft above the terrain
- RFd = denominator of representative fraction of the desired scale
- f = focal length of the camera (in meters)
- elevation = average elevation of area of interest (in meters)

3. Direction of Flight Lines

North-south or east-west, following long dimension of tract to minimize aircraft turns

4. Number of Flight Lines and Ground Distance Between Them

DBFL = (GW)(OG)
4,025 meters = (5,750)(0.70)

NI = (GTW) / (DBFL)
= (20,000) / (4,025)

ABFL = (GTW) / (NI)
4,000 meters = (20,000) / (5)

Where:

- DBFL = distance between flight lines
- GW = actual ground width of the photographic negative
- OG = overlap gain by each frame = (100% - average % sidelap)
- NI = number of intervals between flight lines rounded to nearest whole number plus 1 equals the number of flight lines
- GTW = ground tract width of entire area of interest
- ABFL = actual (adjusted) ground distance between flight lines

5. Actual (Adjusted) Percentage of Sidelap
ASL = [(NW- ABFL) / (ABFL)](100)
30.4 = [(5,750 – 4,000) / 5,750)] (100)

Where:

- ASL = actual (adjusted) percentage of sidelap
- NW = width of the photographic negative
- ABFL = actual (adjusted) ground distance between flight lines

6. Ground Distance Between Frames on Each Line
GDBF = (NW)(FOG)
2,300 meters = (5,750)(0.40)

Where:

- GDBF = ground distance between frames
- NW = width of the photographic negative
- FOG = forward overlap gain by each frame (100% - average % forward overlap)

7. Map Distance Between Flight Lines
(Map Scale is 1:50,000 or 500 meters/centimeter)
1 centimeter/500 meters = X centimeters/4,000 meters;
X = 8 centimeters between flight lines on the map

8. Map Distance Between Exposures on Each Line:
1 centimeter/500 meters = X centimeters/2,300 meters;
X = 4.6 centimeters between photographic negative centers on the map

9. Number of Exposures on Each Flight Line
Find the number of intervals between exposures by dividing tract length (30 kilometers, or 30,000 meters) by 2,300 = 13.04 intervals

NI = (TL) / (GDBF)
13.04 = (30,000 meters) / (2,300)

Where:

- NI = number of intervals between flight lines rounded to nearest whole number plus 1 equals the number of flight lines
- TL = entire tract length
- GDBF = ground distance between frames

Assuming the first exposure is centered on the area of interest boundary, 14 exposures will be required. Normally, to ensure coverage, two additional exposures are made at the end of each flight line, bringing the total frames per flight line to 18.

10. Total Number of Exposures required to Cover Entire Area of Interest
Six flight lines of 18 exposures per line = 108 exposures

Developing a rough estimate of the total number of photos to acquire can help installations evaluate the overall scope and objectives of a proposed project and determine if aerial imagery can be a cost-effective source of information.

Scanning Aerial Photographs

The new standard for aerial mapping products includes a complete package of photography, ground control, and finished planimetric or topographic maps, usually including computer-ready digital photos. Many installations may have old photographic prints or film positives archived and it may be desirable to scan them to a digital form. Low cost flatbed scanners designed for desktop publishing applications are NOT recommended for scanning large scale aerial photographs for mapping purposes, as they may introduce undesired geometric distortions. Top quality scanners designed specifically for digital photogrammetry such as those manufactured by Carl Zeiss, Inc., Helvava Associates, Inc., at costs exceeding $40,000, are beyond the reach of installations. Commercial companies such as Image Scans Inc., Denver, Colorado and Precision Photo Laboratories, Dayton, Ohio, can provide scanning services for a nominal cost and present the data on CD-ROM in common image formats.

The following information may be useful for determining the scan rate and spatial resolution.

Two factors affect what features can be detected in the digital image of the aerial photograph:

- The scale of the photograph (based on aircraft altitude and focal length of the camera when taking the aerial photograph).
- The dots-per-inch (DPI) used to scan the aerial photo.

The final pixel size is the size on the ground (in meters) of one pixel on the digital aerial photograph, and corresponds approximately to the size of the smallest feature that can be detected. Generally, at least two to four pixels are required to represent a feature in an image. It is usually unnecessary to attempt to retain all the resolution in the original photographs and instead choose a scanning resolution set to the coarsest pixel size necessary to identify the smallest features of interest. A pixel size of 1 meter is adequate for many applications. Keep in mind that smaller scale (high altitude) photos will require a higher scanning rate to enable identification of features.

Determining the Scan Rate

The following table provides an example of relationship between DPI, Scan Rate and Ground resolution. In this example, the overflight scale is 1:16,000 and the photographic negative format is 23 x 23 centimeters (9 x 9 inches); using the value for the nominal, average scale, 1 micron on the photo is equal to 16,000 microns on the ground (16,000 *μ* = 0.016 meters).

DPI* (nominal)	Scan Rate μ PHOTO	Pixel Size (meters per pixel*) GROUND
3,000	8.5	0.136
2,500	10	0.16
2,000	12.5	0.20
1,800	15	0.25
1,400	20	0.32
1,000	25	0.40
800	30	0.48
500	40	0.64
400	100	1.60

Pixel commonly refers to screen resolutions; DPI is typically associated with scanning and printing.

Statements of Work

Statements of Work for remote sensing products define the bounds of the study area, the platforms, required degree of accuracy, scale of imagery and resulting products, and processing that adds value (and costs) to the basic imagery. Properly written SOWs can eliminate misunderstanding and allow for periodic checks throughout the project. They are also useful for reviewing a completed project or for resolving conflicts between the customer and contractor.

The following SOW examples include tasks common to most aerial photography and or satellite imagery acquisition efforts.

Example Statement of Work # 1

U.S. Army Construction Engineering Laboratories (USACERL)
STATEMENT OF WORK
Image Scans Inc. Scanning Services

1. INTRODUCTION: The Land Condition Trend Analysis (LCTA) program is a natural resource assessment tool on U.S. Army training lands and has been under development for several years. LCTA data is collected from permanently marked vegetation/wildlife plots at each installation. Measurements are taken from these plots annually. Aerial Photography is an important component of LCTA research and development. Current research projects involving vegetation mapping at Fort Bliss require extensive interpretation and analysis of aerial photography. In order to utilize an image processing software environment in which imagery and ecological field data can be integrated and analyzed to accurately map and monitor changes in vegetation cover and other natural resources, current existing color positive photographs need to be scanned. Because spectral demixing requires accurate radiometric scanning in the green, red, and near infrared wavelengths and USACERL does not own a scanner of this quality, scanning services need to be contracted.

2. OBJECTIVES: The objective of this purchase order is to purchase scanning services for 109 color positive aerial photographs, format digital photos to a .img format, and provide data on CD-ROMs.

3. MAJOR REQUIREMENTS: Scan color positive aerial photos and provide data in an .img format on CD-ROMs.

4. TASK DEFINITION: In order to accomplish the work under this purchase order, the contractor shall complete the following tasks:

> *TASK 1: Scanning.* The contractor shall scan 109 color infrared positive aerial photographs at 25 µ. Photos will be provided to contractor on rolls.
>
> *TASK 2: Formatting.* The contractor shall provide digital scans in an .img format.

TASK 3: Provide Media. The contractor shall supply digital scans on CD-ROMs.

5. GOVERNMENT FURNISHED INFORMATION/ EQUIPMENT: The government will provide rolls of positive color infrared aerial photography and instructions on which photos to scan.

6. POC: The U.S. Army Construction Engineering Research Laboratories technical POC is name, phone number. No government personnel, other than the contracting officer, shall have the authority to do other than clarify technical points, or supply relevant information. Specifically, no requirement in these specifications may be altered as a sole result of such verbal clarification.

7. MEETINGS AND REVIEWS: None required.

8. REPORTS AND DELIVERABLES: Summary.

TASK 1. CD-ROMs containing all 109 digital scans at 25μ in .img format shall be delivered within two weeks after award.

9. TRAVEL REQUIREMENTS: None

10. SPECIAL CONSIDERATIONS:

11. PERIOD OF SERVICE: All work under this delivery order shall be completed within two weeks after award.

12. LEVEL OF EFFORT:

13. VENDOR:

Some Scanning, Inc.

Example Statement of Work # 2

STATEMENT OF WORK

DELIVERY ORDER NUMBER
CONTRACT NO. DACW43-98-D-0512
U.S. ARMY, FORT BRAGG, NORTH CAROLINA
COLOR DIGITAL ORTHOPHOTOGRAPHY & LIDAR DTM DATA
U.S. ARMY CORPS OF ENGINEERS

GENERAL

Color digital orthophotography, Light Detection and Ranging (LIDAR) digital terrain model (DTM) data and 2-m contours shall be produced of portions of Fort Bragg, NC. The areas to be photographed for production of color ORTHOPHOTOGRAPHY will be within the cantonment area approximately 14,000 acres. DTM data will be produced from LIDAR ground elevation data. The DTM data will be obtained for production of the digital orthophotos and will be suitable for generation of 5-ft and 2-m contours. The LIDAR DTM data for 2-m contours will be collected over Fort Bragg proper (approximately 152,860 acres) including the cantonment. The final mapping products requested are a digital terrain model (DTM) at a horizontal scale of 1:5000 and 2-m contours of the area covered by the DTM. Additional products for the cantonment area only are color digital orthophotos at a horizontal scale of 1 in = 400 ft, a DTM generated from the same LIDAR data referred to above, and 5-ft contours of the cantonment area generated from the DTM. The digital orthophotos will have a ground pixel resolution of 2 ft. Airborne Global Positioning System (GPS) control will be used in conjunction with minimal ground survey control to perform aerotriangulation (AT), develop digital terrain models (DTM) and digital orthophoto production. All photography will be flown at approximately 12,000 ft Above Mean Terrain (AMT) at a photonegative scale of 1:24000. **The orthophoto maps will fully comply with ASPRS Class I Standards for mapping at a horizontal scale of 1 in = 400 ft with a ground sample distance of 2 ft. The LIDAR DTM data will be obtained with ground post spacing sufficient to produce a DTM at 1:5000 that will support 5-ft and 2-m contours at ASPRS Class I Standards.**

GOVERNMENT SUPPLIED INFORMATION

a. Map showing project area.
b. Available existing ground control within and around the project site.
c. Existing photo image layout to match newly created DTM files.

DETAILED STATEMENT OF WORK

Contractor shall provide equipment, supplies, facilities, and personnel to accomplish the following work:
The Contractor will establish aerial photo, and LIDAR missions and a ground survey control network including airborne GPS that will support the aerial photo and LIDAR data capture. The Contractor will fly and photograph (in natural color) the **cantonment area** at an altitude of approximately 12,000 ft AMT with a negative scale of 1 inch = 2,000 ft. The contractor will produce a line index of the aerial flight. The line index will be in hard copy and digital format. The digital format for the line index will be Intergraph format. **The aerial photography will be captured during leaf off conditions in the spring (February 15 - April 1, 1999). The LIDAR data capture will be accomplished from September 1998 through February 1999.** The LIDAR data capture altitude will be set to produce a ground post spacing that will support 5-ft.V-15 and 2-m contour generation. The natural color aerial photography and LIDAR data capture will be accomplished with airborne GPS utilizing dual frequency/multi channel receivers. The aerial photography will be flown with 80% forward lap and approximately 40% side lap. GPS data collection and processing will include latitude, longitude and ellipsoid height for each photo center. All airborne CPS planning including survey network layout, benchmarks to be used, etc. shall be approved by CEMVS-ED-S prior to initiation of project. The plan submitted shall include but not be limited to maps indicating proposed GPS network, benchmarks to be used, flight lines, and project area.

b. Additional ground survey data will be collected for use in the mapping process. The plan for additional ground survey control required for mapping and procedures to accomplish the ground survey control will be submitted to CEMVS-ED-SG for approval prior to initiation of the project. **All survey data shall be in the Universal Transverse (UTM) System, Zone 17. Horizontal control shall be in NAD83.**
Vertical datum will be NGVD88. All surveys shall be accomplished in accordance with the technical section of Contract DACW43-98-D-0512.

c. Two sets of natural color contact prints will be made in accordance with the technical section of Contract DACW43-98-D-0512. One set of the prints will be used as control photos for mapping. The control prints will have all ground control marked on the back and front of each photo. All photography will include, in the border areas, the GPS latitude/longitude, the negative scale (as a ratio), the dates of photography, flight line and frame numbers and the title “Fort Bragg, NC.”

d. The Contractor will produce aerotriangulation quality diapositives and orthophoto quality diapositives for the project.

e. Utilizing GPS survey data along with conventional ground control (panel data and photo identifiable data), the Contractor will perform analytical aerotriangulation to generate sufficient photo control points to accomplish ASPRS Class I Mapping at a horizontal scale of 1:5000 with a DTM suitable for generation of 5- ft and 2-m contours.

f. The Contractor will process the LIDAR data to produce digital terrain model (DTM) data for topographic mapping at a horizontal scale 1:5000 with 2-m contours. The DTM shall also fully support orthophoto production at a horizontal scale of 1 in = 400 ft. The DTM files shall be cut to match the client's existing orthophoto map sheets and shall have the dimensions 4,000 x 5,000 m. DTM data will be delivered in digital ArcInfo format (.eOO) on CD-ROM. **All newly created topographic data shall be in UTM Zone 17 and shall be referenced to NAD83 and NGVD88.**

g. The Contractor shall check and approve processed film. Images required for orthophoto production will be scanned for 2-ft pixel resolution utilizing a Zeis SCAI scanner or equivalent.

Digital imagery will be set up and oriented on an Autometric Softplotter System or equivalent and spatial resection and coordinate transformation will be performed. As a quality control check the following will be performed prior to ortho rectification:

> The RMSE of the fiducial will be calculated and examined for accuracy.
>
> RMSE for each control point used in the resection will be reported. Any unacceptable RMSE will be discarded..
>
> The newly re-sectioned image will be visually checked for pixel drop out and/or other artifacts that may degrade the final orthophoto image.
>
> DTM data will be in ArcInfo (.eOO) format and will be checked to verify that each point has a feature code. The coordinate/projection system will also be verified at this stage in the process.
> Scaled and hillshade DTM images will be inspected for missing or poor data.
>
> Rectification of all required imagery will be performed and checked. All control panels or photo identifiable points visible will be visited on the screen and the X and Y of the location will be displayed.
> This information will be checked against the ground survey data. Visual checks of the image quality will be performed. Radiometric variation will be checked with image histogram analysis including linear contrast stretch, user selected contrast stretch, histogram normalization and histogram clipping.

h. Produce digital orthophotos of the site at 1 in = 400 ft with a pixel resolution of 2 ft. Digital orthophoto data will be produced as raster files in TIFF format. The orthophotos will cover the cantonment and will have dimensions of 10,000 x 10,000 ft. **The orthophoto files will be referenced to North Carolina State Plane Coordinate System (SPCS) and NAD83. The spatial units of measurement shall be feet.**

i. The contractor will utilize the DTM data set and produce 2-m contour files over the entire 153,860 acres at Fort Bragg. The contractor will ensure that the DTM points are of sufficient density to adequately generate 2-m contours that will meet or exceed ASPRS Class I Standards for 2-m contours. The contours will be generated with topology. Contours will not be broken and will be based on the NGVD88 vertical datum. The contours will be delivered as a continuous coverage in ArcInfo (.eOO) format on CD-ROM.

j. The Contractor will produce an additional set of DTM files for the cantonment area covered by the orthophotos. The DTM will be referenced to the same datum and map projection as the orthophotos described above. The DTM files will be provided in Intergraph compatible format, cut to the same 10,000 x 10,000 ft sheets. In addition, contours will be generated at 5-ft intervals.

k. The Contractor will produce a digital mosaic of the cantonment area from the orthophoto data. The mosaic file will be compressed using the MrSid compression algorithm. The mosaic file will be written to CD-ROM. The contractor will produce five hard copy plots of the digital mosaic on E-size glossy bond suitable for framing.

DELIVERY ITEMS

a. Copy of computer printout of aerotriangulation solution. Aerotriangulation report as defined in 3 c.

b. Copy of camera calibration reports.

c. One copy of the DTM data files in UTM, **Zone 17 Coordinate System and referenced to NAD83 and NGVD88.** All digital files will be in Arc/INFO compatible format on CD-ROMs.

d. One digital copy of the 2-m contour file in UTM, **Zone 17 Coordinate System and referenced to NAD83 and NGVD88.** in ArcInfo (.eOO) format on CD-ROM.

e. One copy of the DTM files **for the cantonment area only** referenced to NAD83 State Plane Coordinate feet and the NGVD88 vertical datum. The DTM file will be delivered in Intergraph compatible format, cut into sheets of 10,000 x 10,000 ft dimensions.

f. One set of 5-ft contour files **for the cantonment area only** referenced to NAD83 State Plane Coordinate feet and the NGVD88 vertical datum. The contours will be delivered in Intergraph-compatible format, cut into sheets of 10,000 x 10,000 ft dimensions.

g. One copy of digital orthophoto files at a horizontal scale of 1 in = 400 ft. The orthophotos will have a 2-ft ground pixel resolution. **The orthophoto files will be referenced to North Carolina State Plane Coordinate System (SPCS) and NAD83.** The digital orthophoto files will be delivered in two formats: one set as Intergraph geo-referenced .COT files and the second set as Arc/Info compatible .TIF/.TFW. All digital files will be on CD-ROM.

h. All survey data (including ground surveys and airborne GPS surveys), raw GPS files (airborne and ground), and any other survey information developed and or collected for the project.

i. Two sets of prints, and two sets of diapositives (one A/T set and one Ortho set).

j. Flight line index for the project on paper and digital format (Intergraph), indicating the flight lines and beginning and ending frames for each flight line along with altitude and negative scale of the photography.

k. One copy of the compressed (MrSid compression) digital orthophoto mosaic and five copies (paper) of the hardcopy mosaics of the cantonment area.

1. Return all manuscript copies, horizontal and vertical control information, aerial photographs, pugged diapositives, and aerial film to the government when the project is completed.

SCHEDULE AND SUBMITTAL

a. The contractor will deliver all final products including CD-ROM digital data files by August 30, 1999.

b. All material to be furnished by the contractor shall be delivered at the Contractor's expense to:

TIME EXTENSIONS

In the event, these schedules are exceeded due to causes beyond the control and without fault or negligence of the Contractor, this delivery order will be modified in writing and the delivery order completion date will be extended one calendar day for each calendar day of delay.

Example Statement of Work # 3

STATEMENT OF WORK

DELIVERY ORDER NO 17
CONTRACT NO. I-ACW43-96-D-0525
MACDILL AIR FORCE BASE
AERIAL PHOTOGRAPHY AND MAPPING
U.S. ARMY CORPS OF ENGINEERS

DESCRIPTION OF WORK:

The mapping of MacDill Air Force Base and surrounding areas near Tampa, Florida, as indicated on maps previously furnished, has been requested by the United States Air Force. The project consists of flying and producing color infrared aerial photos (1" = 2400' negative scale) and digital orthophotos at 1" = 400' horizontal scale of the main base and accident potential zones (approximately 7930 acre area). Natural color aerial photography (1" = 300' negative scale) of approximately 5,750 acres of the base including the 2360-acre cantonment area as defined on maps previously provided will be acquired. Required ground control will be established for both flights. The ground control for the color infrared photography will support 1" = 400' horizontal scale digital orthophotos. The ground control for the color photography will support 1" = 50' horizontal scale with 1' contours. From the color infrared 1" = 2400' negative scale photography, orthophotos will be produced at 1" = 400' horizontal map scale **(No topo or planimetric data will be collected).** Color 1" = 300' negative scale aerial photography of the entire 2,360 acre cantonment area as defined on maps previously furnished along with required ground control will be used to generate 1" = 50' horizontal color orthophotos with 1' contours and full planimetric detail. In addition aerotriangulation procedures will be performed on the entire 1" = 300' negative scale color photography for future mapping. **Aerotriangulation (AT) will be performed on all photography required for mapping (1" = 2400' and 1" = 300' negative scales).** Digital elevation models (DEM) will be generated utilizing mass points and break lines for the development of orthophotos, planimetric and topographic mapping as described above.

Final mapping products will fully comply with ASPRS Class I Standards for production of orthophotos and digital mapping at the scales, contour intervals, and resolutions listed above.

In addition, several existing digital map layers representing installation managed and maintained on and off base facilities will be added to the final digital mapping data.

2. Information supplied by the Government:

a. Map showing project areas and approximate location of the check profile.

b. Existing MacDill Air Force Base (AFB) installation managed and maintained facilities map data in Intergraph Format on 3.5" diskettes

WORK TO BE PERFORMED BY THE CONTRACTOR:

Contractor shall provide equipment, supplies, facilities, and personnel to accomplish the following work:

a. Contractor will establish a ground survey control network and obtain natural color aerial photography of the 5,750acre main base area at a negative scale suitable for producing digital mapping and orthophotography of planimetric and topographic data at a map scale of 1" = 50' with 1' contour intervals, contractor will also establish a ground survey control network and obtain color infrared photographs of the 7,930 acre area that includes MacDill AFB and the two accident potential zones at a negative scale 1" = 2400' suitable for producing digital orthophoto mapping at a horizontal scale of 1" = 400'. The plan for ground survey control required for mapping and procedures to accomplish the ground survey control will be submitted to CELMS-ED-HG for approval before initiation of the project. All original notes for these surveys shall be submitted and the contractor shall make no copies. **All survey data shall be in the Universal Transverse Mercator (UTM) System, and shall be referenced to** NAD 83. All surveys shall be accomplished in accordance with the technical section of Contract DACW43-96-D-0525.

b. Additional ground survey data will be collected to check the final mapping. **One check profile will be obtained within the 1" = 50' horizontal cantonment mapping area. The check profile will be approximately 1000' in length with an elevation established every 100'. The approximate location of the check profile is shown on previously furnished maps. The check profile data will be checked by the contractor in the field and mailed directly. No copies are to be made and no information regarding the profile is to be given to the mapping staff.**

c. Two sets of natural color prints will be made in accordance with the technical section of Contract DACW43-96-D-0526. One set of the prints will be used as control photos for orthophoto and map production. The control prints will have all ground control marked on the back and front of each photo. All photography will include in the border areas the GPS latitude/longitude, the negative scale (as a ratio), the dates of photography, flight line and frame numbers and the title "MacDill AFB.”

d. Utilizing ground control (panel data and photo identifiable data) perform analytical aerotriangulation to generate sufficient photo control points to accomplish ASPRS Class I Mapping for all orthophotography and mapping at the horizontal scales listed above.

e. Natural color diapositives will be prepared for aerotriangulation procedures and mapping. Digital orthophoto mapping areas will require two sets of diapositive. One set will be for aerotriangulation and one set for orthophoto scanning and production. Simultaneously along with the aerotriangulation analytical diapositives, orthophoto diapositives will be prepared and control transferred to them for digital orthophoto rectification and aerotriangulation.

Prior to transfer, diapositives will be checked for scratches, blemishes, or other abnormal markings. Unacceptable diapositives will be attached to a quality check form indicating the location and type of abnormality and will be returned to the photographic laboratory.

f. Utilizing the color infrared 1" = 2400' negative scale photography develop digital elevation models, scan all required photography required for orthophoto mapping. The 1" = 2400' negative scale area shall be scanned at a pixel resolution that will provide orthophotos with a 2 ft ground pixel resolution.

The contractor will develop Digital Elevation Models (DEM's) for digital ortho-rectification. The following procedure will be used:

DEM data will be captured using analytical stereo data capture systems by means of single point elevations (X, Y and Z). NO BREAKLINES. DEM data will be collected for each map sheet and on completion of each area, all data will be merged into one data set. The data set will then be processed and the DEM reviewed and edited for completeness and correctness.

Checked and approved orthophoto diapositives will be scanned.

Digital imagery will be set up and oriented on a softcopy workstation. As a quality control check the following will be performed before ortho-rectification:

Each fiducial mark will be visited with the system cursor to obtain its sample/line location in the image. The RMSE of the fiducial will be calculated and examined for accuracy. RMSE for each control point used in the resection will be reported. Any unacceptable RMSE will be discarded.

The newly resectioned image will be visually checked for pixel drop out and/or other artifacts, which may degrade the final orthophoto image.

DEM will be in ASCII format and will be checked to verify that each point or break line has a feature code. The coordinate/projection system will also be verified at this stage in the process.

Scaled and hillshade DEM images will be inspected for missing or poor data.

Rectification of all required imagery will be performed and checked. All control panels or photo identifiable points visible will be visited on the screen and the X and Y of the location will be displayed. This information will be checked against the ground survey data. Visual checks of the image quality will be performed. Radiometric variation will be checked with image histogram analysis including linear contrast stretch, user selected contrast stretch, histogram normalization and histogram clipping.

g. Produce color infrared digital orthophotos of MacDill Air Force Base (7930 acre area) at 1" = 400' horizontal scale and deliver the data in Intergraph and Autocadd version 13 compatible formats on CD-ROM.

h. The contract shall utilize the 1" = 300' negative scale photography and associated ground control and produce 1" = 50' horizontal scale color orthophotos with full planimetric detail and 1' contour interval mapping of the 2,360 acre cantonment area as defined on maps previously furnished. Mapping data shall be delivered in Intergraph and Autocadd version 13 compatible formats on CD-ROM.

i. The contractor shall incorporate existing government furnished digital installation facilities mapping layers into a the mapping data base and developing a "Primary Installation" orthophoto map at 1"=400' horizontal scale. The existing map layers needed to complete the "Primary Installation" mapping are on 8mm tape in Intergraph format and are complete and accurate in their coverage. The map development shall be accomplished by creating separate layers for each data sets provided and warping the data sets to "best fit" the 1" = 400' horizontal orthophoto mapping data. The contractor shall then produce one set of mylar orthophoto map sheets at 1" = 400' horizontal scale with the following vector layers overlaying the orthophoto image.

- Property Lines
- Record Flood Contour
- Quantity-Distance explosive safety zone area encompassing all explosive locations
- Alert parking areas
- Existing Facilities tie. Airfields pavements, structures above ground, structures below ground, streets, parking areas, railroads, fuel hydrant outlets, antennas

-Type of construction
Address System and building numbers (base numbering system)
- Grid coordinate system
- Off base streets contiguous to the base
- Identification of streets and roads
- The length, width, true bearing, directional numerals, lateral clearances, clear zones, approach zones, and center lines of each runway
- Arresting barriers and type
- Taxiways identified by number or letter
- The designation of the instrument runway
- Special areas. e.g., recreational, drop zones, fire training, designated training areas for mobility exercises, etc
- Aircraft maintenance light poles or towers, blast deflectors, and aircraft fueling/defueling outlets.
- Helicopter landing areas and clearances applicable for same

j. Provide a total of forty (40) hours of training, for a minimum of two individuals, at MacDill Air Force Base, utilizing existing hardware and software, in the manipulation of the digital orthophotos, contours, and planimetric data being provided under this delivery order.

DELIVERY ITEMS:

a. Computer printout copy of aerotriangulation solution. Aerotriangulation report as defined in 3.c

b. Copy of each stereo model orientation report

c. Six copies of the digital orthophoto file along with planimetric and topograph map files at the horizontal scales listed above on CD-ROM in Intergraph and Autocadd version 13 readable format

d. One set of the "Primary Installation" maps at 1" = 400' horizontal scale on mylar and six copies in Intergraph and Autocadd version 13 readable formats on CD-ROM

e. All survey data (including ground surveys), including survey information developed and or collected for the project and all check profile data

f. Flight line index for the project on paper maps indicating the flight lines, beginning, and ending frames for each flight line along with altitude and negative scale of the photography

g. Return all manuscript copies, horizontal & vertical control information, aerial photographs, diapositives, and aerial film to the government when the project is completed

SCHEDULE AND SUBMITTAL:

a. The contractor will deliver the 1" = 400' "Primary Installation" map data as specified in paragraph by April 30, 1997. The contractor will deliver all remaining products including CD-ROM digital data files by:

b. All material to be furnished by the contractor shall be delivered at the Contractors expense to: U.S. ARMY CORPS OF ENGINEERS, ST. LOUIS DISTRICT, 1222 SPRUCE STREET, ST. LOUIS, MO., 63103-2833

TIME EXTENSIONS:

In the event, these schedules are exceeded due to causes beyond the control and without fault or negligence of the contractor, this delivery order will be modified in writing and the delivery order completion date will be extended one calendar day for each calendar day of delay.

Example Statement of Work # 4

STATEMENT OF WORK

Contract No. DACW43-98-D-0512
SCOPE OF WORK
FORT STEWART, GA
ORTHOPHOTO & DEM PRODUCTION
EARTHDATA INTERNATIONAL, INC.
DELIVERY ORDER NO.

Orthophoto production of portions of Fort Stewart, GA has been requested. The final products needed are color digital orthophotos and DEMs that will meet National Map Accuracy Standards (NAS) at a horizontal scale of 1:5000. Color aerial photography at a negative scale of 1:20000 and a calibration report will be provided by the government. Aerotriangulation (AT) solutions will be furnished by the government to produce a DEM that produces orthophotos at horizontal scale of 1:5000, which meets NAS. The project area is shown on maps previously furnished.

2. Information supplied by the government:

a. Required color aerial photography.

b. AT solution.

c. Approved image selected from samples provided by the contractor. (see changes to section 3.S)

3. Work to be performed by the Contractor: Contractor shall provide equipment, supplies, facilities, and personnel to accomplish the following work:

a. The color aerial film will be scanned directly from the roll for orthophoto preparation and control transferred for digital orthophoto rectification.

Before transfer, diapositives will be checked for scratches, blemishes, or other abnormal markings. Unacceptable diapositives will be attached to a quality check form indicating the location and type of abnormality and will be returned to the photographic laboratory. Upon acceptable completion of diapositive check, control points will be transferred from the analytical diapositive to the orthophoto diapositive using a point transfer instrument or equivalent.

b. The contractor will scan photography for digital orthophoto production with 0.5-m ground pixel resolution.

Checked orthophoto diapositives will be scanned utilizing a QCAI scanner or equivalent. The scanner must be capable of scanning color data in one pass.

Digital imagery will be set up, oriented, and spatial resection and coordinate transformation will be performed.

Rectification of all required imagery will be performed and checked. Visual checks of the image quality will be performed. Radiometric variation will be checked with image histogram analysis including linear contrast stretch, user selected contrast stretch, histogram normalization, histogram clipping and radiometric variation between adjacent images will be minimized.

The Contractor will provide sample digital images in Erdas Imagine format for customer approval of histograms, contrast, etc. before the final product is produced. Subsequent images will be matched as closely as possible to customer-approved sample.

c. Produce DEM for the production of Digital Orthophotos

d. Produce color digital orthophotos of the site at 1:5000 with a pixel resolution of 0.5-m. Orthophoto files will be in ERDAS Imagine (.img) format on CD-ROM. Orthophotos will be in UTM metric, Zone 17, NAD83/NAVD88 coordinates. Each ortho tile will be 3,000 m x 3,000 m.

e. Produce a digital photo index showing the locations of each digital image file in Arc/Info 7.1.2 vector polygon format. The file will contain fields that detail the image file name and identify the deliverable CD.

f. The Contractor will provide compressed orthophoto files utilizing the Mr. Sid compression software. The compressed files will be on CD-ROM. The Contractor will provide six sets of the compressed files on CD-ROM.

g. The Contractor will provide two sets of true color 9 x 9 in. prints from the 1:20000 negative scale photography used in the orthophoto project.

4. Delivery items:

a. Two sets of True Color digital orthophoto files in ERDAS Imagine on CD-ROM disks.

b. DEM suitable **for orthocorrection only** on CD-ROM.

c. One copy of the digital Photo Index in Arc/Info 7.1.2 vector polygon format on CD-ROM.

d. Six sets of compressed (MrSID Compression Software) orthophoto files on CD-ROM.

e. Two sets of true color 9 x 9-in. prints.

5. Schedule and submittal:

a. The contractor will deliver all final products including CD ROM digital data files by:

b. All material to be furnished by the contractor shall be delivered at the contractors expense to: U.S. ARMY CORPS OF ENGINEERS, ST. LOUIS DISTRICT, 1222 SPRUCE STREET, ST. LOUIS, MO., 63103-2833.

6. Time extensions: In the event, these schedules are exceeded due to causes beyond the control and without fault or negligence of the contractor, this delivery order will be modified in writing and the delivery order completion date will be extended one calendar day for each calendar day of delay.

Example Statement of Work # 5

STATEMENT OF WORK

DELIVERY ORDER NO. 23
CONTRACT NO. DACW43-96-D-0525
ITAM, HAWAII
COLOR AND COLOR INFRARED DIGITAL ORTHOPHOTOGRAPHY
U.S. ARMY CORPS OF ENGINEERS
PHOTO SCIENCE, INC.

DESCRIPTION OF WORK

Mapping of portions of military training areas in the state of Hawaii on the island of Oahu has been requested by ITAM. The areas to be mapped are portions of Makua Military Reservation, Schofield Military Reservation, and Schofield East Range. The areas to be mapped are shown on maps previously provided. The final mapping products requested are color infrared (CIR) photography, digital elevation models (DEM), 2-m contour files (over selected portions of the sites) and color infrared digital 1:2500 with a ground pixel resolution of 0.25 m and orthophotos at photo scale of 1:14400 and map scale of resample files at 1-m and 5-m pixel resolution (over entire project site). Selected portions of areas within the overall project areas as defined on maps previously provided shall have Digital Terrain Models (DTM), Triangulated Irregular Network (TIN) files and 2-m contour files generated. Necessary ground control will be planned, established and utilized to perform aerotriangulation (AT), and develop DEM, and DTM files from the color (IR) aerial photography for digital orthophoto production. The maps will fully comply with ASPRS Class I Standards for mapping at a horizontal scale of 1:2500 with 2-m contours.

INFORMATION SUPPLIED BY THE GOVERNMENT:

a. Map showing project area. Maps indicate the overall digital orthophoto mapping areas and the selected areas within the overall mapping areas where contours will be generated ("East Range", "portion of Schofield Barracks", and portion of "Makua Range").

b. Available existing ground control within and around the project site.

WORK TO BE PERFORMED BY THE CONTRACTOR

Contractor shall provide equipment, supplies, facilities, and personnel to accomplish the following work:

a. Contractor will establish a ground survey control network, fly and photograph in color (IR) the Military Reservation areas at a negative scale of 1:14400 for a map scale of 1:2500 for color (IR) orthophotos. Photography will be flown with 80% forward lap and approximately 45% side lap.

b. Ground survey data will be collected to be used in the mapping process. Approximately 23 horizontal/vertical points will be established. The plan for additional ground survey control required for mapping and procedures to accomplish the ground survey control will be submitted to CEMVS-ED-HG for approval before initiation of the project. All survey data shall be in the Universal Transverse Mercator (UTM) System, and shall be referenced to WGS 84. The vertical datum will be referenced to NGVD29. All surveys shall be accomplished in accordance with the technical section of Contract DACW43-96-D-0525.

c. Two sets of color IR prints will be made in accordance with the technical section of Contract of the color (IR) prints will be used as control photos for DACW43-96-D-0525. One set mapping. The control prints will have all ground control marked on the back and front of each photo. All color (IR) photography will include in the border areas, the negative scale (as a ratio), the dates of photography, flight line and frame numbers and the title "ITAM, HAWAII (SCHOFIELD, MAKUA, SCHOFIELD EAST RANGE RESPECTIVELY) .”

d. Utilizing control survey data (panel data and photo identifiable data) perform analytical aerotriangulation to generate sufficient photo control points to accomplish ASPRS Class I Mapping at a horizontal scale of 1:2500 with 2 meter contours.

e. Color (IR) diapositives will be prepared for aerotriangulation procedures and DEM/DTM development. Simultaneously along with aerotriangulation and analytical diapositives, orthophoto diapositives will be prepared and control transferred for digital orthophoto rectification. Before transfer, diapositives will be checked for diapositives will be attached to a quality check form indicating the location and type of abnormality and will be returned to the photographic laboratory. Upon acceptable completion of diapositive check, control points will be transferred from the analytical diapositive to the orthophoto diapositive using a Wild Pug IV point transfer instrument or equivalent.

f. Two meter contour data is requested for selected areas within the total project boundaries. The areas include all of the "East Range,” one portion of "Schofield Barracks,” and one portion of "Makua Range.” The areas and approximate acreages are shown on maps previously furnished. The Contractor shall develop DEM, and DTM in areas where contours are to be produced. The contractor will develop Digital Elevation Models (DEM's) for digital ortho-rectification. The following procedure will be used:

DEM data will be captured using analytical stereo data capture systems by means of single point elevations (X, Y and Z). Digital Terrain Models (DTM) will then be generated in areas where contours are to be produced that will include mass points and breaklines sufficient to produce 1:2500 horizontal scale mapping with 2-m contours.

DEM data will be collected for each map sheet and on completion of each area, all data will be merged into one data set. The data set will then be processed, reviewed and edited for completeness and correctness. The checked and approved orthophoto diapositives will be scanned utilizing an Optronics Pixelgetter scanner or equivalent. The scanner must be capable of scanning color data in one pass.

Digital imagery will be set up and oriented on an International Imaging System IVAS 600 or equivalent and spatial resection to perform coordinate transformation. As a quality control check the following will be performed before ortho-rectification:

Each fiducial mark will be visited with the system cursor to obtain its sample/line location in the image. The RMSE of the fiducial will be calculated and examined for accuracy. RMSE for each control point used in the resection will be reported. Any unacceptable RMSE will be discarded.

The newly resectioned image will be visually checked for pixel drop out and/or other artifacts, which may degrade the final orthphoto image.

DEM will be in ASCII format and will be checked to verify that each point or breakline has a feature code. The coordinate/projection system will also be verified at this stage. Scaled and hillshade DEM images will be inspected for missing or poor data. Rectification of all required imagery will be performed and checked. All control panels or visible photo identifiable points will be visited on the screen and the X and Y of the location will be displayed. This information will be checked against the ground survey data. Visual checks of the image quality will be performed. Radiometric variation will be checked with an image histogram analysis (linear contrast) stretch, user selected contrast stretch, histogram normalization and histogram clipping.

The Contractor shall scan all necessary photography and create1:2500 horizontal scale digital orthophotos. The 1:2500 orthophotography will have 0.25-m ground pixel resolution. Orthophotography will then be resampled for 1-m and 5-m ground pixel resolution. Orthophotography will be in raster file form in TIF and ARC/INFO format (World files included). All digital orthophoto data should come with a Federal Geographic Data Committee (FGDC) compliant metadata file.

g. The Contractor shall utilize the DEM and DTM files to produce Triangulated Irregular Network (TIN) data files and 2- m contour files in selected areas as shown on maps previously furnished. Selected areas include all of "East Range," one portion of "Schofield Barracks" and one portion of "Makua Range." The DTM, TIN and contour files will comply with ASPRS Class I Standards for 1:2500 scale mapping with 2-m contours.

h. The Contractor will incorporate a TIFF image data viewer with the orthophoto data files on CD-ROM.

DELIVERY ITEMS

a. Copy of computer printout of aerotriangulation solution. Aerotriangulation report as defined in 3.c.

b. Copy of each stereomodel orientation report.

c. One copy of digital Color (IR) orthophoto files(including .25 m, 1.0 m and 5.0 m ground pixel resolution files) on CD-ROM. The digital ortho files will be in TIF and ARC/INFO formats. Digital ortho CD-ROM disks will include operational TIFF image viewer.

d. One copy of the DTM, TIN and 2 meter contour files on CD-ROM disks.

e. One set of paper color (IR) paper prints of Color (IR) orthophotos (.25 m ground pixel resolution files).

f. All survey data including raw GPS files, any other survey information developed and or collected for the project.

g. Two sets of color (IR) prints, and two sets of all necessary color IR diapositives.

h. Flight line index for the project on paper maps indicating the flight lines, beginning, and ending frames for each flight line along with altitude and negative scale of the photography.

i. Return all manuscript copies, horizontal & vertical control information, aerial photographs, pugged diapositives, and aerial film to the government when the project is completed.

SCHEDULE AND SUBMITTAL

a. The contractor will deliver all remaining final products including CD ROM digital data files by:

b. All material to be furnished by the contractor shall be delivered at the Contractors expense to: **U.S. ARMY CORPS OF ENGINEERS, ST. LOUIS DISTRICT, 1222 SPRUCE STREET, ST. LOUIS, MO., 63103-2833.**

6. Time extensions:

In the event, these schedules are exceeded due to causes beyond the control and without fault or negligence of the contractor, this delivery order will be modified in writing and the delivery order completion date will be extended one calendar day for each calendar day of delay.

Example Statement of Work # 6

FORT HOOD, TEXAS

CONTRACT NO. DACW43-98-D-0512

U.S. ARMY, FORT HOOD, TEXAS
COLOR INFRARED (CIR) AND NATURAL COLOR DIGITAL ORTHOPHOTOGRAPHY AND DTM DATA COLLECTION
U.S. ARMY CORPS OF ENGINEERS
EARTH DATA, INC.
TASK ORDER NO.

DESCRIPTION OF WORK

Natural Color and CIR digital orthophotography at 1:12000 and digital terrain model (DTM) data with irregular post spacing shall be produced of portions of Fort Hood, Texas. The area for aerial photography collection for the production of Natural Color and CIR orthophotography includes approximately 560,000 acres over Fort Hood and surrounding private lands. DEM data will be obtained for production of the digital orthophotos and will be suitable for generation of 3 m contours. The final mapping products requested are 56 Natural Color and CIR digital orthophoto quarter quads (DOQQs) at a horizontal scale of 1:12000 with a 1-m horizontal resolution delivered as GeoTiff files and a resample to 2.5-m resolution; 3 m contours attributed with appropriate z values delivered as ArcInfo 7.1 coverages as well as Microstation 95 .dgn files with spot elevations (index and intermediate contours will be separate layers); DTM data with irregular post spacing for use in both ArcInfo GRID and ERDAS Imagine .img formats; a compressed data set of the 1-m resolution DOQQs and the 2.5-m mosaic using Mr. SID (six sets to be produced); two sets of the Natural Color and CIR contact prints; Aerotriangulation (AT) solution of the control data and a final A/T report; Airborne Global Positioning System (GPS) control will be used in conjunction with minimal ground survey control, provided by Fort Hood, to perform aerotriangulation (AT); and a digital line index will also be produced. All photography will be flown at approximately 20,000 ft Above Mean Terrain (AMT) at a photo negative scale of 1:40000. **The orthophoto maps will fully comply with ASPRS Class I Standards for mapping at a horizontal scale of 1:12000 with a ground sample distance of 1 m. Datum will be WGS 84/NAD 83 (m), NGVD 29 represented as Mean Sea Level (MSL), UTM Zone (m) 14R.**

INFORMATION SUPPLIED BY THE GOVERNMENT

Maps showing project areas.

WORK TO BE PERFORMED BY THE CONTRACTOR

Contractor shall provide equipment, supplies, facilities, and personnel to accomplish the following:

a. Contractor will establish aerial photo and a ground survey control network including airborne GPS that will support the aerial photography and DEM/DTM data capture. The Contractor will fly and photograph (in Natural Color and CIR) the project area at an altitude of approximately 20,000' AMT with a negative scale of 1:40000 in Natural Color and CIR. The contractor will produce a digital line index in ArcInfo format of theaerial flight. The aerial photography will be captured during leaf off conditions. The Natural Color and CIR aerial photography will be accomplished with airborne GPS utilizing dual frequency/multi channel receivers. The aerial photography will be flown with 80% forward lap and approximately 40% side lap. GPS data collection and processing will include UTM meters and MSL elevation for each photo center. All airborne GPS planning including survey network layout, benchmarks to be used, etc. shall be approved by CEMVS-ED-SG prior to initiation of project. The plan submitted shall include but not be limited to maps indicating proposed GPS network, benchmarks to be used, flight lines, and project area.

b. Additional ground survey data will be collected for use in the mapping process. The plan for additional ground survey control required for mapping and procedures to accomplish the ground survey control will be submitted to CEMVS-ED-SG for approval prior to initiation of the project. Ground control will be provided by Fort Hood. **All survey data shall be in the Universal Transverse Mercator (UTM) System, Zone 14R (meters). Horizontal control shall be in NAD 83/WGS 84. Vertical datum will be NGVD 29 (MSL).** All surveys shall be accomplished in accordance with the technical section of Contract DACW43-98-D-0512.

c. Two sets of Natural Color and CIR contact prints will be made in accordance with the technical section of Contract DACW43-98-D-0512. One set of prints will be used as control photos for mapping. The control prints will have all ground control marked on the back and front of each photo. All photography will include in the border areas the GPS UTM meters, the negative scale (as a ratio), the dates of photography, flight line and frame numbers and the title “Fort Hood, TX”.

d. The Contractor will produce aerotriangulation quality diapositives. The Natural Color and CIR film will be scanned directly from the roll for orthophoto preparation and the control will be transferred for digital orthophoto rectification.

e. Utilizing GPS survey data along with conventional ground control (panel data and photo identifiable data) perform analytical aerotriangulation to generate sufficient photo control points to accomplish ASPRS Class I Mapping at a horizontal scale of 1:12000 with a DEM suitable for generation of 3 m contours.

f. Compression of the DOQQ data using the MrSID software to place all the DOQQs on one CD-ROM (six sets to be furnished).

g. DEM and contour data will be delivered in digital ARC/INFO GRID format and Microstation '95 (.dgn) formats on CD-ROMs.

h. The contractor shall check and approve processed film. Images required for orthophoto production will be scanned for 1-m pixel resolution utilizing a Zeis SCAI scanner or equivalent and resampled to 2.5-m pixel resolution.

Digital imagery will be set up and oriented on an Autometric Softplotter System or equivalent and spatial resection and coordinate transformation will be performed. As a quality control check the following will be performed prior to ortho rectification:

The RMSE of the fiducial will be calculated and examined for accuracy.

RMSE for each control point used in the resection will be reported. Any unacceptable RMSE will be discarded.

The newly resectioned image will be visually checked for pixel drop out and/or other artifacts that may degrade the final orthophoto image.

DEM data will be in ArcInfo GRID format and will be checked to verify that each point has a feature code. The coordinate/projection system will also be verified at this stage in the process.

Scaled and hillshade DEM images will be inspected for missing or poor data.

Rectification of all required imagery will be performed and checked. All control panels or visible photo identifiable points will be visited on the screen and the X and Y of the location will be displayed. This information will be checked against the ground survey data. Visual checks of the image quality will be performed. Radiometric variation will be checked with image histogram analysis including linear contrast stretch, user selected contrast stretch, histogram normalization and histogram clipping.

i. Produce digital orthophotos of the site at 1:12000 with a pixel resolution of 1 m. Digital orthophoto data will be raster file form in GeoTiff format. **The orthophoto files will be referenced to UTM Zone 14R (meters), NAD 83/WGS 84 and NGVD 29 (MSL).**

j. The Contractor will produce one set of the DTM files in ArcInfo GRID format and ERDAS Imagine .img format on CD-ROM.

4. Delivery items:

a. Copy of computer printout of aerotriangulation solution. Aerotriangulation report as defined in 3c.

b. Copy of camera calibration reports.

c. Two sets each of Natural Color and CIR digital orthophoto files and topographic data files at a horizontal scale of 1:12000 with a 1-m pixel resolution as well as files resampled to 2.5-m pixel resolution; the DTM delivered in both ArcInfo GRID and ERDAS Imagine .img formats on CD-ROM; 3-m contour files attributed with appropriate z values delivered as ArcInfo coverages and Microstation 95 .dgn files with the index and intermediate contours as separate layers. The digital orthophoto files will be in GeoTiff format~and the topographic files will be in ARC/INFO Coverages and Microstation 95 .dgn format. All digital files (orthophotos, DTM and contours) will be on CD-ROM.

d. All survey data (including ground surveys and airborne GPS surveys), raw GPS files (airborne and ground), and any other survey information developed and or collected for the project.

e. Two sets of prints, and one set of diapositives (one A/T set).

f. Digital flight line index for the project indicating the flight lines and beginning and ending frames for each flight line along with altitude and negative scale of the photography.

g. Return all manuscript copies, horizontal & vertical control information, aerial photographs, pugged diapositives, and aerial film to the government when the project is completed.

h. A mosaic of the 56 resampled 2.5-m DOQQs, color matched CIR and Natural Color on CD-ROM (two copies).

i. Compression of the 1 meter DOQQ data and 2.5-m mosaic using the MrSID software to place all the DOQQs on one CD-ROM (six sets to be furnished).

SCHEDULE AND SUBMITTAL

a. The contractor will deliver all final products including CD-ROM digital data files on:

b. All material to be furnished by the contractor shall be delivered at the Contractor's expense to: **U.S. ARMY CORPS OF ENGINEERS, ST. LOUIS DISTRICT, 1222 SPRUCE STREET, ST. LOUIS, MO., 63103-2833.**

6. Time extensions:

In the event, these schedules are exceeded due to causes beyond the control and without fault or negligence of the Contractor, this delivery order will be modified in writing and the delivery order completion date will be extended one calendar day for each calendar day of delay.

Example Statement of Work # 7

FORT STEWART, GEORGIA

CONTRACT NO. DACW43-96-D-0525

SCOPE OF WORK

FORT STEWART, GA.
AERIAL PHOTOGRAPHY AND MAPPING
U.S. ARMY CORPS OF ENGINEERS
PHOTO SCIENCE, INC.
DELIVERY ORDER NO.

DESCRIPTION OF WORK

Mapping of portions of Fort Stewart, Ga. has been requested. The area to be mapped is approximately 279,280 acres. The final mapping products requested are digital elevation models (DEM) and color infrared digital orthophotos at a horizontal scale of 1"=10001. Aerial photography will be flown at 20,000 ft above mean terrain (AMT) with a negative scale of 1"=3333' (1:40,000). Airborne Global Positioning System (GPS) control will be used in conjunction with minimal ground survey control to perform aerotriangulation (AT), and develop digital elevation models (DEM) from the color IR aerial photography for digital orthophoto production. **The maps will fully comply with National Map Accuracy Standards for mapping at a horizontal scale of 1"=3333'.**

INFORMATION SUPPLIED BY THE GOVERNMENT

a. Map showing project area.

b. Available existing ground control within and around the project site.

WORK TO BE PERFORMED BY THE CONTRACTOR

Contractor shall provide equipment, supplies, facilities, and personnel to accomplish the following work:

a. Contractor will establish a ground survey control network for airborne GPS and fly and photograph the project area at an altitude of 20,000' AMT with a negative scale of 1"=3333' in color IR. The color IR photography will be accomplished with airborne GPS utilizing dual frequency/multi channel receivers. Photography will be flown with 80% forward lap and approximately forty percent side lap. GPS data collection and processing will include latitude, longitude and ellipsoid elevation for each photo center. All airborne GPS planning including survey network layout, benchmarks to be used, etc. shall be approved by CELMS- ED-HG before initiation of project. Plan submitted shall include but not be limited to maps indicating proposed GPS network, benchmarks to be used, flight lines, and project area.

b. Additional ground survey data will be collected to use in the mapping process and to check the final mapping. Approximately seven horizontal/vertical points will be established. The plan for additional ground survey control required for mapping and procedures to accomplish the ground survey control will be submitted to CELMS-ED-HG for approval before initiation of the project. In addition, CELMS-ED-HG will provide approximate locations for 5 check profiles to be established and submitted directly to CELMS-ED-HG to be used as an additional check of the topographic mapping. The check profiles will be 1000' in length or shorter with an elevation established approximately every100'. All original notes for these surveys shall be submitted and no copies shall be made by the contractor. All surveys shall be accomplished in accordance with the technical section of Contract DACW43-96-D-0525.

c. Two sets of color IR prints will be made in accordance with the technical section of Contract DACW43-96-D-0525. One set of the color IR prints will be used as control photos for mapping. The control prints will have all ground control marked on the back and front of each photo. All color IR photography, in the border areas, will include the GPS latitude/longitude, the negative scale (as a ratio), the dates of photography, flight line and frame numbers and the title "Fort Stewart, GA.."

d. Utilizing GPS survey data along with conventional ground control (panel data and photo identifiable data) perform analytical aerotriangulation to generate sufficient photo control points to accomplish National Map Accuracy mapping at a horizontal scale of 1"=3333' for ortho photography at 1"=1000' horizontal scale.

e. Color IR diapositives will be prepared for aerotriangulation procedures and DEM preparation. Simultaneously, along with aerotriangulation analytical diapositives orthophoto diapositives will be prepared and control transferred to them for digital orthophoto rectification and aerotriangulation.

Before transfer, diapositives will be checked for scratches, blemishes, or other abnormal markings. Unacceptable diapositives will be attached to a quality check form indicating the location and type of abnormality and will be returned to the photographic laboratory.

Upon acceptable completion of diapositive check, control points will be transferred from the analytical diapositive to the orthophoto diapositive using a Wild Pug IV point transfer instrument or equivalent.

f. Utilizing the 1"=3333' photography develop digital elevation models, scan photography at 1250 dpi and create digital orthophotos. The orthophotography will have 3' ground pixel resolution.

The contractor will develop Digital Elevation Models (DEM's) for digital ortho-rectification. The following procedure will be used:

DEM data will be captured using analytical stereo data capture systems by means of single point elevations (X, Y and Z).

DEM data will be collected for each map sheet and upon completion of each area, all data will be merged into one data set. The data set will then be processed and the DEM reviewed and edited for completeness and correctness.

Checked and approved orthophoto diapositives will be scanned for 3' pixel resolution at 1250 dpi utilizing an Optronics Pixelgetter scanner or equivalent. The scanner must be capable of canning color data in one pass.

Digital imagery will be set up and oriented on an International Imaging System IVAS 600 or equivalent and spatial resection and coordinate transformation will be performed, as a quality control check the following will be performed before ortho-rectification:

Each fiducial mark will be visited with the system cursor to obtain its sample/line location in the image.

The RMSE of the fiducial will be calculated and examined for accuracy.

RMSE for each control point used in the resection will be reported. Any unacceptable RMSE will be discarded. The newly resectioned image will be visually checked for pixel drop out and/or other artifacts, which may degrade the final orthphoto image.

DEM will be in ASCII format and will be checked to verify that each point or breakline has a feature code. The coordinate/projection system will also be verified at this stage. Scaled and hillshade DEM images will be inspected for missing or poor data.

Rectification of all required imagery will be performed and checked. All control panels or visible photo identifiable points will be visited on the screen and the X and Y location will be displayed. This information will be checked against the ground survey data. Visual checks of the image quality will be performed. Radiometric variation will be checked with image histogram analysis including linear selected contrast stretch, histogram normalization and histogram contrast stretch, user clipping.

g. Produce digital color IR orthophotos of the site at1"=1000' with a pixel resolution of 3'. Digital orthophoto data will be raster file form in ARC/INFO and ERDAS format.

DELIVERY ITEMS

a. Copy of computer printout of aerotriangulation solution. Aerotriangulation report as defined in section 3c.

b. Copy of each stereomodel orientation report.

c. One copy of digital color IR ortho photo files at a horizontal scale of 1"=1000' at 3'ground pixel resolution on CD- ROM disks. The digital ortho files will be in ERDAS and ARC/INFO formats.

d. All survey data (including ground surveys and airborne GPS surveys), raw GPS files (airborne and ground), any other survey information developed and or collected for the project and all check profile data.

e. Two sets of all necessary color IR diapositives.

f. Flight line index for the project on paper maps indicating the flight lines and beginning and ending frames for each flight line along with altitude and negative scale of the photography.

g. Return all manuscript copies, horizontal and vertical control information, aerial photographs, pugged diapositives, and aerial film to the government when the project is completed.

SCHEDULE AND SUBMITTAL

a. The contractor will deliver all remaining final products including CD-ROM digital data files by:

b. All material to be furnished by the contractor shall be delivered at the Contractors expense to : **U.S. ARMY CORPS OF *ENGINEERS*, ST. LOUIS *DISTRICT*, 1222 SPRUCE *STREET* ST. LOUIS, MO-28336 3103.**

TIME EXTENSIONS

In the event, these schedules are exceeded due to causes beyond the control and without fault or negligence of the contractor, this delivery order will be modified in writing and the delivery order completion date will be extended one calendar day for each calendar day of delay.

Cartography

The analysis of remotely sensed data typically results in the production of a map. A map is a graphical representation of the Earth's surface including features or other spatial phenomena that conveys locations and other features and their attributes. Several map issues, such as feature type, scale and projection parameters need to be taken into consideration when developing a map. The following information provides a basic introduction cartographic terminology and concepts.

Map Feature Types

Point: A single location too small to show as a line or area usually depicted by a symbol and/or label. Examples of point features are plot locations, wells, or nesting sites.

Line: A long narrow mark, streak or stripe representing a linear geographic feature too narrow to be displayed as an area. Defined with a sequence of connected and ordered coordinates.

Area: A closed plane figure bounded by a series of straight lines defining a homogeneous feature too large to be depicted by points or open lines. Usually referred to as a polygon.

Map Characteristics

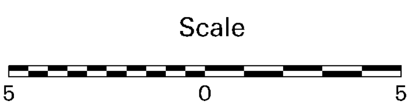
Map scale

Maps and associated features are always shown proportionally smaller than the areas mapped. The proportion chosen for a particular map is its scale.

Scale is shown on maps in three ways:

a. Verbal Scale: 1 inch equals 24 miles

b. Graphic or Bar Scale:



Useful when enlarging or reducing maps by photocopying, as the scale changes with the map.

c. Representative Fraction (RF): 1:24,000

Large is Small

A map scale is usually is given as a representative fraction or a ratio. For convenience of map size, either the scale or the amount of coverage area must be reduced.

When choosing a map scale, the most important consideration is its intended use.

Large Scale: Map has more detail while sacrificing the amount of area covered on the ground.
Example: 1:24,000

Small Scale: Map shows more ground area with less detail.
Example: 1:1,000,000

Converting From One Form of Scale to Another:

Verbal Scale to Representative Fraction

1 inch equals 10 miles
1 inch = 10 miles
1 inch = 10 miles x 12 inches/foot x 5280 feet/mile
1 inch = 10 x 63360 inches = 633,600 inches
1:633,600

Representative Fraction to Verbal

1:250,000
1 inch = 250,000 inches
1 inch = 250,000 inches, 12 inches/foot = 20,833.3 feet
1 inch = 20,833.3 feet, 5280 feet/mile = 4 miles or
1 inch = 250,000 63360 inches/mile = 4 miles
1 inch equals 4 miles

Table Common Map Scales and Their Equivalents

Map Scale	One Centimeter represents	One Kilometer Is Represented by	One Inch Represents	One Mile is Represented by
1:2,000	20 m	50 cm	56 yd.	31.68 in.
1:5,000	50 m	20 cm	139 yd.	12.67 in.
1:10,000	0.1 km	10 cm	0.158 mi.	6.34 in.
1:20,000	0.2 km	5 cm	0.316 mi.	3.17 in.
1:24,000	0.24 km	4.17 cm	0.379 mi.	2.64 in.
1:25,000	0.25 km	4.0 cm	0.395 mi.	2.53 in.
1:31,680	0.317 km	3.16 cm	0.500 mi.	2.00 in.
1:50,000	0.5 km	2.0 cm	0.789 mi.	1.27 in.
1:62,500	0.625 km	1.6 cm	0.986 mi.	1.014 in.
1:63,360	0.634 km	1.58 cm	1.00 mi.	1.00 in.
1:75,000	0.75 km	1.33 cm	1.18 mi.	0.845 in.
1:80,000	0.80 km	1.25 cm	1.26 mi.	0.792 in.
1:100,000	1.0 km	1.0 cm	1.58 mi.	0.634 in.
1:125,000	1.25 km	8.0 mm	1.97 mi.	0.507 in.
1:250,000	2.5 km	4.0 mm	3.95 mi.	0.253 in.
1:500,000	5.0 km	2.0 mm	7.89 mi.	0.127 in.
1:1,000,000	10.0 km	1.0 mm	15.78 mi.	0.063 in.

After: Robinson, A. H. et. al. , *Elements of Cartography*, 5th Edition, New York: John Wiley and Sons, 1984.

Steps to Determine Scale for Known Map Size

It may be necessary to calculate what map scale will fit on a particular size of paper.

Example:
Subject: map of Georgia, USA
Paper size: 8 .5 x 11
Margins: ½ inch
Orientation: Portrait (x=7.5, Y=10)

Calculate XY scales:

North-South

10 in. = 320 mi.
10 in. = 320 mi. x 63360 in. per mi.
10 in. / 10 = 20275200 in. / 10
1 in. = 2027520 in.
RF: 1:2,027,520

East-West

7.5 in = 272 mi.
7.5 in = 272 mi. x 63360 in. per mi.
7.5 in. / 7.5 = 17233920 in. / 7.5
1 in. = 2297856 in.
RF: 1:2,297,856

Therefore, a scale of 1:2,027,520 **(**or less) is necessary to place a map of Georgia on a 8 1/2 x 11 inch sheet of paper.

Map resolution

The map scale chosen directly affects the map resolution. Since map resolution decreases with map scale, it is important to determine the smallest feature that will be mapped. This is defined as the “minimum mapping unit” (MMU). For example, small wetlands may be distinguishable on a 1:10,000 map and not at all on a 1:24,000 map because it is smaller than MMU for the smaller scale map. Generally, the MMU is subject to, and almost always larger than, the spatial resolution of the imagery. It is advisable to specify the MMU for the contractor to use when maps are being created. See the example Statements of Work (SOW).

Map accuracy and standards

Map accuracy is determined by comparing the mapped location of selected points to their “true” location and evaluating statistically whether a certain level of accuracy is met. The “true” location is determined preferably by independent field survey or, though less desirable, by global positioning systems (GPS) or some other technique. In the United States, National Map Accuracy Standards were established in 1941 by the former U.S. Bureau of the Budget and state:

- No more than 10 percent of features shall be more than 1/30th of an inch from their intended locations on maps of scales larger than 1:20,000.
- No more than 10 percent of features shall be more than 1/50th of an inch from their intended location on maps of scale smaller than 1:20,000.

New standards have been developed in response to new mapping techniques and methods such as remote sensing, GIS, and GPS.

In 1996, the Federal Geographic Data Committee (FGDC) used the American Society for Photogrammetry and Remote Sensing (ASPRS) (1990) standards, as the basis for a new draft National Spatial Data Accuracy Standard. As of this writing, these standards have not been finalized. Until the FGDC standards become finalized, the Tri-Service Computer-Aided Design and Drafting (CADD)/GIS Center (1997) recommends that the ASPRS "Accuracy Standards for Large-Scale Maps" be specified in the Statement of Work for any map development project.

Map Projection Concepts

A map projection is a system in which the spherical surface of the earth is transformed to a flat surface. These transformations always introduce distortions in the properties of shape, area, direction, and distance (scale) at varying magnitudes. Some projections were developed to minimize distortions in some of these properties while accepting error in others. Some projections only moderately distort all of these properties. More than 250 different map projection systems have been devised.

Classifications of Projections

Projections are classified according to some geometric form capable of being flattened. Three common classifications:

- Cylindrical
- Azimuthal (plane)
- Conic

Choosing a Map Projection

Since the sixteenth century, there have been three fundamental rules regarding map projection use (Maling 1992):

> **Cylindrical projection:** Should be used for mapping the tropics.
>
> **Conical projection:** Should be used for mapping temperate latitudes.
>
> **Azimuthal projection:** Should be used for mapping the polar regions.

For land managers dealing with maps covering a relatively small area, such as a military installation, virtually any map projection will do. The amount of distortion in a particular projection is barely, if at all, noticeable. However, when mapping large areas such as entire countries, continents, and the world, there may be little or no distortion in the center of the map, but distortion will increase outward toward the edges of the map.

Characteristics of Projections

- **Conformality** (true shape)
- **Equal-Area** (equivalence)
- **Equidistance** (scale)
- **True direction**

Conformality Projections

Conformality is the characteristic of true shape, wherein a projection preserves the shape of any small geographical area. This characteristic is useful for maps used in navigation.

Commonly Used Conformal Map Projections

Mercator
This projection has straight meridians and parallels that intersect at right angles. Scale is true at the equator or at two standard parallels equidistant from the equator. The projection is often used for marine navigation because all straight lines on the map are lines of constant azimuth.

Transverse Mercator
The transverse mercator projection is similar to the mercator projection except that the cylinder is longitudinal along a meridian instead of the equator. Transverse mercator maps are often used to portray areas with larger north-south than east-west extent. Distortion of scale, distance, direction and area increase away from the central meridian. Many national grid systems are based on the transverse mercator projection.

Universal Transverse Mercator (UTM)
The universal transverse mercator projection is used to define horizontal positions worldwide by dividing the surface of the earth into 60 zones numbered from 1 to 60 eastward, beginning at the 180th meridian. Each zone spans 6 degrees of longitude extending from 80 degrees south latitude to 84 degrees north latitude. UTM zones use letters to designate 8 degree zones extending north and south from the equator. Each zone has its own central meridian mapped by the transverse mercator projection.
The UTM system features minimal distortion in the properties of shape and area. Local angles provide true direction, and distance distortions are limited to 0.1 percent within each zone. Error and distortion increase for regions spanning more than one UTM zone.

Equal-Area Projections

This projection is useful for maps used for comparing density and distribution data. Nations, water bodies, and regions of geographical similarity (vegetation, population, climate).

Commonly Used Equal-Area Projections

Albers Conic Equal-Area
This conic projection uses two standard parallels to reduce some of the distortion produced when only one standard parallel is used. This projection is best suited for land masses that extend more in the east-west orientation than those lying north to south. The Alber's Conic Equal –Area system features minimal distortion in the properties of shape and scale between standard parallels. As the name implies, all areas are proportional to the same areas on Earth. Directional distortions are locally true along the standard parallels and distance best in the middle latitudes. Best when used for regions predominately east-west in extent and located in middle latitudes.

Lambert's Equal-Area Projection
Also a conic projection based on two standard parallels. The State Plane Coordinate System uses this projection for all state zones the spread east to west.
This projection portrays the property of shape more accurately than area.

Equidistant Projections

Equidistance is the characteristic of true distance measuring. The scale of distance is constant over the entire map. Equidistance is important in maps that are used for analyzing velocity, e.g., ocean currents.

Commonly Used Equidistant Projections

Equidistant Conic
This conic projection can be based on one or two standard parallels. All circular distances are an equal from each other. The properties of shape and area distortion increase with distance from the standard parallels. The direction is true locally along standard parallels. Distance is accurate along the meridians and the standard parallels.

Platte Carree
A cylindrical projection which converts the globe into a cartesian grid. Each rectangular grid cell has the same size, shape and area. All the graticular intersections are 90 degrees. The central parallel uses the equator distortion of the properties of shape and area increase with distance from the standard parallels. The directions are accurate along grid lines. Distance is correct along all the meridians and along standard parallels.

True Direction Projections

True direction is characterized by a direction line between two points which crosses reference lines, e.g. meridians, at a constant angle or azimuth. These are termed rhumb lines and this property makes it comparatively easy to chart a navigational course. However, on a spherical surface, the shortest surface distance between two points is a great circle along which azimuths constantly change. Thus, a more desirable property may be where certain great circles are represented by straight lines. This characteristic is most important in aviation. Note that all meridians are great circles, but the only parallel that is a great circle is the equator.

Commonly Used True Direction Projections

Azimuthal Equidistant
A planar projection in which both distance and direction are accurate from a central point anywhere on the globe, though usually a polar aspect is used. The properties of shape and area are increasingly distorted with distance from the center. Direction and direction are true from the center outward. However, with the polar aspect, distortion of distance increases along circles of latitude outward from the center but is accurate along the meridians.

Datums

The earth's shape is generally spherical, though with flattened poles and bulging equator, the shape is better defined as a spheroid. The earth's shape has been surveyed many times in order to better understand its true shape. However, odd surface irregularities make it impossible for a single spheroid to define the shape of the earth, making it necessary to choose a spheroid which best defines the shape of the earth for a specific geographic area.

Until recently, the North American Datum of 1927 (NAD27), based on the Clarke 1866 spheroid, was the most commonly used datum in the United States. Almost all maps have used this datum, including those made by the U.S. Geological Survey (USGS).

Recent advances in positioning and navigation technology exposed weaknesses in the existing control point system. The new North American Datum of 1983 (NAD83), based upon earth and satellite observations, has replaced NAD27. In the continental United States, all new maps should be horizontally referenced to NAD83 or to the GPS-based nationwide National Spatial Reference System.

Yet Another New System

Although NAD83 is superior to NAD27, the National Geodetic Survey has discovered through statewide high-accuracy reference networks (HARNs) that high-precision users of GPS often obtain positioning accuracies better than NAD83. A new reference system may take the form of an updated NAD83, taking advantage of improved GPS accuracies. The NGS is considering a new system based upon the International Terrestrial Reference Frame (ITRF) developed by the

International Earth Rotation Service. This global cartesian coordinate system is more closely linked to GPS orbit information and is geocentric to within one centimeter. However, the NGS plans to maintain NAD83 while providing a long-term overlap with the new datum (Woodbury 1998).

Mixing Datums

Care must be taken when using old GIS databased in the NAD27 datum with newly acquired data in NAD83. There can be a shift of as much as 152.4 meters (500 feet). Fortunately, most GIS and remote sensing software packages support a system for converting from NAD27 to NAD83, called North American Datum CONversion algorithm (NADCON). NADCON was developed by the U.S. Geodetic Survey and has an approximate accuracy of 0.15 to 0.5 meters. NADCON is the accepted national standard for datum conversion.

Remote Sensing / GIS Web Links

For an updated list of web links refer to the Remote Sensing Users' Guide on the ITAM home page.

Remote Sensing Links

General Reference Dictionaries and Glossaries (GIS, RS, GPS)

Dictionary of abreviations and acronyms in GIS, Cartography, and Remote Sensing *(UC Berkeley Library)*

Cartographic Terms *(AGI)*

Geography Terms *(AGI)*

GPS Terminology *(CGCC)*

Glossary of GPS terms *(GPS World)*

Remote Sensing and Digital Image Processing *(AGI)*

Photogrammetry and Digital Terrain Modeling *(AGI)*

Space Mission Acronym List and Hyperlink Guide *(NASA)*

Glossary of Terms *(US Geological Survey)*

GIS Dictionary *(Association of Geographic Information)*

Coordinate Systems Overview *(Peter H. Dana, Department of Geography, University of Texas at Austin, 1995)*

Geodetic Systems Overview *(Peter H. Dana, Department of Geography, University of Texas at Austin, 1995)*

Cartographic Communication *(Kenneth E. Foote and Shannon Crum, The Geographer's Craft Project, Department of Geography, The University of Colorado at Boulder)*

Datums, Ellipsoids, Grids and Grid Reference Systems *(DMA Technical Manual 8358.1l)*

Geodesy for the Layman (DMA report)

Construction Tables and Calculators *(Infratech Polymers Inc.)*

FAQs

Satellite Imagery FAQ 1/5

Remote Sensing /Vegetation FAQ *(Terrill W. Ray)*

ASF's SAR FAQ *(Alaska SAR Facility)*

Remote Sensing Organizations

The Remote Sensing and Photogrammetry Society

Tutorials

The Nasa Remote Sensing Tutorial *(NASA)*

SAR Interferometry: An Overview *(Earth Science Dept Emporia, KS)*

Remote Sensing Guide *(Brunel University UK)*

R. S. A. T. Remote Sensing Advanced Technology *(S.W.S)*

How Satellites Work *(NASA)*

NASA's Observatorium

- Reflected Energy *(NASA)*
- Landsat's Thematic Mapper *(NASA)*
- Thermal Infrared *(NASA)*
- Multispectral Remote Sensing *(NASA)*
- Digital Imaging *(NASA)*
- Spatial Resolution *(NASA)*
- Satellite Orbits *(NASA)*
- False Color *(NASA)*

Radar Imaging *(NASA)*

Electro Magnetic Spectrum *(NASA)*

Virtually Hawaii: RS Example *(NASA)*

The Remote Sensing Core Curriculum *(ASPRS)*

Remote Sensing Lecture Materials *(College of Natural Resources Utah State University)*

RSGIS Laboratory *(College of Natural Resources Utah State University)*

Summer Institute: Remote Sensing *(MTU)*

The Journalists' Guide to Remote Sensing Resources on the Internet Version 2.2 *(American University School of Communication)*

Space-borne Platforms and Sensors *(Dr Qiming Zhou, Hong Kong Baptist University)*

ARC/INFO tutorial Home Page *(Shane Murnion, School of Geosciences, Queen's University Belfast)*

Online Lectures / Courses

Department of Geography, Hong Kong Baptist University, Dr Qiming Zhou

- Remote Sensing and Geography
- Electromagnetic Radiation
- Human Vision and Colour
- Photographic Remote Sensing
- Space-borne Platforms and Sensors
- Spectral Signatures and Their Interpretation
- Ground Truthing and GPS
- Image Processing - Rectification

Image   Enhancement

Satellites

Satellites and Sensors Search *(TELSAT Guide is accessible courtesy of BELNE T, the Belgian Research Network - very comprehensive.)*

IRS - Platforms/satellites

EarthWatch Incorporated

Earth Observation Satellites

Spot Image

http://www.spaceimage.com/

CCRS Cover Page / CCT page couverture

The Wonderful World of Satellites

Welcome to RADARSAT Interactive

Earth Observation Satellites Menu *(NASDA Japanese satellites)*

CEO / Facts on Players and Programmes / Earth Observation Satellites *(An abbreviated listing of satellites)*

Current, Planned, and Proposed Land Observation Satellites *(NASA, Satellite Table)*

Supplemental Sattelite Information

Future satellite Systems:
http://www.ersc.wisc.edu/resources/EOSF.html

HyperSpectral:
http://www.techexpo.com/WWW/opto-knowledge/IS_resources.html

Comprehensive List of Imaging Spectrometers:
http://www.geo.unizh.ch/~schaep/research/apex/is_list.html

Airborne Sensor Characteristics:
http://www.geo.unizh.ch/~schaep/research/apex/is_list.html

Map Servers

Color Landform Atlas of the United States *(Johns Hopkins University Applied Physics Laboratory)*

Mapquest *(Well-known free internet map browser with zoom and pan capabilities)*

Free Map Servers *(list of free internet map servers)*

TEC Web Mapping Effort *(Topographic Engineering Center Web Mapping site)*

Interactive Wetlands Mapping (US Fish and Wildlife Service)

Ecoregion Maps

Baily Ecosystem Provinces *(US Forest Service)*

Baily North America Ecoregions Map *(US Forest Service, revised from 1981 version)*

Kuchler Map *(University of Washington Silvaculture Lab)*

Baileys' Eco-Regions *(US Forest Service, Domains, Divisions, Provinces)*

Ecological Subregions of California: Sections *(US Forest Service)*

US Army Corps of Engineers

Photogrammetric Mapping Center of Expertise *(USACE St. Louis District)*

Albuquerque District Collection Metadata Page

Remote Sensing / GIS Center *(Cold Regions Research Lab, GIS Center)*

CADD / GIS technology Center *(USACE Waterways Experiment Station)*

Regional Support Centers

Brochure on RCSs

GIS Data Online

GIS Data Depot *(Free GIS Data)*

GIS Data Sources *(Rowekamp site with links to free GIS data)*

Free Digital GIS Data *(Center for Transportation Research and Education (CTRE), Iowa State University, links to free GIS data)*

Incorporated Places/CDPs Cartographic Boundary Files *(U.S. Bureau of the Census TIGER data freely available in ArcInfo exchange format)*

Metadata

US Army Corps of Engineers Geospatial Data Clearinghouse Node

Upper Midwest Environmental Sciences Center - Available Data and Applications

National Spatial Database

Scdnr GIS Data Information

Links to free data UT Dept. of Geography Resources: Geo-Spatial Datasets

Free Spatial Data

Welcome to the Nebraska Natural Resources Commission

Miscellaneous Links

Remote Sensing Internet Resources Directory *(The GIS Web Ring, UK)*

RS/GIS Publications Online *(University of Minnesota)*

GIS Net Sites *(Harvard Design and Mapping Inc., GPS / Remote Sensing / Space)*

Cartographic and Spatial Data on the Internet *(University of Chicago Joseph Regenstein Library)*

GLOBIS *(University of Utrecht)*

Remote Sensing and GIS Links *(The Remote Sensing and Photogrammetric Society)*

Commercial GIS and Mapping Enterprises *(University of Minnesota, John R. Borchert Map Library)*

Small Spacecraft World Wide Web Links *(RAND 1997)*

NSDI MetaData and WWW Mapping Sites *(BLM)*

GISOnline Links: DGI Links Database *(BYU Geography Department)*

Useful Remote Sensing Resources (*University of NorthUmbria at Newcastle Division of Geography and Environmental Management, UK*

Free Map Servers *(list of free internet map servers)*

Maps and Imagery on the Net *(US Navy)*

GISLinx - Over 1,700 Categorized GIS Links!

Units Conversion

Unit Conversion *(A collection of units conversion calculators)*

Transverse Mercator Calculator *(Converts lat/long to Transverse Mercator projection)*

DD converter *(Converts from Decimal Degrees to Degrees, Minutes, Seconds of arc)*

DMS converter *(Converts from Degrees, Minutes, Seconds of arc to Decimal Degree.)*

Aerial photography

Contractors

ASPRS Resource 2000 *(The Imaging and Geospatial Information Society – Searchable database of geospatial related companies and members)*

FAQ

Aerial Photography Frequently Asked Questions (FAQs) *(USGS)*

Browsing Orthophotos on the Web

The Microsoft® TerraServer

http://www.terraserver.microsoft.com/

A cooperative Research Agreement (CRADA) between Microsoft and the USGS led the way for the creation of the Terraserver.

The Terraserver is an online "store" that allows anyone to download copies of the USGS images. All published USGS data, covering approximately 30% of the United States, are available for browsing. This data is unencumbered and can be freely distributed to anyone.

As additional data becomes available, it will be loaded into the TerraServer.

Wisconsin Catalog of Aerial Photography

Historic Aerial Photo Imagebase - an Illinois Aerial Photograph Search and Retrieval System.

Massachusetts Coastal Orthophotos

http://www.mbr-pwrc.usgs.gov/clickable_map/pwrc.html

Upper Midwest Environmental Sciences Center - Available Data and Applications

USDA, Farm Service Agency, Aerial Photographs
FSA's aerial photographs of U.S. farmlands are used

Texas Natural Resources Information System

Wyoming Natural Resources Data Atlas

History

Kite Aerial Photography - History

Photogrammetry Firms

National Aerial Resources

MAPPS Member Firm Capability Study

General

Samples of aerial photographs resolutions

Terminology

aerial photo glossary (Commonly used terms for aerial photos)

Aerial Photography Terminology

SGS PhotoBASE orthophoto maps

How to order aerial photographs

Product Prices

Aerial Photography and Remote Sensing

Catalog of Aerial Photography at UCB

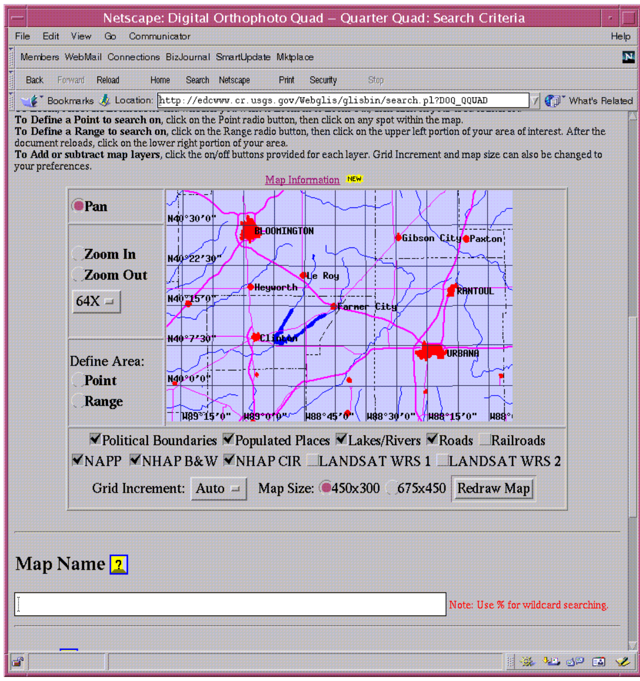
NAPP

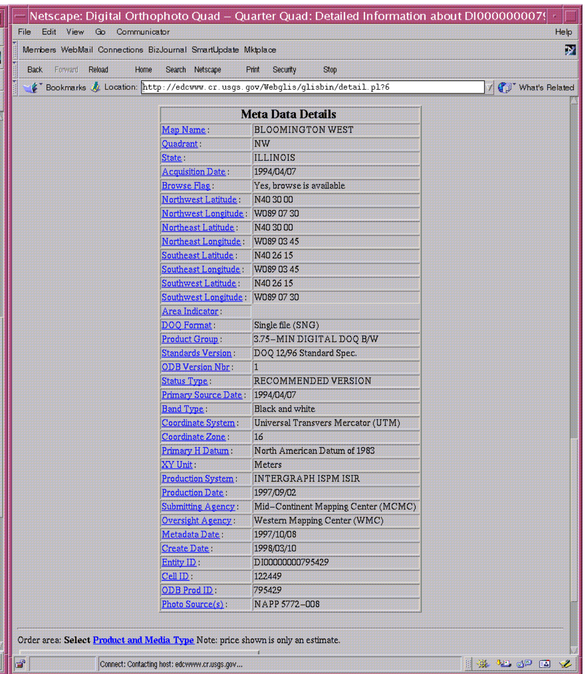
WebGlis

http://edcwww.cr.usgs.gov/webglis

The Global Land Information System (GLIS) is a World Wide Web-based query tool developed by the U.S. Geological Survey to provide data and information about the earth's land surface. This interface features search and browse capabilities for all sorts of geographic data including digital orthophoto quads.

A search begins with the user selecting a data type (i.e., digital orthophoto quad) and a place on earth by selecting an area on a world map. The interactive map features pan and zoom capabilities. Place names by state(s) may be selected, and if the search is successful, a list of photos are displayed matching the search criteria. Many of the DOQs are browse capable, meaning a resampled (8 meter) actual photo may be displayed. Many web browsers enable the resampled browse image to be saved to disk. A full table of metadata is displayed with or without the browse image, depending on availability.





DOQQ tabular metadata

NAPP Status Graphics

Orthophoto Quads

Limitations / Issues

Digital Orthophotography - Principles, Project design Issues,Utility, Accuracy, Economics

General Information

Aerial Archive - Orthophotos

Digital Orthophoto Specs

USGS NSDI Clearinghouse - Digital Orthophoto Quadrangles

Digital Orthophotoquad Production Status

DOQ Status Graphics

Search Services

National Aerial Resources

1 Stop Shop - IDI Sales

Hjw Home Page

JTI Engineering and Management Support

ImageLinks- Linking Earth Image Information

VARGIS Frequently Asked Questions (FAQs)

Examples / Demos

Extraction of Micro-Terrain -- Examples

DRAGON Color InfraRed Aerial Photo
Example of Color Infrared Photo use for

MrSID Bay Area Orthophoto Data

Terrain Modeling and Simulation

Case Study / Demo

Focus on IMAGINE VirtualGIS: Movies

microdem download

FreeGIS

Modular Semi-Automated Forces (MoDSAF)

The ETS News Archive

VIS-SIM.ORG - [Hardware : Image Generators]

Animating our Minds: the Expansion of Visual Dimensions in GIS

ESSP Missions: VCL

Appications Of Advanced Lidar For Dem Applications

Lidar System Finds Fault with Trees: Photonics Technology News August 1999

Software

Terrain Visualization Software *(US Army Corps of Engineers Topographic Engineering Center's Commercial Terrain Visualization Software Product Information* **–** *very comprehensive listing of terrain visualization software)*

Remote Sensing / GIS Software

This is a general compilation of many of the major Geographic Information Software (GIS) and Geographic Image Processing (GIP) packages currently available. The term "GIP" is used to distinguish between traditional image processing software such as Adobe PhotoShop and those packages which are intended to support satellite and airborne derived data. A GIP package must allow geographic rectification, image registration and support map projections, spheroids, etc..

Increasingly, many GIS packages now support at least rudimentary image processing capabilities and, conversely, most GIP packages provide many GIS features.

Another source of information can be found at http://newark.cms.udel.edu/~vinton/gis_gip/pc.html.

Commercial Remote Sensing Software

CARIS, *Universal Systems Limited*

Comprehensive suite of spatial information and GIS solutions for marine and land based industries.

ENVI, *Research Systems Inc.*

Remote sensing software for data visualization, advanced data analysis, feature extraction and map production using satellite and aerial images, as well as GIS data.

Imagine, *ERDAS*

Commercial image processing software for PC and Unix workstations.

Image Analyst, *Intergraph MGE*

Commercial image processing software for PC and Unix workstations.

Khoral Research Inc.

Commercial Digital Image Processing software.

Geomatica, *PCI Geomatics*

Commercial Remote Sensing, Image Processing, GIS/Spatial Analysis, Cartography, and Desktop Photogrammetry software.

TNTmips, *MicroImages*

The TNT products support fully integrated GIS, image processing, CAD, TIN, desktop cartography, and geospatial database management.

Low Cost Commercial Remote Sensing

Avenza, *Avenza Systems Inc.*
Cartographic & GIS Tools for your Vector Graphics Program.

DRAGON, *Goldin-Rudahl Systems*
Low cost commercial image processing software for PCs.

IDRISI32, *Clark Labs*
Low-cost raster GIS and Remote Sensing software for the PC from Clark University.

ILWIS, *ITC-ILWIS*

Remote Sensing and GIS Software for the PC

MacSADIE
Low cost image processing program for the Macintosh.

MicroMSI
A free multi-spectral imagery analysis program for the PC.

MiraMon
GIS and Remote Sensing software.

MultiSpec
Freeware image processing software for Mac and PCs.

TeraVue, *TeraVue Software*
Low cost Remote Sensing and digital cartography commercial software for the PC.

V-image , *VYSOR Integration Inc*

Low Cost Image Processing and GIS Software for PCs

ER Mapper, *Earth Resource Mapping*
Image processing software.

Commercial GIS Software

ESRI Software

MapInfo
GIS software

ESRI ATLAS GIS

Low Cost Commercial GIS Software

EPPL7, *Land Management Information Center at Minnesota Planning*
Low cost raster based GIS

Manifold, *CDA International Ltd*
Low cost GIS software.

VYSOR, *VYSOR Integration Inc.*
Low cost Image processing and GIS software

Free GIS Software

Link to good explanation of licenses for "free" GIS software.
http://www.opensource.org/licenses/index.html

Terrain Tools, *Natural Resource Software*
Surveying and Mapping Software, runs on PC.

Map Maker, *MAP MAKER Ltd*
Free GIS for the PC.

FreeView, *PCI Geomatics*
FreeView allows the view, enhance, and examination of remotely sensed imagery. GIS data overlay and attribute data viewing.

GRASS
Free GIS with raster, topological vector, image processing, and graphics production functionality that operates on various platforms through a graphical user interface and shell in X-Windows.

GMT, *The Generic Mapping Tools*
GMT is a collection of about 60 UNIX tools that allow users to manipulate (x,y) and (x,y,z) data sets (including filtering, trend fitting, gridding, projecting, etc.) and produce Encapsulated PostScript File (EPS) illustrations ranging from simple x-y plots through contour maps to artificially illuminated surfaces and 3-D perspective views in black and white, gray tone, hachure patterns, and 24-bit color. GMT supports 25 common map projections plus linear, log, and power scaling, and comes with support data such as coastlines, rivers, and political boundaries.
License: GPL

iGMT, *Interactive Mapping of Geoscientific Datasets*
iGMT provides a graphical user interface and was built using the Tcl/Tk computer language. Besides supplying a user friendly way of handling GMT, iGMT comes with built-in support for many different geoscientific data sets, such as topography, gravity, seafloor age, hypocenter catalogs, plate boundary files, hotspot lists, CMT solutions etc.
License: GPL

MapServer
CGI-based application delivers dynamic GIS and image processing content via the World-Wide Web (WWW). Also contains a number of stand alone applications for building maps, scalebars and legends offline.
License: MapServer License

MapServer Workbench
MapServer Workbench is a suite of cooperative tools to build MapServer applications. The tools are written in Tcl/Tk, and use the Mapscript/Tcl interface.
License: LGPL

MapIt!
MapIt! is a web application that allows to navigate on rastermaps, zoom in and out, and to choose and identifiy objects (points of interest).
License: LGPL

PMS *Practical Map Server*

Practical Map Server (PMS) delivers geographic content to web browsers and other compatible clients. PMS is written in Java.
License: GPL

Vis5D

Vis5D is a system for interactive visualization of large 5-D gridded data sets such as those produced by numerical weather models. One can make isosurfaces, contour line slices, colored slices, volume renderings, etc of data in a 3-D grid, then rotate and animate the images in real time. There is also a feature for wind trajectory tracing, a way to make text annotations for publications, support for interactive data analysis, etc. GRASS can import and export Vis5D raster data.
License: GPL

OpenMap

OpenMap is a Java Beans based toolkit for building applications and applets needing geographic information. Using OpenMap components, you can access data from legacy applications, in-place, in a distributed setting. At its core, OpenMap is a set of Swing components that understand geographic coordinates. These components help you show map data, and help you handle user input events to manipulate that data.
Version: 4.1.1
License: OpenMap License

GeoTools

GeoTools is a Java based mapping toolkit that allows Maps to be viewed interactively on web browsers without the need for dedicated server side support.
License: GPL

TARDEM

TARDEM is a suite of programs for the Analysis of Digital Elevation Data and mapping channel networks and watersheds.
Version: 4
License: GPL

kdem

kdem is a program for displaying United States Geological Survey (USGS) Digital Elevation Models (DEMs). It offers a number if interesting features.
Version: 1.1.1
License: kdem License

VTP *Virtual Terrain Project*

The goal of VTP is to foster the creation of tools for easily constructing any part of the real world in interactive, 3D digital form. This goal will require a synergetic convergence of the fields of CAD, GIS, visual simulation, surveying and remote sensing. VTP gathers information and tracks progress in areas such as procedural scene construction, feature extraction, and rendering algorithms. VTP writes and supports a set of software tools (VTP Toolbox) and an interactive runtime environment (VTP Enviro).
License: MIT

OSSIM *Open Source Software Image Map*

The OSSIM (Open Source Software Image Map) project will leverage existing algorithms/tools/packages from the open source community in construction of the ultimate Remote Sensing/Image Processing/GIS package.
License: GPL (libraries LGPL)

AVPython

Python Language Support for ArcView GIS AVPython embeds the Python programming language within ArcView GIS. License: AVPython License (MIT-like)

InovaGIS Applications

A collection of mostly IDRIS-like applications for VB, Delphi and Excel. Note:Several proprietary/non-free products are required.
Requirements: A MS OS + VB, Excel, Delphi + InovaGIS 2.0 library.
License: MIT

Adobe SVG Viewer

SVG or Scalable Vector Graphics is a language for describing two-dimensional graphics in XML. SVG is currently being developed as a standard for web-based display of vector data such lines and polygons as well as images and text. The software is implemented in Java as a plug-in that your Web browser will use to render SVG.
License: old BSD with advertising clause

IPW *Image Processing Workbench*

IPW is a UNIX-based image processing system. IPW includes several UNIX filter programs which can be pipe-lined together to form complex and powerful image processing algorithms.

Image Compression Software

MrSID Image Compression Software

Most high-resolution digital image files are so large that users have to view or perform spatial analysis frame-by-frame – essentially taking individual frames out of context. MrSID Portable Image Format™ software from LizardTech allows users to mosaic multiple aerial photos and other GIS images into a single, seamless image that can be zoomed and panned instantaneously, locally or over the Internet.

MRSID Features

- Seamless Wavelet Compression®
- Compress images of virtually any size
- Unsurpassed compression ratios
- Uncompromised image quality
- Automatic seamless mosaicking
- Selective Decompression®
- Selective Multiresolution Browsing®
- Georeference support

MRSID Benefits

- Reduce file size as much as 100:1 (average is 20 to 50:1)
- Instantaneous viewing/browsing
- Maintain superior image quality with high compression ratios
- Maintain complete geometric and geospatial accuracy
- Generate many resolutions in a single file
- Image quality gets better as viewers zoom in
- Decompress only the portion of the image user requests
- Automatically mosaic hundreds of separate images into single seamless image
- Pan and zoom around a single high-resolution image instead of shuffling many small images

Size is No Longer a Constraint

The only limitation to the size of image you can compress is the limitations of your operating system. The largest single image compressed with MrSID is 37 gigabytes. This image is viewed in seconds over the Internet.

- MrSID compressors and viewers run on most platforms and operating systems including Windows
- 95/NT, Solaris, AIX, IRIX and Mac OS
- Fully integrated inside ESRI ArcView GIS 3
- Plug-ins available for Photoshop, Netscape and Internet Explorer

- Future integration with Intergraph, ERDAS Imagine, MapInfo Pro/Business Map, Autodesk
- AutoCAD Map and Bentley Microstation

Vender Information

For more information on MrSID image compression software, contact:
LizardTech, Inc. Tel: (206) 320-9969
1520 Bellevue Ave Fax: (206) 320-0989
Seattle, Washington 98122
email: mrsid@lizardtech.com
web: www.lizardtech.com

3-D Terrain Rendering Software

Commercial

3DEM 8

$35 from Microcomputer Topography viewer and converter for DEM files both non-realtime and realtime rendering, using OpenGL reads DEM, SDTS DEM, GTOPO30, Mars DTM, and CDF writes elevation to TerraGen and many bitmap formats writes textured polygonal scenes to VRML can save flyovers as AVI or MPEG can display GPS receiver waypoints, routes, and tracks.

3DLinX

From Global Majic

ActiveX-based "language-independent 3-D development environment for real time rendering" has some terrain functionality, including vehicles with terrain following

Alias Maya / Terraformer

Apparently Terraformer was a powerful module for creating terrain with water and vegetation, once bundled with Alias Power Animator, not currently mentioned on the Alias|Wavefront site currently Maya contains a module 'Artisan' which allows you to "paint" and "sculpt" terrain surfaces, even non-heightfields like caves ArcView with 3D Analyst $1000 + $2500 from ESRI purchased it and did a detailed evaluation summary: many problems and limitations, not recommended for virtual terrain work Autometric Edge ultra-high-end terrain tools, from a military/government background Edge is the base product, ImageScape and TerrainScape are plugins capable of paging any amount of image texture on demand, written in plain Open GL SGI currently, NT soon.

ERDAS Imagine

Virtual GIS

Virtual GIS supports dynamic visualization, flight sequences, and the management/assimilation of multiple geographic data types in a real-time, 3D environment.

MicroDEM

A Digital Elevation Model visualization and analysis microcomputer mapping program written by Professor Peter Guth of the U.S. Naval Academy. Very nice software that can be used for mosaicing DEMs, image draping on DEMs, hillshading, perspective views, and building great fly-through, which can be saved as .avi or .mov video files.

A site at Fort Leonard Wood provides downloadable instructional videos, documentation, and military application downloads.
http://www.wood.army.mil/TVC/MicroDEMV5/microdem_ver_5.htm

FLY!

PCI

A powerful terrain visualization tool which drapes imagery and vectors over DEM data to create 3-D perspective scenes in near real-time

TruFlite

Powerful 3D landscape rendering systems for PCs.

Genesys International

GIS Software

Vertical Mapper

Northwood Geoscience Vertical Mapper is a raster display and analysis tool that runs as an extension to MapInfo.

ThinkSpace

MFworks

Caliper® Corporation Home Page

Maptitude, TransCad, GISDK

LandForm Gold

Real-Time 3D Terrain Modeller

Create real-time fly through terrain models, superimpose, output VRML models using your desktop PC.

Blue Marble Geographics

Bentley MAINline - The MicroStation Automated Information Network

Rockware Inc.

Geology/geoscience software catalogue

A Dynamic GIS Interface

Geographic Data Technology, Home Page

NIMAMUSE

National Imagery and Mapping Agency's free

PROGIS Software

WinGIS

Terrain Modeling Software

World Construction Set
Terrain Modeling Software

Articles

Terrain Modeling for Virtual Battlefields

Modeling and Simulation
ModSAF

DISCLAIMER:

The writer does not endorse any of the products listed above for any purpose, nor does the writer accept responsibility for any errors or omissions in this list.

Acronyms and Abbreviations

B/W	Black and White
CADD	Computer-Aided Drafting and Design
CAP	Conservation Assistance Program
CCD	Charge Coupled Device
CD-ROM	Compact Disc Read Only Memory
CITO	Central Imagery Tasking Office (NIMA)
CIP	Commercial Imagery Program (NIMA)
CIR	Color Infrared
CNES	Centre National d'Etudes Spatiales
CSIL	Commercial Satellite Imagery Library
DCT	Digital Cassette Tape
DEM	Digital Elevation Model
DMSV	Digital Multispectral Video
DN	Digital Number
DoD	Department of Defense
DOQ	Digital Orthophoto Quad
DOQQ	Digital Orthophoto Quarter Quad
DTED	Digital Terrain Elevation Data
EDC	EROS Data Center
EDC	DAAC EROS Data Center Distributed Active Archive Center
EMR	Electromagnetic Radiation
EOSAT	Earth Observation Satellite Company
ERE	Effective Resolution Element
ERTS	Earth Resources Technology Satellite
FCIR	False Color Infrared
FSA	Farm Service Agency (U.S. Department of Agriculture)
FTP	File Transfer Protocol
GIS	Geographic Information System
GLIS	Global Land Information System
GPS	Global Positioning System
GSD	Ground Surface Distance
HDT	High Density Tape
http	Hyper Text Transfer Protocol
HRV	High Resolution Visible
IFOV	Instantaneous Field of View
IFSARE	Interferometric Synthetic Aperture Radar (also IFSAR)
IR	Infrared
IRS	Indian Remote Sensing
ITAM	Integrated Training Area Management
JWICS	Joint Worldwide Intelligence Communications System
LCTA	Land Condition Trend Analysis
LIS	Land Information System

LISS	Linear Imaging Self Scanning
MIPR	Military Interdepartmental Purchase Request
MIR	Mid Infrared
MS	Multispectral
MSS	Multispectral Scanner
NAD83	North American Datum of 1983
NAPP	National Aerial Photography Program
NHAP	National High-Altitude Photography (Program)
NIMA	National Imagery and Mapping Agency
NMAS	National Map Accuracy Standards
NTP	Notice to Proceed
nm	Nanometer (10 -9)
Pan	Panchromatic (i.e., black and white)
RSC	Regional Support Center (ITAM)
SAR	Synthetic Aperture Radar
S/N	Signal to Noise
SOW	Statement of Work
SPOT	Systeme Pour l'Observation de la Terre
SWIR	Short Wave Infrared
TCX	Technical Center of Expertise (Army Corps of Engineers)
TEC	Topographic Engineering Center
TES	Threatened and Endangered Species
TM	Thematic Mapper
um	Micrometer (10 -6)
USACERL	U.S. Army Construction Engineering Research Laboratories
USAEC	U.S. Army Environmental Center
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
WFS	Wide Field Sensor
WWW	World Wide Web
XS	SPOT Multispectral

References

(1994). "Martin Marietta Buys Equity Position in RADARSAT International." Earth Observation Magazine.

(1995). *EOSAT Note*s, 10(3).

(1996). *ASP&RS Manual of Remote Sensing*, Agbu, P. A., and Nizeyimana, E. (1991). "Comparisons Between Spectral Mapping Units Derived from SPOT Image Texture and Field Soil Map Units." *Photogrammetric Engineering and Remote Sensing*, 57(4), 397-405.

Allen, T. R., Bara, T. J., and Walsh, S. J. (1994). "Observed Biases in the Conterminous US AVHRR Satellite Data Set: A North Carolina Case Study." *Geocarto, International*, 9(2), 52-62.

Anderson, J. R., Hardy, E. E., Roach, J. T., and Witmer, R. E. (1976). "A Land Use and Land Cover Classification System for Use with Remote Sensor Data." *96*4, US Geological Survey, Washington, DC.

Avery, T. E., and Berlin, G. L. (1985). *Interpretation of Aerial Photographs*, Macmillan Publishing Company.

Avery, T. E., and Berlin. G. L. (1992). Fundamentals of Remote Sensing and Airphoto Interpretation, Macmillan Publishing Co., New York, NY.

Baker, R. D. (1989). "Remote Sensor and other Data Sources for Timber Use-Value Assessment." *Photogrammetric Engineering and Remote Sensing*, 55(6), 901-902.

Befort, W. (1986). "Large-Scale Sampling Photography for Forest Habitat-Type Identification." *Photogrammetric ngineering and Remote Sensing*, 52(1), 101-108.

Bolstad, P. V., and Stowe, T. (1994). "An Evaluation of DEM Accuracy: Elevation, Slope, and Aspect." *Photogrammetric Engineering and Remote Sensing*, 60(11), 1327-1332.

Boyd, W.E. (1986). "Correlation of Rangelands Brush Canopy Cover with Landsat MSS Data." *Journal of Range Management*, 39(5), 268-271.

Brannon, R., Yuill, C. B., Warner, T. A., and Perry, S. A. "Mapping Plant Community Alliances in the Central Appalachian Mountains: Spatial Sorting of an Unsupervised Classification of Multi-Temporal Thematic Mapper Data." *ASPRS/ACSM Annual Convention and Exhibition*, Baltimore, MD, 110-121.

Breininger, D.R., Larson, V.L., Duncan, B.W., Smith, R.B, Oddy, D.M., and Goodchild, M.F. (1995). "Landscape Patterns of Florida Scrub Jay Habitat Use and Demographic Success." *Conservation Biology*, 9(6), 1442-1453.

Breininger, D. R., Provancha, M. J., and Smith, R. B. (1991). "Mapping Florida Scrub Jay Habitat for Purposes of Land-Use Management." *Photogrammetric Engineering and Remote Sensing*, 57(11), 1467-1474.

Briggs, J. M., and Nellis, M. D. (1991). "Seasonal Variation of Heterogeneity in the Tallgrass Prarie: A Quantitative Measure Using Remote Sensing." *Photogrammetric Engineering and Remote Sensing*, 57(4), 407-411.

Brockhaus, J. A., Khorram, S., Bruck, R., and Campbell, M. V. (1993). "Characterization of Defoliation Conditions Within a Boreal Montane Forest Ecosystem." *Geocarto International*, 8(1), 35-42.

Cablk, M. E., Kjerfve, B., Michener, W. K., and Jensen, J. R. (1994). "Impacts of Hurricane Hugo on a Coastal Forest: Assessment Using Landsat TM Data." *Geocarto International*, 9(2), 15-24.

Campbell, J. B. (1987). *Introduction to Remote Sensing*, The Guilford Press.

Carter, G.A., and Miller, R. L. (1994). "Early Detection of Plant Stress by Digital Imaging within Narrow Stress-Sensitive Wavebands". *Remote Sensing of the Environment* 50: 295-302.

Carey, J. (1995). "The Next Space Race: Snapshots?" Science and Technology Business Week.

Carter, G.S., Dell, T.R., and Cibula, W.G. (1996). "Spectral Reflectance Characteristics and Digital Imagery of a Pine Needle Blight in the Southeastern United-States." *Canadian Journal of Forest Research-Revue Canadienne De Recherche Forestiere, 26(3) 402-407.*

Carter, V., Malone, D., and Burbank, J. (1979). "Wetland Classification and Mapping in Western Tennessee." *Photogrammetric Engineering and Remote Sensing*, 45(3), 273-284.

Chapman, S. B., Kettle, W. D., and Rich, P. M. "Assessing Shrub Distribution and Impact in Tallgrass Prairie Using Aerial and Ground-Based Mapping." *ACSM/ASPRS*, New Orleans, LA, 13-20.

Chavez, J., P.S., and Kwarteng, A. Y. (1989). "Extracting Spectral Contrast in Landsat Thematic Mapper Image Data Using Selective Principal Component Analysis." *Photogrammetric Engineering and Remote Sensing*, 55(3), 339-348.

Chavez, P.S.,Jr., and MacKinnon, D.J. (1994). "Automatic Detection of Vegetation Changes in the Southwestern United States Using Remotely Sensed Images." *Photogrammetric Engineering And Remote Sensing*, 60(5), 571-583.

Chou, Y., Minnich, R. A., Salazar, L. A., Power, J. D., and Dezzani, R. J. (1990). "Spatial Autocorrelation of Wildfire Distribution in the Idyllwild Quadrangle, San Jacinto Mountain, California." *Photogrammetric Engineering and Remote Sensing*, 56(11), 1507-1513.

Ciesla, W. M., Dull, C. W., and Acciavatti, R. E. (1989). "Interpretation of SPOT-1 Color Composites for Mapping Defoliation of Hardwood Forests by Gypsy Moth." *Photogrammetric Engineering and Remote Sensing*, 55(10), 1465-1470.

Cole, J. (1995). "Eyes in the Skies New Satellite Imaging Could Soon Transform the Face of the Earth." Wall Street Journal, New York City.

Collins, J. B., and Woodcock, C. E. (1996). "An Assessment of Several Linear Change Detection Techniques for Mapping Forest Mortality Using Multitemporal Landsat TM Data." *Remote Sensing of Environment*, 56(1), 66-77.

Conrad, D. J., and Wagner, T. W. (1996). "Improving Vegetation Monitoring and Assessment." *Earth Observation Magazine*, 5(9), 32-34.

Cook, E. A., Iverson, L. R., and Graham, R. L. (1989). "Estimating Forest Productivity with Thematic Mapper and Biogeographical Data." *Remote Sensing of Environment*, 28, 131-141.

Drake, S. (1996). "Visual Interpretation of Vegetation Classes from Airborne Videography: An Evaluation of Observer Proficiency with Minimal Training." *Photogrammetric Engineering and Remote Sensing*, 62(8), 969-978.

Dunham, J. W., and Price, K. P. "Analysis of Nadir and Off-Nadir Hyperspectral and Sunfleck Measurements for Six Prairie Treatments in Kansas." *ACSM/ASPRS*, New Orleans, LA, 54-65.

Dunham, J. W., and Price, K. P. (1996). "Comparison of Nadir and Off-Nadir Multispectral Response Patterns for Six Tallgrass Prairie Treatments in Eastern Kansas." *Photogrammetric Engineering and Remote Sensing*, 62(8), 961-967.

Eastes, J. W. "Infrared Spectral Properties of Some Desert Soils: Implications for Forecasting Vehicle Trafficability and Dust Potential in Arid Regions." *ASPRS/ACSM Annual Convention and Exhibition*, Baltimore, MD, 424-432.

Evans, D.L. (1994). *Forest Cover from Landsat Thematic Mapper Data for use in the Catahoula Ranger District Geographic Information System*. U.S. Dept. of Agriculture. Forest Service General Technical Report, 99.

Evans, D. L., and Smith, M. O. (1991). "Separation of Vegetation and Rock Signatures in Thematic Mapper and Polarimetric SAR Images." , Remote Sensing of Environment, 63-75.

Everitt, J.H., Escobar, D.E., Alaniz, M.A., Davis, M.R., and Richerson, J.V. (1996). "Using Spatial Information Technologies to Map Chinese Tamarisk (Tamarix Chinensis) Infestations." *Weed Science,* 44(1), 194- 201.

Everitt, J.H., Judd, R.W., Escobar, D.E., and Davis, M.R. (1996). "Integration of Remote-Sensing and Spatial Information Technologies for Mapping Black Mangrove on the Texas Gulf-Coast." *Journal of Coastal Research*, 12(1), 64-69.

Everitt, J. H., Lulla, K., Escobar, D. E., and Richardson, A. J. (1990). "Aerospace Video Imaging Systems for Rangeland Management." *Photogrammetric Engineering and Remote Sensing*, 56(3), 343-349.

Faust, N. L. (1989). "Image Enhancement." Volume 20, Supplement 5 *of Encyclopedia of Computer Science and Technology*, edited by Allen Kent and James G. Williams. New York: Marcel Dekker, Inc.

Felix, N. A., and Binney, D. L. (1989). "Accuracy Assessment of a Landsat-Assisted Vegetation Map of the Coastal Plain of the Arctic National Wildlife Refuge." *Photogrammetric Engineering and Remote Sensing*, 55(4), 475-478.

Fiorella, M. and Ripple, W.J. (1993). "Analysis of Conifer Forest Regeneration Using Landsat Thematic Mapper Data." *Photogrammetric Engineering And Remote Sensing,* 59(9), 1383-1388.

Fiorella, M., and Ripple, W. J. (1993). "Determining Successional State of Temperate Coniferous Forests with Landsat Satellite Data." *Photogrammetric Engineering and Remote Sensing*, 59(2), 239-246.

Fouche, P. S., and Booysen, N. W. (1994). "Assessment of Crop Stress Conditions Using Low Altitude Aerial Color-infrared Photography and Computer Image Processing." *Geocarto International*, 9(2), 25-31.

Frank, T. D. (1988). "Mapping Dominant Vegetation Communities in the Colorado Rocky Mountain Front Range with Landsat Thematic Mapper and Digital Terrain Data." *Photogrammetric Engineering and Remote Sensing*, 54(12), 1727-1734.

Frank, T. D., and Isard, S. A. (1986). "Alpine Vegetation Classification Using High Resolution Aerial Imagery and Topoclimatic Index Values." *Photogrammetric Engineering and Remote Sensing*, 52(3), 381-388.

Franklin, J., Davis, F. W., and Lefebvre, P. (1991). "TM Analysis of Tree Cover in Semiarid Woodlands Using a Model of Canopy Shadowing." *Remote Sensing of Environment*, 36, 189-202.

Franklin, S. E. (1994). "Discrimination of Subalpine Forest Species and Canopy Density Using Digital CASI, SPOT, PLA, and Landsat TM Data." *Photogrammetric Engineering and Remote Sensing*, 60(10), 1233- 1241.

Frazier, B. E., and Cheng, Y. (1989). "Remote Sensing of Soils in the Eastern Palouse Region with Landsat TM." *Remote Sensing of Environment*, 28, 317-325.

Goodin, D. G., Han, L., Fraser, R. N., Rundquist, D. C., Stevvins, W. A., and Schalles, J. F. (1993). "Analysis of Suspended Solids in Water Using Remotely Sensed High Resolution Derivative Spectra." *Photogrammetric Engineering and Remote Sensing*, 59(4), 505-510.

Greer, J. D. (1994). "GIS and Remote Sensing for Wildland Fire Suppression and Burned Area Restoration." *Photogrammetric Engineering and Remote Sensing*, 60(9), 1059-1064.

Gumbricht, T., McCarthy, J., and Mahlander, C. (1996). "Digital Interpretation and Management of Land-Cover - A Case-Study of Cyprus." *Ecological Engineering*, 6(4), 273-279.

Heilman, J. L., and Boyd, W. E. (1986). "Soil Background Effects on the Spectral Response of Three-Component Rangeland Scene." *Remote Sensing of Environment*, 19, 127-137.

Helt, T. F., Dobos, E., Micheli, E., Baumgardner, M. F., and Johannsen, C. J. "Integration of Satellite Remote Sensing, Digital Terrain Data, and Soils Information for Quantitative Soil and Terrain Database Development." *ASPRS/ACSM Annual Convention and Exhibition*, Baltimore, MD, 109.

Henley, J. P., and Buntzen, R. "Spectral Reflectance Characteristics of Grass Damaged by Military Vehicle Traffic." *ASPRS/ACSM Annual Convention and Exhibition*, Baltimore, MD, 418-423.

Herr, A. M., and Queen, L. P. (1993). "Crane Habitat Evaluation Using GIS and Remote Sensing." *Photogrammetric Engineering and Remote Sensing*, 59(10), 1531-1538.

Hewitt, M. (1990). "Synoptic Inventory of Riparian Ecosystems: The Utility of Landsat Thematic Mapper Data." *Forest Ecology and Management*, 33-34, 605-620.

Hodgson, M. E., Jensen, J. R., Mackey, J., H.E., and Coulter, M. C. (1987). "Remote Sensing of Wetland Habitat: A Wood Stork Example." *Photogrammetric Engineering and Remote Sensing*, 53(8), 1075-1080.

Hodgson, M. E., Jenson, J. R., Mackey, H. E., and Coulter, M. C. (1988). "Monitoring Wood Stork Foraging Habitat Using Remote Sensing and Geographic Information Systems." *Photogrammetric Engineering and Remote Sensing*, 54(11), 1601-1607.

Hoffer, R. M., Maxwell, S. K., and Ochis, H. W. "Use of Radar Data for Forestry Applications." *ASPRS/ACSM Annual Convention and Exhibition*, Baltimore, MD, 444-453.

Hough, H. (1994). "GIS Modeling Save Utility $10 Million in Flood Study." Earth Observation Magazine, 23-26.

Houhoulis, P. F., and Michener, W. K. "Detection of Vegetation Changes Associated with Tropical Storm Alberto in a Longleaf Pine-Wiregrass Ecosystem." *ASPRS/ACSM Annual Convention and Exhibition*, Baltimore, Maryland, 99-108.

Indorante, S.J., McLeese, R.L., Hammer, R.D., Thompson, B.W., and Alexander, D.L. (1996). "Positioning soil survey for the 21st century", *Journal of Soil and Water Conservation*: 21-28.

Jacobs, D. M., Evans, D. L., and Ritchie, J. C. "Laser profiler and aerial video data for forest assessments." *ASPRS/ACS*M, New Orleans, LA, 135-142.

Jakubauskas, M. E., Lulla, K. P., and Mausel, P. W. (1990). "Assessment of Vegetation Change in a Fire-Altered Forest Landscape." *Photogrammetric Engineering and Remote Sensing*, 56(3), 371-377.

Jensen, J., Hodgson, M., Christensen, E., Mackey, H., Tinney, L., and Sharitz, R. (1986). "Remote Sensing Inland Wetlands: A Multispectral Approach." *Photogrammetric Engineering and Remote Sensing*, 52(1), 87- 100.

Jensen, J., Narumalani, S., and Mackey, J., H. (1991). "Remote Sensing Offers an Alternative for Wetlands Mapping." *Geo Info Systems*.

Jensen, John R. (1996). *Introductory Digital Image Processing: A Remote Sensing Perspective*. Englewood Cliffs, New Jersey: Prentice-Hall.

Jensen, J. R., Ramsey, E. W., Mackey, J., H. E., Christensen, E. J., and Sharitz, R. R. (1987). "Inland Wetland Change Detection Using Aircraft MSS Data." *Photogrammetric Engineering and Remote Sensing*, 53(5), 521-529.

Jensen, P. D., J.R., Narumalani, S., Althausen, J. D., Powell, J. W., Curlis, C., and Mackey, J., Ph.D., H.E. "Analysis of Stereoscopic Aerial Photography and High Resolution Multispectral Scanner Data to Document Historic Logging and Recent Management Practices on a Cypress-Tupelo Forest in South Carolina." *ASPRS/ACSM Annual Convention and Exhibition*, New Orleans, LA, 143.

Jenson, J. R., Narumalani, S., Weatherbee, O., and Mackey, J., H.E. (1993). "Measurement of Seasonal and Yearly Cattail and Waterlilly Changes Using Multidate SPOT Panchromatic Data." *Photogrammetric Engineering and Remote Sensing*, 59(4), 519-525.

Jia, X., and Richards, J.A. (1994). Small class classification for hyperspectral remote sensing data. *Proceedings of the International Geoscience and Remote Sensing Symposium* 1994 (IGARSS'94), Pasadena, CA,USA., (New York: IEEE), pp. 1148-1150.

Johnston, C. A., and Bonde, J. (1989). "Quantitative Analysis of Ecotones Using a Geographic Information System." *Photogrammetric Engineering and Remote Sensing*, 55(11), 1643-1647.

Joria, P. E., Ahearn, S. C., and Connor, M. (1991). "A Comparison of the SPOT and Landsat Thematic Mapper Satellite Systems for Detecting Gypsy Moth Defoliation in Michigan." *Photogrammetric Engineering and Remote Sensing*, 57(12), 1605-1612.

Karteris, M. A. (1988). "Manual Interpretation of Small Forestlands on Landsat MSS Data." *Photogrammetric Engineering and Remote Sensing*, 54(6), 751-755.

Kolm, D.E. (1985). *Evaluation of Techniques for Mapping Land and Crop Irrigated by Center Pivots from Computer-Enhanced Landsat Imagery in part of the James River Basin near Huron, South Dakota.* U.S. Geological Survey Water-Resources Investigations Report 85-1021.

Kumar, A.B., Dwivedi, R.S., and Tiwari, K.N. (1996). "The Effects of Image Scale on Delineation of Eroded Lands Using Remote-Sensing Data." *International Journal of Remote Sensing*, 17(11) 2135-2143.

Lathrop, J., R.G. (1992). "Landsat Thematic Mapper Monitoring of Turbid Inland Water Quality." *Photogrammetric Engineering and Remote Sensing*, 58(4), 465-470.

Lathrop, J., R.G., Castle, J. D. V., and Brass, J. A. (1994). "Monitoring Changes in Greater Yellowstone Lake Water Quality Following the 1988 Wildfires." *Geocarto International*, 9(3), 49-57.

Lathrop, J., R.G., and Lillesand, T. M. (1989). "Monitoring Water Quality and River Plume Transport in Green Bay, Lake Michigan with SPOT-1 Imagery." *Photogrammetric Engineering and Remote Sensing*, 55(3), 349-354.

Lauver, C. L., and Whistler, J. L. (1993). "A Hierarchical Classification of Landsat TM Imagery to Identify Natural Grassland Areas and Rare Species Habitat." *Photogrammetric Engineering and Remote Sensing*, 59(5), 627-634.

Lee, C.T., and March, S.E. (1995). "The Use of Archival Landsat MSS and Ancillary Data in a GIS Environment to Map Historical Change in an Urban Riparian Habitat." *Photogrammetric Engineering and Remote Sensing*, 61(8), 999-1008.

Lillesand, T. M. “Suggested Strategies for Satellite-Assisted Statewide Land Cover Mapping in Wisconsin.” *ACSM/ASPRS*, New Orleans, LA, 193-203.

Lillesand, T.M., and Kiefer, R.W. (1987). "Remote Sensing and Image Interpretation, Second Edition" John Wiley and Sons, New York, New York.

Lillesand, T. M., and Kiefer, R. W. (1994). "Remote Sensing and Image Interpretation, Second Edition" John Wiley and Sons, New York, New York.

Lyon, J. G., and Greene, R. G. (1992). “Use of Aerial Photographs to Measure the Historical Areal Extent of Lake Erie Coastal Wetlands.” *Photogrammetric Engineering and Remote Sensing*, 58(9), 1355-1360.

Lyon, J. G., McCarthy, J. F., and Heinen, J. T. (1986). “Video Digitization of Aerial Photographs for Measurement of Wind Erosion Damage on Converted Rangeland.” *Photogrammetric Engineering and Remote Sensing*, 52(3), 373-377.

Mackey, J., Ph.D., H.E. “Six Years of Monitoring Annual Changes in a Freshwater Marsh with SPOT HRV Data.” *ASPRS/ACSM Annual Convention and Exhibition*, New Orleans, LA, 222-229.

Maracchi, G., Conese, C., Manselli, F., and Bravetti, L. (1996). “Assessment and Examination of Coastal Vegetation Deterioration by Means of Landsat TM Data.” *Journal of Coastal Research*, 12(1) 103-111.

Mahlke, J. E., and Jakubauskas, M. “A Multitemporal Approach to Characterizing Oklahoma Reservoir Wetlands.” *ASPRS/ACSM Annual Convention and Exhibition*, Baltimore, MD, 238-244.

Meyer, P., Staenz, K., and Itten, K. I. (1996). “Semi-Automated Procedures for Tree Species Identification in High Spatial Resolution Data from Digitized Colour Infrared-Aerial Photography.” *ISPRS Journal of Photogrammetry and Remote Sensing*, 51(1), 5-16.

Mills, J. P., and Newton, I. (1996). “A New Approach to the Verification and Revision of Large-Scale Mapping.” *ISPRS Journal of Photogrammetry and Remote Sensing*, 51(1), 17-27.

Mohr, E., Hothem, D., Irvine, J. M., and Erdman, C. “The Multispectral Imagery Interpretability Rating Scale (MS IIRS).” *ASPRS/ACSM Annual Convention and Exhibition*, Baltimore, MD, 300-310.

Moore, M.M. and Bauer, M.E. (1990). “Classification of Forest Vegetation in North-Central Minnesota using Landsat Multispectral Scanner and Thematic Mapper Data.” *Forest Science*, 36(6) 330-342.

Muchoney, D. M., and Haack, B. N. (1994). “Change Detection for Monitoring Forest Defoliation.” *Photogrammetric Engineering and Remote Sensing*, 60(10), 1243-1251.

Mukai, Y., Sugimura, T., Watanabe, H., and Wakamori, K. (1987). “Extraction of Areas Infested by Pine Bark Beetle Using Landsat MSS Data.” *Photogrammetric Engineering and Remote Sensing*, 53(1), 77-81.

Murtha, P. A., and Wiart, R. J. (1989). “Cluster Analysis of Pine Crown Foliage Patterns Aid Identification of Mountain Pine Beetle Current-Attack.” *Photogrammetric Engineering and Remote Sensing*, 55(1), 83-86.

Narumalani, S., and Carbone, G. J. “The Use of Remote Sensing for Crop Simulation Studies.” *ACSM/ASPRS*, New Orleans, LA, 230-239.

Needham, T. D., and Smith, J. L. (1987). “Stem Count Accuracy and Species Determination in Loblolly Pine Plantations Using 35-mm Aerial Photography.” *Photogrammetric Engineering and Remote Sensing*, 53(12), 1675-1678.

Nemani, R., Pierce, L., Running, S., and Band, L. (1993). “Forest Ecosystem Processes at the Watershed Scale: Sensitivity to Remotely-Sensed Leaf Area Index Estimates.” *International Journal of Remote Sensing*, 14(13), 2519-2534.

Olsson, H. (1993). “Regression Functions for Multi-Temporal Relative Calibration of TM Data Over Boreal Forest.” *Remote Sensing of Environment*, 46(1), 89-102.

Ormsby, J. P., and Lunetta, R. S. (1987). “Whitetail Deer Food Availability Maps from Thematic Mapper Data.” *Photogrammetric Engineering and Remote Sensing*, 53(11), 1585-1589.

Paine, D. P., and McCadden, R. J. (1988). “Simplified Forest Inventory Using Large-Scale 70-mm Photography and Tarif Tables.” *Photogrammetric Engineering and Remote Sensing*, 54(10), 1423-1427.

Paisley, E. C. I., Lancaster, N., Gaddis, L. R., and Greeley, R. (1991). “Discrimination of Active and Inactive Sand from Remote Sensing: Kelso Dunes, Mojave Desert, California.” *Remote Sensing of Environment*, 37, 153-166.

Paterson, S., Pultz, T., Saper, R., and Crevier, Y. (1996). “Operational Flood Monitoring: A Reality with RADARSAT?” *Earth Observation Magazine*, 5(9), 18-20.

Pearson, R., Mao, C., and J., G. “Application of an Airborne Multispectral Digital System for Real Time Crop Condition Monitoring.” *ACSM/ASPRS*, New Orleans, LA, 258-264.

Pickup, G., Chewings, V. H., and Nelson, D. J. (1993). “Estimating Changes in Vegetation Cover over Time in Arid Rangelands Using Landsat MSS Data.” *Remote Sensing of Environment*, 43, 243-263.

Pickup, G. and Chewings, V.H. (1996). “Correlations Between DEM-Derived Topographic Indexes and Remotely-Sensed Vegetation Cover in Rangelands.” *Earth Surface Processes and Landforms.* 21(6), 517-529.

Pilon, P. G., Howarth, P. J., Bullock, R. A., and Adeniyi, P. O. (1988). “An Enhanced Classification Approach to Change Detection in Semi-Arid Environments.” *Photogrammetric Engineering and Remote Sensing*, 54(12), 1709-1716.

Post, D.F., Horvath, E.H., and Lucas, W.M. (1994). “Relations Between Soil Color and Landsat Reflectance on Semiarid Rangelands.” *Soil Science Society of America Journal*, 58 (11/12), 1809-1816.

Price, K. P., Pyke, D. a., and Mendes, L. (1992). “Shrub Dieback in a Semiarid Ecosystem: The Integration of Remote Sensing and Geographic Information Systems for Detecting Vegetation Change.” *Photogrammetric Engineering and Remote Sensing*, 58(4), 455-463.

Qiang, T., Lewis, A. J., and Braud Jr., D. H. “Change Detection Using Multi-Temporal Feature Space with Digital TM Data.” *ACSM/ASPRS*, New Orleans, LA, 364-373.

Ramsey, E.W. and Jensen, J.R. (1996). “Remote-Sensing of Mangrove Wetlands - Relating Canopy Spectra to Site-Specific Data.” *Photogrammetric Engineering and Remote Sensing*, 62(8) 939-948.

Reid, R. N. D., Vickery, P. J., Hedges, D. A., and Williams, P. M. (1993). “Measuring the Response of Pasture to Superphosphate Using Aircraft and Satellite Remote Sensing.” *Australian Journal of Experimental Agriculture*, 33(5), 597-600.

Ritchie, J. C., Cooper, C. M., and Schiebe, F. R. (1990). “The Relationship of MSS and TM Digital Data with Suspended Sediments, Chlorophyll, and Temperature in Moon Lake, Mississippi.” *Remote Sensing of Environment*, 33, 137-148.

Rizzo, E., Rogers, A. S., Kearney, M. W., Townshend, J. R. G., and Lawrence, W. T. “Changes in Blackwater Marsh, Maryland , 1938-1993, Determined by Aerial Photography and Thematic Mapper Data.” *ASPRS/ACSM Annual Convention and Exhibition*, Baltimore, MD, 220-229.

Roseberry, J. L., Richards, B. J., and Hollenhorst, T. P. (1994). “Assessing the Potential Impact of Conservation Reserve Program Lands on Bobwhite Habitat Using Remote Sensing, GIS, and Habitat Modeling.” *Photogrammetric Engineering and Remote Sensing*, 60(9), 1139-1143.

Rutchey, K., and Vilcheck, L. (1994). “Development of an Everglades Vegetation Map Using a SPOT Image and the Global Positioning System.” *Photogrammetric Engineering and Remote Sensing*, 60(6), 767-775.

Satterwhite, M. B., and Henley J. P. (1990). Hyperspectral signatures (400 to 2500 nm) of vegetation, minerals, soils, rocks, and cultural features Fort Belvoir, Va.: U.S. Army Corps of Engineers, Engineer Topographic Laboratories.

Schriever, J.R. and Congalton, R.G. (1995). “Evaluating Seasonal Variability as an Aid to Cover-Type Mapping from Landsat Thematic Mapper Data in the Northeast.” *Photogrammetric Engineering and Remote Sensing*, 61(3), 321-327.

Schriever, J. R., and Congalton, R. G. “Mapping Forest Cover-Types of New Hampshire Using Multi-Temporal Landsat TM Data.” *ACSM/ASPRS*, New Orleans, LA, 333-342.

Scott, A. (1994). “Low-Cost Remote-Sensing Techniques Applied to Drainage Area Studies.” *Journal of the Institution of Water and Environmental Management,* 8(5), 497-501.

Senseman, G. M., Nellis, M. D., and Robel, R. J. (1994). “Spatial Analysis of SPOT HRV Digital Data for Measuring Landscape Parameters of Prairie Dog Towns in Meade County, KS.” *Geocarto International*, 9(2), 45-50.

Sharma, S. K., Mukherjee, P. K., Singh, K. P., and Singh, R. N. (1993). “Microwave Remote Sensing of Wheat Affected by Thunderstorms and Rain.” *Advances in Space Research*, 13(11), 135-138.

Singh, A. (1989). Digital change detection techniques using remotely-sensed data, *International Journal of Remote Sensing*, Vol. 10, No. 6. 989-1003

Smith, M. O., Ustin, S. L., Adams, J. B., and Gillespie, A. R. (1990). “Vegetation in Deserts: I. A Regional Measure of Abundance from Multispectral Images.”, *Remote Sensing of Environment*, 27-52.

Spell, R. E., and Ramsey, I., E.W. “Spectral Reflectance and Canopy Structure Characteristics of Gulf Coast Wetland Vegetation Types.” *ASPRS/ACSM Annual Convention and Exhibition*, New Orleans, LA, 353-363.

Spies, T.A, Riple, W.J., and Bradshaw, G.A. (1994). “Dynamics and Pattern of a Managed Coniferous Forest Landscape in Oregon.” *Ecological Applications*, 4(3), 555-568.

Steinmaus, K.L., Reith, E., Lundeen, T. L., Perry, E. M. (1997). Improved Landcover Classification Using Multisensor Data, Proceedings of the ACSM/ASPRS, April 7-10, 1997, Seattle, Washington, Volume 3, *Remote Sensing and Photogrammetry*, p 155.

Stenback, J. M., and Barrett, R. H. (1993). “Mapping Deer Habitat Suitability Using Remote Sensing and Geographic Information Systems.” *Geocarto International*, 8(3), 23-33.

Stenback, J. M., and Congalton, R. G. (1990). “Using Thematic Mapper Imagery to Examine Forest Understory.” *Photogrammetric Engineering and Remote Sensing*, 56(9), 1285-1290.

Stille, A. (1996). “Farsighted Tools Bring Ruins Into Focus.” The Washington Post, Washington, DC, A3.

Taconet, O., Vidal-Madjar, D., Emblanch, C., and Normand, M. (1996). “Taking Into Account Vegetation Effects to Estimate Soil Moisture from C-Band Radar Measurements.” *Remote Sensing of Environment*, 56(1), 52-56.

Talbot, S. S., and Markon, C. J. (1988). “Intermediate-Scale Vegetation Mapping of Innoko National Wildlife Refuge, Alaska Using Landsat MSS Digital Data.” *Photogrammetric Engineering and Remote Sensing*, 54(3), 377-383.

Thelin, G.P. (1987). *Mapping Irrigated Cropland from Landsat Data for Determination of Water Use From the High Plains Aquifer in Parts of Colorado, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming*. U.S. Geological Survey Professional Paper 1400-C.

Thomasson, J.A., Bennett, C.W., and Jackson, B.D. (1994). “Differentiating Bottomland Tree Species with Multispectral Videography.” *Photogrammetric Engineering and Remote Sensing*, 60(1), 55-59.

Tiner, R. W., and Smith, G. S. (1992). “Comparisons of Four Scales of Color Infrared Photography for Wetland Mapping in Maryland.” , US Department of the Interior.

Todd, S.W. (1994). “Spatiotemporal Estimation of Biomass on the Shortgrass Steppe using Landsat TM Vegetation and Soil Indices, Field Data, and Simulation Models (Thematic Mapper).” Dissertation, Colorado State University.

Tripathy, G.K., Ghosh, T.K., and Shah, S.D. (1996). “Monitoring of Desertification Process in Karnataka State of India Using Multitemporal Remote-Sensing and Ancillary Information Using GIS.” *International Journal of Remote Sensing*, 17(12), 2243-2257.

Tueller, P. T., Lent, P. C., Stager, R. D., Jacobsen, E. A., and Platou, K. A. (1988). “Rangeland Vegetation Changes Measured from Helicopter-Borne 35-mm Aerial Photography.” *Photogrammetric Engineering and Remote Sensing*, 54(5), 609-614.

U.S. Geological Survey (1996). "Standards for Digital Orthophotos, Specifications: Reston, Virginia", U.S. Geological Survey

U.S. Geological Survey (1989). "North American Datum of 1983--Map Data Conversion Tables", U.S. Geological Survey Bulletin 1875, 3 v.

Varjo, J. (1996). “Controlling Continuously Updated Forest Data by Satellite Remote-Sensing.” *International Journal of Remote Sensing*, 17(1) 43-67.

Verbyla, D. L., Jazouli, D., and Murphy, D. L. “Evaluation of SPOT Panchromatic Digital Imagery For Updating Road Locations in a Harvested Forest Area.” *ASPRS/ASC*M, New Orleans, LA, 408-414.

Walsh, S. J. “Spatial and Biophysical Analysis of Alpine Vegetation through Landsat TM and SPOT MX/PAN Data.” *ASPRS/ACSM Annual Convention and Exhibition*, New Orleans, LA, 426-437.

Warner, T. A., Campagna, D. J., Evans, C. S., Levandowski, D. W., and Cetin, H. (1991). “Analyzing Remote Sensing Geobotanical Trends in Quetico Provincial Park, Ontario, Canada, Using Digital Elevation Data.” *Photogrammetric Engineering and Remote Sensing*, 57(9), 1179-1183.

Warner, T. A. (1997). Multisensor Classification for Land-Cover Mapping at Fort Benning, GA. Report to the Remote Sensing Group, Pacific Northwest National Laboratory, Richland, WA. 9pp.

Warner, T. A. (1997). NPDF Land-Cover Classification of Mosaicked Daedalus Data of Fort Benning, GA. Report to the Remote Sensing Group, Pacific Northwest National Laboratory, Richland, WA. 9pp.

Welch, R., Remmillard, M. M., and Slack, R. B. (1988). “Remote Sensing and Geographic Information System Techniques for Aquatic Resource Evaluation.” *Photogrammetric Engineering and Remote Sensing*, 54(2), 177-185.

Winterberger, K. C., and Larson, F. R. (1988). “Measuring Crown Cover in Interior Alaska Vegetation Types.” *Photogrammetric Engineering and Remote Sensing*, 54(3), 385-387.

Woodbury S., Wendy, L.S. (1998). *Exploring a New Reference System*, Civil Engineering News, Inc.

Wu, Y.C. and Strahler, A.H. (1994). “Remote Estimation of Crown Size, Stand Density, and Biomass on the Oregon Transect.” *Ecological Applications,* 4(2), 299-312.

Xu, B. B., Li, D. C., Shi, X. R. (1995). "A preliminary study on identification of clay minerals in soils with reference to reflectance spectra." *Pedosphere*, vol. 5 (2): p.135-142.

Zebker, H. A., Werner, C. L., Rosen, P. A., and Hensley, S. (1994). “Accuracy of Topographic Maps Derived from ERS-1 Interferometric Radar.” *Transactions on Geoscience and Remote Sensing*, 32(4).