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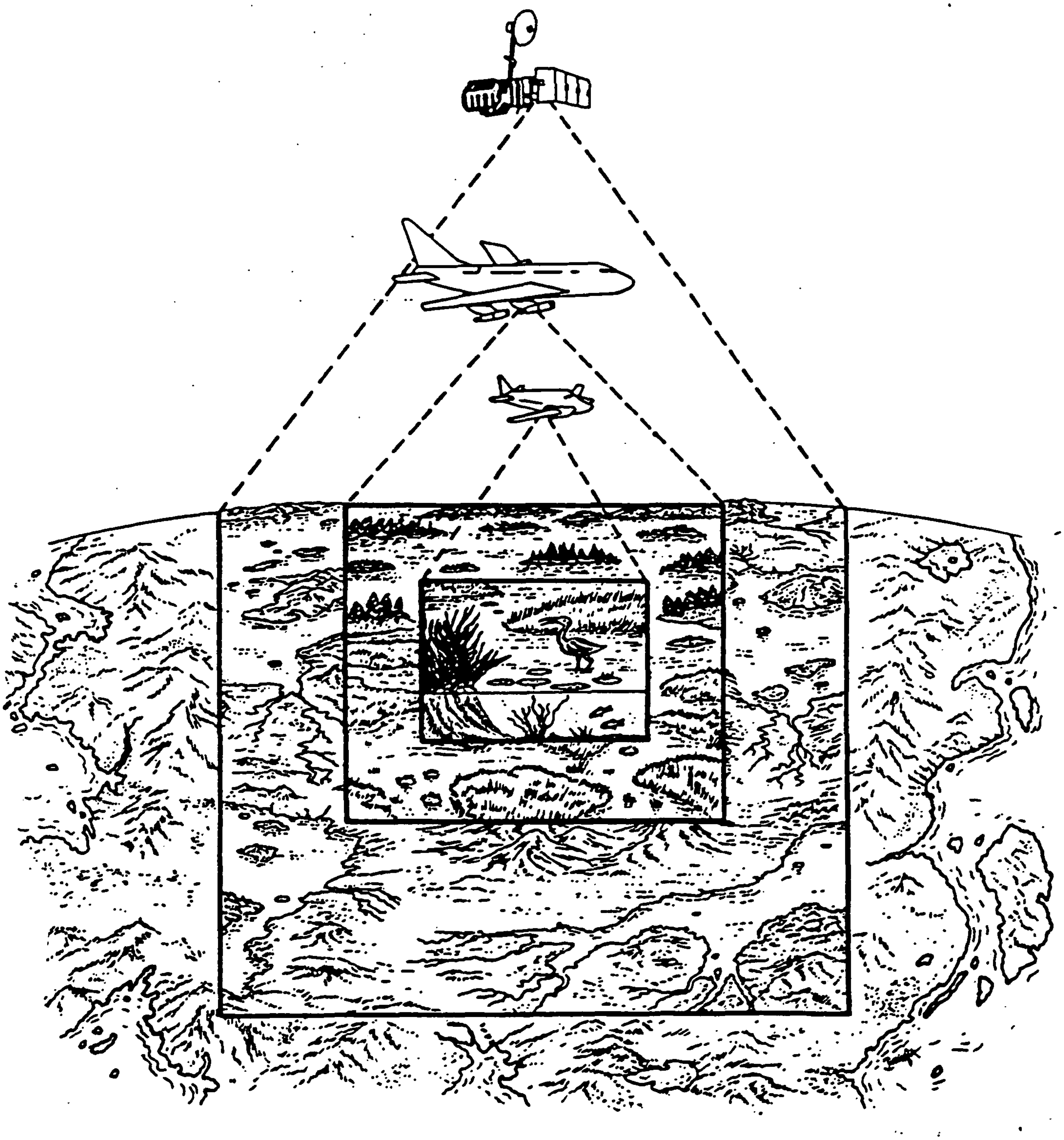

WETLANDS DETECTION METHODS INVESTIGATION

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ABSTRACT

The purpose of this investigation was to research and document the application of remote sensing technology for wetlands detection. Various sensors and platforms are evaluated for: suitability to monitor specific wetland systems; effectiveness of detailing wetland extent and capability to monitor changes; and relative cost-benefits of implementing and updating wetlands databases.

The environment to be monitored consists of physiographic and ecological wetland resources affected directly or indirectly by anthropogenic activity. Aircraft and satellite remote sensing can be used to record and assess the condition of these resources. Monitoring of environmental conditions is based on the observation and interpretation of certain landscape features. Although some forms of monitoring are continuous, resource monitoring from aircraft and satellite platforms is periodic in nature, with change being documented through a series of observations over a given span of time.

This report summarizes the findings of a bibliographic search on the methods used to inventory and/or detect changes in wetland environments. The bibliography contains numerous citations and is not intended to be all-inclusive. Books, major journal and symposium proceedings were examined. The findings documented will provide the potential user with a basic understanding of remote sensing technology as it is applied to wetland monitoring and trend analysis.

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INTRODUCTION

There are two primary types of remote sensing projects relative to wetlands. The first, resource mapping, involves acquisition of baseline data on type, extent, and health of wetland communities. The second involves detection of change, either natural or anthropogenic, in those communities.

Most of the potential users of this data are responsible for the management and protection of the wetland resources within their respective states. To accomplish this, various types of data are required for decision making. In considering use of remote sensing sensors and systems to provide such data, several factors must be considered. What levels of precision and accuracy are required in identifying and measuring wetland resources? How much "leeway" will be tolerated in the correct identification of wetland communities? How "close" can the estimation of areal extent of specific wetland types be when compared to actual acreage? This factor of precision must be viewed from an economic standpoint, i.e., what is the relative cost of each system versus its degree of precision?

Wetlands are dynamic ecosystems which are defined by federal regulating agencies as possessing three essential characteristics: (1) hydrophytic vegetation, (2) hydric soils, and (3) wetland hydrology, which is the driving force creating all wetlands (Federal Interagency Committee for Wetland Delineation, 1989). These ecosystems are difficult to quantify because of complex interactions between these parameters. Water level fluctuations and diverse geographic settings make the many types of wetlands difficult to characterize as a group. Changes occur in wetlands and along boundaries in response to variations in the hydrologic cycle in which seasonal, annual, and long term fluctuations are the driving factors. Wetlands are also changed, altered, and encroached upon by human activity, such as urban and agricultural developments, stream channel alterations, and draining and damming activities.

REMOTE SENSING OF WETLANDS

When wetlands are to be inventoried several issues need to be addressed about the method in which the baseline or change data should be acquired, categorized, verified, integrated, stored, and distributed. Because wetlands generally have poor accessibility due to uneven and unstable terrain and frequently tall vegetation, any field work undertaken to inventory them is usually expensive, time consuming, and sometimes inaccurate in location. Reducing the amount of field work via remote sensing (aerial photography, aircraft or satellite multispectral scanners) is a viable solution. Baseline inventorying should consider climatological influences, and generally should have a multi-seasonal approach to capture all the inherent variances of plant phenology. If wetland maps are based on persistence and extent of surface water alone, their boundaries will vary seasonally. Change detection and trend analysis requires ecological information be collected under optimum conditions so valid comparisons can be made between several points in time. The availability of current and historical climatological and image data are relevant in the wetland inventory planning process. Roller (1977) lists the advantages to monitoring wetlands with remotely sensed data over conventional field surveys as: (1) economy, (2) timeliness, (3) favorable viewing perspective, (4) synoptic observation, and (5) permanent graphic records. It should be added that with the advent of geographic information systems (GIS), land cover/land use data layers derived from aircraft or satellite-mounted multispectral sensors or digitally encoded aerial photographs, can be incorporated fairly easily since their formats are digital. Furthermore, remotely sensed data collected for wetland change or monitoring activities may be utilized in future projects not under consideration at the time of acquisition. With more sophisticated digital image processing techniques available, imagery can be enhanced to answer other environmental questions. Limitations of monitoring wetlands with remotely sensed data are evident when detailed environmental information is required, such as a complete floristic make-up of a plant community, or if controversial regulatory decisions are to be made regarding boundary delineation. Generally there are requirements for field verification (reference data) in order to attach reliability or confidence estimates to the inventory. Logistic difficulties can arise because ideally ground reference data collection should coincide with the acquisition of the remotely sensed data.

When planning wetland inventories or change detection studies which will utilize remotely sensed data, a classification system must be selected or derived which will satisfy the users requirements. Many times the resulting wetland information derived may not be directly compatible or comparable to previously used classification systems or available reference data. Therefore, the end-user must decide the inventory level of detail (vegetal components, minimum mapping unit, classification scheme, etc.) and whether multistage and/or multitemporal sampling is required. Relationships that exist between the desired mapping parameters and pre-existing classifications may form the basis for the final classification scheme. If the classification system is hierarchial, it can be amended when information is attained at a higher level of detail. For instance, satellite data could be used to map an entire state and/or region, small scale photographs for regions and counties, large scale photographs for counties and townships, and hand-held oblique photos from light aircraft or helicopter, with ground transects or plot sampling for individual wetland systems (Roller, 1977).

Howland (1980) found that differentiation between vegetation signatures was best in the longer wavelengths (red through infrared) for the broad variety of wetlands occurring in northern New England. This phenomenon is attributed to the green biomass of vegetation which uniquely absorbs visible light and strongly reflects near infrared (IR). Chlorophyll absorption in the visible spectrum and multiple scattering in the near-IR due to internal plant structure allows for the characterization of vegetative communities based on spectral patterns. In general, vegetation canopies have bidirectional reflectance, but patterns can be further influenced by the understory component, leaf structures, density of vegetation, etc. Furthermore, water absorbs a majority of the infrared energy which results in a sharp contrast between vegetation and water in the IR wavelengths.

Visible wavelengths are more sensitive to atmospheric haze and particle scattering, although the blue-green spectrum can penetrate water for short distances. When submergent vegetation is being targeted, collection of remotely sensed data in the visible wavelengths can provide superior results under the right atmospheric and hydraulic conditions.

Schloesser et al., (1985) found that low-altitude color aerial photography (1:6,000 scale) with limited ground survey information, could economically identify beds of submerged macrophytes in the St. Clair-Detroit River system. Conditions of minimal cloud cover with acquisition time at approximately solar noon allowed maximum solar illumination and water penetration with minimal sun glint. Five macrophyte genera and a sand substrate category were delineated on the photos with a overall accuracy of 68% by six individual interpreters of varying experience. The authors suggest that improved accuracy could result from a more detailed dichotomous key, and greater use of biological experience in development of the key.

CLASSIFICATION SYSTEMS

There are a variety of classification systems used which are generally tailored to satisfy the needs of resource managers who must monitor and regulate wetlands under specific mandates. The result of different systems is maps and inventory products which are not mutually compatible, i.e. different scales, media formats, minimum mapping units, and classification schemes. Moreover, all classification systems are not designed to incorporate the results of digital remote sensing, thereby requiring modifications and/or ancillary data to be incorporated into the inventory to make them complete or compatible.

In 1979, the U.S. Fish & Wildlife Service (USFWS) published a nationwide classification system (Cowardin, et al., 1979) for use in the National Wetlands Inventory (NWI). The Cowardin classification strategy utilizes a hierarchial approach where "Systems" form the highest level. Five systems are defined as marine, estuarine, riverine, lacustrine, and palustrine. Marine and estuarine each have two subsystems, subtidal and intertidal; the riverine has four subsystems, tidal, lower perennial, upper perennial, and intermittent; the lacustrine has two, littoral and limnetic; and the palustrine has no subsystems (Cowardin, et al., 1979). Subsystems contain classes which are based on substrate material, water regime, or vegetative type, and can be further defined within subclass. Dominance type is a level subordinate to subclass and describes the dominant plant or animal species. Special modifiers can also be identified, such as water regime or water chemistry modifiers, and others which describe animal or human modifications to the wetland. This FWS classification is designed to allow: (1) ecological units which contain homogenous attributes to be described and grouped; (2) organization of these units to facilitate resource management decisions; (3) consistent inventory and mapping of wetlands on a national level; and (4) uniformity in concepts and terminology (Cowardin, et al., 1979). The Cowardin system replaced the previous system employed by FWS in their 1955 nationwide wetland inventory which was designed to emphasize the value of wetlands for general wildlife and waterfowl habit, i.e. Circular 39 (Martin, et al., 1953, Shaw and Fredine, 1956).

The accuracy of the NWI has never been tested for the nation as a whole, but a few assessments have been done which compare the NWI classification to localized wetland mapping results. Problems arise when comparisons are made between digitally processed land cover/land use data and a classification system like Cowardin which is designed for use with medium-to-large scale aerial photography. Only generalized classes can be compared when utilizing digital classifications of satellite or aircraft based scanners for comparisons with existing NWI data. An overall identification accuracy of 95 percent was determined by Swartwout, et al. (1981) for the NWI in Massachusetts. Hardin (1985), found similar accuracies for the NWI in Delaware. Luman (1990), found good correspondence in Illinois when the NWI information was regrouped and then compared to satellite-based classifications. Pickus (1990), also found high correspondence (90%) when comparing NWI digital data, that was re-grouped as wetland versus non-wetland, to a satellite-based land cover classification in southeast Louisiana.

There is also a classification system developed by the U.S. Geological Survey (USGS) which is a multi-purpose land use/land cover system designed for remotely sensed data (Anderson, et al., 1976). This system is also hierarchial with a framework of nine general Level 1 categories that are further subdivided into 37 Level 2 categories. Higher detailed categories can be designed into the system to suit the user at the third and fourth levels. Wetland is one of nine Level 1 categories, with a subdivision at the Level 2 for forested versus non-forested wetlands. The flexibility to either generalize or specify species at higher levels allows inventory compatibility when the remotely sensed or ancillary inventory data obtained is not described to the same level of detail. The higher levels (i.e., 3 and 4) are not usually attainable strictly from remotely sensed data, and normally require ancillary information.

PHOTO-INTERPRETIVE PROCESS

The interpretation of aerial photographs to accurately map specific wetland vegetation and boundary information is the most common method utilized by Federal, State, and local agencies. Photo analysis involves the identification and delineation of specific features recognizable by their distinct "signatures" (combinations of image characteristics). These characteristics include: tone, texture, shape, size, shadow height, and spatial relationship. Additionally, examination of the aerial photos stereoscopically enables the interpreter to observe the vertical as well as the horizontal spatial relationships of the subject features. Due to the complexity of the interpretative process and the wealth of data within aerial photos, accurate photo interpretation requires considerable expertise. The accuracy of the interpretations depends on the quality of photography, the experience of the photo-analyst with specific wetland settings, and the amount of ground truth verification to be conducted.

Photographic systems acquire spectral information with films of various spectral sensitivities. In order to maximize the photo-interpretation result, it is important to select a film type which will provide maximum contrast between different plant communities. Choices available for camera systems are color, color infrared, and panchromatic (i.e. black/white) films. Table 1 lists the spectral region and season recommended by Roller (1977), in which to collect aerial photography that would take advantage of phenological differences among common wetland vegetation.

TABLE 1
SPECTRAL REGIONS FOR WETLAND VEGETATION DISCRIMINATION (Roller 1977)

Vegetation type	Season of maximum contrast	Spectral region
Aquatic submergent		
shallow depths	Summer	Near infrared
deeper depths	Fall	Visible
Floating	Summer	Near infrared
Marsh emergent and meadow	Fall	Visible
Shrubs	Summer or Fall	Visible or Near IR
Trees	Fall	Visible

SMALL SCALE PHOTOGRAPHY

The most notable resource mapping effort is that of the National Wetland Inventory (NWI) conducted by the USFWS. Begun in 1977, it creates in map form a database of the Nation's wetlands and deepwater habitats. Updates of specific areas are also conducted to document wetland gains or losses. NWI products have included detailed maps, wetland soils and plant lists, and reports on specific regions or states. Color infrared photography (1:58,000 scale) was acquired nationwide between 1981-1984 by the U.S.G.S. under the National High Altitude Aerial Photography Program (NHAP). Photo interpretations derived from NHAP photography for the NWI were categorized by dominant vegetation and hydrologic characteristics according to the USFWS classification system. The NWI identifies and maps wetlands to the smallest acreage visible on the photographs being used (Carter, 1982). The resulting NWI maps were produced using USGS 1:24,000 scale topographic maps as a base. These topographic quadrangles (when available) are used as base maps because they provide a geometrically accurate starting point on which to compile more recent photo-interpreted information. Standard USGS topographic maps depict vegetative categories by unbounded symbols which makes them useful only for gross generalizations. The smallest area that can be depicted on a 1:24,000 scale map is about 0.4 hectare (0.9 acre). Starting in 1988, the USGS has initiated another nationwide acquisition of high flight CIR photography that is scheduled to be completed in 1992. The National Aerial Photography Program (NAPP) will collect 1:40,000 scale CIR, leaf-on, quarter quad-centered photography on a state-by-state basis.
Small scale CIR photography other than NHAP and NAPP have been utilized to map wetlands. Carter et al. (1979) found that a 1:130,000 scale photograph had a recognizable or interpretable limit of approximately 0.5 hectare (1.2 acre). This fact underscores the need to define the level of detail the wetland inventory will require based on its ultimate use. Wetland mapping projects are usually individually designed programs geared to satisfy either legal requirements for regulation, the needs of the mapping agency, or organizations conducting environmental assessments. For most regulatory permitting procedures and site specific planning activities, accurate boundary delineation is critical. The use of small scale photography (i.e. 130,000 scale or smaller) is primarily limited to the identification of plant communities with distinct spectral characteristics.

MEDIUM TO LARGE SCALE PHOTOGRAPHY

Specific locations and vegetation types are easily identifiable on large scale photography, even by photo users with minimal experience. Very large scale photographs are also useful in investigations of wetlands that are small, isolated, or narrow and linear. These characteristics, especially when combined, make these type wetlands virtually impossible to detect with small scale photography.

AERIAL PHOTO PREVIOUS WORK

In a study reported by Howland (1980), color infrared (CIR) film was found to be superior to color and multi-band black and white photography for vegetation discrimination in a diverse inland wetland in Vermont. Besides film choice, attention must also be given to the time of year and even the time of day when acquiring imagery. Grace (1985) found that for inland non-persistent emergents in the southeastern U.S., mid-August to mid-September was the best time to collect photography for annual comparisons since most species would be represented and in a mature state. A study by Carter, et al. (1979), found that the time period between August to mid-October was optimum for identifying open water and marsh categories in Tennessee. In another study by Gammon and Carter (1979) of the Great Dismal Swamp, it was found that photographs obtained during vegetation dormancy allowed for better identification of wetland boundaries, areas covered by water, drainage patterns, separation of coniferous forest from deciduous, and classification of some understory components. In tidal environments, Brown (1978) found August to early October best for saline wetlands, late June to early September best for fresh/brackish wetlands, and that fresh water wetlands needed coverage twice, mid-to-late June and late August due to specific plant species being predominant at different times.

Wetland resource mapping projects have been performed for advanced wetlands identification projects at EPA's Environmental Monitoring Systems Laboratory (EMSL) in Las Vegas, and the Photo Interpretation Center (EPIC) located in Vint Hill Farms, Virginia (Norton, 1986a, 1986b; Duggan, 1983; D.R. Williams, 1983; Mack, 1980). Hydrogeologic and ecologic evaluation methods are applied in field work to assist in advanced wetlands mapping efforts. Utilizing this type of information allows managers to take a "proactive" stance relative to jurisdictional determinations and suitability of land parcels for development, rather than obtaining data on a case by case basis. Other detailed resource mapping is conducted for EPA's Regional Offices for wetland areas of special or critical concern (Norton, et al., 1985).

The following list of identifiable features is provided to acquaint the reader with data available from such projects. A nominal scale of 1:12,000 -1:24,000 and use of color/CIR photos is assumed.

o Wetland boundary delineation
o Area
o Edge, drainage length/densities
o Shape of upland/wetland edge
o Fetch/exposure
o Vegetation growth form
o Cover density and distribution
o Species composition and health
o Tidal flooding regime
o Tidal conduits, inlets, outlets
o Erosion

CHANGE DETECTION WITH AERIAL PHOTOGRAPHY

Change detection projects which utilize aerial photography involve the use of one to a number of historical sets of photographs to document changes either natural or anthropogenic (D.R. Williams, 1989, 1985; Grace, 1985; Niedzwiedz and Batie, 1984; Hardisky and Klemas, 1983; and others). Listed below are features that are useful in change detection analyses which are interpretable from color/CIR photography with scales ranging from 1:10,000 to 1:24,000.

o Pre-development vegetation patterns
o Natural vegetation removal

o Surface drainage network
o Sediment
o Dredging, turbid water
o Fill or spoil deposition
o Erosion
o Ground staining, scarring
o Vegetation stress or damage
o Contaminant sources

Although there is no "average" change detection project, a description follows of some requirements and products which are typical. Federal agencies charged with enforcement of Section 404 of the Clean Water Act, which authorizes permits for the discharge of dredge or fill materials into the waters of the United States, extensively utilize aerial photointerpretive data to document alleged illegal development of wetland properties. Many times chronological documentation must be performed so that the illegal filling of wetlands can be substantiated. Regulatory enforcement related projects typically involve numerous historical photographs with detailed comparative analysis, interpreted overlays, field verification of interpreted results, and very large scale graphic displays. Therefore, costs for in-depth wetland delineation are substantially higher than for conventional wetland resource mapping efforts. Costs to produce this type of detail, which may be required in court cases, have averaged approximately $1,000 per square mile (D.R. Williams, LESC, Personal Communication, 1990). In other instances, investigations are aimed at quantifying the loss of wetland resources over time by climatological affects. D.C. Williams and Lyon (undated) correlated changing Great Lakes water levels to wetland extent, and Grace (1985) investigated the effect of thermal discharges on seasonal wetland production.

A state agency in Georgia acquires aerial photography at predetermined intervals to monitor development along the Atlantic coastline (S. Stevins, Georgia Dept. of Natural Resources, Personal Communication, 1990). The U.S. Army Corps of Engineers performs similar monitoring in most of their districts, as they are responsible for making jurisdictional determinations of wetlands regulated under Section 404 of the Clean Water Act. The progressive destruction of wetlands in association with hazardous waste sites is also documented, and this information is used to plan clean up activities at CERCLA (Comprehensive Environmental Response Compensation, and Liability Act of 1980) sites (Norton and Prince, 1985).

At an agricultural conversion site in Florida seven sets of available historical photos, black-and-white and color photographs with scales ranging from 1:10,000 to 1:24,000, were acquired and interpreted. The purpose of the investigation was to assess and document the type and amount of wetland habitat destruction (D.R. Williams, 1981). Natural vegetation present before conversion, vegetation removal, and surface drainage network construction were documented over time. Ground information was collected prior to the photo analysis, and comparisons conducted to confirm map accuracy after completion. Frequently, photography is flown at periodic intervals to ascertain if a developer is in compliance with Federal and/or State issued permits. If such investigations become court cases, large courtroom displays of interpreted data are prepared with expert witness testimony usually given by the principal investigator or experienced photo-interpreter.

DIGITAL IMAGE PROCESSING

Digital image processing of satellite or aircraft-acquired data into land cover categories involves the examination of the reflectance or spectral patterns of pixels contained within the image. Image data is organized into a matrix, i.e. raster format, with each pixel (or cell) covering a certain dimension on the ground. Each pixel contains one data value representing the spectral intensity of that location on the earth's surface for a particular wavelength, i.e., 7 wavelength bands, 7 intensity values. Fundamental energy-matter interactions control and influence the spectral characteristics of land cover types. The proportion of energy reflected, absorbed, and transmitted for each cover type varies depending on the material and ground conditions (Lillesand and Kiefer, 1987). Most of the earth's features have unique spectral characteristics, and thereby can be identified and mapped on the basis of their spectral signatures.

Pixels commonly correspond to more than one type of land cover and therefore the pixel value represents a weighted average. The result is that each raster pixel is a combined product of all the resources present at that ground location. Presence of "mixed pixels" causes problems when boundary or edge information is required. Boundary effects can take the form of mixed pixels occurring as transition areas between adjacent cover types. The spectral characteristics of those mixed pixels are unlike the land-cover types on either side, and depending on the classification technique utilized to process the digital data, may be incorrectly grouped as a separate class.

Other possible sources of error or inconsistencies when dealing with satellite or aircraft data originate from atmospheric scattering, sun angle, topographic influences, and the process of geographical rectification of the imagery. The scattering, sun angle, and topography can be modelled or accounted for by assumptions and/or ancillary data, while the rectification process has a reportable positional error once the geometric transformation is completed.

In digital image processing, data can be analyzed in several ways, most commonly with either image enhancement or image classification algorithms. In order to summarize the remotely sensed data into land cover/land use, those processes which are addressed as classification techniques are employed. The general approach in the classification of digital imagery fall into two categories; supervised or unsupervised approaches. In a supervised classification, known land cover types such as forest, agriculture, wetland, and urban have been identified either through field work, aerial photography, maps, or personal experience (Heaslip, 1975). These sites are then located in the image and homogeneous examples are delineated. These delineated areas serve as training sites because their spectral characteristics are related to known resources, and can be used to "train" the classification algorithm (Jensen, 1986). Statistical information is generated for each identified training cover type and subsequently that information is used to classify all unknown pixels remaining in the image. Conversely in unsupervised classifications, the location of particular land cover types is not known, and the statistical parameters required to define the training classes are then determined with clustering algorithms. It is then the responsibility of the analyst to label these clusters with the appropriate land cover category.

Evaluation of the land-cover classification accuracy requires comparison between the classification results and reference data for the area. This reference data can be taken from various sources such as existing specialized maps, photo-interpreted aerial photographs, and actual "field checks" (see Appendix C). However, the reference data which is utilized during classification should not be used in the accuracy assessment as it heavily biases the results. Congalton (1988) compared several sampling schemes for assessing the accuracy of classified remotely sensed data, and found that generally a one percent sample should be obtained. To assess the agreement between the classification and the reference data, site-specific comparisons are made by calculating the frequency of coincident classes, point by point, on the reference data and the classification results. These values are reported in an error matrix (sometimes called a confusion matrix or contingency table). The total overall percent correct is the ratio of the sum of diagonal values to total number of cell counts in the matrix. Proportions of diagonal values to row sums are the category accuracy relative to errors of commission, and proportions of diagonal values to column sums as category accuracy relative to errors of omission (Story and Congalton, 1986). Detailed statements of accuracy are derived from the error matrix in the form of individual land-cover category accuracies. For each class, percent commission and percent omission are calculated from the error matrix as well as the overall accuracy.

CHANGE DETECTION WITH DIGITAL IMAGERY

Change detection projects which utilize digital imagery are generally more limited in the amount and type of historical data available. Digital change detection tasks are somewhat complex and require consistent multiple date imagery acquisition to insure reliable mapping of baseline conditions and change trends. Several different image processing methods can be employed for change detection studies. These methods (image differencing, image ratioing, classification comparison, comparison of pre-processed imagery, and vector change analysis) are specific to the form in which the imagery is obtained, and to what precision the two images can be co-registered (Jensen, 1986). It should be noted that depending on whether the imagery used is "raw" or unclassified, or the result of classification or transformation algorithms, the different methods of digital change analysis will produce slightly different information. For example, image differencing results in an image (or map) that reveals only the locations that have undergone change, and is directly dependent upon the spatial registration between the images. Conversely, comparisons between two classified images depict both the changed area locations and the nature of the change (Howarth and Wickware, 1981). The accuracy of this type of derived change detection map, and the statistics generated from it, are contingent on both the spatial registration between the maps and the individual classification accuracies of the maps (Hodgson et al., 1988). Furthermore, the composite map produced from digital change analysis will not have an accuracy greater than the least accurate map in the analysis (Newcomer and Szajgin, 1984).

Digital change detection offers an alternative to manual photo-interpretation, but can be more difficult to perform accurately due to the spatial, spectral, and temporal constraints placed on multi-date imagery analysis. The results from photo interpretation of large-scale photographs may have higher accuracies, but are time consuming, difficult to replicate, prone to errors of omission, and costly in terms of data acquisition. Digital change detection studies must utilize analysts familiar with the environment to be inventoried, the quality/accuracy of the data set(s), and the characteristics of change detection algorithms in order to be successful (Jensen, 1986).

SATELLITE SENSORS

There are two primary sources for obtaining satellite acquired digital imagery, Earth Observation Satellite Company (EOSAT) and Systeme Pour l'Observation de la Terre (SPOT) Corporation. EOSAT is a participant in a cooperative agreement between the National Oceanic and Atmospheric Administration (NOAA) and the USGS to facilitate the commercialization of satellite based technology to the private sector. At present there are two satellites being operated by EOSAT, Landsat 4 and 5. The Landsat systems carry two types of sensors, the multispectral scanner (MSS), and the thematic mapper (TM). Both the Landsat 4 and 5 satellites have exceeded their design lives by three years with Landsat 5 being the primary system utilized in North America. The MSS provides data in four spectral bands: visible green, visible red, and two reflected infrared bands at about 80-meter ground resolution. The TM has six spectral bands with 30-meter resolution and a thermal infrared band with 120-meter resolution. The Landsat TM sensor possesses higher spectral resolution because of the seven individual bands which capture reflectance data in the visible through the thermal portions of the electromagnetic spectrum. The TM system is the newer of the two systems aboard Landsat 4 and 5, and still has resource mapping capabilities that have not been fully explored. These satellites are in polar orbits and are capable of collecting spectral information every 16 days over the same surface area.

France launched the first SPOT satellite in February 1986. This satellite has sensors on board which are capable of producing 10-meter resolution black-and-white panchromatic images, and 20-meter resolution three band multispectral images. SPOT sensors can be directed off-nadir to produce stereoscopic coverage and have a repeat collection cycle of 26 days. The spatial resolution of the SPOT satellite is finer than Landsat TM, but the lessor spectral resolution and smaller area per scene of SPOT imagery make comparisons difficult between the two sensors. The two systems could be considered complimentary in that the SPOT imagery has been merged with Landsat imagery, with resulting hybrid imagery that reflects the spatial resolution of SPOT with the spectral resolution of Landsat (Salvaggio and Szemkow, 1989; Welch and Ehlers, 1987).

Landsat MSS Previous Work

Landsat MSS has been investigated for its utility in wetland mapping and inventory updating of broad wetland communities (Jensen, et al., 1980; Hardin, 1985; May, 1986; and others). Some of the resource mapping problems encountered with the use of Landsat MSS data for wetlands originate from the low spatial resolution (80-meter) of the MSS sensor which hampers detection of wetlands smaller than 1.6 hectares (4 acres), the inability to place boundaries with high reliability, and uncertain availability of multi-date imagery (16-day repeat cycle and cloud free conditions required) for use in discrimination of different vegetation types based on phenology.

A study by Jensen, et al. (1980) compared Landsat MSS, color aerial photography, and radar images for the identification of giant kelp beds in southern California. It was found that kelp was separable from ocean in Landsat MSS, but that the acreage estimates generated from Landsat MSS were consistently underestimated in comparison to those derived from the color photography. Such underestimations were attributed to the photo interpreter's ability to identify less-dense areas of kelp on the photographs.

A study undertaken by Ernst-Dottavio, et al. (1981) was aimed at determining whether Landsat MSS could identify inland wetlands in northern Indiana. In that study, spectral characteristics of inland wetlands were quantified utilizing a helicopter-mounted radiometer sensitive to the four Landsat MSS channels. The study found hardwood swamps, shallow marshes, and shrub swamps to be spectrally similar, therefore the classification resulted in low individual class accuracies. However, the deep marsh environment showed higher accuracies, and an overall accuracy of 71 percent was reported for the investigation.

In a study by Wood (1983) black-and-white photography, aerial 35mm color slides, CIR highflight photography, Landsat MSS, and Landsat TM simulator were used to document historical changes in wetlands in California. The Landsat MSS classification results showed considerable confusion when compared to land use maps complied from the CIR aerial photography. As a result, the wetland areas were greatly overestimated. Wood suggests that better classification accuracies could have been obtained with perhaps a different image date, or a multi-temporal approach.

Hardin (1985) reported an overall accuracy of 72 percent for distinguishing wetland from non-wetland in Delaware utilizing multi-date Landsat MSS images acquired in 1974. Classification accuracies ranged between 74 percent to 28 percent for individual marine species. Freshwater wetlands were less accurately classified, and most misclassifications occurred between the various wetland types. Hardin believes state statutory requirements make it unlikely for Delaware to ever discard the use of low altitude photography in favor of satellite data, even if accuracy were greatly improved.

In another study using Landsat MSS data, May (1986) evaluated the feasibility of using automated classification techniques to update habitat maps based on the Cowardin system. In comparing the resulting Landsat MSS based habitat classifications with existing habitat maps prepared from aerial photographs, the study found a high degree of omission and commission errors, and low mapping accuracies for all habitat categories. It was noted that the fundamental problem encountered in the study was the inability to accurately co-register the Landsat MSS to the photo-derived habitat maps.

<u>Landsat TM Previous Work</u>

Landsat TM, has improved wetland monitoring capabilities over the Landsat MSS system. In comparison to the Landsat MSS, the TM sensor provides seven narrower spectral bands, better spatial resolution, improved radiometric sensitivity, and a higher number of quantization levels (i.e. digital numbers for TM = 256, for MSS = 128). TM is still subject to a repeat collection cycle of 16 days, and use of the data is contingent upon near cloud-free conditions.

In a study by Wood (1983) Landsat TM Simulator data was acquired over California's Central Valley to supplement existing aerial photography and Landsat MSS. The objective was to develop a series of historical maps to document the extent of wetland change between 1937 and 1982. Very little confusion was found between wetland and other land use classes based on unsupervised classification results. The comparison of four resulting classes (permanent wetland, seasonal wetland, native vegetation, and water) against the manual photo interpretation of CIR transparencies, resulted in an overall agreement exceeding 90%.

In a study by Jacobson, et al. (1987) a waterfowl habitat inventory map was generated for an area northeast of Anchorage using Landsat TM acquired in August 1987. The result was a thematic map depicting six waterfowl habitat classes (deep freshwater, shallow freshwater, turbid water, aquatic bed, deep marsh, and shallow marsh). Direct comparisons between the TM classified waterfowl habitat information and the existing NWI for the area was not possible due to different classification strategies. The 51 unique wetland types identified by the NWI for this area were reduced to 24, and contained only those categories which were related to waterfowl habitat. Frequency analysis was performed between the two data sets. The TM results when compared to the reduced NWI data set as coincident, omitted, or committed categories, achieved an accuracy of over 90% for lacustrine systems and about 25% for seasonal and temporarily flooded wetlands. When point and linear wetlands were removed from the NWI data, the TM classification missed 78% of the wetlands under two acres. The NWI mapped the area as having 83% of the wetland basins under 2 acres in size. The authors conclude that Landsat TM can provide reliable wetland information for basins greater than two acres, and because of the computerized nature of the resulting data bases, updates can be incorporated when more detailed information becomes available. Generally, when current TM imagery and NWI information are combined, wetland preservation and planning issues can be addressed more readily.

A study to identify suitable wetland habitats for wood stork with Landsat TM data was undertaken by Hodgson, et al. (1988) in east-central Georgia. In the analysis, a computer classified foraging habitat map was created using TM imagery collected for two years, with each year having imagery for both "wet" and "dry" seasons. Seven categories were generated: deep water, shallow water, macrophytes, cypress/mixed wetland, bottomland/hardwoods, pine/mixed uplands, and agriculture/clearings. Classification accuracy was evaluated by comparing the TM results to previously verified foraging sites. Overall accuracy results of 74% and 88% for the two years investigated were reported.

Pickus (1990) found Landsat TM to be an effective tool for delineating wetlands under the Environmental Protection Agency's (EPA) Section 404 Wetlands Advanced Identification program in southeastern Louisiana. Based on comparisons between field collected reference data and NWI data, correlation between the classified TM imagery and field verification resulted in an 85% accuracy in distinguishing wetlands. Accuracies of 86% and 71% were obtained in the identification of bottomland hardwoods and uplands respectively. Results were poor for cypress/tupelo (48%) and water (56%) categories. When compared to digital NWI data, the classified TM wetlands identification had a very high correlation (90%). Ancillary information was utilized in this project to create a geographic information system (GIS) which contained in addition to the satellite derived land cover, hydrography, soils, transportation and elevation layers. Pickus concluded that for this project, digital analysis of Landsat TM, when incorporated into a GIS containing ancillary data, was sufficient for advanced wetlands identification.

In the State of Illinois, preliminary evaluations have begun to assess the potential of satellite data for updating of the NWI (Luman, 1990). TM data from May 1987 were classified into generic Anderson Level 1 land-cover categories (agriculture, grass, shrub, forest, wetland, and water) for a study site located in southern Illinois. Sample point comparisons were made against a variety of ancillary data, and the overall map accuracy was found to be 85%. When individual categories were evaluated, accuracies ranged from 52% for shrub, 76% for wetland, and 97% for non-turbid water. Luman concludes that TM data would be useful for detection of previously unmapped wetland habitats.

SPOT Previous Work

Very few references were located in which SPOT imagery was evaluated for wetland mapping applications. SPOT Corporation has published brochures describing applications in which SPOT imagery was used for wetland monitoring and vegetation inventorying projects. One project involved the detailed mapping of a national wildlife refuge into 18 classes based on density, species composition, and other factors. In this instance, SPOT panchromatic and multispectral imagery were merged for analysis with a resulting minimum mapping unit of 0.01 hectare. No accuracy assessment was cited for this example. SPOT also lists projects where submerged aquatic vegetation was located and mapped successfully, and another where a wetland area dominated by a particular species was mapped and correlated to vegetation index factors for assessing biomass distribution. Again, no accuracy statements were made about either of these applications.

In a study by Mackey (1990), eleven dates of SPOT multispectral imagery collected over three years were evaluated to determine seasonal and annual changes in a 400-hectare, southeastern freshwater marsh. Unsupervised classification techniques were used to generate land cover maps for each date. Satellite TM and aircraft multispectral imagery have been analyzed for this site in previous years with reported accuracies ranging from 70% to 85% for distinguishing open water, freshwater marsh, shrub-scrub, and cypress/tupelo cover types (Jensen, et al., 1987, 1986, 1984). No accuracy assessment was performed, but the author contends that accuracies from this project would be consistent with previous work performed by Jensen. The resulting data were analyzed for trend analysis with a prediction for a drier, more persistent wetland community developing.

Luman (1990) analyzed two SPOT scenes (each a hybridization containing both panchromatic and multispectral information) for utility in updating the NWI in Illinois. The existing NWI information was regrouped to match a state-based classification system for direct comparison against the results from digital classification. Good correspondence was found between the satellite-based classifications and the NWI maps, especially where the NWI had been simplified to the state-based classification, and the NWI source information had been of good-to-high quality. Luman concludes that the use of the two SPOT sensors merged (MSS and panchromatic data), is acceptable for detailed analysis of wetland habitat structure, and for validating water regime modifiers within the Cowardin classification. The higher spatial resolution of SPOT appears to provide a tool in which to monitor wetland change effectively.

AIRCRAFT MULTISPECTRAL SCANNERS

Aircraft multispectral scanners (aircraft MSS) are multi-band sensors which can have from four to 230 separate channels or bands in which the sensor collects information from various parts of the electromagnetic spectrum. These systems are designed to measure and record the radiant energy reflected and emitted from the ground, and have a wider range of spectral sensitivity than photographic systems. Their exact configurations vary by the spectral ranges which are sensed and how narrow the bandwidth the sensors are capable of recording. Very specific data acquisition parameters are required for planning aircraft MSS missions. The area to be covered must be specified in terms of location, size, and boundaries, with the position of the flight lines clearly defined (usually lat/long coordinates). If mosaicking of the data is required, all flight lines should be flown in the same direction to minimize illumination differences. Also specified are the appropriate spectral channels, acquisition time (time/day/month/year), and flying height which controls the resulting resolution and amount of digital data obtained. Resolutions as fine as 1 meter are possible from aircraft based sensors. Supporting field data collection requirements should be clearly defined prior to the mission (see Appendix C). Following data acquisition, post-processing is necessary to calibrate the data for systematic scanner distortions. The resulting digital data is in raster format. There are a limited number of these operational systems available for public use (EPA-EMSL, NASA-AMES, GEOSCAN). Landsat TM data is more practical than airborne MSS because it is routinely collected and less expensive. Conversely, aircraft MSS systems can offer flexibility in terms of resolution, timing, and finer spectral sensitivity. Most of the aircraft-mounted multispectral systems are also equipped with mapping cameras to allow simultaneous collection of aerial photography.

The EPA Environmental Monitoring Systems Laboratory - Las Vegas (EMSL-LV) operates an aircraft-based MSS in which a highly precise navigation system has been incorporated to provide very accurate spatial registration. In the past few years, the Air Force's Global Positioning System (GPS) has revolutionized positioning technology. The use of GPS adds a dimension of geometric control and correction that has not been available in the past. The major problem with aircraft scanners is poor geometry with data being adversely affected by variations in aircraft attitude or deviations from the flight line. Relatively inexpensive GPS receivers and computer software are available which allow positional accuracies ranging from 5 to 25 meters to be obtained. This combined with recent developments in digital elevation models (DEMs), offers multispectral data that is geometrically much superior to older previous data.

Applications for aircraft MSS systems include:

- Vegetation classification
- Land cover / Land use mapping
- Water Quality monitoring
- Wetland mapping
- Monitoring of heated water discharges
- Underground fire monitoring
- Map updating
- Geothermal monitoring

EMSL-LV's system and services are available to interested Federal and State agencies through interagency agreements (see Appendix A-EMSL).

Aircraft MSS Previous Work

Savastano et al. (1984) reported the results of a study utilizing aircraft MSS to classify and map diverse nearshore marine and estuarine habitats in St. Joseph Bay, Florida. The objective was to develop methods for separating seagrass and macroalgal habitats from the ocean bottom using a four band (blue through near IR) multispectral scanner. The near IR provided the capability to discriminate between emergent vegetation and water, but contained no useful information on submerged habitats as near-IR energy is almost completely absorbed by water. The information content of the blue band, which can penetrate shallow water environments, was lacking due to a low instrument signal-to-noise ratio. When digitally classified data were compared to ground truth information, it was found that the classification subdivided the desired categories too finely, breaking out classes that could not be identified on the basis of existing information. The study concluded that although it was not possible to collect ground truth information as detailed as the aircraft MSS, the resulting habitat maps were found to be generally accurate.

In an EPA Environmental Monitoring Systems Laboratory (EMSL) study by Page (1982), an 11-channel aircraft MSS was used to map nearshore kelp beds off the southern California coast. The study site was selectively chosen to be an ideal example, as the kelp beds were large and well developed. Unsupervised classification was performed on the aircraft MSS imagery using four of the channels (green, red, reflected IR, and thermal IR), and results were compared to estimates derived from manual interpretation of concurrently collected CIR aerial photography. It was found that the aircraft MSS-derived kelp estimates were considerably lower than the photo-derived estimates. This was attributed to the inherent generalization of mapping boundaries in the photo interpretation process, where the kelp beds were identified as large, visually distinct units. It was concluded that the photo interpretation process resulted in the inclusion of non-kelp features (i.e. ocean) within the kelp mapping units. Page summarized that aircraft MSS data could accurately survey, map, and compile acreage estimates for nearshore kelp resources. It appeared that the digital approach yielded results which had excellent positional agreement with maps produced from photo interpretation, while providing better estimates of kelp bed areal extent.

Extensive work has been done utilizing aircraft MSS data for inland wetlands mapping in South Carolina (Jensen, et al., 1987, 1986, 1984; Grace, 1985). In one investigation, 11-channel aircraft MSS data were collected in March 1981, with 3 meter resolution over the Savannah River floodplain (Jensen, et al., 1986). The data were analyzed to determine the optimum combination of channels for separability of wetland types, with green, red, and two near IR bands being ultimately selected. Supervised classification techniques were employed to map the data into the Cowardin classification system. Categories identified were: persistent emergent marsh, nonpersistent emergent marsh, shrub/scrub, algal mat, mixed deciduous upland forest, and mixed deciduous swamp forest. An overall accuracy of 83% was reported when comparisons were made on a pixel-to-pixel basis to ground transects. Another aspect conducted under this research was an effort to relate the types of vegetation present with water temperature. Daytime thermal-IR data were collected during the same mission, and compared against the classified maps constructed from the four channel subset. A statistical analysis was performed in which it was determined that associations did exist between vegetation types and their apparent temperature class intervals. However, Jensen concedes that other factors besides temperature, such as sedimentation and oxygen stress, may affect the establishment of different plant communities.

In a recent study undertaken at EPA-EMSL by Mynar (1990), an 11-channel aircraft-MSS was utilized to map nearshore habitats in Puget Sound, Washington. The project objective was to develop aircraft MSS data processing protocols with preliminary work focusing on seven test sites. A regional Cowardin classification was developed for the Puget Sound marine estuarine system by the Washington State Natural Heritage Program. MSS data collection corresponded with low tide conditions in July 1988, with CIR aerial photography collected simultaneously at a scale of approximately 1:13,000. The resolution of the MSS data was approximately five meters. The final MSS-derived classifications for two sites were analytically compared with classifications derived from manual interpretation of the simultaneous CIR aerial photography. The overall comparable at the two sites were quite low, 55 and 53 percent. Mynar attributes the low accuracies to poor field verification data, and lack of accurate co-registration between the two databases, i.e. MSS classification and photo-interpreted CIR photography. It should be noted that lack of agreement does not necessarily indicate the MSS classifications did not correctly depict the habitats. A larger "minimum mapping unit" results from photo interpretation methods in which resources are interpreted and outlined on photographs. Low accuracy statistics have previously resulted when manually interpreted results are compared to high resolution MSS classified data where each individual pixel is evaluated and categorized (Page, 1982). The rectification process consisted of three separate, yet related components: MSS data registration to an earth coordinate system (UTM); aerial photo-interpreted results registered to UTM coordinates; and the co-registration of the photo-interpreted results and the MSS data. Due to the nature of the estuarine environment, reliable ground control points were difficult to locate (i.e. shifting sand, mud, and water). Mynar concludes that MSS acquisition must be timed accordingly to capture the resource(s) under investigation, that ground verification data must be compatible with remotely sensed data, and image rectification needs to be more precise in order to access whether MSS imagery is appropriate for nearshore habitat inventories. A future mission is planned for 1991 to acquire aircraft MSS over Puget Sound utilizing the enhanced capabilities of GPS to increase spatial accuracy.

RADAR APPLICATIONS

Radar can be useful for identifying broad wetland classes over large areas, particularly if the area is perpetually cloudy. The longer wavelength radar systems have the ability to penetrate clouds and herbaceous vegetation canopies. Radar is known to be sensitive to differences in the dielectric constant of surface materials, and produces intense backscatter or return signals from some wet forested areas. Disadvantages of using radar are the high costs, limited data availability, and the complexity of the imagery.

In a study conducted by Place (1985), Seasat radar images were evaluated for their ability to improve wetland mapping when combined with conventional sources, i.e. aerial photography. The Seasat satellite was launched in June 1978 and failed later that year in October. It was an L-band (23.5 cm) synthetic aperture radar (SAR), having H-H polarization, and 25-meter resolution. If vegetation or moisture conditions are of interest, Seasat is useful only for areas which are generally flat. Place compared Seasat interpreted imagery and NWI data at four test sites on the coastal plain between Maryland and Florida. Place concluded, based on statistical comparisons, that photo-interpreters who used Seasat radar images to compliment their conventional sources were able to map forested wetland more accurately (greater than 85%), than those who did not.

VIDEOGRAPHY

Airborne videography is not a replacement for aerial photography, but rather a substitute or complimentary data source when the quality and/or cost of an aerial survey can not be supported. Scientists at the USDA Agricultural Research Service Unit at Welasco, Texas, have been doing basic research on applications of both normal color and infrared video for rangeland and other vegetation, and the US Fish and Wildlife Service in North Dakota have been using video to assist in assessments of wetland and riparian ecosystems (Driscoll, 1990).

Advantages of video systems are: immediate availability of imagery; in-flight error-proofing capabilities: ability to use narrow band filters for finer spectral resolution; ability to function in a wider range of atmospheric conditions than conventional photography; and ability to utilize satellite-type data processing software for analysis. Disadvantages include a lower resolving power than aerial photography and difficulties with calibration.

Several video camera systems have been developed ranging from black-and-white with visible/NIR capabilities to multispectral false color systems. A comprehensive description of the various video systems available can be found in Everitt and Escobar (1989). Imagery from these systems have been used successfully to detect and assess ecological conditions such as plant communities and species, insect pests, soil moisture, soil drainage and salinity, grass phytomass levels, and burned areas (Everitt and Escobar, 1989). High resolution airborne video data have also been utilized to update cartographic databases (Ehler et al., 1989). Video image data lends itself to the utilization of automated image processing techniques, which can then be linked to geographic information systems (GIS) and used to update information layers.

Wu (1989) utilized a commercially available VHS-format camcorder as an alternative to conventional color photography for a multisensor mapping effort of coastal wetlands in Louisiana. The video images were used as ground-truth in conjunction with SPOT, airborne MSS, and radar imagery. The airborne video images captured the dynamics, volume, and spatial distribution of the wetland vegetation very well. Wu concludes however, that further study of the spectral response characteristics of vegetation and surface features is needed to determine which video systems have the spectral bands most responsive to the target/scene.

GEOGRAPHIC INFORMATION SYSTEMS

Spatial relationships are apparent when viewed as cartographic products, but to analyze and model spatial processes quantitatively, the information needs to be in digital form. Geographic information systems (GIS) are distinguished from other database management systems by their ability to perform spatial analyses with multiple levels of data in a selected geographic area. Computerized GIS are widely utilized to store, query, retrieve, display, and manage large amounts of digital data assembled from many sources. This data is typically geographic, environmental, cultural, statistical or political. The technological migration from costly minicomputers to inexpensive workstations has greatly expanded the user base of GIS. Use of remotely sensed data has become more common in GIS applications as many commercial GIS packages have image display capabilities and some rudimentary image processing functions. Geographic data can be represented using either vector/polygon or raster/grid data formats.
GIS does not generate primary data, it captures and processes information in a spatial context and serves as a platform on which decisions can be made. The ability to geometrically transform and integrate multiple data types is very important when accounting for differences in scale, projections, resolutions, and coordinate systems. The analysis of the data can be as simple as measuring line lengths and areas, or as complex as using modeling techniques to create "what if" scenarios. Analyses which are commonly used include measurements (distance, area, volume), interpretation or processing of a basic layer of data to create additional layers, boolean analytical processing, overlay analysis, distance searches, statistical calculations, and report generation. It should be noted there are functions which are difficult to perform in an image processing system (raster) that are relatively easy in a GIS (vector) and vice versa. For example, geometric or overlay operations are easier to perform in the raster domain whereas network analysis or topologic operations are more suited to the vector domain (Ehlers et al., 1989).

Both vector and raster methods of representing the spatial extent of geographical information can be translated or interchanged though the use of data exchange formats. The conversion of raster or other forms of spatial data into vector form can be approached in several ways. The most common is manual digitization from existing paper sources which is labor intensive, thereby expensive, and requires in-place quality control procedures to reduce error propagation. Data exchange formats are a common approach to solving the solution of integrating various digital source data. Some GIS software packages offer conversion packages which transform raster or vector data into a single variable file (SVF) format. The (SVF) format is one type of bridge between vector and raster file structures.

The simultaneous display of raster images with vector cartographic data offers the capability to perform change detection analyses. In many applications where GIS databases exist, this tool can be used to update map resource information on a regular basis, or for rudimentary location and query functions. Often just a visual interpretation of geocoded data allows an index to be placed on the surface of the image, which then becomes available for interactive queries in the GIS. For example, a transportation network vector layer might be overlaid on a raster satellite image. The vector file then could be edited and new attributes connected to features for updating statistical information if construction altered the transportation network. Over time newly acquired images could be utilized the GIS with minimal cost and labor.

Burrough (1986) lists the following recommendations for the use of vector and raster data structures in GIS:

Vector: vector for archiving phenomenologically structured data (e.g., soils, land-use units, etc.), for network analysis (e.g., transportation, etc.), for high quality line drawing, and digital terrain modeling.

Raster: raster for map overlays, map combinations, spatial analysis, altitude matrices, and for simulations and modeling when surfaces are encountered.

Combination Vector/Raster: for plotting high quality lines with vectors, in combination with efficient area filling in color with raster structures such as run length codes or quadtrees.

VECTOR GIS SYSTEMS

The most dominant type of GIS are vector-based and have a data structure based on topology to store the relationships among various spatial objects. Cartographic information is characterized by point, line, and area features which are further defined by information about what is on either side, and how it is connected to the other lines. This coordinate information is then cross-referenced to attribute files which contain spatial location in relation to other descriptive attributes. Vector/polygon data structures describe the unique lines or forms of specific geographic features (streets, lakes, rivers, etc). The coordinate space is presumed to be continuous, not quantized as with raster data, which allows all positions, lengths, and dimensions to be defined with vector data structures (Burrough, 1986). This vector representation of data is a way to replicate the feature as exactly as possible in a digital form.

Vector GIS have the capability to organize diverse types of data into a single database which contains the coordinate location of the feature, and it's geographical, cultural, or scientific attributes. These attributes are the key identifiers in organization and description of the data layers contained within the GIS. The relational database capabilities allow for access to non-GIS attribute data. Raster data are processed into a single layer or dimension with one pixel value before becoming a layer in a vector-based GIS. Maintenance of these spatial descriptors as a part of the data base, allows GIS to perform normal data base management functions as well as spatial manipulations.

RASTER GIS SYSTEMS

In a raster environment, each pixel (or cell) represents one data type spatially, so if a house, tree, and road intersect at a pixel those elements are put into separate layers. Raster-based systems are compatible with the data produced by satellite or aircraft based sensors, and raster-based scanned maps and photographs. These systems produce imagery in raster form comprising a rectangular array of pixels, which is then analyzed and stored to create a grid map. The processed data may be in a digital form such as a thematic map created by computer classification, or in graphic form such as a paper map derived from visual image interpretation. Raster systems, because of data storage configuration can take longer to process and display, and usually require more computer disk space. Moreover, raster data may not explicitly represent feature boundaries, and instead have a stair-stepped appearance.

DIGITAL DATA SOURCES

Many digital spatial data sources have come into existence, and the use of such sources compared with generating new data is almost always less expensive and time consuming (see Appendix A). Remote sensing can provide a means for acquiring very recent land cover/land use data, and when merged with other data (i.e. soils, hydrology, roads, etc.) allows the greatest use to be made not only of the remotely sensed data, but all data available to the investigator from other sources. For some applications maps, field data, and/or aerial photography would need to be scanned or manually digitized into a machine-readable form for integration with existing digital products. All data layers, whether procured, generated through digital image processing, or manual digitizing, should have reported spatial and thematic accuracies associated with the real world. When acquiring digital data from reliable sources, minimum standards for accuracy are usually ensured. Data of questionable integrity should be eliminated from consideration unless the intent is to use the information as a data layer on which updates, refinements, or corrections are to made later when more accurate information becomes available. The overall accuracy of any GIS database is dependent upon the data layer with the lowest accuracy or resolution. The integration of various types of spatial and geographic information enables remote sensing to provide useful input for a broad range of applications in a cost-effective manner. For many environmental applications, remotely sensed data represents only one source of input for studying complex environmental problems. Some other sources of spatial data include maps, aerial photographs, census information, field measurements, and meteorological records.

The challenge then, is not only where to get information but how to integrate information flow between different geoprocessing technologies. Once a GIS is functioning, information can be drawn from a single, consistent, uniform database which avoids the possibility of having separate collections of conflicting data. A comprehensive GIS will support various computer mapping and graphic products.

GIS provides a convenient and organized method for analysis of wetland ecosystems. GIS provides flexibility in which to build a cohesive database on which additional information can be incorporated, and refinements made if project objectives change. Relationships can be modeled and different scenarios put forth that may need to be addressed for impact assessments or trend analyses on the wetland ecosystem. The results of such capabilities provide the resource/project manager the best information available for better protection and management of wetland resources.

EXAMPLE PROJECT COSTS

Each wetland resource mapping project is highly individualized depending upon legal requirements and/or the needs of the agency conducting the investigation. The following estimated project costs should be regarded with caution as differing study objectives result in varying costs.

Communication must begin in the planning phase of any inventory project, and focus on data acquisition requirements and subsequent processing/interpretation to ensure that the final product will meet the user's needs. Decisions made regarding the scope of such endeavors must include the RS/GIS specialists so any preconceived expectations can be realistically evaluated and modified if necessary.

Table 2 contains generic information regarding remote sensing system specifications and acquisition costs. Table 3 contains summary information pertaining to described projects/programs found described later in this section.

TABLE 2

REMOTE SENSING SENSOR SPECIFICATIONS & ACQUISITION COSTS

Sensor Costs (sq. mile)	Spatial Resolution	Temporal	Coverage (sq. mile)
AVHRR $0.00017	1.1 x 1.1 km	2/day	1,500,000
Landsat TM $0.32	30 x 30 m	16 days	10,000
SPOT $1.83	10 x 10 m	26 days	1,200
CIR Photo $10-$15	1-3 m (1:40,000)	variable	32
Aircraft MSS & CIR Photo $15-$20	15 x 15 m 1-3 m	variable	variable

EPA-EMSL PROJECTS

The following resource mapping projects were undertaken at EPA's Environmental Monitoring Systems Laboratory in Las Vegas.

Aquatic Macrophyte Mapping - Clark Fork & Tributaries, MT

Color infrared photography, 1:18,000 scale, were collected July 1988 concurrently with aircraft multispectral scanner data. The purpose of the project was shoreline interpretation of wetlands and associated vegetation (algal blooms, rooted macrophytes, and riparian tracts), and non-point pollution source features (cropland, pasture, confined feeding, landfills, waste water treatment facilities, outfall locations, timber harvests, golf courses/urban recreation, nursery/orchard, industrial, commercial, and residential). The areal coverage and interpretation efforts centered on several river courses located in Montana, Idaho, and Washington. Only the area contained within the photographs were analyzed and mapped for the above class groupings.

Project costs reflect EMSL project management, photo acquisition and film processing, manual photo-interpretation of 740 flight line miles, graphic personnel support, and a deliverable of bound reports (3 volumes/set) containing the photo-interpreted overlays attached to the photographs. Not included are costs associated with aircraft usage, flight crew, and aircraft maintenance. No map transfer or digitization of the photo-interpreted data was performed. The cost for this project is estimated at $37.00 per square mile ($0.06 per acre).

Lake Pend Oreille Watershed Characterization Using Landsat TM Data

A Landsat Thematic Mapper subscene (100km X 100km) dated July 1989 was used in this analysis. An Anderson Level 1 land cover characterization (forest, agriculture, rangeland, barren, water, wetland, and urban) was derived using unsupervised image processing techniques. The resulting overall accuracy reported for only the forest, agriculture, rangeland, and barren categories was 78% (Lee, 1990). Statistical data were generated regarding areal extent of land cover resources for approximately 1,000 square miles (640,000 acres). This information was used by the State of Idaho for non-point pollution modeling efforts for the Lake Pend Oreille watershed.

Project costs reflect EMSL project management, TM imagery acquisition, supporting NHAP photographs, image processing, accuracy assessment, final report, and graphic products (slides and map acetate overlays at 1:100,000 scale). The cost is estimated at $20.62 per square mile ($0.03 per acre).

Bottomland Hardwoods Identification Using Landsat TM Data

Subsets of two Landsat Thematic Mapper scenes dated April 1988 and August 1988 were used in a pilot project to assist in advanced identification of wetlands. The analysis focused on four 7.5 minute quadrangles (approximately 240 sq. miles) located in southern Illinois in which several different image processing methodologies were tested for optimum bottomland hardwood wetland identification. Completion of this portion if the pilot is scheduled for September 1990. Once completed, the next phase will apply the derived results to a watershed level analysis of wetland resources (not included in cost estimation). An Anderson Level 1 land cover was derived, except for the wetland class which was further subdivided into a Level 2 classification (forested vs. non-forested wetlands). The overall agreement between the satellite-based classification and photo-interpreted CIR photography collected in August 1988, was approximately 81 percent. A field site verification effort is planned for spring 1991, with an accuracy assessment to follow.

Project costs reflect EMSL project management, TM imagery acquisition, supporting photo-interpretation of existing CIR imagery (1:24,000), image processing, accuracy comparisons between the TM classification and photo-interpretation, final report, and graphic products (slides and plots). The cost is estimated at $122.00 per square mile ($0.19 per acre).

Pearl River Wetlands Advanced Identification

A GIS database was constructed for the Pearl River Watershed (approximately 200 sq. miles) located in southern Louisiana in which layers were generated for hydrography, soils, land cover, transportation, elevation, and field reference data. The data layers were integrated or compiled from digital and map sources obtained from Landsat TM imagery (land cover), NWI, SCS, and USGS. Two dates of Landsat TM imagery were obtained from pre-copyrighted archived data. Wetlands were identified as wetland vs. non-wetland, and further subdivided into local species such as bottomland hardwoods and cypress/tupelo groupings. Overall accuracy between the GIS based wetland identification and the field verification information was 85% (Pickus, 1990).

Project costs reflect EMSL project management, TM image processing, GIS data layer digitization or integration, development of a user friendly GIS interface (ARC/INFO), and a formal project report. The cost is estimated at $133.00 per square mile ($0.21 per acre).

USF&WS NWI PROGRAM

The production of NWI information is performed by blocks of USGS quadrangles. USGS color infrared NHAP and NAPP photography are photo-interpreted according to the Cowardin classification (Cowardin, et al., 1979) with interpreted results transferred to the appropriate quadrangles. These maps are available in paper form by quadrangle, and subsequently become digitized in selected areas where cost-sharing between the USF&WS and the customer/user is provided. To date, 60% of the conterminous U.S., and 20% of Alaska have been completed. The average cost per acre ranges from $0.03 to $0.06, depending on the number and complexity of wetlands found within the quadrangle (D. Woodward, USFWS-NWI, personal communication, 1990.)

USACE PROJECT

The following project is being performed by the U.S. Army Corps of Engineers, Detroit District, Engineering Division, Great Lakes Hydraulics & Hydrology Branch.

Resource Analysis and Land Cover/Current Use Inventory Data Base for the U.S. Side of the Great Lakes, 1989 - Present.

A GIS incorporating land cover/current use inventory information was created with source information derived from photo-interpreted CIR aerial photography (1:24,000 dated Aug/Sept 1988) for approximately 1500 linear miles of the U.S. Great Lakes shoreline excluding the State of Michigan. The State of Michigan has been constructing a digital land cover data base over the past ten years utilizing photo-interpreted 1:24,000 scale CIR photography. The land cover/current use classification used in this Corps project is based upon the classification system utilized by the State of Michigan, Department of Natural Resources called MIRIS (Michigan Resource Inventory System). The MIRIS classification is a refined Anderson Level 3 which subdivides the wetland category into wooded wetlands (wooded and shrub/scrub classes), non-wooded (aquatic beds, emergents, flats), and Great Lakes coastal submergent classes. The final photo-interpreted map overlays are digitally scan-encoded into vector format.

Project costs are based on contracts which required photo acquisition and film processing, manual interpretation, map transfer, and digital scan encoding/quality control to vector form (Intergraph). The costs do not include Corps district project management or additional coordination provided by the State of Michigan. The cost is estimated at $42.00 per square mile ($0.07 per acre) (R.L. Gauthier, USACE, personal communication, 1990).

STATE MAPPING PROGRAMS (Also see Appendix B)

Florida

The Florida Department of Transportation (DOT), State Topographic Office mapped the state's wetland resources under contract to the Florida Freshwater Gaming Commission. Landsat TM data from 1986-88 for the entire state was classified to a user-specified Anderson Level 3. The TM data analysis was supplemented with soils data and existing photography (CIR 1:40,000, B&W 1:24,000) to allow refinement of classes during production. The classification categories included: coastal strand, saltmarsh, wet and dry prairies, swamps (mangrove, cypress, hardwood, bay), pine forest, mixed hardwoods, upland forest, exotic species, disturbed communities, bare ground, and open water. The classified data is available only in digital form with inherent 30 meter pixel resolution. Project costs reflect TM data acquisition, DOT image analysis, and limited field reviews. The costs do not include Freshwater Gaming Commission project coordination, or their independent field reviews of the final classification. The cost is estimated at $9.50 per square mile or $0.02 per acre (G. Maudin/A. Shopmyer, Florida DOT, personal communication, 1990).

Georgia

In 1972, the state passed the Marshland Enforcement Act which mandated an aerial surveillance program be established to monitor and regulate the state's coastal estuaries. Black-and-white aerial photography is periodically acquired at a scale at 1:40,000. In addition, routine light aircraft and helicopter flights collect 35mm photos to monitor shoreline development, assure compliance to state laws, and to locate unauthorized developments. Reports are generated on a case-by-case basis for unauthorized activities. No standard minimum mapping unit was given, but is estimated to be between 0.5 and 1 acre (S. Stevins, GDNR, personal communication, 1990). No cost data were available.

Michigan

In Michigan, the entire state has been encoded into a digital GIS (Intergraph) by the Michigan Department of Natural Resources (MDNR), Michigan Resource Inventory System (MIRIS). Color infrared aerial photography (dated 1979 and 1985, 1:24,000) were photo-interpreted for land cover/land use with a minimum mapping unit of one acre. Wetlands were mapped to an revised Anderson Level 3 (lowland hardwood, shrub wetland, emergent wetland, and aquatic beds). Data is available by county in a variety of formats (digital, map, and statistical). The cost is estimated at $39.00 per square mile or $0.06 per acre (M. Scieszka, MDNR, personal communication, 1990).

Wisconsin

In Wisconsin, the entire state's wetlands were mapped in approximately five years and was completed in 1984 by the Wisconsin Department of Natural Resources (WDNR). Black and white infrared photography at a scale of 1:20,000 were photo-interpreted with acquisition costs averaging $30,000 per county. Interpretative data was transferred to 1:24,000 scale township-centered rectified base maps with a minimum mapping unit of two acres. Data is compiled on a county-by-county basis with three to four counties revised annually. All current work is performed by contractors. The state is in the process of creating a GIS which incorporates both past and ongoing work. The costs reflect Wisconsin DNR project management, photo acquisition and film processing, photo-interpretation, map transfer, and manual digitization of the map overlays. Maps are available in paper and digital formats where digitization is completed. The cost is estimated at $43.00 per square mile or $0.07 per acre (L. Stoerzer, WDNR, personal communication, 1990).

TABLE 3

PROJECT AND PROGRAM SUMMARY TABLE

Project	Data Source	Analysis	Map Transfer	Encoded	Minimum Map Unit	Cost Acre
EPA-EMSL PROJECTS						
Clark Fork	AP/MSS	WL,NPS	No	No	0.5 acre	$0.06
LPO, ID	TM/AP	LC	No	No	1-2 acre	$0.03
BLH, IL	TM/AP	WL, LC	Yes	Yes	1-2 acre	$0.19
Pearl R.	TM	WL	No	No	1-2 acre	$0.21
OTHER FEDERAL PROGRAMS						
NWI	AP	WL	Yes	Yes	1-2 acre	$0.06
USACE	AP	LC, LU	Yes	Yes	1-2 acre	$0.07
STATE PROGRAMS						
Florida	TM/AP	WL	No	No	1 acre	$0.02
Georgia	AP	WL	No	No	0.5-1 acre	N/A
Michigan	AP	LC, LU	Yes	Yes	1 acre	$0.06
Wisconsin	AP	WL	Yes	Yes	2 acre	$0.07

Analysis Symbols
AP - Aerial photography
MSS - Aircraft multispectral scanner
TM - Landsat Thematic Mapper
LC - Land Cover
LU - Land Use
WL - Wetland
NPS - Non-point source

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GLOSSARY

This glossary is included to assist the reader of this report in understanding those relatively uncommon terms that are widely used in remote sensing and space operations. Many of these terms are defined specifically as they are used in remote sensing, space operations, and related activities; these definitions may different from standard definitions for the same word.

TERMS

ABSORPTION. The process by which electromagnetic radiation (EMR) is assimilated and converted into other form(s) of energy, primarily heat. Absorption takes place only on the EMR that enters a medium, and not on EMR incident on the medium but reflected at its surface. A substance that absorbs EMR may also be a medium of refraction, diffraction, or scattering; however, these processes involve no energy retention or transformation and are distinct from absorption.

ABSORPTION BAND. A range of wavelengths (or frequencies) of EMR that is assimilated by a substance.

AIRPHOTO IMAGES. A 9" by 9" photograph acquired vertically downward or obliquely from the air on 10" roll film. Airphoto images may be in the form of paper prints or transparent film.

AIRVIDEOGRAPHY. The growing new field of acquiring vertical airvideo images and making measurements from digitized frames of such imagery for the purpose of monitoring or managing agricultural and natural resources, tax assessment,environmental degradation, etc.

ALGORITHM (computing terminology). A statement of predefined steps to be followed in the solution of a problem.

ARC/INFO. A vector (arc) based Geographic Information System (GIS) developed use on minicomputers and personal computers (PC ARC/INFO).

AVHRR. Advanced Very High Resolution Radiometer imagery produced by NOAA Satellites.

BACKGROUND. Any effect in a sensor or other apparatus or system above which the phenomenon of interest must manifest itself before it can be observed. See background noise.

BACKGROUND NOISE. (1) In recording and reproducing, the total unwanted disturbance within a useful frequency band, independent of whether or not a signal is present. The signal is not to be included as part of he disturbance. (2) In receivers, the random oscillation in the absence of signal modulation on the carrier. Ambient oscillations detected, measured, or recorded with the signal become part of the background noise. Included in this definition is the interference resulting from primary power supplies, that is commonly described as hum.

BAND, SPECTRAL. An interval in the electromagnetic spectrum defined by two wavelengths, frequencies, or wave numbers.

BRIGHTNESS. The attribute of visual perception in accordance with which an area appears to emit more or less light.

BRIGHTNESS VALUE (BV or DN digital number). A number in a range of 0-63, 0-127, or 0-255 that is related to the amount of radiance in Watts/cm striking a detector in the multi-spectral scanner.

BYTE. A unit of measure based upon a base 2 number system where each byte represents 256 data levels.

CELL. In remote sensing, an area on the ground from which EMR is emitted or reflected.

CLASSIFICATION. (1) An administrative system wherein information, equipment, or processes are categorized according to their importance. (2) A systematic arrangement of objects (which have been imaged) into a logical structure or hierarchy. (3) A computer process of determining the grouping of cells in coregistered, multispectral, multitemporal, and/or multisensor rasters to map the location of materials and identify their type (e.g., type of crop, surface cover map, map line type by color, etc,)

CIR IMAGE. A Color InfraRed image or photograph renders healthy, green vegetation in bright red. Damaged, diseased, or dying vegetation will appear in shades of pink, tan, and yellow. The original sensing devise used for collecting color infrared images may be a electronic scanner or special film type which maps the photographic infrared radiation just beyond the range of human vision into the red intensity in the display or film. The red radiation from the scene is mapped into green in the display or film. The green radiation from the scene is mapped into the blue display or film. The blue radiation from the scene is filtered out and not recorded.

A physical or biological impact on growing plants which begins to cause a deterioration in their vigor, that is, their water and/or chlorophyll content, will cause more rapid decreases in their reflectance of photo infrared radiation and corresponding increases in their red reflectance.

CLUSTER. A homogeneous group of units which are very "like" one another. "Likeness" between units is usually determined by the association, similarity, or distance between the measurement patterns associated with the units.

COREGISTRATION. This indicates that the associated raster and vector objects overlay each other accurately in a geographic sense.

DETECTION. The act of discovering or perceiving an object on an image. It does not imply recognition or identification of that object.

D.E.M. Digital Elevation Model data is distributed by the USGS in raster from on open reel magnetic tapes. It consists of two basic types. The DMA type was originally created by the Defense Mapping Agency in a fixed cell size and also a 3 arcsecond by 3 arcsecond cell size and distributed in 1 by 1 degree files. A newer format of elevation data is available for those 7.5' USGS quadrangles which have been processed into 1 by 1 arcsecond elevation cells.

DIGITAL IMAGE (or digitized image, or digital picture function). An image in digital format that is obtained by partitioning the area of the image into a finite two-dimensional array of small uniformly shaped mutually exclusive regions, called resolution cells, and assigning a "representative" grey shade to each such spatial region. A digital image may be abstractly thought of as a function whose domain is the finite two-dimensional set of resolution cells and whose range is the set of grey shades.

DIGITIZATION, MANUAL. The process of conversion of analogue or graphic data into digital form by an operator with or without mechanical or computer aids.

DIGITIZE. To use numeric values to represent data.

DIGITIZER, GRAPHIC. Machine that changes graphic cartographic information into a digital format for computer input.

ELECTROMAGNETIC SPECTRUM. (1) A system that classifies, according to wavelength, all energy that moves, harmonically, at the constant velocity of light. (2) A continuum that is conventionally broken into arbitrary segments (as ultraviolet, visible, radio).

FALSE COLOR. Reproduction that shows objects in colors other than their true color. Usually, the color refers to color infrared, but not necessarily.

GAIN (electronic). Ratio of output signal to input of a device.

GEOMETRIC ACCURACY. Four types: Geographic (latitude-longitude) based on the standard Earth-fixed coordinates reference system, which employs latitude and longitude. Positional - the ability to locate a point in an image with respect to a map. Scene Registration - the ability to superimpose the same point in two images of a scene taken at the same time (different spectral bands). Temporal Registration - the ability to superimpose a point in two images of the same scene taken at different times (same or different spectral bands.

GIGABYTE, GBYTE, OR GB. A computer unit measurement used to indicate 1,000,000,000 bytes, 1,000,000 kilobytes, 1,000 megabytes, or .001 terabytes.

GIS A Geographic Information System is a computer system designed to allow users to collect, manage, and analyze large volumes of spatially referenced and associated attribute data. The major components of a GIS are: a user interface, system/data base management capabilities; data base creation/data entry capacity; spatial data manipulation and analysis packages; and display/product generation functions. From USGS Open File Report 88-105: A Process for Evaluating Geographic Information Systems.

GPS Global Positioning System technology was developed by the US Department of Defense for military applications. The technology makes positioning on Earth possible to within millimeters of accuracy. GPS is based on a constellation of NAVSTAR satellites orbiting earth (by 1992 a total of 24 satellites will have been launched in 12-hour orbits, so at least four satellites - the minimum required to obtain 3D positional data - will be visible to a GPS at almost any point on Earth). The GPS receiver, a small portable device that weighs only a few pounds, acquires the signals from these four satellites and using a method called "satellite ranging", calculates the position on Earth by measuring the length of time it takes for the satellite signal to reach the receiver. Within one second, positional coordinate data - longitude, latitude, and elevation - is displayed on the GPS receiver screen.

GRAY TONE. A number or value assigned to a position (x, y) on an image. The number is proportional to the integrated output, reflectance, or transmittance of a small area, usually called a resolution cell or pixel, centered on the position (x, y). The gray shade can be measured as or expressed in any one of the following ways:

(1) transmittance (2) reflectance
(3) a coordinate of the ICI color coordinate system
(4) a coordinate of the tristimulus value color coordinate system
(5) brightness (6) radiance
(7) luminance (8) density
(9) voltage (10) current

GREEN BIOMASS. Green biomass is synonymous with phytomass. It is the amount of wet or dry weight,growing, chlorophyll containing plant material per unit ground area. It is usually expressed in grams per square meter, tons per acre, or metric tons per hectare.

GREENNESS. The biophysical property of the surface of the earth indicating its greenness in a biological sense as related to vigor, water wellness, and chlorophyll content. This greenness property is a qualitative estimate of green biomass and is the property computed and stored in a raster object by Kauth's greenness, brightness, wetness transformation for LANDSAT MSS or TM images.

GROUND RESOLUTION. The minimum distance between two or more adjacent features or the minimum size of the feature which can be detected; usually measured in conventional distance units, e.g. feet or inches.

GROUND TRUTH. Information concerning the actual state of the environment at the time of a remote sensing overflight.

GROUND CONTROL. Accurate data on the horizontal and (or) vertical positions of identifiable ground points.

HIS Refers to the Hue, Intensity, Saturation color domain where these three characteristic are used to specify a color.

HISTOGRAM. A graphical representation of a frequency distribution by means of lines or rectangles that represent class intervals along the x-axis, and represent corresponding class frequencies along the y-axis. A graphical representation of the number of times a value occurs in a raster image plotted against each of the data values which could be present in the original raster image.

IDENTIFY. The process of recognition or identification whereby an object or unit on an image may be classified or categorized as to a specific function or type.

IMAGE. The recorded representation of an object produced by optical, electro optical, optical mechanical, or electronic means. It is the term generally used when the EMR emitted or reflected from a scene is not directly recorded on film.

IMAGE ENHANCEMENT. Any of several processes to improve the interpretability of an image. These include contrast enhancement, ratioing, spatial filtering, and so on.

IMAGE PROCESSING. All the various operations which can be applied to photographic or image data. These include, but are not limited to, image compression, image restoration, image enhancement, preprocessing, quanitization, spatial filtering, and other image pattern recognition techniques.

IMAGERY. The visual representation of energy recorded by remote sensing instruments.

INFRARED (IR). Pertaining to or designating the portion of EM spectrum with wavelengths from the red end of the visible spectrum to the microwave portion of the spectrum, or from 0.7 micrometer to 1 millimeter.

INTENSITY. One of the three coordinates which specifies color in the HIS color domain. Intensity is that coordinate or value which represents the brightness or average radiance level of a color.

INTERACTIVE IMAGE PROCESSING. The use of an operator or analyst at a console with a means of assessing, preprocessing, feature extracting, classifying, identifying and displaying the original imagery or the processed imagery for his subjective evaluation and further interactions.

INTERPRETER. An individual trained in the process of detecting, identifying, analyzing, locating and quantifying information portrayed on imagery and determining its significance.

KILOBYTE. In computer terminology, refers to 1024 bytes of core memory storage.

LAND COVER. Cultural objects and natural and cultivated vegetation occupying the landscape that can be grouped or classified and subsequently mapped using remotely sensed imagery.

LAI Leaf Area Index is a unitless, biological, measure which is the one sided surface area of the leaves of a crop, forest, grassland, etc. per unit ground area.

LANDSAT. A satellite vehicle used to house the sensor systems which collect multispectral images using at various times a RBV or Return Beam Vidicon device, the MSS or MultiSpectral Scanning device, and the TM or Thematic Mapper scanning device. LANDSAT also relays data from ground observation stations. Originally the LANDSAT satellite was referred to as the ERTS or Earth Resource Technology Satellite.

LEGEND. A description, explanation, table of symbols, scale bar and other information printed on margins of maps or mosaics.

MAP, PLANIMETRIC. Map showing only the horizontal location of detail.

MAP, THEMATIC. Map designed to demonstrate particular features of concepts. In conventional use this term excludes topographic maps.

MEGABYTE, MBYTE, OR MB. A computer unit of measurement used to indicate 1,000,000 bytes, 1,000 kilobytes, or .001 gigabytes.

MICROMETER. Millionth of a meter, a thousandth of a millimeter.

MULTIBAND SYSTEM. A system for simultaneously recording EMR from the same scene in several bands from essentially the same spectral region, such as the visible or visible and near-IR. May be applied to cameras with different film/filter combinations or scanning radiometers that use dispersant optics to split wavelength bands apart for viewing by several filtered detectors.

MULTISENSOR IMAGES. Images collected by different sensors or other devices which have been manipulated so as to be coregistered in both cell size and location are called multisensor data.

MULTITEMPORAL IMAGES. Images collected at different times by the same device and brought into coregistration are multitemporal images. For example, airvideo images collected at approximately the same data on two successive years can be digitized and one of them warped to overlay the other and stored in the same project file. These multitemporal images can then be analyzed in various ways to map the changes between the dates.

MULTISPECTRAL. Generally used for remote sensing in two or more spectral bands, such as visible and IR.

NANOMETER. A unit of measure equal to one millimicrometre (millimicron) or one-millionth of a millimeter.

NASA National Aeronautics and Space Administration.

NEAR INFRARED. The preferred term for the shorter wavelengths in the infrared region extending from about 0.7 micrometers (visible red) to about three micrometers. The longer wavelength end grades into the middle infrared. The term really emphasizes the radiation reflected from plant materials, which peaks around 0.85 micrometers. It is also called solar infrared, as it is only available for use during the daylight hours.

NOAA National Oceanographic and Atmospheric Administration.

NWI National Wetlands Inventory being conducted by the USF&WS.

PICTURE ELEMENT (PIXEL). A unit whose first member is a resolution cell and whose second member is the gray shade assigned by a digital count to that resolution cell.

PIXEL. Abbreviation of picture element.

PLANIMETRY, AUTOMATIC. The process of calculating the area of a patch from data defining the boundary of the patch.

PLATFORM. The object, structure, vehicle, or base upon which a remote sensor is mounted.

POLYGON. Plan figure consisting of three or more vertices (points) connected by line segments or sides. The plane region bounded by the sides of the polygon is the interior of the polygon.

PREPROCESSING. An operation applied before pattern identification is performed. Preprocessing produces, for the categories of interest, pattern features which tend to be invariant under changes such as translation, rotation, scale, illumination levels, and noise. In essence, preprocessing converts the measurements patterns to a form which allows a simplification in the decision rule. Preprocessing can bring into registration, bring into congruence, remove noise, enhance images, segment target patterns, detect, center, and normalize targets of interest.

RANGE, BRIGHTNESS. Variation in light intensity from maximum to minimum. This generally refers to a subject to be photographed.

RANGE, DYNAMIC. The difference between maximum measurable signal and minimum detectable signal. The upper limit usually is set by saturation and the lower limit by noise.

RASTER CELL. A raster is made up of a sequence of numbers representing a measured variable or the results of computing upon such measurements. These numbers have an order and a position in space and describe the variation if some phenomena of interest such as the elevation above sea level of the ground or the intensity of the red radiation in a video image. The individual value in a raster can thus be thought of as the average value representing a specific area or cell of the ground or other area represented. For convenience, this cell is usually thought of as a square or rectangle although many image collection devices actually create the value from the measurement of a circular or elliptical observation cell.

RATIO. A reflectance ratio of any target is the percent of reflectance in one spectral region divided by the percent of reflectance in another region. The display is a representation of the reflectance ratio of the two spectral regions.

RECTIFYING. A process by which the geometry of an image area is made planimetric. For example, if the image is taken of an equally spaced rectangular grid pattern, then the rectified image will be an image of an equally spaced rectangular grid pattern. Rectification does not remove relief distortion.

REFLECTANCE. A measure of the ability of a body to reflect light or sound. The reflectance of a surface depends on the type of surface, the wavelength of the lumination, and the illumination and viewing angles.

REGISTERING. The translation-rotation alignment process by which two images of like geometries and of the same set of objects are positioned coincident with respect to one another so that corresponding elements of the same ground area appear in the same place on the registered images.

REFLECTION (EMR theory) EMR neither absorbed nor transmitted is reflected. Reflection may be diffuse, when the incident radiation is scattered upon being reflected from the surface, or specular, when all or most of the EMR is reflected at an angle equal to the angle of incidence.

REMOTE SENSING. In the broadest sense, the measurement or acquisition of information of some property of an object or phenomenon, by a recording device that is not in physical or intimate contact with the object or phenomenon under study; for instance, the utilization at a distance (as from aircraft, spacecraft, or ship) of any instrument and its attendant recording and display devices for gathering information pertinent to the environment, such as measurements of force fields, electromagnetic radiation, or acoustic energy. The technique employs such devices as the camera, lasers, and radio frequency receivers, radar systems, sonar, seismographs, gravimeters, magnetometers, multispectral scanners, and scintillation counters.

RESAMPLE. The process of interpolating the values of the cells in a raster object to yield a new raster object which has larger or smaller cells and perhaps a raster which has been warped, reoriented and/or rescaled relative to the input raster.

REPRESENTATIVE FRACTION (RF). The relation between map or photo distance and ground distance, expressed as a fraction (1/25,000) or ratio 1:25,000, or 1 mm on map=25,000 mm on the ground.

RESOLUTION. A generic term which describes how well a system, process, component, material, or image can reproduce an isolated object or separate closely spaced objects or lines. The limiting resolution, resolution limit or spatial resolution is described in terms of the smallest dimension of the target or object that can just be discriminated or observed. Resolution may be a function of object contrast, spatial position as well as shape. The ability of a remote sensing system to distinguish signals that are close to each other spatially, temporally, or spectrally.

RESOLUTION CELL. The smallest most elementary areal constituent of grey shades considered by an investigator in an image. A resolution cell is referenced by its spatial coordinates. The resolution cell or formations of resolution cells can sometimes constitute the basic unit for pattern recognition of image format data.

RGB An acronym for Red, Green, and Blue.

SAMPLES. Samples of cells in a raster or image are selected from known areas from ground visitation, detailed airphoto interpretation, or other personal experience and are used to represent a feature or land cover of interest and value in a process such as feature mapping.

SATURATION. One of three coordinates which specifies color in the HIS domain. Saturation is that coordinate or value which designates how far away a color is from gray or neutral color of equal intensity.

SCANNERS. The sweep of a mirror, prism, antenna, or other element across the track (direction of flight); may be straight, circular, or other shape.

SENSOR. An device which gathers energy and presents it in a form suitable for obtaining information about the environment. Passive sensors, such as thermal infrared and microwave, utilize EMR produced by the surface or object being sensed. Active sensors, such as radar, supply their own energy source. Aerial cameras use natural or artificially produced EMR external to the object or surface being sensed.

SIGNATURE. Any characteristic or series of characteristics by which a material may be recognized. Used in the sense of spectral signature, as in photographic color reflectance. A category is said to have a signature only if the characteristic pattern is highly representative of all units of that category.

SPECTRAL BAND. An interval in the electromagnetic spectrum defined by two wavelengths, frequencies, or wave numbers.

SPECTRAL INTERVAL. The width, expressed either in wavelength or frequency, of a particular portion of the electromagnetic spectrum. A given sensor, such as radiometer detector or camera film may be designed to measure or be sensitive to energy from a particular spectral interval.

SUN ANGLE. The angle of the Sun above the horizon. Both the quantity (lumes) and spectral quality of light being reflected to the aerial camera or sensor are influenced by Sun angle. Also called Sun elevation, Sun elevation angle.

THERMAL BAND. A general term for intermediate and long wavelength infrared-emitted radiation, as contrasted to short wavelength reflected (solar) infrared radiation. In practice, generally refers to infrared radiation emitted in the 3- to 5- and 8- to 14-micrometer atmosphere windows.

THERMAL INFRARED. The preferred term for the middle wavelength ranges of the IR region extending roughly form 3 micrometers at the end of the near infrared, to about 15 or 20 micrometers where the far infrared commences. In practice the limits represent the envelope of energy emitted by the Earth behaving as a greybody with a surface temperature around 290 K (27 C). Seen from any appreciable distance, the radiance envelope has several brighter bands corresponding to windows in the atmospheric absorption bands. The thermal band most used in remote sensing extends from 8 to 14 micrometers.

UNIT. The simplest and most practical picture element(s) observed, compared, or measured in a pattern recognition sequence. Most units are not simple picture elements but are often complex spatial formations of picture elements such as houses, roads, forest, etc.

VECTOR. A linear line segment, normally short, used to construct any line form on a plotter, drafting unit or display.

WAVELENGTH. Wavelength = 1/frequency. In general, the mean distance between maximums (or minimums) of roughly periodic pattern. Specifically, the shortest distance between particles moving in the same phase of oscillation in a wave disturbance. Optical and IR wavelengths are measured in nanometers, micrometers, and Angstroms.

APPENDICES

APPENDIX A - SOURCES OF DIGITAL SPATIAL DATA

US GEOLOGICAL SURVEY - NATIONAL MAPPING PROGRAM
EARTH SCIENCE INFORMATION CENTER ADDRESSES
(formerly the National Cartographic Information Center)

Reston - ESIC
U.S. Geological Survey
507 National Center
Reston, VA 22092
(703) 860-6336/FTS 959-6045

Rolla - ESIC
1400 Independence Road
Rolla, MO 65401
(314) 341-0851/FTS 759-0851

Lakewood - ESIC
Federal Center
Box 25046, MS 504
Denver, CO 80225-0046
(303) 236-5829/FTS 776-5829

Los Angeles - ESIC
Federal Bldg., Rm.7638
300 N. Los Angeles St.
Los Angeles, CA 90012
(213) 894-2850/FTS 798-2850

Stennis Space Center - ESIC
Building 3101
Stennis Space Center, MS 39529
(601) 688-3544/FTS 494-3544

Salt Lake City - ESIC
8105 Federal Bldg.
1245 S. State St.
Salt Lake City, UT 84138
(801) 524-5652/FTS 588-5652

Menlo Park - ESIC
Building 3, MS 532
345 Middlefield Road
Menlo Park, CA 94025
(415) 329-4309/FTS 459-4309

Anchorage - ESIC
4230 University Drive
Anchorage, AK 99508-4664
(907) 271-4159/FTS 868-7011

San Francisco - ESIC
504 Custom House
555 Battery St.
San Francisco, CA 94111
(415) 705-1010/FTS 465-1010

Washington, D.C. - ESIC
Dept. of the Interior Bldg.
1849 C St., NW Rm.2650
Washington, D.C. 20240
(202) 208-4047/FTS 268-4047

For more detailed information contact the ESIC office nearest you. Fact sheets, user guides, price lists, and order forms are available upon request. ESIC personnel will assist with ordering available digital products and can provide more technical information. ESIC has established affiliated offices with many State governments.

Available USGS Circulars include:
895-A, Overview and USGS Activities
895-B, Digital Elevation Models
895-C, Digital Line Graphs from 1:24,000 Maps
895-D, Digital Line Graphs from 1:2,000,000 Maps
895-E, Land Use and Land Cover Digital Data
895-F, Geographic Names Information System
895-G, Digital Line Graph Attribute Coding Standards

U.S. GEOLOGICAL SURVEY
DIGITAL CARTOGRAPHIC AND GEOGRAPHIC DATA
US GEODATA

TOPOLOGICAL - TRANSPORTATION, HYDROLOGY, BOUNDARIES

Data Format:
Vector files in DLG format
Scale/Resolution:
1:24,000, 1:100,000, 1:2,000,000
Data Description:
Separate files are available for:
- Land net
- Boundaries
- Transportation
- Hydrography
- Hypsography

Data Coverage:
1:2,000,000 data are available for the entire United States.
1:100,000 data are complete for transportation and hydrology.
1:24,000 are not as well developed.
For current coverage call ESIC.
Media:
9-track magnetic tape and/or paper maps

TOPOLOGICAL - LAND USE/LAND COVER, WATERSHEDS

Data Format:
Vector files in GIRAS format
(GIRAS is an arc-node format. Programs are available from ESIC for converting this format to the DLG standard).
Raster available in binary or character (ASCII or EBCIDIC) form
Scale/Resolution:
Vector 1:100,000 or 1:250,000
Raster 200 meters
Data Description:
Separate files are available for:
- Land use/land cover
- Political units
- Census county subdivisions
- Hydrologic units (watersheds)
- Federal land ownership (park, forest, etc.)

Composite Theme Grid (CTG) which contains all themes available for a given area.
Data Coverage:
Contact ESIC for latest edition of "Index to Land Use and Land Cover Information".
Media:
9-track ASCII tapes and paper maps

U.S. GEOLOGICAL SURVEY
DIGITAL CARTOGRAPHIC AND GEOGRAPHIC DATA
US GEODATA

DIGITAL ELEVATION MODELS

Data Format:
Raster
Scale:
1:24,000
Data Description:
A regular array of elevation values referenced to the Universal Transverse Mercator (UTM) coordinate system with a spacing of 30 meters. Data are collected either by digitizing 7.5 foot contours overlays or by scanning photographs.
Data Coverage:
Scattered 7.5 minute quadrangles throughout the United States. Contact ESIC for the "Index to Digital Line Graph and Digital Elevation Model Data".
Media:
9-track magnetic tape and/or paper maps

DIGITAL ELEVATION MODELS - DEFENSE MAPPING AGENCY AVAILABLE THROUGH USGS-ESIC

Data Format:
Raster
1 degree by 1 degree blocks
Scale:
1:250,000
Data Description:
Data consists of a regular array of elevation values, latitude/longitude, referenced with a spacing of 3-arc seconds. Data were produced from digitizing 1:250,000 topographic maps.
Data Coverage:
Entire United States and many other parts of the world.
Media:
9-track magnetic tape

U.S. GEOLOGICAL SURVEY
DIGITAL CARTOGRAPHIC AND GEOGRAPHIC DATA
US GEODATA
ACQUISITION COSTS

Series	Product (Data Type)
1:24,000	A. Digital Elevation Model B. Digital Line Graph (DLG) Land Net Boundaries Transportation Hydrography Hypsography
1:100,000	Digital Line Graph (DLG) (30′ x 30′ blocks) Land Net Boundaries Transportation Hydrography Hypsography
1:250,000	Land Use/Land Cover (Polygon) Census Tracks Political Boundaries Hydrologic Units Federal Land Ownership Composite Geographic Names by State
1:250,000	Digital Elevation Model (1 deg x 1 deg blocks)
1:2,000,000	Digital Line Graph (DLG) (sold in 21 sections) Boundary Layer (per section) Transportation Layer (per section) Hydrography Layer (per section)

PRICE FOR ANY COMBINATION OF THE LISTED GEODATA PRODUCTS
Prices for orders of five or less are as follows:

Number of files per order	Total Price
1	$40
2	60
3	80
4	100
5	120

Prices for orders of six or more files are as follows:
Base Charge of $90 plus $7 per file.

US GEOLOGICAL SURVEY - NATIONAL MAPPING PROGRAM
EARTH SCIENCE INFORMATION CENTER ADDRESSES
(formerly the National Cartographic Information Center)

NATIONAL WETLAND INVENTORY
U.S. Department of the Interior
Fish and Wildlife Service
National Wetlands Inventory
9720 Executive Center Drive
Suite 101, Monroe Building
St. Petersburg, FL 33702

Data Format:
Generally available in USGS 7.5 minute topographic maps.
Limited digital data available.

Data Description:
Photo-interpreted wetland inventory on USGS base maps. Classification of categories is based on US Fish and Wildlife Service publication "Classification of Wetlands and Deepwater Habitats of the of the United States", USFWS Report No. FWS/OBS-70/31.

Data Availability/Cost
Data may be ordered through any USGS ESIC office.
Paper Composite of NWI 7.5 minute maps are $1.75 each.

CENSUS BUREAU GEOGRAPHIC PRODUCTS

US Department of Commerce
Bureau of the Census
Customer Services Branch
Data User Services Division
(301) 763-4100

Data Format:
ANCII or EBCDID, labeled or unlabeled

Data Description:
TIGER - Topologically Integrated Geographic Encoding and Referencing System. Census Bureau's new digital map data base that provides coordinate based cartographic information by County.
TIGER data base includes:
Features (roads, railroads, rivers), feature names and classification codes, alternate feature names and codes, feature shape coordinates.
Address ranges with ZIP codes for metropolitan areas.
Census statistical area boundaries (census blocks/tracks)
Political boundaries (state, county, and incorporated places)

The TIGER/Line files contain basic data for each individual segment. Each segment record contains the appropriate census geographic area codes, latitude/longitude coordinates, the name and type of the feature, the relevant census feature class code identifying the feature segment by category, and for metropolitan areas, the address ranges and associated ZIP codes for each side of a street segment.

Data Coverage:
Entire United States, Puerto Rico, the Virgin Islands, and US Pacific territories.

Availability:

Precensus TIGER/LINE Files	April 1989
Postcensus TIGER/LINE Files	Late Spring/Summer 1991
TIGER/Data Base	Fall 1991
TIGER/Boundary	Fall 1991
TIGER/Comparability	Fall 1991
TIGER/Area	As Required

Media:
9-track magnetic tape

Acquisition Costs:
$190 for the first county ordered
$ 15 for each additional county ordered within the same state

EOSAT (EARTH OBSERVATION SATELLITE COMPANY)
MULTISPECTRAL SATELLITE

EOSAT Company
4300 Forbes Blvd.
Lanham, MD 20706
1-800-344-9933

Data Format:
U Data - Corrected for radiometric only
C Data - Corrected for radiometric and geometric distortions

Radiometric: Data are scaled to pixel dynamic ranges of 0-256 for TM and 0-127 for MSS, and compensated for detector gain and offset changes.

Geometric: Data are compensated for earth rotation, spacecraft altitude, attitude and sensor variations. (Note: data is not rectified to a coordinate system, geocoded products are available).

LANDSATS 4 and 5

Thematic Mapper (TM) C or U available 4/84 to present
Band sequential (BSQ) - Fast Format only

Multispectral Scanner (MSS)
BSQ or Band interleaved (BIL) - C or U available 6/81 to present
BSQ or BIL - C only for 1/79 to 5/81
BIP prior to 1/79 (U only)

Media:
9-track magnetic tape, 6250 or 1600 bpi

Scale/Resolution:
TM approximately 30 meters with thermal band 6 at 120 meters
MSS approximately 80 meters

Data Description:
As a result of the Land Remote Sensing Commercialization Act of 1984, Landsat data are currently acquired, processed, and distributed by EOSAT Company under a cooperative agreement with NOAA and the USGS. Users must sign a form when acquiring data stating they will not copy or distribute the data without authorization from EOSAT.

EOSAT (EARTH OBSERVATION SATELLITE COMPANY)
MULTISPECTRAL SATELLITE

Spectral Sensitivity of the TM and MSS Sensors

TM data - 7 bands

Band 1 - blue	0.45-0.52	micrometers
Band 2 - green	0.52-0.60	
Band 3 - red	0.63-0.69	
Band 4 - near IR	0.76-0.90	
Band 5 - near IR	1.55-1.75	
Band 6 - thermal IR	10.4-12.5	
Band 7 - mid IR	2.08-2.35	

MSS data - 4 bands

Landsat 4 & 5	Landsat 1, 2,& 3		
Band 1	Band 4	green	0.5-0.6 micrometers
Band 2	Band 5	red	0.6-0.7
Band 3	Band 6	Near IR	0.7-0.8
Band 4	Band 7	Near IR	0.8-1.1

<u>Data Coverage:</u>
Worldwide.
Historical data can be obtained through USGS-EROS Data Center.

<u>Acquisition Costs:</u>

TM Full Scene	(size: 185 x 170 km)	$ 3600
TM Quarter Scene	(size: 92.5 x 85 km)	$ 1800
TM Moveable	(size: 100 x 100 km)	$ 2600
TM moveable	(size: 50 x 100 km)	$ 2000
TM Geocoded	(size: 185 x 170 km)	$ 4900
TM Geocoded	(size: 92.5 x 85 km)	$ 2900
TM Geocoded	(size: 1/2 by 1 degree map sheet)	$2300
MSS Full Scene	(size: 185 x 185 km)	$ 660

EPA-ENVIRONMENTAL MONITORING SYSTEMS LABORATORY MULTISPECTRAL AIRBORNE

U.S. Environmental Protection Agency
Environmental Monitoring Systems Laboratory
Advanced Monitoring Systems Division
P.O. Box 93478
Las Vegas, NV 89193-3478
Ross S. Lunetta
(702) 798-2175
FAX (702) 798-2637

Data Format:
Aircraft-mounted multispectral scanner.
EMSL-LV's scanner system is a Daedalus Enterprises Model 1260 instrument. This system uses a rotating mirror to direct radiated energy from a spot on the Earth's surface onto sensing detectors. Energy is focused on sensors with a telescope assembly, and is split into spectral components by a prism and a dichroic mirror. The Daedalus 1260 is an 11-band system with a sensitivity range from 0.3 to 14 micrometers (ultraviolet though thermal infrared). Geometric control is greatly improved over past missions (FY91) with the use of Global Positioning System (GPS) technology. With a single receiver (autonomous mode) RMS accuracies of fixes are approximately 25 meters unless the Air Force invokes intentional system degradations called "selective availability" (SA), in which case accuracies degrade to approximately 100 meters. However, if a second GPS receiver simultaneously acquires data at a known location, then "differential corrections" can be applied that improve accuracies to approximately 5 meters, whether SA is in effect or not.

GPS fixes are acquired by an onboard GPS receiver and logged on a small computer. The fixes include accurate latitude, longitude, and altitude information which is made more accurate later when differential corrections are applied. The fixes also include precise information about the time that the fixes were taken. This is critical because it takes time for the receiver to report its fix to the computer, and the aircraft has moved an appreciable distance in that time. The recorded times are used later during data reduction. The sequence of precise times and positions from the GPS fixes, and the scan line time are used to interpolate scan-center position and heading. This allows accurate compensation for changes in heading, mispositioning left or right of the scan line, and changes in altitude. In addition to knowing aircraft position, heading and altitude, scan line by scan line, it is important to understand the terrain below. Height above terrain is critical to scanner geometry, as is variation in terrain elevation across the scan line. Digital elevation models (DEM) from the USGS are placed into mosaics covering the mission area, and are used by the geometric correction software.

EPA-ENVIRONMENTAL MONITORING SYSTEMS LABORATORY MULTISPECTRAL AIRBORNE

US Environmental Protection Agency
Environmental Monitoring Systems Laboratory
Advanced Monitoring Systems Division

Media:
9-track magnetic tape.

Data Description:
The MSS is aircraft-mounted and available for contract data collection. The customer has control over the area of coverage, resolution of data, and wavelengths to be collected. Post-processing operations applied include those designed to calibrate the data and to correct for systematic scanner distortions. In addition, simultaneous aerial photography can be collected with a Wild RC-8 metric mapping camera.

Spectral Sensitivity of the Daedalus DS-1260

Channel 1	Near Ultraviolet	0.38-0.42	micrometers
Channel 2	Blue	0.42-0.45	
Channel 3	Blue	0.45-0.50	
Channel 4	Green	0.50-0.55	
Channel 5	Green	0.55-0.60	
Channel 6	Red	0.60-0.65	
Channel 7	Red	0.65-0.79	
Channel 8	Near Infrared	0.80-0.89	
Channel 9	Near Infrared	0.92-1.10	
Channel 10	Mid Infrared	1.50-1.75	

Either one of two thermal detectors can be employed

Channel 11	Thermal Infrared	(InSb)	3.00-5.00
		(MCT)	8.00-14.0

Acquisition Costs:
MSS collection only $15 - $20 per square mile
Simultaneous aerial photography $10 - $15 per square mile

NATIONAL GEOPHYSICAL DATA CENTER
BATHYMETRY, GRAVITY, MAGNETICS, EARTHQUAKE SEISMOLOGY, CHEMICAL ANALYSES, SATELLITE DATA, AND MARINE GEOLOGY AND GEOPHYSICS

National Environmental Satellite, Data, and Information Service
National Geophysical Data Center
NOAA, Code E/GC1
325 Broadway
Boulder, CO 80303-3328
(303) 497-6900

Data Format:

Digital data is distributed on standard magnetic tape: 9-track, ASCII, 1600bpi. Other formats such as 6250 bpi tapes and floppy diskettes may be requested.

Data Description:

Aeromagnetic and geomagnetic data; oil and gas lease data; ocean core sample locations; ocean bottom characteristics; dangers to navigation; coastal, deepwater, or gridded bathymetry; land and marine seismic data; geothermal data; land and marine geology; satellite data (GEOSAT, MAGSAT, GEOS-III, SEASAT); and topography data.

Acquisition Costs:

Varies, call or write for quotes, literature.

SOILS

Soil Conservation Service (SCS)
National Cartographic Center
South National Technical Center
501 Felix, P.O. Box 6657
Fort Worth, TX 76115

Data Format:
Raster encoded as ASCII

Scale/Resolution:
Vector: mostly 1:24,000
Raster: mostly 4-hectare cells

Data Coverage:
Scattered. Call/write SCS at above address for current edition of "Status of Detailed Soil Survey Digitizing" or "Status of Soil Survey Digitizing".

Data Description:
Data are available on a county basis. The program is funded by state SCS offices; thus, extensive data are available for some states, and none for others. For areas that have not been digitized, cost-sharing information may be available form individual state soil scientists.

Media:
9-track magnetic tape

Acquisition Costs:
$150 per tape, $25 additional charge if SCS provides tape.

SPOT: MULTISPECTRAL SATELLITE
SPOT Image Corporation
1897 Preston White Drive
Reston, VA 22091-4326
(703) 648-1813

Data Format:
Raster
Scale/Resolution:
10 meter panchromatic or 20 meter multispectral
Data Coverage:
Worldwide, though historical data are not yet extensive.
Data Description:
The standard product is a SPOT scene measuring 60 km x 60 km when acquired from a vertical (nadir) viewing angle. SPOT's sensors also have an off-nadir viewing capability. Panchromatic and multispectral scenes are available and are processed to one of three levels:
Level 1A - raw data which have undergone radiometric corrections only to normalize detector response within each spectral band. No geometric corrections have been applied to the data.
Level 1B - raw data which have undergone both radiometric and geometric corrections to reduce distortions from systematic orbital effects. Level 1B images have a locational accuracy of about 860 meters and are not considered planimetric.
Level 2 - precision processed data which include radiometric, geometric, and bi-directional corrections based on ground control points (GCP). Imagery is oriented true north and available in several projections. Level 2 data have a location accuracy of approximately 30 meters, provided the image was recorded at a vertical viewing angle and relief is not over 10 meters.

Spectral Sensitivity of the SPOT Sensor

Multispectral	20 meter resolution	
Band 1	green	0.50-0.59 micrometers
Band 2	red	0.61-0.68
Band 3	Near Infrared	0.79-0.89
Panchromatic	10 meter resolution	
Band 1	visible	0.51-0.73 micrometers

Media:
9-track magnetic tape, 1600 or 6250 bpi, BIL format

Acquisitions Costs:

	Panchromatic	Multispectral
Level 1A, 1B	$1900	$1700
Level 2	3500	3200
SPOT QuadMaps		$500

1:24,000 corresponding to USGS 7.5 minute topo.
Most QuadMaps are less than 2 years old.

APPENDIX B - SPATIAL DATA AVAILABLE BY INDIVIDUAL STATES

This listing was extracted from the USGS Earth Science Information Center (ESIC), listing entitled "Sources for Digital Spatial Data".

ALASKA
National Cartographic Information Center, Geological Survey
4230 University Drive, Anchorage, AL 99508 (907)271-4159
Several federal lands inventoried.

ALABAMA
Satellite imagery over Alabama
Geological Survey of Alabama
Box 0, 420 Hackberry, Tuscloosa, AL 35486 (205)349-2852
Complete coverage by Landsat collected between 1972-74, color composites available, non-automated system.

ARIZONA
Arizona Land Resources Information System
State Land Office, 1624 W. Adams, Room 302
Phoenix, AZ 85007 (602)225-4061
General vegetation cover, 50 Meter cells, 1986
Vegetation/land cover, soils 1981

CALIFORNIA
California Department of Water Resources, Planning Division
1416 9th Street, Room 252-3, Sacramento, CA 94236-0001
Land use, agriculture, hydrology
Bay Area Spatial Information Data Base - GEOGROUP
2560 9th Street, Suite 319, Berkeley, CA 94710 (415)549-7030
Hydrography, wetlands, land use, eco-zones

FLORIDA
Florida Agriculture Lands Mapping
Florida Department of Transportation
State Topographic Office, Tallahassee, FL 32301 (904)488-2168
Land cover (15 classes) from Landsat TM imagery, concentration on agriculture, multi-temporal analyses also available. Complete library of Landsat and related image data (1976,1984-85). Users group located at DOT.

HAWAII
Coastal Resource Data Base
Hawaii State Dept. of Planning and Economic Development
250 S. King Street, Honolulu, HI 96813 (808)548-4025

IDAHO
Land Use - State of Idaho
Soil Conservation Service, Soils Division/Carto-GIS Laboratory
304 N. 8th Street, Room 345, Boise, ID 83702 (208)334-1525
Land use, agriculture, forestry, water; 1:100,000 vector

ILLINOIS
Illinois Geographic Information System
Illinois State Geological Survey, Computer Research and Services
615 E. Peabody, Champaign, IL 61820 (217)344-1481
Land resources, ecoregions, surface hydrology

IOWA
Satellite imagery over Iowa
Iowa Department of Natural Resources, Geological Survey Bureau
123 N. Capitol Street, Iowa City, IA 52242
Landsat coverage of the state for MSS 1973-81 and TM 1982-84. Digitized data sets in EROS or Goddard format.

KANSAS
Satellite Imagery over Kansas
Kansas Geological Survey, The University of Kansas
1930 Constant Avenue, Lawrence, KS 66046
Positive and negative transparencies of over 2000 images covering all of Kansas. Non-automated system.

KENTUCKY
Kentucky Natural Resource Information System
Kentucky Natural Resources and Environmental Protection Cabinet
Capitol Plaza Tower, 14th Floor, Frankfort, KY 40601 (505)564-5174. Landforms, surface hydrology.

LOUISIANA
Louisiana Areal Resource Information System
Louisiana Office of State Planning
P.O. Box 94095, Baton Rouge, LA 70804 (504)342-7410
Land use 1979 Satellite imagery over Louisiana
Louisiana Department of Natural Resources
Louisiana Geological Survey
Box G, University Station, Baton Rouge, LA 70893 (504)388-5320
Catalog/Index of available imagery, including the type, quality, data, and scale over the entire state of Louisiana.

MARYLAND
Maryland Automated Geographic Information System
Maryland Department of State Planning, Office of Planning Data
301 Preston Street, Baltimore, MD 21201-2365 (301)225-4450
Vegetation, wetlands

MICHIGAN
Michigan Resource Inventory Program
Michigan Department of Natural Resources, MIRIS
P.O. Box 30028, Lansing, MI 48909 (517)373-1170
Landcover information includes: agriculture, forest, non-forest, water, wetlands, barren lands. 1:24,000 scale, vector format.

MINNESOTA
Minnesota Land Management Information System
Minnesota State Planning Agency, Land Management Information Center
Metro Square Building, Room LL-65, St. Paul, MN 55101 (612)296-1208. Land use, soils, forestry, agriculture, watersheds, 1 ha.

MISSISSIPPI
Mississippi Automated Resource Information System
Mississippi Research and Development Center, GIS Division
3825 Ridgewood Drive, Drawer 2470, Jackson, MS 39211 (601)982-6128
Land use, soils, flood-prone areas, agriculture, 25 hectare cells

NEBRASKA
Nebraska Natural Resource Information System
Nebraska Natural Resources Commission, Data Bank Section
301 Centennial Mall South, Box 94876, Lincoln, NE 68509
(402)471-2081. Land use, agriculture, soils

NORTH CAROLINA
North Carolina Land Resource Information System
North Carolina Dept. of Natural Resources and Community Development
P.O. Box 27687, Raleigh, NC 27611-7687 (919)733-2090
Soils, hydrography, and nursery areas

NEW MEXICO
New Mexico Natural Resource Information System
New Mexico Department of Natural Resources
408 Galisteo Street, Villagra Bldg., Santa Fe, NM 87503
(505)827-7830. Vegetation, Agriculture, hydrography, soils, wetlands

New Mexico MOSS Data
Bureau of Land Management, New Mexico State Office
Box 1449, Federal Bldg., Santa Fe, NM 87501 (505)988-6081
Partial state coverage of vegetation, soils, range management, water

NEVADA
Soil Landform Analysis
Bureau of Land Management, Nevada State Office
300 Booth St., Box 12000, Federal Bldg., Reno, NV 89520 (702)784-5731. Soils, surface water.
Clark County Resources Information System Data Base
Clark County Department of Comprehensive Planning
225 Bridger Ave., 7th Floor, Las Vegas, NV 89115
Land use, vegetation, hydrography, soils. Vector format.

NEW YORK
New York Land Use and Natural Resource Inventory
New York Department of Commerce
99 Washington Ave., Albany, NY 12245 (518)474-7721
Land use, agriculture, forestry, wetlands, water resources

OHIO
Ohio Capability Analysis Program
Ohio Department of Natural Resources, Division of Soils and Water
Fountain Square, Building E-2, Columbus, OH 43224 (614)265-6778
Land use/land cover, soils, watershed boundaries

RHODE ISLAND
Rhode Island Statewide Planning Program
Rhode Island Department of Administration, Statewide Planning Program. 265 Melrose Street, Providence, RI 02907 (401)277-2656
Land use, vegetation, agriculture, wetlands; 10 acre cells

SOUTH CAROLINA
South Carolina Resource Information System
University of South Carolina, Computer Science Division
1244 Blossom Street, Columbia, SC 29208 (803)777-7366
Land use, vegetation

TEXAS
Texas Natural Resources Information System
Texas Department of Water Resources Systems Central
Box 13231, Capital Station, Austin, TX 78711 (512)475-3321
Land resources, surface water, and satellite imagery over Texas
Listing available from above referenced source for the available CCT's located in the archive, contains Landsat MSS and TM imagery.

UTAH
Utah Automated Geographic Reference System
Utah Automated Geographic Reference
1271 State Office Bldg., Salt Lake City, UT 84114 (801)533-6290
Topography, public land survey

VIRGINIA
Virginia Commonwealth Data Base
Virginia Polytechnic Institute, Department of Geography
Blacksburg, VA 24061 (703)961-5841
Landforms, cover types

WASHINGTON
Washington State Digital Land Use/Land Cover
Washington Dept. of Natural Resources, Info Management Division
1102 S. Quince St., EV-31, Olympia, WA 98504 (216)753-01262
Vegetation, cover types, agriculture, forestry; 1:24,000 scale

WISCONSIN
Wisconsin Department of Natural Resources
Bureau of Water Regulation and Zoning
P.O. Box 7921, 101 S. Webster St., Madison, WI 53707
Wisconsin wetland inventory

Wisconsin Department of Natural Resources
Bureau of Information Management
GEO Unit, P.O. Box 7921, Madison, WI 53707
Hydrography boundaries, land use/land cover, non-point watersheds

FEDERAL LANDS

Bureau of Reclamation, Remote Sensing Section D-1524
P.O. Box 25007, Denver Federal Center, Denver, CO 80225

National Park Service, Geographic Information Systems Division
12795 W. Alameda Parkway, Box 25287 GISD, Denver, CO 80225-0287
(303)969-2590 FTS 327-2590

APPENDIX C - FIELD VERIFICATION METHODS

The field verification methods under development at EMSL-LV revolve around a statistical approach employing simple random and stratified random sampling concepts and the use of emerging Global Positioning System (satellite navigation) technology. The primary field verification method is a site visit by a trained individual who will thoroughly describe the site in an objective manner. In situations where site access is very difficult or it is equally acceptable and cost effective, a small aircraft will be flown over the site to acquire verification data. Aerial verification data will be acquired in one of two ways, either by a trained individual and/or by acquiring high resolution photography.

Introduction

Field Verification, sometimes referred to as 'field checking' or 'ground truthing' is an essential part of the science of extracting data from aerial photography, satellite imagery, or other remotely sensed data (Colwell 1975). Ground verification plays an important role in both signature development prior to the interpretation, as well as in the assessment of the accuracy of data extracted, either manually or digitally, from imagery. However, it is extremely important that the same ground data not be used for both signature development and accuracy assessment. The most common approach in expressing accuracy is a statement of percentage of features correctly classified when compared to known, field verified, reference data (Story and Congalton 1986). Since land cover and land use are very temporal in nature, it is critical that field verification data be acquired either simultaneously, as soon as possible after, or during the same season of the year as the satellite or aircraft scanner data and photography. It is also important that the sampling design allow verification of each land cover and land use category mapped. This will provide a complete accuracy assessment.

Sampling Design

If verification takes place after image classification it is recommended that a stratified random sample be used for the field verification effort. If field verification occurs prior to classification, then the simple random sample should be used. The concept of stratified random sampling involves the partitioning of sample space into 'strata' based on prior knowledge of the sampling units that is known independently of the sample. Each stratum is treated as a separate subuniverse to gain efficiency and reduce variance (Kelly 1970). Congalton (1988) showed that simple random and stratified random sample approaches provided the best results when creating error matrices to assess map accuracy when it was necessary to show that small, but important areas were present in the sample. A benefit of the stratified random sample approach is that classes can be stratified, reducing the size of the field verification team to one or two specialists capable of objectively describing the sample area and identifying class types. The number of verification sites is still under development as of this writing, but will be dependent on the number of classes the number of study areas, the ability to group study areas containing similar resources and/or within similar ecosystems, and cost. It has been recommended that a one percent sample is best for assessing classification errors (Congalton, 1988).

Training of the Field Crew

A minimum of three people should be trained by the appropriate staff (i.e., remote sensing scientist, quality assurance specialist, and person(s) familiar with the resources to be mapped) on correct field techniques to acquire verification data. The training will include a theoretical discussion, a detailed step by step explanation of the verification protocol followed by one or two field trials, and a thorough discussion on reporting. The field crew should report directly to the person assigned as the Quality Assurance Officer of the project. During the course of the field verification process, the field crew will be audited to ensure proper implementation of the protocol.

Field Verification Protocol

As stated previously, field verification will be performed in one of two ways. Either a trained field team will actually go to the site, or the site will be observed and photographed from a light aircraft. An aircraft will be used in cases where the site is difficult to access and to provide cost savings in areas where it is expected that the aircraft information will be of the same quality as an actual site visit. In either case it will be important that the verification crew be able to locate the predetermined sample position with a known degree of accuracy.

Spatial Referencing in the Field

Inherently, the process of field verification implies that one must know, to some degree of accuracy, the geographic location with respect to a known reference system of both the object to be verified and of the observer. This can be accomplished in two ways. The most practical method is to use a base map as reference for both the object being verified (thematic polygon) and as directional guidance to the field person. The accuracy of the particular map is the primary operational consideration. A map can be utilized for a project when the sample can be clearly and precisely identified on both the map and on the ground. This is often the case in areas of relatively high anthropogenic activity, where verifiable 'landmarks' can be identified on both the ground and on the map. However, some projects may be in remote areas where there are very few identifiable landmarks. Since using a base map for field guidance in these situations is unacceptable, an alternative method for field navigation is required. Global Positioning System (GPS) technology may be used to guide these field verification activities.

GPS is based on a constellation of earth orbiting satellites that transmit radio signals which can be received anywhere on the earth's surface. By measuring the Doppler shift and/or the timing of the satellite signal, by using known data on the satellite orbit (ephemeris data), and by modelling for known errors caused by atmospheric distortions and clock error, very accurate earth based positions can be obtained. Horizontal accuracies of navigational quality GPS units have been reported to range between 5.5 - 7.9 meters in autonomous (single receiver) mode and 2 - 5 meters in differential (two receiver) mode (Jasumback 1988).

GPS units can instantly compute the receiver location and can therefore be used to navigate field crews to the centroid of thematic polygons. The accuracy of the units in a navigational, autonomous mode is sufficient to insure that variations will fall well within the minimum mapping unit (one hectare) of mapped polygons. The future accuracy of position fixes depends mostly on the actions of the Defense Department (DoD) and how much they will degrade the performance capabilities of the NAVSTAR satellite system for civilian users. This degradation process is called selective availability (S/A). When S/A is operating, the position fixes may wander up to 100 meters from the true position. To get a good position fix in the presence of S/A, differential GPS can be used. Differential GPS utilizes a stationary reference GPS receiver, set up on a known location and set to record a reference file. Any deviations from "truth" in this reference file will allow the generation of a time-tagged position correction that can be applied to a remote GPS data file collected using another receiver, at an unknown location, within a few hundred miles of the reference location. Using differential positioning in this way, the standard deviation of the error for an absolute point location can be reduced to 1.5 meters, from typical stated accuracy on the order of 2 to 5 meters (Lange, et al., 1988). Systems are available to do this differential processing either in real-time or as a post-processing operation.

<u>Verification Procedures</u>

The verification procedures for actual site visits will include location of the sample point, description of the site, photographing the site, and selecting land use and land cover class names. The following detailed procedures will be carried out by the field crew after they receive the latitude/longitude coordinates for the sample sites determined by the sample design.

Differential GPS techniques will be used to locate the ground point corresponding to the latitude/longitude coordinates. The following steps will be carried out to properly identify the ground location: 1)planning; 2) reconnaissance; 3) survey; and 4) data reduction and processing.

1. The planning phase consists of:

* *Defining Project Area* - establishing the overall project area and defining the limits of the sample sites. Maps and/or aerial photos should be utilized extensively to familiarize the crew with the area prior to the actual field work.
* *Scheduling Operations* - This involves determining the precise window of satellite availability and scheduling accordingly. The incomplete status of the satellite constellation dictates that surveys are currently restricted to a few hours per day. Optimization of the schedule is dependent upon the size of the crew, the level of accuracy desired, and the logistics of setup and travel between control points.
* *Establishing Control Configuration* - locating known benchmarks for both horizontal and vertical control to perform differential GPS. This is usually accomplished by researching the records of various Federal, State and local agencies such as the U.S. Coast & Geodetic Survey or the state geodetic survey. It is advisable to have, where possible, at least two control points each for both vertical and horizontal positions so that there is a double check for all control locations.
* *Selecting Survey Locations* - there are several specific considerations: Points should be accessible during the satellite window of availability, often during unusual hours. Points should have continuous and direct line-of-site to the path of the satellites in the sky. Points should not be near power lines, substations or large metal objects which can cause multipath interference and corrupted data.

2. Reconnaissance

The Reconnaissance phase is an important part of a successful GPS operation and is usually performed by an individual or crew at some point prior to the actual acquisition of field verification data. The purpose of this phase is to:

* *Locate and Verify Control Point Locations* - This is critical to the success of the overall survey. Often, monuments have been damaged, stolen, buried or vandalized. If a control point, cannot be recovered, a replacement must be located. This can drastically change the schedule and logistics of the field survey.
* *Preview instrument locations* - obtain permissions and verify that there are none of the above restrictions.
* *Physically establish point locations* - This is accomplished by using a standard surveying marker such as an iron pipe, a hub and tack, or a brass nail. All points should be documented with detailed descriptions.

3. Survey

The actual GPS survey consists of:

* *Establishing a Schedule of Operations* - This involves determining the window of satellite configuration availability and scheduling the GPS sessions. This is dependent on the size of the crew, the level of accuracy desired, and the logistics of setup and travel between control points.
* *Performing GPS Survey* - The crew must warm-up, check and program the receiver for proper operation. Depending on the unit being utilized sufficient battery power must be available and the receiving antenna must be leveled on a tripod and centered exactly over the control point location. Log sheets containing critical information on position, weather, timing, height of instrument, and local coordinates must be maintained. Once the session is completed, the receiving equipment must be disassembled, stored, and log and tape files documented. If another session is scheduled, this process must be conducted quickly and efficiently so that the crew can be at the next location and be set up in time for the scheduled window of satellite availability.

4. Data Reduction and Processing

Data reduction and transfer consists of:

* *Data Transfer* - reading the raw data from the GPS cassette tapes into a structured data base for processing and backup copies made.
* *Pre-processing* - GPS data is not immediately useable and consists of satellite navigation messages, phase measurements, user input field data and other information that must be transferred to various files for processing before network computations can be accomplished. There are five components to the pre-processing phase:
* *Orbit Determination* - The software uses the satellite navigation messages to compute one unambiguous orbit for each satellite.
* *Single-Point Positioning* - Computations of the clock corrections and parameters for each receiver.
* *Baseline Definition* - establishing general locations of receiving stations the computation of best pairs of sites for baseline definition.
* *Single difference file creation* - single differences are the differences between simultaneous phase measurements to the same satellite from two sites. This is the basic data from which network and coordinate data will be derived.
* *Data screening* - This a routine that allows for automatic and manual screening of the single difference files. Breaks, cycle slips, and poor observations can be detected.
* *Computation* - This component uses the pre-processed data to compute the network of sites and give a full solution showing geographical coordinates (latitude, longitude and ellipsoidal

height), distances of the vectors between each pair of sites in the network, and several assessments of accuracy of the various transformations and residuals of critical computations.

After the location of the sample point has been accurately determined, a stake or pole will be driven into the ground at that point. A measuring tape with a length equivalent to 1.5 times the pixel size will be attached to the stake. The tape will be stretched out to inscribe a circle. While the use of a stake and tape are considered ideal to ensure the proper size area is documented, it is recognized that ground conditions and time may preclude the use of these tools. It is highly recommended that the field crew be very familiar with the size of the verification samples, and practice with a stake and tape during training. The area within the circle will be thoroughly described starting at ground-level (0-.3m), then .3 to 2 meters above ground level, and finally the area above 2 meters will be described. After the descriptions are completed a diagram of any resource boundaries will be sketched along with any major features. A photographic documentation of the site will be prepared by taking 35mm slides from the center looking out at eight different directions, namely, N, NE, E, SE, S, SW, W, NW. A member of the field crew should be located at the left edge of the camera frame at the end of the tape. This will provide a relative scale for comparison of feature size as well as demarcating the edge of the sample circle. Extra care should be taken to ensure that the photography encompasses the entire site, from the ground up, in each frame. The final field verification procedure will be the selection of the most appropriate land use and land cover classes for the site.

If the verification data is being acquired via a light aircraft, the point location should be determining using GPS or if GPS is not available then Loran. The area surrounding the point should be described as best as possible using the field verification form and 35mm slides should be taken both vertically and obliquely.

<u>Field Verification Reporting</u>

The following pages present the form which will be filled out in the field during the verification process. This form may and should be customized for unique ecosystems and projects which require different field information. The form will be completed in the order presented with the last component being a selection of land cover and land use class names. The selection of class names is performed last to prevent any bias in the description of field characteristics. Copies of the completed forms will be sent to the Quality Assurance Officer and the technical staff performing the accuracy assessment.

Field Verification Form

Field Crew.
Name:____
Date:________
Location: State____________ Site ID_______________
Lat_____________ Long____________
Method of determining Lat/Long: ___GPS ___USGS map

Weather
Conditions:____
____

Height of GPS_______________ Time of GPS use________________
GPS Satellites: __________________, __________________,
__________________, __________________

General Description
1) Surface (0-.3 meters):
Surface roughness and moisture: check one descriptor from each column which best describes the entire area. If there is a portion of the site which is distinctly different, please label the appropriate descriptor with a location, i.e., SW, S, SE, W, Central, E, NW, N, NE.

Roughness	Moisture	Slope
___smooth noncultivated	___dry	___flat (0-3%)
___hummocky noncultivated	___moist	___gentle (3-10%)
___cultivated	___saturated	___hilly (10-20%)
___no-till	___standing wet	___steep (20-40%)
		___v steep (40-60%)
		___extreme (>60%)

Surface features: record the percentage of each surface type present on the site; also describe any features which are not on this list. If there is a portion of the site which is distinctly different, please label the appropriate descriptor with a location, i.e., SW, SC, SE, WC, C, EC, NW, NC, NE.

___water	___grass	___leaf litter	___clay/silt
___concrete	___herbaceous	___twigs/branches	___sand
___asphalt	___low shrubs	___moss/lichens	___gravel
___paper	___emergents	___other:______	___cobbles
___metal waste	___crops:______________		___stones
___misc. waste	___other:______________		___boulders
___other:________			___bedrock
			___other:___

Please check appropriate category of water from list below.

___lake ___pond ___river ___stream ___ditch ___marsh __tidal

Does the surface appear to be altered by human activity____, or does the surface appear to be in a natural state (this includes areas that may have had historical human activity, but have had time to return to natural species)____.

Surface condition general comments:

____
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2) Near Surface (.3-2 meters)

Near surface features: record the percentage of each type present on the site and if possible list the species; also describe any features which are not on this list. If there is a portion of the site which is distinctly different, please label the appropriate descriptor with a location, i.e., SW, S, SE, W, Central, E, NW, N, NE.

___shrubs (.3-1 meters);
species:____________________________
___shrubs (1-2 meters);
species:____________________________
___trees (.3-1 meters);
species:____________________________
___trees (1-2 meters);
species:____________________________
___metal waste;
describe:____________________________________
___misc. waste;
describe:____________________________________

___other:____

Near surface condition general comments:

____
____
____
____

3) Above Surface (>2 meters)

Above surface features: this category is designed to describe trees and buildings; record the species type, stand density, and for buildings list the type of structure, i.e., single family home, apartment, commercial, industrial, etc. Please indicate if portions of the site are distinctly different.

Trees:
Species:____

Stand
density:____

Is this a tree plantation or orchard: ___yes ___no

Buildings: Type of structure

____
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Above surface condition general comments:

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4) Wetlands and Near Coastal Areas

This resource type is unique since some of the features of interest of submerged. If possible, please check the substrate type. Indicate the water depth, flooding frequency, and water type if possible for each portion of the site by using the following appropriate descriptors: SW, SC, SE, WC, C, EC, NW, NC, NE.

Water depth	Flooding	Water type	Substrate
___0-.3 m	___never	___fresh	___mud
___.3-1 m	___saturated	___salt	___sand (.05-2mm)
___1-2 m	___daily (tidal)	___mix	___gravel (2-8cm)
___2-5 m	___seasonally		___cobbles (8-25cm)
___5-10 m	___intermittently		___stones (25-61cm)
___>10 m	___semipermanently		___boulders (>61cm)
	___permanently		___organic matter
	___artificially		

Please list as best as possible the species present:

Wetlands/Near Coastal general comments:

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Please diagram any distinct resource boundaries or features present within the verification site below. Also indicate any features which would provide a better accuracy assessment of the digital database. Take photographs (8) looking to the N, NE, E, SE, S, SW, W, and NW from the verification site center point.

Roll # __________, Frame #'s ________________________________.