Applications of Landsat Data and the Data Base Approach*

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ABSTRACT: A generalized methodology for applying digital Landsat data to resource inventory and assessment tasks is currently being used by several bureaus and agencies within the U.S. Department of the Interior. The methodology includes definition of project objectives and output, identification of source materials, construction of the digital data base, performance of computer-assisted analyses, and generation of output. The U.S. Geological Survey, Bureau of Land Management, U.S. Fish and Wildlife Service, Bureau of Indian Affairs, Bureau of Reclamation, and National Park Service have used this generalized methodology to assemble comprehensive digital data bases for resource management. Advanced information processing techniques have been applied to these data bases for making regional environmental surveys on millions of acres of public lands at costs ranging from $0.01 to $0.08 an acre.

INTRODUCTION

During the last decade, land satellite remote sensing applications have evolved through three general phases (see Figure 1). In the early 1970's, most analyses of data taken from Apollo, Skylab, and the first Landsat were performed using primarily manual photointerpretation techniques (American Society of Photogrammetry, 1975; Williams and Carter, 1976). Environmental information, including classifications of land use/land cover, was extracted visually from images and manually or graphically synthesized with other types of mapped or tabular information for making resource management plans and policies. Later, with the availability of appropriate equipment and properly

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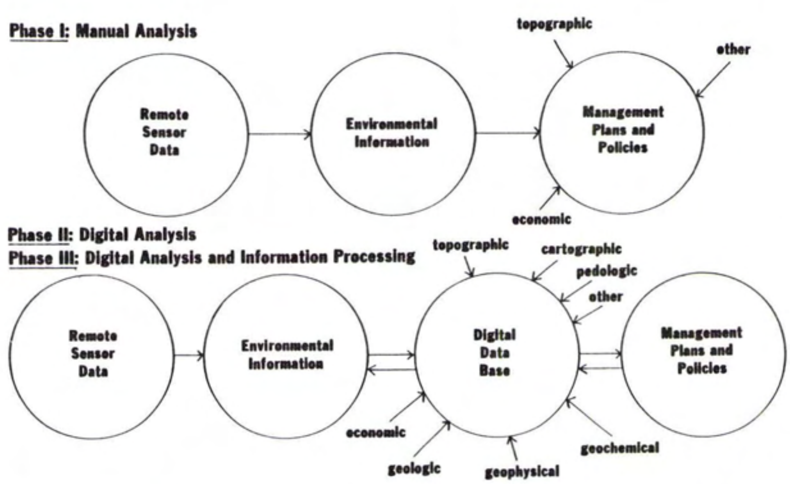

FIG. 1. A gradual evolution of satellite remote sensing applications has occured within the U.S. Department of the Interior over the last ten years. Analytic procedures shifted from manual image interpretation to computer-assisted data enhancement and classification, followed by more advanced digital spatial data handling and analysis techniques. Bureaus and agencies within the Department currently are using Landsat data, digital spatial data bases, and advanced information processing techniques to perform regional environmental surveys.

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trained personnel, emphasis shifted from manual to machine-aided analysis procedures (Aldrich, 1979; Rohde, 1978; Gaydos and Newland, 1978; Pettinger, 1982). However, these automated procedures had some shortcomings, especially for amalgamating disparate types of resource information with environmental information extracted from the remotely sensed data. With recent advancements in equipment and software, and with properly trained personnel, manual synthesis of disparate types of data has gradually been replaced with digital cartographic data base and spatial information processing techniques (see Figure 2). The earlier phases of Landsat applications primarily involved inventory and, occasionally, monitoring tasks, while this most recent phase of applications permits systematic modeling of complex resource processes, as well as more sophisticated and accurate inventory and monitoring (Johnson and Rohde, 1981; Shasby *et al.*, 1981; American Society of Photogrammetry, 1983; Haas *et al.*, 1984).

Resource scientists, land managers, and planners within the U.S. Department of the Interior (USDI) are using a *data base* approach in which satellite and aircraft remotely sensed data are combined with ground verifications and other forms of digital topographic, cartotgraphic, and resource data. It is through this technique of combining various types of data in a digital cartographic data base that satellite remote sensing is having and will continue to have its greatest use.

Recent advancements have been made in applications of satellite remote sensing and other types of digital spatial data for assessing mineral potential, agricultural and range potential, alternative management opportunities, wildlife habitat, and other resource problems (U.S. Geological Survey, 1983). Comprehensive digital data bases are registered to be map compatible, and advanced information processing techniques, including image classification, are applied to these data bases to derive needed resources information. A general methodology for applying digital satellite data, in this case Landsat data, to resource inventory and assessment tasks is presented below.

GENERAL METHODOLOGY

Methodology often used by USDI agencies for applying digital Landsat data to resource inventory and assessment tasks includes definition of project objectives, analysis framework, and desired output; identification of source materials; construction of the digital data base; performance of computer-assisted analyses; and generation of output.

Definition of Project Objectives, Analysis Framework, and Desired Output

The success of Landsat data applications using spatial data handling and analysis techniques is critically dependent upon a full understanding and clear definition of project objectives. Information requirements, resource classification schemes, and accuracy of output are among the factors which need to be defined. Minimum mapping units will often vary from less than 5 acres to 40 acres and larger. A vegetation classification scheme can be based on taxonomic, physiognomic, or ecologic principles (Anderson *et al.*, 1976; Haas *et al.*, 1983). Definition of the analysis framework, in terms of project objectives, will guide decisions regarding level of detail, structure and format of a digital data base, and analysis techniques to be used. Requirements for personnel training, availability of specialized equipment, and expected project costs also must be determined. Output can be derived from a digital data base in a variety of formats including maps, map overlays, statistics, tables and graphs, images, and computer-compatible disks or tapes. The intended use of the output by the resource agency (for example, reporting, management briefings, field support, public relations, etc.) will dictate product format, accuracy requirements, relative detail, and costs. Requirements for personnel training,

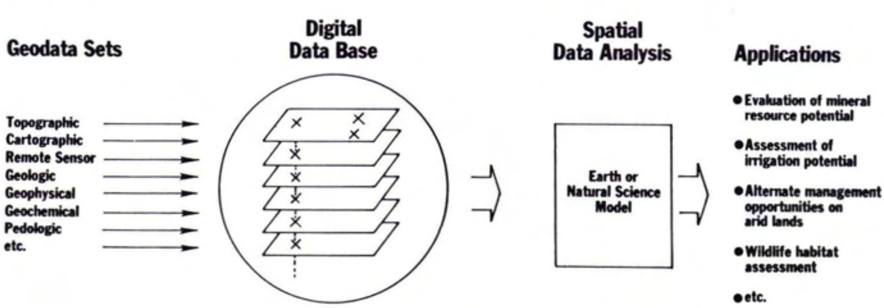

FIG. 2. Recent advancements have been made by the U.S. Department of the Interior in applications of digital spatial data for assessing mineral potential, irrigation potential, alternate management opportunities, wildlife habitat, and other resource problems. Comprehensive digital data bases are registered to be map compatible. Advanced information processing techniques, including Landsat classification, are applied to these data bases to derive needed resources information on public lands.

availability of specialized equipment, and expected overall project costs also must be determined.

Identification of Source Materials

Source materials to be included in a digital data base are characterized as point, line, polygon, cell, and/or surface data, and are often complex and highly diverse. Project objectives will guide decisions regarding what should or should not be included in a data base. A digital data base for regional environmental assessment frequently includes topographic data, such as U.S. Geological Survey (USGS) digital elevation models (DEMs); planimetric data, such as USGS digital line graphs (DLGs); and remotely sensed data, such as Landsat multispectral scanner (MSS) or thematic mapper (TM) data. Often the source materials are in a digital format, such as the three examples mentioned above. The DEMs consist of an array of elevations for ground positions that are usually, but not always, at regularly spaced intervals (U.S. Geological Survey, 1980). The DLGs give line map information representing transportation routes, hydrography, and political boundaries, and Federal land ownership in digital vector form (U.S. Geological Survey, 1982). Likewise, Landsat MSS data, when available, are on computer-compatible tapes in which scene brightness is presented as an array of digital values representing individual picture elements (U.S. Geological Survey, 1979). However, other source materials, such as soils maps or interpretations made from aerial photographs, are usually in map or map-like form, and must be transformed into a digital format through digitizing and coding before they can be entered into the data base.

Construction of Digital Data Base

Project objectives and desired output will guide decisions regarding data format (grid or vector), data geometry (map projection), geographic referencing (coordinate system), and resolution (level of spatial detail) which characterize a digital data base. Because source materials are available in a variety of scales, formats, resolutions, and levels of complexity, the creation of a fully registered, map-compatible digital data base can be a tedious and time consuming process. For example, some data sets (water depth, precipitation, etc.) are presented as point samples identified by geographic coordinates, with attributes associated with each point. The point data can be interpolated into a continuous surface (by means of an inverse distance or a minimum curvature algorithm) and registered with other sources of similarly formatted digital spatial data (Greenlee, 1981). Data bases with a grid cell rather than a vector format have been used in many USDI applications projects because continuous-surface data sets (such as elevation) are often required, image processing and display options are available, and multiple data sets can be easily integrated and modeled. However, a vector format is preferred when fine detail is required, the source materials are dominated by lines and points, and high-quality, cartographic products are required. For example, the U.S. Fish and Wildlife Service (USFWS) Western Energy Land Use Team has successfully developed and used data bases in vector format (Federal Interagency Coordinating Committee on Digital Cartography, 1984), whereas large-area applications projects conducted by several bureaus and agencies within the USDI have used data bases with raster format (Miller *et al.*, 1981; Walker *et al.*, 1982). Grid cells for these data bases vary in size from 50 metres to 1,000 metres, and several map projections have been used, including Universal Transverse Mercator, Transverse Mercator, Albers Equal-Area, or Lambert Conformal Conic (see Figure 3).

Performance of Computer-Assisted Analyses

Landsat data classification is often used in regional environmental surveys. For example, in 1982 the Bureau of Land Management (BLM) categorized land cover for approximately 30–million acres in the western United States by classifying Landsat data. Likewise, similar procedures were used in Alaska by the USFWS and other Federal and state agencies to classify land cover for approximately 100–million acres (U.S. Geological Survey, 1983). The analysis steps used in Landsat classification by the Department of the Interior are shown in Table 1 and typically include (a) screen and preprocess raw Landsat data (fix bad data lines, correct radiometric striping, and mosaic adjacent scenes); (b) register data to a map base (select and digitize control points, generate transformations, and resample and register the data); (c) produce boundaries or administrative masks (digitize boundaries from available maps or derive from DLG data, register with Landsat data, and create masks); (d) stratify raw Landsat data (identify environmentally similar areas, locate training blocks within similar areas, and cluster training block data into spectral classes); (e) produce training statistics (calculate and evaluate spectral class statistics); (f) perform preliminary classification (select classification decision rule, classify training blocks within strata, and assign spectral classes to preliminary resource classification categories); (g) conduct field verification (annotate aerial photos, visit training blocks in the field, and describe land-cover types associated with each spectral class); and (h) finalize classification (edit cluster statistics, apply classification decision rule to entire area, and aggregate spectral classes into final resource classification categories). The Landsat classification procedure described above is referred to as a "modified clustering" approach (Fleming *et al.*, 1975).

Because the Landsat data are incorporated into a digital data base, other types of information in the data base can be used during the classification process, or after classification, to improve Landsat

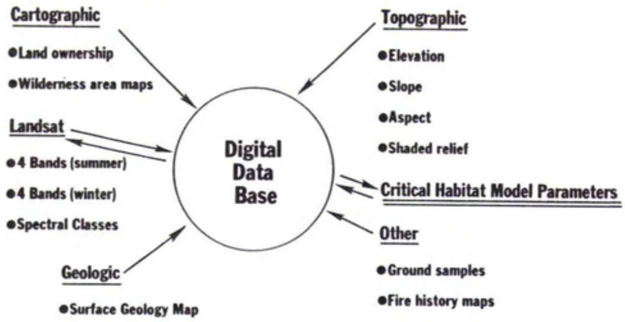

FIG. 3. The U.S. Geological Survey, in cooperation with the U.S. Fish and Wildlife Service, constructed a digital spatial data base composed of Landsat, topographic, cartographic, geologic, and other types of data for approximately 2-million acres in and adjacent to the Kenai National Wildlife Refuge in Alaska. The data base was created in a raster format, transformed to a Universal Transverse Mercator map projection, and resampled to 50-metre grid cell size. The data base was used for classifying land cover/terrain and for assessing wildlife habitat potential.

TABLE 1. TYPICAL LANDSAT CLASSIFICATION PROCEDURE USED WITHIN THE U.S. DEPARTMENT OF THE INTERIOR FOR MAKING REGIONAL ENVIRONMENTAL ASSESSMENTS.

Analysis Steps	Task Examples
Screen and preprocess Landsat data	Fix bad scan lines, perform radiometric destriping, and mosaic adjacent scenes.
Register Landsat and ancillary data to map base	Select and digitize control points, generate transformation, resample, and register digital data base.
Identify area(s) to be classified	Digitize study area boundaries and create appropriate digital masks.
Stratify raw Landsat data	Identify environmentally similar areas, locate training blocks within similar types, and develop training statistics.
Perform preliminary classification	Select decision rules, classify training blocks, and produce preliminary classification map.
Field verification	Visit training blocks in the field and describe areas associated with each spectral class.
Final classification	Use field and laboratory data to edit cluster statistics and reaggregate data clusters. Use post-classification procedures to make final map product.

classification results. For example, digitized physiographic information or soils data can be used to make new strata masks, and cluster statistics can be derived within these masked areas. Digital terrain data can be used in a similar way to create new strata masks based on combinations of elevation, slope, and aspect. Miller and Shasby (1982) showed that, for vegetation classification in Arizona and fuel-type classification in Montana, the accuracy of results were improved from 54 to 73 percent and from 52 to 72 percent, respectively, when digital terrain data were used in the Landsat classification process. It should be noted that the final classification results are added as a new layer in the data base.

A variety of spatial information processing techniques, such as overlay analysis, neighborhood characterization, and distance measurement, can be applied to a digital data base. Selection of specific information processing procedures will be governed by project objectives and expected output. For example, an assessment of irrigation development potential, required for regional planning, was recently completed by the USGS in cooperation with the Bureau of Indian Affairs (BIA) on the Fort Berthold Indian Reservation in North Dakota and the Crow Creek and Lower Brule Reservations in South Dakota (U.S. Geological Survey, 1983). Information processing techniques such as weighted- and logical-overlay analyses were used to combine resource information layers of soils, land use, and land ownership to assess irrigation potential (see Figure 4). Distance-from-point functions can be applied to the digital data base to derive estimated power and water use once the locations of regions suitable for irrigation development have been identified (Loveland and Johnson, 1983).

GENERATION OF OUTPUT

A variety of cartographic displays can be derived using the Landsat, topographic, cartographic, and other information in the data base. These displays can be produced and stored on magnetic tape, cathode ray tube, film, or paper. Examples include maps or map-like products showing elevation zones,

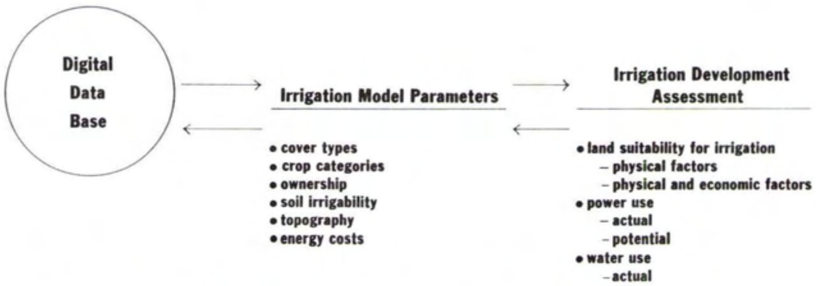

FIG. 4. The U.S. Geological Survey, in cooperation with the Bureau of Indian Affairs, constructed digital data bases composed of Landsat, topographic, cartographic, and soils data on the Crow Creek and Lower Brule Indian Reservations in South Dakota and the Fort Berthold Indian Reservation in North Dakota. Irrigation model parameters were identified and information processing techniques, such as overlay analysis, were applied to generate estimates of land suitability for irrigation, power use, and water use.

slope classes, aspect classes, elevation zones merged with shaded relief, Landsat images in stereo, shaded relief in stereo, Landsat classification results merged with shaded relief, perspective views of Landsat images, and perspective views of Landsat classification results merged with shaded relief. Tabular data files can be created identifying categories or groupings of data from the multiple layers in the data base. Once the data are registered in a data base, any stratification of one or more layers can be the basis for aggregating and summarizing any or all of the layers (Horvath *et al.*, 1984). Products are designed to meet a specific need, and project reports may require totally different products from those needed for field or office use.

DISCUSSION

The general methodology described is being used operationally by the USGS, BLM, U.S. Bureau of Reclamation, BIA, National Park Service, and USFWS. The USDI has established digital data processing and analysis facilities in Reston, Virginia; Sioux Falls, South Dakota; Denver, Colorado; Flagstaff, Arizona; and Anchorage, Alaska, with suitable equipment, appropriate software, and trained personnel. The more commonly used software systems* being used at these facilities are

- *Map Overlay and Statistical System (MOSS)* — This is a *non-proprietary* software system originally developed and implemented by the USFWS's Western Energy and Land Use Team and Autometric Incorporated.
- *ARC/INFO* — This system is a *proprietary* vector-based system developed by Environental Systems Research Institute as a replacement for the earlier Polygon Information Overlay System (PIOS) vector-based system.
- *Systems Applications Group Information System (SAGIS)* — This *non-proprietary* system comprises a collection of software modules developed by USFWS running on a CYBER mainframe computer.
- *Interactive Digital Image Manipulation System (IDIMS)* — This *proprietary* system was developed by Electromagnetic Systems Laboratories Incorporated initially for processing and analyzing raster image data, but now enhanced to process and analyze many different cartographic, thematic, and image data in raster form.
- *Earth Resources Laboratory Application Software (ELAS)* — This is a *non-proprietary*, general purpose image processing system originally developed by National Aeronautics and Space Administration's (NASA's) Earth Resources Laboratory.
- *Automated Geographic Information System/Generalized Balanced Ternary (GBT) Record Access Manager (AGIS/GRAM)* — This system is a *proprietary*, vector-based system produced by Interactive Systems Corporation.
- *Geographic Information Retrieval and Analysis System (GIRAS)* — This *non-proprietary* system was designed by the USGS to support the development of a digital data base of land-use and land-cover data for the United States.
- *Remote Information Processing System (RIPS)* — This *non-proprietary* system was originally developed by the USGS's Earth Resources Observation Systems (EROS) Data Center to provide a low cost, microcomputer-based system for processing and analyzing raster image and cartographic data.
- *Land Analysis System (LAS)* — LAS is a *non-proprietary* raster-based data analysis system currently under development by the USGS's EROS Data Center in cooperation with the NASA Goddard Space Flight Center.
- *Mini Image Processing System (MIPS)* — MIPS was designed by the USGS as a *non-proprietary* research and development image processing system with spatial data handling capabilities and the potential for use in a field environment.
- *Additional Systems* — There are additional software packages that have been implemented within various USDI bureaus on varying hardware configurations. Examples of such software systems include the Surface Display Library (SDL);, Surface Gridding Library (SGL), Interactive Surface Modeling (ISM) Sys-

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tem, Alaska Hydrologic Digitizing System (AHDS), Unified Cartographic Line Graph Encoding System (UCLGES), Graphic Polygon Processing Utility (GPPU), and others.

Data processing and analysis systems, with both public domain and proprietary software, are widespread within USDI and provide diverse functional capabilities that are required to meet program requirements. Data bases for these different systems are derived from a variety of source materials or from other digital data bases. Considerable effort is currently being expended, through several national committees and by researchers at the USGS, to develop data standards and a means of exchanging data that does not conform to these standards. Successful transfer and exchange of spatial data from one system to another is dependent on the preservation of all the data characteristics needed to perform the intended analysis.

In response to Public Law, Secretarial Order, or Office of Management and Budget directive, many offices with the USDI are using Landsat data and spatial data handling and analytic techniques to collect, store, manipulate, and analyze resource information on public lands. These methods and techniques are being used because (a) source materials are readily available; (b) equipment and facilities are in place; (c) software packages have been developed, tested, and evaluated; (d) personnel are trained; (e) analytic procedures are efficient and fast; (f) complex resource problems can be addressed using objective, repeatable analytic procedures; (g) the data base is easily stored, retrieved, and updated; (h) use of the data base for other problems at a later date is possible; (i) the amount of ground data traditionally collected in the field can be greatly reduced; and (j) regional land cover, as well as other kinds of generalized resource information, can be obtained for as little as $0.01 to $0.08 per acre (U.S. Geological Survey, 1983).

Despite the progress made to date by land resource management agencies in integrating satellite remote sensing into resource inventory and assessment programs, there are several major inhibitors to the acceptance of this technology. First, the 80-metre spatial resolution provided by the multispectral scanner (MSS) on Landsat 1, 2, and 3 is often considered too coarse to meet information requirements. However, the 30-metre resolution data from the thematic mapper on Landsat 4 and 5 show considerable promise for increased applications, and further improvements in spatial resolution can be expected from future national and foreign satellite systems. Second, data delivery time, from time of acquisition to time of availability for use, has often been weeks and sometimes months, which impedes analysis of time-dependent phenomena (for example, assessment of catastrophic events, or monitoring environmental quality). Current and future satellite systems are being designed to insure data delivery times of 10 to 14 days, which would meet most needs for timely data. Third, the uncertainties of future data availability have adversely impacted Landsat data acceptance, as the Federal government has had no plan to launch a land remote sensing satellite after Landsat 5. However, the recent commercialization of Landsat technology and transfer of responsibility for operational satellite systems from the government to the private sector are major steps toward insuring continuity of data for the remainder of the 1980s and into the 1990s.

CONCLUSION

A rapid evolution in applications of satellite remotely sensed data has occurred within the USDI during the last decade. Today, Landsat data are often amalgamated into comprehensive digital spatial data bases, in which other types of map, map-like, and tabular data, either available in digital form or easily transferred to digital form, are also stored. Advanced, computer-assisted spatial data processing and analysis techniques are then applied to these data bases for deriving complex, detailed resource information on public land. In the future, even larger and more comprehensive digital spatial data bases will be assembled. Much of the data in the data bases of the future will be available to other Federal agencies, state and local governments, and the private sector through the USGS national digital cartographic data base. Already, certain types of topographic and cartographic data, as well as Landsat data, are available through the USGS National Cartographic Information Center (NCIC) or EROS Data Center. With improvements in spatial resolution and data delivery time, and an assurance of data continuity, satellite remote sensing will continue to be an important component in USDI resource information systems.

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