Research, Investigations and Technical Developments National Mapping Program 1983 - 1984

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Department of the Interior
U.S. Geological Survey
National Mapping Division

UNITED STATES
DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

RESEARCH, INVESTIGATIONS, AND TECHNICAL DEVELOPMENTS NATIONAL MAPPING PROGRAM 1983-84

Edited by Robert B. McEwen

Open File Report 85-304

Reston, Virginia
1985

FOREWORD

The purpose of this report is to provide general information on the research, investigations, and technical developments being conducted by the USGS National Mapping Division. The Division collects, processes, and disseminates geographic, cartographic, and remote sensing information, digital data, and maps for the Nation and it provides technical assistance and conducts research that is responsive to national needs. These functions support the Geological Survey's mission to investigate and classify the Earth and its physical resources.

Basic and applied research in cartography and geography is essential because:

- Increasing population, economic development, and the complexity of modern society requires more-detailed information about the land, its uses, and its resources.

- Development of new concepts, improved methods, and more efficient instruments yields more information of better quality at lower cost.

- The training and development of high-quality technical expertise in the earth sciences is essential for national leadership.

The report covers projects undertaken by staff members in the Office of Research; by personnel in the four Mapping Centers, the EROS Data Center, and the Printing and Distribution Center; and through contracts. It will be of interest to all who are interested in the advancement and application of the cartographic and geographic sciences.

Rupert B. Southard, Jr.
Chief, National Mapping
Division
U.S. Geological Survey

PREFACE

Summaries of selected research projects which were carried on in the Geological Survey's National Mapping Division during 1983 and 1984 are contained in this report. Research projects often continue over several years and many of the projects which were reported on in two previous reports, Research, Investigations and Technical Developments--National Mapping Program, 1981 and 1982 have been brought up to date in this volume. Several developments are reported for the first time. A selected bibliography includes citations of papers and reports authored by Division staff during the 2 years. Compilation of the report and preparation for publication were accomplished by Robert B. McEwen with major assistance from Mary E. Graziani and Cynthia L. Cunningham.

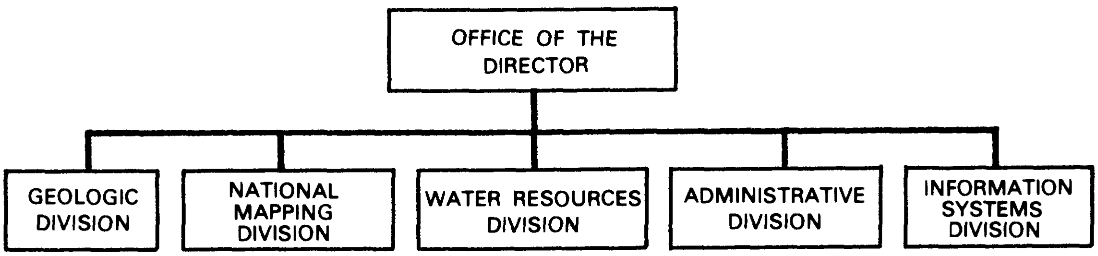
Lowell E. Starr
Assistant Division Chief for Research

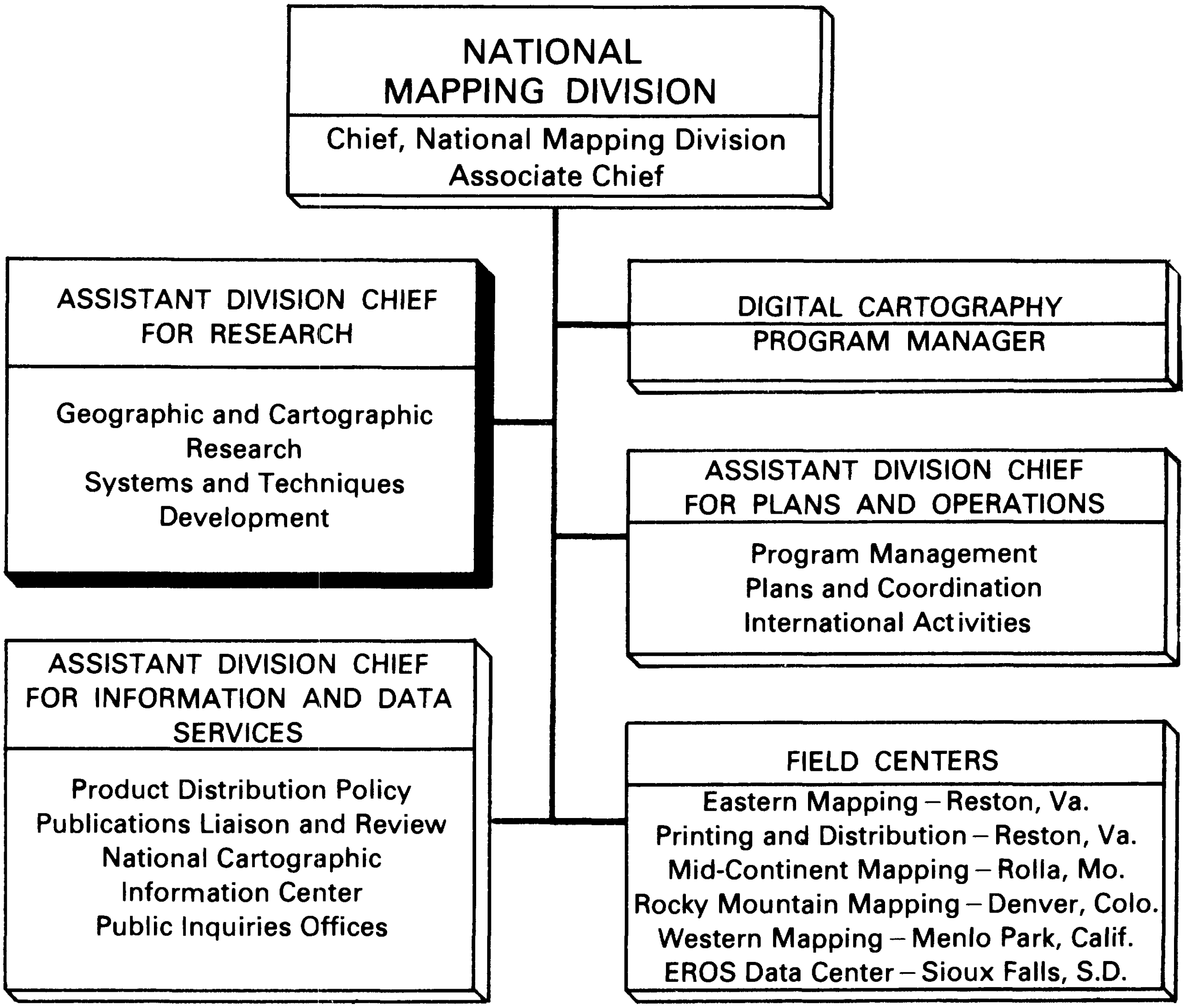
ORGANIZATION

The U.S. Geological Survey Mission and Organization

The U.S. Geological Survey was established in 1879 and charged with the responsibility for the "classification of public lands and examination of the geological structure, mineral resources, and products of the National domain." Over the years the evolution of the earth sciences, the need to carefully manage the Nation's nonrenewable resources and to find new sources of critical energy and mineral commodities, and mounting concern over man's impact on the environment have added numerous other duties including geographic research, hazards studies, topographic and geologic mapping, and water resources assessments. The Survey is an impartial research agency that gathers, interprets, and distributes data in order to advance scientific knowledge of the Earth so that managerial decisions related to natural resources can be based on objective information.

The Geological Survey is headquartered at Reston, Va., and maintains a nationwide organization consisting of more than 200 offices located throughout the United States. The Survey is organized into three program Divisions (Geologic, National Mapping, and Water Resources) and two support Divisions (Administrative and Information Systems), each reporting to the Director of the Survey. The Survey's field organization is made up of Regional Offices at Reston, Va., Denver, Colo., and Menlo Park, Calif., and a network of field and special-purpose offices. These offices coordinate and administer the work of the Survey's widely dispersed activities.

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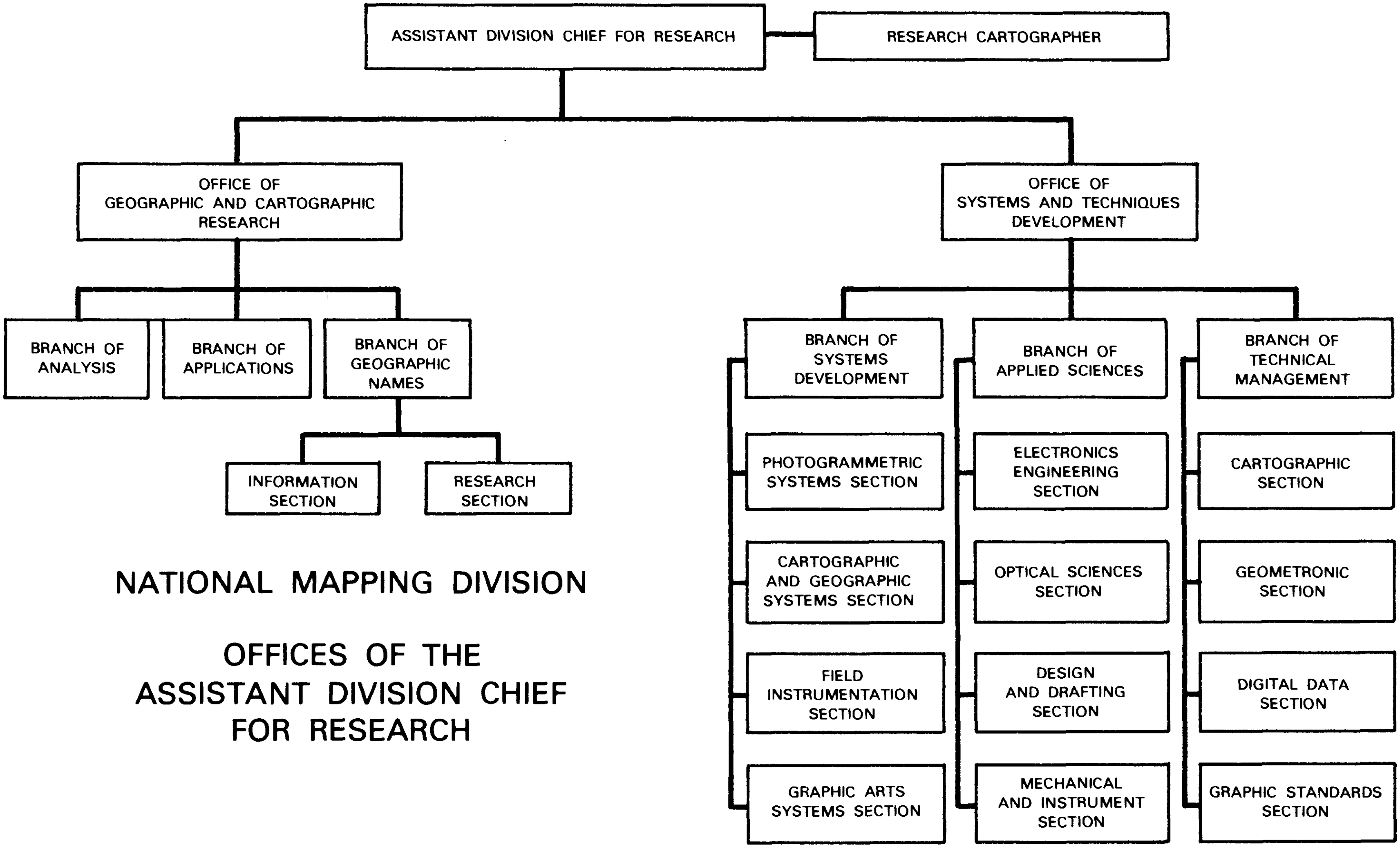
Publications Liaison and Review
National Cartographic Information Center
Public Inquiries Offices
FIELD CENTERS
Eastern Mapping – Reston, Va.
Printing and Distribution – Reston, Va.
Mid-Continent Mapping – Rolla, Mo.
Rocky Mountain Mapping – Denver, Colo.
Western Mapping – Menlo Park, Calif.
EROS Data Center – Sioux Falls, S.D.



NATIONAL MAPPING DIVISION

OFFICES OF THE ASSISTANT DIVISION CHIEF FOR RESEARCH

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U.S. customary units used in this report may be expressed as metric units by the use of the following conversion factors.

Multiply	By	To Obtain
feet	0.3048	meters
statute miles	1.609	kilometers

U.S. metric units used in this report may be expressed as U.S. customary units by the use of the following conversion factors.

Multiply	By	To Obtain
meters	3.281	feet
kilometers	0.6214	statute miles

ABBREVIATIONS AND ACRONYMS

ADNR	Alaska Department of Natural Resources
AID	Agency for International Development
ALMRS	Automated Land and Mineral Record System
AMRAP	Alaska Mineral Resource Assessment Program
ANILCA	Alaska National Interest Lands Conservation Act
APTS	Aerial Profiling of Terrain System
ASDIC	Anti-Submarine Detection Investigation Committee
AVHRR	Advanced Very-High-Resolution Radiometer
BIA	Bureau of Indian Affairs
BLM	Bureau of Land Management
BM	Bureau of Mines
CRAIGES	Cartographic Reproduction and Interactive Graphics Editing System
CRREL	Cold Regions Research and Engineering Laboratory
CUSMAP	Conterminous U.S. Mineral Assessment Program
DBMS	Data Base Management System
DCASS	Digital Cartographic Software System
DEM	Digital elevation model
DLG	Digital line graph
DMA	Defense Mapping Agency
DOI	Department of the Interior
EDC	EROS Data Center
EEZ	Exclusive Economic Zone
EPA	Environmental Protection Agency
EROS	Earth Resources Observation System
FMLIS	Federal Mineral Lands Information System
GIRAS	Geographic Information Retrieval and Analysis System
GIS	Geographic Information System
GLORIA	Geological Long Range Inclined Asdic
GNIS	Geographic Names Information System
GRAMPS	Graphic Map Production System

ABBREVIATIONS AND ACRONYMS---continued

IDIMS	Interactive Digital Image Manipulation System
IGDS	Interactive Graphic Design System
JOG	Joint Operations Graphic
JPL	Jet Propulsion Laboratory
LAMS	Large Area Mosaicking Software
LAS	Land Analysis System
LBR	Laser Beam Recorder
LUNR	Land Use and Natural Resources [New York State Inventory]
MARK II	Second phase of the USGS digital cartographic data base development
MSA	Metropolitan Statistical Area
MOSS	Map Overlay and Statistical System
MSS	Multispectral scanner (on Landsat)
NAD 83	North American Datum 1983
NDCDB	National Digital Cartographic Data Base
NGS	National Geodetic Survey
NMD	National Mapping Division
NOAA	National Oceanic and Atmospheric Administration
RIPS	Remote Information Processing System
RMSE	root-mean-square error
SCS	Soil Conservation Service
SDP	spatial data processor
SLAR	Side-Looking Airborne Radar
SMSA	Standard Metropolitan Statistical Area
SPOT	Systeme Probatoire d'Observation de la Terre (a French satellite)
TM	Thematic Mapper (on Landsat)
UCLGES	Unified Cartographic Line Graph Encoding System
USDA	United States Department of Agriculture
USGS	United States Geological Survey
UTM	Universal Transverse Mercator

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RESEARCH, INVESTIGATIONS AND TECHNICAL DEVELOPMENTS
NATIONAL MAPPING PROGRAM
1983-84

INTRODUCTION

The report is organized into major subject areas of cartography, photogrammetry and surveying, image mapping, remote sensing, land use and land cover mapping, and geographic information systems. The influence of digital cartographic concepts is found throughout and is leading not only to the automation of map making but to the computer analysis of spatial data- -the essence of modern geographic information systems.

There are several activities of special interest. These include the 1:100,000-scale digital cartographic data base, the Landsat Thematic Mapper image map of Great Salt Lake and Vicinity, the successful testing of the Aerial Profiling of Terrain System, several applications of geographic information systems, and publication of the first chapters of The National Gazetteer of the United States.

Publication authorized by the Director, U.S. Geological Survey, on July, 25, 1985.

CARTOGRAPHY

The 1:100,000-Scale Data Base

In late 1981 the USGS and the Bureau of the Census formed an interagency task force to review current and projected requirements of both agencies for cartographic and geographic products. This review was accomplished through a series of research projects that addressed the application of state-of-the-art technology to the production of new and updated maps, related graphics, as well as digital products needed to support the National Mapping Program and the 1990 Decennial Census of Population and Housing. As a result of this activity, the requirement for a digital intermediate-scale (1:100,000) data base was identified.

In early 1983 a cooperative pilot digital production project was begun to collect and process the transportation and hydrographic data shown on the 48 maps at 1:100,000-scale that cover the State of Florida. The purpose of this project was to enable the USGS to develop and test new production procedures and software and to incorporate the Scitex scanning and editing system into a production system. This pilot project was accomplished by:

(1) the USGS performing the initial collection and processing of all transportation and hydrographic information using the Scitex system;

(2) the Census Bureau performing all attribute coding and structuring of the road data;

(3) the USGS performing all attribute coding and structuring of the hydrographic and other transportation data; and

(4) the USGS performing all final verification, testing, and storing of the data.

The successful completion of this pilot project has resulted in the implementation of high-volume digital production systems in both agencies, and the commitment of both agencies for the completion of a national 1:100,000-scale digital cartographic data base by 1987. The production procedures and software which were developed as a result of the Florida pilot project have been implemented in both agencies.

Before the authorization of any 1:100,000-scale map for digitization, the maps are inspected to determine the level of content and complexity of the information to be collected. Based on this review it is determined which of two data collection processes are to be used, either manual tracing or automatic scanning. Features such as railroads, powerlines and pipelines, and all point features are always manually digitized because the symbolization and density of these features on any sheet do not lend themselves to efficient scanning collection operations.

For those maps that have been assigned for scanning data collection, the preparation of materials is very important and is performed at the mapping center where source materials are stored. The preparation of these materials for automated scanning is a two-step process: (1) combination of feature separates in the photolab; and (2) the color coding of features that will require special processing after initial data collection.

After the preparation phase has been completed, the materials to be scanned are sent to the Eastern Mapping Center (EMC) in Reston, Va. With the exception of a very short initial setup procedure in which the colors on the input document are calibrated, the scanning resolution is set, and the limits of the area to be scanned are set, the digitizing operation is automatic. On average, 2 to 2.5 hours are required to scan one 1:100,000-scale composite, at 30 points/mm (approximately 10 feet per point at ground scale), regardless of line density or complexity.

Following data collection, a series of standard batch and interactive editing procedures are performed on the raster file prior to vectorization, structuring, and tagging of the data. These are:

- Cleanup.--Interactively delete extraneous features, correct scanning problems due to color confusion, and clear out coalesced areas.

- Preliminary line skeletonization.--A batch program performs a preliminary line skeletonization of the file. (Lines must be narrowed to a single pixel width skeleton form to be vectorized.)

- Interactive editing.--Interactively inspect and edit the data set by (1) correcting alignment errors due to the skeletonization process, (2) closing breaks in the linework, and (3) breaking lines that were color coded during preparation of the material. This last step indicates to the structuring software, which is run after the data leaves the Scitex system, to insert a node.

- Segmentation.--A batch program segments and numbers the file into 32 new files at 7.5-minute spacing.

- Vectorization.--After segmentation, each 7.5-minute section is vectorized and a special code is added to each of the four corner lines of the neatline, so in subsequent processing the data may be checked for scale and transformed from the Scitex internal coordinate system.

At the conclusion of the raster processing, the data files comprise a set of unassociated line strings. For these data to be stored in the NDCDB, the files must be topologically structured and the line strings tagged with appropriate attribute codes. To place the necessary node and area points manually on an interactive editing station would be labor intensive. To reduce the time required for this process, software was developed that creates the necessary nodes and builds a preliminary topologically structured file from the Scitex output.

This structuring software originally was developed on an Amdahl 470 V7 computer but recently has been transferred to a Perkin-Elmer 3230. This transfer enables the basic structuring of Scitex data to be accomplished in all of the USGS mapping centers. The software performs (1) node generation and line joining to the nodes, (2) clipping of data that extends beyond the established data set edges, (3) assignment of area points denoting areas that fall inside and outside of the graph, and (4) preliminary assignment of a single attribute code to all lines. The attribute code is selected to reflect the most common feature class in the file. In the case of hydrography, the code for perennial streams is usually selected; in the case of roads, the code for a fourth-class road is used.

The editing and tagging of the files is the most time-consuming and labor-intensive part of the current production process. Each separate line segment must be checked to determine if the attribute code assigned during the previous process is valid. If not, it must be changed or other codes added to reflect coincidence with another feature or some other situation. The system currently used by the USGS for this purpose is an Intergraph interactive editing system. It is being used to add all the final attribute tags and any additional structure to the hydrography data sets. The Bureau of the Census is currently using Tektronix 4115B display terminals interfaced to a UNIVAC 1181 mainframe computer to support the interactive tagging and manipulation of the roads data sets.

Following the completion of the editing and tagging operations, both data sets, hydrography and roads, are processed through the Unified Cartographic Line Graph Encoding System (UCLGES). The UCLGES system has been used by the USGS for the past 7 years to perform all final data structuring and verification of DLG files. The system performs several logical checks to verify topology and the proper use of attribute codes. Errors are corrected either through the UCLGES batch editing routines or the data sets are returned to the mapping center for correction. Following the final verification of the data, the completed files are delivered to the Bureau of the Census for inclusion in their digital systems which will support the 1990 Census. The files are simultaneously loaded into the NDCDB maintained by the USGS.

A digital cartographic data base containing transportation and hydrographic features from USGS 1:100,000-scale maps will exist by the end of the decade. The Bureau of the Census will enhance it through the addition of street names and census geocodes. The existence of this data base will enable the widespread use of geographic information systems for a host of resource management, area analysis, and planning activities. Combined with remotely sensed digital data, our ability to study and monitor the Earth's surface will be improved. This data base may well serve as the key catalyst for the widespread use of geographic information systems technology in the United States.

Automated Cartography for Producing 1:50,000-Scale Maps from 1:24,000-Scale Maps

In 1983 the USGS, in cooperation with the Defense Mapping Agency, initiated a joint investigation to determine the feasibility of applying automated cartographic methods to the production of 1:50,000-scale topographic maps and resultant digital cartographic data from existing 1:24,000- and 1:25,000-scale USGS topographic maps. Critical areas of this investigation were: (1) the determination of current industry capabilities in the areas of automatic feature and topography generalization and displacement; (2) the determination of current industry capabilities for the automatic plotting of point, line, and area map symbols and associated text; and (3) the identification of research and development needs in the foregoing areas.

A statement of work was prepared and issued in January 1984 based on the initial investigations into the capabilities of private companies to apply automated cartographic methods to the production of 1:50,000-scale graphics. This statement of work addressed the development of initial contractor capabilities during a pilot year for validation of capabilities followed by up to three 1-year production work loads. Final technical reviews and negotiations are being conducted with contract award scheduled for 1985.

Hydrologic Unit Boundaries for the 1:2,000,000-Scale Data Base

The National Mapping Division and the Water Resources Division have begun a joint effort to create a file of hydrologic unit boundaries and codes as an addition to the 1:2,000,000-scale data base. The new file will provide digital hydrologic unit information registered with other categories of data currently in the data base. The data will be digitized from delineated maps and all files will be topologically structured with lines, areas, and nodes. Areas will be coded with four area codes identifying the type of hydrologic unit. Arbitarary closure lines will be used to close coastal and adjacent units. When completed, these data along with the other categories currently in the 1:2,000,000-scale data base will provide additional capability to produce graphic and statistical information.

Mark II—Long-Term Development of the Digital Data Base Program

In 1980, the NMD Digital Steering Committee recommended that the Division adopt a three-phase digital data base program that would provide an efficient, maintainable system which could expand to meet the majority of user needs by 1990. The first phase of this program, Alpha, was to study the current production system; hardware, software, and production techniques, and to establish a stable, maintainable digital production capability. In 1982 the initial capability represented by the Alpha Study was complete.

In 1983 the second phase of the long-term development effort, Mark II, was begun. A study team was formed, charged with the task of identifying objectives to be addressed during the Mark II development phase. Six major objectives have been identified:

- Continue the development of techniques for mass digitization, especially of 1:24,000-scale materials,
- Develop appropriate techniques for quality control and data verification,
- Maintain the NDCDB in the most current, complete, and accurate form possible that will insure the utilization of digital cartographic data in the mapping process,
- Provide for the interrelationships among products and processes, such as linking GNIS with features in the NDCDB,
- Provide for the use of digital techniques in the production of graphic products.
- Ensure that data are suitable for analysis and applications by geographic information systems and related technology, especially in the long-term context of NMD becoming a provider of information in addition to standard products.

Plans are now being developed to address research and development issues and to acquire the necessary hardware, software, and procedures to achieve the objectives.

Spatial Data Base Design

The NDCDB is expected to be the largest repository of digital cartographic and geographic data in the United States. To insure responsiveness to the needs of present and potential users and to fulfill the responsibility for developing technical standards governing digital spatial data, a series of studies on spatial data base content, structuring, and management are underway. Current DLG structure is based on topological elements which have attributes. At present it is difficult to add names as attributes of a particular element (for example, a street name), and no facility exists to retrieve the complete series of elements that might comprise a cartographic feature (for example, Reston Avenue). Many operations involving the NDCDB will require access to the data by feature name, and the first step in these studies is to define a comprehensive model of the spatial data of concern. Initially, this is limited to static spatial data either defining a surface or occurring upon a surface at a given point in time.

An inventory of existing spatial data structures is being compiled. These include data structures being proposed by the Defense Mapping Agency, the Directorate of Military Survey of Great Britain, and the French Institut Géographique National. These structures will be analyzed with respect to the specific methods of representing the components of the spatial data model. New structures might be developed and analyzed. From existing and new structures, candidate physical implementations for this study will be identified, followed by feasibility studies and prototype implementations.

Production and Editing of Digital Elevation Models

As part of the National Mapping Program, the USGS is building a National Digital Cartographic Data Base (NDCDB) containing certain base categories of cartographic and geographic data. One of the categories is the digital elevation model (DEM) and the NDCDB currently contains in excess of 10,500 DEM's, produced in 7.5- x 7.5-minute blocks. The data are processed to produce a DEM with a 30-meter sampling interval and are stored in one of two sublevel data bases as determined by the tested vertical accuracy: less than 7 meters RMSE; or 7 to 15 meters RMSE. The 7-meter RMSE was determined to be a reasonable goal for DEM data, attainable under a variety of terrain conditions and instrument constraints from 1:80,000-scale photographs. Within the NDCDB the DEM data sets are managed by the system 2000 data base management system, which allows data entry and retrieval, update, query, and recording of all archiving and retrieval actions.

Since the 1970's, the DEM production process has been closely tied to orthophoto production. The NMD uses two types of photogrammetric instrumentation for producing orthophotos. In the first type represented by Kern PG2 and Wild B8 plotters, stereomodels are manually scanned along a predetermined set of parallel lines. The second type is the Gestalt Photo Mapper (GPM) which collects a dense array of elevations using automated stereo image correlation techniques. Perfect image profiling or image correlation is not always possible due to a number of factors. One significant problem is collecting data that accurately depict the surface level of a water body. The water surface lacks vertical reference when viewed in a photogrammetric instrument. The operator or the automatic correlator cannot maintain a matching pair of image points, resulting in disorientation and ultimately an incorrect representation of the surface.

In 1982, several important upgrades were brought to bear on the DEM editing and quality-control operations. Deployment of editing and quality-control processes, including a software routine for editing water bodies and a viewing and editing system, have led to a reevaluation and restructuring of data archiving and distribution policies. All DEM data sets are now reviewed and edited before they are entered into the NDCDB or are distributed, resulting in a general upgrading of all DEM data sets.

Approximately 25 percent of the DEM data residing in the NDCDB have been reviewed and approximately 10 percent of these require editing and 1 percent require complete redigitizing. Presently, DEM data for an area up to 0.5 km^2 can be edited in one operation. To review and manually edit single points of a complete 7.5-minute DEM takes approximately 2 hours. A batch water body editing program then is used to remove errors in ponds, lakes, and double-line streams exceeding 150 x 300 meters in size. Water bodies less than 150 x 300 meters are corrected using a manual edit. The water body is digitized as one or more polygons using a standard topographic map as a base and the correct elevation is assigned to the polygons and merged with the elevation matrix.

The water body editing software, installed on the Multics computer in the late 70's, has been upgraded to handle multiple water bodies, and the current software is installed on Perkin-Elmer computers. To complete a water body edit takes approximately 1 hour.

The visual display and manipulation of a DEM provides a powerful and efficient tool for error detection, error correction, and quality control. This capability is provided by a DEM image display and editing system (IDES) which provides for visual inspection and verification by computer processing of the DEM data to create color image displays of color-banded elevation, shaded relief and slope, and anaglyphic stereo. Image enhancement techniques, such as pseudocolor and histogram equalization, can be applied as well as interactive editing techniques, including single-point editing, based on either simple point replacement or sophisticated neighborhood averaging, and area editing of either previously stored data or of data being collected during online map digitizing.

Design of the IDES was determined by cost, effectiveness of production, compatibility with the NDCDB data structure, capability to display data from a 7.5-minute quadrangle in standard format as well as in the GPM format, and capability to interactively edit individual points and collections of points. Tradeoffs among cost, user training, speed, and memory requirements led to a system based on the Digital Equipment Corporation (DEC) LSI 11/23 microcomputer system and a Comtal display, which brings the functional power of the PDP 11/34 class of minicomputer to the microcomputer level. This powerful image processing system, coupled with interactive software, provides significant error detection and correction capability. The wide color range displayed affords a significant ability to visually detect slope irregularities. The anaglyphic stereo and shaded-relief displays are comparable in quality to those generated on more high-powered and expensive minicomputers. Two systems are now in production and two additional systems are planned.

The main purpose of the IDES is to allow the visual detection of errors and anomalies in the DEM data. These errors may be classified as substantive or cosmetic and may be due to a number of causes; for example, missing or inaccurate data, datum shifts, correlation failures in the case of automatically scanned imagery, overlooked data in the case of manually scanned maps, and aberrations due to software logic. Cosmetic editing may include such functions as eliminating small systematic tilts in GPM patch-derived data, smoothing of shoreline data around water bodies, and edge-matching of GPM patches. Substantive editing may include adding missing profile points based on nearest-neighbor algorithms and correcting water body elevation errors through interactive polygon-fill methods. Substantive editing also includes elimination of gross errors at isolated points, which singly would have little effect on the RMSE of the DEM, but are troublesome to users during data applications.

Three basic editing capabilities have been provided on the IDES for both point and area elevations: (1) averaging, (2) replacement, and (3) increment/decrement. Averaging replaces the value of a point with a weighted average computed using the eight nearest-neighbor points. Replacement simply replaces the value of a point with an operator-selected value, which is entered interactively. Increment/decrement adjusts a point value by plus or minus 1. The system operator interactively selects which capability is to be used for a given editing task.

The location of map features from published maps, map separates, or orthophotos can be transferred to the IDES using a digitizer table. The outline of the feature is traced on the digitizer and transferred to the IDES, where it is loaded into a graphic plane and a map registration program is used to align the graphic plane boundaries with the stored DEM data. After the editing is completed, the display is again updated with the new data.

Improved 1:250,000-Scale Digital Elevation Data

The surface generation procedure that was used for producing digital elevation data from 1:250,000-scale quadrangles created numerous flats that straddle the positions of the contours on the maps. This is sometimes called the wedding cake effect. In an evaluation of the Dyersburg and Chattanooga quadrangles, 30 percent and 50 percent respectively, of all grid cells have elevations that are identical to the original map contours. There is a deficiency of cells with elevations to smooth the transition between contour values. In general, the greater the relief within a quadrangle, more cells have contour elevation values. The flats are fairly narrow on steep slopes but are as much as 25-35 cells wide on shallow slopes, plateaus, and valley bottoms. These flats introduce anomalous areas and features into slope maps and shaded-relief images.

A data improvement procedure was developed to: (1) identify and mask the flats, (2) filter and replace elevation values in the flats with decreasing elevations downslope from the flats and with increasing elevations upslope from the flats, (3) smooth the resulting image to remove echoes and other artifacts of the substitution procedure;

(4) merge original elevation data at some distance from any flat with smoothed data in and near the flats, and (5) document the results and clean the files. The procedure ignores small, inconsequential flats.

The result of the procedure (fig. 1) is smoothed elevation data containing few remnant flats. A few very large flats, such as those in playas, are not removed. Although, elevation contours do not have the same detailed configuration as the original data because of smoothing, more accurate slope maps can be obtained, and flats do not appear on shaded-relief images.

Digital Elevation Models from Contours

Digitizing the contour information from film separates of the more than 50,000 published 1:24,000-scale quadrangle maps will be a major method for adding DEM data to the NDCDB. Through various test projects, the Division has determined that efficient production procedures can be designed and implemented using existing data acquisition, processing, and editing systems. In one project, the film separates were scanned and edited using the Scitex Response System, and the resulting raster-formatted digital data then converted to vector format. Using an Intergraph system, the vector linework is edited and tagged with elevation values using USGS-developed contour tagging software. The resulting contour and water-body data are converted to a DEM on the Perkin-Elmer computer using contour-to-grid processing software developed by Zycor, Inc. The USGS has also procured two Laser Scan Automated Map Production Systems (LAMPS) which are being evaluated. Upon completing the pilot project, the NMD expects to have one or more production flows which can produce high-quality DEM data at minimal man-hour cost and product throughput time.

Digital Revision Study

The objective of the digital revision study was to develop and implement a digital map revision program. A six-phase study was prepared as follows:

(1) analysis of current map revision processes,

(2) assessment of available hardware and software,

(3) recommendations for future developmental efforts required to achieve a digital revision capability,

(4) experimentation with digital revision techniques through pilot tests,

(5) design of a digital revision system, and

(6) implementation of a digital revision system.

The first phase examined current mapping center revision procedures and production records, identified source material and product characteristics, and listed equipment and technology used in revision activities. The second phase, assessment of hardware

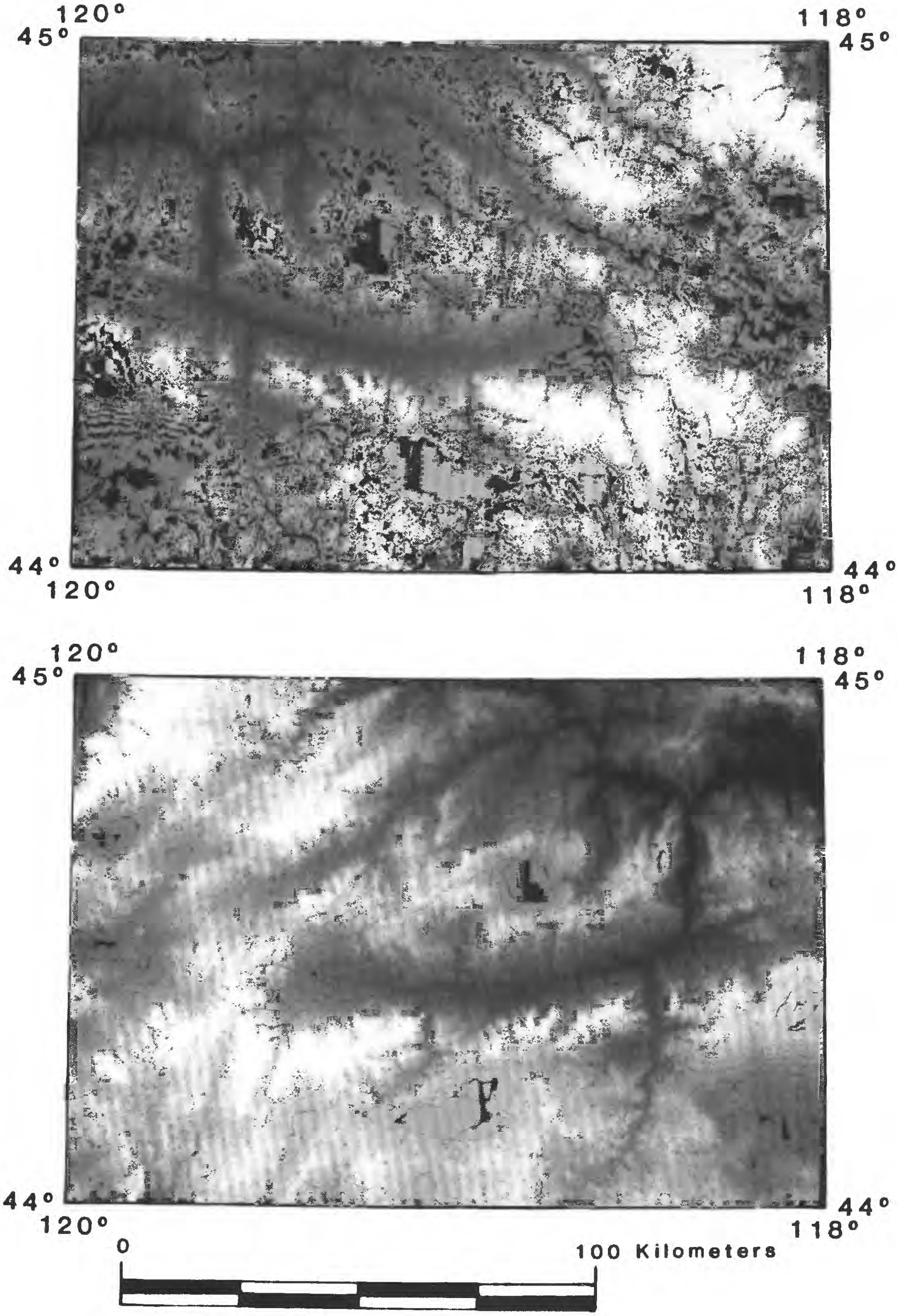


Figure 1.--Level flats are shown as black areas on the original elevation data (top) and on the improved data (bottom) for the Canyon City, Oregon, quadrangle.

and software, evaluated raster-to-vector technology, text and type capabilities, symbolization capabilities, and assessed the hardware and software identified during the first phase. The third phase, recommendations for future development, included generalizing revision flowchart information, development of production and response times, identification of revision process choke points, identification of areas needing further development, and consolidation of the first three phases into a single report.

The fourth phase, pilot tests, will be completed in 1985. These explore the use of digital techniques in photorevision, evaluate the use and availability of existing digital data bases for revision purposes, develop procedures for digitizing existing color map separates and color lithos through raster scanning and manual digitizing methods, study the use of vector files derived from rectified photographs or orthophotos, and investigate the merging of raster and vector revision data to generate a revised graphic.

Digital Generation of Thematic Structure Symbols

A geologic symbol overlay for any given thematic map is generally composed of many structure symbols, some of which are graphically complex and occur repeatedly at various angles. The most complex overlay may have several thousand symbols, most of which have been manually scribed. A small percentage are ordered on waxed film and placed manually.

A prior investigation resulted in an automated map symbol placement system utilizing an Altek angle-measuring acquisition system to collect and format data input to a Kongsberg flatbed plotter. The Kongsberg can plot symbols requiring an x,y, and rotational position by a single photographic exposure utilizing a negative-image symbol disk mounted on the photohead projector. However, the available symbol disk was extremely limited in its usefulness for any specific mapping application. Therefore, in order to maximize effectiveness, a new symbol disk for geologic structure symbols was developed. Approximately 150 symbols were considered. The physical limitation of each disk is 96 symbols in two concentric circles of 48 symbol positions. The final 96 symbols were selected on the basis of frequency of use and graphic complexity. The remaining symbols were programmed into the plotter memory via macro commands and can be plotted in vector fashion if needed.

An Intergraph interactive graphic design system was used to design the masters for each of the 96 symbols positions on the disc. This system provided interactive graphic creation, editing and display capabilities as well as multiscreen operating modes and multilevel display capabilities that increased the effectiveness and accuracy of the symbol design. Registration cells and aperture openings were initially created and then displayed throughout the design of each of the 96 symbol masters to correctly center and scale each symbol in compliance with Kongsberg specifications.

Film negatives were generated for each symbol master to etch the symbol image onto the disc surface. A comparison of manual scribing and placement versus automated plotting of geologic symbols showed that automated plotting increased production by up to 11 times over the manual procedure.

Maps for the Exclusive Economic Zone

The United States Exclusive Economic Zone (EEZ) was established by Executive Order in 1983, thus extending the Nation's domain 200 nautical miles seaward over an area larger than the 48 conterminous States. The USGS is planning digitally produced maps covering the EEZ as well as land extending approximately 100 miles inland. Current plans call for the maps to be produced at a scale of 1:1,000,000. Several types of geologic and geophysical data will be displayed on the base map by the Geologic Division as each map is completed. The base data categories will include selected metric contours and State boundaries for the land portions of the maps and shoreline and bathymetric contours for the EEZ offshore. The onshore contours are being generated from 1:250,000- scale DEM data produced by the Defense Mapping Agency and processed through the CPS contouring software. The boundary information is available from the 1:2,000,000-scale data base of the USGS. Sources for the shoreline and bathymetric contours as well as other graphic or digital data that are appropriate for use in the EEZ project are being investigated by USGS and NOAA.

Mapping the Dome of Mt. St. Helens

Since the devastating eruption of Mt. St. Helens in 1980, a new dome has been developing in the floor of the crater and in early 1983 a series of contour maps of the dome were compiled. These maps are at scale of 1:2,000 and 1:4,000 with a contour interval of 2 meters. The 1:4,000-scale map covers the entire crater floor and provides control for the more detailed 1:2,000-scale maps of the dome. Ground control was established by field methods during the summer of 1982 generally around the rim of the crater. These control points were paneled and aerial photographs were obtained, but the almost constant presence of steam clouds in the crater makes it very difficult to obtain good mapping photography. Subsequent minor eruptions have destroyed some of the control points and movements around the entire crater area have rendered other points unusable. Good relative horizontal and vertical scale has been maintained between both maps. Digital data were derived from the photogrammetric models with hopes of automatically generating contours but this met with limited success.

1:25,000-Scale Inset Mapping of Alaskan Villages

There are approximately 200 towns and villages in Alaska, ranging in population from a few to nearly 5,000 inhabitants, for which updated larger scale mapping does not exist. Even though a 1:25,000-scale metric mapping program of the more built-up areas of Alaska has been initiated to supplement standard 1:63,360-scale coverage, this has had little impact on the more isolated native villages.

A pilot project has been developed to place a 1:25,000-scale inset of the built-up area of a village side-by-side with the existing 1:63,000-scale quadrangle which is then partially revised to agree with the inset. The concept of showing a map inset to supplement smaller scale map coverage is not an original idea and mapmakers have shown insets for centuries to emphasize or show greater detail in specific areas. The practice has not been generally used in the National Mapping Program.

Bethel, Alaska was chosen for the initial pilot project. Located in southwestern Alaska, it has grown considerably in recent years, serving as a commercial and air hub for southwest Alaska, with a large Indian school, hospital, and commercial fishing enterprises.

The area is covered by 1:63,360-scale mapping of 1954, partially revised in 1977. Recent aerial photographs were available and horizontal and vertical field control was accomplished during the summer of 1984, along with the classification of all mapworthy features and the location and identification of BLM subdivision corners and other permanent monumentation. Aerotriangulation and photogrammetric compilation of the 17-square-mile inset has been completed along with the final redrafting.

The plan was to place the newly mapped 1:25,000-scale inset of the native village side-by-side with the existing 1:63,000-scale quadrangle on standard 22- x 27-inch paper. The original 1:63,000-scale quadrangle is partially revised to agree with the inset and the project, grid, collar data, and format are patterned after standard 1:25,000-scale mapping specifications. Units of measure of the inset are consistent with the smaller scale map. Unfortunately, the east-west dimension of this inset is too long to be printed side-by-side with the 1:63,360-scale map on standard sized paper, and therefore it will have to be printed on the reverse side.

PHOTOGRAMMETRY AND SURVEYING

Implementation Impact of North American Datum 1983

Investigations are continuing on the economic and technical aspects of implementing the North American Datum 1983 (NAD 83). The NAD 83 is a readjustment of the horizontal datum resulting from extensive precise measurement of the Earth's surface using new techniques, especially satellites, to relate this surface to the Earth's center of mass. The NAD 83 is compatible with other modern world geodetic systems and conversion to such a system from the current North American Datum of 1927 has been recommended by the National Academy of Sciences and supported by the Federal mapping agencies. NOAA has been responsible for the geodetic computations.

Table 1 gives the predicted range of the map projection readjustment resulting from NAD 83, in ground distances and in map distances, at three representative scales—1:24,000, 1:100,000, and 1:250,000.

Table 1.—Predicted range of adjustment in map projection from NAD 83.

SHIFT IN MAP PROJECTION					
		GROUND	MAP DISTANCES - INCHES		
		METERS	1:24,000	1:100,000	1:250,000
Conterminous	North-South	0–40	0–0.066	0–0.016	0–0.006
48 States	East-West	0–100	0–0.164	0–0.039	0–0.016
Alaska	North-South	40–150	0.066–0.246	0.016–0.059	0.006–0.024
	East-West	70–160	0.115–0.262	0.028–0.063	0.011–0.025
Hawaii	North-South	335–357	0.550–0.586	0.132–0.141	0.053–0.056
	East-West	284–292	0.466–0.479	0.112–0.115	0.045–0.046

The adjustments refer to the map projection and are related directly to the point-by-point change of geodetic coordinates (latitude and longitude) of a ground feature. Coupled with NAD 83 is the adoption of a new ellipsoid, referred to as GRS-80 (Geodetic Reference System). The State Plane Coordinate Systems (SPCS) and the UTM projection will be redefined in accordance with the parameters of the GRS-80 ellipsoid and the position of the SPCS and UTM grids relative to the map projection and map features will change due to the new ellipsoid parameters and normally will differ from the geodetic adjustment for the map projection.

The USGS currently has over 60,000 different map products. The 7.5-minute mapping program is nearing completion and the intermediate-scale mapping program of the conterminous United States is scheduled for completion of the planimetric editions by 1986. Implementation of NAD 83 will have profound impact on these and all other map products. It will have an impact on the National Digital Cartographic Data Base (NDCDB) and other data bases which include positioning information. The change to NAD 83 will not occur instantaneously and interim steps will be taken to help map users cope with the transition. Four options currently under consideration include:

- Continue producing maps on the 1927 datum and show the NAD 83 corners together with a description of the components of the projection shift between the two datums in the map margin (current practice); or conversely,

- Cartographically adjust map features to the NAD 83 position and show the four corners, based on the 1927 datum in the margin; or

- Recompile maps to a photogrammetric control solution based on NAD 83 (most expensive and probably impractical); or

- Recast only the map projection and grids to NAD 83 and fit to the existing compilation of the mapped area (very effective and economical, but map corners will not be even multiples of degrees and minutes).

A final selection from these options will be made in the near future.

The Global Positioning System

The Global Positioning System (GPS) is a worldwide satellite navigation and positioning system under development by the Department of Defense. The GPS is scheduled to replace the U.S. Navy Navigation Satellite System (NNSS) sometime after 1987. Use of the GPS promises to provide the capability of attaining geodetic position data with much less effort and time than is required for current surveying techniques.

There are presently about a half-dozen GPS satellites in orbit and available for simultaneous tracking during a 3- to 4-hour period each day. A Macrometer instrument has been used by USGS to measure precise positions on two occasions. A triangle was surveyed in the APTS calibration range to verify the accuracy of coordinates being used and the positions of a 13-station network were measured to provide test data for the APTS. Both uses were successful in that high accuracy was achieved for each line measured in a short 1-hour observing time.

The development of the Advanced Geodetic Receiver, under the direction of an interagency team comprised of USGS, DMA, and the NGS, is nearing completion. The first group of instruments, manufactured by Texas Instruments, have undergone field testing and are being modified to correct deficiencies. The second group are in production and will be delivered during 1985. The USGS is scheduled to receive five units, which will be used for establishing horizontal map control, for testing contract mapping, for geophysical surveys, and for special control surveys in areas where traditional surveying methods are costly due to problems with terrain, weather, or vegetation.

Map Projections

The first comprehensive map projection manual published by the USGS (Bulletin 1532), initially printed in 1982, has entered a third printing large enough to meet requirements for 2 or 3 years while a revised and expanded edition is being prepared. Reviews have appeared in six foreign journals and all have been generally favorable.

The chief criticism has been the deliberate limitation to projections used by the USGS; therefore, it is planned to incorporate additional projections into the next edition.

"Computer-Assisted Map Projection Research," (U.S. Geological Survey Bulletin 1629, 1985), which is the latest Survey publication of map projections, describes the derivations and computer programs involved in: (1) calculating polynomial coefficients for general data transfer between maps, (2) determining projection parameters for a map with insufficient labeling, and (3) using least-squares analysis to determine optimum parameters for minimum-error maps of given regions. The latter program is used for several new maps currently being produced.

A new publication, tentatively entitled "An Album of Map Projections," will include computer-generated outline maps based on several dozen different map projections with brief descriptions and categorizations. This forthcoming work will assist in the selection and understanding of the wide range of available projections. A minimum of mathematical emphasis will be confined to an appendix; distortions will be displayed with specially prepared computer-generated maps.

A new mathematical development has resulted in formulas for the conformal mapping of the triaxial ellipsoid, anticipating the increased use of this shape to describe some extraterrestrial planets and satellites. Also, ellipsoidal versions of the oblique and transverse Cylindrical Equal-Area projections have been derived to provide more accurate large-scale equal-area mapping of a region predominantly north-south in extent. Techniques are also now available to permit construction of minimum-error maps of regions bounded by rectangles (fig. 2) and other polygons. Prior to the availability of modern computers, most of these derivations would have been impractical to use.

Aerial Profiling of Terrain System

The development of the Aerial Profiling of Terrain System (APTS) by the USGS is nearing completion. The development began in 1974 with an engineering study by the Charles Stark Draper Laboratory of Cambridge, Mass., for a precision airborne surveying system. It was concluded that ground profiles accurate to 0.5 feet vertically could be established with an airborne inertial navigation unit and a laser profiler if a coordinate update was provided every 3 minutes. The technique proposed to provide update data was a laser tracker that would lock onto and track ground positioned retroreflectors as the aircraft passed overhead. A series of contracts was initiated to design, fabricate, install and flight test the APTS in a Twin Otter aircraft (fig. 3). At present, the APTS has successfully undergone performance evaluation tests and is engaged in a series of application tests.

The performance evaluation test flights are being made in an area west of Boston, Mass., where extensive ground control surveys have been done. The point positioning mode of operation was tested by several north-south flights in which seven retroreflectors located at surveyed sites were tracked. The results indicted that the APTS can establish point positions with an accuracy of ± 13 cm vertically and ± 45 cm horizontally (standard error) when updates occur at 5-minute intervals. The profiling mode of operation was tested by comparing APTS profiles with ground

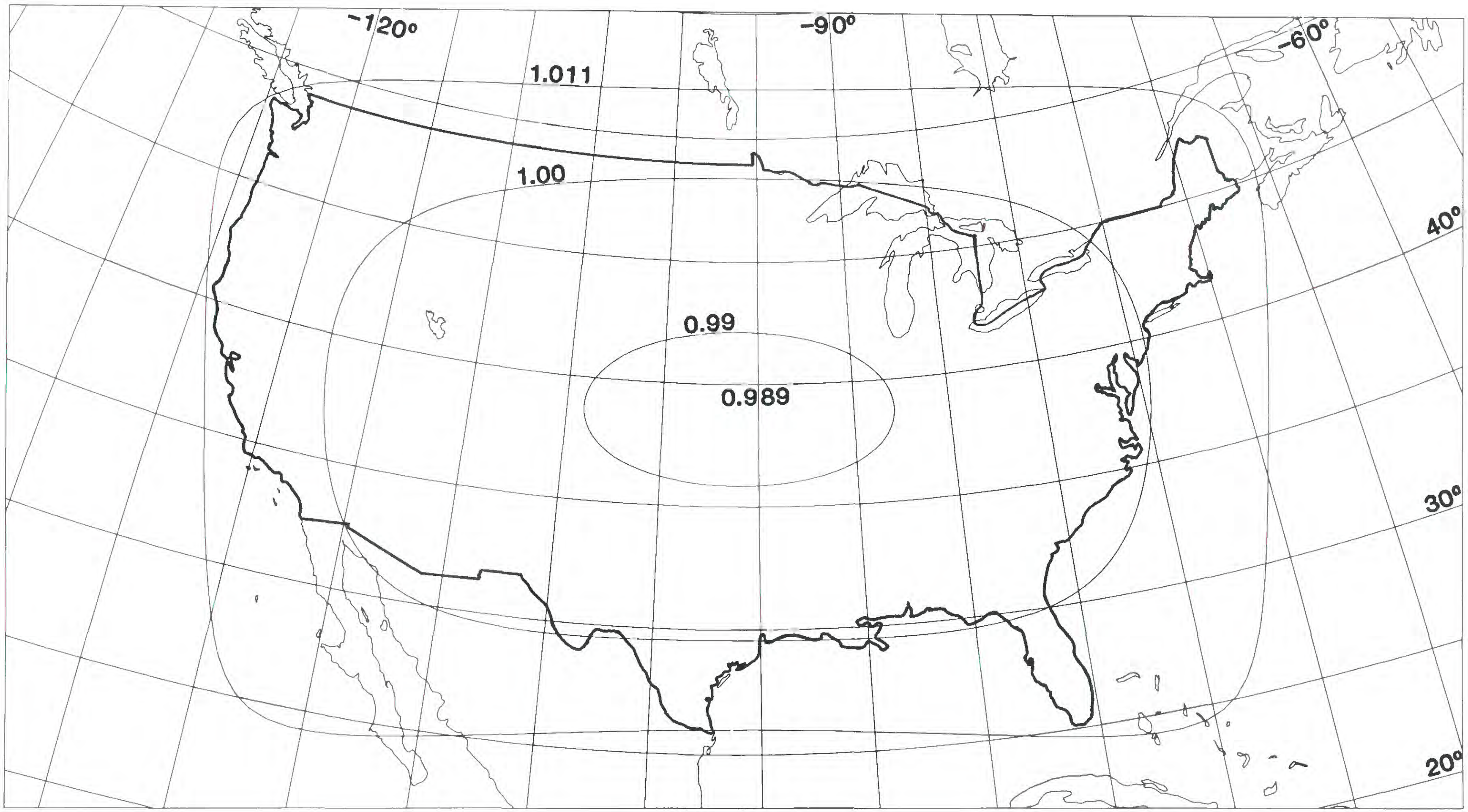


Figure 2.--An outline map of the United States, using a special conformal projection in which the country is enclosed within a near-rectangle of constant scale. The enclosed region is shown with less overall error than with any other conformal map projection. The numbers represent the ratios of local scale to nominal map scale.

Figure 3.--APTS-equipped Twin Otter aircraft over Nagog Pond, Concord, Mass.

surveyed points at three different sites where large-scale orthophoto maps had been made and contoured at a 1-foot interval. The profile data from 54 different passes were analyzed to obtain the accuracy of the navigation positions.

This combined with the profile standard error, produced a ±14 cm vertical error at 90 percent confidence with 3-minute updates. The horizontal accuracy of the profile points appeared to meet the desired accuracy of ±60 cm, but could not be directly checked due to the weak definition of the video imaging system.

The application testing program began with a project along a 28-mile reach of the Charles River near Needham, Mass. The purpose of this test was to survey several well sites marked by retroreflectors along the river and to determine the river surface elevations near these sites. The Doppler satellite translocation technique was used to position four retroreflector sites which provided control for the airborne surveys. Data collection flights on this project were completed in 1984 after several operational problems were corrected.

Data collection flights for three additional projects located near Plymouth, Mass., have now been completed and reports for these are being prepared. These are:

- The Kettle Pond project was to determine APTS effectiveness in measuring the water surface elevation of more than a 100 ponds to provide data for developing a model of the acquifer.

- Profiles were measured on four USGS topographic maps to determine the APTS capability in testing older maps.
- The point positioning capability of APTS was tested further in the Plymouth area and the results are impressive. The flight mission is shown on figure 4 and the errors from two APTS surveys are given in table 2.

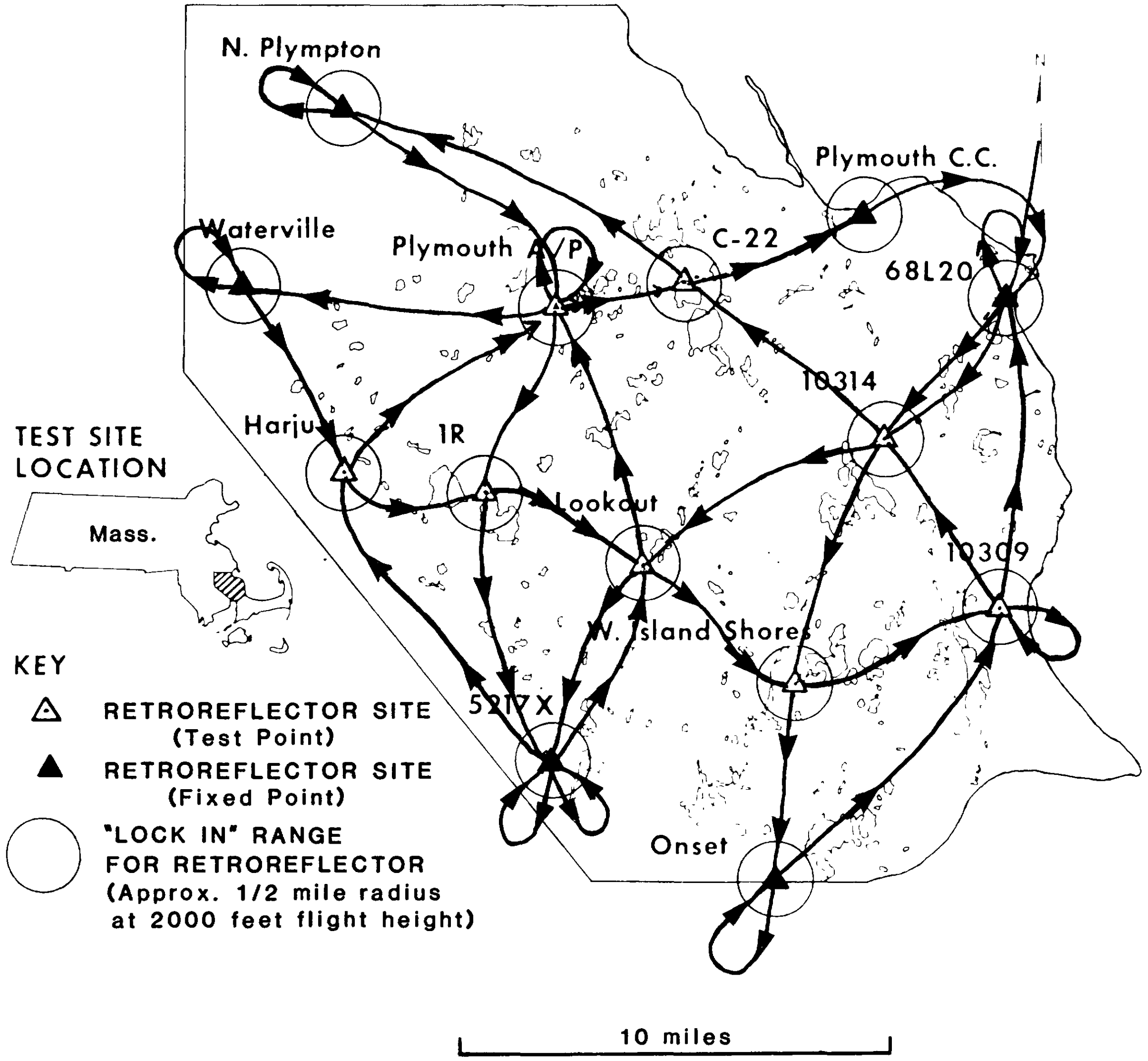


Figure 4 .—Flight plan of Plymouth, Mass., point positioning project for APTS application testing.

Several more application test projects are planned. These include establishing profiles across stream valleys for flood studies along the Farmington River, Conn.; measuring point positions in support of a gravity survey near Lebanon, N.H; and establishing profiles near Fitchburg, Mass. to control aerial photography coverage in

Table 2.--Coordinate errors from Plymouth, Massachusetts APTS point positioning project, December 1984

Retroreflector		Flight of December 4 cm	Flight of December 4 in	Flight of December 7 cm	Flight of December 7 in
10314	Lat.	10.0	(3.9)	-7.5	(-2.9)
	Long.	15.4	(6.1)	11.6	(4.6)
	Elev.	-5.6	(-2.0)	6.8	(2.7)
1R	Lat.	-1.6	(-0.6)	-9.8	(-3.9)
	Long.	3.4	(1.3)	-7.2	(-2.8)
	Elev.	2.9	(1.1)	1.6	(0.6)
Airport	Lat.	14.4	(5.7)	-1.8	(-0.7)
	Long.	15.3	(6.1)	-4.7	(-1.8)
	Elev.	-4.3	(-1.7)	2.9	(1.1)
Harju	Lat.	-12.3	(-4.8)	-16.6	(-6.5)
	Long.	7.1	(2.8)	7.8	(3.1)
	Elev.	-4.3	(-1.7)	-21.5	(-8.5)
Lookout	Lat.	-1.9	(-0.7)	-12.5	(-4.9)
	Long.	0.5	(0.2)	-12.8	(-5.0)
	Elev.	2.0	(0.8)	6.3	(2.5)
White Island Shores	Lat.	-0.9	(-0.3)	-6.7	(-2.6)
	Long.	2.3	(0.9)	-6.9	(-2.7)
	Elev.	-4.0	(-1.6)	-3.6	(-1.4)
C22	Lat.	-3.2	(-1.3)	-9.8	(-3.9)
	Long.	11.1	(4.4)	-7.2	(-2.8)
	Elev.	-6.1	(-2.4)	3.3	(1.3)
10309	Lat.	9.3	(3.7)	-25.5	(-10.0)
	Long.	-9.6	(-3.8)	-28.9	(-11.4)
	Elev.	7.8	(3.1)	3.7	(1.5)
STANDARD ERRORS	Lat.	±8.4	(±3.3)	±13.1	(±5.2)
	Long.	±9.7	(±3.8)	±13.1	(±5.2)
	Elev.	±4.9	(±1.9)	±8.6	(±3.4)

a standard quadrangle mapping project. Also planned are tests to determine the foliage penetration of the APTS profiler and to determine the effectiveness of combining a Global Positioning Receiver (GPS) with the APTS.

Application testing continued through June 1985. Then the APTS became operational and will be used to execute surveys for earth science projects of the USGS as well as for use by other agencies which have a need for the APTS capability.

Geodetic Observations for Earth Dynamics Studies

Southern California Uplift Area: In support of Earth dynamic studies by the Office of Earthquake Studies, first-order, class III, leveling was begun in 1982 in the Southern California uplift area. Three lines observed were observed in the Glendale-Palmdale-Ventura area; one north of San Bernardino, and one north of Morchogo Valley. The length of these lines totaled 470 kilometers.

The Wild N3 level and 1 centimeter rods were used to measure the elevations. A special instrument was designed and built to accurately measure temperatures at 0.5 and 2.5 meter height above the ground surface. After the data were collected and checked for quality, they were turned over to the National Geodetic Survey for final reduction. Preliminary results indicated the closures were well within the requirements for the survey.

Long Valley Caldera: A network of level lines has been established in the vicinity of Mammoth Lakes, Calif., to support geologic and hydrologic investigations related to suspected crustal movements within the Long Valley Caldera. One hundred and thirty kilometers of second-order, class I, leveling were run in 1982, consisting of 55 kilometers of new lines and 75 kilometers of reobservation of pre-1980 lines which revealed a measurable uplift within the caldera. During 1983, 170 kilometers of second-order, class I, levels were run, including 125 kilometers of reobservation and 45 kilometers of new line. Results confirmed the 1982 work and indicated additional uplift. During 1984, a total of 165 kilometers of existing level lines were reobserved, this time using first-order, class III, standards similar to those used by NGS for the transcontinental network. The 1984 observations continue to confirm earlier work and indicate a small amount of additional uplift in the caldera area.

Yucca Mountain: Long-term geodetic monitoring designed to reveal crustal motion which may be detrimental to underground hazardous nuclear waste disposal was initiated in 1983. Five quadrilaterals have been established in order to monitor known geologic faults surrounding Yucca Mountain near the Nevada Test Site. Each quadrilateral has been observed with second-order trilateration procedures, and selected sides of the quadrilaterals have been leveled to second-order, class I, standards. In addition, 80 kilometers of second-order, class I, levels have been established from the NGS first-order line along U.S. 395 across Yucca Mountain to a terminus approximately 20 kilometers west of Mercury, Nev. Plans are to tie the line back to the NGS first-order line south of Mercury during 1985. During late 1983 and, again in late 1984, the quadrilaterals were reoccupied, with no apparent changes observed either horizontally or vertically. In addition, the level line over Yucca Mountain was reobserved in late 1983 with good replication of the initial observations. Observations of the quadrilaterals and the level line are planned again for 1985.

Programmable Calculators in Field Surveying

The use of programmable hand-held calculators as a data collector for field survey observations has been increasing throughout NMD in recent years. They are extensively used to record observations in first- , second- , third- , and fourth-order level operations and supplemental control by vertical angle traverse.

The Hewlett-Packard HP-41 CX, the newest update in the series, with two HP-82181A extended memory modules, contains 600 registers in extended memory and 319 registers in program and main memory. Software has been developed for recording all data observed, including, when required, mark identification, field party, and weather conditions. Data entry is prompted and entered through the keyboard as it is observed. An audible warning is given if specified parameters, such as sight length, section imbalance, and rod-reading checks, are exceeded. Peripheral support includes an HP-862161A cassette drive and an HP-82162 Thermal Printer interfaced through an HP-IL module. The data recorded are dumped to tape at the end of each day and an archival graphic is made. The tape is returned to the mapping center and read into an HP-85 microcomputer for processing. Software is recorded on magnetic cards and accessed with an HP-82104A card reader. Reobservation of lines due to errors and excessive closures has been reduced by this method. In the office, the HP-41 CX serves as a desk-top computer, relieving some of the load on computer operations. Coordinate transformations, Polaris observations, three-point problems, and geodetic forward and inverse solutions are computed for single points in this fashion.

Instrumentation for Orthophoto Production

The USGS and DMA currently have a contract with Baker and Associates for the development of a large-format Offline Orthophoto Printing System (OLOPS). USGS will use the system to accommodate a variety of source materials, to take advantage of the increased availability of digital elevation data, and to replace equipment that is approaching obsolescence. The OLOPS will be used to scan aerial photographs that will then be electronically transformed to produce orthographic projections of the terrain surface, rectified photographs, stereomates, or digital representations of the aerial photograph. The system components include:

- Input stage - 254 x 508 mm
- Output stage - 600 x 762 mm
- Scanner subsystem
- Printer subsystem
- Control computer
  - 128k 16-bit-word memory
  - CRT display terminal
  - line printer
  - magnetic tape drive (800/1600 BPI)
  - disk drive (10-MB)

The system specifications are:

- Accuracy
  - static 4 microns RMSE
  - dynamic 16 microns RMSE
- Magnification - 1x to 32x
- Resolution - 60 lines per millimeter at 1x
- Input image data
  - frame photographs
  - panoramic photographs
  - digital images

The OLOPS system has been delivered and installed and is currently under acceptance testing. It became operational for production use in 1985.

Analysis of the Image Chain in the Orthophoto Production System

The purpose of this study was to evaluate the aerial image in terms of resolution degradation after being processed through each transformation sequence—the photogrammetric instruments, the photographic processing, and the printing operations. Beginning with the original aerial image and progressing through to the final lithographic printing, an image is processed through six to nine operations, depending on the instrumentation. In order to evaluate the image resolution in line pairs per millimeter (lp/mm), an image control target consisting of five U.S. Air Force 1951 resolution targets, was processed through the same sequence as an aerial image. The resolution targets were evaluated at the end of each operation in the chain. The sequence of steps and the results of this study are compiled in figure 5.

The greatest reduction of resolution occurred in the scanning/enlarging process. There, the resolution targets were reduced to 6 lp/mm on the Gestalt Photo Mapper (GPM-2); 12 lp/mm on the Gigas Zeiss (GZ-1); 16 lp/mm on the Wild Avioplan (OR-1), and 14 lp/mm on the Wild Rectifier (E-4). On viewing the final printed copy with magnification, only the dots of the screened aerial image can be measured for resolution value. Therefore, the final printed image resolution is reduced to the 6 lp/mm halftone (150-line screen ruling divided by 25.4) regardless of the lp/mm resolution of the images processed prior to halftoning.

Stereomodel Digitizing

The stereomodel digitizing process within the USGS has been refined to be an effective automated cartography procedure. The system stores x,y coordinates and feature attributes on magnetic tape during stereocompilation. These coordinates

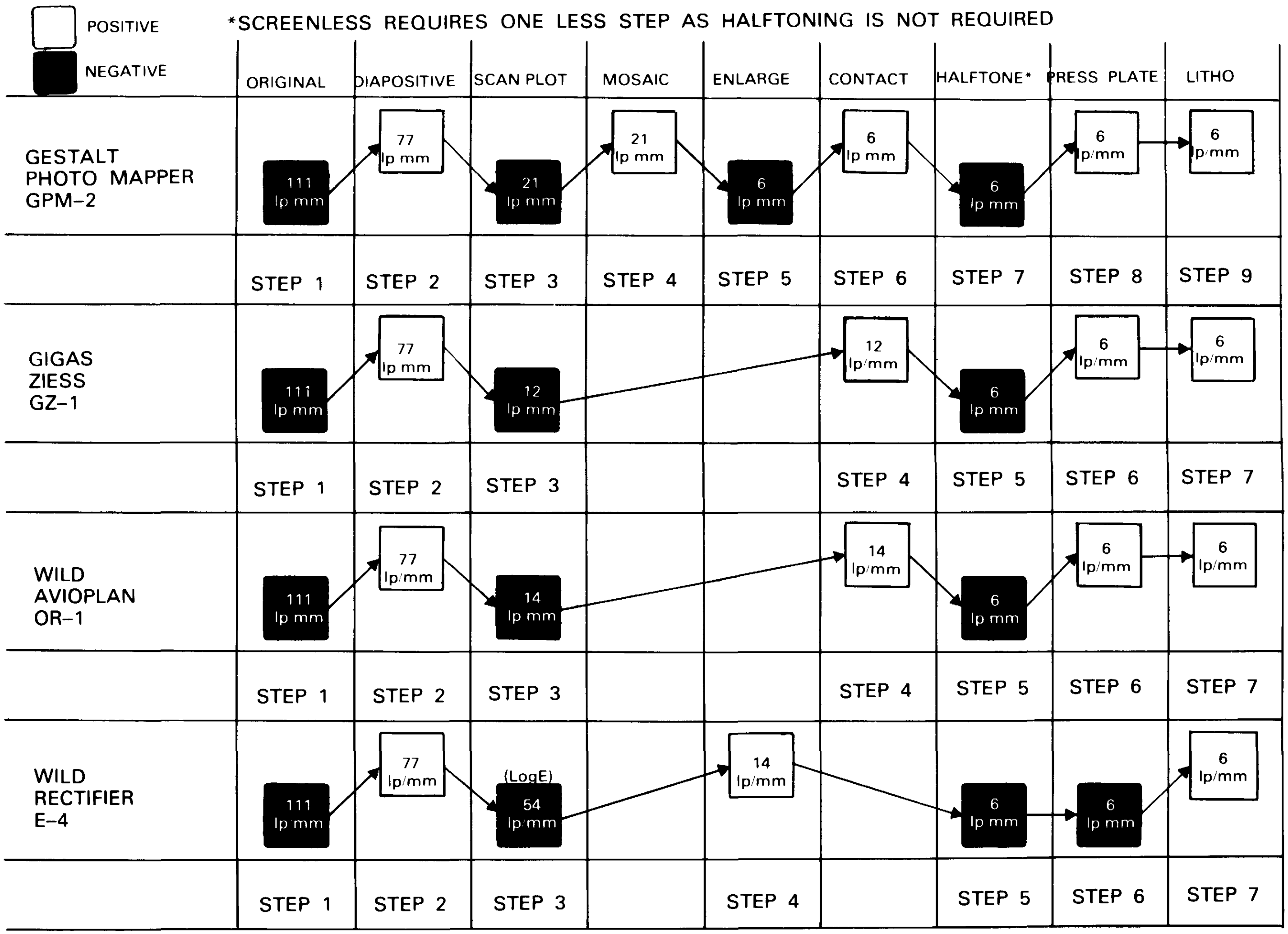


Figure 5 .—Methods of orthophotoquad processing and resolution at each step.

and attributes are used as input to the Digital Cartographic Software System (DCASS) and the Graphic Map Production System (GRAMPS) to produce digital elevation models and final quality provisional map separates. The current system is cost competitive with traditional stereocompilation and map finishing procedures.

IMAGE MAPPING

FIRESCOPE Mapping Program

The FIRESCOPE project provides assistance in coordinating the response to wildfires by fire services spread over nine counties of southern California. A part of this project was the FIRESCOPE mapping program, which provides the nine counties with a standard set of maps and orthophotoquads to meet emergency response needs and a computer-compatible data base to support fire modeling.

The NMD cooperated, first with the U.S. Forest Service, and later with the State of California Office of Emergency Services when the program was turned over to the State. Products furnished under the cooperative agreement are orthophotoquads, line map separates, and DEM data. Response books used by the fire services are composed of 1:24,000- and 1:12,000-scale line maps and orthophotoquads of all areas. In urban fringe areas a 1:6,000-scale line map and orthophotoquad were added. Originally, the orthophotoquads were scanned from 1:80,000-scale high-altitude photographs, and covered an entire 1:24,000-scale 7.5-minute quadrangle. The need for higher resolution imagery necessitated the use of quarter-quadrangles photographs at 1:40,000-scale. Of the 357 orthophotoquads in the nine-county area, 210 have been prepared from quarter-quad-centered photography.

These FIRESCOPE project maps are available for other uses and have been used for search and rescue in cases of missing hikers and downed aircraft and for other similar problems, including many uses during the Olympics.

Side-Looking Airborne Radar Mapping

In 1980, the USGS began a Side-Looking Airborne Radar (SLAR) program and since then more than 400,000 square miles of SLAR data have been acquired in the contiguous United States and Alaska. Approximately 150,000 square miles are planned for fiscal year 1985. The Survey has supported over 60 studies addressing geologic, hydrologic, cartographic, and engineering applications of radar technology. Since radar is an active sensor that provides its own source of illumination, imagery can be obtained through clouds and rain, day or night. One of the primary cartographic applications of SLAR is for the preparation of image-base maps of perpetually cloud-covered areas where conventional aerial photographs are very difficult to obtain.

The cloud-penetration capability of SLAR provided the opportunity to obtain cloud-free synthetic-aperture radar imagery of the Aleutian Island arc in Alaska. The imagery was used to prepare twelve 1:250,000-scale image mosaics of the Aleutian Islands. Radar image strips at 1:400,000 scale were enlarged and photomechanically mosaicked after matching the imagery to geodetic control points and to image points on the corresponding 1:250,000-scale line maps. The radar mosaics were printed back-to-back with the line maps, which were updated to show the latest feature names, township and range lines, and locations of offshore leasing tracts.

High-resolution x-band (3-cm) imagery from both real- and synthetic-aperture radar systems was acquired for selected areas of the Alaska Peninsula. A set of radar image products of the 1:250,000-scale Ugashik, Alaska, quadrangle was prepared to provide comparative imagery from the two systems. The Ugashik quadrangle was selected because it is an area where extensive geologic analysis using SLAR has been published. The set includes: four mosaics depicting real- and synthetic-aperture imagery from four different look angles, radar image strips from both systems for stereo viewing, and one color-enhanced radar mosaic overprinted with line map data. The set also includes descriptive text on the geology of the Ugashik area, the principles of radar imaging, and a set of references.

A combined geologic map and radar image of northeastern West Virginia was prepared as part of a project to evaluate radar imagery for its use in geologic and hazards mapping in the folded and thrust-faulted valley and ridge portion of the Appalachian Mountains. This image product merges the physiographic information of the radar image (drainage, fracture patterns, and discontinuities in bedding traces) with the color-coded stratigraphic information from the geologic map. The merged print simulates the image which results from superimposing a geologic map over a radar image on a light table, and shows information not readily apparent when the data sets are viewed separately. Geologic contacts can be compared to the topographic expression of the SLAR image, and areas where the map and image show lack of correlation can be readily noted for field checking. This technique of combining geologic data with high-resolution radar imagery of intensely folded and faulted terrain provides a unique map base for correlation of similar geologic structures and identification of anomalous geologic trends.

Sonar Image Mapping

The USGS and the British Institute of Oceanographic Sciences (IOS) have been involved in a cooperative program over the past 5 years in collecting, processing, and analyzing sonar images of the ocean bottom. The side-scan sonar images have been collected by the GLORIA (Geological Long Range Inclined Asdic) system, which was designed, built, and is operated by IOS.

GLORIA was first used to collect data for the USGS in 1979 when sonar images were collected of selected areas along the U.S. Atlantic coast. These data were recorded only in analog format; some digital processing was used on a few digitized negatives. Several preprocessing, sonar-specific algorithms were developed by the USGS to remove shading and geometric problems. In 1982 the USGS and IOS again participated in a joint project to collect sonar image data using the GLORIA system in the Gulf of Mexico. Many more data were recorded during this 29-day cruise, and the output included digital data on computer-compatible tapes. Selected subsets of these data were processed and new algorithms were designed and added to the preprocessing software package. However, due to funding limitations and reorganization within the USGS, this project was given low priority and the full data set was not processed.

From April to June 1984, GLORIA was used to collect sonar image data off the west coast covering part of the newly declared Exclusive Economic Zone (EEZ). The EEZ area extends from the U.S.-Mexico border to the U.S.-Canadian border and 200 miles out to sea from the U.S. coastline. Due to the increased volume of data collected over 90 days and the high interest in the EEZ, the software to process the GLORIA data was refined and expanded on the Mini Image Processing System (MIPS) (see article on MIPS in this report). Some of the software was redesigned and made into an operational production package and then transferred to two MIPS in Menlo Park where the production processing and mosaicking will be done. The second MIPS in Menlo Park is used by the Office of Marine Geology, Geologic Division, to do detailed processing and analysis of selected areas using the extensive general processing and analyses capabilities. The production processing is being done in Menlo Park so that geologists will be able to control on a daily basis, the generation of the final image products.

The GLORIA processing software includes the following programs:

GLORIA	Tape-to-disk and reformatting of the original GLORIA computer-compatible tapes.
NAV2DK	Tape-to-disk conversion of the navigation data.
MERGE	Combines some navigation information with the image data using specified header locations.
SLR2GR	Converts image data from slant-range to ground-range (CORH20) geometry, and also corrects/removes the water column distortion present in the data.
SHAD2	Automatic shading correction of the sonar image data using a modified technique developed earlier for radar shading correction.
DELTAV	Corrects the sonar image data for geometric problems caused by changes in the ship's velocity. It also corrects the aspect ratio distortion present between the along-track resolution (approximately 125 m) versus the across-track resolution (approximately 50 m).
BARSCL	Inserts a north pointer at a user-specified spacing (default set at 500 lines) and generates a mark every 0.25 degrees of latitude.
PRTNAV	It generates a hardcopy printout of various navigation parameters, including the ship's velocity and distance traveled, at a user-specified time interval.

Once the above preprocessing algorithms are applied, any of the general MIPS processing capabilities can be used for further information extraction, image enhancement, or analysis. These can include spatial filtering for low or high frequency enhancement, interactive color coding or contrast stretching, or further numerical evaluation.

Figure 6 shows a small area about 100 miles off the Southern California coast. The scale is about 1:382,000 and the various preprocessing steps have been applied. The shading correction has improved the amount of detail visible in the near-range and far-range areas. The geometric corrections have improved the cartographic aspects of the various features. In particular, the large volcanoes shown on the left side of the image have geometric shapes that are closer to the expected shape than does the original image.

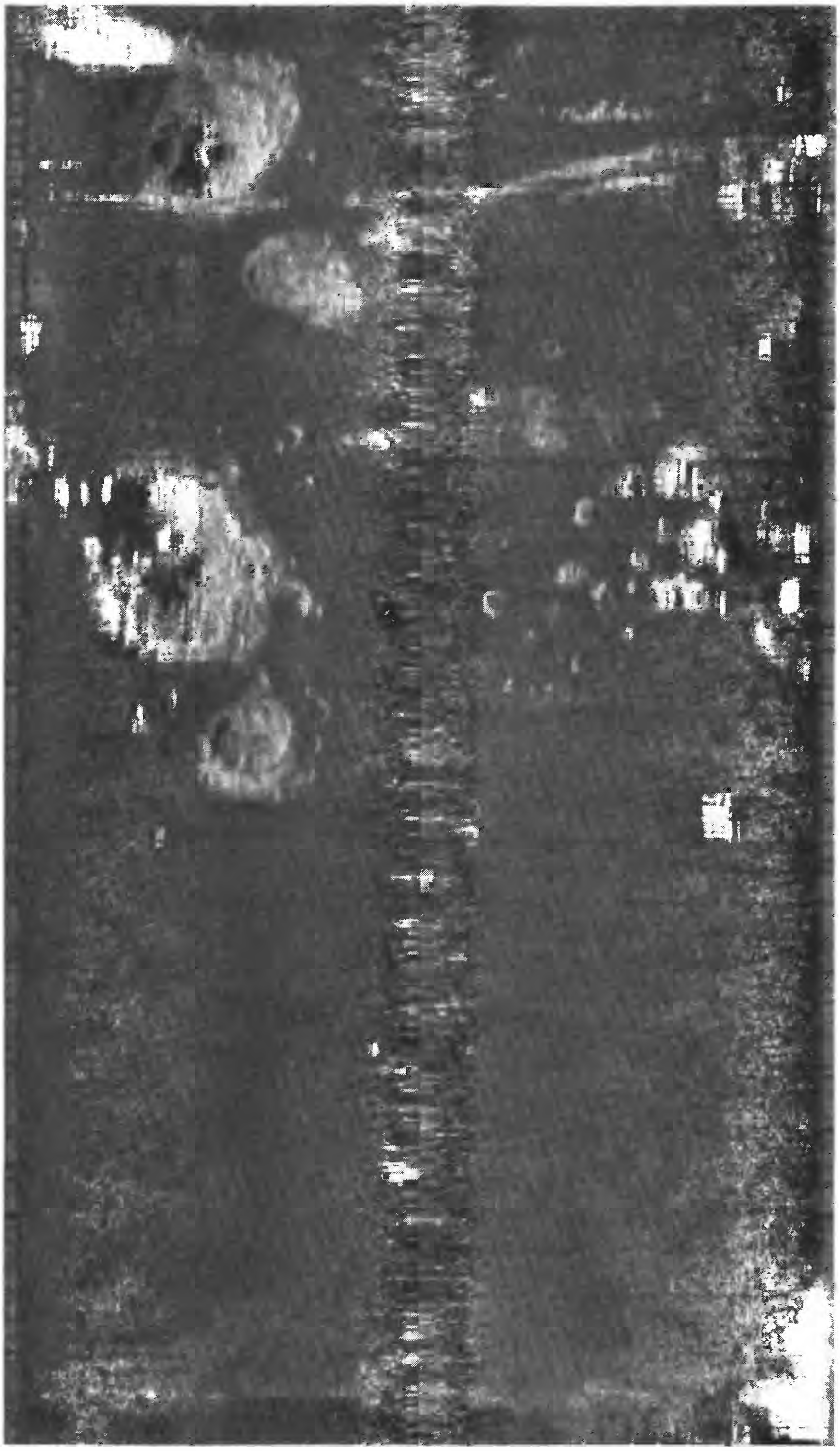


Figure 6.—Sonar image of area off southern Calif. coast after preprocessing to correct for radiometric and geometric distortions. There is improved detail at near and far range with a circular shape of the volcanoes. Shown here at approximately 1: 382,000 scale.

Plans for this program include the generation of 33 2- x 2-degree sheet mosaics of the west coast data and the collection of new data during the summer of 1985 to cover most of the Gulf of Mexico and the extreme southern portion of the Atlantic coast. These data will be processed and analyzed on a new PDP 11/73-based MIPS in Reston having two display stations. One station will be used for production processing and the second for research and analysis. Also, work will continue to rasterize the bathymetry and magnetic data recorded on the navigation tape. The data will be used in surface generation software to create 2- x 2-degree images to overlay digitally on the digital sonar data. Research also will continue into the extraction of topographic information.

Satellite Image Mapping

The USGS has long recognized the need for image maps as tools for resource analysis and as map supplements, as well as a means to provide coverage of unmapped areas. After Landsat 1 was launched in 1972, the Survey began to produce multicolor maps from the MSS imagery, and Earth scientists quickly recognized the global application of small-scale image-base maps for compiling and analyzing land use, geologic, and hydrologic data over regional areas. The Survey has continued to develop techniques for producing color image maps from multispectral imagery. Recently, imagery from the higher resolution Landsat 4 Thematic Mapper (TM) has made possible the production of color image maps at 1:100,000 scale. Advances in image mapping science are reflected in the development of techniques for use of geodetic control, computer processing for enhancement of digital image data, photographic and digital mosaicking, and calibrated lithographic printing.

Development of an image map production system increased considerably during 1984. Prior to this time image maps of Dyersburg, Tenn., and Las Vegas, Nev., had been produced on an experimental basis to test newly acquired geometric registration and digital mosaicking capabilities. Recent work has centered on the refinement of procedures and specifications to provide a standard production system. Projects completed during 1984 included image maps of Washington, D.C., and Vicinity, Great Salt Lake and Vicinity, the Mandera Quadrangle, Kenya, and the Western Sahara project. These provided a diverse product mix with which to develop appropriate techniques.

Geometric registration accuracies were improved with the addition of a precise registration table on the Image 100 system. A registration test that was completed using three map scales---1:24,000, 1:64,000, and 1:250,000--demonstrated much better operator accuracy and consistency. A refinement in the procedures used for control point selection was achieved which has reduced the number of control points needed to accurately register an image.

The large area mosaicking software (LAMS) obtained from the Jet Propulsion Lab (JPL) was installed on a VAX 11/780 computer. The previous Image 100 system was capable of mosaicking four Landsat MSS scenes while LAMS could be used to mosaic any number of scenes, limited only by the amount of disk storage space available. The system provides better geometric control between neighboring frames by selecting tiepoints along a predefined contour and uses a finite-element method of generating the transformation grid which forces control points to a specified output location. Radiometric matching is accomplished by collecting brightness-value information at the geometric tiepoints. A rubber-sheet correction is applied automatically to match an image to its neighbors. The software has the ability to hold the control information for all images of a mosaic in a single file in order to provide better data management capabilities.

Production specifications have been established for first-generation black-and-white transparencies that are produced on the laser beam recorder (LBR). These transparencies are used to prepare lithographic products for publication. The four areas addressed in the specification are the brightness-value-to-density transformation curve (look-up table), the output format, the film annotation, and the amount of edge enhancement that should be applied prior to LBR processing.

In addition to the look-up table used to generate the transparencies for lithographic reproduction, a look-up table is being developed which will generate a color photograph that emulates the hue, contrast, and density of the lithograph. Normally, the greater density range of photographic materials over lithographic materials is misleading when visually predicting the appearance of the printed image.

Current research includes: (1) refining computer techniques for digital mosaicking of Landsat image data over areas as large as 6 degrees in both latitude and longitude and then extracting the individual quadrangles for more efficient image map production; (2) developing methods to prepare final-scale map separates directly from computer tapes; (3) improving digital techniques for geometric correction and image enhancement; (4) combining Landsat data with other digital data sets, such as elevation data; and (5) application of filtering techniques. Future research will continue to address these areas to evaluate mapping applications of higher resolution imagery from new satellite sensors. Emphasis will be placed on techniques from merging space-acquired image data with conventional cartographic and Earth resources data sets in digital form for rapid analysis to meet the challenging national goal of developing more timely and effective methods of Earth resources assessment.

Conventional base maps depict features of general interest as opposed to specialized (thematic) depictions. The interpretation of the land to water interface is of fundamental importance and the interface exhibited by the three TM infrared bands (0.76 to 0.90 μm, 1.55 to 1.75 μm, and 2.08 to 2.35 μm) display what appears to be different shorelines in certain areas. The apparent shoreline of the Patuxent River and the shoreline in the evaporation salt pond areas of the Great Salt Lake are two examples that have been investigated. At this time, it is not known which of the three TM bands (4, 5, or 7) best defines the land-water boundary.

Cultural features are of general cartographic interest, but in an area of growing vegetation, band 4 does not give as strong a response to road and cleared areas as it does to vegetation. Thus, cultural features tend to be subdued in such areas when band 4 is used. For this reason, band 5, which is less sensitive to growing vegetation was utilized for both the Dyersburg and the Washington, D.C., and Vicinity image maps.

Washington, D.C., and Vicinity

The Survey has developed experimental image maps from the Landsat program at both 1:250,000 scale (from the MSS) and 1:100,000 scale (from the TM). During 1984 this research was continued and resulted in two image products of the Washington, D.C., area, both derived from the TM. The first was a 1:100,000-scale map, Washington, D.C. and Vicinity, which utilized the blue (band 1), red (band 3), and near-infrared (band 5) printed in yellow, magenta, and cyan, respectively. The second was the "Landsat Thematic Mapper (TM) Color Combinations, Washington, D.C., and Vicinity," published as Geological Survey report I-1616. This report graphically illustrated the various color combinations and permutations that are possible from six spectral bands. The report also quantitatively describes the rationale behind spectral band selection in order to present the maximum information for a given scene.

One significant finding is the establishment of a picture-element (pixel)-to-scale relationship criterion of 3.3 pixels per mm at map scale. This means that the 75- to 80-meter pixels of the Landsat MSS are suitable for 1:250,000-scale image mapping; the 30-m pixels of the TM are suitable for 1:100,000 scale; and 15-m pixels will be needed for 1:50,000 scale.

Mandera Quadrangle, Kenya

A digital mosaic of the Mandera 1:250,000-scale quadrangle was produced at the request of AID. The five Landsat 2 MSS scenes used in the project were geometrically registered using both 1:250,000-scale Joint Operations Graphic (JOG) sheets and 1:100,000-scale maps which were supplied by DMA. No larger scale map coverage was available. The output was produced on a UTM projection and was resampled, using cubic convolution, to 50-m pixels. Negative first-generation black-and-white transparencies were produced on the laser beam recorder using a 0.038-mm spot size, a 5- x 5-edge enhancement, and a multipoint linear stretch designed to equalize the histogram. The black-and-white negatives were used to train representatives from the Regional Remote Sensing Facility in Nairobi on image map printing procedures. Final-scale halftone separates were prepared during this training program to be used at a later date by Kenya to produce a lithographic product.

Western Sahara Project

The objective of the Western Sahara project was to produce, in cooperation with DMA, thirteen 1:250,000-scale false-color image maps from Landsat MSS data. DMA provided ground control for registration and prepared the culture and collar separates. The data from 13 scenes were mosaicked and divided into an equal number of 1° x 1° 30-minute quadrangles. First-generation film positives were enlarged to make 1:250,000-scale color composite images of each quadrangle. The positive transparencies and color prints were used along with the map separates to prepare press plates for the final lithography.

The Western Sahara project was the first major use of LAMS. In addition to using the mosaicking techniques, procedures were developed for handling the enormous digital mosaic data base and for enhancing the mosaicking techniques to fine-tune of the radiometric match between neighboring frames. The final product was resampled, using cubic convolution, to 50-m pixels in a transverse Mercator projection. A 3- x 3-pixel edge enhancement and a multipoint linear stretch, designed to equalize radiometric balance between quadrangles, was also performed. The black-and-white positive transparencies were produced on the laser beam recorder using a 0.057-mm spot size.

The positive transparencies were used to prepare publication-scale halftone separates through the use of a Hell CP-340 color graphic arts scanner/plotter. In addition to the 1:250,000-scale quad maps, an investigation was started to identify methods of preparing smaller scale maps at 1:500,000 and 1:1,000,000 from the same data set.

Great Salt Lake and Vicinity

The Great Salt Lake and Vicinity Landsat TM image map was prepared during the latter part of 1984 at a scale of 1:100,000 (fig. 7). It involves several new developments in the art of image mapping.

Four images spanning an 8-day period were required to produce the mosaic and required precise geometric and radiometric adjustment to a common base. This operation was carried out totally in the digital domain. Since the lake itself dominates the map, different band combinations and processing algorithms were used for the open-water area and for the land area. This resulted in the display of more detail in both the water and land area than would have been possible with one selection of bands and one algorithm such as was applied to previous satellite image maps.

In another innovation, contours taken from conventional line maps were added to an image map. Three were bathymetric contours and one was topographic. Care was required in adding the contours as even small errors on contour position became obvious when superimposed on the exact shoreline displayed by the image.

Although the map required 7 months to produce after image acquisition, this is a far shorter period than can be expected for conventional map production. The map displays a transitory phenomenon of high importance as this is the highest level of the Great Salt Lake in over 100 years. The time required to produce such image maps can be further reduced where the situation so demands. Thus, the timely display of important transitory phenomena in map form becomes an obvious new application.

Image Processing

Digital Processing Techniques for Image Mapping with Multispectral Data

In this study, comprised of two parts, enhancement algorithms were implemented to improve the detectability of terrain features and patterns, and statistical analysis methods were used to determine the amount and distribution of information contained in simulated SPOT and Landsat TM data sets. The purpose was to identify band combinations that contained the most information and the least amount of duplication. Table 3 shows the spectral characteristics of the two imaging systems.

Two test sites were used that included both TM and simulated SPOT data. A site in northern Arizona is a semi-arid and rural environment, whereas a site near Washington, D.C. is a highly vegetated and urban area. The data were collected during different seasons, the TM data in the winter and the simulated SPOT data in the summer, and it was difficult to compare them directly to each other, especially

Figure 7.--Reduced version of the image used for the Great Salt Lake and Vicinity Landsat TM image map. Shown here at approximately 1:683,000 scale.

Table 3.--Spectral band characteristics of simulated SPOT and Landsat thematic mapping (TM) data

MEASURE	SPOT		TM	
Spectral bands (μm)			band 1	0.45 - 0.52
	band 1	0.50 - 0.59	band 2	0.52 - 0.60
	band 2	0.61 - 0.68	band 3	0.63 - 0.69
	band 3	0.79 - 0.89	band 4	0.76 - 0.90
			band 5	1.55 - 1.75
			band 6	10.40 - 12.50
			band 7	2.08 - 2.35
Analog to digital conversion (bits per pixel)	8		8	

for the highly vegetated area. Multispectral SPOT data were collected for the Arizona site and panchromatic data were included with the multispectral data for the Washington, D.C. site. The SPOT multispectral data has a ground resolution cell of 20 meters; the panchromatic data has a 10-meter cell. Landsat TM data have a ground cell of 30 meters except for the 120-meter thermal band.

Digital enlargement combined with spatial filtering was used to merge low- and high-resolution data for the Washington, D.C., site. A digital image that is optically enlarged near the limits supported by its pixel resolution will have a blocky appearance and the individual pixels become so large that the viewer does not easily perceive multipixel patterns and features. Often a fine screen pattern can be seen as each pixel is viewed separately as an individual feature or pattern.

To solve this problem a combination of digital enlargement by pixel duplication has been used, followed, if necessary, by spatial filtering for smoothing and edge enhancement. The number of pixels in the image is increased so that a smaller optical enlargement is needed to obtain the desired scale. However, if only pixel duplication is used, the image will still appear blocky and may be more obvious than in the original image.

To eliminate this effect, a smoothing filter is applied. The size of the filter is critical and must be equal to the size of the digital enlargement so that it doesn't over- or under-smooth the data (fig. 8). By using a smoothing filter that is the same size as the digital enlargement, the values of the pixels at the center of the enlarged arrays will not change. This has the same effect as separating the original pixels by the digital enlargement factor and then using a two-dimensional interpolation technique to fill in the missing pixels.

Statistical analysis produced the correlation matrix for the Landsat TM and simulated SPOT data shown in tables 4 and 5. In the northern Arizona area, the correlation matrix shows that the three 20-m SPOT bands are highly correlated with each other and little new information is added by using three bands instead of a single band in this area.

Figure 8.--TM band 4 image of Washington D.C. area with a 3x digital enlargement and a 3 x 3 smoothing filter. The blocky appearance usually seen in digital enlargements is gone and edges are more continuous. An edge enhancement could be applied to further sharpen the image. Shown here at approximately 1:37,000 scale.

For the Washington, D.C. site, the 20-m data were digitally enlarged by 2x and a 2- x 2-pixel smoothing filter was applied to generate a digital array equal in size to the 10-m data. The correlation matrix shown in table 8 was generated to identify the 20-m band that could be replaced with the higher resolution 10-m panchromatic band with a minimum effect on the spectral characteristics of the resultant three-band combination. Both SPOT bands 1 and 2 are highly correlated with the 10-m

Table 4.--TM and SPOT band correlation matrix for Northern Arizona area

	TM Band 1	2	3	4	5	6	7
TM 1	1.000	--	--	--	--	--	--
2	.974	1.000	--	--	--	--	--
3	.967	.986	1.000	--	--	--	--
4	.948	.974	.986	1.000	--	--	--
5	.897	.933	.945	.965	1.000	--	--
*6	.070	.098	.134	.106	.105	1.000	--
7	.888	.928	.946	.962	.985	.162	1.000

*6 – Thermal Band

	SPOT Band 1	2	3
SPOT 1	1.000	--	--
2	.995	1.000	--
3	.982	.991	1.000

Table 5.--TM and SPOT Band Correlation matrix for Washington, D.C. area

	TM Band 1	2	3	4	5	6	7
TM 1	1.000	--	--	--	--	--	--
2	.891	1.000	--	--	--	--	--
3	.788	.859	1.000	--	--	--	--
4	.333	.513	.346	1.000	--	--	--
5	.449	.587	.595	.728	1.000	--	--
*6	.265	.314	.316	.508	.580	1.000	--
7	.623	.725	.759	.557	.902	.524	1.000

*6=Thermal Band

	SPOT Band 1	2	3	**4
SPOT 1	1.000	--	--	--
2	.969	1.000	--	--
3	-.189	-.288	1.000	--
4	.952	.954	-.218	1.000

**SPOT 4 = SPOT 10-meter black and white band, as well as with each other. Band 2 was replaced with the 10-m band and this combination was used for a color composite. It was one of the better simulated SPOT products for image mapping (fig. 9).

Figure 9.--Color composite of an area in the vicinity of Washington, D.C.,using simulated SPOT 20-m multispectral data with 10-m panchromatic data. Shown here at approximately 1:98,000 scale.

Another method to analyze the information content and distribution of SPOT and TM image data is to generate two-dimensional scattergrams. A computer program takes three bands, two at a time, and projects the three possible scattergrams or clusters of data onto individual planes. With SPOT data, for example, plane one is band 1 versus band 2, plane two is band 1 versus band 3, and plane three is band 2 versus band 3. The three combinations then are projected onto a three-dimensional grid. The clustered data within the scattergrams are normalized and smoothed. The amount of correlation is indicated by the extent of the distribution (wide or narrow) and by the linear relationship between the various bands. The amount of variance in the data can be seen by the distribution of data that lies within the scattergram;

e.g., does it fill a large or small percentage of the plane. Color-coded scattergrams for the simulated SPOT multispectral data for the Washington, D.C., site are shown in figure 10.

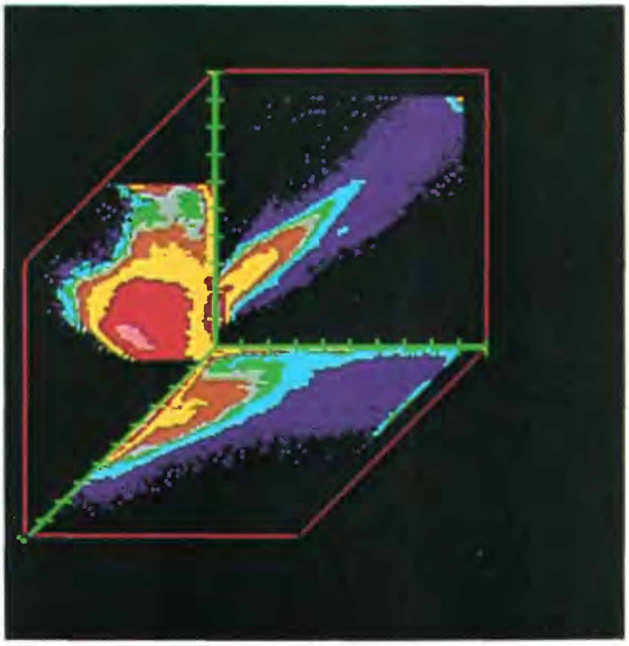


Figure 10.-- Scattergram of band ratios of simulated 20-m multispectral SPOT data of the Washington, D.C., site. Band 1 versus band 2 is on plane 1; band 1 versus band 3 is on plane 2; and band 2 versus band 3 is on plane 3.

It is probable that a useful image map can be generated from the 10-m SPOT panchromatic data, 20-m SPOT, or 30-m Landsat TM multispectral data. Edge enhancement can be applied to the digitally enlarged and smoothed 20- or 30-m data and, if Landsat TM data are used, the resultant product will have the high-frequency information of the 10-m SPOT data and the spectral resolution of the Landsat TM data.

Resampling

A study was conducted to investigate two algorithms for resampling Landsat MSS data. A direct comparison between cubic convolution and the restoration resampling technique developed at the Environmental Research Institute of Michigan was performed for two Landsat MSS scenes-- one acquired over the area surrounding Washington, D.C., and the other acquired over an arid area near Needles, Calif. The scenes were geometrically registered and resampled using both algorithms and were compared on the basis of: (1) difference images that show the magnitudes and loca- tions of differences, (2) line-scan profiles showing edge responses, (3) two-dimensional Fourier analysis showing the difference in frequency content, (4) statistics from identical training sites in corresponding images, and (5) enlargements of sections of images with specific features showing visual differences in texture and detail.

The research results show that restoration resampling produces a sharper image with less edge blurring than is obtained with cubic convolution. Small features are generally better defined spatially on the restored image. In addition, the restored image exhibits more detail in areas that otherwise appear uniform on the cubic convolution image. Other studies investigating the radiometric characteristics of restored and cubic convolution resampling have shown that a higher classification accuracy is obtained with the restoration resampling technique.

A contract for developing a restoration resampling capability has been awarded to the University of Arizona. Under this contract the system parameters required for performing restoration of Landsat MSS and TM imagery as well as SPOT imagery will be obtained. Evaluation of the restoration algorithms will be made through comparison of restored MSS and TM imagery with imagery obtained from high-resolution airborne scanners and by comparison with imagery resampled using the conventional cubic-convolution algorithm.

Destriping

Destriping is an image processing technique used to suppress detector striping caused by non-uniform detector calibration. Research was conducted to compare linear and nonlinear destriping techniques with a statistical modification incorporated into each algorithm. Two traditional and two modified destriping algorithms were separately applied to a subscene of Landsat MSS data. The analysis was conducted after subtracting the four destriped images from their respective bands in the original unprocessed scenes. Scene statistics such as means and standard deviations were tabulated to ascertain which algorithm most closely maintained the original image statistics and the histograms were compared. The comparisons showed the statistically modified linear destriping algorithm produced a scene which had less detector striping and the processed scene retained more closely the original image statistics. It has been recommended that the statistically modified linear destriping algorithm be implemented into image map production.

Contrast Enhancement

Several techniques for performing radiometric enhancements of Landsat data were implemented and tested. These included (1) histogram equalization, (2) local range modification, (3) locally adaptive gain control (3 versions), and (4) a reflectance transformation to normalize the Landsat digital values. Each technique was evaluated in regard to characteristics important for the production of image maps. Evaluation began on the effects of contrast enhancement related to each processing step, such as resampling and noise removal. A technique was developed for quantifying visual characteristics of color imagery based on hue, intensity, and saturation transformation. This technique will be compared with the subjective evaluation of the contrast enhancement techniques to determine the usefulness of quantification for deriving a measure of the quality of a color image.

Digital Processing of High-Contrast Images

A problem that is often encountered because of the large area covered by most satellite imaging systems is the very high contrast range within images, which makes it difficult to display information in both dark and bright regions on a single product. Examples of such scenes are images which have both a desert and a volcanic field; a desert and highly vegetated mountains; a flat urban or agricultural area with vegetated mountains nearby; or an area with large amounts of snow or ice and some vegetation or soils exposed. A high-contrast situation which occurs in an image as a very low (or broad pattern) frequently presents the most problems. Figure 11 shows a full Landsat MSS image of a portion of Tunisia where this situation can easily be seen. The image has a dark vegetated area in the upper left and gradually changes to a bright desert environment in the lower right.

Information in local areas cannot be optimally shown for both the dark and bright areas simultaneously. In order to enhance and display the brightness or color information, the data must either undergo two contrast stretches, the first to enhance the dark regions and the second to enhance the bright ones, or the data can be spatially filtered to enhance the local detail. However, contrast stretching the data twice generates two products, and normal spatial filtering causes a loss of brightness or color information.

An alternative is to sacrifice the quality of the final product by applying a very soft contrast stretch to the data. This is accomplished by using minimum and maximum density values covering a relatively large range to stretch the data without saturation at either the dark or bright end. This results in a very low contrast or flat image because the range is too large, and little, if any, contrast enhancement is achieved. Figure 11 is an example where this has been done to try to show information in both the dark and bright regions in the image. The minimum and maximum values applied to the Landsat MSS bands 4, 5, and 7 before color compositing were selected by subtracting and adding 3.5 times the standard deviations to the median values. In this case, these values were approximately equal to the averages of the three bands. Note that information can be seen in the bright areas in the lower part of the image; but even with this soft stretch the details in the dark areas cannot be seen very well.

A method that can be used to minimize this problem is to apply a spatial filter to the data, but the window size of the filter must be large enough so that only the broad, low frequency pattern is removed. A percentage of the original image must be added to the filtered results (similar to an edge enhancement where 100 percent is added back) to retain the brightness or color relationship between the various cover types. The size of the spatial filter will depend on the resolution of the image and the size of the low frequency pattern that is to be removed. The percent of the original image to be added to the results after spatial filtering will depend on the amount of contrast in the original image and will usually range between 30 to 60 percent. The spatial filter program used by the MIPS software has the option to use pixel window sizes from 3 x 3 to 501 x 501 (or any M x N array in this range with $M =$ or $\neq N$) with anywhere from 0- to 100-percent addback. A small window size (for example, 5 x 5) with 100-percent addback is commonly used for edge enhancement.

Figure 11.--Standard false color composite of Tunisia using MSS bands 4, 5, and 7 with a linear contrast stretch. Shown here at approximately 1:1,000,000 scale.

If the filter window is too small, some frequencies related to color information will also be removed, and relative color between the various cover types will be lost. If the amount of addback is too large, the dynamic range or contrast will be similar to the original image, and the same problem will exist. The size range of spatial filters that have been found effective for Landsat MSS data is approximately from 51 x 51

Figure 12.—Enhanced false-color composite of Tunisia using MSS bands 4, 5, and 7 with a 101 x 101 high pass spatial filter and 40 percent addback followed by a linear contrast stretch. Note the enhanced detail in the dark and bright regions compared to figure 11 while preserving the color relationship. Shown here at approximately 1:1,000,000 scale.

to 201 x 201 pixels with the addback between 30 to 60 percent. Figure 12 shows the results of the 101 x 101 spatial filter with 40 percent addback followed by a linear contrast stretch.

Color Printing

Printing Manual

A manual has been prepared which describes procedures and standards used in the USGS printing plant in the production of image map products. It includes a glossary of printing terms and a description of printing equipment. The manual is limited, however, to pressplate preparation and standard process-color printing on a 60-inch, 5-color Harris offset sheetfet press.

Multiple-Map Projects

Refinements in the printing and prepress processing of image maps are being made as steps in image processing are identified for improvement. Map projects with numerous adjoining sheets are particularly difficult to control. The 13-quadrangle Western Sahara project, for example, was processed as a single unit with scene-to-scene radiometric match. Each quadrangle, however, did not have an optimum contrast stretch for detail. If the range of detail on each quadrangle is optimized, it results in multiple sheets which do not match.

A procedure was developed to photographically color proof the imagery so it will better match lithographic printing. This procedure is significantly better than color prints that have not been photographically adjusted. The Western Sahara project imagery was also photographically proofed at 1:500,000, 1:1,000,000, and 1:2,500,000 scales and compared to the 1:250,000-scale published maps. Using identical reproduction tone curves, the smaller scale maps lack contrast, detail, and are dull in color compared to the larger scale maps. To optimize color and detail, an adjustment will be needed for contrast stretch because the individual quadrangle brightness-value histograms are different from those of the assembled quadrangles. An added complexity is caused by progressively smaller color gamuts (fig. 13) between electronic color displays, photographic print dye colors, and lithographic pigment colors. Artistic skill, as well as visual perceptions and experience in lithographic reproduction of multicolor images, continues to play a key role in image map production.

Photographic Color Proofs

Currently two sets of continuous-tone film positives are made to improve viewing the color and tone relationships between photographic prints and lithographic prints. Figure 14 shows the film-positive tone-curve adjustments made for producing photographic color prints. Photographic color prints made from the S-shaped tone curve in quadrant I will better approximate the final lithographic printing. The photographic color proof exposure is preferably controlled to produce a density range of 0.3 to 1.8 to match the 1.50 density range obtainable in three-color process ink printing. The 0.3 density, however, will give the photographic print a gray cast when compared to white lithographic paper; but photographically, the important imagery is controlled along the straight-line portion of the tone curve with less important imagery in the toe and shoulder parts of the curve. The linear tone curve for film positives made on the laser beam recorder were used in producing the enlarged halftone film separations on a Hell CP-340 graphic arts scanner/plotter.

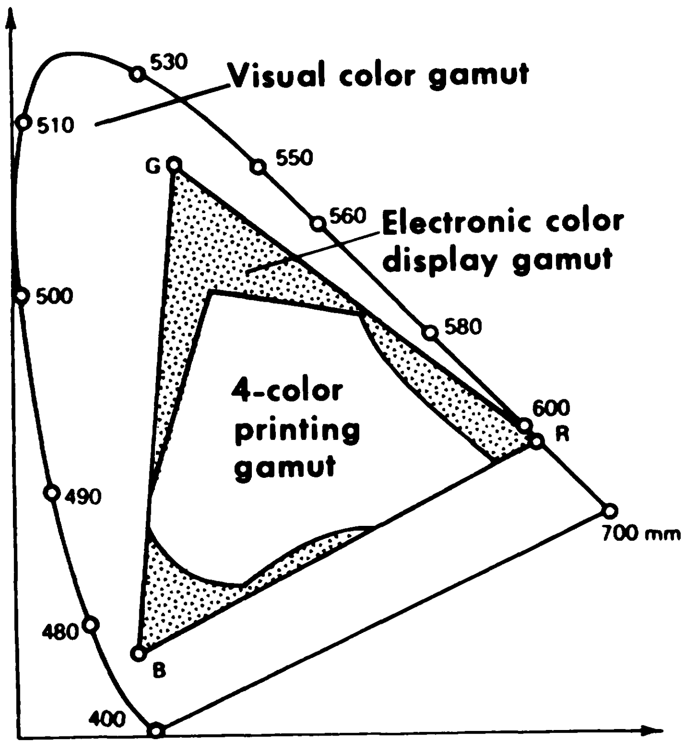


Figure 13.—Comparison of visual, electronic, and four-color printing gamuts.

Enlargement and halftoning by electronic methods using a graphic arts scanner/plotter retains resolution, geometry, and radiometric control to an extent not possible by photomechanical methods. A photographic color proof from electronically adjusted tone curves and graphic arts scanner/plotter film enlargements results in far fewer processing variables.

Tape-To-Film Process

Lithographic color printing using digitally processed magnetic tape for directly producing final-scale halftone film separations may soon be possible. The procedure uses a standard Landsat image format recorded on 9-track 1,600 bits-per-inch magnetic tape in band-sequential separate files with no headers. The number of pixels representing the width of the imagery must be limited to a maximum of 4,999 pixels due to limitations of the Scitex laser plotter. Any number of files can be joined by Scitex software to accommodate wider pixel maps. The maximum size limit for the Scitex laser plotter is the 40- x 72-inch drum dimension. A MacDonald Dettwiler and Associates Color Fire 240 first was used to proof the Western Sahara tapes by recording directly on 9- x 9-inch color film without using the LBR film separations. Then, prepress DuPont Cromalin halftone color proofs were produced at 1:500,000, 1:1,000,000, and 1:2,500,000 scales using a Scitex Response 300 system at the National Geographic Society to make the film separations directly from the magnetic tape data. This newly developed procedure eliminates the intermediate film steps with the LBR film recording on 9-inch film followed by the Hell CP-340 scanner/plotter procedure for enlargement and halftoning. The NMD expects to

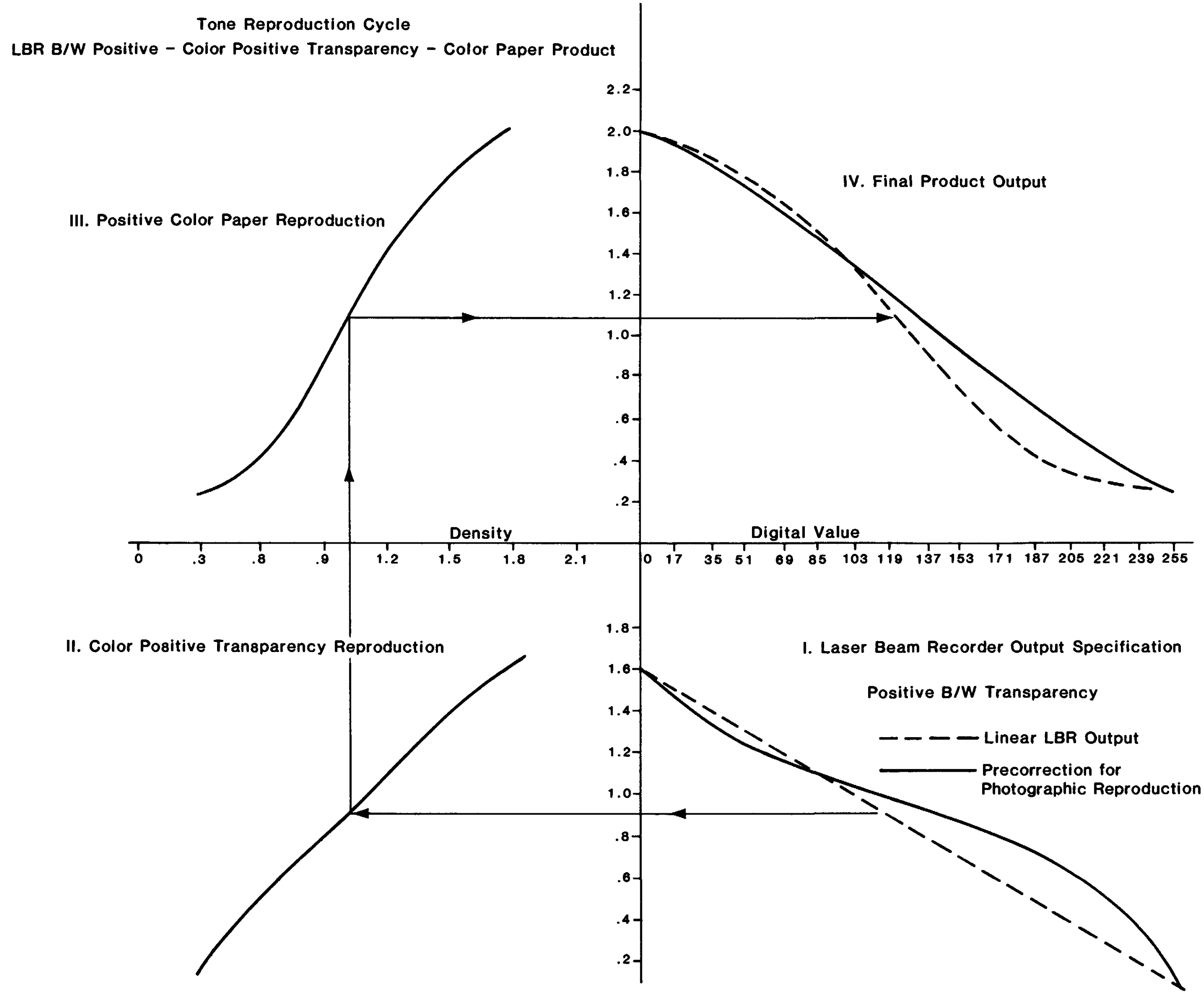


Figure 14.—Transformation of Landsat brightness digital values to final photographic color proof that approximates a lithographic product.

upgrade its Scitex 280 laser plotter to a 300 system in early 1985. The demonstration, however, indicates that substantial developmental work will be required to develop a production procedure.

Screenless Printing

Screenless printing experimentation has been curtailed due to the unavailability of uniformly coated pressplates sensitive to a density range of 1.00 ± 0.10. Experience gained in screenless lithographic printing and color proofing of photographic continuous-tone imagery will be applied to the use of a newly developed microlenticular screen. The resolution of this new screen is estimated to be equivalent to 600 lines per inch (24 line pairs per mm). It is similar to screenless lithography but is anticipated to be easier to control in printing, as conventional presensitized pressplates may be used. A 50- x 50-inch microlenticular screen has been purchased for delivery in early 1985.

REMOTE SENSING TECHNIQUES AND DATA ANALYSIS

Automated Identification of Road Networks

When digital cartographic data are derived from existing maps or aerial photographs, manual photointerpretation is first required to describe features of interest. A new approach is being investigated using digital image analysis to automate both the recognition and digitization of roads on aerial photographs. Aerial photographs are scanned, digitized, and color separated to create three bands of raster data. Automatic digital processing techniques, developed for the analysis of Landsat multispectral data, were employed to identify land cover classes from the scanned data. Using interactive computer graphics programs, spectral clusters were assigned to land cover classes and later grouped into map feature classes, including a road class. In an early test, a color infrared photograph of a test site in Cupertino, California was color-scanned to form a 3-band multispectral digital data set. Use of 1:25,000-scale photographs, scanned at 50 microns, resulted in a pixel size corresponding to 1.25 meters on the ground. Software was developed to write feature class images to magnetic tape in the specific format required by the Scitex 250 editing station.

Analysis programs were run to produce a refined representation of the roads in the test site. They were smoothed to straighten road edges. Wide linear raster features were skeletonized to a narrow line of a single pixel width. The reduced image was converted to a vector representation, then converted back to raster, a process that eliminated kinks and smoothed the linear representation. Further refinement of the technique is needed to remove short vectors appearing in the middle of blocks.

Advanced Very-High-Resolution Radiometer Data Analysis

Since 1982, the utility of advanced very-high-resolution radiometer (AVHRR) data has been investigated for a variety of resource management and planning activities. Preliminary studies have shown that multi-date analyses are useful for monitoring senescence and seasonal changes of herbaceous vegetation over large areas. These data have also been used to monitor and map fire fuels in support of the national fire management program. As a result of this activity, the BLM is presently using AVHRR data to map fire fuels for 180 million acres of wildland vegetation in the western United States. Ongoing investigations with the BIA show that AVHRR data of southwestern U.S. rangelands can be grouped into categories that are related to herbage production. In each of these research activities, the AVHRR data were successfully merged with digitized map data.

When multiple AVHRR images were used in a time-series analysis, the best results were obtained when one image was registered to a map base using cubic convolution resampling, and all other images were registered to the base image. A second-degree polynomial equation was suitable for modeling the fit between scenes and minimizing overall registration errors to less than one pixel. Only scenes positioned near the nadir or in the same direction off the nadir have been tested. The registration of two scenes on opposite sides of the nadir has not been tested.

AVHRR false-color composites are generally created by photographically recording channel 1 data in blue and green and channel 2 data in red. This approach produces a useable composite, but obviously does not contain as much spectral information as a typical Landsat composite because of the redundant use of channel 1. Research results show that hue-intensity-saturation color-space transformations using scene-independent input parameters can be successfully used to develop an enhanced AVHRR color composite image (fig. 15) and provide three channels of non-redundant information that can be independently manipulated to spectrally discriminate and enhance cover-type relationships.

At the present time, AVHRR data are not readily available in support of operational resource management and planning activities. A study has been initiated to determine the functional requirements of a system to routinely acquire AVHRR data so that agencies can have access to it within 24 hours of acquisition.

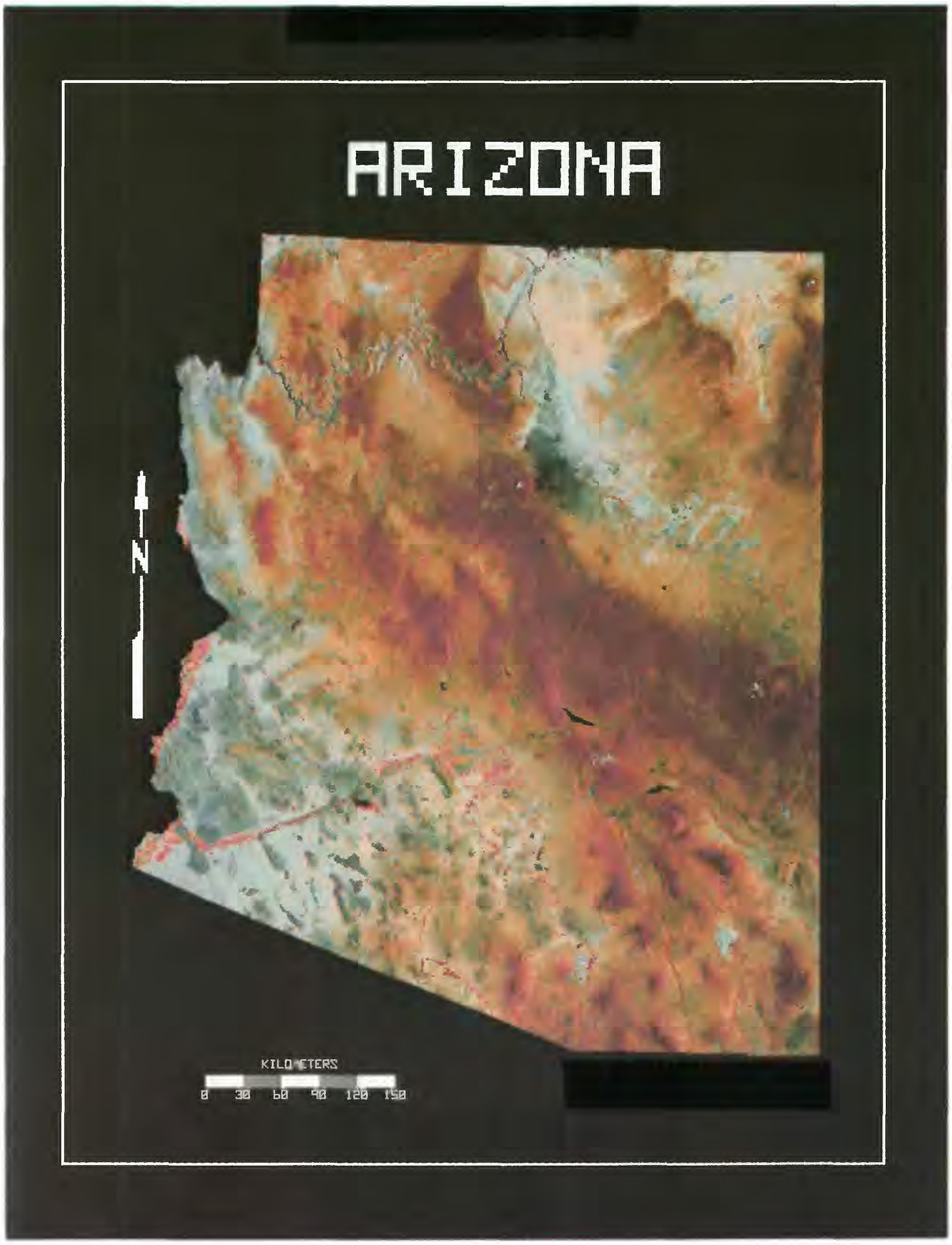


Figure 15.--Enhanced AVHRR image of Arizona using hue-intensity-saturation transformations. Shown here at approximately 1:5,833,000-scale.

Thematic Mapper Evaluation

Research is being conducted to analyze and define pertinent Landsat TM characteristics as they apply to image mapping and resource analyses. The three primary characteristics examined are (1) spatial resolution, (2) geometric fidelity, and (3) radiometric response. Applications testing provided a comparative evaluation of TM to MSS data from the same Landsat satellites.

Since the TM produces 30-m picture elements (pixels), the spatial resolution of any resultant product is limited by this factor. However, the digital, photographic, and lithographic processing involved also have a profound influence on the resolution of the final printed map product. Experience to date indicates that when processing is properly controlled, the printed map should be of a scale which produces at least 3.3 original pixels per millimeter. For the TM this scale is 1:100,000.

A multiple-point linear stretch is often applied to improve contrast, and edge enhancement is applied as necessary. A further technique involving a spatial filter, the digital equivalent of Log-E-Tronic printing, is also being tested. TM data can be categorized in four distinct geometric forms as follows:

(1) Raw data as received from the satellite. No attempts have been made to analyze or utilize this type of data.

(2) Data processed by NASA without ground control. The geometry of such data depends on the capability to reconstruct the geometry of the acquisition system, to correct the data for geometric anomalies, and to cast the data on a defined map projection. Analyses made of such data indicate high internal geometric fidelity with errors (rms) of less than the 30-m pixel.

(3) Data processed by NASA with ground control. This is the standard Thematic Mapper Image Processing System (TIPS) product for areas such as the United States when ground control is available. While one report indicates that such data is meeting the Landsat 4 and 5 specification for geometric fidelity of 0.5 pixel (15 meters), accuracy of only 1 to 2 pixels (30-60 m) has been achieved to date in published cartographic products.

(4) TIPS data resampled a second time. USGS maps are cast on map projections which differ from the Space Oblique Mercator customarily used by NASA. The TIPS data can be converted to any other defined projection by simply applying a computer transformation to the data. However, the procedure utilized is to select new control points since, until recently, the geometric fidelity of the TIPS data had not been fully verified. Tests made to date have not indicated any appreciable increase in geometric fidelity by this second resampling.

Of the seven TM wave bands, all but band 6 (thermal) are considered suitable for general-purpose image mapping. Band 6 records the highly transitory phenomenon of thermal response and its application is rather specialized. The way each of the other six bands (3 in the visible and 3 in the near infrared) is processed and enhanced has a profound influence on the final image map. Image maps made to date have merely scratched the surface insofar as displaying the possible variations in the Earth scene that can be derived from the six distinct wavebands.

More natural resources information generally could be derived from TM data than from MSS data. The separability of mean data values for several land cover classes of the East Coast region was greater for TM spectral bands 2, 3, and 4 than for the nearly equivalent MSS bands 1, 2, and 4. The within-class variations were usually lower for the TM bands than for the corresponding MSS bands, and improved multispectral discrimination of land cover classes was obtained. The mid-infrared spectral bands (TM bands 5 or 7) were helpful because of the large spectral variation between several land cover classes, and the low correlations with other spectral bands for vegetated and standing water surfaces. The mid-infrared bands provided significant spectral information as they dominanted the third principal component from a six-band input. Low correlations between the blue band (TM band 1) and other TM bands suggest band 1 applications involving water and vegetated land cover.

The addition of bands 5 and 7 on the TM system resulted in improved geologic mapping. This was demonstrated in analyses of sedimentary basins in the Rocky Mountain region and for alteration studies in heterogeneous geologic areas of the Basin and Range region in the Southwest. The new spectral dimensions contribute to the detection of iron- and hydroxl-bearing minerals and to the identification of hydrothermally altered rocks. The overall increase in spatial and spectral resolution of TM data yielded more detailed structural and lithologic interpretations when compared to similar analyses of MSS data.

Improved spatial resolution of TM data acquired over the upper Midwest region aided in locating roads, small stock ponds, and many other land and topographic features of interest. The improved spatial resolution of TM data, compared to MSS data, permitted more efficient visual interpretations of land use and resource types, and improved assessment of the ecological status of natural vegetation. The added spatial and spectral information were useful for both manual interpretation and digital data classification of water and vegetation resources.

Visual interpretation tests were conducted on TM data acquired over Washington, D.C., and the surrounding area. These tests agreed with the Great Plains, South Dakota, and Kansas results in that interpreters had a preference for a black-and-white image of band 5 or 7 over a black-and-white image of other bands for making distinctions in 8 out of 11 resource categories that were addressed. Results of interpreting color composite images acquired over a variety of landscapes showed highest interpreter preferences for a standard color-infrared composite image (bands 2, 3, and 4) or a color composite image consisting of bands 3, 4, and 5. A natural-color composite image (bands 1, 2, and 3) showed high interpreter preferences for resource categories involving distinctions within water areas or in predominantly nonvegetated areas.

Statistical Methods to Analyze Remote Sensing Data

The TM imaging system onboard Landsats 4 and 5 provides much more comprehensive data than the Landsat MSS system. It is a major challenge to efficiently process and analyze the larger volume of data resulting from the increased spatial and spectral resolution.

One primary product generated from the TM data is a color composite using three of the six bands (excluding the thermal band). Because a total of 20 combinations can be made from the six TM bands, taken three at a time (ignoring the permutations of bands and display colors), deciding which combination contains the most information on the basis of visual analysis can be difficult and time consuming. A technique called the optimum index factor (OIF), developed earlier for Landsat MSS ratios, has been used to rank the 20 possible combinations in various test sites. The OIF technique ranks all possible combinations based on the amount of correlation and the total variance present between the various data sets being used; for example, six TM bands. The algorithm used to compute the OIF value for any subset of three bands is:

$$OIF = \sum_{i=1}^{3} SDi \,/ \sum_{j=1}^{3} |CCj|$$

where, SDi = standard deviaton for band i
|CCj| = absolute value of the correlation coefficient between any two of the three bands being used.

The combination having the largest OIF value should have the most information (as measured by variance) with the least amount of duplication. Often the combinations that are within two to three ranking positions of each other appear similar, and distinct feature differences cannot be detected. This is because there is little difference between closely ranked combinations as far as total information content is concerned. Table 6 shows the correlation matrix and the OIF rankings for four sites using the TM data.

The Death Valley data has an arid environment; the Washington, D.C., area is an agricultural and urban setting; the San Francisco site includes agricultural, highly urban, and water settings; and finally, the Dyersburg, Tennessee, site is mostly an agricultural setting. From the analysis of the data and the OIF rankings it was found that; in general, the three-band combinations that included one of the visible bands (TM 1, 2, or 3) and one of the longer wavelength infrared bands (TM 5 or 7) combined with TM band 4 were usually ranked high by the OIF technique. It indicates these bands have the most information with the least amount of duplication. This is because of the high correlation that exists between TM bands 1, 2, and 3 and between TM bands 5 and 7.

Visual analyses of several TM band combinations in the Death Valley image have produced some interesting results. There are some surficial anomalies that are readily apparent in this area on TM band combinations 1, 5, 7 (fig. 16), and 1, 4, 5, combinations ranked 1 and 3 by the OIF techniques. On TM band combinations 1, 2, 3, (fig. 17) and 2, 3, 4 (natural-color bands and MSS-equivalent bands respectively), there are no signs of the same anomalies. Several of these anomalies were field checked and verified to be of different composition than the surrounding rock.

Additionally, in an attempt to maximize the amount of information contained in a final three-band combination and to minimize the information lost due to not using the other three bands, selective principal component analysis can be used. Selective principal-component analysis involves using only highly correlated subsets or pairs of

Table 6.--Correlation matrix and OIF ranking of TM data for Death Valley, Calif.; Washington, D.C.; San Francisco, Calif.; and Dyersburg, Tenn.

Death Valley Area Correlation Matrix

	TM Band						
	1	2	3	4	5	*6	7
1	1.000	-	--	--	--	--	--
2	.975	1.000	-	--	--	--	--
3	.947	.983	1.000	--	--	--	--
4	.888	.942	.972	1.000	-	--	--
5	.579	.693	.765	.806	1.000	--	--
*6	.184	.249	.297	.277	.494	1.000	--
7	.503	.623	.704	.742	.965	.531	1.000

OIF Ranking

RANK	**COMBINATION	OIF
1	(1,5,7)	27.75
2	(1,3,5)	24.94
3	(1,4,5)	24.74
4	(1,2,5)	23.64
5	(1,3,7)	22.00
6	(1,4,7)	21.80
7	(3,5,7)	21.77
8	(2,5,7)	21.47
9	(4,5,7)	20.73
10	(1,2,7)	20.64
11	(3,4,5)	20.62
12	(2,3,5)	20.20
13	(2,4,5)	19.83
14	(3,4,7)	17.65
15	(2,3,7)	17.13
16	(2,4,7)	16.76
17	(1,3,4)	16.68
18	(1,2,4)	15.26
19 (NC)	(1,2,3)	15.05
20 (MSS)	(2,3,4)	13.46

Dyersburg Area Correlation Matrix

	TM Band						
	1	2	3	4	5	*6	7
1	1.00	--	--	--	--	--	--
2	.93	1.00	--	--	--	--	--
3	.94	.94	1.00	--	-	--	--
4	-.36	-.33	-.47	1.00	-	--	--
5	.42	.48	.43	.29	1.00	--	--
*6	.40	.42	.42	-.16	.50	1.00	-
7	.69	.72	.73	-.10	.89	.57	1.00

OIF Ranking

RANK	**COMBINATION	OIF
1	(1,4,5)	26.82
2	(2,4,5)	25.07
3	(4,5,7)	24.92
4	(3,4,5)	24.90
5	(1,4,7)	21.40
6	(2,4,7)	20.29
7	(3,4,7)	19.58
8	(2,5,7)	16.09
9	(1,3,4)	12.71
10	(1,2,4)	12.55
11 (MSS)	(2,3,4)	12.26
12	(3,5,7)	11.17
13	(1,5,7)	11.03
14	(2,3,5)	10.17
15	(1,2,5)	9.78
16	(1,3,5)	8.96
17	(1,3,7)	6.61
18	(2,3,7)	6.05
19	(1,2,7)	5.79
20 (NC)	(1,2,3)	4.10

*TM6 = THERMAL BAND NOT USED
**SIX BANDS COMBINED THREE AT A TIME GIVES 20 COMBINATIONS

Table 6.--Correlation matrix and OIF ranking of TM data for Death Valley, Calif.; Washington, D.C.; San Francisco, Calif.; and Dyersburg, Tenn.--continued

Washington, D.C. Area Correlation Matrix

	TM Band						
	1	2	3	4	5	*6	7
1	1.000	--	--	--	--	--	--
2	.91	1.00	--	--	--	--	--
3	.83	.89	1.000	--	--	--	--
4	.27	.42	.34	1.000	--	--	--
5	.45	.56	.62	.67	1.000	--	--
*6	.24	.26	.32	.44	.55	1.000	-
7	.65	.72	.78	.46	.90	.49	1.000

San Francisco Area Correlation Matrix

	TM Band						
	1	2	3	4	5	*6	7
1	1.000	--	--	--	--	--	--
2	.960	1.000	--	--	--	--	--
3	.933	.972	1.000	--	--	--	--
4	.348	.469	.548	1.000	--	--	--
5	.431	.542	.638	.856	1.000	--	--
*6	-.296	-.351	-.399	-.435	-.316	1.000	--
7	.561	.636	.718	-.739	.829	-.344	1.000

OIF Ranking (Washington, D.C.)

RANK	**COMBINATION	OIF
1	(1,4,5)	23.46
2	(3,4,5)	19.64
3	(2,4,5)	18.61
4	(1,4,7)	17.70
5	(4,5,7)	17.00
6	(1,3,4)	15.24
7	(3,4,7)	15.12
8	(1,5,7)	14.61
9	(1,3,5)	14.08
10	(2,4,7)	14.04
11	(1,2,5)	13.18
12	(1,2,4)	12.82
13	(2,5,7)	12.52
14	(3,5,7)	12.51
15 (MSS)	(2,3,4)	12.20
16	(2,3,5)	12.06
17	(1,3,7)	8.26
18	(1,2,7)	7.52
19	(2,3,7)	7.03
20 (NC)	(1,2,3)	5.63

OIF Ranking (San Francisco)

RANK	**COMBINATION	OIF
1	(1,4,5)	28.14
2	(1,5,7)	23.93
3	(2,4,5)	21.69
4	(1,4,7)	21.28
5	(3,4,5)	20.81
6	(1,3,5)	20.46
7	(1,2,5)	20.17
8	(2,5,7)	18.96
9	(4,5,7)	18.60
10	(3,5,7)	18.33
11	(1,3,4)	17.75
12	(1,2,4)	17.15
13	(2,3,5)	16.48
14	(2,4,7)	16.03
15	(3,4,7)	15.74
16	(1,3,7)	13.58
17 (MSS)	(2,3,4)	13.55
18	(1,2,7)	13.00
19	(2,3,7)	10.54
20 (NC)	(1,2,3)	8.88

*TM6 = THERMAL BAND NOT USED
**SIX BANDS COMBINED THREE AT A TIME GIVES 20 COMBINATIONS

bands as input to principal-component analysis and not using all the bands simultaneously. Because the bands selected for principal-component analysis are so highly correlated, most of the information is mapped into the first component. With the TM data processed so far, the subsets or pairs of bands used as input to selective principal-component analysis have been TM bands 1, 2, and 3 as one group and TM 5 and 7 as the second group. The first component of each of the two results is then combined with TM 4 to make a new data set that can be used as input for further processing; for example, contrast and edge enhancement for color compositing or input to digital classification.

In areas where this has been done, between 96 to 98 percent of the information (variance) contained in the six bands was mapped to the new three-band combination. Silver Bell, Ariz. was one of the sites processed by selective principal-component analysis and the results are shown in table 7. The user does have to be careful to check the components not used to make sure that information of interest has not been isolated or mapped to one of the lower components. This did occur in the Silver Bell data where most of the information about an alteration zone of geologic interest was mapped to component number two of TM 5 and 7.

Table 7.--TM band correlation matrix and results of selective principal-component analysis of the Silver Bell area, Arizona (TM6, thermal band, not used)

	TM Bands					
	1	2	3	4	5	7
1	1.00	---	---	---	---	---
2	.96	1.00	---	---	---	---
3	.94	.97	1.00	---	---	---
4	.83	.88	.92	1.00	---	---
5	.75	.81	.85	.87	1.00	---
7	.76	.81	.84	.87	.95	1.00

SELECTED SUBSET OF BANDS FOR "SELECTIVE" PRINCIPAL COMPONENT ANALYSIS BASED ON HIGH CORRELATION

I.	TM1	PC13	---------------- 96.8% OF VARIANCE
	TM2	PC23	---------------- 2.6% OF VARIANCE
	TM3	PC33	---------------- 0.6% OF VARIANCE
II.	TM5	PC12	---------------- 98.4% OF VARIANCE
	TM7	PC22	---------------- 1.6% OF VARIANCE

III. USE PC13, PC12, AND TM4 AS THREE-COMPONENT DATA BASE FOR ANALYSES, CLASSIFICATION, OR COLOR COMPOSITING. CONTAINS A MINIMUM OF 98.3% OF SIX-BAND VARIANCE.

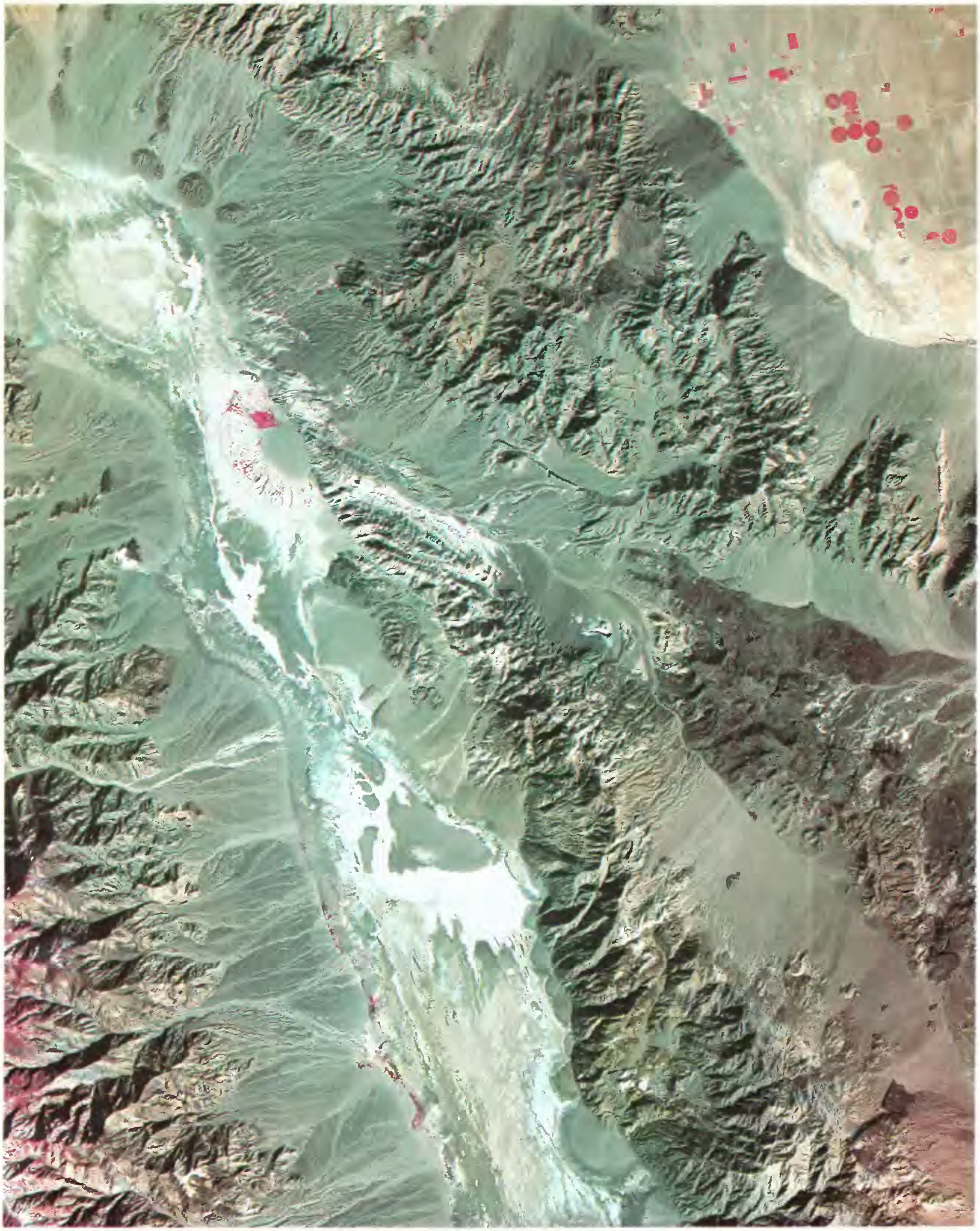


Figure 16.--Color composite of TM bands 2, 3, and 4 of Death Valley, Calif., area. These are similar spectral bands to MSS bands 4, 5, and 6 or to SPOT bands. Shown here at approximately 1:250,000 scale.

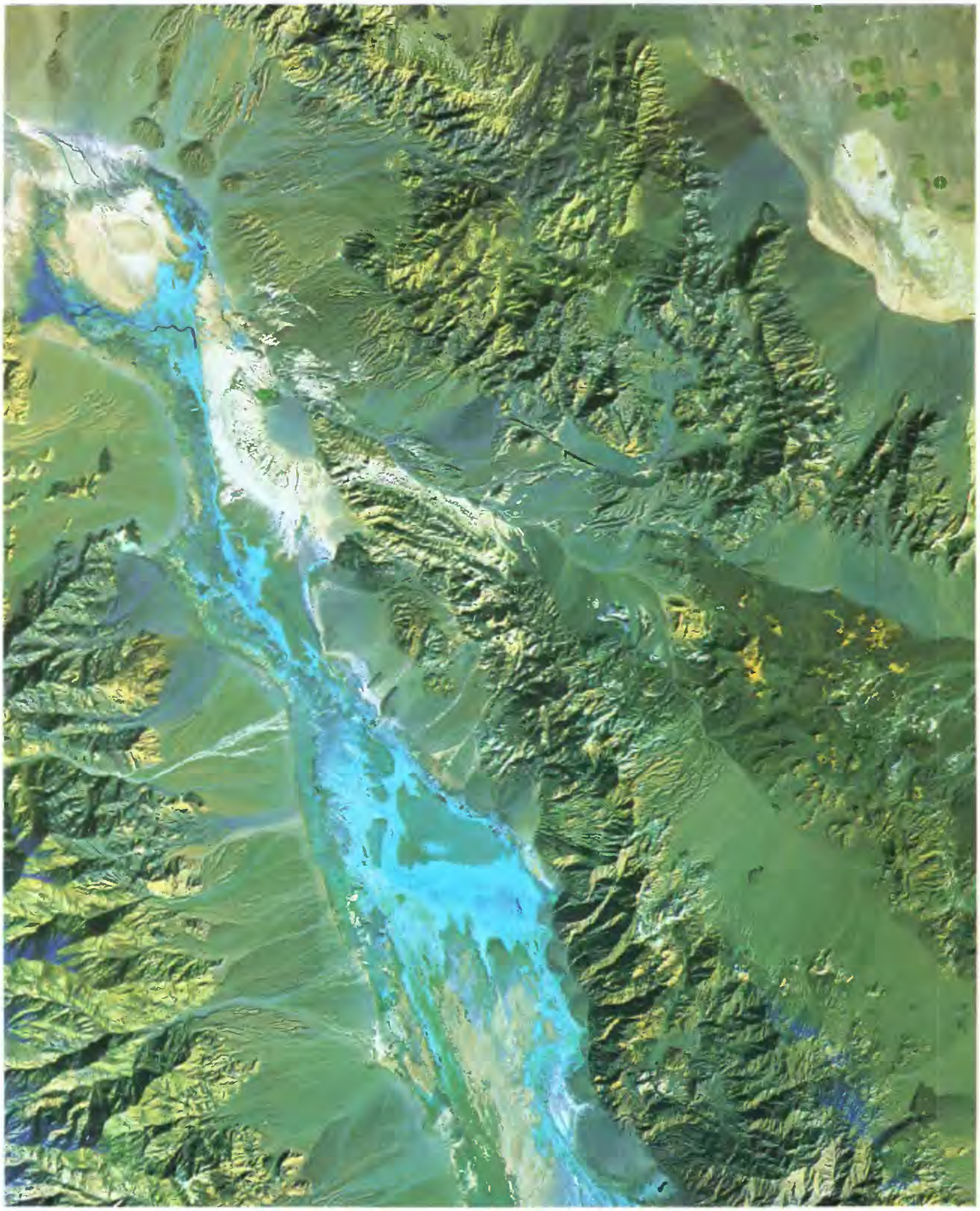


Figure 17.—Color composite of bands TM 1, 5, and 7 of the Death Valley, Calif., area. This combination was ranked as number 1 by the OIF technique. Alternation anomalies show up in bright yellow in the dark volcanic field to the right of center. The various shades of blues in the floor of Death Valley and on the mountains indicate possible soil moisture information. Shown here at approximately 1:250,000 scale.

Evaluation of Simulated SPOT Data

Simulated SPOT data were collected over the Split Mountain region of Utah and were digitally enhanced and studied to evaluate their contribution as a tool for geologic mapping. Enhanced SPOT images and the corresponding geologic interpretations were evaluated against simulated TM images similarly acquired over the same area and enhanced and interpreted. Previous studies have documented the improvements in sedimentary rock discrimination attained from the analysis and interpretation of TM data as compared with Landsat MSS data. This study was an extension of previous work with the objective to investigate and document any improvements in sedimentary rock discrimination.

Simulated TM, and SPOT data were registered to a UTM grid, using nearest neighbor resampling and various image enhancement techniques were applied with the objective of producing images which best discriminate the lithologic units in the study area (figs. 18-21). The color composites which displayed the greatest overall spectral variation were those produced by band ratioing and principal components analysis. A linear contrast stretch was applied to each of the black and white single bands prior to merging the images into color composites. Geologic interpretations were made from each of the composite images printed at similar scales. The effect of improved spatial resolution of the SPOT data was evident by the amount of detail in the resultant interpretation descriptions. The spatial detail of drainages, land forms, and other features augments the investigator's ability to interpret structural and lithologic information that relates to variations in topographic expression. The variation in tone and color on these images correlates very closely with the different rock units shown on the geologic map. Although the emphasis in these studies was to evaluate the capabilities of SPOT data for mapping sedimentary rock types, improved structural mapping could be inferred from the imagery as well.

Results of this study indicate the superiority of simulated SPOT data in discriminating rock-stratigraphic units exposed in the Split Mountain area, yet caution must be exercised in predicting the improvements in geologic mapping from operational SPOT data. In areas where hydrothermal alteration or marine limestones are present, for example, it is likely that TM data would provide better spectral separation of rock types.

Landsat Principal Component Analysis for Mapping Mineral Alterations in Alaska

Landsat MSS imagery was used to aid in locating surface alteration in the Port Moller, Stepovak Bay, and Simeonof Island 1:250,000-scale quadrangles as part of the Alaska Mineral Resource Assessment Program (AMRAP). The altered areas identified on the imagery could then be field-checked or related to stream-sediment or hand-sample geochemical data.

Landsat imagery can be used to delineate areas of surface alteration by their unique spectral characteristics. Barren areas, consisting primarily of rock and soil, were first separated from areas of vegetation, snow, and water. Contrast stretches, band ratios, classification based on spectral brightness, principal component transformations, and color transformations were applied to the rock and soil class data. The best technique for detecting known altered areas was obtained with a principal

Figure 18.- -Simulated SPOT false-color composite image with band 1 (blue), band 2 (green) and, band 3 (red) of Split Mountain region, Utah. Shown here at approximately 1:67,000 scale.

Figure 19.--Simulated TM false-color composite image with band 2 (blue), band 3 (green), band 4 (red) of Split Mountain region, Utah. Shown here at approximately 1:67,000 scale.

Figure 20.--Simulated SPOT color composite image with principal components 1 (blue), 2 (green), and 3 (red) of Split Mountain region, Utah. Shown here at approximately 1:67,000 scale.

Figure 21.—Simulated TM color composite image with principal components 1 (blue), 2 (green) and 3 (red) of Split Mountain region, Utah. TM bands 2, 3, and 4 were transformed so as to facilitate a direct comparison with simulated SPOT results. Shown here at approximately 1:67,000 scale.

component transformation where the first principal component contained the largest possible variance of the data. Each succeeding principal component accounted for the largest possible remaining variance, while remaining orthogonal to all previous principal components.

Areas of known alteration were delineated and when threshold values were exceeded in both the third and fourth principal components, other areas of potential surface alteration with spectral characteristics similar to the known altered areas were clarified. All areas of known and potential surface alteration were located on an image, enhanced to show geomorphic variations, and used for field checking.

Most digitally classified areas corresponded well with areas of surface alteration. All areas of previously known surface alteration were visible on the image except where an area was in shadow. In addition, previously unknown areas of alteration were indicated. Field-checking suggested that an important characteristic of the targeted areas was the presence of iron staining, which is associated with the most common form of surface alteration on the Alaska Peninsula.

Limitations of the procedure are (1) surface alteration must be exposed, though some vegetation cover will not significantly affect the detection of an area; (2) shadowed areas tend to be masked and, therefore, not detected; (3) the surface alteration must cover at least 1 acre to be detected, although intensely altered smaller areas may be detected; and (4) not all areas of surface alteration are mineralized and not all mineralized areas display evidence of iron staining. However, Landsat-derived images are a significant aid in the resource assessment and early stages of evaluation of an area, allowing rapid detection of areas for detailed field examination and geochemical sampling.

Radar Studies of Forested Wetlands

Distinguishing forested wetland from dry forest using aerial photographs has been handicapped because photographs often do not reveal the presence of water below the tree canopies. Images obtained during the summer months of 1978 by the Seasat satellite's L-band (23-cm) radar reveal forested wetland as patterns of high radar reflection in the Atlantic coastal plain between Maryland and Florida (fig. 22).

Potential exists for Seasat radar images to complement aerial photographs in the compiling of maps of wetland. A test was conducted with four experienced photo-interpreters which revealed that interpretation accuracy was significantly higher when the Seasat radar images were used than when only conventional sources were utilized. USGS land use and land cover maps, which show forested wetland, were used as a reference base.

Systematic Detector Offset for Solid-State Multispectral Imaging Systems

During 1984 a new concept in sensor design for recording and processing of multispectral data was formulated. It was submitted to the Department of the Interior in January 1985 in a report of invention.

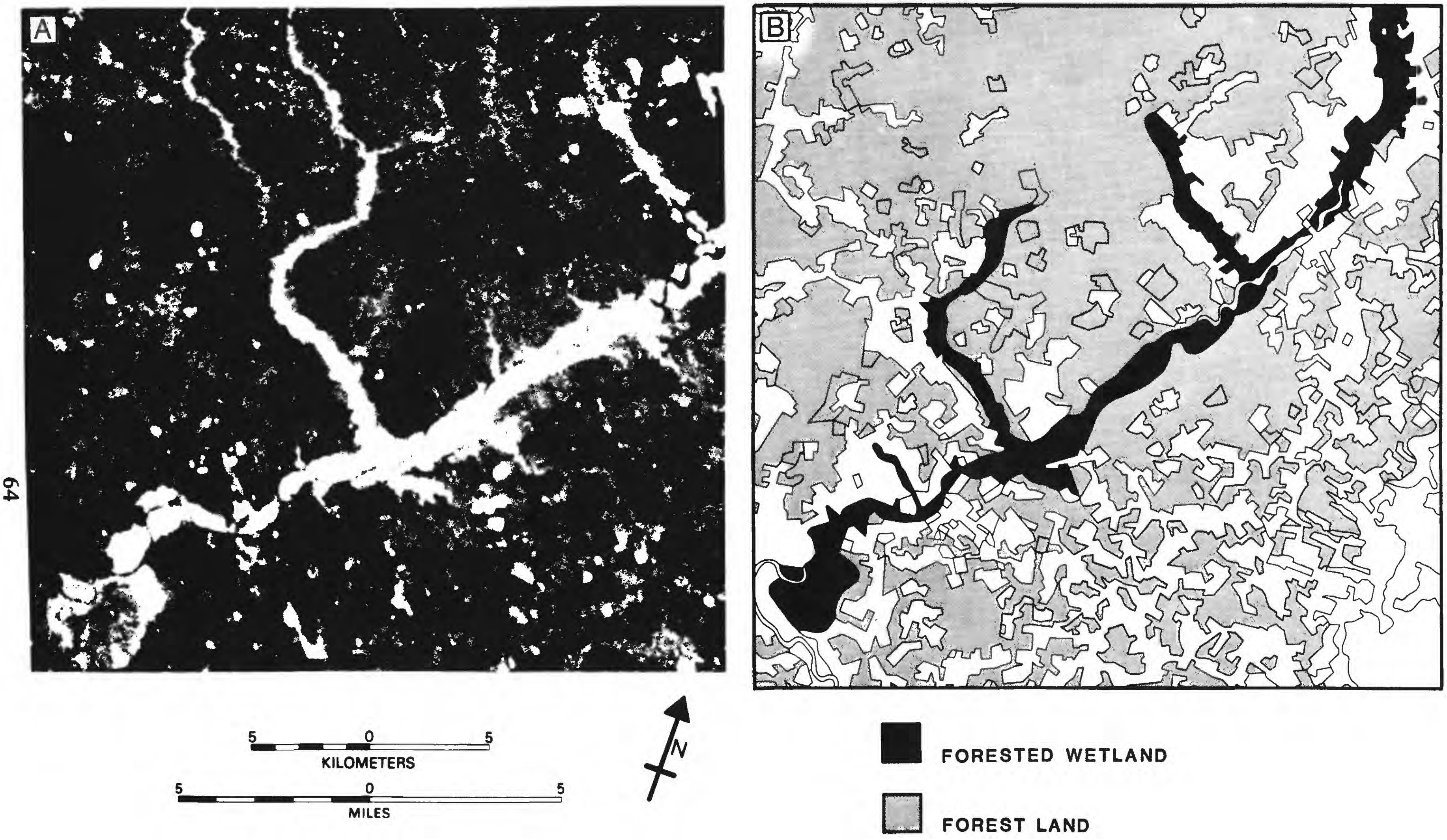
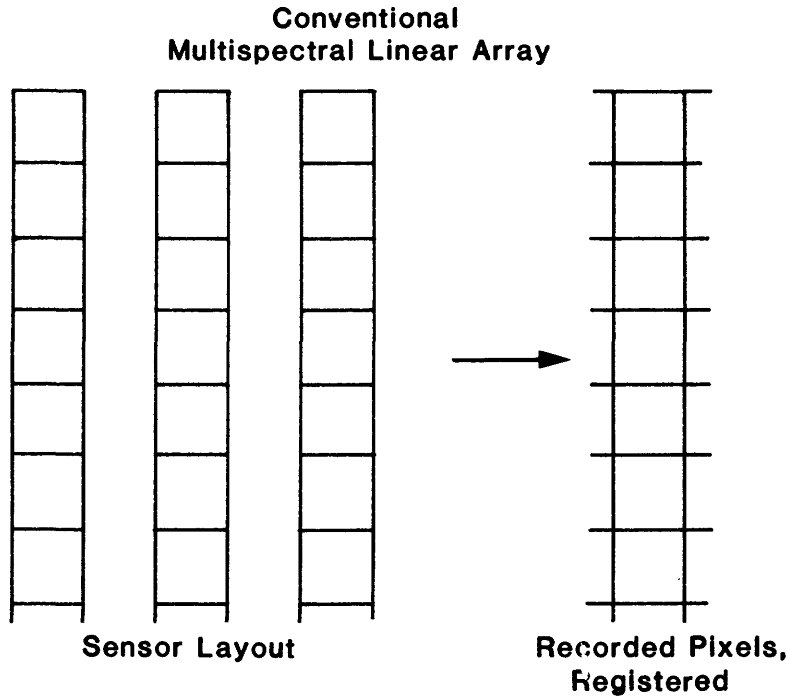


Figure 22.--Comparison of Seasat synthetic-aperture radar image (A) with a land cover map (B) of the same area of the Pocomoke River, east of Chesapeake Bay in Maryland. There is a similarity of pattern between the radar return (white) and the forested wetland (black).

The concept (see fig. 23 and 24) is best expressed through the use of solid-state linear arrays in a space-borne sensor, but it has equal application to two-dimensional arrays in any camera which records discrete picture elements (pixels). In an example where three spectral bands are involved, the concept provides nine different elements of information as opposed to one when conventional registered pixels are involved. This does not mean there is nine times as much information, but it does mean that with appropriate computer algorithms applied, the resolution, micro-geometry, and radiometry of a scene can be substantially improved. Moreover, it does so with the same amount of original data.

During the latter part of 1984, computer testing of the concept, in simulated form, was initiated. Tests to date indicate that the concept does indeed improve image quality, but quantitative results have as yet not been documented. A patent application was submitted by the Department of the Interior on April 2, 1985.



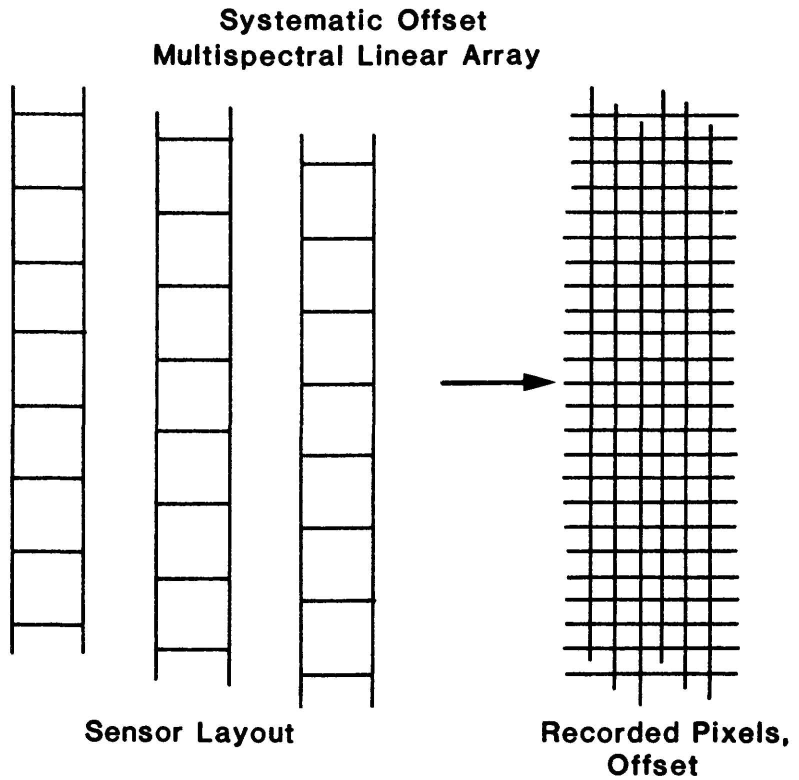
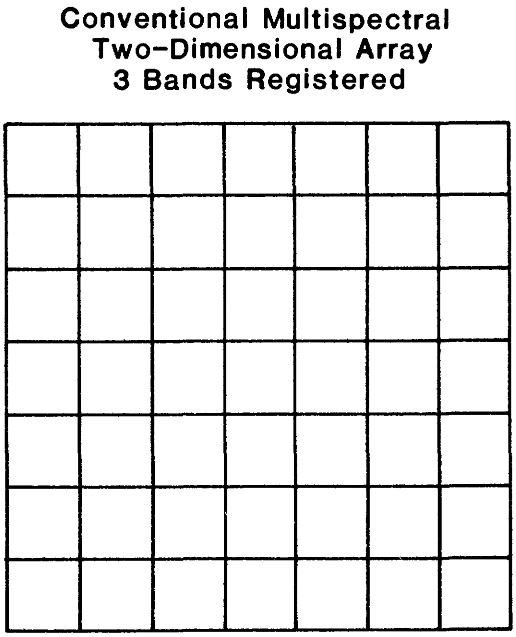


Figure 23.—Comparison of conventional registration and systematic offset of the pixels for multispectral solid-state linear array imagers.



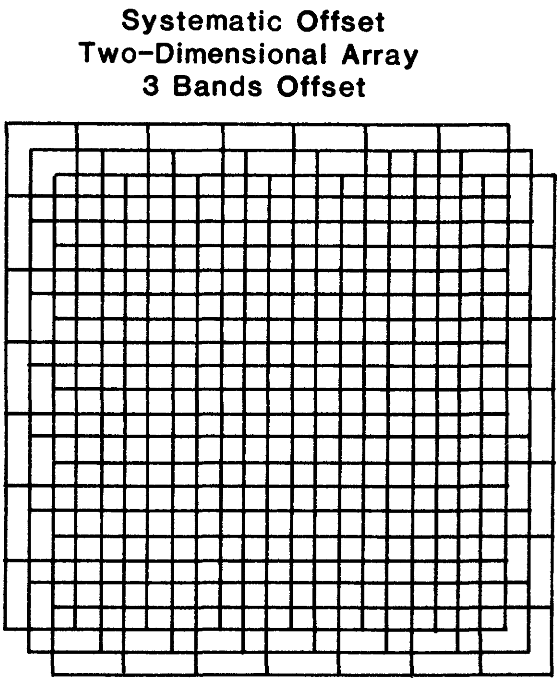


Figure 24.--Comparison of conventional registration and systematic offset of the pixels for multispectral solid-state, two-dimensional arrays.

LAND USE AND LAND COVER MAPPING

Alaska Interim Mapping Program

While most of the 48 contiguous States have been scheduled for conventional land use and land cover mapping, only one quadrangle in Alaska has been mapped and no additional quadrangles have been proposed. Because there was limited availability of high-altitude photographs of Alaska prior to 1978 combined with limitations of the existing classification system for describing Alaska's predominantly wildland environment, the program has concentrated on the conterminous 48 States.

Meanwhile, NMD has been assisting the State of Alaska and other Federal agencies in the State to produce digitally processed land cover classifications from Landsat MSS data for specific regional areas of interest. The enactment of the Alaska National Interest Lands Conservation Act (ANILCA) in December 1980 required that each land management agency in Alaska provide comprehensive resource management plans. Each agency adopted its own approach, and although mapping requirements varied from one agency to another, all agencies based their land cover classifications on the "Revision of the Preliminary Classification System for Vegetation of Alaska." [1]

Recognizing the need for an immediate statewide program of land cover mapping using a single classification system, USGS proposed an interim program to pull individual agency efforts together based on the 1:250,000-scale quadrangle series. The classification system proposed in table 8 was derived from the ground-based Veireck system and the level II USGS classification system for use with remote sensor data. The proposed classification has been approved for use in Alaska by a subcommittee of the Committee on Natural Resource Information Management. The interpretation of the vegetation and land cover classes is to be derived from digitally processed MSS and DEM data with other ancillary data as needed.

The proposed program provides a complete interim land use and land cover classification system, including maps, registered Landsat digital data, and area summaries by land cover class. In 1985 six maps are to be processed: Dillingham, Arctic, Fairbanks, Valdez, Mt. Michaelson, and Meade River. These maps and accompanying products will be subjected to evaluation before plans are made to complete the remainder of the State.

Land Cover Mapping of National Wildlife Refuges and Other Federal Lands in Alaska

Over the past 5 years, cooperative projects with several Federal and State resource management agencies have produced land cover classifications for approximately 150 million acres of Alaska. The need for current land cover information in Alaska comes principally from the mandates of the Alaska National Interest Lands Conservation Act (December 1980), which requires major land management agencies to

[1] Viereck, L.A., Dyrness, C.T., and Batten, R.A., 1982, Revision of the preliminary classification for vegetation of Alaska: Institute of Nor. For., U.S. Forest Service, Fairbanks, AK 72 p.

Table 8.—Classification system of land cover and dominant vegetation for Alaska interim land use and land cover mapping

Forest
Needleleaf Forest
Broadleaf Forest
Mixed Forest
Shrublands
Tall and Low Shrublands
Dwarf Shrublands and Related communities
Herbaceous
Dry or moist Herbaceous
Wet Herbaceous
Aquatic Herbaceous
Mosses
Lichens
Agriculture
Urban
Barren
Sparse vegetation
Non-vegetated (rock, soil)
Water
Clear and (or) Deep
Turbid and (or) Shallow
Ice and Snow
Shadow
Clouds

prepare comprehensive management plans assessing wildlife habitat, oil and gas exploration and development, wild and scenic rivers, land disposal, timber production, and archeological and cultural resources. Accordingly, the Bureau of Land Management, Fish and Wildlife Service, and Forest Service together with the Alaska Department of Natural Resources, have engaged in cooperative land cover mapping projects with the USGS.

Land cover categories vary both between and within agencies. All agencies, however, are using the "Revision of the Preliminary Classification System for Vegetation of Alaska" to describe the plant communities. The methodology for all of the mapping projects has been similar and employs digital Landsat MSS data, DEM terrain data, and development of a digital data base approach. The procedures may be summarized in eight basic steps: (1) screen and preprocess MSS and DEM data; (2) register MSS, DEM, and any ancillary data to a common base; (3) select training blocks for development of spectral statistics and acquisition of field reference information; (4) acquire field data for selected vegetation polygons within the study blocks; (5) develop training statistics and label spectral classes through correlations with field data; (6) perform a preliminary computer classification of the entire study area; (7) refine the classification through stratification using terrain information (elevation, slope, aspect, and solar illumination), MSS data from winter scenes, and other ancillary data such as digitized physiographic maps and digital hydrography files; and (8) produce final land cover classification maps in hardcopy and digital form.

The resultant land cover and terrain maps and associated data bases are used for various resource assessment, management, and planning purposes. For example, the Fish and Wildlife Service has produced land cover maps for the Alaska Peninsula, Arctic, Becharof, Izembek, Kanuti, Kenai, Tetlin, Togiak, and Yukon Flats National Wildlife Refuges. Maps for the Yukon Delta, Koyukuk, Nowitna, and Selawik Refuges are in preparation. The maps and data bases are being used to develop comprehensive refuge plans, to assess species-specific habitat suitability through modeling with a geographic information system, and to produce lake inventory data.

The Bureau of Land Management has produced land cover maps for the Unalakleet/Anvik area, and the Iditarod/George area, and has combined existing land cover maps and digital terrain data to produce data bases within the National Petroleum Reserve. These are being used to assess environmental impacts associated with oil and gas leasing.

The Forest Service has produced land cover classifications for the Tanana River Basin. These data are used in a four-phase sample design to inventory land cover, timber production, and habitat types in Alaska as part of the National Resource Inventory.

The Alaska Department of Natural Resources cooperated to produce land cover maps for the Gulkana, Nabesna, Valdez, and McCarthy quadrangles in the Copper River Basin. The State will use these data along with other soils, hydrography, geology, land form, terrain, and habitat data to assess land use on State-owned lands.

The land cover mapping program in Alaska has demonstrated an operational application of digital Landsat MSS analysis. Accordingly, NMD has recently approved an interim land cover mapping program to compile land cover maps in Alaska by 1:250,000-scale quadrangles using a common statewide land cover classification. The data-base approach will provide a dynamic product which can be utilized for a range of applications.

Copper River, Alaska, Land Cover and Terrain Mapping

The Alaska Department of Natural Resources requires land cover and terrain maps for a variety of mandated responsibilities and is constantly seeking innovative, cost-effective approaches for developing the required data bases. As a result, a project was initiated to apply digital Landsat and DEM data to the task of mapping land cover and terrain data for the 17.3 million-acre Copper River study area. The cooperative project produced both digital files and maps for the Gulkana, Valdez, McCarthy, and Nabesna 1:250,000-scale quadrangles that comprise the study area. The themes classified in the digital files and on maps were:

- digital files
  - elevation
  - slope
  - aspect
  - preliminary vegetation classification
  - final detailed vegetation classification
  - general land cover
  - smoothed general land cover

- maps
  - smoothed general land cover for each quadrangle at a scale of 1:250,000

The results were dependent upon two primary data sources. The elevation, slope, and aspect files were derived from 1:250,000-scale DEM data covering the study area. The preliminary land cover/vegetation classification was interpreted using both digital Landsat MSS data and the three terrain variables. The land cover mapping was completed using a controlled clustering classification procedure with pre-classification stratification based on terrain variables used to separate vegetation types with similar spectral signatures. Post-stratification refinement was a crucial step due to the large number of initial spectral classes that represented two or more land cover/vegetation types. Nearly 90 percent of the original spectral classes required stratification. Typical problems included closed spruce forest confused with open water, woodland spruce confused with open dwarf shrubs, and sediment laden water confused with barren areas. Elevation and solar illumination (also derived from DEM) were the most useful stratification criteria. While the classification process was straightforward, enhancements to traditional methods were needed in order to process the eight Landsat scenes covering the study area. The process of assigning vegetation types to the nearly 400 specified classes was improved through the use of a data base management system. The field-collected vegetation data was entered into the data base and cross referenced to spectral classes to define their vegetation characteristics. This same process was also used to automate the definition of post-classification stratification criteria. The resulting data base and maps from this project were prepared to allow future updating or refinement without having to repeat the entire analysis process. These techniques may permit tailoring land cover maps to unique requirements of land managers.

Revision of Land Use and Land Cover Maps with Local Government Cooperation in Colorado

The introduction of digital cartographic data bases in northern Colorado has generated widespread interest and several public and private organizations are producing land use maps or land use data in a variety of formats. Few such data bases meet the needs of more than one user. Existing USGS land use and land cover data for northern Colorado are in need of revision and, in general, are not detailed enough for local government uses. However, the USGS data base does provide a standardized level II national classification system and uniform digital data for the northern Colorado Front Range region. An experiment was conducted to determine whether a more detailed and current level III land use data base could serve the needs of both local and Federal agencies, if agreement on technical standards was maintained. Detailed data from local government sources could then be used for future updates of the more general USGS land use and land cover data base.

Two Federal agencies (USGS and the SCS) and three county planning departments (Larimer, Boulder, and Jefferson) participated in the experiment. The first step was an attempt to determine compatibility of land use data needs, given the potential for digital aggregation, disaggregation, and data exchange. The result was a hybrid land use and land cover classification scheme that would meet the needs of the three counties at 1:24,000 mapping scale and also could be aggregated to smaller-scale maps using the categories needed by USGS and SCS.

An experimental land use and land cover map, showing a 186-square-mile test site in southeast Boulder County, was compiled at a scale of 1:24,000 using 1982 data and the hybrid classification scheme. Data for the same area, from the 1976 USGS land use and land cover data base, was transferred manually to the 1:24,000-scale base maps by using a reflecting projector. The difference in map scales of the original compilation (1:250,000 compared to 1:24,000), and the difference in map projections, made both photographic or digital enlargement impractical. The detailed 1982 data was compiled using aerial photographs for about 70 percent of the information needs. Local government source materials and fieldwork were used for the remaining 30 percent.

A digital data base in polygon format was then created and procedures are being developed to permit partitioning and aggregating of the detailed data into categories needed by each user. Table 9 lists the compilation categories arranged in USGS format, and indicates the aggregation required for the standard USGS level II classification system. In the meantime, land use change maps were compiled manually, demonstrating that land use change data and an updated land use and land cover map from the 1976 USGS data base can be derived using this cooperative method. Assuming that suitable software can be made available, the experiment indicates that there may be a considerable advantage to both USGS and other agencies in cooperative arrangements for sharing digital land use and land cover data bases.

Level III Land Use and Land Cover Mapping in Connecticut

The State of Connecticut has identified a need for level III land use and land cover maps which can be correlated effectively with water use and evapotranspiration coefficients to produce data for the Connecticut water user information system and to develop water balance models for drainage basins in Connecticut. The USGS and the State of Connecticut have cooperated in the development of a Level III land use and land cover classification system (table 10), which includes definitions and mapping specifications. Two test sites, the Broad Brook and Ellington 7.5-minute quadrangles were chosen as the sites for testing the classification system and the mapping specifications. The Level III land use and land cover classification system

Table 9.—Experimental level III land use classification scheme for Larimer, Boulder, and Jefferson Counties, Colorado

1 URBAN OR BUILT-UP LAND
- 11 Residential
  - 111 Single-family
    - 1111 Less than 1 acre/dwelling
    - 1112 1 to 2.5 acres/dwelling
    - 1113 More than 2.5 acres/dwelling
  - 112 Multi-family
  - 113 Mobile homes
    - 1131 Mobile homes in parks
    - 1132 Other mobile home dwellings
  - 114 Group quarters
  - 115 Undifferentiated
- 12 Commercial and Services
  - 121 Commercial, mostly retail
    - 1211 Retail
      - 12111 Retail, general
      - 12112 Retail with open storage
    - 1212 Junk yards
    - 1213 Intensive recreation
    - 1214 Parking not with other uses
    - 1215 Animal husbandry, boarding
  - 122 Office
  - 123 Combination retail/services/offices
  - 124 Warehousing/wholesaling
    - 1241 Commercial warehousing/wholesaling
    - 1242 Grain elevators or agency storage bins
  - 125 Undifferentiated commercial
  - 126 Government
    - 1261 Government administration
      - 12611 Government administration, general
      - 12612 Government communication facilities
    - 1262 Government correctional facilities
    - 1263 Military
    - 1264 Public transportation maintenance
    - 1265 Public highway maintenance
    - 1266 Agricultural research
  - 127 Quasi-Public
    - 1271 Educational
    - 1272 Religious
    - 1273 Medical
  - 128 Cultural facilities
  - 129 Undifferentiated public/quasi-public
- 13 Industrial
  - 131 Light manufacturing
  - 132 Heavy manufacturing
  - 133 Industrial warehousing
  - 134 Open storage
  - 135 Undifferentiated industrial
  - 136 Surface extractive non-processing facilities
  - 137 Sub-surface extractive non-processing facilities
  - 138 Oil/natural gas
  - 139 Processing of extracted material
- 14 Transportation, Communications, and Utilities
  - 141 Transportation right-of-way
  - 142 Airports
  - 143 Terminals
    - 1431 Passenger
    - 1432 Freight
  - 144 Water treatment/storage
  - 145 Sewage treatment
  - 146 Communication facilities
  - 147 Gas/electric utilities/pipelines
- 15 Industrial and Commercial Complexes
- 16 Mixed Urban or Built-Up Land
  - 161 Mixed urban, with residential
  - 162 Mixed urban, without residential
- 17 Other Urban or Built-Up Land
  - 171 Vacant
    - 1711 Vacant lots
    - 1712 Other vacant land
  - 172 Cemeteries
  - 173 Non-intensive recreation
  - 174 Public zoos, botanical gardens
  - 175 Water control structures

2 AGRICULTURAL LAND
- 21 Cropland and Pasture
  - 211 Cropland
    - 2111 Irrigated
    - 2112 Non-irrigated
  - 212 Pasture
    - 2121 Irrigated
    - 2122 Non-irrigated
- 22 Orchards, Nurseries, Horticultural Areas
  - 221 Orchards
  - 222 Horticultural and nurseries
- 23 Confined Feeding Operations
- 24 Other Agricultural Land
  - 241 Animal husbandry, breeding
  - 242 Dairies
  - 243 Agricultural structures

3 RANGELAND
- 31 Herbaceous Rangeland
  - 311 Herbaceous
  - 312 Pasture (SCS) - Herbaceous rangeland (USGS)
- 32 Shrub and Brush Rangeland
- 33 Mixed Rangeland
  - 331 Mixed
  - 332 Pasture (SCS) - Mixed rangeland (USGS)

4 FOREST LAND
- 41 Deciduous
  - 411 10-25% crown density
  - 412 25-50% crown density
  - 413 50-100% crown density
- 42 Evergreen
  - 421 10-25% crown density
  - 422 25-50% crown density
  - 423 50-100% crown density
  - 424 Timber harvest areas
    - 4240 less than 10% crown density
    - 4241 10-25% crown density
    - 4242 25-50% crown density
    - 4243 50-100% crown density
- 43 Mixed
  - 431 10-25% crown density
  - 432 25-50% crown density
  - 433 50-100% crown density

5 WATER
- 51 Streams and Canals
- 52 Lakes
- 53 Reservoirs

6 WETLAND
- 61 Forest and Shrub
- 62 Non-forested

7 BARREN LAND
- 72 Beaches
- 73 Sandy Areas other than Beaches
- 74 Bare Rock or Ground, Below Tree Limit
- 75 Strip Mines, Quarries, and Gravel Pits
- 76 Transitional Areas
  - 761 Transitional, general
  - 762 Sanitary landfill

8 TUNDRA
- 81 Shrub and Brush
- 82 Herbaceous, and Mat and Cushion
- 83 Bare Rock or Ground, Above Tree Limit
- 84 Wet
- 85 Mixed

9 PERENNIAL SNOW OR ICE
- 91 Perennial Snowfields
- 92 Glaciers

Table 10.--Proposed Connecticut level III land use and land cover classification system

Level I		Level II		Level III	
1	Urban or Built-up Land	11	Residential	111	Rural
				112	Low Density
				113	Medium Density
				114	High Density
		12	Commercial and Services	121	Low Impervious Cover
				122	Medium Impervious Cover
				123	Medium Impervious Cover, Mostly Buildings
				124	High Impervious Cover
				125	High Impervious Cover, Mostly Buildings
		13	Industrial	131	Electric-power Generating Stations
				132	Other Industrial
		14	Transportation, Communications, and Utilities	141	Limited Access Highways
				142	Railway Facilities
				143	Airports
				144	Port Facilities
				145	Oil and Gas Storage Facilities
				146	Water Treatment Facilities
				147	Sewage Treatment Facilities
				148	Waste Disposal Sites
				149	Other Transportation, Communications, and Utilities
		17	Other Urban or Built-up Land	171	Golf Courses
				172	Other Urban or Built-up Land
2	Agricultural Land	21	Cropland and Pasture	210	Cropland and Pasture
		22	Orchards, Groves, Vineyards, Nurseries, and Ornamental Horticultural Areas	221	Orchards
				222	Greenhouses
				223	Other Groves, Vineyards, Nurseries, and Ornamental Horticultural Areas
		23	Confined Feeding Operations	231	Dairy Confined Feeding Operations
				232	Poultry Confined Feeding Operations
				233	Other Confined Feeding Operations
		24	Other Agricultural Land	240	Other Agricultural Land

Table 10.--Proposed Connecticut level III land use and land cover classification system--continued

	Level I		Level II		Level III
3	Rangeland	32	Shrub and Brush Rangeland	321	Eastern Brushland
4	Forest Land	41	Deciduous Forest Land	411	Deciduous, 10-50 percent crown cover
				412	Deciduous, greater than 50 percent crown cover
		42	Evergreen Forest Land	421	Evergreen, 10-50 percent crown cover
				422	Evergreen, greater than 50 percent crown cover
		43	Mixed Forest Land	431	Mixed, 10-50 percent crown cover
				432	Mixed, greater than 50 percent crown cover
5	Water	51	Streams and Canals	510	Streams and Canals
		52	Lakes	520	Lakes
		53	Reservoirs	530	Reservoirs
		54	Bays and Estuaries	540	Bays and Estuaries
6	Wetland	61	Forested Wetland	611	Deciduous Forested Wetland
				612	Evergreen Forested Wetland
				613	Mixed Forested Wetland
		62	Nonforested Wetland	621	Freshwater Nonforested Wetland
				622	Brackish and Saltwater Nonforested Wetland
7	Barren Land	72	Beaches	720	Beaches
		73	Sandy Areas other than Beaches	730	Sandy Areas other than Beaches
		75	Strip Mines, Quarries, and Gravel Pits	751	Sand and Gravel Pits
				752	Other Strip Mines and Quarries
		76	Transitional Areas	760	Transitional Areas

was developed using established USGS Level II category definitions. Residential areas are subdivided in Level III according to dwelling unit density, while areas designated commercial, services or institutional are classified according to percent of impervious surface and how much of it includes buildings. All sanitary landfills, past and present, are mapped using supplemental source materials. The results were analyzed by Connecticut personnel and changes were made where necessary. Documentation is currently being developed to train compilers to map the entire State of Connecticut using remotely sensed data and other source material. Computer tapes of the Level III land use and land cover data, the hydrologic units data, and the political units data have been created. These tapes can be used to produce computer-generated maps for the Broad Brook and the Ellington 7.5-minute quadrangles.

Development of a Sampling Template to Estimate Acreage Values

There are occasions when area calculations of USGS land use and land cover maps must be performed manually. Two typical situations are when open-file maps have not yet been digitized, or after the maps are digitized but administrative areas other than a county, Census county subdivision, Federal or State land ownership, or hydrologic cataloging units are divided. Depending upon the accuracy required, and the equipment available, several methods can be used to prepare suitable estimates of land use acreage. The purpose of this research was to design a sampling template that would provide land use acreage estimates within several percentage points of the values that are calculated from the digital data and would require less than 16 hours for a 1:250,000-scale USGS land use and land cover map. Drawing from previous USGS land use map accuracy sampling research, a stratified systematic sampling procedure was employed. The number of sample points required was determined from Tortora's[2] formula for estimating the sample size for multinomial proportions based on the approximate large sample equations for simultaneous confidence limits.

The ranges of administrative areas for counties were identified from information on county areas contained in the U.S. Bureau of the Census County Area File for 1980. Nine ranges of county areas were identifed, with the smallest from 0 to 63 square miles, the second from 64 to 127 square miles, the third from 128 to 255 square miles, up to the ninth range of more than 8,192 square miles. Software used in the USGS land use map accuracy procedures was modified to generate the positions of the sampling points for a square template. These values were plotted by hand and acreage estimation tests performed for several counties for which USGS digital land use and land cover data existed. The results confirmed that the procedure worked satisfactorily. However, the small square-shaped template had to be repositioned too frequently and a set of nine templates at the same sampling density were prepared with a software plotting program. Most counties or administrative areas exhibit denser land use patterns in urban areas. Accordingly, a procedure was developed to recognize areas which required a denser sampling template. A land use acreage tabulation worksheet was designed to record the number of sample points falling within each land use type.

[2]Tortora, R.D., 1978, A note on sample size estimation for multinomial population: The American Statistician, August 1978, v. 23, no. 3, p. 100-102.

County land use acreage values were prepared for Texas County, Missouri, using the sampling template, a dot grid template, a polar planimeter, and an electronic planimeter. The acreage results were compared to the USGS digital land use acreage values and the time required to complete the acreage estimates noted. On the average, land use acreage estimates can be obtained for a 500-square mile county in approximately 15 minutes. For Texas County (1,175 square miles), it took only 27 minutes with the sampling template, 75 minutes with the dot grid template, and approximately 10 hours with either the manual or electronic planimeters to obtain land use acreage values.

Eighty-six counties in Missouri, Kansas, Louisiana, and Florida were examined using the sampling template. Six of the counties were also examined using the dot grid template. The acreage results were compared to the USGS digital statistics and the percentage differences noted. The comparisons between the land use acreage sampling template results and the USGS digital statistics revealed that more than 88 percent of the sampling template estimates were within 1 percent of the USGS digital statistic values. Only 0.6 percent of the sampling template estimates deviated by more than plus or minus 7 percent from the digital statistic values.

Plans are to prepare a USGS Open File report describing the use of the 1:250,000-scale land use estimation sampling templates and to provide access to the templates and the tabulation worksheet.

GEOGRAPHIC INFORMATION SYSTEMS DEVELOPMENT

Framework for Development

A framework for the development and use of geographic information system (GIS) capabilities (fig. 25) include: (1) providing an effective means to input vector and raster encoded data from a variety of sources including maps, digital tapes, and tabular records; (2) developing a generalized data structure for the storage of point, line, and area data in vector form, attribute data, and raster data with variable spatial resolution; (3) allowing for selective data retrieval using geographic characteristics or physical attributes; (4) providing the capability for integrated analyses of vector and raster data; and (5) providing a capability to produce cartographic and tabular products on a variety of mediums, including magnetic tape, photographic film, and paper.

Data capture of spatial and attribute information is being investigated in support of digital cartographic production and for geographic information system applications. Spatial information includes point, line, and area features, and attributes include the various types of descriptive information linked to the spatial features. The capabilities addressed provide for the capture and edit of geographic information, the capture and edit of textual, decimal, and integer attribute information, and encoding of additional attribute information suitable for geographic information systems and resource analysis applications. One development has been the cartographic reproduction and interactive graphics editing system (CRAIGES) software that is installed on the Intergraph system. It provides faster input, output, and display updating, as well as increased flexibility for geographic data capture.

Tabular data structures are being investigated as entities for transfer between different spatial data structures, for analysis of attribute data, and for use apart from a digital spatial data base. The goal was to create a primary attribute data set or table which has a one-to-one correspondence to each unique spatial entity together with a set of secondary attribute data sets which may be of one-to-many, one-to-one, or many-to-one correspondence with the primary attribute data set. Tabular data handling was defined to optimize transportability and analysis by designing around a relational database management system and a statistical analysis system.

Application projects often require specialized, one-of-a-kind products, the design of which depends on a highly flexible and interactive graphics capability. The Applicon inkjet plotter with Infomap software is used to plot either raster or vector formatted data using a palette of 4,913 colors. Techniques were developed for the Applicon to plot single-band classified images, plot three-band spectral images in one pass, use Infomap software to create panelled plots, thereby tripling virtual plot size, and to combine a raster map collar with a raster image. The Versatec electrostatic printer with Versaplot software is used to create monochrome plots of either raster or vector formatted data. Techniques included a utility program for plotting points, lines, and regions with attribute labels from a relational data base, and software to plot from a vector data storage format. A large Versatec color plotter is being installed for evaluation.

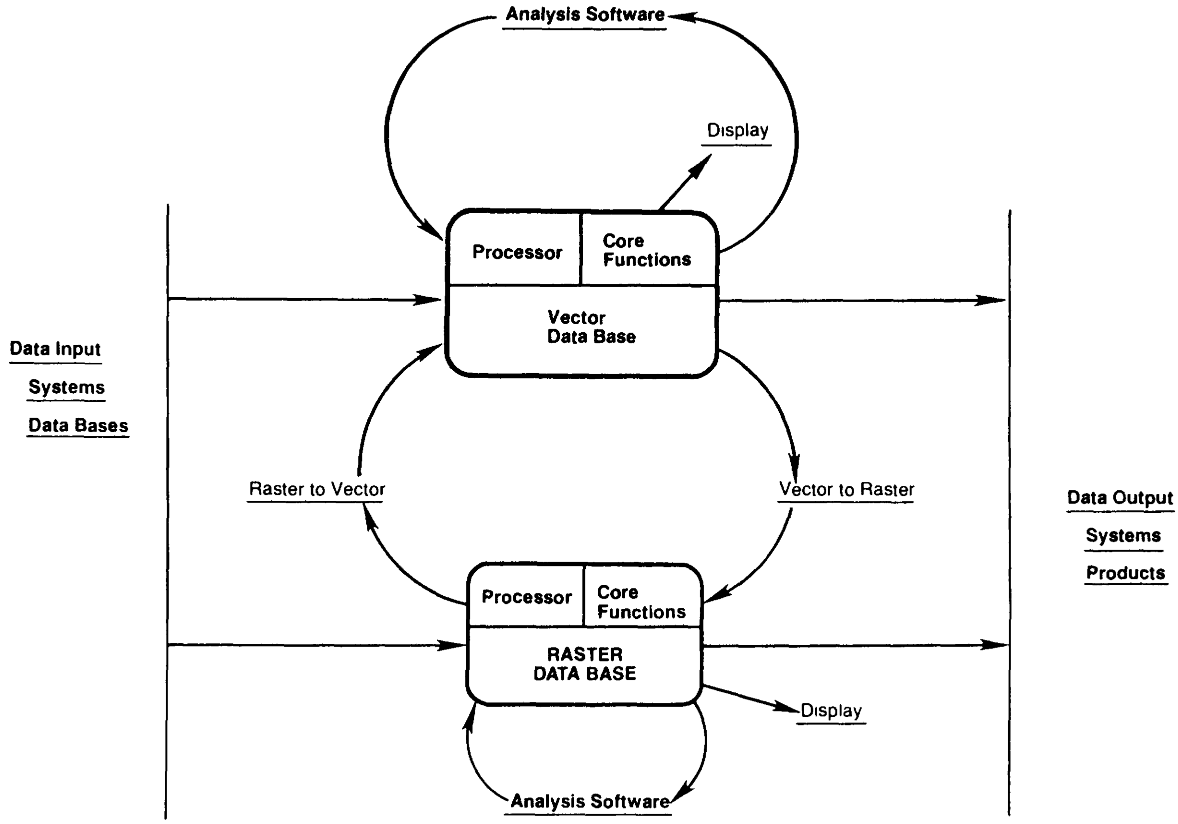


Figure 25.—Framework for the development of geographic information system capabilities.

Raster Data Processing with the Land Analysis System

In 1984, cooperation was initiated between NASA and USGS for the development, implementation, and maintenance of the Land Analysis System (LAS). LAS is a raster data processing system consisting of complex interrelated hardware and software components for processing geographic information and related remote sensing data. This cooperative development effort will provide augmented processing capabilities for a variety of image processing and spatial data handling requirements in such areas as image mapping, automated cartography, data base development, and technique and applications development for Earth resources information systems.

Key objectives in the development of this data processing and geographic information system are:

- Software that can be easily installed on a variety of computer systems and transported to other government facilities.
- A comprehensive user interface and array of executive services that support raster and vector data retrieval and display, graphic functions, data storage and management, and data communications.

- Reliable and easily supported applications software libraries that can be configured into production job streams for routine operational tasks.

- A flexible environment to support research and development on techniques and algorithms for processing raster and vector data.

This cooperative effort will develop more than 200 application modules for remote sensing data input, geographic data input, preprocessing, signal processing, image classification, image display, spatial manipulations, tabular data processing and statistical analysis, and data output.

Vector Data Interchange

With the proliferation of GIS software and of methods for representing coordinate information, the exchange of data from one vector format to another has become an increasingly important problem. One design of a coherent vector data interchange concept revolves around a relational data base hub. Interfaces to various vector analysis systems or transport data structures are arranged conceptually as spokes about the hub. Vector data from a given system may be introduced and transformed into the interchange structure of the hub using relational operators and data manipulation. Data in the interchange structure can then be transformed into any well-defined vector structure for use by another vector analysis system. Each interface is approached in four steps. First, the vector data structure is analyzed, rigorously defined, and the conversion of a test data set is accomplished. Once an effective transformation process is accomplished, the overall procedural flow is implemented in a command language and the interchange process is made available for further testing and use. Finally, depending on usage, an interchange process can be optimized. The following interchanges are being developed to interface with the structure at the hub:

- To and from digital line graph (DLG)
- To and from ARC/INFO geographic information system
- To and from Intergraph systems
- To and from raster-formatted data
- From Geographic Entry System (GES)
- From Automated Mapping System (AMS)
- To Automate Geographic Information System/Generalized Balanced Ternary Record Access Manager (AGIS/GRAM)

Comparative Evaluation of Raster and Vector-Based Systems

Studies are continuing to evaluate GIS technology for natural resource applications. Selected raster capabilities of the Interactive Digital Image Manipulation System (IDIMS) were compared with the vector capabilities of the Map Overlay and Statistical System (MOSS). The Federal Mineral Lands Information System data base for

Medford, Oreg., was used in each system in order to determine comparative procedures, time, and overall system performance. In acreage comparison of surface ownership, it was observed that while there is little difference between the systems for the estimated total area, the individual ownership categories had a range of differences between 0 and 14 percent. The large differences in measured acreage occurred for spatially complex ownership categories. It required 21.6 megabytes of disk space to store the raster database and 3.39 megabytes to store the data base within MOSS, but elapsed computer times for MOSS analytical functions were greater than for parallel analytical functions in IDIMS.

Spatial Data Processor

A study has been completed to determine the feasibility of developing a spatial data processor (SDP) as a standalone image processing and geographic information system capable of manipulating imagery and digital cartographic data in an office environment. A key phase involved determining the operational functions required for spatial data processing; a set of 16 was identified (table 11). This set provides useful criteria not only for evaluating existing systems but also determining the capabilities required of new systems. A review of several existing systems determined that no one system provided all the functional capabilities for working with either raster or vector data. It is evident that raster-based systems are more standardized in functionality and more consistent in data base design and structure. For these reasons the raster processing components of an SDP can probably be extracted directly from existing systems. A system that ranks high in most functional components is the USGS Mini Image Processing System (MIPS).

Although the majority of current image processing and geographic information system applications can be handled using raster data, the functions of a complete spatial data processor require both raster and vector data types. The most expeditious way to build a spatial data processor would be to (1) utilize existing raster-processing software functions, (2) identify functions that require vector capabilities and develop and incorporate software modules to perform those tasks, and (3) integrate the raster and vector functions.

Automated Geographic Information System

The Automated Geographic Information System (AGIS) is being procured from Interactive Systems Corporation. Several major components of the system have been installed including data entry and edit, the spatial data base management system, GRAM (generalized balanced ternary record access manager), an interface to the RIM (relational information management) system for attribute management, and the interactive graphics controller which provides interfaces to a digitizing table, plotter, and a high-resolution vector display. The contract also specified an overlay processor with a single query language which includes spatial operators and boolean selection expressions for attributes. The spatial operators include four overlay capabilities (point-in-polygon, intersection, union, and complement) and a proximity search. These spatial operators can be combined with boolean selection expressions based on map feature attributes.

Table 11.--Functional components of a spatial data processor

Data Capture: assembling analog source data in digital form; for example, line digitizing, raster scanning.

Structuring: processing data from initial digital form into a resident model; for example, skeletonizing scanned line data, deriving topology, polygon chaining.

Editing: inserting, deleting, and changing attribute and geometric elements to correct and (or) update model; for example, node snapping, sensor noise removal.

Representation/Structure Conversion: moving between representations and the structures associated with them; for example, raster-to/from-vector, polygon-to/from-grid, digital elevation model-to/from-contour, polygon-to/from-arc-node.

Geometric Correction: fixing model to ground or image space in some referencing system; for example, adjustment of map or image to control points.

Projection Conversion: transforming coordinates between alternative referencing systems; for example, geographic-to/from-UTM.

Spatial Definition: paneling and clipping to achieve the spatial limits for data in a model; for example, limiting data to within a county boundary.

Generalization: reducing detail in the model; for example, resampling to larger spacing, reduction of points in a line.

Enhancement: modification of detail in the model; for example, edge definition.

Classification: analysis and interpolation of the model to form classes; for example, classification of spectral response data, choropleth mapping.

Statistical Generation: deriving descriptive statistics and (or) measurements from model; for example, histograms.

Retrieval: selective extraction of data from the model by attribute and (or) spatial searches or neighborhood analysis; for example, categories within a circle of given radius from a point.

Overlaying: relating two models in a Boolean and (or) arithmetic manner; for example, creating composite maps, image ratios.

Display: generating a graphic image from the model; for example, color CRT displays, symbolized line maps.

Analytical Technique Support: using analytical manipulations and computations on data model; for example, Markov chaining, network analysis, location/allocation.

Data Management: managing access and archiving of data models; for example, storage, retrieval, update, security protection, data base sub-schemas, transaction records.

ARC/INFO Software

The ARC/INFO software developed by Environmental Systems Research Institute (ESRI), has been recently installed on a VAX 11/780. ARC/INFO is based on a topological arc data structure combined with INFO, a data base management system distributed by Hennco, Inc. ARC/INFO provides a vector overlay and display system and includes a DLG interface and the Generalized Coordinate Transformation Package geometric transformation. A critical vector data interface has been developed so that the functionality of ARC/INFO would be generally available to projects employing other raster image processing and vector data capture systems. ARC/INFO has been used on an acid rain building materials inventory project, the Connecticut hydrologic information project, and several smaller projects.

Map Overlay and Statistical System

The Map Overlay and Statistical System (MOSS) is GIS software developed by the Fish and Wildlife Service to provide capabilities for the storage, retrieval, analysis and display of map and other information. The limitations of existing raster-based processing systems in providing capabilities for the merging and processing of both raster and vector data, prompted interest in enhancing vector-based GIS capabilities. In 1981-82, an investigation of the vector-based geographic information systems available in both proprietary and non-proprietary form indicated that while a number of commercial offerings were available, the pre-eminent system available in the public domain was MOSS, which also boasted a broad and well-established DOI user community involved in land resource management and planning. Growing interest in MOSS and the development of new analysis techniques and applications continue to place increasing demands on its functional capabilities, which may require extensive enhancements.

A limited investigation of spatial data processing with MOSS was undertaken in an effort to evaluate current geographic information systems technology. DLG, DEM, and land use and land cover data were used as inputs and statistical information and plots were produced. MOSS is adequate for elementary spatial analysis, but the interfaces do not permit the effective use of all types of data.

In 1984 a contract was awarded to Autometric, Inc., for the completion of a feasibility and design study for MOSS enhancements. The goal is to identify enhancements to MOSS which increase its reliability, improve its efficiency, and lay a foundation for future functional enhancements. The three main areas being addressed include the incorporation of an arc/node (topological) data structure, the implementation of a reliable arc/node-based overlay processor, and improved attribute data handling.

Remote Information Processing System

In 1983 the Remote Information Processing System (RIPS) progressed from research to operational support and, in 1984, the first users conference was held. By then, the total number of prototype and operational RIPS systems in the field had increased to about 80. Highlights of the transition period included acceptance, checkout, and installation of 11 systems at user sites; baseline release of 69 applications programs, 100 support routines, more than 500 pages of documentation, and definition of RIPS standard products and services. In 1984, RIPS software Version 2 was released which included new software for performing topographic analysis and display of DEM data products on floppy disk. Also software was released for two-way file transfer of binary image data from RIPS to the VAX and HP3000 systems. With the research effort winding down in the development of this generation of RIPS, additional applications software has been prepared by the user community.

Mini Image Processing System

The USGS Mini Image Processing System (MIPS) was designed for research and development in an office environment with the potential of being used in a field environment. The PDP 11/23 hardware and the RSX-11M operating system software were selected in order to make MIPS compatible with the existing image processing system which operates on PDP 11/45 and 11/44 computers using the RSX-11M operating system located in the computer center in Flagstaff, Ariz. MIPS was designed in this manner to avoid the large expense that can be incurred for software development and conversion, which can easily exceed the cost of the hardware. Thus, the MIPS design has available over 80 man-years of image processing software developed for the Flagstaff system. Because of this compatibility, new software can be interchanged easily between the two systems.

The main objective in designing MIPS was to assemble an office system that would be relatively inexpensive, but still powerful enough to operate alone. Therefore, once digital data are available on magnetic tape, MIPS is able to reduce, store, edit, enhance, analyze, display, and correlate spatial data without having to go back and forth to a mainframe computer (fig. 26 and 27).

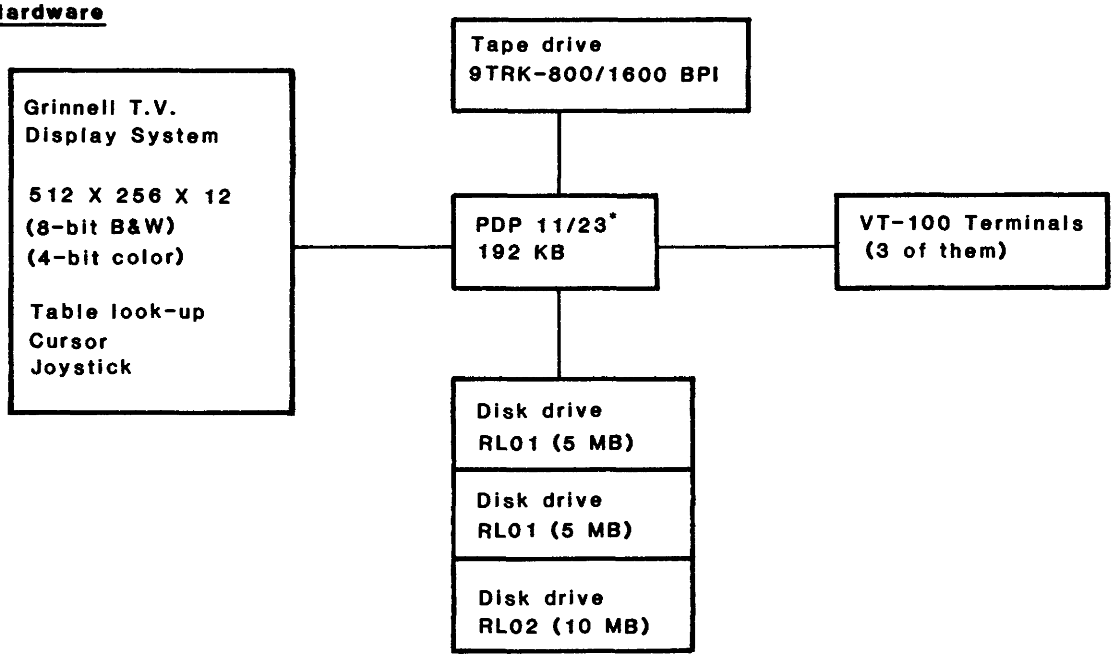
Functionality is considered to be one of the most important factors and is determined by the number of available options, the efficiency of processing, the maximum size of data set that can be processed, the ease of adding new functions, and the ease with which the system can be used. If the options and functions are not designed correctly, the system will be either too slow or will be unable to handle a large enough data set.

Although the functional capabilities of the central image processing system and MIPS are identical, the MIPS version has undergone modifications to upgrade the internal program documentation and improve its user interface, and these modifications have helped improve external documentation. The software is composed of individual programs and operations that are functionally independent. However, they can be applied sequentially to a common data base to generate the desired results. In addition, the design allows easy implementation of new programs that will execute in an efficient manner.

Some examples of execution speed on the current MIPS for a spatial array of 500 x 500 pixels are as follows:

- shaded relief image of an 8- or 16-bit input file--2 minutes;
- stereopair generation--3 minutes;

Hardware



*Currently being upgraded to an 11/73

Software

Operating System RSX11M
FORTRAN............................FORTRAN-4 Plus
Macro.................................PDP Assembler
Application.........................All written in Flagstaff by USGS in FORTRAN and Macro

Figure 26.--Hardware and software configuration for current Mini Image Processing System.

- spatial filtering using a 3 x 3 to 501 x 501 (or M x N, M = or ≠ N) filter with anywhere from 0- to 100-percent addback of 8- or 16-bit input images--3 to 3.5 minutes;

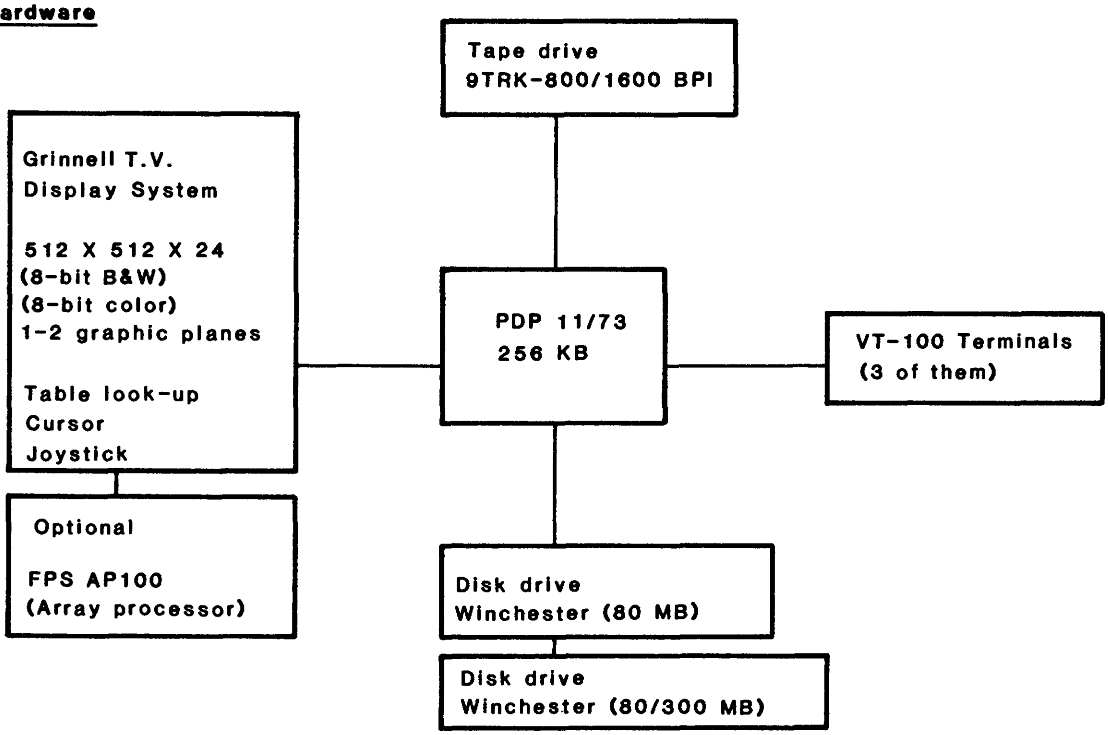
- ratio of two images--2.5 minutes; and

- nearest neighbor geometric resampling--2.5 minutes.

Also, using the 512 x 256 refresh memory, MIPS can accomplish color coding or contrast stretching, with any desired amount of operator control, of an 8-bit image in near realtime. The MIPS processing functions can be categorized as: (1) geometric corrections, (2) radiometric processing, (3) information extraction and data manipulation, and (4) utility/miscellaneous software.

Many programs have been written using a concept in which all machine-dependent operations are isolated from applications routines, making it easy to add new software and transport the existing software to other systems. The concept was developed in 1974 and is designed to accomplish four specific goals in the programming

Hardware



Software

Operating System............... RSX11M (11/73 can run UNIX)
FORTRAN........................... FORTRAN-4 Plus
Macro................................ PDP Assembler
Application......................... All written in Flagstaff by USGS in FORTRAN and Macro

Figure 27.--Hardware and software configuration for proposed upgraded Mini Image Processing System.

and user environment: (1) reduce the amount of program coding for new spatial processing software, (2) minimize the amount of system level details that need to be considered when developing new spatial processing programs, (3) provide program standardization for the user, and (4) make it easier to transport the software to other systems. By utilizing the concept, a software package can be used on other systems with a limited investment in software conversion.

The MIPS software package has been designed to allow optimization of the processing speed with a minimum use of assembler code. The I/O handling tasks are coded in assembler and are easy to use with FORTRAN calls. The amount of code needed to generate new software has been minimized and made more transportable. The program documentation, screen formatting, and user-prompting modifications have greatly improved the user interface of the system. Because of the modular aspects, it is easy to incorporate these capabilities into new software.

MIPS has over 80 man-years of software available to it, providing an excellent range of functional capabilities. The software base and design make it a very efficient system. Optimization has been done wherever possible without writing the entire software package in assembler language. Because the hardware consists of off-the-shelf components and the software has been written and is constantly used by the USGS, the system has the basis for good long-term support.

Computer Systems Integration

A prototype local area network was configured at the EROS Data Center (EDC) to integrate several minicomputer systems to support processing of earth science data and the transfer of related data files between systems. Transition of the network protocol software to a more complete operational network system is continuing.

Communications software has been completed for two VAX systems running under the VMS operating system and for the SEL 32/87 and SUN workstations running under versions of the UNIX operating system. Additional systems are under procurement to augment this network with minicomputers for scientific data processing and a business information system. The software development is utilizing the C programming language primarily because of its portability between different computer systems. This development is progressing under a joint agreement with the NASA Goddard Space Flight Center.

Specialized devices including a color film recorder and a color raster plotter were integrated for output product generation under the standards imposed by a transportable applications executive. This executive, developed by USGS and NASA, provides an excellent user interface standardized for all types of scientific applications. For enhanced transportability it is also being developed and implemented under the UNIX operating system. Device-independent display software was implemented with with DeAnza display systems and will be converted to UNIX for use with Raster Technology displays in a workstation configuration.

GEOGRAPHIC INFORMATION SYSTEMS APPLICATIONS

Federal Mineral Land Information System

The Federal Mineral Land Information System (FMLIS) is being developed by the USGS to allow land managers, policymakers, and others to rapidly retrieve, display, and analyze minerals information on Federal lands. This program stems from the Department of the Interior's interest in knowing the coincidence of Federal land, mineral deposits, and restrictions to mining. Federal policies regarding exploration and development of minerals on Federal land can be a major determinant of domestic mineral production. This program is coordinated with the Bureau of Land Management (BLM) and Bureau of Mines (BM). Started in FY 1983, the program is in a conceptual demonstration phase with plans to reach operational status by 1986. The objectives are to (1) develop a national level geographic data base of published information on surface and subsurface ownership, restrictions to mining, and mineral assessments and deposits, and (2) develop procedures for accessing and analyzing these data with available geographic information system technology. The data base is to be used for policy decisions at the State, regional, and national levels.

The first pilot project for FMLIS was conducted to test the concepts of the program and provide materials for further discussion of data base development. The area of the Medford, Oreg., 1:250,000-scale quadrangle was selected because Federal surface, subsurface, and restrictions data were available from BLM 1:100,000-scale Surface-Mineral Management Status maps. The USGS Geologic Division had released a Conterminous U.S. Mineral Assessment Program (CUSMAP) report for the Medford quadrangle, and extensive deposit data were available from the USGS Mineral Resources Data System (MRDS). These data were registered to the Universal Transverse Mercator projection with a 10-acre grid-cell raster format. Retrieval and analytical tasks were performed with the Interactive Digital Image Manipulation System (IDIMS). A series of land management and mineral development policy questions were then posed of the data base.

- Which Federal agencies own or manage land in an area, how many acres are involved, and where do the lands occur?
- Which federally owned or managed lands are restricted to mineral development?
- What mineral deposits occur, or have a estimated potential for occurence, and where do they occur?
- On what federally owned or managed land does a particular mineral occur where the Federal government has subsurface mineral rights and there are no restrictions to mining?

Answers to these and other questions were produced in the forms of maps and tabular reports. Results of this pilot effort demonstrated the viability of the concepts proposed by the FMLIS program.

A second FMLIS project is development of a data base for Alaska. Mineral resource and land status information were available, providing an opportunity to test and evaluate existing geographic information system technologies for large volumes of data over a large area. Project results would have immediate use for policymaking. Begun in 1983, the project is being addressed in three phases. The first, completed in 1984, was the development and demonstration of a FMLIS data base for the Seward and Dillingham 1:250,000-scale quadrangles. The second phase is the development of a data base for a 20-quadrangle area in south-central Alaska. The third phase is the development of the data base for the remainder of Alaska. Surface and subsurface ownership data and Federal restrictions to mining data are provided by the BLM Alaska Automated Land Record System. Minerals data are provided from the USGS Alaska Mineral Resource Assessment Program (AMRAP), 1:250,000-scale maps, the regional RAMRAP 1:1,000,000-scale maps, and the Mineral Resources Data System (MRDS) point data. DLG's are the source for roads, hydrography, and political boundaries. All data are being registered to the Albers Equal-Area Conic projection, but capabilities exist to reformat to other projections. All data will be in a raster format at grid-cell sizes of 1 square mile and 40 acres.

A third pilot project has been initiated on the Silver City, New Mexico-Arizona, 1:250,000-scale quadrangle. This third effort is aimed at developing compatibility between the BLM Automated Land and Mineral Record System (ALMRS) and FMLIS. BLM is developing ALMRS for the purpose of automating their land recordkeeping and when established, it will supply important land status data. Arizona and New Mexico are pilot States for ALMRS development. USGS also digitized, in standard DLG format, the surface ownership, subsurface mineral rights, withdrawals, and land net from the four BLM 1:100,000- scale Surface-Mineral Management Status maps covering the study area. These data will be used as a comparison with ALMRS data, as well as in other analyses involving mineral resource potential.

Information Processing in Support of Mineral Assessments

Several 1:250,000-scale quadrangle areas are being evaluated for mineral resource potential using digital analysis techniques. These include Dillon, Mont., Tonapah, Nev., and Bendeleben and Solomon, Alaska. Each quadrangle was selected on the basis of the status and scheduled completion of geologic mapping, the geologic and mineralogic diversity, and the anticipated needs for data manipulation. A digital geologic data base is being implemented for each quadrangle to further develop, test, and demonstrate the application of digital spatial data handling techniques to current mineral assessment requirements. These include a comparison of raster- and vector-based spatial data processing functions for modeling geological, geochemical, and geophysical variables, an evaluation of new types of interim and final map products that integrate and summarize cartographic and geologic information relevant to mineral resource appraisals, and the development of analytic techniques for quantifying the significance of stream sediment geochemical anomalies based on their spatial reference to geologic and topographic data.

Acid Rain Project

In 1983 and 1984, the USGS assisted the Interagency Task Force on Acid Precipitation, established by the Environmental Protection Agency (EPA), in compiling a prototype regional inventory of building material surfaces susceptible to damage

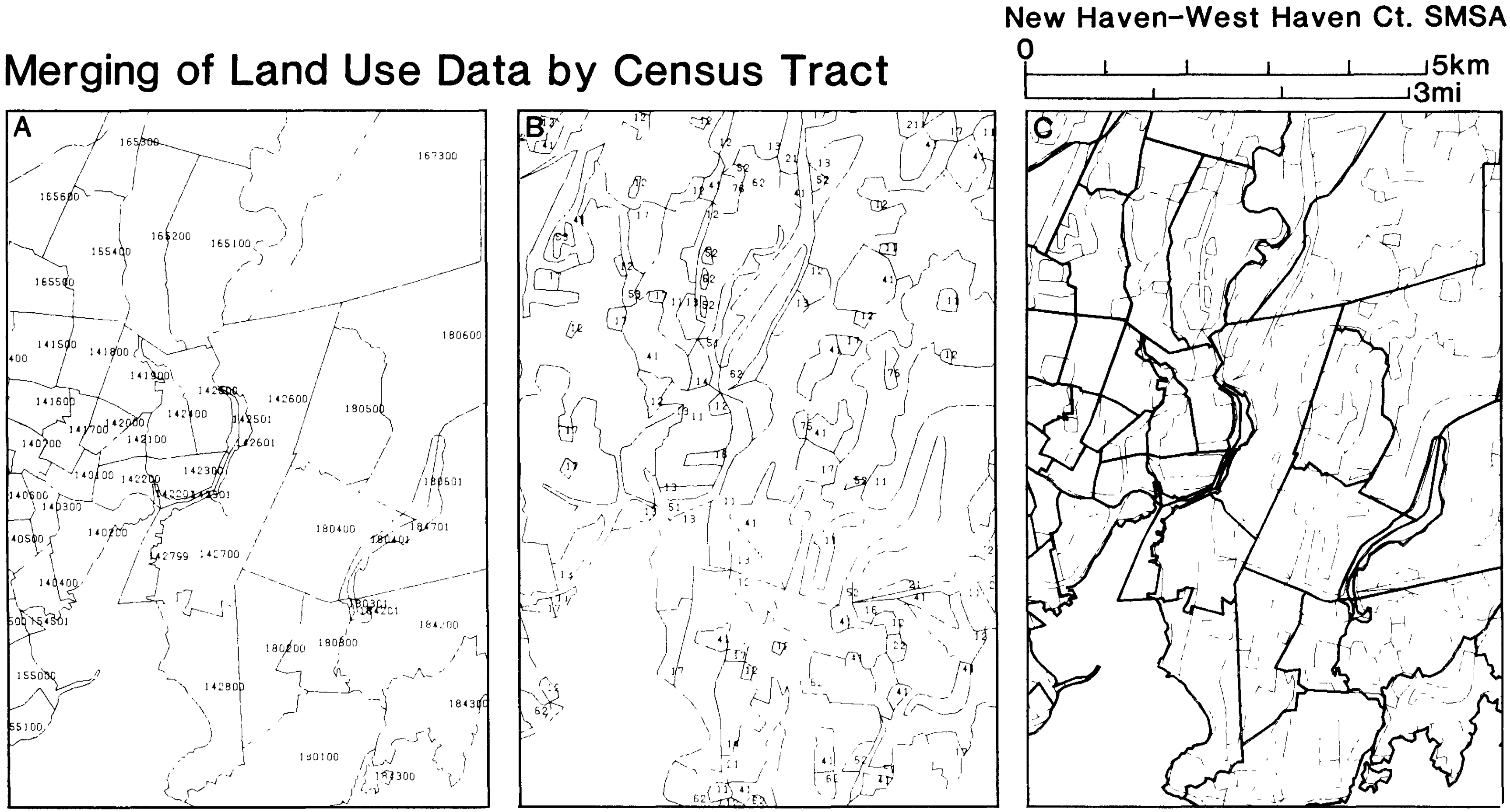


Figure 28.—Portion of the New Haven–West Haven SMSA showing (a) census tract polygon boundaries and codes, (b) land use and land cover polygon boundaries and codes,and (c) overlaid tract and land use polygons for area measurement of land use attributes by tract. (Census tract boundary data in digital form are from the Tract 80 file by Geographic Data Technology Inc., Lyme, N.H.; digitized land use polygon data are from USGS.)

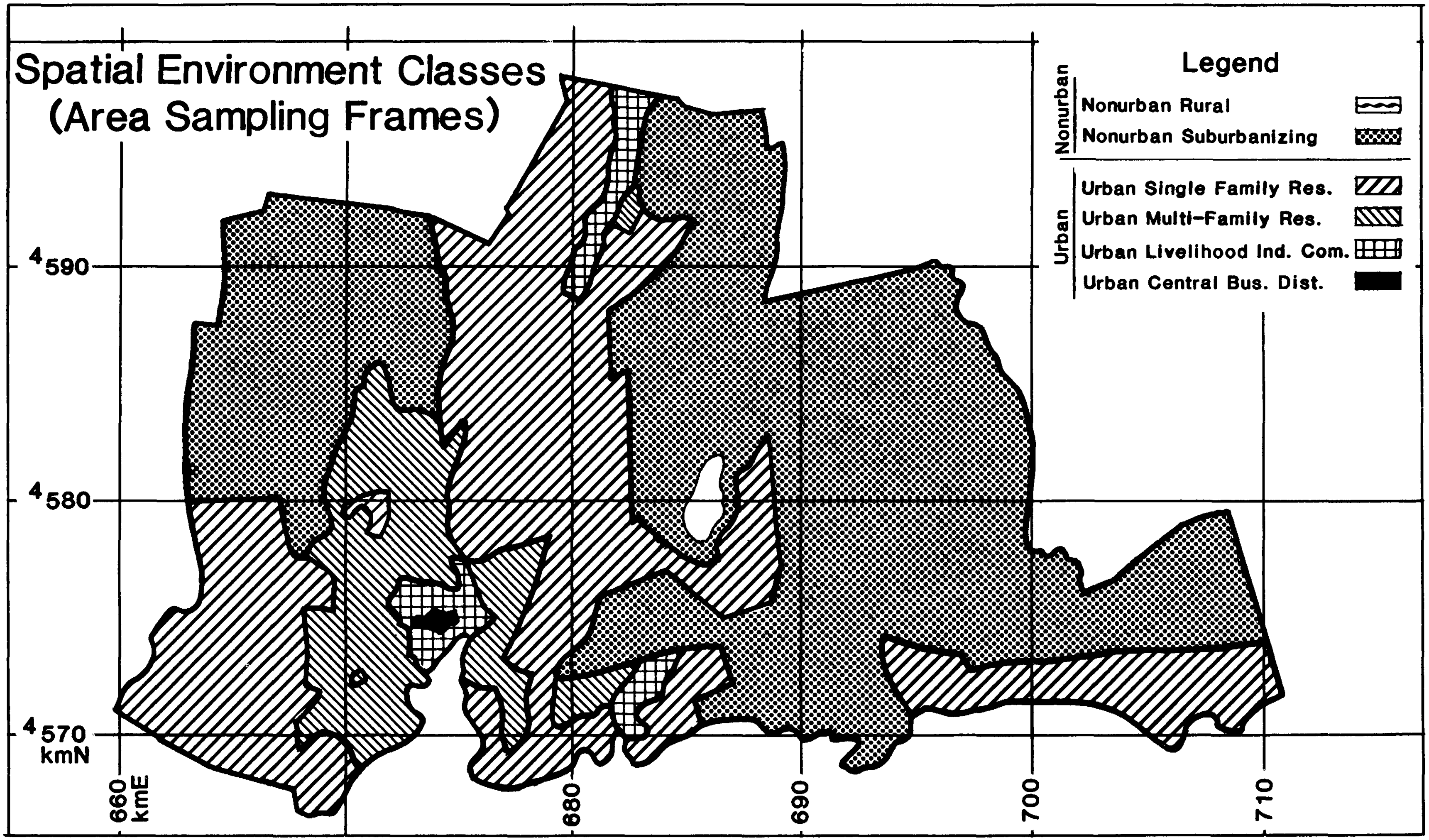


Figure 29.—Map of the New Haven-West Haven SMSA, Conn., 1980, showing census tract groups as spatial environment classes (area sampling frames) derived by multivariate analysis of selected demographic and land use data for all 93 census tracts. Seventy-six tracts comprising the central contiguously urban tracted area approximately correspond to the New Haven Urbanized Area, 1980. The white area is a lake and the Nonurban Rural class is not present in this area. The use of a common map projection and coordinate system (UTM) allow data overlay and statistics computation.

from acid deposition. This involved merging existing USGS land use and land cover data with data from the 1980 Census, at the census tract level, to construct a statistical sampling model to estimate the amount, kind, and location of exterior building materials. The project is part of a National Park Service study conducted cooperatively with the Cold Regions Research and Engineering Laboratory (CRREL) operated by the Army Corps of Engineers and with the Department of Energy Oak Ridge National Laboratories (ORNL).

One underlying assumption is that building and land occupancy patterns discerned from remotely sensed data helped to define and map the land use and land cover information. The land use interpretation serves as a model of the kind and location of buildings and of the materials from which they are constructed. The census data, on the other hand, include actual enumeration information (such as total population and housing units) which imply intensity of residential land use, if not its location, within a census statistical area (fig. 28a). The land use information, meanwhile, does show where people are likely to sleep or work within the boundary of the census statistical area (fig. 28b). The merged data sets--when reasonably contemporaneous--thus give much more information than either data set by itself (fig. 28c).

From five variables in the merged data sets for 26 Standard Metropolitan Statistical Areas (SMSA) in New England, and for the Pittsburgh and Cincinnati SMSA, a prototype spatial environment classification of census tracts was produced. This scheme recognizes four urban classes and two nonurban classes (fig. 29). These classes were used as area sampling frames for selecting sampling points and sample buildings in likely land use classes. Intermediate maps were prepared by computer graphics to analyze and evaluate the statistical classifications and to select sampling points.

Then, in three metropolitan areas, the exterior materials surfaces of the sample buildings were inventoried. From the materials sample measurements and from the comprehensive land use area measurements, each materials class is extrapolated to its total surface area, by sampling frame, county, State, and region. Another Task Force group translates all impact assessments into estimated costs if nothing is done to mitigate the hazard. Then the benefits and costs of various mitigation strategies will be evaluated against the cost if nothing is done in order to recommend a cost-effective mitigation program. The scenario not only demonstrates potential application of the USGS land use information but also how a digital cartographic data base and spatial analysis can be applied to an environmental problem affecting many States and the programs of many Federal agencies.

Similar operations are being performed on data for New York State using ARC/INFO to overlay and plot 1982 Census tract data with USGS land use data. New York Land Use and Natural Resources (LUNR) inventory data from a 1-km grid were converted to an arc format and intersected with census tracts in eight SMSA's. The LUNR data were used because much of western New York is not included in USGS land use data. To check for consistency, LUNR and USGS data for a 1:24,000-scale quadrangle in Albany, N.Y. were compared after conversion and regrouping. A test case also was conducted for the New Haven, Conn., SMSA and compared with results of a similar procedure developed by ORNL. Area summaries were nearly identical. The Task Force acquired digitized land use data for tracked SMSA's in 17 additional northeastern States to be processed in time for its 1985 assessment. Data for the remaining States are to be processed for the 1987 assessment.

Connecticut Project

The USGS and the State of Connecticut are developing a demonstration of a GIS utilizing data from the Broad Brook and Ellington 7.5-minute quadrangles. This was demonstrated at the 1985 meeting of the Association of American State Geologists in Mystic, Conn., and will serve as an example of how diverse sets of data from the USGS and the States can be merged to form a viable and useful system.

Digital data for the GIS was obtained from various sources including DLG-formatted geographic and hydrographic data, DEM data, Landsat MSS data, and Soil Conservation Service DLG-formatted soils data. Other map overlays at 1:24,000 scale have been digitized including land zoning, public water supply wells, solid waste landfills, point-source discharge sites, sanitary sewer service areas, water supply service areas, water quality classifications, biophysical-ecological land classifications, wetland classifications, surficial geology, bedrock geology, elevation of bedrock surface, and elevation of the water table. The GIS is both raster and vector based. However, the greater proportion of the data sets are in vector format, and procedures for interchanging data between raster and vector formats have been developed. Such procedures allow, for example, land cover change classifications, interpreted through raster image processing of Landsat MSS data, to be compared with land use and land cover data in vector format.

Studies are planned to (1) determine where land suitable for development is currently developed or zoned for development, (2) assess hazards to public water supply wells from pollution sources, (3) examine areas for construction of future public water supply wells, (4) develop input for hydrologic models, and (5) determine potential source areas for sand and gravel. These will enable the State of Connecticut to evaluate the usefulness of a GIS for natural resource planning purposes as well as show how a State can integrate State and Federal data.

Mapping Wildland Fire Fuels

Studies were conducted in cooperation with BLM and NOAA to evaluate the utility of Advanced Very High Resolution Radiometer (AVHRR) data for mapping fire fuels over millions of acres of BLM land west of the Mississippi River. Previously, information relating to fire fuels was obtained through the manual interpretation of 1:250,000-scale Landsat MSS images. Since manual interpretation of MSS images is labor-intensive, BLM was interested in determining if digital image analysis of AVHRR data could provide similar results for less cost. A 42 million-acre study site in eastern Oregon was selected for which fire-fuel information, derived by manually interpreting Landsat MSS images, already existed for a 6.4 million-acre portion of the area. Using digital analysis of multi-temporal AVHRR data collected during the spring of 1983, a preliminary fire-fuel map was developed for the entire 42 million-acre study site. This map (fig. 30) was refined using digital terrain data, field verification, and the expertise of resource personnel.

Using stratified random sampling, 165 samples were independently selected for field verification from the 6.4 million-acre area. The results indicated that both sources of information were similar in accuracy (approximately 90 percent correct), and the cost for an area of this size for deriving the fire-fuel information using either data source was about the same ($12,000 or 0.19 cents per acre). When digital analysis of AVHRR data was used to derive fire fuel information for the entire 42 million-acre

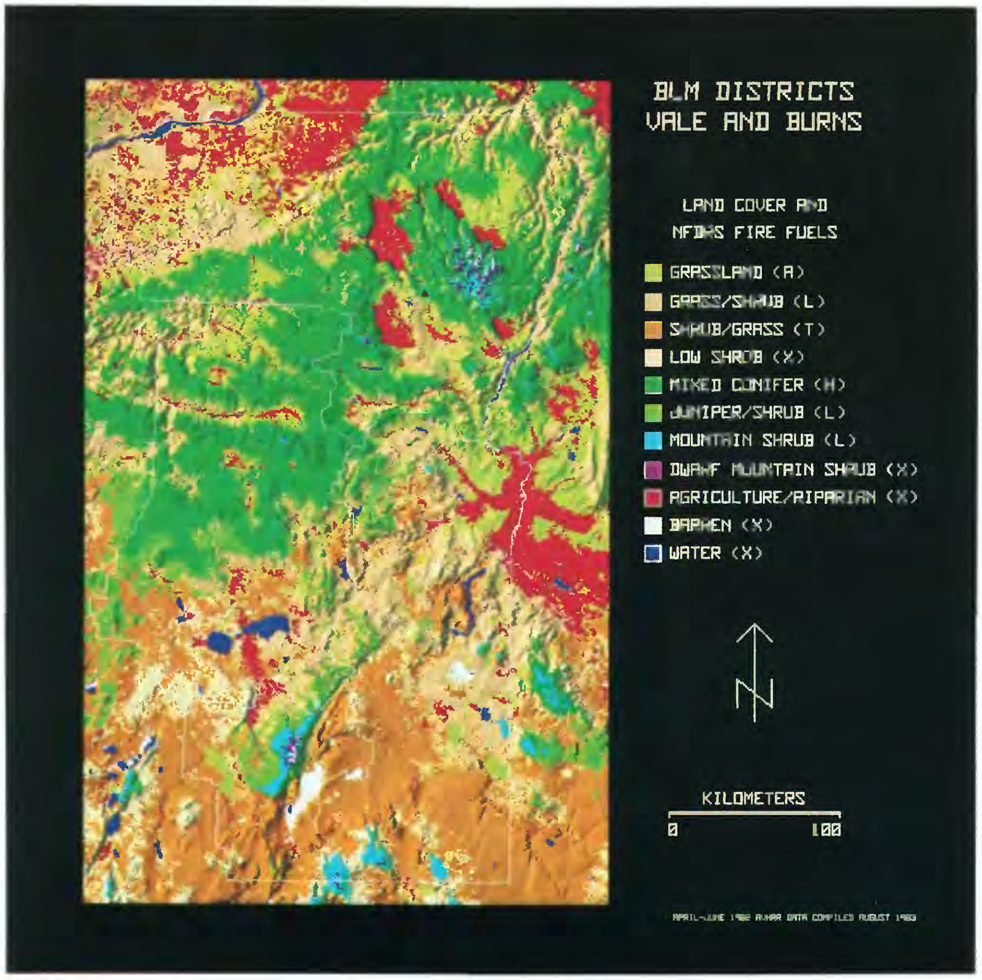


Figure 30.—Land cover and fire–fuel map developed for 42 million acres in eastern Oregon. Shown here at approximately 1:3,650,000 scale.

study site, the cost per acre (0.04 cents) was substantially lower. BLM is presently mapping fire fuels, in support of its national fire program, using digital analysis of AVHRR data and plans to map all 180 million acres of BLM land in the western United States using this method.

Integrated Resource Information Program

A 3–year study that began in 1983 is being conducted with the Bureau of Indian Affairs (BIA) to investigate the functional requirements and capabilities of a GIS to support BIA resource management and planning needs at different levels of management. A series of small cooperative projects was initiated in order to support this activity by: (1) establishing an understanding of typical BIA functions, (2) evaluating staff expertise and level of technology, (3) determining current problems and processes for resource management, and (4) documenting the role for cartographic, topographic and remote sensing data. These projects also helped to define additional informational requirements to be met by further projects.

An investigation was conducted on the Fort Berthold Indian Reservation in North Dakota to define, construct, and demonstrate the use of a digital spatial data base for the assessment of rangeland and agricultural management opportunities. A specific objective of the study was to develop a spatial data base suitable for updating and refining the range unit payout program. Ownership information is the basis for the range unit program, as well as many other resource management programs on the reservation, and consequently was the primary layer in the data base. All other categories which shared common boundaries with ownership, such as range unit boundaries and public land survey data, were precisely registered to the ownership base category. Soils, land use, and range site data were also included. The data were combined to develop a data set which included all unique intersects, which were tabulated and entered into a relational data base management system. The relational data base was used to merge the spatial data with tabular data used by BIA in the range payout program. The integration enabled computation of range payout based on land productivity.

To provide BIA with standalone capability to access and manipulate the range unit payout data as well as all other data categories, the entire data base was subset by township (39 townships) and down-loaded to a Remote Information Processing System (RIPS) microprocessor. Software was developed to undertake all file management and access through the use of menus, and routine procedures used by the BIA were streamlined to allow easy access by personnel with minimum knowledge of computers. The software also provided several data analysis functions and graphic display of the data. The microprocessor-based system and analysis capabilities are currently being evaluated by BIA.

Rangeland Utilization Assessment

Studies at the Crow Creek Reservation, S.D., showed that Landsat TM data are a source of information for monitoring the status of vegetation in highly productive grassland ecosystems. The TM images when acquired on a regular basis are useful for analyzing grazing patterns, for planning range improvement practices, for monitoring the ecological status of plant communities, and as a permanent documentation of local conditions (fig. 31).

Initial results obtained from manual interpretation indicated that there was a strong interpreter preference for the color composite image from TM bands 3, 4, and 5 for evaluating vegetation conditions. However, the color composite image from TM bands 2, 3, and 4 provided a product familiar to interpreters experienced in working with color-infrared aerial photographs or standard Landsat MSS images. Even though TM bands 2, 3, and 4 may be preferred in some cases, images with TM bands 3, 4, and 5 have the greatest dynamic range of the seven TM bands recorded by the satellite. Some interpreters found the substitution of the short-wavelength visible band 1 for TM band 3 in the color composite image (TM bands 1, 4, 5) aided in locating roads and areas of low vegetation cover.

The 1:100,000 scale (approximately 5/8 inch = 1 mile) was determined to be a practical working scale for county-wide or area-wide surveys. Interpreters could locate image features accurately because terrain features are shown in detail. Much of the identification capability came from improved spatial resolution, permitting the detection of small water bodies, roads, railroads, and pipeline rights-of-way.

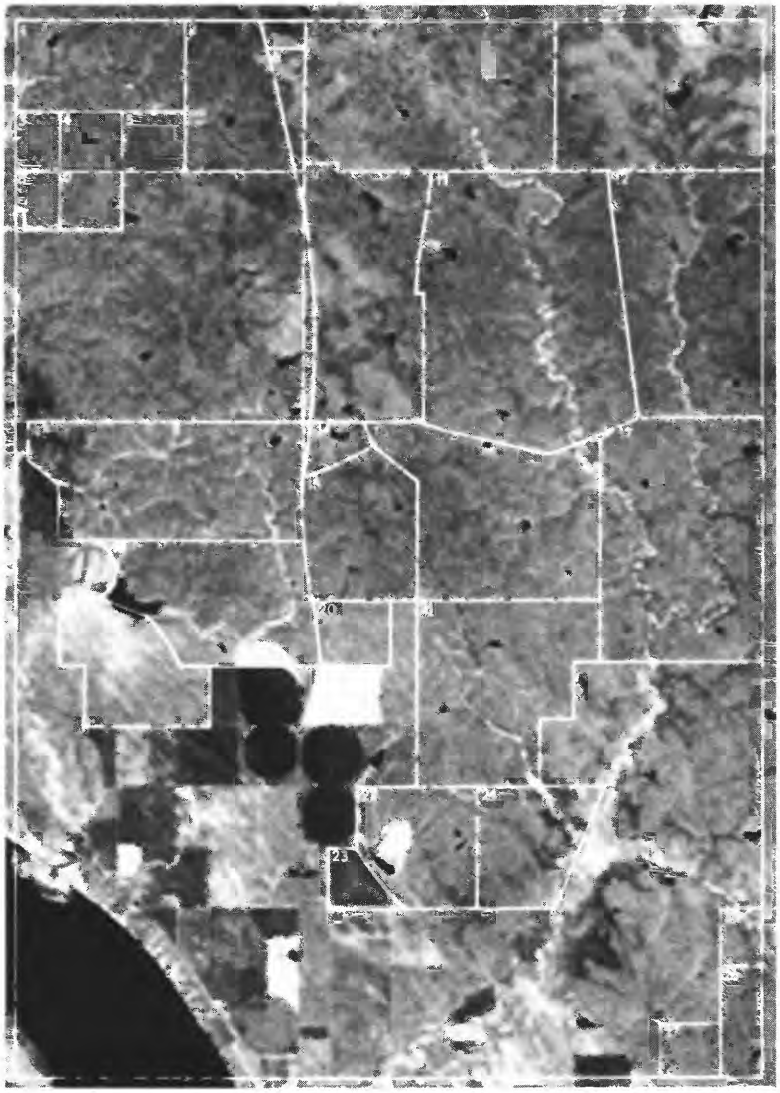


Figure 31.—TM image (band 4, 0.76–0.90 µm) of the Big Bend Dam SE quadrangle area, showing management units (pastures) on the Crow Creek Indian Reservation in central South Dakota on June 8, 1984. Shown here at approximately 1:100,000-scale.

Use of a Spatial and Tabular Data Base for Soil Surveys

Although national cooperative soil surveys are available for nearly 1.3 billion acres, over one-third of the United States still lacks a modern soil survey. A cooperative study with the Soil Conservation Service and the Bureau of Land Management investigated ways in which modern sources of information and computers can be used to assist in the soil survey process using digital elevation data to produce maps of slope, aspect, and elevation. Such maps were used with aerial photographs and topographic maps by soil surveyors to speed up their fieldwork. Landsat images were used to assess the spectral diversity of the land surface and to show the relationships among geology, soil, and vegetation. These maps and images were combined with topographic and soil map information in the computer. The combination and the interactive use of the information in the computer not only expedited the completion of soil surveys, but also provided added flexibility and versatility. These procedures were developed and tested as part of four operational soil surveys conducted by the Soil Conservation Service on approximately 1.5 million acres in Wyoming, Nevada, and Idaho. A spatial data base consisting of digital elevation and Landsat MSS data was registered to a UTM projection. Slope and aspect were calculated, plotted at 1:24,000-scale, and used with standard topographic maps and orthophotos as interpretation aids to prepare a preliminary map for use during a field soil survey. The preliminary soil maps were then digitized and registered to the data base.

Procedures were developed to summarize statistics derived from the spectral and elevation data for each polygon. This resulted in a tabular data base which was indexed to the spatial data. A management system to organize and query the data base was used by the soil survey field team during the fieldwork and the description phases of the soil survey. After fieldwork and preliminary reviews were completed, the preliminary soil maps were edited to correspond with the final soil survey and used to update the data base. Field evaluations showed a general accuracy of 88 to 98 percent for slope and aspect-class maps and for the soil maps generated with the aid of these products.

Landslide Hazards Analysis

Each year in the United States, landslides result in substantial loss of life and property. In a recent project, a model was tested to estimate the probability of landslides, given the physical characteristics of an area. The selected study area for the landslide hazard assessment project spanned portions of six 7.5-minute quadrangles in and around Cincinnati, Ohio. Over 20,000 grid cells (100-meter) in UTM coordinates covered the study area and DEM data were used to compute the average and maximum slope for each cell. Codes indicating whether a cell was upslope from a cell in which new construction had occurred were introduced from building permit records and geologic data were used to determine the local shear strength of the soil in each cell. The full data set was used to develop a probability model for estimating future landslide risk locations. These cell locations were evaluated in a economic model which determined the benefit of landslide mitigation strategies in relation to the associated costs. Statistical analyses were performed and the numerous results were displayed in map form to illustrate alternatives.

Landform Classification Using Digital Elevation Data

The feasibility of mapping landforms using information obtained from digital elevation data was investigated. Different criteria must be used in a digital classification of landforms than in a visual identification (table 12). The approach used in this study consisted of first characterizing neighborhoods.

Table 12.--Criteria for classification of landforms

Visual:

1. Map, profile, or three-dimensional shape (arc delta, volcano, drumlin, parabolic dune).
2. Topographic position and association (alluvial valley, natural levee, point bar, pediment, mesa).
3. Bedding configuration (plateau, hogback, anticline).
4. Texture and pattern (lava flow, till plain, sinkhole plain).
5. Dissection and stage of erosion (lacustrine plain, badland, peneplain).
6. Similar features or a sequence (dune field, beach ridges, ridge and valley topography, tilt block).

Computer:

1. Topographic characteristics (slope, ridge, valley, knob, sink, saddle).
2. Neighborhood characteristics (slope, rate of change of slope, texture, shape or curvature, amount of curvature).

Five measures are necessary to describe the characteristics around any point: slope, rate of change of slope (second derivative), texture (local relief), amount of curvature, and shape of curvature. The standard deviation of elevation gave a good measure of texture, and curvature measures were obtained from the high spatial frequencies of the elevation data. Four data sets--slope, second derivative, standard deviation, and high frequencies--were combined into a multiband image for landform classification. Selected slope ranges were used to mask the image, statistical files were developed for the masked areas, and these files were the basis of a maximum-likelihood classification. The resulting landform classes have increasing mean values of slope, rate of change of slope texture, and amount of curvature.

Calculation of chi-square values for the classified cells indicated an 88-98 percent probability of correct classification. Shape information can be added to the landform classes as a post-classification procedure. For this purpose, the original histogram of the high spatial frequencies was separated into three portions, representing concave, straight (or nearly straight), and convex shapes and were then used to create these three masks for the landform classes. Digital elevation model data from both 1:24,000-scale and 1:250,000-scale maps were used to develop and test the landform classification procedure.

Hydrologic Analyses in the Black Hills Region, South Dakota and Wyoming

An investigation is in progress to determine the effect of geology on statistical indices of streamflow in the Black Hills of South Dakota and Wyoming. A part of this study required an analysis of the topographic location, position, slope, attitude, and geomorphology of the outcropping geologic units. Previous research showed that a shaded-relief image is the best base for this type of analysis.[3] Thus, bedrock lithologies were digitized from 1:125,000-scale geologic map folios and registered to digital elevation data on a UTM map projection at 50- x 50-meter spacing. Color codes were next selected (fig. 32) for each sedimentary formation, all combined metamorphic rocks, and all combined igneous rocks. A computer algorithm was then used to add shadowing to the color-coded geology (simulating a shaded-relief image) by reference to the registered elevation data. Analysis of the resulting image along with review of the hydrologic literature for the region indicated that nine sedimentary formations are probably the most important hydrologically. Outcrop areas of these nine formations and stream channel length in each output were then measured in each drainage basin. These measures will be tested for significance on streamflow by multiple regression analysis.

Hydrologic Analyses of the John Day River Basin, Oregon

The USGS Water Resources Division, several agencies in the State of Oregon, and the USGS NMD have developed a GIS for hydrologic applications in the John Day River Basin in Oregon; the GIS contains 24 map and 32 tabular files. Map files were created by digitizing maps at scales between 1:100,000 and 1:500,000 or using existing digital data including DEM and DLG. Tabular files were created by entering data into a data base management system or converting existing digital data. Map data entered into the system includes hydrography, land ownership, geology, elevation, precipitation, boundaries, land zoning, and wildlife habitat. Tabular data includes mining sites, water quality, water rights, crop consumption, water use, fish habitat, discharge measurements, minimum flow recommendations, and points of water diversion.

All map data were converted into a raster form compatible with the VAX-based Interactive Digital Image Manipulation System (IDIMS) at NASA Ames Research Center. In this form each map was represented by a matrix of 3,000 x 3,000 grid cells, each representing one hectare (100 m x 100 m) on the ground. For comparison, a Landsat MSS image contains 2,983 x 3,548 grid cells or pixels.

Tabular data were accessed using the INFO data base management system available on a Prime 750 computer. Each tabular data file was referenced to map coordinates and contained attribute information for corresponding maps or site-specific data not presently mapped.

Both systems were used to explore three applications of the GIS. Map and tabular data were used (1) to determine the impact of hypothetical water development at a specific site and its economic feasibility, (2) to determine the advisability of issuing permits for placer mining by assessing projected impacts, and (3) to narrow down a list of potential reservoir sites by identifying those posing the least amount of conflict with stated policy. Representatives of State agencies stated the objectives, defined the assumptions, and used the GIS to explore relationships between data sets that could lead to better decisionmaking (fig. 33).

[3] Darton, N.H., and Paige, S., 1925, Geologic Atlas of the United States, Central Black Hills folio: U.S. Geological Survey Folio 219, 33 p.

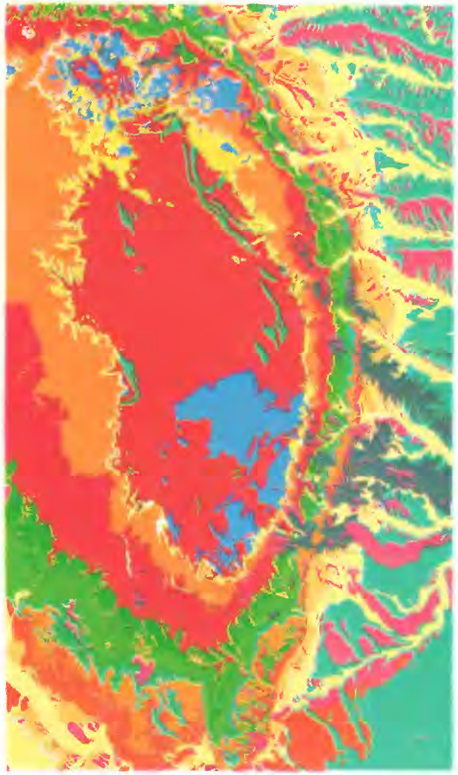


Figure 32.—Computer-generated geologic image of the Black Hills, South Dakota and Wyoming. Geologic interpretation from Darton and Paige.

The State is experimenting with new methods for managing water resources that will involve more State agencies, that will include groundwater data, and that will provide common data format for computerized systems. The John Day River Basin system satisfies the criteria and can be used to demonstrate a wide variety of applications.

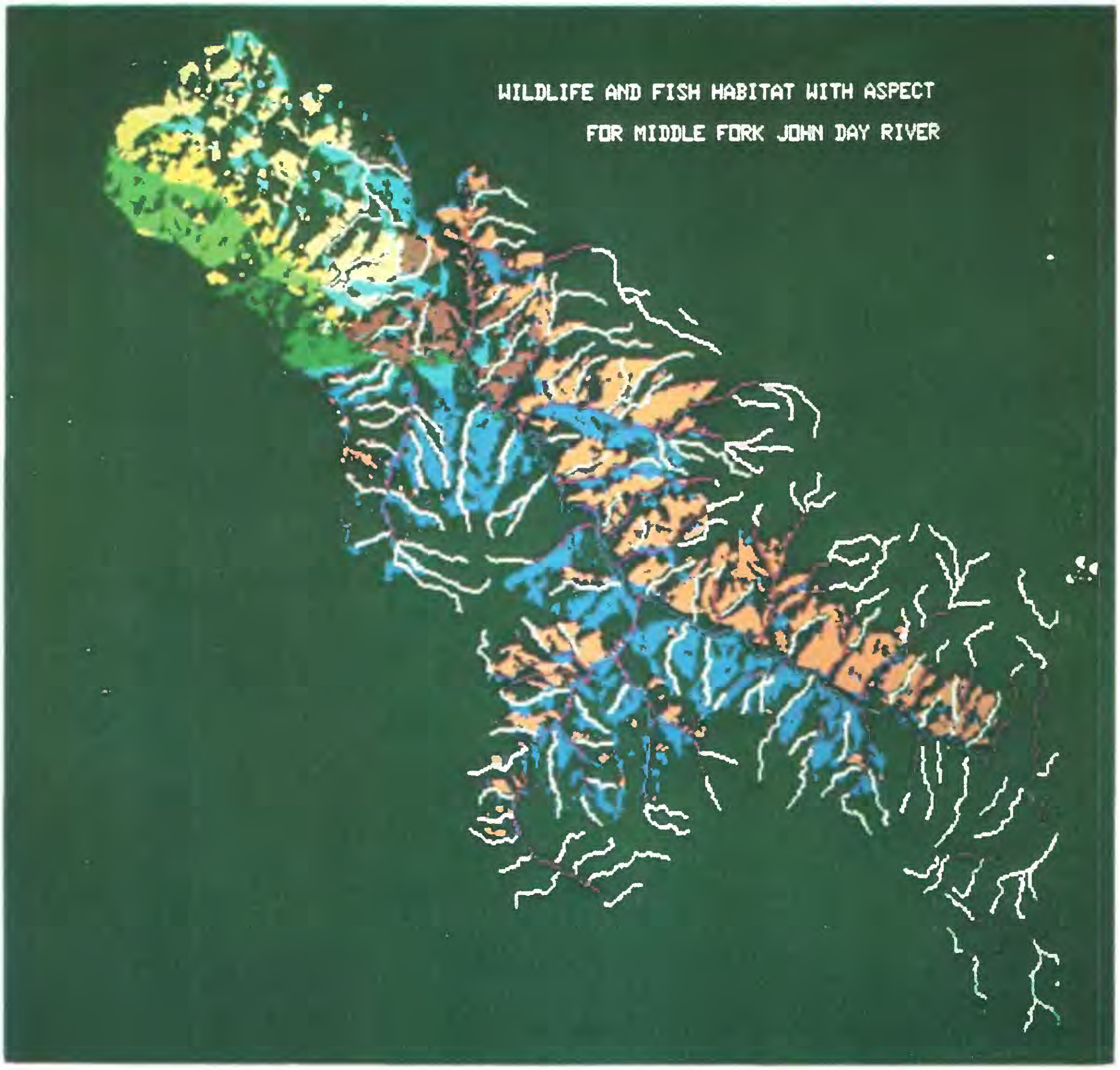


Figure 33.— Four data categories (deer, elk, and fish habitats, and terrain aspect) were combined using the GIS for the John Day River Basin, Oreg. The blues and greens describe north-facing slopes; the yellows and browns describe south-facing slopes. Variations of these colors describe summer and winter deer range and elk habitat. Colored streams indicate fish habitat with white indicating a lack of critical habitat. Displays such as this are an aid to resource managers who must consider impacts of hydrologic development before issuing or denying permits for water withdrawal or discharge.

Digital Mapping Technology to Display Hydrologic Information

The Fox-Wolf River basin in east-central Wisconsin was selected by the USGS Water Resources Division and NMD to test concepts of a water resource information system using digital mapping technology. A large amount of recently updated hydrologic information is available in this 16,800 km^2 basin. Several characteristics of the basin are similar to those in many areas of the country. There are four surface water cataloging units and three important aquifers, neither great shortages nor great surpluses of water, and local water problems are not extreme. The principles exemplified by information system processing in the Fox-Wolf basin are the same as those that can be used in other areas (see fig. 34). Fifty data sets were included in the Fox-Wolf information system, not counting different forms of the same data set. Many data sets were digitized in vector form from 1:500,000 scale maps and overlays. All data were geometrically transformed to a Lambert Conformal Conic map projection and converted to a raster format having a 1-km grid cell spacing for further processing. In this format, the Fox-Wolf basin is an array of 160 by 250 grid cells. The result of digitizing and preliminary processing is a group of spatially registered data sets.

Parameter evaluation, areal stratification, data merging, and data integration were used to achieve the processing objectives and to obtain analysis results. Parameter evaluation includes the visual interpretation of individual data sets and digital processing to obtain new derived data sets. In the areal stratification stage of data processing, masks were used to extract from one data set all features that are within an area selected on another data set. Most processing results were obtained by data merging. Merging is the combination of two or more data sets into a composite product, in which the contribution of each original data set is apparent and can be extracted from the composite. One processing result was also obtained by data integration. Integration is the combination of two or more data sets into a single new product, from which the original data cannot be separated or calculated.

The storage and processing of digital maps cannot accomplish all objectives of a water resources summary. Some factors, relationships, and problems are best described in narrative form. Also, some data types, relationships, and totals are more understandable when shown in graphic, tabular, or statistical form. Spatial processing and display mainly offer a highly useful, objective method of showing facts, relationships, and results in readily understandable maplike forms.

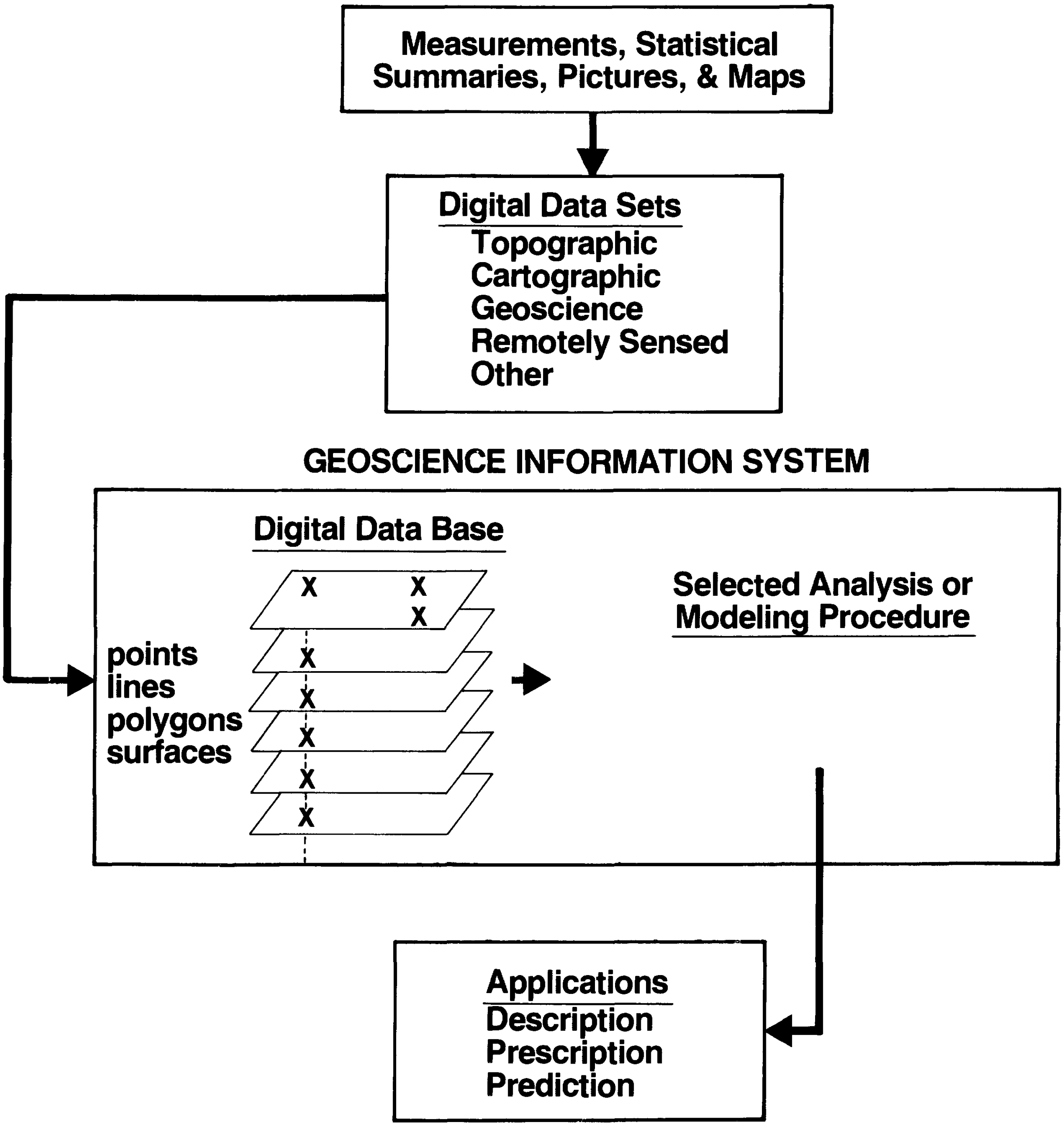


Figure 34.—A water resources information system shown as a multicategory, georeferenced digital data base that can be used for description, problem solving, and prediction in an area. It includes various data processing options in the available software.

TECHNICAL INSTRUCTIONS AND STANDARDS

USGS Digital Cartographic Data Standards

The last 2 years have witnessed a dramatic increase in digital cartographic data acquisition, processing, and applications and the Director of the Office of Management and Budget has issued a memorandum calling for coordination of the digital cartographic activities of all Federal agencies. One aim of this coordination effort was the establishment of data standards for content, format, and accuracy to aid in the multipurpose use and exchange of data. The USGS, and more specifically NMD, was identified as the lead agency in this coordination activity, and a two-level effort was initiated to develop standards. At the national level, the Federal Interagency Coordinating Committee on Digital Cartography was formed with representatives from 23 Federal agencies. Several working groups were formed within this committee, and a standards working group was established to provide for development and review of Federal digital cartographic data standards. The USGS also supports the work of the National Committee for Digital Cartographic Data Standards through the auspices of the American Congress on Surveying and Mapping (ACSM).

The USGS has completed and published seven chapters of Circular 895, USGS Digital Cartographic Data Standards. This circular provides an overview of USGS digital cartographic activities and describes the content and format of data currently being collected in the National Digital Cartographic Data Base (NDCDB). The information in these circulars is being updated and extended to cover additional data sets being added to the NDCDB and is being incorporated into the Technical Instructions which establish the digital cartographic standards applicable within NMD.

Technical Instructions for the National Mapping Program

Technical documentation of NMD products and services of the National Mapping Program is being prepared to update and expand the Manual of Technical Instructions, which sets forth policies, standards, and procedures. It includes:

- Standards - Documents which are used as the basis for establishing and judging the quality of NMD products and services. The core standards for cartographic products are the map symbol specifications and the National Map Accuracy Standards. In general, standards do not incorporate instructions as to how the standards are to be met. Such descriptions are left to Procedure Manuals. Portions of the following standards have been drafted or completed:

  - 1:24,000- and 1:25,000-scale Quadrangle Maps
  - 1:50,000- and 1:100,000-scale County Formatted Maps
  - 1:100,000-scale Quadrangle Maps
  - Land Use and Land Cover Maps and Digital Data
  - Digital Line Graphs
  - Digital Elevation Models

- Procedure Manuals – Procedure manuals provide guidelines for the production processes necessary to create products to meet the standards. Procedure manuals drafted or completed include:

  - Management of Scientific Computer Software
  - Calibration of Comparators
  - Calibration of Photogrammetric Cameras
  - Preparation of Satellite Image Maps

- Software Documentation – Software documentation provides the maintenance programmer with the information needed to understand a program, its operating environment, and required maintenance procedures. Existing divisionwide scientific software that has never been documented is now being documented with emphasis on programs that are used as subroutines in other programs or that interface with other programs. New software is documented by the programmer who develops it.

- Users Manuals – Users Manuals provide information in non-technical terms on how to use a program correctly, including how to prepare the input data, execute the program, and interpret the results. Users manuals are prepared by someone who understands how the program works.

- Data Users Guides – Data Users Guides provide the user or potential user with an overview of how the data were created and are structured.

OTHER ACTIVITIES

Geographic–Cartographic Applications Laboratory

The NMD has developed laboratory support to accomplish key research tasks. Many of these tasks are concerned with digital techniques, and a laboratory with integrated computer hardware and software and the personnel necessary for operation and maintenance has been established in the Office of Research. Because the demands of any given research project are, by the nature of research, largely unknown until the project is fairly well developed, two primary requirements of a research laboratory involve versatility and flexibility. These qualities should be reflected in all areas of the computing environments, but especially in operating systems, utility-type software support tools, communications, and varied peripheral support.

To satisfy the requirements in our key research areas, a wide range of graphic input, display, and output devices are required. Cartographic and geographic data are quite often voluminous for even a small study area, therefore, graphic manipulation and display functions can be extremely computer-intensive. A multi-processor environment with specialized workstations sharing the computing load, and communicating within a high-speed local area network, is the best architecture to meet our current research requirements.

The facility provides an environment for software development, hardware testing and evaluation, data applications, and demonstrations of technology. In addition to basic and applied research, the facility serves for evaluation of various pieces of equipment before procurements are made.

Equipment now installed or planned includes the following:

- Digital Equipment Corp. VAX 11/750 minicomputer, with
  - Ethernet local area networking
  - Tektronix 4115B color display terminal
  - Versatec electrostatic color matrix printer plotter
  - Sun graphics workstation
  - Intergraph workstation (MicroVAX II)
  - Altek Digitizer
- Data General S-140 minicomputer, with
  - Ramtek color image processor
  - Benson Matrix Plotter
- Data General 10SP Desktop microcomputer, with
  - Houston Instruments digitizer
  - Houston Instruments plotter

- Spectral Data RIPS image analysis system, with
  - 12 MB Winchester disk
- Five Cromemco microcomputer systems

Aerial-Camera Calibration Laboratory

The NMD Optical Science Laboratory continues to provide scientific-quality camera calibration services for the civilian mapping community and has been modernized with the installation of a microcomputer. Previously, calibration data were recorded on punched cards, which were then carried to the central Amdahl computer for processing. With the new system, the digitized data from the system digitizer are recorded and sorted in the microcomputer and are transmitted via phone line to a minicomputer for processing and output. The microcomputer is also used for formatting the camera calibration report, which is then printed on a letter-quality printer. All data bases are stored and updated in the microcomputer except the contractor camera calibration data base, which is still maintained on the Amdahl computer.

During the past year, calibrations have been performed on 98 aerial mapping cameras and five camera lenses submitted by such agencies as NASA Ames Research Center, Tennessee Valley Authority, USDA—Forest Service, Environmental Protection Agency, DMA—Inter-American Geodetic Survey, and private mapping contractors. Four Hasselblad cameras also were calibrated, two for the Forest Service and two for an engineering firm that is under contract with the Nuclear Regulatory Commission for monitoring the integrity of nuclear power plant structures.

Laser Optical Disk

Optical disk technology may offer significant advantages over conventional storage and retrieval devices. Magnetic tapes and disks normally degrade after 2 or 3 years, while optical disks are estimated to have a shelf life of at least 10 years. Optical technology also offers far higher data density, with a single 12-inch disk able to store up to 4×10^9 bytes of data—an amount equivalent to 25 6250 bpi magnetic tapes, or 2,000,000 pages of text. In the future large capacity disk libraries should be available to store and archive multiple disk data bases. Development efforts then will move toward improving the data structures, data access methodologies, and data processing procedures to efficiently use the technology in large geographic information systems.

Scientific and Technical Reference Collection

In 1982 the Office of Research established a reference collection to provide access to scientific and technical reports, publications, and information pertinent to its research aims. The functions of the reference collection, which supplements the USGS Library collections, are to: (1) provide and maintain a current collection of scientific and technical reference materials, (2) acquire new or additional materials and maintain them, and (3) provide reference services to NMD staff. An advisory committee offers assistance in acquisitions and policy decisions. The core of the reference collection consists of more than 2,000 volumes accumulated over a period of some years in the former Topographic Division and additional publications which have been added since 1982. The collection was weeded of some noncurrent publications, and is being classified and cataloged so that it can be used to better advantage.

The USGS library classification system is used to prepare catalog cards for all of the works in the collection. This classification system was also expanded to allow more detailed reference classes in the fields of computer sciences, cartography, remote sensing, space sciences, satellites and geography. To facilitate this project, a computer-based catalog was developed which can be used for preparing reference lists, bibliographies, and subject searches as well as for providing printed catalog cards.

A dBase II program was written as an experiment using an available Compustar with an attached 10 mb disk. The basic file structure, how many characters per bibliographic element to fulfill cataloging needs, and additional programming to enable us to print out catalog cards for main and subject entries for each item were determined. The program takes these data elements and structures them into standard library Anglo-American Cataloging Rules (AACR-II) catalog format in computer memory. Other command files then take the stored information and print out up to eight separate main entry and subject cards. The computer file that is produced as a byproduct of this operation is searchable by any of the terms in these elements. Another command file can structure the data into USGS bibliographic format (rather than AACR-II format) and can be used to prepare lists of research reports for publication.

During this period, all current holdings have been cataloged in the fields of cartography, computer sciences, and geography, and have been entered into the computer record with prepared catalog cards which are filed by author/editor and cross-referenced by title and subject.

A separate archival collection now includes a total of 860 reports, articles, and other publications by NMD personnel. All papers and technical reports prepared by NMD staff will be added, and this collection will continue to grow in value and usefulness. Some of the archival works are large enough to be filed on the shelf, but others, such as copies of published articles, must be filed in folders. A computer-record of the archives has been created and a card file, indexed by author, aids in using the collection. All of the works are indexed by author and by a sequential archival number.

The historical map collection, an archival collection of every map and map edition printed and published by the Division, has been moved into new space and additional map flat files have been acquired.

The Geographic Names Information System

The USGS has developed an automated national geographic names data base which gives the United States a single repository from which information for most known named geographic entities will eventually be available for use by all levels of government and the private sector. The system, known as the Geographic Names Information System (GNIS), is capable of retrieving, manipulating, arranging, and analyzing names information to meet the needs of a wide variety of users for either research or application. The system is maintained on a continuous basis and a variety of products are available including interim listings and topical files, which are also available as microfiche and on magnetic tapes. Interactive search and retrieval is available from USGS information facilities.

The National Gazetteer of the United States

The National Gazetteer series is being published, in cooperation with the U.S. Board on Geographic Names, as U.S. Geological Survey Professional Paper 1200, with each State and territory issued as a separate volume. Each volume is published after two phases of compilation. Phase I (complete for all States and territories) includes the compilation of most of the two million named features (except roads and highways) found on the large-scale topographic maps of the USGS. Phase II includes research and compilation from other Federal and State sources as well as historical material. In 1982, New Jersey was the first volume published in the Gazetteer series. Volumes for Delaware and Kansas have been published, and Arizona and Indiana are scheduled for publication in 1985. An abridged, or concise, volume containing the major populated places, physical features, and other key entries is also scheduled for publication in 1985. Currently, research and compilation on volumes for Oregon, South Dakota, North Dakota, Iowa, Florida, Idaho, Alabama, and Mississippi is underway. Each gazetteer contains official, unofficial, and historical geographic names listed in alphabetical order. Variant names are cross-referenced to official or primary name listings, and each entry also includes information on the type of feature, official status of the name, county in which it is located, geographic coordinates (including sources of linear features), elevation of place or feature, and the name of the topographic map on which the feature is found.

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