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RESOURCE MAPPING BY LANDSATS IN DEVELOPING COUNTRIES

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ABSTRACT

The objective of this paper is to describe a methodology of resource mapping based on Landsat multispectral images, with particular emphasis on its application in developing countries. Their faster economic development depends, to a large extent, on the availability of reliable inventories of natural resources. A practical example from Indonesia has been selected to demonstrate how the use of Landsat images can significantly speed-up completion of the reconnaissance stage of resource inventories and provide a basis for planning more detailed surveys.

Described are the main tasks in resource mapping based on Landsat multispectral images, incl. analog and computer-assisted methods of image processing, cartographic processing and accuracy evaluation. Integration of these tasks and available options are presented in system flowcharts. Discussion includes the expected impact of remote sensing from land resources satellites on resource mapping and the appropriateness of satellite-based resource mapping technology for developing countries.

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INTRODUCTION

Resource mapping is a task of high priority in all developing countries. Their economic infrastructure is based on natural resources and related primary industries, such as agriculture, forestry, mining and fishing. Completion of resource inventories and their continuing revisions are prerequisites for the rational planning of their more rapid economic development.

The objective of this paper is to discuss a methodology of vegetation and land-use mapping, based on multispectral images recorded by the land resources satellites, Landsats. Although the first Landsat was launched in 1972, the operational utilization of Landsat images has been below the expected rate, even in regions where these data represent the only up-to-date records of the area. It is postulated that an increase in their utilization and thus their usefulness, will ultimately depend on our ability to transform the image data into information describing particular resources in terms of their type (class), condition and location. Such a transformation is best achieved through the process of thematic mapping.

Landsat images are available either in photographic format, printed on film or paper, or in digital format, recorded on computer compatible tapes. At present, most of the users of Landsat images, such as geologists, foresters, agronomists, regional planners, etc., do not have the facilities needed for digital image processing. Yet the information content of digital image data is far superior to that of film images, because the latter are degraded during each photographic reproduction. The thematic information about forest and agricultural lands, derived from the Landsat multispectral digital images is compatible, in terms of map content and its geometric accuracy, with the 1:250 000 scale, while thematic information derived from film images is compatible with 1:1 000 000 scale only. This restricts the application of Landsat film images to the most general, reconnaissance resource mapping.

Another constraint limiting the use of Landsat-based thematic mapping technology, is the lack of professional manpower with remote sensing expertise in most developing countries. It is often forgotten that application of remote sensing to resource mapping and inventories can be learned only to a limited extent in countries with entirely different environmental and economic conditions, and thus with entirely different requirements from thematic mapping. Consequently, those who were trained in applications of remote sensing abroad, often find that the methodology they learned is of little use when they get back home.

Selection of thematic mapping techniques for inventories of natural resources depends on the type of resources and their development priorities, as well as on the prevailing climatic conditions. For example, mapping of the tropical rain forest with hundreds of tree species in an area of few hectars, high density of crown canopy and several levels of understorey, will require different remote sensing techniques than mapping of the single-storeyed forest with about twenty well defined tree species present, as is usual in the temperate climatic zone. (Allen R., 1975; Howard, 1976-b; Piran Wiroatmodjo, 1978; Sayn-Wittgenstein et al., 1978). Similarly, microwave remote sensing systems, such as imaging radar, capable of recording the earth surface through the clouds, will have a special appeal in regions where clouds occur most of the year, although their images may be more difficult to interpret than those recorded in the visible or near-infrared portions of the electromagnetic spectrum. (Allen P.E.T., 1975; Gelnett et al., 1978; van Roessel & de Godoy, 1974).

LAND RESOURCES SATELLITES - LANDSATS

An important requirement for the operational utilization of satellite remote sensing in thematic mapping is the continuity of the land resources satellite program and its technological as well as pricing stability. (Frosch, 1979; Hempenius et al., 1976; Kalensky et al., 1977). While the continuation of the Landsat program has been assured by a recent decision of the President of the United States (Brzezinski, 1979), the technological parameters (in particular the orbits of the satellite platforms and sensors) and the pricing policies are still far from a desirable degree of stability. The developing countries would be well advised to build their own facilities for receiving and processing Landsat images, provided that their areas and potential applications justify it, rather than depending on the U.S. or regional image supply and processing services. Costs of Landsat ground receiving stations and image processing systems have decreased to levels at which their acquisition can be justified by national resource mapping programs alone.

Caution should be exercised in selection of these systems to assure that they are compatible with the parameters of Landsat-D, planned for launching in the second half of 1981. This new, advanced land resources satellite will form a transitional stage between experimental and fully operational systems (Covault, 1979). Its remote sensing payload will consist of a global satellite positioning system and of two line scanning systems: the four-band multispectral scanner (MSS), with the same spatial and spectral parameters as the MSS of Landsats 1&2, and the seven-band Thematic Mapper (TM). Three TM bands will be in the visible, three in the solar infrared and one in the thermal infrared portions of the electromagnetic spectrum. These will enable spectral discrimination of more vegetation and land-use classes than MSS. Their nominal ground resolution (pixel size) will be 30m x 30m in the visible and solar infrared bands and 120m x 120m in the thermal infrared band. The MSS ground pixel size is 79m x 79m. The orbital altitude of Landsat-D will be 700 km, that is 200 km lower than the altitudes of Landsats 1,2&3. The lower orbital altitude will facilitate servicing of Landsat-D by shuttle and will yield the 30m ground resolution. On the negative side, the lower orbital altitude will reduce coverage of the ground receiving stations and size of the MSS scenes. The operational range of a 10m antenna with 5° horizon clearance will be reduced from 2 600 km to 2 200 km. Thus part of the territory covered by ground receiving stations at present will lose coverage unless the antennas are modified or supplemented. Another important change is selection of X-band frequency for TM data transmission at the rate of 90 megabits per second, in order to accommodate the increased volume of data. The S-band frequency, used by Landsats 1,2&3, will be retained for transmission of MSS data at the present rate of 15 megabits per second, although the MSS data can also be transmitted at the X-band. (Bracken et al., 1979.)

Landsat ground receiving stations covering developing countries are at present in Australia (Papua-New Guinea and part of Indonesia), Brazil, India, Italy (northern part of Africa), Japan (North and South Koreas) and U.S.A. (Mexico). The Landsat station in Iran was closed, after a brief operating period, in January 1979 as a result of the political situation in that country. There was a temporary Landsat station in Pakistan used for monitoring agricultural crops. A new Landsat station in Argentina is expected to become operational in 1980. (CCRS, 1978-1979; Hempenius, 1978; NASA, 1975-1979; Taranik, 1978; U.S. Dept. of Interior & NASA, 1978-1980).

RESOURCE MAPPING FROM LANDSAT IMAGES

Most developing countries have at least one good quality Landsat coverage of the whole territory. These images usually represent the most recent record of vegetation and land-use patterns and their disturbances. Yet, they are of little use if they are not interpreted, transformed to a location-specific data base and displayed in an easily readable format. In many applications this will be best achieved through the process of thematic mapping.

The usefulness of satellite remote sensing in resource mapping and inventories is greatly increased if it constitutes part of a multistage remote sensing system. Such a concept is similar to that of a statistical sampling design and follows the golden surveying rule: "From general to particular". Landsat images provide synoptic overviews of large areas and thus facilitate planning of more detailed surveys by aerial photography. This may be complemented by other remote sensors, such as SLAR or thermal radiometers and, ultimately, by field sampling. The configuration of a multistage remote sensing design will depend on the objectives of the particular applications, climatic conditions, availability of remote sensing and data processing systems and on the cost-effectiveness of various options. (D'Audretsch, 1978; Gimbarzevsky, 1973; Howard, 1976-a & -c; Kalensky & Wightman, 1976; Kaser, 1977; Kondratyev et al., 1979; Michel, 1979; Sayn-Wittgenstein, 1976.)

Our discussion will be limited to the first, reconnaissance stage of resource surveys and mapping, for which Landsat images provide the main input data. Resource maps produced at this stage range in scale from 1:1 000 000, if they are compiled from Landsat-1,2 or 3 film images, to 1:250 000, if digital images and computer-assisted processing are used. The 1:250 000 scale provides a practical mapping limit, in terms of thematic content and geometric accuracy for present Landsats and image processing methods. (Fleming, 1976; Kratky, 1974; Leatherdale, 1978; Orth et al., 1978-a; Strome et al., 1978.) Further increase of mapping scale would not reveal more information and thus would not be compatible with the map content, even if the lower geometric accuracy were acceptable. In 1974, the most recent year for which a global mapping census is available, the mapping coverage at 1:250 000 scale was 66% in Africa, 90% in Asia and 19% in South America (Brandenberger, 1976). Most of these maps were compiled as line maps from aerial photographs taken during the nineteen-forties. Their quality varies widely and the thematic data on vegetation are often incomplete or missing. Furthermore, small scale line maps do not provide enough cartographic detail in remote areas with little or no cultural features, where resource mapping in developing countries so often takes place. Completion of national mapping coverage at 1:250 000 scale should be high on the list of priorities of any developing country. Suitability of Landsat images for this task has been demonstrated by number of pilot studies (Braconne et al., 1979; Kalensky et al., 1978; Orth et al., 1978-b).

A schematic flowchart of resource mapping based on remote sensing is shown in Fig. 1. It expresses the interrelationships between the following main tasks:

1. Resource management.
   - Specifications for required resource information;
   - Time and budget constraints.

2. Remote sensing project management.
   - Project formulation; specifications for remote sensing and cartographic tasks; supervision.

3. Data acquisition.
   - Existing data (aerial photographs, maps, resource inventories);
   - New data (Landsat images, new aerial photographs, SLAR, field surveys in sample areas).

4. Image processing (analog or computer-assisted).
   - Transformation of image data into the resource information (radiometric and geometric corrections, image enhancement, classification and coding).

5. Cartographic processing (analog or computer-assisted).
   - Transformation of resource information into maps and location-specific resource statistics (compilation of a base map and thematic overlays, cartographic reproduction and printing, tabulation of statistical summaries, accuracy analysis).

While the first four tasks are part of every remote sensing project applied to resource mapping, the cartographic processing has often been neglected. Annotated hard-copy products of image processing, such as photographically or digitally processed color film images, with colors corresponding to ground scene classes or features, have been the final results of most pilot projects up-to-date. Their utility for operational resource management is limited, even if they were geometrically rectified and overprinted with a coordinate grid. One of the reasons is the lack of direct correspondence between Landsat scene classes and the thematic map content required by resource management. Some of the map content cannot be obtained from Landsat data and has to be added during the cartographic processing (e.g. land ownership, land improvements, scheduling of crop rotations or forest logging, etc.). Routine cartographic completion includes mosaicking of Landsat scenes into standard map sheet formats, enhancement of selected features (roads, pipelines, hydrolines, shorelines, administrative borders, etc.), map annotation, frame and legend.

An important part in the cartographic processing of resource maps is the preparation of a base map. In the past, most thematic maps were based on scaled topographic line maps. However, photomaps have gradually gained acceptance as the preferred medium for the display of results of resource inventories. Their advantages are manifold. They display the recorded scene without any generalization. Hence the map content is determined by ground resolution and spectral sensitivity of the remote sensing system and by the timing of data recording (selection of particular climatic season or phenological stage of vegetation), rather than by a cartographer's decision. Although the original image data are degraded by the time they are displayed on printed maps, they still offer infinitely more information about the ground scene than line maps and thus broaden the range of their potential applications. The advantages of photomaps are particularly distinct in those areas with little or no cultural features. If most of the area covered by a map sheet consists of forest or grassland, there is little cartographic information displayed on a line map besides contours, rivers and lakes. On the other hand, a photomap displays variations in forest types, old burns, erosion patterns, etc., which may be used as landmarks for orientation during field surveys and which facilitate the transfer of interpreted data from aerial photographs to maps.

Cartographic applications of satellite remote sensing will be greatly enhanced by the Spacelab Metric Camera mission, planned for 1981. Spacelab is a multipurpose space laboratory which will be carried by the space shuttle. The metric camera will use a high resolution photographic film which will be returned to the ground for processing. Photographs will be taken with 60% to 80% overlap at the scale of 1:820 000. Ground resolution corresponding to one line-pair (lp), out of the expected average image resolution of at least 30 lp/mm, is 30m which is equal to the nominal ground resolution of the Landsat-D Thematic Mapper. Each photograph will record a ground area of approx. 190 km x 190 km in size. (ESA, 1978; Konecny, 1978.) For areas without clouds, these photographs will provide an ideal input for compilation of orthophoto base maps for resource mapping. Depending on the film-filter combination, type of vegetative cover, land-use patterns and image quality, they will be compatible with resource mapping at scales of 1:250 000 to 1:100 000, possibly 1:50 000.

A system flowchart for resource mapping based on Landsat film images is shown in Fig. 2. The advantage of this approach is the low cost and easy availability of Landsat film images. In addition, their further photographic processing (enlargement, enhancement, color composite printing) can be done in any well equipped photointerpretation laboratory. Interpretation of Landsat multispectral film images would be greatly assisted by the availability of a color additive viewer. It enables their optical registration, enlargement and color enhancement. Some models are equipped with drafting and photo-reproduction attachments. (Hilwig, 1979; Murtha, 1977; Parry, 1978.)

A system flowchart for resource mapping based on Landsat digital images and their computer-assisted processing is shown in Fig. 3. The advantage of using this approach is that it enables the extraction of the most information data recorded by the multispectral scanner. Once the video signals are digitized on board the satellite, there is no further image degradation. In addition, the digital techniques provide more flexibility in image enhancement and enable classification of the recorded scene based on the statistical distribution of multispectral image data. (Hoffer, 1976; Kalensky, 1974 & 1976; Swain & Davis, eds., 1978.)

The decision whether to use the Landsat film or digital images and processing techniques will depend on the particular application, its budget, available equipment and expertise.

APPLICATION OF LANDSAT IMAGES TO RESOURCE MAPPING IN INDONESIA

The Government of Indonesia, responding to the lack of reliable resource inventories, has started a program of comprehensive resource mapping of the whole country. The project is unique because of its size, concept and mapping technology.

The Indonesian archipelago consists of some 13,660 islands extending 5 100 km along the equator and covering a land area of nearly 2 million km^2. Terrain topography ranges from tidal swamps to mountains over 5 000m high. This diversity of topography is matched by great variations in geology, soils, vegetation, land-use patterns and climate.

The specialized resource agencies, traditionally entrusted with the responsibility for resource mapping, could not alone undertake such a large mapping project. Hence a new resource mapping concept, based on cooperation between mapping and resource agencies, has been adopted. The mapping agency is responsible for procurement of the images, preparation of a base map and for cartographic completion and printing of thematic maps. The resource agencies are responsible for the interpretation of images and the compilation of thematic overlays for the base maps.

Such a production-sharing arrangement results in higher quality as each agency is doing only that part of the work for which it is best qualified: the mapping agency is looking after the mapping aspects, the resource agencies are responsible for the thematic content of resource maps. It also facilitates standardization of mapping production, map formats and accuracy criteria. Particularly important for developing countries is the elimination of duplicity in the number of map production tasks, such as compilation of base maps and cartographic completion of resource maps.

The mapping technology is based on multistage and multispectral remote sensing, including Landsat MSS, SLAR, high and medium altitude aerial photography with a dual camera system. The primary mapping scale is 1:50 000 (1:25 000 for densely populated Java, Madura and Bali). The orthophoto base maps are overprinted with forest, agricultural, pedologic, geologic and land-use/land capability data, compiled by the respective resource agencies. Resource photomaps at 1:250 000 scale precede the medium scale mapping in areas with good quality Landsat images. In regions covered most of the year by clouds, the 1:250 000 mapping is based on SLAR mosaicks.

Mapping control is provided by Doppler satellite positioning and densified with aerial triangulation. Supplementary vertical control is obtained by the airborne profile recorder (APR).

The orthophoto base maps for 1:50 000 mapping are compiled from panchromatic aerial photographs at approx. 1:100 000 photoscale. The resource data are interpreted from color-infrared photographs at approx. 1:60 000 photoscale, taken simultaneously with the panchromatic photography.

An important part of the Indonesian resource mapping project is the establishment of the National Environmental Geographic Information System (NEGIS). Addressed by the geographic or U.T.M. coordinates, it prints listings of all the records relevant to resource mapping and inventories (type of survey, scale, date, etc.) and the resource descriptors. (Asmoro, 1976, 1978-a & b; Asmoro et al., 1978.)

The first Landsat-based resource map at 1:250 000 scale was produced within the framework of this project for the Lombok Island. The standard map sheet format of 1° in latitude and 1.5° in longitude was obtained by mosaicking images of two Landsat scenes. Geometrically corrected multispectral images of band 7 (the second solar-IR) were selected for compilation of the base map because they provided the best overall image contrast.

Input data for computer-assisted interpretation of vegetation and land-use classes consisted of Landsat MSS digital images recorded at two dates and of sample aerial photographs at 1:50 000 scale. These data were further supplemented by small format aerial photography of selected areas, taken with a hand-held camera from a low flying aircraft and by spot ground checks.

Supervised scene classification, using the Gaussian maximum likelihood algorithm, was done with a digital image processing system ARIES of the Canadian Forestry Service. The Lombok Island scene was categorized into the following nine classes: primary forest; secondary forest; coconut plantations; bush and scattered shrubs; dry fields; rain-fed rice fields; irrigated rice fields; water; others (clouds and unclassified). The categorized data were color-coded and printed on 70mm color film by a digital film recorder DICOMED. Optical enlargements of the 70mm "thematic" images were used for compilation of thematic overlay which was overprinted on the base map.

The accuracy analysis consisted of evaluation of the classification and mapping accuracies. The classification (statistical) accuracy provides an estimate of the error in the size of each class. The mapping (positional) accuracy provides an estimate of the class displacement. (Kalensky & Scherk, 1975.) The overall classification accuracy for the eight Lombok Island ground classes was 83%, the overall mapping accuracy 74% (Kalensky et al., 1978).

The obtained results proved the usefulness and the practicality of Landsat-based vegetation and land-use mapping at 1:250 000 scale. Furthermore, the geometrically corrected and scaled Landsat images also enabled revisions of shorelines and small islands on topographic maps.

CONCLUSION

In the past, resource mapping has been neglected by the professional mapping community and left in charge of the drafting sections of resource institutes. That was acceptable when resources were plentiful, or so we thought. This situation is now changing because of the higher quality requirements of resource maps, their more frequent revisions and their compatibility with location-specific resource data banks. In the years to come, resource mapping will have the same priority as topographic mapping has always had.

We are at the threshold of a fundamental change in the technology of resource mapping. New, advanced methods of satellite remote sensing and computer-assisted image data processing will play an increasingly important role. What is now needed is the integration of knowledge in the fields of remote sensing, photogrammetry and cartography in order to speed up production and to increase the quality of resource maps.

In the first few years of the Landsat program, opinions were sharply divided about its usefulness for resource mapping and inventories. On one hand, there was the uncritical enthusiasm, accompanied by claims of near-perfect accuracy in the classification of detailed vegetation classes, such as tree species and of the compatibility of Landsat-derived thematic maps with 1:50 000 scale. On the other hand, there was a refusal to even consider a dynamic imaging system, such as the Landsat MSS, for mapping. At the present time, eight years after launching of the first Landsat, resource mapping and change monitoring from space platforms have been accepted and applied in most countries regardless of their stage of development. Yet the developing countries stand to benefit most from this new technology. They urgently need reliable resource inventories and maps to provide a basis for more rapid, geographically balanced and ecologically sound economic development. Large countries, like Indonesia, cannot hope to achieve this goal by using outdated surveying and mapping techniques.

An opinion is often voiced that a new technology should be introduced as gradually to the developing countries as it was to the industrialised ones. We are being advised that the old, labor intensive, low productivity methodologies are the most suitable ones for developing countries, because they provide employment for a larger number of people, with a lower standard of education and skills. Such a policy, if adopted, would unnecessarily prolong the misery of the majority of people in the developing countries. Limiting the access to the benefits of the most advanced technology would further contribute to the ever increasing gap in living standards between the industrial and developing countries. Instead of sharing our resources, both natural and man-made, for the benefit of all, still more walls would be erected for the benefit of none.

Satellite remote sensing is the product of the most advanced space technology available to man. It is to the credit of the United States that they underwrote the tremendous investment needed by this program and let any country to use its results. It does not provide magic solutions to any of the problems plaguing our planet. Nevertheless, multistage remote sensing, which includes recording of the Earth's surface from satellites as well as from aircraft at gradually increasing scales, is an efficient method which speeds-up the mapping of natural resources and enables near-real time monitoring of their changes. Indeed, it is the only method which makes possible completion of comprehensive resource mapping programs in developing countries within the life-span of this generation. (Arnold, 1978; DuBois & Bruce, 1978; Hossain, 1978; Morley, 1977.)

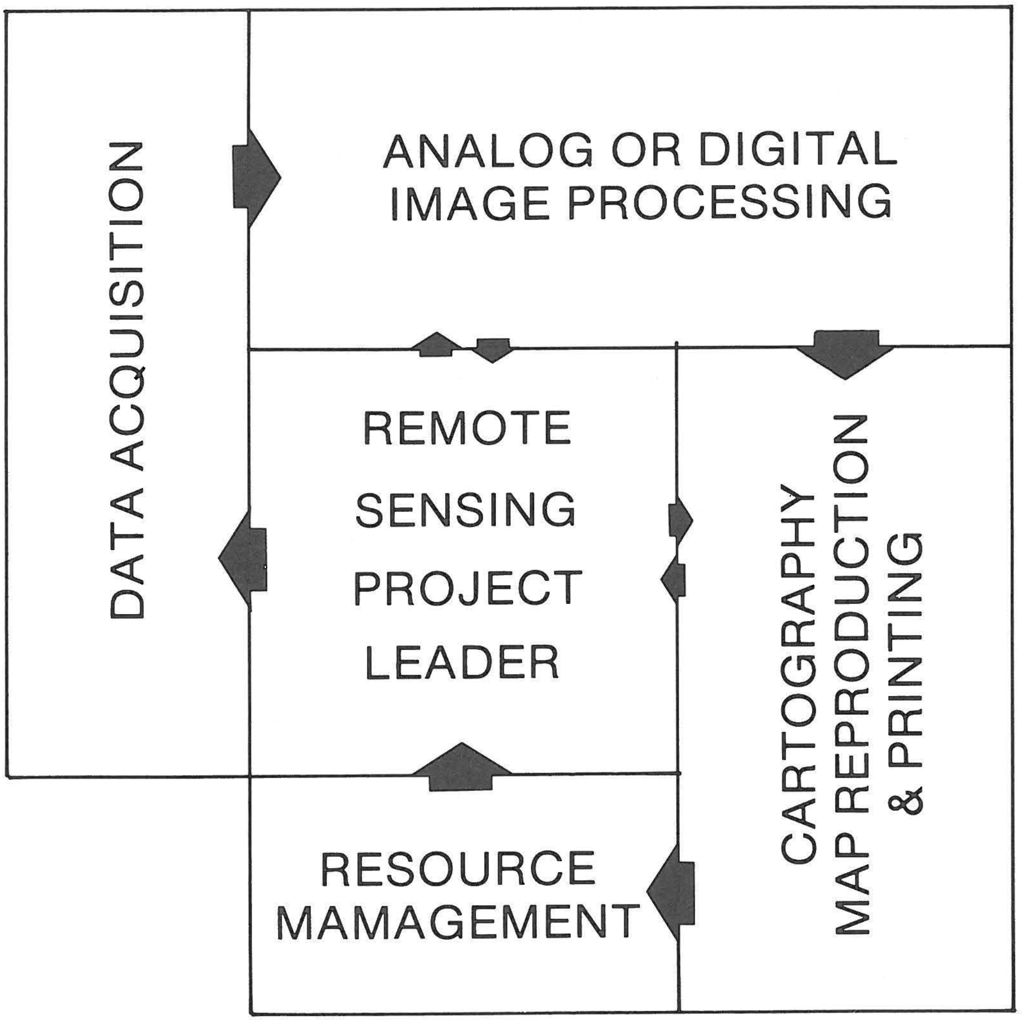

FIG. 1. SCHEMATIC FLOWCHART OF OPERATIONS IN RESOURCE MAPPING BY REMOTE SENSING

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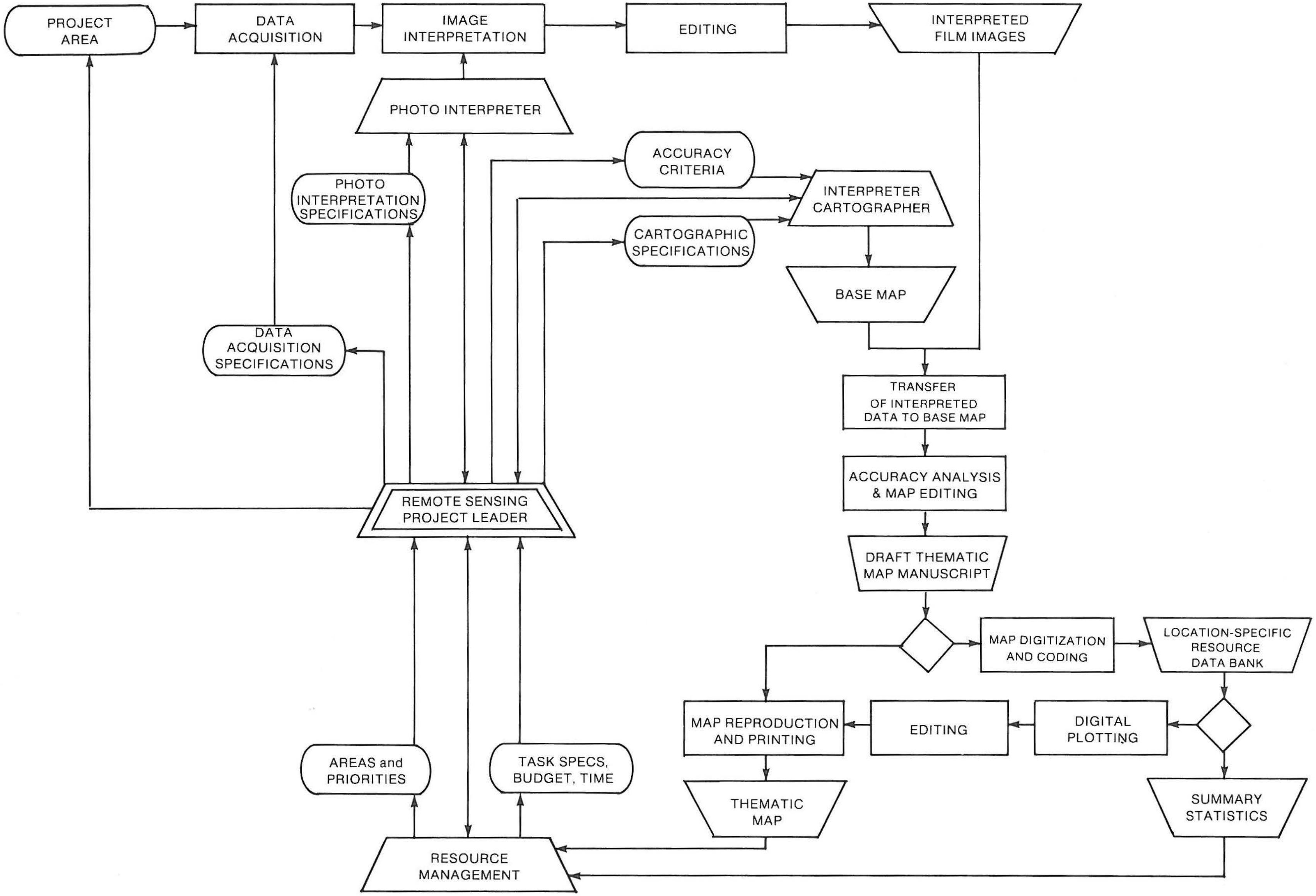

FIG. 2. SYSTEM FLOWCHART FOR METHODOLOGY OF RESOURCE MAPPING FROM FILM IMAGES

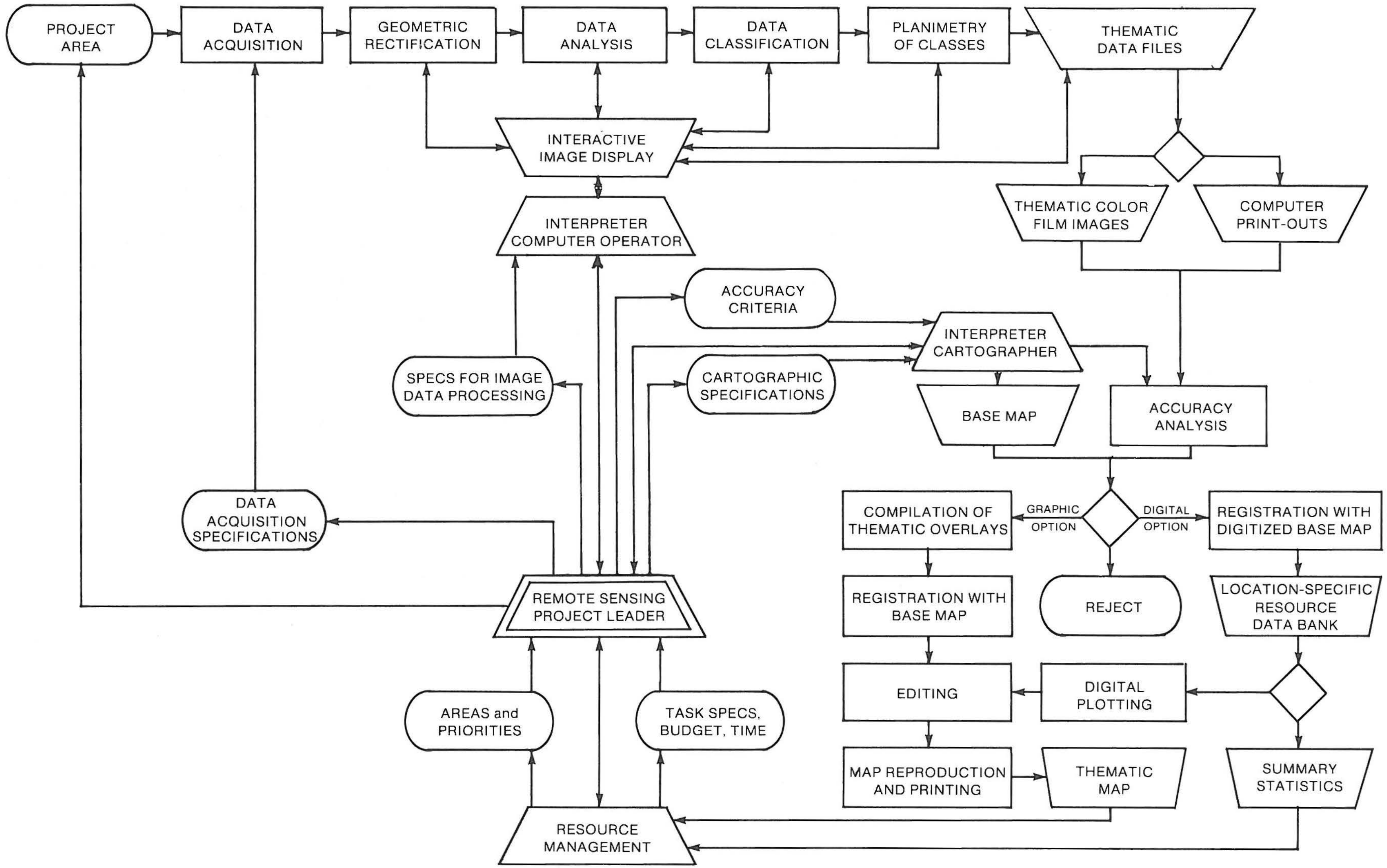

FIG. 3. SYSTEM FLOWCHART FOR METHODOLOGY OF RESOURCE MAPPING FROM DIGITAL IMAGE DATA