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AID'S REMOTE SENSING GRANT PROGRAM

THOMAS W. WAGNER & DONALD S. LOWE
Applications Division

AUGUST 1978

Agency for International Development
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16. Abstract

This report describes the administration and results of a three-year small grant program to transfer remote sensing technology to ten developing countries. The program included: (1) awarding financial grants to investigators in developing countries, (2) providing technical assistance to those investigators, and (3) carrying out several special studies at AID's request. The ten countries that had grant projects selected on the basis of competitive proposals were Bangladesh, Bolivia, Chile, Lesotho, Pakistan, Peru, Philippines, Sri Lanka, Thailand, and Zaire. Each of the grant projects was different in its focus and results. Seven of the ten projects were successfully concluded, and, in general, the grant approach was an appropriate mechanism for transferring this technology. The four special studies concerned (1) remote sensing in Africa, (2) the Upper Volta Regional Center, (3) AID's requirements for a Landsat follow-on system, and (4) the use of remote sensing to obtain agricultural crop statistics in developing countries.

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PAKISTAN
BANGLADESH
THAILAND
PHILIPPINES
SRI LANKA
ZAIRE
LESOTHO
PERU
BOLIVIA
CHILE
AID GRANT COUNTRIES

PREFACE

This report summarizes a three-year program sponsored by the U.S. Agency for International Development (AID) to assist developing countries in testing and evaluating remote sensing techniques for varied natural resource assessment and planning activities. The program involved: (1) awards of financial grants to investigators in developing countries; and (2) provision of technical assistance to these investigators. It also included carrying out special studies at the request of the Office of Science and Technology of AID's Development Support Bureau (formerly the Technical Assistance Bureau).

The program was initiated in 1974 by the Environmental Research Institute of Michigan (ERIM) in cooperation with System Planning Corporation (SPC). In 1975 ERIM assumed entire responsibility for the program under the direction of Mr. Donald S. Lowe, Director of ERIM's Applications Division.

Numerous people contributed to this program in various capacities. These people include Robert Summers (formerly of SPC) and William Smith (formerly of SPC and ERIM), as well as several people from ERIM: Raymond Laurin, Fabian Polcyn, Franklin Sadowski, and Thomas Wagner, under the supervision of Frederick Thomson; in addition, John Colwell, Jerald Cook, and Laurence Istvan contributed to special AID studies, while Elaine Marinello, Diana Rebel, Norman Roller, and Harvey Wagner conducted important data analysis tasks.

Primary credit for the success of this program is due the Principal Investigators (grantees) in the ten countries which received AID grants, who diligently pursued projects to use remote sensing data for their countries' development. Thanks are also extended to the many host country officials

and AID Representatives who encouraged and assisted these investigators in their tasks.

Finally, we wish to acknowledge the valuable assistance, guidance, and counseling of Mr. Henry Arnold, Mr. Merrill Conitz, and Dr. Charles Paul of AID's Office of Science and Tehnology in the conduct of this program. The latter two served as AID's technical monitors for this program.

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1
GRANT PROGRAM OVERVIEW

1.1 INTRODUCTION

In August 1974 the Environmental Research Institute of Michigan, in cooperation with System Planning Corporation and Mathematica, Incorporated, published a comprehensive two-volume report for AID detailing the significant economic contributions that U.S. satellite data can make to developing countries [1]. The report cited substantial quantitative benefits of using Landsat data for a variety of applications - including crop forecasting, range management, mineral exploration, water resources management, and cartographic mapping. The report strongly urged AID to encourage and support projects applying the use of satellite data in developing countries, particularly pilot projects that (1) were "directed toward national problems identified by knowledgeable people within each country", (2) had nationals actively involved, and (3) were supported by suitable training and technical assistance. The AID Grant Program described here was a result of that recommendation.

The purpose of the grant program was to support the establishment of an indigenous capability in developing countries to obtain and use appropriate remote sensing technology. In instituting the grant program it was recognized that developing country planners and scientists are frequently in the best position to determine their country's priority development needs and whether remote sensing is likely to contribute to them. This program provided small grant awards and technical assistance (training, procurement of equipment and supplies) to developing country investigators for the pursuit of remote sensing application projects in their local agencies or institutions.

Ten grants were selected on a competitive basis from twenty-five proposals submitted to a committee composed of remote sensing specialists from AID, U.S. Geological Survey, National Aeronautics and Space Administrations, SPC, and ERIM. Table 1 lists the countries and the principal investigators (grantees) and organizations of the grant program.

Table 1

AID GRANTS

Country	Grantee
Bangladesh	Prof. M.I. Chowdhury, Chairman Dept. of Geography, Jahangirnagar Univ., Savar, Dacca
Bolivia	Dr. Carlos Brockman, Director Program de Satelite Technologio de Recursos, GEOBOL, La Paz
Chile	Messrs. German Errazuriz & Arnoldo Ortiz R Instituto de Investigacion de Recursos Naturales, CORFO, Santiago
Lesotho	Messrs. Anthony Jackson & Edwin M. Seitlheko Biology Dept., National University of Lesotho, Roma
Pakistan	Dr. M. Shafi Ahmad, Director SPARCENT, Pakistan Space & Upper Atmosphere Research Committee (SUPARCO), Karachi
Peru	Mr. Walter Danjoy Arias Oficina Nacional de Evaluacion de Recursos Naturales (ONERN), Lima
Philippines	Mr. J.C. Fernandez, Director Bureau of Mines, Dept. of Natural Resources, Manila
Sri Lanka	Mr. Chris Nanayakkara, Deputy Surveyor General Survey Department, Ministry of Agriculture & Lands, Colombo
Thailand	Dr. Somnuk Striplung, Director Division of Agricultural Economics, Ministry of Agriculture & Cooperatives, Bangkok
Zaire	Dr. Sendwe Ilunga, Director ERTS-Zaire, Bureau du President, Kinshasa

In addition to administering these grants, ERIM was asked to conduct several special studies during the program covering various issues of importance to AID in its expanding role in the international remote sensing community. Detailed summaries of the studies are contained in Appendix B.

1.2 RESULTS

The most significant findings and results of the program are listed below. The remaining sections of this report, including the appendices, provide additional background and detail on the conduct of the program. The summary below highlights the outcome of the grant program in terms of how it was designed and administered, and what was accomplished both technically and institutionally.

1.2.1 OVERALL PROGRAM SUCCESS

In general, the grant program was highly successful. Since early 1975 scientists from ten countries have had an opportunity to design, conduct, and evaluate the use of remote sensing in connection with their individual resource planning and assessment programs. While a detailed summary of the individual country projects is presented in Section 2, the following results characterize both the scope and quality of accomplishments achieved under this program. (Table 2 presents an overview of the objectives and accomplishments in each country.)

1. Seven of the ten projects are judged as either successful or highly successful - that is they met the original goals and in several instances greatly exceeded expectations. One grant is listed as probably successful, but information is currently incomplete.
2. In the two cases where grant objectives were not met, unforseeable circumstances such as personnel changes and problems in acquiring needed data and materials hampered attempts to complete those projects.
3. Grant projects completed to date provide clear evidence that remote sensing, especially with Landsat data, can supply diverse and useful information for developing countries. The successful projects include applications to agriculture,

Table 2. OVERVIEW OF

Country	Discipline	Purpose
Bangladesh	Agriculture	Obtain agricultural area and land-use information for optimal development of haor areas of northeastern Bangladesh.
Bolivia	Geology	Identify and delineate areas of significance for exploration of iron-rich formations in eastern Bolivia.
Chile	Regional Planning	Update maps and inventory resources of Tarapaca and Antofagasta Provinces of northern Chile.
Lesotho	Agriculture	Investigate snowfall, drainage patterns, and vegetation distribution in relation to needs for soil conservation.
Pakistan	Coastal Development	Provide vegetation and coastal data required for planning new port development on the Indus Delta.
Peru	Forestry	Map forest communities and identify economically important Aguaje Palm stands.
Philippines	Geology	Provide forest, agricultural, and geological information for Mindoro Island.
Sri Lanka	Agriculture	Develop and demonstrate techniques for obtaining quantitative information concerning crop production in Sri Lanka.
Thailand	Agriculture	Provide crop-signature and acreage information in connection with annual agricultural surveys.
Zaire	Cartography	Demonstrate annotated Landsat images for use as map substitutes.

AID GRANT PROJECTS

Results	Assessment
•Boro rice and Rabi crop information obtained for 1975 winter crop season. •Stream and pond network delineated for haor areas. •Information useful for regional and local planning.	Complete Successful
•Geological outcrop areas identified and delineated in two study-area locations. •Digital image-enhancement useful for geological reconnaissance.	Complete Successful
•Revised maps published for geology, geomorphology, hydrology, land-use, vegetation, and natural drainage. •Methology being applied to other provinces.	Complete Very Successful
•Detailed drainage map digitized and reproduced.	Complete Limited Success
•Detailed maps and images used to identify Mangrove and agricultural areas, coastal sedimentation, salt water intrusion, and current patterns.	Complete Successful
•Areal extent and acreage of Aguaje Palm and other lowland forest communities obtained for two test sites.	Complete Very Successful
•Important new geological information mapped from Landsat images of Mindoro. •Forest area shown to be rapidly depleting.	Complete Successful
•Digital analysis system operational in Colombo. •Grant provided basis for establishment of new Remote Sensing Center.	Complete Very Successful
•Extensive crop information collected and imagery examined. •Results form basis for continuing research.	Complete Partly Successful
•Four annotated image-maps produced. •Photo-mapping facilities repaired and operating. •Survey activities continuing.	Incomplete

cartography, forestry, geology, and coastal zone monitoring.

4. The ingredients for successful grant projects proved to be high-level management support, an enthusiastic and resourceful investigator (grantee), and involvement in operational programs of prime concern to the country.
5. The grant projects were designed to be short-term, low-budget activities. Therefore most were completed within a two-year period and in a very cost-effective manner. No more than $20,000 was available as a cash award to any one grantee; several received considerably less.
6. No "ideal" institutional arrangement appreared as a model for effective and successful grant implementation - different countries had different needs and ways of getting things done.
7. The assignment of different ERIM staff to coordinate and support specific projects worked well throughout the program. This allowed these individuals time to concentrate on specific user programs and problems, and develop necessary rapport with the grantees.
8. Over a dozen professional publications, and considerably more workshop and seminar presentations, have been produced by the investigators as a direct result of this program (See Table A-2).
9. In almost all instances remote sensing activity has continued within the grantees' institutions since the conclusion of the projects - these appear to be valuable and self-sustaining activities.
10. Almost all of the grantees' countries have recognized and are supporting remote sensing programs at the national level. The AID grants have either initiated or contributed to these national efforts.

1.2.2 GRANT PROJECT FORMULATION

The grant program required investigators to design and administer

their own projects, and to seek assistance (technical support, training, equipment, etc.) as each grantee felt necessary. The approach was consistent with the objective of giving grantees the opportunity, as well as the responsibility, to evaluate the technology and integrate remote sensing into the technical and institutional framework of their respective countries. This process, on balance, has worked well under this program.

1.2.3 GRANT ADMINISTRATION

ERIM provided the overall grant administration on behalf of AID. ERIM staff provided direct technical assistance to the countries as required, planned and conducted varied training programs both in-country and in the U.S., acted as a procurement agency for needed equipment and supplies, and assisted AID staff on specific assignments. This arrangement greatly facilitated the timely planning, conducting, and successful conclusion of such an administratively complex program.

1.2.4 SPECIAL STUDIES

ERIM conducted four special studies (see Appendix B) in support of an expanding role for AID in the transfer of remote sensing technology to the developing world. These studies were:

- AID's Landsat Follow-On Requirements
- Evaluating Remote Sensing in Support of Crop Surveys in Developing Countries
- Economic Commission of Africa (ECA)/Remote Sensing Team Report
- West Africa Receiving and User Assistance Center (Ouagadougou, Upper Volta)

1.3 CONCLUSIONS

This grant program has been AID's most comprehensive effort to date for the transfer of appropriate remote sensing technology to

developing countries. The program has been markedly successful in accomplishing its objectives in a timely and cost-effective manner. Thus, remote sensing was promoted as a practical and appropriate tool for making various types of environmental assessments and resource surveys. Such information is critically needed and appreciated by those institutions in developing countries responsible for making decisions concerning national economic development.

The individual grantees demonstrated great initiative and resourcefulness in adapting remote sensing technology to the different goals in their respective countries. This program clearly shows that capable and dedicated nationals are available to complete the process of technology transfer if they are provided with the necessary technical and administrative back-up.

With a relatively modest expenditure of AID funds the grant program generated successful and self-sustaining remote sensing activities in most of the grant countries. The diverse grant projects developed and conducted by investigators in these countries demonstrate the appropriateness of remote sensing technology for helping to supply important resource information. Such demonstrations clearly caught the attention and generated positive interest on the part of high-level decision makers within the grant countries, and promoted the practical results of the U.S. space program.

As administrator of the program ERIM developed a flexible and responsive support mechanism for the grantees (see Appendix A). In particular, the assignment of different ERIM personnel to work directly with the grantees greatly facilitated the exchange of technical and procedural information. The technical depth and multidisciplinary experience of the contractor's staff allowed support requirements, including professional and linguistic skills, to be tailored to the diverse needs of individual grantees. Recognized remote sensing expertise was supplied in the areas of geology, agriculture, forestry, hydrology, geography, and data processing. Digital technology was developed to

suit the specific capabilities of grantee institutions.

Several special studies provided AID administrators with the technical basis for making recommendations and decisions concerning the current and future roles of remote sensing in developing countries. These studies highlighted the state-of-the-art and made recommendations concerning implementation of AID remote sensing initiatives - most of which were subsequently adopted and are currently being implemented.

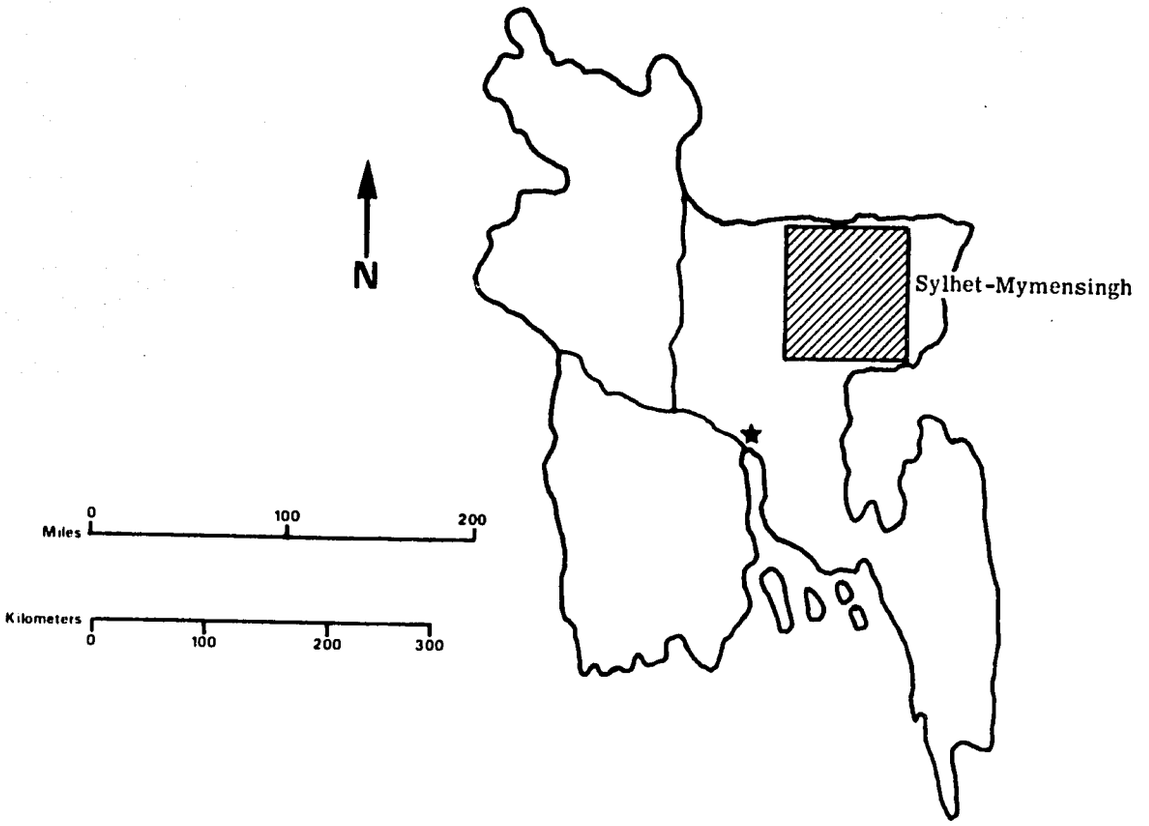
1.4 RECOMMENDATIONS

We recommend that AID carefully consider the success of the grant approach in its efforts to transfer remote sensing technology to developing countries. While other mechansims, such as regional centers and demonstration projects are needed, the effectiveness of the grant approach at the local and institutional levels within developing countries can complement and pave the way for these larger and necessarily more complex undertakings.

AID missions and regional bureaus should use the grant mechanism to support the transfer of remote sensing technology.

AID's Office of Science and Technology should continue to provide AID missions with the technical and administrative back-up required by investigators using remote sensing in developing countries.

BANGLADESH



PI/Agency: Professor M.I. Chowdhury/Institute of Environmental Sciences, Jahangirnagar University, Dacca

Start Date: March 1975

Funding: $20,000

Project: Test and use Landsat data to provide agricultural and land-use information for optimal development of the haor areas of north-eastern Bangladesh.

Results: Landsat data was used to obtain regional information on patterns of Boro rice and Rabi crop production during the 1975 winter season. Landsat data provided detailed temporal information concerning changing pond, stream, and flood patterns. This information was concluded to be important for development planning at the regional, district, and village level in Bangladesh.

BANGLADESH

PROBLEM

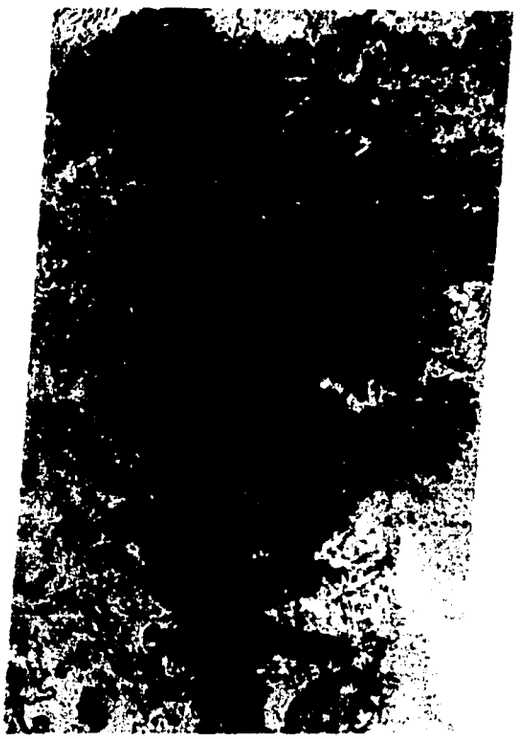
Aerial views of most of Bangladesh show a vast alluvial plain only a few feet above sea level, disected by meandering rivers. Often villages are built on the highest available land and are surrounded by fruit trees and palms. During the rainy season (June to September) much of this land is submerged and the villages appear as islands in a shallow sea.

This description characterizes the Haor region of Sylhet and Mymensingh districts in northeastern Bangladesh. A "haor" is a broad shallow land depression which can be used for a variety of activities, including agriculture, during the dry season when much of the rest of the country is fallow. Because of their different potential and the conflicting uses to which they can be put, precise land use information is needed for planning further development of these areas.

The haor region chosen for this project covered an area of 3,128 square miles. During the rainy season the broad funnel-shaped basin is flooded, but the same area is vegetated during the dry season — note the change in image tone on the two frames of Landsat imagery shown on the following page. The extent and duration of flooding greatly influence land use. The highest land is used for homesteads, orchards, and permanent pastures. The lowest land, which is permanently flooded, is used for fish and waterfowl production. Land in between is variously used for grazing and the cultivation of jute, vegetable and oil-seed crops, and different rice crops — depending on the nature of the soil and the duration of flooding.

Since population density now stands at 1,291 people per square mile and is increasing at a rate of 3.2% per year, there is need for more intensive use of the available land. As a result, many of the haors are being drained earlier in the season to plant winter (boro)

Dry Season
(Landsat frame E-2064-03434,
27 March 1975)



End of Rainy Season
(Landsat frame E-2316-03414,
4 December 1975)

TWO LANDSAT BAND-7 IMAGES OF THE HOAR REGION IN NORTHEAST BANGLADESH. The extent and duration of flooding largely determines how land is used in this region. Flooded areas appear dark in the second image.

rice. In addition, the grazing lands and marsh habitats are gradually being converted to rice fields. Currently more than 97% of the cropped area is oriented toward rice production at some time of the year, leaving less than 3% for other crops.

This project sought to better describe the alternatives for optimal land use based on the interpretation of newly available Landsat data and aerial photography. The study, as described in the grantees report [2], dealt mainly with the following four aspects:

(1) the applicability of remote sensing to Bangladesh information needs;

(2) the assessment of land use and terrain conditions in the haor regions of Sylhet and Mymensingh;

(3) methods of resource inventory and measurement with remote sensing data; and

(4) uses of the information obtained for planning optimal resource development in northeast Bangladesh.

PROCEDURE

This study was principally directed at manual interpretation of Landsat data and extensive ground truth collection in Bangladesh, supplemented by some computer processing in the U.S. 1:1,000,000 and 1:500,000-scale black and white prints of individual Landsat bands were used for the most part, although several false-color composites were also helpful. Standard techniques relying on image tone, texture, shape, and pattern provided the basis for most of the interpretations.

Broad geomorphic and cultural features were identified on Landsat images obtained on different dates since 1972. The interpretation process consisted of three stages for the identification of landscape features. At the initial stage only the black and white images were used. In the second stage color-composite prints at a scale of 1:250,000 and transparencies at a scale of 1:1,000,000 were used. In the final stage,

the computer-processed data was analyzed at scales of 1:250,000 and 1:62,500.

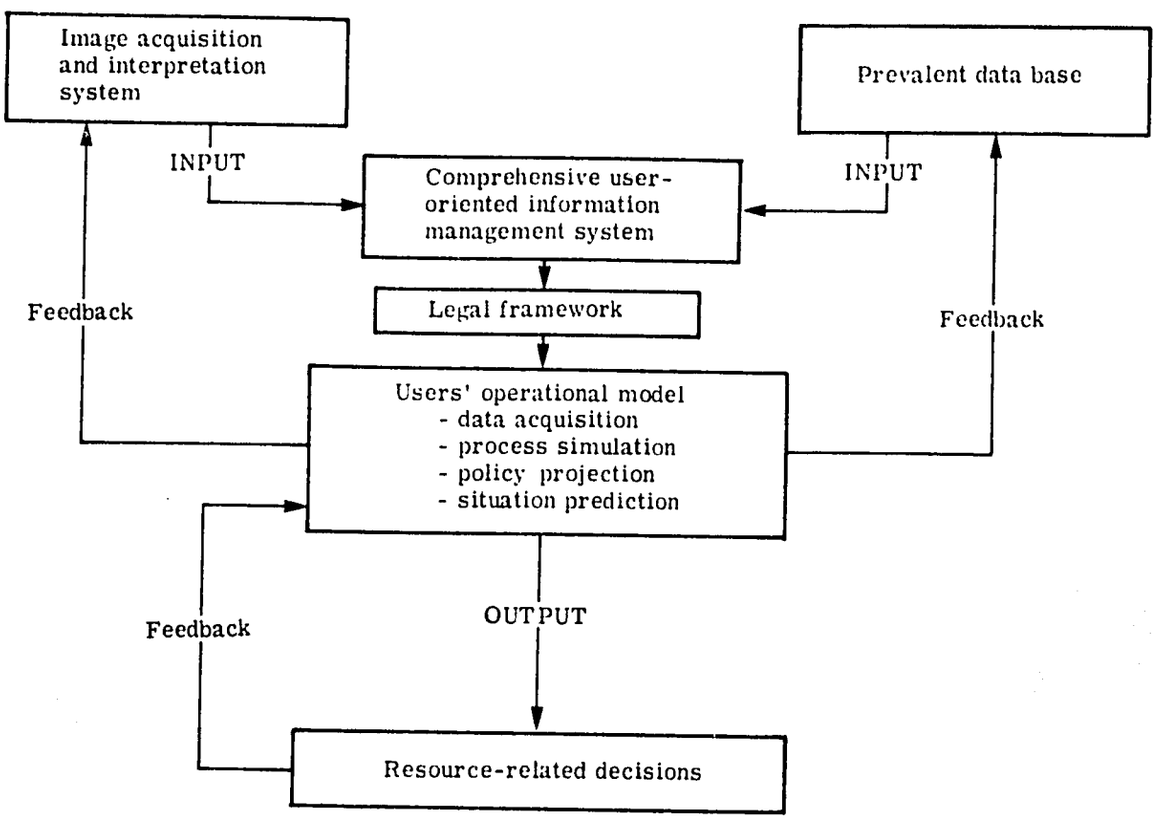
Much effort centered on collecting essential ground truth information for interpreting the imagery and evaluating the results. The seasonally variable and diverse nature of the land use patterns in Bangladesh made this activity important. Good aerial photography from 1975 was available for a portion of the haor region. This was projected stereoscopically, interpreted, and mosaiced at the beginning of the project; it proved to be of immense value in selecting ground truth sites and for subsequent interpretation of the satellite images.

Two ground truth sites were selected for detailed study, and several visits were made to both areas during this project. In addition, a low-flight, aerial reconnaissance mission covered representative terrain conditions and man-made features. Valuable aerial photography and other records were obtained at this time (early 1977). In addition to aerial imagery and on-site observations, various books, maps, and other reference materials were consulted throughout the project.

Computer-compatible tapes (CCTs) offered the great opportunity for quantitative data analysis. The CCTs were digitally processed to identify a variety of terrain (especially vegetative) features and to determine the total area represented by each identifiable feature. The ERIM Multivariate Interactive Digital Analysis System (MIDAS) was used to perform the classification and to produce geometrically rectified, color-coded, hard-copy maps of the entire haor area at a scale of 1:250,000 and of the Astagram-Bhatsala area at a scale of 1:62,500.

The resulting maps were checked in the field in early 1976 to establish their accuracy. Broad land use patterns and geomorphic features could be readily identified, while soil types and moisture conditions could be discerned from the imagery in association with aerial photographs.

Data integration involved the development of a generalized data-flow model that identified inputs of imagery in relation to other data sources and user requirements (see diagram below).



This flow diagram of the Bangladesh project shows the input of remote sensing data into an information model for making resource-related decisions. Note the provision of feedback loops at each stage in order to incorporate all essential data inputs and modify input requirements as needed.

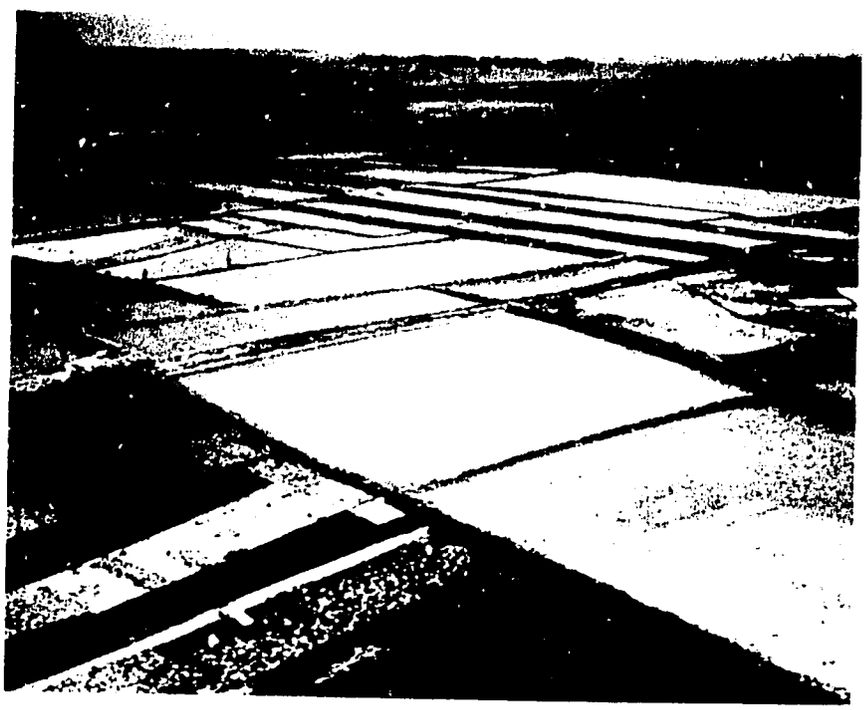
RESULTS

The results of the Bangladesh grant project were both interesting and beneficial. The Landsat black and white images in many instances could be used to designate settlements, crop land, grazing land, and areas planted to rice. The figure below shows an interpretation of a portion of a Landsat Band 5 (red) image of the area around the village of Baniachang. Settlements could be recognized by the presence of trees and small ponds which appear relatively dark compared to grazing land and cropped areas. Rice growing areas were fairly light while the fields were being prepared and planted, but became dark as the rice grew. The aerial photographs of a village and of cropland in the haor region show the vegetation around settlements and the small (usually less than half a hectare) agriculture fields.

1. Settlements and associated features
2. Cropped areas
3. Grazing lands
4. IRRI and boro rice lands

A LANDUSE MAP DERIVED FROM LANDSAT IMAGERY (Frame E-2316-03414-5, 4 December, 1975)

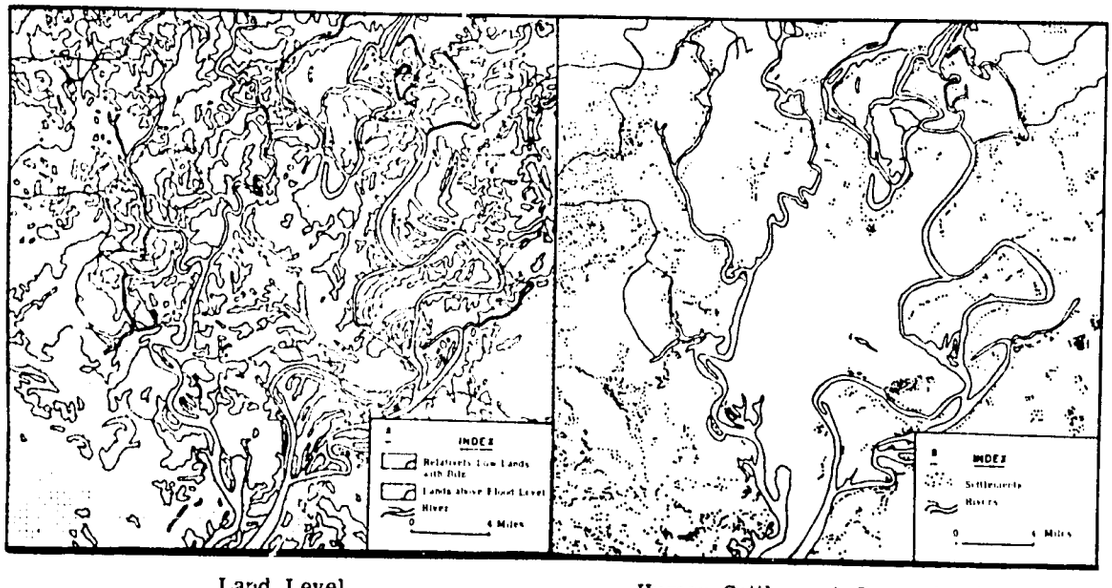
Typical Village



Cropland

AERIAL VIEWS OF THE HOAR AREA

Actual settlements are best identified from aerial photography, but the extent of flooding, as observed from Landsat, provides a clear indication of their probable location. The following figure shows an interpretation of Landsat imagery for general land elevation and for the location of human settlements. In general it can be seen that the settlements occur on land above the average flood level.



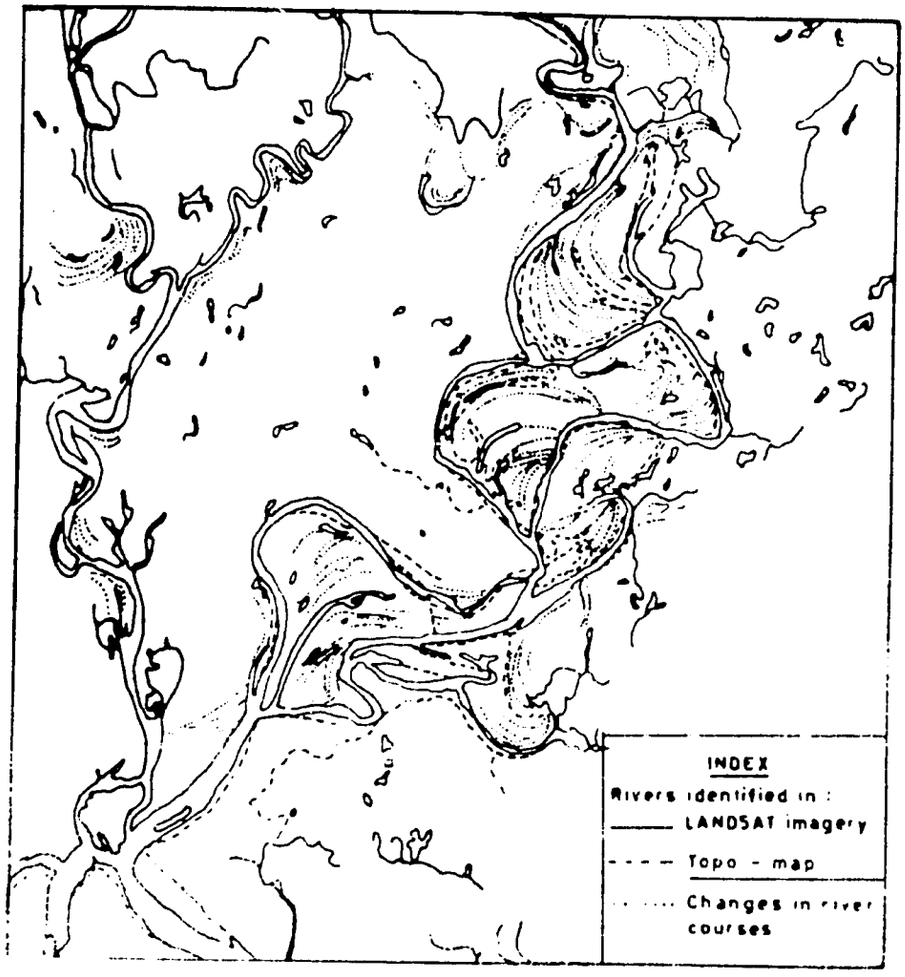
Land Level

Human Settlement Concentrations

LANDSAT IMAGE INTERPRETATIONS FOR THE SYLET-MYMENSINGH HOAR REGION OF BANGLADESH. Image date was 22 Nov. 72 (several months after rainy season when hoars are still flooded).

Landsat Band 7 (infrared) images provided detailed information concerning the vital and seasonally changing water patterns. As we previously remarked, much of the region is flooded during the rainy season and gradually dries out during the winter. In addition to these seasonal changes in the amount of open water, yearly changes in the major river channels were noted. The next figure shows the complex changes in a stretch of the Meghna and Kalni river near Astagram. Many of the old ox-bow lakes and cut-offs could be mapped with Landsat data, and changes in the river course since the publication of the latest topo-

graphic maps were noted. This information is useful in planning further development and for anticipating environmental problems, such as the shifting of river courses into development project areas or settlements. While the major and many of the minor streams were identified and mapped using Landsat imagery, village ponds were sometimes so choked with water hyacinths and algae that they could not be detected as open water. The ponds appeared similar to green field crops.



A STRETCH OF THE MEGHNA-KALNI RIVER AS SHOWN ON LANDSAT IMAGERY AND ON TOPOGRAPHIC MAPS.

Digital processing of Landsat data identified several broad classes of agricultural land but identification of individual fields was not possible owing to their small size in relation to the 1.1 acre area of a Landsat picture element ("pixel"). The pattern shown in the color-coded digital map of the region shows the fallow land (too dry for cultivation) surrounding the cropped haor area. The region is a large bowl-like depression; maturing boro rice grows on the higher slopes while immature rice is recognized in the lower areas. Some flood water still stands in the lowest portion of the depression in the north. Orchards and rabi vegetable crops are seen on the levees adjacent to major streams, but are not detected in the major boro rice producing areas — although they do occur there.

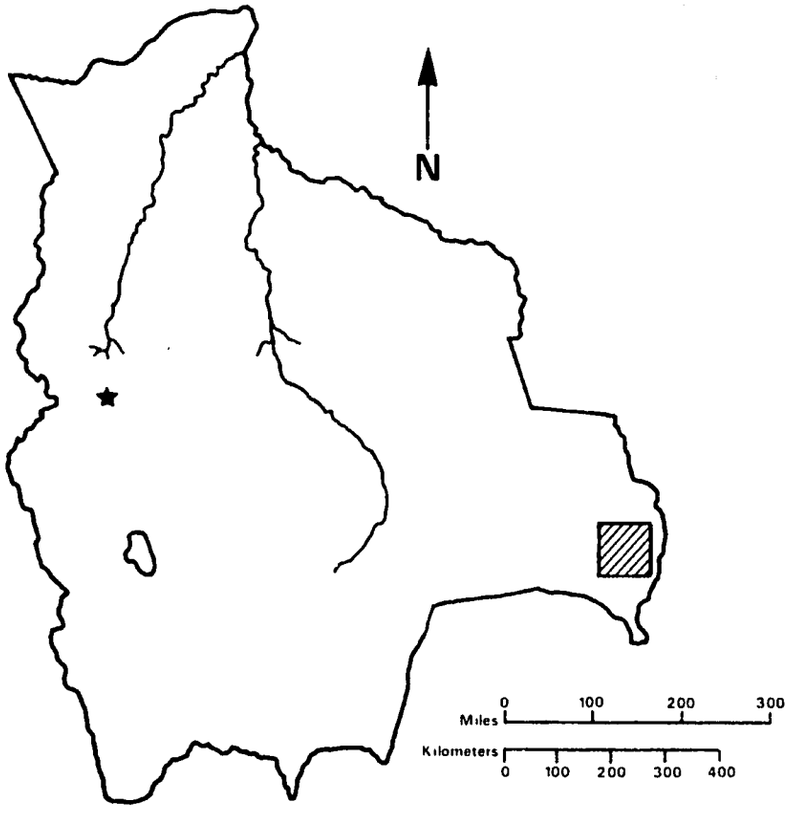
Small rural settlements — since they are a relatively complex mix of orchards, perennial trees, gardens, cattle yards, etc. — could not be located with confidence. But larger settlements such as Astagram, Baniachang, and a few others were identifiable. Transportation networks, with the exception of the rivers, were usually difficult to detect. Main (kutcha) roads and roadside canals (khals) were generally too narrow to see, but roads associated with high embankments (bandh) were discernable in some areas.

While digital processing offered some distinct advantages, it was concluded that much of the important agricultural activity could be mapped and monitored using manual interpretation of Landsat data.

The results from this project have been widely distributed in Bangladesh and form the basis for continuing applications of Landsat data to regional planning — for both the haor area and other regions. These results also were presented to high-level decision makers during the AIDSAT demonstration of U.S. satellite technology in Dacca in 1977.

COMPUTER GENERATED MAP OF HOAR REGION, 27 March 1975.

BOLIVIA



PI/Agency: Dr. Carlos Brockman/Servicio Geologico de Bolivia, La Paz

Start Date: March 1975

Funding: $10,000

Project: Investigate and develop an ability to obtain useful geological information from specially processed Landsat products.

Results: Landsat data delineated exclusively the iron-rich Banda Alta formation in the Mutun area and a sandstone outcrop in the Santo Corizon area of eastern Bolivia. The digital technique proved successful for optimum image enhancement of geological outcrop areas and was concluded to be a useful approach for geological reconnaissance in Bolivia.

BOLIVIA

PROBLEM

Although mining is Bolivia's most important industry, much of the eastern part of the country has hardly been explored for economic minerals. Little is known geologically of large regions in the upper Amazon and Paraguay River basins that lie east of the Andes and the populated great central plateau. The objective of this AID grant project was to develop and test techniques for obtaining geological information of economic significance for these areas, using available Landsat data.

The initial test site for this project was a rectangular area on the western side of the Paraguay River, which marks the border with Brazil. It is located just west of Corumba, Brazil — an important iron and manganese mining area. Much of the region is low-lying, swampy, or otherwise vegetation-covered. The few high plateaus that rise above the level plain are covered by scrub forest, cactus, and grassland. Some small tracts have been cleared for agriculture, but the population of the area is very sparse.

Iron-bearing sedimentary rocks are known to occur in isolated hills which rise above the level plain. In particular the Banda Alta formation, which outcrops in a V-shaped ridge near Mutun, is thought to contain deposits of exploitable iron ore. The soils and vegetation of the Banda Alta formation appear different from those of the surrounding level areas — providing a possible basis for delineating the extent of the actual formation. Such a delineation would be useful for identifying areas which warrant more intensive exploration and for estimating the amount of probable ore reserves. Also, other areas in the region may have hitherto unknown ore reserves or potential reserves. For this project the grantee proposed using Landsat data to help define the extent of the Banda Alta formation and to determine if additional iron-bearing formations could be located in other areas.

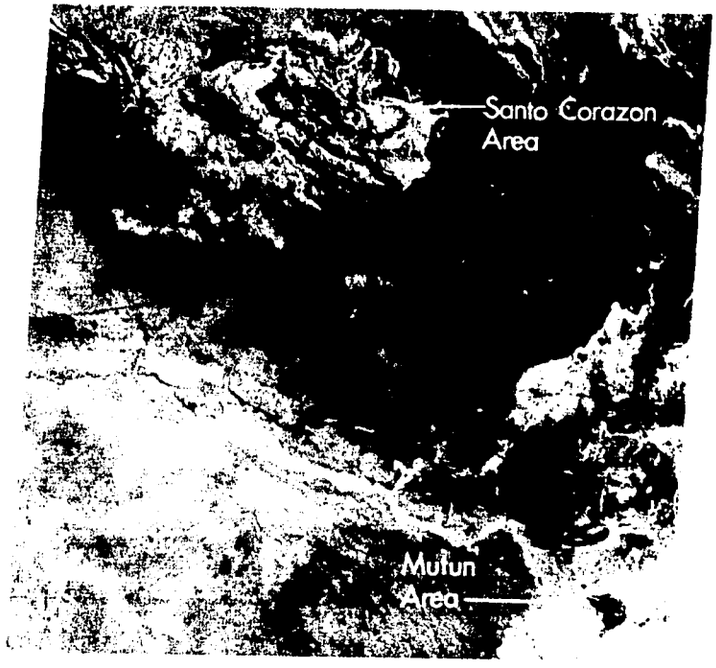
PROCEDURE

This project involved laboratory spectral analysis of various rock samples (including iron ore from the Mutun area) as well as the selection and interpretation of Landsat data, processing of that data to determine the best methods for enhancing geologic outcrop patterns, and producing optimal Landsat images of the test areas. A follow-up verification trip, using observations from a low-level aircraft, completed the grant project.

The known outcrop of the Banda Alta formation near Mutun provided the basis for testing and evaluating the use of various digital processing techniques. A Bolivian geologist, Sr. Raul Ballon, initially explored the Mutun area and located iron deposits on black and white Landsat images and on false-color diazochrome transparencies. Subsequently, he conducted the spectral analysis of rock samples and assisted in the digital processing of Landsat data at ERIM. Landsat frame 2125-13123, obtained on 25 May 1975 (shown in the figure below), was used for the processing. Both conventional and innovative digital techniques were tested.

Displays of Landsat Bands 5 and 7 were made and sample test sites were located on the imagery. Standard pattern recognition, single-band level slices, and various ratio combinations were tested using the computer. Nine image-maps were produced and compared with 1967 panchromatic aerial photography and ground information.

When an optimal processing technique had been defined, the Landsat data was processed to determine if the technique worked for other areas as well. A 1977 low-altitude flight provided the basis for evaluating the results, both for the new area near Santo Corazon and for the known Mutun area.



LANDSAT IMAGE OF EASTERN BOLIVIA

RESULTS

The results of the Landsat data processing were the clear identification of a hematite escarpment and the plateau surface of the Banda Alta formation near Mutun, the delineation of sandstone outcrops near Santo Corazon , and an appraisal of the value of these techniques for reconnaissance-level geologic mapping in Bolivia. These results were reported at the Conference on Mineral Exploration Techniques in Tropical Rainforests, held in Venezuela in November 1977.

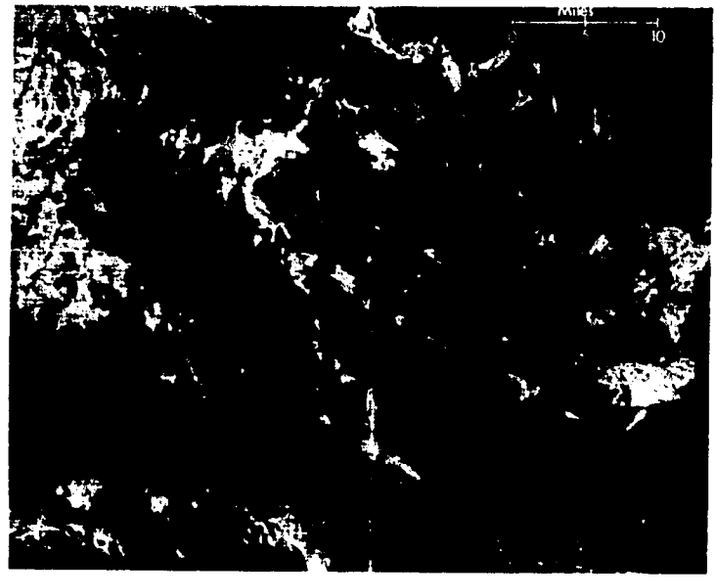
The most accurate recognition of the Banda Alta Formation was achieved using a combined image comprised of ratios of Landsat Bands 5 and 6 and Bands 4 and 5. A ratio of Band 4 and a near-infrared Band (6 or 7) significantly reduced the effects of illumination variations and accurately delineated forest-covered areas. Unlike Band 5, Landsat Band 4 separates the Banda Alta Formation from other Quaternary deposits which appear similar. This separation is perhaps

made possible by differences in vegetation and the absorption of green light by iron-stained materials. In heavily forested areas it was not possible to discriminate any underlying lithology (limestone, Quarternary, arkose, etc.). Only in situations where the vegetation was distinctive or the rock surfaces were significantly exposed was it possible to map geologic materials using Landsat data.

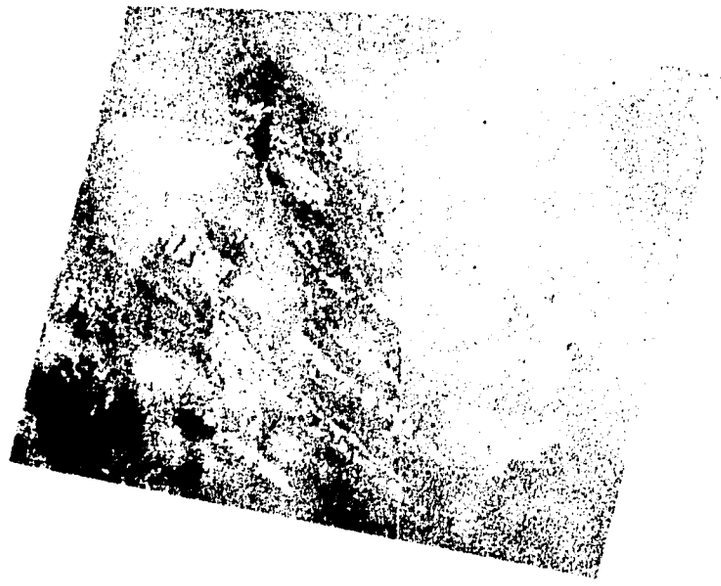
Digital image maps of the Santo Corazon area, northwest of Mutun, were tested using this additive ratio procedure (see the following figure). Although the region was remote, essentially unknown geologically, and unmapped, a reconnaissance still determined that Mutun-type iron formations did not exist in the vicinity of Santo Corazon.

During the reconnaissance flights over dense jungle with few landmarks, the Landsat imagery was very useful in keeping track of aircraft position and heading. Major features such as forested areas, grasslands, swamps, bare surfaces, and topographic features often were well defined. At Mutun the hematite escarpment was clearly identified and the iron-formation plateau surfaces were seen to be covered by grasslands with very few trees. There were some areas of exposed rock and soil, and others that were brush-covered. The locations of these areas compared well with those shown on the digital map products. Certain talus slopes were found to be essentially hematite and large areas of iron-rich debris were seen adjacent to the hematite escarpment.

This project was successful in its first objective — to exclusively delineate the outcrop of the iron-rich Banda Alta formation near Mutun; but similar iron-rich outcrops were not located in the Santo Corazon area. However, the techniques were useful enough that the Bolivian government is vigorously pursuing the establishment of its own processing facilities. Such facilities, using procedures developed and tested under this grant, are likely to make a significant contribution to geologic exploration in Bolivia.



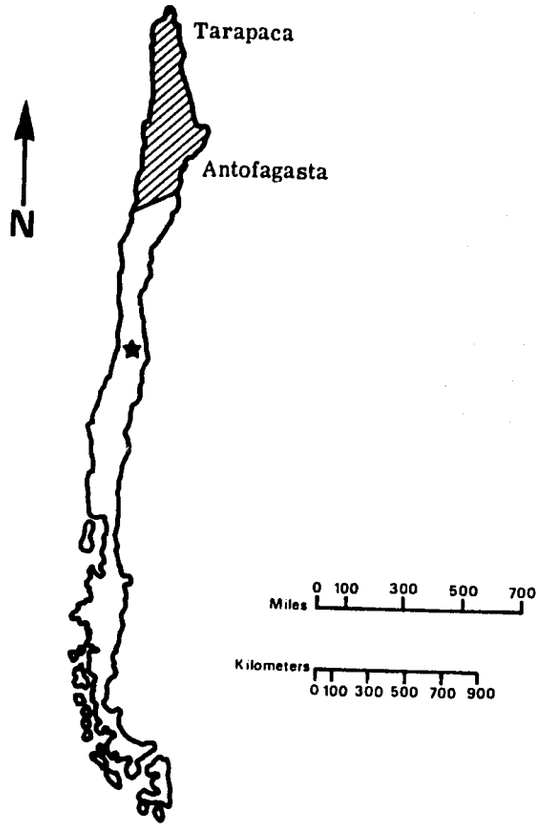
Landsat Band 5 Image



Computer Processed Image-Map. (Lighter areas indicate sandstone outcrops).

COMPARISON OF LANDSAT IMAGE WITH COMPUTER-PROCESSED MAP OF THE SANTO CORAZON AREA

CHILE



PI/Agency: Sr. Arnoldo Ortiz R/Instituto de Investigation de Re cursos Naturales, Santiago

Start Date: April 1976

Funding: $10,000

Project: Use Landsat images to inventory the natural resources of Tarapaca and Antofagasta Provinces of northern Chile as a prerequisite for integrated regional development.

Results: Two sets of reports were published concerning the resources of Tarapaca and Antofagasta. The reports included revised maps of the geology, gemorphology, hydrology, land use, vegetation, and drainage based largely on manually interpreted Landsat images. These results provide a methodology for revising maps for the entire country on a province-by-province basis.

CHILE

PROBLEM

The Instituto de Investigacion de Recursos Naturales (IREN) requested grant support for an integrated resources survey and mapping project in the two northernmost provinces of the country, Tarapaca and Antofagasta. Remote sensing was essential for inventorying the resources of this 212,000 km^2 area, and Landsat data was needed to update obsolete maps and contribute to new mapping efforts, prior to the initiation of regional development programs.

Tarapaca is located in the extreme north, bordered on the west by the Pacific Ocean, on the north by Peru, and on the east by Bolivia. Antofagasta borders Tarapaca on the south. These provinces are characterized by high desert with scattered oases and long east-west valleys which reach to the Andes (see the following figure). The valleys are used for intensive vine cultivation and other agriculture where sufficient water is available. The rigorous climate and topography of Tarapaca restrict most of the population to a few coastal towns and fertile valley areas — including the capital, Iquique, and the industrial center, Arica. The economy is based on fishing, mineral extraction, and limited agriculture.

IREN's main objectives were to provide geologic, geomorphic, hydrologic, soils, and vegetational information in map form and to establish the use of satellite imagery as an operational tool for similar comprehensive regional surveys. The AID grant helped supply the necessary Landsat imagery and certain photographic reproduction equipment, as well as training and field support for the project staff in Chile.

LANDSAT BAND 5 IMAGE SHOWING THE LARGEST EAST-WEST CANYONS THROUGH THE DESERT IN NORTHERN CHILE. (Frame 1155-14102, December, 1972)

PROCEDURE

Manual image-interpretation techniques provided the basis for this resources inventory and mapping project. The project was conducted in two stages for each region. The first stage involved interpretation of Landsat imagery at scales of 1:500,000 and 1:250,000 to identify general terrain conditions and features. False-color images, using both a diazo printer/developer and a multiband viewer, were produced at scales from 1:3,360,000 to 1:250,000. Some 22 different images were used. This stage was followed by detailed field studies of the areas which appeared to have particular economic significance — especially the oases, valleys, and gorges. Aerial photography also was used during this latter stage.

Because of the complexity and interrelated nature of the resources in this arid region, emphasis was placed on multidisciplinary team efforts to interpret the data. Interpretative keys and descriptive legends were established for each of the resource disciplines and the resource patterns were then field-checked and mapped. ERIM provided

technical training in Chile for the image enhancement and interpretation techniques.

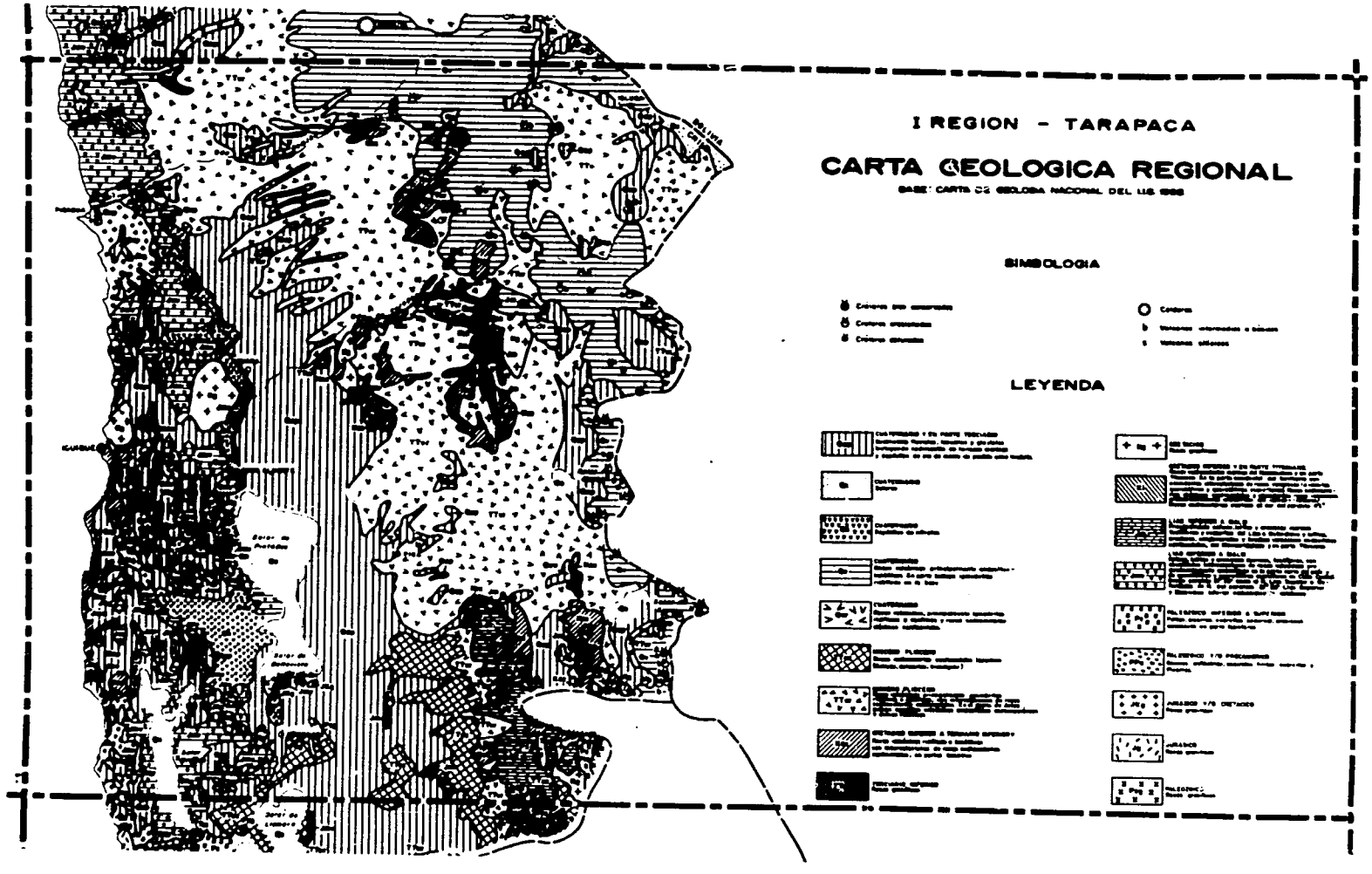
RESULTS

IREN produced comprehensive reports of the resources in both Tarapaca and Antofagasta provinces. These reports provided separate descriptions and maps of the geology, geomorphology, hydrology, soils, vegetation, agriculture, land use, and climate of each of the provinces. For example, the next figure shows a portion of an updated geology map for Tarapaca. In addition, evaluations involving highway development, communication facilities, locations of airports, and urban development were discussed.

Among the many technical results of this mapping project were:

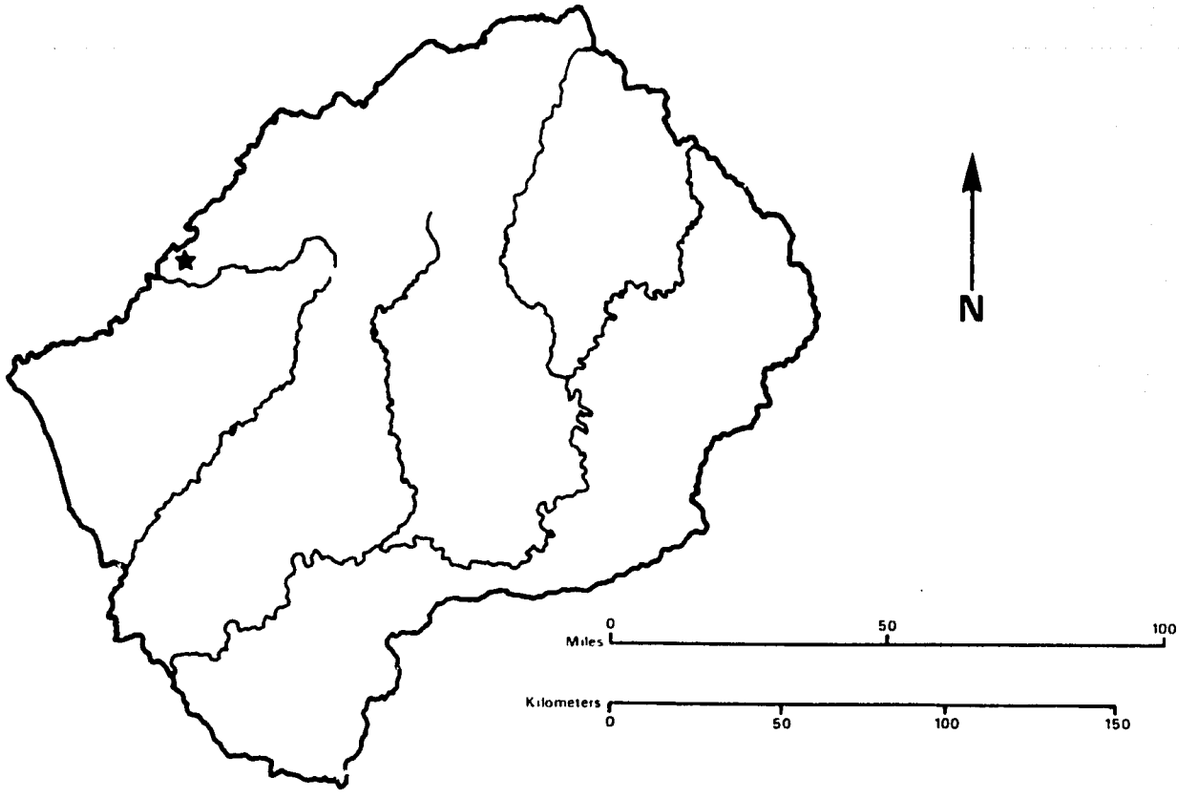
(1) the detection of 18 new areas recommended for exploration – for copper, manganese, iron, silver, lead, and zinc deposits;
(2) the mapping of more than 30 landforms which are significant to planning development projects;
(3) the mapping of 12 vegetation units which provided the basis for establishing basic ecological zones; and
(4) the identification of about 60 soil associations and their limitations for agriculture (15 of which are being studied for actual farm use).

As a result of this grant project IREN has adopted the use of Landsat imagery as an operational tool for performing integrated regional mapping projects in their national resources inventory program. Thus the entire country will eventually be studied and mapped on a province-by-province basis, using these techniques. Such studies and maps are a prerequisite to sound development planning and implementation.



GEOLOGY MAP OF TARAPACA, CHILE, UPDATED USING LANDSAT DATA

LESOTHO



PI/Agency: Mr. Anthony Jackson, Mr. Edwin Seitlheko/Biology Department, National University of Lesotho, Roma

Start Date: March 1975

Funding: $18,000

Project: Investigate snowfall, drainage patterns, and vegetation distribution in relation to requirements for soil conservation.

Results: Detailed drainage network of the entire country was digitized from Landsat data and reproduced in map form at different scales. A preliminary vegetation map was also produced as a basis for planning conservation measures.

LESOTHO

PROBLEM

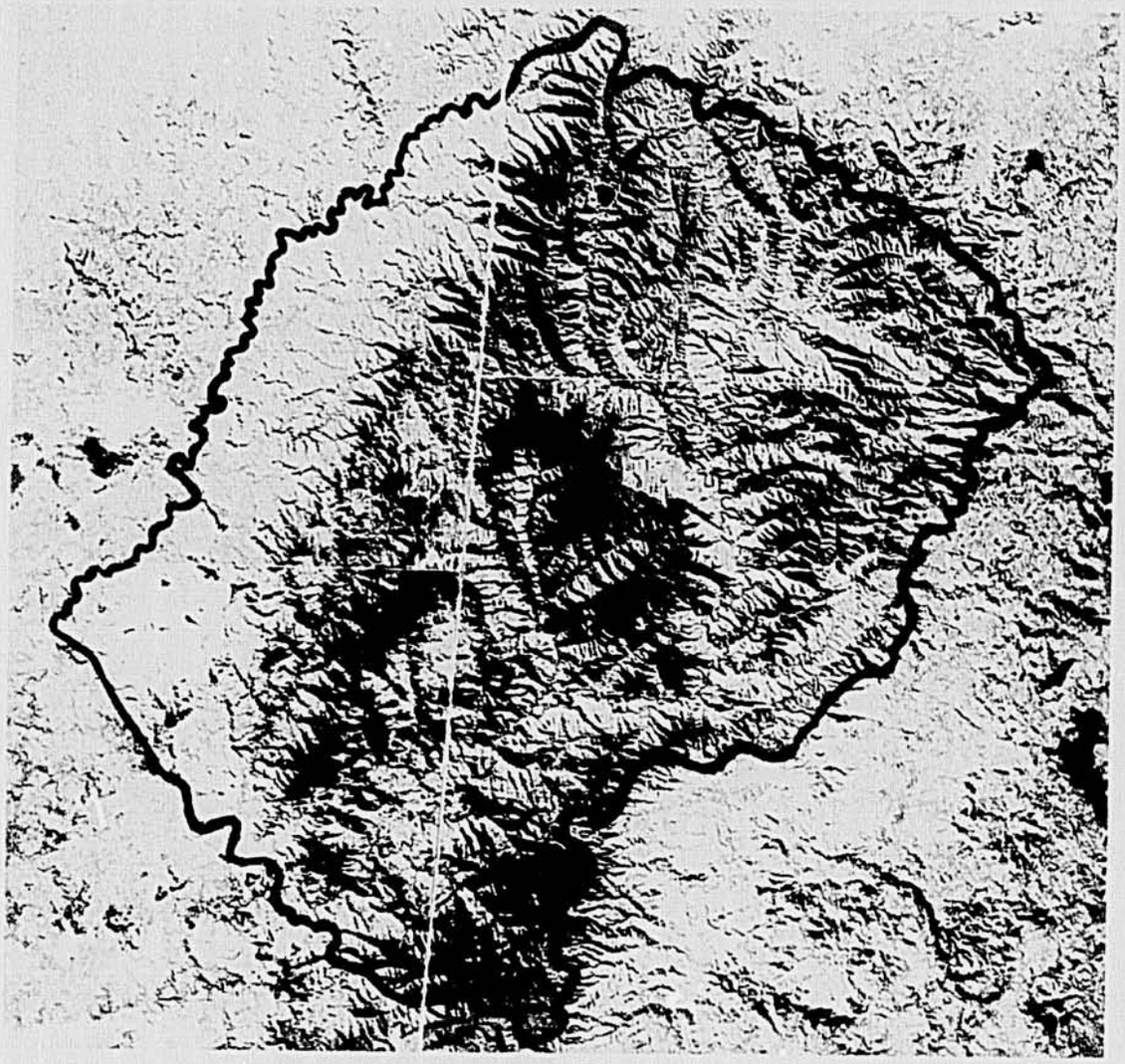
Lesotho is a small, mountainous country of about 30,350 square kilometers, completely surrounded by the Republic of South Africa. As such, its economy is uncomfortably tied to that of South Africa and the government wishes to develop greater independence in the areas of food production and opportunities for local employment. (It is estimated that about half of the working-age male population of Lesotho obtain jobs in South Africa for some portion of the year, and that more foodstuffs are imported than exported.)

Soil erosion is without a doubt the most critical problem besetting land development in Lesotho, and AID is sponsoring a three-million dollar, eight-year program of soil conservation there. Severe soil erosion occurs as a result of overgrazing on the extensive highlands and unsound cultivation practices in the densely populated lowlands.

The objective of the grant project was to prepare drainage, soils, and vegetation maps and to provide information on snow cover for use in national conservation and development programs.

PROCEDURE

Landsat data was used to provide information about factors which affect the extent and intensity of the soil erosion process — vegetation cover, soil and land use patterns, and the area of snow that annually melts and runs off during spring in the southern hemisphere (September - December). Unfortunately good Landsat imagery of Lesotho for the winter season showing snow cover was not available during this project. However, intensive digitization of drainage patterns did result in new detailed stream maps.



LANDSAT BAND 5 MOSAIC OF LESOTHO. Original Scale 1:500,000.

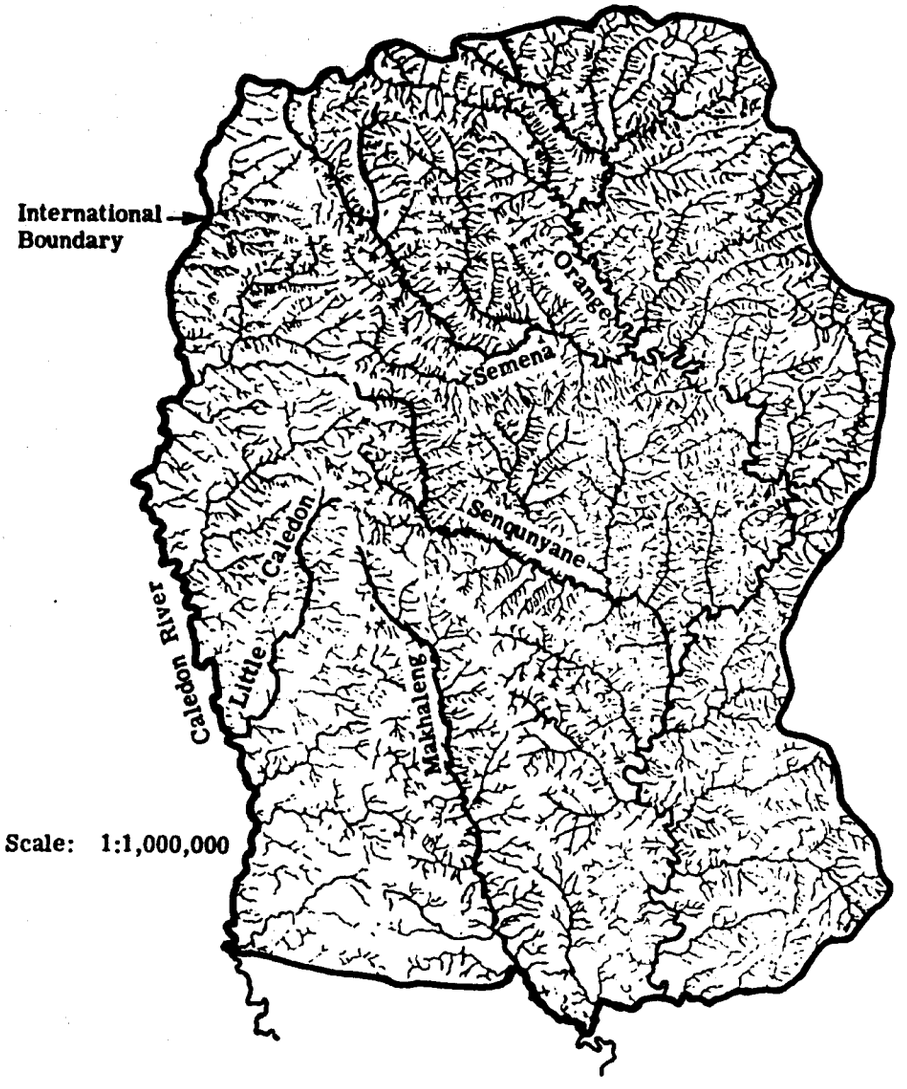
Primary mapping was by conventional photographic-interpretation techniques, apart from certain test areas for which CCT data was used. The images used were of several types: standard 1:1,000,000-scale black and white prints and transparencies; standard false-color composites, also at 1:1,000,000; black and white enlargements at 1:250,000; and non-standard diazo false-color composites at various convenient scales. The 1:1,000,000 prints were not used directly, but details were

enlarged on an optical pantograph (Wild Plan-Variograph) to a scale of 1:250,000. Ground truth was obtained by field trips and random sampling in selected areas. No specific ground truth was collected for the delineation of rivers.

In addition to using manual interpretation techniques this grant project involved modification of a small local computing capability (Hewlett-Packard 9830 programmable calculator) to handle digitized imagery, including Landsat data. For that reason a digitizer in combination with a densitometer was purchased from grant funds. After preliminary mapping, the maps were digitized and stored in digital form on magnetic tape cassettes. The digitization was carried out using a Hewlett-Packard 9864A Digitizer linked to the HP 9830 programmable calculator.

RESULTS

In producing the Lesotho drainage map it was found that the patterns were more easily discernable in the eastern (highland) part of the country, because of greater topographical relief. Very few of the rivers and streams in the country are broad enough for water to be visible in any Landsat data, and drainage mapping was therefore dependent on the correct interpretation of relief. In the mountains, relief is clear because even the relatively small streams have cut clearly defined valleys. In the lowlands, however, much of the higher-order drainage is via erosion gulleys ("dongas") which are narrow and present little contrast with the surrounding terrain. As a result, the drainage map seems to indicate a higher drainage density for the eastern part of the country than for the west.

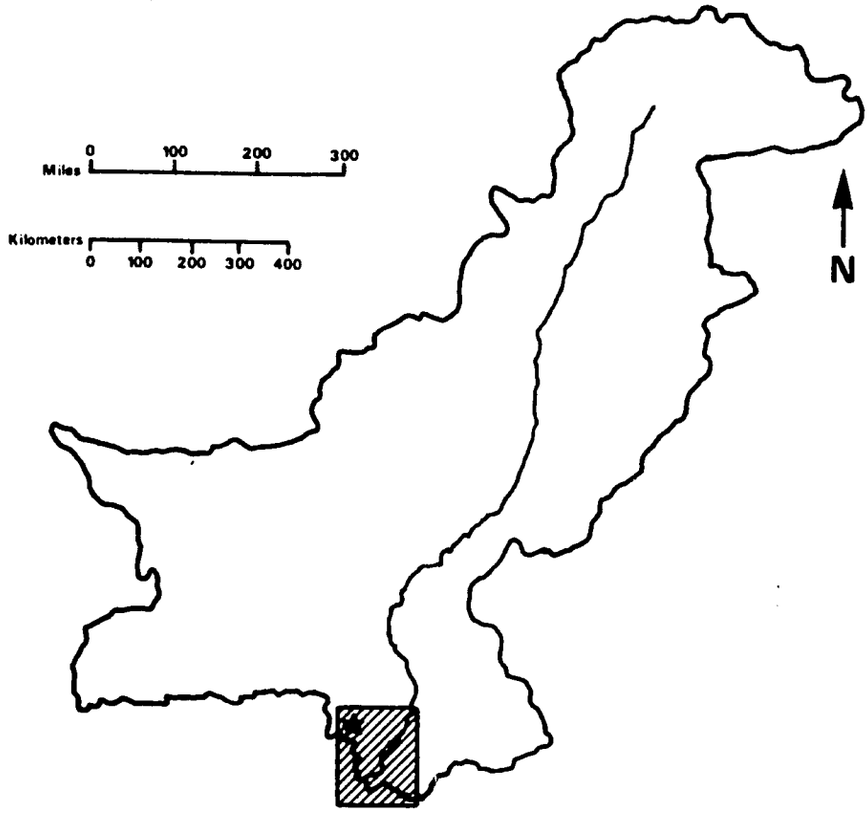


DRAINAGE MAP OF LESOTHO, PRODUCED FROM LANDSAT IMAGERY

While the Lesotho grant project provided some excellent basic data concerning the drainage patterns of the country, the institutional isolation and eventual departure of the principal investigator from the country prevented widespread dissemination of his results — and more importantly, the continued development of the techniques for analyzing Landsat data. The project did indicate, however, that

Landsat data can be used to supply information for conservation planning and appropriate land use in countries such as Lesotho, which have severe erosion problems. Consequently the successor to the original principal investigator received individualized training in the U.S. under this grant program in early 1977 and is attempting to make continued use of remote sensing techniques and Landsat data in Lesotho.

PAKISTAN



PI/Agency: Dr. M. Shafi Ahmad/Space Sciences Laboratory, Pakistan Space and Upper Atmosphere Research Committee, Karachi

Start Date: March 1975

Funding: $20,000

Project: Provide information concerning vegetation and coastal conditions applicable to planning new industrial port construction in the Indus delta.

Results: Computer maps and map overlays showing vegetation patterns, extent of saltwater intrusions, and patterns of coastal currents were produced. The results were based on Landsat data and specially flown aerial photography.

PAKISTAN

PROBLEM

Despite its location at the mouth of one of the world's great rivers, the changing patterns of the Indus delta have for centuries confounded attempts at navigation and development. The large load of silt deposited by the Indus — coupled with the ever-changing channels, tides, and currents along the coast — causes the delta to change significantly from one year to the next. Some 20 centuries ago, the shore was probably 50 to 80 miles from the present coast and the river was easily navigable via two large tributaries. Since that time, and particularly within the last two centuries, the delta has changed rapidly. Between 1873 and 1904 more than 100 square miles of land were added, and during the next 50 years the coastline advanced five miles in some places.

Needless to say, the ruins of important coastal cities that once enjoyed a flourishing sea trade now lie abandoned in the interior of the delta. The modern city of Karachi is located on a rocky ledge just west of the delta, 50 kilometers from principal outlet channels of the Indus. At high tide the whole delta is submerged for three to four miles inland, and the ground is swampy for two miles beyond the high water mark.

Port Qasim, a large new industrial port designed to serve Karachi's heavy industry, is being constructed several miles east of the city on one of the channels of the delta. The purpose of the AID grant to Pakistan was to use Landsat data to obtain information about the changing morphology of the delta as an aid to navigation and also for planning the development of the new port.

PROCEDURE

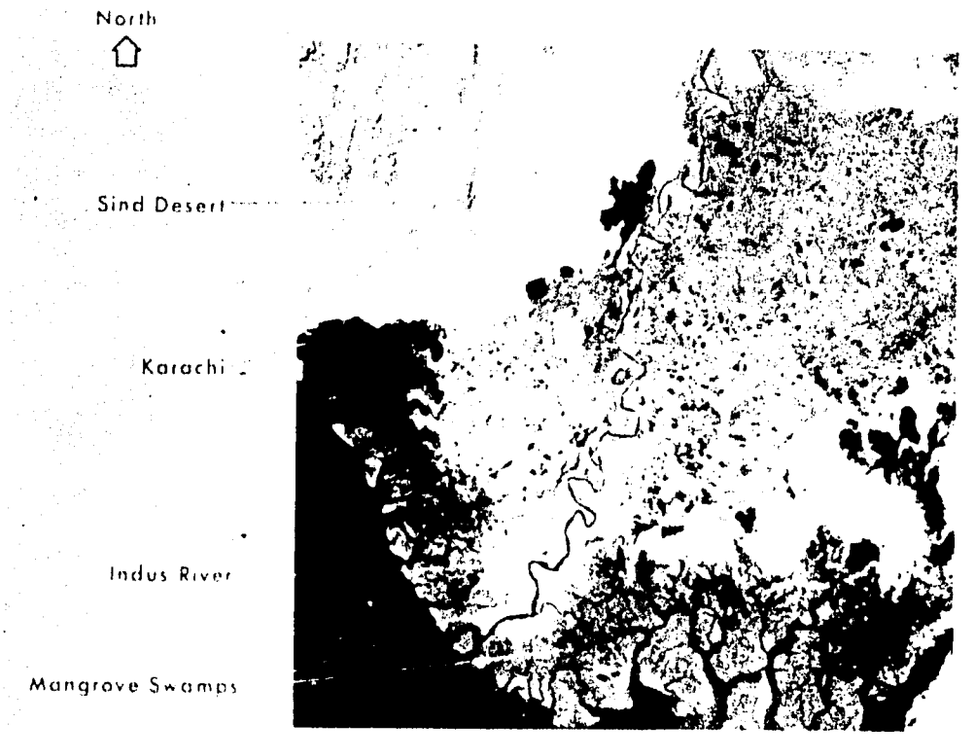
SUPARCO staff members developed a work plan for manual and computer-assisted analysis of Landsat data of the delta. In addition, special

MANGROVE SWAMP, WITH KARACHI HARBOR IN BACKGROUND

aerial photography for measuring wavelengths and directions was collected. ERIM was asked to generate four maps: one depicting water quality (chlorophyll), one showing water condition (sediment load), and two the vegetation in the project area.

The Landsat frame selected, dated December 21, 1973, shows the Indus River flowing from northeast to southwest (in the center of the image). The delta is an arc-shaped feature covering most of the southern half of the frame; the northern half shows the rocky or sandy arid plain north of Karachi, which lies just off the western edge of the frame (see figure below). Only the southwestern corner of this

frame was used for computer processing. It includes most of the terrain and water characteristics of interest for this study -- including the planned site of the new industrial port, Port Qasim.



LANDSAT IMAGERY OF THE INDUS DELTA

Several computer-enhanced images of coastal processes were made at ERIM in support of the project. The next figures shows the result of ratio-mapping Landsat Band 5 to Band 4. Offshore features are interpreted to show circulation patterns through varying concentrations of suspended sediments. One important consideration in choosing the site for the new port was the need for constant dredging to keep it open. A knowledge of sediment-distribution patterns is aiding in determining dredging requirements for proper navigation of the channels to the port.

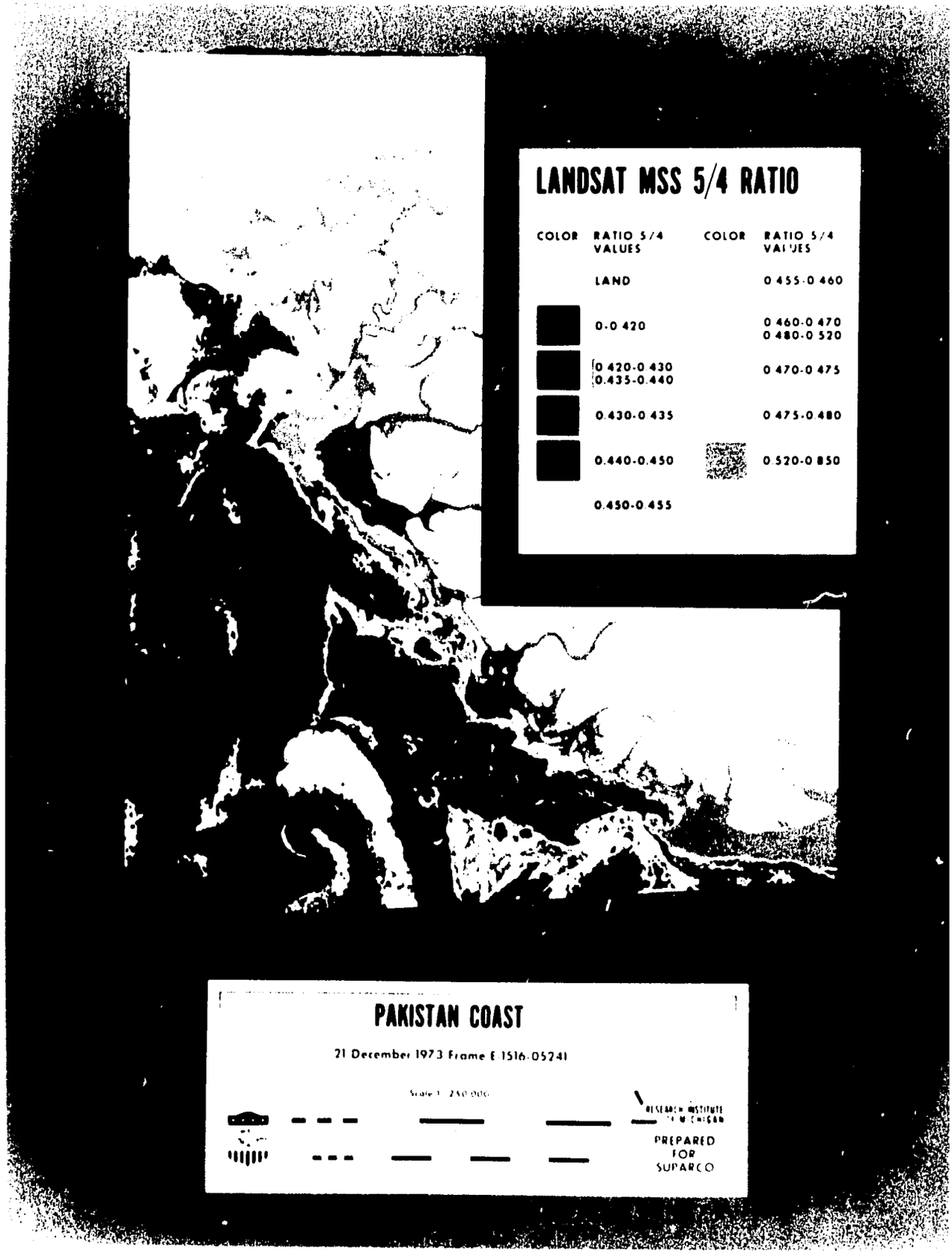
Unsupervised, statistical, pattern-recognition procedures were used to produce the two vegetation maps of the western portion of the Indus delta, one of which is shown in the second color plate. These maps are based on 22 discrete spectral signatures which were selected by an ERIM clustering algorithm from a sample area. Experience in interpreting the spectral characteristics of certain types of terrain features helps to broadly identify these signatures. Field checking related the map classes to sedge marsh, forest, irrigated crops, barren land, irrigation channels, surface water, and several densities of mangrove swamp. A full 13 of the classes were uniquely identified from field checks.

RESULTS

Landsat Band 7 images provided an excellent basis for mapping the changing channel patterns and the extent of inundation ("salt water intrusion") at high and low tides. This information, which was not available before, is very useful for fishing boat navigation and may have value for proposed wetlands development in the delta.

Sequential Band 5 and Band 4 Landsat imagery clearly depicts patterns of coastal currents and sedimentation. These are being used to record areas of rapid erosion and accretion and to observe the action of currents and tides, particularly in relation to dredging requirements for the Port Qasim channel. Field checks showed that certain nearshore features (i.e., underwater areas with mud and sand, shoals, and sand bars) could be identified on the ratio maps.

The Landsat imagery brought out some significant differences in comparison with currently available maps of the area and it is regarded as more accurate for showing the actual location and extent of the channels. The information provided by this study has contributed greatly to an improved understanding of the morphology and process of



LANDSAT RATIO MAP OF THE PAKISTAN COAST

SIGNATURE	1,2	3,9,10	4,6,7,15	5	8	11,14,16,21	12	13	17	18	19	20	22	Unclassified

VEGETATION MAP-INDUS DELTA

21 December 1973 Frame E-1516-05241

Scale 1:250 000

RESEARCH INSTITUTE OF MICHIGAN

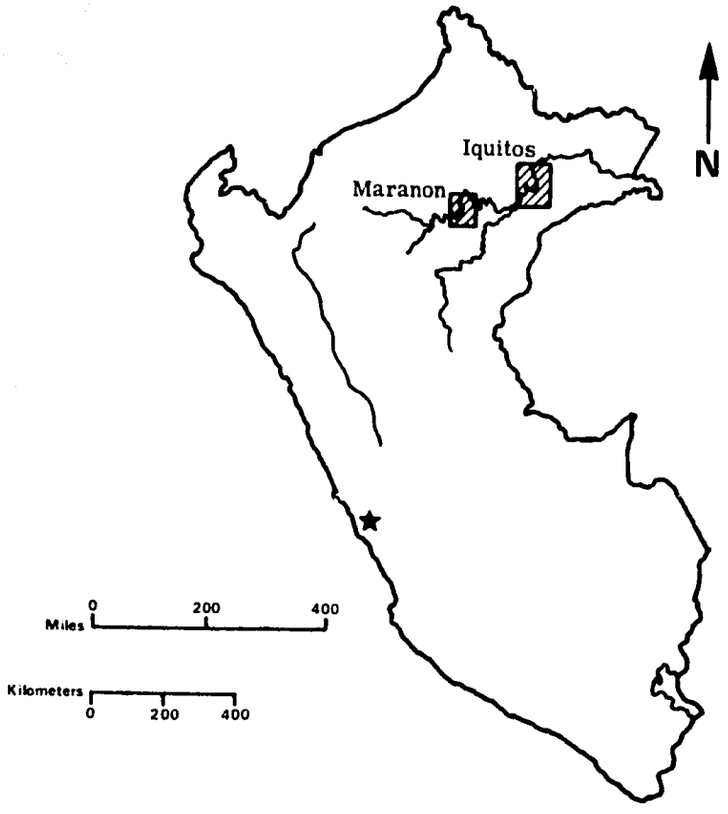
PREPARED FOR SUPARCO

the Indus delta area. Much of the benefit from this new knowledge will be derived from the continuous use of these results.

The results of this and other remote sensing analyses, plus existing imagery, are being made available to a wide variety of users in southern Pakistan. The departments of Agriculture and Forestry are evaluating and using the classified vegetation maps, and the Port Qasim Development Authority is making primary use of the channel and littoral zone maps and other information.

In their preliminary stage, these results attracted much interest and comment at the Pakistan-United Nations Regional Training Seminar on Remote Sensing Applications, which was hosted by SUPARCO in January 1977. SUPARCO activities will provide a basis for continuing AID grant support to further develop Pakistan's remote sensing activities.

PERU



PI/Agency: Ing. Walter Danjoy/Oficina Nacional de Evaluacion de Recursos Nautrales, Lima

Start Date: September 1976

Funding: $20,000

Project: Identify and map the extent of the economically important Aguaje palm in portions of the Amazon jungle.

Results: Processed Landsat data provided quantitative information concerning the areal extent of the Aguaje palm and other lowland forest communities in eastern Peru. Landsat data is providing the basis for further ongoing forestry surveys in Peru.

PERU

PROBLEM

Eastern Peru, the area known as the Peruvian Amazon Region, has considerable potential for forest resource development. This humid jungle region is characterized by a very heterogeneous forest species composition that is present in a volume — estimated at approximately 100 m^3/hectare. There are also small areas of more or less homogeneous forest that contain "Aguaje" (Mauritia flexuosa L.), a type of palm with considerable economic potential. Intensive management of the aguaje forests could provide a domestic source of palm oil production, edible food products for humans and livestock, and lignocellulose for the wood pulp and paper industries. However, incomplete inventories of much of the region have made implementation of aguaje management programs difficult.

Little information regarding the location and extent of aguaje exists because the vastness and inaccessibility of the Peruvian Amazon Region make data collection by conventional ground-survey methods tedious and costly. Although aguaje forests are estimated to cover some two million hectares, they constitute only two percent of the natural forest area of the region, which has very few roads. Large-area aerial photo coverage is limited by the short supply and high costs of equipment, as well as by the frequent, unpredictable cloud cover.

Landsat offers the potential for accelerating the inventory process. Its synoptic view and repetitive coverage potentially enable imaging the entire region with a relatively small number of frames. Furthermore, the data is provided in formats that facilitate both manual and computer interpretation in a relatively short span of time. The results of Landsat data interpretation constitute a first-stage reconnaissance for the entire region. Such a survey could then be used to define specific locations from which to obtain more detailed information, thus

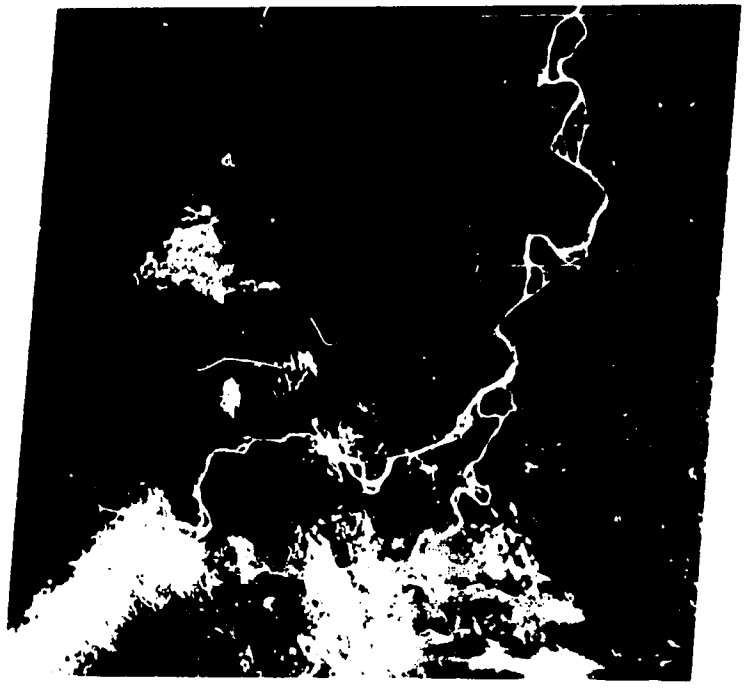
hastening the development of management programs for aguaje and other commercial forest associations.

PROCEDURE

Manual interpretation and digital processing procedures were outlined for two separate test sites. The lack of detailed ground information and aerial photographs for the sites placed maximum emphasis on the interpreter's knowledge and experience during his initial analysis of the Landat imagery. Those results then formed a basis for beginning the digital analysis. Finally, results of both procedures were compared to ground conditions as observed from a light plane.

Portions of two Landsat frames were digitally processed. Frame E-1502-14320, collected on 7 December 1973, shows the point at which the Ucayali and Maranon Rivers merge to form the Amazon River. The northeast quarter of the frame — containing the city of Iquitos, the Amazon River, and extensive known areas of aguaje forest — comprised the Iquitos Test Site.
Frame E-1071-14400, collected on 2 October 1972, shows an area west of the above frame. The southeast quarter of the frame shows the Maranon River and adjacent areas of various jungle species that reportedly include aguaje. This area was referred to as the Maranon Test Site. Landsat data for both test sites was processed in similar fashion as two separate data sets. Engineer Walter Danjoy assisted in the processing at ERIM in June 1977 and did follow-up work in October.

The initial optical analysis involved a thorough consideration of all four spectral bands of Landsat imagery. A light table and magnifying glass were used to observe standard image products of 1:1,000,000, black-and-white positive transparencies. A Diazo machine was used to enhance the contrast of some bands and to create several combinations of false-color composite images. All information delineated on transparencies was subsequently transferred to prints of Landsat Band 7 images that had been enlarged to a 1:250,000 scale.



IQUITOS, PERU TEST SITE (Landsat Band 5. Frame E-1502-14320, 7 December 1973)

Both supervised and unsupervised signature-extraction techniques were used to help define appropriate signatures for all scene classes in the digital Landsat data for the Iquitos and Maranon test sites. For supervised signature extraction, existing forest survey maps and the results of Landsat imagery interpretation were utilized to aid the location of training sets. Unsupervised signature extraction was performed with an automatic clustering algorithm that combined a systematically drawn sample of pixels into a relatively small number of signatures on the basis of their data values in all four Landsat bands. Although the certain identification of all the cluster signatures was not known, they provided a basis of comparison with the supervised signatures for determining whether all the significant spectral scene classes in the test sites had been accounted for.

Spectral overlap among the forest signatures suggested that a conventional multispectral classification technique could lead to a

substantial amount of pixel misclassification for some forest classes. Therefore, a specialized multi-element classification technique was implemented.

RESULTS

Manual interpretation of Landsat images provided the generalized location of large expanses of aguaje. Although many areas were similar in tone and texture, others were less so, probably as a result of variations in tree density and/or species composition. These latter areas were not reliably mapped. Boundaries around aguaje areas were not always accurately defined because of the continuum of tonal variations that can occur between such areas and other vegetation.

Manual interpretation also enabled the discrimination of other forest associations that correspond closely to drainage conditions which prevail in the low jungle. These associations were identified as permanently flooded forest, forest subject to temporary flooding, non-flooding alluvial forest, and hill forest. However, precise delineation of boundaries was frequently not possible and areas of interwoven erosional and depositional patterns were inadequately mapped.

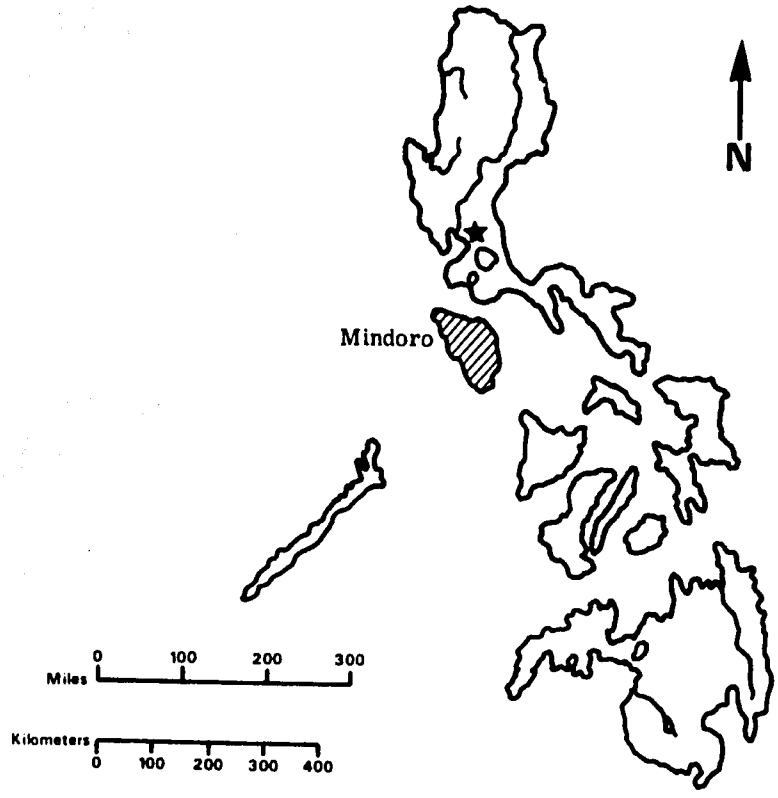
Other features observed on Landsat images included swamps of sparse vegetation, open lakes, and rivers. Results of the digital processing procedure are presented in the following color plate. Forest and other terrain classes were the same as those identified on the Landsat images. In general, aguaje and other forest associations were judged to be in good agreement with ground conditions. Boundaries between forest classes were considerably more accurate, and aguaje occurring within complex areas of interwoven erosional and depositional patterns was readily discriminated. Thus, the digital maps provided an accurate portrayal of the heterogeneous vegetation patterns that occur within the low jungle.

DIGITALLY CLASSIFIED DATA FOR THE IQUITOS TEST SITE.

The application of a multi-element classification contributed significantly to the appearance of the digital map; the maps of the Maranon test site compare results obtained with a multi-element classification technique to those obtained with the conventional single-element technique. Clearly the incorporation of proximity information reduces the speckled effort of single-element classification and thus provides better boundaries between features. Such maps simplify the complex ecotonal nature of the boundaries between vegetation features and enable better definition of large-scale regional patterns. For example, the pattern of aguaje in both figures corresponds with the suspected recent alluvial sedimentary deposits of the Holocene Age along both banks of rivers in the low jungle. Such maps may be very appropriate for resource surveys conducted on a regional or national scale.

The results of this study show that Landsat has considerable potential for discriminating aguaje and other forest associations within lowland areas of the Peruvian Amazon River. While manual interpretation techniques were useful for discriminating the general locations of large expanses of these forest features, digital processing techniques were considerably more precise in locating boundaries between complex features. Thus, these digital processing procedures are receiving further testing and consideration for eventual operation in Peru.

PHILIPPINES



PI/Agency: Mr. Juanito Fernandez/ Philippine Bureau of Mines, Manila

Start Date: March 1976

Funding: $20,000

Project: Provide natural resource information for the integrated economic development of the island of Mindoro.

Results: Copies of four processed Landsat images at a scale of 1:250,000 were made available to user agencies. Extensive new geological information was documented, including the identification of volcanic cones and fracture lineaments. Certain circular features identified are thought to be indicative of the presence of economically valuable minerals such as copper. Landsat data is concluded to be "indispensable" to the geological mapping of Mindoro.

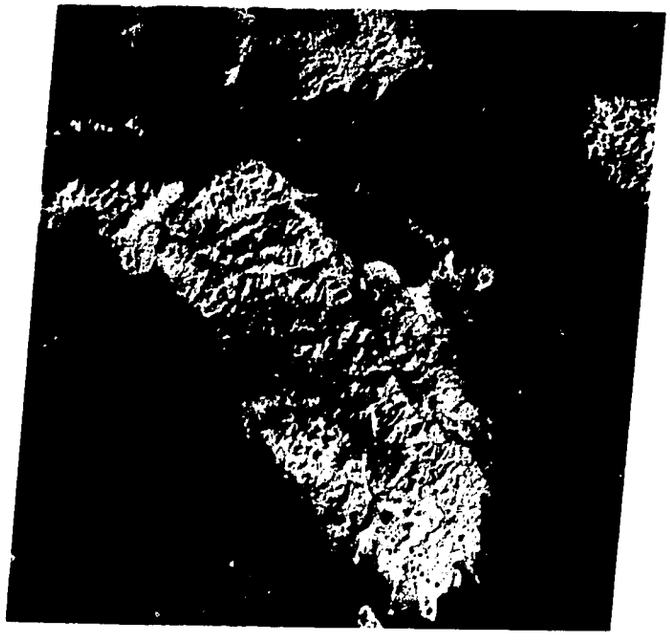
PHILIPPINES

PROBLEM

Mindoro is the seventh largest island in the Philippines and comprises 10,244 square kilometers (3,955 square miles) of hilly or mountainous terrain and narrow coastal lowlands. It is located due south of the Island of Luzon and 130 kilometers from Manila. Mindoro has a population estimated at 475,000, many of whom belong to tribal groups with fairly primitive methods of fishing and shifting agriculture. Development has lagged on this island owing to the relatively small proportion of arable land in relation to the extensive areas of forested mountain slopes — about 80% of the island is mountainous and largely non-arable. The island is rich in primary forests, aquatic resources (fishing), and possibly minerals.

Mindoro is positioned such that the entire island is usually recorded on a single Landsat image frame. The first satellite picture of the island was obtained in the fall of 1972, and the island has subsequently been imaged more than a dozen times on successive Landsat passes. Cloud cover is always a problem in viewing Mindoro because the northwest-southeast trending mountain ranges are perpendicular to the directions of the moisture-carrying monsoons. Clouds usually cover either the northeastern half or the southwestern half of the island. Only occasionally is Mindoro largely free of cloud cover. Landsat-1 data collected on December 23, 1975 showed relatively few clouds; this was the information used for the project.

The initial goal of the grant project was to supply land cover and cartographic information, derived from Landsat data, to a number of agencies involved in the coordinated economic development of Mindoro — Bureau of Mines, Mindoro Integrated Rural Development Office, Bureau of Soils, Bureau of Public Works, Bureau of Coast and Geodetic Survey,

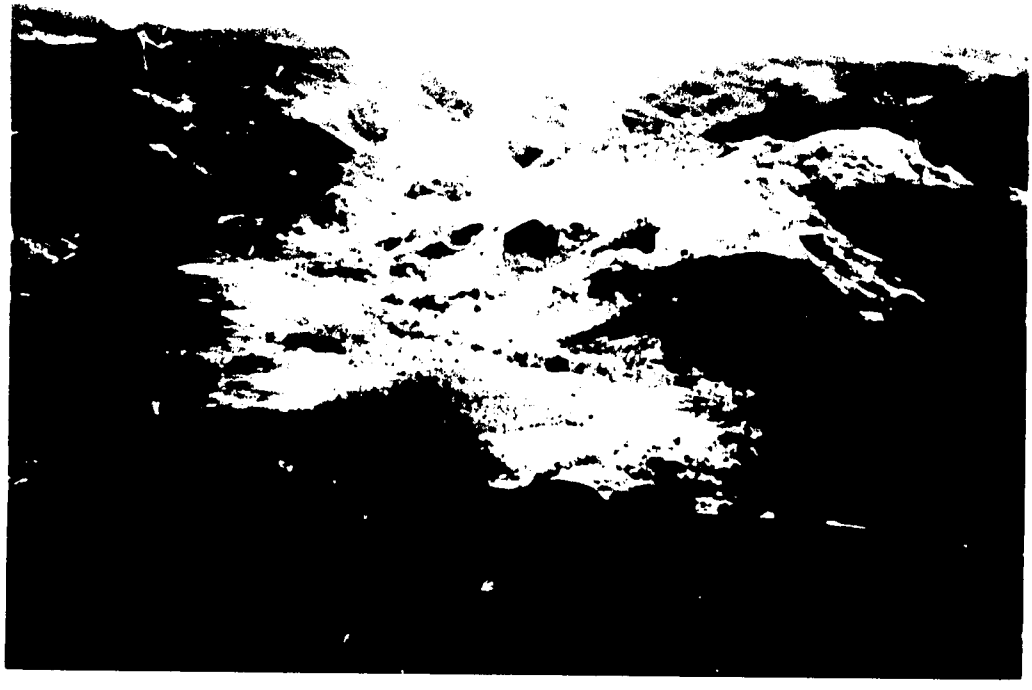


LANDSAT IMAGE OF MINDORO. Note the northwest-southeast mountain range which separates Mindoro into two climatic regimes with growing seasons 6 months out of phase with each other.

Bureau of Forest Development, Bureau of Plant Industry, and Bureau of Fisheries. The remote sensing data included existing Landsat data of Mindoro and multiband aerial photography of selected areas. As the project progressed, coordination between the different agencies diminished and the primary activity was concerned with geological interpretation and mapping by the Bureau of Mines. The project results were documented in a final report entitled "Geological Interpretation of Landsat-1 Imagery of Mindoro Island, Philippines."

PROCEDURE

Primary emphasis was on the use of manual techniques to enhance and interpret images. Interpretation principally concerned analysis of positive black-and-white prints of Landsat Band 7 and Band 5 and diazochrome color-composite transparencies of Bands 4, 5, and 7. A



TWO AERIAL VIEWS OF MINDORO, PHILIPPINES. The infrared aerial photograph (top) shows deforested and eroded mountain slopes, with agricultural land in the valleys; the lower shows the boundary between the forested slopes and the agricultural lowlands, which were dry when this picture was taken.

multispectral color-additive viewer was also used to test enhancement by different band combinations. From these images a series of 1:1,000,000, transparent overlays was produced showing different geological features.

Some digital processing was also pursued, both in the Philippines and at ERIM. Listings and documentation for a simple software system, LIGMALS/B, for processing Landsat data were sent to the Bureau of Mines. This system was programmed for use on the Bureau of Lands IBM 5/360-30 computer and provided a capability to do simple analysis of Landsat CCTs, as well as to make greymap and ratio-map digital printouts. Not yet fully operational, this capability is continuing to be developed with ERIM assistance.

The purpose of the computer processing at ERIM was to produce enhanced images, thematic maps, and areal statistics which would assist in development planning. Several different terrain and cover classes were selected and mapped at a scale of 1:250,000. The satellite data was grouped into five general classes on the basis of spectral characteristics: (1) forests (including primary and secondary), (2) agricultural lands, (3) natural aquatic vegetation (swamps and marshes), (4) geological structure and drainage patterns, and (5) coastal water quality (primarily turbidity). Three maps were produced. One showed agricultural lands, the second displayed forests and aquatic vegetation, and the third combined geological structure and water-quality information. A digitally produced false-color image at a scale of 1:250,000 was also provided. In addition, a newly developed linear-enhancement technique, using the LIGMALS software, was demonstrated for a portion of Mindoro and reported to the Bureau of Mines. This linear-enhancement technique had the effect of surpressing terrain detail and enhancing linear patterns associated with structural features such as fault zones and major drainage networks.

Available published and unpublished data were consulted and provided important ground truth information. A 1:1,000,000 geological map of Mindoro was copied from the 1963 edition of "Geological Map of the Philippines," and fragmentary data from reconnaissance and semi-detailed surveys was consulted. Aerial photographs, including low-altitude multispectral photography, were of particular help. Specific ground observations were made in conjunction with outgoing field-mapping exercises.

RESULTS

Identification of geological features — such as broad lithologic units, young volcanic cones, and fracture lineaments — was accomplished using a combination of image-enhancement and manual-interpretation techniques. Geomorphological and lithological boundaries of major units were most easily delineated in Landsat Band 5 and Band 7 images. Lineaments and young volcanic cones were conspicuous in the diazochrome color composites and on the computer-classified maps. However, the various rock types that constituted the broad lithologic units and/or detailed geological features were mapped using the 1:40,000-scale aerial photography.

Lithologics were delineated on the basis of the degree of rock induration as indicated by image texture, pattern, and tone. Ultra-mafic rocks were likewise delineated despite some regional variability resulting from different physiographic conditions.

Some of the lineaments identified corresponded to known major faults, in particular a major, northeast-dipping gravity fault in the eastern part of the island. This fracture lineament was recognized in the Landsat imagery by its tonal differences in vegetation and the alignment of subsequent stream segments. Lineaments identified, but not associated, with known geological features may be related to as yet unmapped deep-

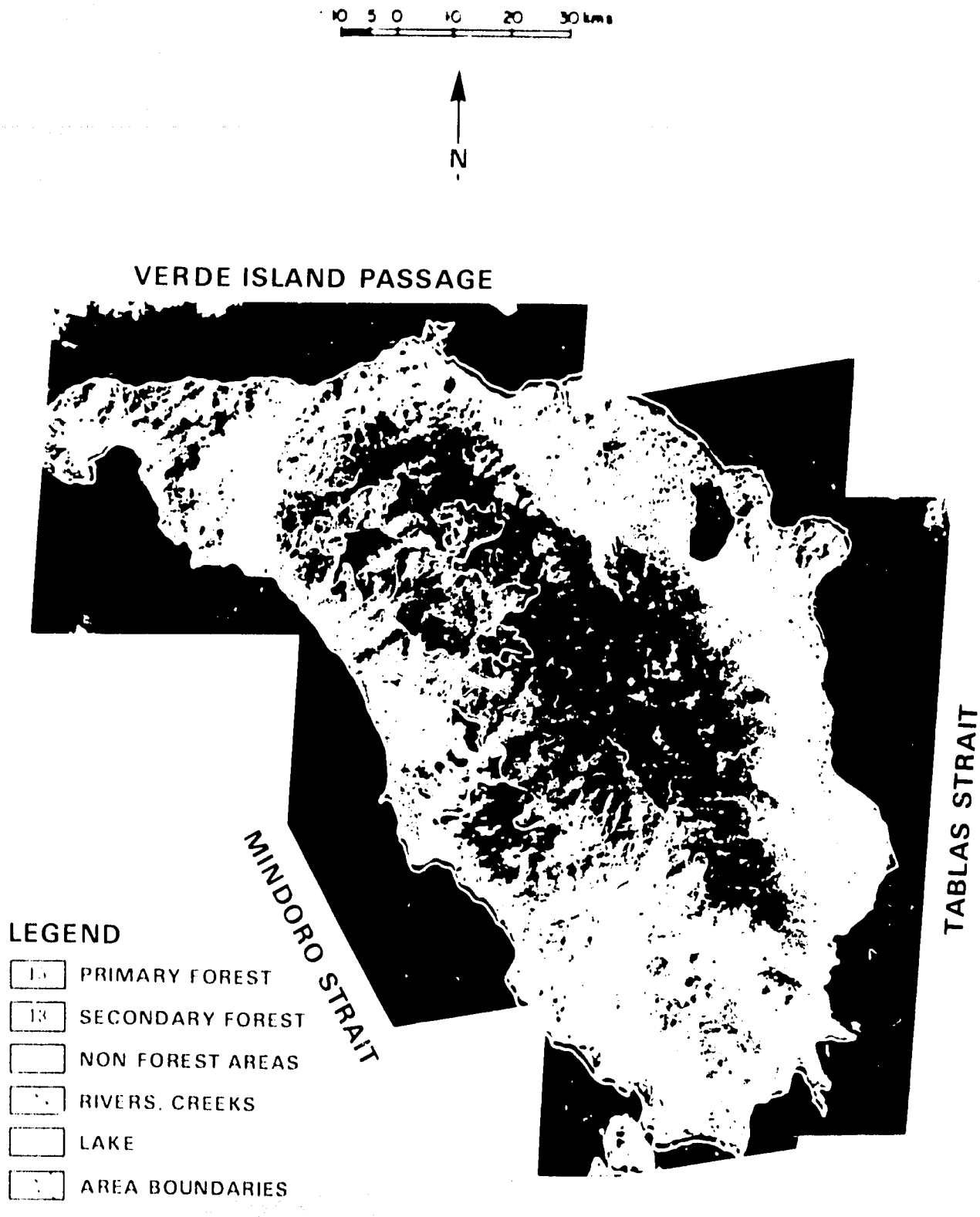
seated structures, some of which appear to control the elongation and trend of the ultramafic intrusive rocks.

In addition to these new linear features, interpretation of Landsat data allowed the identification of several circular structures not previously noted in field mapping or air-photo interpretation. Some of these circular features seem to be related to relatively young, intermediate intrusive rocks which, on the basis of similar structures elsewhere in Mindoro, may indicate the presence of economic minerals such as copper.

The ground truth compiled from forestry maps apparently showed that the ERIM-produced, digital forest-classification map was in considerable error. The digital map showed less than 1/3 of the island to be covered by primary forest while the ground truth indicated 2/3 of the island is still covered by relatively undisturbed forest. An aerial flight in early 1978 to resolve these differences showed the digital map to be largely correct. The forest ground truth map was based on forestry data collected in the early 1960s; extensive forest clearing has taken place since that time.

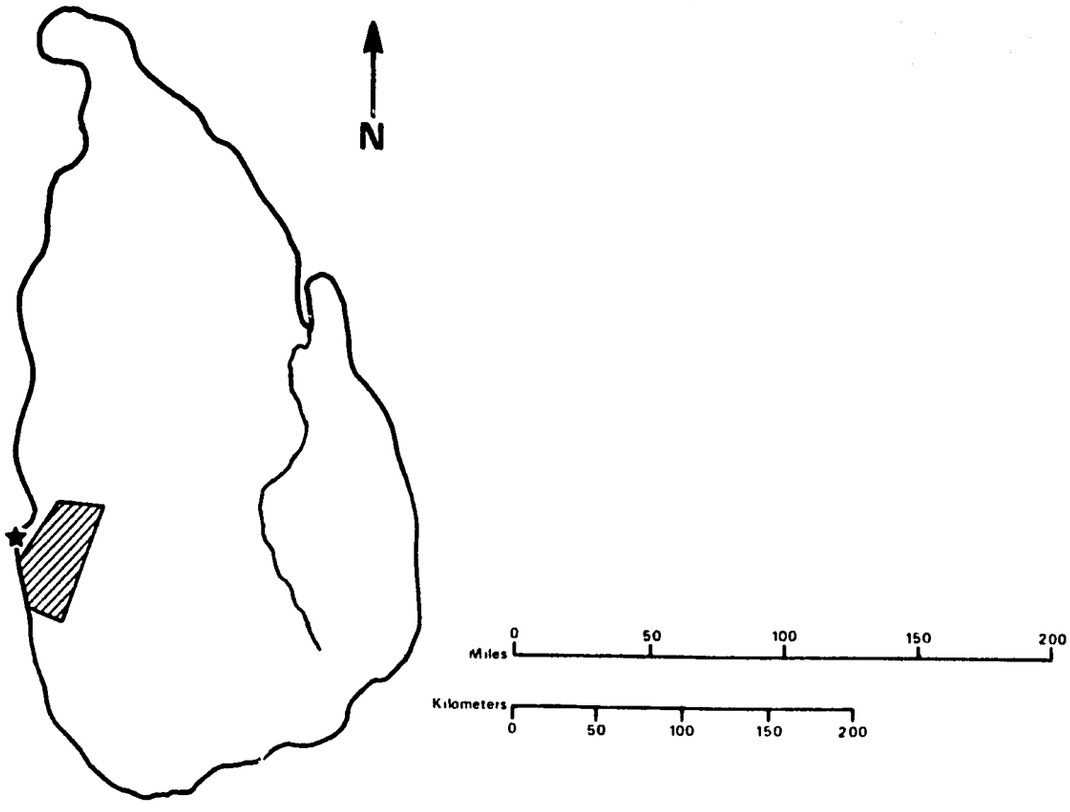
As a result of this project the Bureau of Mines has concluded that Landsat imagery is "apparently an indispensable element in producing an objective, precise and complete geological map of Mindoro, which can be utilized for development planning of the island's mineral resources." The Bureau plans to continue making use of Landsat data in connection with its geological mapping responsibilities.

GEOLOGIC STRUCTURES INDICATED BY INTERPRETATION OF LANDSAT DATA.
Many of these are newly discovered.



COMPARISON OF MAPPED FOREST AREA (1963) WITH FOREST AREA AS INDICATED BY PROCESSED 1973 LANDSAT DATA. The differences indicate a substantial reduction in the total forest area during this 10 year period.

SRI LANKA



PI/Agency: Mr. Chris Nanayakkara, Ministry of Agriculture and Lands, Colombo

Start Date: March 1976

Funding: $20,000

Project: Develop and test simple digital techniques for obtaining quantitative agricultural information from Landsat data.

Results: Digital system for processing Landsat data is operational on Department of Census and Statistics computer (IBM 360/25). Landsat data is being analyzed by trained personnel in newly established Remote Sensing Center.

SRI LANKA

PROBLEM

Sri Lanka, formerly known as Ceylon, is an island nation whose economy is almost entirely dependent on the agricultural sector. Sri Lanka imports nearly 50% of its food supply (mostly rice). To pay for these imports, it exports tea, rubber, and coconut products. The success of the rice crop determines the need for imports and is subject to the uncertainties of the monsoon climate and crop conditions. A priority need for this country is more accurate and timely information to help predict shortfalls — such as the 950,000 metric tons for cereal grains in 1974.

The Ministry of Agriculture and Lands requested AID assistance in helping to establish an indigenous capability to use remote sensing technology for supplying accurate, up-to-date agricultural information. In particular, assistance was requested in the area of digital processing of Landsat data.

PROCEDURE

The technical approach called for development of in-country capabilities for both manual and simple digital analysis of Landsat data, as well as for evaluating various satellite-imagery products for application to crop and water resource assessment. While extensive manual image analysis was performed using standard satellite-image products, digital processing was perceived as the key to quantitative agricultural surveys in a country with small field-sizes, such as Sri Lanka. Under this AID grant the following specific activities were performed:

(1) Image analysis equipment was acquired (Zoom Transfer Scope and a digital programmable calculator).

(2) Imagery and supplies were obtained (Landsat images, film, digital tapes, reference books).

(3) A simple, computer-software package was modified and adopted for operation on the computer facility at the State Department of Census and Statistics.

(4) Advanced digital processing of Sri Lanka data was carried out in the U.S. and evaluated in Sri Lanka.

These supplies and equipment, by the way, are currently being used by various agencies in the newly established Remote Sensing Center in Colombo.

A working group was formed within the Survey Department, consisting of personnel experienced in photogrammetry, computer programming, photo laboratory techniques and photo interpretation. Through the grant program, the University of Michigan LIGMALS software system became available. This system was highly suitable for existing hardware after certain adaptations were accomplished. The figure below shows a schematic diagram of the routines as they were modified for the IBM 360/25 computer belonging to the Department of Census and Statistics. This processing capability is now operational in Sri Lanka.

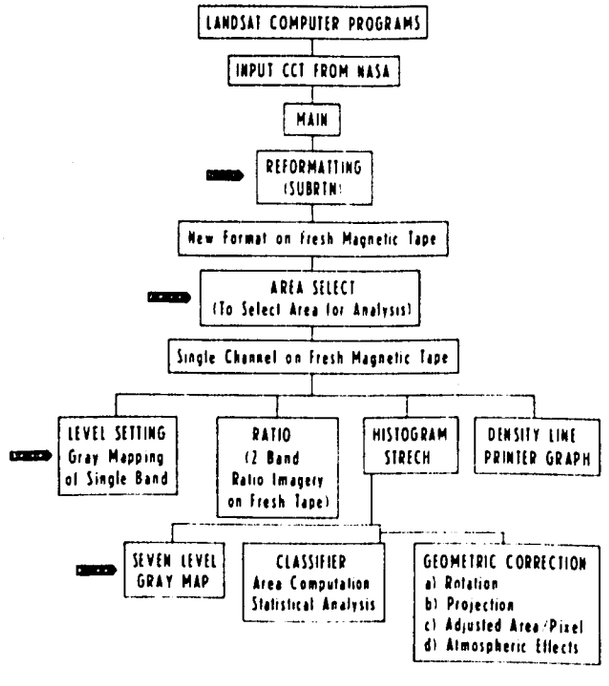
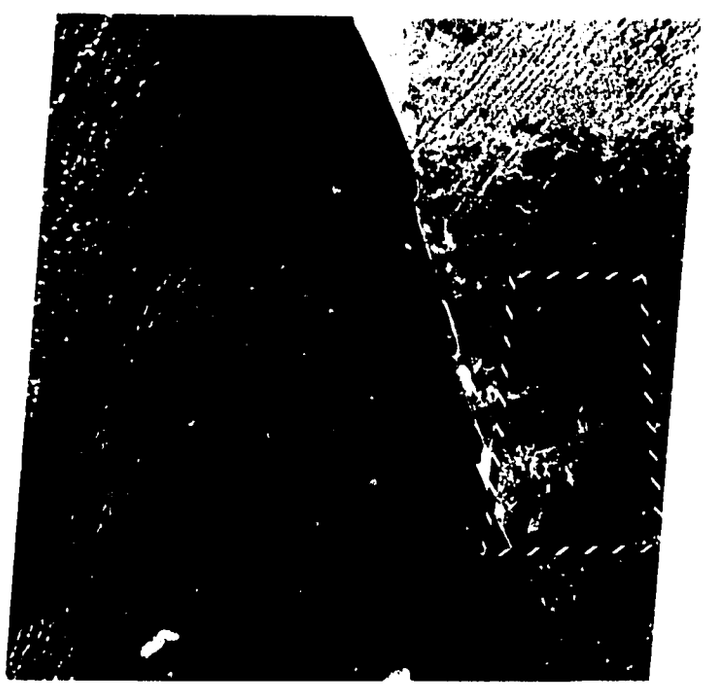


DIAGRAM OF PROGRAMS ADAPTED FROM LIGMALS FOR PROCESSING LANDSAT DATA IN SRI LANKA.

In addition, Landsat imagery of southwestern Sri Lanka (obtained on 27 December 1975) was used to test advanced, data analysis techniques. The grantee provided ground truth information and assisted in all stages of the processing effort at ERIM. The purpose was to provide quantitative terrain information and to obtain attractive image-map displays.

Basically, three different maps were produced from the classified Landsat data of a 28 by 40 mile trapazoidal area just east of Colombo (shown in the figure below). Test sites for specific scene classes were identified from aerial photography. Several limited combinations of colors were used to produce three classification maps at a scale of 1:250,000 and five smaller images — at a scale of 1:62,500 — to match the aerial photography.



LANDSAT IMAGE OF SOUTHWESTERN SRI LANKA. The box marks the area used for computer processing in the U.S.

RESULTS

The original LIGMALS package was divided into the five different stand-alone programs for batch-mode operation. From these programs a number of digital outputs were generated, including graymaps of single bands or ratios of bands, histogram plots, and computations of classified data. Each digital character represents an area of 1.1 acres — for example, the surface of a reservoir area was determined to cover 572 acres. This area-tabulation capability is essential to the quantitative use of Landsat data in Sri Lanka for monitoring large irrigation tanks (reservoirs).

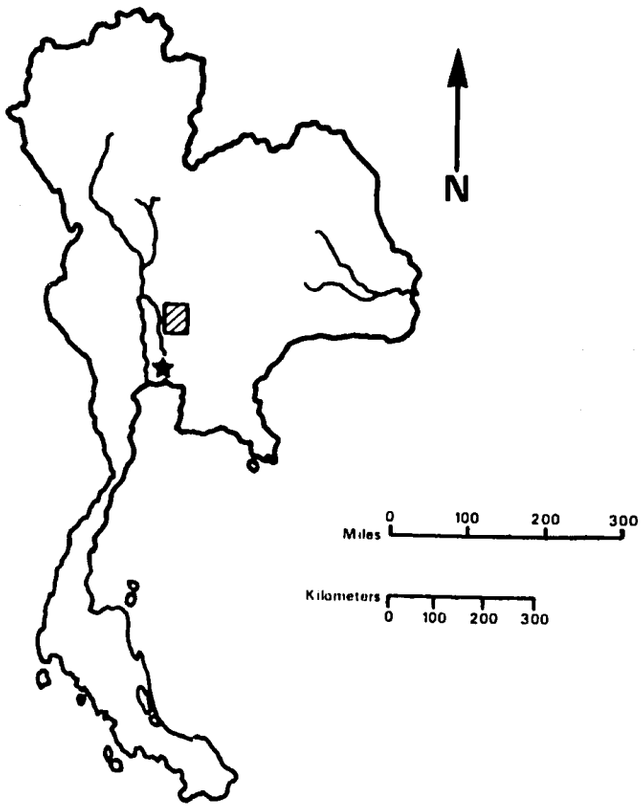
One computer image-map provided the distribution of forest cover. This includes mixed stands of trees associated with homesteads, agricultural areas, and forest reserves. Non-forest areas were identified as padi, bare ground, and water. A different map showed forest areas as a single unit but variations in agricultural fields as different shades (see following figure). Ground observations made in 1977 showed the water, padi fields, and bare surfaces to be accurately identified within the resolution of the system. A third image-map emphasized structural topographic features. The western and central portions of the area comprise a rolling plain, and a high-relief ridge and valley region parallel the eastern side of the map. By printing only floodplains and terrain sloping to the north or west, linear patterns associated with geological structure were enhanced. Since this has the effect of emphasizing linear details related to folding and faulting, it is of great use in geological mapping.

The results of this USAID Sri Lanka Grant project are positive. While questions remain concerning the continuing availability of Landsat data and the precise accuracy of the data in identifying crop acreages, the project has resulted in an operational, in-country manual and digital analysis capability, as well as a clear idea of the nature and

AERIAL PHOTOGRAPH AND AGRICULTURAL MAP OF KELANI GANGA. In the computer-processed map, note the ability to accurately delineate the level (Light-toned), rice-growing floodplain areas. Forested and homestead areas are shown in green.

uses of Landsat data. Based on these results and the high-level national attention they are receiving, a national Remote Sensing Center was established in the Survey Department in early 1978. A vigorous program is continuing to refine the capability to identify areas of irrigated and rain-fed rice, rubber, coconut, sugar cane, and tea production.

THAILAND



PI/Agency: Dr. Somnuk Striplung/Division of Agricultural Economics, Ministry of Agriculture and Cooperatives, Bangkok

Start Date: March 1975

Funding: $20,000

Project: Provide crop signature and acreage information as part of annual rice, corn, and sugar cane surveys.

Results: Extensive crop information was collected for agriculturally productive areas of central Thailand. Multi-data imagery was examined and analyzed. A partial areal frame sampling scheme was established. The project and overall approach are still on-going.

THAILAND

PROBLEM

Thailand is a major food-exporting country and depends greatly on the foreign exchange generated by such exports. However, exports vary greatly with the success of the crop harvest and prevailing market conditions. In 1976 Thailand exported 1.9 million metric tons of rice. In 1977 Thailand's rice export set a record at 2.9 million tons, but the 1978 crop is expected to fall back to 1.8 million tons as a result of drought. Similarly corn, sugar, and cassava exports vary greatly from year to year. Thailand is concerned about the effects of variable production and exports on the availability of domestic supplies. Above all, it needs better crop information for setting export policies.

The Thailand grant proposal requested AID assistance in making use of Landsat data to improve forecasts of rice, corn, cassava (tapioca), and sugar cane production. Thailand was the focus of considerable U.S.-sponsored training in remote sensing and had at that time a U.S. expert in residence to help with the project. In cooperation with the U.S. Department of Agriculture, Thailand was also developing an areal frame sampling technique that relies greatly on aerial photography for use with crop inventories. Its program using teams of enumerators to collect crop information in the field was fairly well developed and could benefit from the use of current Landsat data.

PROCEDURE

Two mains lines of project investigation were followed. One involved visual interpretation of black-and-white and false-color Landsat images showing sample areas of interest (shown on the second color plate); the other was directed toward developing computer procedures in Thailand. Major grant assistance involved the purchase of two vehicles for conducing essential ground-truth operations.

Initial stages of the project concerned selecting and observing field test sites for the four major crops to be studied. Rice and sugar cane are grown primarily in the central plains region of the country, while corn and cassava are cultivated in several regions, mainly on the margins of the central plain and on higher Korat Plateau areas in the northeast. One test area was used initially for sugar cane and two each for rice, corn, and cassava. Information from these test sites was gathered during the 1975 growing season by teams of enumerators in the field. Experienced enumerators leading each team recorded weather conditions, crop vigor and ground cover, and evidences of stress or disease. Efforts were made to develop interpretation rules for discrimination of crops using imagery.

RESULTS

The first enumerative survey was finished in October 1975 and a second was conducted in three locations from late December 1975 to mid February 1976. Experimental plots were established on 1 October 1975 for observing the status of corn, rice, and cassava at 18 day intervals — corresponding to times of the Landsat overpass.

Unfortunately, no usable Landsat data was collected from central Thailand during this period. Attempts to acquire Landsat data showed almost continuous cloud cover on three different occasions. The only good Landsat data obtained was for 18 January 1976 — after most of the crops had been harvested. This lack of Landsat data coincident with the collected field data was a severe setback to the project. While good Landsat imagery existed for the 1972 and 1973 growing seasons, appropriate field data was not available for these years.

Digital data analysis also proved to be a problem. The IBM 1130 computer at the Division of Agricultural Economics was too small to accomodate even simple, Landsat data processing software; and the IBM 370, which had been newly installed at the Asian Institute of Technology, was

RICE AND CORN CULTIVATION IN CENTRAL THAILAND.

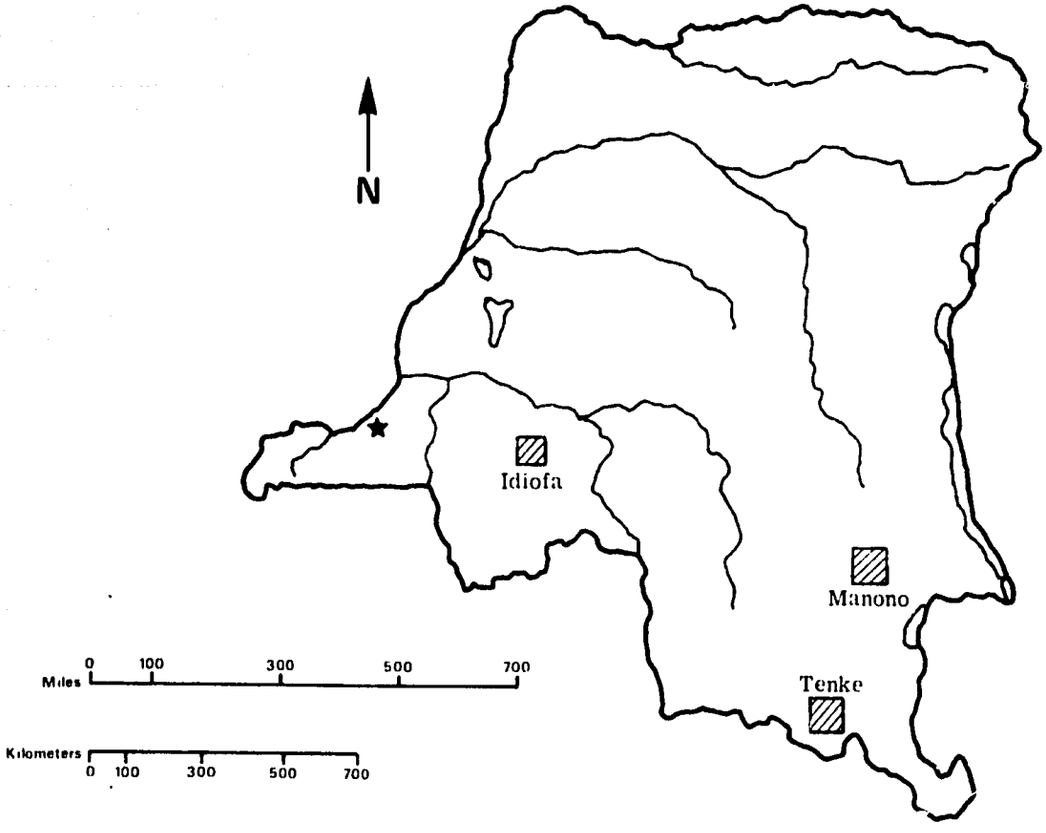
A PORTION OF A LANDSAT FALSE-COLOR COMPOSITE IMAGE SHOWING THE LOCATION OF FIELD SAMPLE SITES (Landsat frame E 2361-02523 18 January 1976)

not yet programmed for processing Landsat data. (Subsequently a small-scale computer, the Burroughs 1700 at Chulalongkorn University, was successfully programmed to process Landsat computer-compatible tapes using ERIM-supplied software [3]; but it did not become operational in time to contribute to this project.)

Using the 18 January 1976 data, ERIM prepared digital graymaps — Landsat Band 5, Band 7, and a ratio of 5/7 - of four portions of the central Thailand agricultural area (near Sara Buri and Lop Buri, but the Thai personnel were not successful in locating the small (<2 hectares) test fields on them. In September 1976 one of the principal technical personnel accepted a scholarship to study agricultural economics in the U.S., and continuing activity on the project became minimal.

While this particular grant project did not reach a successful conclusion — in large part as a result of unforeseen circumstances — it is clear that the high-level interest in remote sensing, particularly in Landsat data, continues unabated in Thailand. AID is anticipating continuation and expansion of this important agricultural remote sensing approach under separate project funding and in close cooperation with the U.S. Department of Agriculture. If Landsat data can be shown to supply timely agricultural information to developing countries which are economically dependent on agriculture, such as Thailand, this will be a significant accomplishment.

ZAIRE



PI/Agency: Dr. Ilunga Sendwe, ERTS-Zaire, Bureau du President - in cooperation with Institute Geographique du Zaire, Kinshasa

Start Date: September 1976

Funding: $20,000

Project: Develop and demonstrate use of annotated Landsat images as cartographic substitutes for four selected areas of Zaire.

Results: Two Landsat frames were annotated and field checked for accuracy; two others remain to be field checked. Photo-mapping facilities of the Institute Geographique du Zaire have been repaired and are operating. Information is incomplete on the project's final results.

ZAIRE

PROBLEM

Zaire covers an area of more than 905,000 square miles (roughly the size of the U.S. east of the Mississippi River), but has a population of only 26 million. It is rich in mineral, water, forest, and land resources; only a small portion (between 10 and 20 percent) of the arable land is cultivated. Basic medium-scale cartographic information required for planning and development of Zaire's extensive resources is either non existent or out-of-date for most areas of the country. Nor does Zaire have the survey capabilities needed to acquire this information in the near future.

The project in Zaire, therefore, was designed to use the map qualities of Landsat imagery for obtaining basic information and preparing plans for large-area development. The grant provided for the repair of a large-format mapping camera, the purchase of needed photo supplies and field equipment, and the production of four digitally processed Landsat maps of Zaire. The overall purpose of the project was to demonstrate the use of Landsat imagery as a substitute for maps.

PROCEDURE

Good quality Landsat data was selected from several areas in need of new cartographic information, and the Landsat images were interpreted and annotated as standard cartographic products. (Technical support and data processing for this project were supplied by the Earthsat Corporation under direct agreement with the grantee.)

Four recent Landsat frames were selected and processed in the U.S. to provide enhanced or classified imagery. Two of the frames were produced as edge-enhanced, false-color products; and two were classified using spectrum-matching techniques. Subsequently, the ERTS-Zaire staff

prepared overlays for the Tenke, Manono, Lomela, and Idiofa sites and also developed technical legends. (These results demonstrated that significant errors in the location of features existed on previously compiled maps.) These images were then photographed and reproduced using facilities located at the Institute Geographique du Zaire (IGZ).

In addition to preparation of these Landsat images, AID grant funds were used to repair a large mapping camera at the Institute and to supply photographic materials needed for the reproduction of the annotated images. The photographic materials were ordered by ERIM from standard Belgian sources and shipped directly to Zaire. Laboratory and field equipment for analyzing and interpreting the Landsat imagery were supplied to ERTS-Zaire.

RESULTS

The final results of this project, and hence its impact on Zaire's overall remote sensing program, are as yet unknown. However, it has provided a basis from which ERTS-Zaire (a self-contained entity within the Bureau du President which is dedicated to developing Landsat applications) can communicate and interact with IGZ, a user agency. The annotated maps for Lomela and Idiofa are complete, and work on the Tendo and Manona maps is continuing. Current limitations on the broader use of Landsat data in Zaire are partly administrative, preventing the large volume of existing imagery from reaching the hands of those agencies which can make best use of it.

If successfully concluded, this project will contribute to AID's efforts to establish a comprehensive national user-assistance role for ERTS-Zaire and to demonstrate an application to a critical national need for basic map information. Already the project has helped promote institutional contacts between technical and user agencies — a key activity before Landsat-derived information can be employed for extensive development planning.

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3. Prasit Prapinmongkolkarn and Chavalit Thisayakorn, "Feasibility Study of System Implementation for the Digital Processing of Landsat Data," Chulalongkorn University, Bangkok, August 1977.

APPENDIX A

GRANT PROGRAM ADMINISTRATION

A.1 INTRODUCTION

In September 1974 the Agency for International Development's Office of Science and Technology established a competitive grant program to help developing countries use data from NASA's Earth Resources Technology Satellites (Landsat, formerly ERTS-1 and-2) for solving problems related to resource development and environmental monitoring. The program was administered for AID by the Environmental Research Institute of Michigan (ERIM). This appendix describes the administration of the program.

The grant program was designed to test and demonstrate specific applications of remote sensor data which were of particular importance to the countries involved. Grants were awarded to investigators proposing projects in one or more of the following areas:

* Agriculture
* Range Management
* Water Resources
* Environmental Monitoring
* Forestry
* Land Use
* Rural and Regional Development
* Cartography
* Geology and Mineral Exploration
* Marine Resources

ERIM organized a panel to review, evaluate, and make the final selections of grant proposals for award on the basis of the criteria listed in Section A.3. ERIM then negotiated specific agreements with the appropriate sponsoring agencies to define projects, schedules, budgets, and reporting procedures, and administered and monitored the selected grants.

A.2 SOLICITATION AND REQUIREMENTS

In September 1974 AID missions in developing countries distributed announcements of the competitive grants program to agencies or organizations

which might be interested in participating. Since funding was limited, it was suggested that no more than two proposals be submitted by a single country. At the same time, ERIM distributed the announcement directly to LDC principal investigators already involved in Landsat investigations with NASA, to advise them of the existence of the program.

The following information was requested to be included in the proposals.

Objective: Describe the resource inventory and management or environmental problems you propose to analyze, and alternative decisions or actions that may be taken, based on the information derived from Landsat data.

Technical approach: This should include a summary of the types of information sought from Landsat and other sources, and general procedures for processing and analyzing these data. Requirements for Landsat data should specify geographic area to be covered, coverage dates, and type of data products needed. Outline the effect that the resulting information is expected to have on existing programs in your country.

Previous experience, if any, with remote sensing.

Principal personnel to be assigned: Indicate experience and current responsibilities of principal investigator and other key personnel, and estimate man-months of participation.

Itemized budget and technical assistance: Include itemized budget for the expenditures to be covered by grant funds. Estimate the type and amount of consultation, training, computer processing, and other technical assistance desired in support of your project. Distinguish between that assistance which is required and that which is highly desirable but not essential. Equipment purchases require specific approval of the project monitor.

Supplementary effort: Indicate the amount and kind of support your organization will provide to supplement the grant funds, including

both financial support and personnel.

Project time schedule: All proposals should be for projects which can be completed and reported in no more than 13 months. Earlier completion dates are desirable. Completed proposals are due on or before January 1, 1975 and should be sent to the Environmental Research Institute of Michigan.

On 22-23 January 1975, an AID Grant Proposal Evaluation Panel met to evaluate 15 grant proposals for Landsat data utilization submitted by developing countries. Members of the panel were:

Mr. Donald S. Lowe, ERIM
Mr. Frederick J. Thomson, ERIM
Dr. Robert A. Summers, SPC
Mr. William L. Smith, SPC
Mr. Merrill Conitz, OST/AID
Mr. J.D. Blumgart, Africa Bureau/AID
Mr. Charles J. Robinove, EROS/USGS
Mr. James Zimmerman, OIA/NASA
Mr. Tobert Pogson, CRED/U. Mich

A.3 SELECTION CRITERIA

AID required that a participating country had to have a program approved by NASA to be eligible for consideration in the grant program. This requirement insured that Landsat data would be available. The proposed grant activities should, however, constitute new efforts and should not duplicate experiments which the countries had already agreed to perform under terms of their agreement with NASA. The following criteria were used in making the final selections:

1. importance of the proposed project to the priorities and needs of the grant country;
2. assurance that the information sought would be of value to and used by a decision-oriented agency;
3. technical validity of the proposal and probability of successful accomplishment;

4. probability that the success of the project would lead to a continuing program for utilizing Landsat remote sensing data in the recipient country;
5. grantee's technical and managerial competence to implement the project, or the need to develop this competence within the country;
6. the contribution of personnel or financial resources by the grantee's sponsoring institution, or justification for lack of such support;
7. assurance that the grant was not to be used as a substitute for, or as a basis for funding of, existing experimental program activities.

A.4 GRANT SELECTION

In January 1975 the review panel selected six proposals - from Bangladesh, Bolivia, Chile, Lesotho, Pakistan, and Thailand - for funding under the original grant program. A year later more funds became available and grants were awarded to the Philippines and Sri Lanka. In mid-1976 additional allocations allowed the funding of solicited proposals from Peru and Zaire.

The ten AID grant countries - three in South America, two in Africa, and five in South and Southeast Asia - provided a good cross-section of developing countries for evaluating the use of remote sensing for national development.

The specific objectives of the ten grants also varied considerably, reflecting both the wide range of applications for remote sensing data and the different information needs of different developing countries. Four of the projects (in Bangladesh, Lesotho, Sri Lanka, and Thailand) were primarily concerned with the application of remote sensing to agriculture - although the approaches were different in each case. Two grant programs (Chile and the Philippines) were concerned with the use of multidisciplinary information on resources for planning the

integrated development of large under-utilized regions. Other projects concentrated on cartography (Zaire), forestry (Peru), geology (Bolivia), and coastal zone development (Pakistan).

A.5 FUNDING

Seven of the grants were for the sum of $20,000; one was for $18,000 (Lesotho) and two others for $10,000 (Chile and Bolivia). The lesser amounts awarded to Chile and Bolivia took into consideration the existence of relatively well-established remote sensing programs in those two countries.

Grant funds were available for acquisition of data, supplies, equipment, training, and - in several cases - advanced data processing in support of the projects. Funds were not to be used for salaries or expenses incurred in connection with the investigators' normal duties. The time of the investigators and their colleagues were donated by their respective institutions, and facilities existing within the grant countries were expected to be made available as required. In eight of the projects the investigators were national government employees; in the two other cases they were university faculty.

Under the terms of the agreement, the grantee's institution received the cash award in four equal quarterly installments. With the exception of the initial installment, each installment became available upon receipt of a short fiscal report for the previous period. Final fiscal and technical reports were due at the end of the grant project.

To expedite the purchase of necessary supplies and equipment, most of the grantees elected to establish escrow accounts at ERIM with some portion of their grant funds. These funds were administered by the grant monitor at the specific direction of the grantee. These ERIM-based grant accounts worked very efficiently. Developing countries often have rigorous and time-consuming regulations concerning the transfer of funds overseas. Since most of the required equipment and materials were of U.S. manufacture, direct payments from these ERIM

accounts permitted their timely acquisition. The ERIM-based accounts also made financial monitoring easier and left the investigator with fewer records to maintain.

A.6 TECHNICAL ASSISTANCE

In addition to financial aid, the grantees were provided with technical support to pursue their projects. It was recognized that investigators undertaking remote sensing projects for the first time usually need technical support and guidance. For an investigator in a developing country the opportunity to test and demonstrate applications of modern remote sensing data carries professional risks along with the prestige associated with utilizing a space-age technology. Typically the investigator has neither the experience nor the tools with which to complete his proposed project; nor does he have ready access to sources of data or expertise that may be required.

At the time of a grant award an ERIM grant monitor was assigned to respond to requests for advice and assistance from the grantee. In most cases the technical monitor had experience in the application area of the project to which he was assigned. Thus, the technical monitor for the Bolivian iron ore mapping project was an ERIM geologist; for the Indus Delta project in Pakistan, an ERIM oceanography expert and a geomorphologist; and for the Peruvian aguaje palm project, a forester.

At the beginning of each project the technical monitor visited the grantee to facilitate negotiations and to assess the kinds of technical assistance that would be required. In several cases the grantees had considerable experience in working with remote sensing data and required little help; in others, fairly comprehensive technical assistance and training were required. These visits also gave the technical monitors an opportunity to establish personal relations with the grantees. In retrospect, this rapport was a key element in determining the success of the various projects.

Technical assistance included monitoring the grant activity, providing individual training and advice, purchasing necessary data,

equipment and supplies and - in a number of cases - producing computer-processed images and maps at the request of the investigator.

New equipment was a major item required for most of the grant projects. While the equipment was selected by the grantee and paid for from individual grant accounts, the project monitor usually approved and arranged for the purchase. All items valued at $1,000 or more also required prior AID approval. Table A-1 lists some of the equipment acquired by various grantees. Note that most of the items are used in connection with relatively simple image enhancement and analysis techniques, which are appropriate to the technological level of most of the developing countries, as well as to particular project requirements. The use of this equipment is discussed under individual grant descriptions in the body of this report.

TABLE A-1

EQUIPMENT OBTAINED UNDER VARIOUS GRANT PROJECTS

Equipment	Purpose	Country
Zoom Transfer Scope	Projects image information onto a map base	Chile, Sri Lanka
Diazochrome Printer and Developer	Produces color transparencies directly from positive black and white transparency	Chile, Peru, Philippines
ERTS-Radiometer	Measures light in 4 Landsat spectral bands	Philippines
Cibachrome Processing Kits	Color photo-reproduction with simple equipment	Sri Lanka
Digital Densitometer	Allows accurate recording of film densitites	Pakistan
Off-Road Vehicles	Access to rural areas for ground truthing	Thailand
Digital Calculator and Planimeter	Digital data analysis	Sri Lanka, Zaire
35mm Camera	Image-record of test site conditions	Peru
Binocular Stereoscope	Stereo viewing of aerial photography	Pakistan
Map Coordinate Digitizer	Compiles linear information in digital format	Lesotho

Photographic supplies and satellite data were frequently ordered by the technical monitor at the request of the grantee. While most of the grantees have modest photographic facilities at their disposal, film, paper, and photo chemicals were usually in short supply. Available satellite imagery was ordered directly from the U.S. Geological Survey's EROS Data Center and sent to individual investigators. In several cases a number of enlarged Landsat images were printed at ERIM and sent to the investigators when their own photographic facilities were not suitable for that purpose. Landsat Band 5 and Band 7 black and white prints at a scale of 1:500,000 were found to be particularly convenient for handling and subsequent analysis. Aerial photographic film was ordered for test site overflights to complement satellite imagery in Pakistan and the Philippines.

Books, reports, and other pertinent literature were recommended to and usually acquired by grantees. In several cases grant funds helped establish a "remote sensing library" at the agency of the principal investigator. Appendix D contains a list of some of the literature considered to be generally useful to those starting remote sensing projects.

Seven of the grantees requested that computer processing of satellite data be undertaken in the U.S. in connection with their projects. These requests were appropriate when the processing results clearly contributed to the objectives of the proposed project, and the cost of the processing was a minor portion of the grant allocations (usually less than 25%). Usually the grantee or his representative directly assisted in the computer processing task and thus received "on the job" training in the process.

The computer-processed results served several technical and administrative purposes. Technically, computer image maps and statistics provided detailed spatial information which was generally unavailable from normal, manual, image analysis techniques. These products provided analytical results which, after being checked in the

field, could be used directly by national planners and resource managers.

Several investigators were interested in the nature and limitations of state-of-the-art processing procedures hoping that, if the results of such procedures were more useful than manual techniques, they might convince their governments to work toward developing a digital processing capability. Usually, however, the investigators found that manual techniques are essential in most remote sensing applications projects. This discovery enhanced the investigator's confidence in the continuing need for simple, manual techniques and recognition that computer processing is at best a complement, not a replacement, for such manual analysis and interpretation.

Administratively, the production of computer processed maps served several purposes. They frequently provided a means by which technical personnel could begin to interpret and extrapolate field and laboratory observations, and compare the uses of manual techniques. Color computer images provided impressive displays which investigators could use to promote further remote activities within their institutions and to publicize their grant projects outside their institutions. In several cases high-ranking decision makers took an increased interest in the grant projects after being shown these displays.

A.7 PROJECT REPORTING

Under the grant agreement, individual investigators were requested to provide quarterly reports concerning the progress of their project and the expenditure of funds. A comprehensive final report documenting the objective, approach, and results of the investigation was required at the end of the project. The investigator was also asked to describe the impact of the project within his country's institutional framework and to make recommendations concerning the direction of future remote sensing activities.

Formal reporting proved to be difficult for some grantees - both because of internal institutional approvals required and because of

uncertainties with written English. For that reason informal communication and personal contacts were emphasized; non-English speaking grantees frequently used Spanish (Chile, Bolivia) or French (Zaire) in their written communications. In many cases informal communication and correspondence between the investigator and his monitor provided most of the information. The most successful grants were characterized by frequent informal communication, with the grant monitors playing an important role in encouraging and supporting the various projects. Lack of such communication, on the other hand, generally indicated a lack of progress.

A.8 PUBLICATIONS

The investigators were encouraged to make the results of their efforts known both within their countries and to the international community by publicizing their grant activities in seminars, lectures, and published papers. Table A-2 is a list of these publications. In addition, ERIM has helped prepare descriptive and display material concerning the grant program for various briefings and discussions. For example, annotated, remote sensing slide-sets have been made for the grants in Bangladesh, Pakistan, Peru, and Sri Lanka and others are in publication.

TABLE A-2

PUBLICATIONS OF AID GRANT PROJECTS

Ahmad, M. Shafi. "Simple and Advanced Digital Analysis of Landsat Data for the Indus Delta." Presented at the United Nations Regional Training Seminar on Remote Sensing Applications, Karachi, 17 - 28 January 1977.

Ahmad, M. Shafi et al. "An Investigation of Landuse and Coastal Waters in the Indus Deltaic Region." Proceedings of the 12th International Symposium on Remote Sensing of Environment, Ann Arbor, 1978.

Chowdhury, M. I. and K. M. Elahi. "Aspects of Land Utilization in the Sylhet-Mymensingh Haor Areas of Bangladesh: An Analysis of Landsat Data." 2nd Annual Conference, Bangladesh Association for Advancement of Science, Bangladesh Agricultural University, Mymensingh, January 1977.

Chowdhury, M. I. and K. M. Elahi. "Land Utilization and Ecological Aspects in the Sylhet-Mymensingh Haor Region of Bangladesh: An Analysis of Landsat Data," Proceedings of the 11th International Symposium on Remote Sensing of Environment, Ann Arbor, 1977, pp. 1183 - 1196.

Chowdhury, M. I, A. F. M. Kamaluddin, K. M. Elahi, S. D. Shamsuddin. "Optimization of Benefits from the Haors of Sylhet and Mymensingh - An Analysis of Landsat Data." Final Report, Department of Geography, Jahangirnager University, Dacca, 1977.

Colwell, J. E. "Uses of Remote Sensing for Agricultural Statistics in Developing Countries." ERIM Report 111800-18-T, August 1977.

Conitz, M. W. and D. S. Lowe. "Remote Sensing Utilization by Developing Countries: An Appropriate Technology." Proceedings of 11th International Symposium on Remote Sensing of Environment, Ann Arbor, 1977, pp. 1055 - 1064.

Danjoy, Walter A. "Use of Remote Sensing Systems: Evaluating the Potential of the Aguaje Palm Tree in the Peruvian Jungle." Final Report, ONERN, Lima, November 1977.

Danjoy, W. and F. Sadowski. "Use of Landsat in the Study of the Forest Classification in the Tropical Jungle." Proceedings of the 12th International Symposium on Remote Sensing of Environment, Ann Arbor, 1978.

TABLE A-2 (CONTINUED)

ERIM Staff. "A Preliminary Assessment of AID's Requirements for a Landsat Follow-on Satellite." ERIM Report 111800-15-P, August 1976.

Fernandez, J. C. et al. "Geological Interpretation of Landsat I Imagery of Mindoro Island, Philippines." Proceedings of the 12th International Symposium on Remote Sensing of Environment, Ann Arbor, 1978.

Nanayakkara, C. "Problems of Organizing Remote Sensing Applications in a Developing Country." Proceedings of the 12th International Symposium on Remote Sensing of Environment, Ann Arbor, 1978.

Nanayakkara, C. and H. Wagner. "Digital Processing System for Developing Countries," Proceedings of 11th International Symposium on Remote Sensing of Environment, Ann Arbor, 1977, pp. 1123 - 1126.

Ortiz, R. Arnoldo. "Advance in the Research and Use of Remote Sensors in Natural Resources Development Studies, Chile." Proceedings of the 12th International Symposium on Remote Sensing of Environment, Ann Arbor, 1978.

Ortiz, Arnoldo et al. "Inventario de Recursos Naturalis Por Metodo de Percepcion del Satelite Landsat I Region - Tarapaca." 2 Volumes, Instituto de Investigacions de Recursos Naturales - CORFO, Informe 36, 1977.

Shamsuddin, S. D. "Satellite Remote Sensing and Its Application to Resource Inventorying: A Case Study of the Sylhet-Mymensingh Haor Area." 2nd Annual Conference, Bangladesh Association for Advancement of Science, Bangladesh Agricultural University, Mymensingh, January 1977.

Wagner, H. "An Interactive Digital Multispectral Data Processing Software Package." Remote Sensing of Earth Resources, 5th Annual Conference, Tullahoma, Tennessee, March 1977, pp. 173 - 178.

Wagner, T. W. and J. C. Fernandez. "Applications of Landsat Data to the Integrated Economic Development of Mindoro, Philippines," 11th International Symposium on Remote Sensing of Environment, Ann Arbor, 1977, pp. 1375 - 1380.

Wagner, T. W. and D. S. Lowe. "A Small Grant Program for Remote Sensing Technology Transfer." Proceedings of 12th International Symposium on Remote Sensing of Environment, Ann Arbor, 1978.

APPENDIX B
SPECIAL STUDIES

B.1 INTRODUCTION

Associated with AID's objective of contributing to the development of less developed countries by transferring remote sensing technology was the need for several ad hoc studies which addressed specific issues. As AID's role in transferring remote sensing technology expanded over the contract period, questions developed concerning the applicability of remote sensing to agricultural surveys, the feasibility of supporting regional reception and user assistance centers, and the significance to developing countries of proposed advances in the U.S. space program. The following studies were conducted by ERIM at the request of AID; they are more completely documented in several references listed in Appendix D.

B.2 AID'S LANDSAT FOLLOW-ON REQUIREMENTS

In mid-1976 the National Aeronautics and Space Administration invited AID and other federal user agencies to comment on a proposed Landsat follow-on program for the early 1980s. The follow-on program would extend the demonstrated applications of the current Landsat system by supplementing the existing Landsat multispectral scanner system (MSS) with a superior system known as the thematic mapper (TM).

ERIM conducted a study of the technical features of the proposed program and how they would affect applications in developing countries. At least half of the current applications would benefit from the superior spectral and spatial resolution of the TM system - especially agricultural applications such as crop inventory and soil hazard monitoring, due to the small field sizes and the economic importance of agriculture in developing countries. Certain other applications such as mineral exploration would also benefit from the improved sensor system, but would not need the frequent coverage required by agriculture and hydrology.

The primary technical issue that concerned AID was the rate of data collection by the satellite and its subsequent reception on the earth. The ability of the TM system to collect and transmit data is an order of magnitude greater than the current MSS and requires a reception technology generally out of reach of most developing countries. Therefore, the means whereby foreign countries could obtain this superior TM data of their own territory is an important technical and political issue.

B.3 CROP SURVEYS IN DEVELOPING COUNTRIES

Agriculture is a key factor in the economies of most developing countries and is thus a focus for AID efforts to help the poor majorities. To help AID determine the role of remote sensing in supplying agricultural statistics, ERIM prepared a report entitled "The Use of Remote Sensing in Producing Agricultural Statistics in Less Developed Countries." This report was designed to assist AID personnel in evaluating the technical and economic feasibility of using aircraft and/or satellite data for making agricultural production estimates.

To help determine crop production in developing countries, remote sensing could be used for crop identification, acreage determination, and/or yield determination. Many factors affect the performance, usefulness, and cost-effectiveness of remote sensing technologies in developing countries. For example, local cultivation practices and climate (especially cloud cover in relation to the crop-calendar) are recognized as major environmental factors which influence the role of remote sensing. These factors vary considerably with different countries, and the overall utility of remote sensing within an agricultural information system must be determined individually for particular countries and regions. The key is to design a sampling strategy within an appropriate agricultural information system in which remote sensing is only one of the sources of data. Remote sensing should be seen as an important, but not the only tool for gathering crop information.

B.4 ECA REMOTE SENSING TEAM

As a result of a 1975 resolution by the Council of Ministers of the Economic Commission of Africa (ECA) to promote and establish regional satellite ground receiving and data handling centers in Africa, a team of international development experts was assembled to provide recommendations on the feasibility of such an undertaking. Mr. Donald Lowe of ERIM provided technical support for this international team.

The team's mission was three-fold:

1. Review existing plans for receiving stations at Kinshasa, Ouagadougou, Fucino, and Teheran in relation to Africa's needs.
2. Suggest modifications which might be technically or financially beneficial, and evaluate the significance of the plans for remote sensing capabilities for all of Africa.
3. Evaluate existing or planned African national or regional training centers for applications of remote sensor data, including data processing and analysis, on-the-job training, and formal classroom training.

As a result of extensive travel and discussion within Africa in March-April 1976, the team made the following recommendations.

1. A comprehensive Remote Sensing Program for Africa should be initiated to develop (within a few years) an operational remote sensing system for Africa. An expert in remote sensing should be assigned to ECA to work out the details of this program.
2. A comprehensive management, coordination, and information network should be established for the African Remote Sensing program so that each part of it remains in balance with the other parts.
3. Guidelines should be established for the development of a remote sensing training program in Africa (see list).

GUIDELINES FOR DEVELOPING
A REMOTE SENSING TRAINING
PROGRAM IN AFRICA

- The remote sensing program should be developed on a long-term basis as an integral part of a total remote sensing program. It should have continuity and it should develop to meet the various and changing needs of the region served by the center. It should provide training at both the managerial and technical levels.
- The training center should have a full-time staff of three-five highly qualified experts who would:
  1. assess the training needs of the region served by the center, develop curricula, acquire the necessary training facilities and instructors, and manage the courses;
  2. conduct their own application projects in the region;
  3. accept a limited number of student helpers for on-the-job training;
  4. provide user assistance.
- Training can begin immediately without waiting for an African Landsat station to be constructed because much information on Africa is already available.

The mission also made the recommendations below as a technically feasible solution to the problems of acquiring Landsat coverage for virtually all of Africa and of providing adequate training and assistance in using the data - taking into account existing facilities, institutions, plans, and proposals.

1. The ERTS-Zaire national program should be converted to a regional one. The presently planned reception, data processing, and data reproduction facilities are adequate to meet regional needs; but training, user assistance, and data distribution facilities must be expanded.

2. A Regional Landsat Reception, Processing, Training and User Assistance Center should be established at Ouagadougou.

3. A Regional Training and User Assistance Center should be established in Nairobi and should share facilities with the Regional Center for Services in Surveying Mapping.

4. The Government of Egypt should be approached about converting the present Remote Sensing Research project of the Academy of Scientific Research and Technology to a regional program. Training would emphasize computerized data processing and on-the-job training.

5. In the event that the National Zaire Reception Center does not materialize, a complete Regional Remote Sensing Center should be established in Nairobi or another location which would, in conjunction with any ongoing stations, provide better overall coverage of Africa.

6. Consideration should be given in the future to additional possibilities for training and user assistance:

- to colocate a Remote Sensing Center with the Ile-Ife Regional Center for Aerial Survey;
- to use any newly created regional centers established for specialized services or applied research in the fields of minerals, water, or natural resources development for on-the-job training in remote sensing;
- to participate in the special inter-regional training courses organized by various international agencies.

APPENDIX C

REMOTE SENSING AND RESOURCES DEVELOPMENT

C.1 INTRODUCTION

The primary value of information is in helping managers make better decisions based on more accurate understanding. Remote sensing information is usually concerned only with the physical resources of a country or area. Clearly, efficient use of that information in a larger management context must be considered. The approach of this grant program is to make better resource information available to developing country planners and administrators directly, rather than to try to devise development plans for them. This is the principal justification for the effort to collect, analyze, and interpret remote sensor data at the local level.

The concept of "appropriate technology" has gained increasing attention from those concerned with the transfer of "Western" ideas and institutions to the developing countries of Latin America, Africa, and Asia.* Does remote sensing qualify as an "appropriate technology"? In what developmental or environmental context might it be considered appropriate or inappropriate? If remote sensing is appropriate, what results might be expected or hoped for in its transfer to developing countries?

This appendix is intended to place the functions of the grant program in context for those relatively unfamiliar with the nature of remote sensing.

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*Note that the term "appropriate technology" is not necessarily the same as the late E.F. Schumacher's term "intermediate technology" as defined in his book Small Is Beautiful.

C.2 AN APPROPRIATE TECHNOLOGY?

Remote sensing is not a single technology. Instead, it is a complex of related, but not necessarily dependent, technologies. Some of these technologies may be appropriate for a given country and its needs; others may not be appropriate. The remote sensing technologies cover a whole range of techniques, from the simple interpretation of photographic images by the human eye to advanced satellite data-collection systems and computer-aided analysis.

For many countries, developed and developing alike, the relatively simple techniques are generally appropriate and practical. Standard image-interpretation techniques can provide a wealth of information to the trained interpreter, with little expense of time and funds. Most countries already have some aerial photography and satellite imagery. In many countries new aerial photography can be acquired from commercial firms or national agencies at moderate cost, and satellite images are available for most of the land areas of the earth at very nominal prices. To obtain useful information from these images frequently all that is required is a hand lens, overlay material, a stereoscope, familiarity with the environment, and a knowledge of what constitutes usable natural resource information. This last requirement assumes some familiarity with the use of various resources such as timber, minerals, crops, fisheries, grazing land, or water. Most countries have people who, either through experience or previous training, are capable of competent image interpretation.

Intermediate technologies which can be applied to remote sensor data include optical image processing techniques. Equipment such as diazo "color" film printers, densitometers, color-additive viewers, and zoom-transfer scopes, and special, but not complex, photographic techniques are required. These intermediate technologies cost from less than $1,000 to more than $5,000 - depending upon the equipment and supplies required - and their use can greatly facilitate and extend simple techniques of image interpretation. For individuals in

developing countries who are already familiar with standard image interpretation, this intermediate range of remote sensing technology is highly useful and appropriate.

The digital processing equipment and advanced analysis techniques which are being developed in the West are applied to certain types of remote sensing data (e.g., multispectral scanner data), and may not be appropriate for some developing countries. Lesser developed countries do not have the necessary trained personnel, nor do they have the sort of resource-assessment institution that requires a constant data collection and analysis program to support its mission. Digital analysis technologies often require the use of special-purpose hardware and provide results which may or may not satisfy specific information requirements. On the other hand, simple digital techniques and quantitative data processing are within the capabilities of many developing countries that have even small general-purpose computers. Unfortunately, officials in many developing countries often perceive the most advanced digital techniques as being necessary for the practical use of satellite data - a misconception too often endorsed by digital equipment manufacturers.

Countries which already do some digital data processing on small or medium-size general-purpose computers may find it worthwhile to develop some simple satellite-data processing capabilities using existing software designed for that purpose. For example, Thailand and Sri Lanka (the latter under this grant program) have had some success in producing computer satellite maps using existing hardware and specially adapted software. The practical benefits of such processing are currently being developed and demonstrated.

"Appropriate technology" is sometimes used to mean small- or medium-scale technology, but the term is ambiguous without reference to the level of development and needs of the society in question. The great range of economic development which occurs between, and sometimes even within, developing countries makes any specific technology

appropriate for some and inappropriate for others -- regardless of its scale or sophistication. Remote sensing, however, offers a range of techniques, some of which will be suitable for almost any country, developed or developing.

C.3 AIRCRAFT SENSOR SYSTEMS

Aerial photography is recognized as a major and usually necessary component of the resource investigations needed for economic development. Aerial photographs are routinely used in geology, forestry, soil, vegetation, land use, and cartographic surveys in both advanced and less developed countries. The aerial photograph provides a spatially detailed and accurate representation of surface features. No other method provides so much potentially usable information over large areas in as short a period of time. The acquisition of aerial photographs and their subsequent interpretation make up a well-established process which is important for obtaining the kind of resource information required for rational economic planning in less developed countries. Its application is documented in a number of excellent publications.*

Both color and false-color (color infrared) films add a new dimension to the interpretability of aerial photographs which is particularly useful in vegetation studies. With finer grain films, aerial photography can be collected at higher aircraft altitudes (and consequently of larger areas) with no loss of scene detail. Different film-filter combinations can be used to highlight or suppress various kinds of terrain or water features. For example, certain filters should be used to obtain maximum clear-water penetration for bathymetry purposes, and infrared film with an appropriate filter is

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*For example: Aerial Surveys and Integrated Studies (1968) UNESCO, Paris, and/or Physical Resource Investigations for Economic Development (A casebook for OAS Field Experience in Latin America) (1969) Organization of American States, Washington, D.C.

excellent for identifying the extent of water bodies.

Under certain circumstances aerial scanners and radars can contribute unique data required for resource development. Thermal scanners mounted in light aircraft can map temperature patterns that reflect geothermal activity, surface moisture differences, rock-type variations, and the upwelling of fresh water adjacent to sea coasts. The large-area coverage and cloud-penetration capabilities of side-looking radars may be especially useful for certain portions of the developing world. The vast Amazon River valley was imaged in 1970 by radar, after many years of unsuccessful aerial photographic missions.* Some of these new types of aerial remote sensing data are being explored by developing countries under this AID program. Special aerial films and photo analysis equipment, for instance, were ordered for Pakistan and the Philippines.

C.4 LANDSAT (AND OTHER SATELLITE) SENSOR SYSTEMS

The first earth resources observational satellite, Landsat-1, was launched by the National Aeronautics and Space Administration (NASA) in mid-1972. Landsat-2 was launched in 1975 and a third Landsat was launched April 1978. These satellites are providing valuable information concerning the location and distribution of agricultural, hydrological, mineral, timber, and other important national resources for regional resource mapping and assessment.

The advantages of earth observation by satellite are large-area imaging on both a synoptic and a repetitive basis. Therefore, features which occur over large areas (such as geological structures) and/or change periodically (such as crop vegetation) are ideally recorded by satellite sensors. In general, the value of satellite sensing is significant when the region under observation (1) is remote or otherwise inaccessible, (2) covers an extensive area, or (3) has an inadequate or temporally variable information base.

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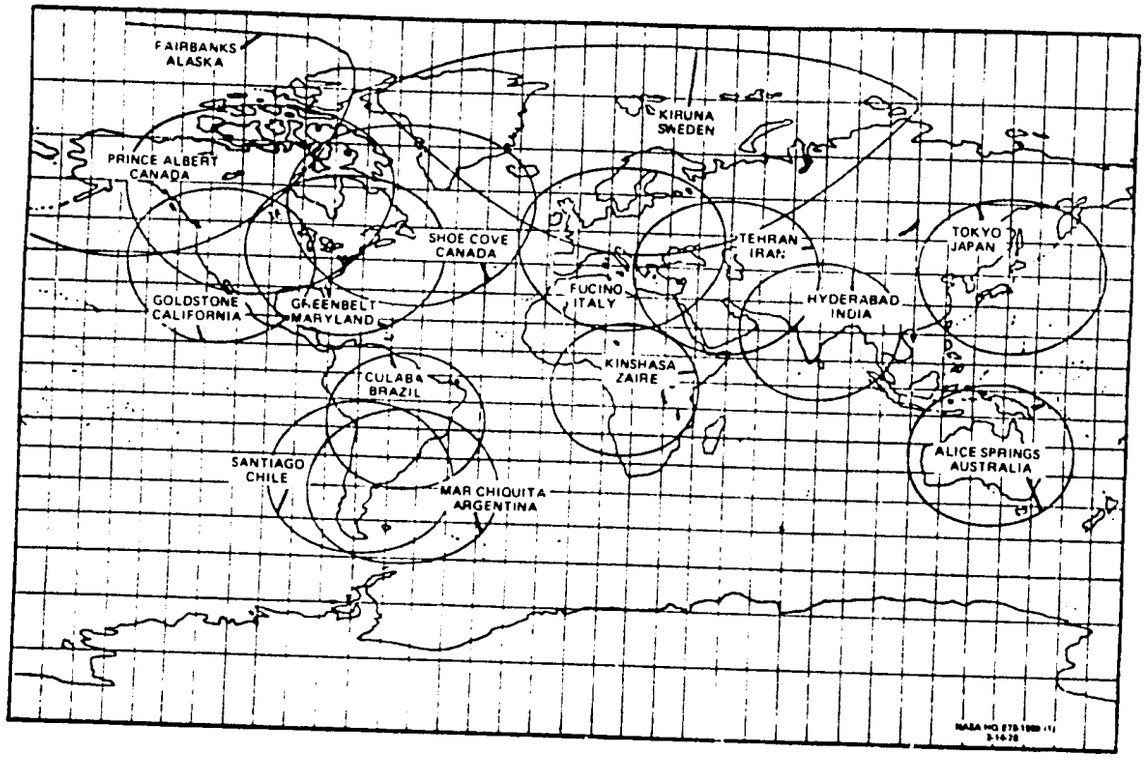
*See Chapter 14. "Fundamentals of Image Interpretation", Manual of Remote Sensing (American Society of Photogrammetry) 1975, for further discussion of radar image applications.

Landsat data has been recorded and is now available at nominal cost for more than 80% of the land surface of the earth and for large areas of the oceans. Some areas in North America and other parts of the world have been recorded more than 50 times since mid-1972. Most developing countries have been completely recorded under favorable conditions (few clouds) at least once, and many countries several times. Imagery in the form of negative and positive transparencies, prints, and color-composites are available at several different scales from the U.S. Geological Survey's EROS Data Center in Sioux Falls, South Dakota. Computer-compatible tapes of the data are also available for digital analysis.

The anticipated utility of Landsat data has been such that four countries besides the U.S. - Canada, Brazil, Italy, and Iran - have constructed multi-million dollar stations to receive the data directly. Additional stations are being planned for Japan, Australia, Upper Volta, and India. Each station can collect data over a 3,000-km region, which can cover many contiguous countries. The following figure shows those parts o the world that are now or shortly will be obtaining Landsat data directly.

An in-satellite tape recorder is programmed to collect data for those parts of the world that do not have regional reception stations. After being recorded in the satellite, the data is transmitted to U.S. receiving stations. From there it can be catalogued and archived, and imagery and digital tape products can be sent to requestors as needed. Since 1972 some 93,800 scenes have been recorded on board Landsat-1 and Landsat-2, while over 330,000 scenes have been collected via direct reception to ground receiver stations.

Other types of satellites and sensor systems will also provide useful observations of developing countries. The currently operating meteorological satellites provide timely data on cloud cover, weather systems, and surface temperatures and albedo. Sophisticated microwave-sensing satellites such as Seasat, will also be useful. For example, Seasat has an L-band radar that can observe the earth through cloud



CURRENT AND PROBABLE LANDSAT GROUND STATIONS

cove: nd collect ground imagery with a resolution of 25 meters. The manne: space shuttle will provide numerous opportunities to observe and collect resource data from space for both developing and developed countries.

C.5 RESOURCE INFORMATION SYSTEMS

Remote sensing technology is only one element in a much larger information system. To specify the use and value of remote sensing, the operation of the entire system must be analyzed. Remote sensing information must be combined with other data and the results of other analyses in order to arrive at a useful management decision. Frequently economic, social, and political needs and constraints must be considered in addition to the basic resource information derived from remote sensing and other sources.

APPENDIX D

SELECTED REMOTE SENSING REFERENCES

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